Land Cover Land Use Change

LCLUC is an interdisciplinary scientific theme within NASA's Earth Science Enterprise (ESE). The ultimate vision of this program is to develop the capability to perform repeated global inventories of land-use and land-cover from space, to develop the scientific understanding and models necessary to simulate the processes taking place, and evaluate the consequences of observed and predicted changes. The underlying philosophy of the ESE LCLUC Program is to further the understanding of the consequences of land-use and land-cover changes for continued provision of ecological goods and services.

LCLUC Headlines

- **Fourth NASA LCLUC Science Meeting**, April 3-5, 2000 at Sheraton in Reston, Virginia
- **NRA-99-OES-06 selections** are announced **(Acrobat PDF)**
- **Significant results** synthesis available at ftp://www.gecp.virginia.edu/lclucsigresults.ppt

Products and Data

- Abstracts
- Announcements
- Annual Progress Reports
- Data Access
- Strategies and Planning Papers

Contact Information

- Project Management and Funding
- Project Investigators

References & Resources

- Bibliography
- Funding
- Related Sites

Last updated April 05, 2000.
Mail questions and comments about the site to:
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NOTE: Many of documents on this site are available in **Adobe Acrobat** format.

Land Cover Land Use Change

INTRODUCTION AND STRATEGY OVERVIEW

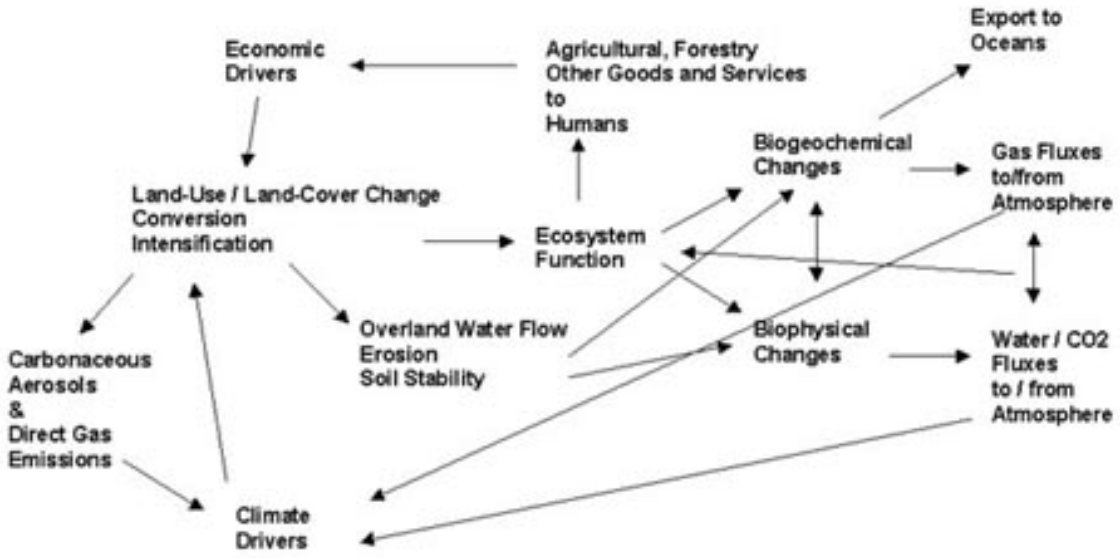
Land-Cover and Land-Use Change (LCLUC) is an interdisciplinary scientific theme within NASA's Earth Science Enterprise (ESE). ESE is NASA's enterprise to study the Earth as an integrated system, emphasizing observations made from the unique perspective of space together with underlying laboratory, field, theoretical, and modeling research. LCLUC will use NASA remote sensing technology to improve our understanding of human interaction with the environment, and thus provide a foundation for sustainable use and management of our natural resources.

The goal of the ESE LCLUC Program is to further the understanding of the consequences of land-cover and land-use change for continued provision of ecological goods and services.

The ultimate objective of the LCLUC program is to develop the capability to perform repeated global inventories of land-cover from space, and to develop the scientific understanding and models necessary to simulate the processes taking place, and evaluate the consequences of observed and predicted changes.

LCLUC has been designed initially around a series of regional studies that are complemented by several methodological studies exploring the production and validation of particularly important regional remote sensing datasets. The case studies use a combination of space observations, *in situ* measurements, process studies and numerical modeling to address a combination of forcing factors of change involving climate, ecological and socioeconomic drivers, the processes of change and the responses and consequences of change. LCLUC recognizes that land use and land cover change involves a series of complex interactions between biophysical and socioeconomic variables. An interdisciplinary approach is required. Case studies within LCLUC are structured to strengthen interdisciplinary science, in most cases involving collaborations among ecologists, economists, political scientists, and remote sensing specialists. The figure below gives examples of these various interactions and an indication of the discipline linkages that need to be developed.

Interactions of Land-Use/Land-Cover Change



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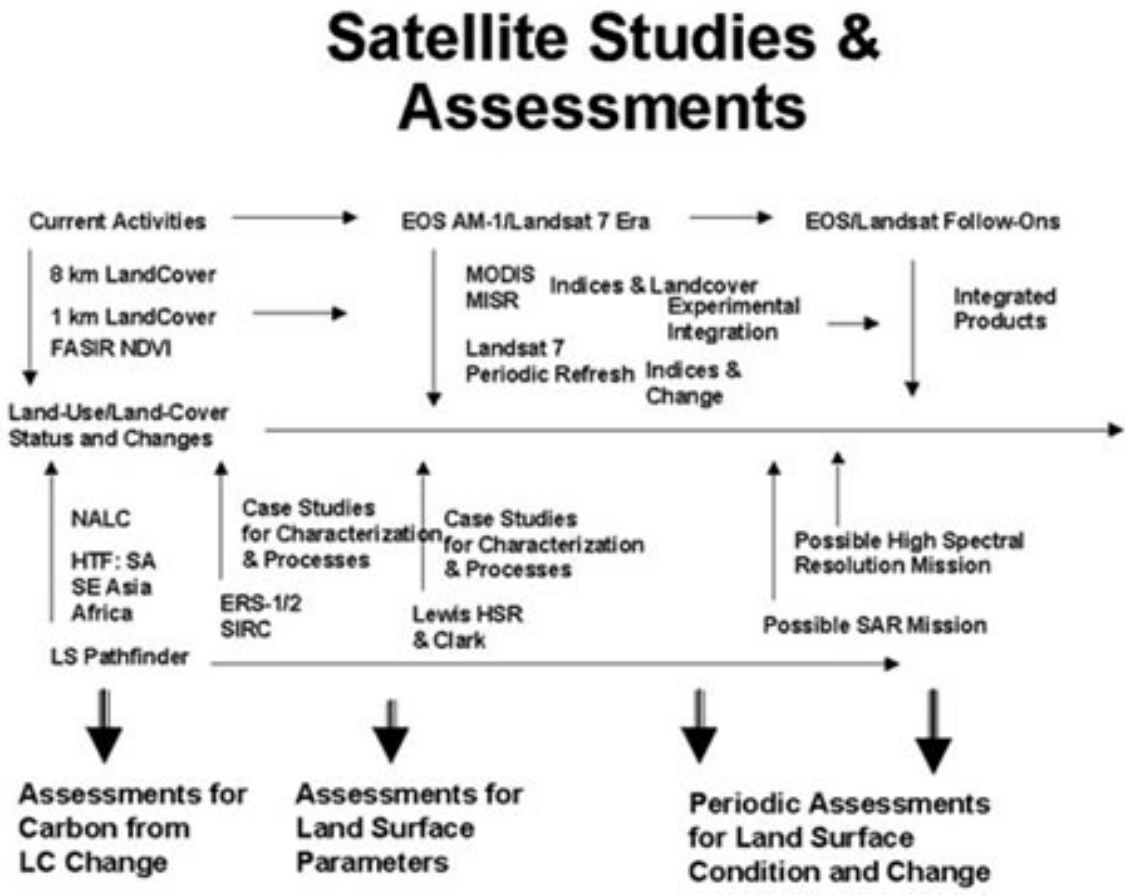
The figure below provides examples of satellite data sets and associated studies that will evolve as planned missions from NASA and other satellite agencies around the world come on-line. Over the next several years, particular emphasis will be given to utilizing the improved sensing and data systems developed by the Earth Observing System and Landsat 7.



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PRIORITIES FOR LCLUC

- Forcing Factors
- Responses and Consequences
- Modeling and Implications
- Techniques and Methods
- Priority Regions for Case Studies

a) Forcing Factors

(1) Climatic and ecological drivers: The NASA Land-Cover and Land-Use Change program will rely primarily on existing components of ESE and national and international science agencies for the development of historical and climatic data sets.

(2) Socioeconomic drivers: The NASA program will investigate the human dimension processes directly when they are coupled to observed recent changes in the landscape or regional predictive models.

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b) Responses and Consequences

(1) Land-cover conversion: The primary NASA interest is to identify the current distribution of land-cover types, and to track their conversion to other types.

(2) Land-use intensification: To understand the consequences of intensified management of agricultural, agroforestry, and grazing systems, particularly in the tropics and sub-tropics. To measure the longer-term in situ degradation of forested ecosystems that occurs.

(3) Land degradation in arid and semi-arid environments: To define, develop, and evaluate improved remote sensing measurement techniques and data integration methods for characterizing land degradation. The objective of the research is to provide scientific understanding and observational techniques required for improved efficiency in the management of both managed and unmanaged land resources.

LCLUC researchers are encouraged to use both remote sensing and in situ data, integrated with

geographic information system (GIS) techniques, in a manner which enables improved assessments of causes of land degradation, vulnerability to further degradation, and the development of options for more sustainable land uses.

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c) Modeling and Implications

It is important to develop, parameterize, and evaluate models that couple the biogeochemical and biophysical dynamics of the land surface and atmosphere. This initiative will emphaize the development of data sets and techniques that use representations of the actual land-cover present and changes in land-cover, rather than potential natural vegetation. Links to other process studies in tropospheric chemistry, aerosol radiative forcing and hydrometeorology will be explored to gain a better understanding of the relationship between changes in land-cover, the processes that drive those changes, and biogeochemical and physical changes in the Earth's atmosphere and climate system.

Ultimately, it will be the ability to model systems undergoing land-use change that will provide tools for both scientists and decision-makers to evaluate the potential consequences of different management practices, and to assess the consequences of policies that affect land-cover conversion.

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d) Techniques and Methods

Close coordination is sought between this initiative and the algorithm development and testing which is being supported by the remote sensing science component of the NASA Terrestrial Ecology Program, the NASA Pathfinder Program, the EOS Interdisciplinary Science and Instrument Science Teams. The LCLUC Program will provide a focus for these activities and should make use of the global archives of high resolution satellite data acquired over the last twenty years for addressing land-cover and land-use change.

Of particular interest is the development of new techniques that focus on the use of soon-to-be-available remotely sensed data. In particular, NASA is interested in receiving proposals that explore the potential applications of hyperspectral and very high resolution satellite data. The advent of the Landsat 7, Lewis and Clark missions and the recent declassification of very high resolution imagery from defense satellites provide opportunities for exploratory research. The LCLUC Program is interested in technical research oreinted towards operational techniques for automated change detection at the regional scale or improved classification algorithms, in order to improve the state of the art with respect to documenting land-cover and land-use change.

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Priority Regions for Case Studies

US and the Americas: The LCLUC program is supporting development of new and improved

land-cover and land-use data for the US at regional and continental scales. In addition, NASA is interested in well-documented regional case studies that couple land-use, land-cover, atmospheric and climate data, and ecosystem modeling in order to evaluate the response of ecological systems to multiple stresses. Studies that provide insight into the vulnerabilities of ecosystem goods and services to a combination of anthropogenic stresses, management regimes, and climatic variability will receive priority. Special attention is being given to research that improves our understanding of the influence of local and regional management decisions on the functioning of the landscape.

Southeast Asia: A base of scientific investigations must be built within Asian and Southeast Asian countries that will assess the consequences of forest conversion to agriculture, the long-term, in situ degradation of the forested landscape, and agricultural intensification. Proposals that demonstrate linkages to in-country scientists and direct links to regional IGBP projects will receive priority.

Southern and Central Africa: The land transformations currently going on in the dense humid forests, the seasonal woodlands, and savanna systems of Africa are of considerable interest to this program. The LCLUC regional activity will be developed and implemented in conjunction with international programs such as the USAID Central Africa Project for the Environment (CARPE), IGBP, LUCC and START and the host countries. Proposals that demonstrate linkages to in-country scientists and direct links to regional IGBP projects will receive priority.

Russia and the Countries of the Former Soviet Union: The primary LCLUC efforts in this region will be to take advantage of data sets and studies that have been developed within the context of the Earth Sciences Joint Working Group, and to coordinate activities with those of other agencies with particular interests in the boreal forest. Investigations that focus on understanding the effects of fire and logging of timber concessions will receive priority. Proposals that demonstrate linkages to in-country scientists and direct links to regional IGBP projects will receive priority.

Amazon Basin: the Amazon Basin is a key target area for NASA LCLUC activities. In order to tie closely to other parts of the ESE program, LCLUC joined in a solicitation with the NASA Terrestrial Ecology Program's as part of the Large-Scale Biosphere-Atmosphere Experiment in Amazonia (LBA).

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PROGRAM IMPLEMENTATION

The LCLUC program has begun with a combination of regional satellite-based studies, representative field-based process and parameterization studies and regional to global modeling efforts. Strong linkages are being made to existing and planned national and international programs.

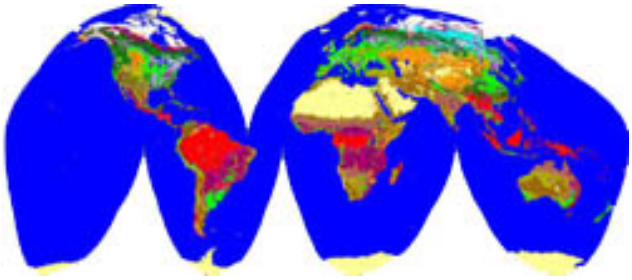
In the first phase of the program (1996-1999), the focus is on funding a small number of regional activities in areas where important changes are currently taking place, or have recently taken place. The initial priorities for regional studies are provided below. The short term emphasis on (1) new and improved regional data sets; (2) coupled land-use and ecosystem process model development; and (3) field process and parameterisation studies is aimed at providing a foundation for a longer-term research effort to assess the provision of ecological goods and services under changing management and climate scenarios. It is part of NASA's goal for the LCLUC program that its projects will provide appropriate prototypes for future Pathfinder-type efforts, i.e. scientifically-driven projects that provide the rationale for assembling and distributing to the scientific community large remote-sensing data sets for analysis.

A complete list of Projects and Principal Investigators, with supporting information, can be found on this web-site.

In the second phase of the program (1999-2002) the emphasis will shift to verification of models and their application to land-use change and land-management issues, especially utilizing satellite data from the EOS suite of sensors (e.g. TRMM, Landsat 7, MODIS, MISR and ASTER).

Land Cover Land Use Change

PRODUCTS



Project Abstracts

All Abstracts

LCLUC, LBA, Disturbance, GOFC

Global Studies

Regional Studies

Amazon Africa

Alaska

Presentations

LCLUC Meeting Presentations

Programmatic Presentations

Progress Reports

2000, 1999, 1998, 1997

Strategy and Planning Documents

Land Cover Land Use Change

RESOURCES

- **Bibliography of LCLUC Products**
- **Contact Information**
  - Project Management
  - Principal Investigators funded through LCLUC
- **Data Access**
- **Related Sites**

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Land Cover Land Use Change

DATA ACCESS

Each of the LCLUC projects will be developing data sets and following NASA data policy will make these data available to the broader community. Special consideration is being given to implementing an effective data policy with respect to local scale socioeconomic data which may have information privacy implications.

In addition to data that will be distributed by the project there are other sites which distribute data of direct relevance to those undertaking LCLUC research. Example sites are provided below.

- AVHRR GAC Pathfinder at the Goddard DAAC
- Earth Observing System Data Information System (EOSDIS)
- Earth Resources Observation Systems Data Center Distributed Active Archive Center (EDC DAAC)
- Earth Science Information Partnership
- Food and Agriculture Organization of the United Nations
- Global Emissions Inventory Activity
- Global Land 1-km AVHRR Project
- Global Land Cover Characterization
- Global Rainforest Mapping
- IGBP-DIS Global Fire Product
- Ionia 1 km AVHRR Global Land Data Set
- JPL Imaging Radar
- Landsat Pathfinder Humid Tropical Deforestation Project: Pan-Amazon/Africa (UMD)
- Landsat Pathfinder Humid Tropical Forest Inventory Project: Amazon/Southeast Asia (UNH)
- Landsat Pathfinder Humid Tropical Forest Inventory Project: Pan-Amazon/Africa (UNH)
- North American Landscape Characterization
- SEDAC Socioeconomic Datasets
- University of Maryland Land Cover Facility (NASA ESIP)
- USGS Land Cover Land Use Data

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- Commerical Remote Sensing Program
- Earth Science Enterprise
- EOS Project Science Office
- EOS Instrument Science Teams and Investigations
- Earth Observatory
- Landsat Program
- LBA Ecology Project Office
- Earth Observing System Data and Information System (EOSDIS)
- Distributed Active Archive Systems
- Earth System Information Partners
- The U.S. Global Change Research Program (USGCRP)
- United States Geological Survey (USGS)
- National Oceanic and Atmospheric Administration (NOAA)
- United States National Fish and Wildlife Foundation
- United States Agency for International Development (USAID)
- Central African Regional Program for the Environment (CARPE)
- USDA Forest Service
- The U.S. Global Change Research Information Office (USGCR)
- USGCRP Southwest Impacts Workshop
- US Country Studies Program
- USGS National Biological Survey
- Large Scale Biosphere-Atmosphere Experiment in Amazonia (LBA)
- IGBP/IHDP Land Use and Cover Change Project
- Global Observation of Forest Cover (GOFC)
- Global Climate Change (GCC) Africa
- International Geosphere - Biosphere Program (IGBP) Secretariat (Sweden)
- IGBP Data and Information System (IGBP-DIS)
- IGBP/GCTE Home Page
- International Human Dimensions Programme on Global Environmental Change
- System for Analysis, Research and Training (START)
- United Nations Environments Programme (UNEP)
- Climate change and human response in the semi-arid Near East
- Global Terrestrial Observing System (GTOS)
- Modeling Land-Use and Land-Cover Changes in Europe and Northern Asia (LUC)
- The Intergovernmental Panel on Climate Change (IPCC)

- The Large Scale Biosphere-Atmosphere Experiment in Amazonia
- NASDA Japanese Satellite Data
- Southeast Asian Impacts Centre (IC-SEA)
- Tropical Ecosystem Environment observation by Satellite (TREES)
- The Global Fire Monitoring Center (GFMC), Freiburg
- PARN (Projet d'Aménagement des Ressources Naturelles en République Centrafricaine)
- University of Maryland Land Cover Facility (NASA ESIP)
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- SEDAC Socioeconomic Datasets
- IGBP-DIS Global Fire Product
- Food and Agriculture Organization of the United Nations
- Earth Science Information Partnership

Land Cover Land Use Change

DATA ACCESS

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Land Cover Land Use Change

Product Results of Type Abstract

1999	Agricultural Colonization in the Ecuadorian Amazon: Population, Biophysical, and Geographical Factors Affecting Land Use/Land Cover Change and Landscape Structure	Richard Bilsborrow
1998	Hierarchical Investigation of Socioeconomic Drivers of Decadal Scale Land-Cover Changes in the Upper Midwest	Daniel Brown
1998	Characterizing Land Cover Heterogeneity and Land Cover Change from Multisensor Satellite Data	Ruth DeFries
1998	Coupling Land Use and Land Cover Changes, and Ecosystem Processes in Miombo Woodlands	Paul Desanker
1998	Accuracy Assessment of the IGBP Fast-Track 1 Km Land Cover Data Set	John Estes
1998	Time Scales of Land Use Change and Export of N and P from Coastal Plain Basins to the Coastal Zone	Thomas Fisher
1998	Causes and Consequences of Land Cover in a Greater Ecosystem: Trend Assessment, Monitoring, and Outreach	Andrew Hansen
1998	Modeling Carbon Dynamics and Their Economic Implications in Two Forest Regions: Pacific Northwestern USA and Northwestern Russia	Mark Harmon
	Modeling Carbon Dynamics and Their Economic Implications in Two Forest Regions: Pacific Northwestern USA and Northwestern Russia	Mark Harmon
1998	Land-cover Change in the Great Plains: Predicting Impacts of Regional Forest Expansion on Biogeochemical Processes	Loretta Johnson
1999	Effects of the Development of the Baikul-Amur Mainline Railroad on Patterns of Boreal Forest Cover and Carbon Fluxes in Southern Siberia	Eric Kasischke
1998	Modeling and Forecasting Effects of Land Use Change in China Based on Socioeconomic Drivers	Robert Kaufmann
	Anthropogenic Landscape Changes and the Dynamics of Amazoniam Forest Biomass	William Laurance
1998	Land-Use and Land-Cover Change in Sonora, Mexico: Trajectories of Agricultural Intensification and Consequences for Non-Agricultural Ecosystems	Pam Matson
1998	The Role of Land-Cover Change in the High Latitude Ecosystems: Implications for the Global Carbon Cycle	David McGuire
	Human and Physical Dimensions of Land Use/Cover Change in Amazonia: Forest Regeneration and Landscape Structure	Emilio Moran
1998	The Dynamics of a Semi-Arid Region in Response to Climate and Water-Use Policy	John Mustard
1998	Assessing Future Stability of US High Plains Landcover: Integration of Process Modeling with Landsat, In situ Modern and Paleoclimatic Data	Jonathan Overpeck
	Deforestation and Degradation in Southern and Central African Savannas	Stephen Prince

1999	**Soils, Water, People and Pixels: A Study of Nang Rong**	Ronald Rindfuss
1998	**Study of Land-Use and Deforestation In Central and West African Tropical Forest Using High Resolution SAR Satellite Imagery**	Sasan Saatchi
1998	**Time-Series Land Cover/Land Use Change and Socio-Economic Driving Forces in the Northern Peten Region, Guatemala**	Steven Sader
1998	**Case Studies and Diagnostic Models of the Interannual Dynamics of Deforestation in Southeast Asia: Is the Missing Sink for Carbon in Land Cover Change**	David Skole
	Pattern to Process in Amazonia: Measurement and Modeling of the Inter-Annual Dynamics of Deforestation and Regrowth	David Skole
1998	**Land-Cover and Land-Use Change in the Southern Yucatan Peninsula Region**	B. Turner II
1998	**Quantifying Grassland-to-Woodland Transitions and the Implications for Carbon and Nitrogen Dynamics in the Southwest United States**	Carol Wessman

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LBA Abstract

Agricultural Colonization in the Ecuadorian Amazon: Population, Biophysical, and Geographical Factors Affecting Land Use/Land Cover Change and Landscape Structure

Richard Bilsborrow, Stephen Walsh, Aaron Moody, Laura Murphy, Danilo Silva, Lawrence Band

We propose studies in two theme areas of LBA Ecology: land use and land cover change (LULC), and Carbon Storage and Exchange. This will involve examining the human and biophysical dimensions of LULC in the Ecuadorian Amazon associated with high rates of spontaneous colonization (land clearing) by agricultural settlers migrating into the region since the early 1970s. A satellite time series from the 1970s through 1998, along with GIS thematic coverages of biophysical gradients and geographical accessibility, will be linked to data collected on the ground from a unique scientific sample of georeferenced farm household plots and nearby communities. Data will be collected from the latter in 1998-99 on the same settler plots surveyed in 1990 to measure LULC over time in detail, and to relate it to population and socioeconomic characteristics of settler households. Image processing to characterize LULC and spatial analyses of landscape structure will be used to assess the rate and nature of LULC and to model the effects of LULC, secondary plant succession, and land fragmentation on carbon budgets and assimilation rates for landscape strata and the study area as a whole. Statistical models will be used to estimate the demographic, socioeconomic, biophysical, and geographic determinants of LULC at the farm and community levels. Agricultural extensification and intensification will be documented at the three spatial scales of the farm plot, the sector or community of which it is a part, and the region.

The project will be carried out in an area which is in the Amazon headwaters, one characterized by extraordinary biodiversity, undergoing more rapid colonization and deforestation than elsewhere in the Western Amazon due to its being opened following the discovery of large oil deposits. A scientifically representative sample of 480 household settler plots interviewed in 1990 will be re-visited in 1998 to provide a unique, representative assessment of changes in LULC over time, including land extensification, land intensification (and sustainability of agricultural technology), land abandonment, and secondary sucession, with implications for the carbon budget. Lessons will be learned about the process of LULC and its implications for carbon budgets as well as policies to promote to improve sustainability of methods and forest preservation.

Research Team

Richard Bilsborrow, University of North Carolina: LULC, survey design and data collection, statistical modeling

Stephen Walsh, University of North Carolina: LULC and carbon measurements, GIS imagery

Aaron Moody, University of North Carolina: LULC and carbon measurement, GIS imagery, statistical modeling and projections

Laura Murphy, University of North Carolina: LULC, data collection and processing, statistical estimation

Lawrence Band, University of North Carolina: carbon measurements

Danilo Silva, Ecociencia, Quito, Ecuador: LULU, data collection and GIS imagery

Gustavo Rodriguez, Quito, Ecuador: LULU, data collection, cleaning, analysis

Project Site

The central part of the two northern Ecuadorian Amazon provinces of Napo and Sucumbios, the principal area of oil discovery, road-building, and in-migration in Ecuador since the 1970s.

Activities

(This assumes we can begin field activities in mid-1998 at the latest.)

- GIS: Acquire remote sensing images, historical and current base maps and maps of roads and towns and infrastructure (to the extent possible, such as of schools, health clinics, oil camps and pumping stations and pipelines, etc.), hydrography, topography, aerial photography. Order GPS units and load software onto laptops for data collection and correction. Preprocessing of satellite data and digitization of map data into ARC/INFO format. Train Ecociencia (Ecuador) staff in use of GPS devices and GIS. 1998

- Household and Community Surveys. Prepare/revise household- and community-level questionnaires. Hire and train interviewers in Ecuador. Conduct pretests of questionnaires and of GPS devices and calibrate measures of land use with satellite imagery. Procure equipment for fieldwork. Conduct field surveys. Clean and process survey data. 1998 to mid-1999.

- LULC classification validation using both ground/survey and satellite data. 1999

- Carbon storage and sequestration. Estimate biomass and leaf area. Assess pattern metrics and landscape structure associated with fragmentation. Estimate carbon dynamics associated with LULC. 1999-2000

- Assess extent of extensification and intensification and determinants thereof. Conduct multivariate and multi-level analyses of LULC, derive policy implications, and prepare papers for presentation at conferences, journal submission and a book in both English and Spanish. 1999-2000

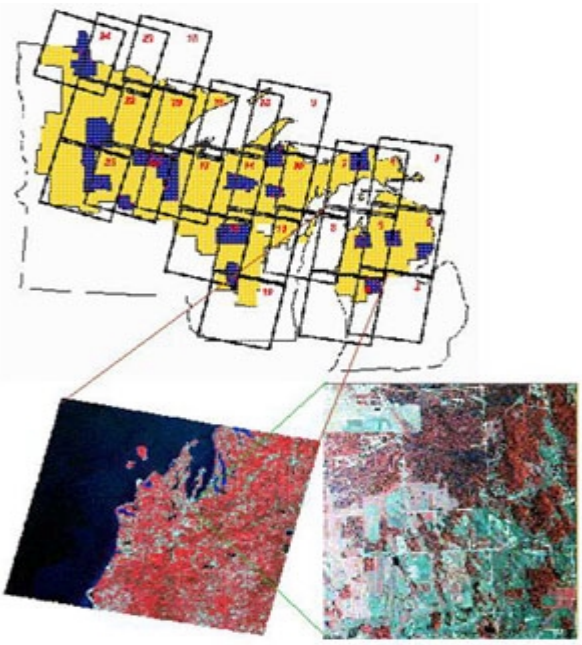
- Transfer of data and technology to Ecuador and other LBA investigators. 2000

LCLUC Abstract

Hierarchical Investigation of Socioeconomic Drivers of Decadal Scale Land-Cover Changes in the Upper Midwest

<http://www.msu.edu/user/brownda/research/nasa.html>

Daniel G. Brown



This project examines changes in land cover patterns as a function of socioeconomic changes, dispersed development, and subsequent changes in the spatial patterns of land ownership in the Upper Midwest (defined to include forested regions of Michigan, Minnesota, and Wisconsin). Spatial patterns of land ownership (i.e., parcel size and pattern) and their trajectories through time provide a critical link in understanding the environmental implications (i.e., LCLUC) of societal and economic factors. This project will involve (a) mapping multi-temporal patterns of land cover from historical aerial photographs (at resolutions similar to the TRW/Lewis and CTA/Clark panchromatic data) and NASA Pathfinder data (i.e., North American Landscape Characterization--NALC) and (b) modeling rates and types of change in land cover patterns as functions of rates of change in land ownership patterns and socioeconomic factors. Spatial and temporal exploratory statistical analyses will be used to quantify the relationships between socioeconomic processes, changes in the patterns of land ownership and cover patterns observed for a set of 136 area frame samples throughout the region. The observed relationships will be used to parameterize a GIS-based, spatial-temporal model of land use/cover and pattern change. The predictive ability of the spatial-temporal model will be assessed at the pixel, site, county, and regional scales using NALC MSS triplets.

LCLUC Abstract

Characterizing Land Cover Heterogeneity and Land Cover Change from Multisensor Satellite Data

Ruth DeFries

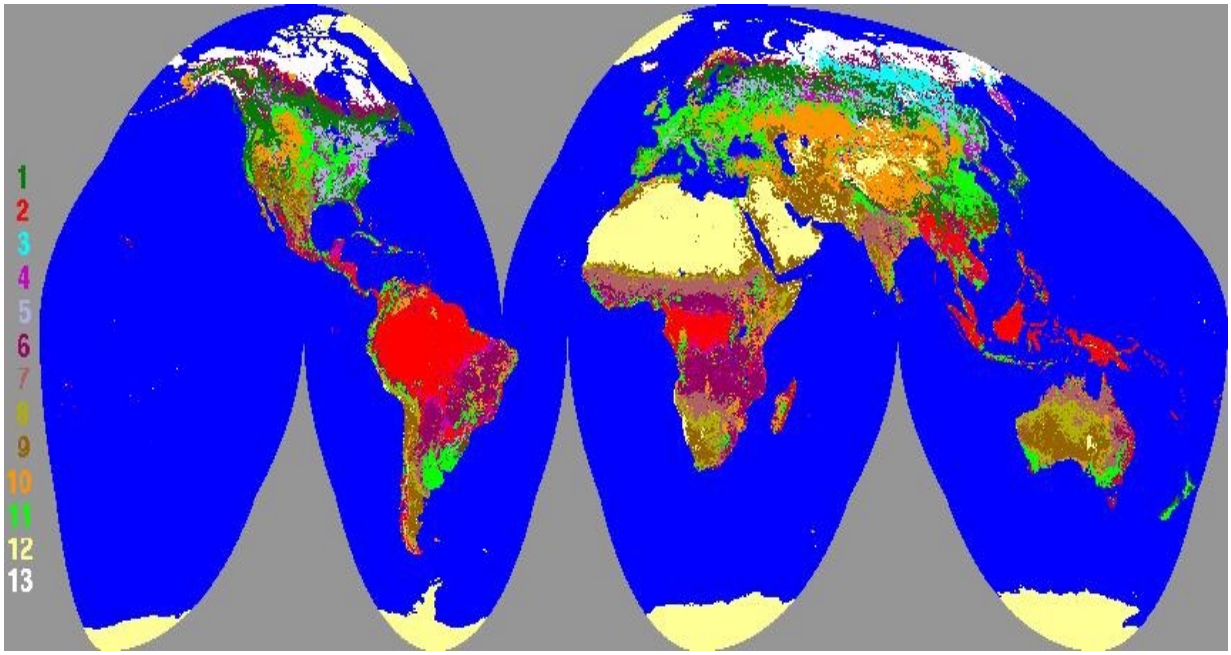
The proposed research addresses the need to develop improved regional and global land cover products that incorporate spatial and temporal heterogeneity of vegetation. The applications for these products are primarily regional and global biosphere-atmosphere models. The proposed research focuses on both conventional land cover classification products and alternative approaches to depict land cover heterogeneity and land cover changes over large areas. We propose to:

1. develop global land cover products at 8 km spatial resolution indicating temporal variability for the years over the length of record for the AVHRR Land Pathfinder data (1982-94)
2. develop global data planes indicating the proportional cover of vegetation displaying different growth forms (woody vegetation, herbaceous vegetation, or bare ground), leaf longevity (evergreen or deciduous), and leaf type (broadleaf or needleleaf) using 8 km and 1 km AVHRR data as well as MODIS data when available
3. apply the methods for estimating proportional cover to the multiyear 8 km data set to identify land cover change.

We will test these results with deforestation estimates from the Landsat Pathfinder Humid Tropics Deforestation project. To enhance the current IGBP effort to produce a global 1 km land cover classification product, we also propose to produce a global land cover data set describing the geographic distributions of major biomes using the global 1 km AVHRR data set. We will make available our global data set of training and validation sites developed by analysis of over 160 Landsat MSS scenes. Finally, we propose to assess the significance of land cover heterogeneity for several global biosphere-atmosphere models using the 1 km and 8 km products developed in the project.

Links to Related Sites:

- University of Maryland Land Cover and Remote Sensing Research Web Site <http://www.geog.umd.edu/landcover/>
- One Degree Land Cover Map Derived From AVHRR Data <http://www.geog.umd.edu/landcover/1d-map.html>
- Grand Challenge for Land Cover Dynamics <http://www.umiacs.umd.edu/research/GC/>



A Key to the Related Map:

1. Evergreen needleleaf forest
2. Evergreen broadleaf forest
3. Deciduous needleleaf forest
4. Deciduous broadleaf forest
5. Mixed forest
6. Woodlands
7. Wooded grasslands/shrublands
8. Closed bushlands or shrublands
9. Open shrublands
10. Grasses
11. Croplands
12. Bare
13. Mosses and lichens

LCLUC Abstract

Coupling Land Use and Land Cover Changes and Ecosystem Processes in Miombo Woodlands

IGBP/LUCC Miombo Home Page <http://miombo.gecp.virginia.edu/>

Paul V. Desanker

The overall goal of this project is to develop a better understanding of the patterns and causes of change in land use and land cover in the miombo ecosystems of central Africa; their impacts on the functioning of these systems, and the longer-term consequences of these changes on ecological functioning and socio-economic conditions in the region. The study aims to combine remote sensing, ground data collection, and ecological modeling to document and interpret the patterns and trends in land use and associated land cover in miombo and consider their consequences. Miombo ecosystems comprise mainly tropical woodlands dominated by trees of the genera Brachystegia, Julbernardia and Isoberlinia, occurring on infertile soils under seasonal subhumid climate. They cover almost 3 million km2 of southern central Africa from Zimbabwe to Tanzania, and constitute the largest more-or-less contiguous block of deciduous tropical woodlands and dry forests in the world. They have the potential to be a significant source or sink for carbon within the global cycle, depending on land use and management.

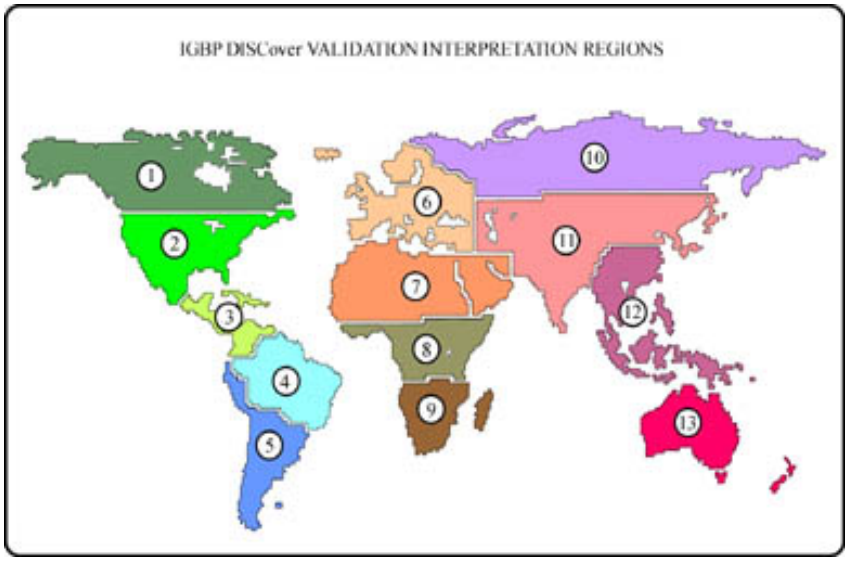
The proposed activities will be centred on six study areas in Zimbabwe, Malawi and Zambia, arranged variously along gradients of increasing rainfall and increasing land-use intensity. Each study area comprises one Landsat TM scene. Land use and associated land-cover attributes will be sampled within a number of broadly representative land-cover types in each area, as determined from initial analyses of Landsat TM imagery. Multi-temporal imagery will be used to map and track changes in land cover over the past 20 years. Information on land-use changes will be obtained from local key informants, archival material, where it exists, and interpretations of aerial photographs. The choice of study areas is related in part to the presence of other studies that can provide data on socio-economic circumstances that, together with additional information obtained during field surveys, can be used as preliminary inputs to understanding the human-induced drivers behind changes in land use and land cover. Tree data will be collected for development of patch dynamics models, and a soil-biophysics model for quantifying site potential productivity. A land use change model (LUCM) will be adapted to the miombo environment. Modeling will be used to integrate the information obtained, to assess the impacts of the changes that have occurred over the past 20 years particularly in relation to changes in carbon pools in the vegetation and soils, and to project likely future trends in land use, land cover, and the availability

of key natural resources. The project is designed to be an initiating activity of the Miombo Network, a proposed intercore activity of the IGBP/IHDP Land-Use and Land-Cover Change core project/research programme.

LCLUC Abstract

Accuracy Assessment of the IGBP Fast-Track 1 Km Land Cover Data Sets--- Methodological Development, Execution, and Lessons
<http://keystone.geog.ucsb.edu/igbp.html>

John E (Jack) Estes



We propose to assess the accuracy of the IGBP Global 1-km Land Cover Data Set (v.1.0, "Fast Track" or IGBP-DIScover) which is now being prepared from 1-km AVHRR composited NDVI data for completion on June 30, 1997. This data set arises from the mandate of the IGBP-DIS to provide accurate, fine-resolution land cover data for use by IGBP Core Projects. The data set recognizes 17 types of land covers with a list of units developed in concert with and approved by the Core Projects.
Accuracy of the Fast Track product will be assessed by a core sample of approximately 425 samples drawn by stratified, systematic, unaligned sampling in a procedure that yields confidence limits on the accuracy of classification as well as on specific probabilities of misclassification. In addition, the core sample will be expanded into larger regions around each sample center that will be used for tests and experiments as specified in the IGBP-DIS protocol that further characterize the Fast Track data and land covers at each site. These confidence sites will also form the vanguard of an ongoing global network of test sites for accuracy assessment of successive land cover maps by the IGBP and the global land cover community at large.

This research directly addresses the primary LCLUC goal of developing the capability to perform global inventories of land cover and land use from space, of which accuracy assessment is a critical part. It directly addresses the call for development of techniques and methods for applying satellite data to land use and land cover problems. It indirectly addresses the goal of modeling the response of land covers to change processes because the results will allow modelers to assess the sensitivity of their models to specific errors in calibration parameters inferred from land cover type.

A high degree of international participation is planned, and the results are highly relevant to EOS land cover activities. The benefits to the international research community and to the IGBP in particular will be very significant.

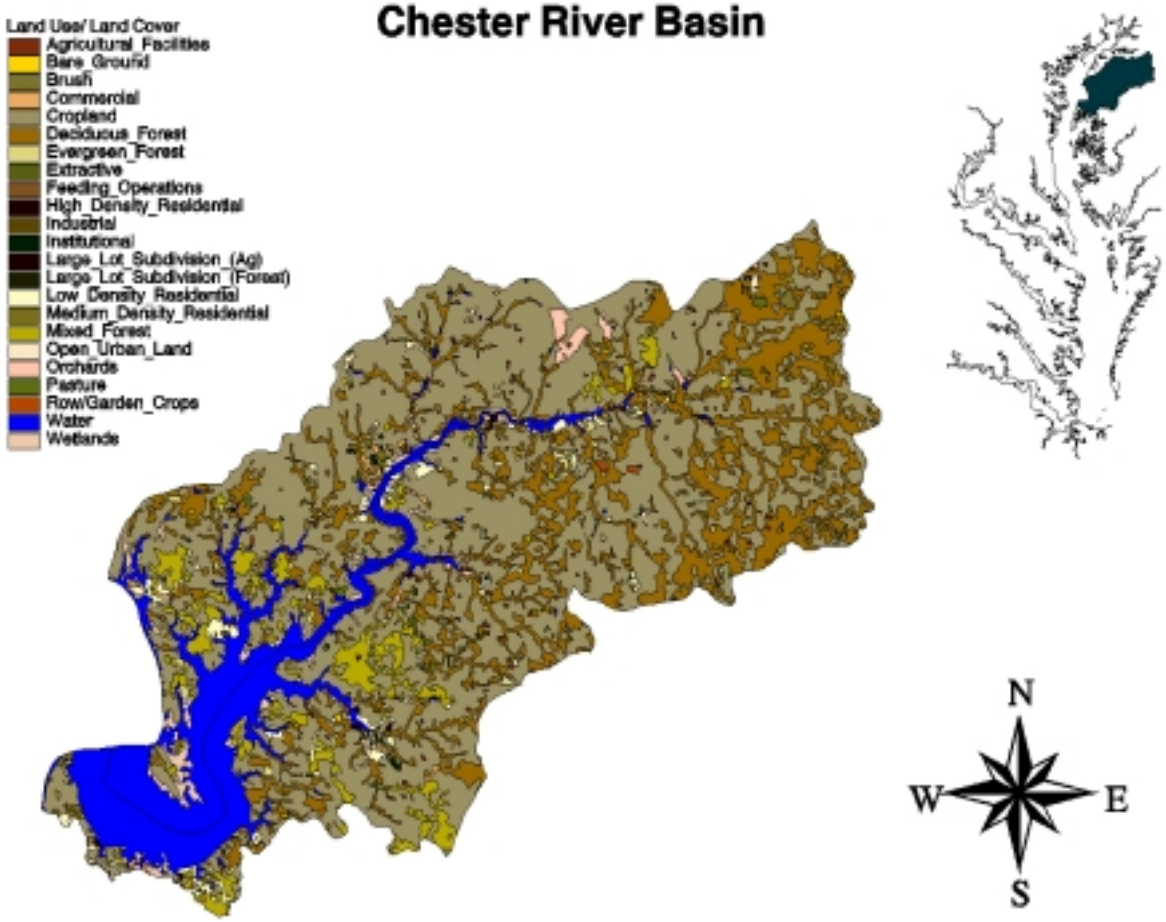
LCLUC Abstract

Time Scales of Landuse Change and Export of N and P from Coastal Plain Basins to the Coastal Zone

<http://people.hpl.umces.edu/~klee/timescale1.html>

Thomas R. Fisher

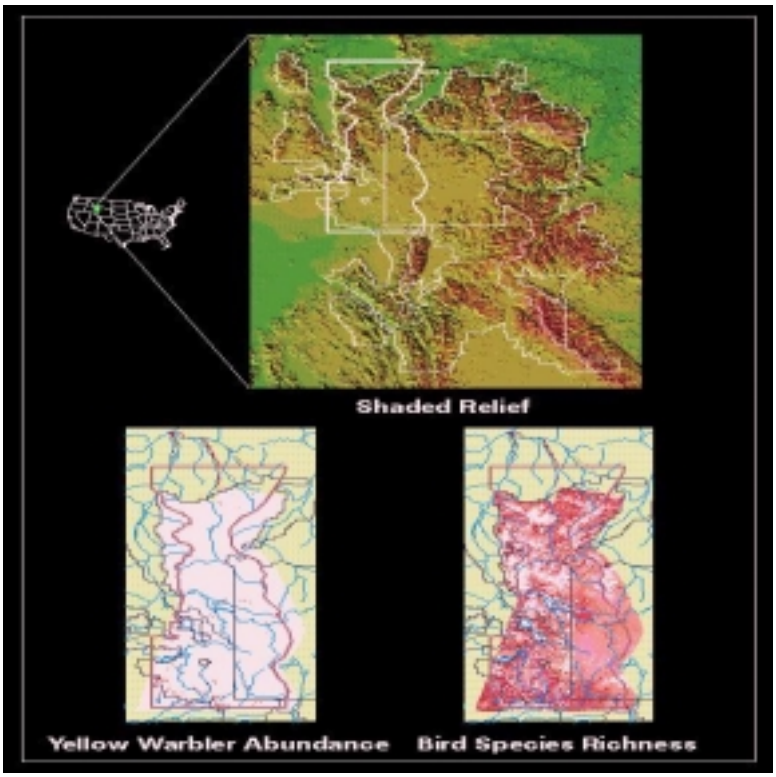
Changing landuse has been an important determinant of terrestrial export of N and P leading to eutrophication of the coastal zone, including estuaries such as Chesapeake Bay. I propose to link (1) our current efforts to model N and P export from two coastal plain watersheds of subestuaries of Chesapeake Bay with (2) historical landuse patterns derived from LANDSAT imagery, aerial photographs, and local landowner records. Landuse changes will be derived over the last 20 years from Landsat images, over the last 50 years from aerial photographs, and over the last 70 years from maps and plats. Changes in landuse will be used to estimate export of N and P at several time scales, and we will also use these watersheds as field verification sites for extrapolation over a larger region of the coastal zone under current conditions.



LCLUC Abstract

Causes and Consequences of Land Cover in a Greater Ecosystem: Trend Assessment, Monitoring and Outreach
<http://www.homepage.montana.edu/~ubiah/hansen/nasa.html>

Andrew Hansen



"Greater ecosystems" are areas where nature reserves are surrounded by gradients in land use. Thought of as refugia for biodiversity, greater ecosystems around the world now have rapid human population growth. Thus, the ecological characteristics that attract human emigrants to greater ecosystems may be at risk from increased human land use. Therefore, we propose to study interactions between the ecological and human community of the Greater Yellowstone Ecosystem.

Objectives are:

1. Quantify changes in natural and human forcing functions, ecological processes, land cover and use, and ecological responses across the GYE from 1972-1996.

2. Test hypotheses on forcing functions, ecological processes, land cover, and ecological responses:

   H1: High elevation and patchy distributions of topography, climate, and soil cause net primary productivity (NPP) to be low and variable over most of the GYE.

   H2: Species abundances and richness are correlated with abiotic gradients and NPP and are high only in localized hot spots across the landscape.

   H3: Human population growth is most rapid in counties with high opportunities for economic diversification, due in part to ecosystem-based businesses.

   H4: Human land use is correlated with environmental gradients such that land use is most intense at hot spots for ecological productivity and biodiversity.

   H5: Intense land use reduces NPP and native bird abundance, diversity and nest success.

3. Assess current and future risk to ecological hot spots and potential for restoration.

4. Develop and implement an approach to monitor ecological and human interactions.

5. Communicate results to stakeholders via workshops, publications, and decision-support tools.

Land cover/use and other key human and ecological variables will be quantified for 1995 using satellite, field, and in situ data. An innovative change-detection approach will be tested and used to create land cover/use maps at five previous time periods back to 1972 (date of earliest available satellite data). Accuracy assessments will be done on all resulting maps using aerial photos and field data. Hypotheses will be tested primarily by multivariate correlation analyses across space and time. Some hypotheses are also being tested with field experiments under other funding. The results will be used to determine the places in the landscape most important to biodiversity and under the greatest risk from changing land use. Places with high potential for restoration will be identified. Feedbacks from the ecosystem to the human community will also be examined. Continued monitoring is essential for ecosystem management, and we will develop and demonstrate an approach for taking the ecological and human "pulse" of the GYE in the future. Finally, outreach projects will be designed to quickly communicate results of the study to stakeholders and policy makers.

This study is unique in testing important new ecological theory concerning abiotic controls on biodiversity. It also will directly examine the notion that human communities are closely tied to the surrounding ecosystem. The apparent mismatch between ecological and administrative boundaries may underlie many of the resource conflicts in the GYE. The results will provide a basis for managing the GYE to sustain both ecological and human communities. Our methods will be exportable to other greater ecosystems and, hopefully, will facilitate sustainable management strategies before these refugia for biodiversity are jeopardized by unplanned human-population growth.

LCLUC Abstract

Modeling Carbon Dynamics and Their Economic Implications in Two Forest Regions: Pacific Northwestn USA and Northwestern Russia

(http://www.fsl.orst.edu/lter/research/hjarel/russia.htm)

Mark E. Harmon

Our proposed project will compare two significant forest regions of the globe, the Pacific Northwest, USA and northwestern Russia with the overall objective of determining the relative importance of land-use versus biogeoclimatic factors in controlling spatial and temporal patterns of carbon dynamics.

Our four specific objectives are:

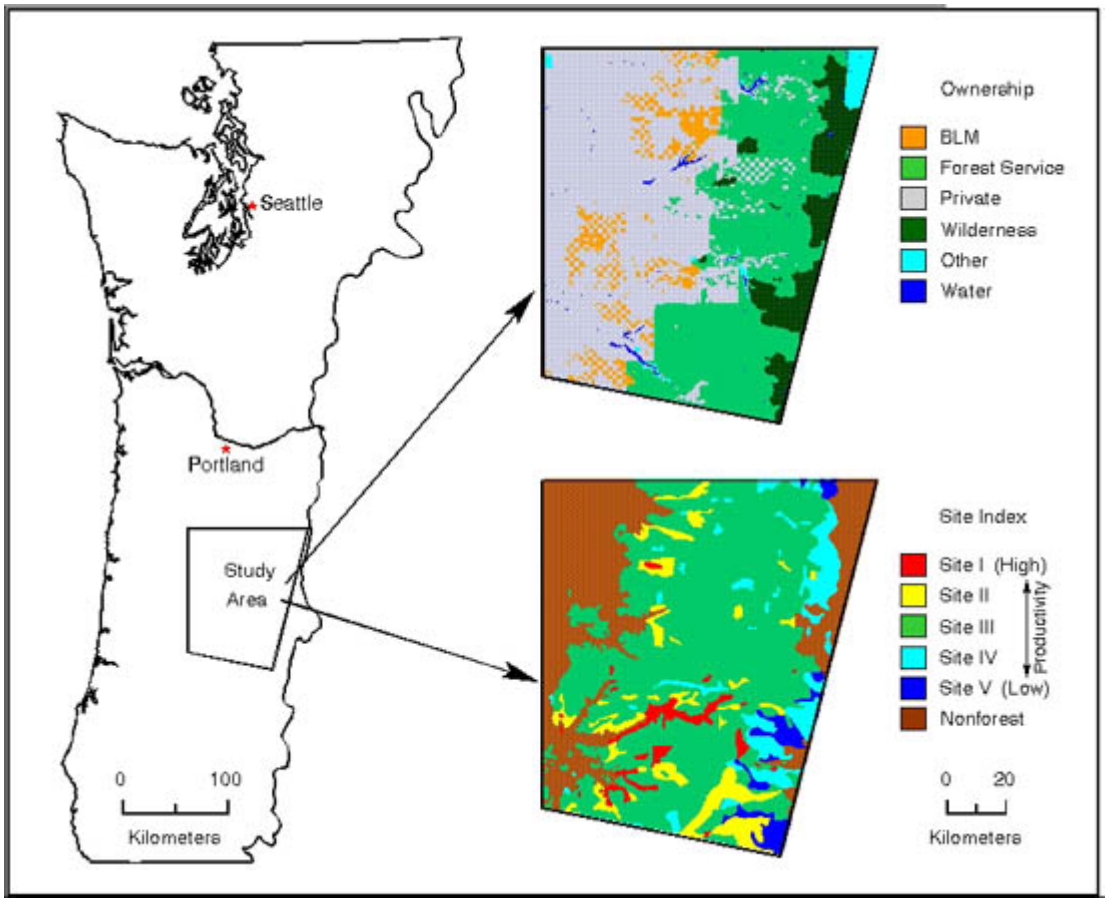
1. Link remotely sensed and biogeoclimatic data to ecosystem models at three spatial scales (region, landscape, and stand) to predict changes in regional carbon stores

2. Assess the major uncertainties introduced by complex and interactive natural processes and evaluate how these uncertainties propagate during the integration of scales

3. Use this analysis system to compare the changes in carbon stores in the Pacific Northwest and northwestern Russia over the last 25 years

4. Link our carbon stores analysis system with forest market models to determine the economic consequences accompanying changes in carbon stores.

The proposed research involves the continued integration of five highly complementary and interdependent carbon models into an overall regional analysis system. Each model addresses a particular process or pattern at a specific spatial scale, is linked to remotely sensed and biogeoclimatic data relevant to that scale, and will be tested with independent data from the Pacific Northwest and northwest Russia. Regional patterns of maximum potential carbon stores will be based on biogeoclimatic factors, potential vegetation, and maximum potential leaf area index. Landscape patterns of carbon flux will incorporate those constraints, but focus on the changes in carbon stores that result from changes in age structure caused by disturbances and the fate of carbon in forest products. Stand level patterns of carbon flux will incorporate the constraints of the previous two scales, but focus on the interactions of tree species, physiognomic forms, and small-scale disturbances (i.e., thinning) and their effects on successional changes in carbon stores. Once we have performed sensitivity analysis and corroborated the predictions of the separate system components, we will examine how uncertainty propagates in the overall analysis system, focusing on parameters and driving variables that the component models are most sensitive to and for which the largest uncertainty exists. Our analysis will also include a comparison of future scenarios of regional development for the next 25 years as a way to compare the overall "inertia" of these two regions to change in the current carbon flux.



Concurrent with assessing the uncertainty of our regional estimates, we will analyze the economic implications of changing harvest rates and other management treatments (i.e., planting, precommercial thinning, commercial thinning) as well as the manufacturing efficiency and use of forest products. Each of these changes entails a cost of implementation as well as changes in the quantity, quality, and timing of forest harvests. Analysis of these costs will allow us to generate schedules of the marginal cost of carbon storage for each type and location (PNW versus Russia) of treatment. The final result will be calculations of the relative efficacy of various management options and improvements in processing efficiency that can help guide decision makers intent on managing carbon emissions from forests.

LCLUC Abstract

Land-cover Change in the Great Plains: Predicting Impacts of Regional Forest Expansion on Biogeochemical Processes

<http://climate.konza.ksu.edu/general/nasalandcover/landuse.html>

Loretta C. Johnson

Eastern Kansas (KS) has the largest expanse of tallgrass prairie remaining in the world and is second only to TX in livestock productivity. However, in the last several decades, forest cover has doubled in KS and may jeopardize future sustainability of these productive grasslands. This proposed study will quantify land-cover change in eastern KS and its consequences for ecosystem C and N dynamics and fluxes of CO2, energy, and H2O. Although this study is focused in KS, the results will help predict consequences of forest expansion also occurring throughout the Great Plains.

Land-cover change and vegetation shifts can be expected to:

1. profoundly affect the quantity, quality, and distribution of plant C input to soil
2. alter N availability and N cycling through vegetation-induced changes in C quality
3. ultimately affect long-term ecosystem C balance.

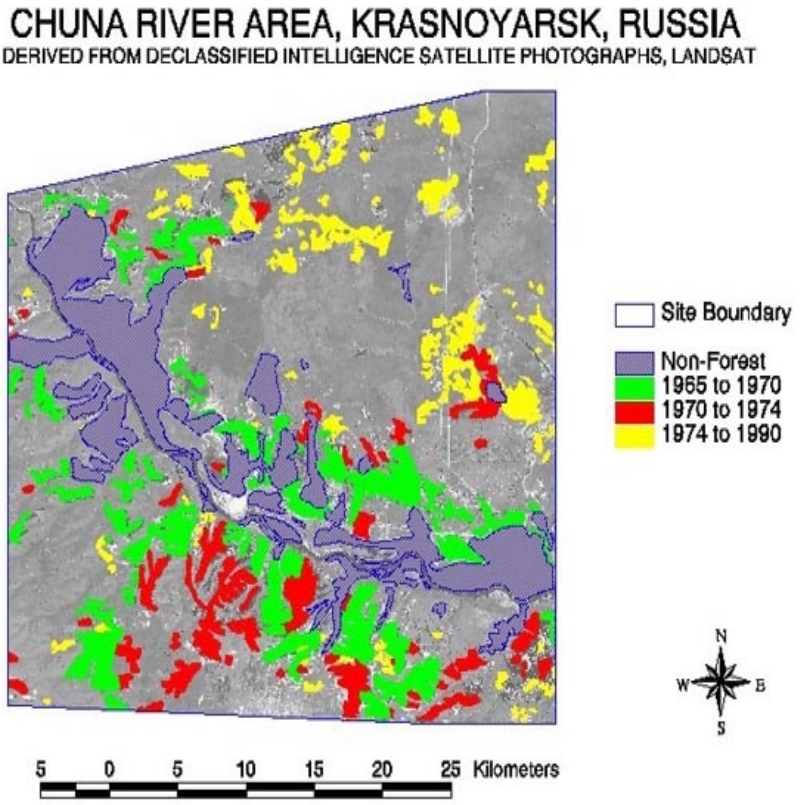
Furthermore, understanding relationships between changes in life-form and the abilities of terrestrial ecosystems to act as C sources or sinks is critical to predict potential responses under changing climate and land management scenarios.

The ultimate goal of this research is to evaluate the ecosystem consequences of observed and predicted land-cover change in the Great Plains. Without an understanding of the biogeochemical consequences of such major land-cover change as is occurring in the eastern Great Plains, we will lack the scientific foundation needed to insure sustainable use of our natural resources. To achieve this goal, we will use remote sensing imagery coupled with in situ process-level biogeochemical and ecosystem flux studies. We will link the biogeochemical studies to land-cover change using the MBL-General Ecosystem Model (GEM) and GIS techniques and ultimately predict long-term ecosystem changes on a regional scale.

LCLUC Abstract

Effects of the Development of the Baikal-Amur Mainline Railroad on Patterns of Boreal Forest Cover and Carbon Fluxes in Southern Siberia
<http://ewg.gecp.virginia.edu>

Eric S. Kasischke



The region encompassed by the boreal forest contains over one-third of the carbon stored in all terrestrial ecosystems, making it one of the largest pools. Since three-quarters of the world's boreal forests are located in Russia, understanding the consequences of human activities on patterns of forest growth in this region is a critical to more accurately quantifying human impacts on the global carbon budget. As a regional case study of boreal forest carbon dynamics, this project will to focus on a large area of the boreal forest which has undergone significant development over the past 40 years. In 1974, the Russian Government initiated the completion of the building of the Baikal-Amur Mainline Railroad (BAMRR), which runs between the northern tip of Lake Baikal and the port of Vanino on the east coast of Russia. Completed in 1980, The BAMRR spans a distance of 2500 km through the southern Siberian boreal forest, and opened this region to large-scale forestry activities. In addition, the railroad construction and increased human settlements reportedly resulted in an increase in the frequency of large-scale wildfires occurring in these regions. The overall goal of this research project is to quantify how the building of the Baikal-Amur Mainline Railroad (BAMRR) has altered the patterns of forest cover and carbon source/sink relationships in the southern Siberian boreal forest. More specifically, the

research will use archived satellite remote sensing data, ground-based data sets, and forest process models to quantify patterns of forest change and carbon source sink/relationships in the study area. The first step of the analysis will use Landsat imagery, recently declassified reconnaissance imagery, and AVHRR imagery to map patterns of deforestation and fire disturbances along the BAMRR. We will evaluate the utility of Landsat data to monitor patterns of forest regrowth after disturbance as well as using other systems (ERS, Radarsat, and ATSR) to estimate other surface characteristics (soil moisture and temperature and patterns of burn severity) important in predicting forest succession. The ground-based data bases and theoretical models needed to estimate patterns of forest succession and carbon flux associated with human and natural disturbance of forests along the BAMRR will be developed. A comparison will be made between the Landsat-observed patterns of regrowth with those predicted by forest successional models. An evaluation of the information derived from satellite data on soil temperature and moisture and fire severity to improve the performance of forest succession models in the test regions will be performed. Finally, we will develop and exercise landscape-scale models which utilize remote sensing observations in combination with ground-based data sets and theoretical models to estimate the effects of land cover change and fire along the BAMRR on carbon fluxes in the Southern Siberian boreal forests. The research project addresses three of the priority topical issues identified in NASA's Land Use/Land Change program area. First, the results will develop a clearer understanding of how two of the primary ecological drivers responsible for land cover change in boreal forests (fire and forest succession) interact with anthropogenic deforestation to influence the carbon balance in this important terrestrial biome. Second, the proposed research will develop new approaches to use information derived from satellite remote sensing systems to parameterize and evaluate models that couple biogeochemical dynamics in terrestrial biomes with the atmosphere. Finally, this research project will develop and evaluate new algorithms to analyze temporal sequences of spaceborne multispectral scanner data. These algorithms not only can be applied to current or existing systems (e.g., Landsat MSS and TM, AVHRR, ADEOS, ATSR, etc.), but also to future EOS era systems (Landsat 7, MODIS, etc.). Finally, the proposed research project focuses on one of the priority case study area: understanding the effects of fire and logging in Russia.

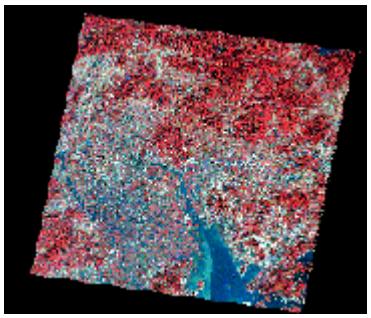
LCLUC Abstract

Modeling and Forecasting Effects of Land-Use Change in China Based on Socioeconomic Drivers

<http://www.bu.edu/CEES/lcluc.html>

Robert Kaufmann

Rapid rates of economic growth in the People's Republic of China over the last two decades have led to the widespread conversion of natural ecosystems to farmland and industrial areas. Moreover, economic development has resulted in the replacement of existing agricultural areas by commercial and residential structures. With 20 percent of the global population and an economy which is estimated to become the world's largest within the next decade, economic development and land-use patterns in China will have environmental effects beyond the country's borders. The size and rate of these significant conversions have the potential to affect the earth's climate and biogeochemistry. This project aims to understand and model the socioeconomic forces which drive land-use changes in the Pearl River Delta of Guangdong Province in Southern China. Quantifying this relation will allow us to predict future land-use conversion and its impact on global biogeochemical cycles and biophysical parameters.



The Pearl River Delta Region of Guangdong Province in Southern China.

This is a Landsat TM scene from 1995, bands 432.

This study will analyze land-use change in the Pearl River Delta in four steps. First, we will use Landsat images to analyze land-use changes from 1973 to 1996. Land-use will be classified into urban areas, agricultural lands, and natural vegetation. Multitemporal maximum and range NDVI values will be used to identify areas which have been converted to urban areas from agricultural and natural terrains. In the second step, we will build a statistical model that identifies and quantifies the effects of socioeconomic variables on land conversion. Model output will generate land conversion factors, which provide information on the direct, short-term effects of various economic activities on land-use patterns. These conversion factors will be used to calculate the multiplier effects of land conversion, which represent the indirect, long-term effects of economic development on land use. In the third step, these land conversion factors and multiplier coefficients will be combined with scenarios of economic development developed by Project LINK to predict the effect of economic growth on land-use patterns. In the last step, we will use these forecasts of land-use change to estimate the corresponding changes in the biophysical and biogeochemical environment. Understanding the driving forces behind human-induced modifications of terrestrial ecosystems provides crucial information for modeling the rate of larger biophysical and biogeochemical changes.

LBA Abstract

Anthropogenic landscape changes and the dynamics of Amazonian forest biomass
<http://www.nmnh.si.edu/biodiversity/>

William F. Laurance, Jim Tucker, Rita Mesquita, G..Bruce Williamson

Our study addresses the LBA Ecology theme of carbon storage and exchange. We propose a combination of field studies and computer modeling to estimate above-ground biomass in con tinuous forest, forest fragments, and secondary forests of different types through time and re late these measures to remote sensing data from LANDSAT TM images for a modified land scape in central Amazonia. Our objective is to develop a predictive model of carbon stocks and their dynamics based on readily identifiable landscape features derived from remote sens ing imagery.

BIOMASS DYNAMICS IN CONTINUOUS PRIMARY FOREST AND REMNANTS

We will use extensive existing data from a long-term phytodemographic project in the Amazon, coupled with additional field work, to estimate standing biomass in continuous forest plots and forest fragments. This unique data-set includes over 57,000 marked trees in 66 permanent, one-hectare plots. These plots were surveyed initially more than 15 years ago, and have been recensused 2-5 times to estimate tree growth, mortality, damage, and recruitment, thereby allowing us to monitor the dynamics of Amazonian tree communities and their intrinsic carbon stocks at a landscape level (ca. 1000 km2). In this project we will resurvey tree communities in all 66 permanent plots. Lianas will also be included in these surveys because recent results suggest that they could exhibit markedly increased growth rates in response to increasing atmo spheric CO2.

BIOMASS DYNAMICS OF REGENERATING FORESTS

We will develop biomass estimates for different ages and types of secondary forest, in order to assess the rate of carbon accumulation in fallow and regenerating lands following different successional trajectories. Both species-specific allometric equations and true destructive sampling in the field will allow the calculation of biomass estimates.

LANDSCAPE ANALYSIS

We will use detailed time-series remote sensing imagery of our extensive (20 X 50 km) research landscape in the central Amazon to produce a model of car bon dynamics as a function of identifiable landscape features (e.g. fragment size and shape, and the area and age of secondary forests). The procedure for the satellite analyses will be the following:

1. register all the thematic mapper images to a high resolution UTM map with precision GPS data from the field;
2. image to image registration will then be performed using the base map as the reference base;
3. an unsupervised cluster classification will be run in conjunction with a knowledge-based classifier to classify the 20 x 50 km
4. proposed study area into the 11 categories above;
5. the resulting classification will field checked and cor rected where necessary for each of the satellite images used in this study, based upon reference data collected in the field

using GPS, photographs, field notes, and aerial overflights; the resulting classification will be "vectorized" into an ArcInfo coverage and further edited where necessary;
6. additional GIS layers of topography, river courses, roads, and biological infor mation, including biomass estimates for each time frame, will be coregistered with the satellite data and included into the GIS; and
7. the resulting combination of the satellite classification(s) from 1982-1984-1986-1988-1990-1992-1994-1996 will be used to extrapolate the biological data spatially over the landscape.

PRODUCTS OF PROPOSED RESEARCH

The proposed research will provide the following products within the three years of operation:

1. Estimates of above-ground biomass stocks and their dynamics in primary tropical rainforest, in rainforest patches of varying sizes, and in different types and ages of secondary forests.
2. A spatially-explicit model that links temporal changes in the BDFFP landscape to predicted above-ground biomass stocks and their dynamics of above-ground biomass.
3. A working model of biomass dynamics and landscape features, available for testing in other Amazonian landscapes .
4. Training Brazilian graduate students and research professionals (in-country capacity-build ing).

RESEARCH TEAM

Claude Gascon, Smithsonian Institution: Biomass estimates and GIS Coordination

Jim Tucker , NASA/Goddard Space Flight Center: Remote Sensing imagery processing

William F. Laurance, Biological Dynamics of Forest Fragments Project, Biomass estimates in forest fragments and continuous forest reserves.

Rita Mesquita, Instituto Nacional de Pesquisas da Amazonia, Biomass Dynamics of Regenerating Forests.

G..Bruce Williamson, Louisiana State University, Biomass Dynamics of Regenerating Forests.

SITE

Work will be carried out at the INPA reserve site "Biological Dynamics of Forest Fragments Project".

ACTIVITIES

- 1980-1996 biomass estimates in forest fragments and forest reserves: June 1998 - June 1999
- Field recensus of plots: June 1998 - June 2000
- Secondary forest estimates of biomass: June 1998 - June 1999
- Remote Sensing and GIS modeling: June 1998 - Dec. 2000

LCLUC Abstract

Land-Use and Land-Cover Change in Sonora, Mexico: Trajectories of Agricultural Intensification and Consequences for Non-Agricultural Ecosystems

Pamela A. Matson

Since the beginning of the Green Revolution, development and utilization of improved cultivars and increased use of fertilizers, pesticides, and irrigation have lead to dramatic increases in grain production worldwide. This "intensification" of agriculture has accounted for more of the global food production increase than has expansion of agricultural land and is likely to continue to do so. Intensification of land-use, however, carries implications not only for agricultural production but also for off-site land-use and land-cover change.

The objective of this proposed research is to evaluate the causes and consequences of agricultural development in the Yaqui Valley of northwestern Mexico. The Yaqui Valley is the home of the Green Revolution for wheat, and one of the most productive breadbaskets of Mexico. Until the first half of this century, it was primarily a desert scrub ecosystem; development of irrigation and fertilization systems has lead to dramatic changes in the Valley, and potentially in surrounding regions as well. We propose to analyze the critical links among agricultural policy and agricultural extent and productivity within the Valley, as they have changed over the last fifty years and continue to change. Moreover, we will utilize remote sensing data to evaluate the off-site consequences of these agricultural land-use decisions for land-use and land-cover in the surrounding region, focusing on

1. the extensive changes in land use in the areas surrounding the agricultural valley (e.g., expansion of grazing systems in the scrub desert ecosystems at the edge of the Yaqui Valley)
2. alteration of native ecosystems as a result of down-wind deposition of anthropogenic nitrogen from the Valley.

We will collate or develop and use three data bases:

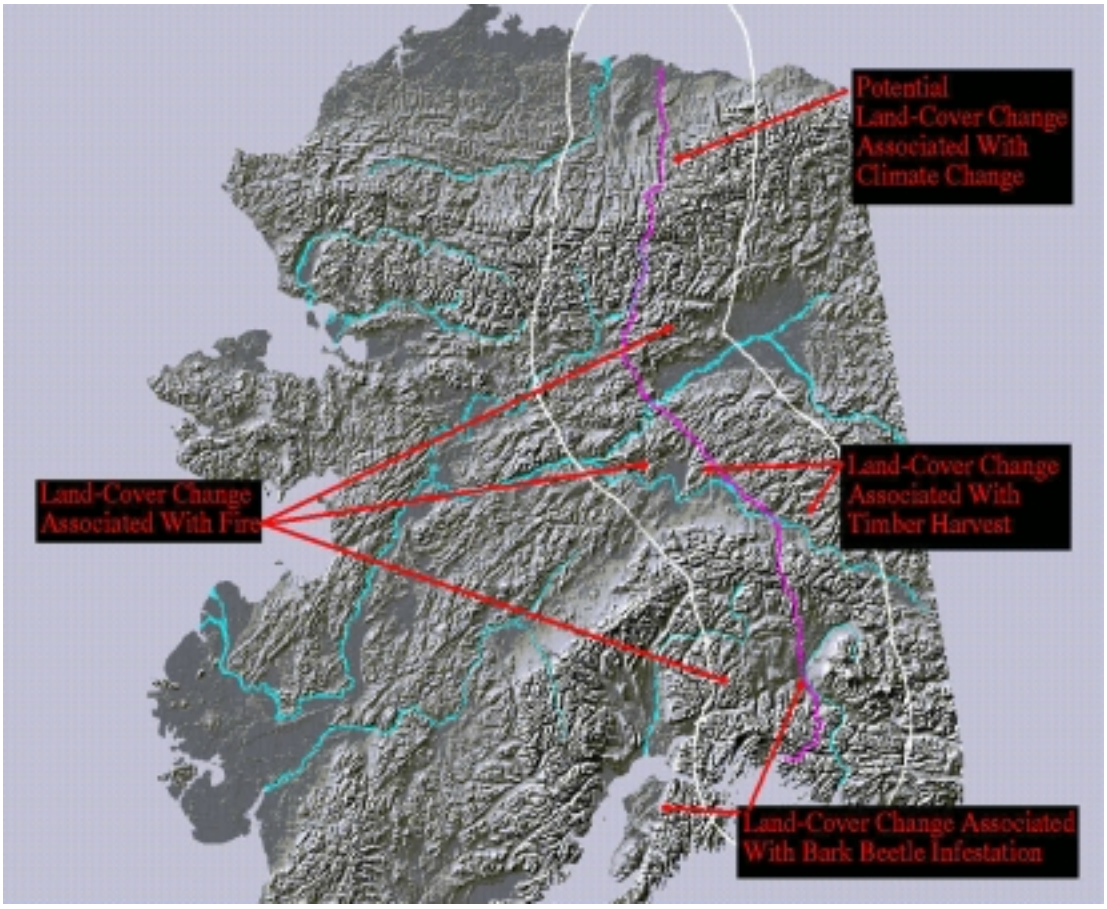
1. historical data from the Yaqui Valley Irrigation District
2. farm-level socio-economic and agronomic surveys conducted by CIMMYT and by Naylor during the past 15 years
3. MSS, TM, and AVHRR data registered in an ARC/INFO based GIS, along with climate, soils, and topographic data bases, for the Valley and surrounding regions.

The proposed work will build on our long-term experience and previous studies of biogeochemistry, agronomy, and economics in the Yaqui Valley.

LCLUC Abstract

The Role of Land-Cover Change in High Latitude Ecosystems: Implications for the Global Carbon Cycle
<http://alces.sel.uaf.edu>

A. David McGuire



The land cover of northern boreal regions is likely to change substantially during the next century because of disturbances related to climate change, fire, logging, and insects. Changes in land cover of high latitude regions may potentially affect the earth's climate system by influencing the global carbon cycle. We propose a study focused on Alaska to develop a prototype spatially explicit modeling framework capable of using satellite-derived data to estimate how changes in land cover cause changes in ecosystem carbon storage at high latitudes.

Our strategy for this study involves four tasks:

1. development of spatially explicit contemporary land-cover data sets in Alaska
2. development of transient spatially explicit land-cover data sets for the historical satellite record in Alaska
3. development of a successional biogeochemical model
4. application of the modeling framework for estimating the consequences of land-cover change on terrestrial metabolism in retrospective, contemporary, and prognostic analyses.

The development of spatially explicit contemporary land-cover data sets is important for identifying vegetation types relevant to the biogeochemical model and for identifying vegetation that is recovering from specific disturbances. Some of the vegetation types in Alaska that are relevant to the successional biogeochemical model include tussock tundra, shrub tundra, alpine tundra, non-forested boreal wetland, lowland boreal conifer forest (black spruce/Siberian larch), upland boreal conifer forest (white spruce), coastal conifer forest (Sitka spruce/western hemlock), upland deciduous forest (aspen), and grassland/steppe. Additionally, we will to identify vegetation types that are recovering from fire, insect, and logging disturbances. We will focus the development of the contemporary land-cover data set along the Alyeska Pipeline corridor where the timing and spatial extent of disturbances from fire, logging, and insect infestation are well documented. At least three types of remotely-sensed imagery (TM, ERS1, AVHRR) will be used in developing the contemporary land-cover data sets. The development of transient land-cover data sets is important for identifying the timing of disturbances from fire, logging, and insects for the successional biogeochemical model. We will use Landsat MSS scenes along the transect to develop a data set of land- cover from the 1970s. The successional biogeochemical model, which will be based on a transient version of the Terrestrial Ecosystem Model (TEM), will be designed so that it can operate in either a diagnostic or prognostic mode. In the diagnostic mode the model will use the timing of disturbance identified in the transient land-cover data sets to begin modeling ecosystem recovery from disturbance. Retrospective analyses with the diagnostic mode of the model are necessary for testing the dynamics of ecosystem recovery in the model. This testing will be important for establishing confidence in applying the prognostic mode of the model, which will predict simultaneous responses of land-cover and ecosystem function to global change. The prognostic mode of the model will consider land-cover change driven by ecological process and land-cover change driven by human land use. The development of a capability to predict the pattern of ecological land-cover change will build on an ongoing collaboration that is using TEM to develop a dynamic ecosystem/vegetation model. We will work with the agencies and organizations planning future land-use in Arctic and interior Alaska to develop spatially and temporally explicit land-use scenarios for our modeling efforts.

The proposed research will contribute significantly to the NASA ESE Land-Cover and Land-Use Change Program. First, it will develop new and improved regional data sets on land-cover change in high latitude regions. Second, it will use data from process studies of ecosystem responses to land-cover change in the development of a successional

biogeochemistry model. Finally, the linkage of land-cover data with a successional biogeochemistry model will provide a framework for how spatially explicit land-cover change influences carbon storage in high latitudes. The development of this framework complements other development projects with TEM funded by NASA EOS. This research also complements the LTER/NASA MODIS Cross-Site Validation. The proposed research will also contribute significantly to assessments of the role of high latitude ecosystems in stabilizing or destabilizing the atmospheric concentration of CO2, which may have important social and economic consequences for countries that occupy high latitudes. Thus, the prototype spatially explicit modeling framework developed in this study will help provide scientists and decision-makers with a tool to evaluate the consequences of policy decisions that influence land-cover throughout high latitudes in Russia, Canada, Scandinavia, and Alaska.

LBA Abstract

Human and Physical Dimensions of Land Use/Cover Change in Amazonia: Forest Regeneration and Landscape Structure

<http://www.indiana.edu/~act/>

Emilio F. Moran, Eduardo S. Brondizio, Dalton M. Valeriano, Flavio J. Ponzoni, Paul Mausel, and J.C. Randolph

Building on 25 years of research experience in the Eastern Amazon, this study will focus on advancing our understanding of land use and land cover change. It will develop a Spectral Library that will serve the research community and assist in testing of a new generation of sensors (e.g. TM7). This project will build on a seven-region study, along the LBA transects, supported for the past six years by NSF and NIGEC, and encompassing a sample of 100+ sites. We used a nested-georeferenced approach that included soil analysis, vegetation stand structure and composition, land use histories, institutional analyses, demography of households, and land cover classification using Landsat TM multitemporal data to understand the rates of growth of secondary vegetation. The seven regions provide a wide array of land uses and land cover along an east-to-west transect extending from the Amazon estuary and Bragantina region east of BelTm near the Atlantic coast, all the way to the Tapajos/Santarem region. This 160,000 km2 area will be examined for land cover changes and their relation to past patterns of land use for a minimum of no less than 25 years. We propose in this NASA/LBA project to extend this work by:

A. Quantifying ecological thresholds driving structural and functional dynamics (e.g. rates of regrowth and species replacement) of secondary succession areas subjected to different land use histories across the seven study regions;

B. Generating models that incorporate socioeconomic, institutional, and demographic determinants of land use and cover change at a variety of scales;

C. Developing a Spectral Library of land cover classes present that can be applied to previous (MSS and TM5) and forthcoming sensors (TM7) through the integration of vegetation inventories, image calibration, and hyperspectral field assessment;

D. Providing hands-on experience to a cohort of Brazilian doctoral students in their work on land use/cover change and the human dimensions of such change in research in the Amazon region, and to provide other opportunities for mid-career training preferentially to colleagues at Amazonian institutions.

This study will provide the research community with a Spectral Library to facilitate inter-image comparisons of land cover classes and land use dynamics at the center of the LBA campaign. Hyperspectral calibration of a range of land covers of interest to LBA, such as mature upland and floodplain forests, stages of secondary successional vegetation, selectively logged forests, pastures, annual and perennial cropped fields, and savannas, will be an important component of this study. Building this Spectral Library is a challenge that we can undertake only because of the comprehensive nature of past georeferenced field research encompassing physical, biological and social science variables, and because of its spatial distribution over seven different regions that permits scaling from farm/household to regional dimensions of land use and land cover.

RESEARCH TEAM

Dr. Emilio F. Moran, Director, Anthropological Center for Training and Research on Global Environmental Change (ACT), Indiana University

Dr. Eduardo S. Brondizio, Assistant Director, Anthropological Center for Training and Research on Global Environmental Change (ACT), Indiana University

Dr. Dalton M. Valeriano, Instituto Nacional de Pesquisas Espaciais, Department of Remote Sensing

Dr. Flavio J. Ponzoni, Instituto Nacional de Pesquisas Espaciais, Department of Remote Sensing

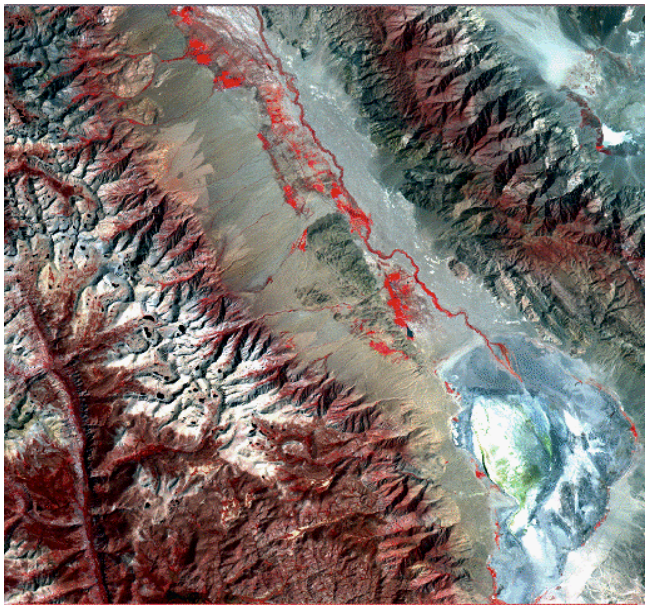
Dr. Paul Mausel, Department of Geography & Geology, Indiana State University

Dr. J. C. Randolph, School of Public and Environmental Affairs, Indiana University

LCLUC Abstract

The Dynamics of a Semi-Arid Region in Response to Climate and Water-Use Policy
<http://www.planetary.brown.edu/planetary/LCLUC_Owens/>

John Mustard



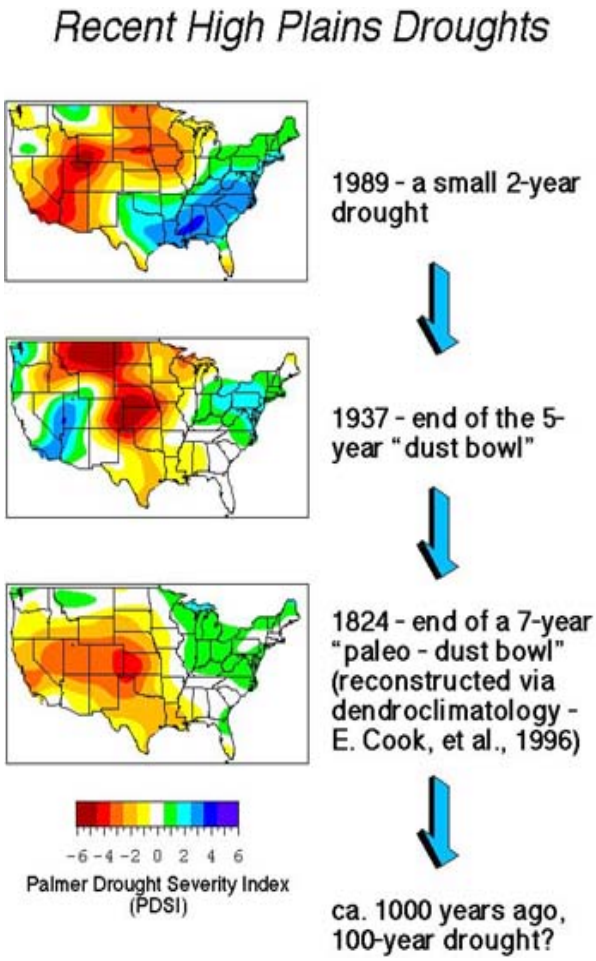
We propose to investigate the modes of response of land cover units in Owens Valley to recent environmental stress related to both climatic (drought between two wet periods) and social (high volume groundwater extraction during the drought period) factors. The land cover of the Owens Valley consists of shrub communities on the bajada surfaces flanking the valley floor, and a mosaic of shrub land, phreatophyte and riparian communities, agricultural, and developed land on the valley floor. Although the entire valley was affected by a drought from 1987 to 1992, only the southern reaches of the valley floor were directly affected by groundwater pumping to supply water to the city of Los Angeles. This matrix of temporally variable water availability and spatially distinct land-uses provides the ideal environment in which to examine the sensitivity of remotely sensed data for identifying changing vegetation patterns.

Landsat TM data acquired during September of each year from 1985-1996 will be analyzed with a spectral mixture model to quantify the surface abundance of the primary constituents. The September reference frame effectively captures the integrated annual growth of shrubs in this region. These results will then be incorporated into a high resolution GIS data base of the region to assess the modes of response of specific land cover types to the multiple stresses. An existing GIS data base contains extensive information related to land-cover units, changes in vegetation cover, location and amount of groundwater pumping, depth to water table over time, and other key information. The remotely sensed data provide the essential scaling information necessary for investigating these modes over much larger areas and in specific locations than is possible from the field surveys. Since there exist a number of ecological and land cover units, and differences in the amount of groundwater pumping between the southern and northern sections of the valley, a number of responses will be investigated. Due to a decline in the ecological health of phreatophyte communities during the drought, a policy change was affected in the amount and timing of groundwater withdrawal. This allows us to assess the effectiveness of this policy change on ecosystem response, changes in species composition, and productivity. The proposed work represents a well controlled case study of land degradation in a semi-arid environment. The combination of physical and social drivers results in multiple stress which have affected land cover and ecological responses. The proposed study will provide insight into the vulnerability of semi-arid regions to a combination of anthropogenic stresses, management strategies, and climate variability.

LCLUC Abstract

Assessing Future Stability of U.S. High Plains Landcover: Integration of Process Modeling with Landsat, In Situ Modern and Paleoclimate Data

Jonathan Overpeck



The U.S. High Plains, stretching from Wyoming and Nebraska southward through New Mexico and Texas contains some of the most economically significant, yet potentially endangered land-cover of the country. Land-cover in this region is susceptible to both human land-use and climate-induced land-cover change. Recent (e.g., 1995-6, 1950's and 1930's) climatic extremes (i.e., drought), and their impacts, demonstrate that climate-induced change is the largest threat to land-cover on the over 100,000 km2 of stabilized eolian (wind-generated) deposits of the High-Plains, a fact made even more clear by the paleoclimatic observation that much bigger land-cover change took place prior to significant human land-use than after. Although climatic change, and to an equal extent human land-use, has caused small areas of the High Plains eolian deposits (e.g., sand dunes and sand sheets) to mobilize during the 20th Century, the paleoclimatic record indicates much greater amounts of wind-generated eolian land-cover change took place during the last 10,000 years of interglacial climate. Since this climate regime was not dramatically unlike that of this century, it is likely that a small future shift in climate forcing could have a profound impact of the natural and agricultural land-cover presently stabilizing the over 100,000 km2 of "paleo" eolian deposits. For this reason, it is key that we develop an effective means to assess how this economically critical land-cover will be affected in the future, both by natural (climatic) and human-related processes. Furthermore, a proven assessment strategy for this U.S. region should provide the foundation for similar assessments of how the land-cover of other, "at risk", semi-arid regions around the world might change in the future.

We propose to develop the needed land-cover change assessment strategy by coupling an existing NASA ESE effort ("Land and Land-Use Change in the Climate Sensitive High Plains: An Automated Approach with Landsat;" A. Goetz, PI) with new research focused on the integration of the Landsat data with process modeling to understand the sensitivity of High Plains land-cover to climate and human land-use forcing. More importantly, we will calibrate our model-based assessment methods with paleoclimatic data to ensure that we can simulate the full range of

possible climate-induced land-cover change. The existing ESE program is using Landsat TM data spanning the period 1988 to 1998/98 to develop a land-cover (natural and anthropogentic) GIS database that also includes in situ information on soils, eolian landforms and climate. Our proposed work will build on this effort in several ways. First, our new research will augment the existing ESE effort by collecting/collating field "ground-truth" data needed to characterize the soil, vegetation cover, and recent paleoclimatic history of High-Plains land-cover units defined from Landsat data. Second, our proposed research will integrate climate (GCM and meso-scale) and vegetation/ecosystem (CENTURY) models to simulate the observed relationships between climate, land-cover, and stabilization-status of High-Plains eolian deposits. Our goal is to use the integrated modeling scheme to predict the susceptibility of each High-Plains vegetation and eolian land-cover unit to the full range of possible climatic change. The Landsat-based GIS will then serve to track human-induced land-cover change, and translate our model-based assessments to all land-cover units mapped in the GIS.

From paleoenvironmental data we already know that drought extremes and eolian land-cover change were significantly larger prior to the extensive land-use of the 20th Century. Assessments of future land-cover change that fail to incorporate this fact would obviously be misleading. For this reason, we will couple our assessment models with paleoclimatic data to ensure that our methods are able to simulate the dramatic pre-20th Century climate, vegetation, and eolian land-cover change. Lastly, we will use our "paleo-calibrated" methods to assess the susceptibility of each land-cover unit mapped in our GIS to a range of future climatic changes. We will work with land-use planners/ decision-makers to ensure that our assessments are of maximum economic value.

LCLUC Abstract

Deforestation and Degradation in Southern and Central African Savannas

Stephen D. Prince

An integrated land degradation and deforestation detection system will be developed for the Southern African Development Community (SADC) region plus southern Zaire. The scale for the inventory and monitoring will be 1 km2. Using our past experience with degradation studies in Africa, the analysis of very large volumes of Landsat data, socio-economics of land and fuelwood, and inference of biophysical variables for large areas from remotely sensed measurements, we will map land cover and biophysical properties of the land surface related to degradation, thus moving beyond classification of land cover to monitor the processes involved. Socio-economic drivers of land cover change as well as biophysical factors will be employed to select processes that can be expected to cause degradation and to choose representative study areas. Radar and optical methods will be implemented to measure biomass. Primary productivity of crops, rangelands and forests will be monitored using models driven by remotely sensed data. Soil moisture and runoff will be derived from surface water and energy balance models also driven with remotely sensed data. Finally biophysical, socio-economic and cultural variables will be combined to create empirical models that we hope will identify leading indicators of environmental degradation. The 15 year archive of Advanced Very High Resolution Radiometer data constitutes a baseline having an appropriate temporal scale for this purpose. Up to ten detailed study sites will be selected in which representative degradation processes are known to occur. Landsat (1972-present) and synthetic aperture radar data will be acquired where higher spatial resolution is needed to understand the mechanisms of land cover change that are taking place. The aim of the study will be to develop a prototype degradation early warning system (DEWS) that can be applied to the whole of southern and central Africa and provide a pattern for similar areas worldwide.

LCLUC Abstract

Soils, Water, People and Pixels: A Study of Nang Rong

<http://www.cpc.unc.edu/projects/nangrong/nangrong_home.html>

Ronald Rindfuss

This research combines Landsat, SPOT, and GIS data with detailed individual, household, and community longitudinal data to examine the effects of biophysical, geographic, and human dimensions on land use/ land cover (LULC) change. The study area is Nang Rong district, Buriram province, Northeast Thailand. The first subproject uses village level data collected from 310 villages in 1994, remotely sensed data from 1994, and measures of land suitability to examine the immediate and lagged impacts of human, biophysical, and geographic factors on LULC in 1995 and 1997 for the land surrounding these villages. The second subproject uses a subset of the 310 villages drawing on data available from 1984, 1988, and 1994 to look at effects of social processes on LULC in 1987, 1991, and 1997 respectively, controlling for land suitability and prior measures of LULC. The third subproject, again using all 310 village, investigates scale dependence among biophysical, geographic, and social variables, and assesses the range of spatial scales in which biophysical and geographic variables are related to social factors. The fourth subproject uses remotely sensed data and ground control information to see whether integrated Landsat and SPOT can distinguish between transplanted versus broadcast rice fields, an important distinction from the perspective of human dimensions. Finally, 1994 survey reports about the size and use of agricultural plots are used to cross-validate and clarify the interpretation of measures of LULC obtained from remotely sensed data.

LCLUC Abstract

Study of Land-Use and Deforestation In Central and West African Tropical Forest Using High Resolution SAR Satellite Imagery

<http://www-radar.jpl.nasa.gov/africamap/>

Progress Report, July, 1997 - February, 1999

Sasan S. Saatchi

Deforestation in tropical Africa is driven by a variety of socio-economic and environmental factors, and has resulted in land cover changes that threatens biodiversity, water and energy resources, and contributes to trace-gas emissions. Several conservation and development studies have concluded that the deforestation in Africa is closely tied to demographic conditions such that the greatest loss of rainforests has occurred in countries with higher population growth. However, because of the lack of reliable data and survey information in some countries, the estimation of areas of intact forest and/or under land use change and their relation to economic indicators have been surprisingly difficult to establish. Consequently, the extent and rate of deforestation Africa are less well known than other regions of tropics.

In this study, we propose to use high resolution satellite imagery to map areas of forest clearing and general land cover types in the entire Central African tropical region. Images acquired by JERS-1 SAR instrument during its global rain forest mapping (GRFM) phase will be the main source of data for this study. By using a combination of radar backscatter and texture analysis, and a SAR-specific classifier, we propose to classify the images into five categories of forest, nonforest, savanna, flooded forest, and open water. Approximately 4000 images for two periods of dry and wet seasons will be processed and delivered to the NASA/Jet Propulsion Laboratory and the European Commission Joint Research Center in Italy for generating a geocoded 100 m resolution mosaic of image data and a land cover map. The thematic interpretation of JERS-1 data and the validation of the land cover map will be supported by available Landsat TM images acquired by NASA pathfinder project, ERS-1 mosaic of Africa generated by ESA TREES (Tropical Ecosystem Environment Monitoring by Satellites) project, and vegetation maps and field data provided by collaborators from national institutions in the region.

The proposed work includes four distinct phases:

1. Data collected by JERS-1 radar instrument will be processed at NASDA (Japan) and delivered to JRC (Joint Research Center, Italy). Radar images will be used through a post-processing chain at JRC to generate a 100 m resolution mosaic over the entire area for two seasons.

2. High resolution data (12.5 m) and 100 m mosiac images will be delivered to JPL for data analysis, land cover classification and validation. The land cover and forest inundation maps will be generated for two data sets. The maps will be stored as high and low resolution mosaics.

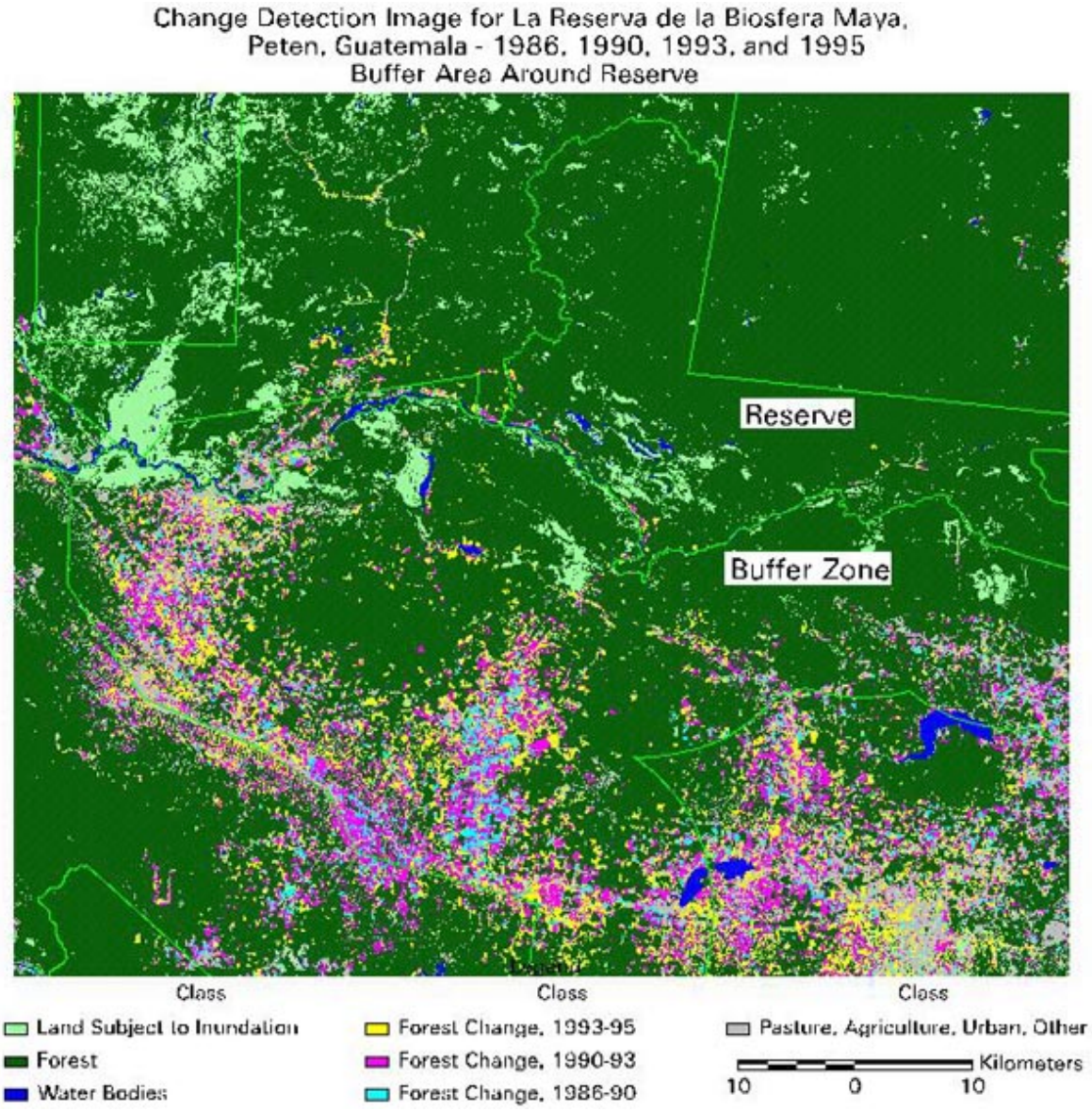
3. Through a collaborative effort between JPL, University of Maryland Landsat Pathfinder Project and JRC TREES project, the land cover maps will be analyzed in order to estimate deforestation and the rate of forest clearing and to improve the classifcation based on Landsat and AVHRR images.

4. The results of the analysis will be published in peer review journals and technical reports. The 100 m mosaic data setes for two seasons, land cover maps, and inundation maps will be distributed on CDROM and through the web sites.

LCLUC Abstract

Time-Series Forest Change, Land-Cover/Land-Use Conversion and Socio-Economic Driving Forces in The Northern Peten District, Guatemala

Steven A. Sader



The three year investigation will analyse time-series Landsat imagery (>20 yrs) for land-use conversion trends and socio-economic driving forces for a 25000 sq. km study area in the northern Peten district of Guatemala. Land-cover types and regeneration age classes will be identified and coded into land use history strata for sampling. Vegetation measurements,GPS readings and household farmer/rancher interviews will be conducted at sample locations. In year two, synthetic aperture radar(SAR) imagery will be processed to test for relationships between

SAR backscatter and successional forest age class canopy structure. Aerial videography linked to GPS on the aircraft will be collected each year to suppliment field data collection and to improve field sampling efficiency. In year three, we will conduct spatial analysis and fragmentation studies and reconstruct the criteria that slash-and-burn farmers (and ranchers) use to make land-use conversion decisions. Socio-economic and biophysical data will be linked with our time-series GIS and field surveys to analyse driving forces influencing land-use change within the Maya Biosphere Reserve management units and buffer zone. The ultimate goal of the project is to provide better understanding of deforestation processes and address uncertainities or data gaps in existing regional and global climate models. The project is a cooperative effort between the University of Maine - forest management department, Conservation International, and NASA Stennis and Marshall Space Flight Centers. The research will complement an ongoing sustainable development program administered by Conservation International - ProPeten in Flores, Guatemala with funding support from the U.S. Agency for International Development.

LCLUC Abstract

Case Studies and Diagnostic Models of the Inter-annual Dynamics of Deforestation in Southeast Asia: is the missing sink for carbon in land cover change?

David L. Skole

This proposal will develop regional research on the dynamics of land use and cover change in Southeast Asia in collaboration with a team of regional scientists who have been working together since 1993. The proposal focuses on merging satellite remote sensing data from existing NASA programs, in particular the Landsat Pathfinder project, with new remotely sensed data and socio-economic data to improve our understanding the inter-annual dynamics of deforestation, regrowth and a suite of other land use transitions in this important region. This work will lead toward the development of empirical diagnostic models of the deforestation process and improve our understanding of the causes of deforesation. Models which result from this research will capture the fine spatial and temporal patterns of deforestation and will be better able to compute future trends in deforestation. This research will greatly improve terrestrial ecosystem and carbon cycle models and help ellucidate the cause of dampened biogenic source terms observed in inter-annual measurements of atmospheric CO2 and O2 for the tropics. Measurements from remote sensing data and socio-econometric modeling of the controls on rates of deforestation and abandonment on an annual basis from 1986 to 1994 will ellucidate the role of land use change as a missing sink for carbon.

OVERALL RESEARCH RATIONALE

Tropical deforestation is an important source of greenhouse gases, but large uncertainties in the exact magnitude exist due to imprecise data on the rates of deforestation in a few key regions of the tropics, particularly Southeast Asia. In recent years there has been much progress in acquiring and analyzing satellite data from Landsat and Spot to better quantify the average annual rate of deforestation over the last 10-20 years. NASA's Landsat Pathfinder project, the UN Food and Agriculture Organization's Tropical Forest Assessment, and the European Union's TREES project have all contributed to improving the measurements of the rate of deforestation using decadal or semi-decadal estimates. The Landsat Pathfinder Project, for instance, estimated the rate of deforestation in Southeast Asia between 1973 and 1985 and 1985 and 1992 using complete inventories of Landsat data at each of these dates.

Although these estimates provide a sound basis for constraining the relative magnitude of the deforestation flux over a timeframe consistent with most previous modeling efforts, it is also important to obtain interannual rates of deforestation to be used in conjunction with new interannual constrained source-sink models (e.g. Ciais et al. 1995, Keeling et al. 1995, Bender et al. 1996, Keeling et al. 1996).

The global budget for sources and sinks of carbon deduced from changes in annual atmospheric CO2 or O2 measurements suggest that the tropics are neither a strong source nor a strong sink (Keeling et al. 1996). Ciais et al. (1995) estimate that the northern tropics are a source, but the southern tropics are a small sink. They propose two explanations for the sink-to-neutral magnitude: (i) an increase in tropical Net Ecosystem Production to offset deforestation sources, and (ii) evidence for a combination of reduced rates of deforestation and increased regrowth of previously cleared land "which underscore the uptake of carbon by recovering forests on land abandoned by shifting agriculture and also suggest reduced clearing rates based on satellite analyses".

Such observations are somewhat inconsistent with interdecadal deforestation data from satellites suggest that tropical deforestation has contributed to a significant net source of carbon. One important explanation is that there are significant interannual differences in the rates of deforestation leading to periods of asynchrony in the relative contribution to the net flux from clearing vs. regrowth. In this scenario two important conditions must be met: (1) large interannual departures in rates of deforestation from the decadal mean values reported by Pathfinder results, and (2) abandonment of land to secondary forests which accumulate carbon is an important part of the deforestation process, accounting for large areas. In years in which deforestation rates are greatly less than the decadal mean, and with the large abundance of areas of secondary succession and forest regrowth due to high rates of abandonment in previous years we would expect to see a significant dampening of the carbon source computed from the decadal mean data alone.

RESEARCH QUESTIONS ADDRESSED BY THIS PROPOSAL

This proposal will be constructed around two overarching research questions:

1. Are the inter-annual dynamics and rates of deforestation and abandonment to secondary forest significantly different than the decadal mean in Southeast Asia, and can this account for a dampening of the biogenic source of carbon apparent in annual observations of atmospheric carbon dioxide and oxygen?

2. Through the integration of socioeconomic and satellite data and the development of dynamic deforestation models, can we improve our understanding of the dynamics of deforestation in the tropics and the various controls (proximate and distant determinants) on rates of deforestation and regrowth and land use transition sequences?

The project is focused on global change research related to the global carbon cycle, and is thus related to the programmatic objectives of NASA's Earth Science Enterprise, but it concentrates heavily on the specific aspects of land use and cover change rather than biogeochemistry. The results of this work will couple to biogeochemistry and carbon cycle models, but will focus on developing new insights into causes of the fine scale spatial and temporal patterns of cover change. We will use empirical observations from satellites and couple these to integrated models. We propose our research around a framework of Case Studies in intensive study sites and regional analysis for large-scale integration of results.

LBA Abstract

Pattern to Process in Amazônia: Measurement and Modeling of the Inter-Annual Dynamics of Deforestation and Regrowth

David L. Skole, Robert T. Walker

INTRODUCTION

This proposal seeks to understand the interannual variability in deforestation and abandonment rates in the Brazilian Amazon region. We propose six Tasks which integrate satellite remote sensing measurements at basin and site scales, field-based case studies at the farm and household scale, and models. We propose to couple our results with other projects and studies under LBA, providing data and models on deforestation rates, its spatial pattern, and regrowth. We pose two questions:

(i) Are the inter-annual dynamics and rates of deforestation and abandonment to secondary forest significantly different than the decadal mean values in Amazonia , and can this account for a dampening of the biogenic source of carbon apparent in annual observations of atmospheric carbon dioxide and oxygen?

(ii) Through the integration of socioeconomic and satellite data and the development of dynamic deforestation models, can we improve our understanding of the dynamics of deforestation and the various controls on rates of deforestation and regrowth?

To answer these question we will measure inter-annual rates of deforestation and regrowth for the whole basin using stratified sampling methods with Landsat data. We then establish intensive case studies using multi-temporal (annual) satellite data at specific sites to estimate transition dynamics and transition probabilities for secondary growth turnover in simple LUCC models. Finally we Conduct field-based case study analyses of the decision-making processes for farmers and other land-managers, using key informant surveys and models. This is new work, not currently funded by another source, but we collaborate with other funded projects to meet our objectives.

RATIONALE

Land-use / land-cover change (LUCC) is an important driver of ecological change in Amazonia. It has a large influence on hydrology, climate, and global biogeochemical cycles (Crutzen and Andreae 1990, Houghton 1991, Houghton and Skole 1990, Salati and Vose 1984, Shukla et al. 1990). Although important, our understanding of Amazonian land cover change is inadequate for three reasons:

(i) we lack accurate measurements of the inter-annual variations in the rate and geographic extent of deforestation and we do not know if interannual variability in deforestation rates significantly influences fluxes in water, energy, carbon, and trace gases.

(ii) we do not know the quantitative importance of secondary growth and its annual variability, nor do we understand the overall dynamics of secondary growth, including its probability distribution function from one region of Amazonia to the next, how fast it regrows, how long it persists before being recleared, how often it is recylced, how land management affects these processes.

(iii) we have a poor understanding of the human and land use factors which control the rates of deforestation and abandonment, and the role secondary growth as part of land use system.

We propose research which will significantly enhance our understanding of tropical land use and cover change by analyzing in fine spatial and temporal detail the dynamics of forest clearing and abandonment in the Brazilian Amazon. We build upon previous research but propose much more detailed analyses than before by exploring the inter-annual variation in deforestation rates and the dynamics of secondary growth, and by investigating the factors which control land use processes at a range of scales from the farm-scale using case studies in the field to the basin scale using demographic and economic statistical databases.

Research Questions. This proposal will be constructed around two research questions:

1.) Are the inter-annual dynamics and rates of deforestation and abandonment to secondary forest significantly different than the decadal mean values in Amazonia, and can this account for a dampening of the biogenic source of carbon apparent in annual observations of atmospheric carbon dioxide and oxygen?

2.) Through the integration of socioeconomic and satellite data and the development of dynamic deforestation models, can we improve our understanding of the dynamics of deforestation and the various controls on rates of deforestation and regrowth?

GOALS AND OBJECTIVES

The overall goal of the research is to improve our understanding of the process of land use and land cover change in Amazonia through an approach which links satellite observations of land cover change at fine spatial and temporal resolution (patterns) to case-study-based analyses of land use changes (processes). We aim to understand what controls the relative magnitude of clearing and abandonment on an annual basis, leading to the development of simple diagnostic LUCC models which could link to carbon and ecosystem process models derived in other parts of LBA.

An important part of this work will be the development of models which track perturbations and responses on an annual basis. This would begin the next generation of completely coupled models, using non-average datasets, satellite measurements, and measures of human disturbance.

These overall goals are consistent with the goals defined in the NRA under Theme 1: Land Cover and Land Use Change:

How we will link the spatial and temporal dynamics of patterns of land-cover change with analyses of the underlying proximate, intermediate, and ultimate determinants of land-use change;

How we will develop new diagnostic and prognostic models of land-cover and land-use change with direct coupling to feedbacks from biophysical processes provided by other components of LBA research;

How we will derive an improved understanding of spatial and temporal scaling, from the farmer to the basin scales; and

How our work contributes directly to the IGBP/IHDP LUCC Focus 1 and Focus 2.

We propose a research effort with the following specific Research Objectives:

Research Objective 1: To measure inter-decadal rates of deforestation and regrowth and its spatial pattern at less than 100 m resolution over the whole using Landsat data from Landsat Pathfinder;

Research Objective 2: To measure inter-annual rates of deforestation and regrowth for the whole basin using stratified sampling methods with Landsat data between the inter-decadal inventories from Objective 1;

Research Objective 3: Amazônia-wide coupling of sociodemographic, agricultural, and econometric data at the municipio level for a suite of specific variables in order to develop land-use change variable sets;

Research Objective 4: Establish intensive case studies using multi-temporal (annual) satellite data at specific sites to estimate transition dynamics and transition probabilities for secondary growth turnover in simple LUCC models;

Research Objective 5: Conduct field-based case study analyses of the decision-making processes for farmers and other land-managers, using key informant surveys and models;

Research Objective 6: Couple empirical results and models of LUCC at the basin and site level to biogeochemical models through collaboration with other teams and utilization of an existing terrestrial carbon model.

Objectives 1, 2, and 3 are analyses at the basin scale. Objective 1 provides insight into the inter-decadal trend in deforestation rates and secondary growth (a synoptic approach). Objective 2 provides through annual sampling an estimate the inter-annual deforestation

rates for the aggregate region; it does not provide a detailed map, but it would elucidate the interannual variation in clearing and abandonment rates. Objective 3 utilizes standard Brazilian demographic, agricultural and economic census data in conjunction with the satellite analysis from Objective 1 at the municipio level to investigate basin-wide relationships between land use change and land cover change for basin scale models.

Objectives 4 and 5 are analyses at the Study Site scale. Objective 4 quantifies, through satellite measurements, detailed land cover transition sequences, transition probabilities, and interannual LUCC dynamics across a range of environments and situations to develop a process-level understanding of the land management controls on clearing and abandonment at the field level. Objective 5 couples the satellite observations to field-based surveys to develop diagnostic models of the LUCC process, which can be scaled to the basin in conjunction with Objectives 1-3.

Research Objective 6 is a synthesis effort which ties the LUCC analyses and models to biogeochemistry, in particular carbon models, to explore the significance of interannual variability. We will complete in collaboration with other members of the LBA Science Team.

LCLUC Abstract

Land-Cover and Land-Use Change in the Southern Yucatan Peninsula Region

<http://earth.clarku.edu/lcluc>

B. L. Turner II

The project seeks to improve understanding of global land-use/cover change through a study of the southern Yucatán peninsular region (SYPR). SYPR contains one of the largest expanses and oldest tropical forest in the Americas outside Amazonia. Akin to the Amazonia frontier, SYPR has witnessed significant changes in its land uses and land covers over the past 30 years registered in a boom-bust pattern. Following the international science plan on Land-Use/Cover Change (LUCC) of the IGBP-IHDP, this project seeks to contribute to NASA,s LCLUC program specifically by: (i) identifying the regional dynamics and their linkages that are driving land-use/cover change in SYPR, both documenting in detail and modeling the land-use changes (Focus 1); and (ii) extending these findings to the land-cover changes that have occurred there, leading to new versions of probbility (e.g., Markov-chain) analysis for near- to mid-term projections of land-use and land-cover change (Focus 2).

Focus 1 identifies the "regional situation" or basic character of land-use/cover change (tropical deforestation and agricultural development and expansion) over the past 30 years as detailed through the transforming processes acting on the land managers. The evidence will be derived from analysis of historical data (e.g., census documents, local land-use maps), structured and informal surveys with current land managers, and observations. The results will provide the details (narrative) of the history of land-use change, a test of certain critical variables required for a new, generic LCLUC model, and the development of a spatially explicit, SYPR -LCLUC model linked to remotely sensed imagery.

Focus 2 links land uses with land covers, extends the spatial coverage of both over the entire region, and develops new generation of empirical probability (Markov-chain) models useful for LCLUC analysis. The use-cover linkage and spatial reach is made through the use of remotely sensed imagery (Landsat TM data) and geographical information systems. The evidence generated informs the development of „probability‰ models based on past changes but improved through the addition of spatial explicitness (where the change takes place) and the consideration of the type of manager/user in charge of the land (the socioeconomic condition/character of the land managers).

Both approaches will be linked to field studies of ecosystem fragmentation and diversity issues, conducted by Harvard Forest and ECOSUR-Chetumal. The aim is to link explicitly land-use changes with its land-cover impacts as defined, and to assess the biophysical impacts of the cover changes on land use and management strategies.

The Focus 1 and 2 approaches not only provide understandings of LCLUC in SYPR, they can be compared and merged. Comparisons provide insights about the robustness of two kinds of models, indicating in what conditions (e.g., temporal scales) Markov based and behavioral and structural based models are useful, as well as role of biophysical impacts on both. And, by linking Focus 1 models to the pixel and Focus 2 pixels to the social and biophysical dynamics, ultimately the two approaches merge into hybrid model. The outputs of the study provide a basis for monitoring and assessing LCLUC in SYPR as well as for projecting scenarios of change, both major needs of the global change community of researchers. Finally, a longer term aim of the

project is to compare results with those elsewhere in the tropical Latin American transect of the IGBP to determine the value added or lost by "scaling up" to a pan-Latin American model˜a central need of the human dimensions program on LUCC.

The work will link various major units in the global change community. The SYPR involves research: (i) at the GPMI, Clark University, on land-use/cover change models of various kinds (Focus 1 and 2); (ii) at ECOSUR-Unidad Chetumal on various land-use and -cover analyses of the region (the unit seeks to develop long-term monitoring and assessment of LCLUC in this tropical forest realm); (iii) at Harvard Forest on land-cover change; (iv) in cooperation with Carnegie Mellon University's "Center for Integrated Study of the Human Dimensions of Global Change" on advances in LCLUC modeling and its place within integrated studies more generally; and finally, (v) comparisons with Focus 1 modeling efforts in Costa Rica by Wageningen Agricultural University (Netherlands) and in Amazonia by the University of New Hampshire and University of Florida.

LCLUC Abstract

Quantifying Grassland-to-Woodland Transitions and the Implications for Carbon and Nitrogen Dynamics in the Southwest United States

<http://cires.colorado.edu/wessman/research/lcluc/>

Carol A. Wessman

Environmental impacts associated with slashing and burning of tropical rain forest have received considerable attention and are the focus of much current research. However, reductions in biomass associated with deforestation are in stark contrast to vegetation changes occurring on many arid/semi-arid rangelands, where grasslands and savannas are being replaced by shrublands and woodlands. Though not well quantified on a global scale, this vegetation change has been widely reported in tropical, temperate and high-latitude rangelands worldwide (Archer 1994). These changes in vegetation structure are relevant to global change as (a) they may reflect historical shifts in climate and land use and (b) they may influence biodiversity, productivity, above- and belowground carbon and nitrogen sequestration and biophysical aspects of land surfacePatmosphere interactions.

Our overall goal is to investigate how changes in the relative abundance of herbaceous and woody vegetation affect carbon and nitrogen dynamics across topoedaphically diverse landscapes. Grassland-to-woodland transitions occur at small scales relative to the spatial resolutions of current and planned sensors having regional- to continental-scale monitoring capabilities (e.g. AVHRR, MODIS). The functional properties of heterogeneous savannas and shrub/woodlands will likely go undetected by single indices such as the NDVI as structural and background factors confound the remotely sensed signal. We propose to refine and apply a sub-pixel analytical technique (spectral mixture analysis) to determine grass-woody fractional cover. By linking actual land-cover composition with a process-based ecosystem model, Century, we will generate explicit predictions of the C and N storage in plants and soils resulting from changes in vegetation structure. We will base our studies on a grassland-to-woodland chronosequence in Texas which represents the range in vegetation structure expected in the southwestern United States and having functional counterparts in Central and South America, Africa, Asia and Australia. Our specific objectives will be to (1) continue development and test applications of spectral mixture analysis across grassland-to-woodland transitions; (2) quantify temporal changes in plant and soil C and N storage and turnover for remote sensing and process model parameterization and verification; and (3) couple landscape fraction maps to Century to observe biogeochemical dynamics under changing landscape structure and climatological forcings. We will utilize high spectral and spatial resolution data (AVIRIS, TM, and Lewis) to establish landscape-level predictions and then extrapolate to the southwestern United States using MODIS and readily available climate data.

Land Cover Land Use Change

Product Results of Type Abstract>LCLUC

1998	Hierarchical Investigation of Socioeconomic Drivers of Decadal Scale Land-Cover Changes in the Upper Midwest	Daniel Brown
1998	Characterizing Land Cover Heterogeneity and Land Cover Change from Multisensor Satellite Data	Ruth DeFries
1998	Coupling Land Use and Land Cover Changes, and Ecosystem Processes in Miombo Woodlands	Paul Desanker
1998	Accuracy Assessment of the IGBP Fast-Track 1 Km Land Cover Data Set	John Estes
1998	Time Scales of Land Use Change and Export of N and P from Coastal Plain Basins to the Coastal Zone	Thomas Fisher
1998	Causes and Consequences of Land Cover in a Greater Ecosystem: Trend Assessment, Monitoring, and Outreach	Andrew Hansen
1998	Modeling Carbon Dynamics and Their Economic Implications in Two Forest Regions: Pacific Northwestern USA and Northwestern Russia	Mark Harmon
	Modeling Carbon Dynamics and Their Economic Implications in Two Forest Regions: Pacific Northwestern USA and Northwestern Russia	Mark Harmon
1998	Land-cover Change in the Great Plains: Predicting Impacts of Regional Forest Expansion on Biogeochemical Processes	Loretta Johnson
1999	Effects of the Development of the Baikul-Amur Mainline Railroad on Patterns of Boreal Forest Cover and Carbon Fluxes in Southern Siberia	Eric Kasischke
1998	Modeling and Forecasting Effects of Land Use Change in China Based on Socioeconomic Drivers	Robert Kaufmann
1998	Land-Use and Land-Cover Change in Sonora, Mexico: Trajectories of Agricultural Intensification and Consequences for Non-Agricultural Ecosystems	Pam Matson
1998	The Role of Land-Cover Change in the High Latitude Ecosystems: Implications for the Global Carbon Cycle	David McGuire
1998	The Dynamics of a Semi-Arid Region in Response to Climate and Water-Use Policy	John Mustard
1998	Assessing Future Stability of US High Plains Landcover: Integration of Process Modeling with Landsat, In situ Modern and Paleoclimatic Data	Jonathan Overpeck
	Deforestation and Degradation in Southern and Central African Savannas	Stephen Prince
1999	Soils, Water, People and Pixels: A Study of Nang Rong	Ronald Rindfuss
1998	Study of Land-Use and Deforestation In Central and West African Tropical Forest Using High Resolution SAR Satellite Imagery	Sasan Saatchi
1998	Time-Series Land Cover/Land Use Change and Socio-Economic Driving Forces in the Northern Peten Region, Guatemala	Steven Sader

1998	**Case Studies and Diagnostic Models of the Interannual Dynamics of Deforestation in Southeast Asia: Is the Missing Sink for Carbon in Land Cover Change**	David Skole
1998	**Land-Cover and Land-Use Change in the Southern Yucatan Peninsula Region**	B. Turner II
1998	**Quantifying Grassland-to-Woodland Transitions and the Implications for Carbon and Nitrogen Dynamics in the Southwest United States**	Carol Wessman

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Land Cover Land Use Change

Product Results of Type Abstract>LBA

1999	**Agricultural Colonization in the Ecuadorian Amazon: Population, Biophysical, and Geographical Factors Affecting Land Use/Land Cover Change and Landscape Structure**	Richard Bilsborrow
	Anthropogenic Landscape Changes and the Dynamics of Amazoniam Forest Biomass	William Laurance
	Human and Physical Dimensions of Land Use/Cover Change in Amazonia: Forest Regeneration and Landscape Structure	Emilio Moran
	Pattern to Process in Amazonia: Measurement and Modeling of the Inter-Annual Dynamics of Deforestation and Regrowth	David Skole

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Land Cover Land Use Change

>Disturbance

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Land Cover Land Use Change

Product Results of Type Abstract>Global

1998	**Characterizing Land Cover Heterogeneity and Land Cover Change from Multisensor Satellite Data**	Ruth DeFries
1998	**Accuracy Assessment of the IGBP Fast-Track 1 Km Land Cover Data Set**	John Estes

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[Microsoft][ODBC SQL Server Driver][SQL Server]Syntax error converting the nvarchar value 'APR' to a column of data type int.

/newlcluc/products/results.asp, line 24

Land Cover Land Use Change

>1997

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LCLUC NRA-99 Selectees

The Land Cover and Land Use Change NRA-99 had two elements:
1) Human and natural disturbance and the implications for carbon dynamics, and
2) Development of remote sensing techniques and data sets that could lead to operational forest monitoring systems (Global Observation of Forest Cover - GOFC)

143 proposals have been received. The proposals were sent for mail review, and were subsequently evaluated by a peer review panel of 17 scientists working in the field of Land Cover and Land Use Change that met January 11-13, 2000.

At this stage in the program we are investing in a new-start disturbance research activity and a strategic contribution to GOFC:

- strengthening the NASA carbon program to include disturbance
- laying the science foundation for the proposed 'Recovery' mission
- providing a contribution to GOFC (IGOS-P Carbon Theme - forest cover monitoring, fire and biophysical characteristics)
- developing regional and global data sets
- researching new methods
- transitioning research to the operational domain and using these data and methods for carbon research.

Disturbance Selectees

Susan Conard (USFS) Estimating and Monitoring Effects of Area Burned and Fire Severity on Carbon Cycling, Emissions, and Forest Health and Sustainability in Central Siberia

Andrew Hansen (Montana State U.) Monitoring Forest Response to Past and Future Global Change in Greater Yellowstone

Michael Binford (U.Florida) Land-Use and Land-Cover Change: Decadal-Scale Dynamics of Land Ownership Land Management and Carbon Storage Patterns in the Southeastern Lower Coastal Plain Region of the U.S.

Janet Franklin (San Diego State U.) Operational Monitoring of Alteration in Regional Forest Cover Using Multitemporal Remote Sensing Data

Marc Imhoff (NASA GSFC) Measuring Human Impacts on the Biodiversity of Ecosystems

Chris Elvidge (NOAA NGDC) Development Sprawl Impacts on the Terrestrial Carbon Dynamics of the United States

John Pastor (U.Minnesota) Mapping and Modeling Forest Change in a Boreal Landscape

Global Observations of Forest Cover (GOFC) Selectees

Regional Forest Monitoring and Characterization Studies, Collaboration with GOFC Regional Networks

Nadine Laporte (UMD) An Integrated Forest Monitoring System for Central Africa

Jiaguo Qi (Michigan State U.) GOFC Data and Information for Tropical Forest Assessment and Management

Paul Desanker (U. Virginia) Operationalizing GOFC in the Miombo Region and Questions of Carbon: Miombo Region a Source or Sink?

North American Land Cover and Fire Studies

Peng Gong (UC, Berkeley)* Development of a Long-term Inventory of Fire Burned Areas and Emissions of North America's Boreal and Temperate Forests

Wei Min Hao (USFS)* Biomass Burning in the United States: Past, Present, and Future

Tom Loveland (USGS) The Spatial and Temporal Dimensions of Contemporary U.S. Land Cover and Land Use Change and Implications for Carbon Dynamics

Josef Cihlar (CCRS)** Satellite Observation of Boreal Land Cover: Methods, Data Sets and Applications

* Combined into one project
** Foreign (Canada)

SAR Studies and Datasets

Guoqing Sun (U. Maryland) Monitoring Forest Dynamics in Northeastern China in Support of GOFC

Bruce Chapman (JPL) The Development of a Fine Resolution, Continental Scale Forest Monitoring System Using SAR Imagery

Kyle McDonald (JPL) Monitoring Boreal Landcover and Ecosystem Dynamics at Regional Scales using Integrated Spaceborne Radar Remote Sensing and Ecological Modeling.

Advanced Method Development

Ruth DeFries (U. Maryland) Towards Methodologies for Global Monitoring of Forest Cover Characteristics with Coarse Resolution Data

John Townshend (U. Maryland) Improvements in Landsat Pathfinder methods for monitoring tropical deforestation and their extension to extra-tropical areas

Land Cover Land Use Change

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Land Cover Land Use Change

MEETINGS AND PROGRAM ANNOUNCEMENTS

- **Research Announcements**
- **LCLUC Annual Science Team Meetings**
- **Recent Events**
- **Past Events**

Research Announcements

- A new LCLUC NRA is planned for late Summer, 2000.
- NRA-99-OES-06 Selections are announced. (Acrobat PDF)

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LCLUC Annual Science Team Meetings:

- The Fourth NASA LCLUC Science Meeting, April 3-5, 2000, Sheraton Reston, Virginia.
- The Third NASA LCLUC Science Meeting, May 18-21, 1999, Airlie Conference Center, Warrenton, Virginia.
- The Second NASA LCLUC Science Meeting, March 29 to April 1, 1998 Airlie Conference Center, Warrenton, Virginia.
- The First NASA LCLUC Science Meeting, April 8-10, 1997, Airlie Conference Center, Warrenton, Virginia.

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Recent Events: Special session on the effects of land use change at the Estuarine Research Federation Meeting in New Orleans, USA, 25-30 Sept 1999. The session focused on: "Historical changes in land use and effects on nutrient delivery to estuarine and coastal waters." This will be session 1.E under the Program Topic: Thematic Session - Eutrophication, chaired by Thomas R. Fisher, Horn Point Lab, University of Maryland.

- Patterns and Processes of Land Use and Forest Change in the Amazon. 48th Annual Conference Sponsored by the Center for Latin American Studies University of Florida. March 23-26, 1999, Gainesville, Florida.

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Past Events: Earth's Changing Land GCTE-LUCC Open Science Conference was held in Barcelona, Spain from March 14-18, 1998.

The LUCC Data Requirements Workshop, organized by IGBP/IHDP LUCC and IGBP-DIS, was held in Barcelona, Spain from November 11-14, 1997.

The START/NAFCOM Workshop on Land Use and Land Cover Change (LUCC) in West/Central Africa was held in Accra, Ghana from November 3-5, 1997

The LUCC/START/DIS Workshop on Land Uses and Land-Cover Change in Miombo Ecosystems was held in Lusaka, Zambia from October 26-November 1st, 1997.

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4th NASA Land Cover Land Use Change Science Team Meeting
Sheraton Hotel, Reston, Virginia, April 3 - 5
Agenda Final Draft

Based on the comments from the last meeting I have tried to be a little more creative with the upcoming LCLUC ST meeting, avoiding parallel sessions.
We do have a number of programmatic objectives for this meeting which I would like to see accomplished:

1) Presentation of final results from the Round 1 LCLUC projects
2) Presentation of preliminary results from the Round 2 LBA projects
3) Brief the Science Team on recent developments in ESE and LCLUC
4) Brief the team on status of Landsat7 and Landsat Follow-on programs
5) Develop plans for packaging the results in an LCLUC Book

In advance of the meeting - I would like the PI's to update (or in some cases produce!) their 'Significant Results' Overheads that were generated after the last meeting as 2 –3 vugraphs and submit these as power point files to Lynn Hedlund (lhedlund@virginia.edu), prior to the meeting – a full set of these results will then be provided to the PI's at the meeting to help in the synthesis.

I am hoping that each of the LCLUC studies will provide a paper summarizing their results in detail later in the year for inclusion in the NASA LCLUC Book. We can develop a workable schedule at the meeting.

I would like to have the LBA P.I.'s present their intermediate results as (20 minute) project presentations on Day 1 (in the way that we did at the last meeting – i.e. objectives of the research, intermediate results, mid course corrections and revised deliverables and schedule).

But rather than have an endless series of project presentations from the Round 1 studies and having circulated the 'Significant Results' material in advance – we can use the meeting to look at the research from a more thematic perspective, with each Round 1 study presenting more detailed material from their research according to a research theme – I have identified the following themes:

quantifying the pattern of LCLUC (observations and assessments),
modeling the process of LCLUC (process studies),
quantifying the impacts of LCLUC (impact studies).

We would then have a breakout-session to summarize and synthesize these findings – the breakout sessions will hopefully lead to some synthetic chapters for the LCLUC Book.

I have tentatively put PI's in different sessions based on my perception of where they are focusing and in response to some email traffic.

Agenda - Final Draft

Monday April 3 *– Plenary*

Introduction 9am START
Welcome and Objectives of the Meeting – Garik Gutman (LCLUC Program Manager) – (20 mins)
State of the LCLUC Program – Chris Justice (LCLUC Project Scientist) – (20 mins)
Plans for the LCLUC Book – Chris Justice - (10 mins)

LBA Session - Preliminary Results Presentations (20 minutes each + questions)
LBA Status report – Michael Keller 15mins
William Laurance
Richard Bilsborrow
Emilio Moran
Bob Walker

12.30 Lunch

Monday 3 April PM – ***Plenary Start 1.30pm***

LBA Session *Continued* (20 minutes)
Dave Skole
Dan Nepstad
Open Discussion

LCLUC Round 1 Theme Presentations (20 minutes)

Quantifying Patterns of LCLUC (Observations and Assessments)
Dan Brown
Paul Desanker
Tom Fisher
Ruth DeFries
Olga Krankina (*Mark Harmon, PI*)
Sasan Saatchi
Dave Verbyla

End of Session 5.30pm

Tuesday April 4 – Plenary Start 9am

Modeling the Process of LCLUC (Process Studies) (20 mins)
Jackie Geoghegan (Co-PI, SYPR Project)

Steve Sader
Ron Rindfuss
Dave Skole (S.E. Asia)
Robert Kaufmann

Quantifying the Impacts of LCLUC (Impact Studies) (20 mins)
Changsheng Li
Andy Hansen
Robert Webb (*Jonathon Overpeck, PI*)

Lunch – 12.30pm

Tuesday April 4 - ***Plenary Start 1.30pm***

Greg Asner (*Carol Wessman, PI*)
Dave McGuire
Eric Kasischke / Kathleen Bergen
Pam Matson
John Mustard
Loretta Johnson
Steve Prince
Navin Ramankutty
Steve Running

End 5.30pm

Invited Speaker 8.00 – 9.00pm, *Plenary*
Anthony Janetos (WRI) – 'Carbon, Land Use and the IPCC'

Wednesday April 5 – Plenary Start 9am

Status of the Carbon Program
Lisa Dilling (NOAA) – Status of the Interagency Carbon Initiative (20 mins)

Jack Kaye (NASA HQ) – The NASA Contribution to the Carbon Initiative (20 mins)
Discussion

Breakout Groups 10am – 12.30pm

Breakout Discussion Groups on LCLUC Scientific Synthesis: Advances in the Study of Land Cover and Land Use Change

Observations and Assessments (Chair:Ruth DeFries, Rapporteur:Paul Desanker)
LCLUC Process Studies (Chair:Jackie Geoghegan, Rapporteur: Eduardo Brondizio)
Quantifying Impacts of LCLUC (Chair:John Mustard, Rapporteur:Steve Prince)

LCLUC and Carbon Budget (Chair:Dave Skole, Rapporteur:Dave Kicklighter)
Future Directions for LCLUC (Chair:Billie Turner, Rapporteur:Pam Matson)

Lunch 12.30pm

*April 5 Wednesday PM – **Plenary 1.30pm***

John Townshend – Global Observation of Forest Cover (20 mins)

Darrel Williams – Landsat 7 and Landsat Follow-on Status (20 mins)

Report Back from Breakout Group Chairs (15 mins) :
Methods,
Process Models,
Impacts
LCLUC and the Carbon Budget
The Way Forward for LCLUC
Discussion

Chris Justice – Meeting Summary and Recommendations (20 mins)

Garik Gutman - Forthcoming LCLUC NRA's and Next Steps for the LCLUC Program (20 mins)

Finish – 4.30pm Wednesday

3rd NASA LCLUC Science Team Meeting,

Airlie House, Warrenton, Virginia May 18-21, 1999

Meeting Agenda

Programmatic

Background

Global Studies

North America

Russia

Alaska

China

Central and South America

Central and Southern Africa

Middle East

Amazon Basin

Southeast Asia

3rd LCLUC Science Team Meeting

Airlie House, Warrenton, Va

May 18-21 1999

May 18th Day 1, 9.00 am

Plenary Session - The Jefferson Room
Welcome and Objectives of the Meeting – C. Justice / J. Ranson
Programmatic - LCLUC the first years: a programmatic retrospective – A. Janetos
Programmatic - Current Status of the LCLUC program – C. Justice

Concurrent Session 1A – The Jefferson Room
10 – 10.45 Early Results - The dynamics of a semi-arid region in response to climate and water use policy – J. Mustard
10.45- 11.30 Early Results – Assessing future stability of US High Plains landcover integration of process modeling with Landsat, in-situ, modern and paleoclimate data - J. Overpeck
11.30 – 12.30 Identifying the significant results, new and improved methods, emerging theories and policy implications from the case studies: discussion. Co Chairs: A. Janetos / D. Brown

Concurrent Session 1B – The Audubon Room (located in auxiliary building)
10 – 10.45 Early Results - Land Cover Change in the Great Plains: predicting impacts of regional forest expansion on biogeochemical processes – L. Johnson
10.45- 11.30 Early Results – Quantifying Grassland to Woodland Transitions and the implications for carbon and nitrogen dynamics in the Southwest United States – S. Archer
11.30 – 12.30 Identifying the significant results, new and improved methods, emerging theories and policy implications from the case studies: discussion. Co Chairs: P. Matson / T. Fisher

LUNCH 12.30 – 1.30 The Airlie Room

May 18th Day 1, 1.30pm

Plenary Session - The Jefferson Room
1.30 – 1.50 pm Programmatic - Land use change and policy implications – A. Janetos
1.50 – 2.10 pm Programmatic – The IPCC Report Structure and the Land Cover Chapter – R. Houghton
2.10 – 2.30 pm Programmatic – The USGCRP Carbon Cycle Initiative and Land Use Change – L. Dilling /E.Spiker

Concurrent Session 2A – The Jefferson Room
2.30 – 3.15 Early Results –Modeling carbon dynamics and their economic implications in two forest regions: pacific northwestern USA and northwestern Russia – J. Kerkvliet
3.15 – 4.00 Early Results – Effects of the development of the Baikal Amur mainline railroad on patterns of boreal forest cover and carbon fluxes in southern Siberia – E. Kasischke
4.00 – 4.45 Early Results – The role of land-cover change in high latitude ecosystems: implications for the global carbon cycle – D. McGuire - MOVE to Thursday am - Concurrent Session 5B-10.45am
4.00 – 5.30 Identifying the significant results, new and improved methods, emerging theories and policy implications from the case studies: discussion. Co Chairs: R. Houghton / D. Kicklighter

Concurrent Session 2B – The Audubon Room
2.30 – 3.15 Early Results – Modeling and forecasting effects of land use change in China based on socioeconomic drivers – R. Kaufmann
3.15 – 4.00 Early Results –Time series forest change, land cover/land use conversion and socio-economic driving forces in the Northern Peten District, Guatemala – D. Hayes
4.00 – 5.30 Identifying the significant results, new and improved methods, emerging theories and policy implications from the case studies: discussion. Co Chairs: R. DeFries / S. Archer

DINNER 6.30pm – The Airlie Room

7.30 – 8.15 After Dinner Speaker (The Jefferson Room) – NSF and Land Cover and Land Use Change: status and future directions - Tom Baerwald

Day 2. May 19, 9.00 am

Plenary Session – The Jefferson Room
9.00 – 9.20 Meeting Report - Integrating social, ecological and remote sensing information on secondary growth – R. Walker
9.20 – 9.40 Meeting Report – Amazon LCLUC Pattern to Process – C. Wood
9.40 – 10.00 Programmatic – New developments in the IGBP/IHDP LUCC program – E. Moran
10.00 - 10.10 Programmatic - Upcoming Amazon LCLU meeting announcement - Foster Brown

Concurrent Session 3A - The Jefferson Room
10.00 - 10.45.Early Results – Land cover and land use change in southern Yucatan Peninsular Region – B. Turner
10.45 – 11.30 Land Use and Land Cover Change in Sonora, Mexico: trajectories of agricultural intensification and consequences for non-agricultural systems – P. Matson
11.30 – 12.30 Identifying the significant results, new and improved methods, emerging theories and policy implications from the case studies: discussion. Co Chairs: R. Walker / T. Stone

Concurrent Session 3B – The Studio
10.00 – 10.45 Early Results – Deforestation and degradation in Southern and Central Africa Savannas – S. Prince
10.45 – 11.30 Early Results – Coupling land use and land cover change and ecosystem processes in Miombo Woodlands – P. Desanker
11.30 – 12.30 Identifying the significant results, new and improved methods, emerging theories and policy implications from the case studies: discussion. Co Chairs: R. Rindfuss / L. Johnson

LUNCH 12.30 – 1.30 **The Airlie Room**

Day 2. May 19, 2.00pm

Plenary Session – The Jefferson Room 2.00 – 3.00pm
Meeting Report – Fire Management in African Savannas – P. Frost
Research Presentation – Deforestation Dynamics on the Bolivian Frontier – S. Hecht

Concurrent Session 4A – The Jefferson Room
3.00 – 3.45 Early Results – The Process of Land Cover and Land Use Change in Central Africa – D. Wilkie
3.45 – 4.30 Early Results – Study of land use and deforestation in Central African Tropical Forests using high resolution SAR satellite imagery – S. Saatchi
4.30 – 5.30 Identifying the significant results, new and improved methods, emerging theories and policy implications from the case studies: discussion. Co Chairs: R. Bilsborrow / C. Dobson

Concurrent Session 4B – The Studio
3.00– 3.45 Early Results – Case studies and diagnostic models of the interannual dynamics of deforestation in Southeast Asia – D. Skole
3.45 – 4.30 Early Results – Soils, water, people and pixels: a study of Nang Rong – R. Rindfuss
4.30 – 5.30 Identifying the significant results, new and improved methods, emerging theories and policy implications from the case studies: discussion. Co Chairs: R. Kaufmann / C. Wood

DINNER 6.30pm – **The Airlie Room**

7.30pm After Dinner Presentation - OSTP

Day 3, May 20th

Plenary Session – The Jefferson Room
9.00 – 9.30 Programmatic – The GOFC Project and the role of LCLUC – J. Townshend
9.30 – 10.00 Programmatic – An assessment of the availability and utility of microwave data for the study of land use and land cover change: a review – G. Sun

Concurrent Session 5A – The Jefferson Room
10.00 – 10.45 Early Results – Hierarchical investigation of socioeconomic drivers of decadal scale land cover changes in the upper Midwest – D. Brown.
10.45 – 11.15 Early Results – Causes and Consequences of land cover in a Greater Ecosystem: trend assessment, monitoring and outreach – A. Hansen
11.15 – 12.00 Identifying the significant results, new and improved methods, emerging theories and policy implications from the case studies: discussion. Co Chairs: S. Prince / J. Kerkvliet

Concurrent Session 5B – The Studio
10.00 – 10.45 - Early Results - Characterizing land cover heterogeneity and land cover change from multi-sensor satellite data – R. DeFries
10.45 – 11.15 - Early Results – The role of land-cover change in high latitude ecosystems: implications for the global carbon cycle – D. McGuire
11.15 – 12.00 Identifying the significant results, new and improved methods, emerging theories and policy implications from the case studies: discussion. Co Chairs: C. Woodcock /P. Desanker

LUNCH 12.00 - 1.00 – **The Airlie Room**

Plenary Session – The Jefferson Room

1.00 – 1.30 Programmatic – The direction of NASA ESE and the role of LCLUC - J. Kaye
1.30 – 2.00 Research Presentation – Climate sensitivity of the Middle East landscape - R. Smith

2.00 - 2.15 Packaging early results for the NASA LCLUC program – C. Justice

2.15 – 4.00 **Co Chairs summary reporting of the significant results, new and improved methods, emerging theories and policy implications from the case studies from the concurrent sessions – Presentation and Discussion**

Concurrent Session 4.00 - 5.30
5A **Synthesis Group** (The Jefferson Room) - developing a synthesis of program findings - Co Chairs – B. Turner / D. Skole

5B **Packaging Group** (The Studio) –packaging of program results – Co Chairs – J. Ranson / S. Archer

DINNER 6.30 – The Airlie Room

7.30 – 8.15 Possible after dinner speaker (The Jefferson Room) -

Day 4, May 21st

Plenary Presentation 9.00 – 12.00 – The Jefferson Room

9.00 – 9.30 Programmatic - The Landsat 7 Program: status report – J. Irons
9.30 – 10.00 Programmatic - Future Satellite Missions Relevant for LCLUC – J. Ranson

10.00 – 10.20 Synthesis of Findings – group report back - Skole / Turner

COFEE BREAK

10.30 – 10.40 Packaging the Results – group report back - Ranson / Archer

10.40 – 11.40 Programmatic - Future science directions and priority focus areas for the NASA LCLUC program: towards the next LCLUC NRA: ideas and open discussion – Chris Justice / Jon Ranson

11.40 – 12.00 Programmatic – Next steps for the LCLUC Program and Action Items from the meeting – Chris Justice

12.00 Close of Meeting, Lunch and DEPARTURE

Programmatic

LCLUC the first years: A Programmatic Retrospective - A. Janetos

Current Status of the LCLUC program- C. Justice

New developments in the IGBP/IHDP program - E. Moran

Land use change and policy implications - A. Janetos

The GOFC Project and the role of LCLUC - J. Townshend

The Landsat 7 Program: Status Report - J. Irons

Future Satellite Missions Relevant for LCLUC - J. Ranson

Packaging results and next steps for the NASA LCLUC program - C. Justice

Land-Cover and Land-Use Change: Retrospective

Tony Janetos

World Resources Institute

Land-Cover and Land-Use Change: Program Vision

- Capability to perform repeated global inventories from space
- Evaluate consequences of observed change

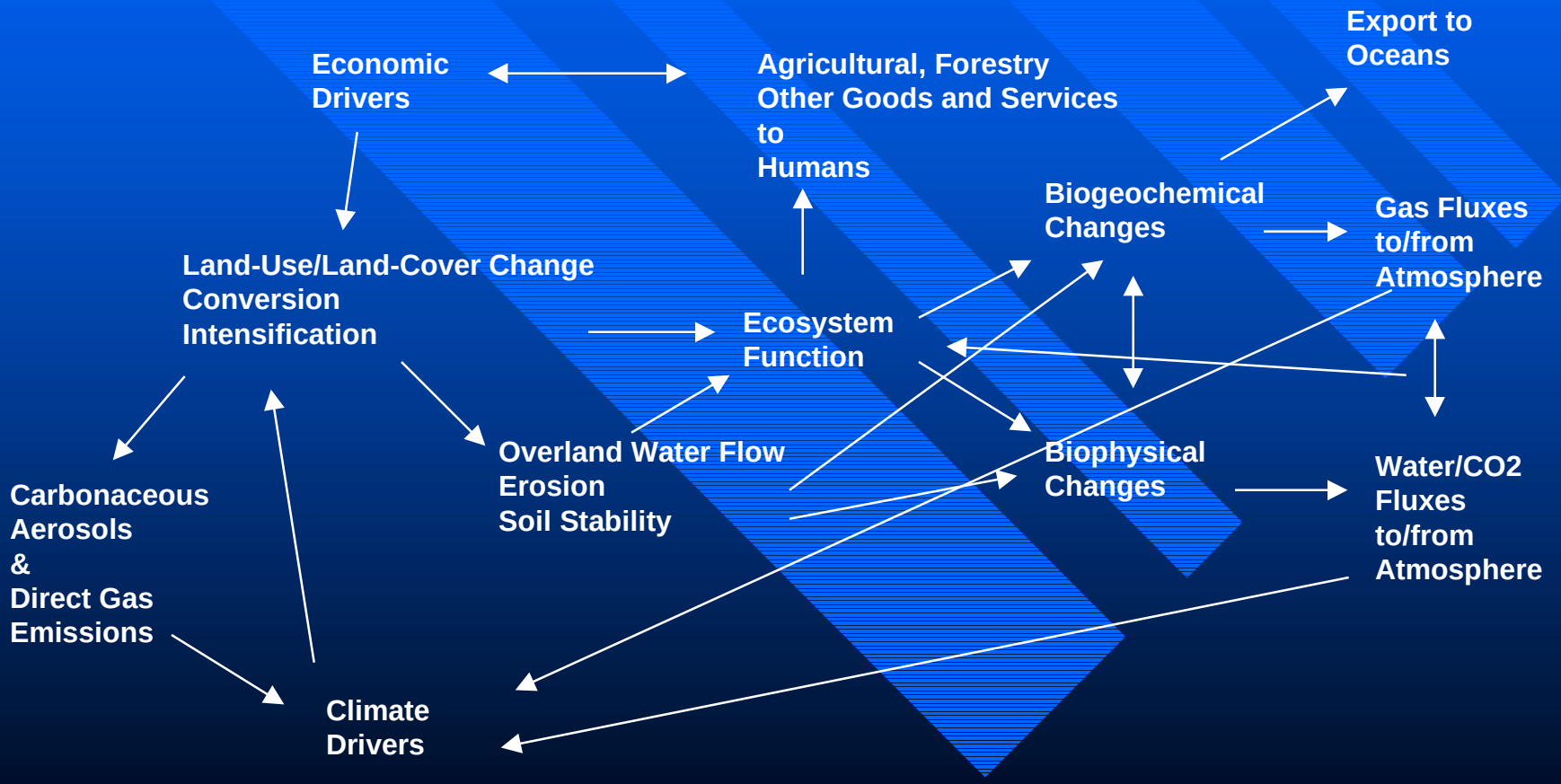
Land-Cover and Land-Use Change: Program Goals

- Land-cover conversion
  - Identify current distribution of land-cover types
  - Track conversion to other land-cover types
  - Primary interest in conversion of forest ecosystems to other types
- Land-use intensification
  - Understand consequences of intensified management of agricultural and agroforestry systems in tropics and sub-tropics
  - Measure the long-term *in situ* degradation of forest ecosystems

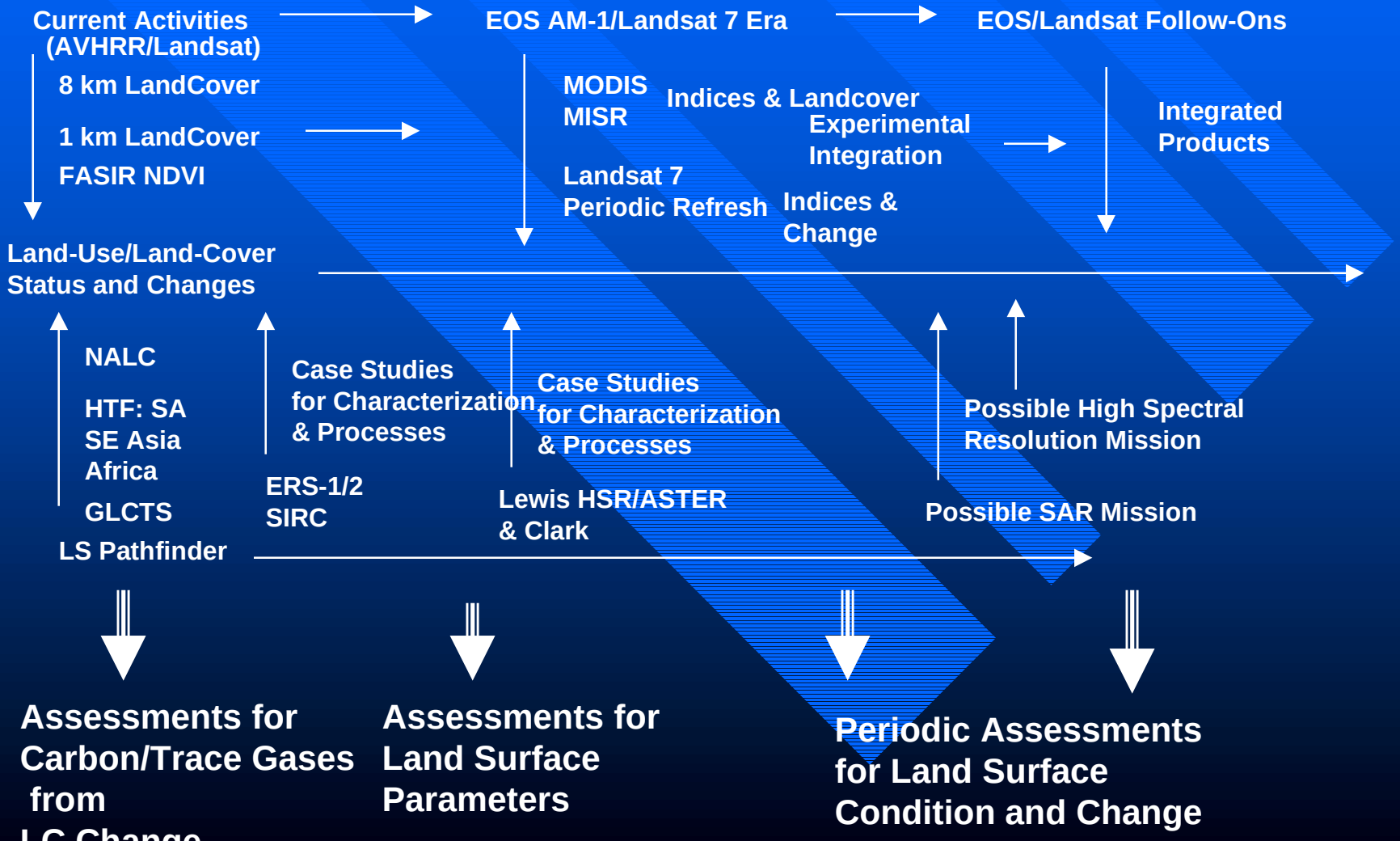
Land-Cover and Land-Use Change: Program Goals

- Verification
  - Understand consequences of international agreements
  - Investigate forestry and agriculture in temperate and boreal climates
- Modeling
  - Develop techniques to incorporate actual land-cover

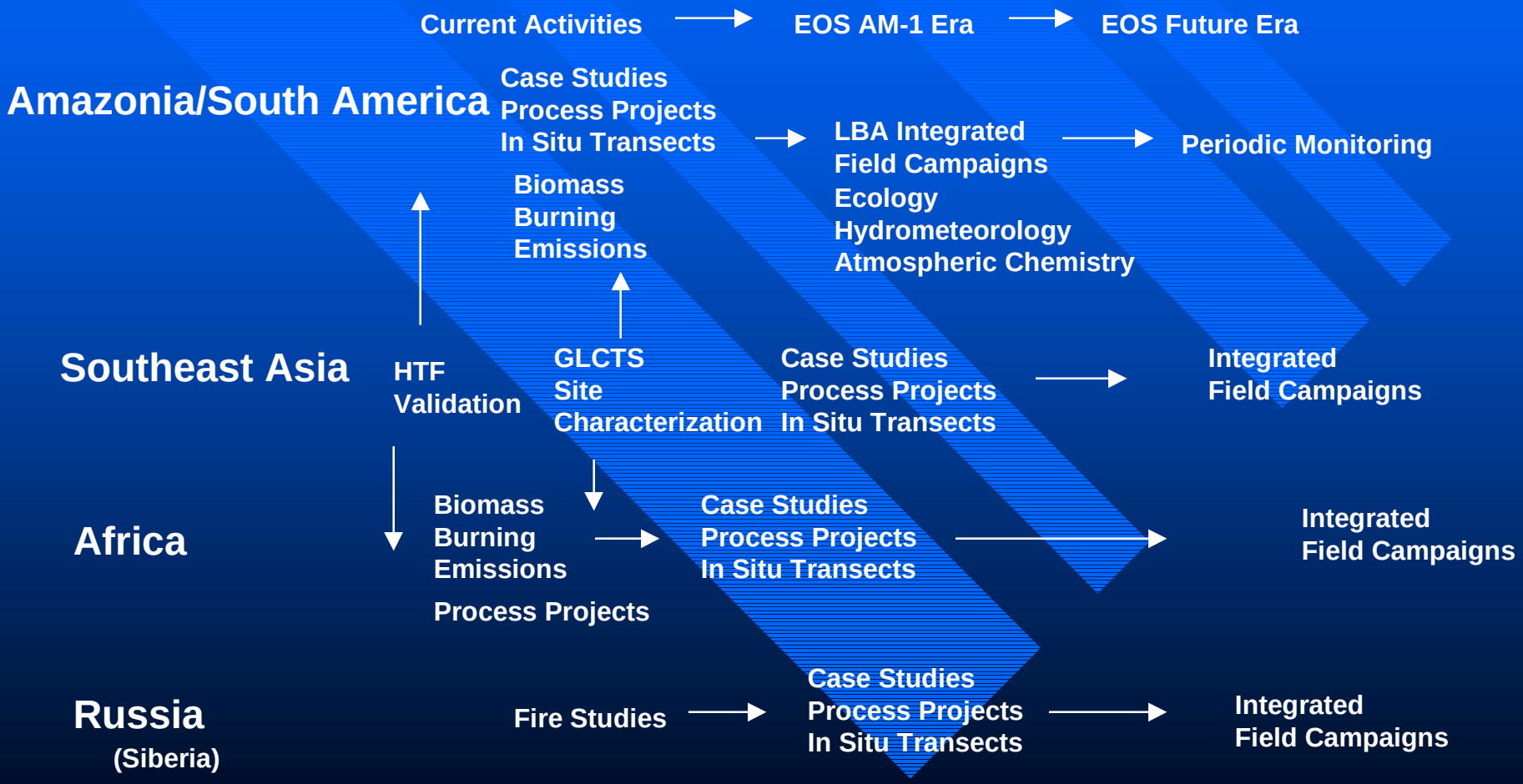
Interactions of Land-Cover/Land-Use Change



Satellite Studies & Assessments



Land-Cover/Land-Use Change: Field Studies & Campaigns



Land-Cover and Land-Use Change: Selected Accomplishments

- Deforestation rates for Brazilian Amazon quantified for late 1970's-1980's
- Estimates of regrowth in Amazon as high as 30% of the area
- Satellite observations of distribution and frequency of fires in southern African savannas
- Increases in boreal fire frequencies could potentially contribute another 0.3-0.8 GtC/yr to the atmosphere as a consequence of increased greenhouse warming

Land-Cover and Land-Use Change: A View Ahead

- Premier example of interdisciplinary study of land-use in the USGCRP
- Important contributor to US National Assessment of Potential Consequences of Climate Variability and Change
- Important contributor to international scientific assessments related to land-cover and land-use
- Must now incorporate new measurement and modeling capabilities
- Must now become major contributor to policy-relevant issues internationally and domestically

3rd LCLUC Science Team Meeting

Airlie House, Warrenton, Va

May 18-21 1999

Objectives of the Science Team Meeting

- **Program Updates**
  - current status of NASA LCLUC
  - the first years: a retrospective
  - status of LCLUC across USGCRP - US Carbon / HD / National Assessment
  - status of IHDP / IGBP LUCC
  - LCLUC related meeting reports - community updates
- **Presentation of Early Results from Round 1 Funding**
  - research findings and identification of mid-course corrections
  - new methods, emerging theories and conceptual advances, policy and resource management implications
- **Planning for Packaging of Round 1 and LBA LCLUC early results**
  - identification of significant results, major achievements
  - An LCLUC Book - plans and potential contributions
  - LCLUC Web site update and LCLUC outreach initiatives
  - assess role of LCLUC in regional assessments
- **LCLUC data initiatives**
  - regional CD's, LC ESIPS, Fire Web
  - Landsat 7 status, follow-on rationale and data needs
- **Science Team input to future directions of NASA - LCLUC**
- **Future NASA missions and LCLUC - post Easton**

Audiences and Approaches

Scientific Community (Primary Audience)

Peer reviewed papers / Conference presentations / Special Editions
Project data and products - partner with ESIPS / PI Web Sites / Regional data CD's
LCLUC Book: case studies, methods, emerging theories, comparisons, synthesis
Regional / Thematic Scientific Networks (e.g. Miombo / SEASIA)

NASA Management

Summary achievements; keeping it up to date (*Focus for this afternoon*)
Back up material / LCLUC WEB (format, attribution) - project scientist
Abstracts - Annual Reporting - Publications list - Web Site
IWG ?? WG's - presentations - LCLUC results overview presentation

Science / Policy 'Brokers' (e.g. OSTP / WRI / etc)-

cautious translation of hard results into policy context, press release management
LCLUC areas of emphasis - carbon FCCC / national assessments
NASA LCLUC and Carbon Workshop 2000 - policy participation
rapid response mechanism e.g. NASA Fire Web Site, SAFARI, % cover Poster

Land Management Community

targeted topical workshops (funding opportunities ?)
involvement in national / regional assessments - land use stakeholders
partner with RESACS - applications program

Education / Public Outreach

Web Site - tutorials - slide show - page links

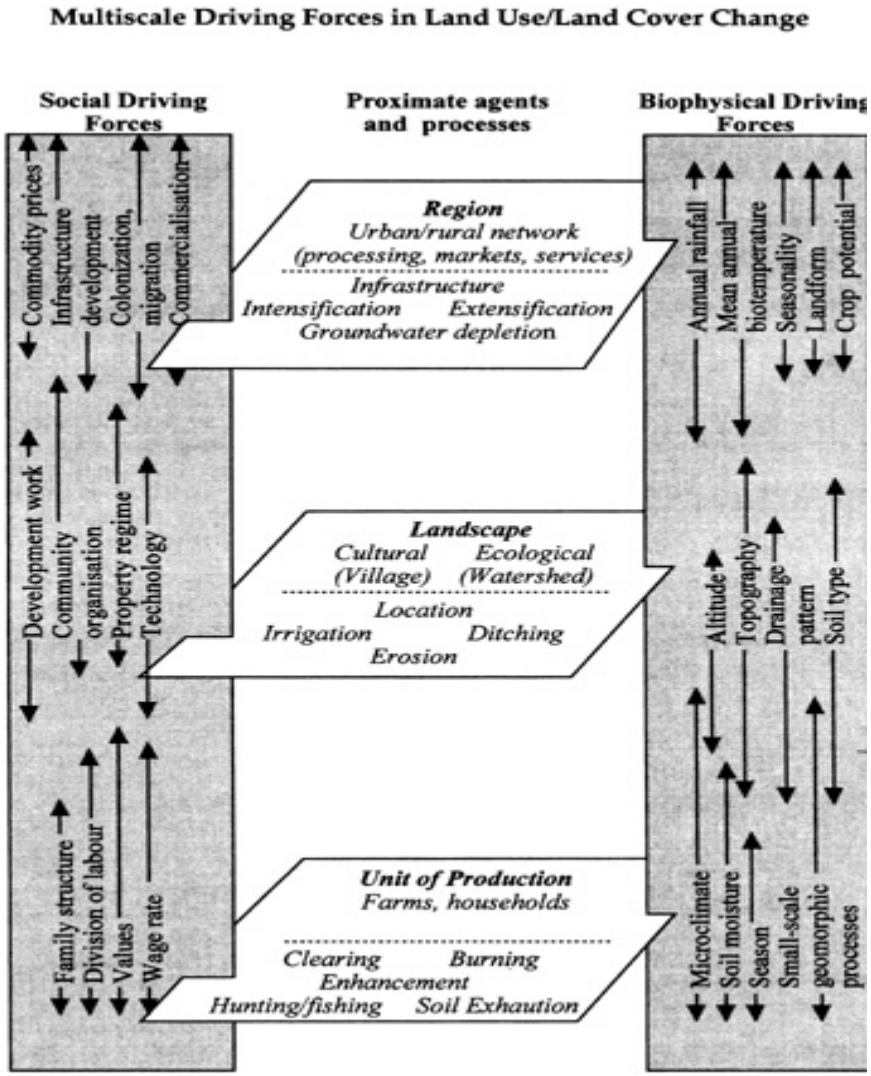
Significant Results Might:

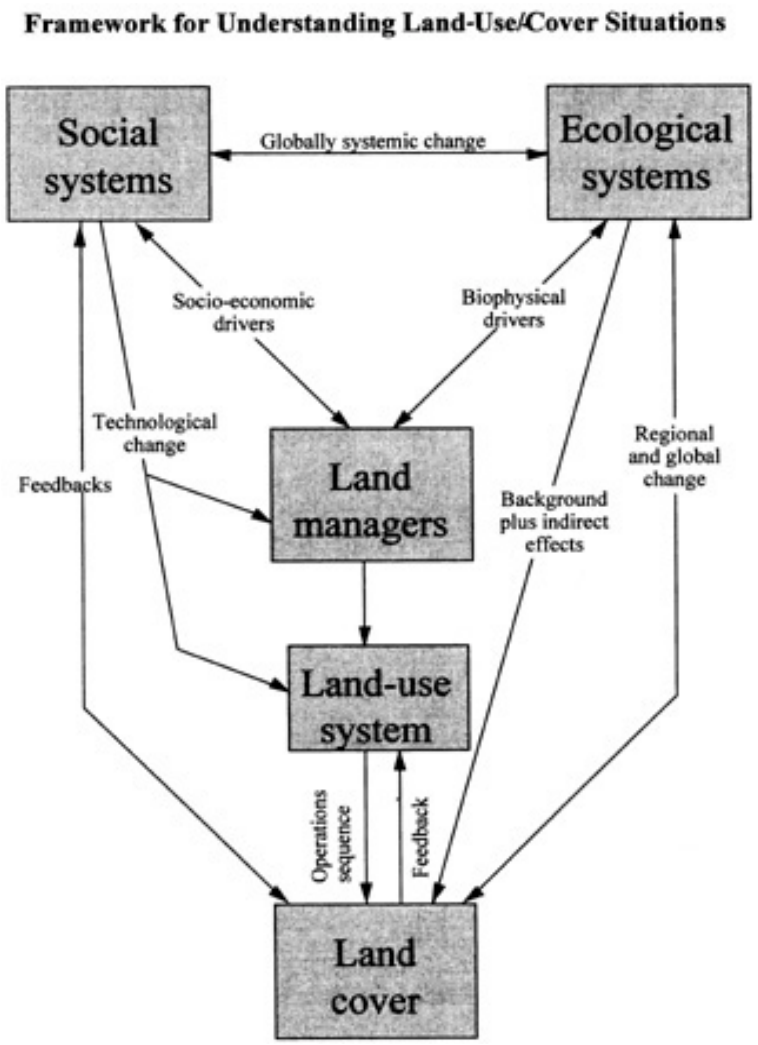
- Provide a new insight or advance in our understanding of the processes taking place
- Contradict or confirm current theory
- Answer some outstanding research question
- Quantify the drivers or impacts of land cover and land use change
- Enable informed decision making concerning resource use
- Enable improved land cover or land use management

New or Improved Methods Might:

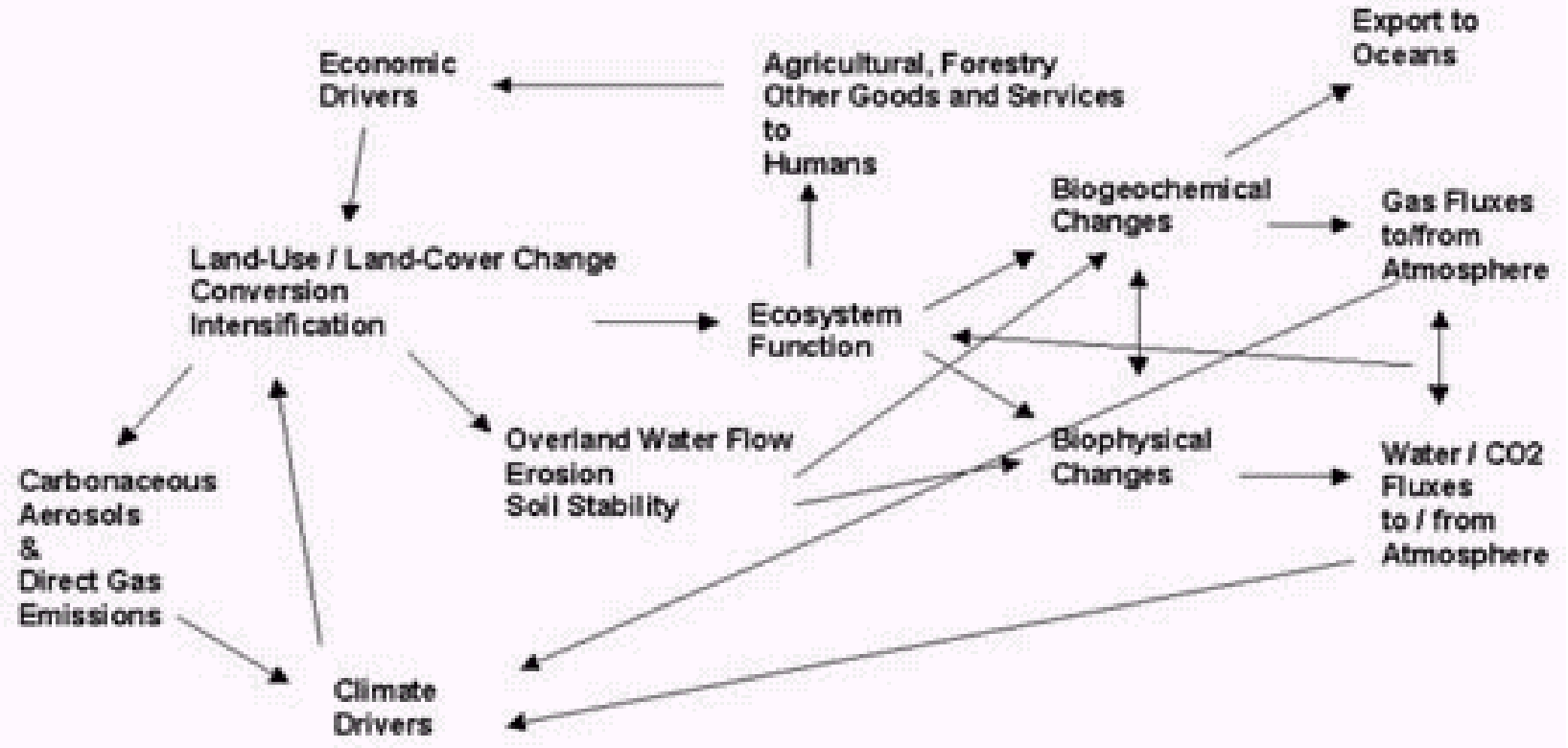
- Involve new or improved data collection techniques
- Involve new or improved data processing and analysis approaches
- Provide an independent validation of a modlel or derived data products
- Provide an improved model or predictions capability
- Enable improved assessments of land cover or land cover change
- Enable remote determination of land use

Concept and Theory of LCLUC





Interactions of Land-Use/Land-Cover Change



Current Status of the LCLUC Program

Land Cover and Land Use Change and Global Change

- **LCLUC is the most immediate and visible form of environmental change**
- **Little has been developed in terms of the underpinning science of LCLUC, understanding the impacts of LCLUC and predicting LCLUC**
- **LCLUC will continue to be important for the foreseeable future, driven by the demand for land, world population growth, the need for an increased food supply and wood products**
- **LCLUC contributes to climate change e.g. source of greenhouse gases**
- **LC and LU are impacted by climate change - effect of interannual, decadal and centennial climate variability and trends on land cover and land use**
- **LC and LUC can have an impact on the provision of ecological goods and services e.g. food supply, water quality, biodiversity**

Context for NASA's LCLUC Program

USGCRP Overall Goal

•Observe, understand, predict, and assess the critical natural and human-induced dynamic states and trends of the Earth's global environmental system across a wide range of time and spatial scales

•Address those uncertainties and gaps in scientific knowledge central to the Nation's global environmental change policy interests

•Deliver timely information and data products essential to informed decision making that protects the environment, enhances socioeconomic development, and ensures a sustainable future for the Nation and the world

USGCRP Program Elements

- Understanding the Earth's Climate System
- Biology and Biogeochemistry of Ecosystems
- Composition and Chemistry of the Atmosphere
- Paleoenvironment/Paleoclimate
- Human Dimensions of Global Change
- The Global Water Cycle
- Carbon Cycle Science

LCLUC and Carbon

- **Much of the current emphasis on LCLUC has come through attention being given to the carbon cycle - estimation of the sources e.g. rates of tropical deforestation national anthropogenic emissions estimates from land use**
- **Attention is now turning to quantifying sinks - associated with recovery of previous disturbance e.g. tropical regrowth, northern hemisphere 200 yr historical land use, modeling initiatives**
- **The FCCC is giving increased visibility to carbon budgets and trading opportunities, new research initiatives on carbon sequestration are likely - human use of the land will need to be factored in. Increased attention being given to carbon and land management - issues of the Clean Development Mechanism (CDM)**
- **There will ultimately be a need for an independent 'carbon' monitoring system.**
- **Although carbon has dominated the discussion, human alteration of the nitrogen cycle is significant as are other trace gases**
- **Carbon will continue to dominate the 'policy arena' for some time to come**

USGCRP Phase II Objectives

•The need to broaden and advance the earth sciences research agenda to embrace the whole-system problem of a dynamical ***climate system*** coupled to a complex and diverse set of large scale ***ecological systems***, both interacting on multiple time and space scales with omnipresent human ***socioeconomic systems*** and their effects.

• The need to study systematically ***how these interactions constrain human activity and how a predictive understanding of them creates the opportunity to make economic systems more efficient,*** enabling - rather than hindering - development.

• The need to organize in a way which will ensure, nationally and internationally, the capacity of the scientific community to deliver on a continuing basis, beginning now and constantly improving in quality, the information products needed **to enable informed decisions about resource management and economic issues** in a broad spectrum of decision frameworks worldwide, both public and private.

USGCRP and Land Cover and Land Use Change (Our Changing Planet - FY 2000)

- **Biology and Biogeochemistry of Ecosystems: key research challenges**
  - Changing Land Use and Land Cover
    - relationship between LCLUC and weather/climate
    - relationship between climate change and LCLUC
    - the effects of LCLUC on ecosystems, hydrology, species distribution and human social systems
  - Changes in Global Nitrogen Cycle
  - *Multiple stresses of ecosystems*
- **The new USGCRP Carbon Cycle Initiative includes:**
  - Effect of past and current land use change on carbon storage
  - Inventory and long term monitoring of carbon stocks

US/GCRP Carbon Cycle Science Initiative

Long Term Goals:

QUANTIFY	Partitioning of CO2 between ocean and terrestrial sinks
	Spatial and temporal distribution of sources and sinks on a regional scale
UNDERSTAND	Processes that control source and sink distribution
	Factors that regulate net sequestration of anthropogenic CO2
PREDICT	Lifetime, sustainability and variability of sources and sinks of CO2

NASA LCLUC Components

- **Forcing Factors**
  - Climate and Ecological Drivers
  - Socioeconomic Drivers
- **Responses and Consequences**
  - Land cover conversion, abandonment
  - Land use intensification
  - Land degradation
  - Landscape fragmentation
- **Modeling and Implications**
  - LCLUC modeling
  - coupled modeling of biogeochemistry e.g. carbon/nitrogen/trace gases
  - modeling land atmosphere interactions
- **Technique Development**
  - Remote Sensing R and D
  - Data Management
  - In-situ data collection - surveys / validation / process studies

NASA LCLUC: current situation

- Tony Janetos and Bob Harriss have left NASA
- Jon Ranson 6 month secondment from GSFC as Project Manager - Justice remains Project Scientist
- New NASA science management less familiar with LCLUC concepts
- Janetos replacement in process
- LCLUC NRA due any day now
- CEOS Global Observation of Forest Cover emerging
- LBA and SAFARI 2000 campaigns underway - GCIP in progress
- NASA Strategic Planning document drafted
- Planned Missions - Landsat 7, Terra, EO1, EOS PM, VCL
- New missions pending - Landsat follow on, NPP, Recovery, NPOESS, LightSAR
- EOS DIS/ DAACS, PI processing, ESIPS and New DIS
- Relationship with other NASA elements e.g.
  - Instrument teams
  - R and A Ecol/Biogeo, Hydrology
  - Data systems, Commercial Data Buy,
  - Applications Program

- **Why should NASA have a LCLUC element ?**
  - **NASA sensing systems provide data essential to the inventory and monitoring of land cover. Remote sensing is the only way to provide some of the necessary data sets**
  - **There are compelling GC research questions of LCLUC that can in part be addressed by remote sensing. LCLUC is highly relevant to society**
  - **The study of LCLUC at regional to global scales provides a data management challenge. NASA is investing in advances in data management and distribution**
- **Do we need and can we create an LCLUC funding wedge ?**
  - **As a new activity for NASA need to justify the existing investment and make the case for continued or increased funding**
  - **Need a continued clearly articulated rationale for LCLUC**
  - **Need to package the program results and future directions for the research in an easily understandable and compelling way**
- **How do we secure the LCLUC mission needs ?**
  - **Landsat 7 / Terra / PM**
  - **The rationale and specifications for future missions**

Strategic Questions

(1) What is the current distribution of global land cover and how is this changing?

(2) What are the interrelationships of interannual climate variability and land cover change?

(3) What are the driving forces behind land cover and land use change and how do past land cover distribution and land use changes affect the current distribution of land cover and land use?

(4) What are the consequences of land cover and land use change on biogeochemical cycling, biophysical processes, and biodiversity of ecosystems?

(5) What are the implications of natural and anthropogenic disturbances on the carbon cycle?

The Role of the LCLUC Science Team

- **Generate high quality individual or collaborative research - peer reviewed articles**
- **Teamwork is needed to make the program goals - interdisciplinary skill mix / broad experience base / regional expertise**
- **The program needs highly visible results and contributions:**
  - **responsive program e,g, OSTP**
  - **up to date LCLUC WEB site**
  - **regional CD's**
  - **IPCC contributions**
- **The Science Team needs to help justify the existing investment and make the case for continued or increased funding for the study of LCLUC**
  - **up to date summary presentation material**
- **Need to package the program results and articulate future directions for the research in an easily understandable and compelling way**
- **Need to contribute to the advance of the LCLUC 'discipline'**

LCLUC and Global Observation of Forest Cover

- **The CEOS GOFC Pilot Project**
  - **provides an opportunity to secure long-term 'operational' systems to support the study of land cover change - focus on global change / carbon cycle data needs**
  - **operational pilot for the Integrated Global Observing System**
- **Forest Cover and Cover Change**
  - **Combines global coverage at moderate resolution (1km-250m) with targeted regional coverage at high resolution (30-10m) and sample hyperspatial resolution data (<10m)**
  - **Wall-to-wall high resolution coverage of forests every 5 years;**
- **Forest Fire Mapping and Monitoring**
  - **Active fire detection, burn scar mapping, multi-source satellite data**
  - **Web based data delivery systems**
- **Forest Biophysical Functioning**
  - **Methods and algorithms for LAI/ fPAR/ NPP, above ground biomass, vegetation composition and structure**
  - **Creation and validation of regional/global data fields**

LCLUC - Landsat 7

- Landsat 7 is a critical component of the LCLUC program
- Permitting periodic assessments of land cover and land cover change
- Continuing the long- term high resolution record - mid 80's
- LCLUC will contribute to the science rationale for a Landsat follow-on
- Issues
    - Need an effective global acquisition strategy - repeated coverage
    - Need for data processing and distribution capability
    - Landsat Pathfinder Humid Tropical Forest Project
    - Need methods for large area mapping
    - Need relationships with foreign ground stations
    - Need to explore cost efficient ways for providing data

EOS and LCLUC

- **EOS Terra (July launch ??) - new sensors for the study of LCLUC**
- **MODIS - AM/PM (2330 km swath)**
  - **Land Cover Parameterization (UMd) - Townshend and DeFries**
  - **Land cover change (UMd) - Townshend and DeFries**
  - **Fire and Burned Area (UVA/UMd) Justice/Roy**
  - **Land Cover and Interannual Variability (BU) - Strahler**
  - **BRDF (BU/UCL) - Strahler / Muller et al.**
- **ASTER (60km swath)**
  - **Spectral range: VNIR 0.5-0.9 µm, SWIR 1.6-2.5 µm, TIR 8-12 µm**
  - **Spatial resolution:15 m (VNIR: 3 bands), 30 m (SWIR: 6 bands), 90 m (TIR: 5 bands)**
- **MISR (360km swath)**
  - **Spectral bands 446, 558, 672, 866 nm**
  - **BRDF / Vegetation Structure**

What is LUCC?

- A core project of the IGBP and IHDP
- Integrates the physical sciences and the social sciences
- Focus on land-use, land cover and integrative modeling
- A network of scientists
- Facilitate syntheses through workshops

LUCC Objectives:

- Understand global land-use and land cover
- Investigate temporal and geographical dynamics
- Link sustainability and land uses
- Understand interactions between land-use/cover, biogeochemistry, and climate

LUCC's Three Focus Areas

- FOCUS 1: Land Use Dynamics:
  Comparative Case Studies
- FOCUS 2: Land Cover Dynamics:
  Observations and Diagnostic Models
- FOCUS 3: Regional and Global Integrated Models

Focus 1

Land-Use Dynamics

Case Studies to Analyse and Model the Processes of Land-Use Change and Land Management in a Range of Generalised Situations Globally

Activity 1: Understand How People Make Land-Use Decisions

- Develop standardisation of methodologies and experimental protocols for effective evaluation of how people make decisions.
- Develop a strategic framework for achieving a globally distributed network of case studies.
- Identify gaps in knowledge and encourage new studies
- Comparative examination of cases.

Activity 2: From Process to Pattern: Linking Local Land-Use Decisions to Regional and Global Processes

- Develop linked activities to Focus 2 to achieve a meso-level integration of upscaling processes by Focus 1 and downscaling by Focus 2.
- Characterise agents and land users appropriate for regional modelling.
- Examine international agreements and national environmental policies, and how they have affected land use (or not) how, why , where, when, how long?)

Activity 3: The Future: Sustainability and Vulnerability Scenarios

- Identify key biogeochemical and climate variables associated with changes in land cover over long time periods (hundreds and thousands of years).
- The transition to sustainability: Simulation modelling of LUCC to identify sustainable future scenarios.
- Growing vulnerabilities, simulation models that identify key interactions associated with degradation and vulnerability.
- Validate and inter-calibrate global data sets.

Focus 2

Land-Cover Changes

Direct Observations and Diagnostic

Models of Land-Use/Land-Cover Changes

Activity 1: Land-Cover Change "Hot Spots" and Critical Regions

- Monitoring biophysical and socio-economic variables
- Definition of land-cover change indicators
- "Hot-spot"detection and alarm system

Activity 2: "Socialising the Pixel"

- Transition probability models
- Spatially-explicit models
- Linking patterns of land-cover to household-level data (link to Focus 1).

Activity 3: From Patterns to Processes

- Dynamic, causal models and short-range projections.
- Definition of risk zones and potential impacts.

Focus 3

Regional and Global Models

Development of a Framework and Tools for Integrative Assessments

Activity 1: Review and Comparison of Past and Current Regional Modelling Studies

- Inventory and review of regional and global models used for projections of land use/cover.
- Review and report on state-of-the-art of regional modelling of land-use/land-cover changes.
- Model comparison workshops

Activity 2: "Big Issues" in Methodologies of Regional Land- Use/Land-Cover Change Models

- Coping with heterogeneity and scales in regional models.
- Improving the environment-economy linkage.
- Dealing with technological change.
- Policies and institutions - representing the regulatory context in regional models of land-use/land-cover change.

Activity 3: Land-Use/Land-Cover Change and the Dynamics of Interrelated Systems

- Rural-urban dynamics (“land-use synergies and tensions”).
- Water issues in regional land-use/land-cover change (“integrating land and water”).

Activity 4: Scenario Development and Assessments of Critical Environmental Themes

- Scenario development in the context of a growing world population.
- Land-use/land-cover change in global environmental assessments.

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Land-Cover and Land-Use Change: New Policy Dimensions

Tony Janetos

World Resources Institute

Land-Cover and Land-Use Change: New Policy Dimensions

Selected Major Issues

- Food Production and Distribution
- Carbon Sources and Land-Use
- Carbon Sinks and Land-Use
- Management of Ecosystems for Goods & Services
- Preservation of Unique Places

Land-Cover and Land-Use Change: New Policy Dimensions

Food Production and Distribution

- World must roughly double food production in next 40-50 years
- Where will the land come from?
- How can we manage the agricultural land we have more intensively without adverse environmental consequences?

Land-Cover and Land-Use Change: New Policy Dimensions

Carbon Sources and Land-Use

- Land-use change in tropics roughly 20-30% of total anthropogenic flux to atmosphere
- Non-Annex I countries have no formal commitments under Kyoto Protocol
- What are appropriate incentives to reduce this flux without adverse impacts on local livelihoods?

Land-Cover and Land-Use Change: New Policy Dimensions

Carbon Sinks and Land-Use

- Roughly 1-2 GtC per year are taken up by terrestrial ecosystems in north temperate/boreal latitudes
- Are there ways to maintain or enhance this sink?
- Can carbon offset or trading programs result in real gains and revenue streams for other policy goals, e.g. biodiversity conservation?

Land-Cover and Land-Use Change: New Policy Dimensions

Management of Ecosystems for Goods & Services

- Consumption trends for most ecosystem-derived commodities have been rising for several decades
- Can we create appropriate policy mechanisms to sustain those goods for which substitution is difficult?
- Can we create appropriate mechanisms to value non-market services?

Land-Cover and Land-Use Change: New Policy Dimensions

Preservation of Unique Places

- How can diversity of life be valued such that unique places are preserved?
- How can diversity of life and habitats be managed so that local societies benefit?
- Can we finance biodiversity goals through other mechanisms?

Landsat 7: Early On-Orbit Performance

by

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Biospheric Sciences Branch / Code 923
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May 21, 1999

Introduction

- The Landsat 7 mission began after a spectacularly successful Delta 2 launch on April 15, 1999 from the Vandenberg Air Force Base in California.
  - weather was so clear that cameras tracked it down range ~ 500 miles
- The first images were acquired on Sunday, April 18, just three days after launch
  - purely by “luck of the draw” the first usable image included Sioux Falls/EDC (honest!)
  - Level 1 systematically corrected products were generated via the Image Assessment System (IAS) @ EDC within a few hours
  - this first image was officially released on Earth Day, Thursday, April 22
  - Normal post launch engineering checkout activities are continuing according to the on-orbit independent verification plan (OIVP)
  - it will take ~ 75 days to complete OIVP ==> plan to be “operational” **on/about July 1**
  - during OIVP, numerous activities such as “out-gassing” are required to acclimate the instrument to its space environment; “out-gassing” was successfully completed on April 30, and the collection of 8-band imagery, for engineering checkout purposes, commenced according to the OIVP
  - as of last Friday, May 14, we had acquired ~ 1600 images of engineering data
    - this engineering data will not be distributed to the public

Introduction *(cont)*

- Additional OIVP activities include preparation to underfly Landsat 5. Meticulous planning is required to position the Landsat 7 spacecraft in proximity to the Landsat 5 spacecraft using orbit adjust maneuvers to raise the Landsat 7 orbit and slow down its drift rate. Once this proximity has been achieved, the two Landsat's will collect selected observations simultaneously over a 3 day period to permit cross-calibration, thus establishing a base line for understanding the respective imaging characteristics of the two instruments. We expect the underfly to occur June 1 - 3.
- Upon completion of the Landsat 5 underfly maneuver, Landsat 7 will be positioned in its nominal operational orbit (an altitude of 705 km vs. the current ~ 680 km) by mid-June.
- Landsat 7 will be positioned to collect observations consistent with the Landsat 4 / 5 WRS, but phased eight paths to the East of Landsat 5.
- 8 day repeat coverage will exist as long as Landsat 5 remains operational

Why No Distribution of Engineering Data

- It is important to note that until final orbital positioning is completed (~ mid-June), Landsat 7 will not begin to collect data for the global archive, and subsequent production operations.

- All data acquired prior to that time will be considered “engineering” checkout data. All engineering data have certain “abnormalities” due to the fact that the spacecraft is flying lower and faster than normal, and it is drifting across the WRS paths -- all these factors yield non-standard scenes and data
- Please be assured that all data abnormalities are well understood and will not exist once the satellite reaches it’s final orbital altitude

- Selected scenes, subscenes, or swaths acquired during this period will be extracted and used for evaluation and/or release of photographic imagery for PR or other non-scientific interests, but it will not be offered as “standard” products for sale
  - also during this period, selected data will be extracted and provided to international ground station cooperators and system developers for testing purposes, but with caveats pertaining to their use.

Image Assessment System

- An Image Assessment System (IAS) has been implemented at EROS Data Center in concert with the Landsat Project Science Office at NASA Goddard to perform on-orbit radiometric and geometric calibration and daily image quality assessments throughout the life of the mission
- the IAS at EDC has been responsible for processing all of the Landsat 7 imagery that has been released so far
  - once EDC goes operational, the Landsat Product Generation System (LPGS) will be responsible for routine generation of products for distribution
  - the IAS will be operated in the background to look at a random subsample of imagery each day to look for any data anomolies and to perform radiometric and geometric calibration functions
- The early performance results to be reported in the following charts are representative examples of the capabilities and functions of the IAS

Some Spacecraft Performance Highlights

- OIVP Requirements Verification Status (as of 5/13/99):
  - Total on-orbit verification requirements:153
  - Total on-orbit requirements verified to date: 66
  - On-Orbit requirements to be verified: 87
- attitude subsystem is in precision pointing mode

  – working with the IAS / ground geometric calibration group at EDC to quantify precision *(early results indicate locational accuracies of ~ 100 m vs. the spec of 250 m)*
- power subsystem is operating nominally; solar array fully operational and tracking the sun; battery temp's are stabilized and battery charge control is under software management; no power problems during imaging day or night
- solid state recorder has successfully recorded and played back both wideband and narrowband data
- we have fully exercised all three gimballed x-band antennas and all four x-band frequencies, using the Landsat Ground Station at EROS Data Center and the stations at Svalbard, Norway and Poker Flat, Alaska

Some Instrument Performance Highlights

ETM+ Noise Performance:

- **Initial on-orbit data is consistent with pre-launch thermal vacuum (T/V) test data there is no evidence of instrument change going into orbit**
- **Several detectors in Bands 1 and 8 show coherent noise in the shutter region only -- *this noise is not present in the image data* -- hence the higher standard deviations for the "shutter" vs "image" data as shown in the Table**
- **no on-orbit data yet acquired in Band 8 high gain mode**
- **Bands are generally in specification except for some Band 8 detectors**
- **Performance, in general, seems to be slightly better in both T/V and on-orbit environments than under ambient (i.e., room temperature) testing conditions.**
- **Noise specification is at 2 non-zero signal levels. A model fit to these two data points was used to extrapolate the specification to zero signal level**

Partial Aperture Solar Calibrator

- Partial aperture solar calibrator reflects sunlight through a small 0.16 inch diameter aperture and auxillary optics into ETM+.
- Image *(next vu-graph)* is stretched along scan about 9:1 as orbital pitch (360°/99 minutes) determines sun scanning rate.
- Imaging occurs before terminator is reached (i.e. superimposed on a dark earth background).
- Typically we receive 3 images (off of three different sets of optics) per acquisition at different along track and across track positions -- the PAC image shown in the next vu-graph represents the first of the 3 images.
- Image is scalloped due to the scan line corrector

Landsat-7 ETM+ Partial Aperture Solar Calibrator Image

Creating and Refreshing a Global Archive

- Working with the Landsat Science Team, the Landsat Project Science Office established the concept and mechanism for acquiring a U.S.-held archive of ETM+ images covering the global continental surfaces on a "seasonal" basis
  - created a **Long Term Acquisition Plan (LTAP)** to optimize scene acquisitions
  - promoted the incorporation of cloud cover predict into the daily acq. scenario
  - implemented an improved automatic cloud cover assessment (ACCA) algorithm
  - advocated the concept of acquiring all scenes when flying over all 50 states, not just the lower 48 *(except mid-winter, low light scenes in Alaska)*

Long Term Acquisition Plan -- Overview

- Goal: to optimize use of the on-orbit asset to create a U.S.-held archive of sunlit, cloud-free, ETM+ data providing global coverage of the Earth's continental and coastal surfaces, refreshed on a periodic (seasonal) basis

- Problem: how to schedule ETM+ data acquisition, on-board storage, transmission, and ground processing in light of satellite-system resource limitations
  - satellite power and ETM+ duty cycle
  - data transmission rates (150 Mbps from each of 3 X-band antennas)
  - contact time with U.S.-operated ground station antennas
  - capacity of the on-board solid-state recorder (100 ETM+ scenes)
  - ground data processing system capacity and performance

- Ground Rules: the ETM+ will acquire data every time Landsat 7 passes over all 50 states, irregardless of cloud cover, and the data will be down-linked (or shipped) to the Landsat Ground Station at EDC for archival; EDC will be capable of capturing and archiving 250 ETM+ scenes/day

Long Term Acquisition Plan -- Overview*(cont)*

- LTAP Land Data Base identifies every WRS scene containing land within its boundaries:
  - all continents, with Antarctica starting at minimum ice pack limits
  - Arctic islands
  - inland seas and bays to extent that the WRS scene contains any land
  - unnamed islands, shoals, reefs, rocks, banks
  - within vast shallow coastal areas (<200m deep)
  - scenes close to continental coasts and well within the shallows
- Our current land data base contains approximately 14,000 WRS scenes out of a total of 57,784 scenes
- The scheduling algorithm uses LTAP to assign priorities to the WRS scenes within view of the ETM+ on any particular day. The ETM+ and Landsat 7 satellite will then schedule the acquisition, storage, and transmission of those 250 scenes assigned the highest priorities.

Long Term Acquisition Plan Simulations

- Many 80-day scenarios (i.e., five 16 day cycles) have been run to understand the interplay between archive requests and Int'l Ground Station (IGS) requests
  - working with USGS/EDC to maximize IGS acquisitions and support MOU negotiations
  - trying different combinations of priorities and stations to understand the LTAP/scheduler

    software behavior

- Recent simulation results
  - simulation runs show that 90% of the land scenes defined in the data base are acquired

    within 3 months; dependent on cloud cover since we avoid taking scenes with above

    average cloud cover
  - these runs also show that IGS's, on average, receive 95% coverage of their national

    boundaries and 75% coverage of territory outside their national boundaries

Long Term Acquisition Plan -- Summary

- Given the implementation of LTAP, the need for considering special requests for specific scene acquisitions is minimized -- basically, if an area is highly likely to be cloud-free, it will probably be scheduled for acquisition (also, IGS' will be collecting full coverage within their acquisition range)
- ***Thus, the ground data system at EDC has not been configured to accept individual acquisition requests, at least during the first year of operations.***

Summary

- The Landsat 7 system (spacecraft, instrument, and ground system) is performing well, and we are delighted with the quality of the early results.
- However, we are not in production mode, and will not be, until we have completed the on-orbit verification plan. If activities proceed as we have planned, Landsat 7 data products should be available for sale & distribution on or about July 1, 1999.
  - be assured that the Landsat 7 Team will provide ample notification prior to beginning production operations so that users can plan their orders for Landsat 7 digital data products
- The Long Term Acquisition Plan assures periodic refresh coverage of all major land masses of the world. Therefore, the ground data system at EDC has not been configured to accept individual acquisition requests, at least during the first year of operations.

Summary *(cont)*

- With the Long Term Acquisition Plan and the Image Assessment System, we have put in place two totally new system components that should enhance significantly the quality of the data to be acquired and archived
- The fundamental goal of the Landsat 7 mission is to maintain Landsat data continuity and we feel that there is not doubt that Landsat 7 will meet that objective.
- We feel that the Landsat 7 ETM+, along with LTAP, the IAS, and the rest of ground processing system at EDC, will dramatically enhance the use of remotely sensed data in our daily lives, as well as stimulate the commercial, value-added and education communities.

Packaging the Results from the LCLUC Program

Approach:

- Generating Scientific Results - *Our Primary Objective*
- Making available our Data and Products *- Our Responsibility*
- Targeting the Audiences
  - Crafting the message(s)
  - Delivery / access and timing
  - Identifying intermediaries

Land-Cover and Land-Use Change: Selected Accomplishments

- Deforestation rates for Brazilian Amazon quantified for late 1970's-1980's
- Estimates of regrowth in Amazon as high as 30% of the area
- Satellite observations of distribution and frequency of fires in southern African savannas
- Increases in boreal fire frequencies could potentially contribute another 0.3-0.8 GtC/yr to the atmosphere as a consequence of increased greenhouse warming

Future Science Directions for LCLUC

Previous Thinking

- Causes and Process of Change
- Impacts of Change
- Predictive capability
- Assessments
- LCLUC and Sustainability
- LCLUC and Biodiversity

Possible Areas for future LCLUC Activity

- Extending existing studies to address
  - synthesis across existing case studies - concepts / rules / theory development and testing
  - results pqckaging
  - management aspects / stakeholder concerns
- Additional Regional Case Studies - causes and impacts (priority regions)
- Impacts of Land Cover and Land use Change on
  - carbon / biogeochemistry
  - biodiversity
- LCLUC and Water
- Climate as a driver of Land Use Change - and socioecon impacts
- Regional Assessments - integrated modeling
- Developing a Predictive Capability of LCLUC
- New Techniques and Data sets - new systems - science
- Critical Thresholds for Land Use Change
- LC Product Validation
- LCLUC and Social Welfare ??

Background/Overview

The LCLUC and the IPCC report - R. Houghton

The USGCRP Carbon Cycle Initiative (CCI) and land use change - L. Dilling

Integrating social, ecological and remote sensing information on secondary growth - R. Walker

An assessment of the availability and utility of microwave data for the study of land use and land cover change: a review - G. Sun

Land Cover and Land Use Change and the Kyoto Protocol

- **The Protocol**
  - **commitment**
  - **implementation**
- **The Carbon Cycle**
  - **global**
  - **regional**
- **Carbon sources and sinks**
- **Future Needs**

THE PROTOCOL

The Commitment

Annex 1 countries (industrial nations and nations with economies in transition) have agreed to reduce greenhouse gas emissions to about **5% of 1990** emissions by the Commitment Period (2008-2012)

THE PROTOCOL

Implementation

Increasing carbon sinks through **land-use change** is considered equivalent to reducing emissions (sources) of carbon though only three types of land-use change are presently recognized by the protocol:

Afforestation (planting new forests where none previously existed)
Reforestation (growing forests where they did exist previously)
Deforestation (converting forests to other landscapes)

Other 'activities' may be added to these ARD activities, such as:
Degradation of forest biomass – through harvests, shifting cultivation
Changes in soil carbon as a result of agricultural management
Changes resulting from fire management
All changes in carbon, whether attributable to activities or not

CARBON CYCLE

Global Scale (PgC/yr averaged for the 1980s)

Atmospheric C increase	=	fossil fuel	+	land-use change	-	oceanic uptake	-	terrestrial uptake (not due to landuse change)

$$3.3(\pm 0.2) = 5.5\ (\pm 0.5) + 2.0(\pm 0.8) - 2.0(\pm 0.8) - 2.2\ (\pm 1.3)$$

Regional Scale

~75% of fossil fuel emissions are from temperate –zone and boreal countries (Annex 1 countries)

~100% of the net flux of carbon from land-use change is from tropical countries (non-Annex 1 countries)

CARBON SOURCES and SINKS

- **Example Types:**
  - **Sources - Industrial activity** (dominant source of CO_2)**, clearcutting, fire**
  - **Sinks – forest regrowth/plantations**

    About half of the 2.2 PgC/yr terrestrial sink unrelated to land-use change has been 'observed'.
  - **Management**

    Long-term growth on permanent sample plots suggests an uptake of 0.6 PgC/yr in unmanaged tropical American forests.
- **Pools lifetime**
  Forest growth observed in forest inventories exceeds growth expected from land-use change by 0.6 PgC/yr in northern temperate-zone and boreal regions.
- **Measurement**
  Attributing cause to observed changes is difficult; for example partitioning the cause of observed forest growth among management, CO2 fertilization, climatic variability, N deposition, or attributing loss of forests observed with remotely sensed data to "deforestation", as opposed to natural fire requires integrated measurement protocols.

FUTURE NEEDS

•Need to generate national estimates of forest gain / loss and degradation since 1990 baseline (some national statistics already exist, compilation of existing information is necessary)

•Remote sensing could provide a system to provide all countries high level products for determining changes of forest area (maps for 1990, 2008 and 2012) - high resolution systems e.g. Landsat

•Need to address role of remote sensing data for primary data or for verification of national claims of sources and sinks or both 20m data and 1m verification

•Development of new technologies to measure above ground biomass directly

•Establishment of infrastructure for data collection by non Annex 1 nations

Carbon Cycle Science USGCRP Initiative

Context of the Program Element

Scientific Rationale

The need to understand how carbon cycles through the Earth system is critically important to our ability to predict future climate change.

- **Carbon dioxide is one of the most important gases in the atmosphere affecting the radiative balance of the earth.**
- **About half of the CO2 released by human activities remains in the atmosphere, and the rest is taken up by the ocean and terrestrial biosphere.**

The carbon cycle must be studied as an integrated system, as the atmospheric concentrations depend on the behavior of the other two reservoirs

Context of the Program Element

***Scientific Rationale** (cont.)*

Current projections of atmospheric carbon dioxide concentrations assume that the carbon cycle will continue to operate as it has in the past few decades. However, there is increasing evidence that this may not be the case:

- The storage capacity of terrestrial ecosystems is unknown
- Reorganizations of the physical climate system may reduce uptake of carbon by the ocean.

Context of the Program Element

***Scientific Rationale** (cont.)*

Although it is the carbon dioxide in the atmosphere which affects the radiative balance of the atmosphere and climate change, carbon cycles throughout the the ocean, atmosphere and land biosphere.

- The carbon cycle must therefore be studied as an integrated system, as the atmospheric concentrations depend on the behavior of the other two reservoirs.
- Techniques used to study one reservoir can also provide information on carbon fluxes to the other reservoirs

Context of the Program Element

Policy Relevance

Need for Information

- Unbiased scientific knowledge and analysis must be provided and effectively communicated to inform a political debate marked by sharp controversy.
- Policy debates have demonstrated the need for a scientific basis for evaluating potential carbon sequestration strategies and measurement of net emissions from major regions of the world.

Context of the Program Element

Scientific readiness:

- Significant advances in our ability to measure and model carbon fluxes.
- Major change in our thinking about the role of the terrestrial biosphere
  - Terrestrial biosphere can be a significant sink and not only a large source.
  - Human activities may be significantly enhancing carbon uptake in some regions.

Recommendations:

- NRC Pathways Report called for more coherent and integrated carbon cycle research
- Scientific Community ask for a comprehensive and integrated interagency program

Overview of Carbon Cycle Science Initiative

- **The carbon cycle program will provide the scientific foundation for estimating the capacity of ecosystems on land and in the ocean to sequester and store the considerable quantities of carbon dioxide anticipated from human activities in the future.**

- **The program will identify and quantify regional to global scale sources/sinks for carbon dioxide and understand how these sources and sinks will function in the future, providing essential information for future climate predictions.**

Carbon Cycle Science Interagency Working Group

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Goals and Objectives

Overall Goal

To understand, monitor, observe and model the carbon cycle as an integrated system in order to provide critical scientific information on the fate of carbon dioxide in the environment and how the cycling of carbon may change in the future.

Long-term questions

- What has happened to the carbon dioxide that has already been emitted by human activities?
- What will be the future atmospheric carbon dioxide concentration resulting from past and future emissions?

Goals and Objectives

Key research challenges

- **Northern Hemisphere terrestrial carbon sinks:** Establish accurate estimates of the location, magnitude, and sustainability of Northern Hemisphere terrestrial carbon sinks, including understanding its interannual variability, spatial distribution and sensitivity to climate change.
- **Oceanic carbon sink:** Establish accurate estimates of the oceanic carbon sink, including understanding its interannual variability, spatial distribution and sensitivity to climate change.
- **Land use change and forestry:** Establish accurate estimates of the impact of historical and current land use change, timber harvest, and deforestation on carbon sources and sinks.

Goals and Objectives

Key research challenges (cont.)

- **Enhanced carbon sequestration:** Develop the scientific basis for evaluating potential management strategies to enhance carbon sequestration.
- **Future atmospheric carbon concentrations**: Improve projections of future carbon dioxide atmospheric concentrations by incorporating improved understanding of the stability/integrity of sources and sinks and appropriate carbon cycle-climate feedbacks into global climate and carbon cycle models.

Interagency Coordination and Interdependencies

Future interagency coordination mechanisms being considered -

- Interagency Working Group
- Scientific advisory committee (SAC)
- Joint RFPs
- Joint research projects with common, integrated plans (but tasks may be selected through separate mechanisms)
- Joint decision-making and/or priority setting for key research sites, infrastructure, and data sets
- Focused workshops and symposia
- Model intercomparison
- Cooperation in the development, integration, and intercomparison of key data sets
- Model intercomparisons

Relevance

- Variability and major changes in carbon cycle behavior are not represented in climate models-- predictions of future CO_2 levels are likely inaccurate

- IPCC 2000 will have a special report on carbon sources and sinks, and will likely address the need to understand the carbon cycle in a dynamic way

Relevance cont.

- Both corporate and policy decision-makers are acting to address atmospheric CO_2, even before a Protocol is agreed upon

- Maximizing sinks, either artificially or by taking advantage of the natural cycle, requires knowledge of location, magnitude and responsible processes

Relevance cont.

- As policies are enacted to maximize sequestration on land and in the ocean on a regional basis, the assessment process may begin to require regional carbon cycle information

Priorities of USGCRP Carbon Cycle Science Initiative - FY 2000

- Produce State of Science Report
- Implement Integrated Observation, Research and Modeling on North American Terrestrial Carbon Sink
- Synthesis of Global Ocean Carbon Dioxide Data
- Improve Research on Processes Controlling Carbon Exchange and Storage
- Improve Long-Term, Integrated Carbon Measurements in Atmosphere, Ocean and land Ecosystems

U.S. Government Agency Priorities in FY 2000

- *DOE -- Flux Measurements (Joint Agency)*
  - Strategic Plan for Eddy Co-Variance Sites
  - 10 Additional Flux Measurement Sites
  - Expand Aircraft Flux Measurements
- *DOE -- Manipulation Experiments - Terrestrial Ecosystems*
  - Place Current Program on Sound Operational Foundation
  - Focus on Below Ground Processes
  - Improve Estimates of Carbon Sequestration
- *DOE -- Ocean Research*
  - Synthesis of Carbon Dioxide Data (Joint with NOAA)
  - Linkage Between Carbon and Nitrogen Cycle Using Molecular Biology Tools

U.S. Government Agency Priorities in FY 2000 (cont.)

- ***NOAA (Interagency) -- Magnitude, Location of N. Hemisphere Terrestrial Carbon Sink***
  - **Design Integrated Plan for N. Hemisphere Carbon Research**
  - **Aircraft Campaign Linked to Tall Towers**
- ***NOAA -- Ocean Carbon Sink***
  - **Understand Controls on Air-Sea Flux**
  - **Develop Autonomous Sensors for Monitoring**
  - **Synthesis of Carbon Dioxide Data (Joint with DOE)**
- ***NOAA -- Modeling***
  - **Carbon Cycle Modeling Consortium**
  - **New Coupled Carbon Cycle - Climate Model**

U.S. Government Agency Priorities in FY 2000 (cont.)

- ***USGS -- Landscape Dynamics and Vegetation Change***
  - **Data Bases for Landscape Modeling**
  - **Regional, Global Scale Vegetation Analysis**
- ***USGS -- Biogeochemical Cycling***
  - **Carbon and Nutrients in Soils, Rivers and Lakes**
  - **Carbon Sequestration in Sediments**
- ***USGS -- Carbon in Alaskan Landscapes***

U.S. Government Agency Priorities in FY 2000 (cont.)

- ***NASA -- Observations from Space***
  - **Land-Cover Change**
  - **Ocean Color and Synoptic Physical Parameters**
- ***NASA -- Field Campaigns and Modeling***
  - **Estimate Terrestrial Carbon Sources and Sinks at Regional Scale**
  - **Ecosystem Modeling**

U.S. Government Agency Priorities in FY 2000 (cont.)

- ***U.S. Forest Service -- Carbon Inventory and Life Cycle Analysis***
  - **Quantify Carbon Sources, Sinks and Fluxes**
  - **Relate Carbon Budgets to Land-Use Change**
  - **Extend Life Cycle of Wood products**
- ***U.S. Forest Service -- Increase Carbon Storage in Forests***
  - **Reforestation, Afforestation and Vegetation Management**
  - **Sequestration in Woody Biofuels**
  - **Soil Carbon Sequestration**

U.S. Government Agency Priorities in FY 2000 (cont.)

- ***NSF -- Synthesis and Modeling Project***
  - **Regional Processes and Components of Marine Carbon Cycle - North Atlantic, Equatorial Pacific and Arabian Sea**
  - **Air-Sea Exchange, Carbon Cycling in Upper Ocean and Export to Abyss**
- ***NSF -- Biogeochemical Cycles and Ecological Interactions of Marine***
- ***Carbon Cycle***
  - **Interconnected Cycles of Nitrogen, Silicon and Iron**
  - **Evaluate IronEx Studies**

U.S. Government Agency Priorities in FY 2000 (cont.)

- ***USDA/ARS -- Monitoring and Data Base Development***
  - **Monitor Changes of Carbon Balance in Forage and Rangeland Systems**
  - **Develop Data Bases for Process Models and Balance Sheet Analysis**
    - **Greenhouse Gas Emissions**
    - **Carbon Sequestration**
- ***USDA/ARS -- Model Development and Validation***
  - **Reduced Form Models to Predict Carbon Carbon Change as Function of Management Practice**
  - **Process Models of Soil Carbon Change**
- ***USDA/ARS -- Process Research***
  - **Residue/Microbial Transformation of Carbon**
  - **New Technology for Measuring Fluxes**
  - **New Technology for Measuring Methane Emissions**

Carbon Cycle Science Plan Working Group Members

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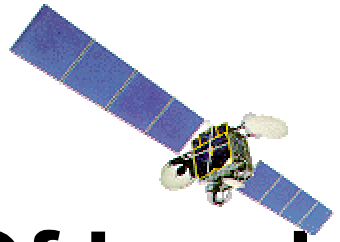
Inez Fung	University of California, Berkeley
Ralph Keeling	University of California, San Diego
Jim McCarthy	Harvard University
Steve Pacala	Princeton University
Mac Post	Oak Ridge National Laboratory
Jorge Sarmiento	Princeton University, Co-Chair
Eileen Shea	East-West Institute, Hawaii
Dave Schimel	NCAR
Eric Sundquist	US Geological Survey
Pieter Tans	NOAA/ CMDL
Ray Weiss	Scripps Institution of Oceanography
Steve Wofsy	Harvard University, Co-Chair
Jim Yoder	University of Rhode Island



Imaging Radar For The Study Of Land Cover And Land Use Change*A Brief Review*

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OUTLINES

- **Introduction**
- **Scattering Mechanisms and Radar Image Characteristics**
- **Data Availability**
- **Example of Applications**
- **Potential and Limitations**
- **Future Radar Missions**

INTRODUCTION

- Provide a brief overview of the utility, availability, and limitation of imaging radar data for the study of land cover and land use change
- Not intend to review all important works
- Try to balance between potential and limitation

Scattering Mechanisms

-Surface scattering
-Double-bounce scattering
-Volumetric scattering

Factors that effect radar backscattering include:

Radar parameters:

Incidence angle
Wavelength and polarization

Targets:

Surface roughness
Moisture contents
Scatterer's geometry

Major backscattering components from a forest canopy:

-Volumetric scattering from tree crowns
-Ground surface scattering
-Trunk-ground double-bounce scattering
-Crown-ground multiple scattering

Penetration capability of multifrequency radar

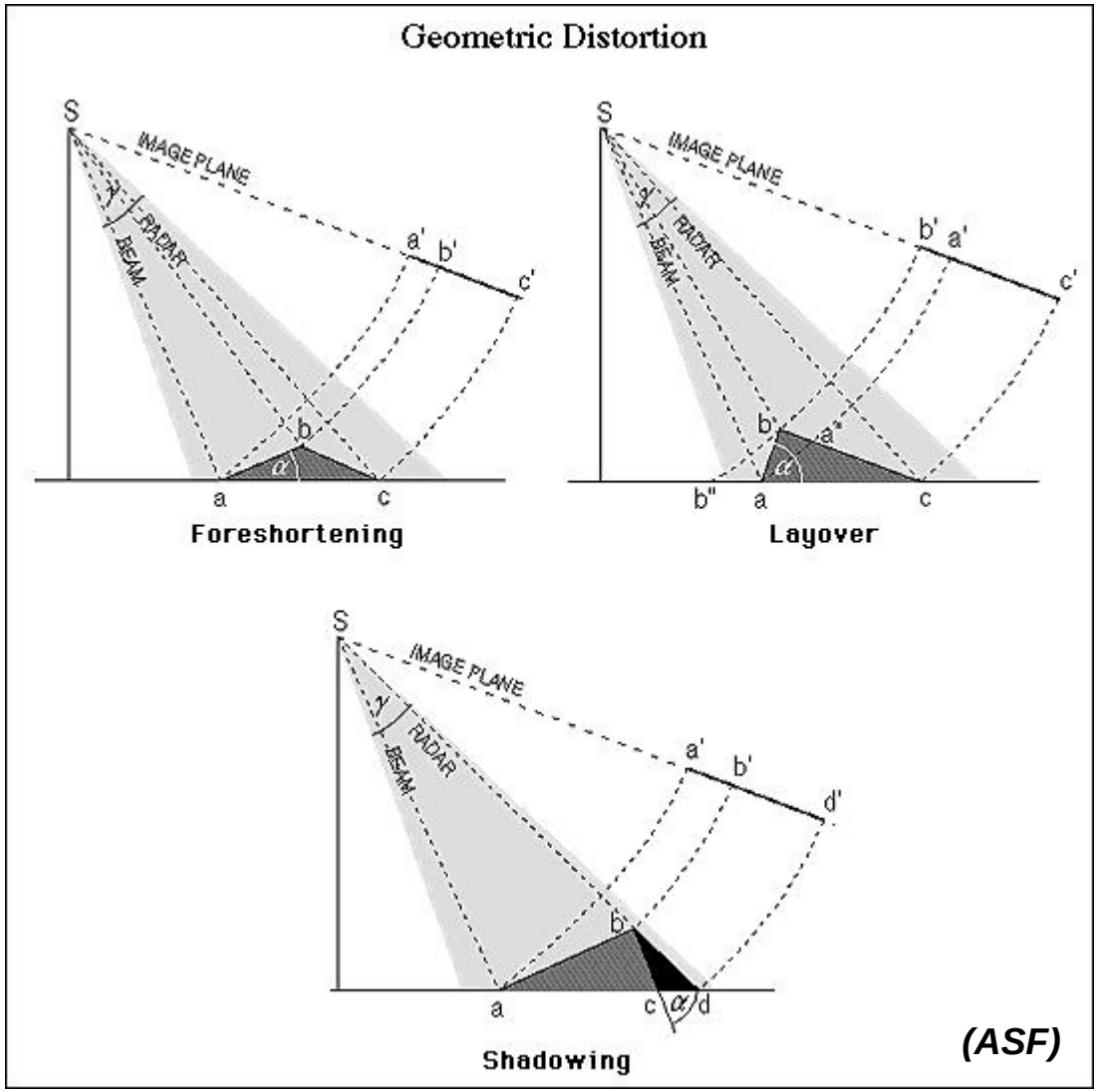
The penetration depth of radar beam depends on

1) radar wavelength Longer wavelength has deeper penetration

2) radar polarization e.g. vertical thin dielectric cylinders have less penetration at V than at H polarization

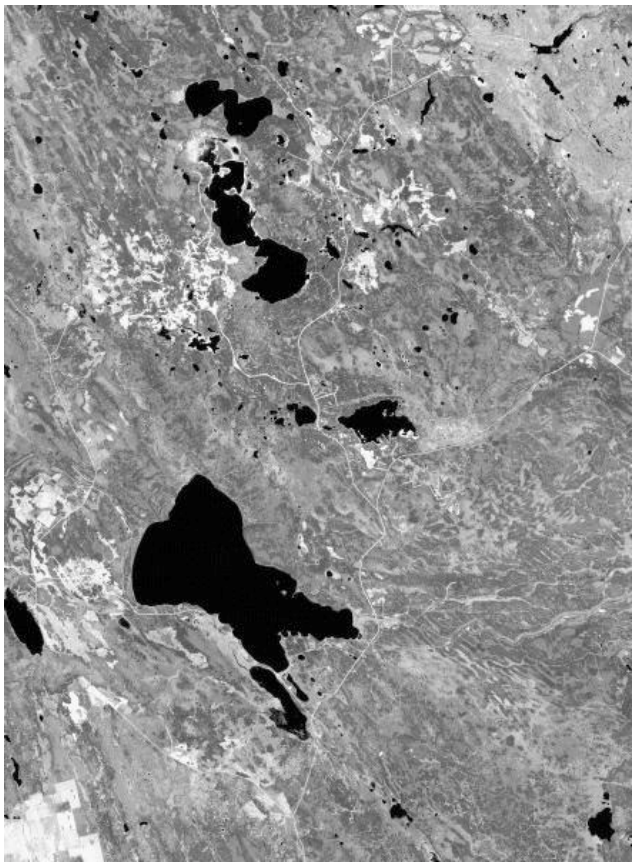
3) target properties e.g. dense vegetation, wet soil have less penetration

Geometric Distortion of Radar Images

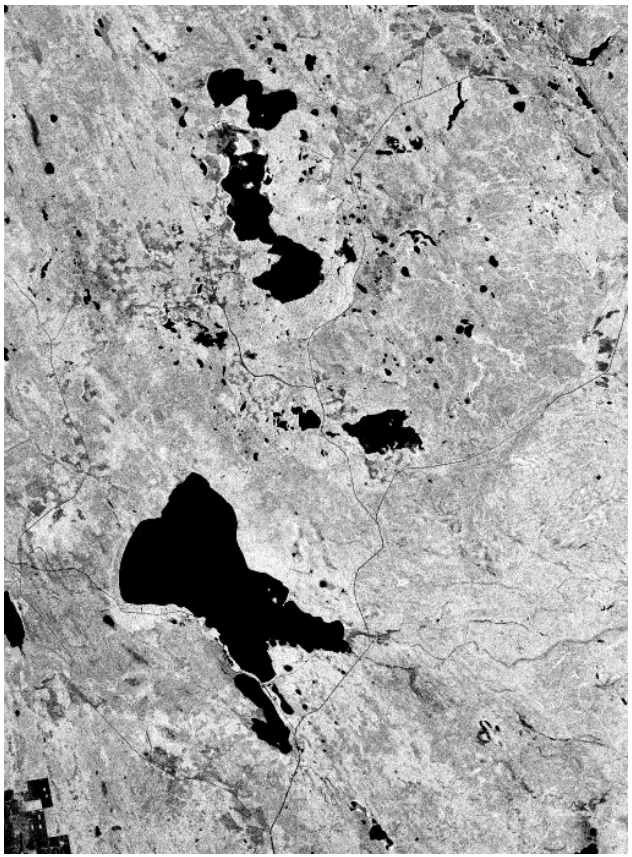


Complementarity Between Optical and Microwave Sensors

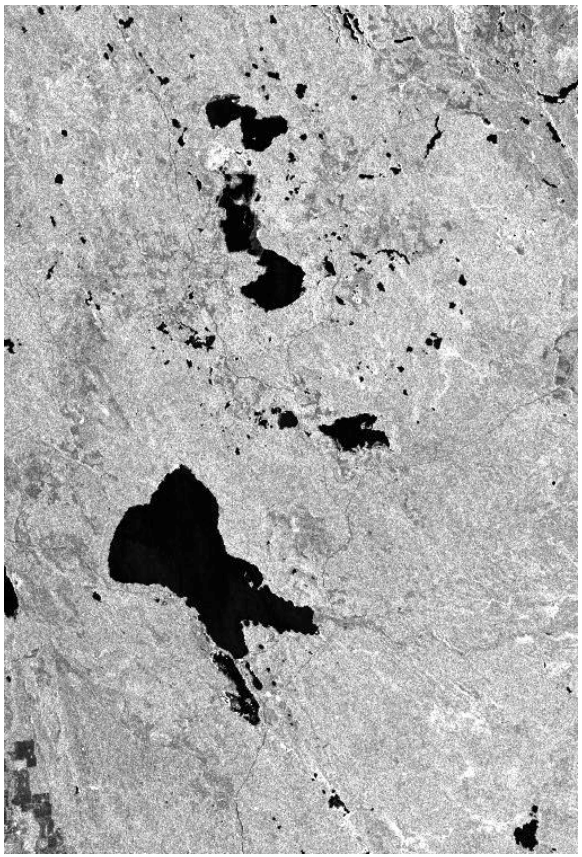
TM band 5
September 1994



JERS-1 L HH
August 1994

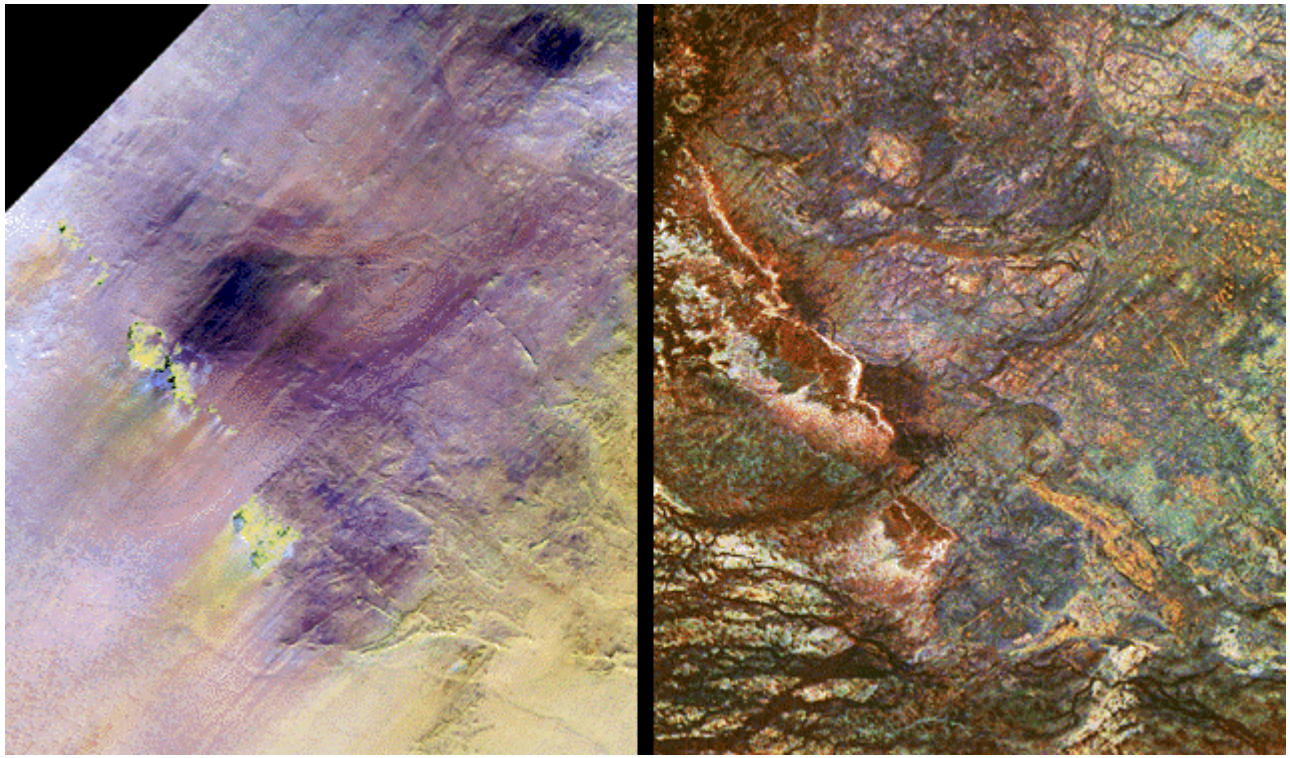


RADARSAT C HH
August 1996



Bright areas on TM5 image are young healthy vegetation (grass, shrub, young aspen, etc).
Bright areas on JERS-1 LHH image are mature forests with high woody biomass, and bright areas on RADARSAT C HH image are rough surfaces, flooded low vegetation along river, at fen sites, etc.

TM bands 7,4,1 false color **SIR-C/XSAR Lhh, Chh, Xvv**



(JPL)

Safsaf Oasis, Egypt

Potential of Imaging Radar
(Temporal, Polarimetric, Interferometric)

- Timely data (all weather, day and night)
- Penetration into canopies, desert, ice
- Sensitive to 3D structure of targets (tree geometry, building type, etc.)
- Direct information about biomass
- Vertical canopy structure from InSAR

Imaging Radar Applications in Land Cover and Land Use Change Studies

Forest characterization
- Forest mapping, biomass estimation, monitoring disturbances

Agriculture
- Crop classification, monitoring and yield estimation

Urban Development
- Land use analysis, Population estimation

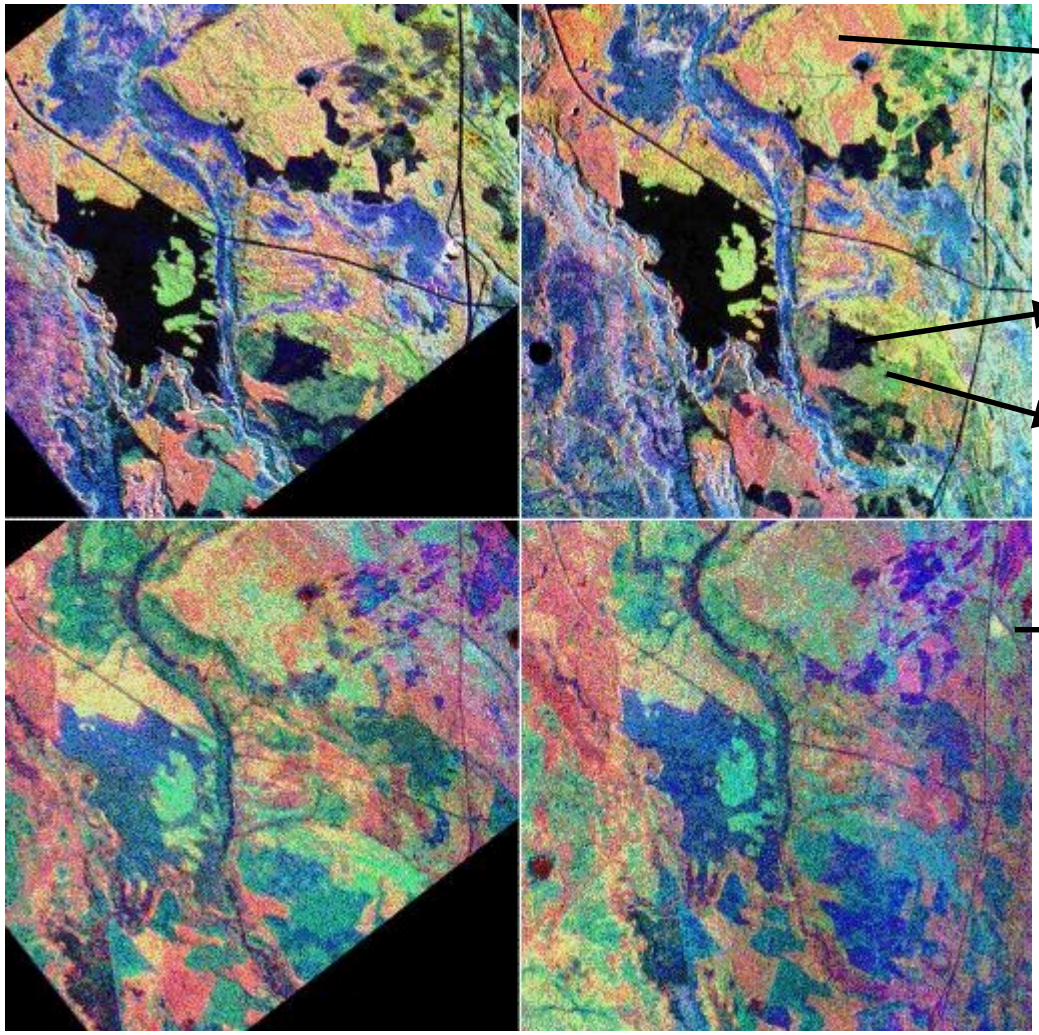
Others

AIRSAR Images (NASA/JPL)

August 12, 1993 April 22, 1994

Total Power P, L, C Bands

HH/VV Ratio P, L, C Bands



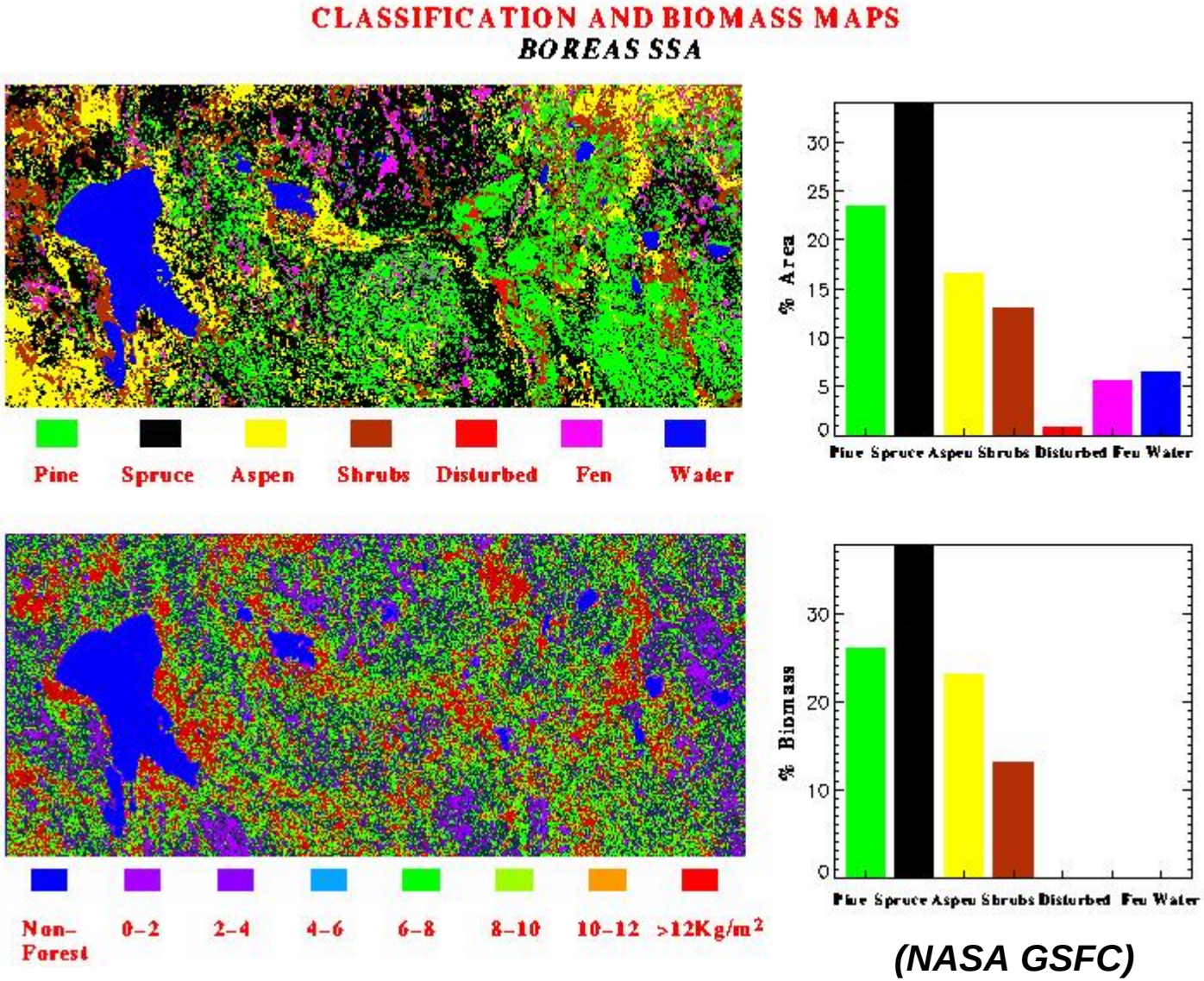
Old Jack Pine
Reddish areas are wetter, with alders

Clear cut, very young jack pine

Young Jack Pine ~ 15 years old

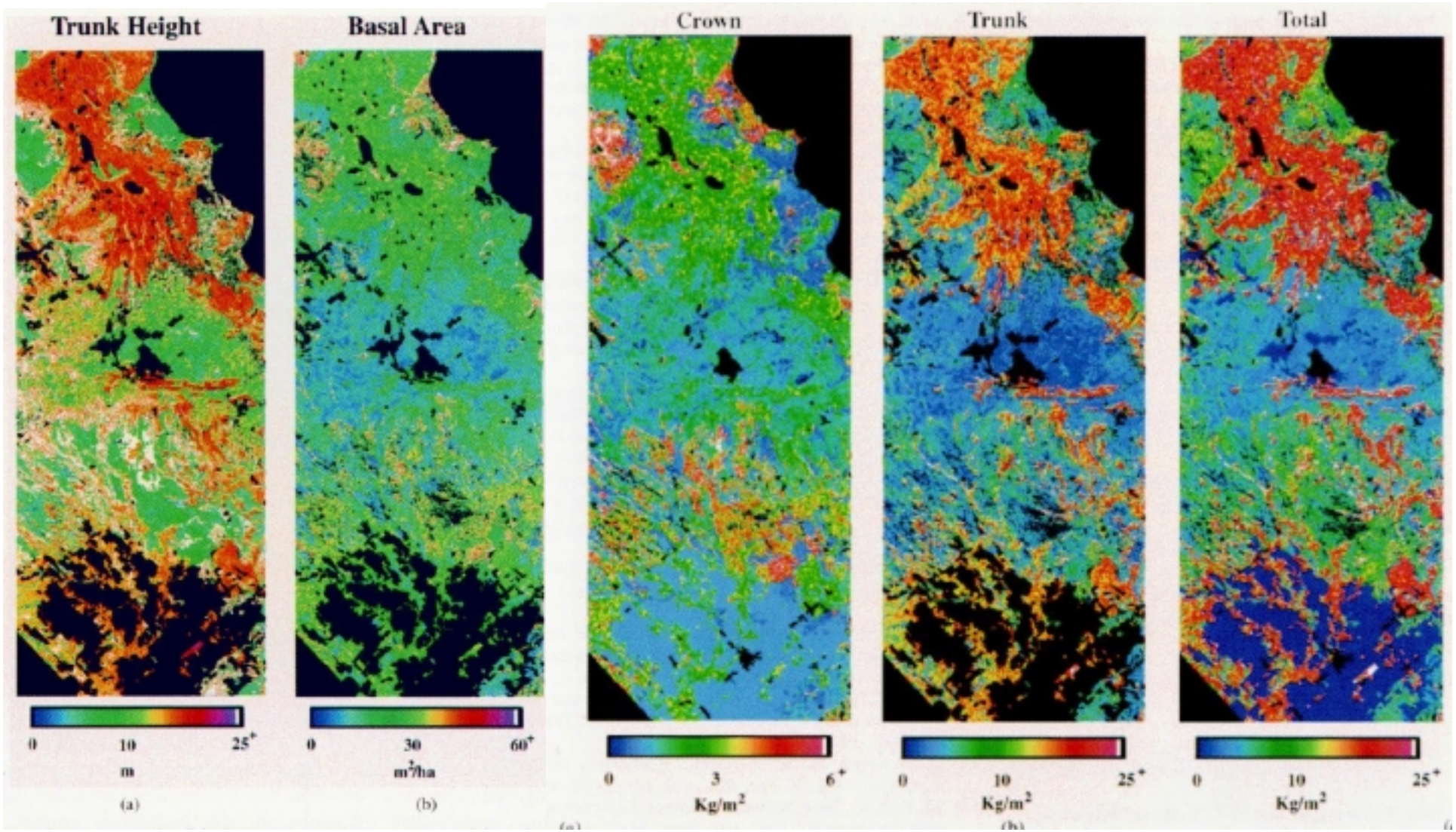
New burns in 1993 trees dead, but only leaves and small branches burned

Forest Classification and Biomass Estimation From SIR-C Radar Images, in Canada

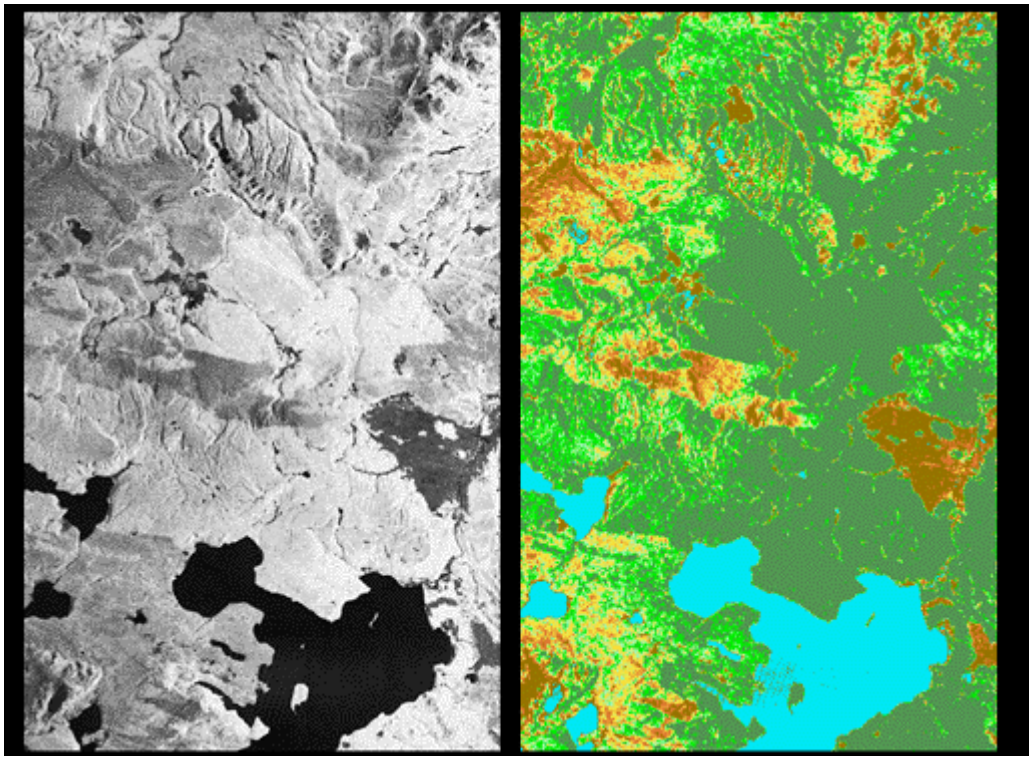


(NASA GSFC)

Trunk Height, Basal Area, Biomass of Crown, Trunk, and Total From SIR-C Data (Dobson et al)



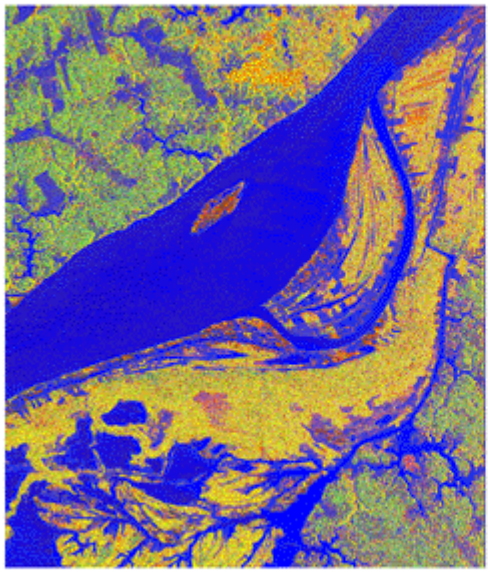
Non-burned Forests and Forests at Different Stages of Fire Succession



Yellowstone National Park, Wyoming, The image at the left is L band HV image obtained on Oct 2, 1994 by SIR-C/XSAR Mission. The image on the right is derived biomass image, showing the non-burned forests and recovery of forests after a fire.
Colors of brown, light brown, yellow, light green , green represent biomass levels of <4, 4-12, 12-20, 20-35, and > 35 tons per hectare.

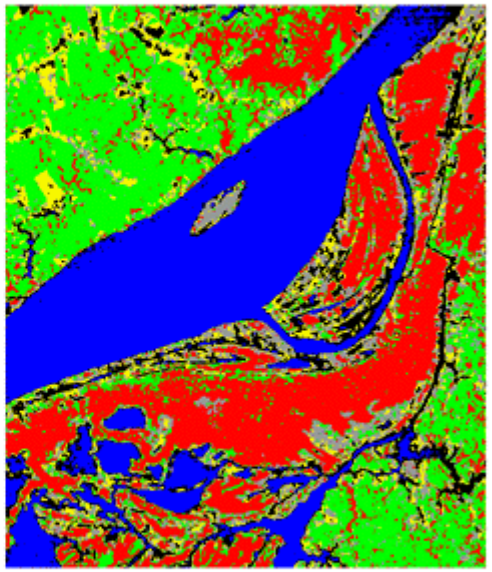
(NASA JPL)

SIR-C/X-SAR
MANAUS, BRAZIL SUPERSITE
INUNDATION MAP
APRIL 12, 1994



SIR-C IMAGE

- LHH
- LHV
- LVV INVERTED

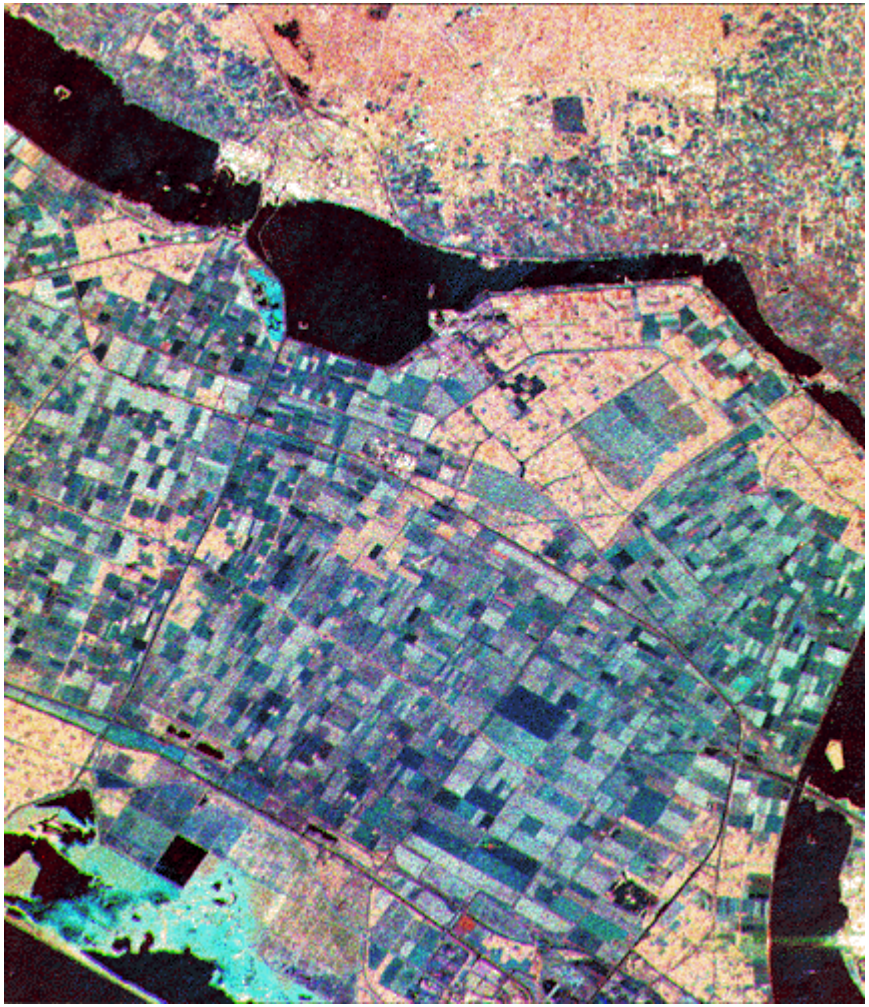


INUNDATION MAP

- FLOODED FOREST
- UNFLOODED FOREST
- OPEN WATER
- UNFLOODED FIELDS
- FLOODED SHRUBS
- FLOATING/FLOODED GRASSES

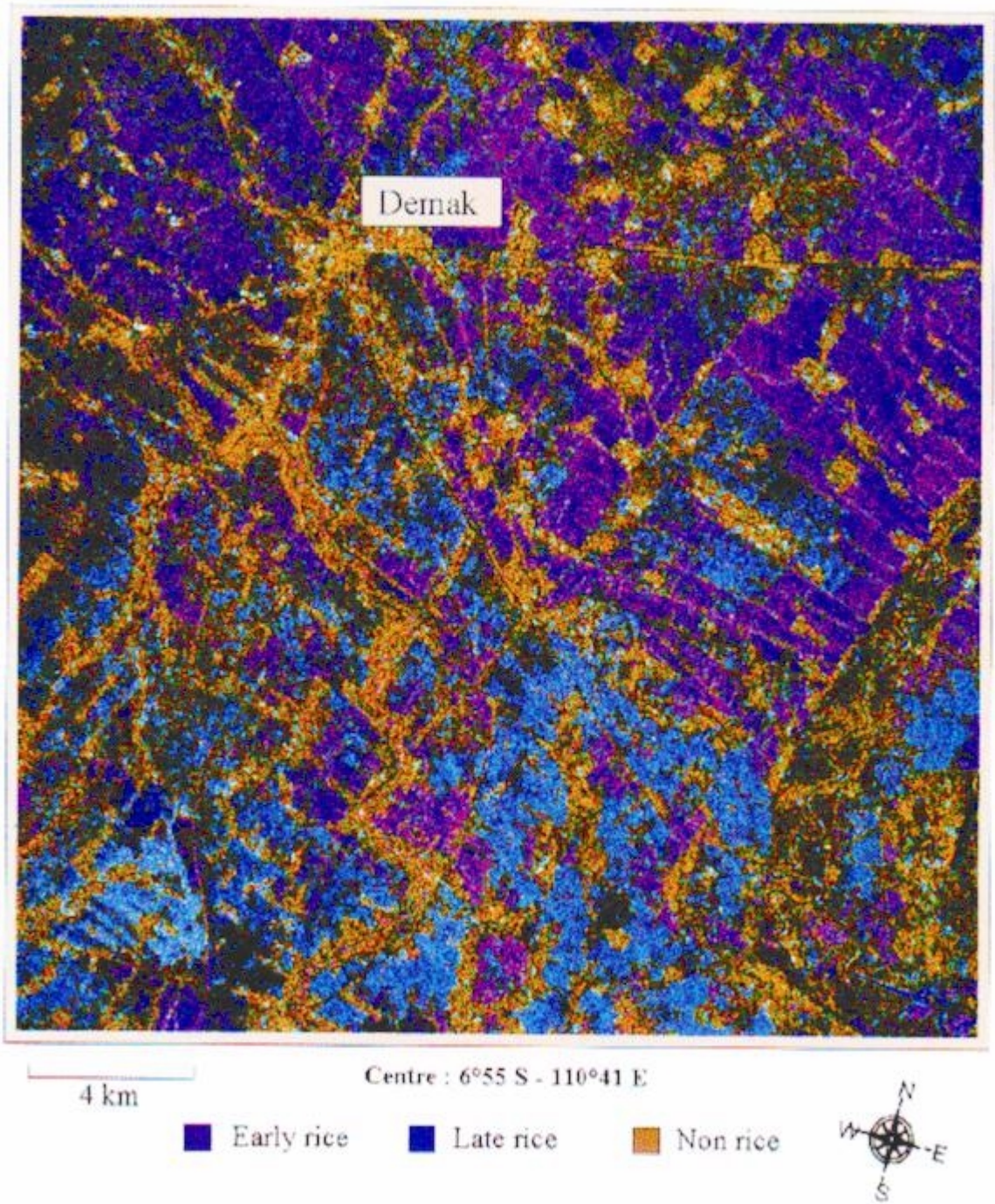
(NASA JPL)

Agriculture, SIR-C/XSAR Image



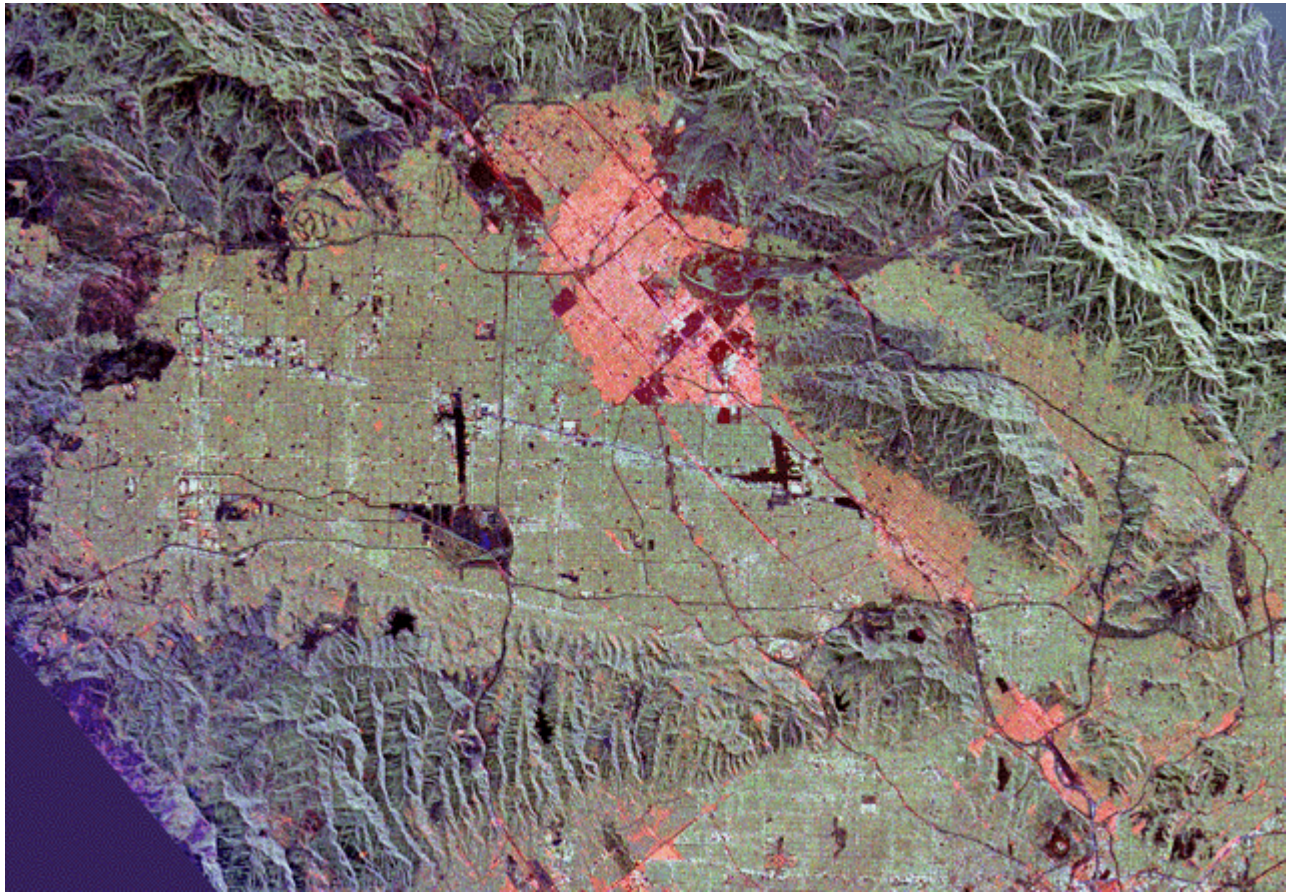
This is a three-frequency, false color, SIR-C/X SAR image (L band total power - red, C band total power - green, and X band vv - blue) of Flevoland, The Netherlands, taken on April 14 1994. At the top of the image, across the canal from Flevoland, is an older forest shown in red. At this time of the year, the agricultural fields are bare soil, and they show up in this image in blue. The changes in the brightness of the blue areas are equal to the changes in roughness.

(NASA JPL)



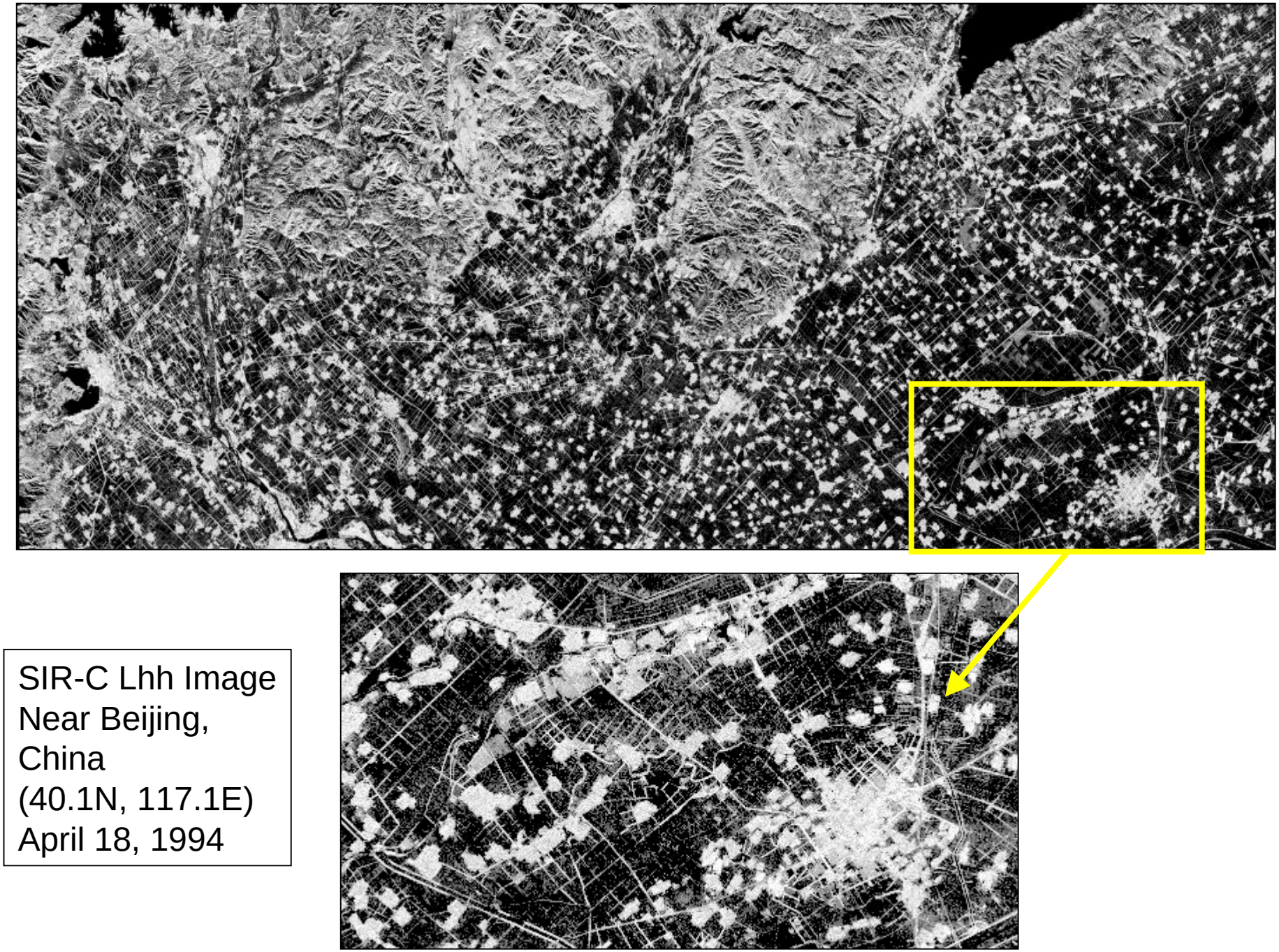
Rice field identification and classification from temporal ERS-1 data

SIR-C Lhh, Lhv, Chv False Color Image

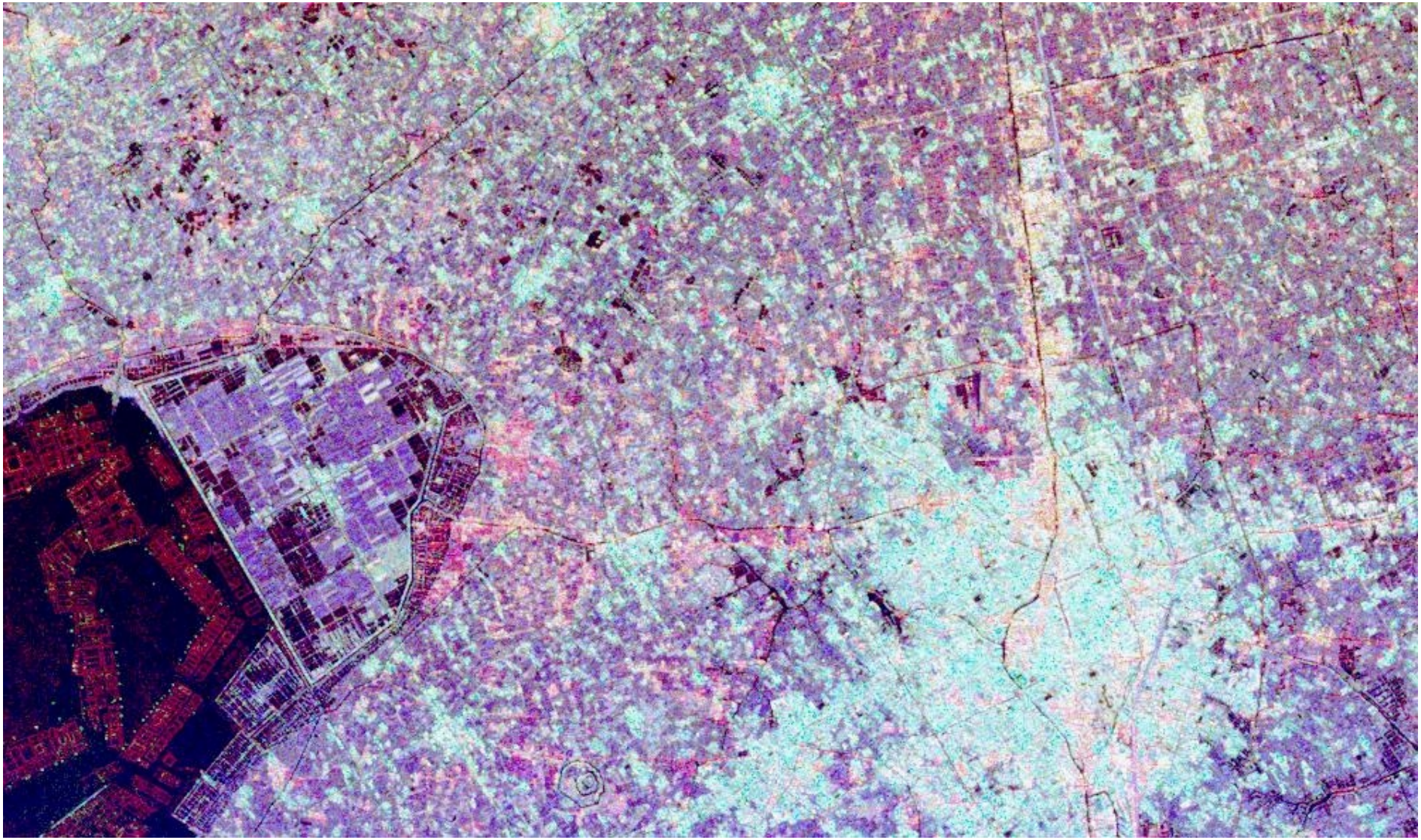


(NASA JPL)

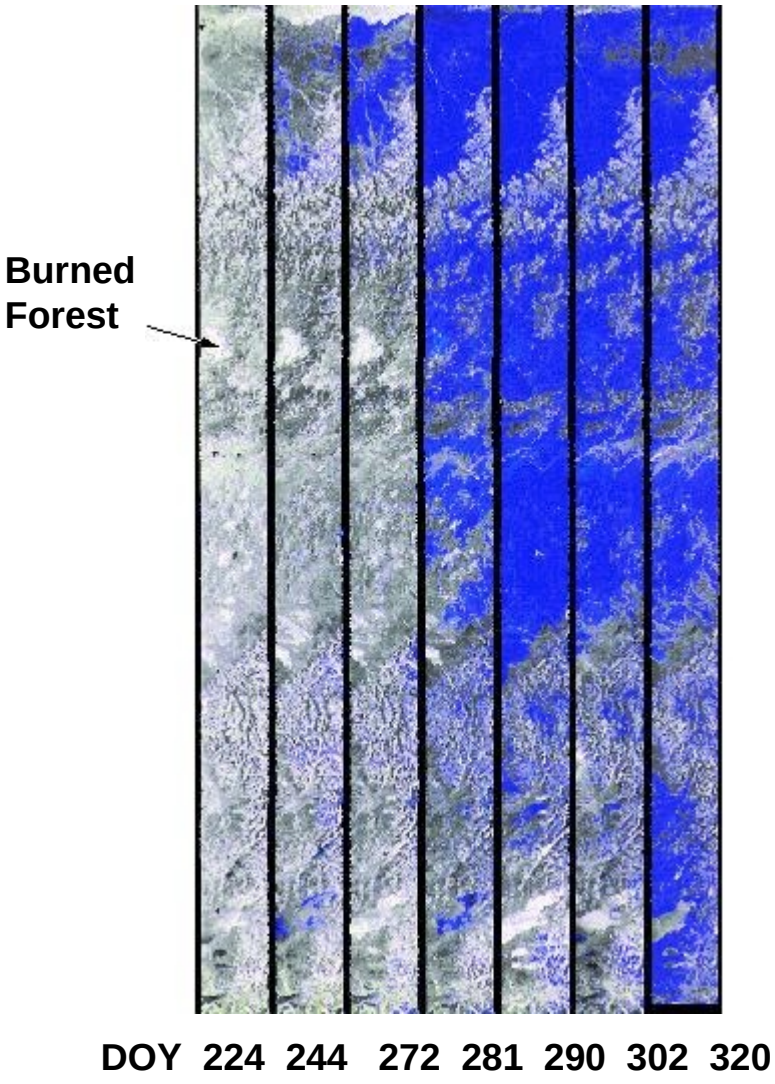
San Fernando Valley, California



SIR-C Lhh Image
Near Beijing,
China
(40.1N, 117.1E)
April 18, 1994



SIR-C Image of Changzhou (31.6N, 119.6E), China. April 18, 1994. Lhh, Lhv, Chv



Thaw/frozen condition

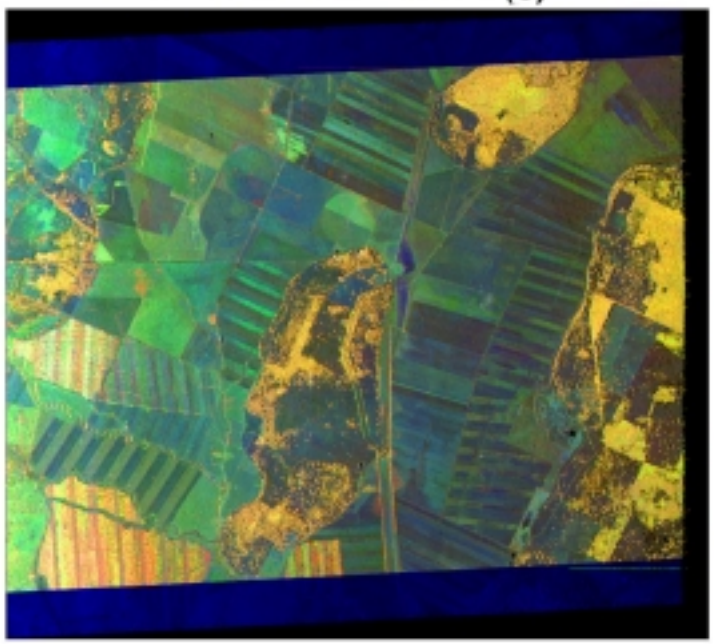
from ERS-1 data
Acquired across Alaska
in 1991
Each transect is
100 km by 1400 km
Areas which show a decrease
in backscatter larger than 3 dB
are coded blue

(Rignot and Way, 1994)

INTEGRATED AIRSAR PROCESSOR

JPL TOPSAR

LIVERPOOL PLAINS 344-1 (C)



Radar Illumination

Velocity

0 1 kilometers

Pixel Size = 10 m

Date Acquired: 6 Sept 1993

Date Processed: 5 June 1995

CCT ID: TS0049

P-Band Total Power

L-Band Total Power

C-Band VV

North

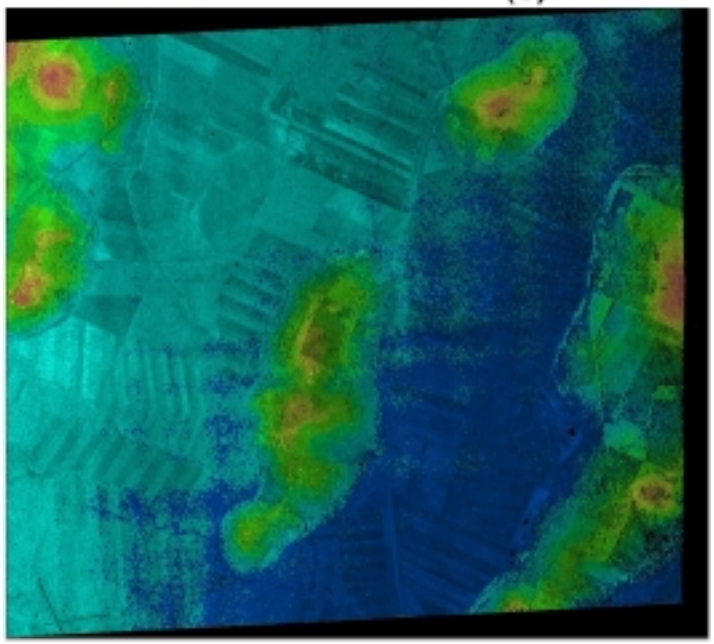
Approximate Image Center:
Latitude: -31.52
Longitude: 150.54

Lines in Image: 1062
Samples per line: 1180

INTEGRATED AIRSAR PROCESSOR

JPL TOPSAR

LIVERPOOL PLAINS 344-1 (C)



Radar Illumination

Velocity

0 1 kilometers

Pixel Size = 10 m

Date Acquired: 6 Sept 1993

Date Processed: 5 June 1995

CCT ID: TS0049

Elevation (meters)

300 450

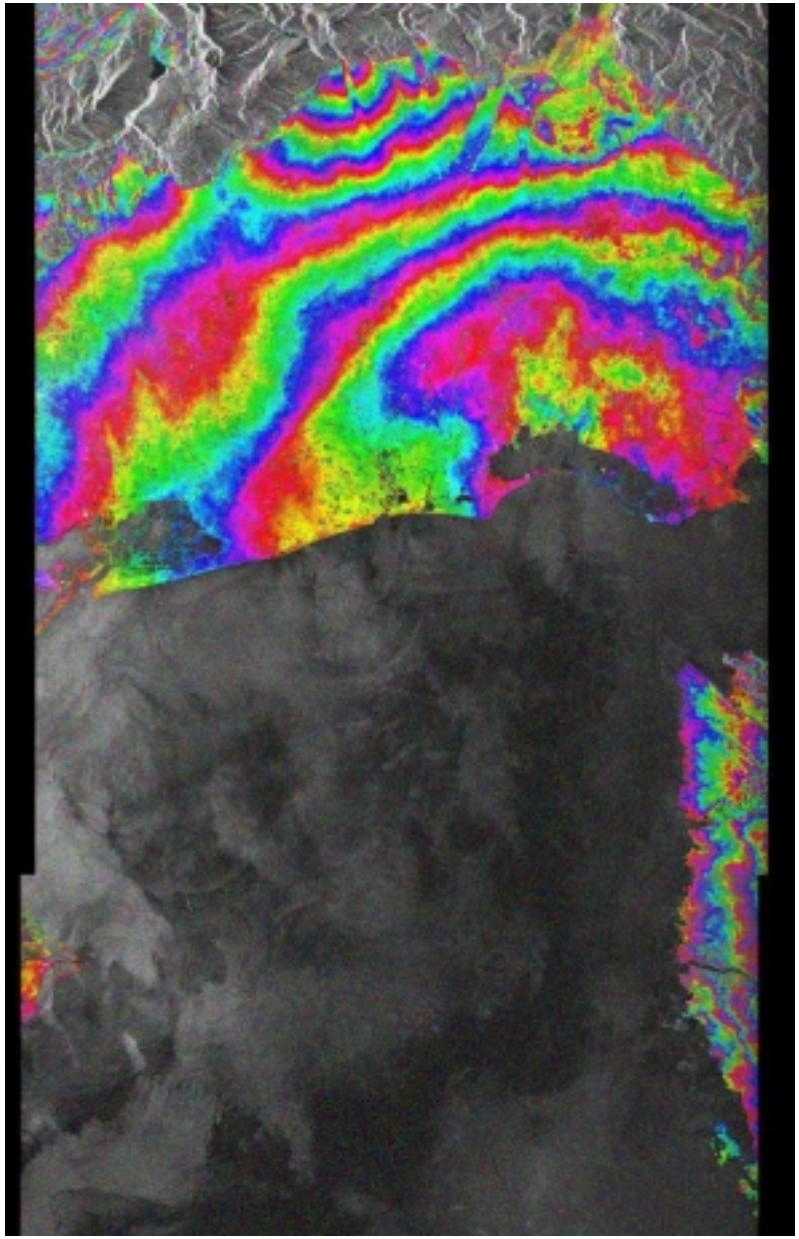
Brightness: C-Band VV Radar Cross-Section

North

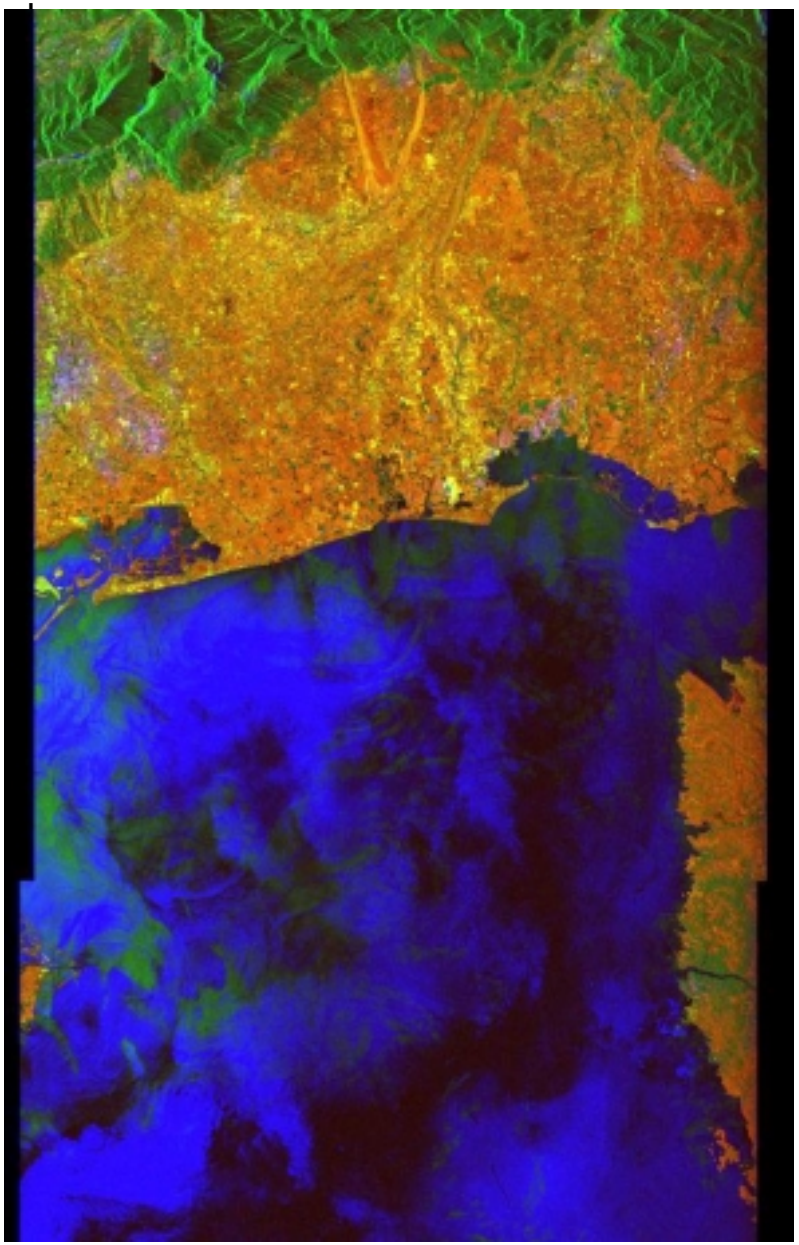
Approximate Image Center:
Latitude: -31.52
Longitude: 150.54

Lines in Image: 1062
Samples per line: 1180

Interferometric Phase Image - a cycle of colors represents phase change of 2 PI



Interferometric Land-use Image - Red: Interferometric
coherence, Green: Average intensity, Blue: Intensity



Vince, Italy

Green area - Heavy vegetation
Blue area - Water
Red area - Bare surface
Yellow area - Urban center

(From European Space Agency - ESA)

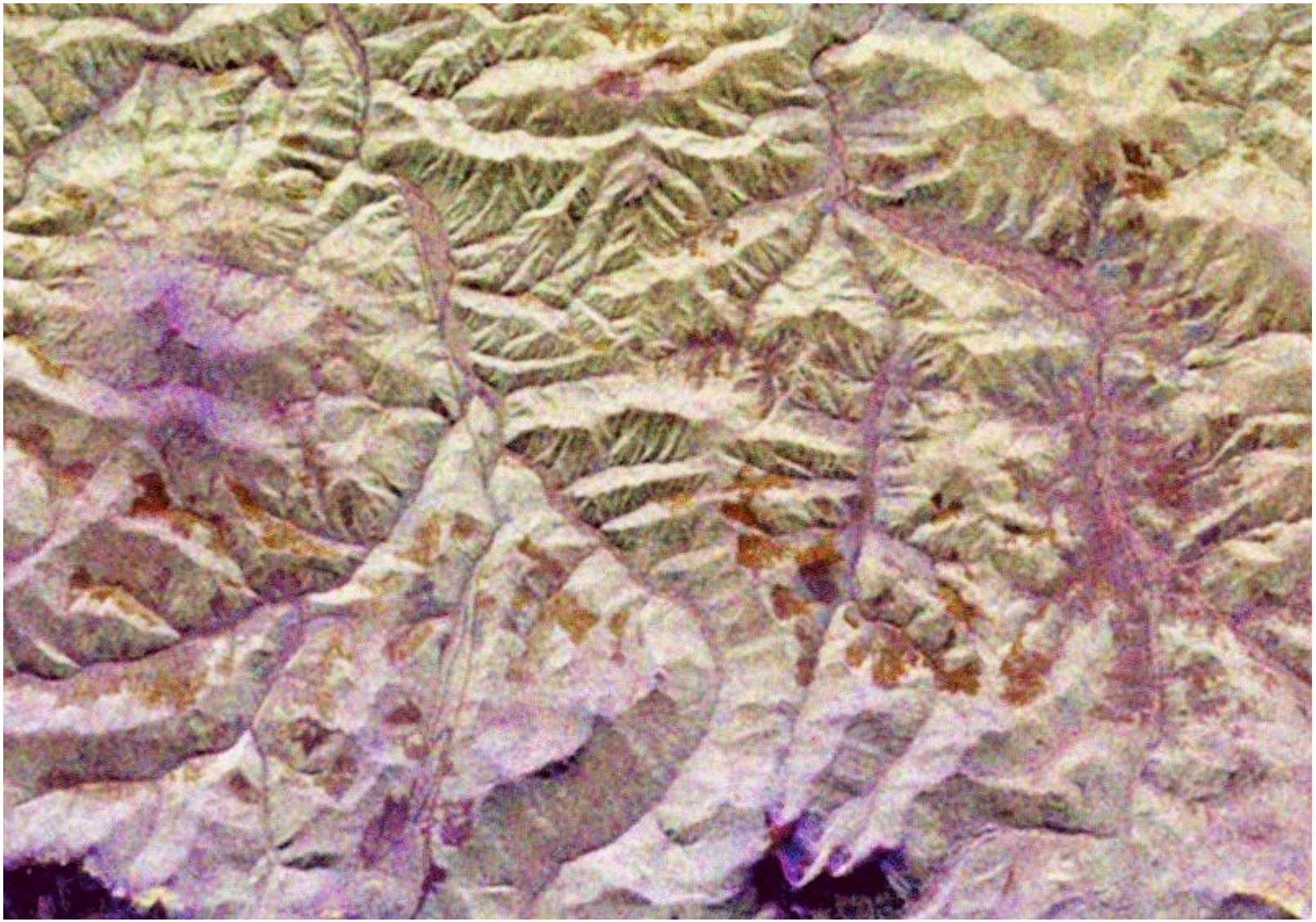
Interferometric Land-Use Image (Virginia Beach, USA)

(From European Space Agency - ESA)

Disadvantages and Limitations of Imaging radar

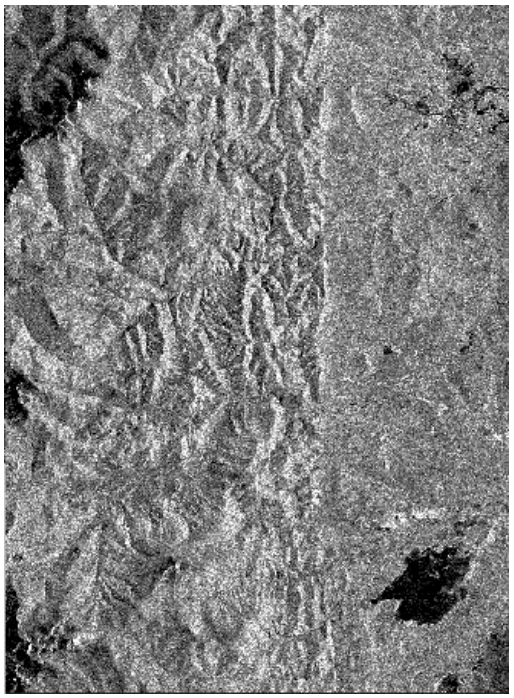
- Speckle degrades image (reduce by multi-look and filtering) and poses difficulties for machine interpretation
- Terrain effect complicates image processing
- Composite signal requires more effort to extract information from it
- Data is not widely available (will be better soon)

Forest clearcut on Mountains of Western Sayani, Russia. SIR-C image, April 16, 1994
Red - L band HH, Green - L band HV, Blue - C band HV, Brown areas are clearings

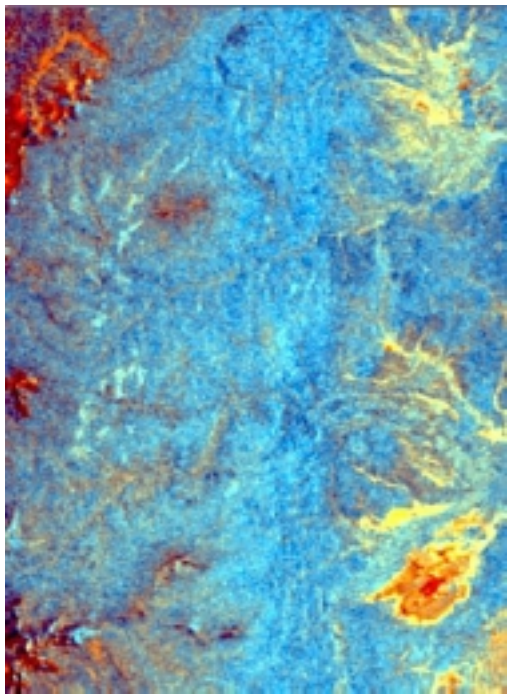


Mapping Forests in Sayani Mountains, Siberia Using SIR-C SAR Data
- Using DEM data for orthorectification and terrain effect correction, or using image ration to reduce terrain effects

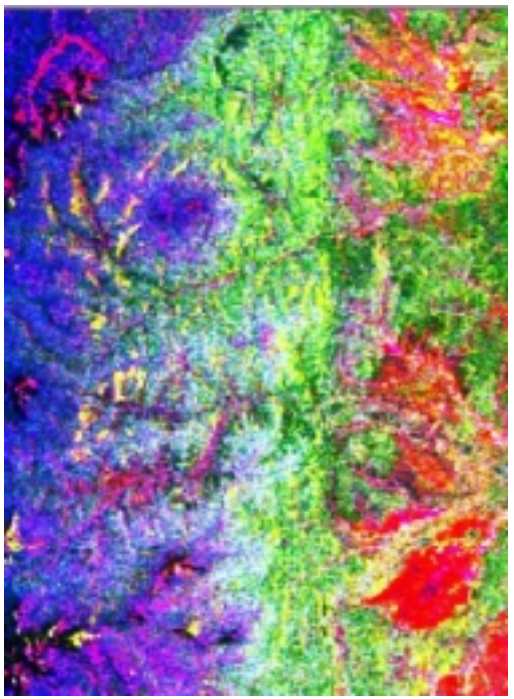
Lhh SIR-C radar image



Ratio Images



PC of ratio images



Existing SAR Data

- SIR-C/XSAR data: April and October, 1994, order from EROS, USGS, (http://edcwww.cr.usgs.gov/landdaac/sir-c/survey.html) $15 per scene (both L and C bands)
- ERS-1/2 data: Global cover since 1991, ~$1500 per scene
- JERS-1 data: 1992-1998, ~$1500 per scene
- RADARSAT data: $3500 per scene, NASA has a share
- Data received and processed by ASF (Alaska SAR Facility) - $15 per scene

FUTURE SAR MISSIONS

- SRTM (Shuttle Radar Topography Mission) C and X bands InSAR - Sept. 1999, NIMA, NASA, DLR, ASI
- ASAR (Advanced SAR) on ENVISAT-1, C band multi-pol, 2000, ESA
- RADARSAT-2, C band multi-pol, 2001, CCRS, Canada
- ALOS-PALSAR, L band multi-pol, 2002, NASDA, Japan
- LightSAR, L band full-pol, C band hi-res, 2003, NASA

SRTM

(NIMA, NASA, DLR, ASI)

September 16-27, 1999
C and X band InSAR
Coverage: from 60^{o} N to 56^{o} S
Data Products:

1 Terrain height data - Pixel spacing 1” (15-30 m), 5^{o} x 5^{o}
  Absolute accuracy:
    horizontal 20 m
    vertical 16 m
2 Random height error data sets
3 Strip orthorectified image data
    Pixel spacing 15 m

ENVISAT-1 ASAR

(Advanced Synthetic Aperture Radar)

Launch: 2000
Wavelength: C band
Polarization: HH & VV,
HH & HV, VV & VH
Image Products:
Single-look complex - Resolution ~6 m
Image size 100 km x 100 km
Multilook precision - Resolution < 30 m
Image size 100 km x 100 km
Median resolution image: Resolution < 150 m
Image size: Normal 100 km x 100 km,
Wide swath: 400 km x 400 km
Global monitoring: Pixel size 1 km

A Coherent Active Phased Array C band SAR

ASAR's five mutually exclusive modes of operation:
Global monitoring, Wave mode
Image mode (HH or VV)
Alternating polarization mode (Two polarization),
Wide swath mode (HH or VV)

European Space Agency - ESA

RADARSAT-2
(CCRS, CANADA)

Launch: 2001
C band
HH, VV and HV & VH

RADARSAT-2 IMAGING MODES

Beam Modes	Nominal Swath Width	Incidence Angles	Number of Looks	Approx. Resolution
Standard	100km	20-50	1x4	25m x 28m
Wide	150km	20-45	1x4	25m x 28m
Low Incidence	170km	10-20	1x4	40m x 28m
High Incidence	70km	50-60	1x4	20m x 28m
Fine	50km	37-48	1x1	10m x 9m
ScanSAR Wide	500km	20-50	4x2	100m x 100m
ScanSAR Narrow	300km	20-46	2x2	50m x 50m
Standard Quad Polarization	25km	20-41	1x4	25m x 28m
Fine Quad Polarization	25km	30-41	1	11m x 9m
Triple Fine	50km	30-50	3x1	11m x 9m
Ultra-fine Wide	20km	30-40	1	3m x 3m
Ultra-fine Narrow	10km	30-40	1	3m x 3m

ALOS-PALSAR

Phased **A**rray type **L**-band **S**ynthetic
Aperture **R**adar (PALSAR)
NASDA, JAPAN
Launch 2002
on ALOS
(Advanced Land Observing Satellite)

Altitude: 700 km
Inclination: 98^{o}
Recurrent: 45 days

L band, Multiple polarization

Mode	Resolution	Swath
Fine resolution	10-20 m	70 km
ScanSAR	100 m	250 - 360 km

LIGHTSAR

New earth-imaging Radar Satellite
NASA
Launch Date 2003

L band multiple polarization, resolution 25 m
Swath 100 km
C (X) band high resolution (1-3 m) with narrow swath in the middle of L band swath
Multiple operation modes: Spotlight, High resolution strip, Dual or Quad polarization, Repeat pass interferometric, and ScanSAR

SUMMARIES

- Imaging Radar contributes to LCLUC studies by providing timely, unique and complementary data
- Complexity in Radar image processing and interpretation requires more efforts
- Imaging radar has bright past and future - From Seasat (1978) to LightSAR (2003)

Global Studies

Early Results- Characterizing land cover herogeneity and land cover change from multi-sensor satellite data- R. DeFries

CHARACTERIZING LAND COVER HETEROGENEITY AND LAND COVER CHANGE FROM MULTISENSOR SATELLITE DATA

R. DeFries

M. Hansen

J. Townshend

X. Zhan

Laboratory for Global Remote Sensing Studies

Department of Geography

University of Maryland, College Park

PROJECT OBJECTIVES

- **Improve characterization of land surface in regional and global earth system models**
  spatial: land cover heterogeneity
  temporal: interannual variability and land use change
- **Contribute to LCLUC goal to "develop the capability to perform repeated global inventories of land use and land cover from space"**

ORIGINAL PROPOSAL

- **GLOBAL LAND COVER CLASSIFICATION**
  apply methodology from previous work to 1km AVHRR data
- **ALTERNATIVE DEPICTION OF LAND COVER AS "CONTINUOUS FIELDS"**
  8km AVHRR time series to identify land cover change
  1km AVHRR
- **SIGNIFICANCE FOR BIOSPHERE-ATMOSPHERE MODELS**

EARLY ATTEMPT AT GLOBAL LAND COVER CLASSIFICATION FROM REMOTE SENSING

- Based on phenology of vegetation types represented in temporal NDVI profile
- Derived from NOAA's AVHRR data
- Coarse one by one degree resolution
- Maximum likelihood classification algorithm
- Designed for use in biosphere-atmosphere models

IMPROVEMENTS IN GLOBAL LAND COVER CLASSIFICATIONS

- Based on higher resolution AVHRR data (8km and 1km)
- Training data from interpretation of global network of Landsat scenes
- Decision tree algorithm
- Based on multitemporal metrics using all bands in addition to NDVI

ALTERNATIVE CHARACTERIZATION OF LAND COVER AS “CONTINUOUS FIELDS”

- Describes proportional coverage of life form, leaf type, and leaf longevity for each pixel
- Removes discrete boundaries between cover types to more realistically depict land surface heterogeneity
- Allows inclusion of subpixel interannual variability and land use change in models
- MODIS post-launch product

8km CONTINUOUS FIELDS TIME SERIES

- Continuous fields derived independently for each year in 1982-95 AVHRR Pathfinder series
- In stable locations, %woody varies up to 10%
- Comparison with Landsat Pathfinder results from Bolivia

1km CONTINUOUS FIELDS

- Integrates mixture model result with 1km classification
- % tree cover to be available on-line
- Prototype to be revised using multiple endmembers

1km CONTINUOUS FIELDS IN CASA

- Continuous fields used for NPP allocation to wood, leaf, root
- .5 degree run with veg type mosaic from 1km classification
- .5 degree %woody for each veg type from continuous fields

WHAT'S LEFT?

- Final version of 1km land cover classification to include additional types
- Improvements on method for continuous fields with multiple endmembers
- Continued validation with high resolution data
- Application of methods to MODIS data
- Modeling applications!!

North America

The dynamics of a semi-arid region in response to climate and water use policy - J. Mustard

Assessing future Stability of US high Plains landcover integration of process modeling with Landsat, in-situ, model and paleoclimate data - J. Overpeck

Land Cover Change in the Great Plains: predicting impacts of regional forest expansion on biogeochemical processes - L. Johnson

Quantifying grassland to woodland transitions and the implications for carbon and nitrogen dynamics in the southwest United States - S. Archer

Early Results- Hierarchical investigation of socioeconomic drivers of decadal scale land cover changes in the upper Midwest - D. Brown

Early Results- Causes and consequences of land cover in a Greater Ecosystem: trend assessment, monitoring and outreach - A. Hansen

The Dynamics of a Semi-Arid Region in Response to Climate and Water-Use Policy

PI: John F. Mustard		Brown University
Co-Investigators:		
Steve Hamburg	Ecol.	Brown University
John Grant	Hydrol.	Buffalo State
Sara Manning	Ecol.	Inyo Co. Water Dept.
Aaron Steinwand	Hydrol.	Inyo Co. Water Dept.
Chris Howard	GIS	Inyo Co. Water Dept.

Students:

Andrew Elmore
Virali Gokaldos
David Lobel

PROJECT OBJECTIVES

5 Principal Areas of Investigation:

1) Response of bajada and valley floor shrub communities to a pronounced drought
2) Response of riparian and phreatophyte communities to a pronounced drought
3) Response of riparian and phreatophyte communities to additional stress imposed by groundwater drawdown
4) Response of all of these groups to increased precipitation and groundwater recharge, and reduced groundwater pumping (recovery)
5) Characteristics and magnitude of change of both the natural and managed systems of Owens Valley over 15 years in response to natural and socially-driven forces

PROJECT OBJECTIVES

What are the modes of response of arid and semi-arid systems to climatic variability and anthropogenic stress?

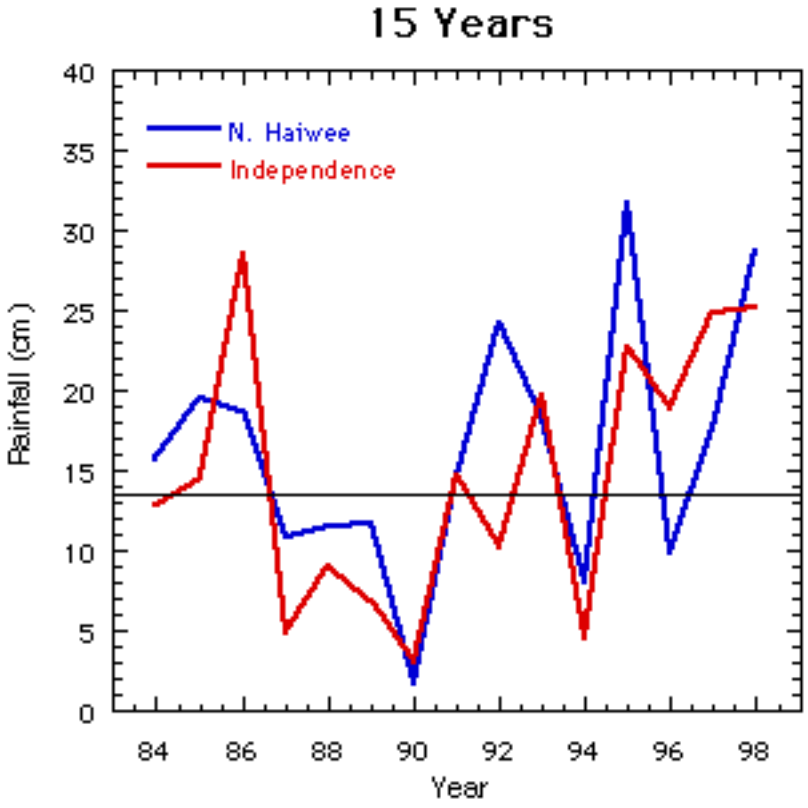
Case Study in Owens Valley CA

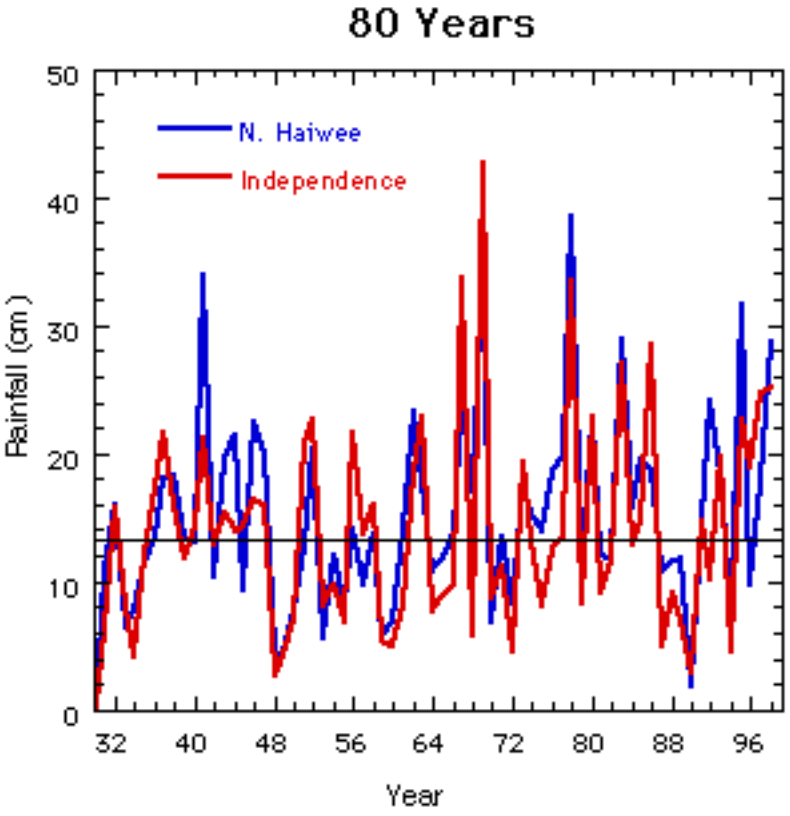
- Climate variability over the last 20 years
- Mosaic of ecosystems (riparian => shrubland)
- Competition for water resources:
  - Ecosystems ⇔ Local ⇔ Regional
- Large changes observed
- Excellent ground control at specific sites
- Management of resources tied to ecological health
- Remotely sensed data required to scale local observations to regional perspectives

METHODOLOGY AND APPROACH

- Reduction of Remote Sensing Data to obtain estimates of green vegetation abundance, validation of technique
- Classify change vectors into functional response groups
- Establish relationships between functional groups and physical/climatological/land-use data base
- Determine response of systems to both climatic variability and anthropogenic stress

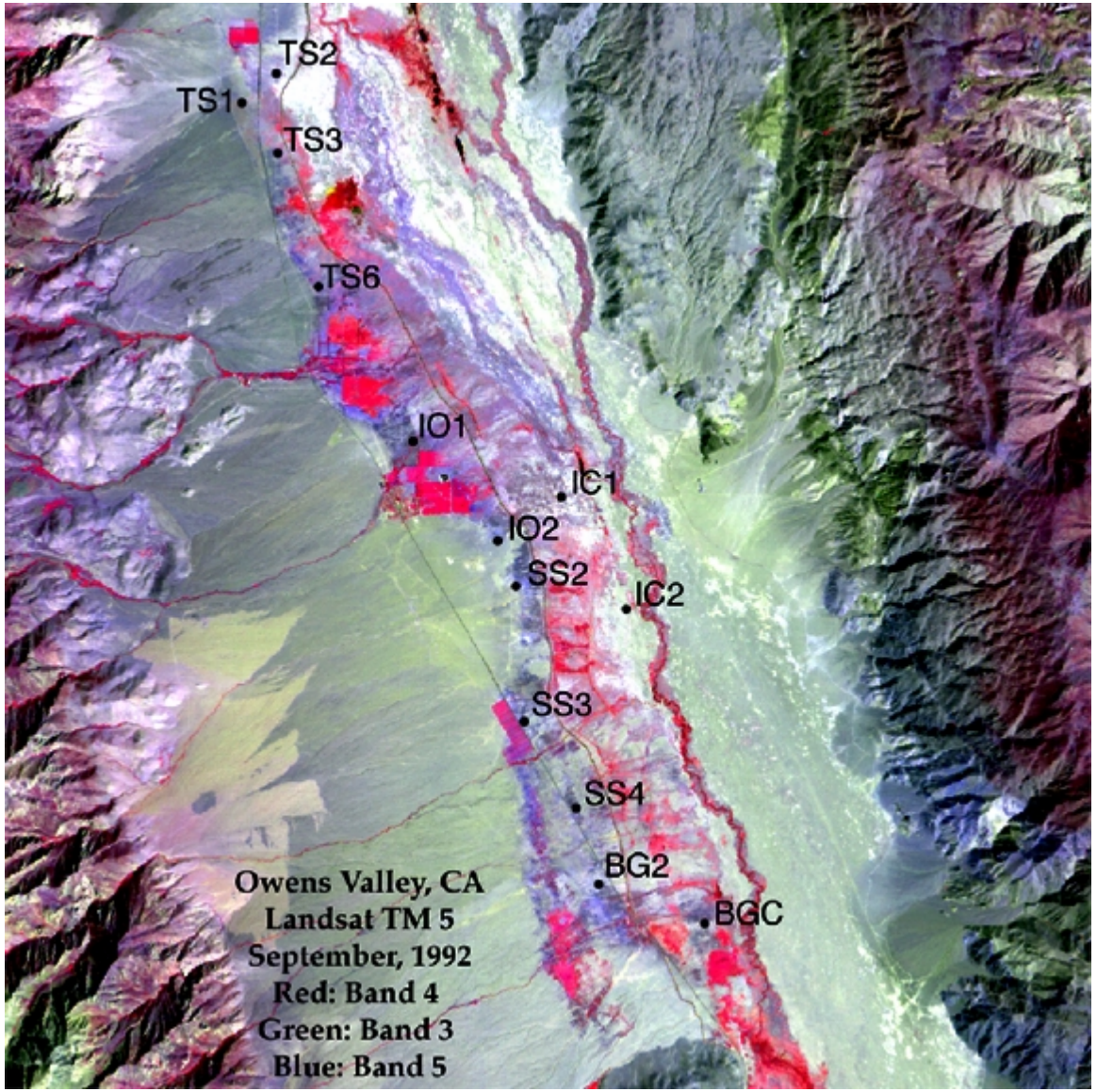
Precipitation





Processing Steps

- Co-registration
- Geo-referencing
- Spectral Calibration
- Spectral Mixing Model
- Field Measurements
- Field Site Location Finding
- Statistical Analysis

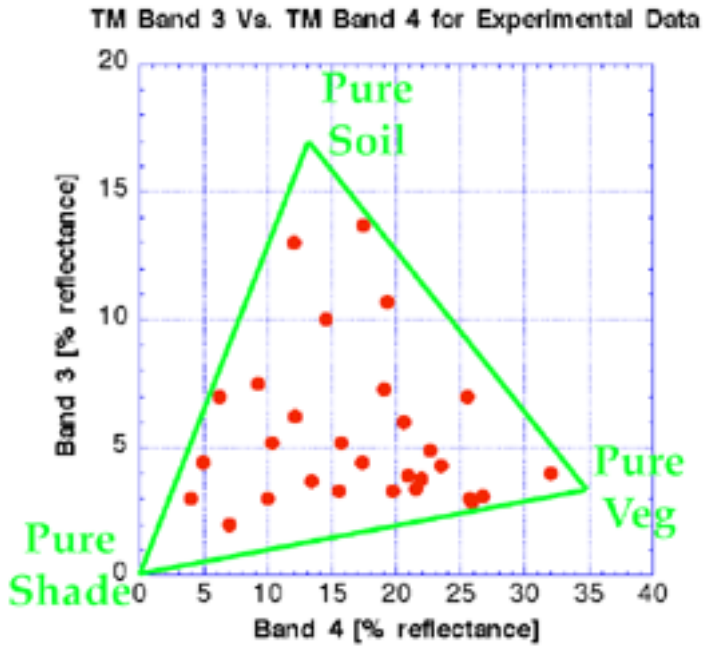

TS2
TS1
TS3
TS6
IO1
IC1
IO2
SS2
IC2
SS3
SS4
BG2
BGC
Owens Valley, CA
Landsat TM 5
September, 1992
Red: Band 4
Green: Band 3
Blue: Band 5

Spectral Mixture Analysis

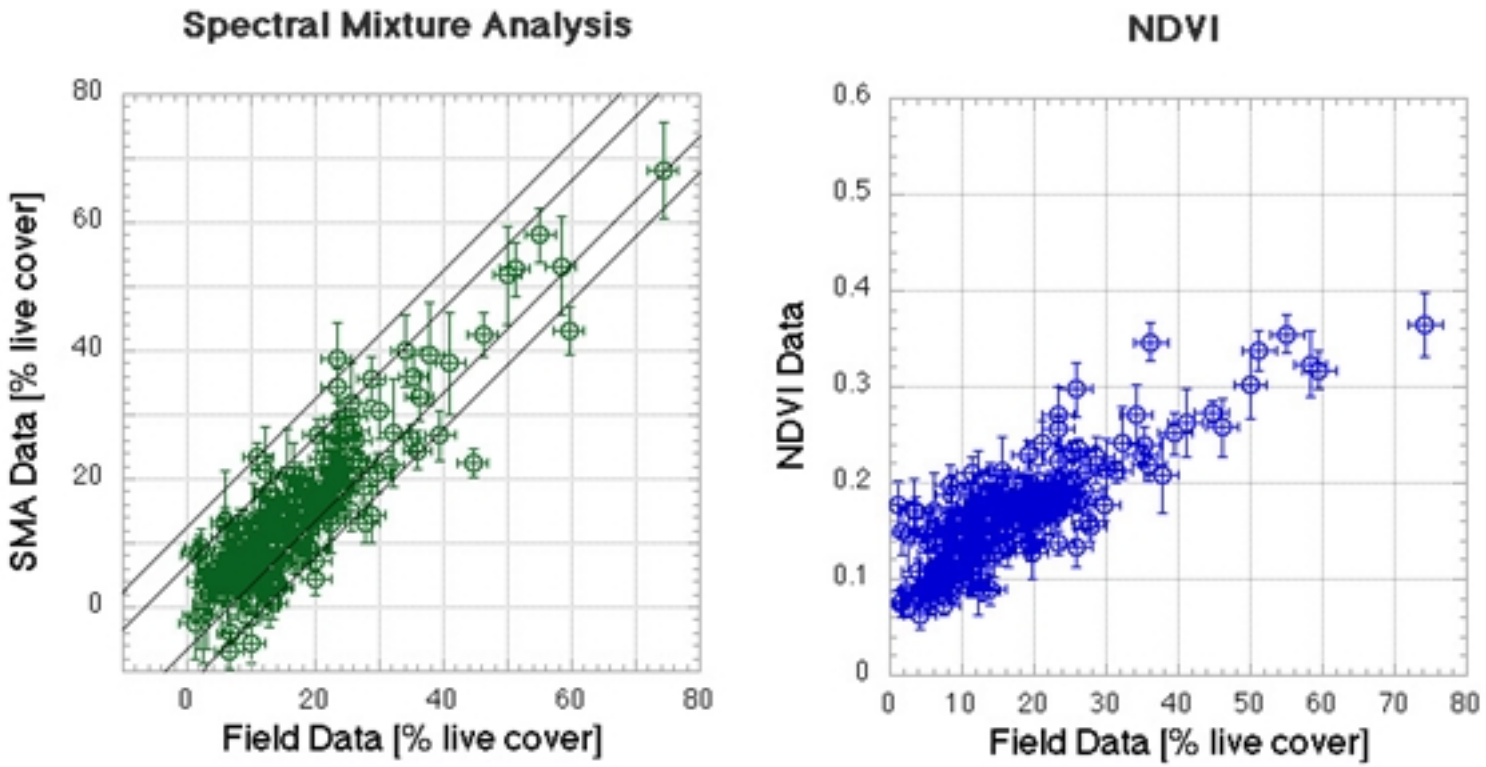
$$DN_b = \sum_{i=1}^{N} F_i DN_{i,b} + E_b$$

$$\sum_{i=1}^{N} F_i = 1$$

- These two equations utilize all 6 (non-thermal) TM bands.
- Constrained so that the sum of the fractions must equal 1.

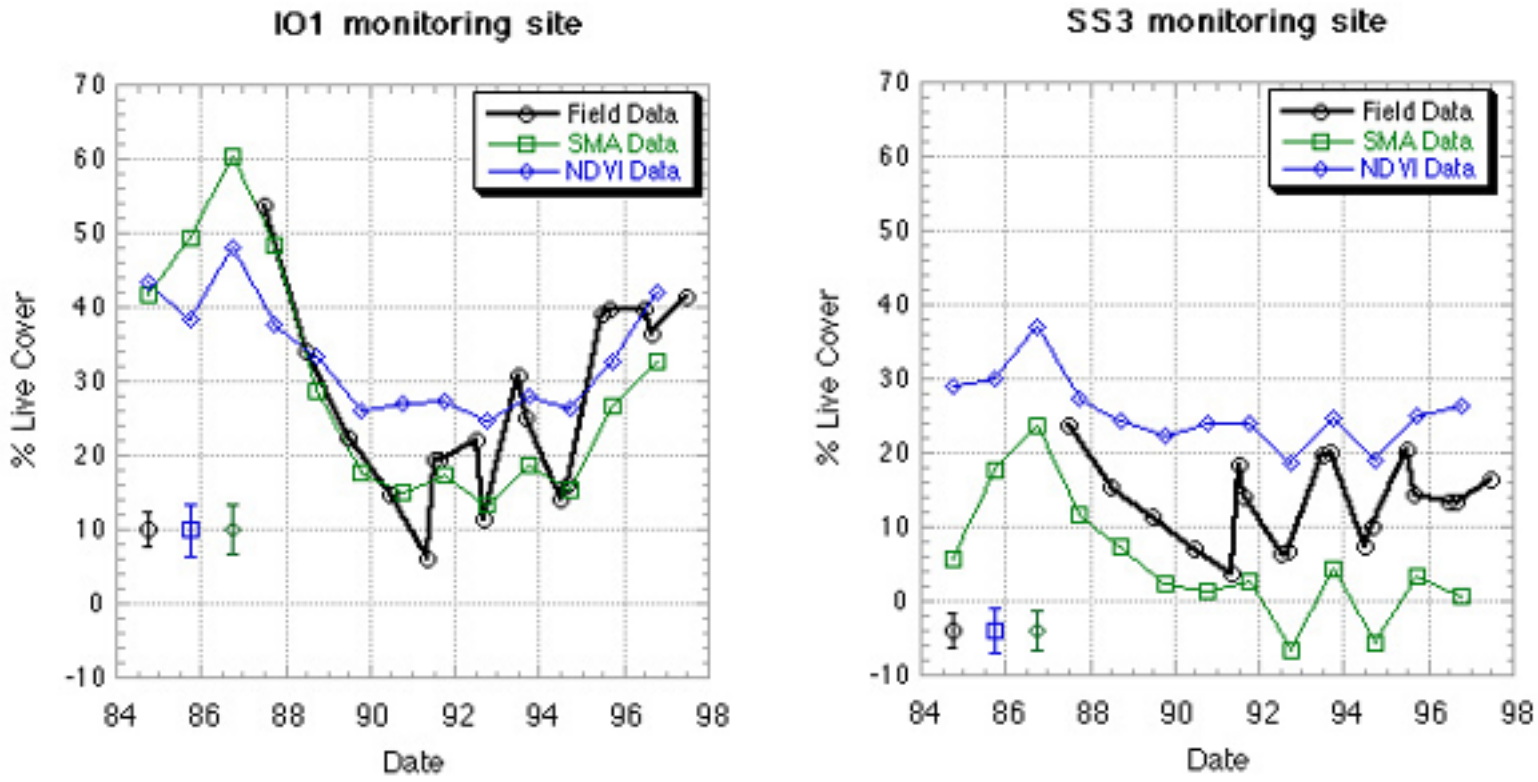


Absolute Abundance



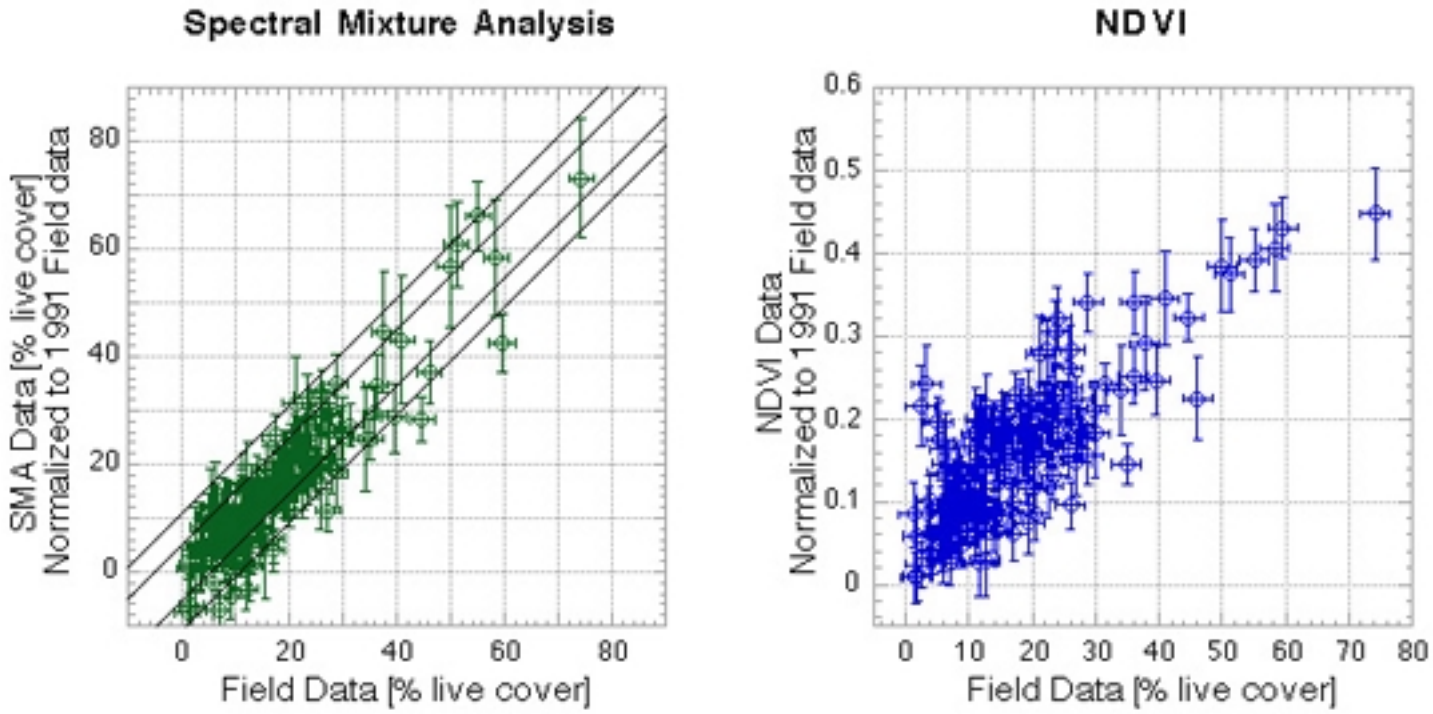
Correlation between field data (x-axis) and remotely sensed parameters (y-axis) showing a linear relationship for SMA. However, NDVI saturates at high vegetation abundance.

Field, SMA, and NDVI Data for Two Sites



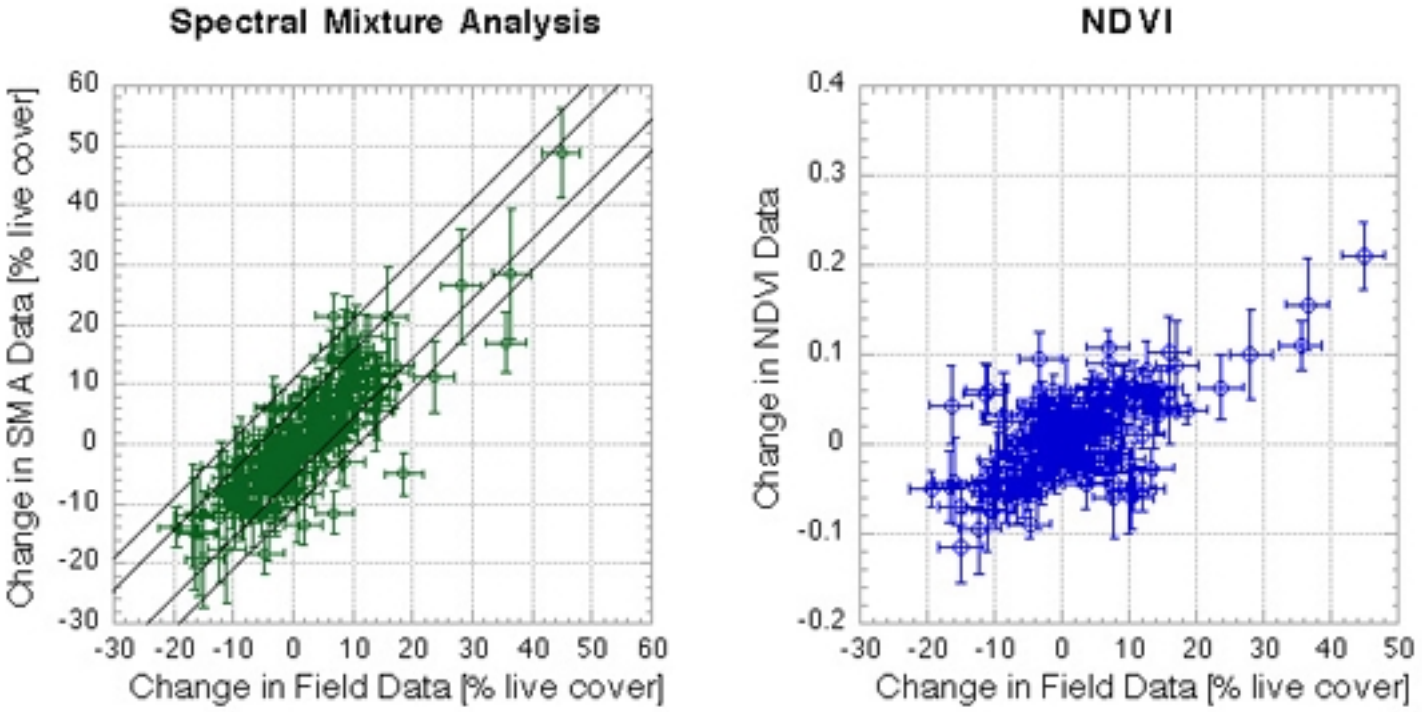
Some field sites show one to one correlation between SMA and Field data (IO1 - left) while others are correlated but offset (SS3 - right). NDVI is also correlated but the offset often varies through time.

Normalized Abundance



By subtracting the offset seen in the previous graph the remotely measured data can b
normalized to the field data at a single date. The SMA results are more correlated to t
field measures, while the NDVI correlation becomes worse.

Yearly Change in Abundance



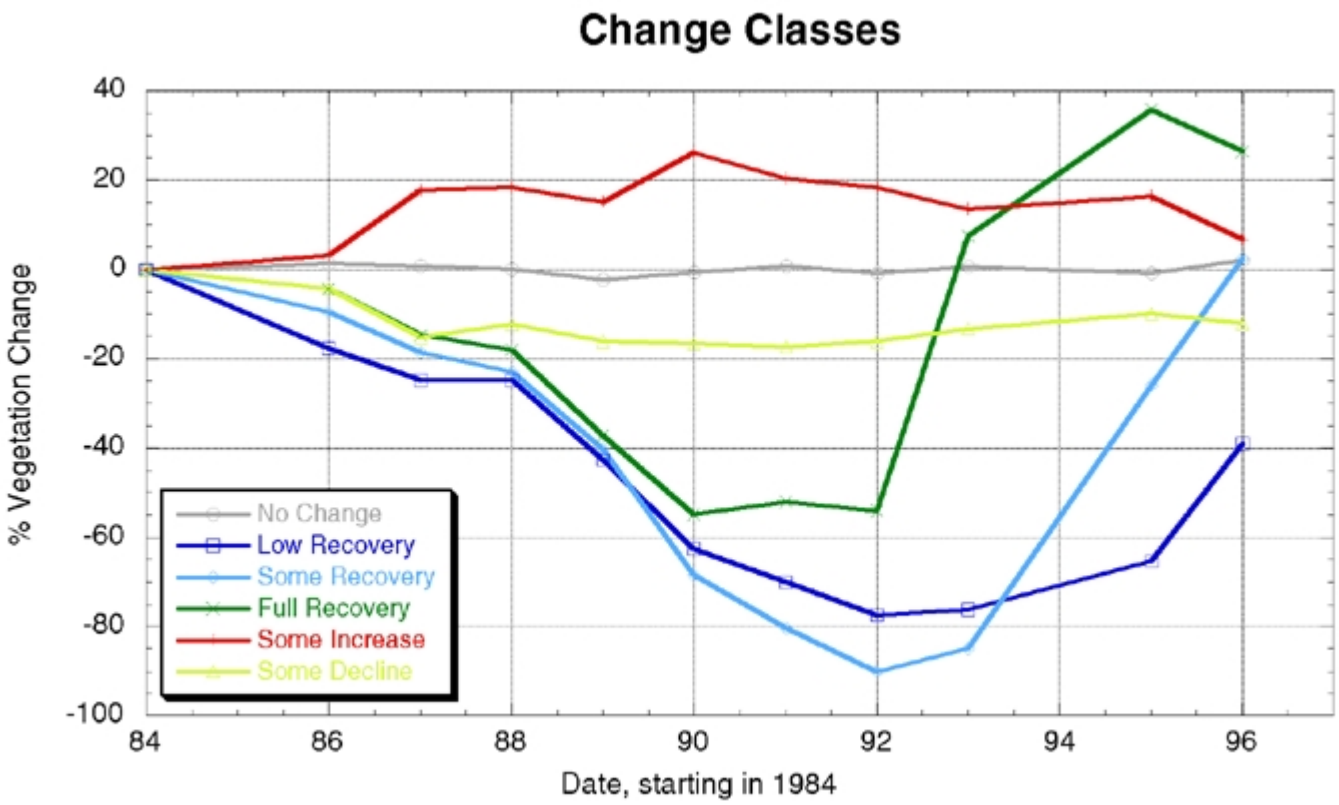
Year to year change in % live cover can be quantified to a +/- 3.8%lc for the SMA results. NDVI, however, quantifies change poorly.

SMA Results

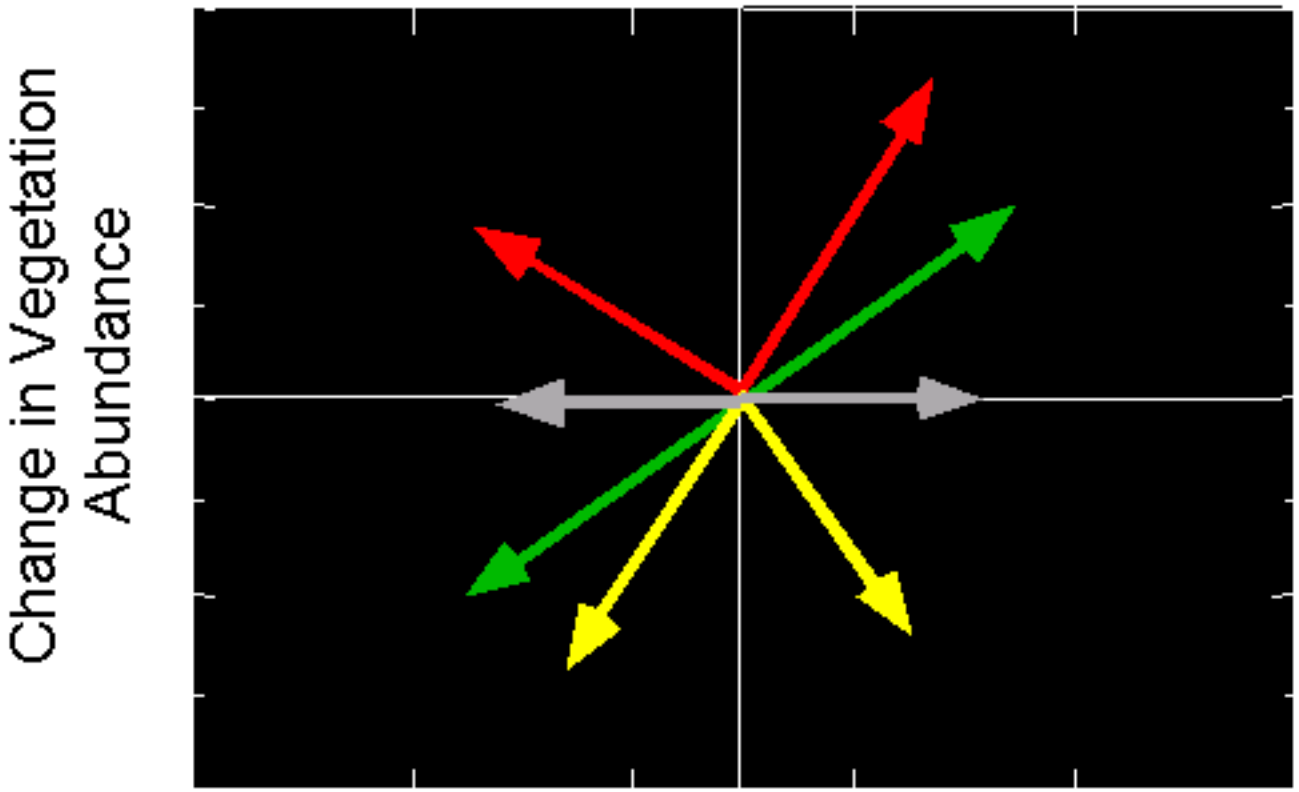
- SMA is linearly correlated with field measures of % live cover.
- Absolute % live cover accuracy +/- 4.0%
- Yearly change in % live cover precision +/- 3.8%
- SMA produces the correct sense of change in 86% of the data vs. 67% for NDVI.

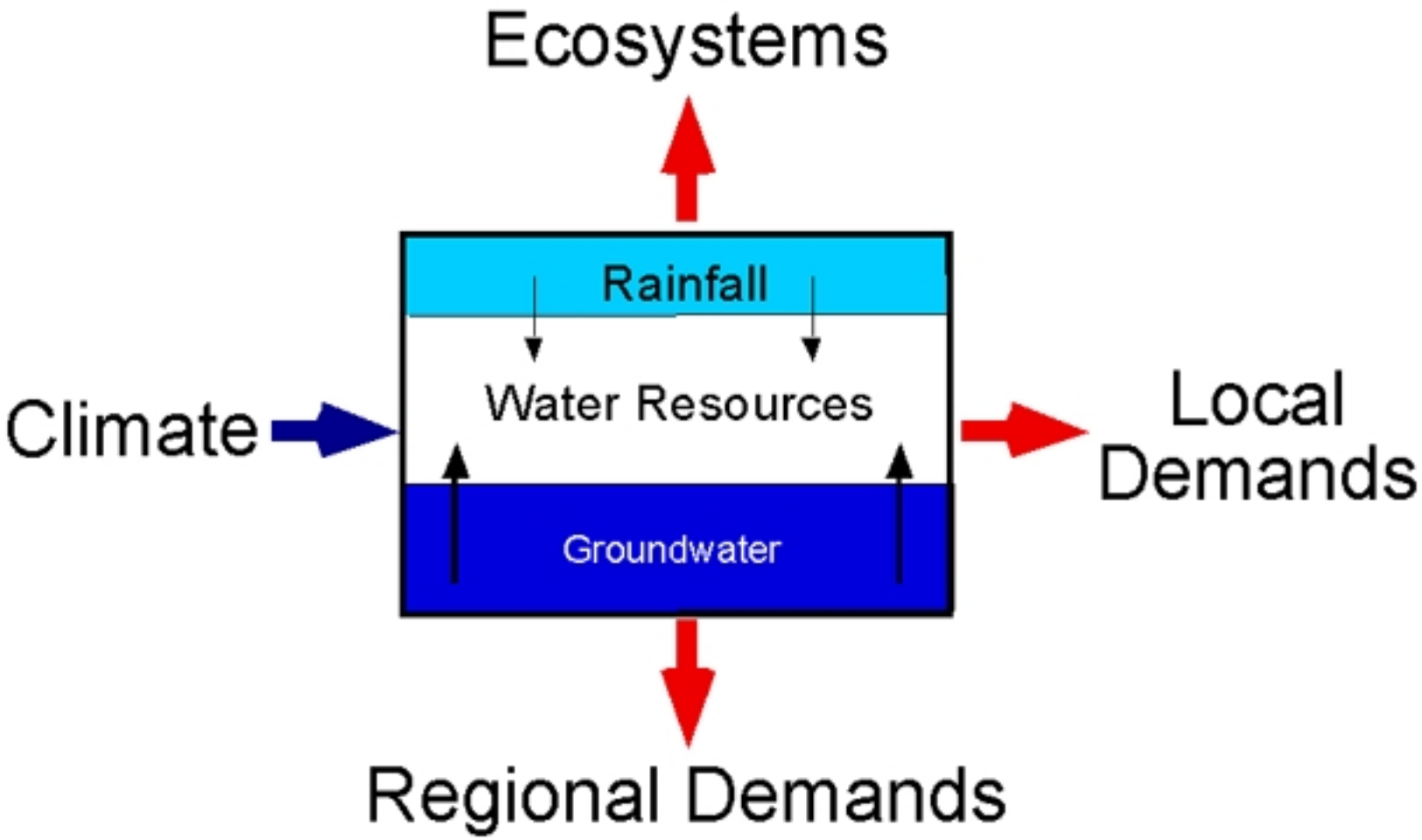
Response Analysis

- Identify and map common modes of response from remotely sensed data
- Link common modes to the permanent monitoring sites and then to the key physiographic, land-use history, and water resource history
- Scale the detailed site analysis up to the regional perspective
- Bring analytical modeling in as a tool to relate observed patterns of change to water resource, ecosystem, and management issues

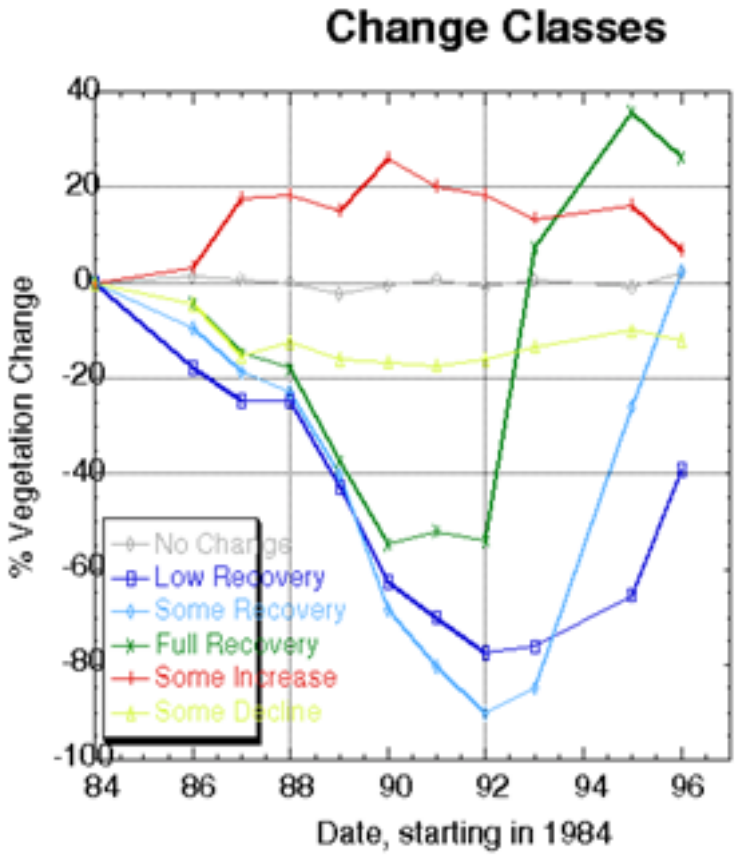

Change Classes
40
20
0
-20
-40
-60
-80
-100
% Vegetation Change
84
86
88
90
92
94
96
Date, starting in 1984
No Change
Low Recovery
Some Recovery
Full Recovery
Some Increase
Some Decline

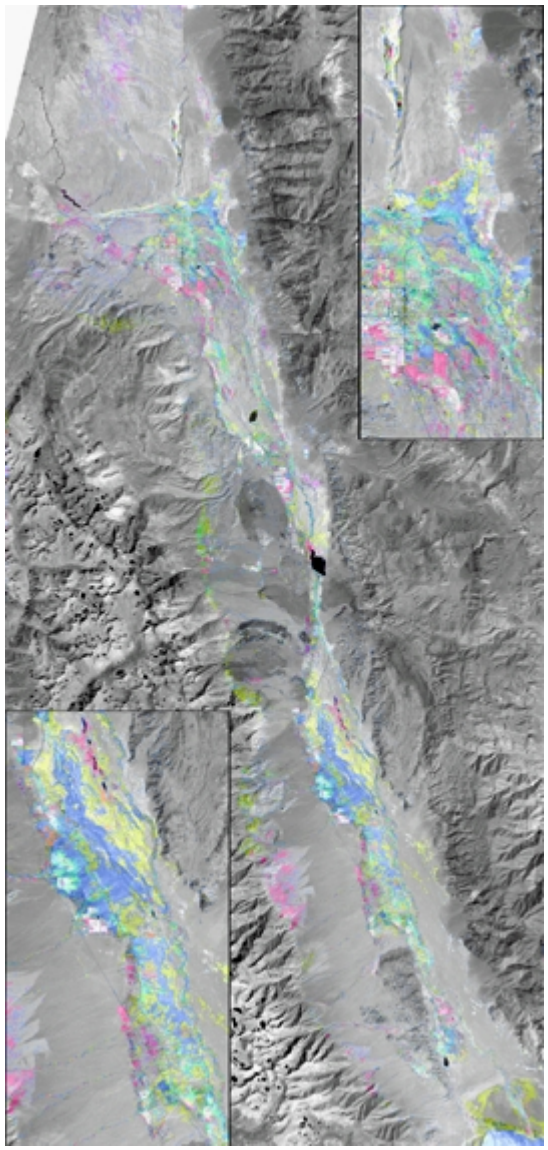
Different Responses to Forcing



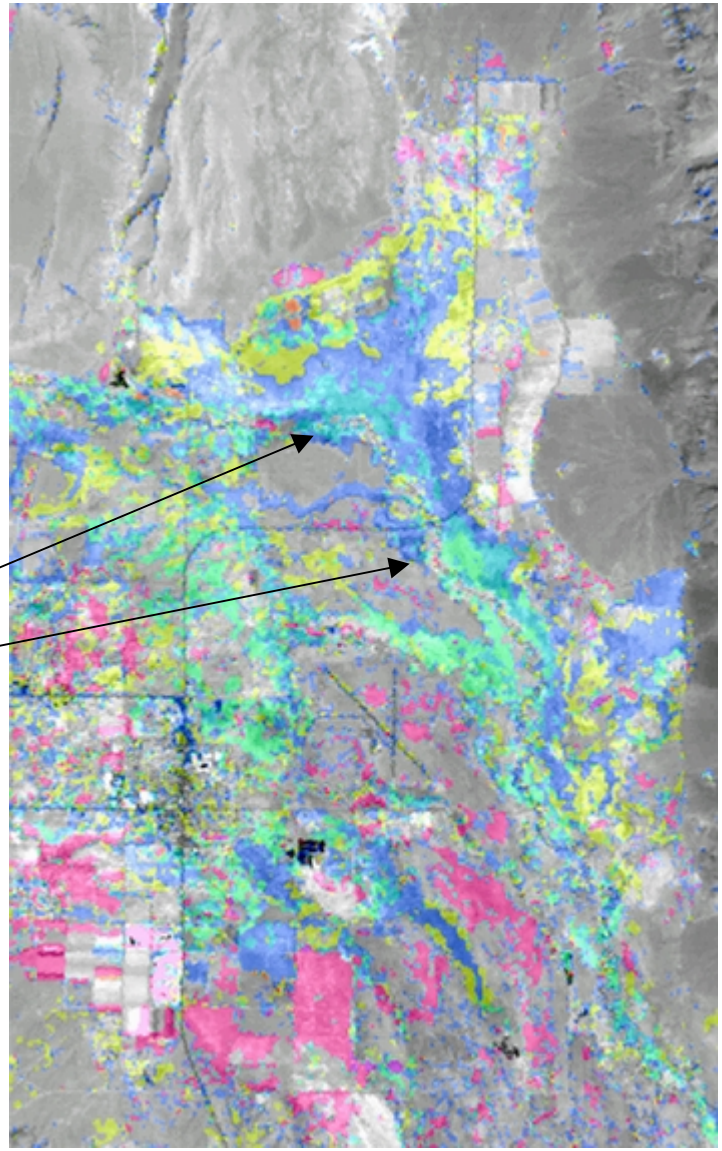

Ecosystems
Rainfall
Water Resources
Climate
Local
Demands
Groundwater
Regional Demands

Change Class Image: Each Change Class is represented by a different Color.

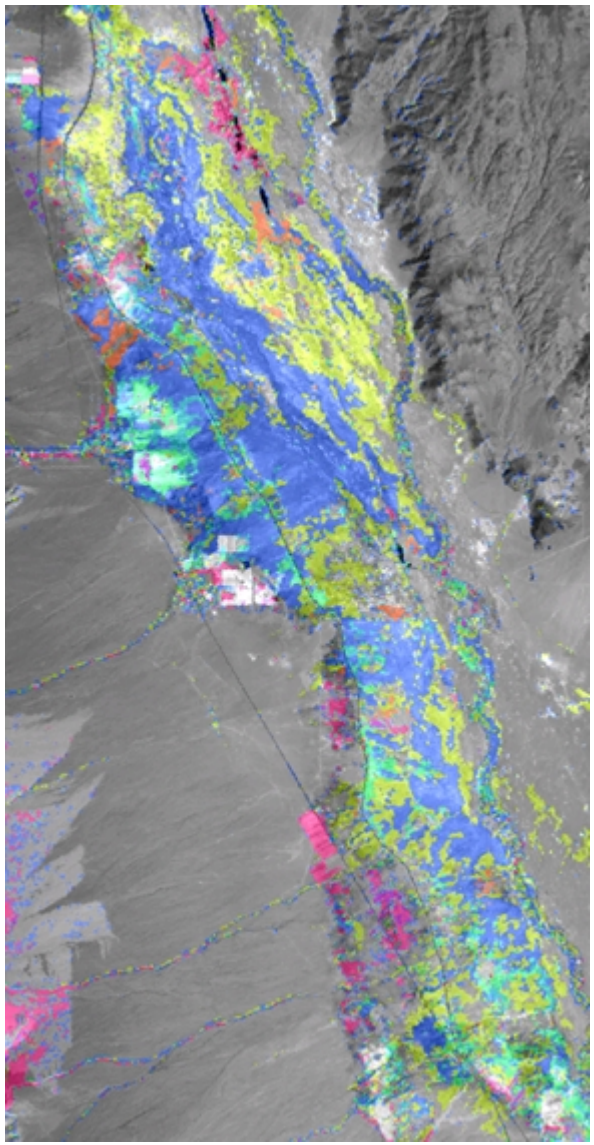




The Laws area is an example of a region where change classes form “bulls-eye” patterns around areas of intense ground water pumping.



The area around Independence is extremely complex - showing many change classes. This is due to ground water draw down coupled with land use practices such as irrigated grazing and controlled surface water flooding to recharge ground water aquifers.



LAND-USE HISTORY

- What is the effect of prior land use on response?
- What is a successional model for semi-arid systems?
- Key stages of land use have been documented:
  - Pre-1900
  - 1926 detailed land use maps
  - Aerial photography 1944, 1969, 1983
- Preliminary work to define history for 3 type localities

PROJECT STATUS

- Progress is about where we anticipated we'd be at this stage
- Detailed validation and verification of mixture model and remote sensing was required to accommodate the needs of LADWP
- Response analysis is beginning and indicates extraordinary levels of information
- Completion of entire project to the level of full publication of results will extend beyond the formal end date

Assessing future stability of US High Plains land-cover integration of process modeling with Landsat, *in-situ*, modern and paleoclimate data

Cast of Characters:

- Jonathan Overpeck, PI
- Robert Webb, Co-PI
- Alex Goetz, Co-PI
- David Schimel, Co-PI
- Gifford Miller, Co-PI
- Connie Woodhouse, Collaborator
- Jennifer Mangan, Graduate Student
- Noah Daniels, Graduate Student

Assessing future stability of US High Plains land-cover integration of process modeling with Landsat, *in-situ*, modern and paleoclimate data

Overview of Presentation

- Project Overview - Why??
- Defining the Full Range of Drought and Land-cover Variability
- Modeling Climate-induced Land-cover Change
- Simulating Spatially-explicit Land-cover Change
- Linking Land-cover Assessments to “Stakeholder” Needs

Assessing future stability of US High Plains land-cover integration of process modeling with Landsat, *in-situ*, modern and paleoclimate data

Project Overview - Why??

- **Important regional land-cover (think "food", but much more...)**
- **20th-Century droughts devastating**
- **100,000 km^2 of eolian dunes and sandsheets**
- **Potential for unprecedented natural disaster**
  - ➡ Natural variability
  - ➡ Human-exacerbated change (e.g., land/water use, global warming)

Defining the Full Range of Drought and Land-cover Variability

Progress to Date:

- State-of-the-art review: 2000 years of drought
  - ✓Woodhouse and Overpeck, *BAMS* 1998
  - ✓Graduate research of Noah Daniels
- NASA/NOAA Workshop: Assessing the full range of central North America Droughts and Associated Landcover Change, Boulder, Colorado, June 2-4, 1999
- Concentrated attack on geochronology

NASA/NOAA US High Plains Workshop Goals:

1. Generate state-of-the-art paper describing what we know and do not know about the full range of drought and associated land-cover change
   - Extend back ca. 7,000 years
   - Cover climate **and** land-cover change
   - Examine cause and effect (e.g., with modelers)

2. Define community research priorities required to develop a predictive capability

3. Identify mechanisms for community coordination (e.g., geochronology capabilities, sample material/data/information sharing)

4. Continue development of WWW data and information site for support of
   - Climate change research
   - Land-cover change research
   - Climate and land-cover change assessments (i.e., with “stakeholders)

Modeling Climate-induced US High Plains Land-cover Change (J. Mangan et al.,)

Progress to Date:

- Adapted CENTURY ecosystem model for Sandhills, Nebraska study area
- Carried out CENTURY simulations
  - 20th century observed climate
  - ca. 6000 years ago
  - series of increasingly severe drought scenarios

Simulating Spatially-explicit US High Plains Land-cover Change (J. Mangan et al.,)

Progress to Date:

- Developed High Plains GIS
  - Political boundaries, fluvial, topography, land-cover, soil, climate, etc.
- Selected regions and years for multi-temporal analysis using Landsat
- Acquired Landsat scenes
- Analyzing land-cover variations for selected areas

Linking Land-cover Assessments to "Stakeholder" Needs

Progress to Date:

- Climate change press-conference yielded strong interest in and out of scientific community
- NASA/NOAA Workshop to bring in climate assessment community
- Linkages developed with other relevant climate change assessment programs
  - Water in the West (University of Colorado)
  - Central Great Plains (Colorado State)
  - Southwest (U. Arizona)

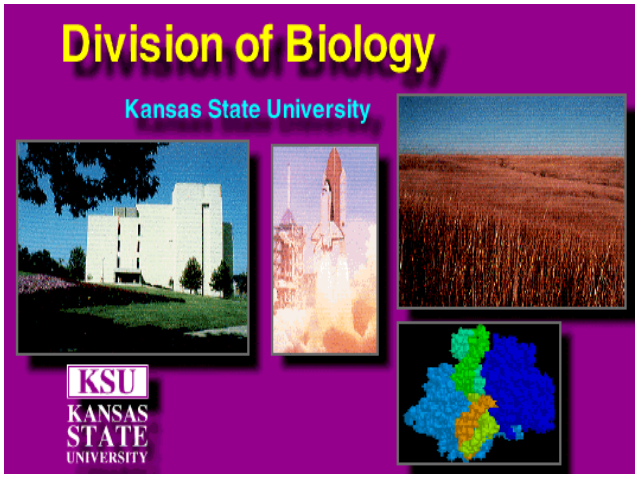
Assessing future stability of US High Plains land-cover integration of process modeling with Landsat, *in-situ*, modern and paleoclimate data

The next steps...

- Extend to southern (drier) region
- Rigorous model improvement &validation
  - versus recent spatially-explicit changes (w/Landsat)
  - versus larger range of paleo change
    - improved (coupled atmosphere-ocean) climate simulations
    - improved observations
- Assess possible future climate and land-cover change (with climate simulations, CENTURY and Landsat)

Land Cover Change in the Great Plains:Predicting The Impact of Regional Forest Expansion on Biogeochemical Processes

* Loretta Johnson (Biology, KSU) CO-PI
  Dixie Smith - PhD student
* John Briggs (Biology, KSU) CO-PI
  Greg Hoch - PhD student
* John Blair (Biology, KSU)
  Mark Norris - MS student
* Jay Ham (Agronomy, KSU)
  Dale Bremmer - postdoc
* Robert McKane (US EPA, Corvallis OR)
* Charles Rice (Agronomy, KSU)
* Clenton Owensby (Agronomy, KSU)



Destination: Earth
The Official Website for NASA's Earth Science Enterprise

COLLEGE OF AGRICULTURE
KANSAS STATE UNIVERSITY

UNITED STATES ENVIRONMENTAL PROTECTION AGENCY

Research Objectives

* Assess the current and historic extent of red cedar forest using present-day and historic aerial photography and satellite imagery and a GIS database

* Quantify the effects of forest expansion on biogeochemical processescontrolling the storage, quantity, quality, and distribution of soil C and N cycling and availability

* Determine how the life form shifts alter ecosystem balance and fluxes of CO_2, H_2O, and energy

* Link spatially-explicit land cover change models to existing biogeochemical models to predict the ecosystem consequences of future forest expansion

Hypotheses

Land management, interacting with climatic variability, is the key factor controlling land-cover change at the forest-grassland ecotone in KS and perhaps the Great Plains and,

Fundamental changes in biogeochemical cycling and ecosystem function will accompany this land-cover change. Vegetation shifts can be expected to:

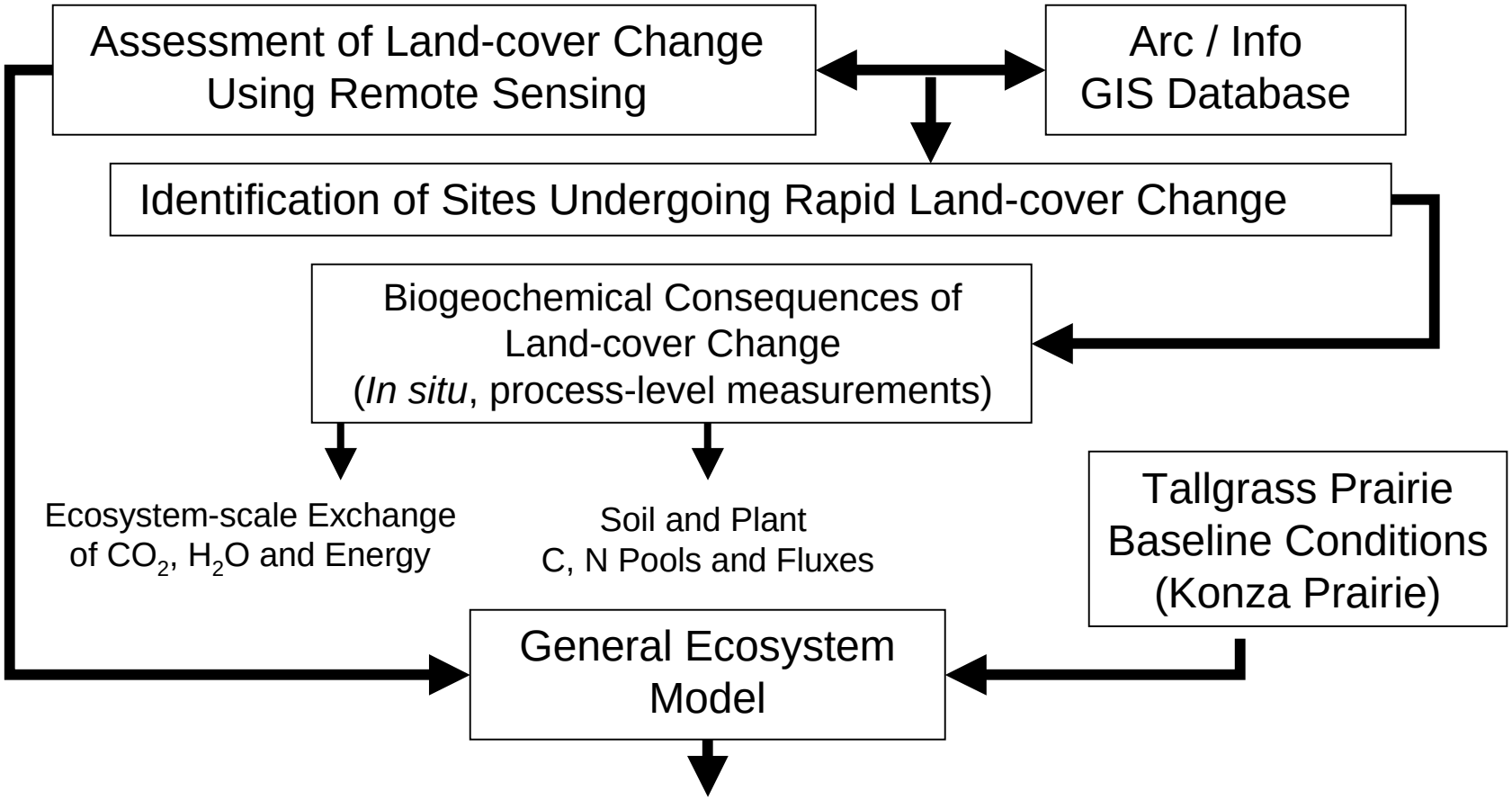
1) profoundly affect the quantity, quality, and distribution of plant C input to soil,

2) alter N availability and N cycling through vegetation-induced changes in C quality,

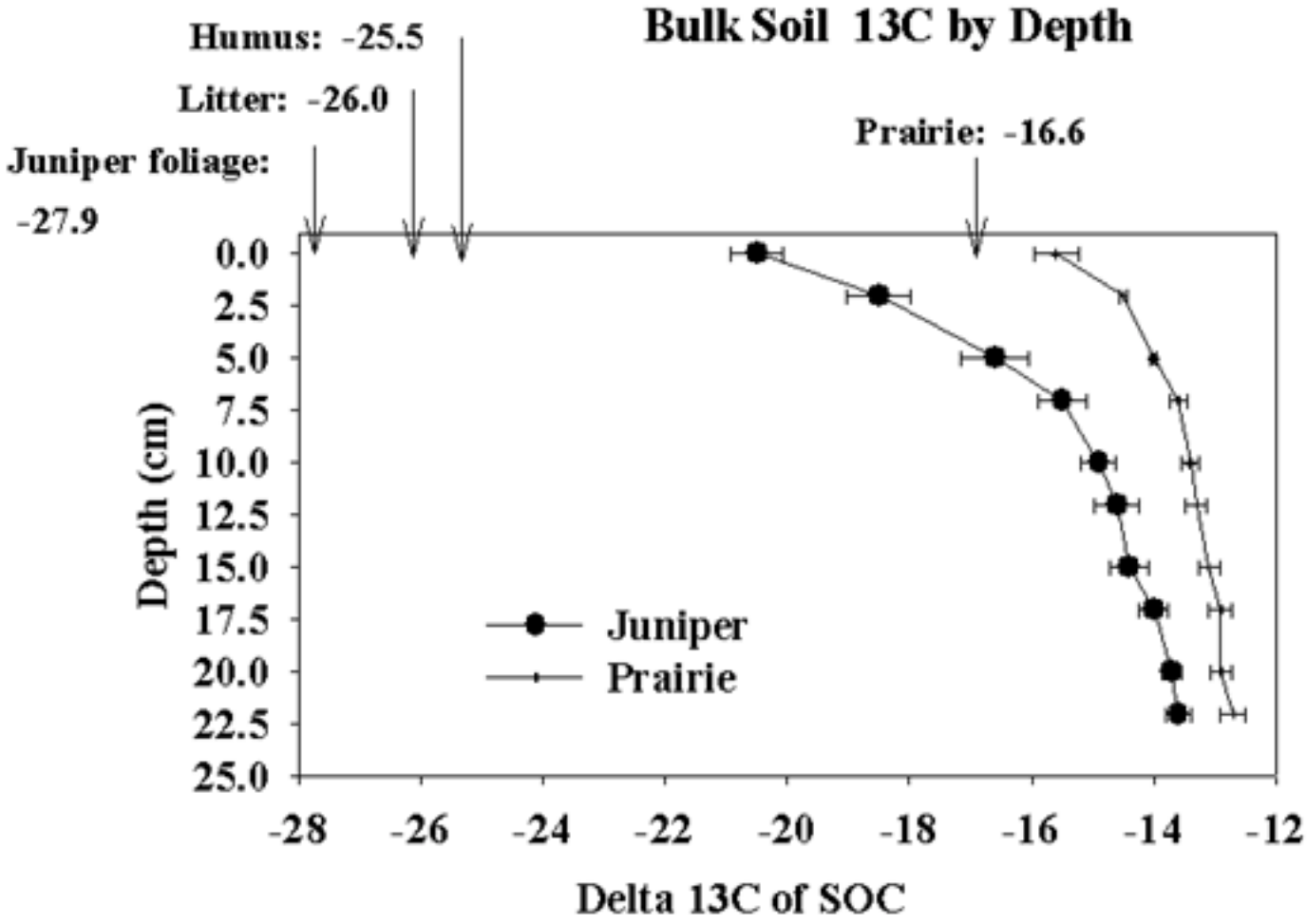
3) ultimately affect long-term soil C storage as soil organic matter and

4) alter ecosystem-scale fluxes of CO_2, H_2O and energy.

Flow diagram showing the integration and interdisciplinary nature of the research program

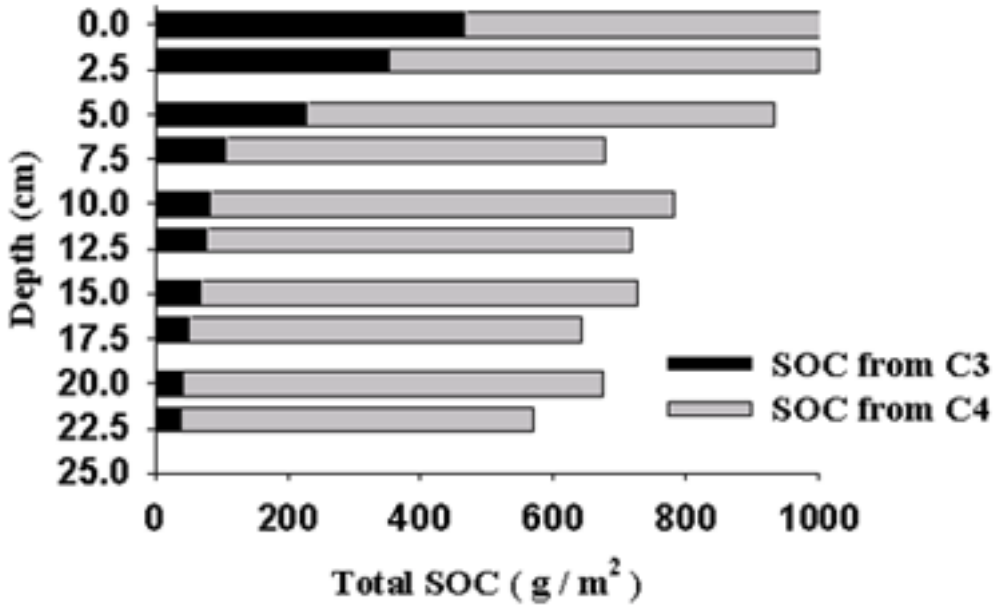


$\delta\ ^{13}C$ reveals vegetation origin, forest or prairie, of soil organic carbon (SOC).



Based on changes in $\delta^{13}C$ with depth and using soil bulk density, we estimate that forest carbon inputs already contributed about 20% of total SOC.

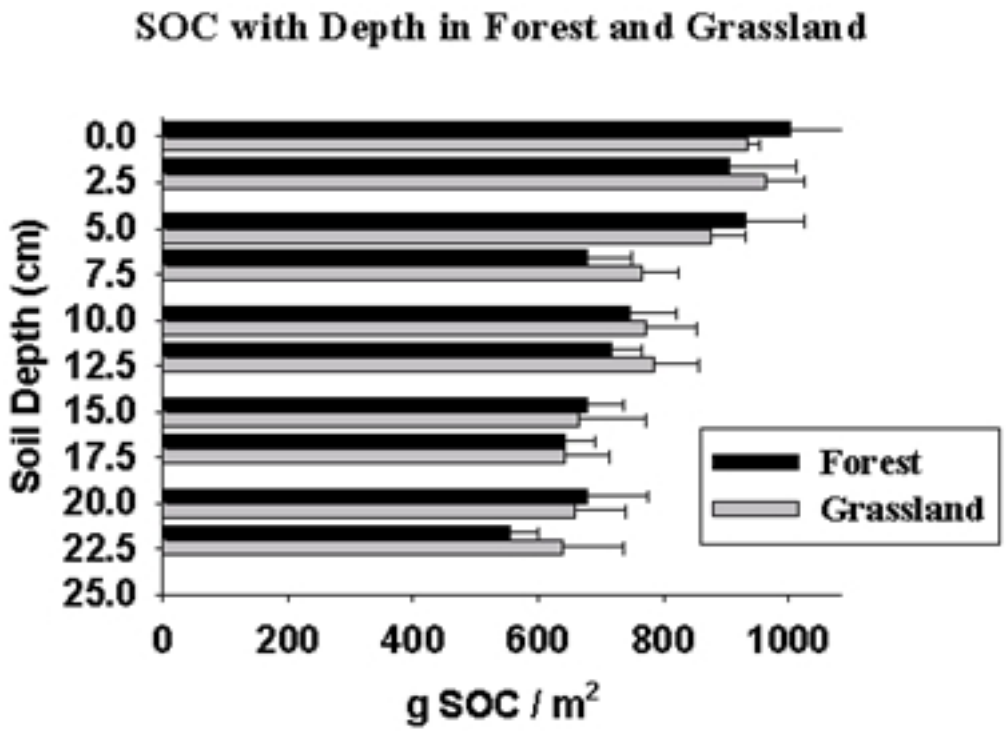
Total Forest SOC from C3 and C4 Vegetation



Cumulative Forest SOC = 20 % Total

1527 g C / m^2 C3 Forest vs. 6199 g C / m^2 C4 Grass

Regardless of vegetation, total SOC (g/m^2) doesn't differ between forest and prairie. The accumulated humus and litter does contribute about 1 kg/m^2.

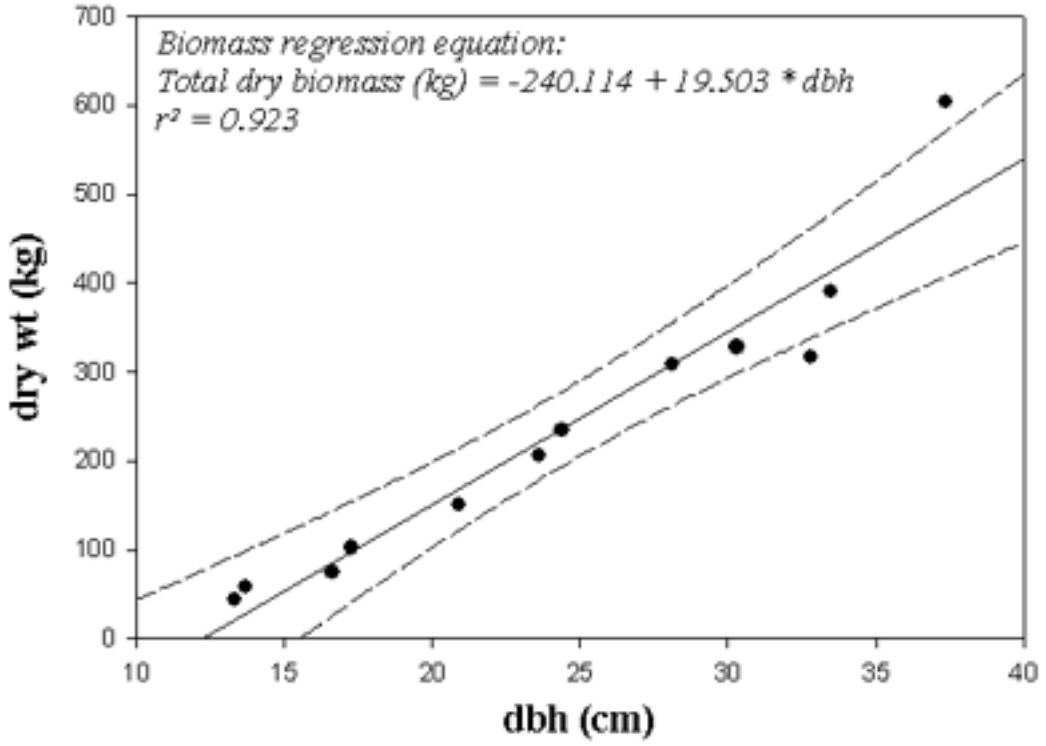


Cumulative SOC

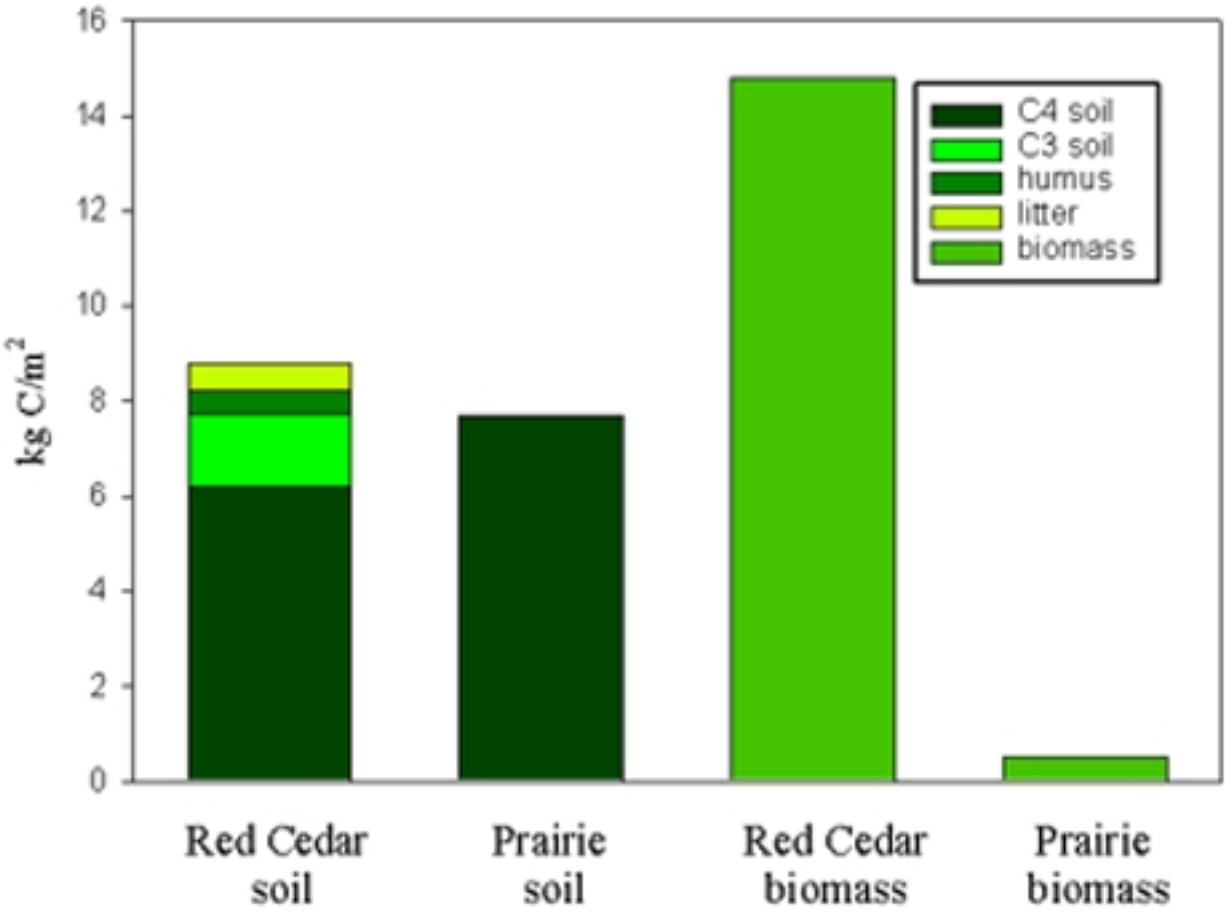
Forest Litter:	**576.0 g C/m^2**	**Grass Litter:**	**0.0 g C/m^2**
Humus:	**481.0**	**Humus:**	**0.0**
Soil:	**7537.0**	**Soil:**	**7698.2**
Total:	**8594.0 g C/m^2**	**Total:**	**7698.2 g C/m^2**

Allometric growth equations, tree density, and percent carbon can be used to determine aboveground biomass and carbon stocks.

Biomass regression for eastern red cedar
***based on OK and KS data (n=12)**
(with 99% confidence intervals)



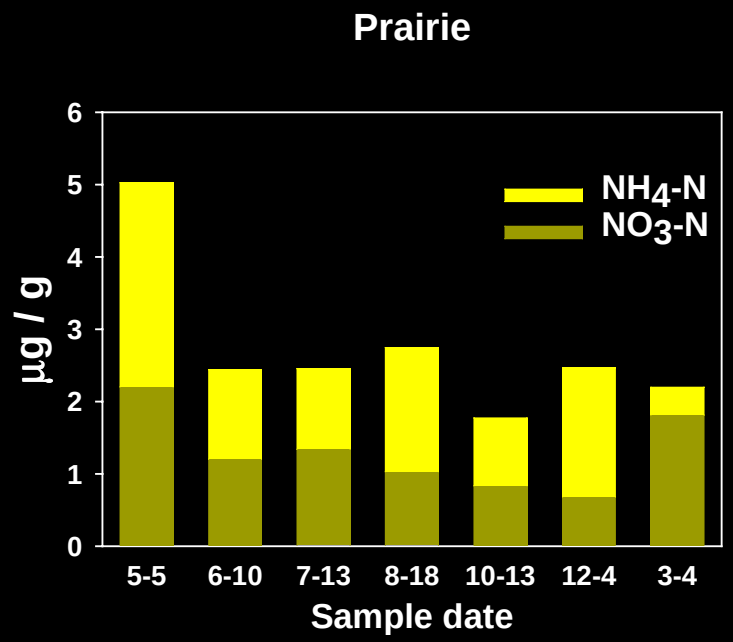
The biggest effect of forest expansion on the carbon cycle is the accumulation and storage of C in aboveground biomass.

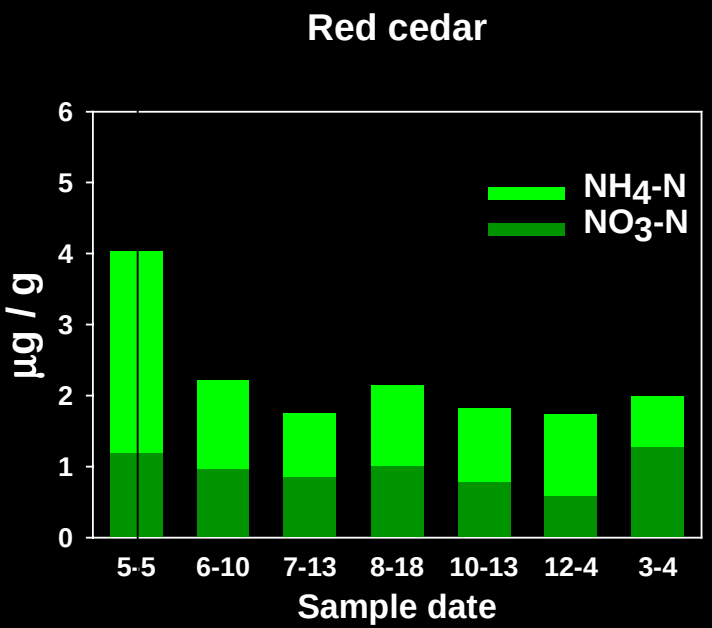


Based on data collected from the first 18 months of this project, we estimate that if forest expansion continues, it may result in up to 0.5-1.0 Pg C stored in these forests.

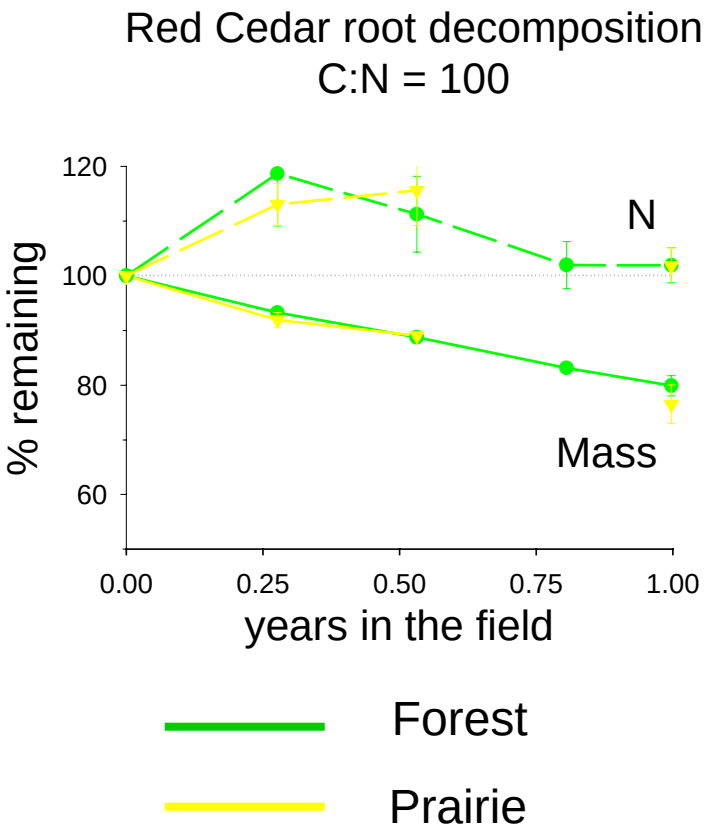
This C storage is at least regionally significant. Comparatively, continental US forests store approximately 12 Pg C.

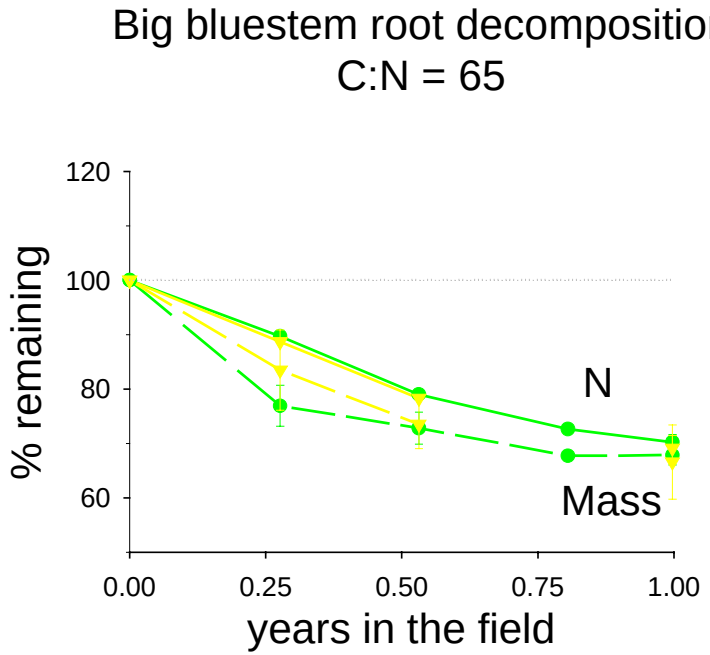
Forest expansion decreases N availability early in the spring relative to prairie, but by mid-summer N availability does not differ from prairie.



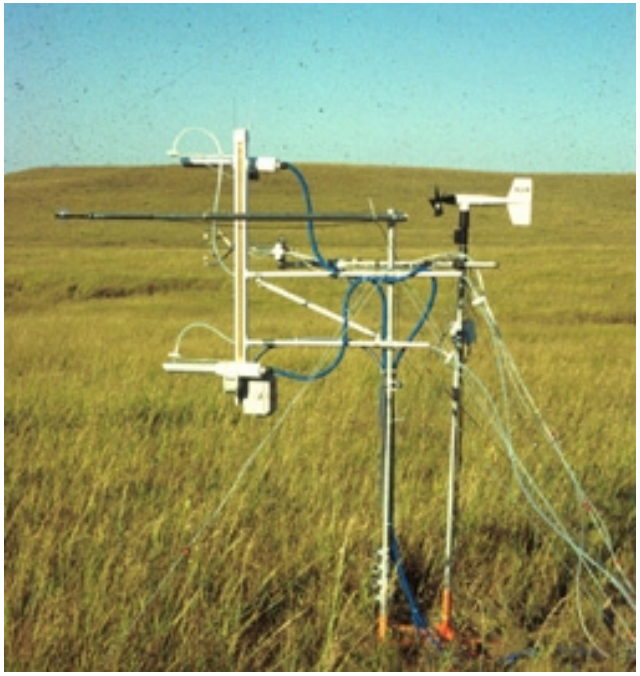


Litter decomposition is slower in the forests. This is primarily due to the quality of cedar litter, not microclimatic effects.



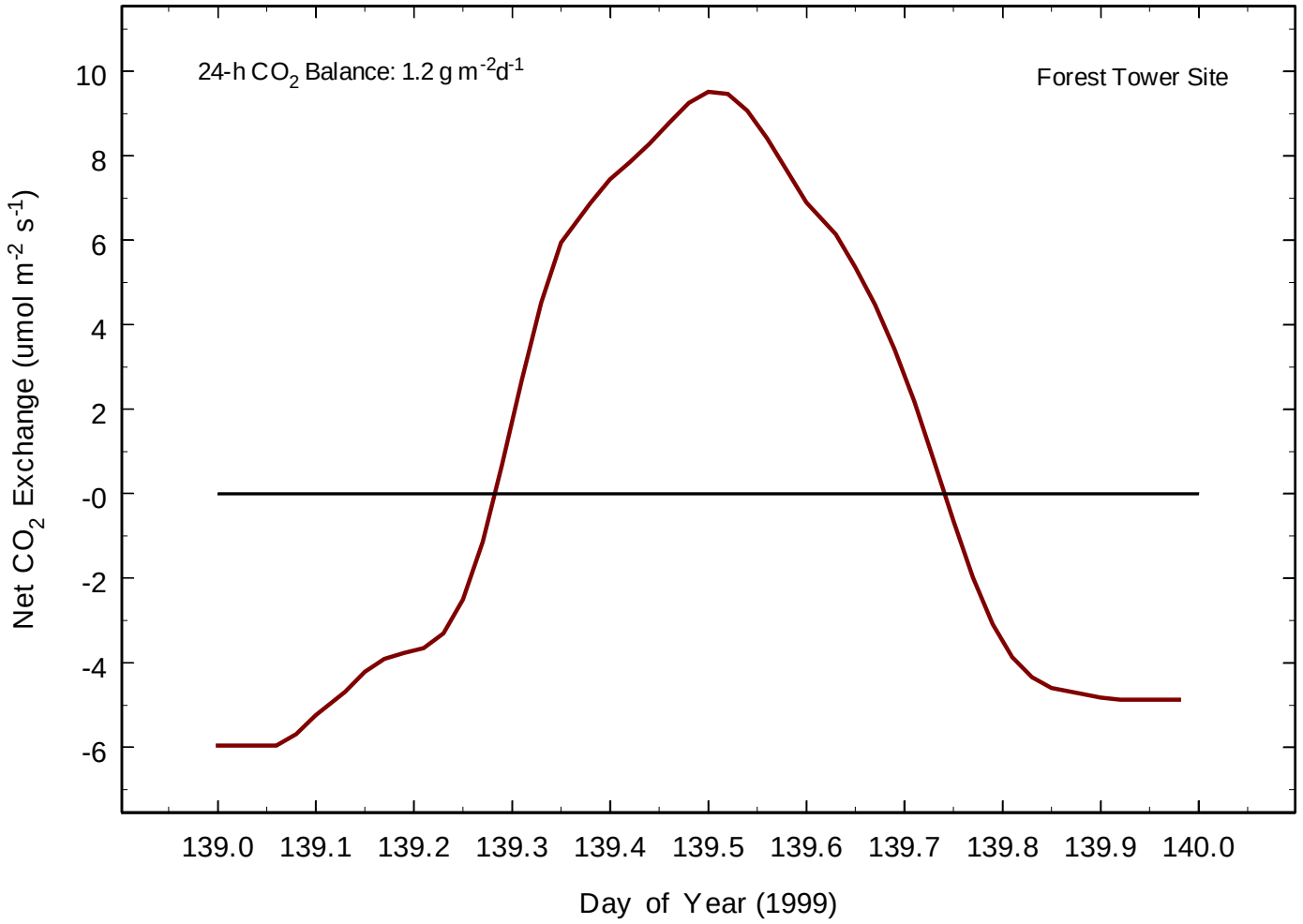


Are forests sources or sinks for CO_2?



Eddy Flux Towers in Prairie and
Cedar Forest

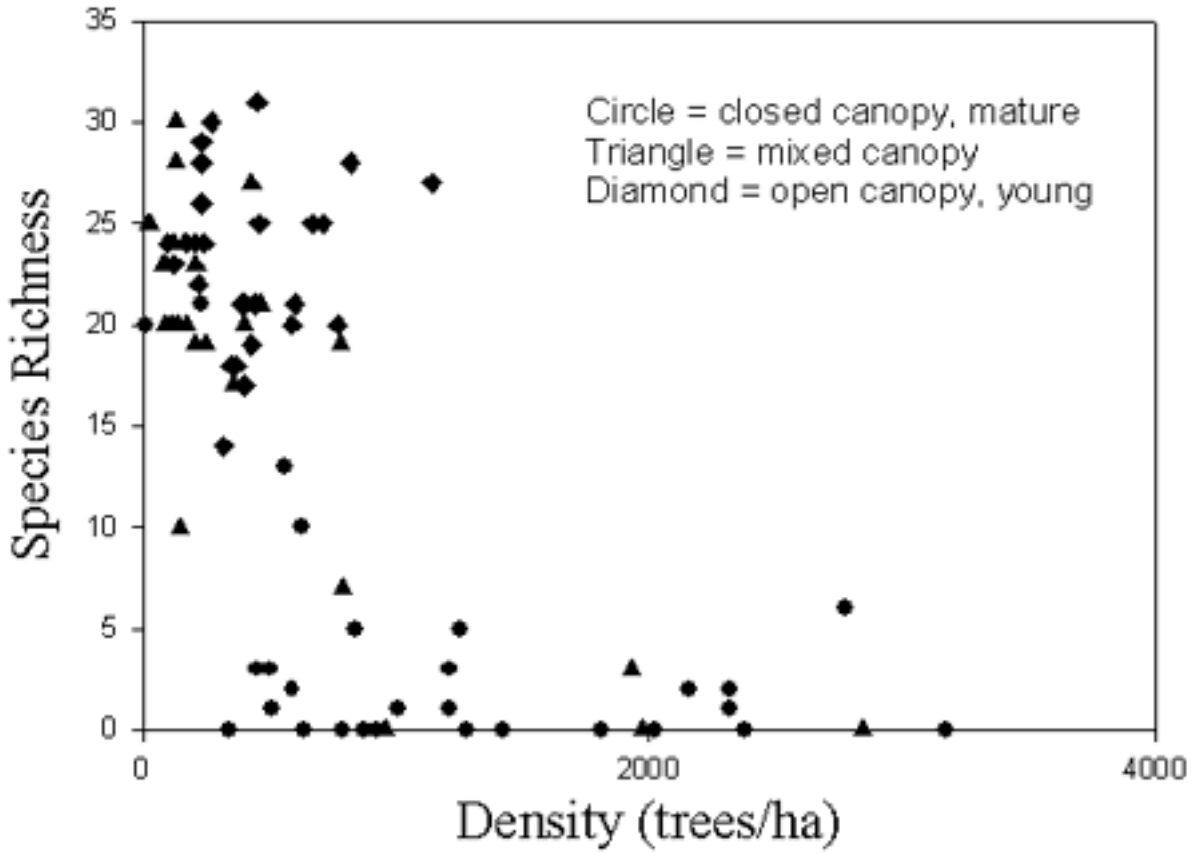
Comparative grassland and forest data integrated over the year will indicate differences in net CO_2 exchange.



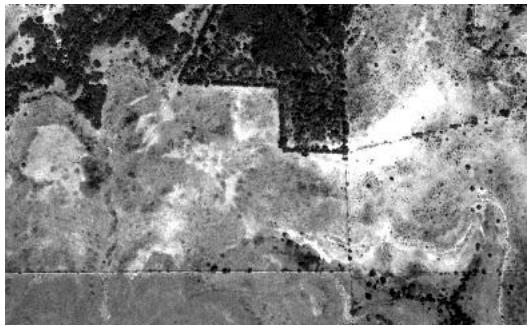
Diurnal CO_2 Flux in Forest Site

Forest expansion reduces herbaceous species diversity.

Herbaceous biomass in closed canopy forests is approximately 0.18 g/m^2 compared to 300-700 g/m^2 in prairie .

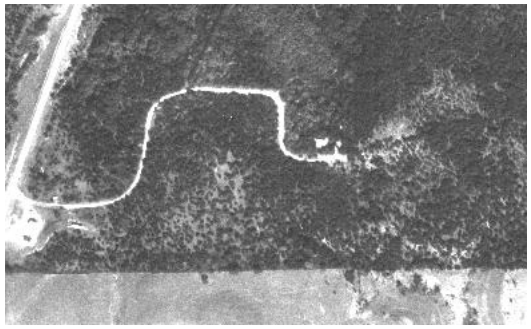


Using historic aerial photos we can determine rates of cedar expansion at fine scales.

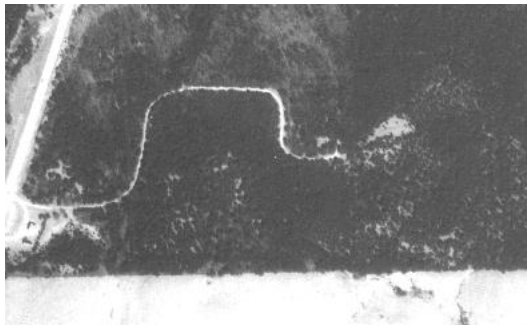


1956

1969



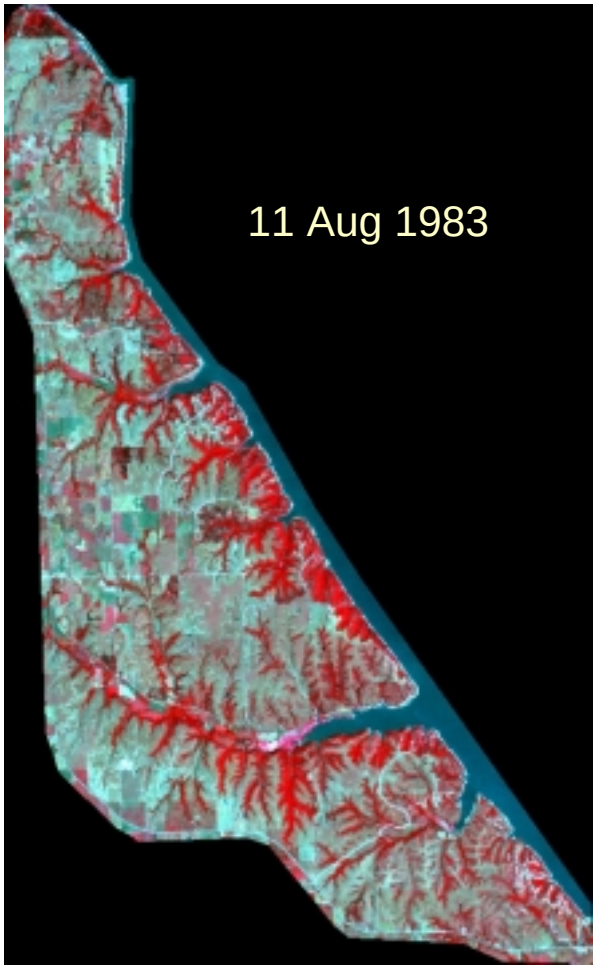
1978



1996

Images approximately 440 x 240 m

Landsat TM images from northern extent of study area showing increase in cedar with arrows



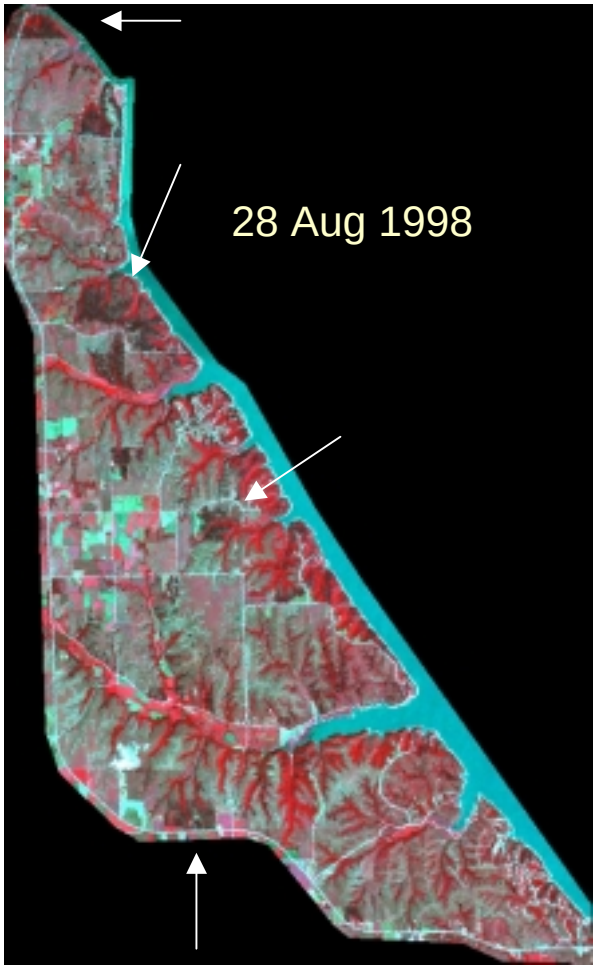
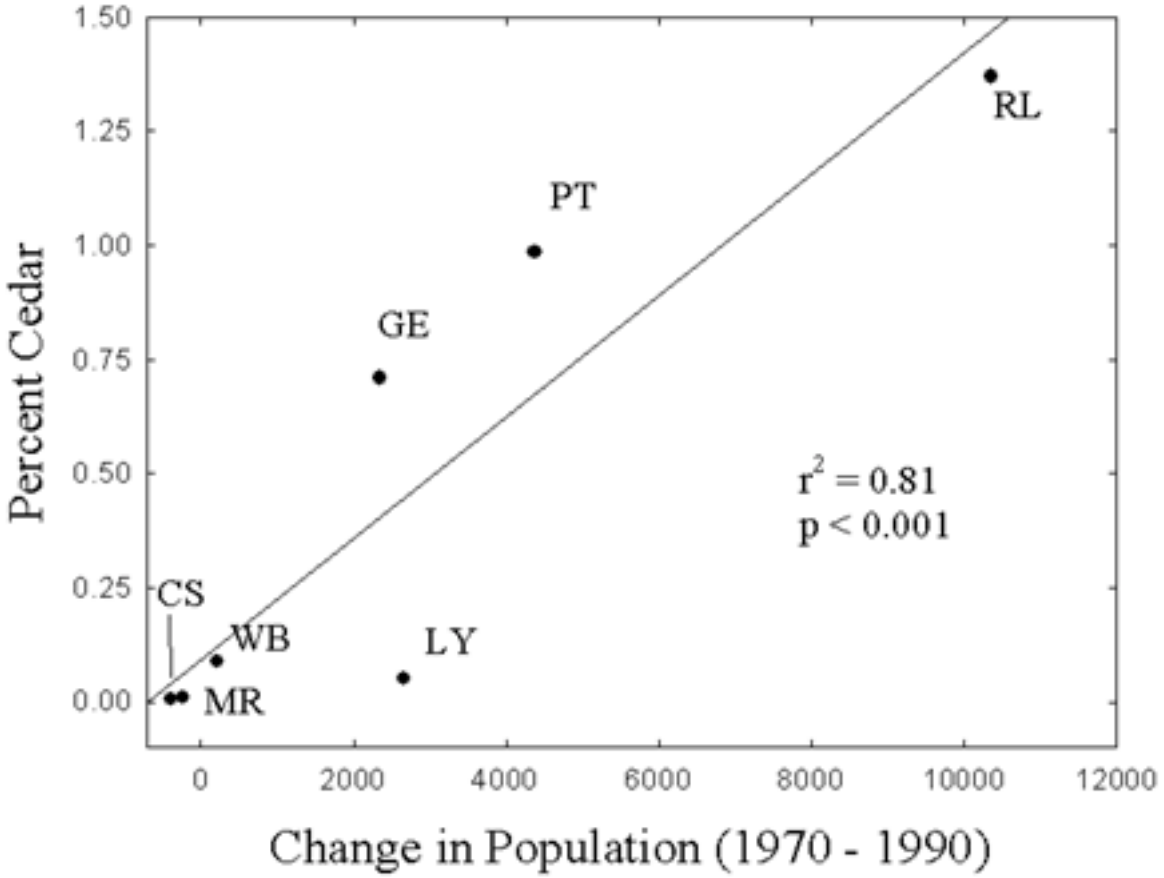
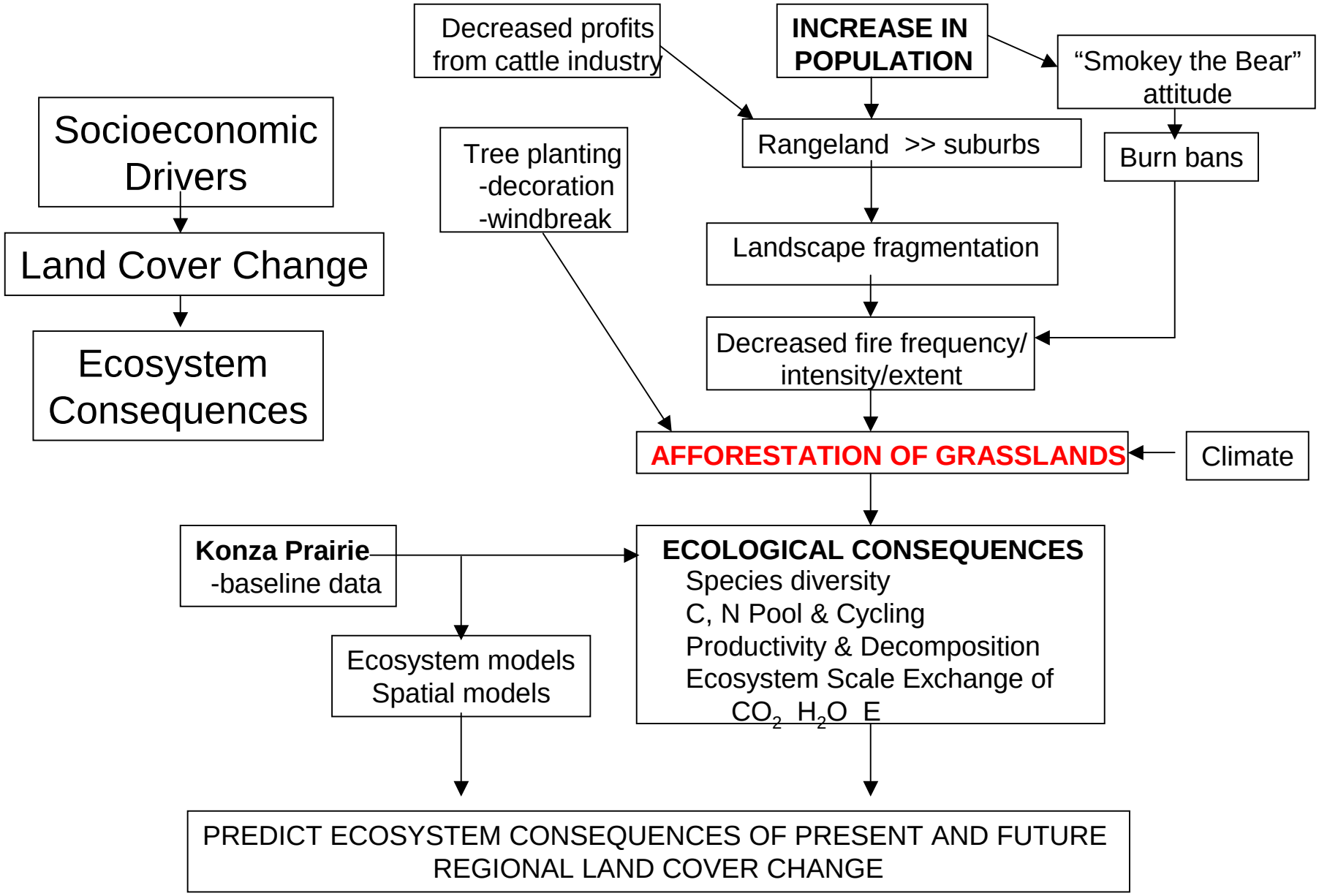


Image approximately 21 km N-S

Relationship between population growth in counties (previous slide) and percent closed canopy red cedar forest



Conceptual Model of Causes of Forest Expansion



Next Steps:

1) We will use a linear spectral mixing model of the tasseled cap bands to identify partial canopy forests and measure rates of canopy closure from 1983 to 1998.

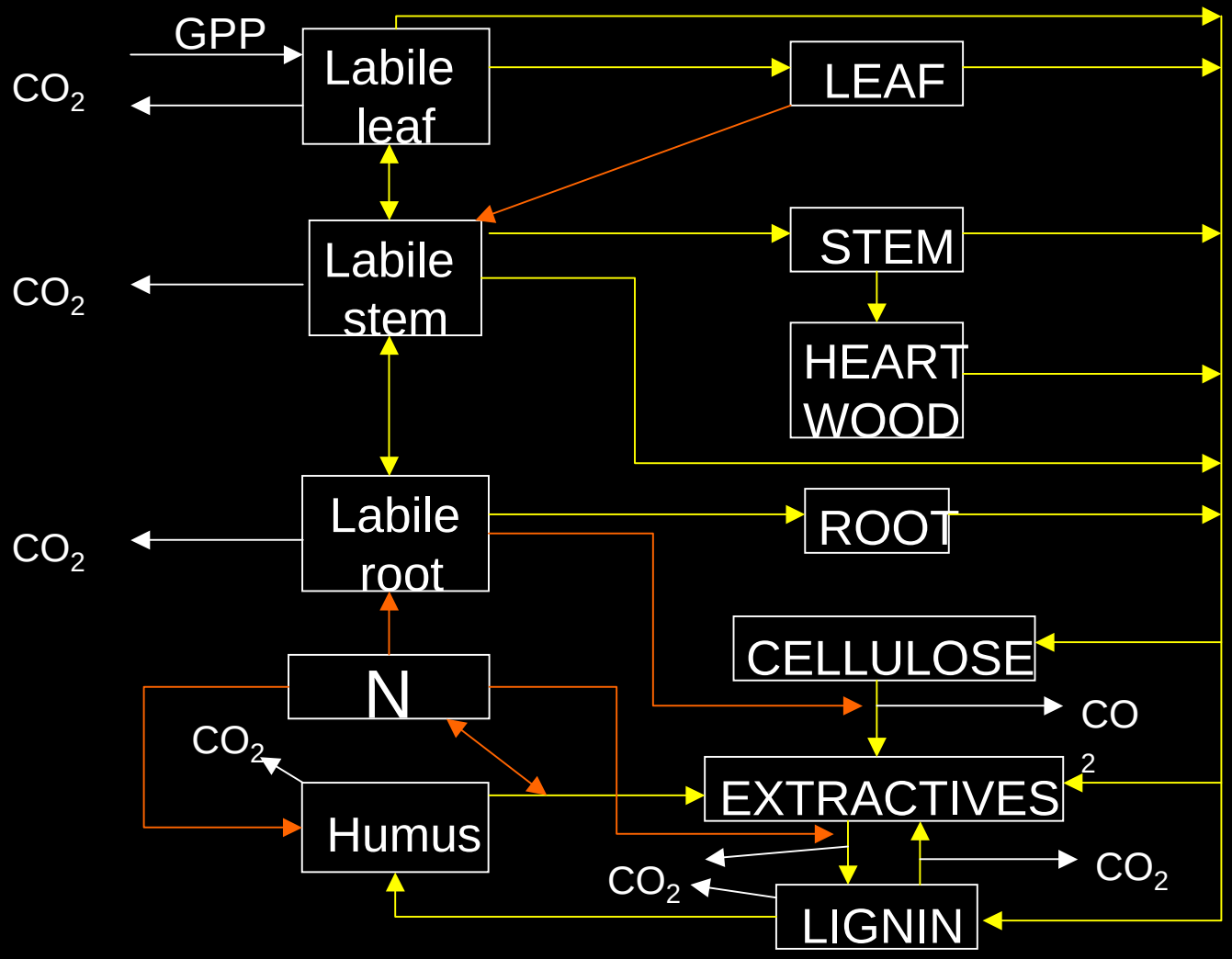
Cedar83 = 97.78 - 0.886*Bright - 0.370*Green + 0.685*Wet

$r^2 = 0.90$ $p = 0.0001$

Cedar98 = 262.9 -1.856*Bright -0.272*Green - 0.013*Wet

$r^2 = 0.73$ $p = 0.0009$

2) We will use our process-level biogeochemical results as input to our biogeochemical model (GEM) to predict ecosystem consequences of regional forest expansion.



C

N

C&N

Quantifying Grassland-to-Woodland Transitions

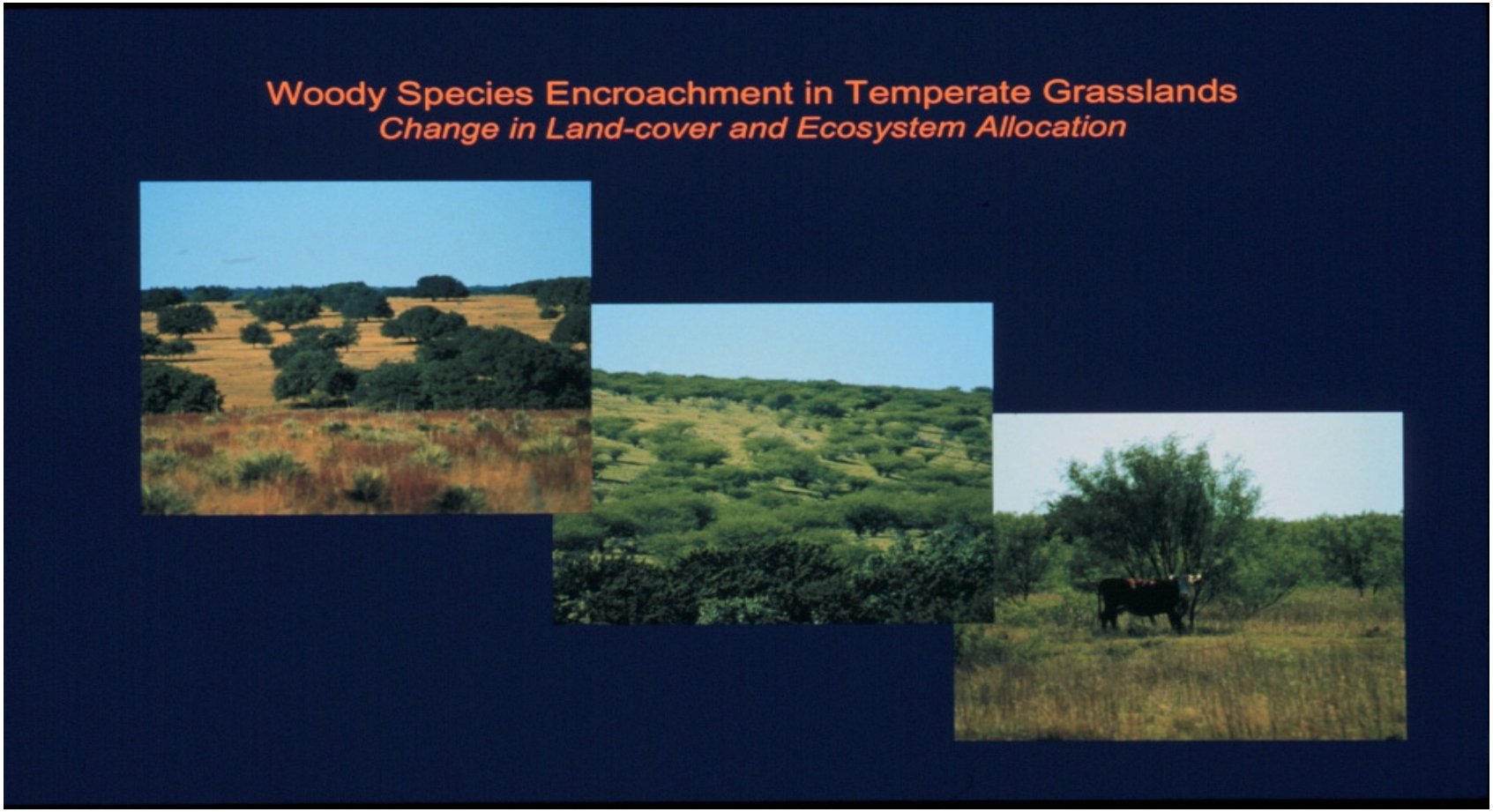
The Implications for Carbon and Nitrogen Dynamics in the Southwest United States

Carol A. Wessman [1], Steven R. Archer [2],

Gregory P. Asner [3], C. Ann Bateson [1]

[1] University of Colorado, [2] Texas A&M University,

[3] Stanford University



Many dryland ecosytems are mixtures of grasses, shrubs and trees. The balance between these contrasting lifeforms is regulated by complex interactions between climate, soils, herbivory and disturbance. A shift in one or more of these factors can dramatically alter ecosystem structure and function. In many drylands, woody plants have displaced grasses in recent history….

Santa Rita Experimental Range, Arizona
(from Martin 1975)

A desert grassland landscape photographed in 1903...

… had become a mesquite shrubland by 1941

Project Goal

- To understand how changes in vegetation structure (relative abundance of grass and woody species) associated with human-driven perturbations affects sequestration or liberation of C and N across topoedaphically diverse landscapes

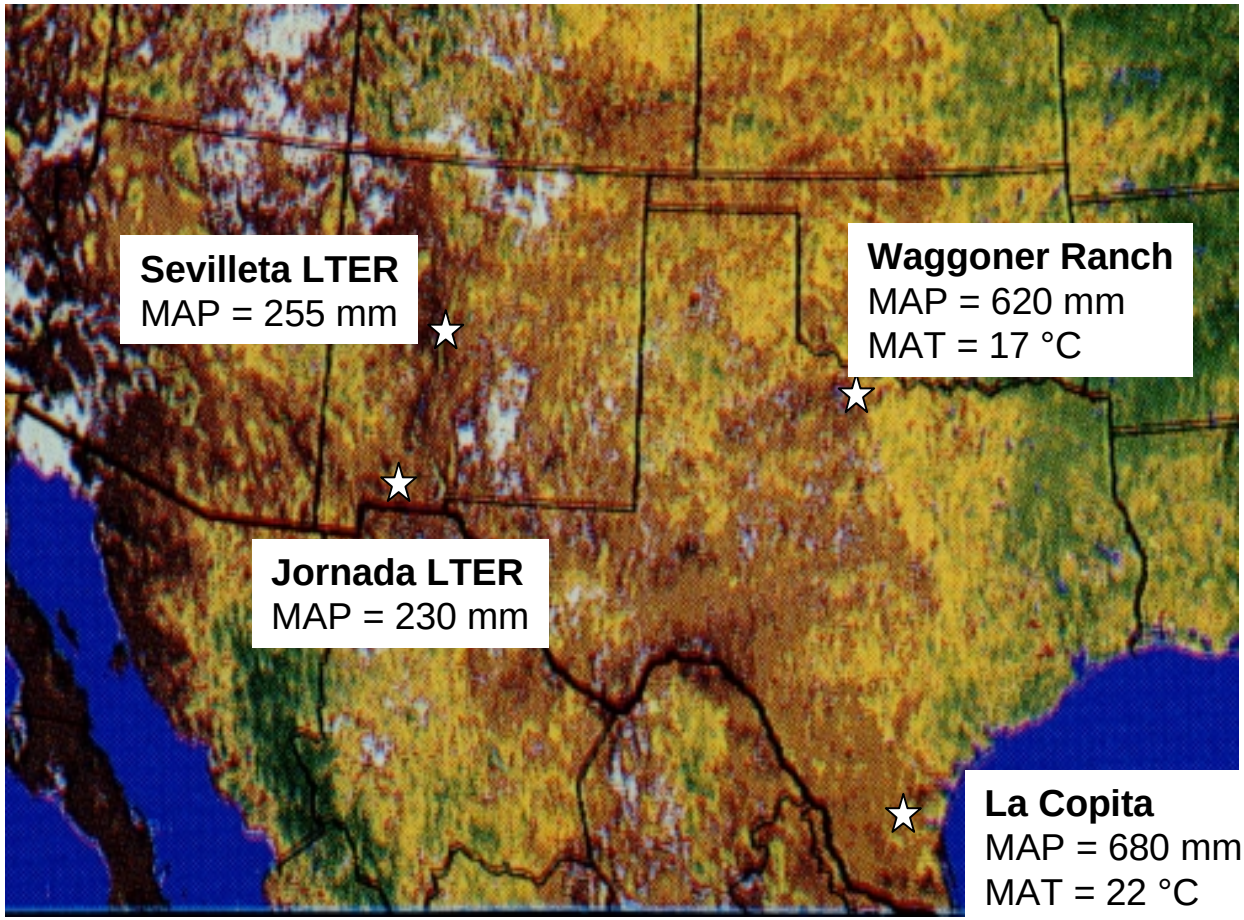
Objectives

- We seek to:
  - Improve our ability to remotely quantify grass and woody plant abundance
  - Generate a comprehensive database on temporal changes in plant and soil C and N for grassland-to-woodland chronosequences
  - Couple remotely-sensed canopy variables with ecosystem simulation models to track biogeochemical dynamics under variable landscape structure and climatological forcings

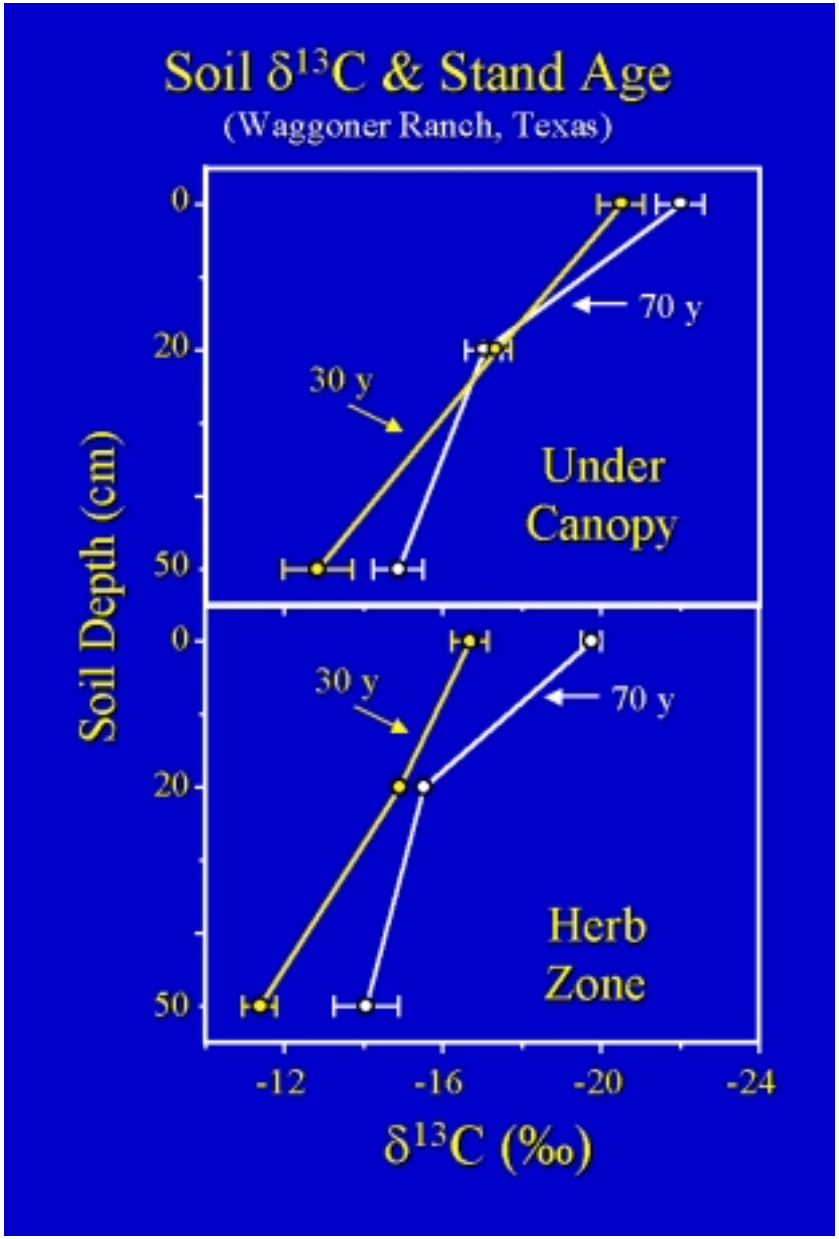
Project Methods

- Two primary components:
  - Develop remote sensing capability to measure spatial distribution and biophysical characteristics of semi-arid rangeland vegetation at regional level, but at high spatial resolution
  - Develop link between remotely sensed information and ecosystem models to gain understanding of regional-level biogeochemistry associated w/ natural variability and human-driven land use pressure (grazing, fire)

Study Sites



MAP = Mean Annual Precipitation MAT = Mean Annual Temperature



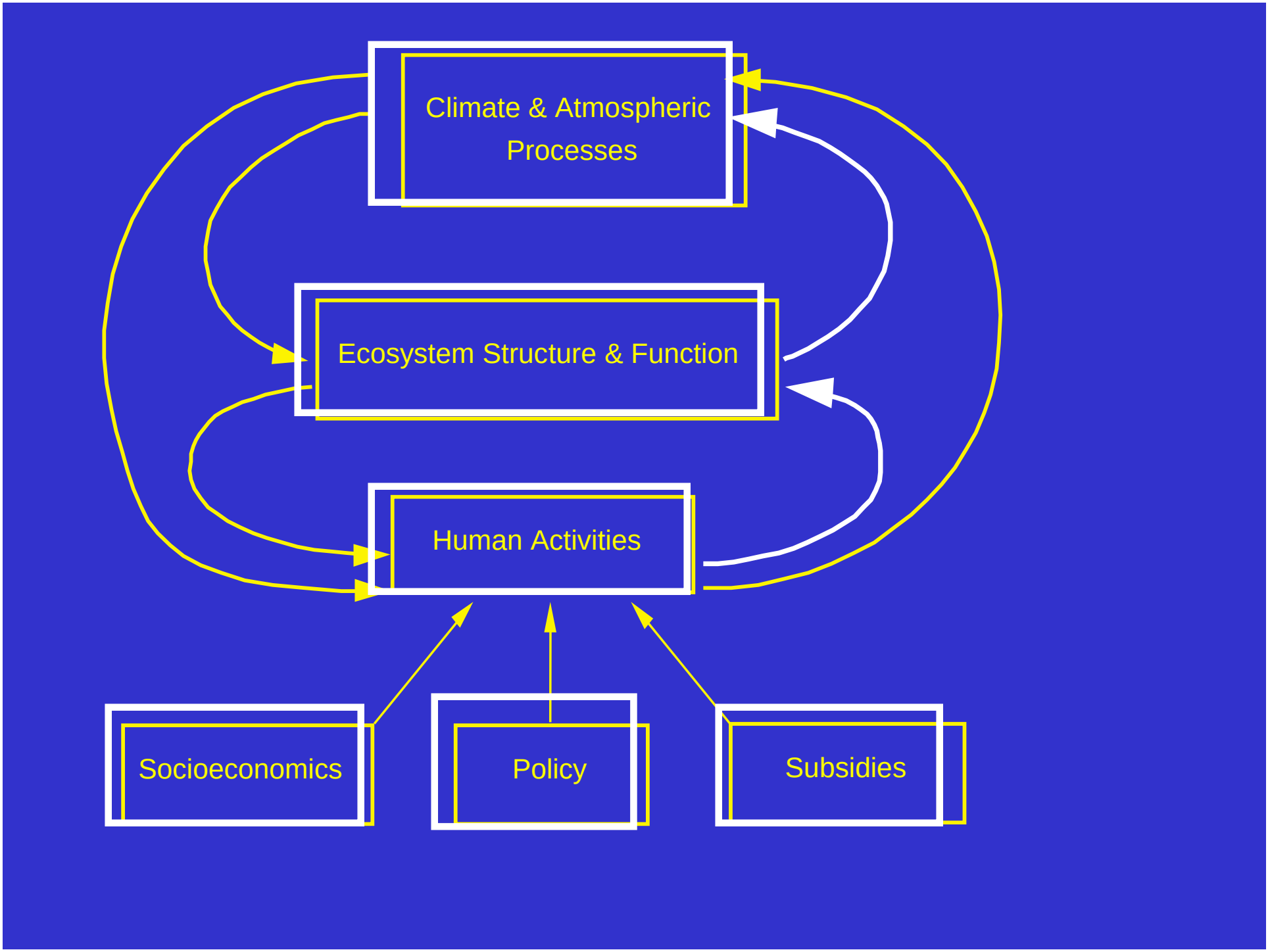
On sites where vegetation history is Not known, $^{13}C/^{12}C$ ratios provide direct, spatially explicit evidence that C_3 shrubs have displaced C_4 grasses.

Current vegetation at this site is dominated by C_3 woody plants.

Soil carbon at depth, indicates past domination of the site by C_4 grasses

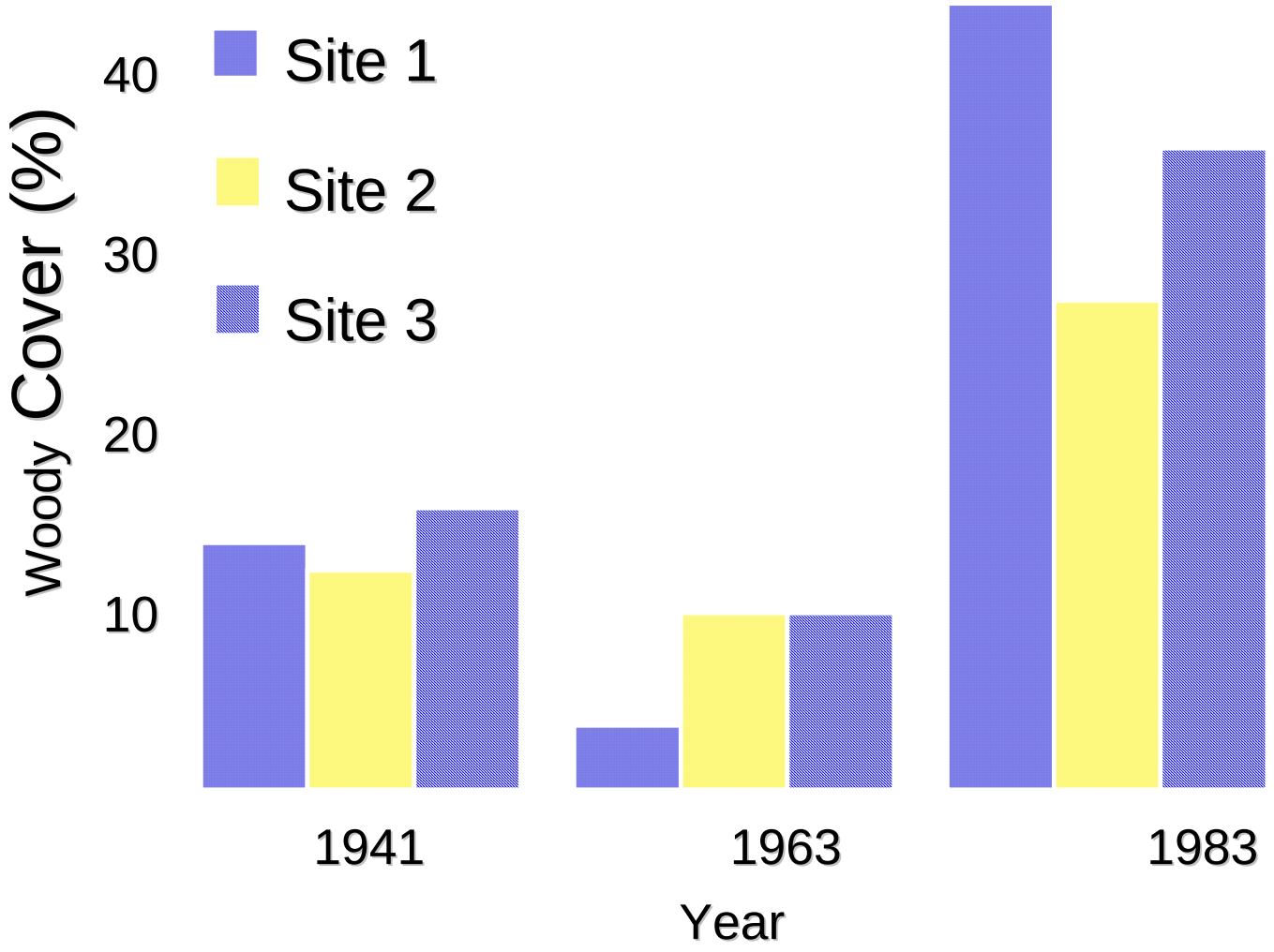
Causes for Woody Encroachment ?

- Natural
  - Climate Change
  - Changes in native herbivore (browser vs. grazer) populations
- Anthropogenic
  - Species introductions
  - Species eradications
  - Atmospheric CO_2 enrichment
  - Altered fire regime
  - Altered grazing regime
- Interactions
- Necessary and Sufficient Conditions


Climate & Atmospheric Processes
Ecosystem Structure & Function
Human Activities
Socioeconomics
Policy
Subsidies

Rates/Dynamics of Change?

Changes in woody plant cover are rapid, non-linear, and may be triggered by extreme environmental events (e.g. drought of 1950s). Data below are from the La Copita site in southern Texas

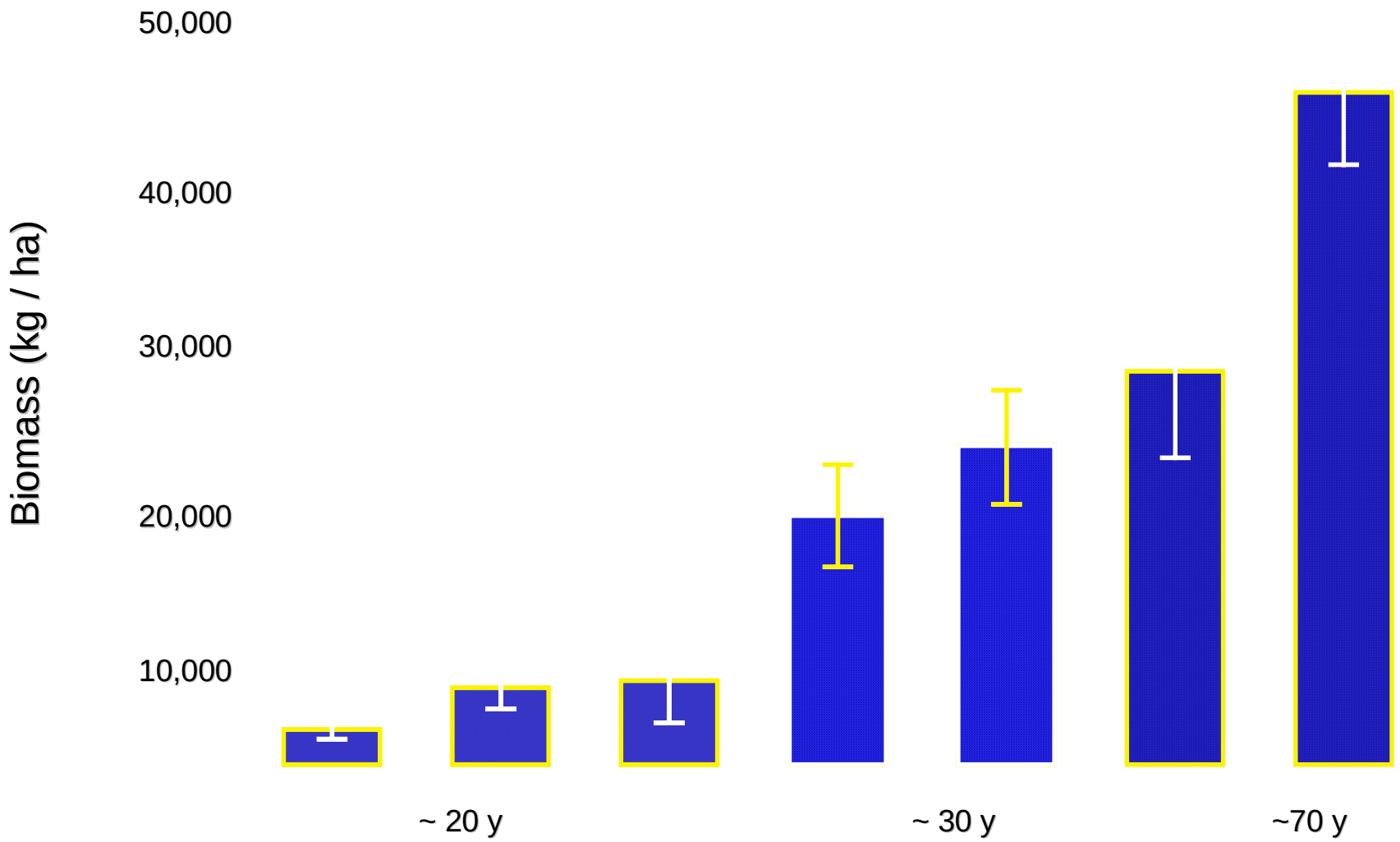


‘Brush Management’ is critical to sustainable livestock production in many rangelands.

Mechanical (top panel) and herbicidal (bottom panel) treatments are expensive; results are often short-lived and may have adverse environmental consequences

Within a region, woody plant cover/ biomass may thus vary, depending on site management history

Aboveground Biomass of *Prosopis* on Sites with Contrasting Brush Management Histories (Gin Pasture, Waggoner Ranch, Texas)



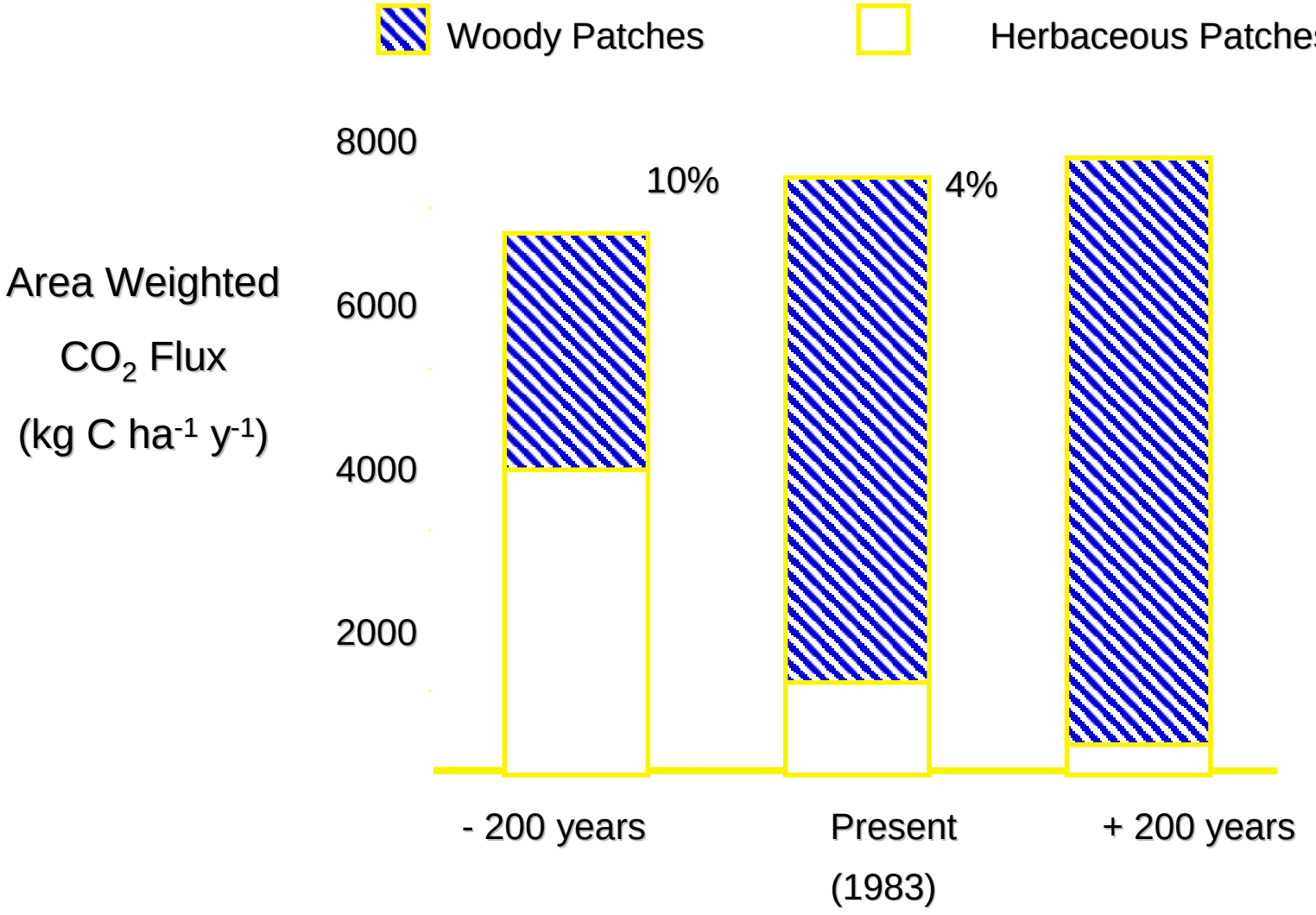
Socioeconomic Implications of Bush Encroachment

* Rural Economies
  ** Commercial Enterprises
  ** Pastoral Societies
* Food, Fiber, Economic Stability
* Sustainability

ECOLOGICAL CONSEQUENCES OF WOODY PLANT INCREASE IN DRYLANDS?

- WOODY PLANTS MODIFY SOILS & MICROCLIMATE
  - C and N Flux From Soils Increases
  - C and N Pool Sizes in Plants and Soils Increases

Annual measurements of soil respiration (McCulley 1999) coupled with a successional model of vegetation change (Scanlan & Archer 1991), indicate soil CO_2 flux may have increased ca. 10% subsequent to woody plant encroachment



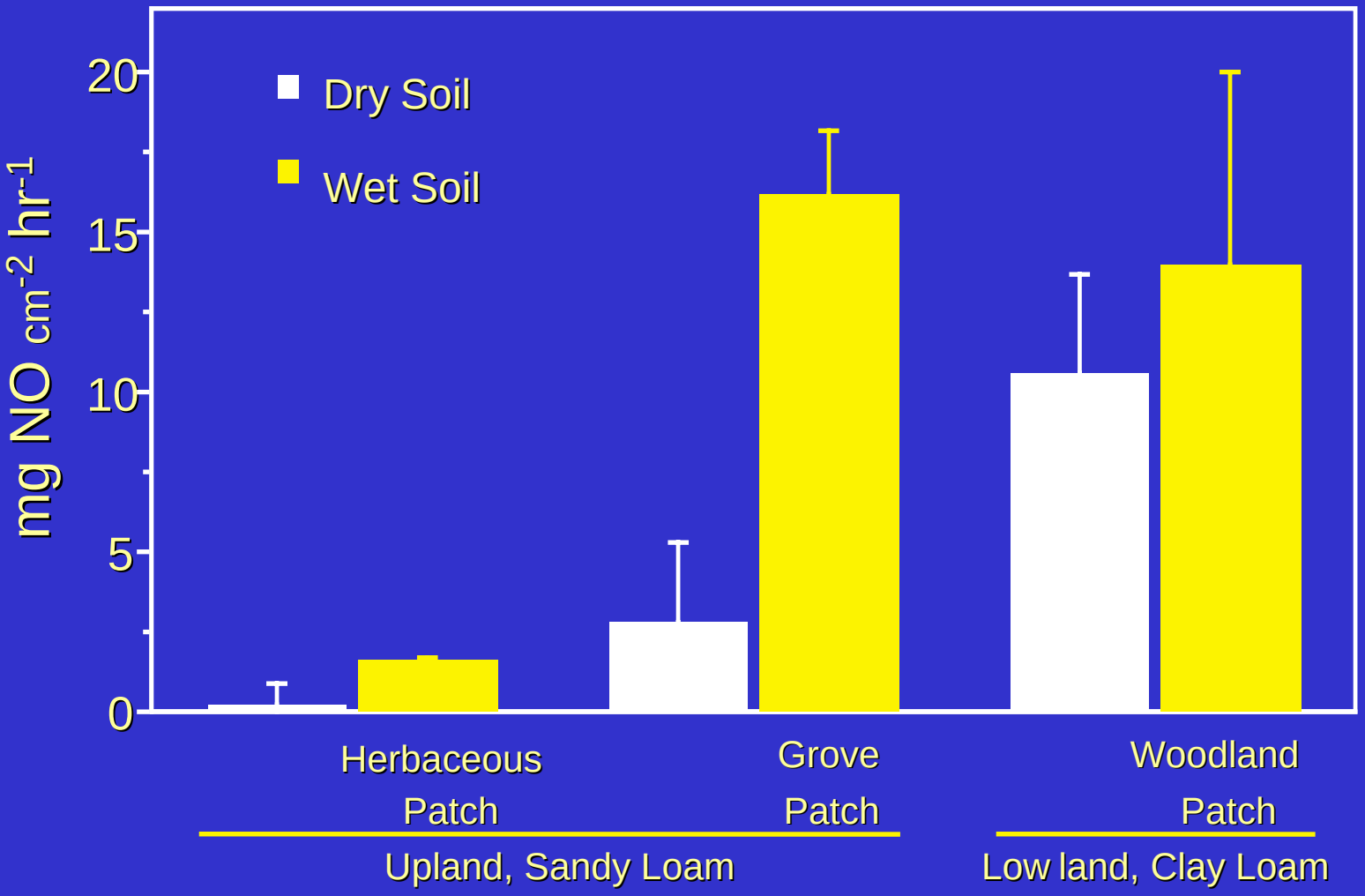
Patch Type	Annual N-Mineralization ($\mu g\ g^{-1}\ y^{-1}$)
Herbaceous	42 ± 5
Shrub Cluster	200 ± 18
Grove	137 ± 16
Woodland	127 ± 29

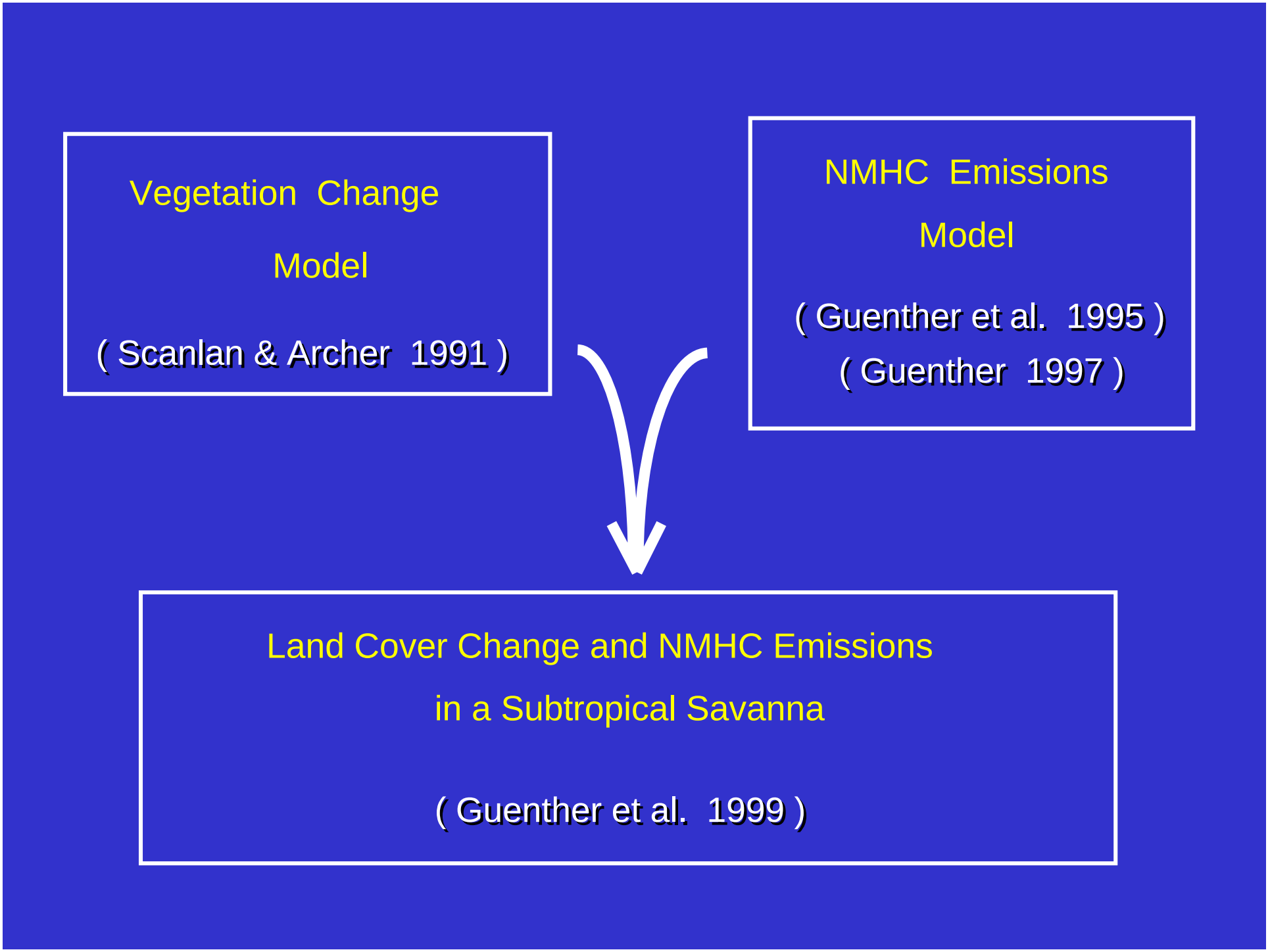
Annual nitrogen mineralization rates at the La Copita site in southern Texas are highest in soils associated with woody vegetation known to have developed over the past century

From Hibbard 1995

NITRIC OXIDE FLUXES

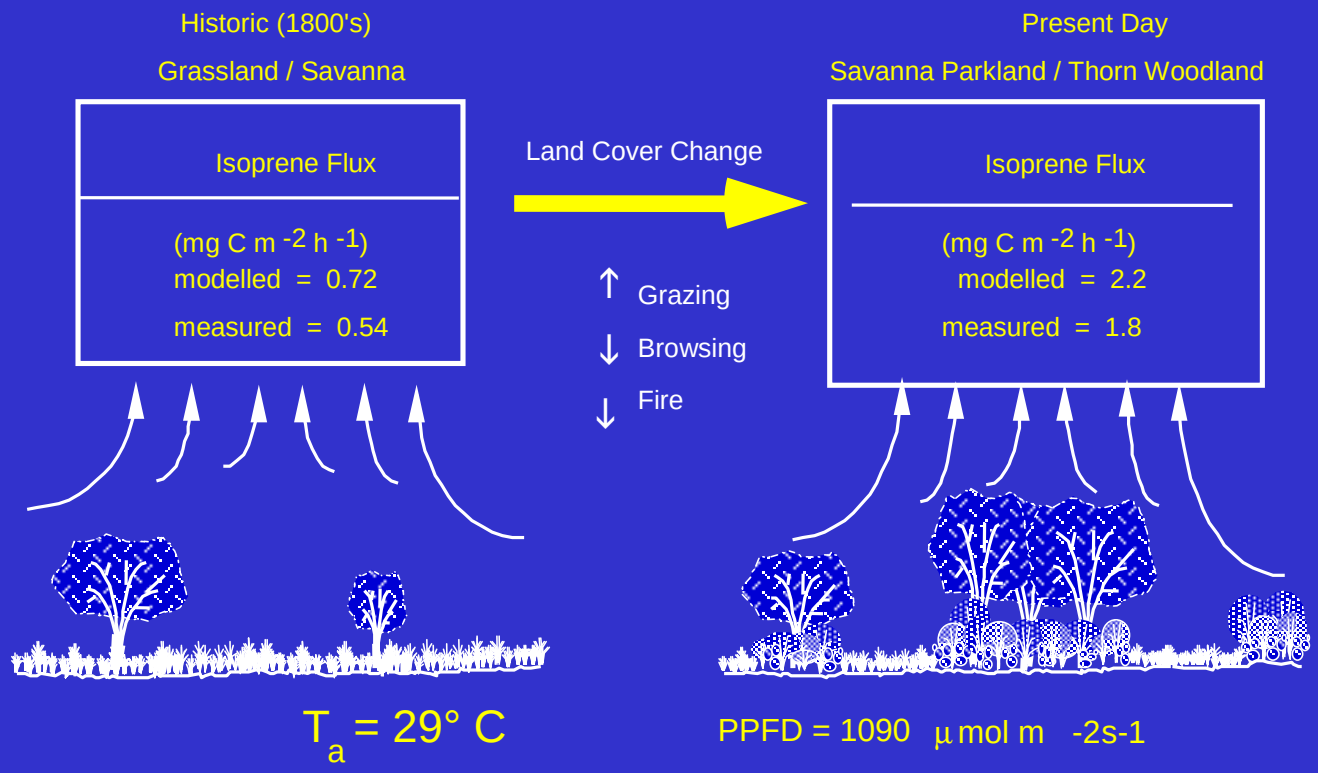
La Copita Site, Texas



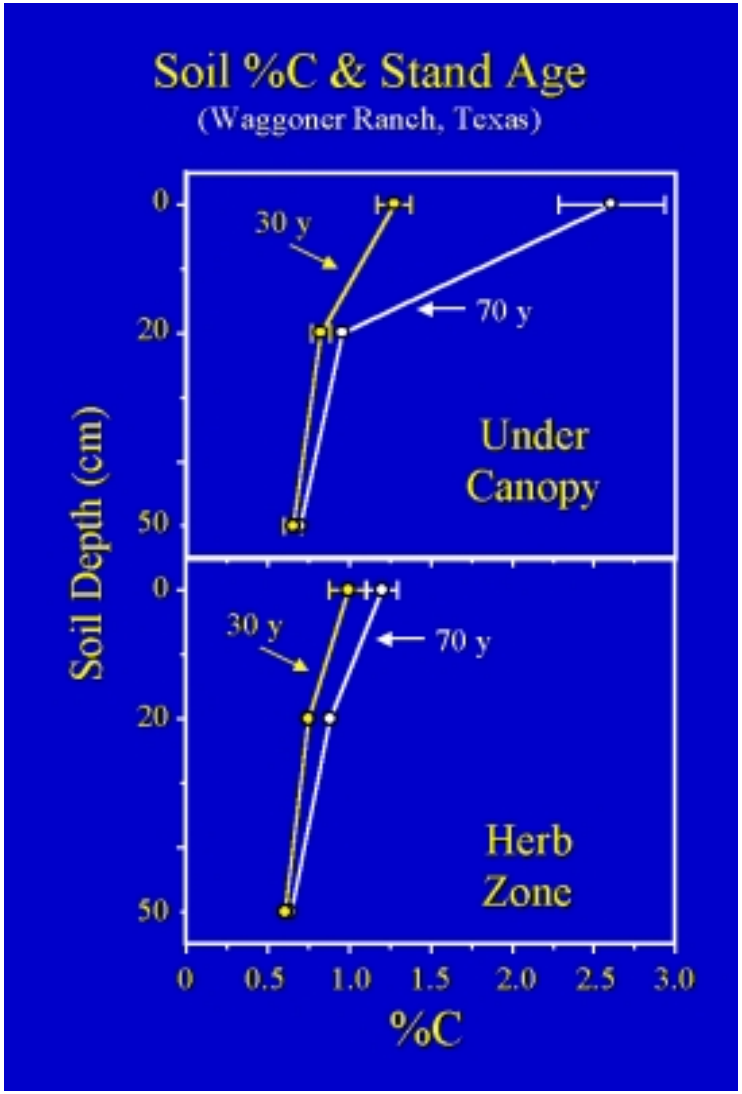

Vegetation Change
Model
(Scanlan & Archer 1991)
NMHC Emissions
Model
(Guenther et al. 1995)
(Guenther 1997)
Land Cover Change and NMHC Emissions
in a Subtropical Savanna
(Guenther et al. 1999)

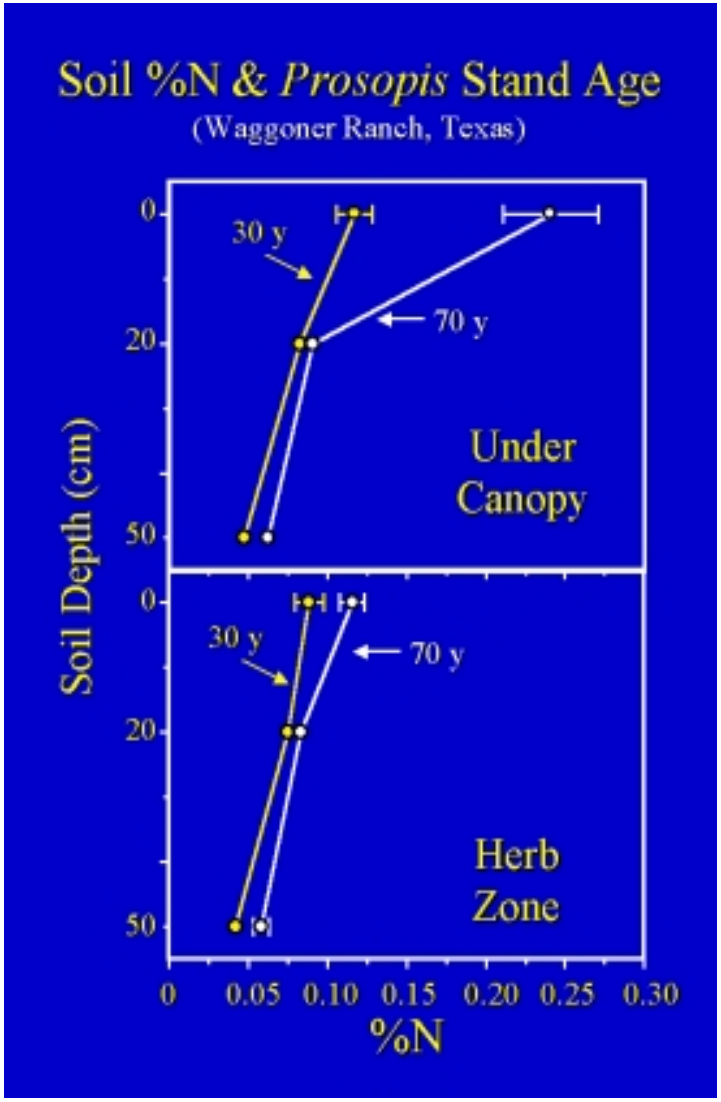
NMHC Emissions & Land Cover Change

(Guenther et al. 1999)

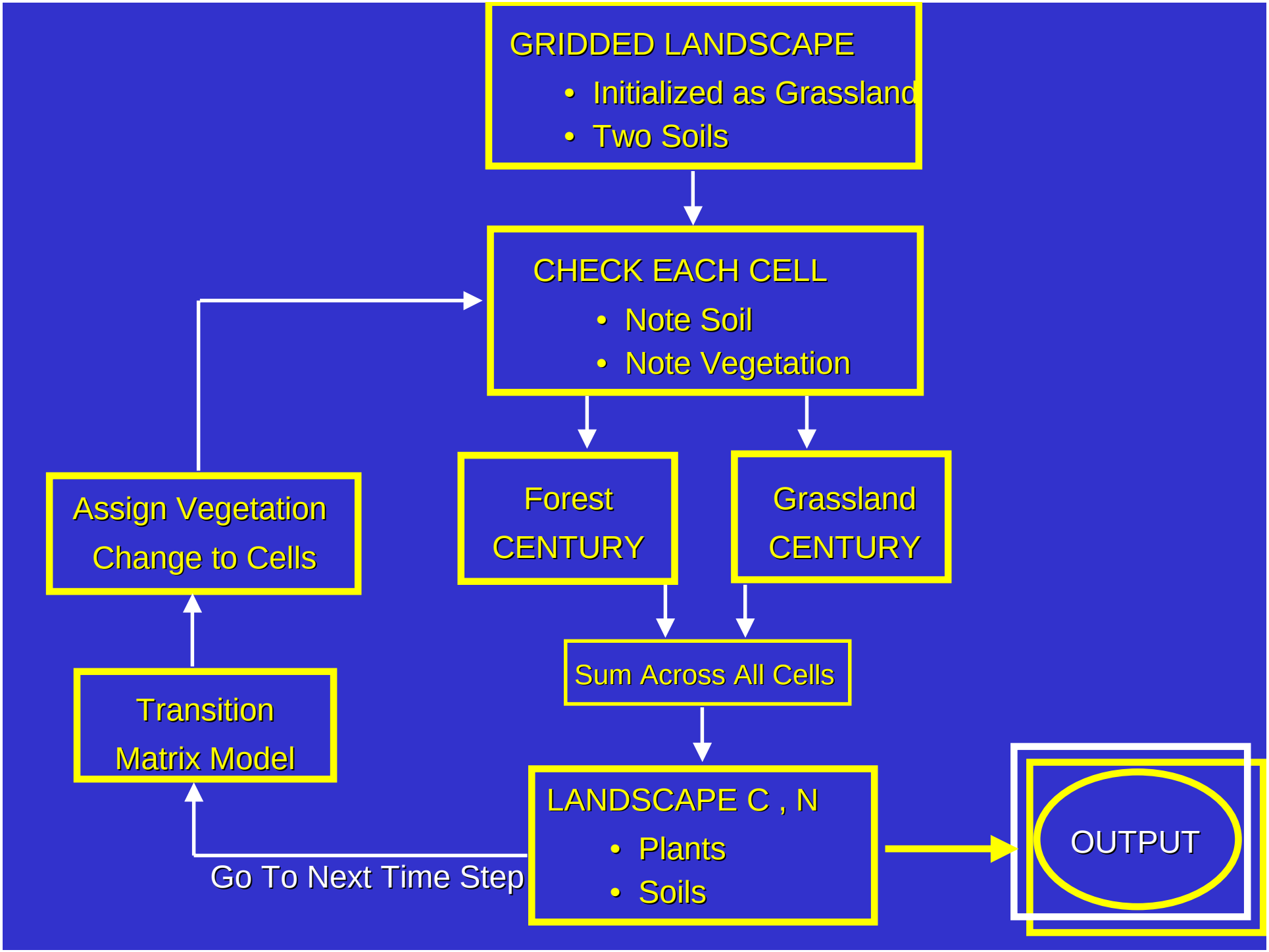


Non-methane hydrocarbons affect tropospheric chemistry (greenhouse gas half-life, ozone production, OH^- radical chemistry). Increases in woody plant abundance have increased NMHC emissions 3-fold at the La Copita site.

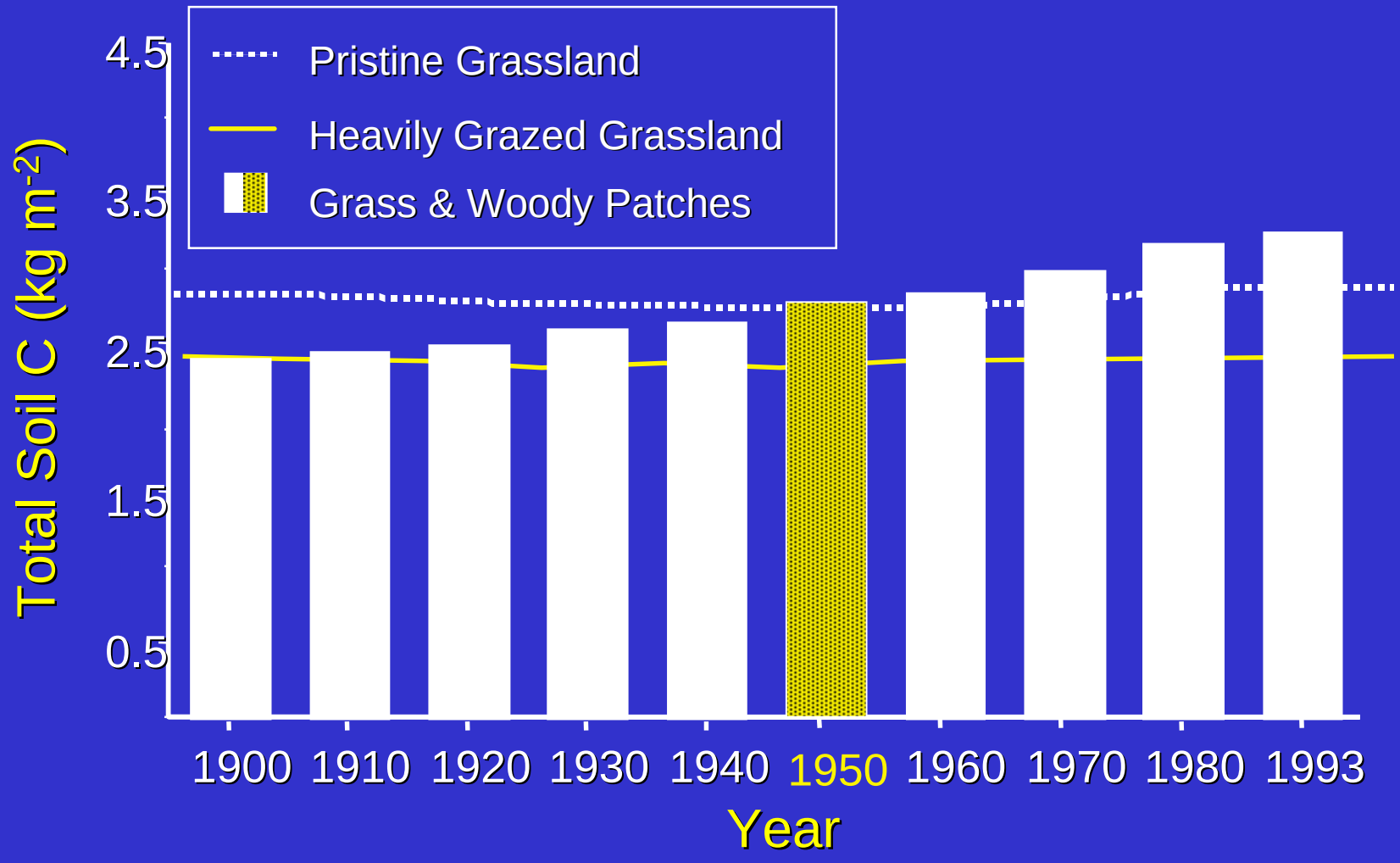




Soil carbon and nitrogen concentration and mass increase subsequent to woody plant establishment.


GRIDDED LANDSCAPE
• Initialized as Grassland
• Two Soils
CHECK EACH CELL
• Note Soil
• Note Vegetation
Forest CENTURY
Grassland CENTURY
Sum Across All Cells
LANDSCAPE C , N
• Plants
• Soils
OUTPUT
Go To Next Time Step
Transition Matrix Model
Assign Vegetation Change to Cells

LANDSCAPE-SCALE SOIL CARBON MASS



Estimates of C-sequestration by dryland woody plants must account for deep root systems (photo by S. Archer, La Copita site, Texas)

ASSESSMENT OF CONSEQUENCES

ULTIMATELY DEPENDS ON ACCURATE, REGIONAL MONITORING OF:

- Pattern And Extent Of Encroachment
- Net Outcome Of Encroachment vs. Clearing
- Rate Of Regeneration After Clearing

REMOTE SENSING: A CRITICAL TOOL

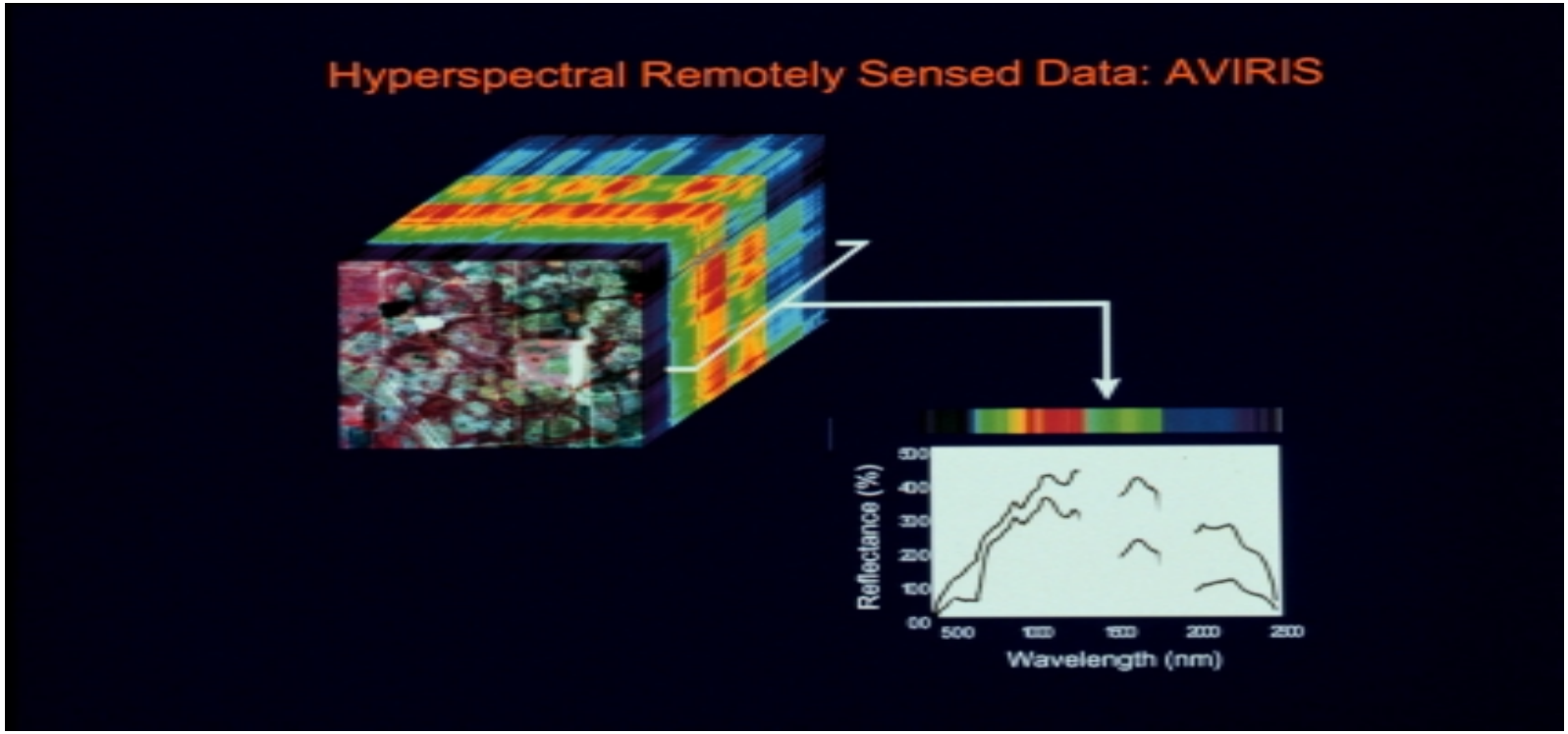
Quantitative Remote Sensing

- Spectral vegetation indices such as NDVI are single values attempting to describe a multivariate condition.
    * NDVI:biophysical relationships are often locationally-, temporally- and vegetation-dependent
- Techniques utilizing canopy radiative transfer theory and sub-pixel analyses quantify contributions of individual landscape components (e.g. green foliage, litter) to measured reflectance.
- Quantitative remote sensing measures the key structural attributes, vertically and horizontally, in changing landscapes.

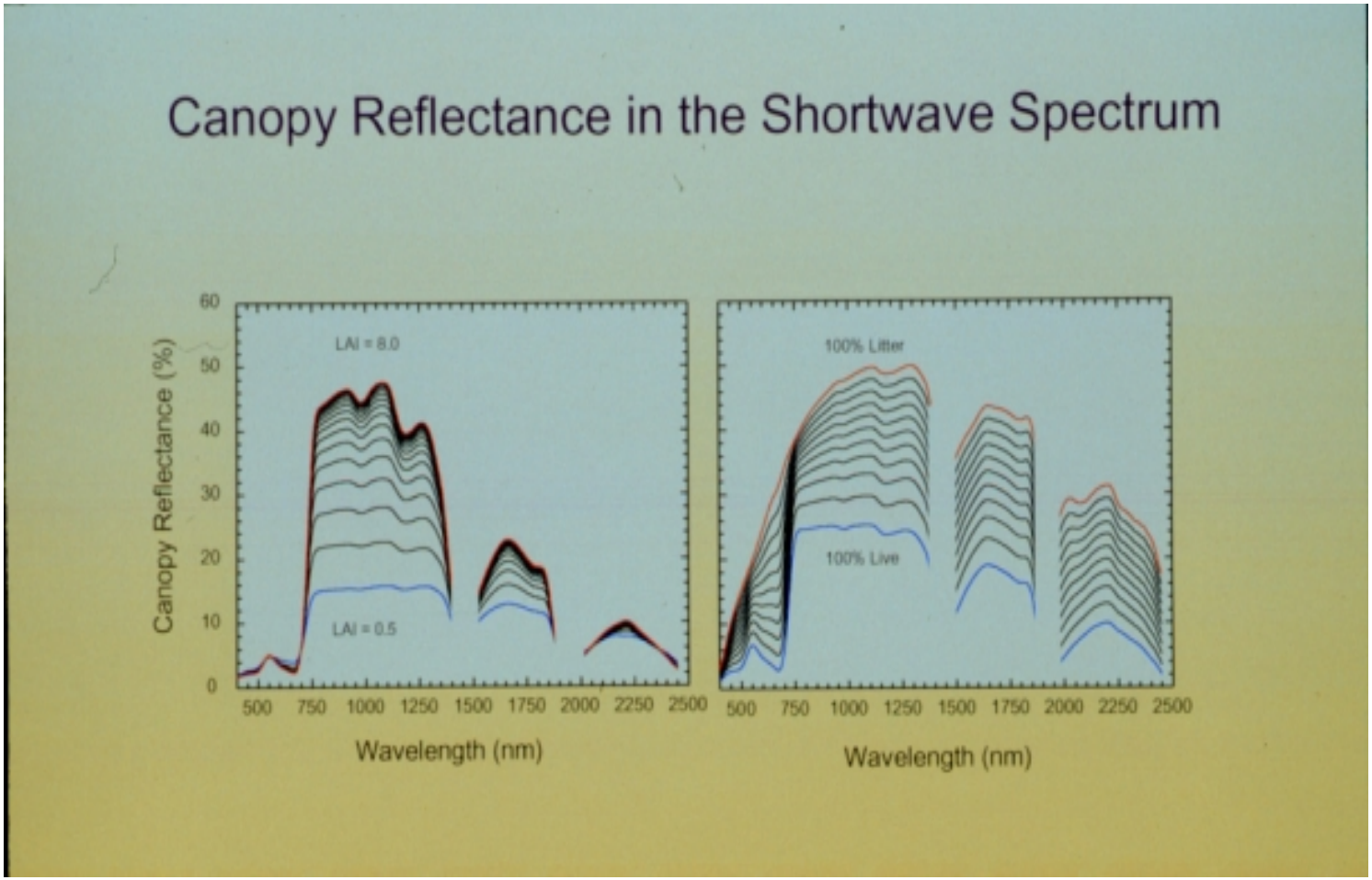
Spectral Mixture Analysis

Reflectance from a heterogeneous canopy or landscape is:

- A composite of signals from each component
- A function of the type and quantity of the reflecting components and their relative influence on the measured response.



A cube of AVIRIS data showing how endmembers of landscape components can be distinguished. The high spectral resolution (~10 nm) gives a nearly continuous reflectance signal which can be used to differentiate landscape/ vegetation components when used in conjunction with radiative transfer and mixing models.



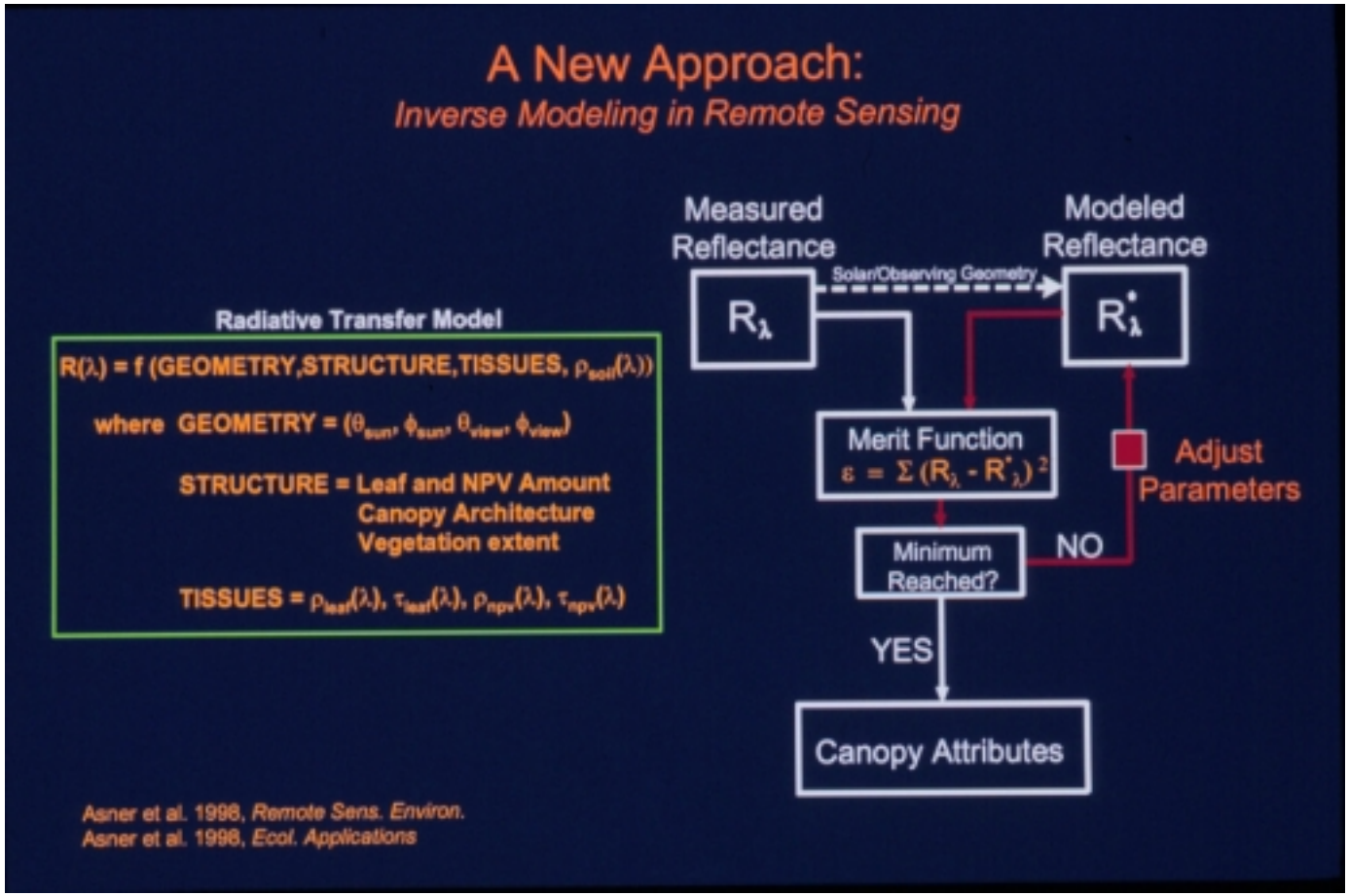
Magnitude of the hyperspectral reflectance signal is highly sensitive to leaf area and non-photosynthetic (litter, woody stems) materials in plant canopies (Asner *et al.* 1998. *Ecol. Appl.* 8:1022-1036)

Radiative Transfer Model

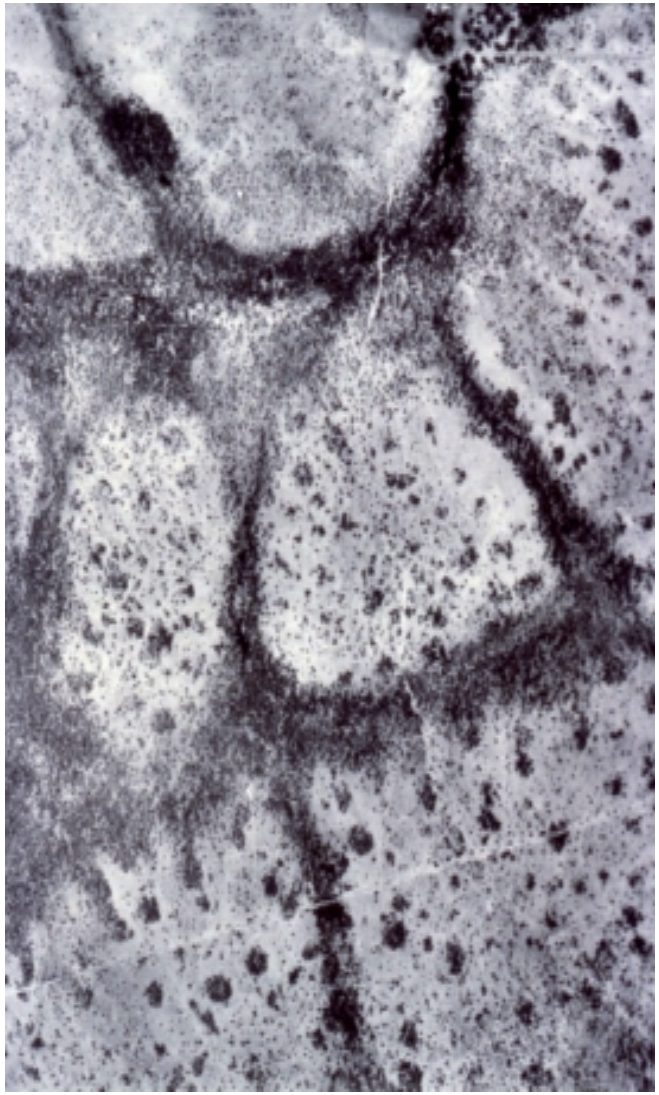
Produces top-of-canopy reflectance spectra from:

- LAI
- NPVAI*
- Leaf/stem orientation
- Leaf/stem optical properties
- Sun/view orientation
- % Vegetation cover
- Soil reflectance

*Non-Photosynthetic Vegetation



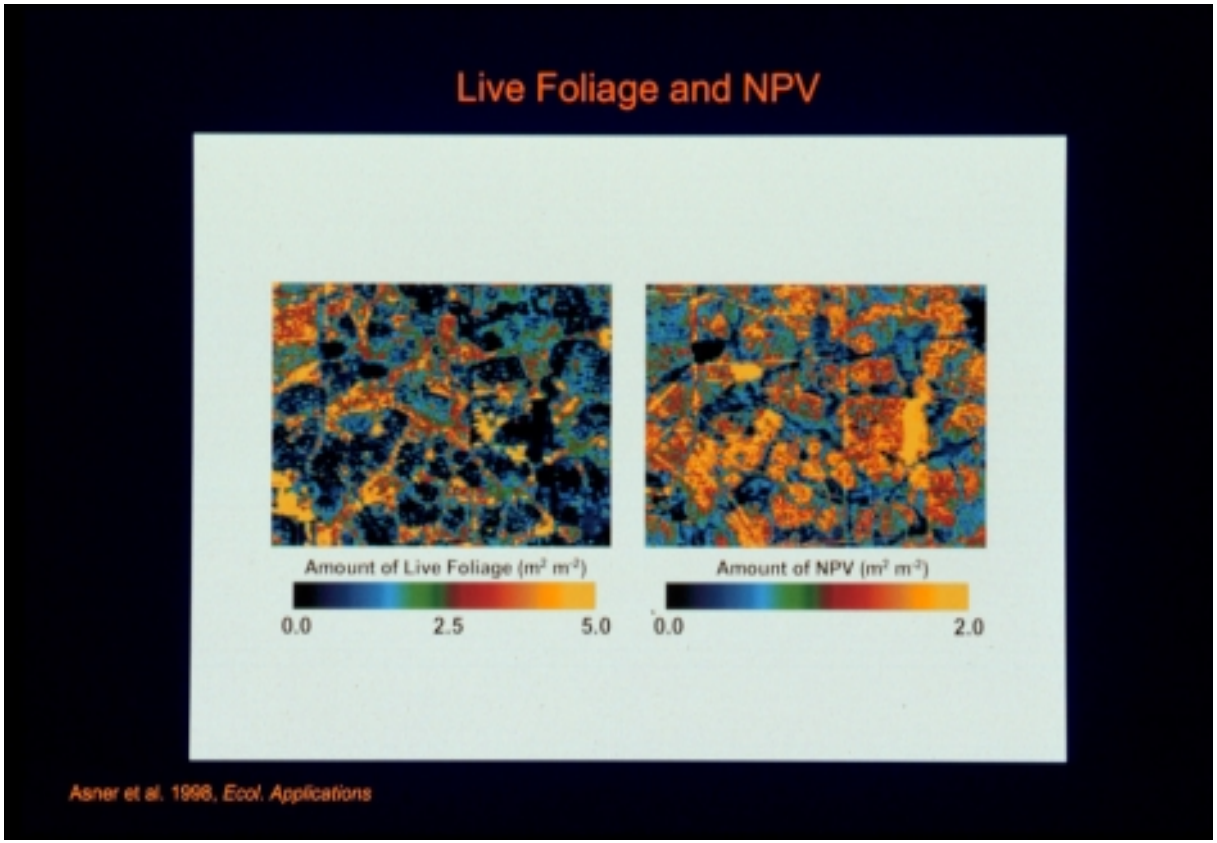
Structural attributes producing the canopy reflectance observed by a remote sensing instrument can be derived from radiative transfer models which have been appropriately constrained (Asner *et al.* 1998. *Ecol. Applications* 8:1022-1036).



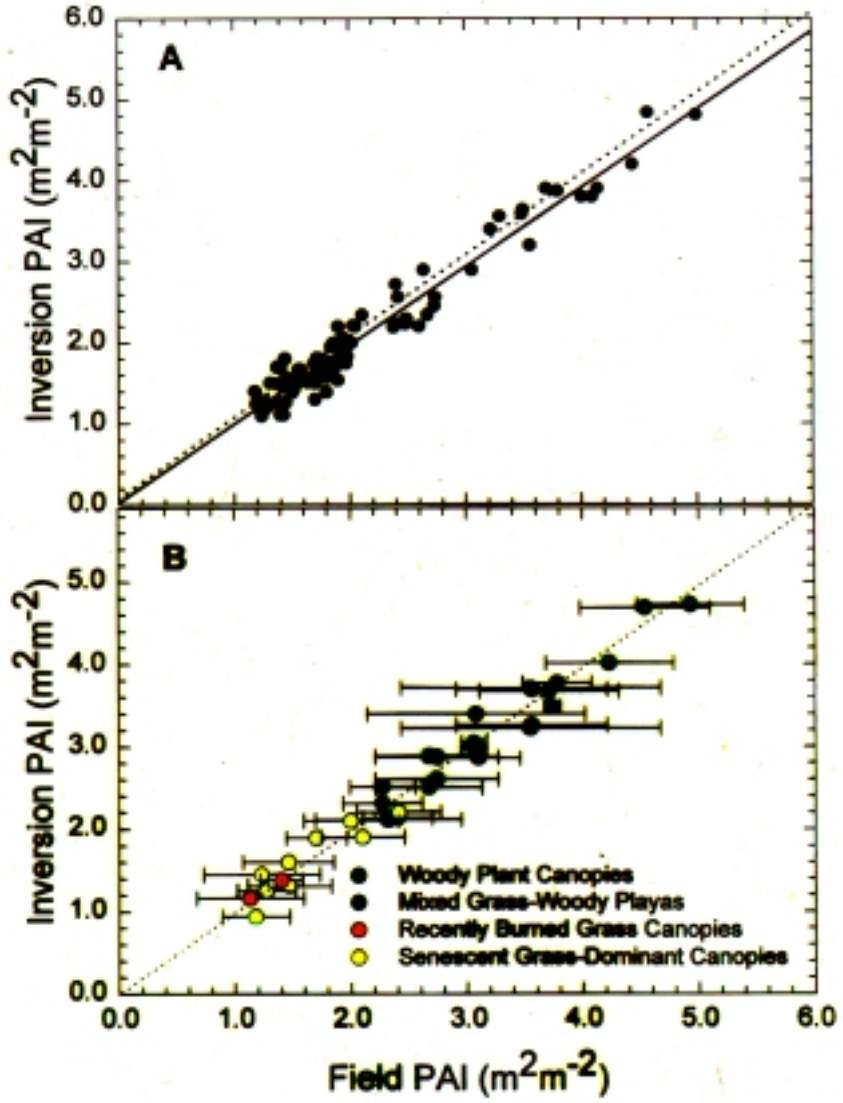
Black & white aerial photo of the La Copita site in southern Texas, showing rheticulate , polygonal vegetation patterns.

Black areas are woody plant canopies; grey areas are dominated by grasses. Sandy loam uplands are characterized by discrete shrub clumps dispersed in a grassy matrix; these give way (1-3% slopes) to closed-canopy woodlands in clay loam intermittent drainages

AVIRIS was successfully used to quantify structural and functional attributes of this complex landscape (next slides)



Spectral Mix. Anal. --> Live v. Dead Fractions --> RT Model Inversion --> area indices of live foliage and non-photosynthetic vegetation (NPV) at La Copita site, Texas (Asner *et al.* 1998. *Ecol. Appl.* 8:1022-1036). AVIRIS imagery is from August 1993 when grasses are dormant and shrubs are green and physiologically active.



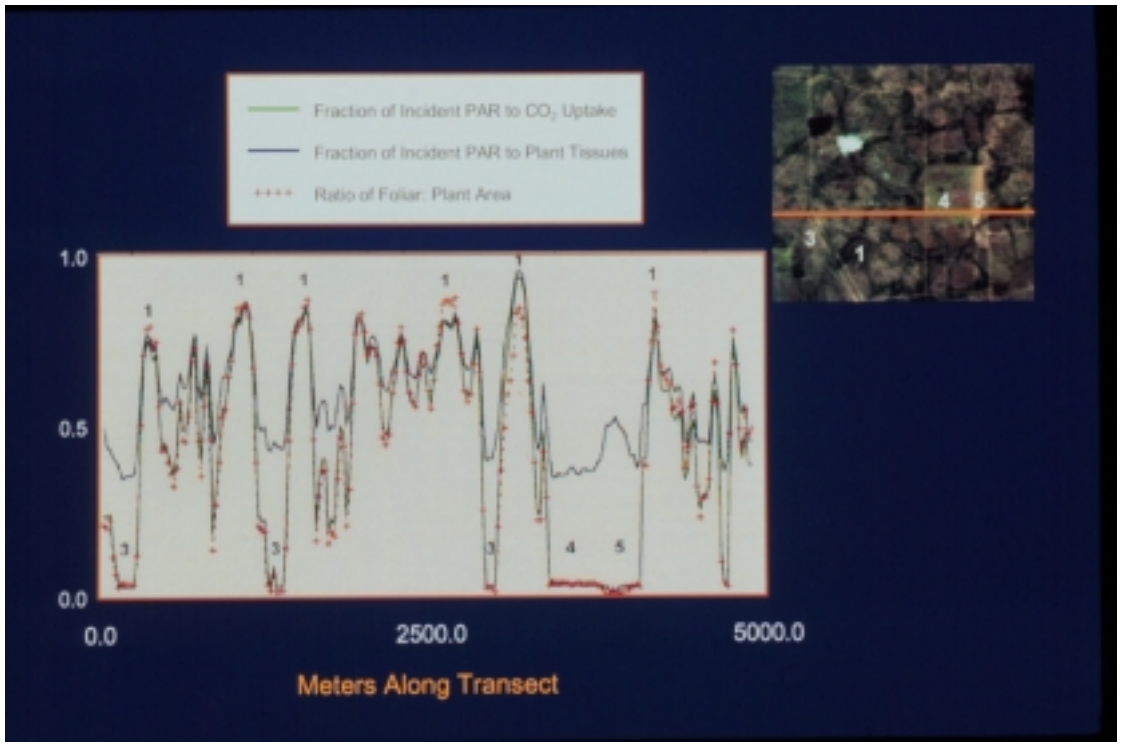
Agreement between ground (LAI-2000 instrument) and remotely sensed estimates of Plant Area Index, La Copita site, Texas

A). Area-weighted field data w/i AVIRIS pixels

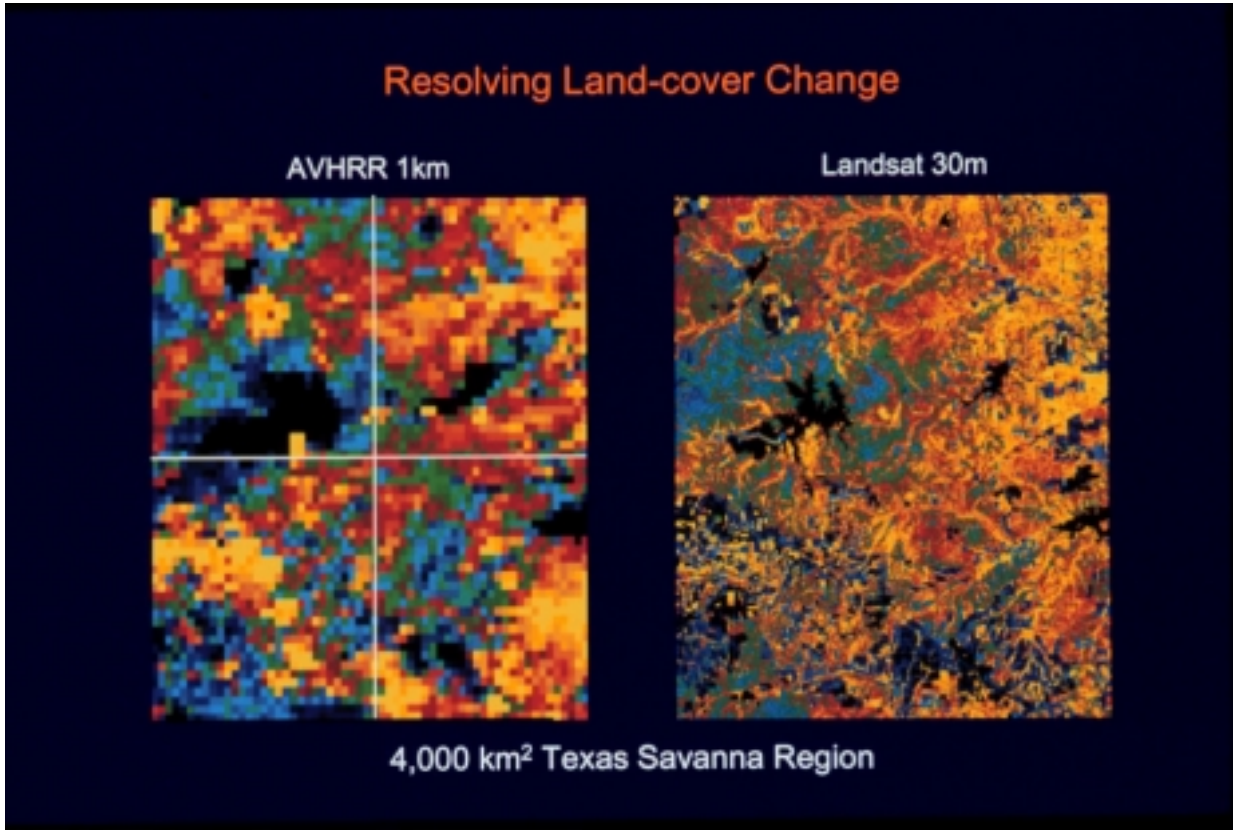
B). Not area-weighted

Asner *et al.* 1998. *Ecol. Appl.* 8:1022-1036

Asner *et al.* 1998. *Ecol. Appl.* 8:1022-1036



1 = closed-canopy woodland
2 = playas
3 = uplands
4 + 5 = pasture
6 = cropland
7 = cloud/shadow

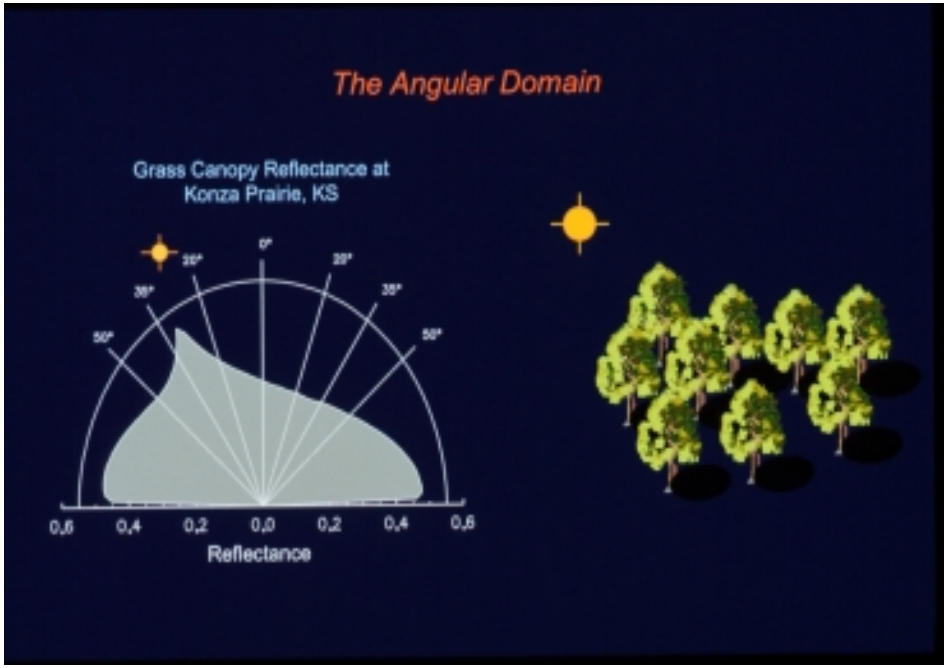


Land cover heterogeneity and change seen at 30 m resolution is lost at coarse (1 km) resolution. However, AVHRR can be used in conjunction with radiative transfer models to generate information useful for interpreting vegetation structure/function in TM scenes.

Satellite Data Fusion and Radiative Transfer Inverse Modelling
(Asner *et al.* 1998. *JGR* 103:28,839-28,853)

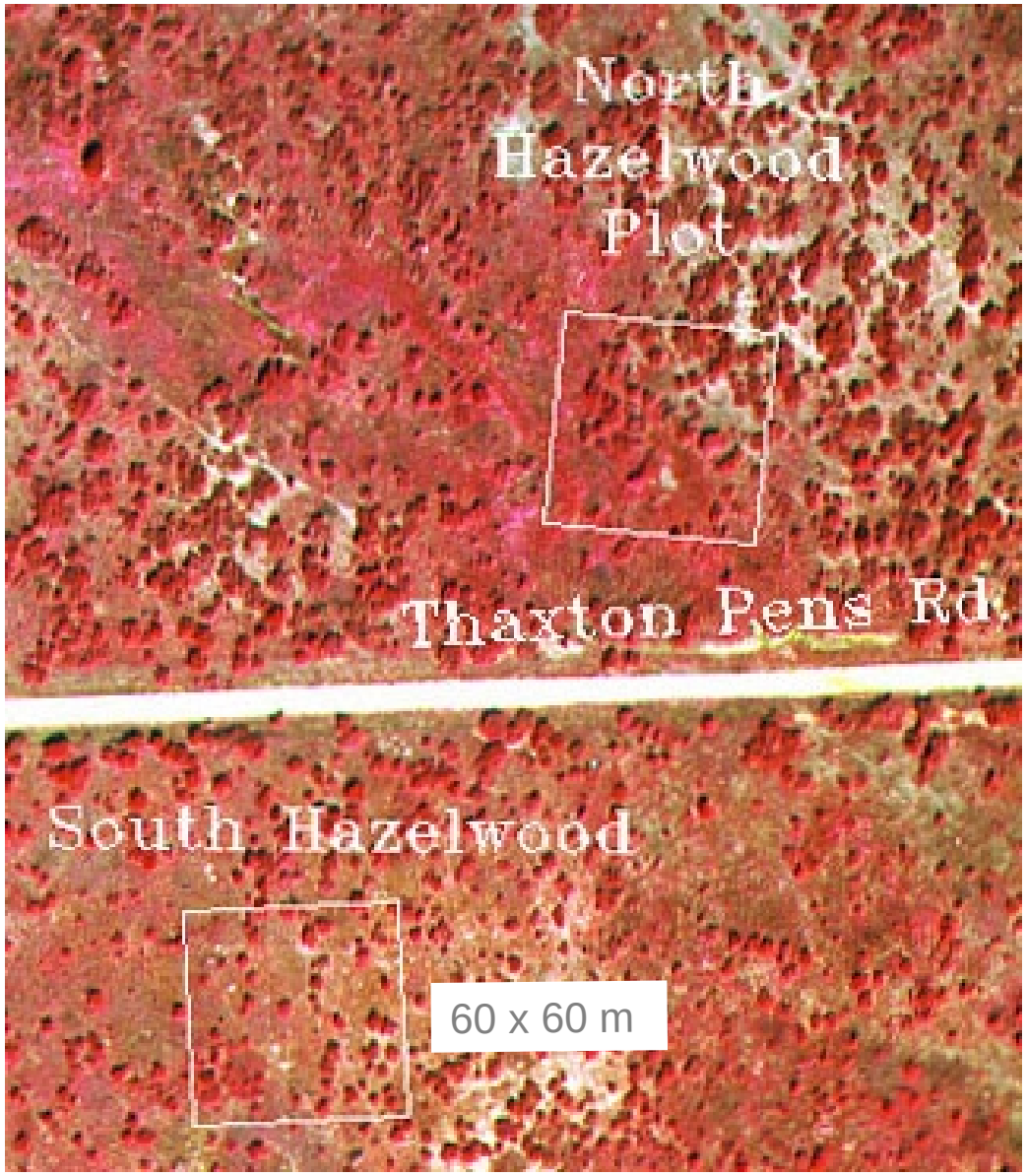
- Spectral mixture analysis of LANDSAT image (Sep 92) used to quantify tree, grass and soil fractions, tree density and tree crown dimensions.

- AVHRR multi-angle reflectance analyzed with RT model to estimate LAI



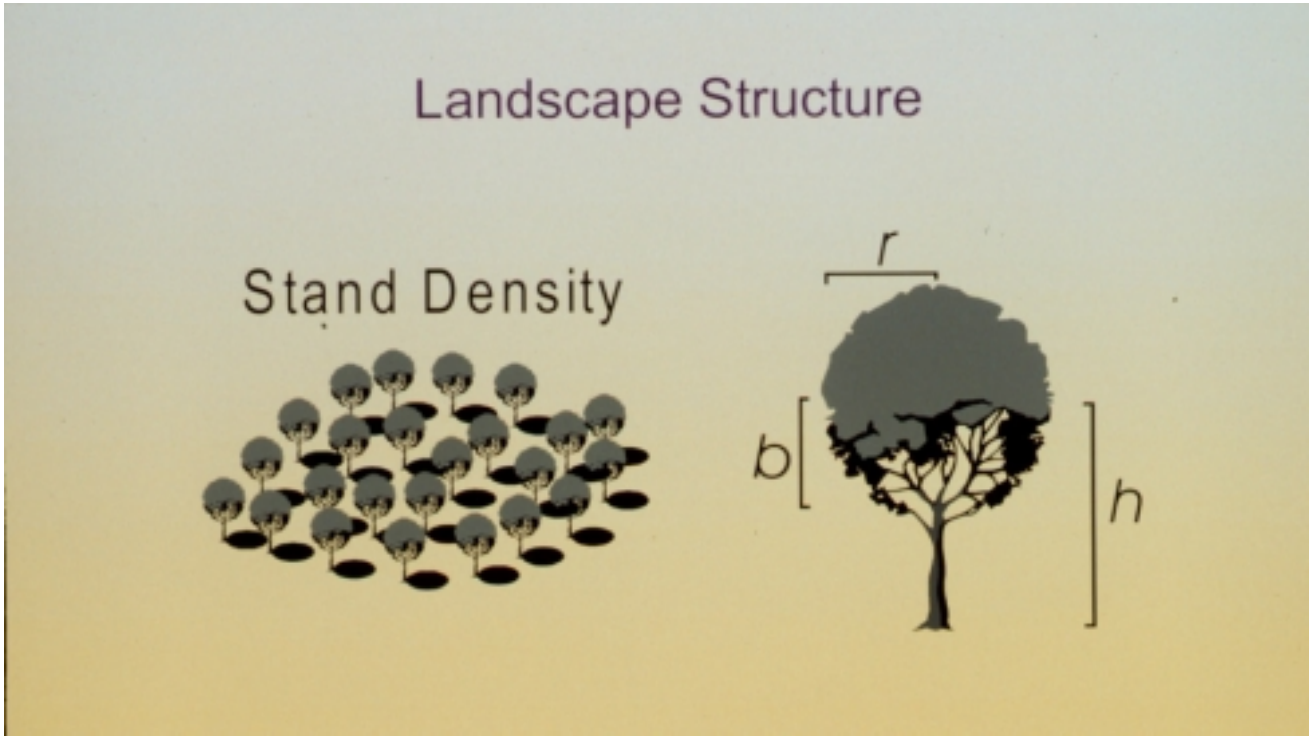
• 13 AVHRR images were acquired over a 10 day period in July 1992 for our north Texas site.

• The slight differences in view angles from these images produced a series of unique reflectance values that were interpreted by inverting a radiative transfer model



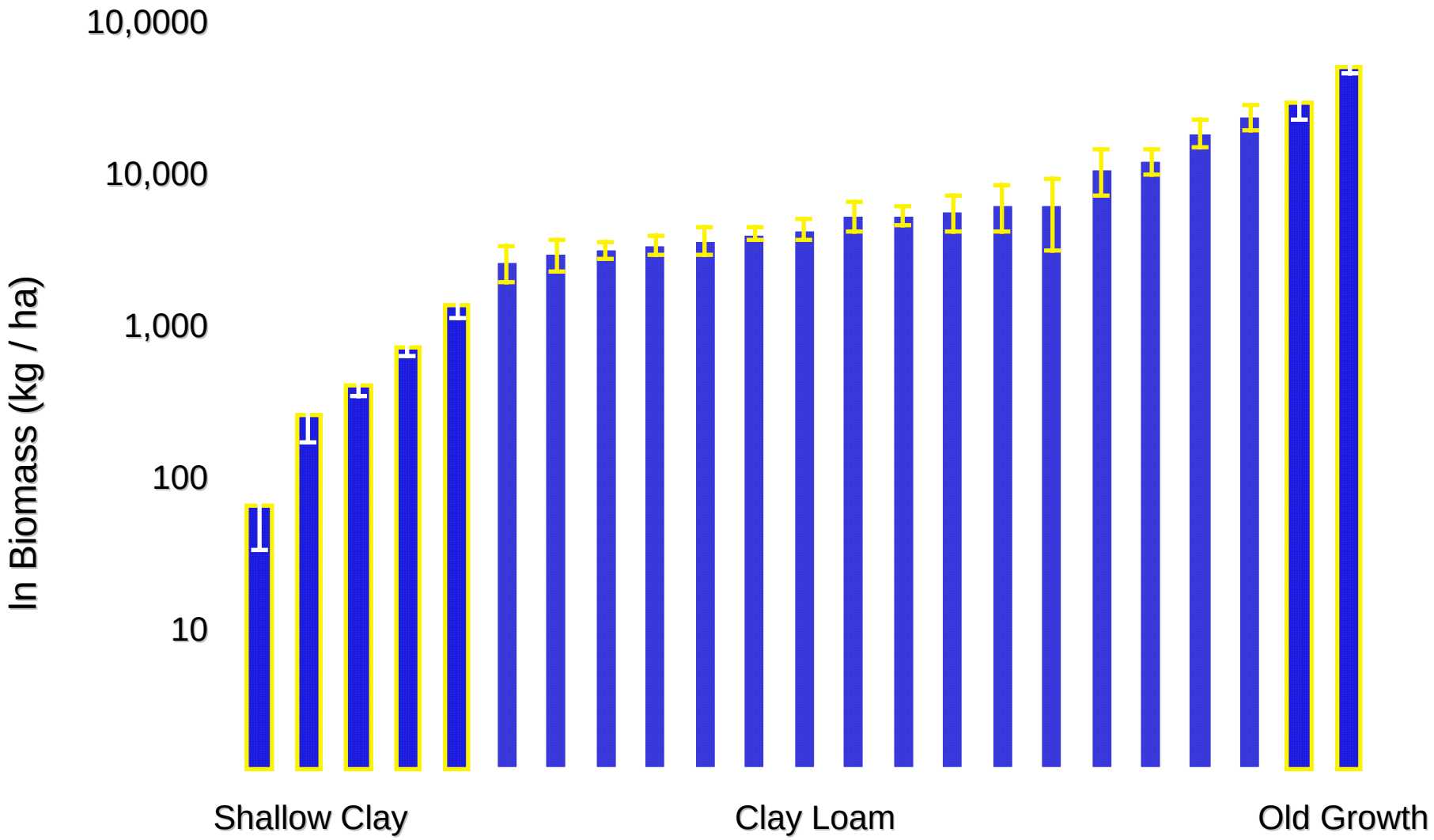
Ground Truth Plots Waggoner Ranch (n=23)

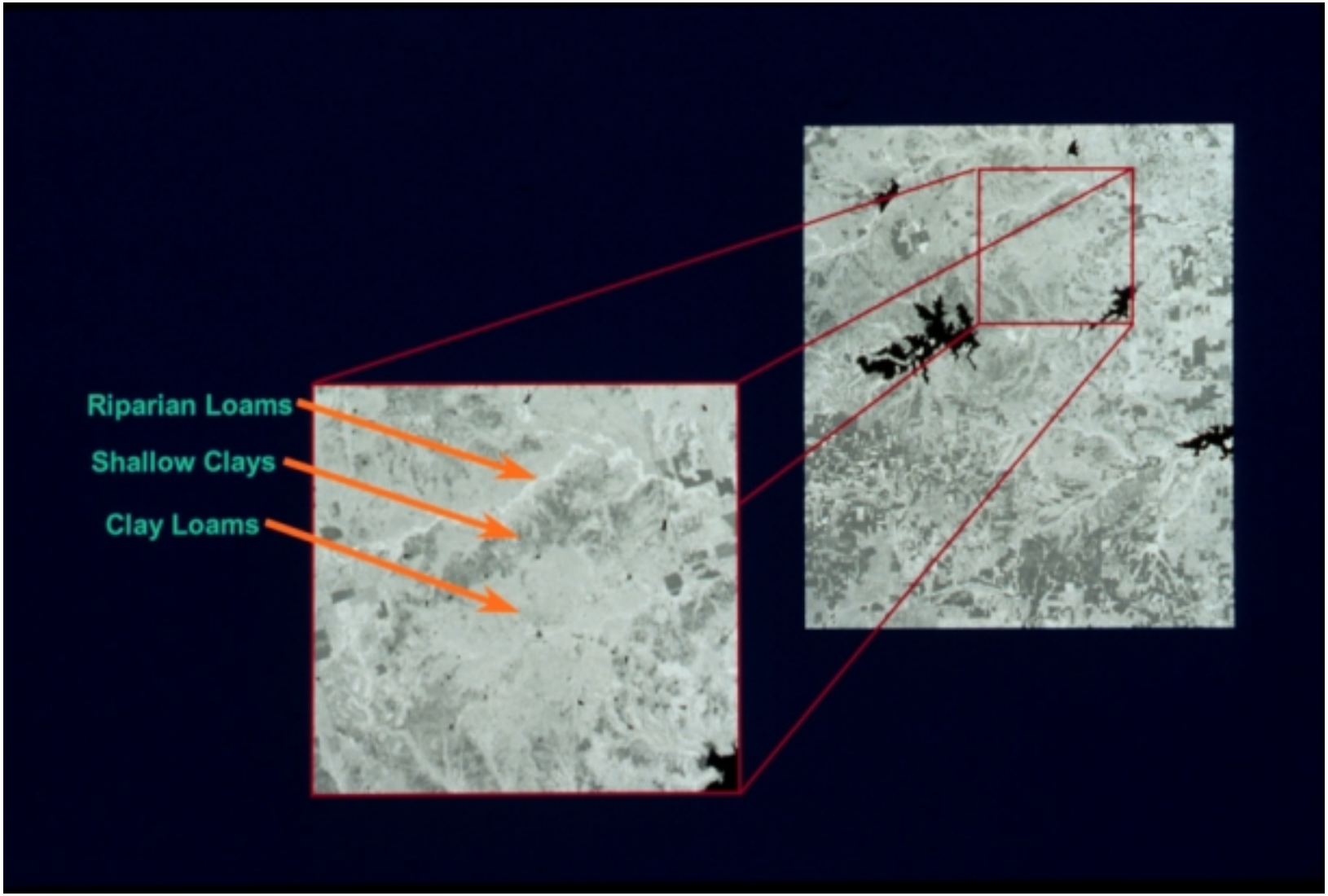
- LAI/PAI
- Leaf, Litter, Bark Optics
- Stem/Canopy Density
- Canopy Area
- Biomass (Allometry)
- Soil $\delta\ ^{13}C$, $\delta\ ^{15}N$,BD[C] , [N]



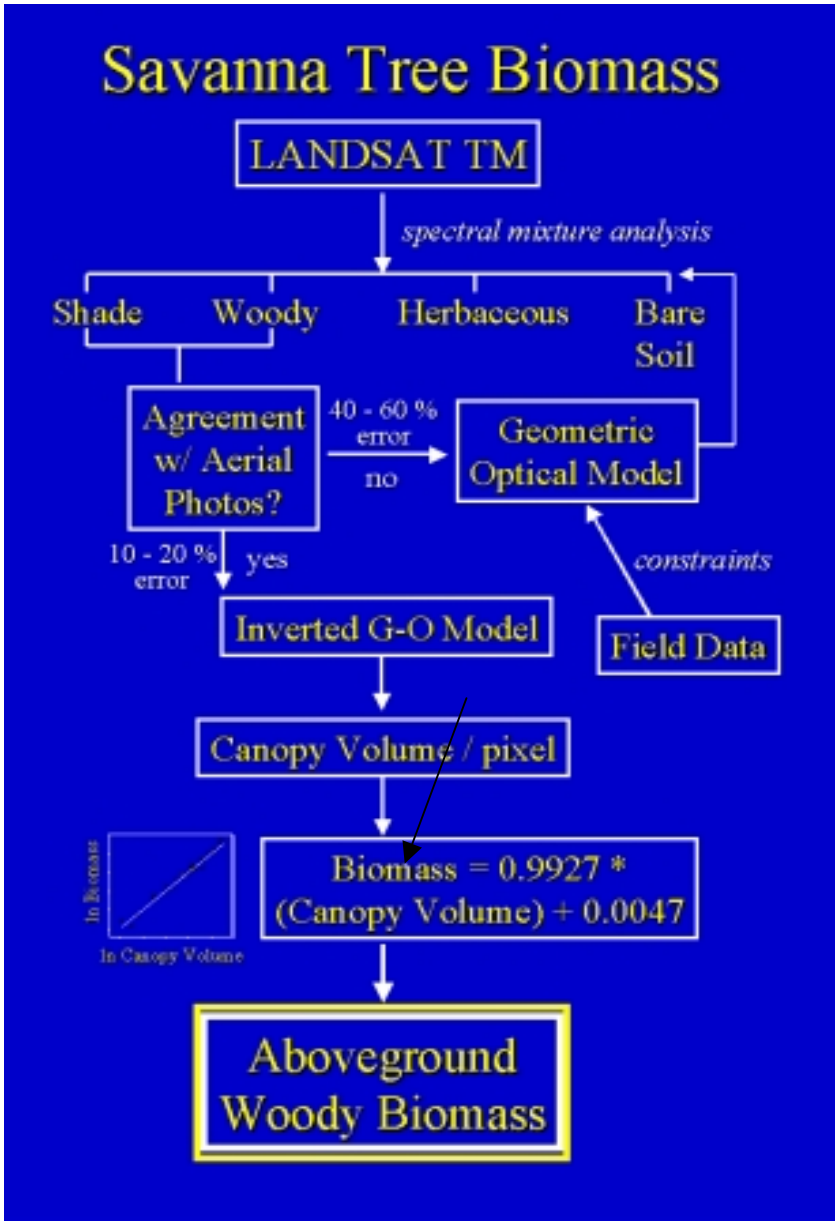
Shading between overstory/understory canopies was derived from tree crown dimensions and their ratios. These relationships were used to Parameterize a geometric-optical model and produce shadow-corrected LANDSAT cover fractions for AVHRR (Asner *et al.* 1998. *JGR* 103:28,839-28,853).

Prosopis aboveground biomass in ground truth plots, Waggoner Ranch, Texas spans 3 orders of magnitude and is a function of soil depth and brush management history.



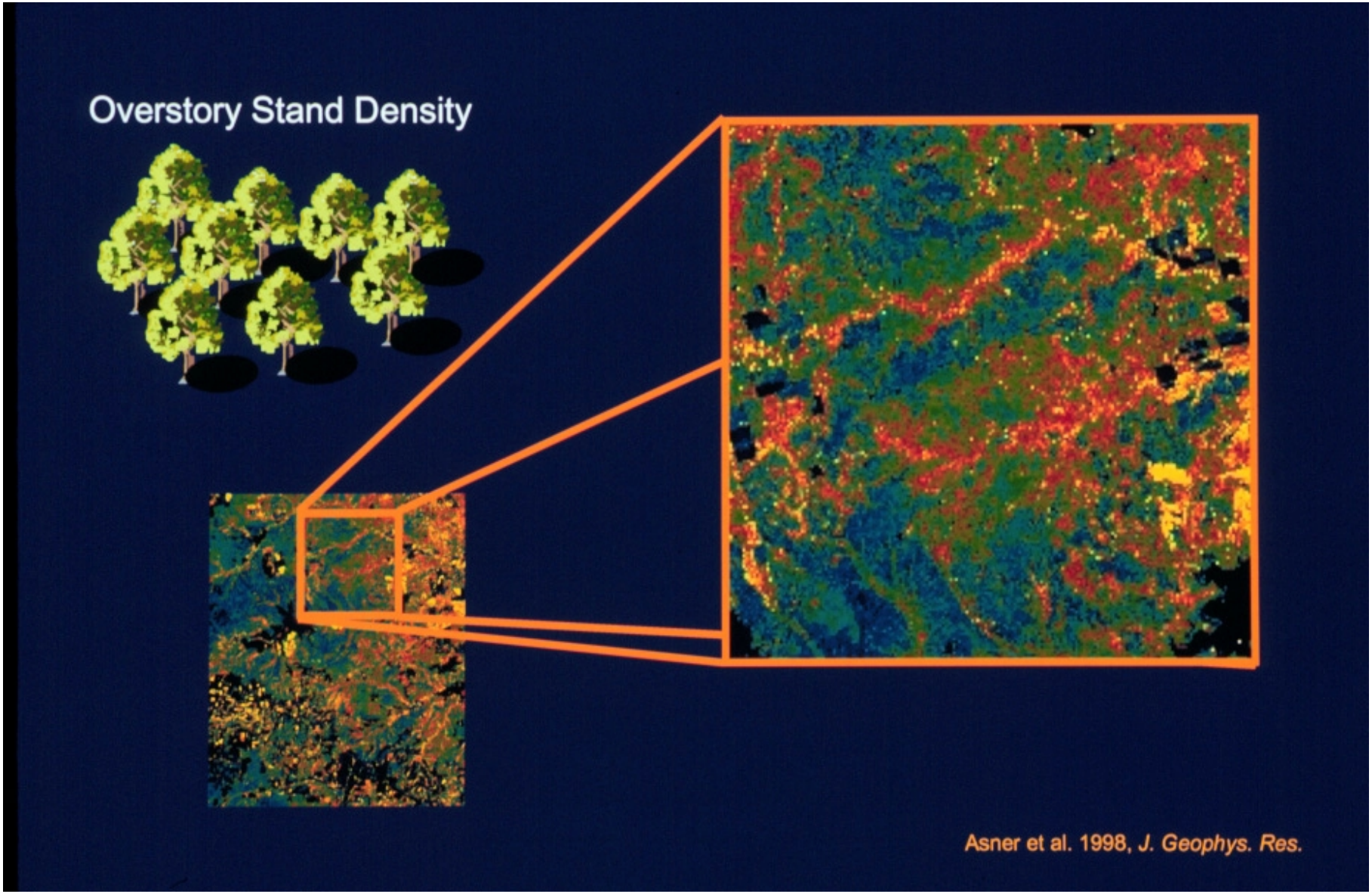


NDVI image, northern Texas savanna region,
Including 200,000 ha Waggoner Ranch

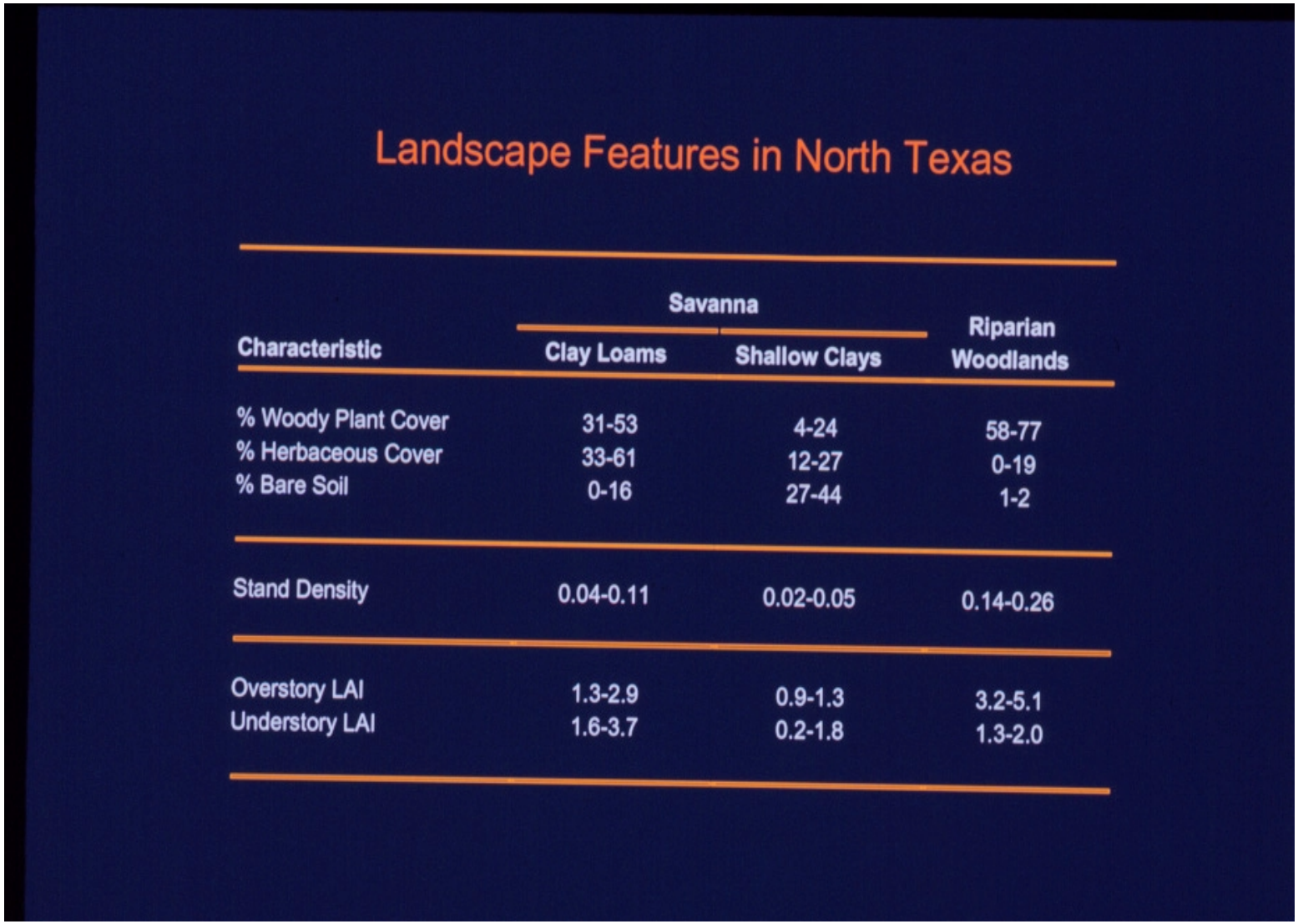


Protocol for estimating savanna tree biomass at Waggoner Ranch, Texas

(Asner *et al.* 1998. JGR 103:28,839-28,853)

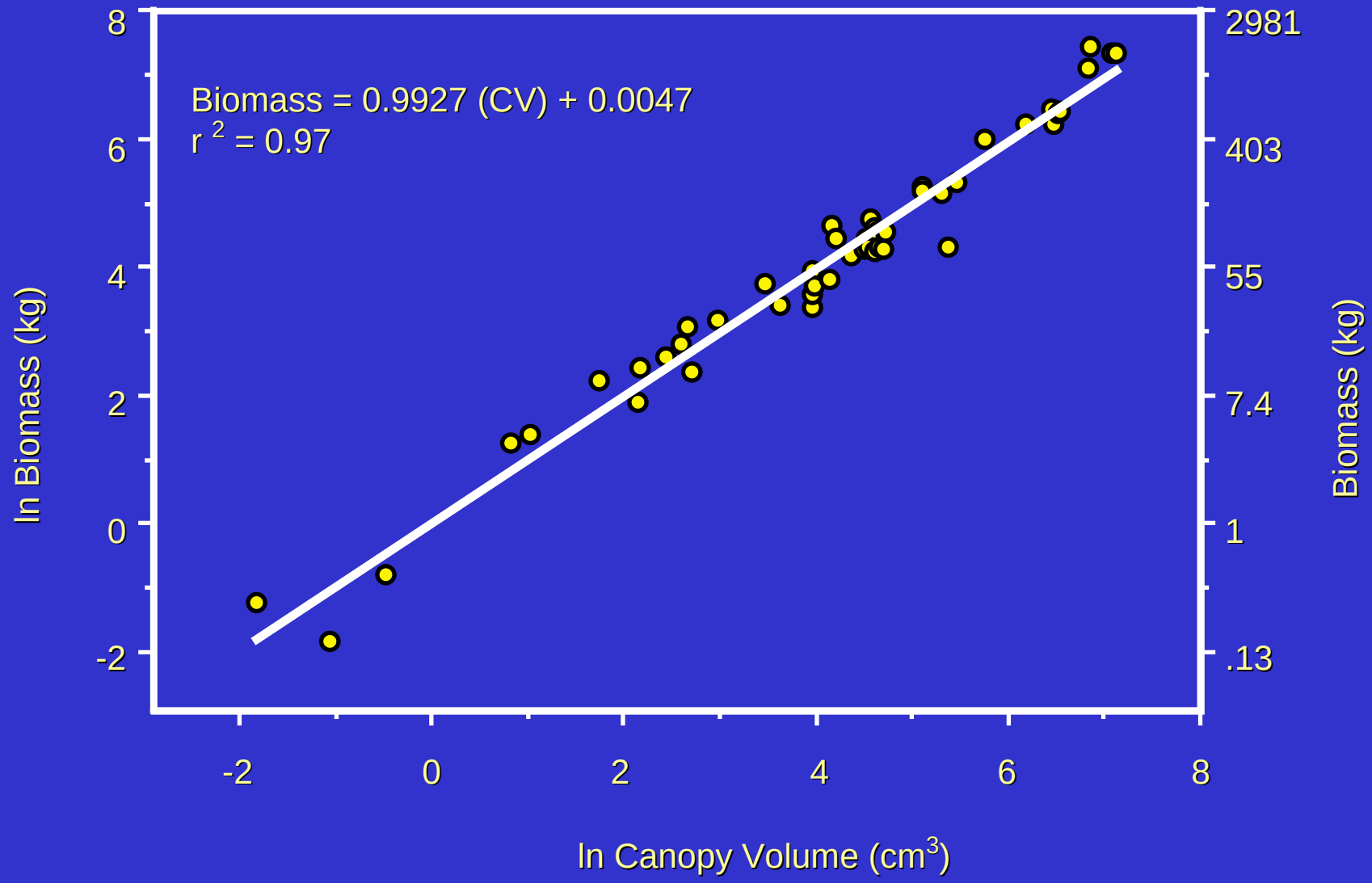


Prosopis overstory stand density, Waggoner Ranch, Texas

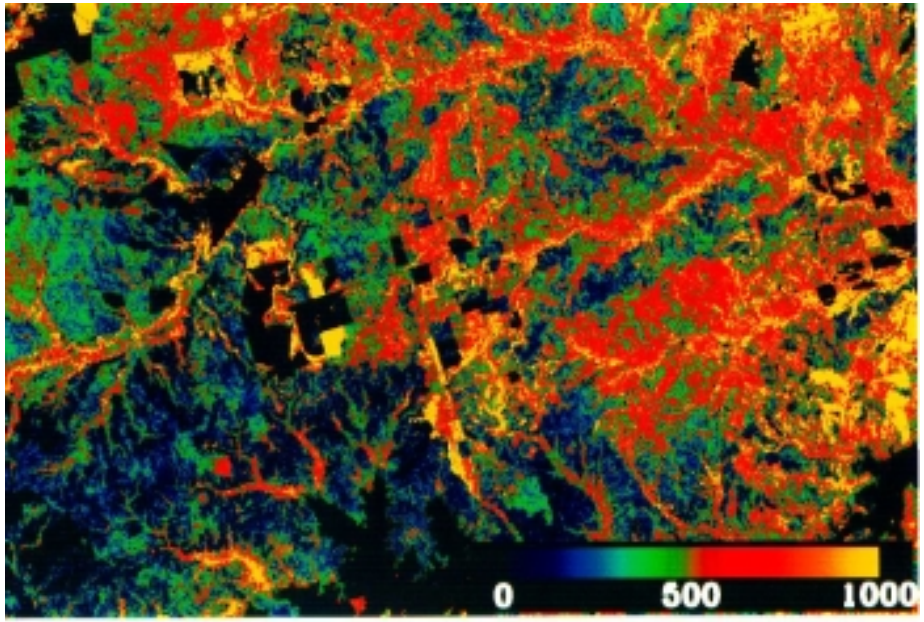


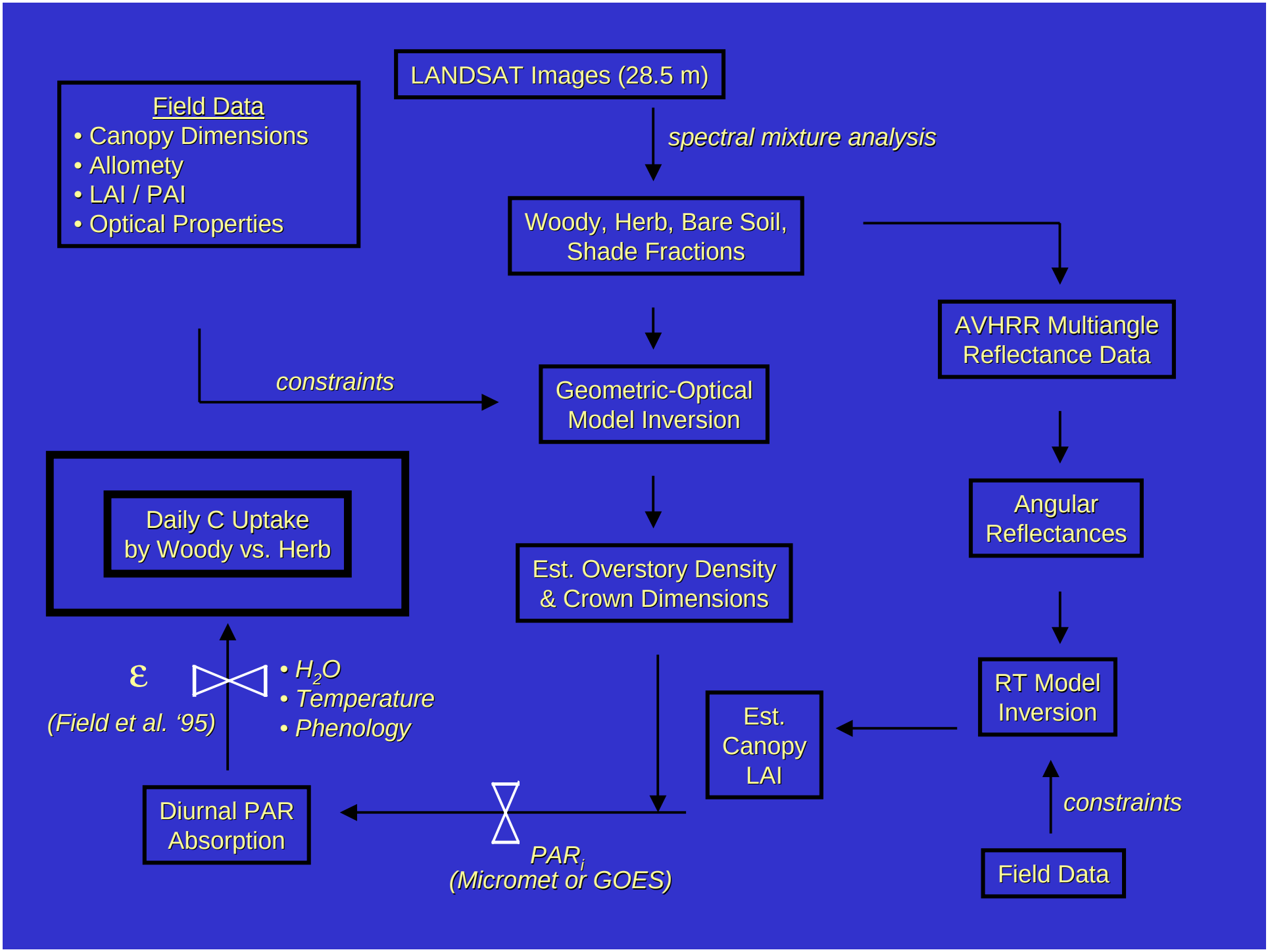
Canopy and landscape attributes acquired through spectral mixture analysis and inverse modeling (Asner *et al.* 1998. *JGR* 103:28,839-28,853).

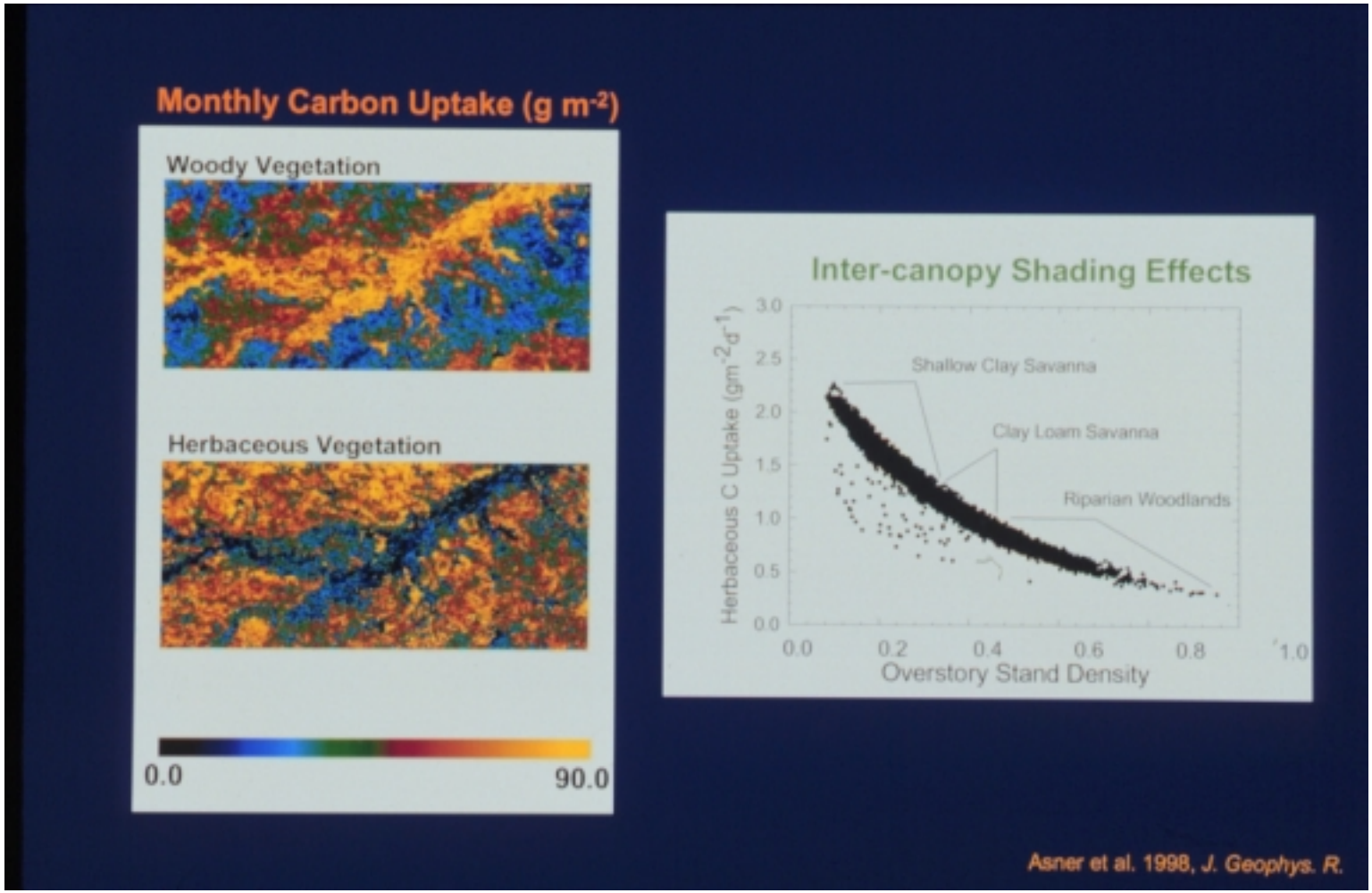
Relationship between *Prosopis* biomass and plot-level canopy volume from ground truth plots, Waggoner Ranch, Texas. Remotely sensed estimates of stand density/canopy volume can be converted to biomass using this relationship.



Biomass Estimates for North Texas Site




LANDSAT Images (28.5 m)
Field Data
• Canopy Dimensions
• Allometry
• LAI / PAI
• Optical Properties
spectral mixture analysis
Woody, Herb, Bare Soil, Shade Fractions
AVHRR Multiangle Reflectance Data
constraints
Geometric-Optical Model Inversion
Angular Reflectances
Daily C Uptake by Woody vs. Herb
Est. Overstory Density & Crown Dimensions
ε
(Field et al. '95)
• H_2O
• Temperature
• Phenology
RT Model Inversion
Est. Canopy LAI
Diurnal PAR Absorption
PAR_i
(Micromet or GOES)
constraints
Field Data



Regional Heterogeneity of C Uptake:

Riparian Woodlands > Clay Loam Savannas > Shallow Clay Savannas

Tree-Grass Interactions at Regional Scale:

The functional form of this curve mimics those developed from field studies of savanna's world-wide.

LINKING MODELING - REMOTE SENSING

- Integrated biophysical-biogeochemical model completed April 1999
- CSCM: Colorado-Stanford-Carnegie Multi-element Model
- Driven by remote estimates of structure (veg cover, LAI, litter) & function (fPAR) obtained via radiative transfer inverse models
- Inter-canopy/inter-vegetation effects regulated via nutrients, light, temp and hydrology
- Multiple element limitation of NPP and NEP (developed at Stanford with JC Neff, W Riley, PA Matson, and CB Field)

LINKING MODELING - REMOTE SENSING (cont)

- First tests scheduled for Wessman and Matson LCLUC projects
  (Asner New Investigator Project)
    - Evaluate highly constrained CSCM against CENTURY (non-remote sensing constrained)

- Collaborators/Contributors:
    - PA Matson, CB Field, JC Neff, W Riley,
    - R Jackson
    - W Parton

Heading Toward Project Completion

- Push research agendas at contrasting sites
  - Vegetation Structure
  - Climate

Jornada LTER Site

- Part of the Jornada del Muerto Basin in southern New Mexico at the northern end of the Chihuahuan desert

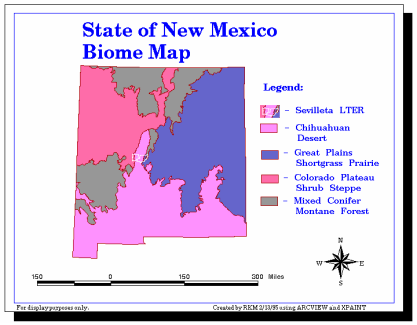
- Natural and human-induced desertification have changed ecosystem processes

- MAP 230 mm delivered in local, intense summer storms

- Max monthly temp 13 - 36 °C

Sevilleta LTER Site

- A biome transition zone: Great Plains Grassland, Chihuahuan Desert, Great Basin Shrub-Steppe, Interior Chaparral, P-J Woodland, and Montane Forest



- Operated as a cattle ranch until late 1972

- MAP= 280 mm
  Range = <100 - >500 mm

- Mean monthly temp 2.5 - 27 °C

Heading Toward Project Completion

- Poised to utilize MODIS and MISR Data at Terra Launch
- Utilize improved capabilities offered by Landsat 7 and the EO-1 satellites
  - Multi-angle/multi-spectral radiative transfer algorithms ready for surface reflectance products

Heading Toward Project Completion (cont.)

- Landsat 7, EO-1 *ALI*, and EO-1 *Hyperion*
  will be used to separate herbaceous - woody
  vegetation types on seasonal basis

  - Expect better accuracy (from 40-60 to ca. 20% error) in shade & woody cover; ∴ improved estimates of woody biomass (from 10-20% to < 5% error after geometric-optical model correction).

- Vegetation types will then be represented in
  radiative transfer model to unmix LAI, litter,
  and fPAR estimates acquired daily-weekly from
  MODIS+MISR

Student Participation

- Texas A&M University
  - Mark Simmons - Tree/Grass & Tree/Tree Interactions
  - Andy Hubbard - Soil Respiration & Root Turnover

- University of Colorado
  - Nancy Golubiewski - Land Use in SW Rangelands
  - Seth Zunker - Nitrogen Fixation
  - Kevin Cody - Aerial Photography/GIS

Research Associates

R. Flint Hughes: CIRES Visiting Fellow/
Biosphere-Atmosphere Research Training
(BART) Postdoctoral Research Associate
(University of Colorado)
Chad McMurtry (Texas A&M)

New Collaborators

X. Ben Wu: Landscape ecologist (Texas A&M)

Related Projects

- USDA Ecosystems: soil respiration, biomass, root turnover
- NIGEC: non-methane hydrocarbon emissions
- NCEAS Tree-Grass Model Comparison Project

  - SAVANNA - CENTURY - MUSE - GRASP

- NASA-EOS Interdisciplinary Science
- NASA-NIP: landscape to regional biogeochemical modeling (CSCM model)
  - Robin Martin (Ph.D. student) - N trace gases (Sept '99)
  - Sharon Hall (Post-Doc) - lysimetry, trace gases (Oct '99)
- NSF-Ecology: Overstory-Understory Interactions (Sept '99)

Hierarchical Investigation of Socioeconomic Drivers of Decadal Scale Land-Cover changes in the Upper Midwest

Daniel Brown
Remote Sensing/GIS

Bryan Pijanowski
Land Use Modeling

Michael Vasievich
Resource Economics

MICHIGAN STATE UNIVERSITY

FOREST SERVICE U.S. DEPARTMENT OF AGRICULTURE

Rural Population Growth

DEMOGRAPHICS

Population of Rural America Is Swelling

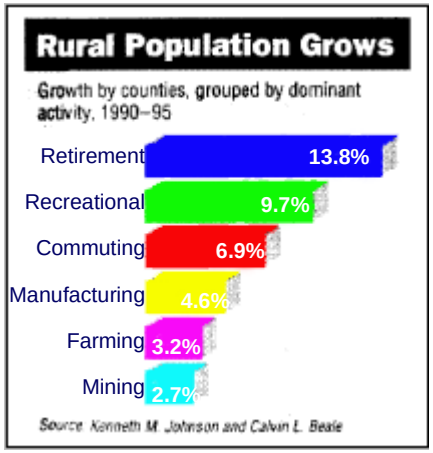
By Scott Kilman
And Robert L. Rose
Staff Reporters of The Wall Street Journal

Pat Murphy is moving his family to Algona, Iowa, from Stockton, Calif., to escape crime, expensive car insurance and slumping home values. But he's also in search of something he can't find in the city.

"In the doughnut shop, the customers are considerate enough to pour each other coffee," he says of life in northern Iowa. "You don't see that in California."

The 1990s, it turns out, are full of Pat Murphys trading in urban life for country living. At the same time, more people in rural areas are staying put. The result: Rural America is making a surprising comeback in population.

New research by two prominent rural demographers finds that most rural areas of the country are growing at their fastest rate in more than two decades. The demographers, Kenneth M. Johnson of Loyola University in Chicago and Calvin L. Beale of the U.S. Agriculture Department, found



says Mr. Beale, who is credited with calling a previous rural population turnaround, when decades of migration out of rural areas were reversed in the 1970s.

Metropolitan areas, meanwhile, have had a 5.8% increase in population over the same period, still higher than the rural

South. But even places that are lagging, such as counties dependent on farming and mining, are faring far better than they did in the 1980s. And while the population turnaround in rural areas flies in the face of conventional wisdom, it doesn't surprise the people who are witnessing the comeback.

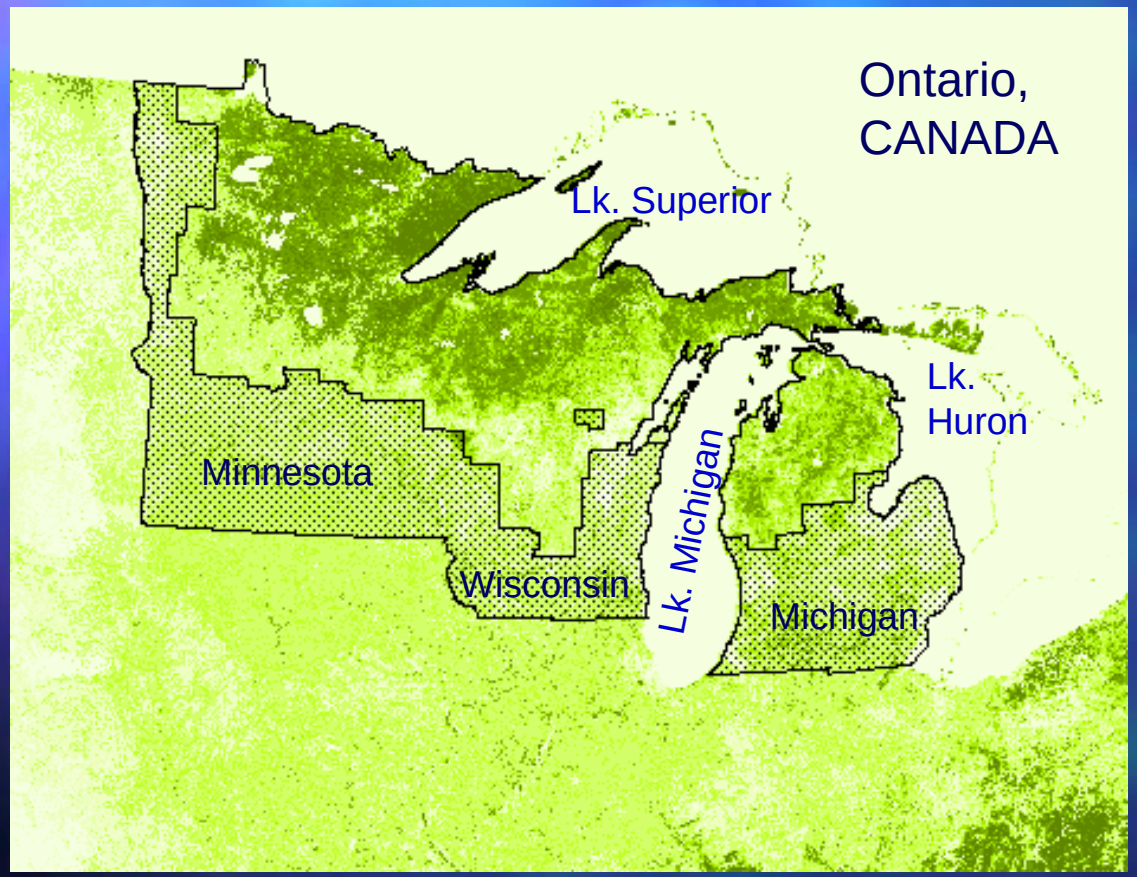
Mt. Pleasant, Iowa, grew 5.2% between 1990 and 1994 to 8,374 people. The southeastern Iowa town is in the middle of a boom in home-building. Main Street landlords are renovating second floors to accommodate the demand for retail space. "Life is a lot more peaceful here and homes are a lot cheaper," says Daniel Peterson, a local merchant and former pilot who once lived in Denver.

Others are finding they can enjoy rural life even while working for a big-city employer, either through telecommuting or long-distance commutes. The demographers found that 90% of the counties with a large portion of commuters are growing.

Jobs also appear to be drawing some city dwellers to the country. According to

Wall Street Journal

Study Area - Upper Midwest, USA



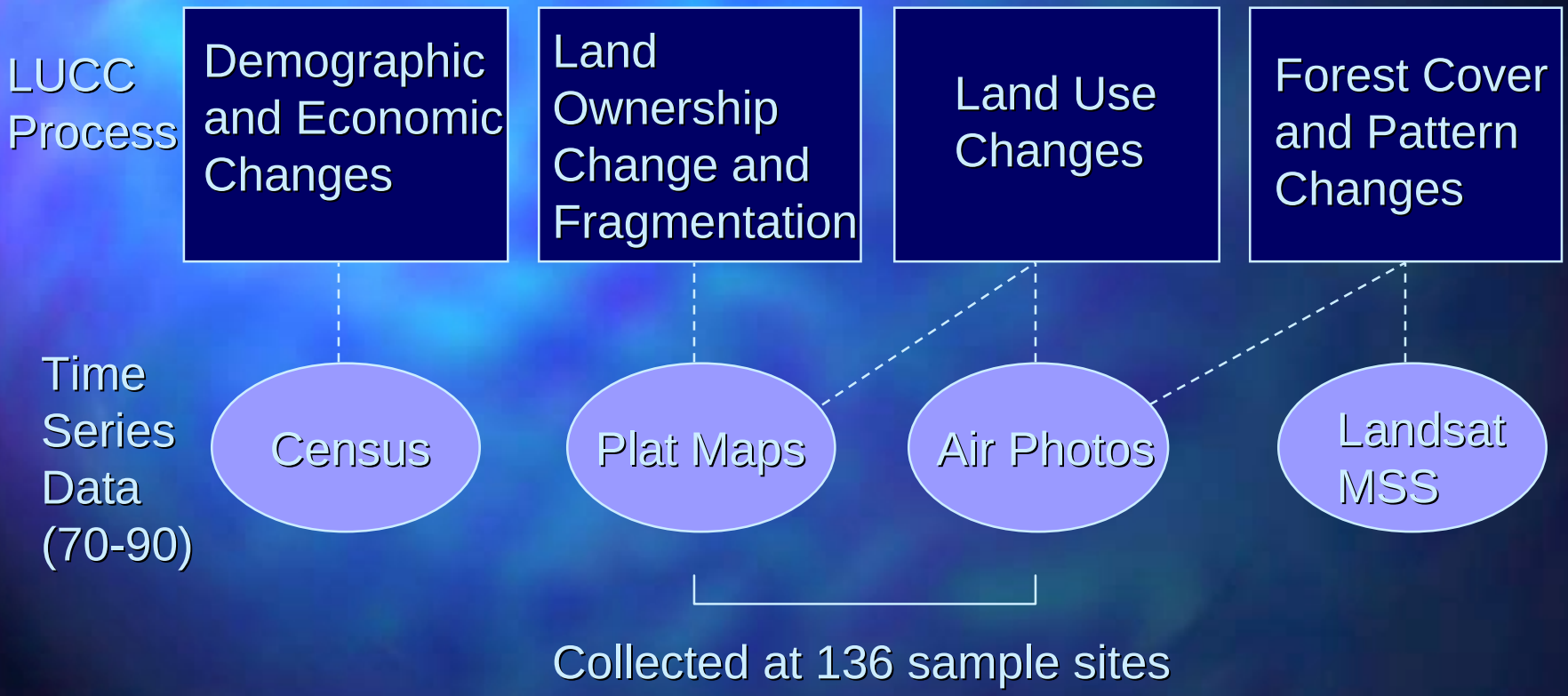
- About 2/3 forested, mostly rural
- Forest cover has been increasing per inventories
- Nearly completely deforested by 1910

Percent forest cover image from AVHRR and USFS FIA data by Zhu and Evans, 1994

Research Questions and Interim Progress

1. What were the types and rates of land cover change and fragmentation over two decades in the study region?
   - Pilot study in three county area of Michigan, methodological progress.
2. What is the sensitivity to the scale/resolution at which those changes are monitored (air photo versus MSS)?
   - Land use from air photos and fores cover from Landsat; thematic detail.
3. How are the changes and fragmentation related to changes in the fragmentation of land ownership?
   - In general, land ownership is fragmenting and forest cover is increasing, and often defragmenting, but the causal relationships require land use information.
4. What quantitative functions describe the effects of socioeconomic processes on observed rates of land cover composition and pattern change?
   - Economic, demographic, environmental, and institutional/policy factors.

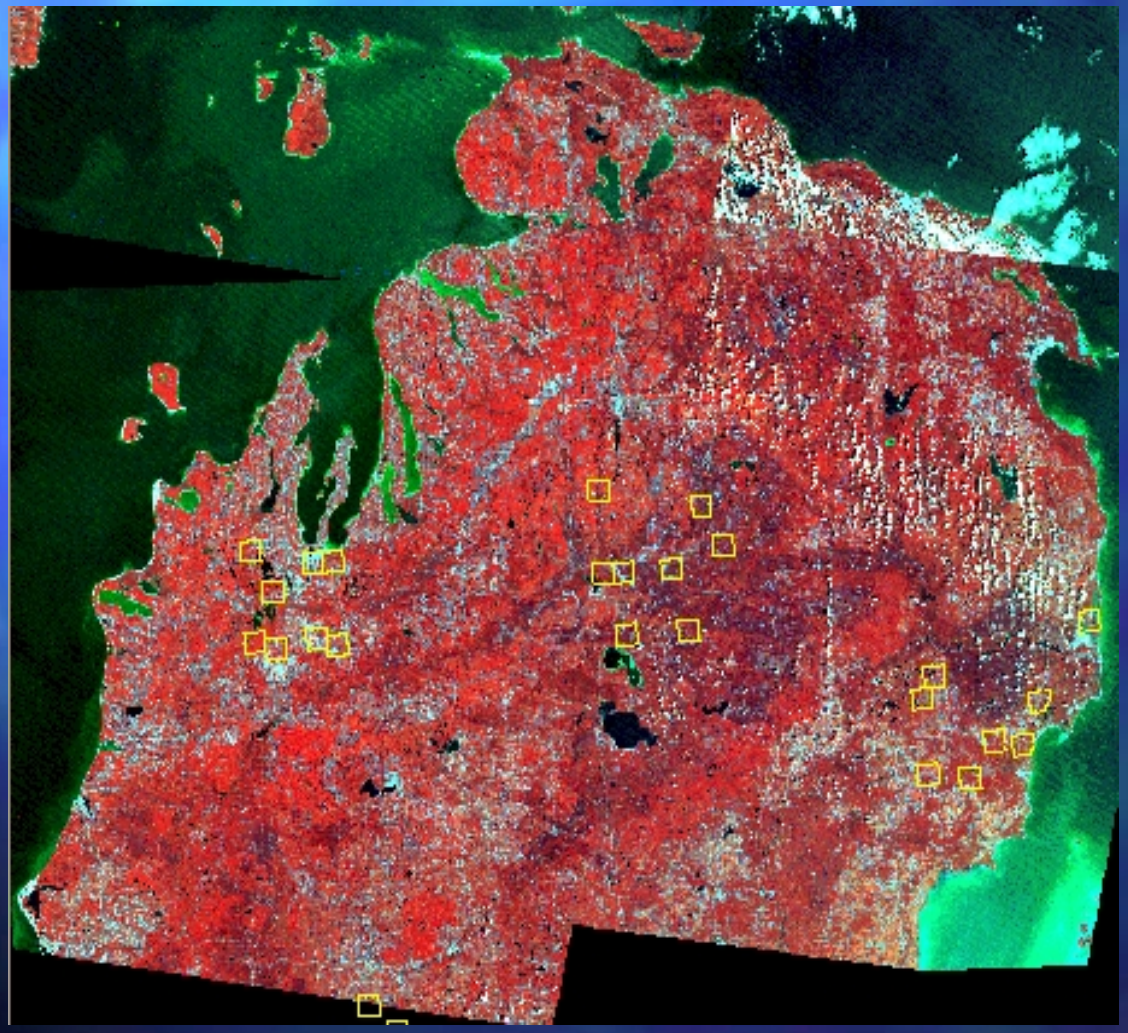
Empirical Observation of LCLUC



Methods to Date

- Forest cover and pattern mapping (NALC)
  - Pre-processing, classification, and accuracy assessment
  - Parcel fragmentation and forest cover change in three Michigan counties (S.A. Drzyzga, Master's Thesis)
  - Error in change analysis based of pattern metrics
- Land use mapping and change analysis
  - Arc/Info based tools for: (1) mapping from air photos & parcels
    (2) quality control (near complete)
- Model development
  - County-level land use estimates
  - ArcView model & GUI with stochasticity and dynamics
  - Link with SNNS for artificial neural network analysis
  - Pilot-testing calibration and validation procedures

Forest Cover Pattern and Change

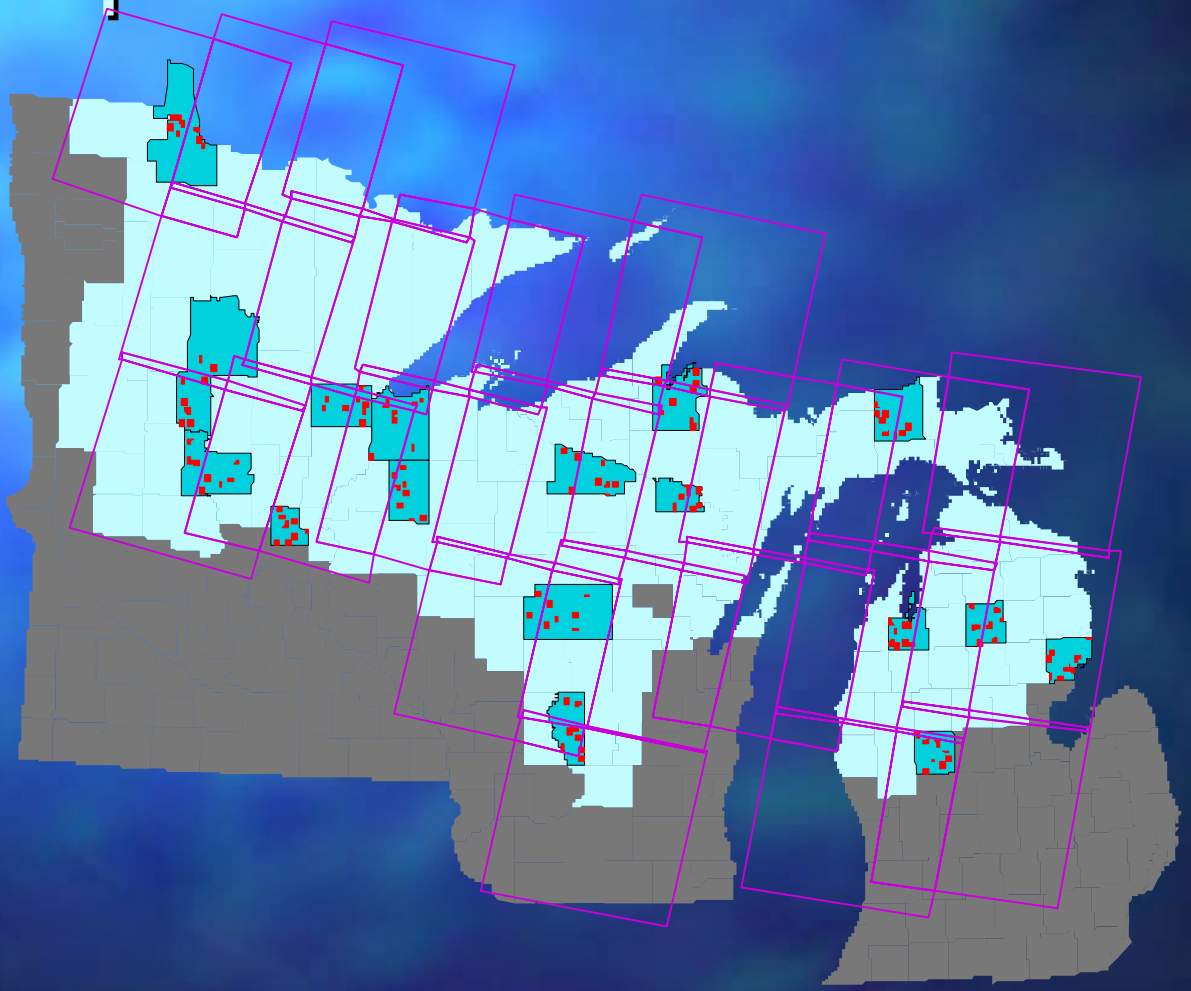


Based on North American Landscape Characterization (NALC) data.

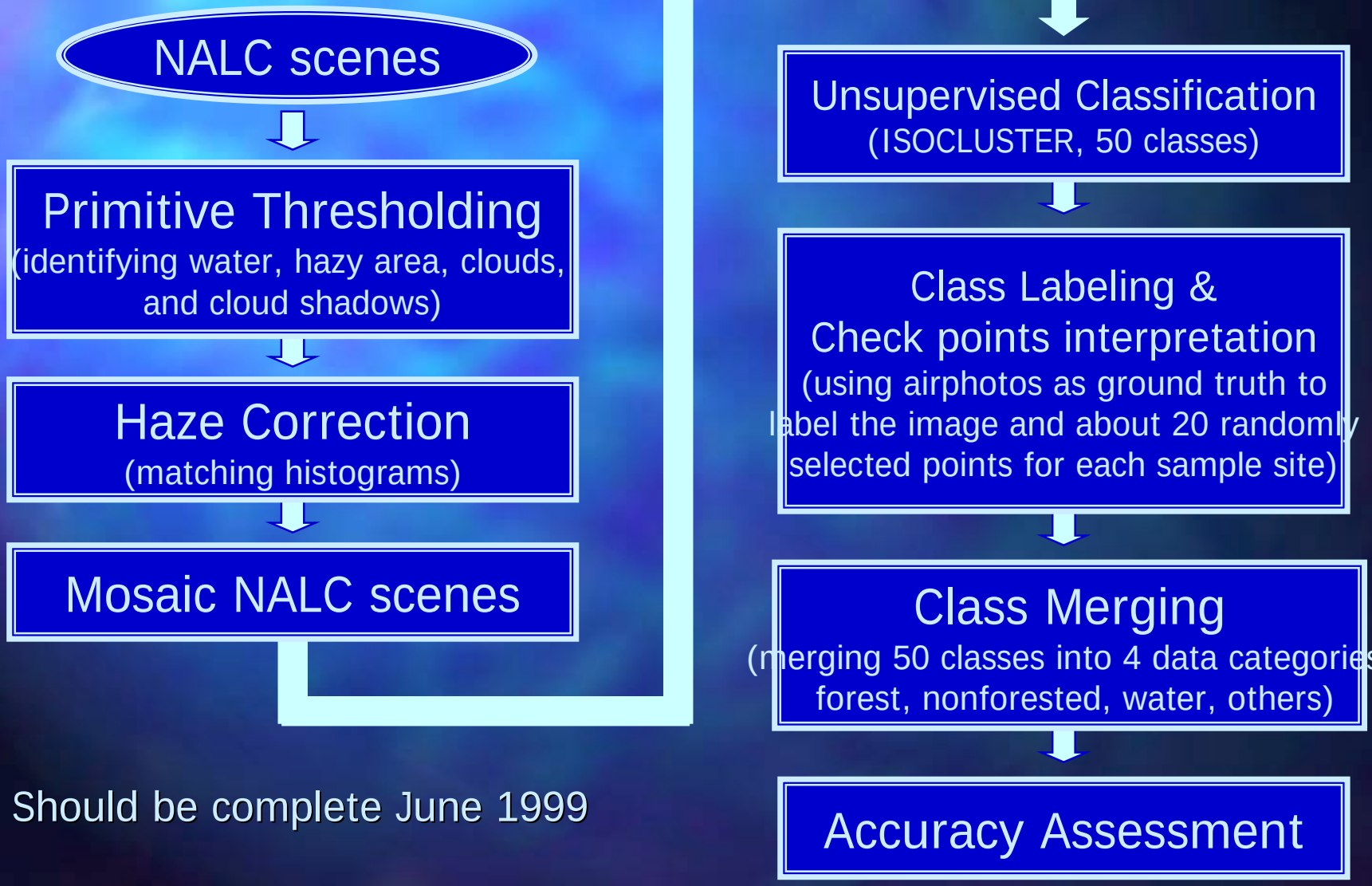
NALC Mosaic of the Northern Lower Peninsula of Michigan

1991

Locations of Landsat Scenes, Sample Counties and Sites

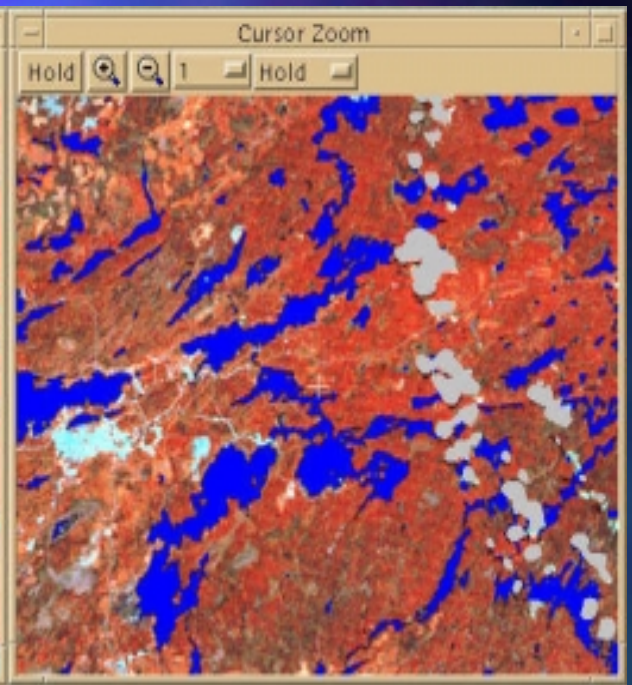


NALC Processing Procedures



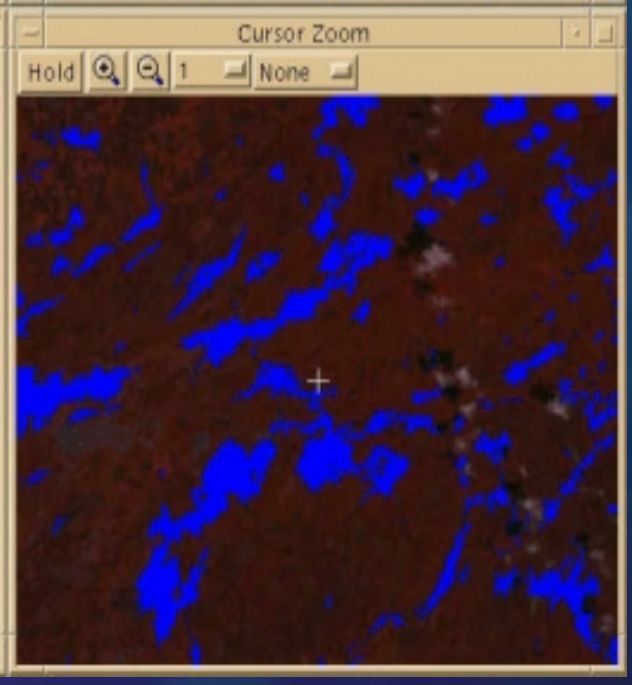
Should be complete June 1999

NALC scene



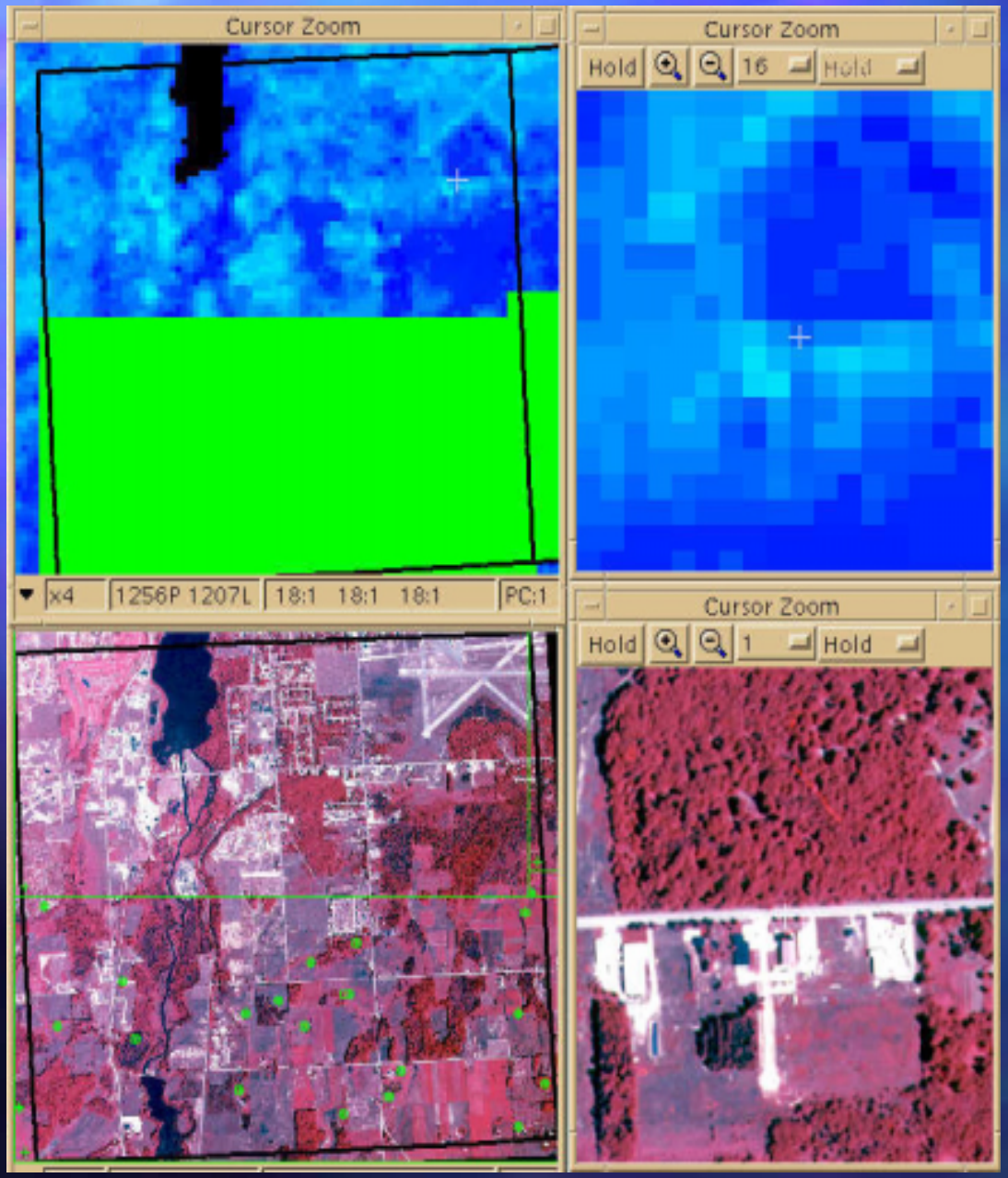
NALC scene with masks

Clouds & shadows mask



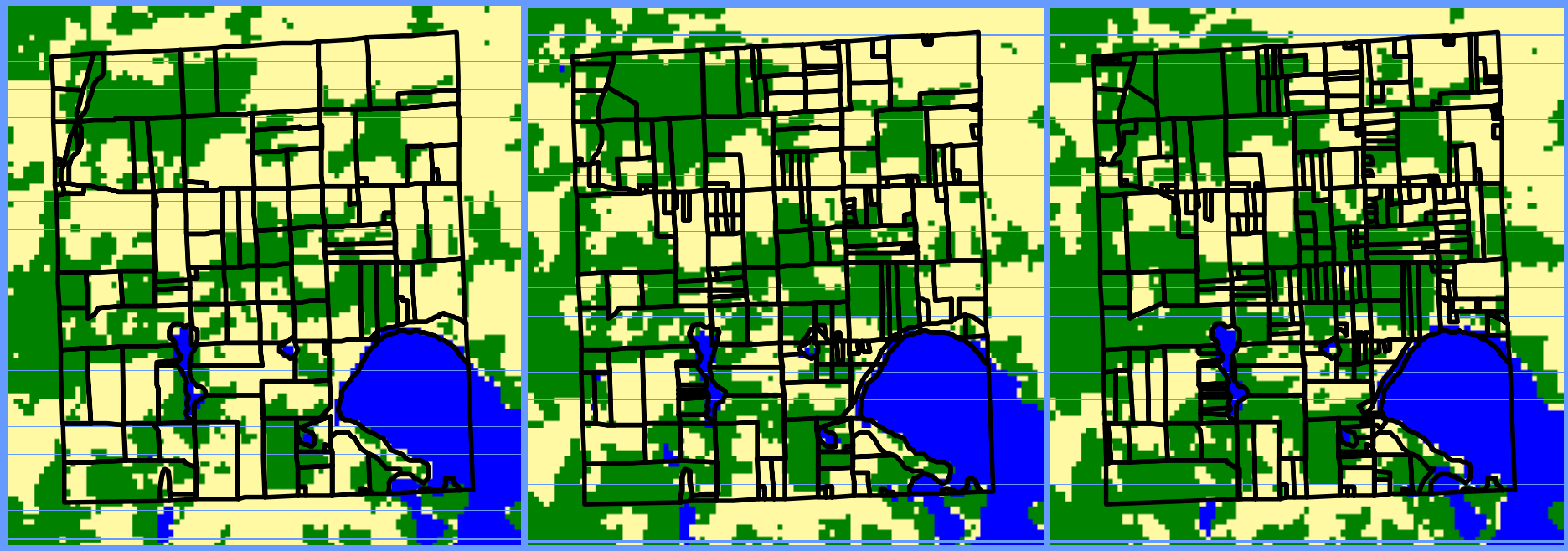
Water mask

Labeling classes by using airphoto as ground truth



Sample points for accuracy assessment (green lines depict the actual pixel size on NALC)

Forest Cover Change



1973 1985 1991

Forest Nonforested Water

Forest Fragmentation Pilot Studies

- Sample area study to quantify errors in measuring forest fragmentation dynamics.
- Small area study to test for meaningful relationships between parcel changes and forest cover change and fragmentation.

NALC Data for Change Analysis

Pre-registered Landsat MSS Scenes

60 m resolution

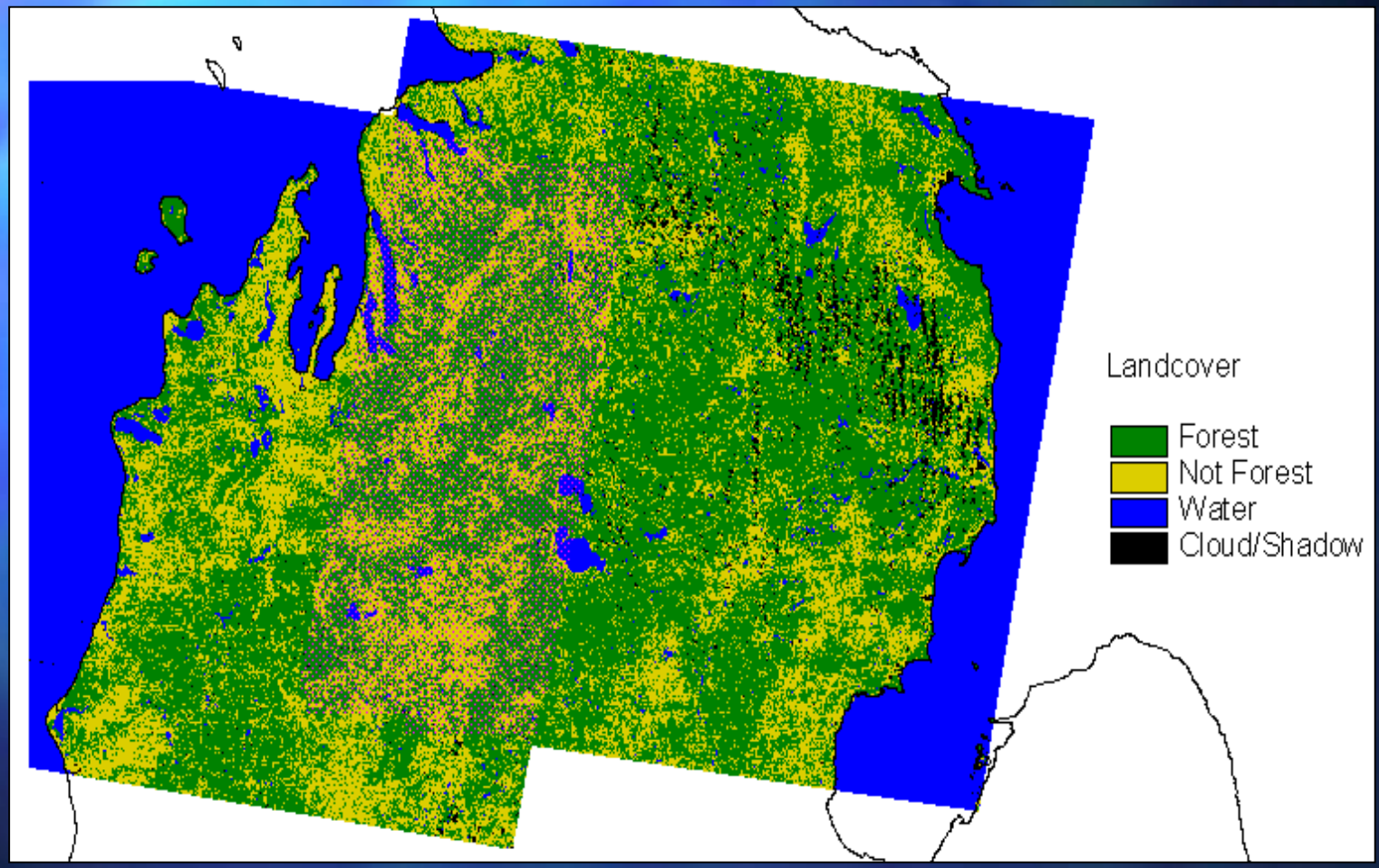
About 25 % overlap between adjacent scenes

1972-1975

1985-1987

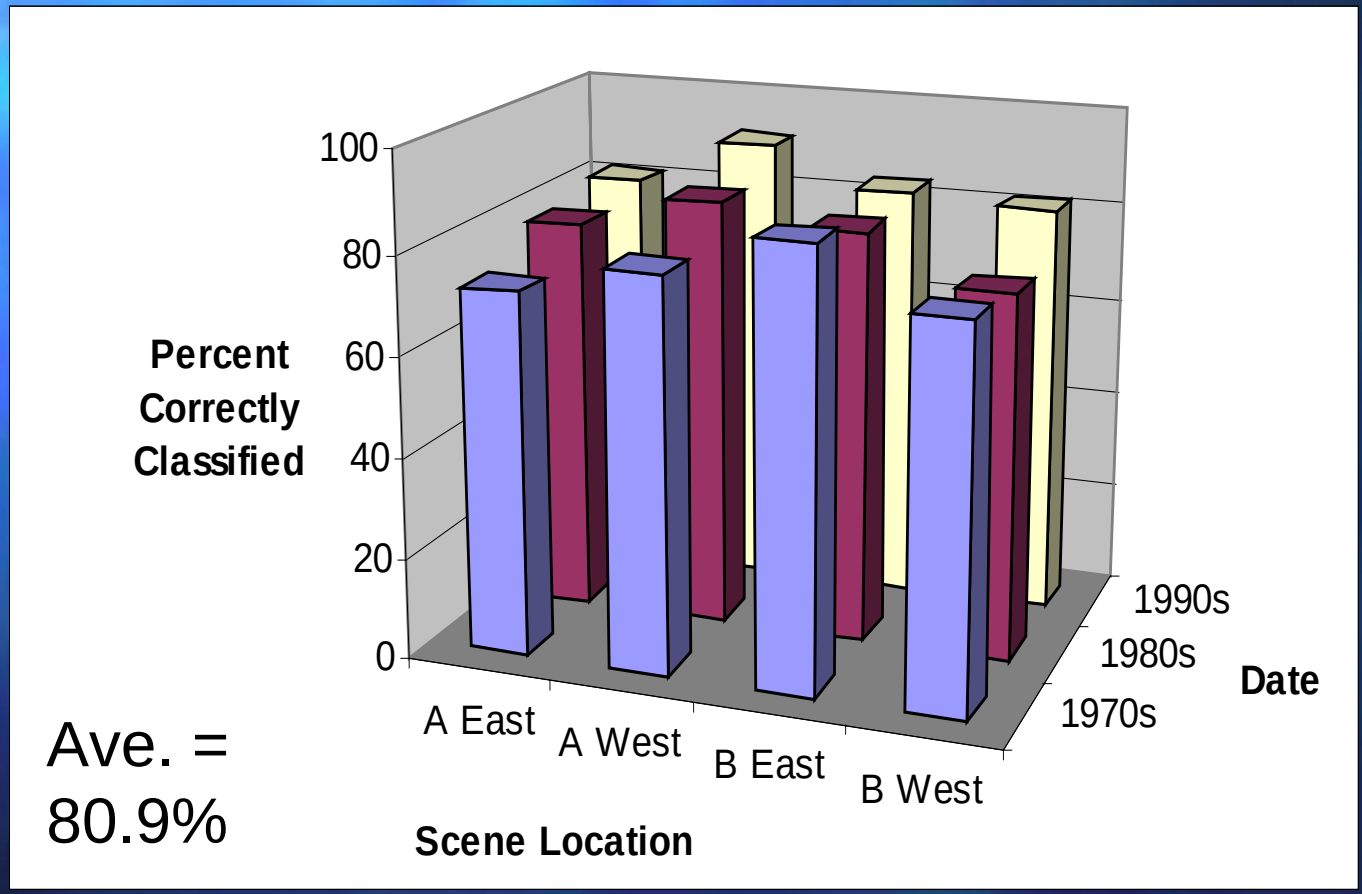
1990-1992

Classified Land Cover: Site A 1990s



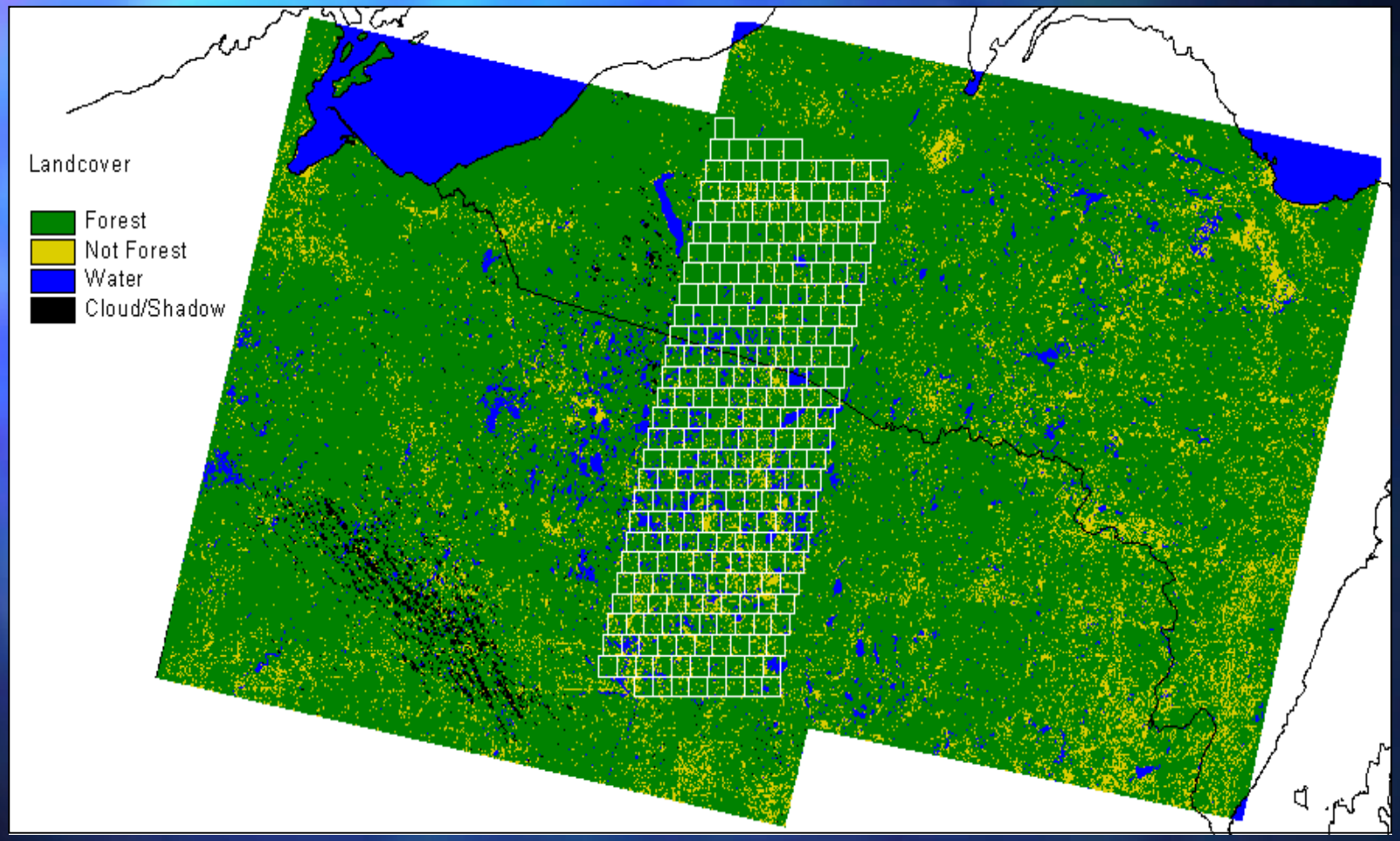
Shading indicates overlap area

Classification Accuracies



Ave. = 80.9%

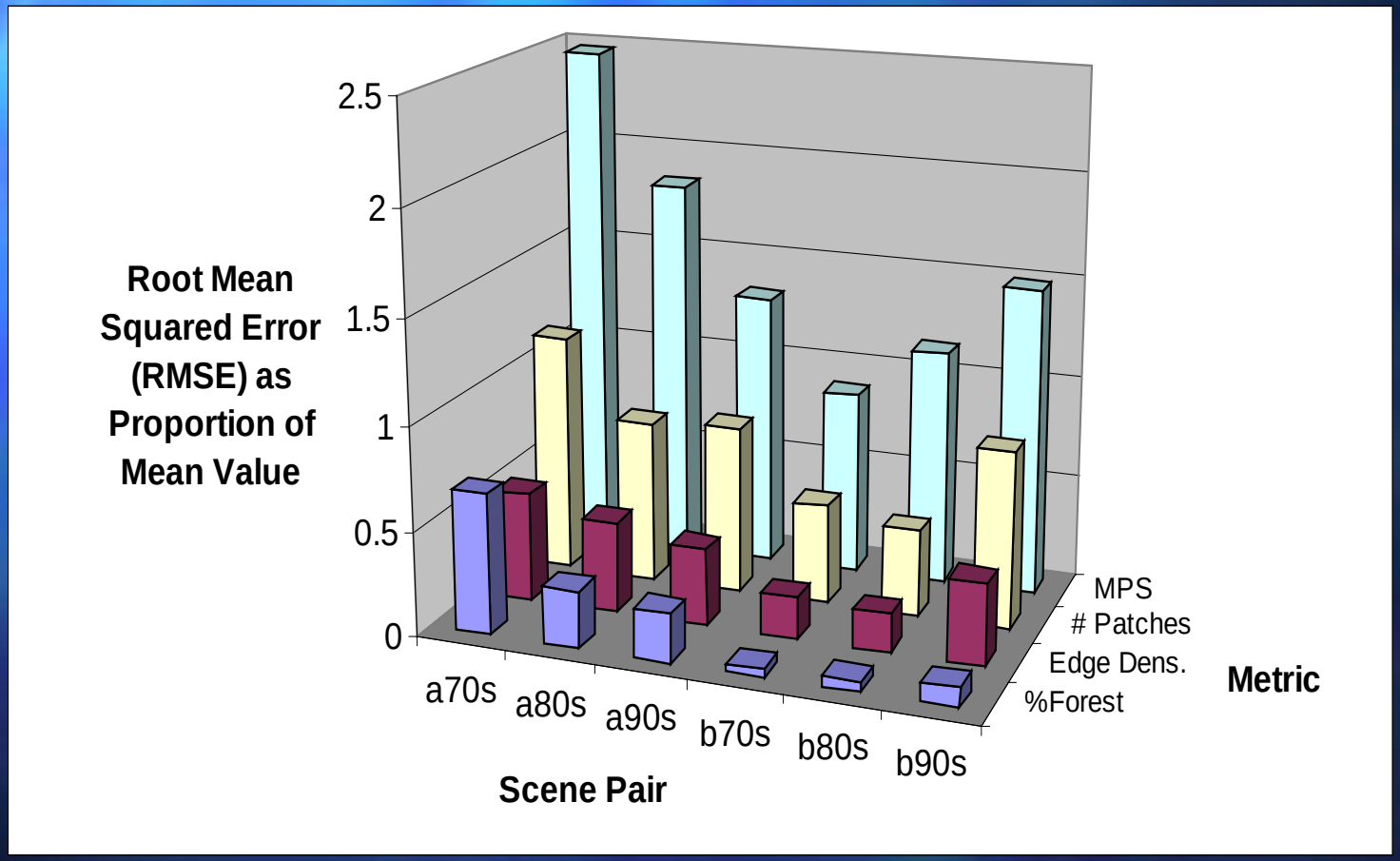
Classified Land Cover: Site B 1990s



Landscape Metrics Assessed

Metric	Abbr.	Definition
percent forest	PF	proportion of the landscape covered by forest
number of patches	NP	number of forest patches
mean patch size	MPS	average size of forest patches
edge density	ED	length of forest/non-forest edge ÷ landscape area

Summary of Errors in Image Pairs



Model of Error in Metric Differences

Hypotheses

Errors are larger where:

- forest is near parity with non-forest
- haze is more prevalent
- image pair is taken under divergent phenological conditions

Variables

- 2nd-order polynomial of ave. percent forest
- % of site with haze
- diff. in image avg. NDVI or difference in Julian date

Predicting Error in Percent Forest

Error in Percent Forest =

$-7.93 + 0.45\,(PF) - 0.005\,(PF^2) + 0.12\,(haze) + 1.99\,(diff\ NDVI)$

- F-test = 423.84 ($p > 0.99$); Adj. R^2 = 0.50

With difference in Julian Date instead of diff NDVI

$-4.87 + 0.37\,(PF) - 0.004\,(PF^2) + 0.06\,(haze) + 0.31\,(diff\ Days)$

- F-test = 284.02 ($p > 0.99$); Adj. R^2 = 0.40

all variables are significant at $p > 0.99$

Predicting Error in # of Patches

Error in Number of Patches =

$-27.00 + 2.03\,(PF) - 0.02\,(PF^2) + 0.42\,(haze) + 7.56\,(diff\ NDVI)$

- F-test = 453.23 ($p > 0.99$); Adj. R^2 = 0.51

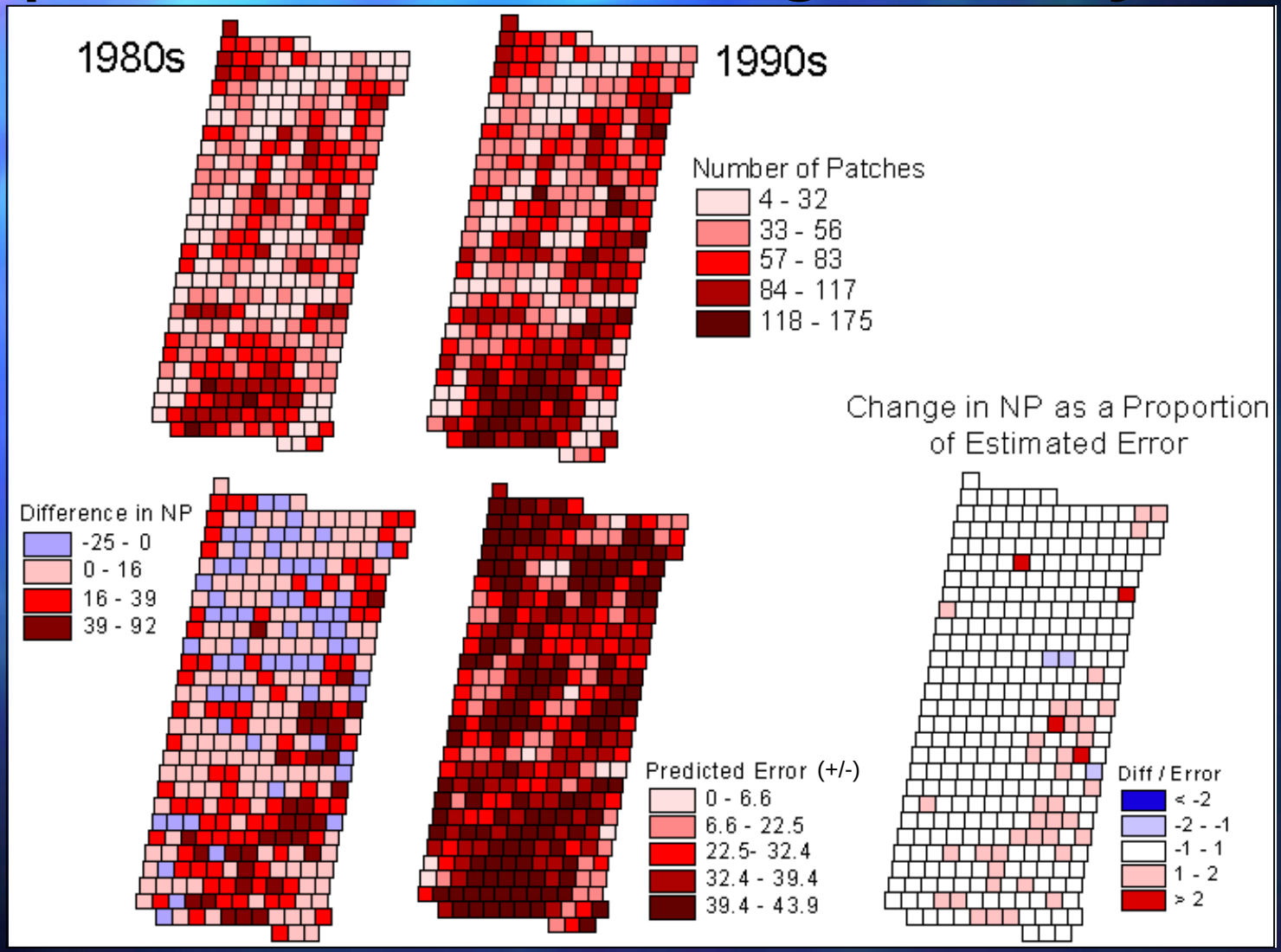
With difference in Julian Date instead of diff NDVI

$-9.85 + 1.71\,(PF) - 0.02\,(PF^2) + 2.00\,(haze) + 1.01\,(diff\ Days)$

- F-test = 307.81 ($p > 0.99$); Adj. R2 = 0.42

all variables are significant at $p > 0.99$

Application to Change Analysis



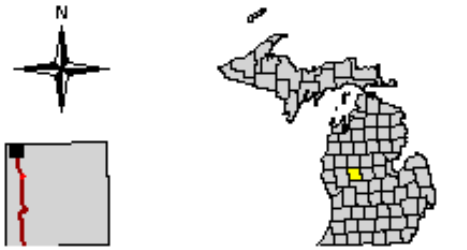
Conclusions from Pilot Study I

- Landscape metrics calculated from satellite images are subject to measurement error.
- Increasing size of landscape partitions decreases error, but map generalization through sieving or filtering has inconsistent effect on error.
- Error at a location for some metrics can be estimated using percent forest, haze, and difference in phenological condition.

Land Parcel Changes

Ownership Characteristics

Mecosta County, MI



Site Locator County Locator

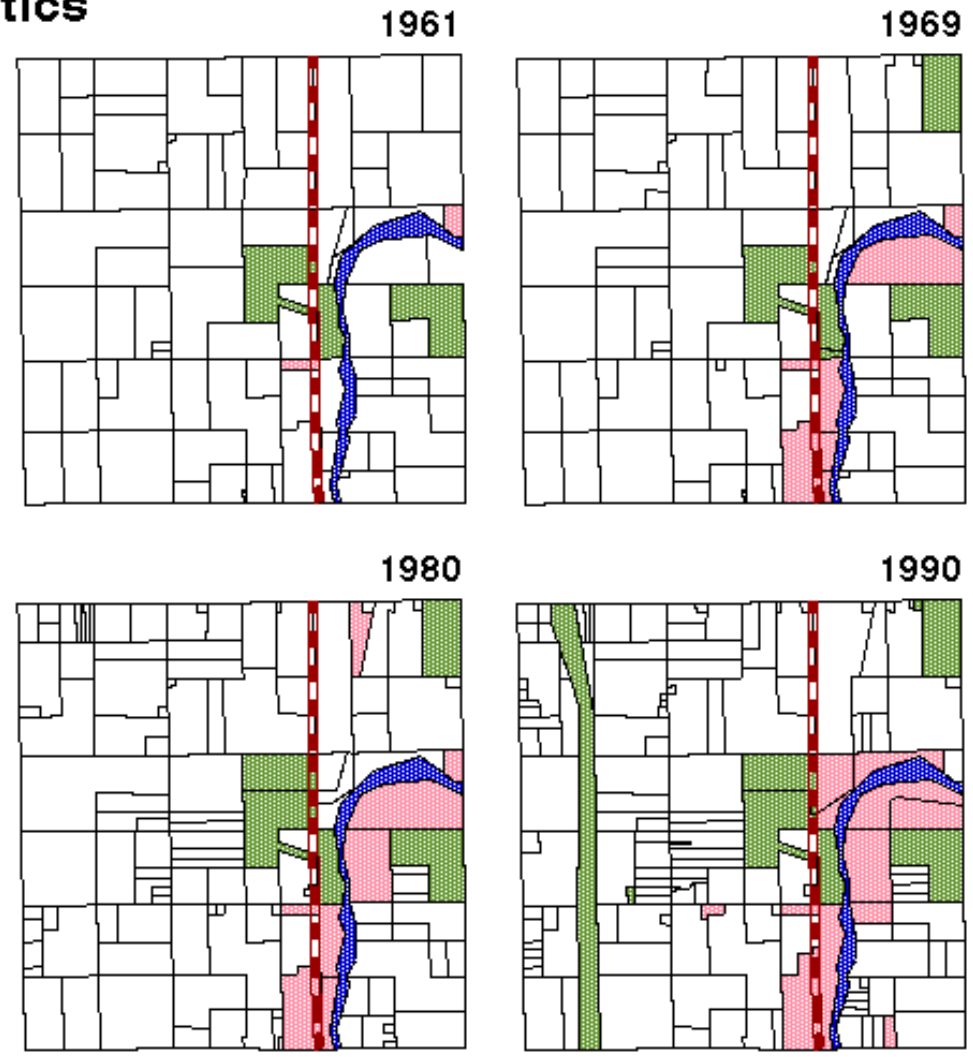
Legend

- Water Features
- Public Lands
- Small Parcels
- Parcel Boundaries
- Major Highway

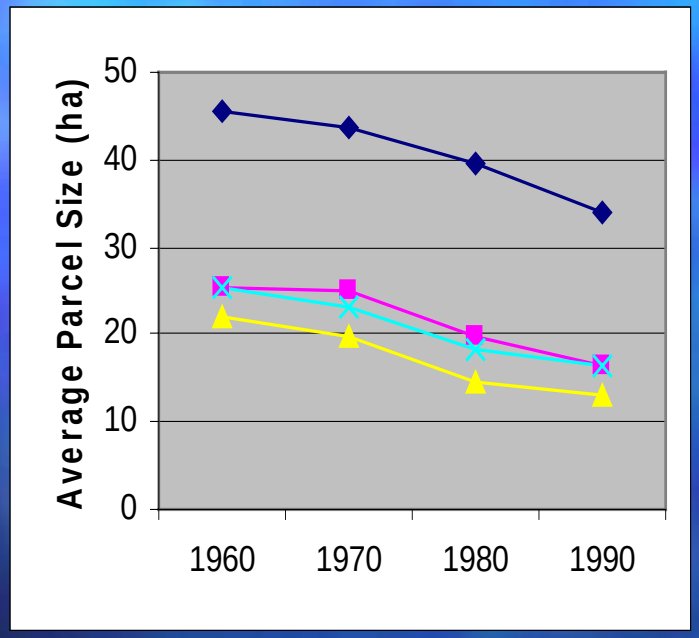
Land Ownership:
Rockford Maps Publishing

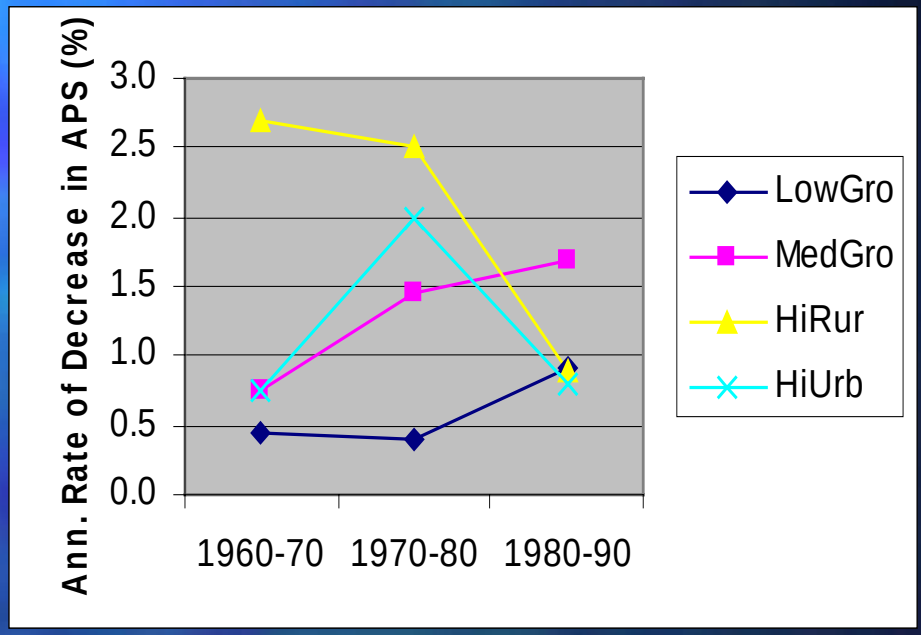
Natural Features:
USGS 1:100000 Topographic Maps

Compilation: Scott A. Drzyzga



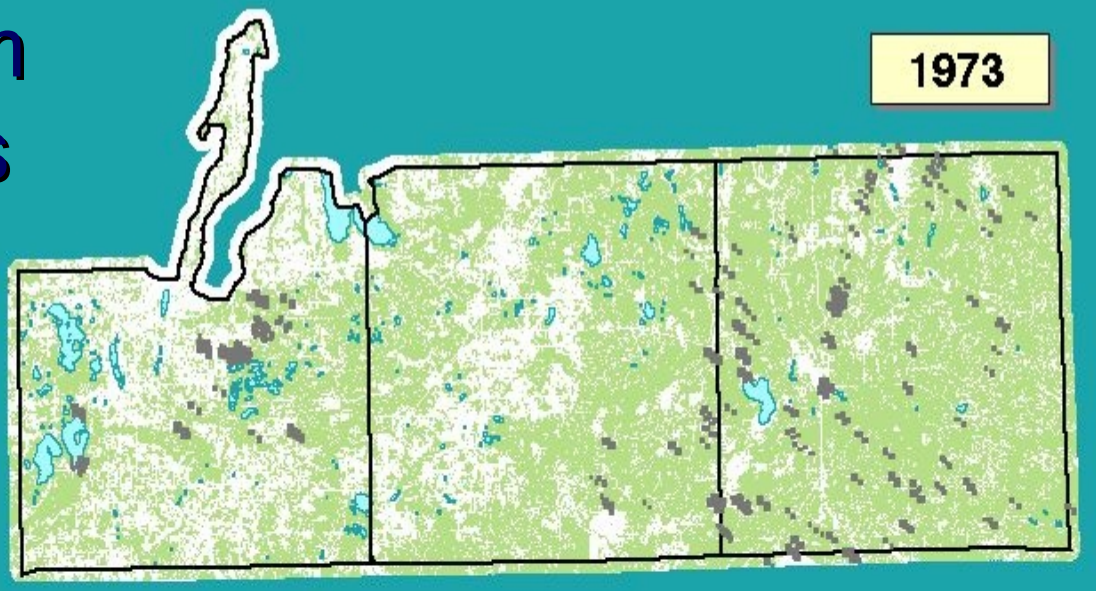
Parcel Size Average and Change by County Type

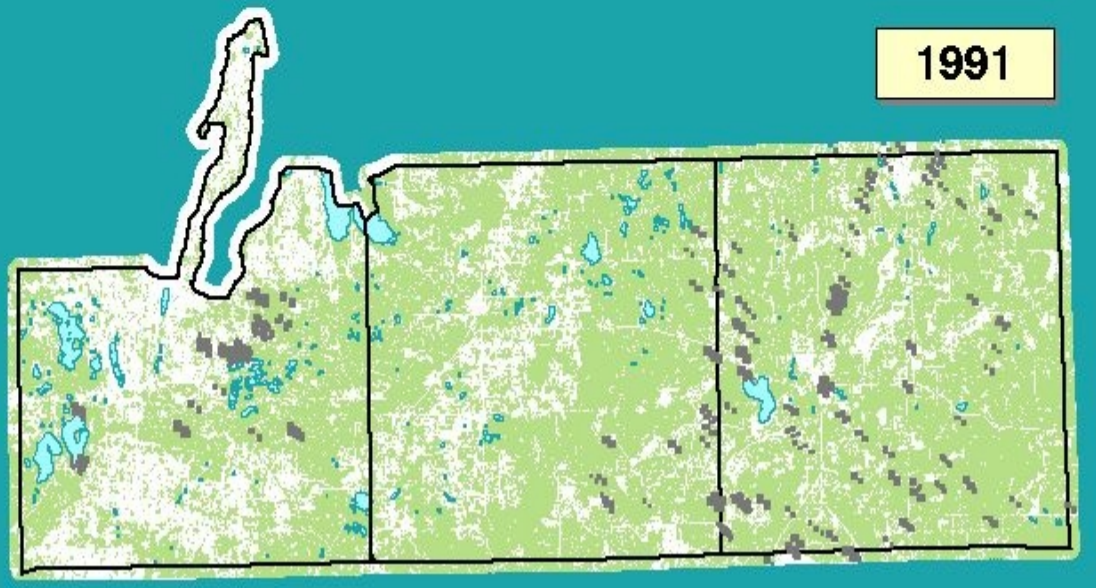




Forest Cover from NALC Composites

Pilot study area used for a student thesis. Forest fragmentation was compared with ownership parcelization at county, township (MCDs), and survey section scales.





Conclusions from Pilot Study II

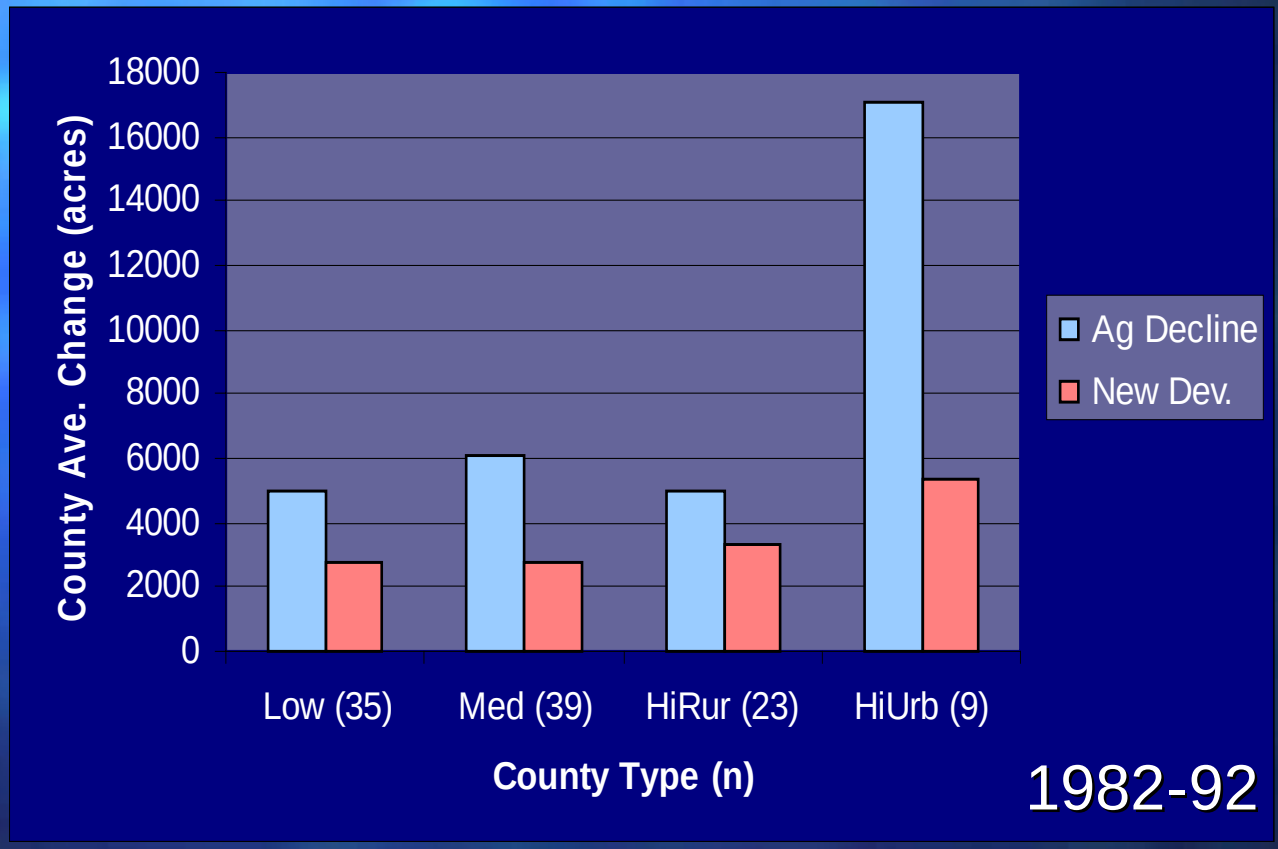
- Forest cover increased from 1973-91 and became less fragmented.
- Kalkaska County, with high population growth rate (156% over period) but low initial population (5272), experienced greatest forest regrowth (22.4%) and defragmentation (24%).
- Spatial patterns tend to be at scale of MCDs.
- Although consumption theory of land rent explains a good deal of variation in parcel sizes, relationship with forest cover is inconclusive.

Hypothesized Land Use Drivers

- Development of agricultural lands
  - Ag to developed, with some forest recovery
- Development of undeveloped lands
  - undeveloped (including forest) to developed
- Agricultural abandonment
  - Ag to undeveloped, usually with regrowth
- Recreation and tourism based development
  - any conversion to recreation-based use (includes seasonal homes)

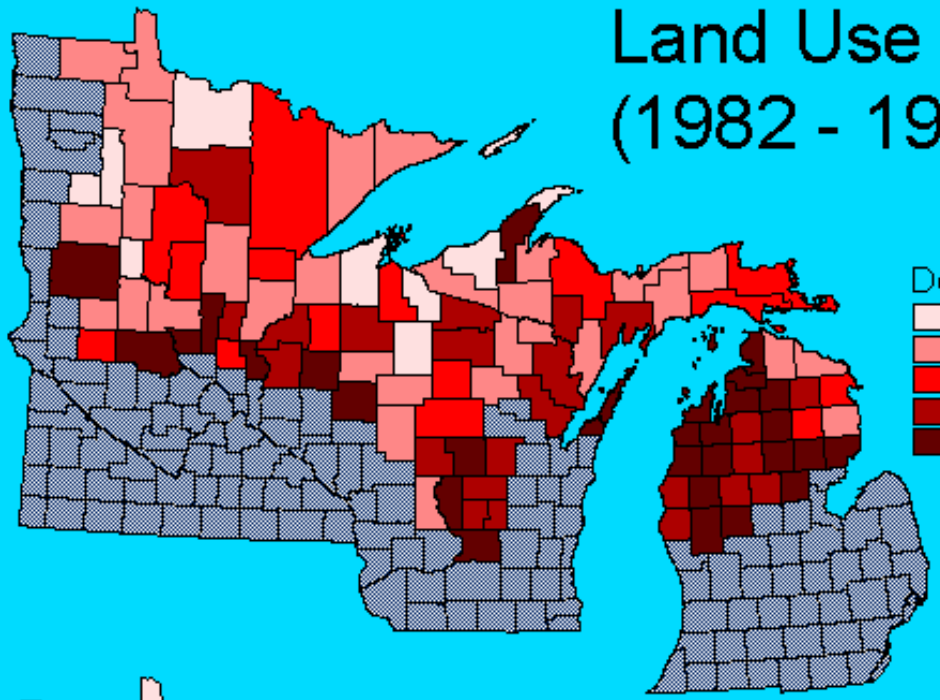
South Park Homes

Land Use Drivers in the Region

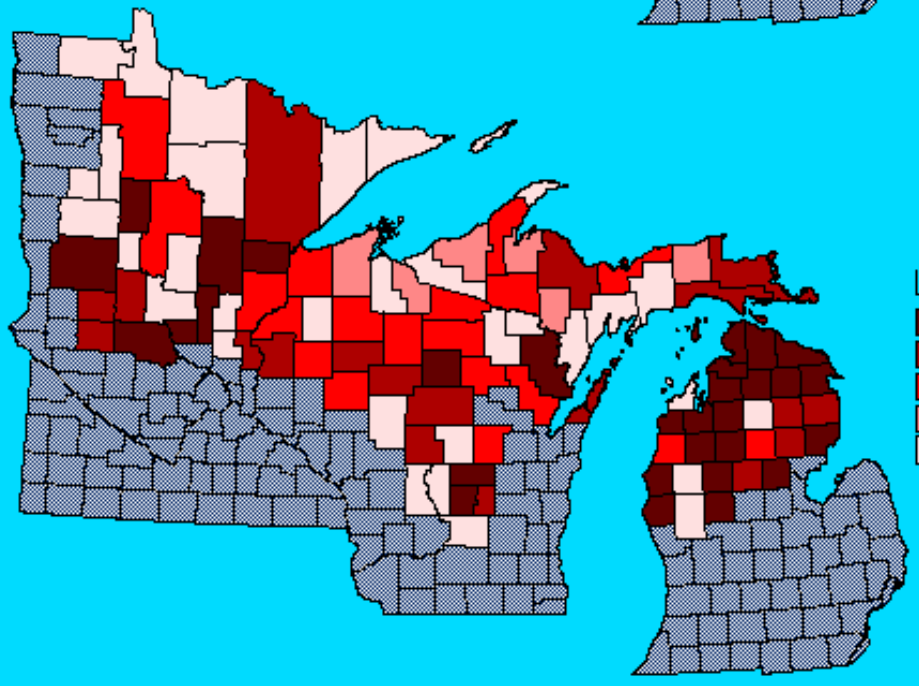


Source: Natural Resources Inventory (NRI), NRCS

Land Use Change (1982 - 1992; NRI)



Development (%)
- -0.15 - 0
- 0 - 0.31
- 0.31 - 0.42
- 0.42 - 0.82
- 0.82 - 3.24



Loss of Agricultural Land (%)
- -11.28 - -1.56
- -1.56 - -0.87
- -0.87 - -0.04
- -0.04 - 0
- 0 - 3.59

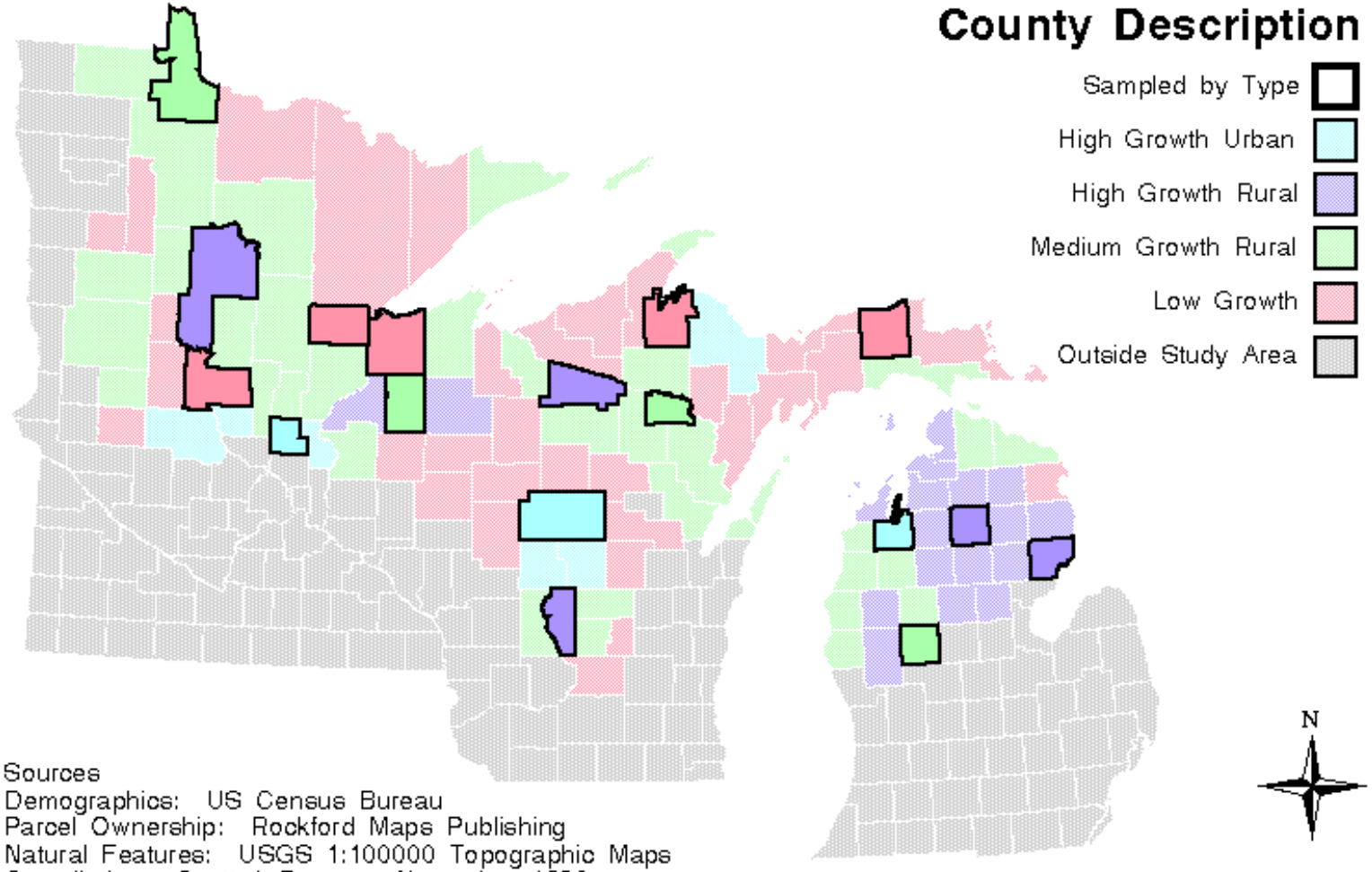
Air Photo Archive & Parcel Data

- 136 sample sites (~2500 ha) three epochs each (early 1970s, early 1980s, early 1990s)
- >1,200 archival photos scanned, rectified, mosaiced (2 m resolution)

- >10,000 polygons per epoch georeferenced & digitized from plat books.

Demographic / Economic County Types

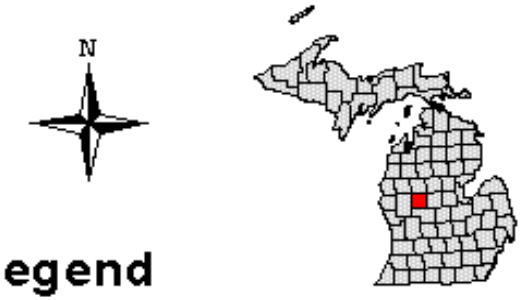
Area Frame Sampling

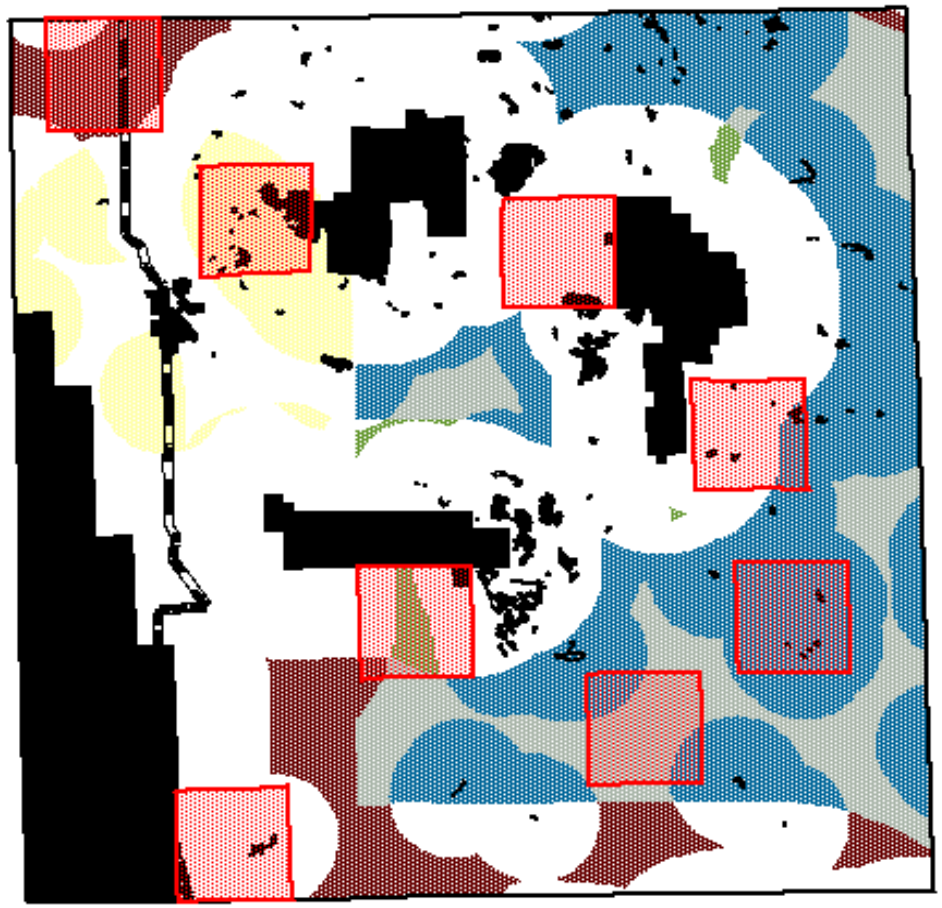


Sources
Demographics: US Census Bureau
Parcel Ownership: Rockford Maps Publishing
Natural Features: USGS 1:100000 Topographic Maps
Compilation: Scott A Drzyzga, November 1996

Stratified Sample Site Selection

Mecosta County Buffered Features





Legend

- Sample sites
- Buffered Features
- Under all influence
- Road-only influence
- Public land-only influence
- Hydro-only influence
- Under no influence
- Under multiple influence

Source: USGS 1:100000 Topographic Quad Maps

Compilation: Scott A Drzyzga 11/10/96

Land Use Classification

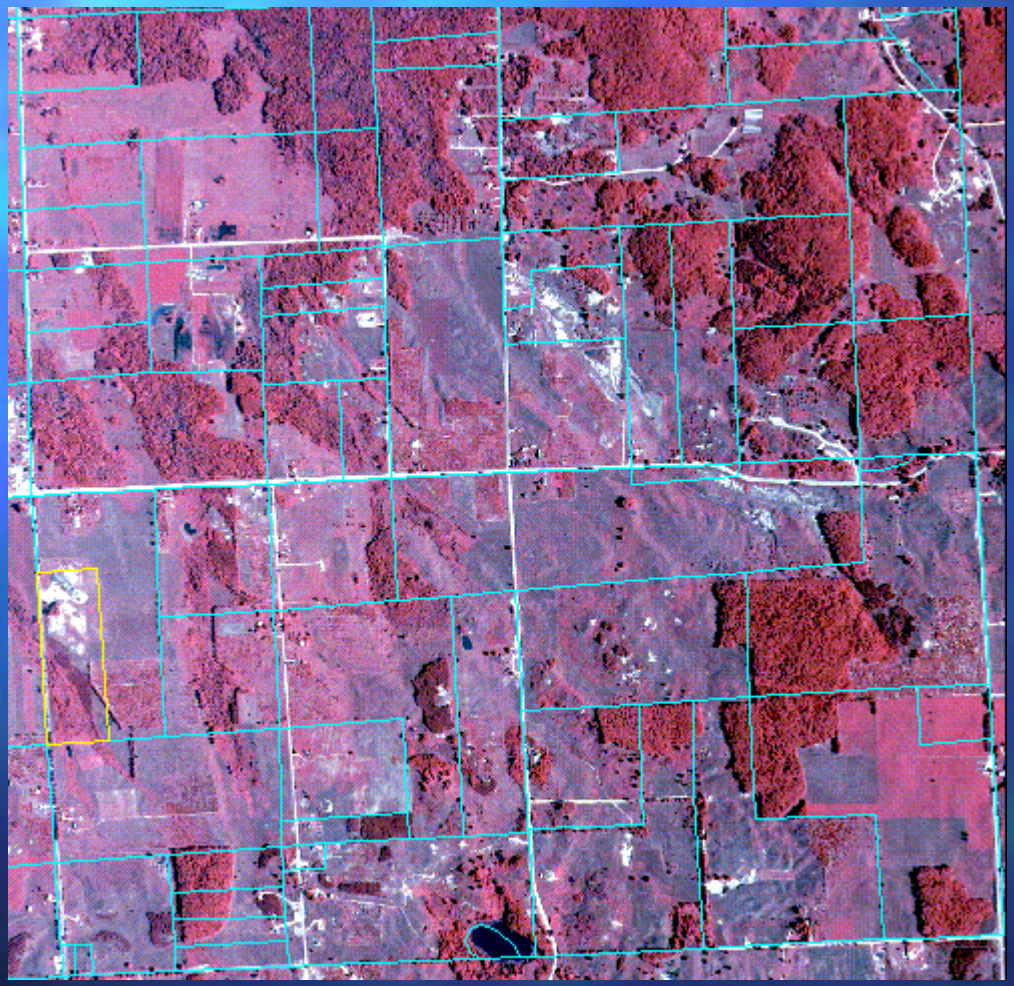
Students trained to identify classes using rules based on

- photo interpretation
- parcel size

Code	Land Use Type
100	**Developed**
110	Residential
111	High density Residential
112	Low density Residential
120	Retail/Office
130	Industrial/Warehouse
140	Infrastructure/Transportation
141	Airport
142	Transport Corridor or Terminal
143	Utility corridor or station
144	Institutional
150	Site-based outdoor recreation
151	Campground
152	Golf course
153	Ski area
154	Marina
155	Park and outdoor assembly
160	Mining/extractive
170	Other developed

200	**Agriculture**
210	Row crop
220	Non-row crop
230	Pasture/grazing
240	Other agriculture
300	**Undeveloped**
310	Open/grass
320	Old field/young forest
330	Mature Forest
340	Tree Plantation
350	Open Water
360	Wetland
370	Riparian Zone / Forested Wetland
380	Other Undeveloped

Land Use Patterns and Change

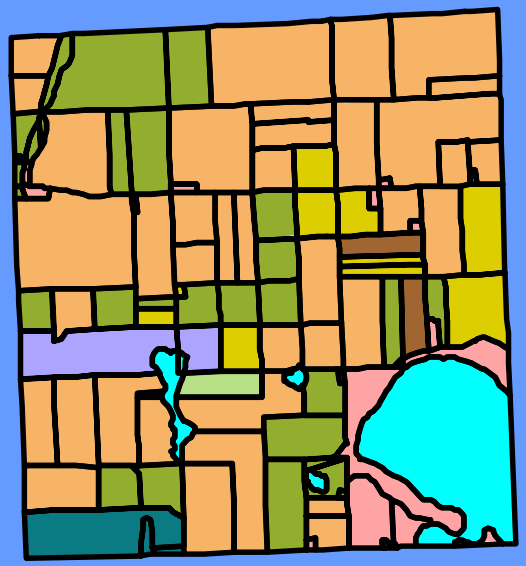


Digitized parcel map and aerial photography

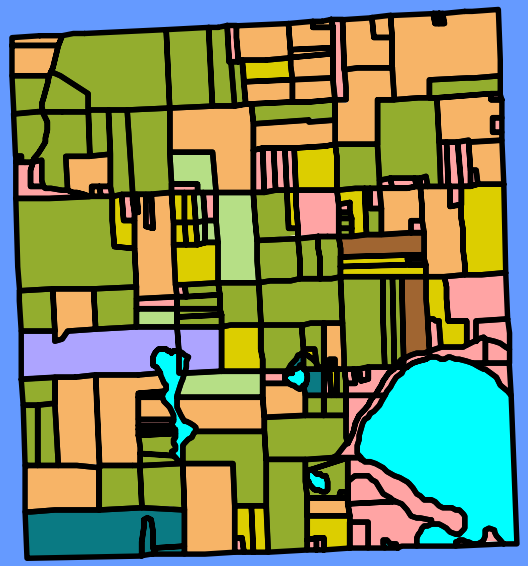
Interactive Land Use Classification System

CONSOLE
ARCEDIT
Pan/Zoom
x,y: 394443.67186,243641.65802
dx,dy: 2805.43379,-649.29262
dist: 2879.59019
1970
1980
1990
Transition
Three Classe
Oscillation
Missing Data
CLASSIFICATION
COVERAGE PUBLIC CONFIDENCE SECONDARY PRIMARY
COUNTY mecosta
EDIT COV 1990
1970 1980 1990
Area (ha) 24 15 14
Area (ac) 60 36 35
Primary LD Residential Pasture Row Crop
Percent PRI 40 70 40
Ownership Private Private Private
Confidence Above Avg High High
Secondary Retail/Office LD Residential LD Residential
Percent SEC 10 10 10
Public
Editphoto DATE 6/10/72 May-81 Jun-92
Editphoto TYPE B&W BCIR COLOR
REFRESH SCREEN
SAVE CHANGES
Edit PARCELS 1970 1980 1990
1970 Landuse LD Residential
1980 Landuse Pasture
1990 Landuse Row Crop
Site 1 2 3 4 5 6 7 8 CO
Show SHOW FLAGS SHOW PARCELS
Error Type Transition
Select Parcel * SELECT PARCEL *
LPQC - Quality Control
IMAGE_1970
Pan/Zoom
IMAGE_1980
Pan/Zoom
PARCELS_1990
Pan/Zoom
1970
1980
1990
Transition
Three Classes
Oscillation
Missing Data

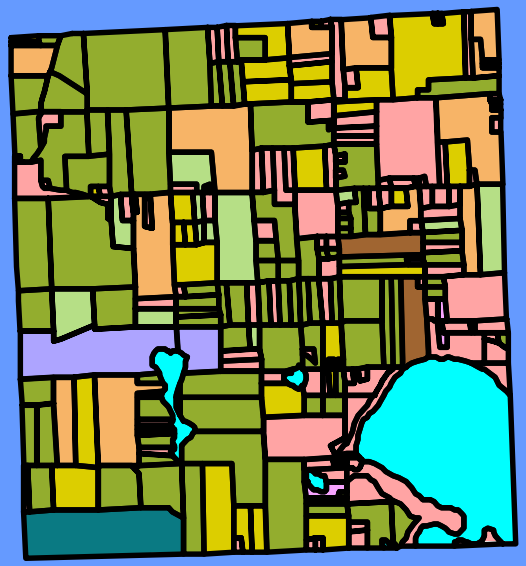
Interpreted Land Use



1973



1985

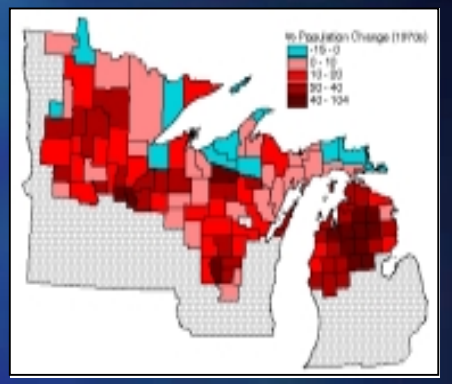


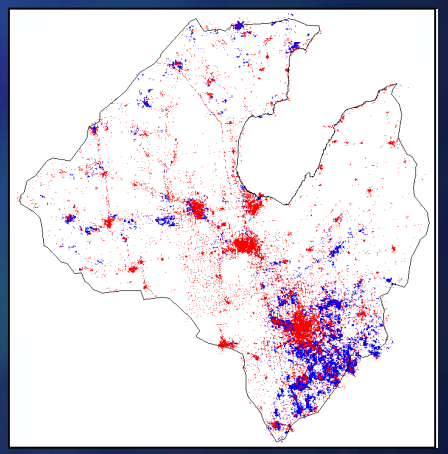
1991

- Unclassified
- Residential
- Commercial
- Trans/Utility
- Recreational
- Mining/Extract
- Other/Cemetery
- Agriculture
- Open/Grass
- Old Field/Yng Forest
- Forest
- Open Water
- Wetland
- Other Undev

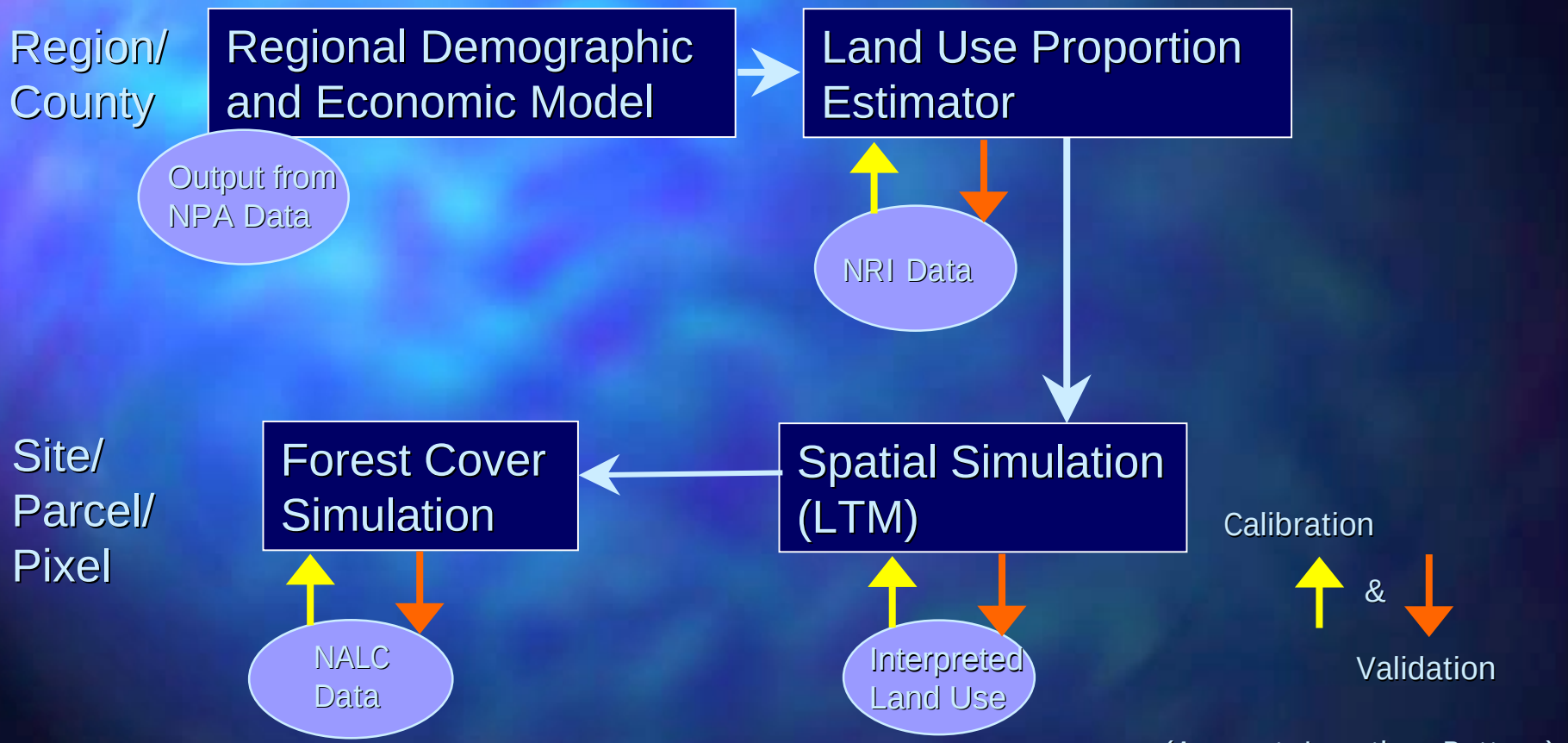
Approach to LCLUC Modeling

- Regional economic & demographic model produces county-level estimates.
  - statistically calibrated to project change in land use proportions using NRI data.
- GIS-based Land Transformation Model (LTM) used to spatially disaggregate and map LU changes.
- Probabilistic link between LU and forest cover change.





Modeling of LCLUC



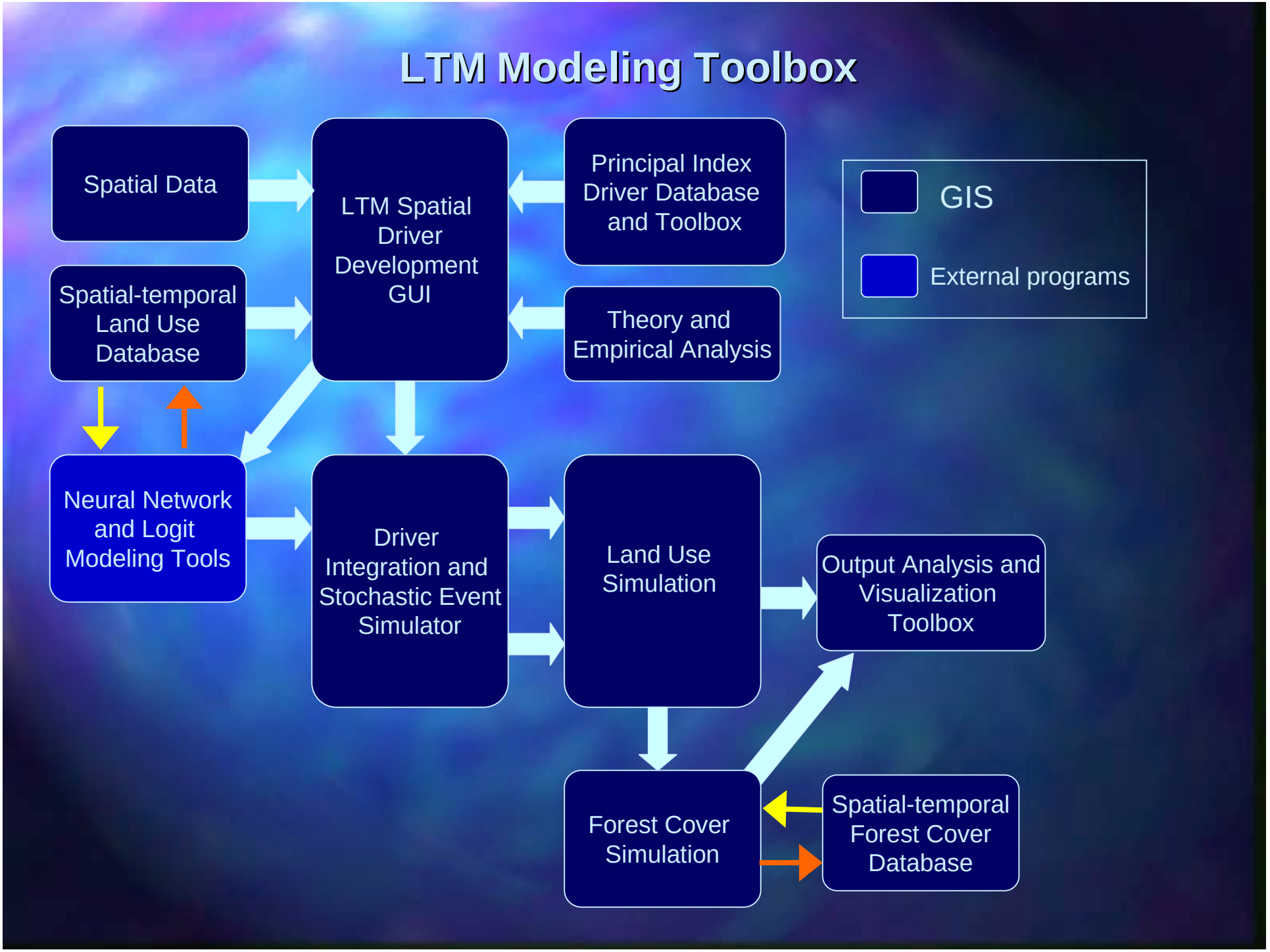
Land Use Proportion Estimates

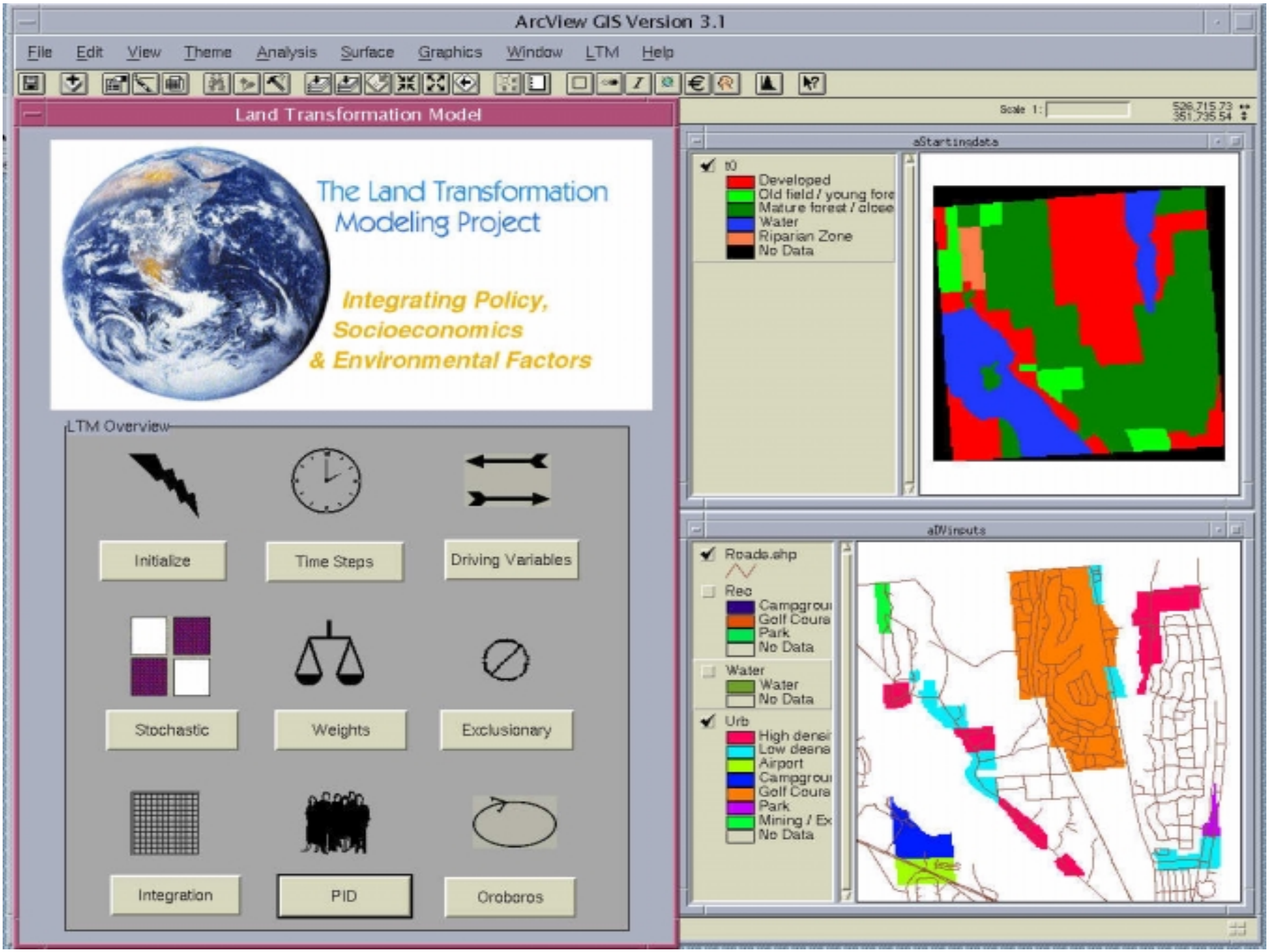
Change in land use proportion = f(

- change in population and number of households
- initial populations and numbers of households
- initial land use proportions
- change in employment and income by 1-digit SIC code
- average climate and soils
- change in population age structure
- state-level policy differences)

To be estimated using NRI data (1982, 1987, 1992) and socioeconomic data from NPA Data Associates (1967-2030).

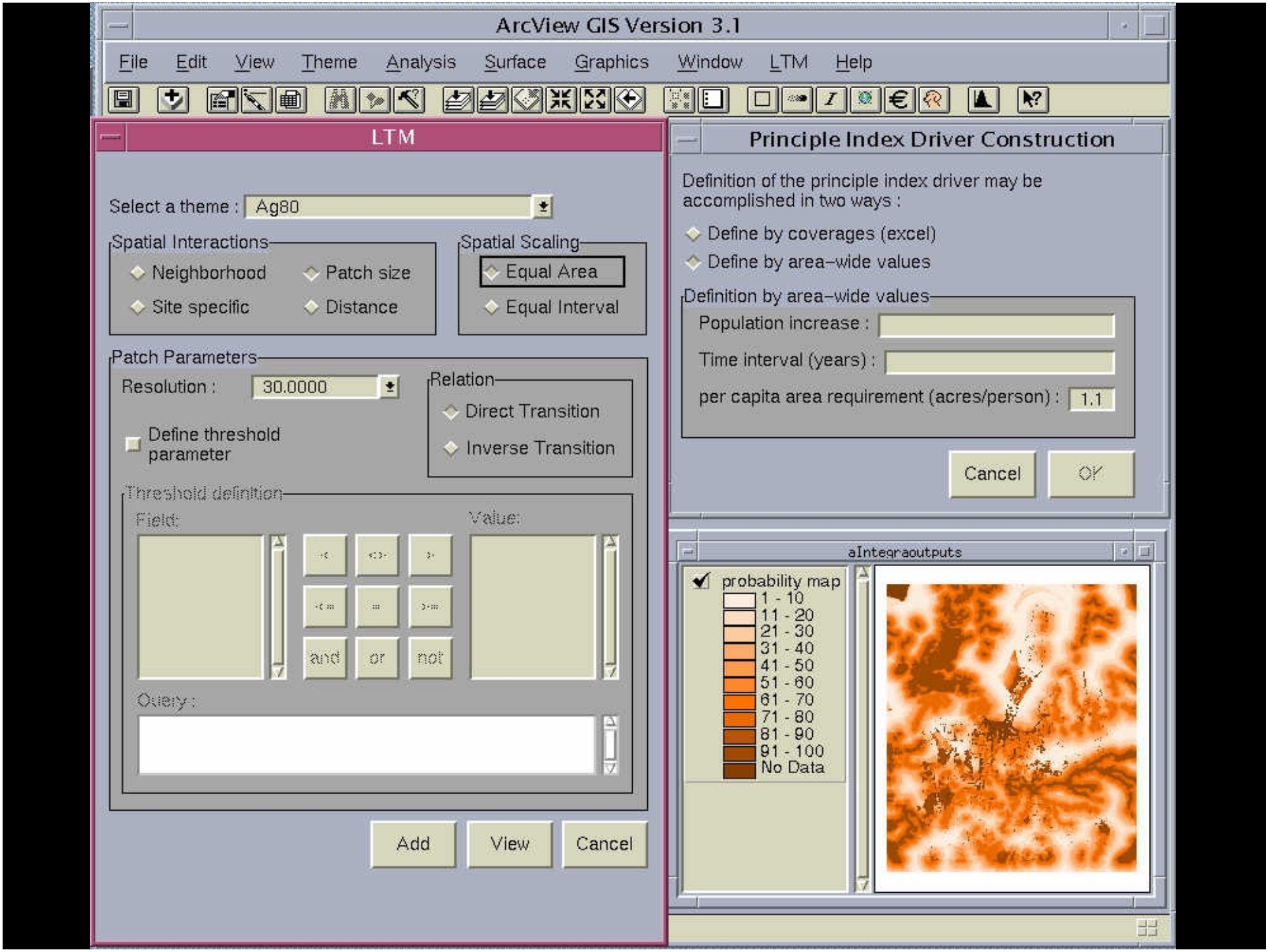
LTM Modeling Toolbox




ArcView GIS Version 3.1
File Edit View Theme Analysis Surface Graphics Window LTM Help
Land Transformation Model
The Land Transformation Modeling Project
Integrating Policy, Socioeconomics & Environmental Factors
LTM Overview
Initialize
Time Steps
Driving Variables
Stochastic
Weights
Exclusionary
Integration
PID
Oroboros
Scale 1:
aStartingdata
t0
Developed
Old field / young fore
Mature forest / close
Water
Riparian Zone
No Data
aDVinputs
Roads.shp
Rec
Campgrou
Golf Cours
Park
No Data
Water
Water
No Data
Urb
High densi
Low dens
Airport
Campgrou
Golf Cours
Park
Mining / Ex
No Data

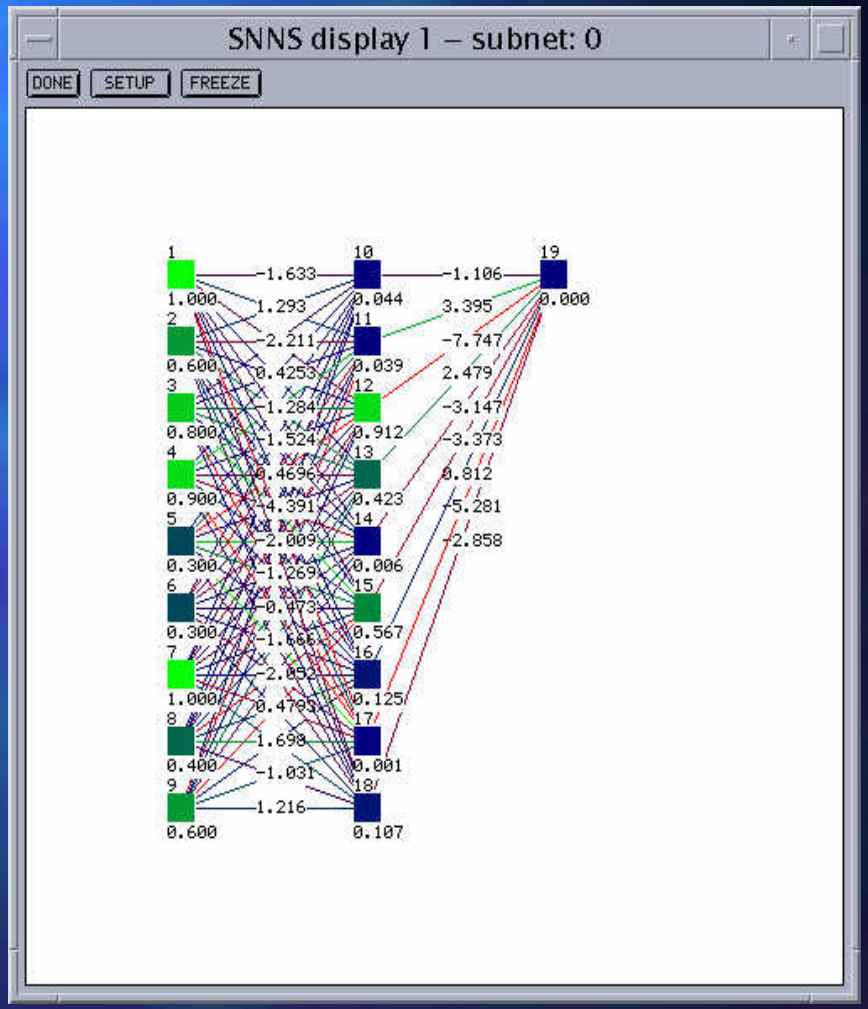
Spatial Variables

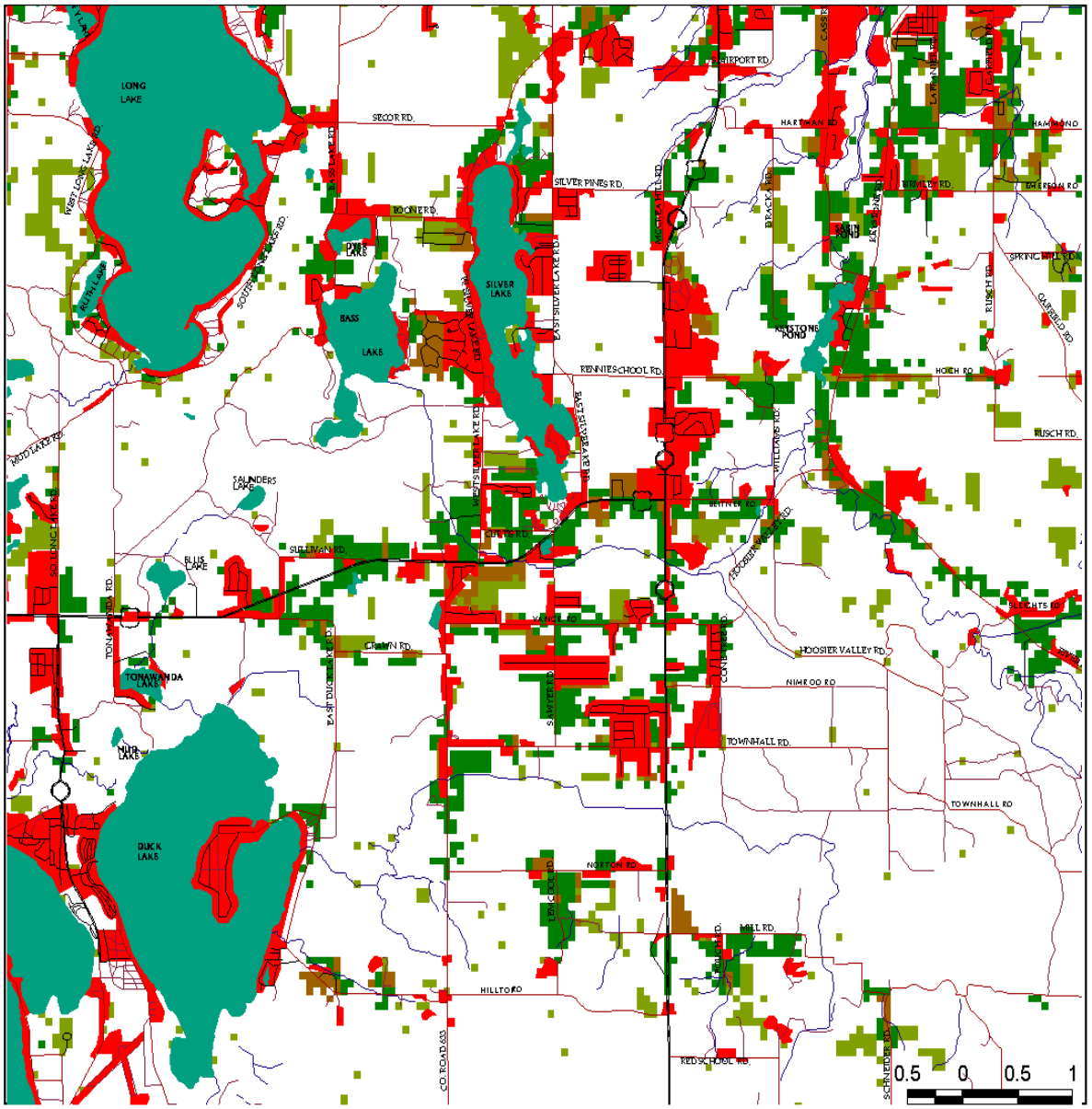
- soils
- terrain
- waterfronts (lakes and rivers) and views
- surrounding land use and existing urban
- roads
- parcel sizes
- public land ownership (constraint)


ArcView GIS Version 3.1
File Edit View Theme Analysis Surface Graphics Window LTM Help
LTM
Select a theme : Ag80
Spatial Interactions
Neighborhood
Patch size
Site specific
Distance
Spatial Scaling
Equal Area
Equal Interval
Patch Parameters
Resolution : 30.0000
Define threshold parameter
Relation
Direct Transition
Inverse Transition
Threshold definition
Field:
Value:
and
or
not
Query :
Add
View
Cancel
Principle Index Driver Construction
Definition of the principle index driver may be accomplished in two ways :
Define by coverages (excel)
Define by area-wide values
Definition by area-wide values
Population increase :
Time interval (years) :
per capita area requirement (acres/person) : 1.1
Cancel
OK
aIntegraoutputs
probability map
1 - 10
11 - 20
21 - 30
31 - 40
41 - 50
51 - 60
61 - 70
71 - 80
81 - 90
91 - 100
No Data

Artificial Neural Net (ANN) Modeling

- Use ANN to learn how factors influenced historical land use change
- Software link written between LTM in ArcView and SNNS neural net software.
- Drivers include: prior land use, roads, distance to urban, prob. of farm closure, infrastructure, surrounding land use.



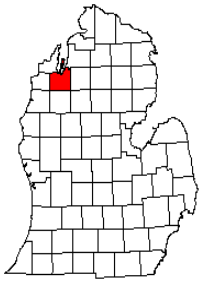


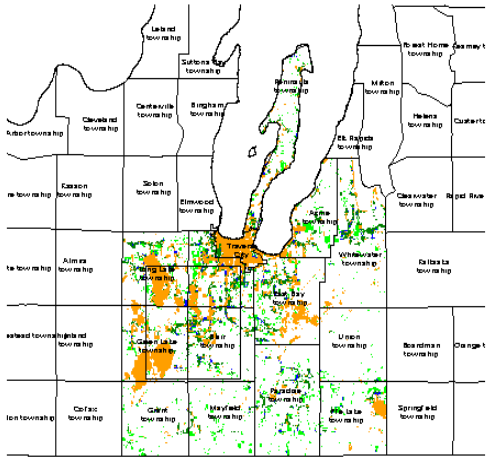
Predicted and Not Predicted

County Roads
Highways
Streets
Rivers
Lakes

urban Land Use 1980
non-urban

Changemap
not transitioned and not predic
transitioned, not predicted
not transitioned but predicted
transitioned and predicted
No Data





Methodological Contributions to Date

- Procedures and tool development for land use change mapping.
- Error estimation in quantifying forest cover change and fragmentation.
- Incorporation of neural network estimation, stochastic events, and dynamics into a nested version of GIS-based Land Transformation Model.

Possible Policy Implications

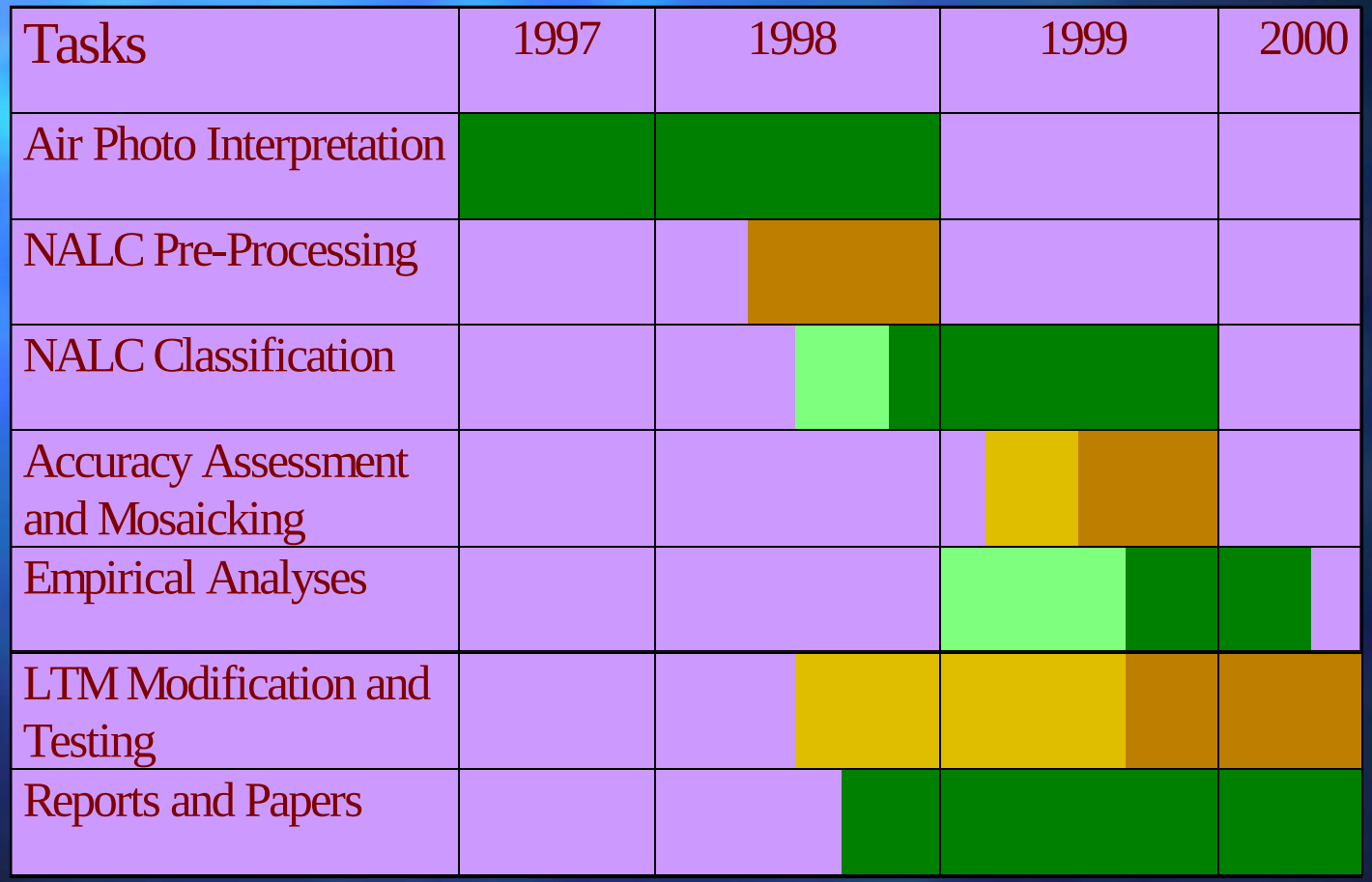
- Current patterns and trends in forest cover and pattern change tend to be positive (says nothing of forest characteristics).
- Development has not yet had a significant negative influence on forest cover, but ag. abandonment has had a positive influence.
- Ownership fragmentation increases complexity of management and likelihood of land use conflict.
- Agriculture is interrelated with forest regrowth and carbon sequestration. We need a good model of agricultural abandonment.

Outreach

- USGCRP National Assessment
  - Land use/cover change is often not included in assessments of system response to climate change (e.g., VEMAP I). Data and models will help.
- Upper Great Lakes RESAC
  - Output from project supports delivery of land use/cover change tools and data to agency-based stakeholders (DNRs, USFS, USGS, NRCS).

Project Timeline

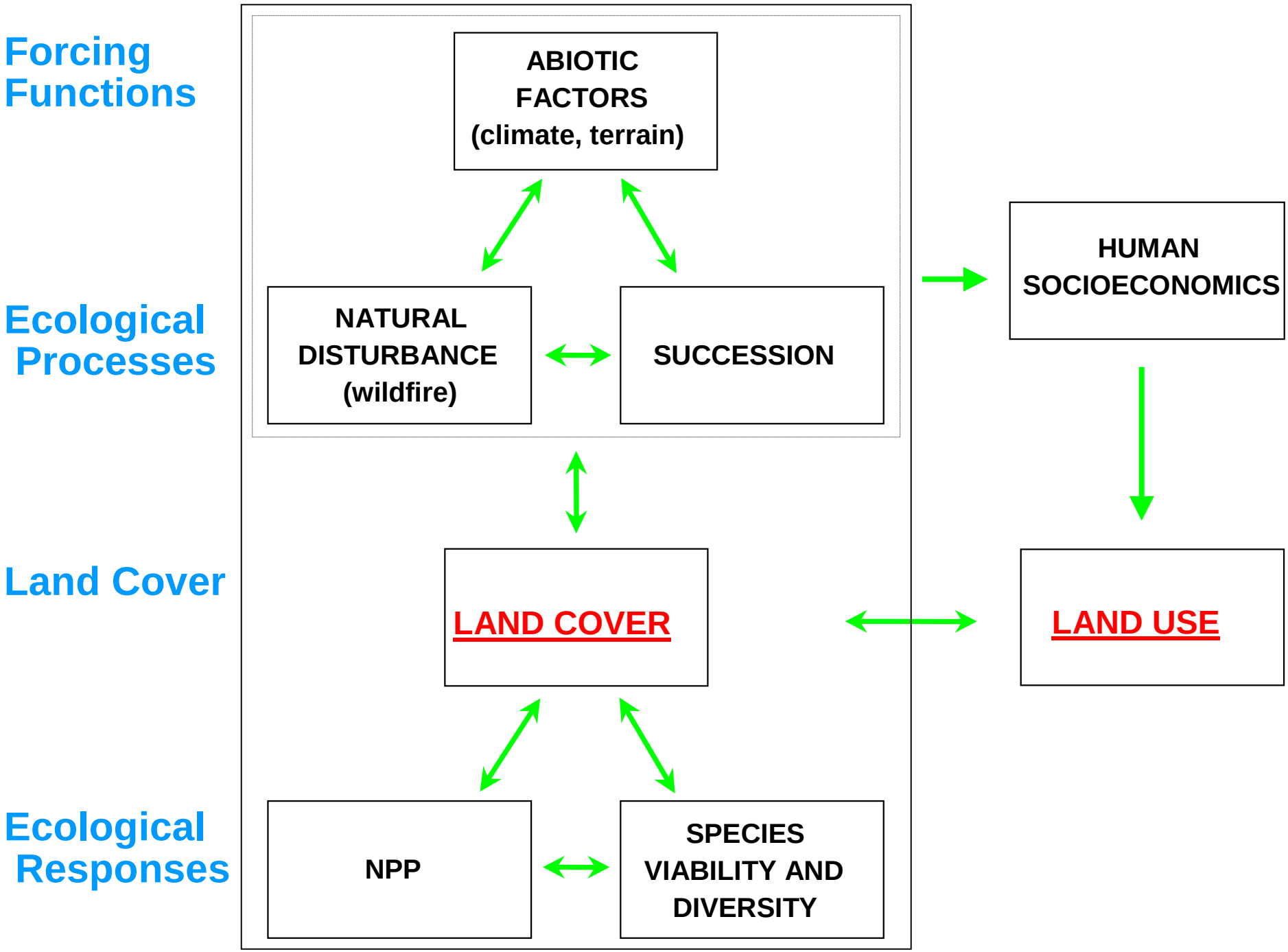
Tasks	1997	1998	1999	2000
Air Photo Interpretation				
NALC Pre-Processing				
NALC Classification				
Accuracy Assessment and Mosaicking				
Empirical Analyses				
LTM Modification and Testing				
Reports and Papers				



Interactions among Biodiversity and Socioeconomics in the Greater Yellowstone Ecosystem

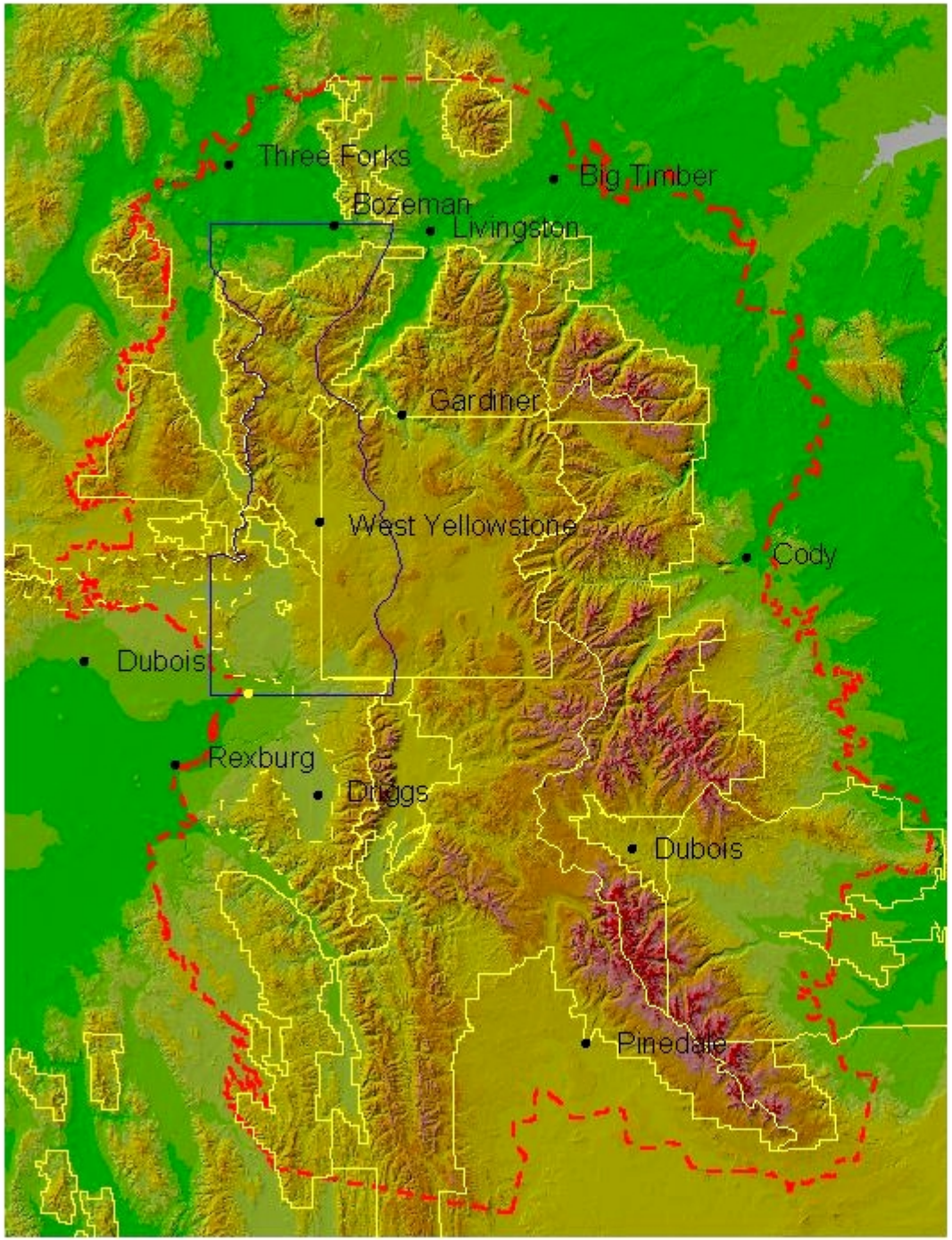
A. Hansen, W. Cohen, J. Johnson, B. Maxwell, R. Rasker, J. Rotella, A. Wright, A. Gallant

Funded by: NASA, USDA-NRI, USFS, MFWP, USFWS

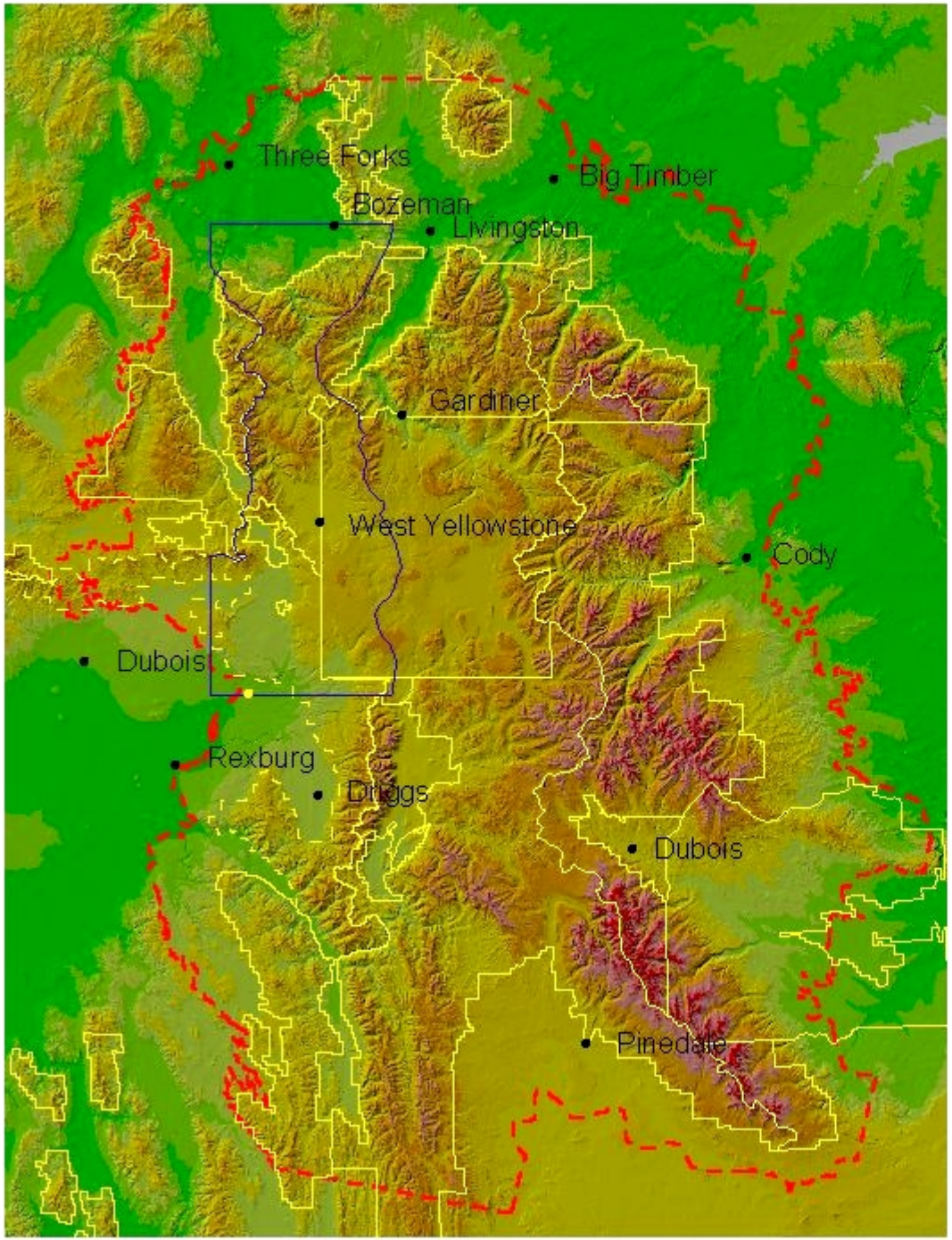

Forcing Functions
Ecological Processes
Land Cover
Ecological Responses
ABIOTIC FACTORS (climate, terrain)
NATURAL DISTURBANCE (wildfire)
SUCCESSION
HUMAN SOCIOECONOMICS
LAND COVER
LAND USE
NPP
SPECIES VIABILITY AND DIVERSITY

Objectives

- **1. 25-Year History of GYE:** Quantify changes in biophysical gradients, biodiversity, and land use and socioeconomic factors across the GYE from 1972-1996.
- **2. Causes and Consequences:** Test hypotheses on interactions among biophysical gradients, biodiversity, and socioeconomic patterns.
- **3. Risk:** Assess current and future risk to ecological hot spots and potential for restoration.
- **4. Pulse Taking:** Develop and implement an approach to monitor ecological and human interactions.
- **5. Policy:** Communicate results to stakeholders.



Study Area Boundaries



Study Area Boundaries

- 98,000-km^2
- 7 Landsat TM scenes
- 1500-3800 m elevatio
- 3 states
- 7 national forests
- 2 national parks
- 20 counties

Obj 1. 25-Year History of GYE

Variable	Source	Scale
Land cover/use	Landsat-TM, MSS	30-80 m
Biodiversity	Field/GIS	2 ha
Human Demographics	Census	County
Human Economics	Public records	100 m
Human Sociology	Bur. Econ. Ana.	County
Climate	PRISM	1 km

Land Cover Approach

Experimental Design

- **3 Pilot Areas**
- **3 Years of Imagery:** 1976, 1985, 1994
- **2 Dates per Year:** (June, August)

Each Pilot Area

- **Reference Data**: Collect calibration for each pilot area.
- **Classification Model:** Develop CART model.
- **Image Classification:** Apply CART model to image.
- **Change Detection:** Quantify change over time.

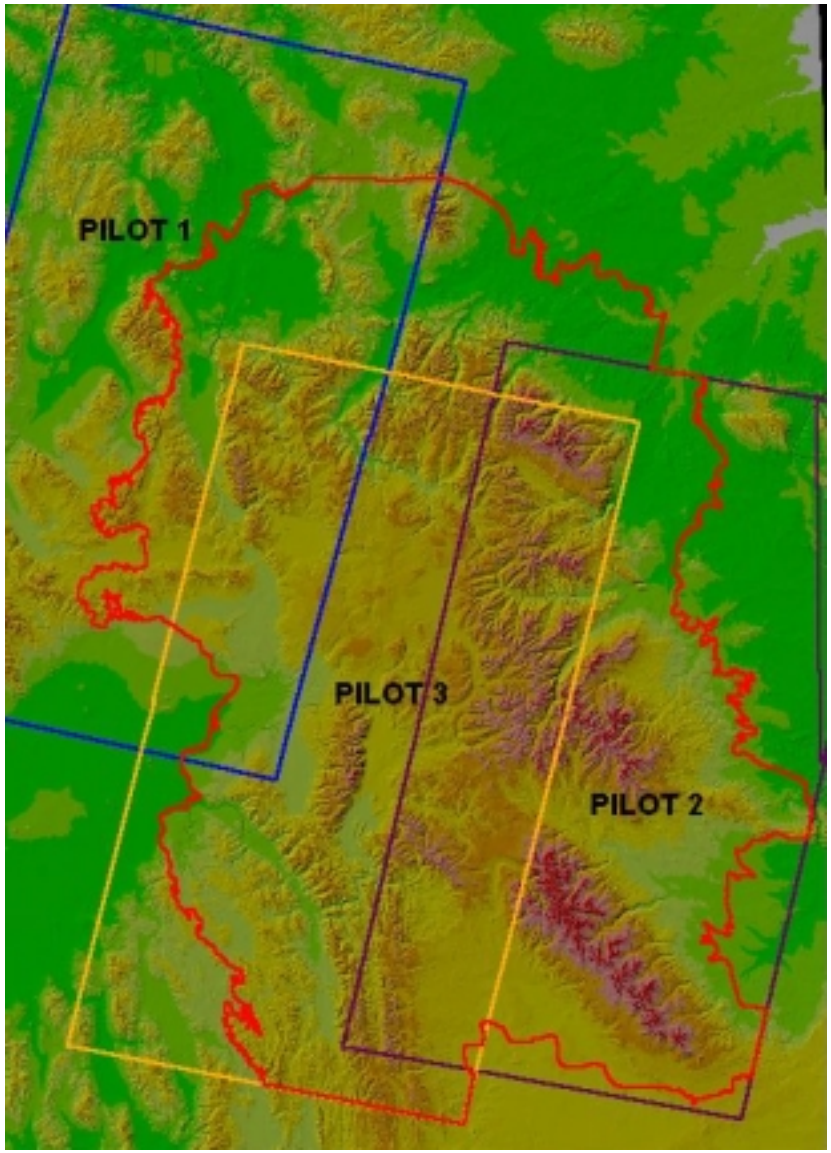
GYE-Wide

- **Image Classification:** Apply CART across GYE.

Land Cover Classes

LEVEL I	LEVEL II	LEVEL III
Non Veg	Snow/Ice/Cloud	
	Bareground/Rock	
	Water	
	Urban	
Agriculture	Agriculture	Perennial (Grazing/Pasture/CRP)
		Annual (Crop/Hay/Fallow)
Natural Vegetation	Conifer	- Conifer (mixed)
		- Douglas Fir
		- Clearcut
		- Burned
	Hardwood	- Aspen
		- Willow
		- Cottonwood
	Herbaceous	- Sage
		- Grassland

Pilot Areas



GYE Boundary

Pilot 1 Boundary

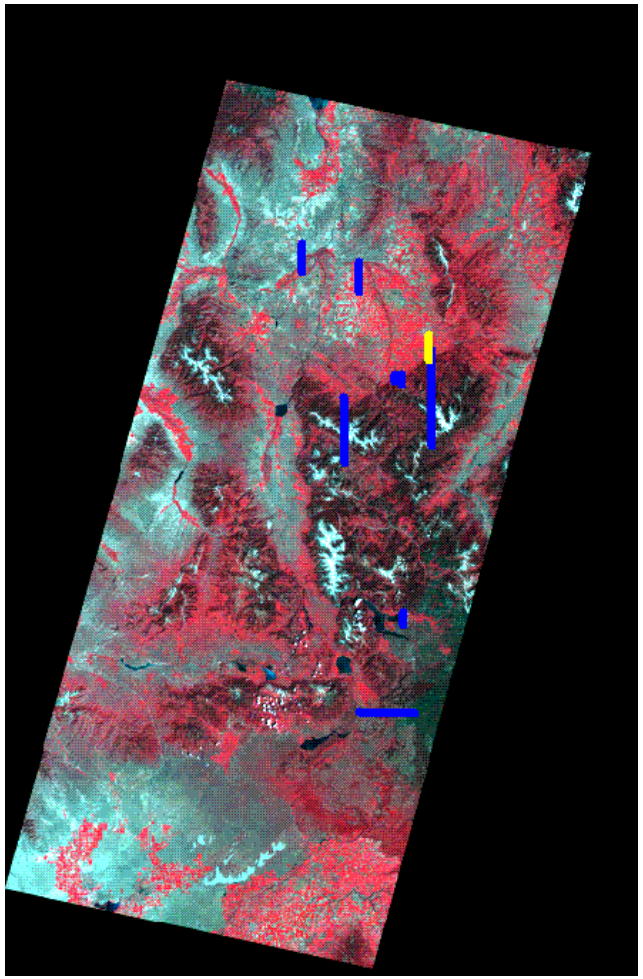
Pilot 2 Boundary

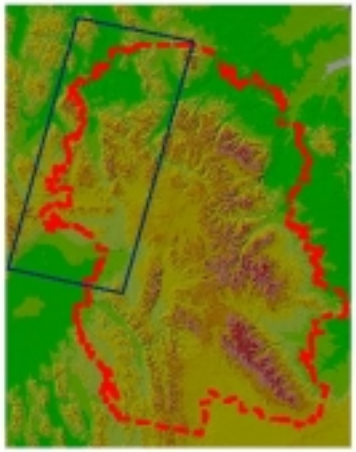
Pilot 3 Boundary

Reference Data Collection

- 1. Designate transects within pilot areas.
- 2. Identify random points along transects within cover type, elevation, aspect strata.
- 3. Sample 30-100 points per cover type distributed across elevation and aspect.

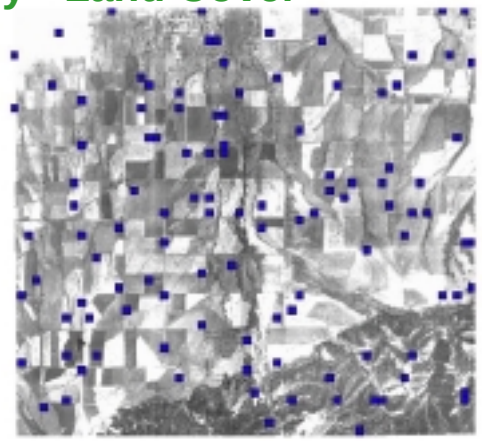
25-Year History - Land Cover





Transects for Reference Data: Pilot Area 1

25-Year History - Land Cover



Sample Points on Aerial Photos

Sample Points on Landsat Image

Land Cover Identification

Reference Data: Pilot Area 1

Number of Photo Interpreted Plots by Year and Land Cover				
Class		1976	1985	1994
LEVEL 1	Agriculture	198	181	194
	Non-Vegetation	383	372	340
	Natural Vegetation	25	21	18
	LEVEL 1 TOTALS	542	574	646
LEVEL 2	Conifer	148	160	171
	Hardwood	50	45	36
	Herbaceous	60	90	75
	LEVEL 2 TOTALS	282	295	258
LEVEL 3	Perennial Agriculture	41	32	41
	Annual Agricuture	76	97	88
	Conifer	38	40	40
	Douglas Fir	23	22	25
	Aspen	32	32	32
	Cottonwood	17	18	18
	Willow	23	21	20
	Sage Grassland	21	21	21
	Grassland	19	19	19
	LEVEL 3 TOTALS	303	202	290

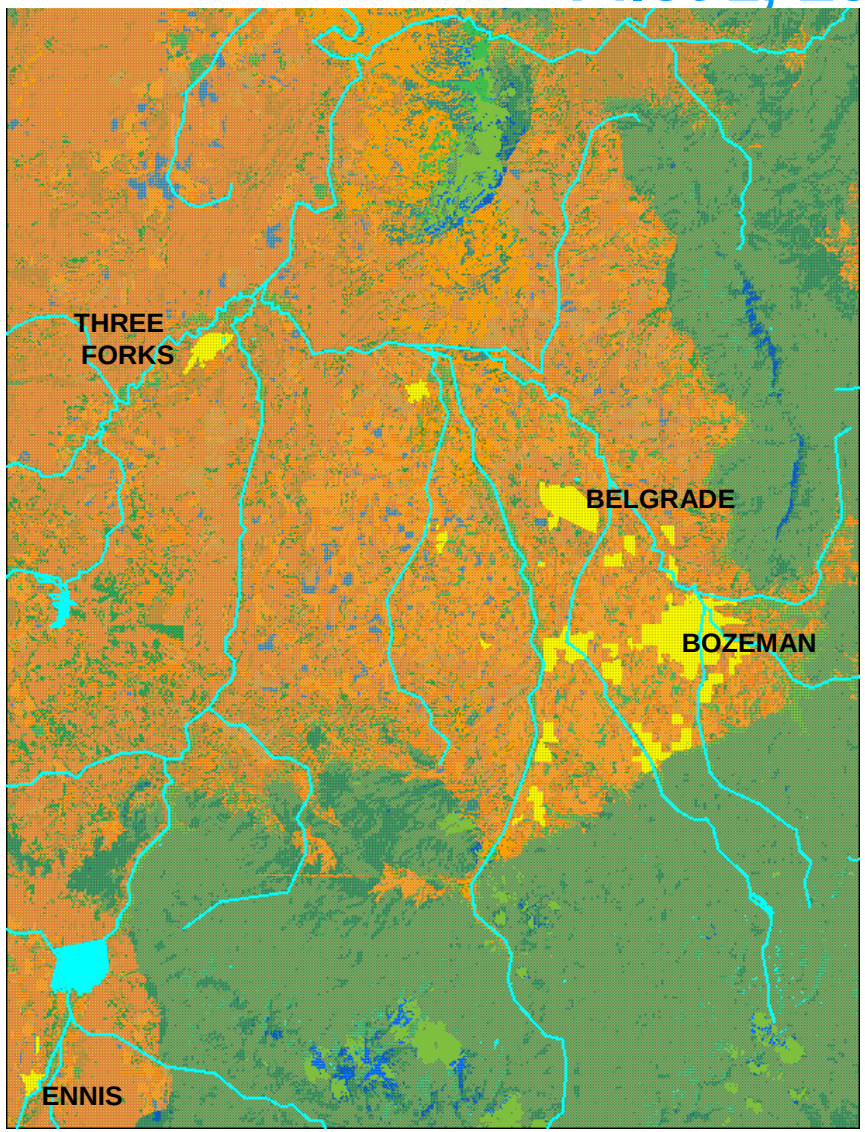
Classification Methods

- **1. Extract Explanatory-variable Data:** for each reference data point.
- **2. Develop CART Rules:** for each classification level and cover type using reference and explanatory data (32 variables).
- **3. Apply Rules:** create a classified map for each level.
- **4. Evaluate Accuracy:** use independent validation data
- **5. Extrapolate:** apply classification rules across the GYE for all years, all levels

25-Year History - Land Cover

Preliminary Classification Results

Pilot 1, Level 1, 1994



User's Accuracies for Level 1

AGRICULTURE	84%
NON-VEG	75%
NATURAL VEG	97%

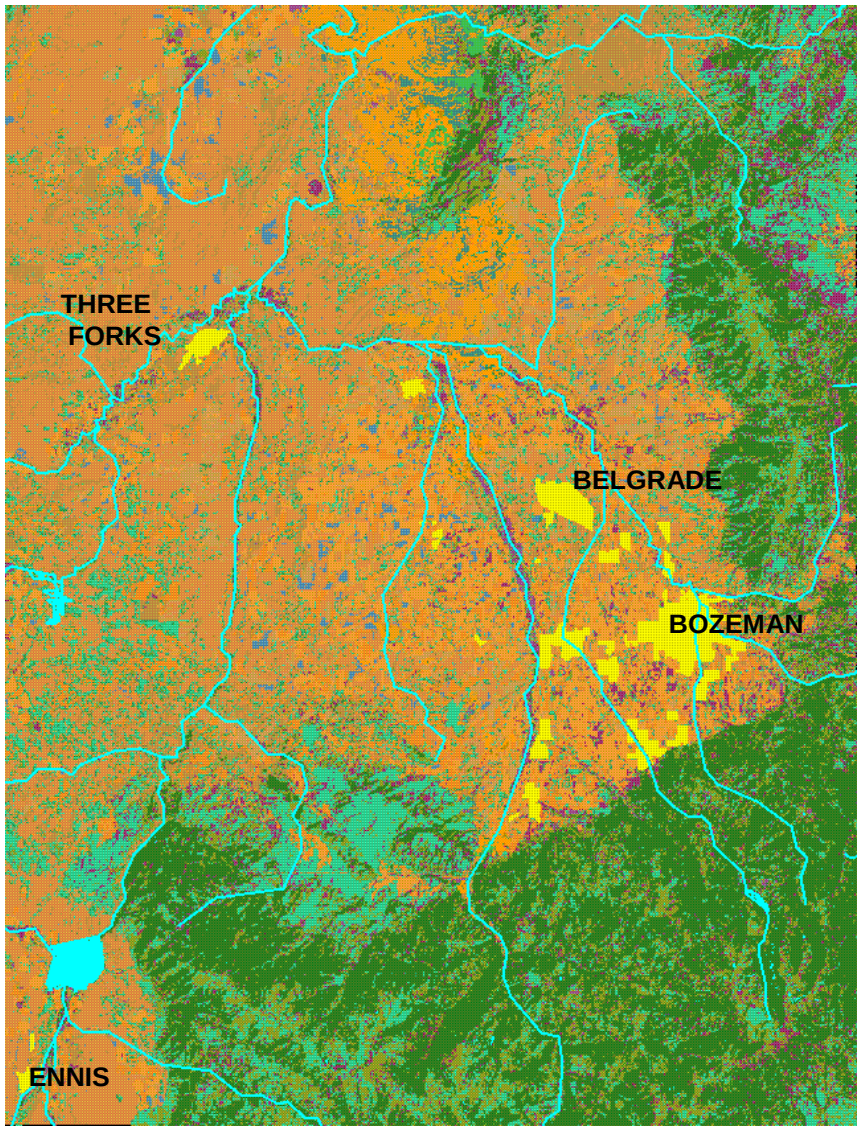
Overall Classification Accuracy = **91%**

- **Agriculture**
- **Natural Vegetation**
- **Non-Veg (Soil and Rock)**
- **Water**
- **Urban**

25-Year History - Land Cover

Preliminary Classification Results

Pilot 1, Level 2, 1994



User's Accuracies for Level 2

CONIFER	87%
HERBACEOUS	70%
HARDWOOD	73%

Overall Classification Accuracy = **76%**

Level 1

- Agriculture
- Non-Veg
- Water
- Urban

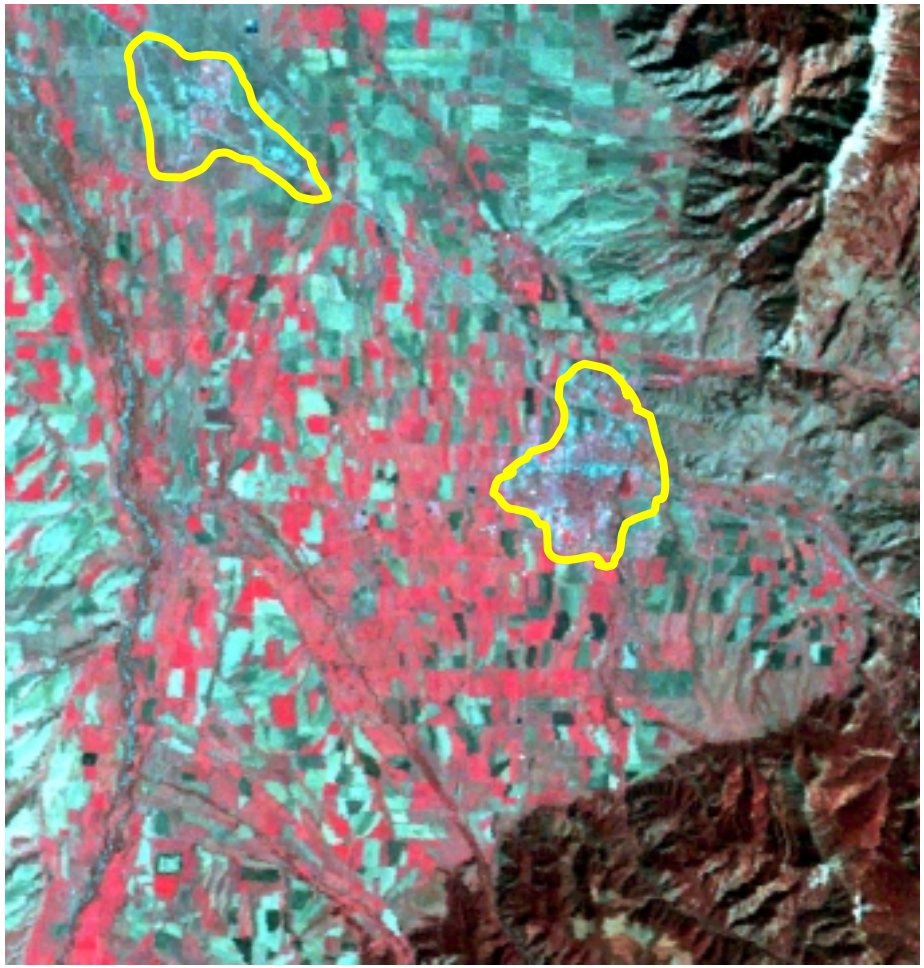
Level 2

- Conifer
- Herbaceous
- Hardwood
- Mixed Conifer-Herb
- Mixed Hardwood-Herb

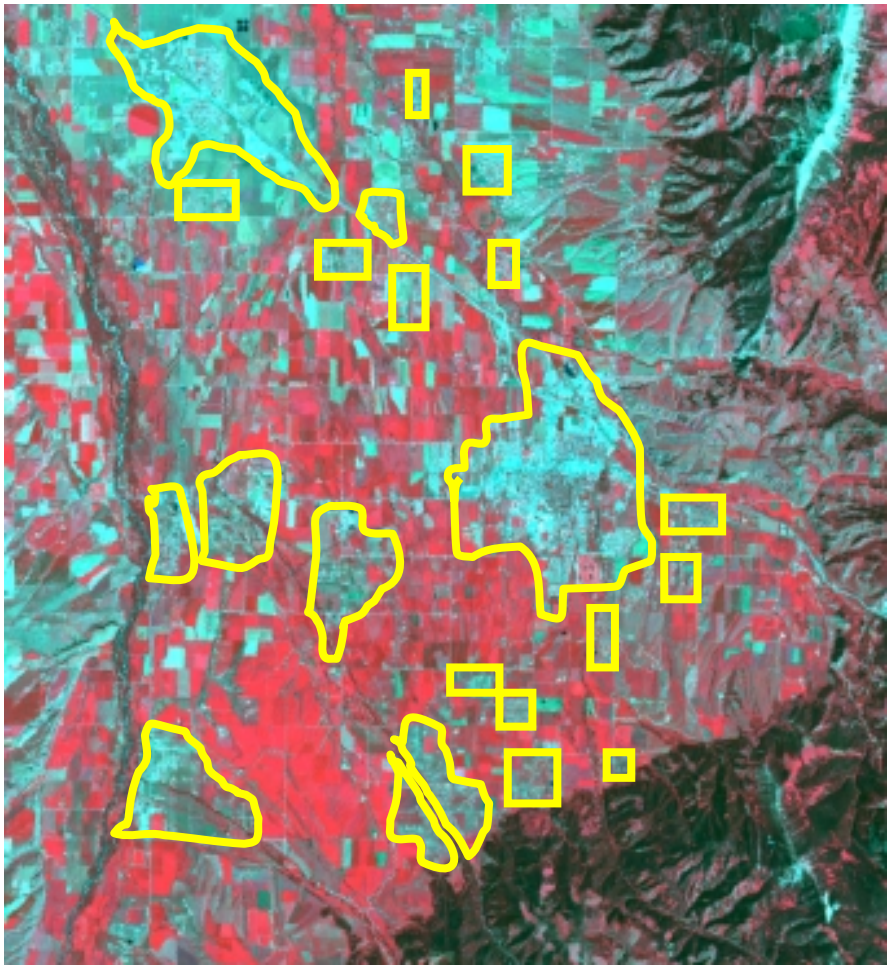
Change Detection

- **Method 1: Traditional Difference Approach**
- **Method 2: Cohen Difference Threshold Approach**
- **Compare Methods 1 and 2 and use best.**

Change:Gallatin Valley, MT



1976
MSS Imagery 4-2-1



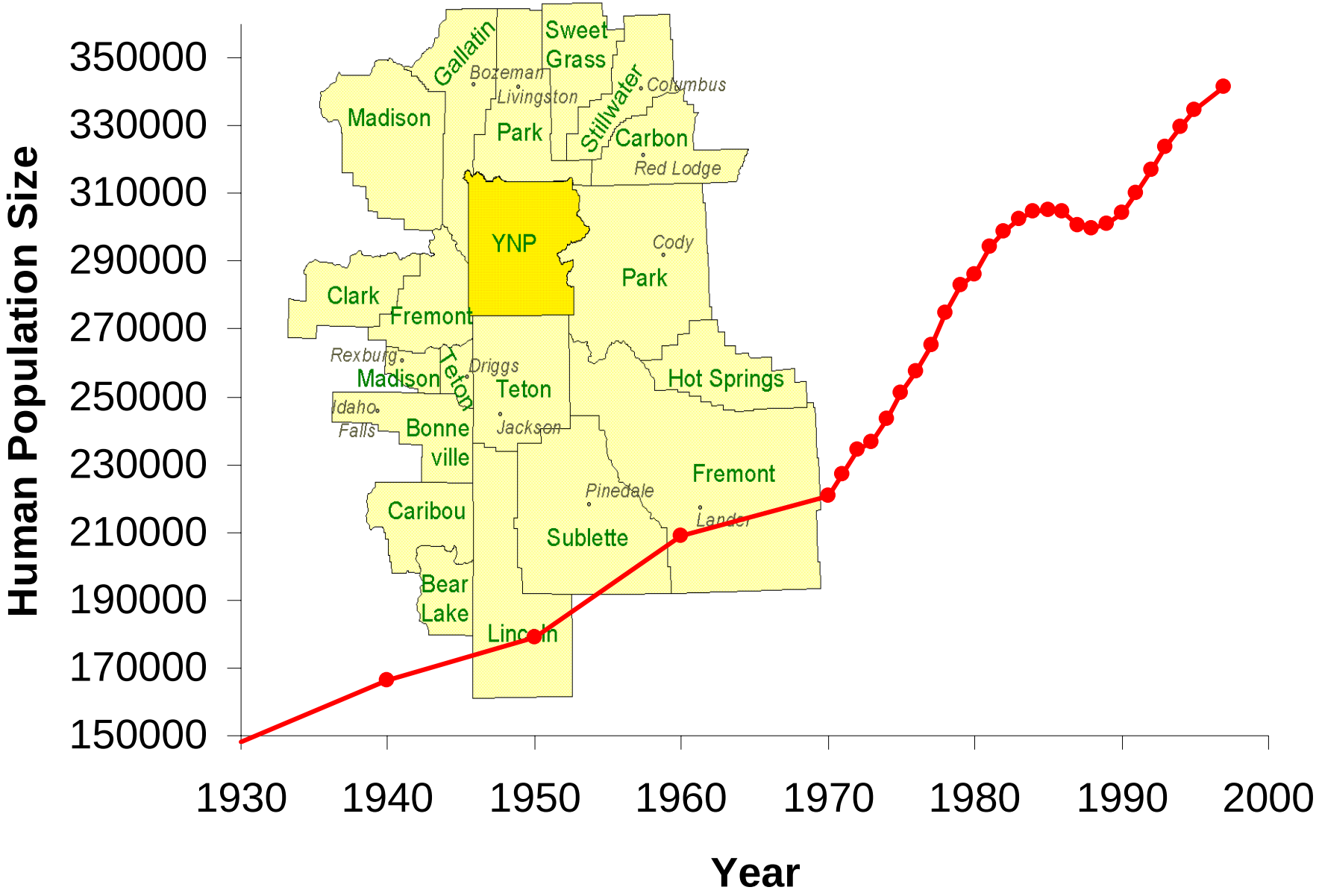
1994
TM Imagery 4-3-2

Land Cover Classification: Status

Task	Area			
	Pilot 1	Pilot 2	Pilot 3	GYE
Develop methods	X	X	X	X
Acquire imagery	X	X	X	X
Obtain reference and predictor data	X	X		
Classify and Validate	X			
Detect Change				

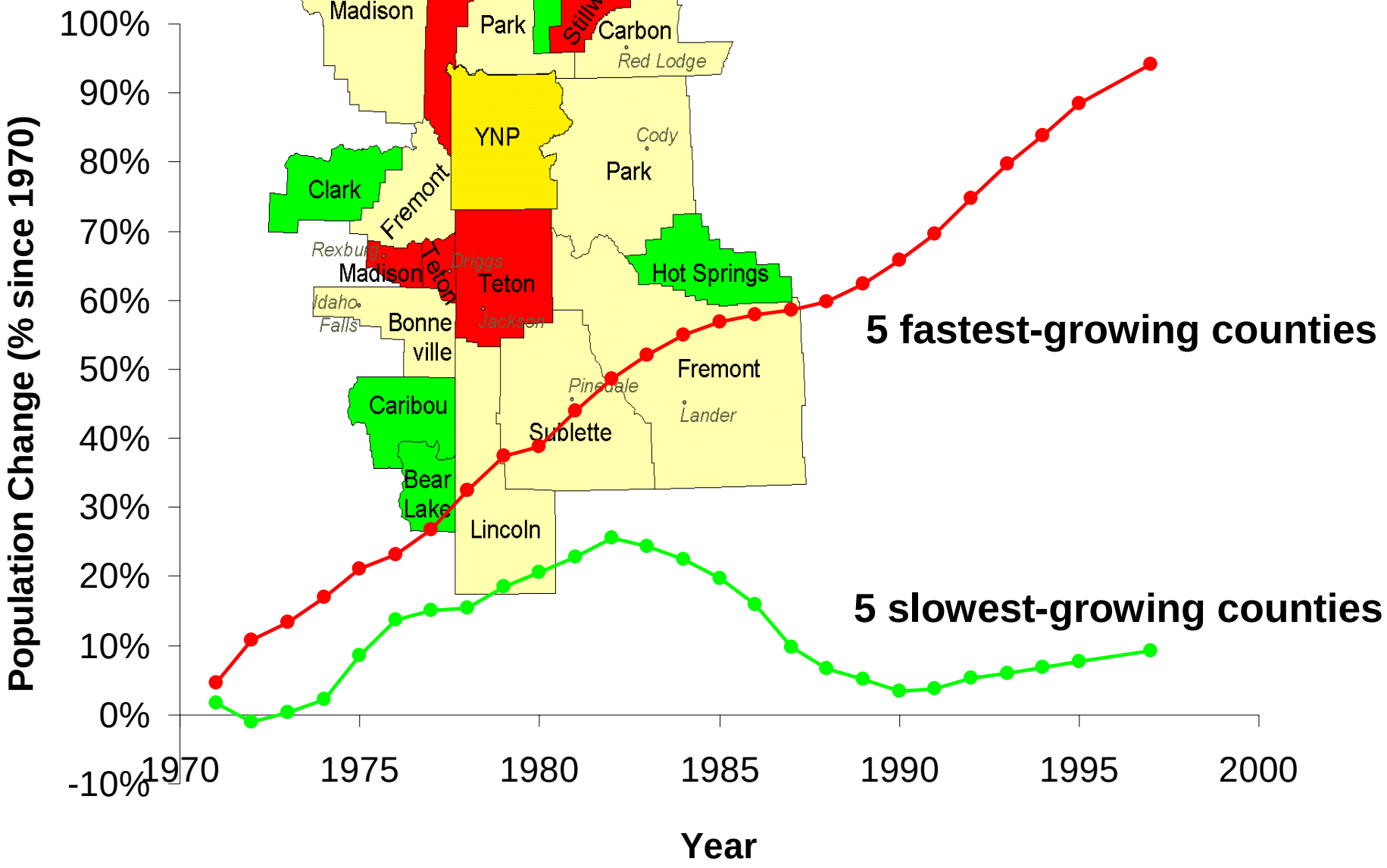
25-Year History

Human Demography - GYE-Wide



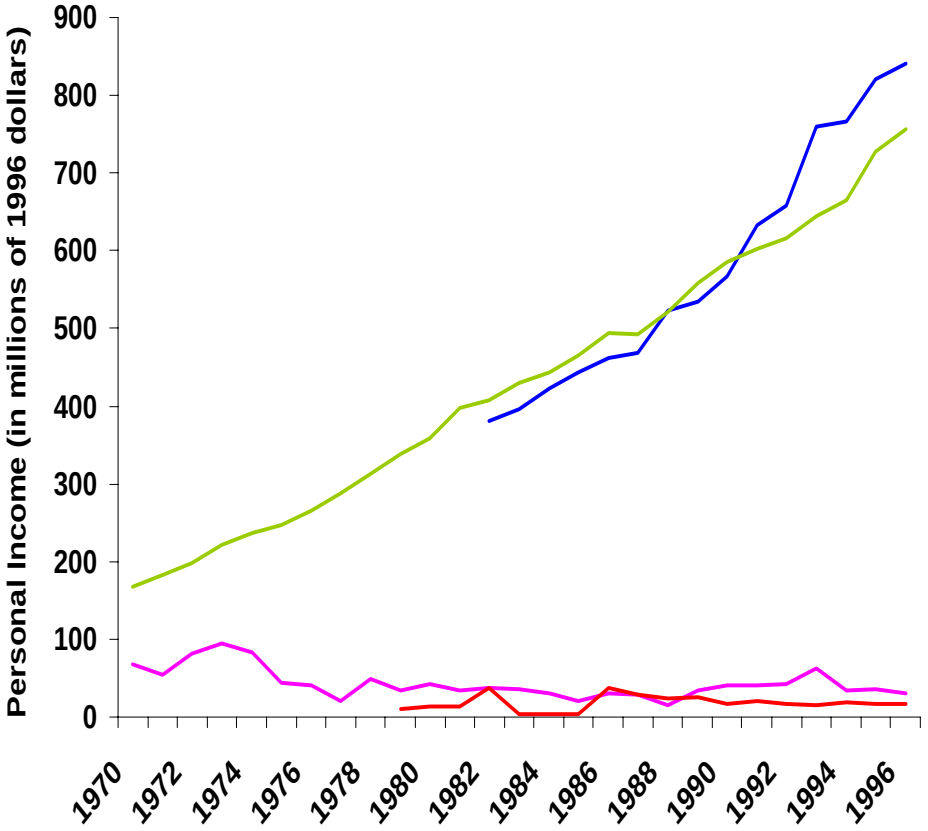
25-Year History

County Differences

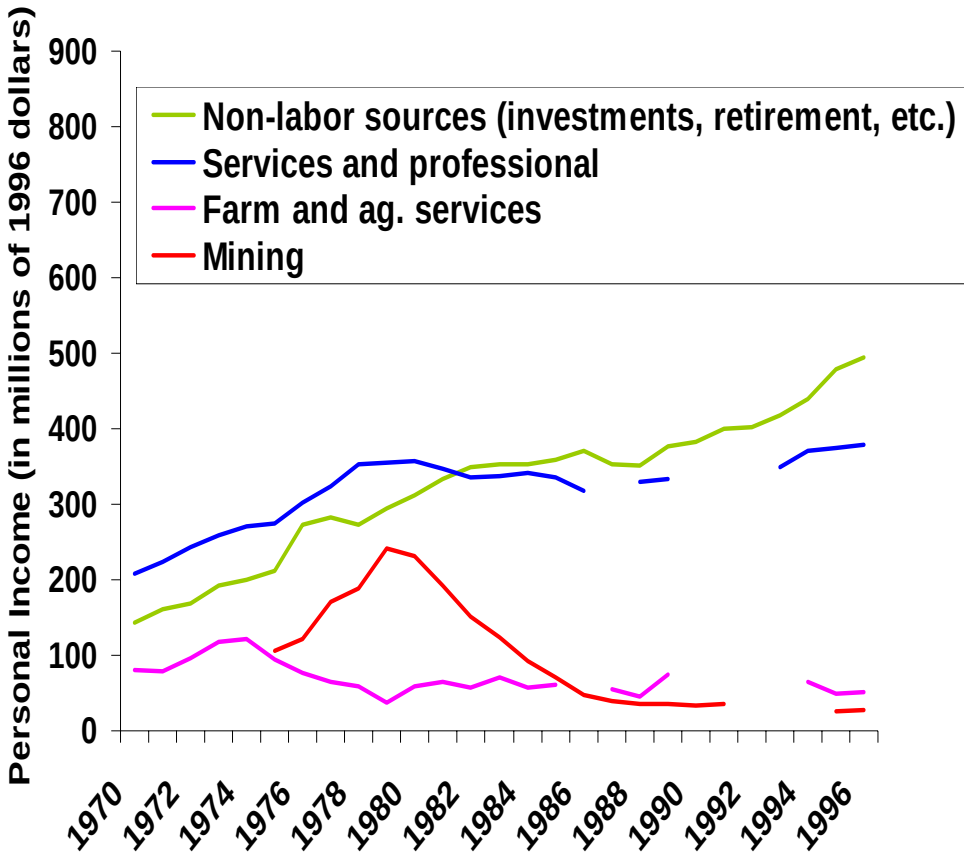


Economic Trends: County Differences

Four Fastest Counties

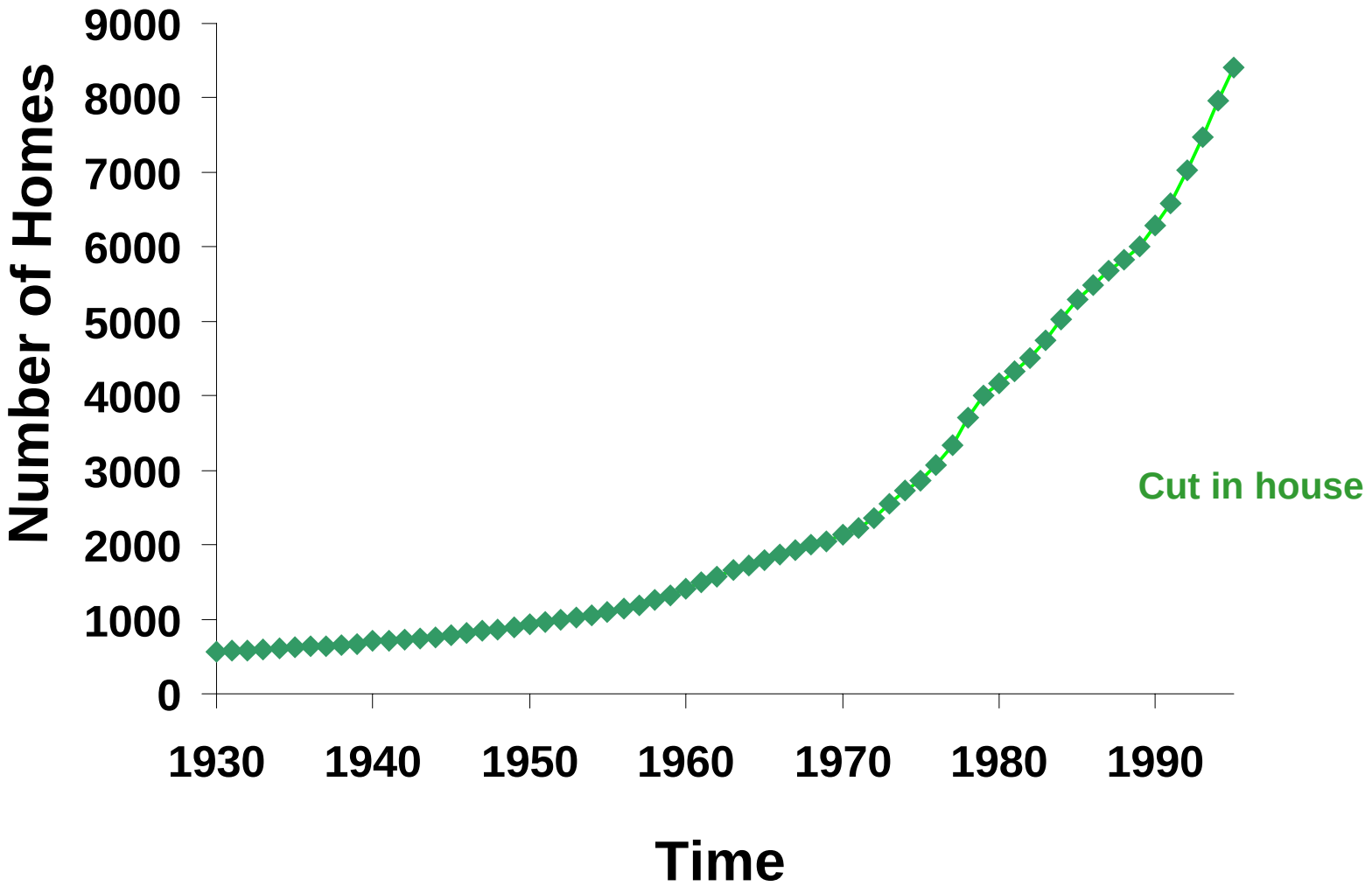


Four Slowest Counties



25-Year History

Rural Residential Development: Gallatin Co, MT



25-Year History: Status

Task	Topic			
	Demo-graphy	Economic	Social	Biodiversity
Obtain data	X	X	X	
Analyze data	X	X		
Prepare publications				

Expected Products:

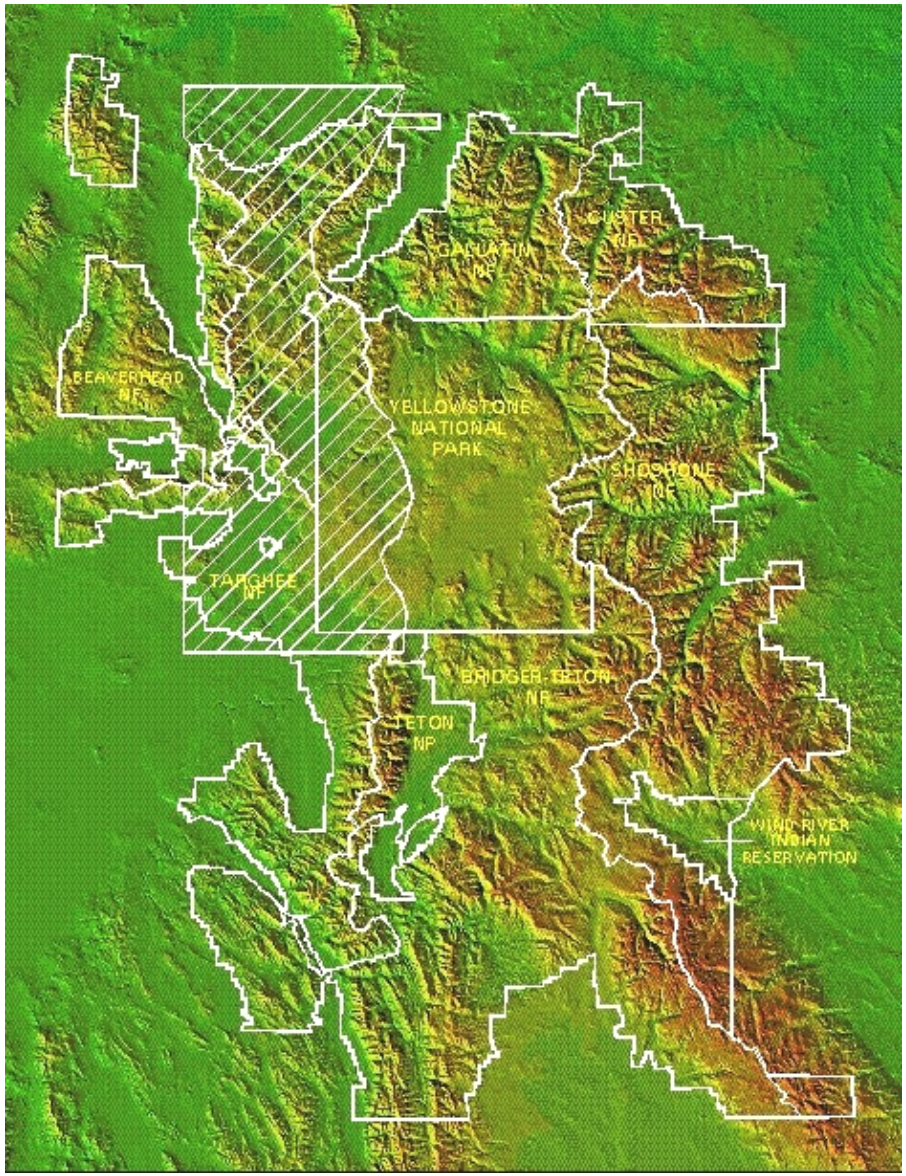
•Hansen et al. Twenty-five year history of the Greater Yellowstone Ecoystem. (2000).

Objective 2: Hypotheses

- **H1: Abiotic factors cause NPP to be low and variable over most of the GYE.**
- **H2: Biodiversity is correlated with abiotic gradients and NPP and is high only in hot spots.**
- **H3: Human land use is most intense near hot spots.**
- **H4: Socioeconomic performance is influenced by ecological factors.**
- **H5: Intense land use reduces the population viability of some native species.**

Obj 2: Hypothesis testing

SPATIAL PATTERNS OF NPP



Hypothesis 1:

Patchy topography, climate, and soil cause NPP to be low and variable over most of the GYE.

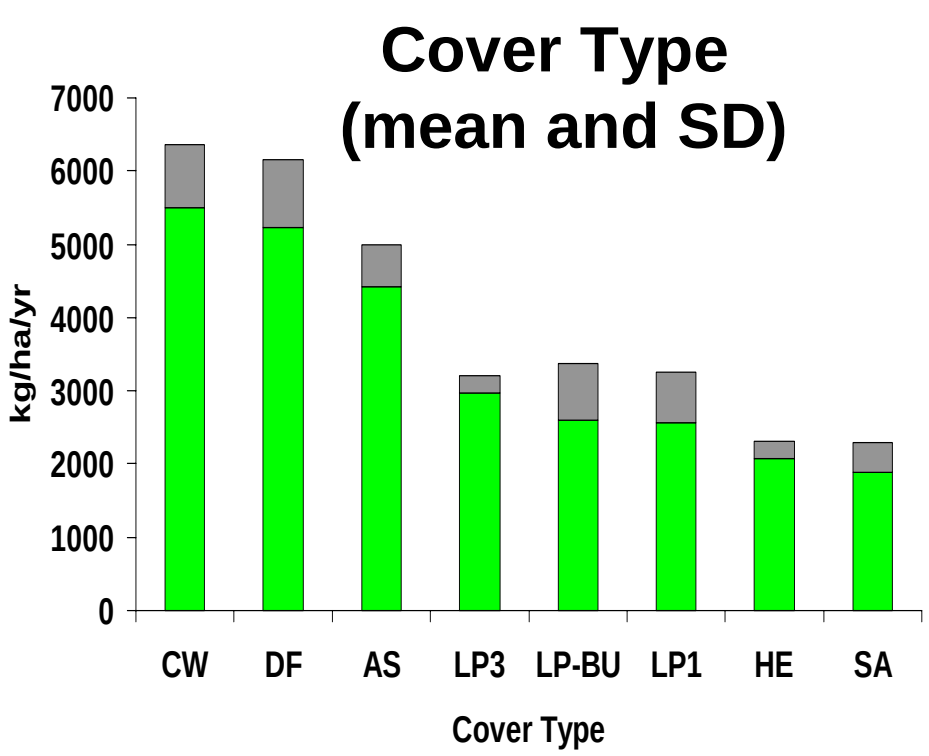
Methods

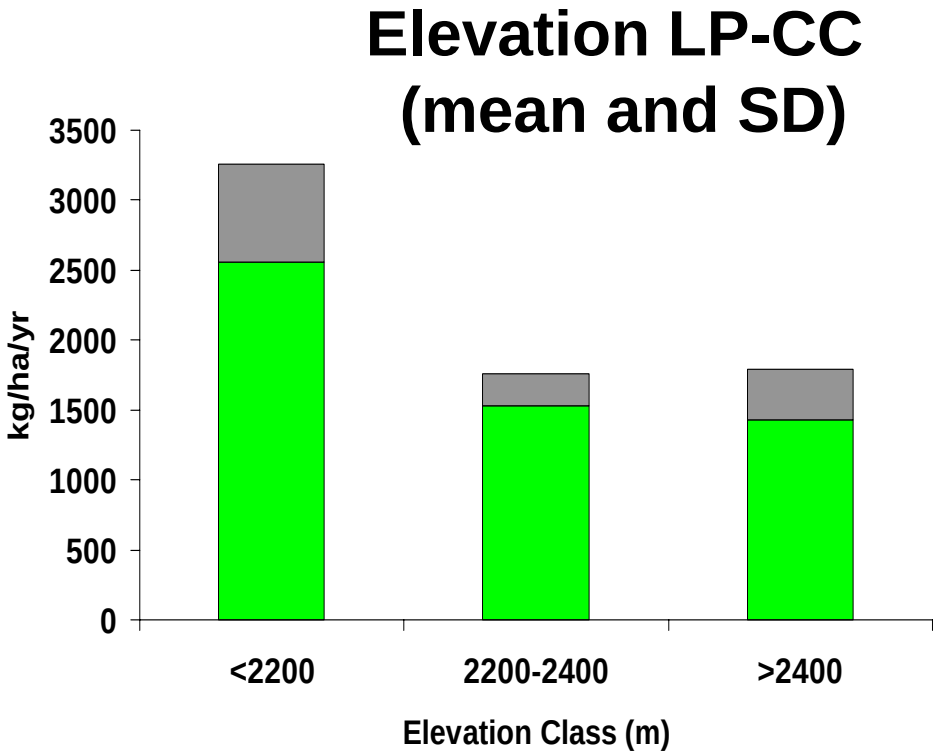
- **Select field sites (100) stratified over biophysical gradients.**
- **Collect data on vegetation dimensions and growth rates.**
- **Use allometric relationships to predict biomass change/year.**
- **Extrapolate ANPP from sites to study area.**
- **Analyze spatial patterns of ANPP.**

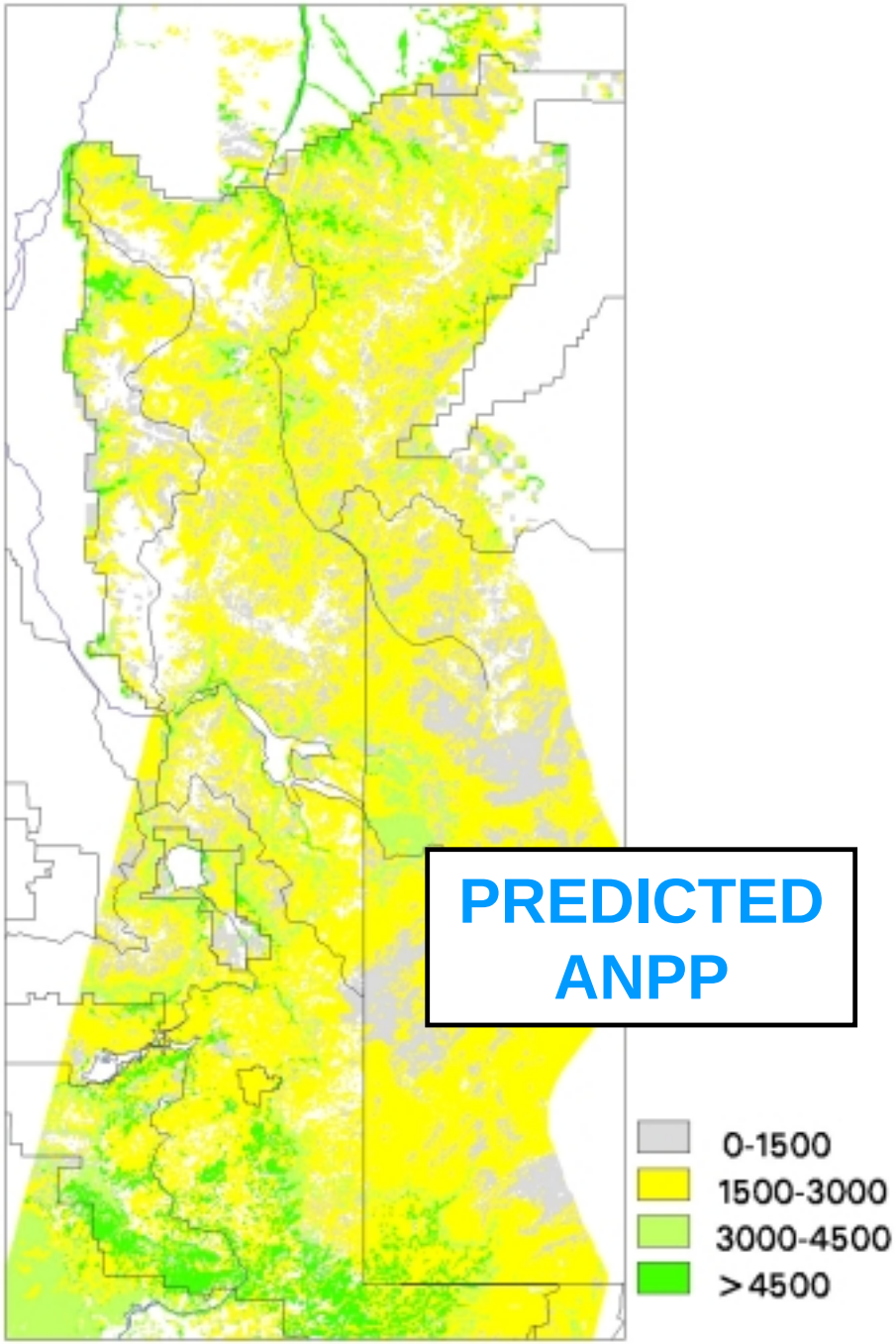
Results

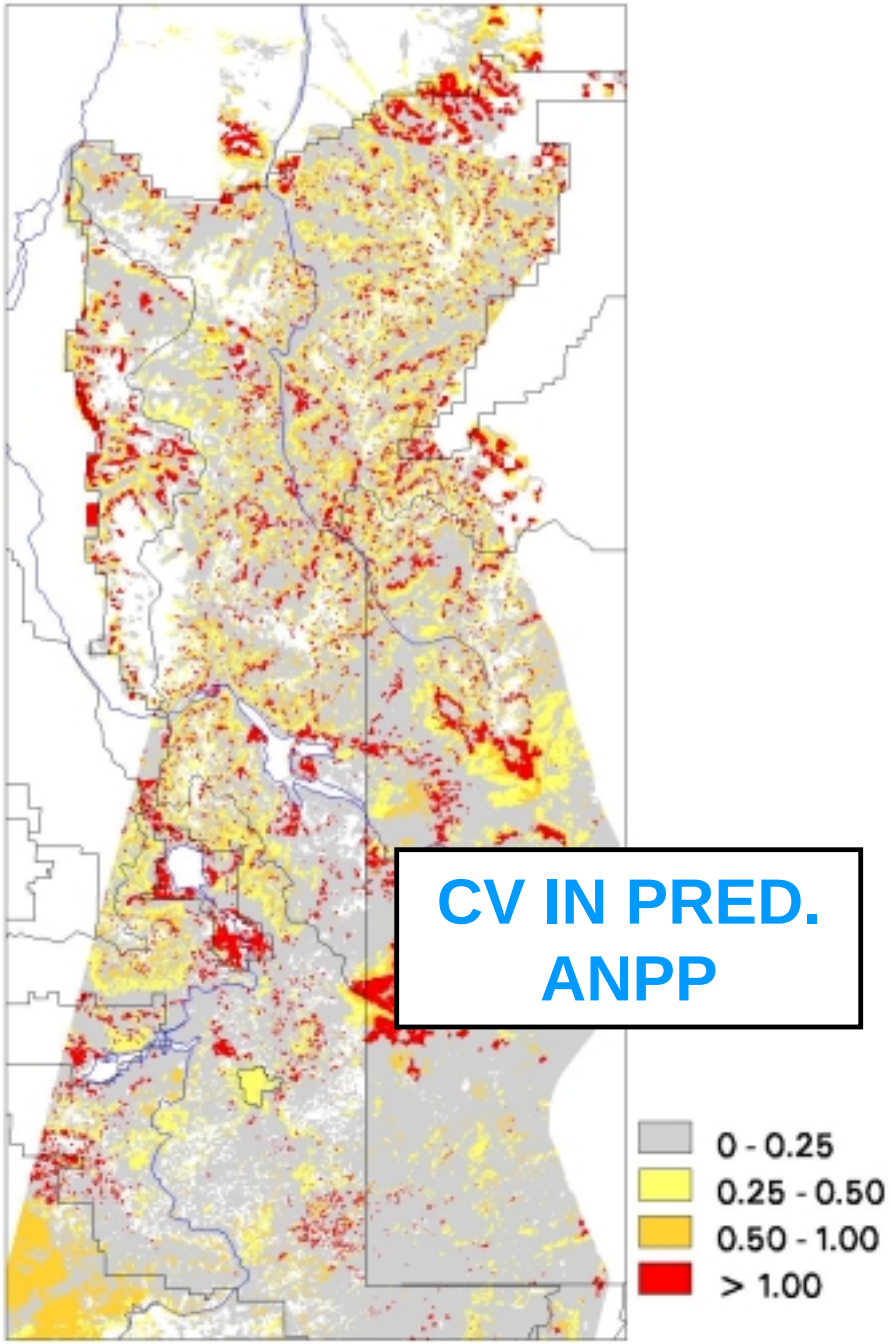
- **Predictor variables evaluated: elevation, slope, aspect, specific catchment area, parent material, cover type.**

- **Best Model: ANPP = cover type, elevation, interaction (R^2=.89, P<.0001).**






PREDICTED ANPP
0-1500
1500-3000
3000-4500
>4500


CV IN PRED. ANPP
0 - 0.25
0.25 - 0.50
0.50 - 1.00
> 1.00

SPATIAL PATTERNS OF BIODIVERSITY

Hypothesis 2:

Strong abiotic gradients (topography, climate, soil) cause native species abundances and richness to be high only in localized hot spots across the landscape.

Methods

- Select field sites (100) stratified over biophysical gradients.
- Collect data on abundance of bird, shrub, and tree species.
- Extrapolate species abundances and richness from sites to study area.
- Analyze spatial patterns of biodiversity.

PREDICTOR VARIABLES

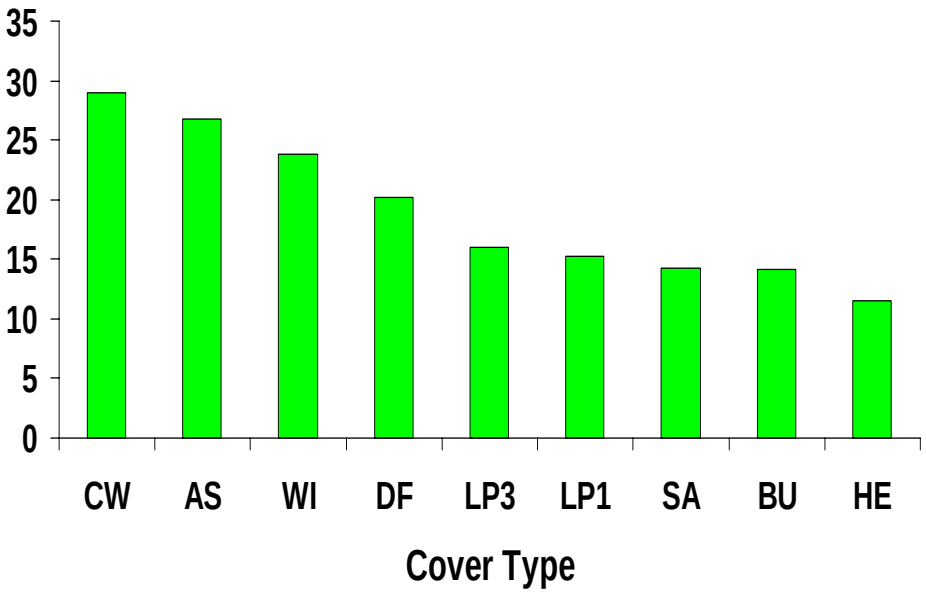
Theme	Source	Methods
Elevation, Slope, Aspect	USGS DEM	Derive from DEMs
Specific Catchment Area	DEM and	Derive with Arc-Info Watershed Function
Monthly Temp., Monthly Precip., Snow-melt Date	Met Stations	Regressed based on elevation and/or latitude. Averaged over 1995-97
Parent Material Type	Soils Maps	Soil types grouped into parent material classes
Vegetation Cover Type	Field	Simple cover type classification
Vegetation Structure	Field	Structural complexity indicies developed from field data
ANPP	Field	Total, deciduous, and coniferous ANPP developed with BIOPAK and field data.

Results: Bird Richness

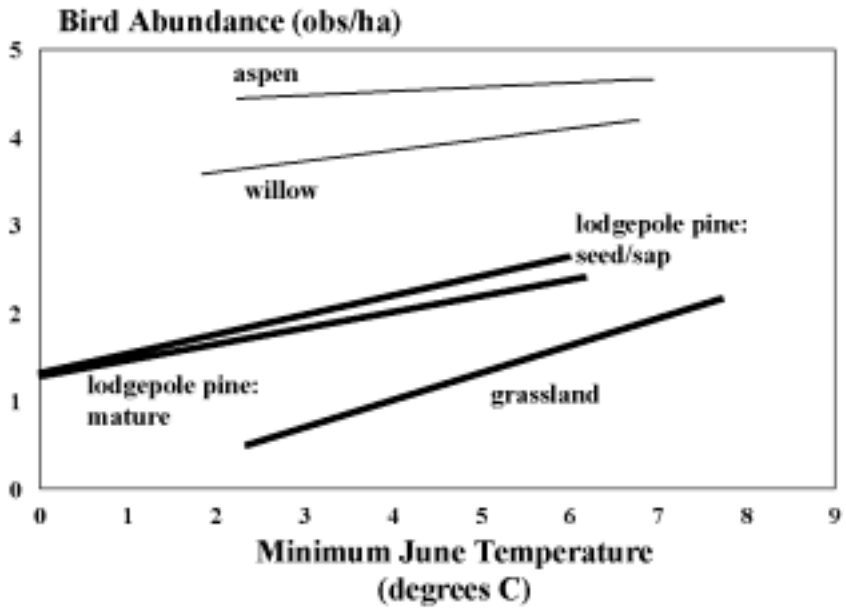
- **<u>Predictor variables evaluated</u>: elevation, slope, aspect, parent material, climate (6 variables), veg structure, ANPP, cover type.**

- **Best Model: Richness = cover type, climate, parent material (R^2=.89, P<.0001).**

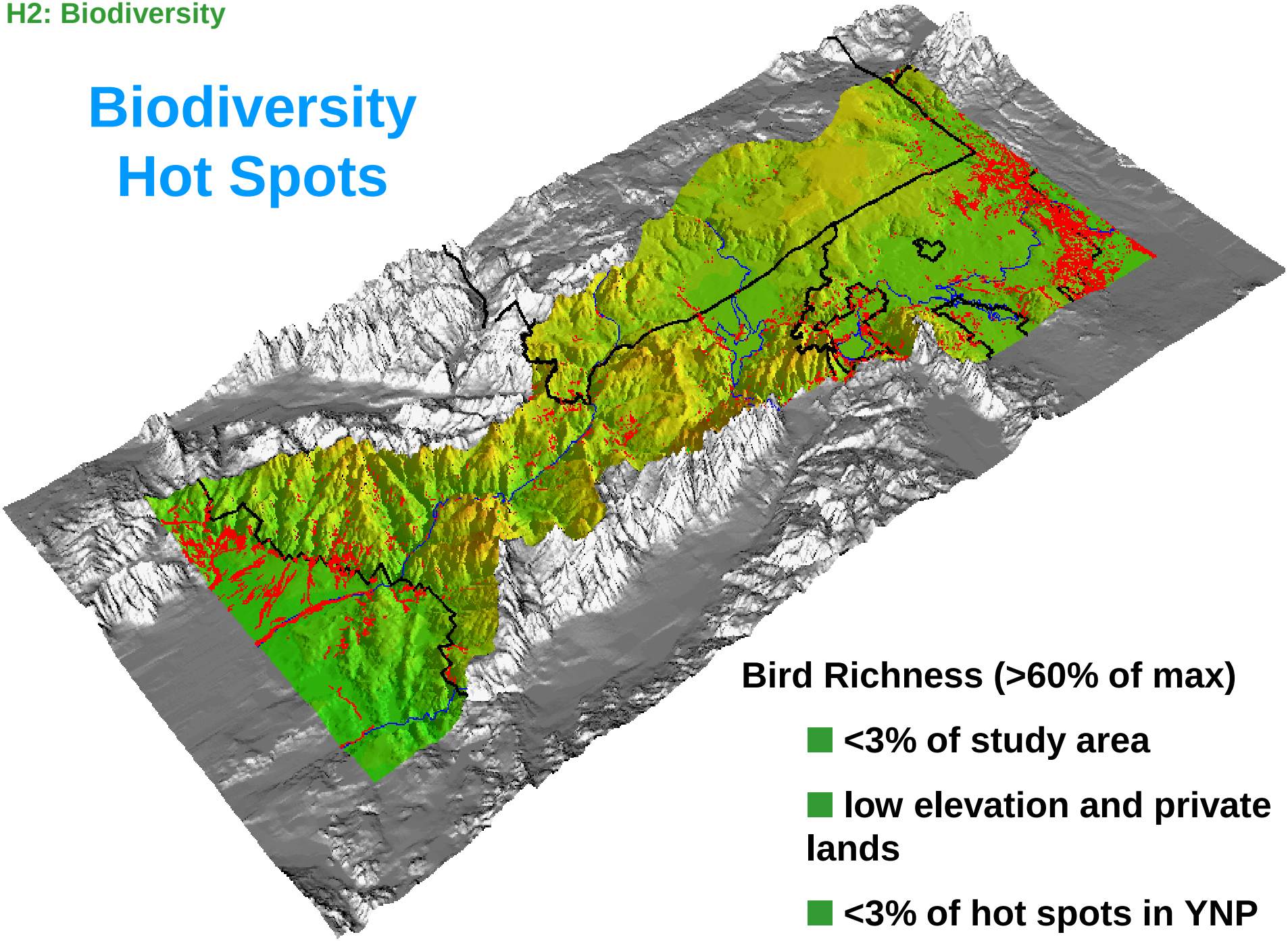
Cover Type



Climate



Biodiversity Hot Spots



Bird Richness (>60% of max)

- **<3% of study area**
- **low elevation and private lands**
- **<3% of hot spots in YNP**

Human Settlement and Biodiversity

Hypothesis 3:

Human land use is correlated with environmental gradients such that land use is most intense at hot spots for biodiversity.

Methods

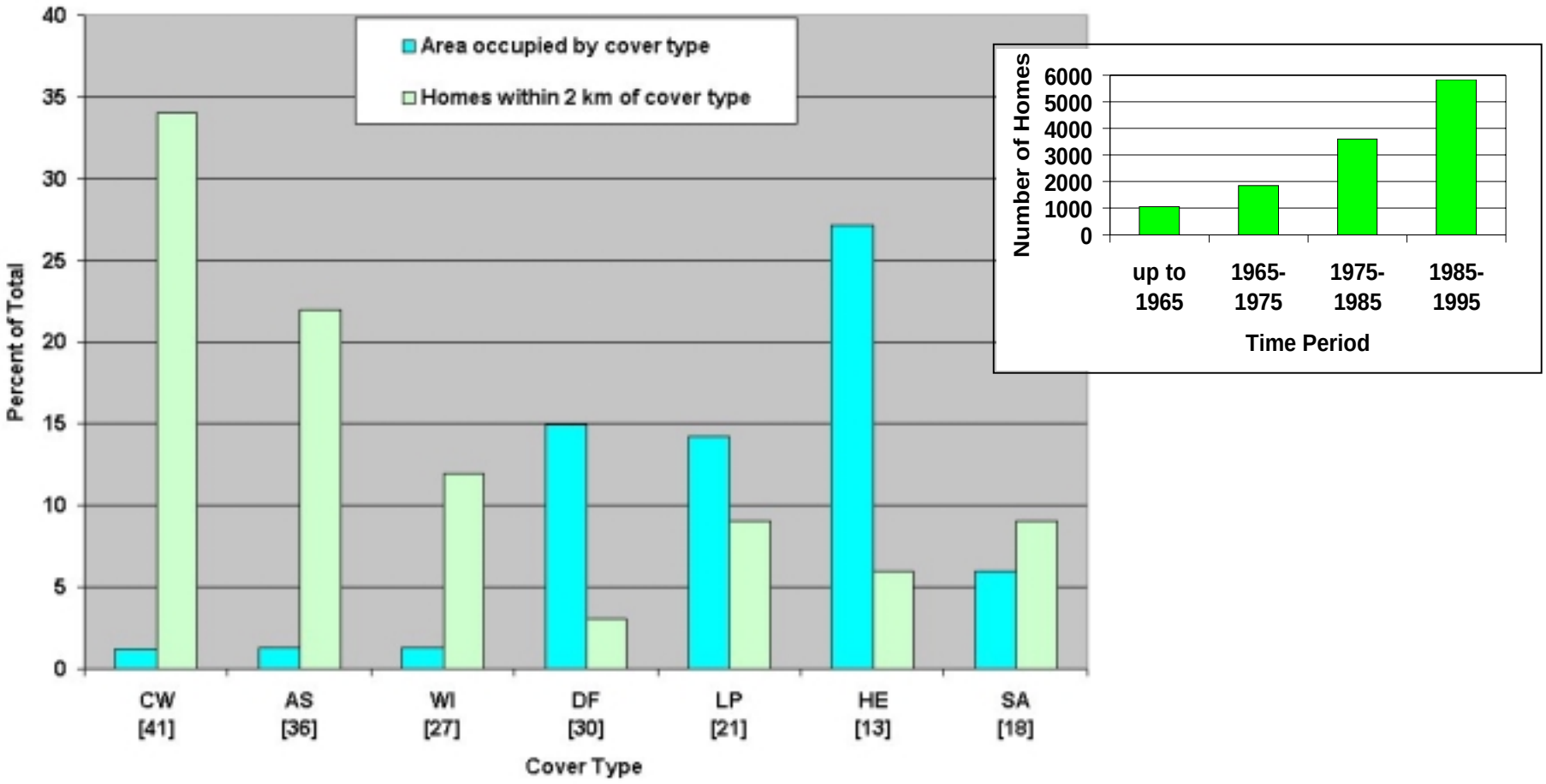
- Obtain home locations from sewer and well records, aerial photos, and field survey.

- Analyze spatial distribution relative to ecological, social, economic factors.

- Evaluate causes of home location from home-owner surveys.

H3: Human Settlement

Preliminary Results



Distribution of Homes Relative to Cover Types

Socioeconomic Performance and Biodiversity

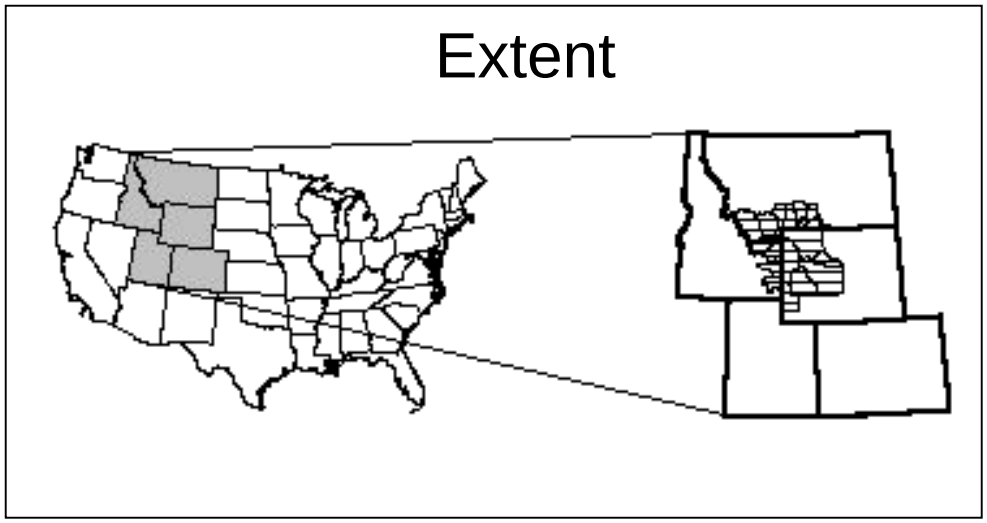
Hypothesis 3:

Population and income growth are associated with both socioeconomic and ecological factors .

Methods

socioeconomic performance = f(x_1, x_2, ….. X_n)

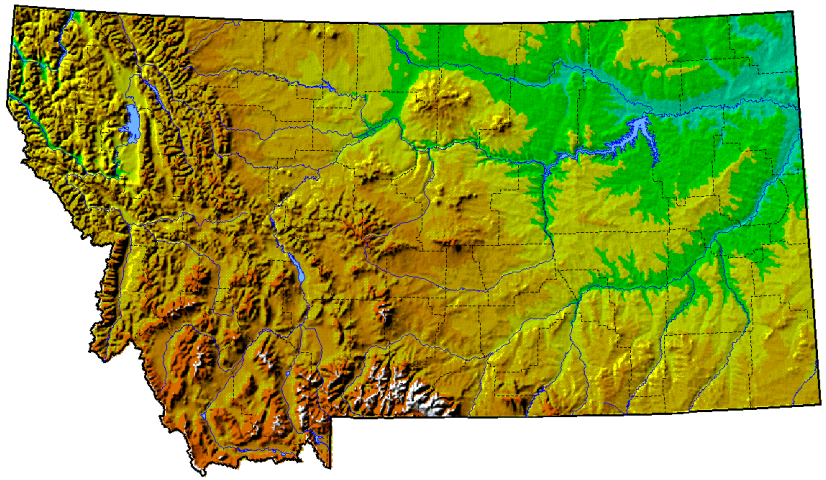
x_1 = ecological factors (topography, soils, water, climate, vegetation, biodiversity)
x_2 = education
x_3 = justice
x_4 = commerce
x_5 = transportation
x_6 = health
x_7 = recreation

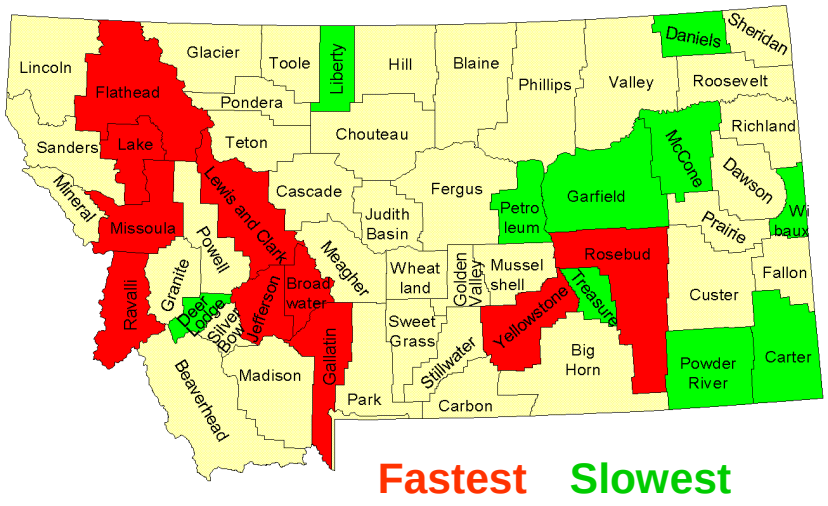


Results: Rocky Mountains

- 87% of income growth in services (especially producer) and nonlabor sectors.
- Extractive industries had only 2% of new income.
- Rural counties with high socioeconomic performance are characterized by growth in producer services. e.g., Aspen, Co., Telluride, Co., Vail, CO., Bozeman, MT., Sun Valley, ID.
- Correlates with "producer service" counties: college ed (% of pop.) and airport service. Not proximity to wilderness, national park, wildlife refuge.

Results: Montana





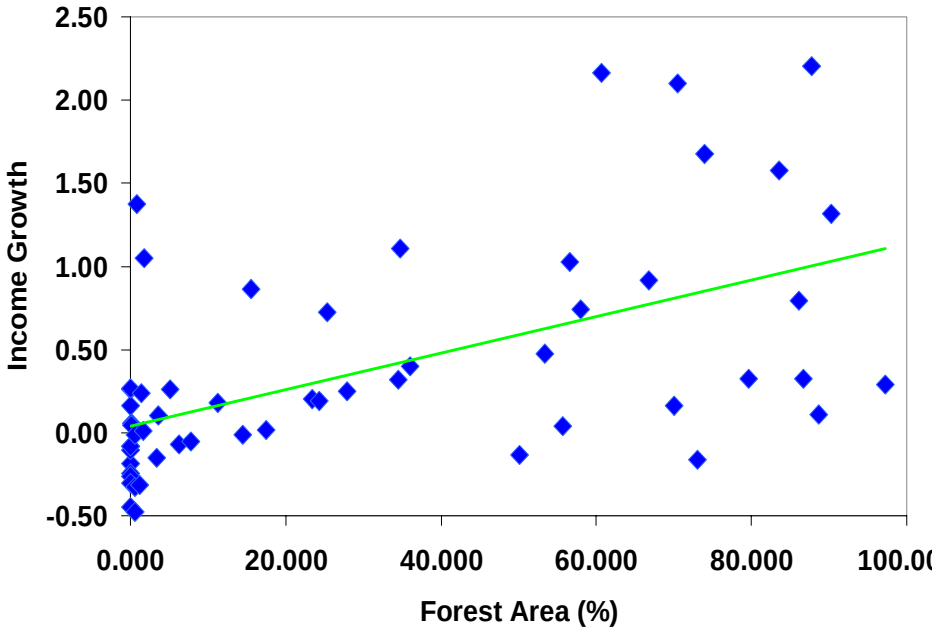
Potential Predictors

elev ppt temp forest reserves, streams, lakes

Best Model

forest tempsd tempm

R^2=.41 P<.001



Land Use Effects on Species Viability

Hypothesis 5:

Intense land use reduces the population viability of some native species.

Methods

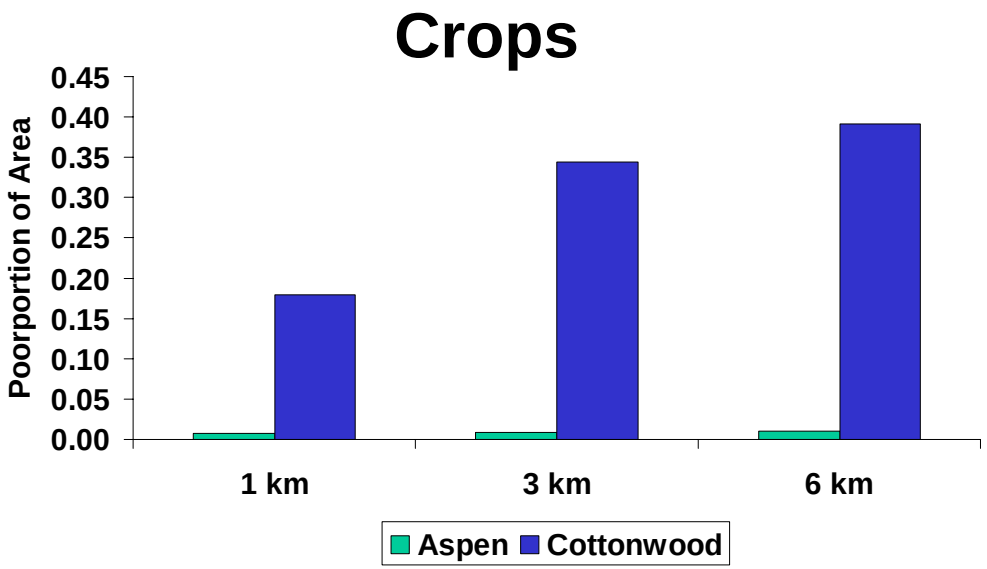
- Locate nests in hot-spot and extensive habitats.
- Monitor reproductive success.
- Analyze data to determine vital rates and association with land use.
- Simulate population growth and probability of extinction.

Results: Demography

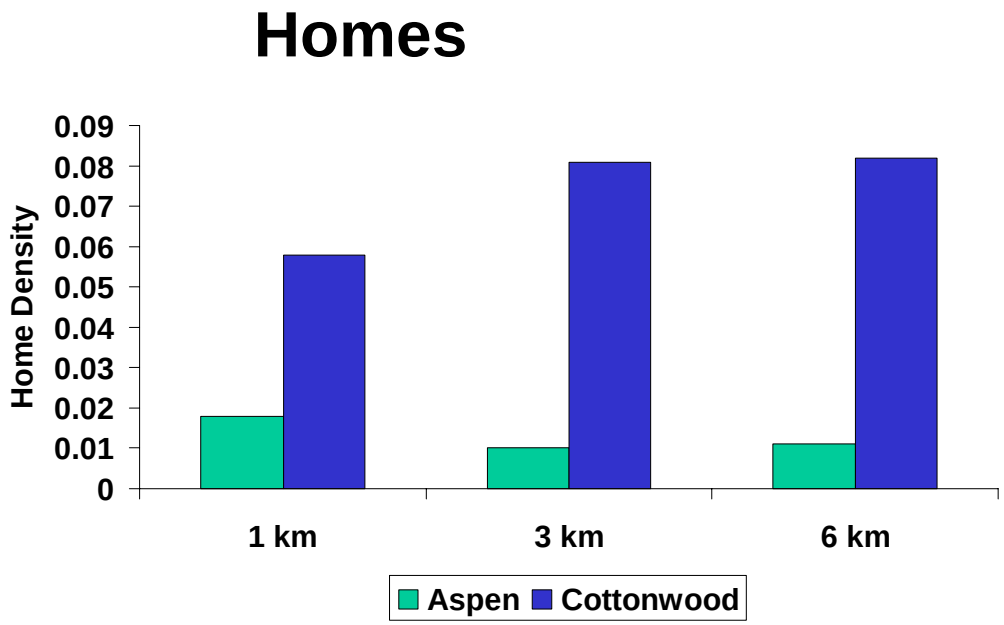
Habitat	Nest Succ.	# Female Fledglings	Pop Growth Rate
AS	54%	0.81	1.13
LP	30%	0.44	0.90
CW	38%	1.32	0.94

Open-Cup Nesters Vulnerable to Cowbirds

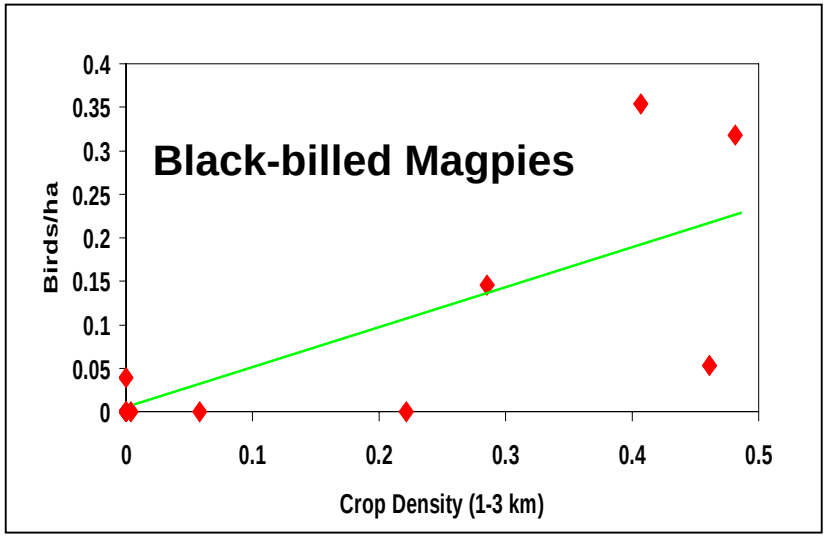
Results: Land Use



Proximity Homes, Crops, Cattle

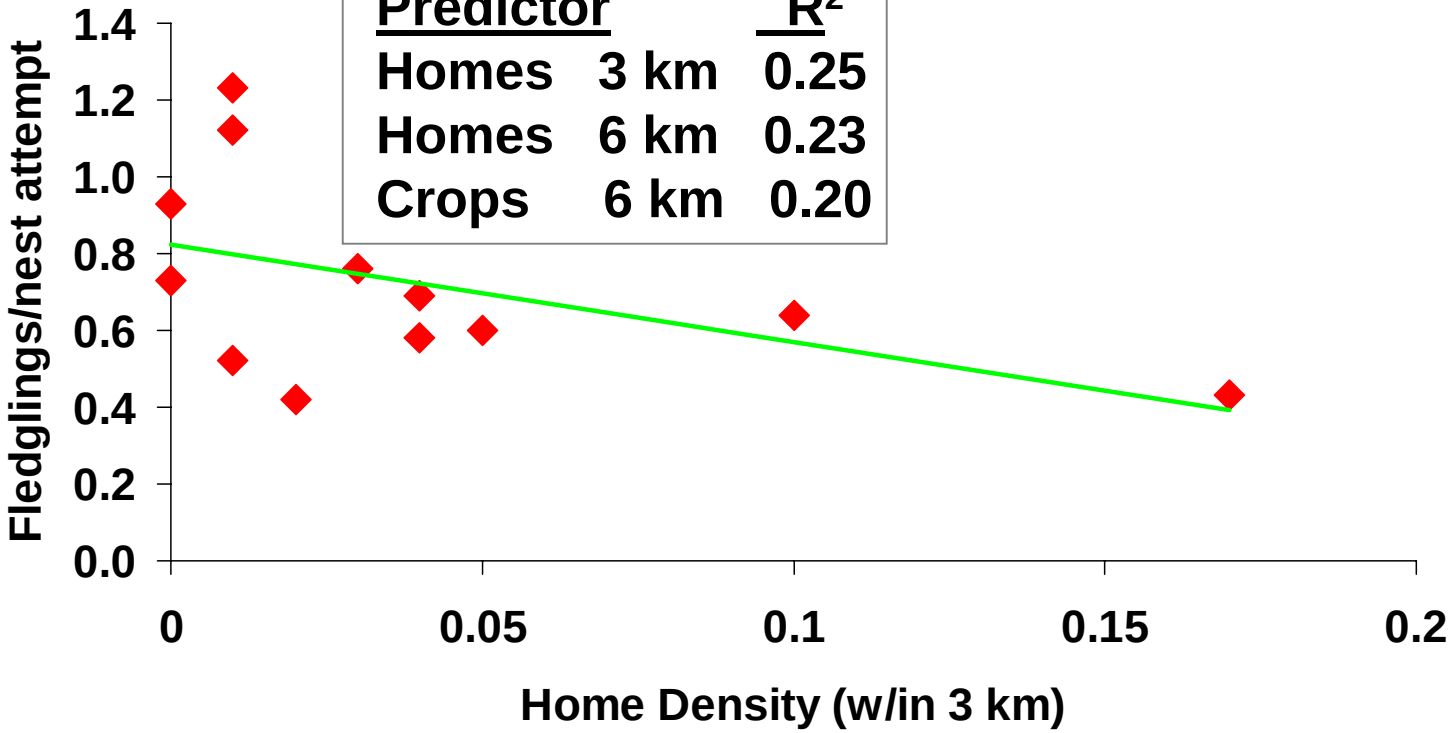


Results: Land Use

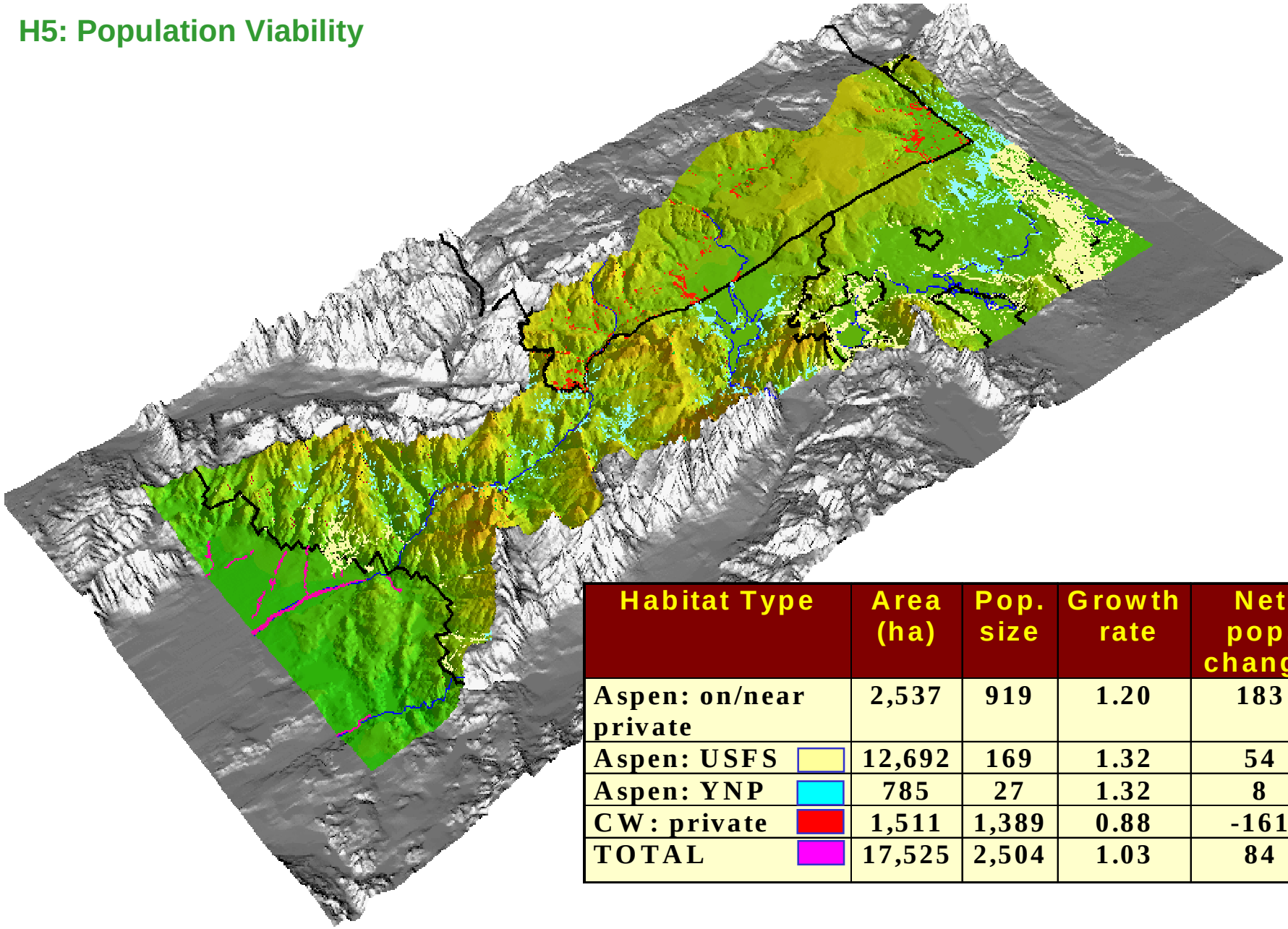


Reproductive Output

Predictor		R^2
Homes	3 km	0.25
Homes	6 km	0.23
Crops	6 km	0.20



H5: Population Viability



Habitat Type	Area (ha)	Pop. size	Growth rate	Net pop. change
Aspen: on/near private	2,537	919	1.20	183
Aspen: USFS	12,692	169	1.32	54
Aspen: YNP	785	27	1.32	8
CW: private	1,511	1,389	0.88	-161
TOTAL	17,525	2,504	1.03	84

Yellow Warbler Sources and Sinks

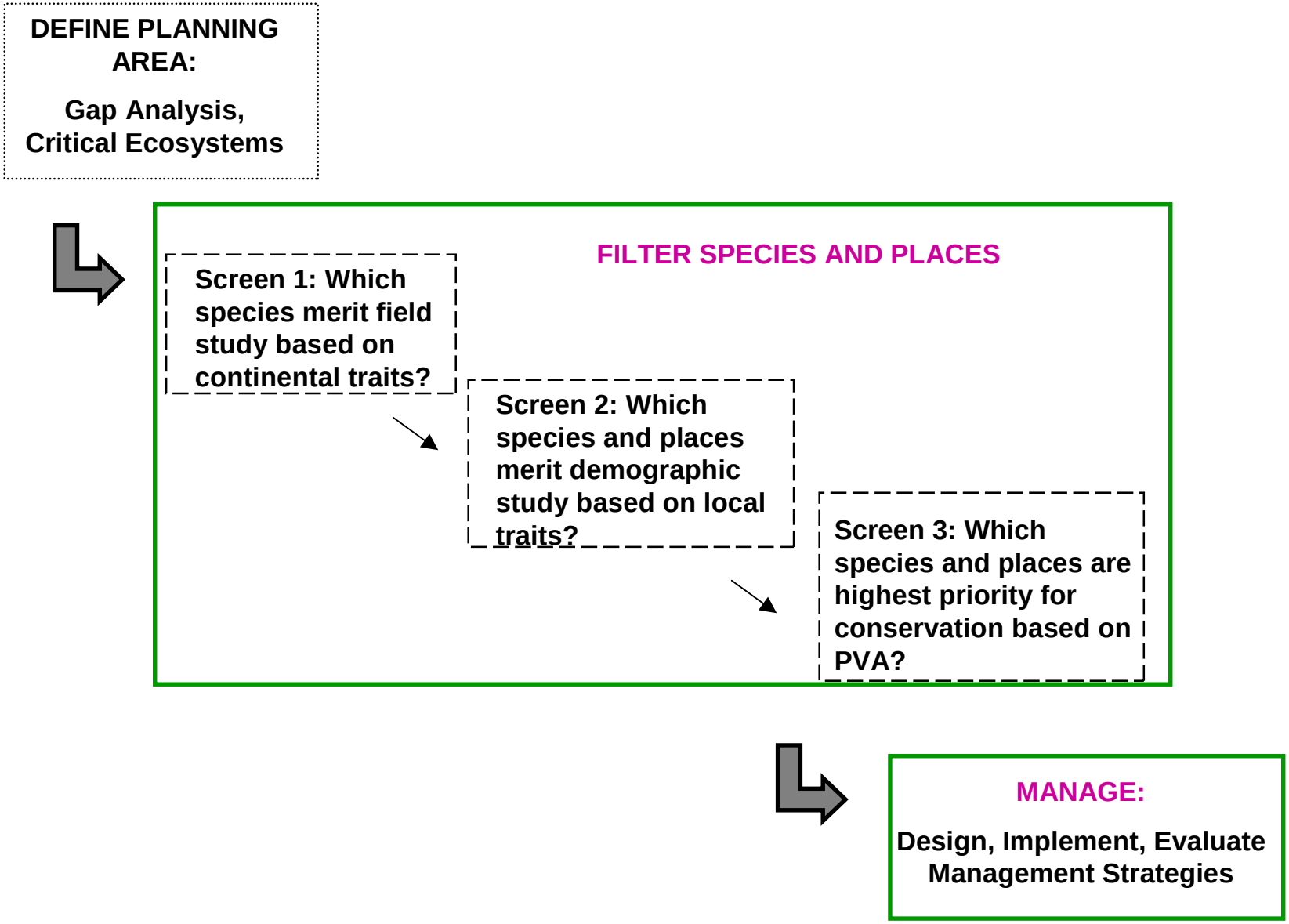
Objective 3: Risk Assessment

Approach

- Develop a systematic approach for identifying which species are most at risk of extinction and what places in the landscape are required by these species.
- Apply the approach to the current GYE landscape as a basis for conservation.
- Develop and apply a system to predict future land use on private lands.
- Assess biodiversity risk under the simulated future landscape.

Obj 3: Risk Assessment

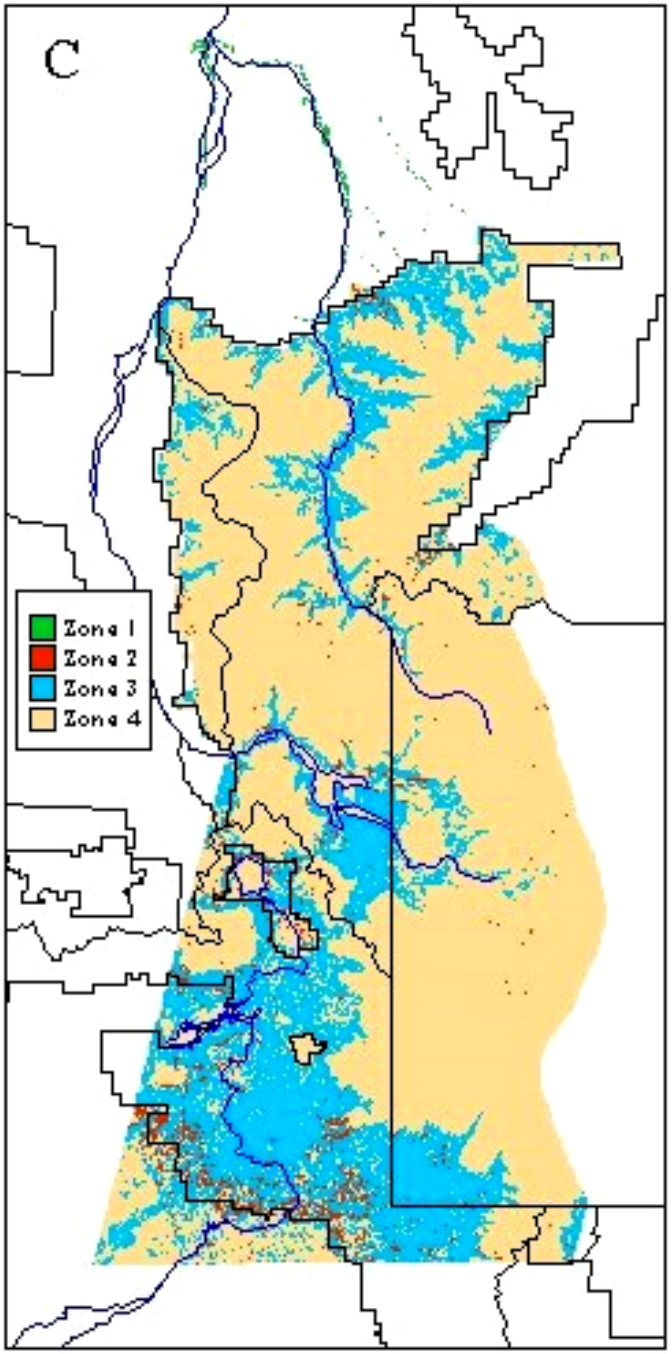
DYNAMIC HABITAT AND POPULATION ANALYSIS



Examples of Species Deemed Most At Risk

- American redstart
- Willow flycatcher
- Veery
- Boblink
- Western woodpeewee
- Hammond's flycatcher
- Red-naped sapsucker
- Orange-crowned warbler
- Northern oriole
- Ruffed grouse
- Black-backed woodpecker

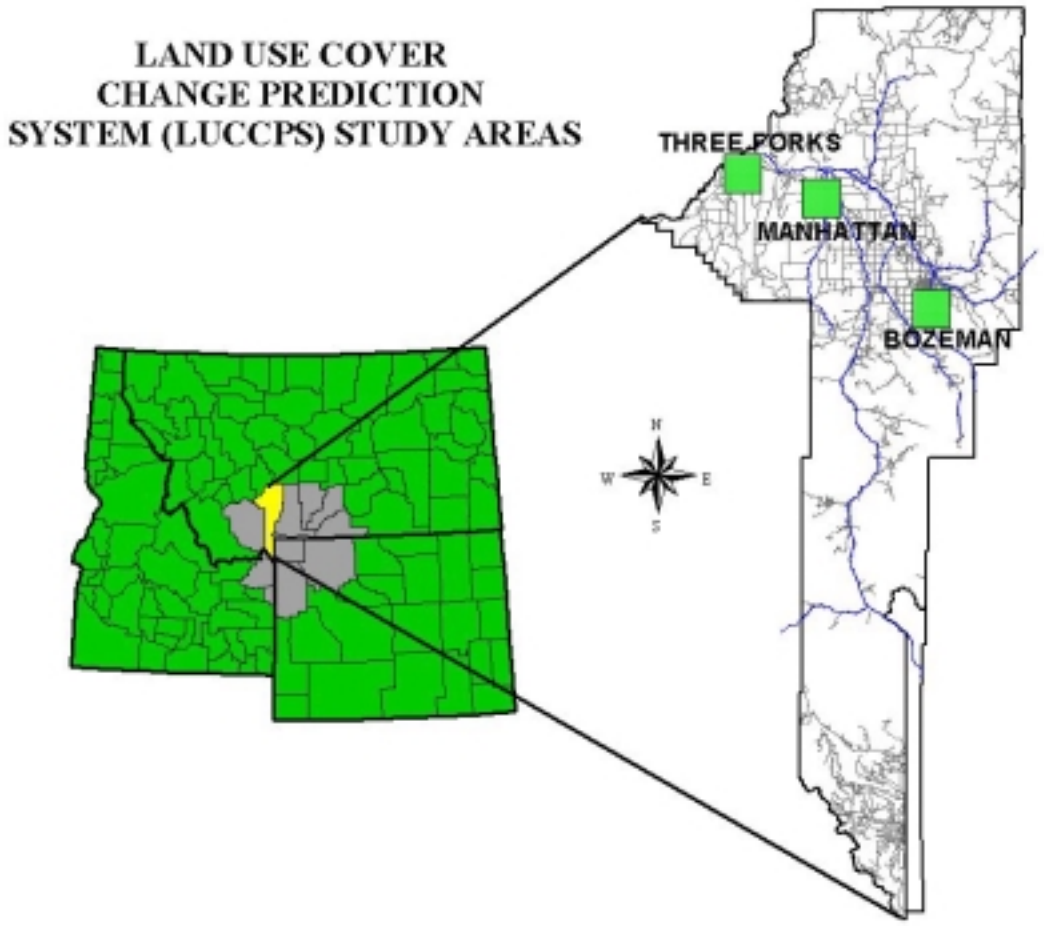
Obj 3: Risk Assessment



Example of Conservation Plan

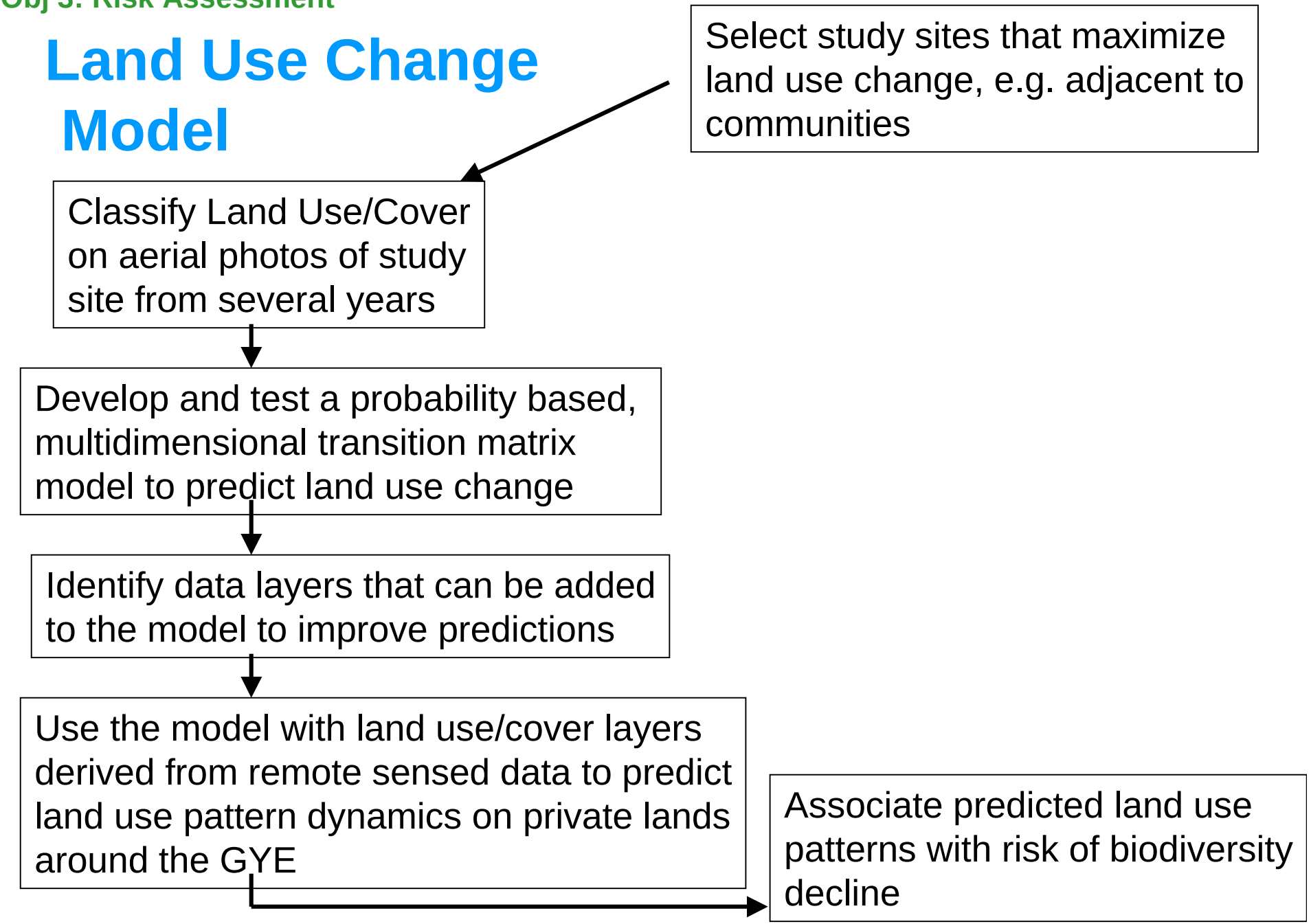
Obj 3: Risk Assessment

Land Use Cover Change Change Prediction System (LUCCPS)

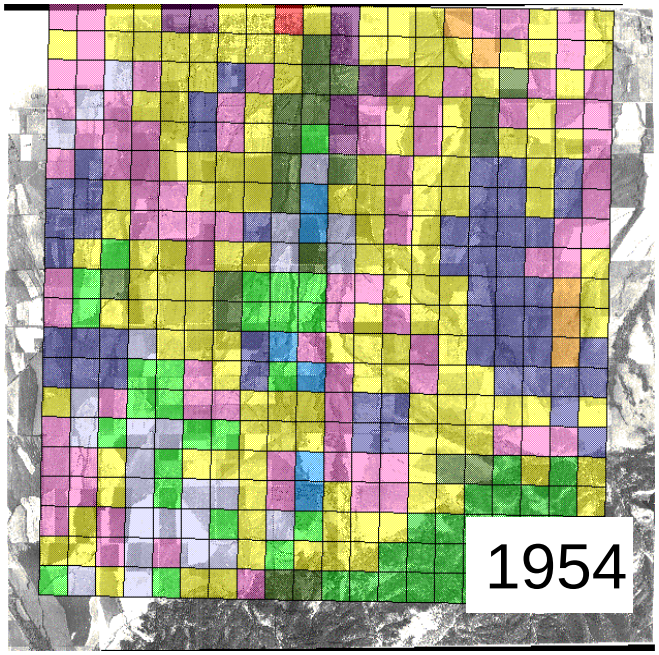


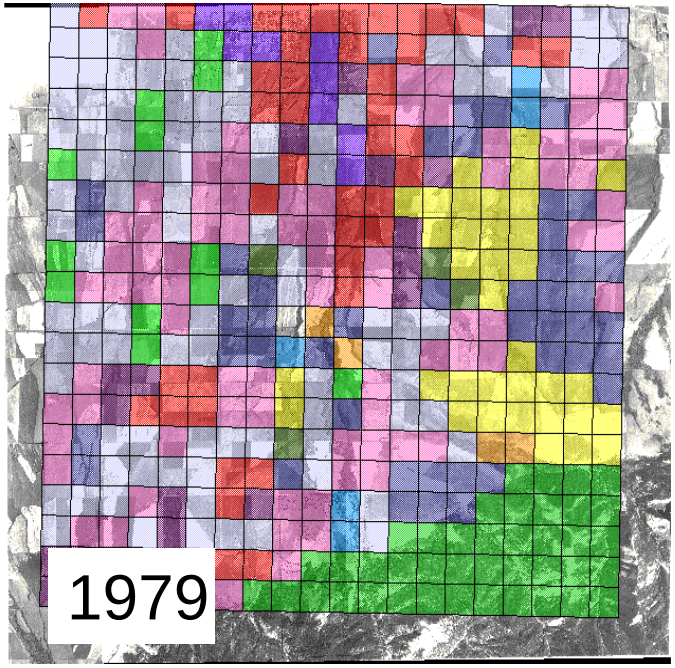
Obj 3: Risk Assessment

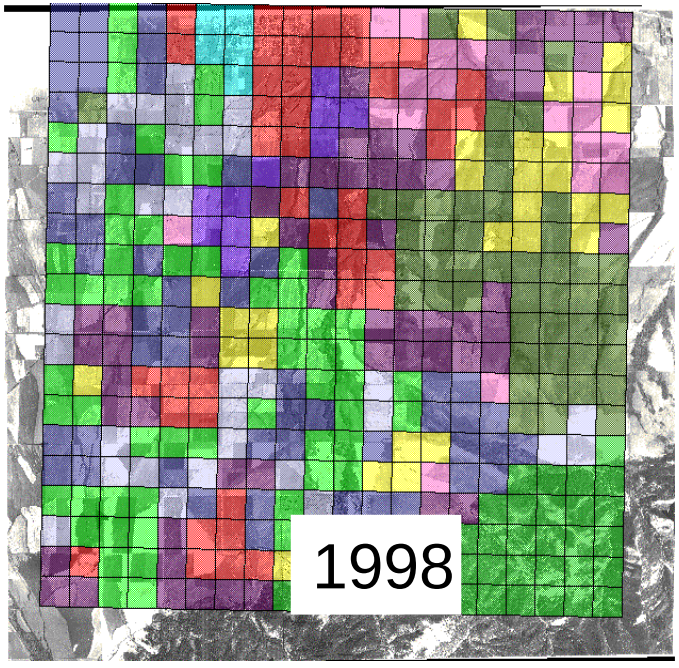
Land Use Change Model



Land Use Change : Bozeman, MT.

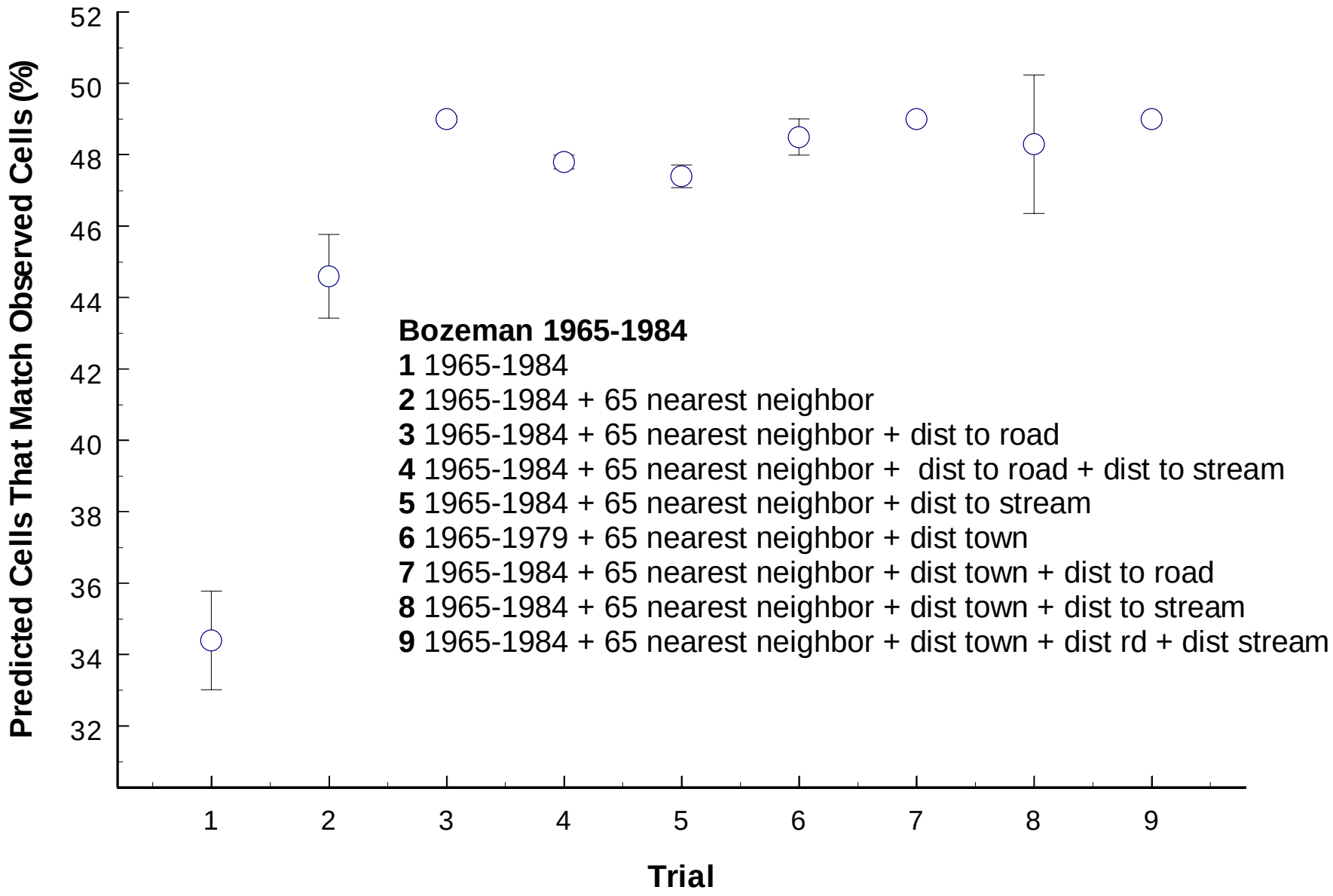




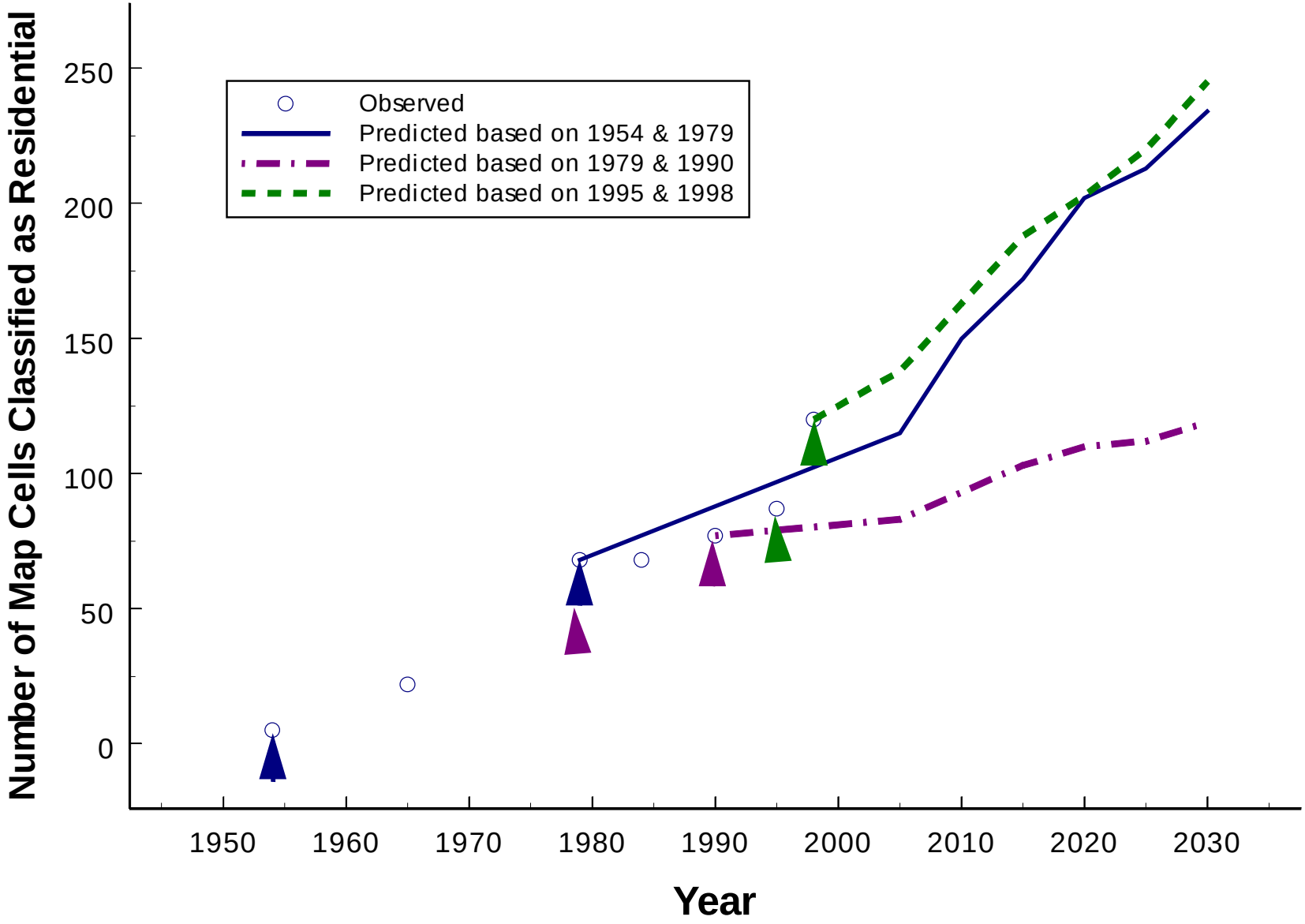


- Residential
- Low Density Housing
- Turf, Golf Course & Open Space
- Industrial, Commercial & University
- Dryland Crop Production
- Irrigated Crop Production
- Dryland Hay
- Irrigated Hay
- Shrub Rangeland
- Dryland Pasture
- Bottomland Native Range
- Riparian Zones
- Conifer Forest

Modified Transition Probabilities



Predictions of Residential



Objective 4: Monitoring

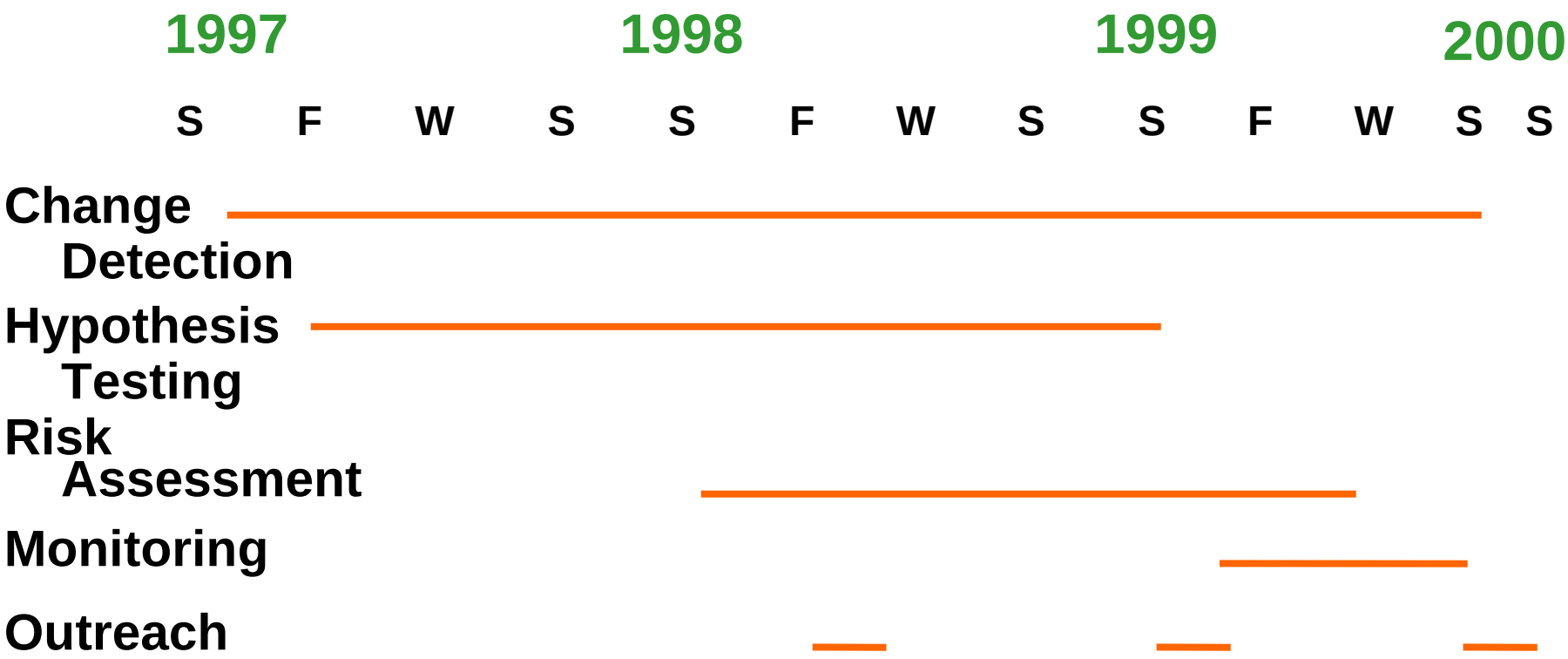
Approach

- **Identify methods and data sources to “Take the pulse of the GYE” periodically.**

Objective 5: Outreach

- **Workshops: Bozeman, MT 1998, Jackson, WY 1999, Cody, WY 2000.**
- **Presentations: >15/yr to science, policy, management forums.**
- **Tools: land use model, risk assessment approach, socioeconomic workbook.**
- **Data: MSU:GYE Clearing house**
- **Media: Radio (Living on Earth, Morning Edition, High Country News Radio); Press (local newspapers and magazines).**

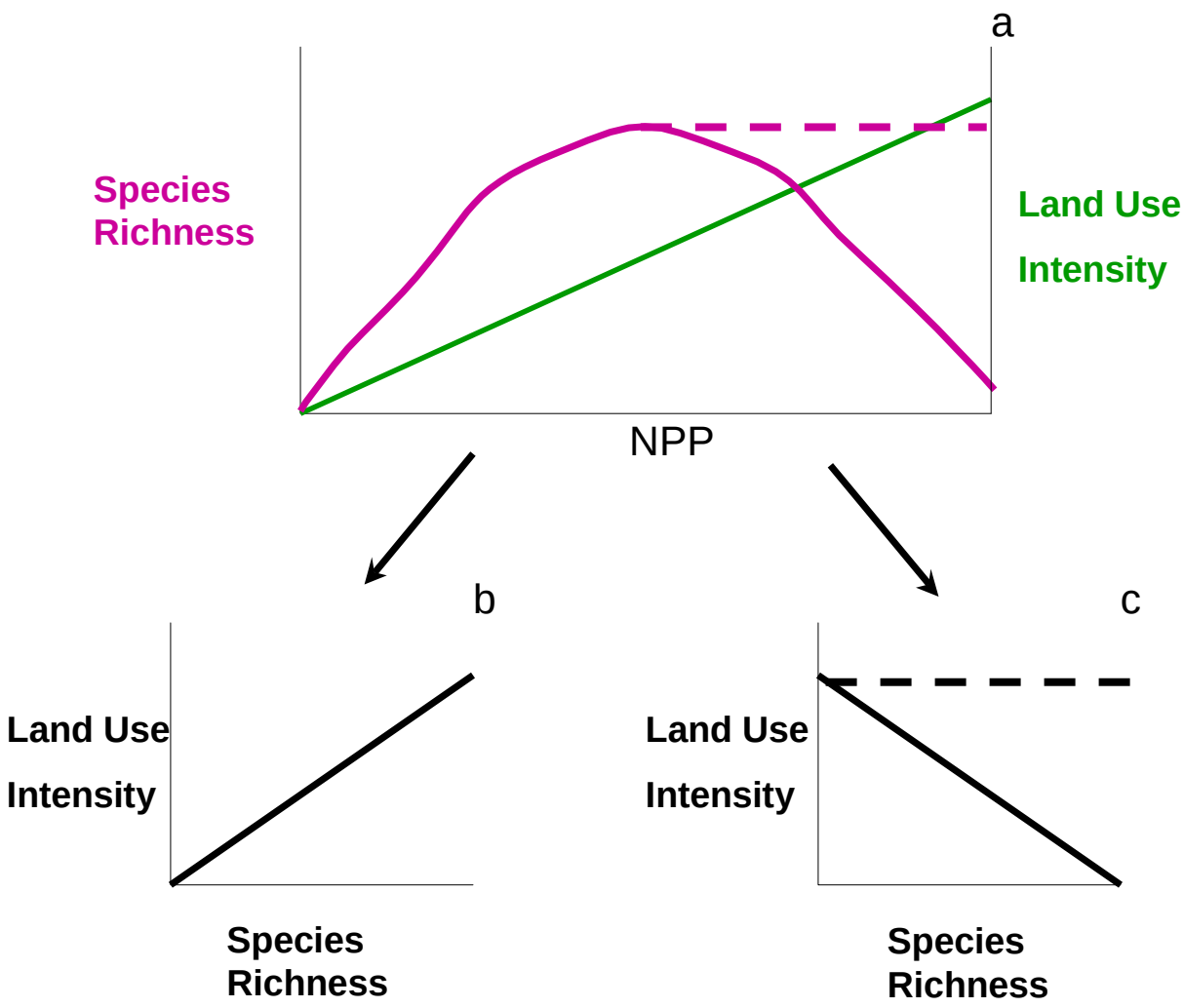
SCHEDULE


1997
1998
1999
2000
S F W S S F W S S F W S S
Change Detection
Hypothesis Testing
Risk Assessment
Monitoring
Outreach

Next Steps

- **GYE: Validation, Monitoring (e.g.,** Hansen and Rotella. IN Review. Indicators of biotic integrity and diversity in Greater Yellowstone: Development, validation, and application. **EPA.**
- GYE: Population Viability (e.g., Hansen and Rotella. In review Avian Population Viability in a Greater Ecosystem: Interactive Effects of Climate and Land Use. USDA-NRI.)
- **Regional Comparision (e.g. Interactions among biodiversity and land use across greater ecosystems.**

Generality to Other Greater Ecosystems



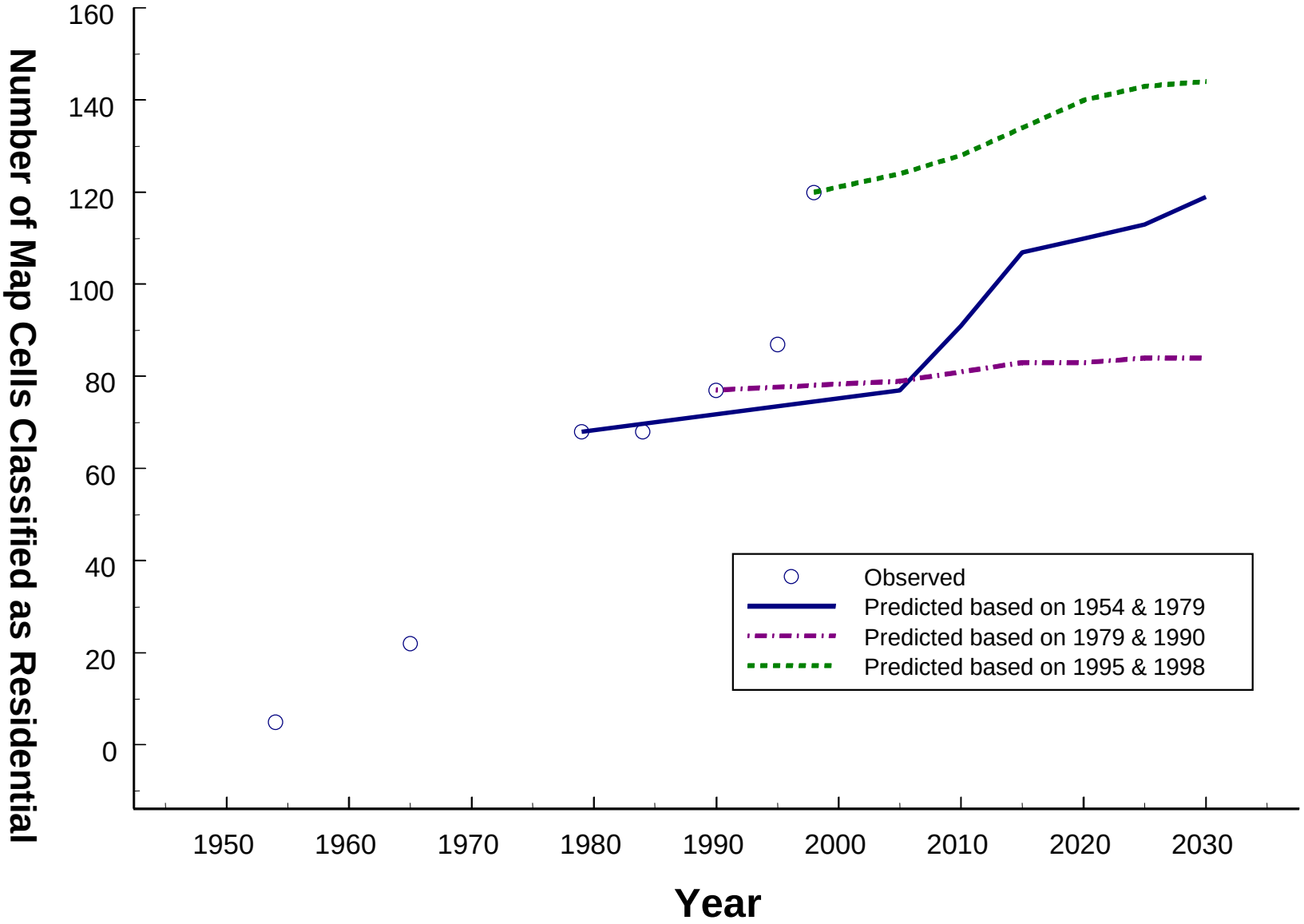
Land Cover Classification Methods

Change Detection

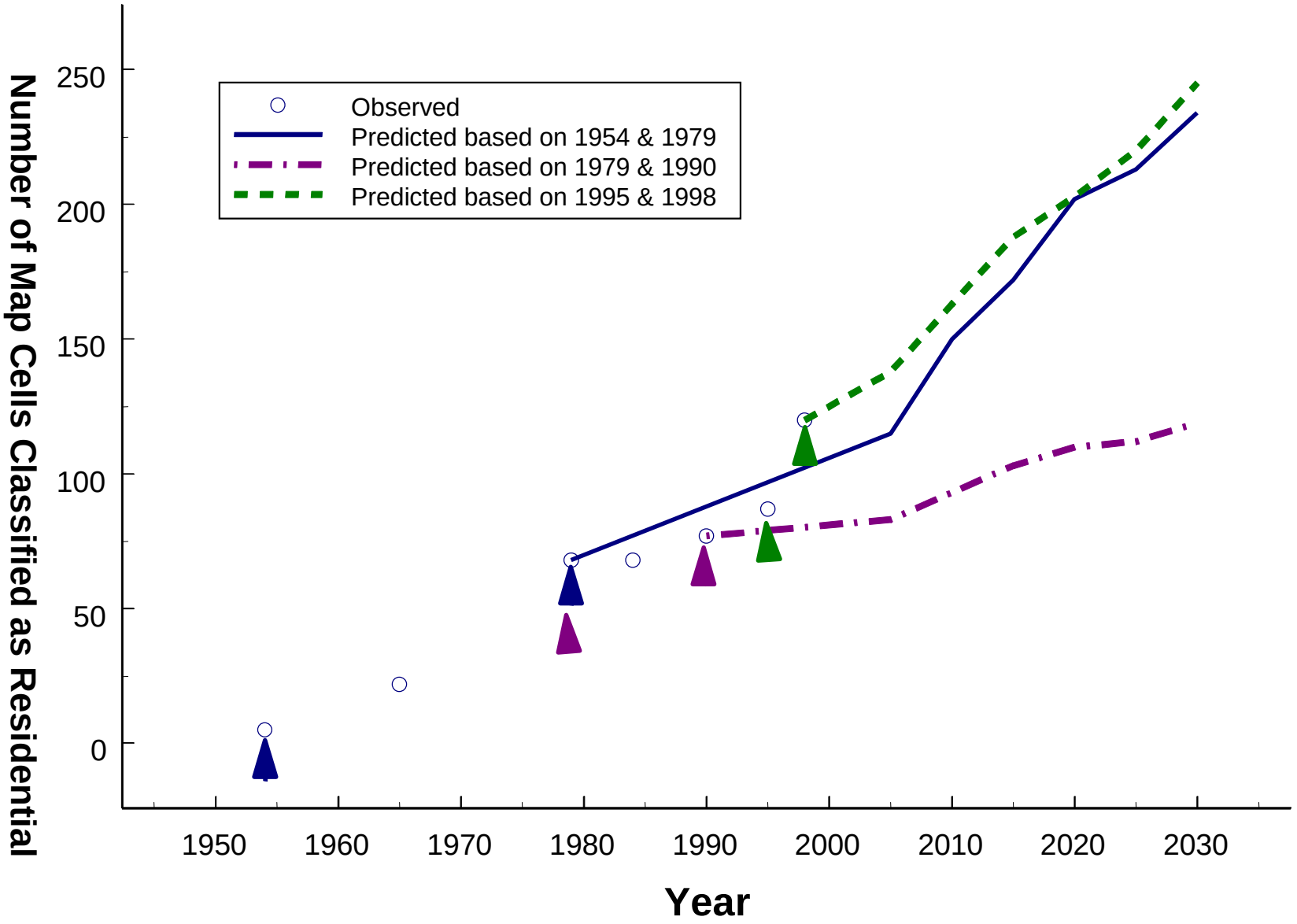
- **1. Obtain imagery:** 1976 Landsat MSS, 1985 Landsat MSS and TM, 1994 TM
- **2. Identify difference thresholds:** examine multispectral imagery and denote changes in cover type between 1985 and 1994
- **3. Determine change function:** identify type of previous cover type for areas that change
- **4. Assign cover type:** for each pixel in imagery. For cells unchanged, assign 1994 cover type.
- **5. Validate for accuracy:** use independent data

South of Bozeman Study Area

using nearest neighbor layer



South of Bozeman Study Area



Correlation-based designation of single ground control point

Subset from
Input Image

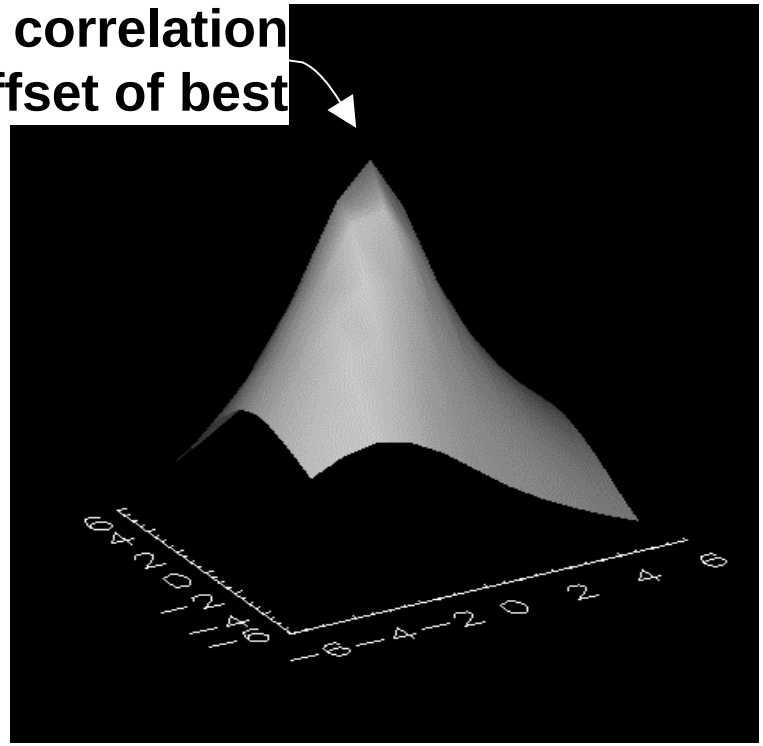
"Floating"

Y-offset

X-offset

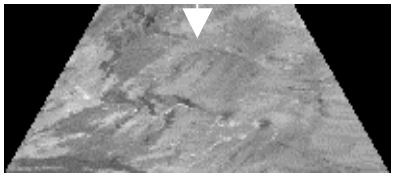
Offset used to calculate
coordinates of GCP

Peak of correlation
at offset of best



Calculate correlation at each
offset

"Anchored"



Subset from
Reference Image

Russia

Early Results- Modeling carbon dynamics and their economic implications in two forest regions: pacific northwestern USA and northwestern Russia - J. Kerkvliet

Early Results- Effects of the development of the Baikal Amur mainline railroad on patterns of boreal forest cover and carbon fluxes in sourthern Siberia - E. Kasischke

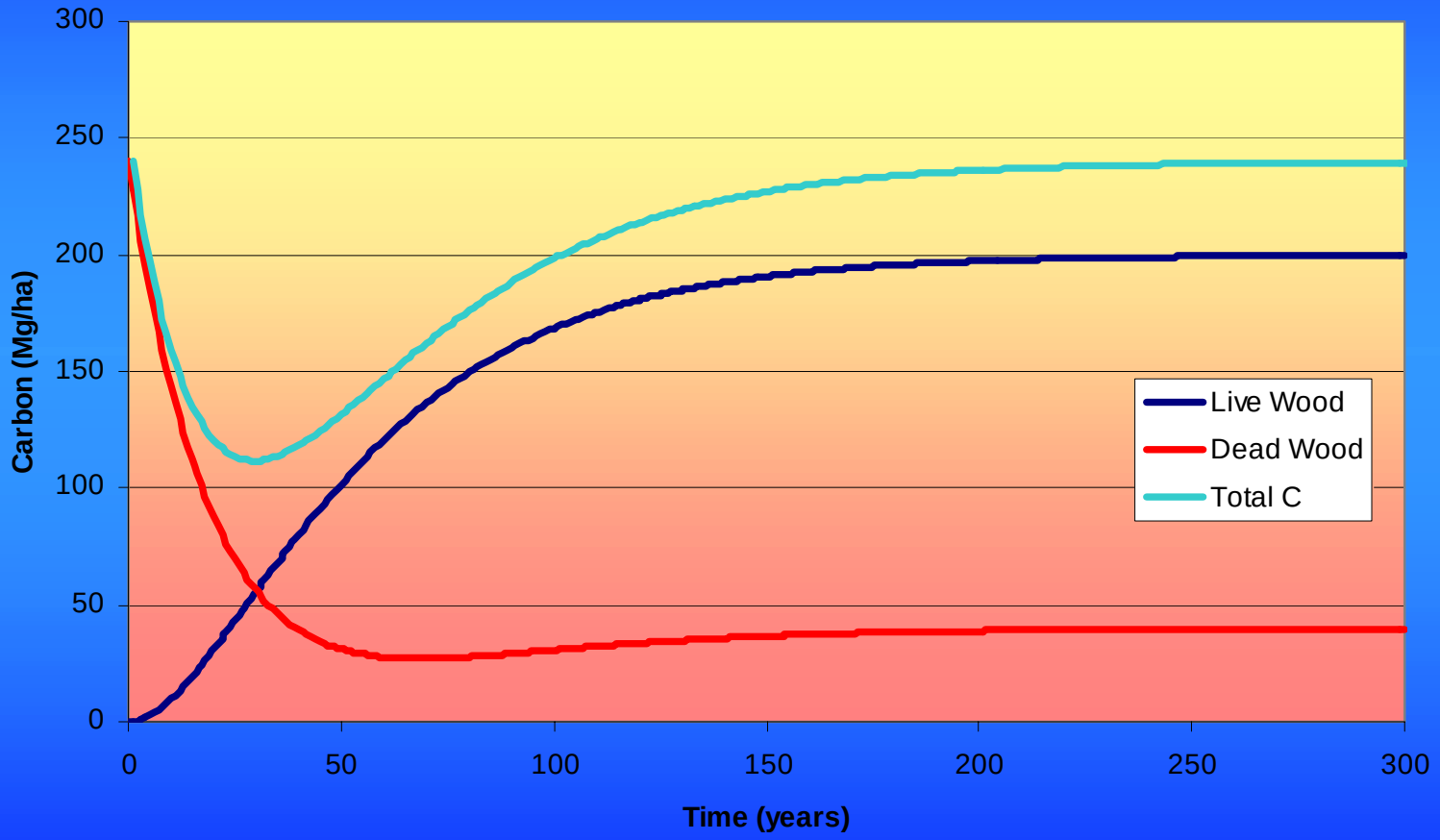
Modeling Carbon Dynamics and their Economic Implications

W. Cohen, Mark Harmon, Joe Kerkvliet, Olga Krankina, David Wallin

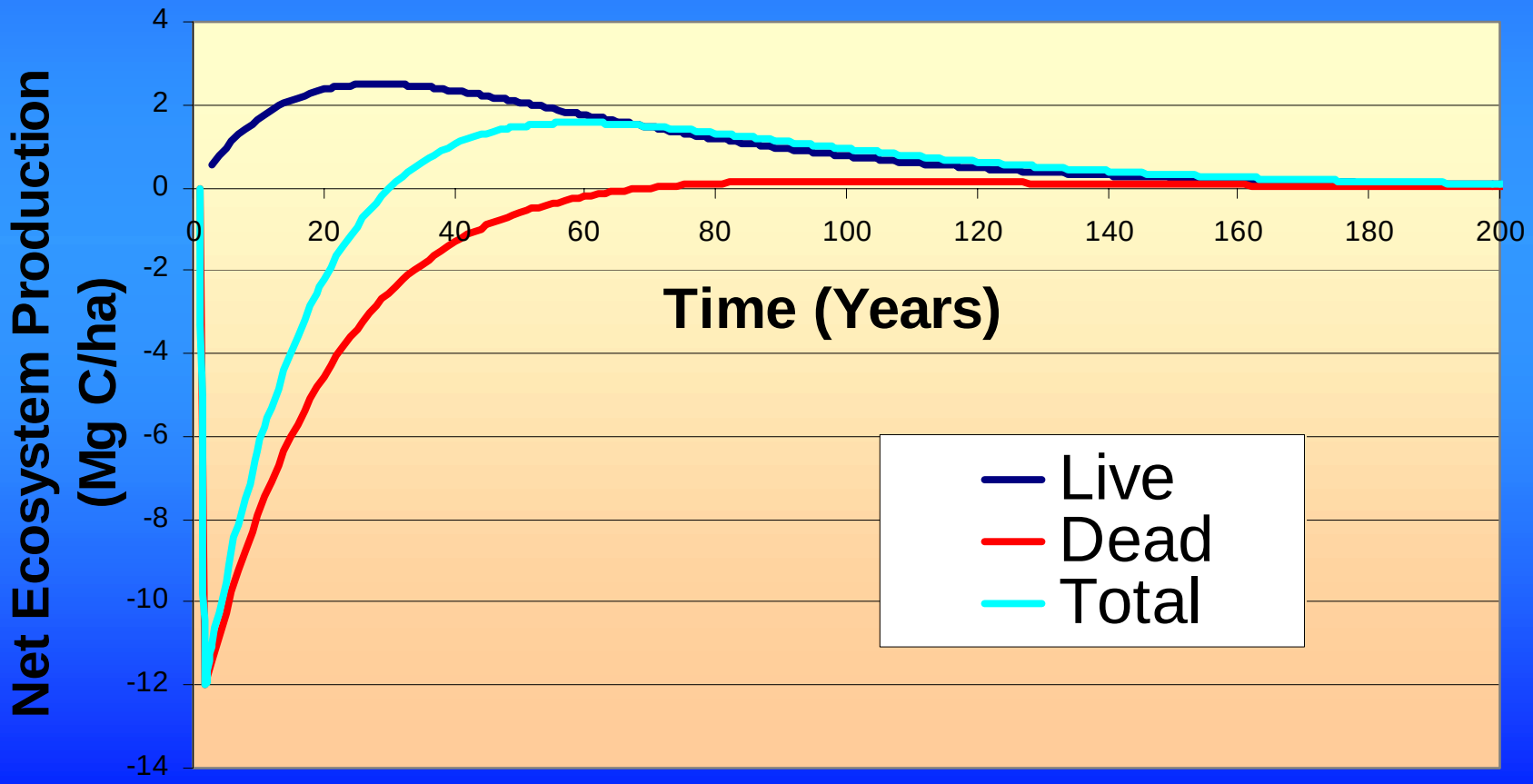
It Depends on How We Treat Them

- Deforestation
- Aforestation
- Reforestation
- New Forestation

Change in Carbon Stores



Change in Exchange of Carbon



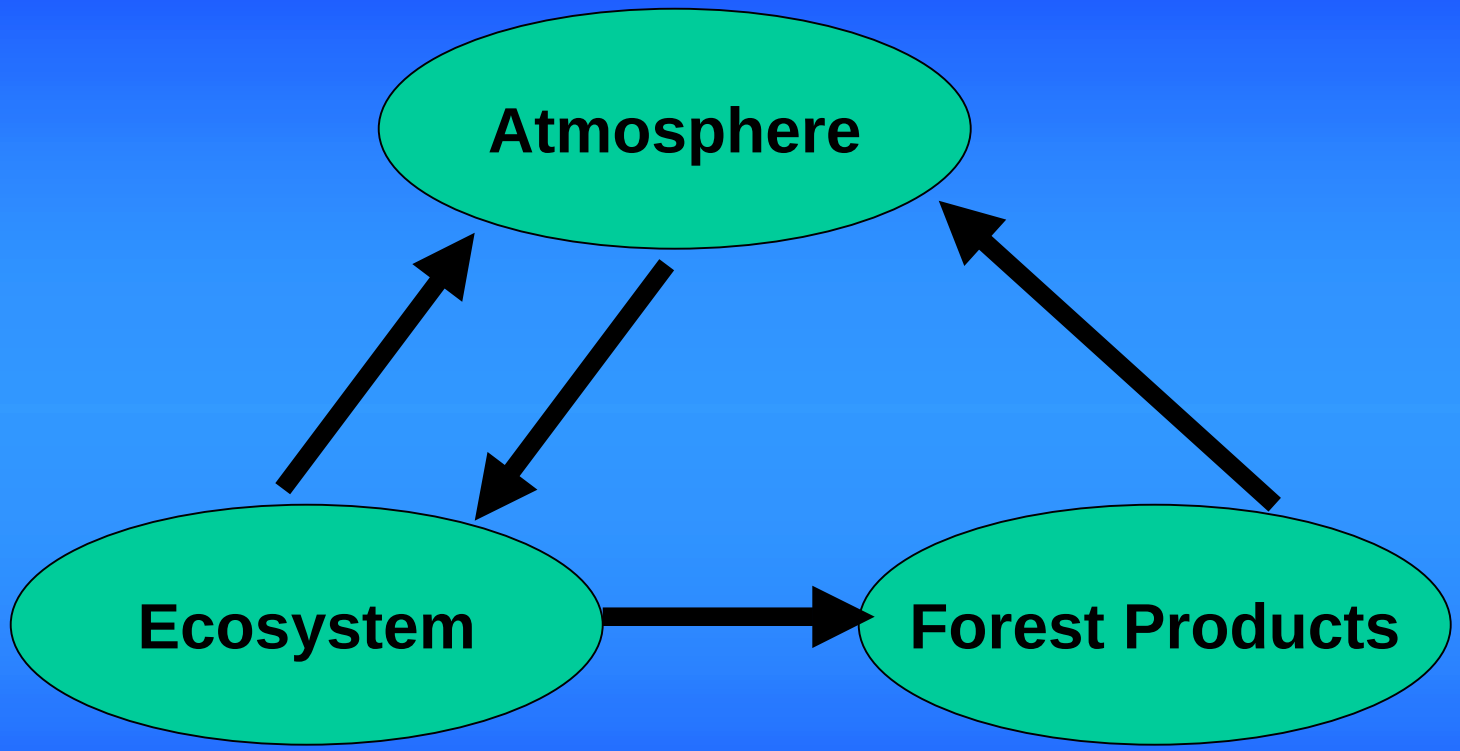
Effects on Carbon Storage of Conversion of Old-Growth Forests to Young Forests

MARK E. HARMON, WILLIAM K. FERRELL, JERRY F. FRANKLIN

Pool	60 year-old	Old-growth
Foliage	5	6
Live Wood	152	349
Roots	35	77
Detritus	26	123
Soil	56	56
Total	**274**	**611**

If Not Here Then Where Else?

Expanding the System



Two Approaches

- Measurement--Harvest and Forest Cover Maps of Oregon Forests
- Modeling-Standcarb-Micro Forest Dynamics. Computes transitions after disturbance
- Modeling-Regioncarb-Steady-state landscape. No transitions, but fast.

Two Decades of Carbon Flux from Forests of the Pacific Northwest

Estimates from a new modeling strategy

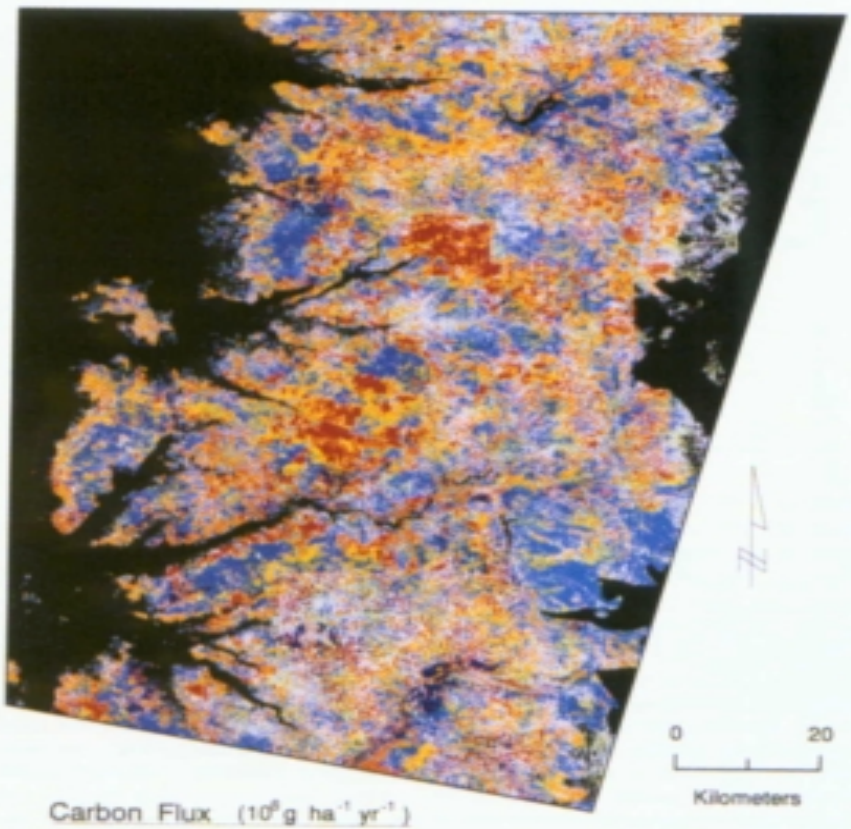


Figure 3. Net carbon flux over the subset study area between 1972 and 1991.

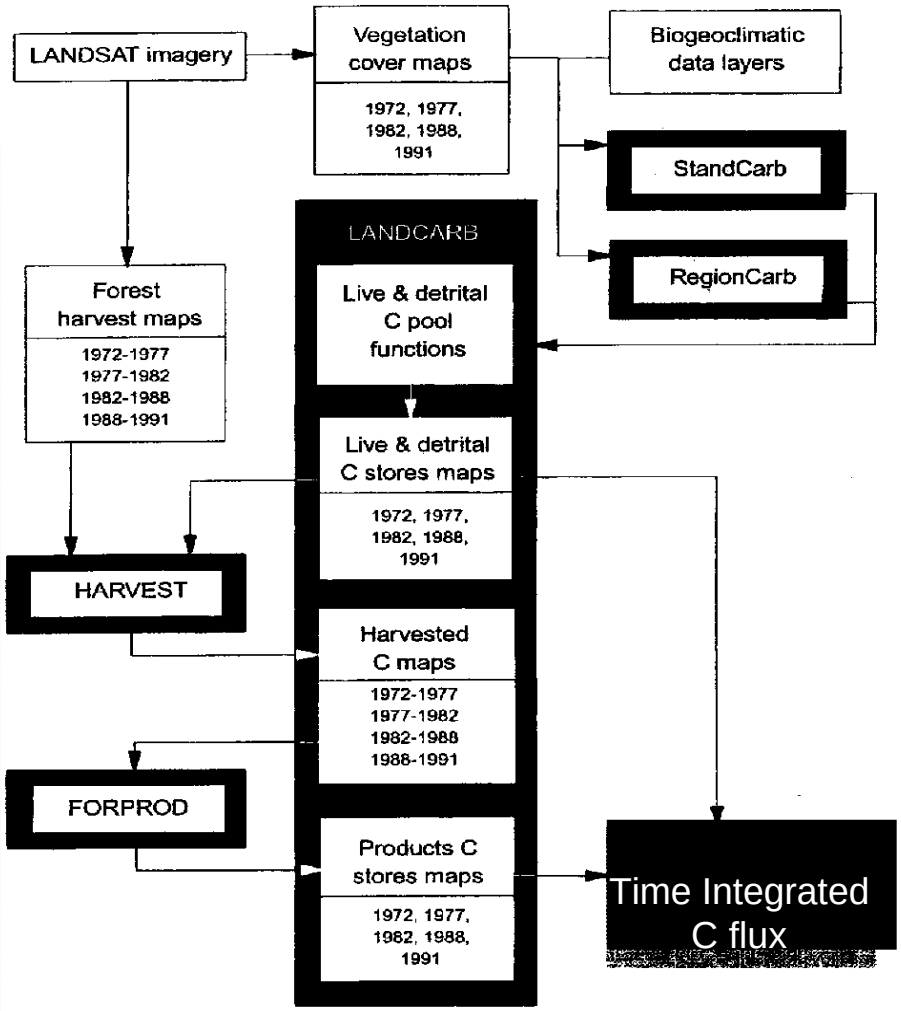


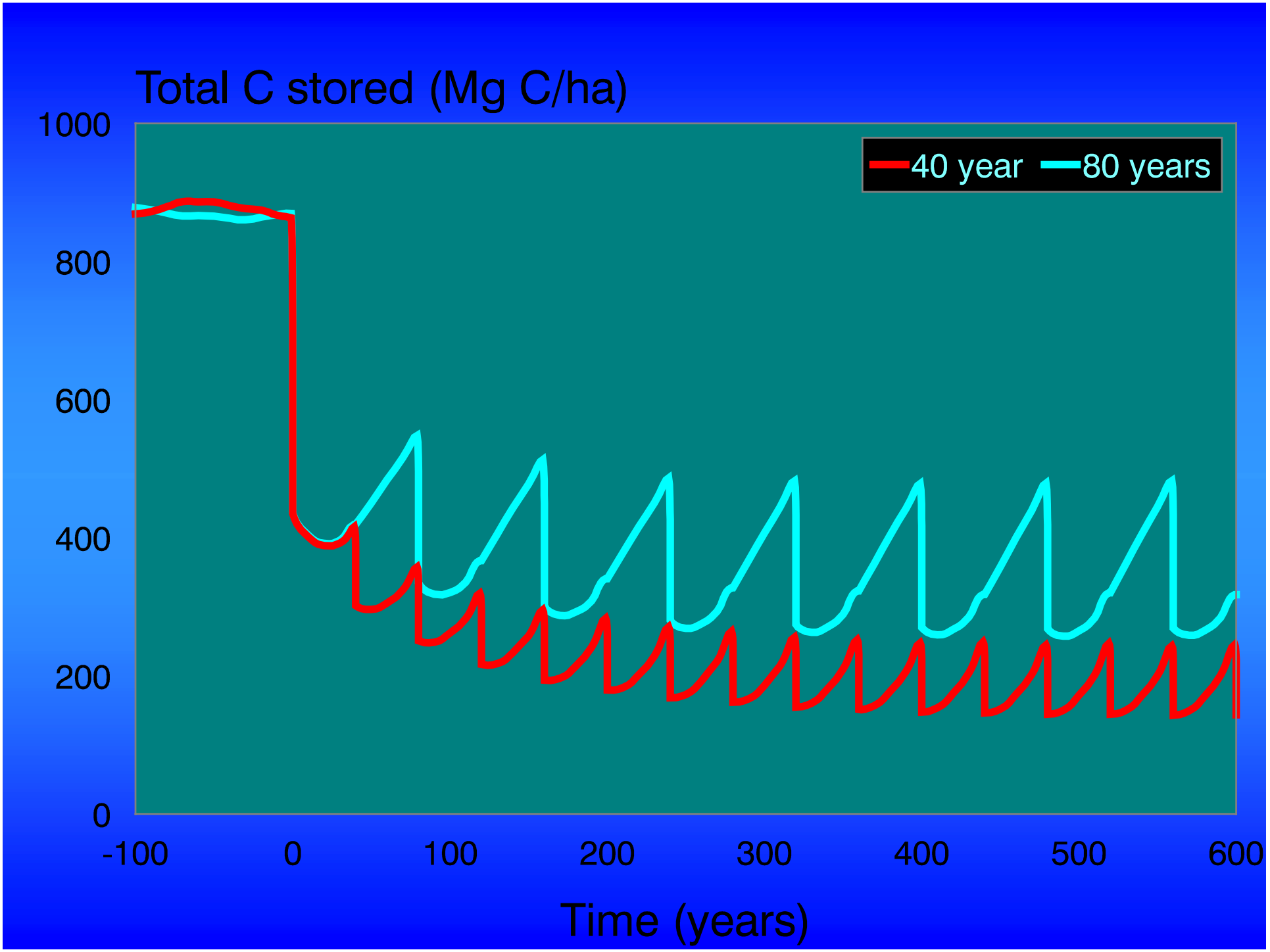
Figure 1. Schematic for the overall modeling strategy used to estimate carbon flux.

NET RESULT OF MEASUREMENT

- THREE DECADES OF PACIFIC NORTHWEST FOREST MANAGEMENT
- NET SOURCE OF ATMOSPERIC CARBON

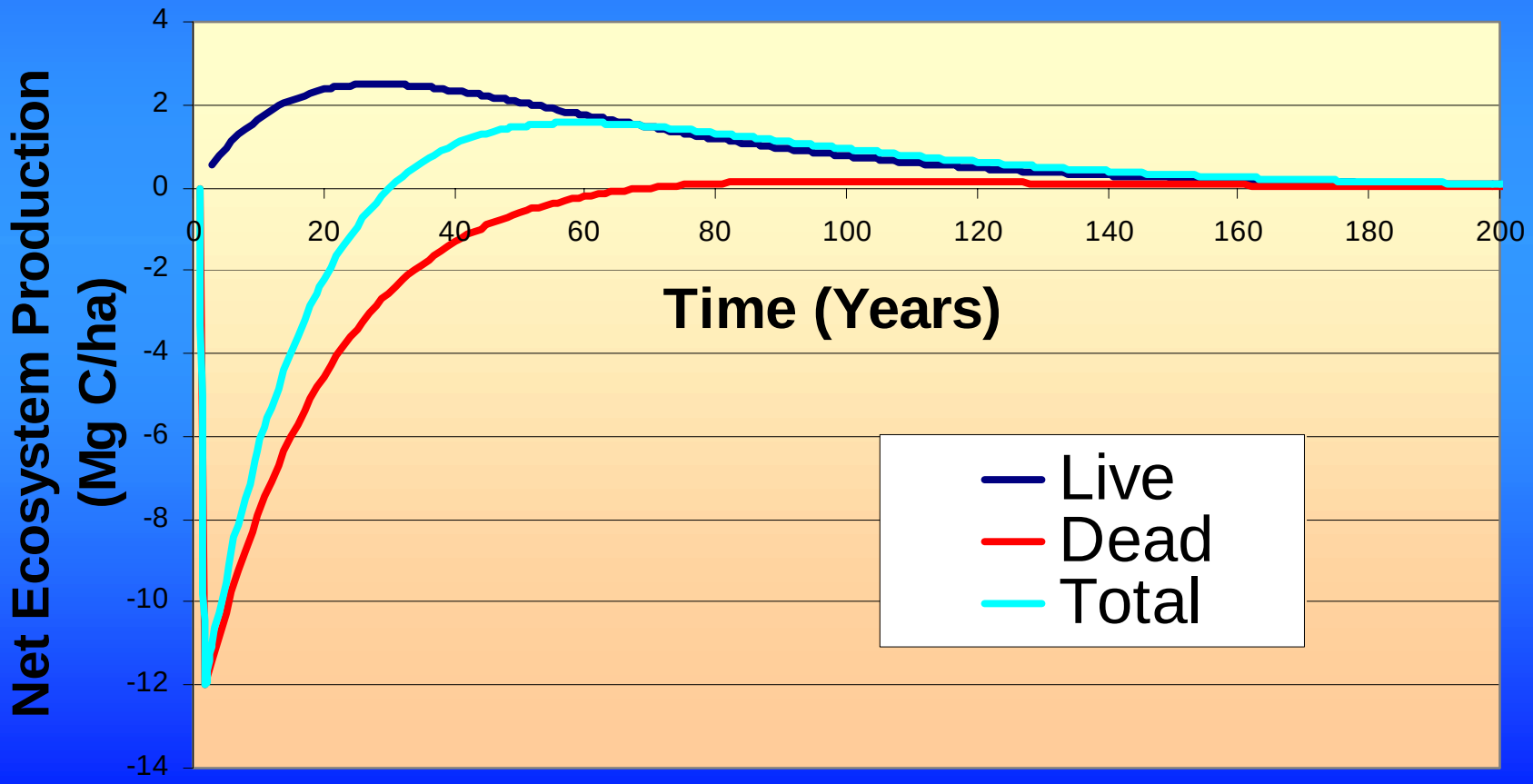
CARBON STORAGE SENSITIVE TO FOREST MANAGEMENT

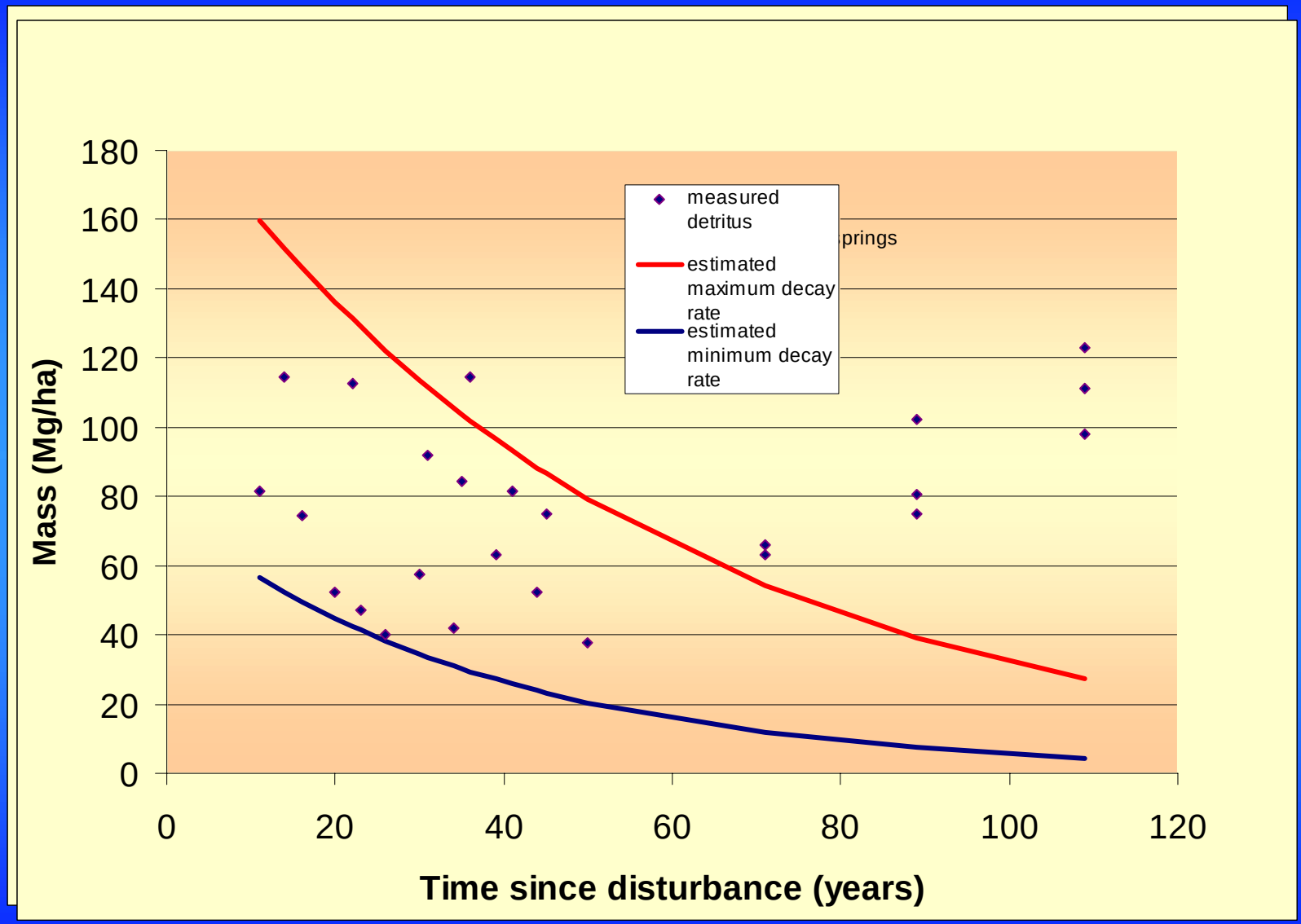
- ROTATION LENGTH
- CLEARCUTTING VERSUS OTHER METHODS
- PRE-COMMERCIAL AND COMMERCIAL THINNING
- PLANTING
- HIGH INTENSITY VERSUS LOW INTENSITY HARVESTING

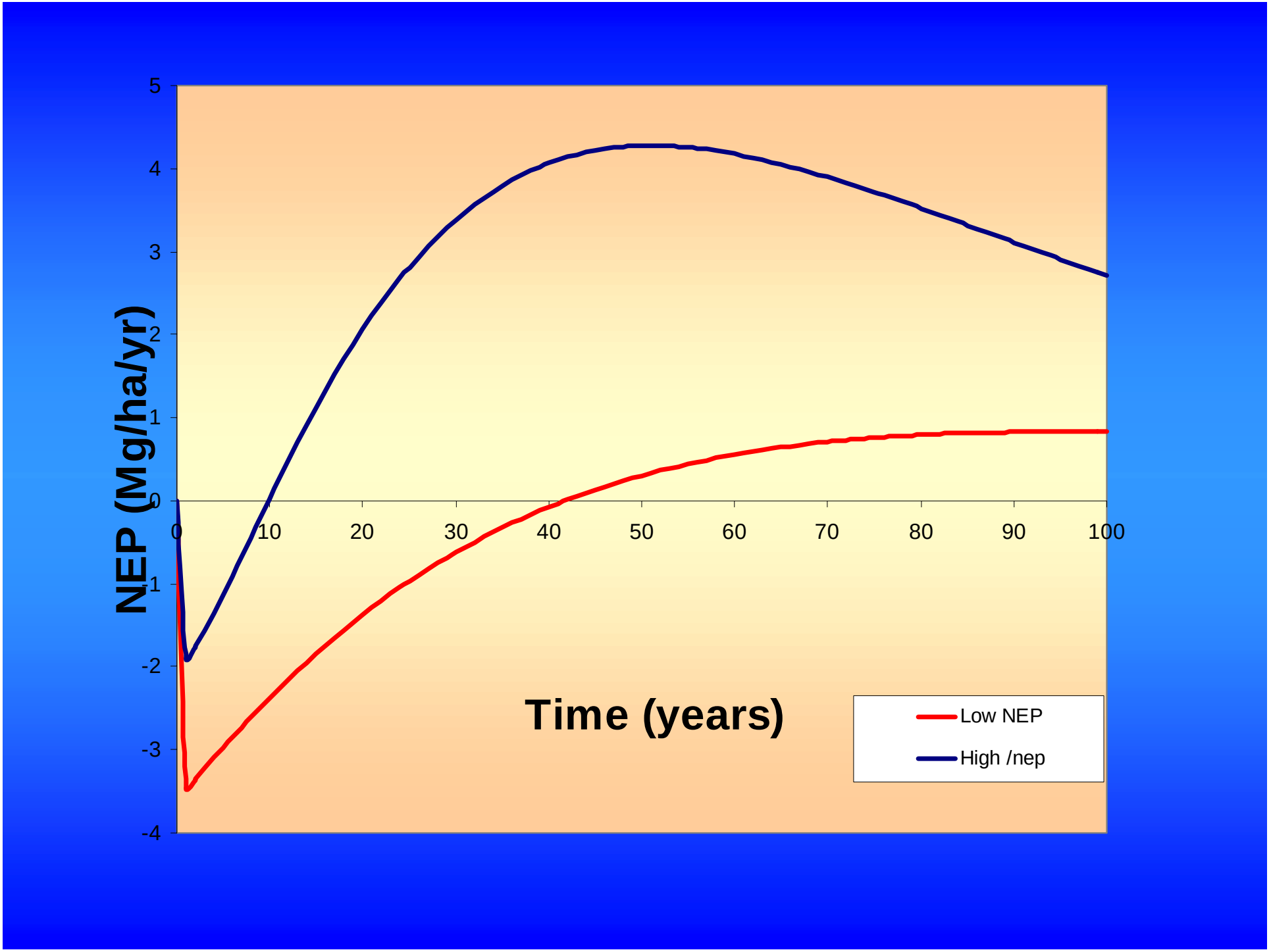

Total C stored (Mg C/ha)
1000
800
600
400
200
0
40 year
80 years
-100
0
100
200
300
400
500
600
Time (years)

BUT ALWAYS A TRANSITION PERIOD OF NEGATIVE N.E.P.

Change in Exchange of Carbon

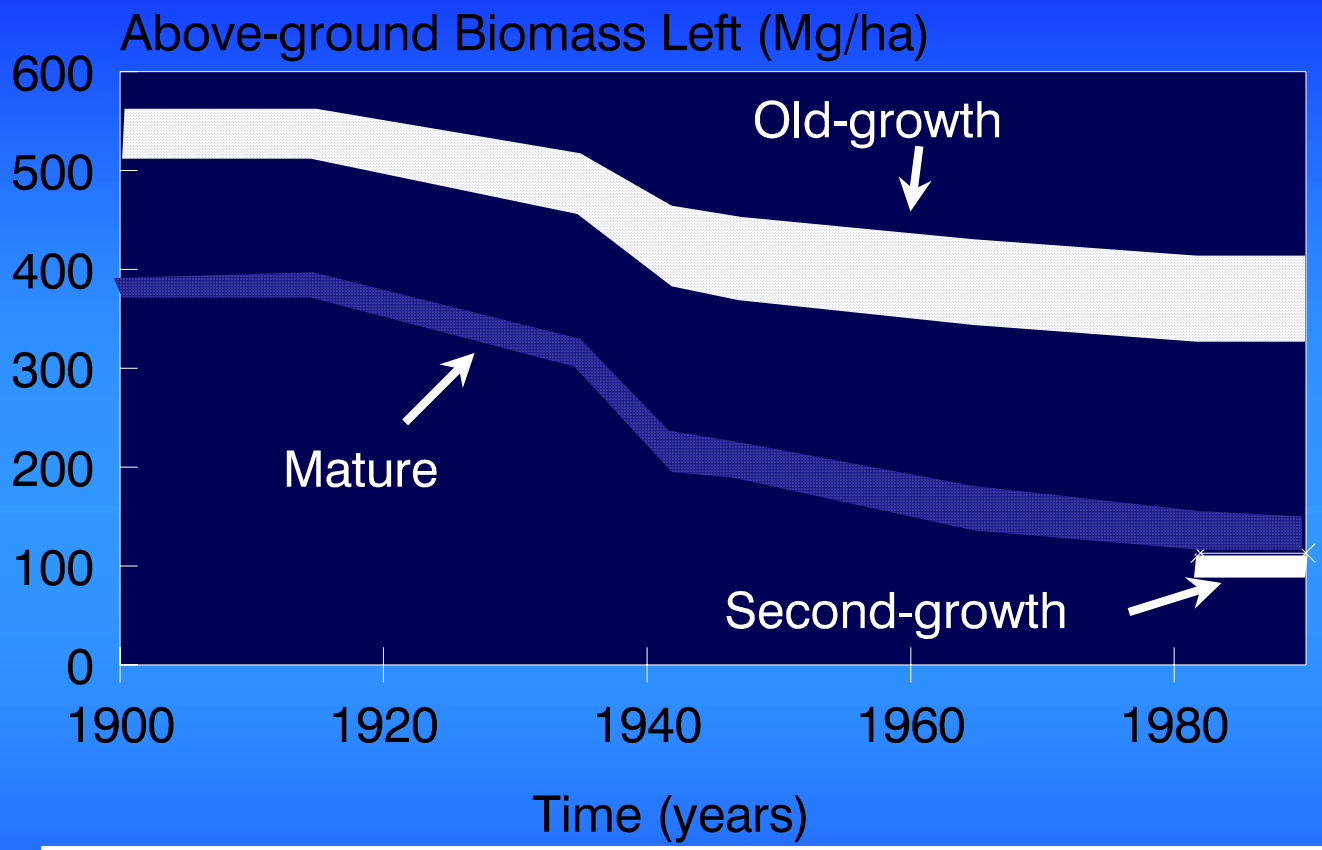



180
160
140
120
100
80
60
40
20
0
Mass (Mg/ha)
0
20
40
60
80
100
120
Time since disturbance (years)
measured detritus
estimated maximum decay rate
estimated minimum decay rate
prings


NEP (Mg/ha/yr)
5
4
3
2
1
0
-1
-2
-3
-4
0
10
20
30
40
50
60
70
80
90
100
Time (years)
Low NEP
High /nep

FORESTRY PRACTICES ARE ALWAYS CHANGING

Historical Changes in Harvest

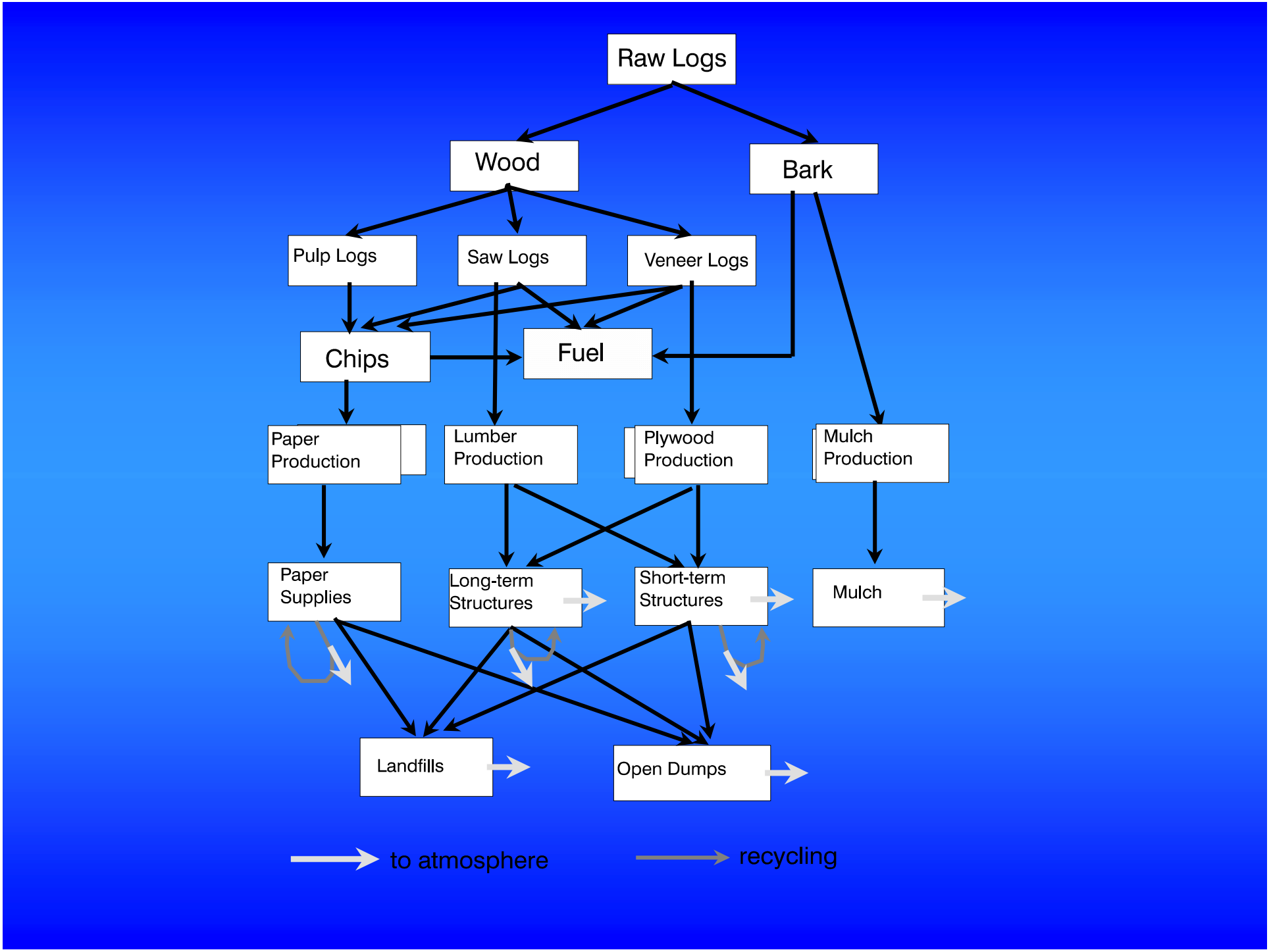


MODELING HISTORICAL PATTERNS OF TREE UTILIZATION IN THE PACIFIC NORTHWEST: CARBON SEQUESTRATION IMPLICATIONS[1]

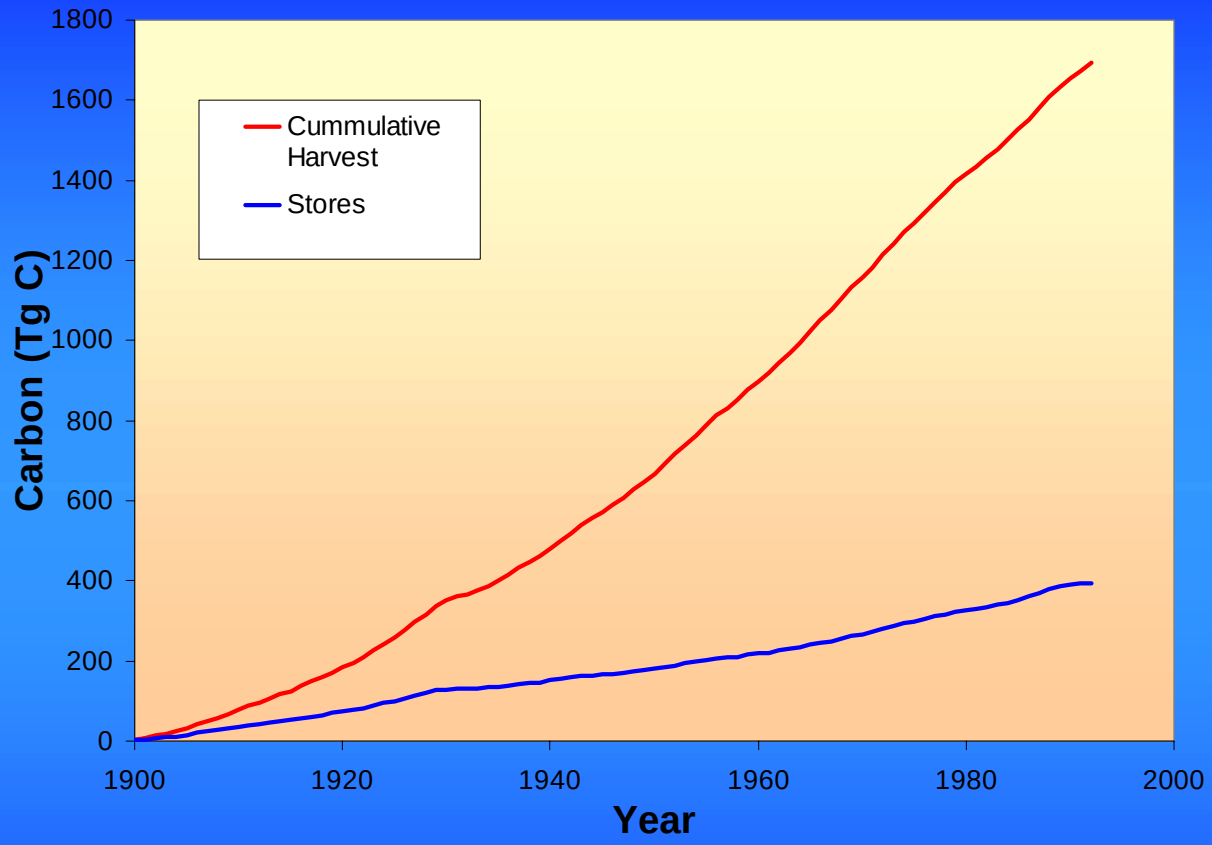
MARK E. HARMON, STEVEN L. GARMAN, AND WILLIAM K. FERRELL
Department of Forest Science, Oregon State University, Corvallis, Oregon 97331-7501 USA

The Changing Nature of Harvests

AND FOREST PRODUCT USE IS ALWAYS CHANGING


Raw Logs
Wood
Bark
Pulp Logs
Saw Logs
Veneer Logs
Chips
Fuel
Paper Production
Lumber Production
Plywood Production
Mulch Production
Paper Supplies
Long-term Structures
Short-term Structures
Mulch
Landfills
Open Dumps
to atmosphere
recycling

Only 20% of Harvest is Stored

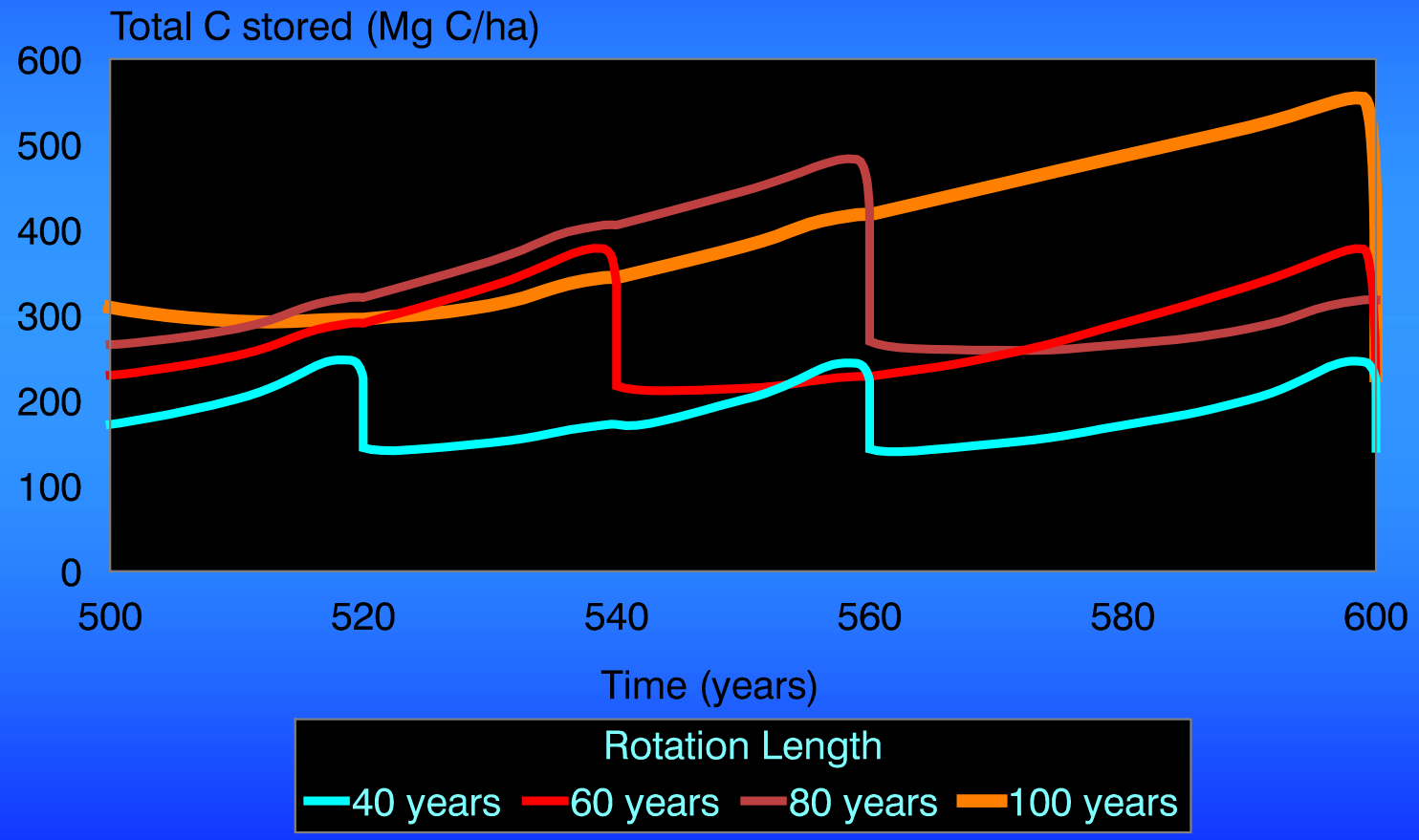


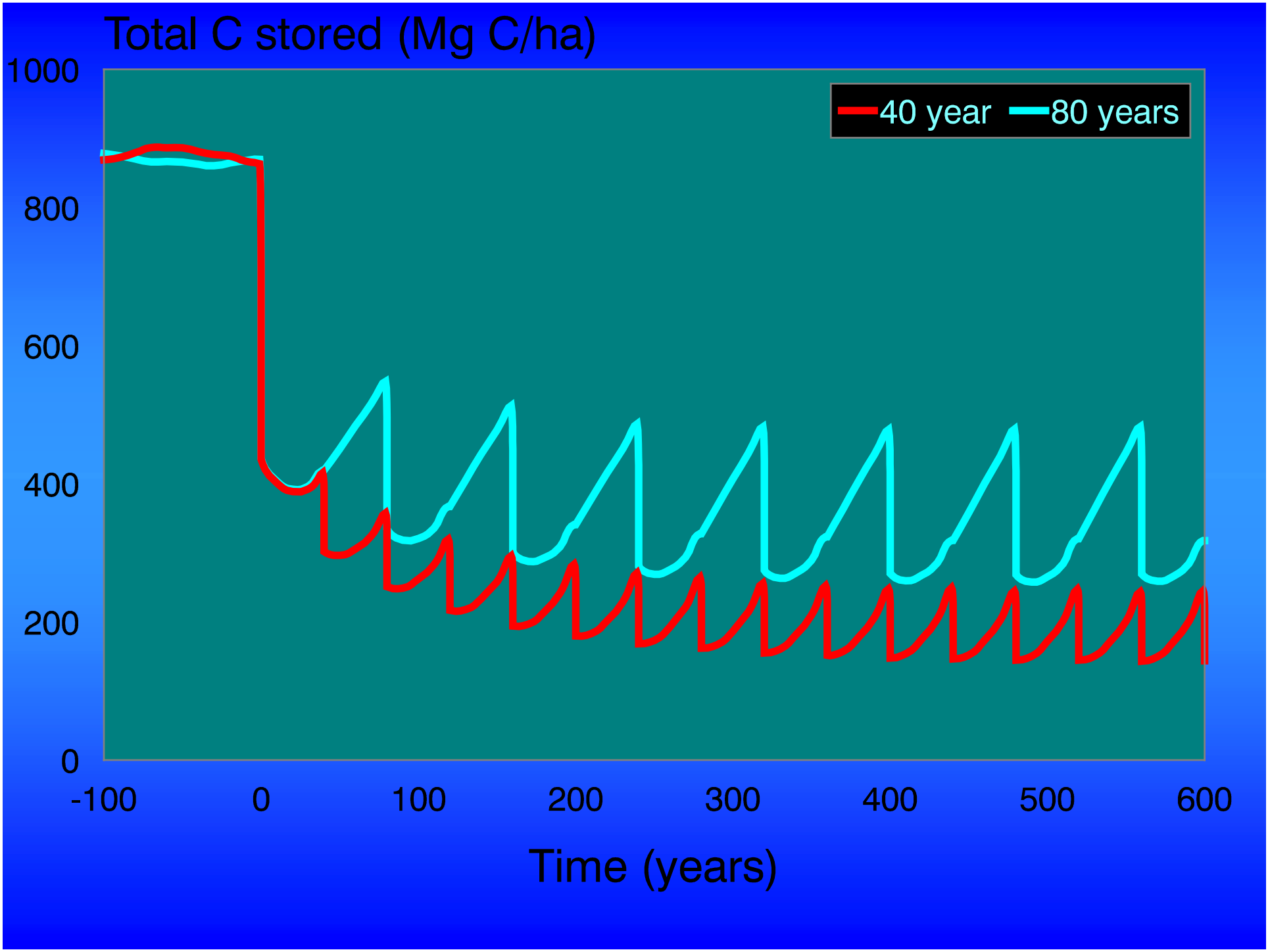
MODELING CARBON STORES IN OREGON AND WASHINGTON FOREST PRODUCTS: 1900–1992

MARK E. HARMON, JANICE M. HARMON and WILLIAM K. FERRELL
Department of Forest Science. Oregon State University, Corvallis, OR 97331, U.S.A.

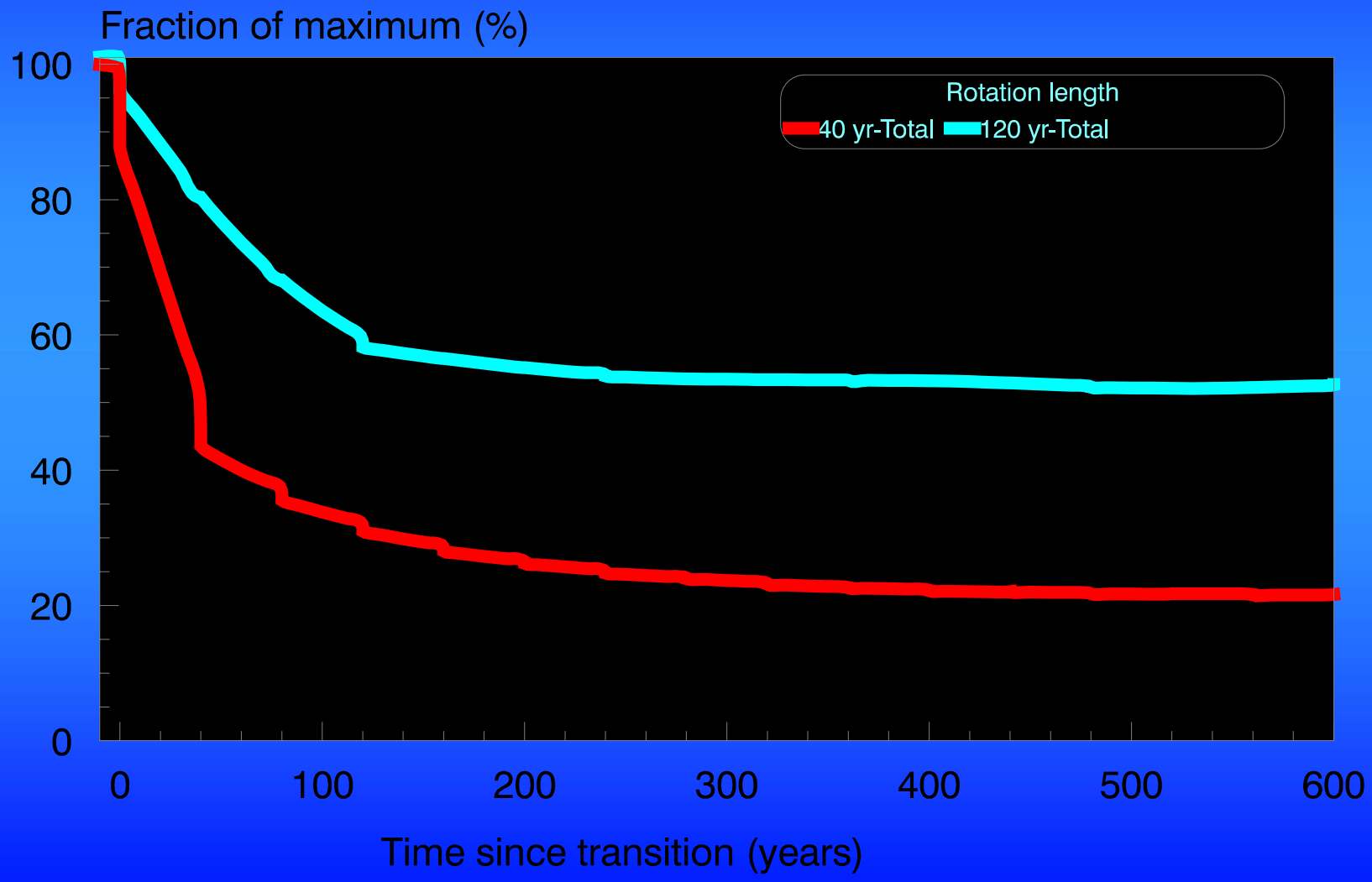
DAVID BROOKS
USDA Forest Service, Forestry Sciences Laboratory, Corvallis, OR 97331, U.S.A.

Which One Stores More Carbon?????

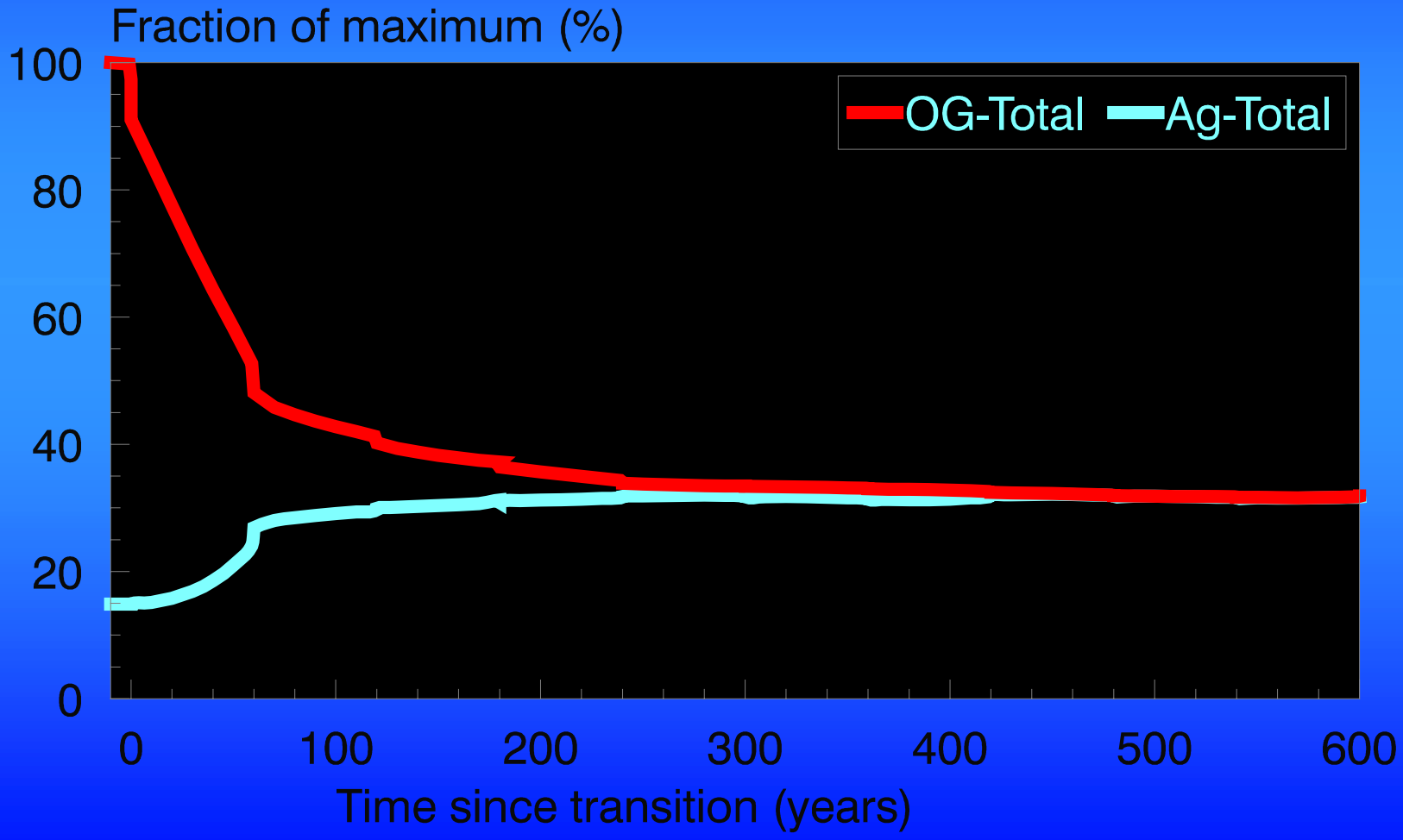



Total C stored (Mg C/ha)
1000
800
600
400
200
0
40 year
80 years
-100
0
100
200
300
400
500
600
Time (years)

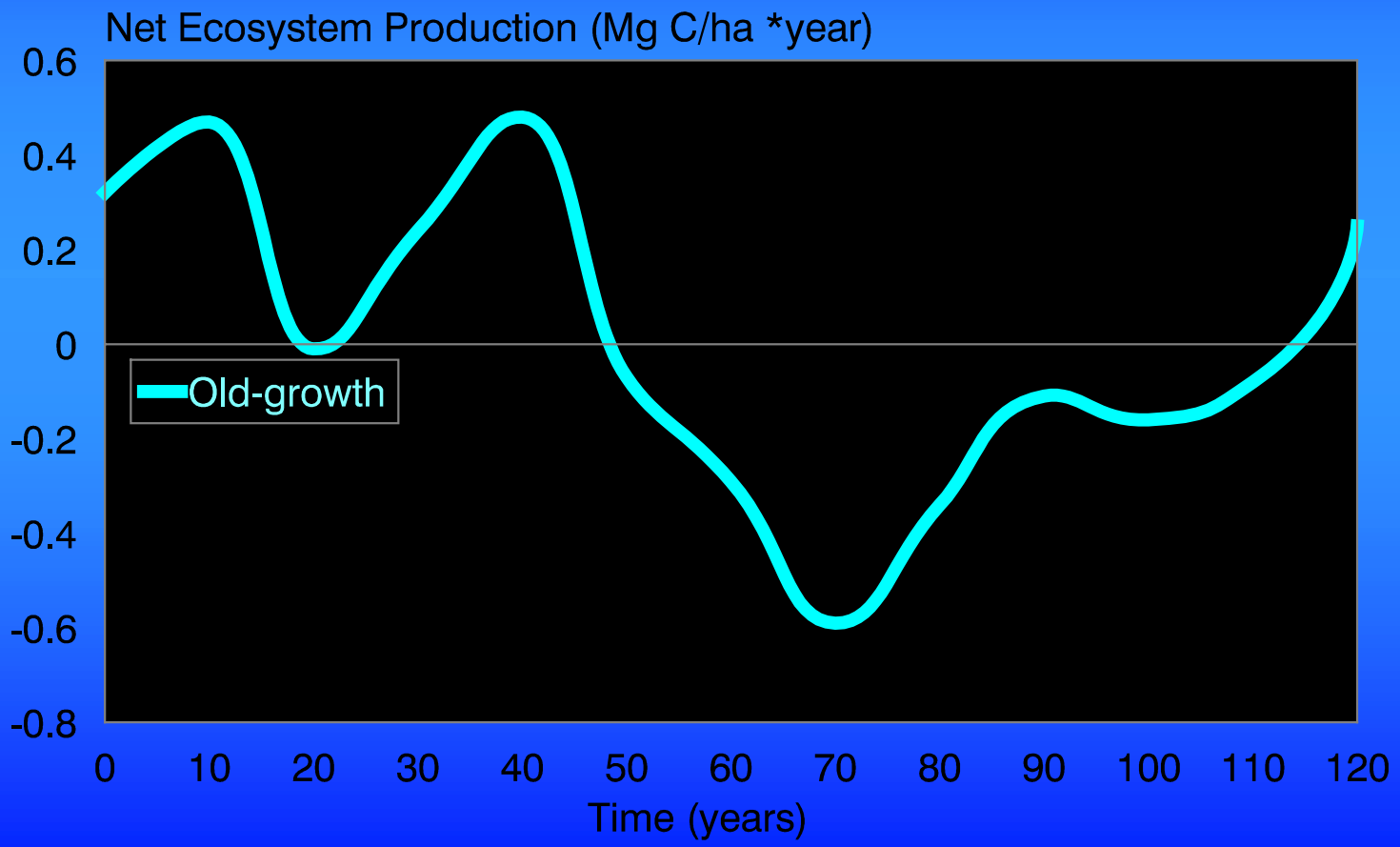
Landscape Level



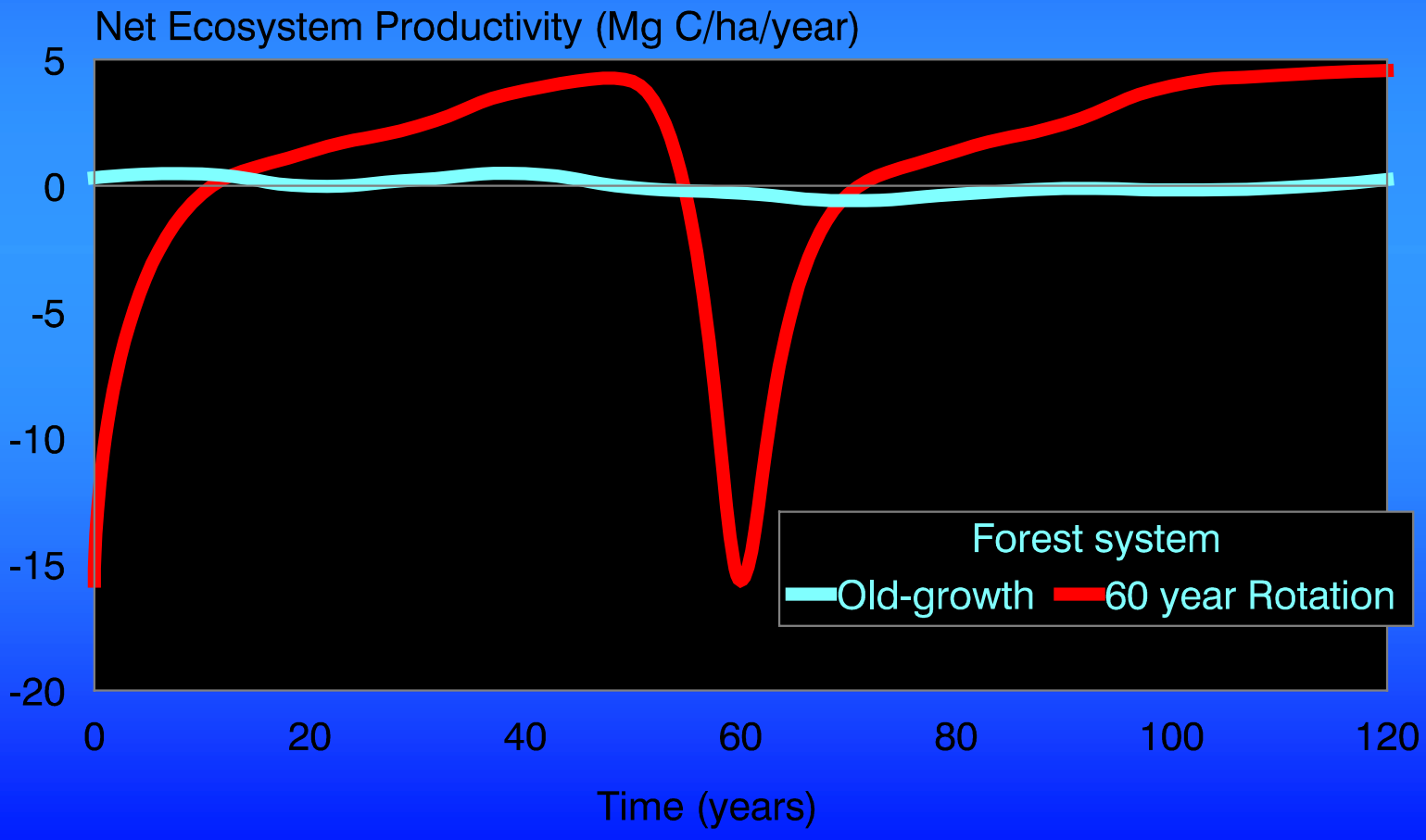
All Roads Lead to ??????



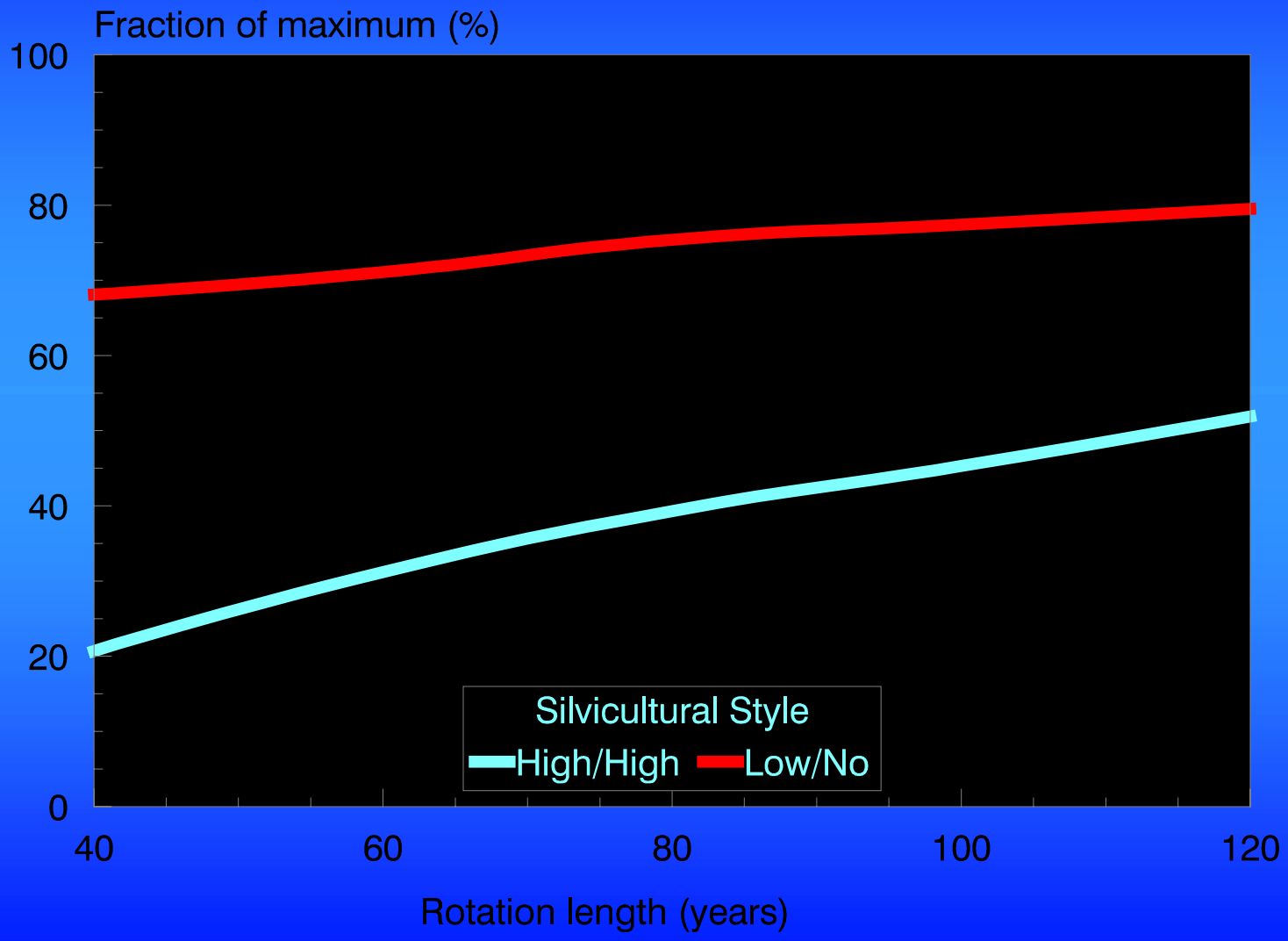
Old-growth Systems are in Balance



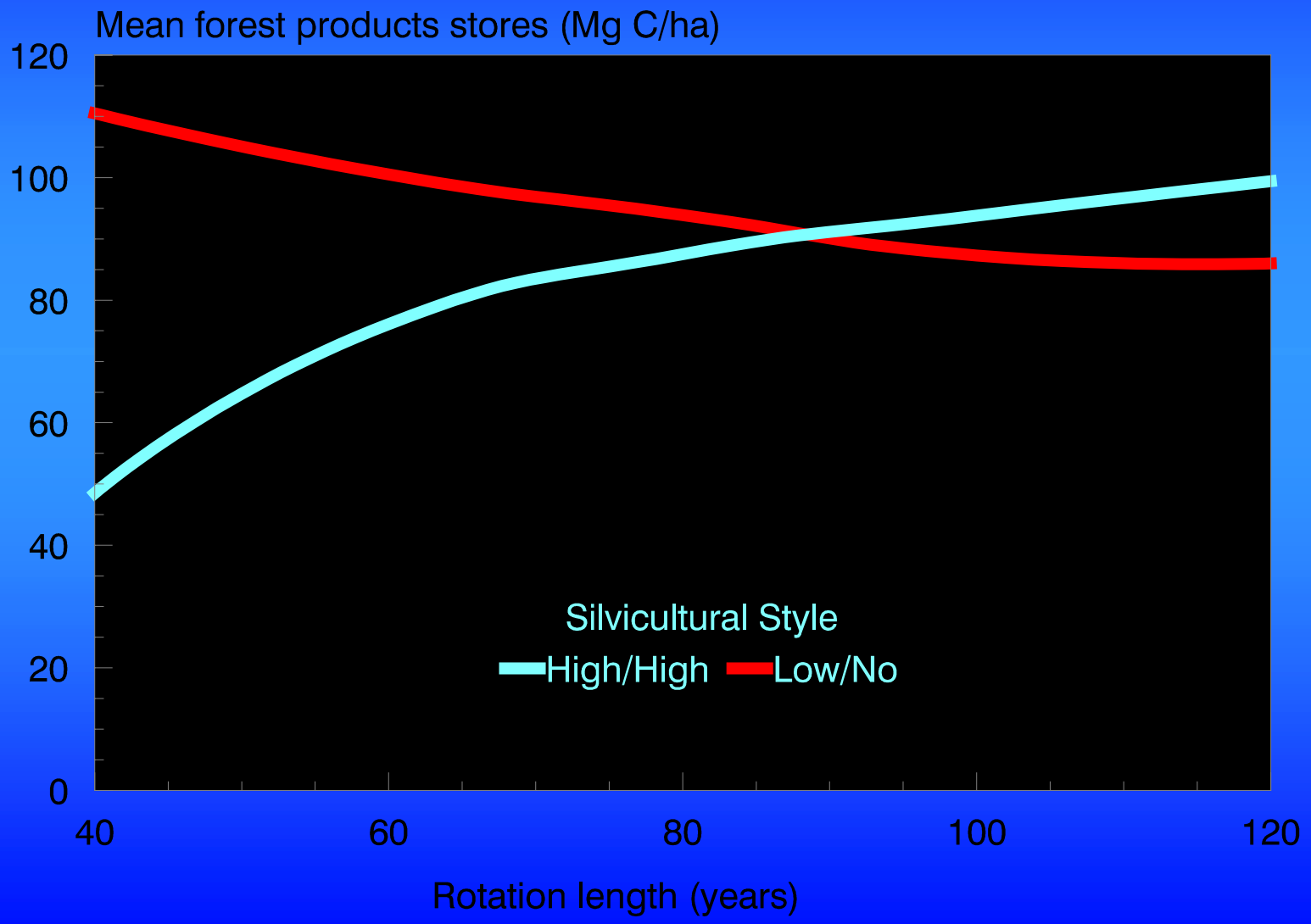
Net Exchange at Landscape Level is the Same



Can We Store More?



Do We Have to Do Without?



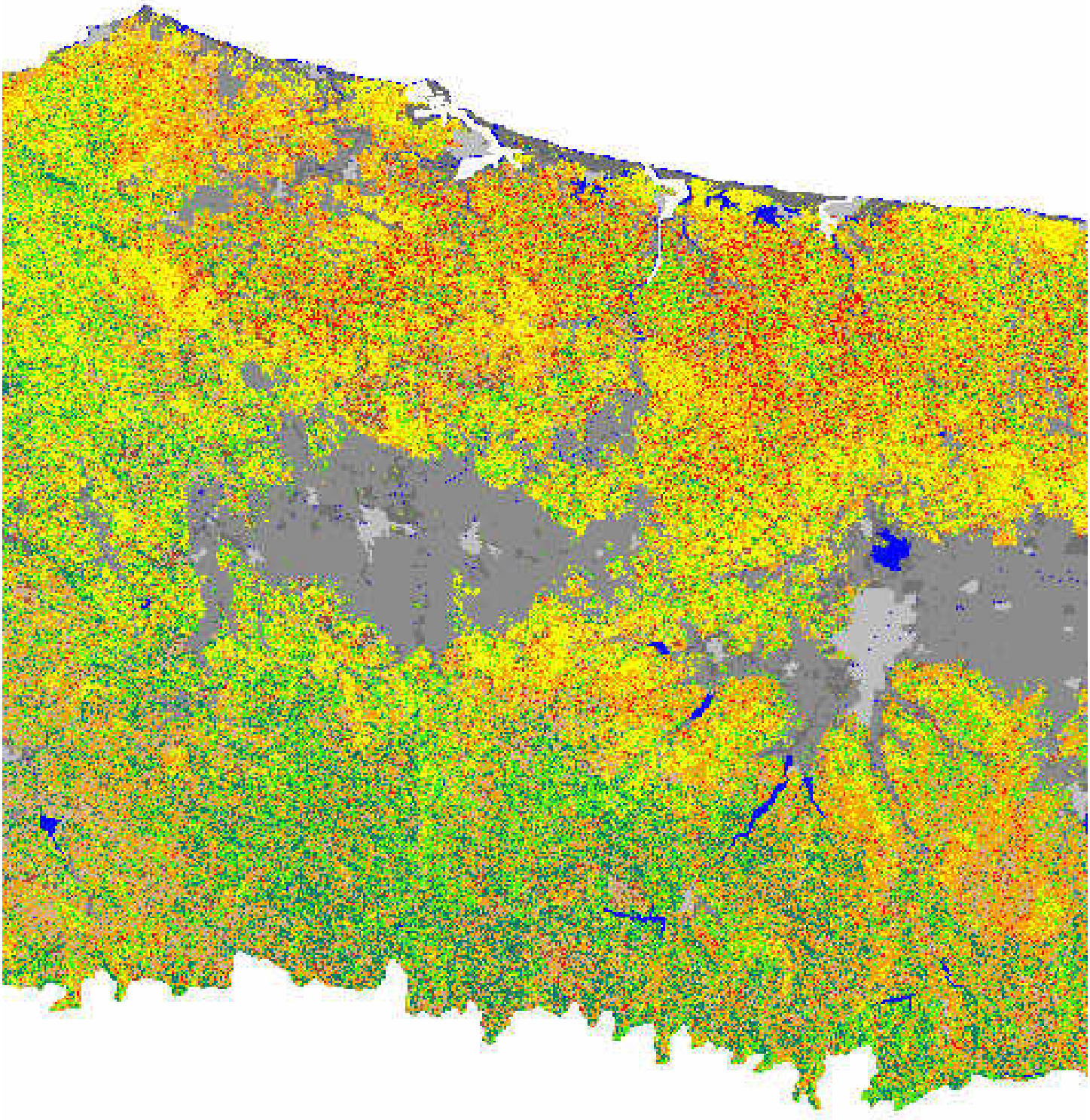
KEY PLAYERS IN FOREST MANAGMENT

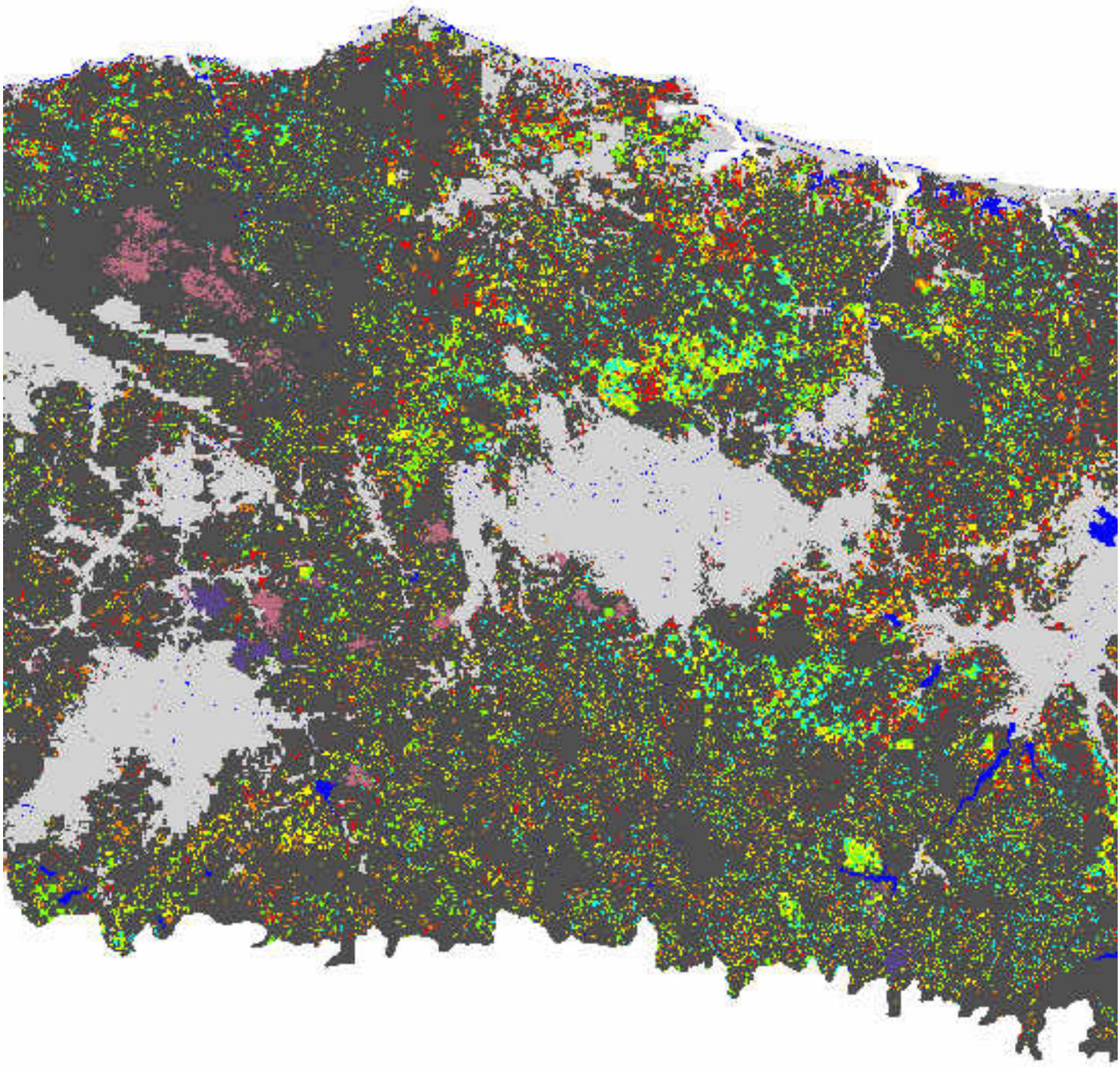
- FOREST OWNERSHIP VARIES
- FEDERAL LANDS -- 41 %
- STATE LANDS--5 %
- INDIAN LANDS--3 %
- NON-INDUSTRIAL--16 %
- INDUSTRIAL--35 %

ECONOMIC INCENTIVES FOR AT LEAST 60 % OF FOREST LANDS

3 Billion tons of Carbon

WHAT IS THE PRIVATE COST OF STORING CARBON????



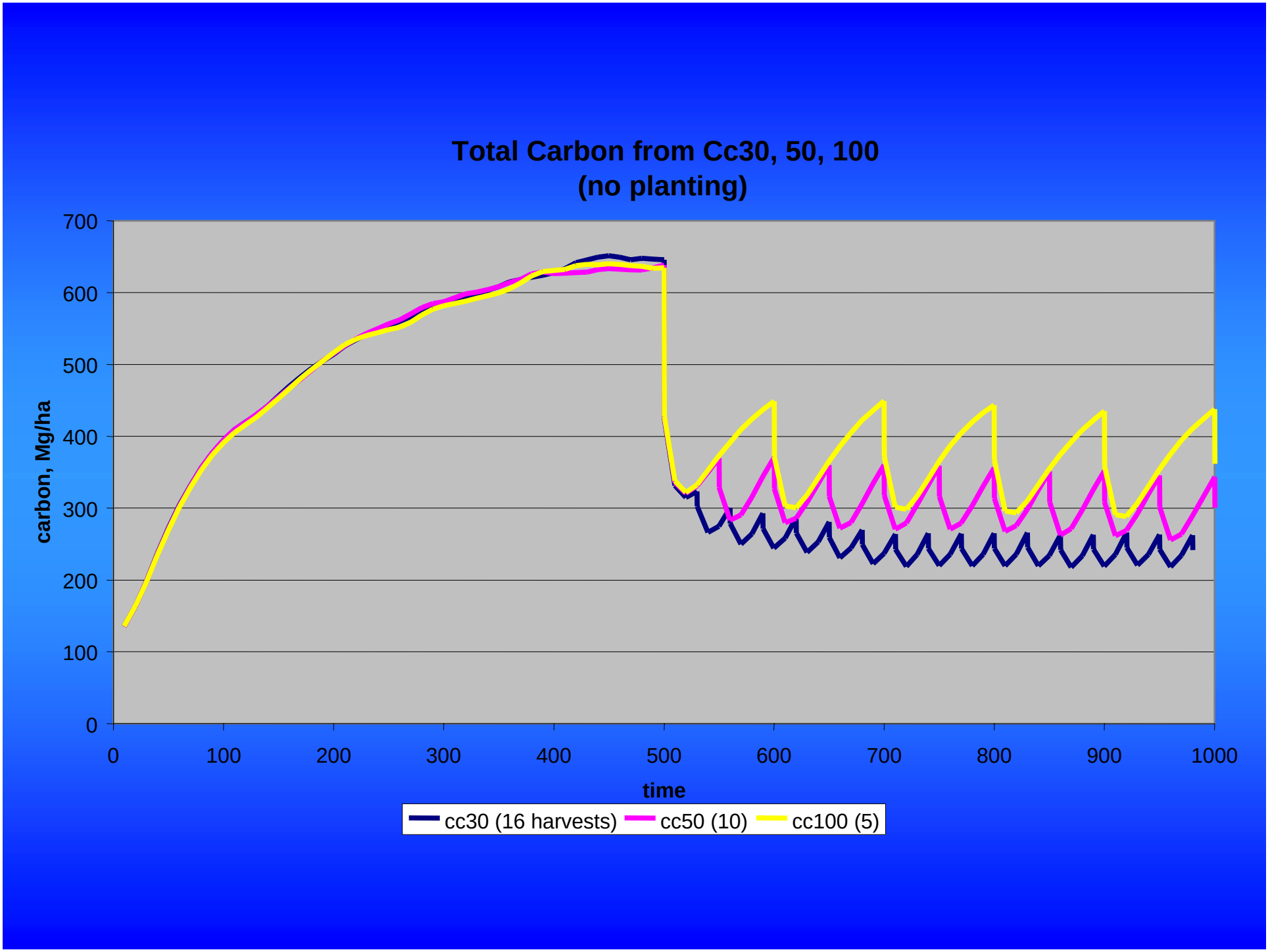


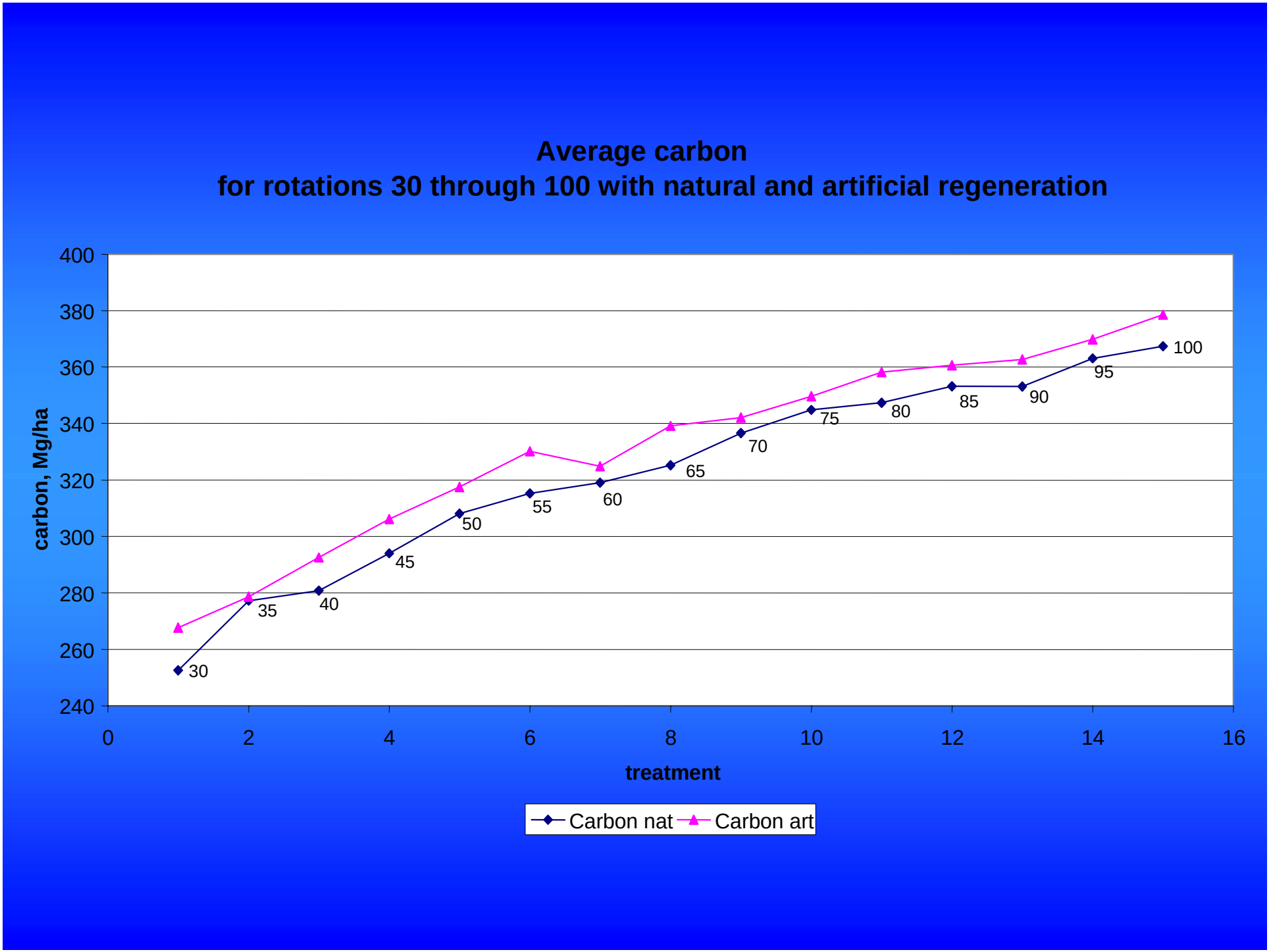
MODELLING APPROACH

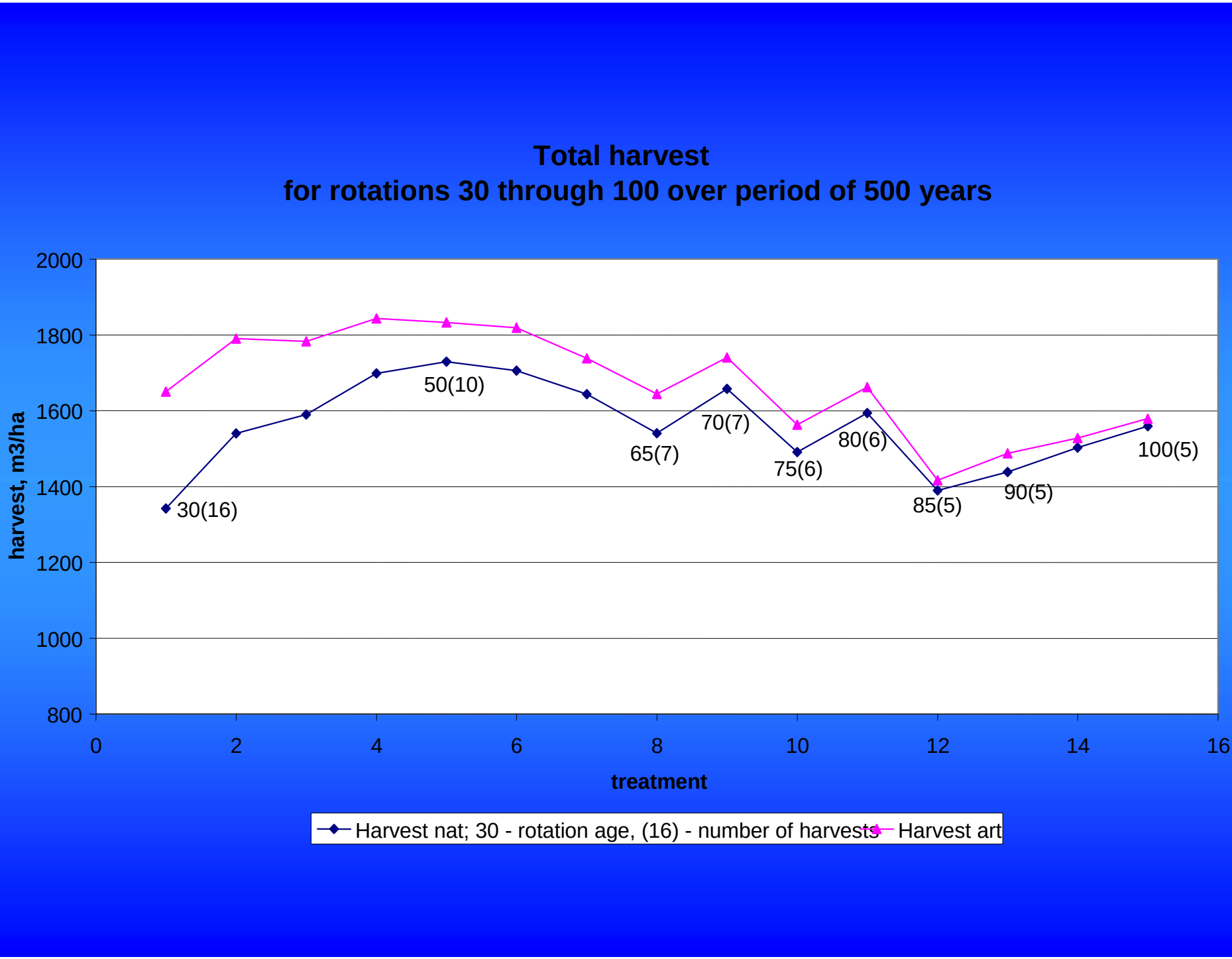
- USE STANDCARB TO SIMULATE OUTPUTS OF FORESTRY PRACTICES
- ESTIMATE NET VALUE OF THESE OUTPUTS IN A TIME SENSITIVE MANNER

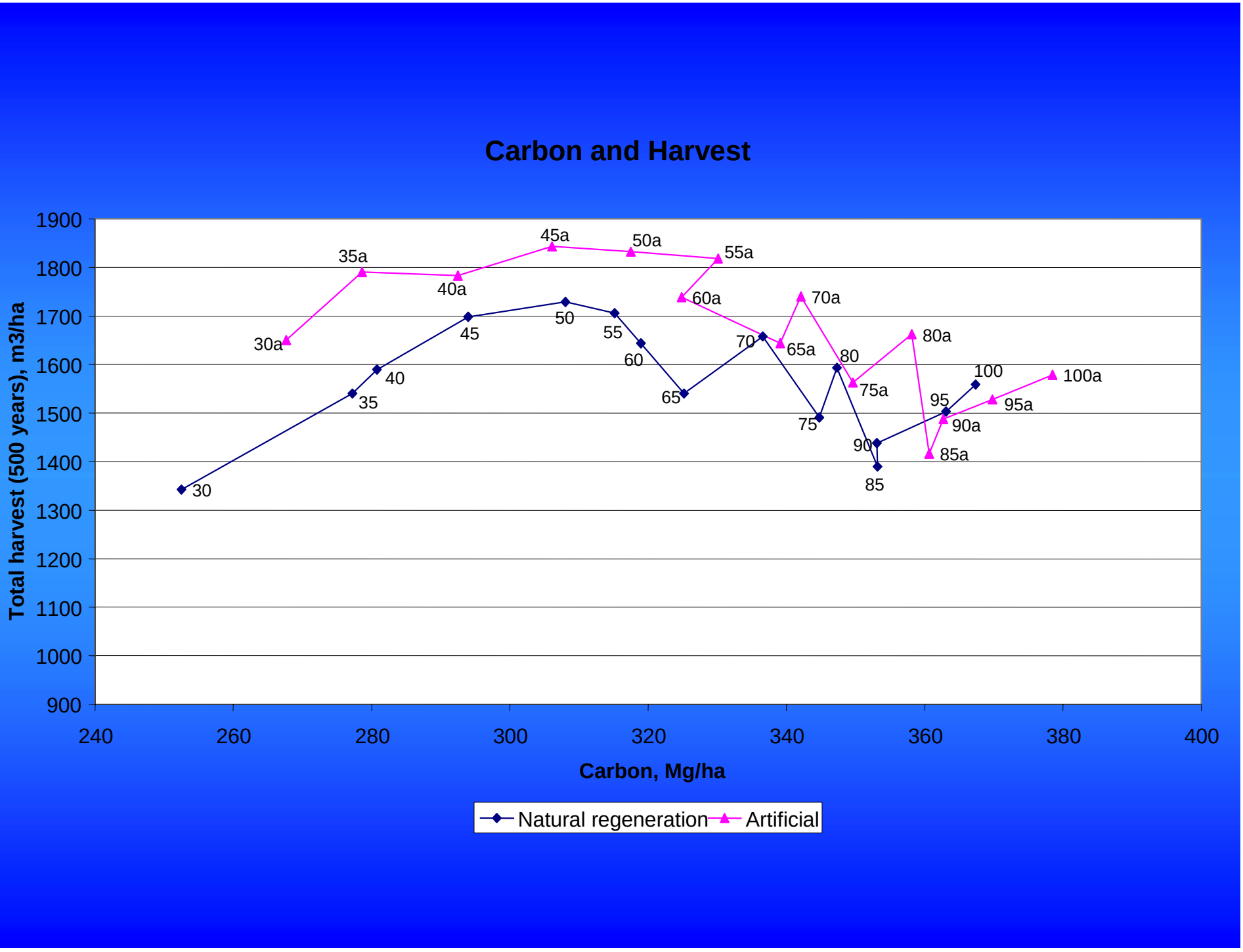
- ROTATION LENGTH
- PLANTING
- PRE-COMMERCIAL THINNING
- COMMERCIAL THINNING
- HIGH INTENSITY OR LOW INTENSITY

SOME EARLY RESULTS


Total Carbon from Cc30, 50, 100
(no planting)
carbon, Mg/ha
0
100
200
300
400
500
600
700
0
100
200
300
400
500
600
700
800
900
1000
time
cc30 (16 harvests)
cc50 (10)
cc100 (5)


Average carbon
for rotations 30 through 100 with natural and artificial regeneration
carbon, Mg/ha
400
380
360
340
320
300
280
260
240
0
2
4
6
8
10
12
14
16
treatment
30
35
40
45
50
55
60
65
70
75
80
85
90
95
100
Carbon nat
Carbon art


Total harvest
for rotations 30 through 100 over period of 500 years
harvest, m3/ha
2000
1800
1600
1400
1200
1000
800
0
2
4
6
8
10
12
14
16
treatment
30(16)
50(10)
65(7)
70(7)
75(6)
80(6)
85(5)
90(5)
100(5)
Harvest nat; 30 - rotation age, (16) - number of harvests
Harvest art


Carbon and Harvest
Total harvest (500 years), m3/ha
1900
1800
1700
1600
1500
1400
1300
1200
1100
1000
900
240
260
280
300
320
340
360
380
400
Carbon, Mg/ha
30
35
40
45
50
55
60
65
70
75
80
85
90
95
100
30a
35a
40a
45a
50a
55a
60a
65a
70a
75a
80a
85a
90a
95a
100a
Natural regeneration
Artificial

EARLY CONCLUSIONS

- PLANTING CAN INCREASE BOTH HARVEST AND CARBON, BUT IS IT PROFITABLE?
- AT LONG ROTATIONS, PROBABLY NOT.
- AT LONGER ROTATION HARVEST MUST BE GIVEN UP TO OBTAIN MORE CARBON STORAGE
- TREATMENT OF TERMINAL VALUES IMPORTANT

STILL TO DO

- DETAILS, DETAILS….
- SENSITIVITY TO MANAGEMENT COST PARAMETERS
- FOCUS ON ONLY PROFITABLE TYPES OF MANAGMENT
- *THORNY PROBLEMS…..*
- *RATES OF TIME PREFERENCE FOR FOREST OWNERS*
- *WHAT DO PRIVATE NON-INDUSTRIAL OWNERS WANT?*

Effects of the Development of the Baikal-Amur Mainline Railroad on Patterns of Boreal Forest Cover and Carbon Fluxes in Southern Siberia

Eric Kasischke (Co-Principal Investigator)
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Canadian Forest Service

Contents

- **Part 1: Perspectives on Land Cover Change in the Boreal Forest Region (E. Kasischke)**

- **Part 2: Monitoring Land Cover Changes in the BAM Regions - Examples and Challenges (E. Kasischke)**

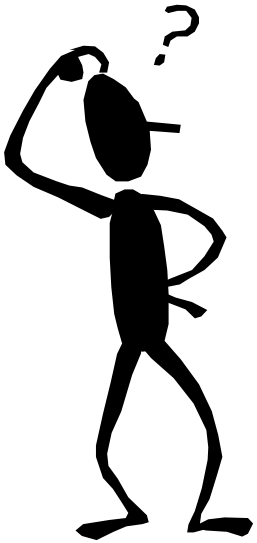
- **Part 3: Modeling Forest - Carbon Dynamics in the Western BAM - Importance of Disturbance (H. Shugart)**

Part I.
Perspectives on Land Cover Change in the Boreal Forest Region

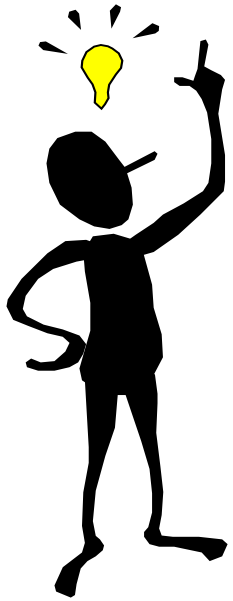
Issues in Conducting Global Change Research in the Boreal Forest Region - Dealing with Scientific Perspectives

The Scientific Process has 3 important steps
=

Examine the Data



Ponder the Facts



Form Conclusions

Issues in Conducting Global Change Research in the Boreal Forest Region - Dealing with Scientific Perspectives

- **Problems**
    - **In the terrestrial science community, global change science is often not conducted by researchers who are trained using a global perspective, but by researchers with unique biome or geographic perspectives**
    - **Conclusions are often drawn about specific processes in a biome/region based upon perspectives developed in other biomes/regions**
- **Examples**
    - **Fire in the boreal forest is not an important process on a global scale**
    - **Just as in the temperate forest, tropical forest and savanna regions, human activities are a primary driver behind land cover change**

Relative Importance of Fires in the Boreal Forest (as viewed by the "global" fire community)

Biome	Carbon Released (Tg/yr)	Percent of Total
Savanna	1660	70
Tropical Forests	570	24
Temperate Forests	107	5
Boreal Forests	23	1

Seiler and Crutzen 1980; Hao, Liu and Crutzen 1990

Estimated Annual Rates of Disturbance in the Boreal Forest(millions of hectares)

Source of Disturbance	Area (average)	Percent (average)
Total	6 to 24 (15)	
Human land clearing	2 (2)	33 to 8 (13)
Insects/pathogens	2 to 4 (3)	33 to 17 (20)
Fire	2 to 18 (10)	33 to 75 (67)

Data Availability for Studies of Land Cover Change in the Boreal Forest Region

Over the past decade, the satellite remote sensing community has created a nur of important initiatives to collect the data sets necessary to document patterns disturbance and land-cover change in many regions of the earth

Biome/Region	*Disturbance/Land Cover Change Pattern*	*Data Set Initiative*
Temperate Forests/U.S.	Patterns of forest clearing and regrowth	NALC, MLRC
Tropical Forests/S. America, SE Asia	Deforestation	AVHRR/Landsat Pathfinders
Savannas, Tropical Forests/SE Asia, Africa, S. America	Seasonal fires	Global AVHRR/ATSR Fire Maps
Boreal Forest/Russia, N. America	Summer fires, insects, deforestation	???????

Key Unresolved Questions with Respect to Land Cover Changes in the Boreal Forest Region

- **What is the annual area burned and area disturbed by insects and diseases?**
- **Are fires in the Russian boreal forest predominately surface fires (as maintained by Russian forestry community) or crown fires (as suggested by satellite observations)?**
- **What are the levels of greenhouse gases released directly from fires and during the years immediately after fire (due to post-fire soil respiration enhancement)?**
- **In the southern and far-eastern portion of the Russian boreal forests, what are the rates of forest clearing due to human activities?**

Key Unresolved Questions with Respect to Land Cover Changes in the Boreal Forest Region

- **In response to recent distinct trends in warming in the boreal region:**
- **Are levels of fire increasing in the boreal region (in terms of area burned as well as fire severity)?**
- **Are levels of insect and disease infestation increasing?**
- **At what rate are the northern boundaries of the boreal forest expanding?**
- **Are patterns of forest recovery after disturbance changing (indicated by a shift from coniferous forests to deciduous forests)?**
- **Is the ratio between forest area and non-forest area (peatlands) in the boreal region increasing or decreasing?**
- **Will the boreal forest region remain an atmospheric carbon sink or will it become an atmospheric carbon source?**

Episodic Fire Years in the Boreal Forest

Region	*Year*	*% of Total Area Burned*
Khabarovsk/Sakhalin Island	**98**	**5.0**
Boreal Plains	**80-81**	**4.2**
Alaska Boreal	**90-91**	**4.2**
West Taiga Shield	**94**	**4.8**
West Boreal Shield	**80-81**	**4.4**
East Taiga Shield	**90**	**3.0**

The Role of Land Cover Change in the Boreal Forest Region

- **On a relative scale, direct human activities are responsible for a small portion of land cover change in the boreal region**

- **Natural disturbances (fire, insects, disease) play a far greater role in land cover change than do human disturbances**

The Role of Land Cover Change in the Boreal Forest Region

- **The increase in large-scale, natural disturbances associated with climate change will have significant socio-economic impacts on human society**
- **Increased fire activity represents a significant and direct threat to human life and property**
- **Any human-related activity that occurs in the boreal region has to consider fire, especially those associated with exploitation of natural resources**
- **Increased fire and insect/diseases will reduce the amount of wood and fiber available for harvesting**
- **Increased fire will change the habitat for a wide range of fish, bird and wildlife species, many of which are commercially exploited or used by indigenous peoples**
- **Increased fire will alter the availability of other products harvested from forested landscapes (mushrooms, berries, etc.)**

The Role of Land Cover Change in the Boreal Forest Region

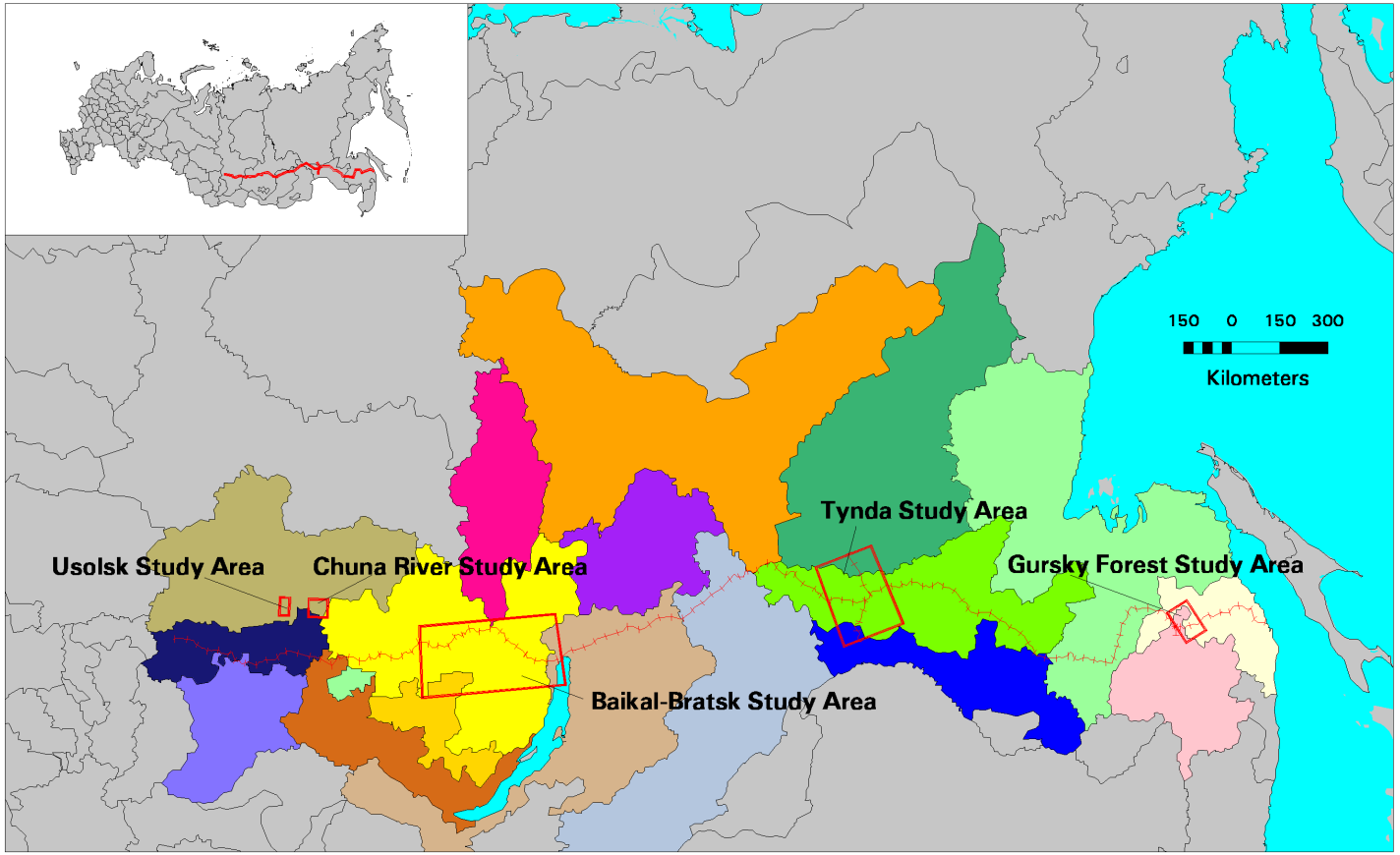
- **Alteration of the fire regime will have significant impacts on global climate change treaties**
- **Issue of carbon credits in the Kyoto Protocol**
- **Increased fire will influence the debate on allocation of funding for natural resource management**
- **Command and Control Viewpoint**
  - **Given sufficient resources (manpower and equipment), all fire can be controlled**
- **Ecological viewpoint**
  - **Even with unlimited resources, natural fire cannot be controlled or even reduced. Efforts should be focused on protecting high-priority life and property**

Values at Risk in the Boreal Forest

- **While the boreal forest region has a low population density, it is home to a large population of Native Peoples who maintain traditional, subsistence-based lifestyles**
- **The southern boreal forest contains significant timber resources that may be exploited in the future**
- **The boreal forest region contains the largest terrestrial carbon reservoir**
- **Significant non-renewable resources exist in this region, and the routes for NRR in the Arctic go through the boreal forest**
- **The boreal forest region provides habitat for a large number of fish, bird and mammal species**

Part 2:
Monitoring Land Cover Changes
in the BAM Regions - Examples and Challenges

BAM Intensive Study Sites



- Verkhne - Lensky Mountain Middle Taiga
- Sredne - Lensky Middle Taiga
- Nishne-Amur Mountain Middle Taiga
- Katanga Middle Taiga
- Angara Southern Taiga
- Vitim Mountain Middle Taiga
- Zeja-Selemdga Mountain Middle Taiga
- Shilka Mountain Middle Taiga
- Angara-Lena Southern Taiga
- Priamursky Mountain Southern Taiga
- Tunkino-Sabaikalsk Mountain Middle Taiga
- Sredne-Sikhote-Alinsky Mixed Forest
- Kansk-Achinsk Forest Steppe
- Sredne-Amur Southern Taiga
- Sajano-Pribaikalsky Mountain Middle Taiga
- Sajan Mountain Middle Taiga
- Water
- Angara Forest Steppe
- Angara Forest Steppe
- Baikal-Amur-Magistrale Rail
- Intensive Study Region

Summary of Project Goals, Objectives, and Deliverables

- **Goal: Develop a better understanding of the role of human disturbance on patterns of carbon storage and assessment along the Baikal-Amur Mainline (BAM) Railroad**

- **Objectives:**
  - **Create a baseline map of forest fire locations for the BAM for the period of 1980 through 1990 and later periods where possible**
  - **Use the fire maps to estimate the amounts of carbon lost from fire along the BAM**
  - **Using available Landsat imagery, create maps of human-caused deforestation and patterns of reforestation along the entire length of the BAM**
  - **Develop models of forest regrowth for the different forest ecoregions along the BAM**
  - **Combine the forest regrowth models with information on patterns of forest disturbance and regrowth derived from satellite imagery to estimate carbon forest fluxes along the BAM**

Mid-Course Corrections

- **An analysis of the Landsat archive revealed there is not enough imagery available to achieve Objective 3 of the study**
- **Over the past year, we have developed approaches to merge use higher resolution (5 to 80 m) satellite imagery from multiple sources to monitor and map forest clearing and regrowth at our test sites**
- **Based on these analyses, we have decided to limit our studies to four specific test sites that have varying degrees of human and natural disturbance:**
  - **Chuna Test Site - high rates of human land clearing over a very long time period (1960 to present)**
  - **Usolsk Test Site - more recent (after 1980) human land clearing combined with heavy disturbance from insects and moderate fire disturbance**
  - **Tynda Test Site - Human land clearing since the 1980's combined with moderate natural fire**
  - **Gursky Test Site - Heavy disturbance from fire, especially in 1998**

Common Interest with other LCLUC Projects

- **We have established links with several other LCLUC projects**
  - **We will work with the McGuire Project to estimate carbon emissions from fire for the entire boreal forest**
  - **Will will work with the DeFries Project to evaluate the ability of the continuous forest cover product to detect deforestation in boreal forests**

Key Components of BAM Study

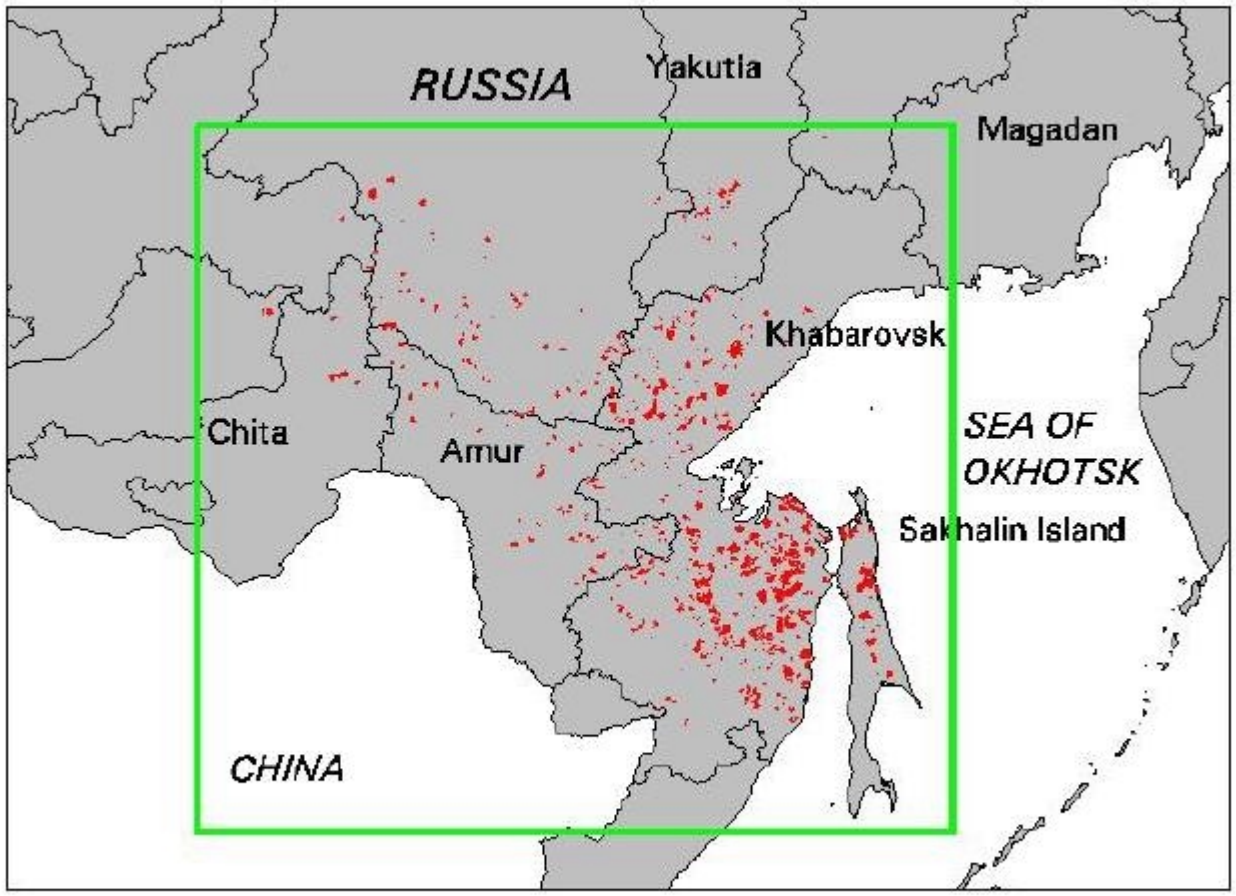
- **Patterns of Fire Disturbance Using AVHRR Imagery**
- **Sub-regional scale patterns of deforestation/reforestation using multiple-resolution satellite imagery**
- **Modeling patterns of forest regrowth/carbon sequestration**

Patterns of Fire Disturbance Using AVHRR Imagery

Patterns of Fire Disturbance Using AVHRR Imagery

- **Use AVHRR to document location and extent of fires in the Russian boreal forest during the 1980's and early 1990's**
- **Study spatial/temporal patterns of fire**
  - Relative to the BAM
  - Relative to other boreal regions (North America)
- **Estimate greenhouse gas emissions from Russian fires**
  - Compare to North American estimates

Significant Event in the Study Area: 1998 Severe Fires in Eastern Siberia Mapped from AVHRR



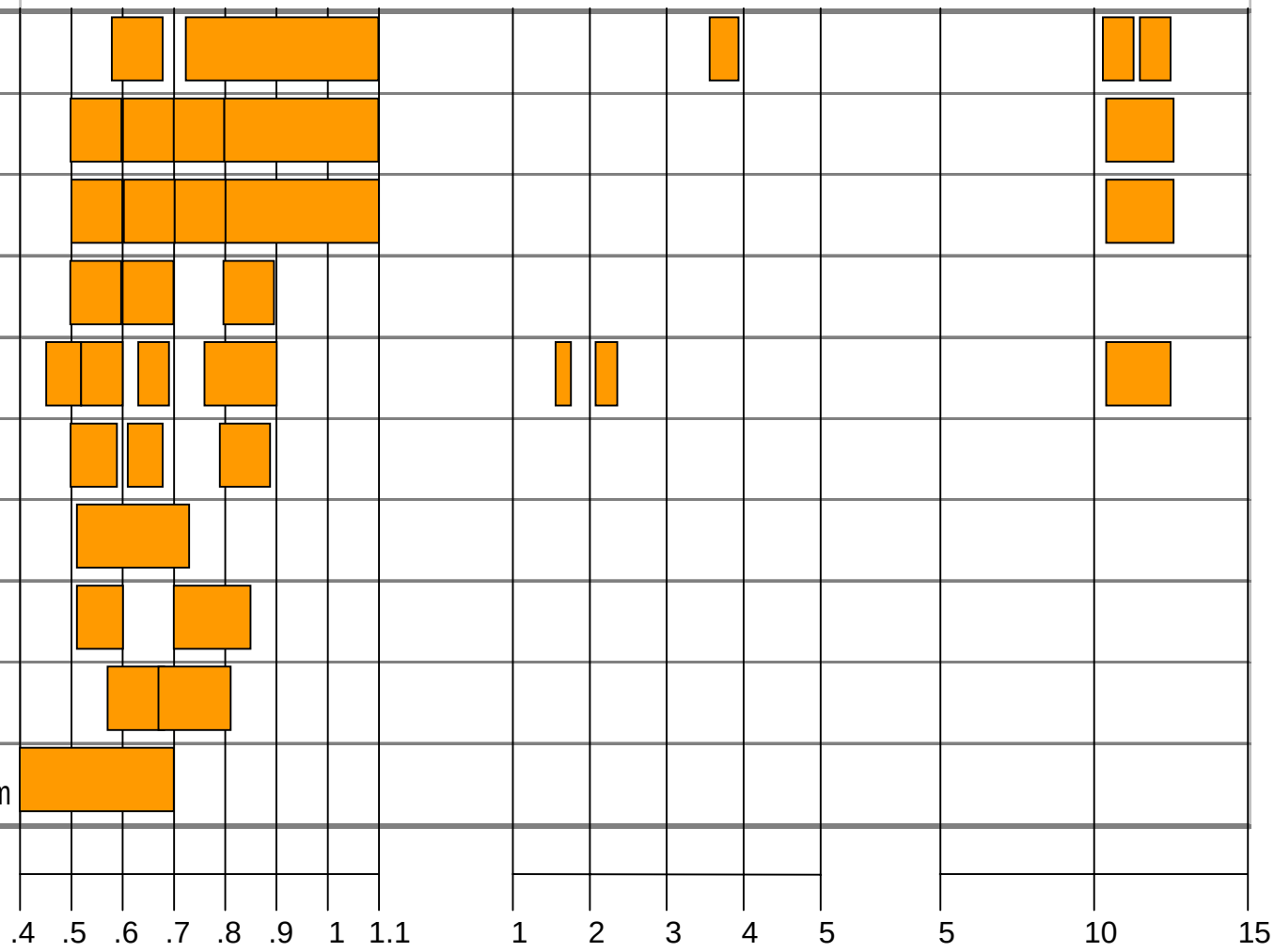
Sub-regional scale patterns of deforestation/reforestation using multiple-resolution satellite imagery

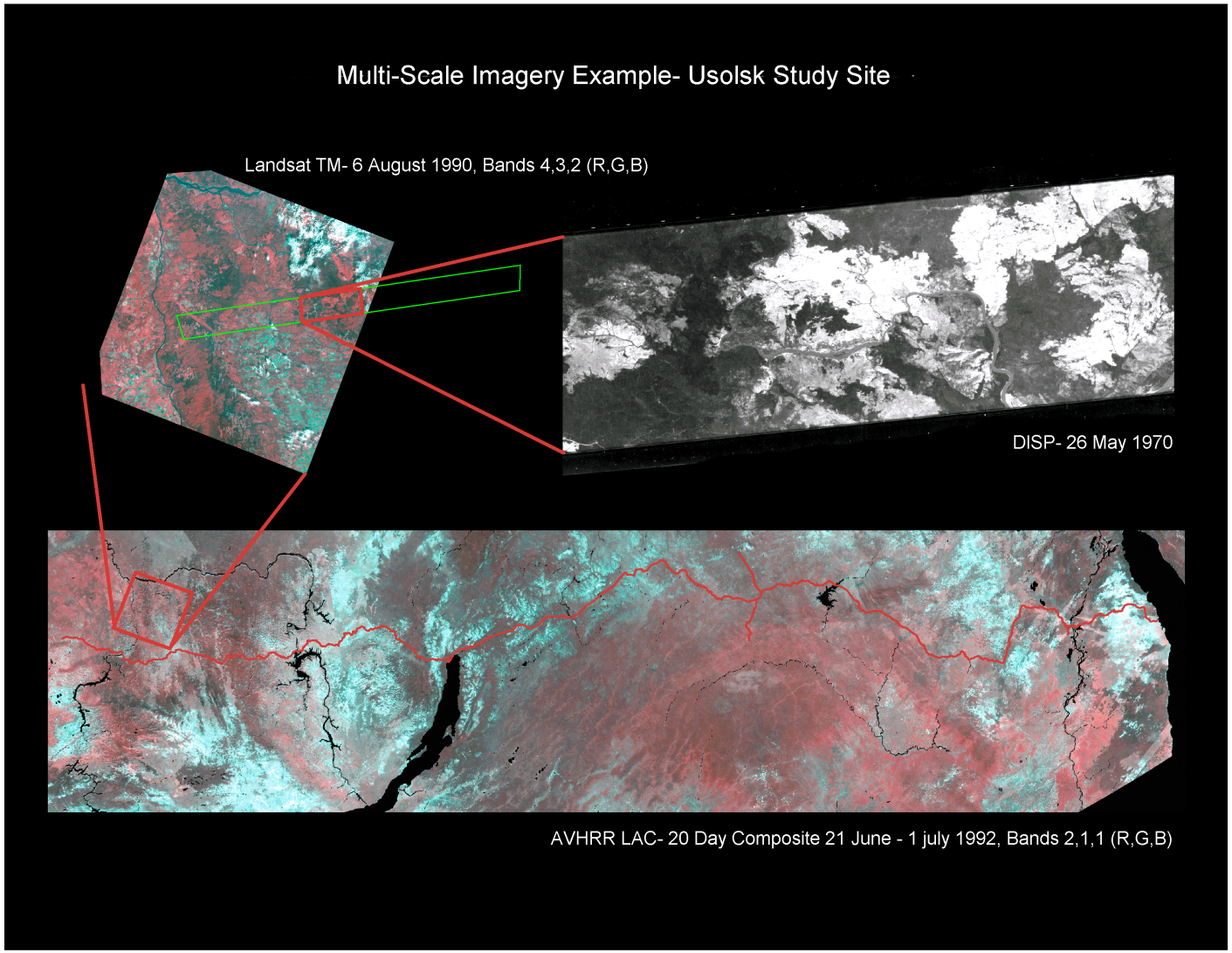
Sub-regional Scale Patterns of Deforestation/Reforestation Using Multiple-Resolution Satellite Imagery

- **Focus on three regions of Russia where anthropogenic deforestation is occurring**
  - Biryusa River Basin (two sites)
  - Tynda Region
  - Gursky Forest Region
- **Address issues related to using satellite imagery to monitor changes in forest cover in these regions**
- **Detection of disturbance as a function of system resolution**
- **Analysis of deforestation using multiple-satellite systems**
- **Analysis of reforestation using time-series MSS data**
- **Comparison to theoretical forest growth models - model validation**

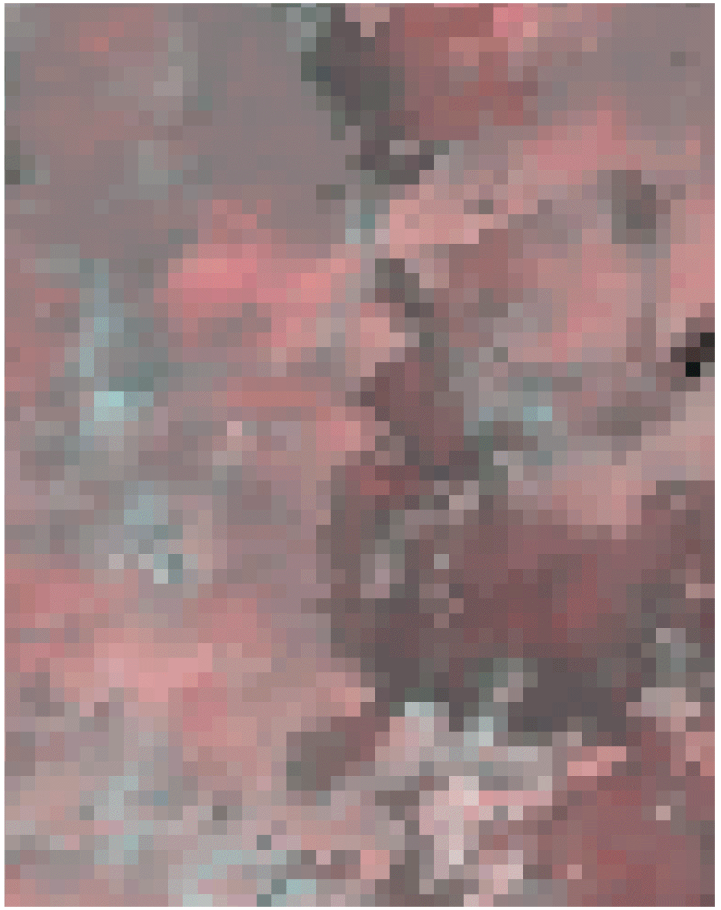
Sensor Characteristics

Sensor	Resolution	Extent	Spectral Range
AVHRR	1.1 km	2580 km	
MSU-SK	170 m	250km	
MSS	80 m	185 km	
MSU-E	45m x 33 m	45 x 220 km	
TM	30 m	185 km	
SPOT-XS	20 m	60 km	
SPOT-PAN	10 m	60 km	
MK-4	~6 m	120 km	
KFA-1000	5 m	60 km	
DISP	~6 m	~15 x 209 km	

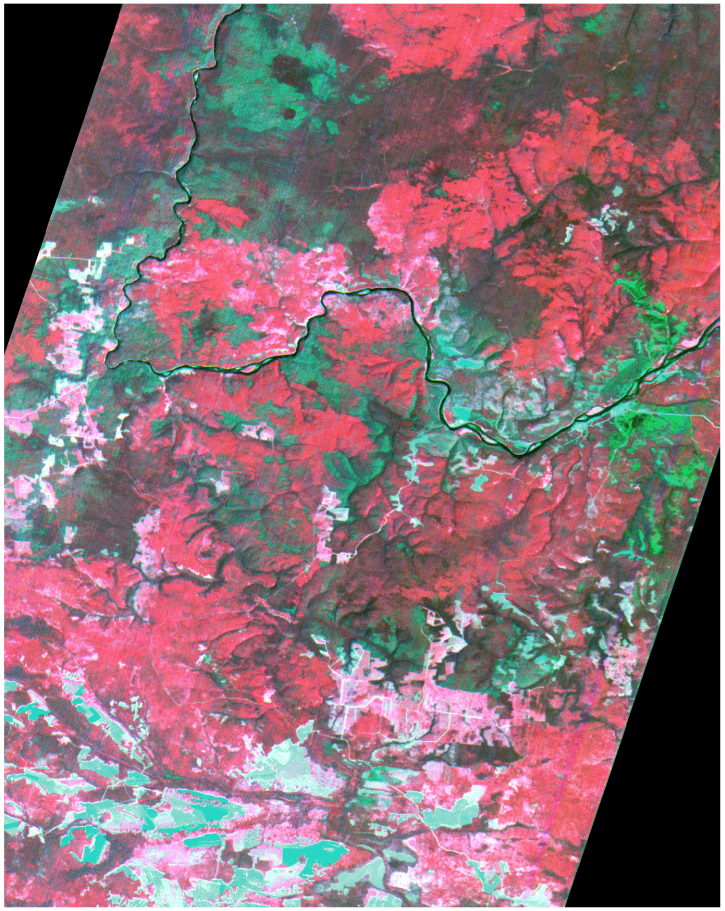



Multi-Scale Imagery Example- Usolsk Study Site
Landsat TM- 6 August 1990, Bands 4,3,2 (R,G,B)
DISP- 26 May 1970
AVHRR LAC- 20 Day Composite 21 June - 1 july 1992, Bands 2,1,1 (R,G,B)

Usolsk Study Area- Image Resolution Comparison



1 km Cell Size
AVHRR 20 Day Composite-
21 June 1992 - 10 July 1992, Bands 2,1,1 (R,G,B)



35 M Cell Size
MSU-E- 28 June 1997, Bands 3,2,1 (R,G,B)

Chuna River Forest Change Study

ISSUES UNDER INVESTIGATION

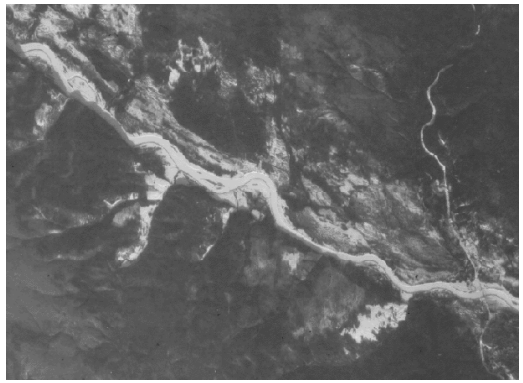
- Extraction of useful information
  - Forest cutting
  - Forest regeneration

- Extraction of comparable information from different types of remote sensing data (for example, DISP, Landsat, KFA-1000)

- Assessment of data adequacy
  - Geographic coverage
  - Temporal frequency
  - Phenological equvalence
  - Phenomenologic suitability

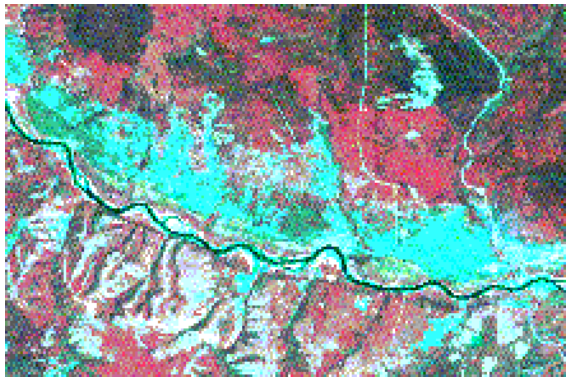
Time Series/Sensors for Chuna Site

Four decades by combining U.S. and Russian Sources

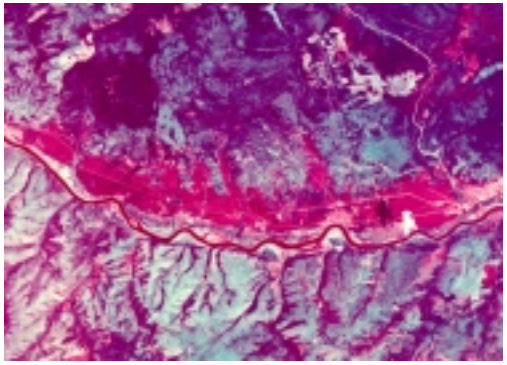


DISP
1965

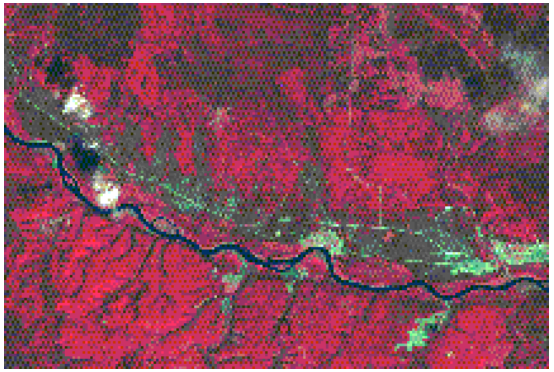
DISP
1970



LANDSAT MSS
1974



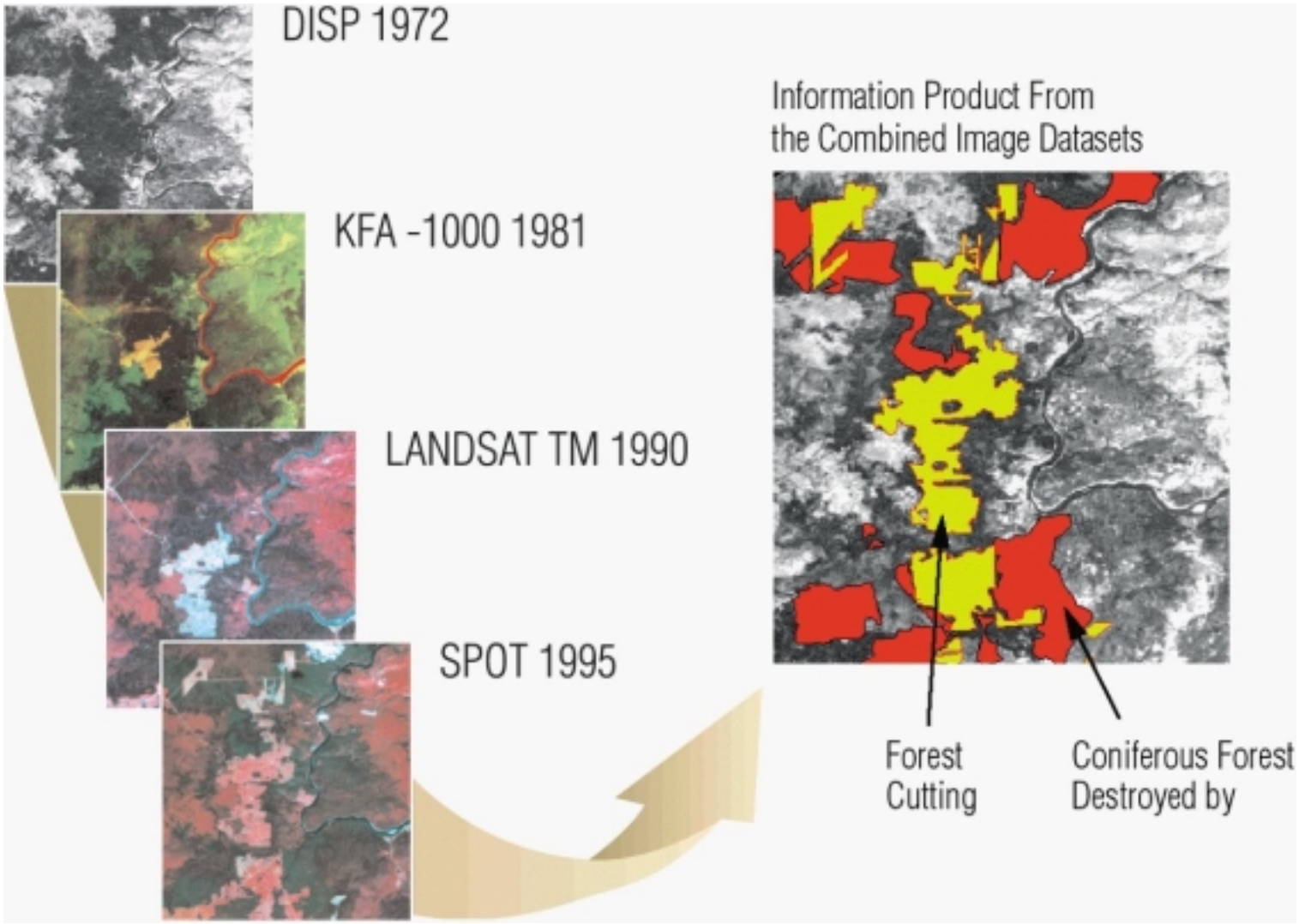
KFA-1000
1983



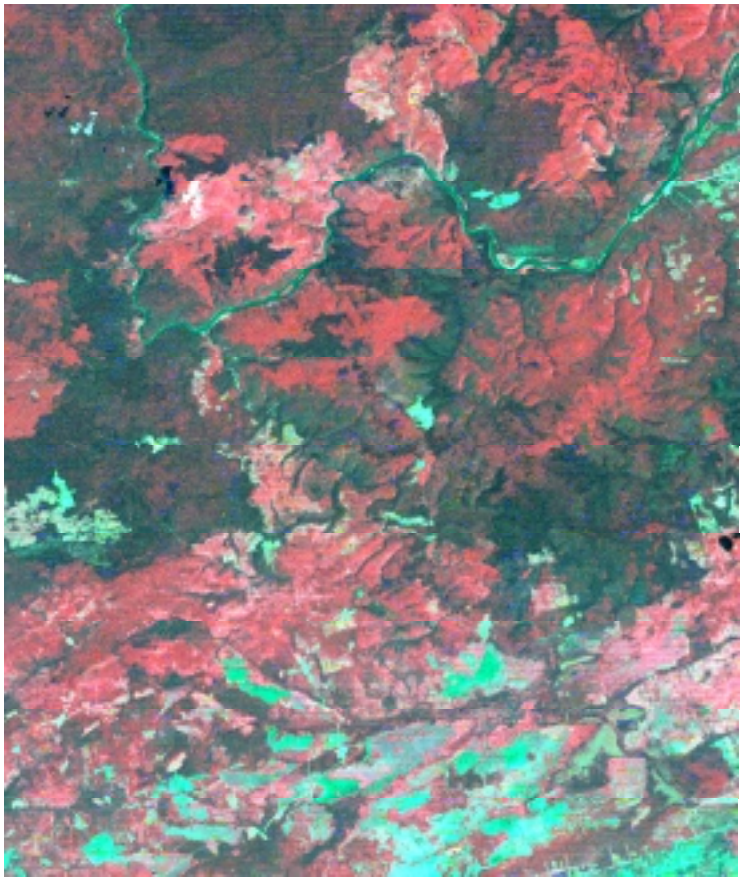
LANDSAT TM
1990

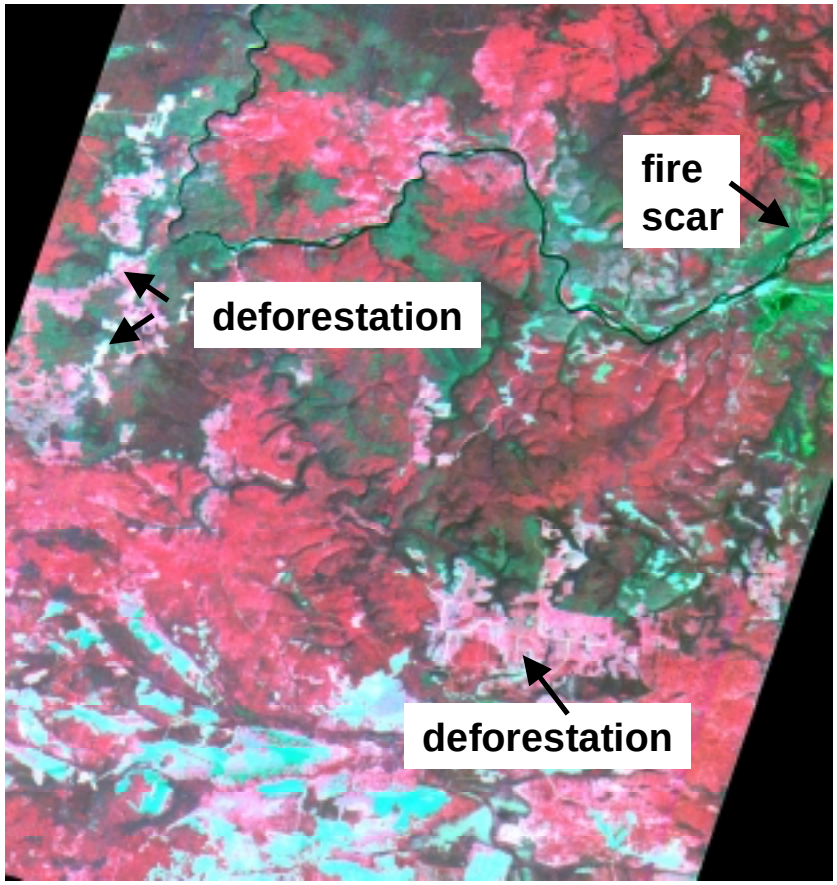
Congratulations on a Successful LANDSAT 7 Launch!

LANDSAT TM
1999


DISP 1972
KFA -1000 1981
LANDSAT TM 1990
SPOT 1995
Information Product From
the Combined Image Datasets
Forest
Cutting
Coniferous Forest
Destroyed by

Additional Site Example: Krasnoyarsk--Usolsk





1980 U.S. Landsat MSS

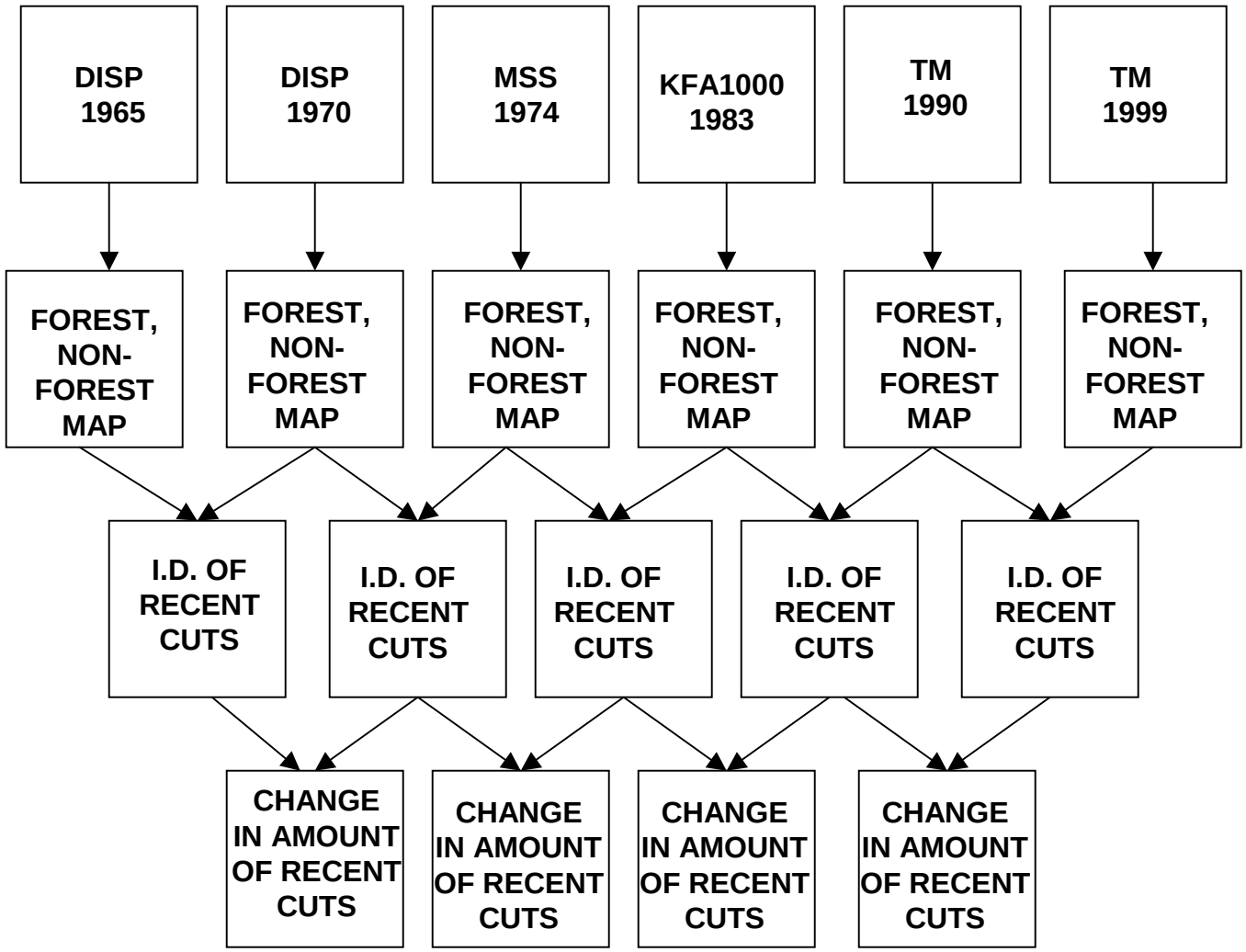
0 10 km

1997 Russian MSU-E

Overview of Forest Harvesting Procedure

- **Forest harvesting is characterized by removal of tree cover.**
- **Removal of tree cover produces a distinct change in the spectral properties of an area.**
- **For each acquisition of remote sensing data, the study area is categorized into forest and non-forest.**
- **Areas that change from forest to non-forest are considered to have been cut during the time interval between acquisitions.**
- **Annualized cutting is calculated by dividing the area cut within a time interval by the number of years in the interval.**
- **Trend information is derived from the change in the amount of area cut per time interval.**
- **Sustainability of forest cutting is estimated by comparing the average annual cut with the nominal rotation cycle of the forest type being cut.**

Forest Harvesting



Data (images)

Status Information (maps)

Temporal Analysis (maps)

Trend Information (statistics)

OVERVIEW OF FOREST REGENERATION ASSESSMENT PROCEDURE

- **Forest regeneration assessments will be made on areas where removal of forest cover is detected, based on acquisitions after the removal of forest.**

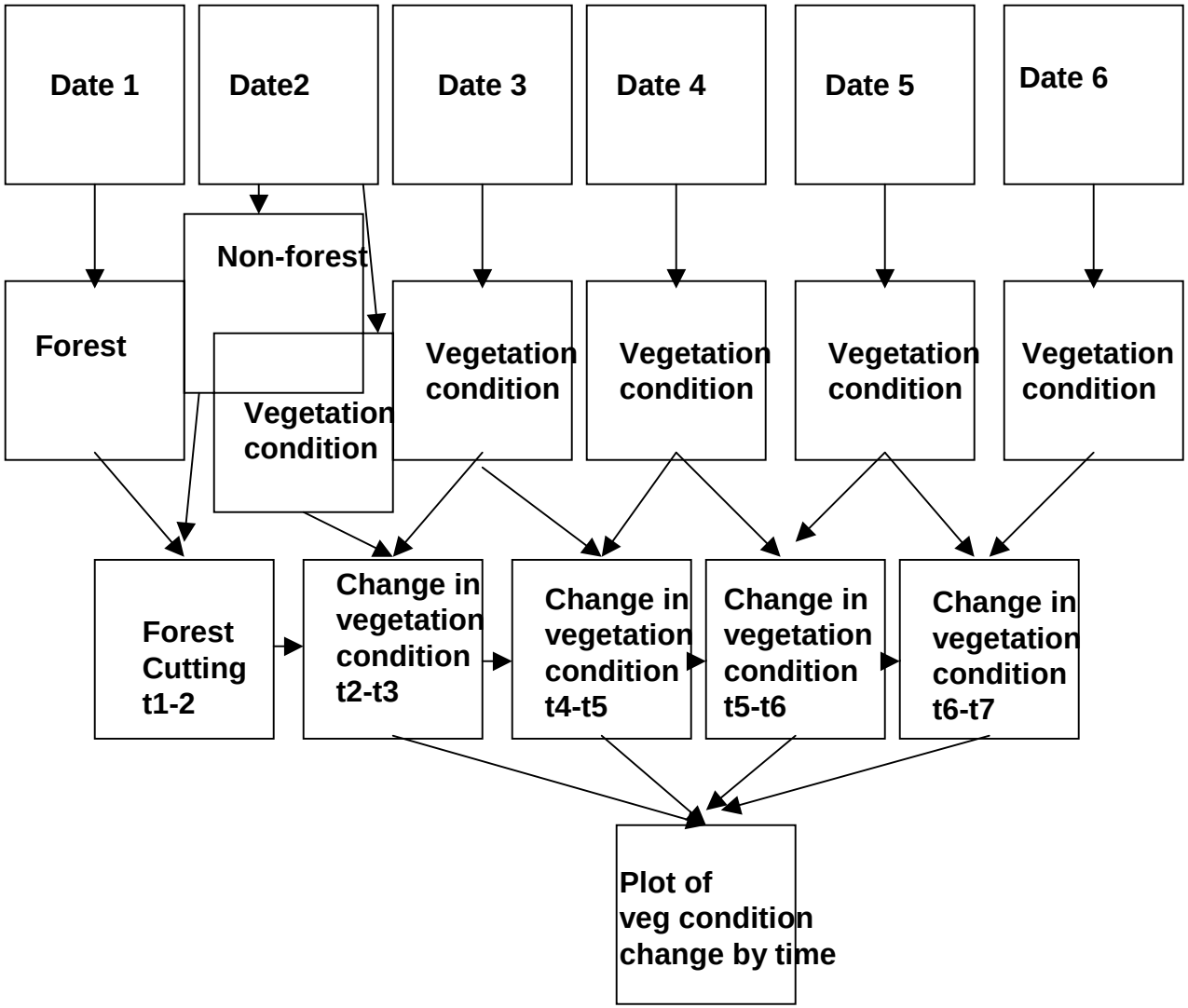
- **Removal of forest cover is detected by comparing land cover categories between pairs of images.**

- **Regeneration assessment is based in part on the condition, and changes in condition of the vegetation cover that is present in the time intervals following forest clearing.**

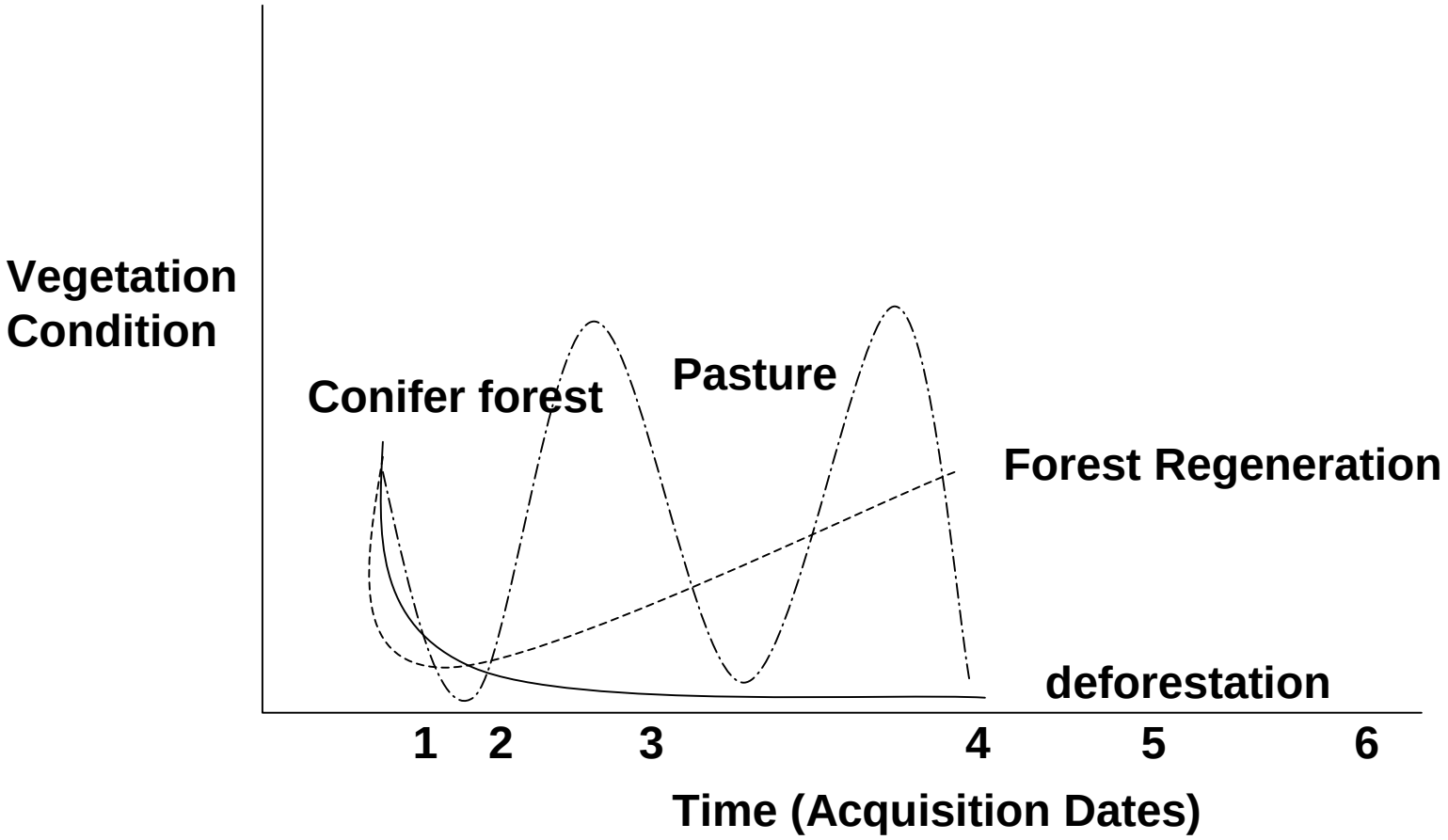
- **The length of the regeneration period available for analysis depends on in which time interval forest cutting was detected.**

- **For areas where regeneration has had many years to develop, it may be possible to assess the relative amount of hardwoods versus conifers present.**

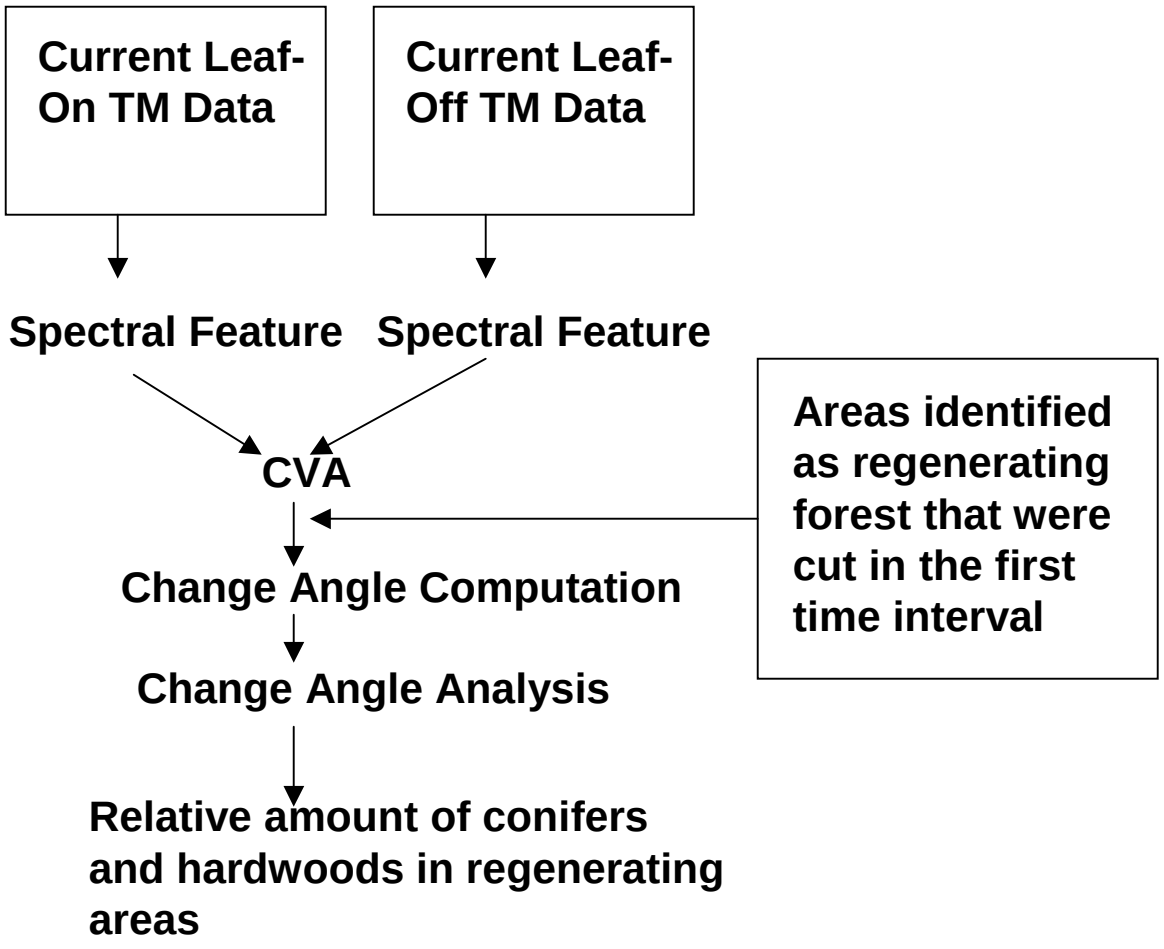
FOREST REGENERATION ASSESSMENT FOR FIRST TIME INTERVAL



VEGETATION CONDITION TRAJECTORY ANALYSIS FOR AREAS CUT IN FIRST TIME INTERVAL



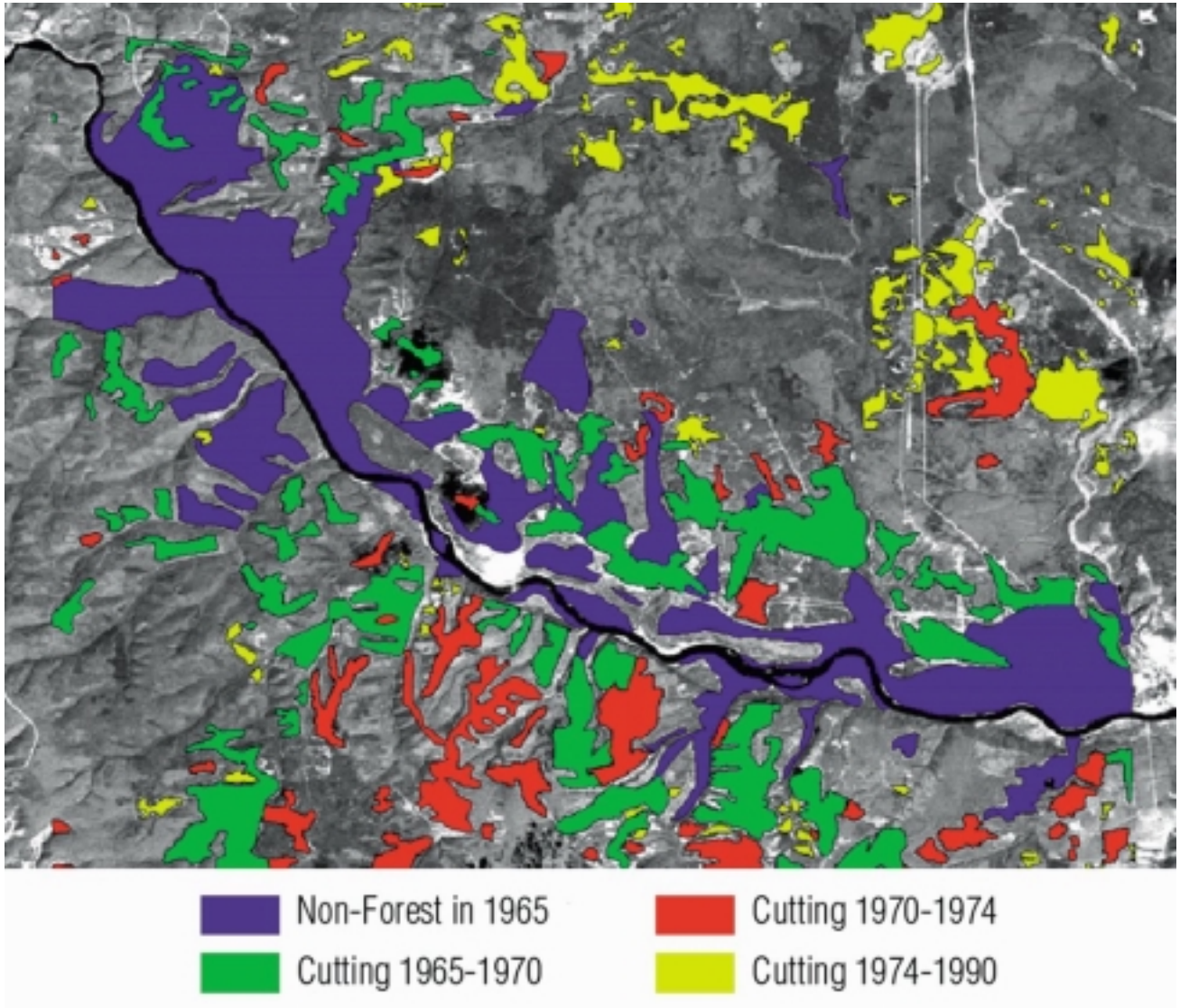
FOREST REGENERATION COMPOSITION ASSESSMENT FOR AREAS CUT IN FIRST TIME INTERVAL



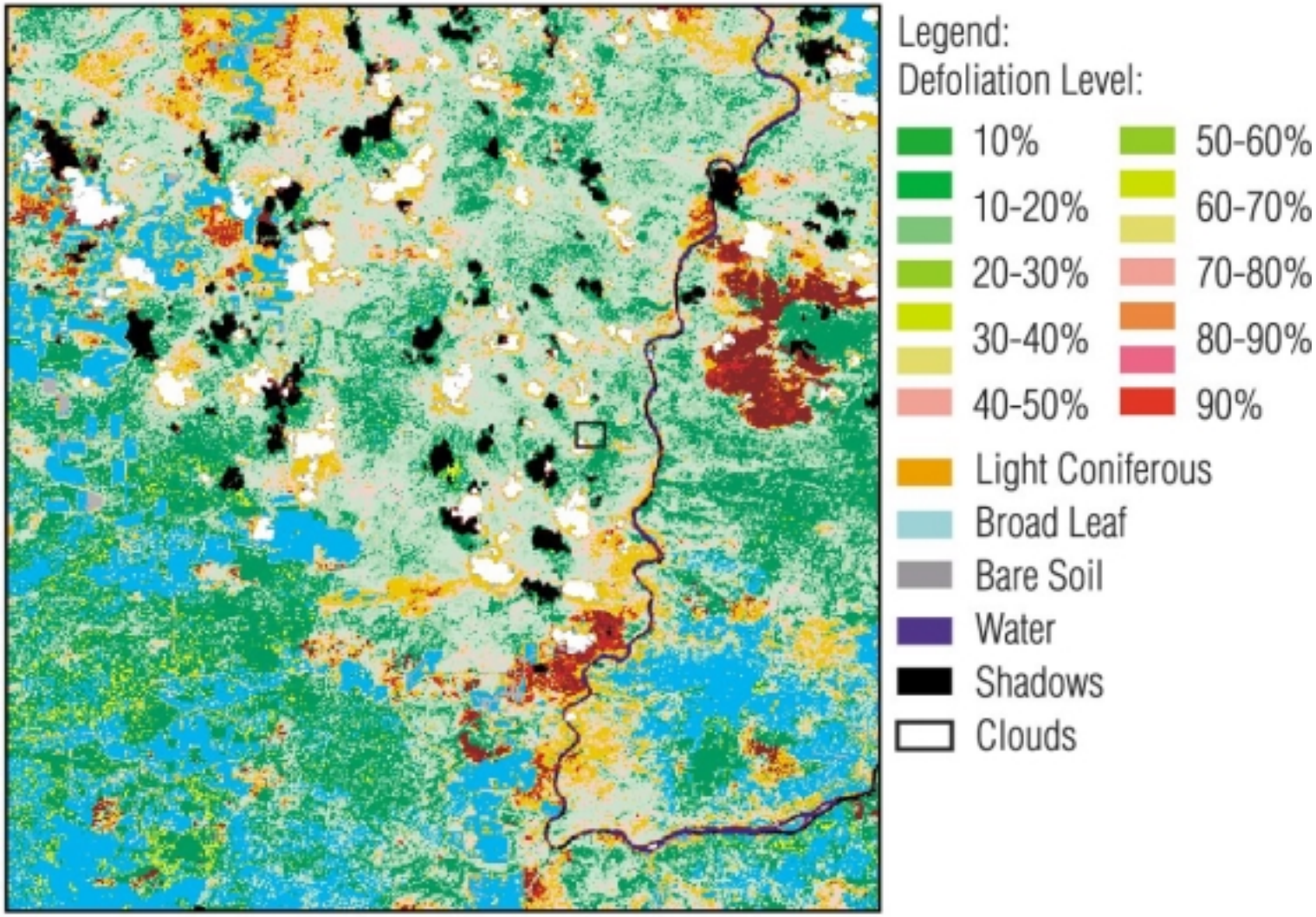
Chuna River: Preliminary Results

- **Equivalent information about forest harvesting can be extracted from a variety of combinations of historical remote sensing data. This capability makes it possible to assemble a set of acquisitions with sufficient temporal frequency to effectively monitor forest cutting.**
- **Phenological timing of some of the acquisitions may make regeneration assessment more difficult.**
- **Large area coverage sensors (like Landsat) may help assess the representativeness of information derived from higher spatial resolution sensors (like DISP).**
- **Data adequacy is likely to vary on a case-by-case basis. DISP data may limit geographic coverage. Differences in phenology between acquisitions may make interpretation difficult.**
- **Ortho-rectification of the DISP and KFA data is difficult, but should greatly facilitate comparisons between acquisitions.**

Deforested Areas near the Chuna River 1965-1990
Generated Through Analysis of DISP and Landsat



Map of Defoliation in the Biryusa River Basin from Siberian Silkworm Outbreaks 1994-1996 using SPOT Imagery



Map of Forest Defoliation Created by SPOT Imagery

Part III.
Modeling Patterns of Forest Regrowth/Carbon Sequestration

Modeling Boreal Forest Succession and Disturbance in the Krasnojarsk Kray Forest of Siberia

A. J. Hill, D.F. Clark and H.H. Shugart

Russia: Administrative Divisions
Republic, oblast, or kray boundary
Autonomous okrug (AOk) or autonomous oblast (AO) boundary
National capital
Oblast center
Republic
Oblast
Kray
An oblast is named only when its name differs from that of its administrative center. Moscow and St. Petersburg are federal cities having oblast-level status.
Arctic Ocean
Bering Sea
East Siberian Sea
Laptev Sea
Kara Sea
Barents Sea
Baltic Sea
Black Sea
Caspian Sea
Aral Sea
Lake Baikal
Lake Balkhash
Sea of Okhotsk
Sea of Japan
North Pacific Ocean
SVALBARD (NORWAY)
FRANZ JOSEF LAND
SEVERNAYA ZEMLYA
NEW SIBERIAN ISLANDS
Wrangel Island
NOVAYA ZEMLYA
U.S.
Chukotka (AOk)
Koryakia (AOk)
Kamchatka
Magadan
Petropavlovsk-Kamchatskiy
Taymyria (AOk)
Yakutia [Sakha]
Evenkia (AOk)
Krasnoyarsk
Khabarovsk
Amur
Birobijan (Yevrey AO)
Sakhalin
occupied by Soviet Union in 1945, administered by Russia, claimed by Japan
KURIL ISLANDS
Yuzhno-Sakhalinsk
Primorskiy [Maritime]
Komi
Yamalia (AOk)
Khantia-Mansia (AOk)
Nenetsia (AOk)
Permyakia (AOk)
Murmansk
Arkhangel'sk
St. Petersburg
Kaliningrad
Pskov
Novgorod
Tver'
Smolensk
Moscow
Yaroslavl'
Kostroma
Ivanovo
Vologda
Kirov
Perm'
Nizhniy Novgorod
Sverdlovsk
Yekaterinburg
Chelyabinsk
Bashkortostan
Kurgan
Tyumen'
Tomsk
Omsk
Novosibirsk
Kemerovo
Khakassia
Altay
Gorno-Altay
Tuva
Irkutsk
Ust'-Orda (AOk)
Buryatia
Aga (Aginskiy Buryat AOk)
Chita
Lake Baikal
Orenburg
Saratov
Volgograd
Rostov
Kalmykia
Astrakhan'
Dagestan
Ulyanovsk
Samara
Penza
Tambov
Voronezh
Belgorod
Kursk
Lipetsk
Bryansk
Oryol
Tula
Kaluga
Smolensk
Tver'
Pskov
Novgorod
Leningrad
Vologda
Yaroslavl'
Ivanovo
Kostroma
Vladimir
Nizhniy Novgorod
Kirov
Perm'
Sverdlovsk
Tyumen'
Kurgan
Chelyabinsk
Yekaterinburg
Tomsk
Omsk
Novosibirsk
Kemerovo
Altay
Gorno-Altay
Tuva
Irkutsk
Buryatia
Chita
Amur
Khabarovsk
Primorskiy [Maritime]
Sea of Japan
JAPAN
CHINA
MONGOLIA
KAZAKHSTAN
UZBEKISTAN
TURKMENISTAN
KYRGYZSTAN
TAJIKISTAN
AFGHANISTAN
IRAN
IRAQ
TURKEY
GEORGIA
ARMENIA
AZERBAIJAN
SYRIA
NORTH KOREA
SOUTH KOREA
MONGOLIA
BELARUS
UKRAINE
MOLDOVA
ROMANIA
POLAND
GERMANY
SWEDEN
FINLAND
DENMARK
1 Krasnodar
2 Stavropol'
3 Adygea
4 Karachay-Cherkessia
5 Kabardino-Balkaria
6 North Ossetia
7 Ingushetia a
8 Chechenia a
9 Mordovia
10 Chuvashia
11 Mari El
12 Udmurtia
a Boundary between Chechenia and Ingushetia has not been established.
b Chukotka may be independent of Magadan Oblast.
Names of administrative divisions are not authoritative. Boundary representation is not necessarily authoritative.
0 750 Kilometers
0 750 Miles
Base 802336 (R00183) 8-94

Permafrost Regions in the Soviet Union

Objectives:

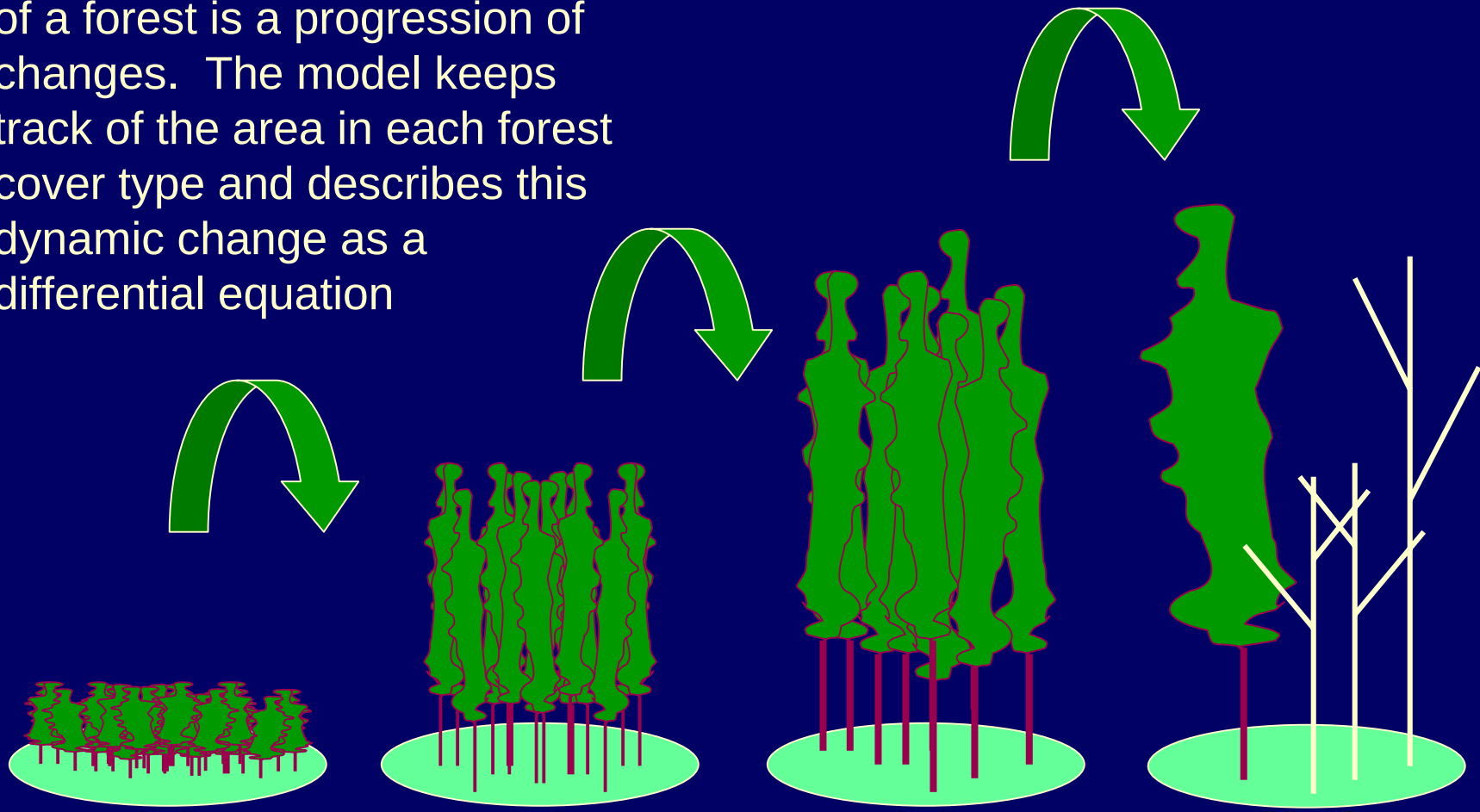
- To create a landscape scale succession model of Krasnojarsk, Siberia that incorporates fire and insect infestation.

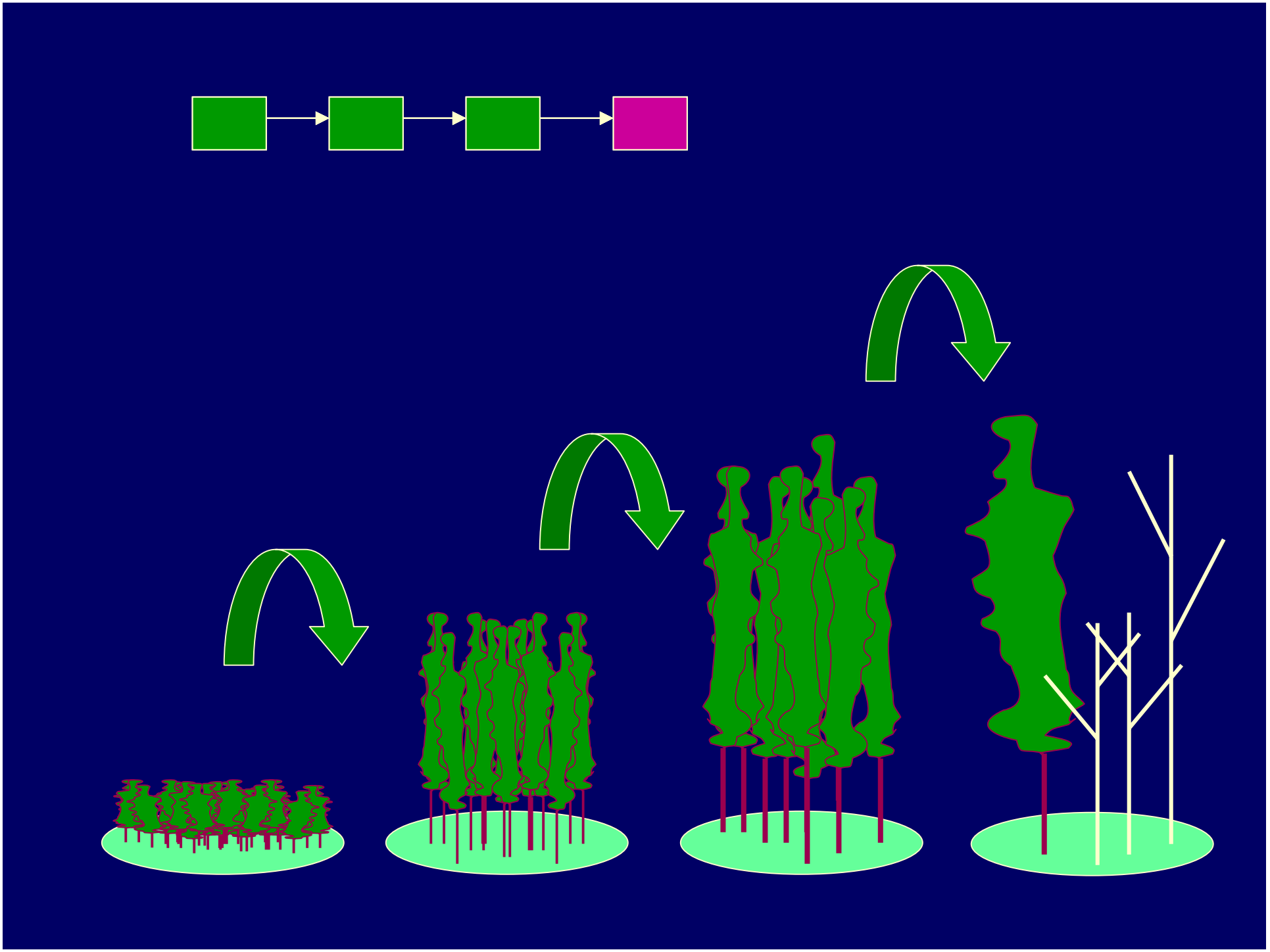
- To investigate forest composition under shifting disturbance regimes at times scales that are difficult to empirically investigate.

- **An initial model uses differential equations to simulate large areas of forest being transferred from one cover state to another.**

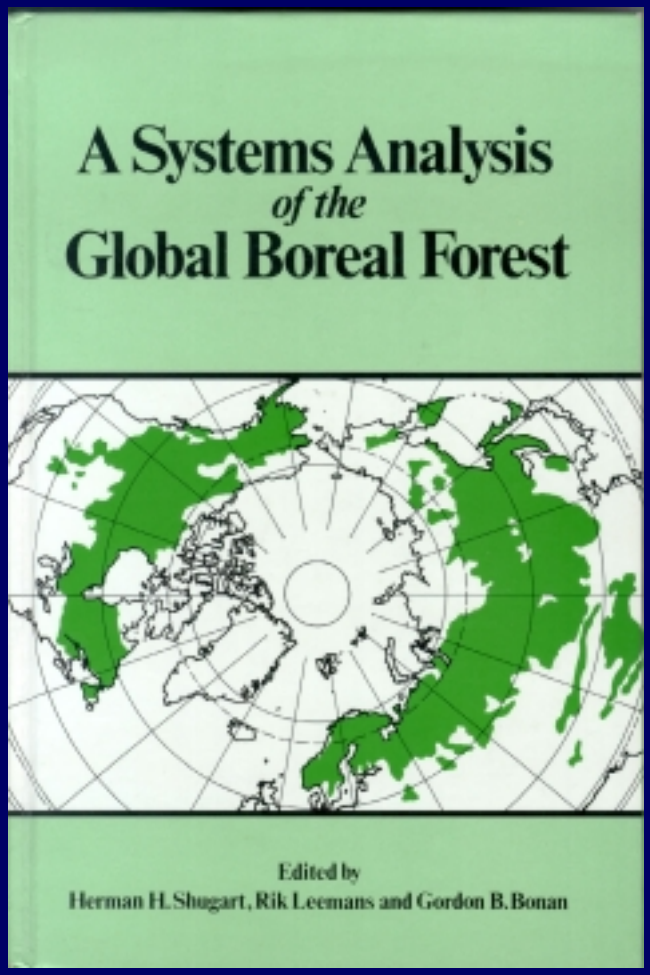
- **Rates of change and transfers among cover states are determined from species attributes or direct empirical measurements.**

The fundamental idea is that the successional development of a forest is a progression of changes. The model keeps track of the area in each forest cover type and describes this dynamic change as a differential equation





We used an already compiled synthesis of boreal sylvicultural data to estimate the rates of expected landscape change.



Using silvicultural descriptors to estimate change

Table 2.15. *Silvical parameters of boreal tree species in Eurasia*

Values for *ETSmax*, *ETSmin* and *Tcold* are estimated by overlapping of species distribution maps and climatic maps prepared by Dr. W. Cramer (personal communication). Values for *Hmax* in brackets are obtained in estimating *IS* from height and diameter data (see parameter explanation). Values for *B2* and *B3* are estimated so that the parabolic function for the diameter–height relation matches the asymptotic one (see explanation for parameter *IS*). Values for *Tl*, *Tdr* and *Tn* are based on unpublished data by N. P. Polikarpov. Unknown values are indicated by dashes.

Species	*ETSmax*	*ETSmin*	*Tcold*	*SFrq*	*Disp*	*Sfire*	*Smsl*	*Sm*	*Sdr*	*Slmin*	*Rlr*	*SprTnd*	*SprMax*	*SprMin*
Abies sibirica	1450	510	−35	30	T	F	F	T	F	4	T	0	0	0
Betula pendula	2300	410	−40	90	T	T	F	F	T	—	F	—	—	—
Betula pubescens	2050	340	−40	90	T	T	T	F	F	—	F	—	—	—
Chosenia arbutifolia	1750	240	−45	90	T	T	T	F	F	—	F	—	—	—
Larix gmelinii	1500	250	−45	33	T	T	T	F	T	—	F	0	0	0
Larix sibirica	1500	300	−33	20	T	T	T	F	T	—	F	0	0	0
Larix sukaczewii	1750	390	−22	20	T	T	T	F	T	—	F	0	0	0
Picea abies	2250	470	−17	24	T	F	T	F	F	5	T	0	0	0
Picea ajanensis	1800	750	−38	40	T	F	F	T	T	—	T	0	0	0
Picea obovata	1500	320	−40	8	T	F	F	F	F	—	T	0	0	0
Pinus pumila	1600	240	−45	90	F	F	F	F	T	—	T	0	0	0
Pinus sibirica	1450	490	−35	65	F	F	F	F	F	6	F	0	0	0
Pinus sylvestris	2350	450	−40	24	T	T	T	F	T	—	F	0	0	0
Populus tremula	3000	400	−40	35	T	T	T	F	F	—	F	—	—	—

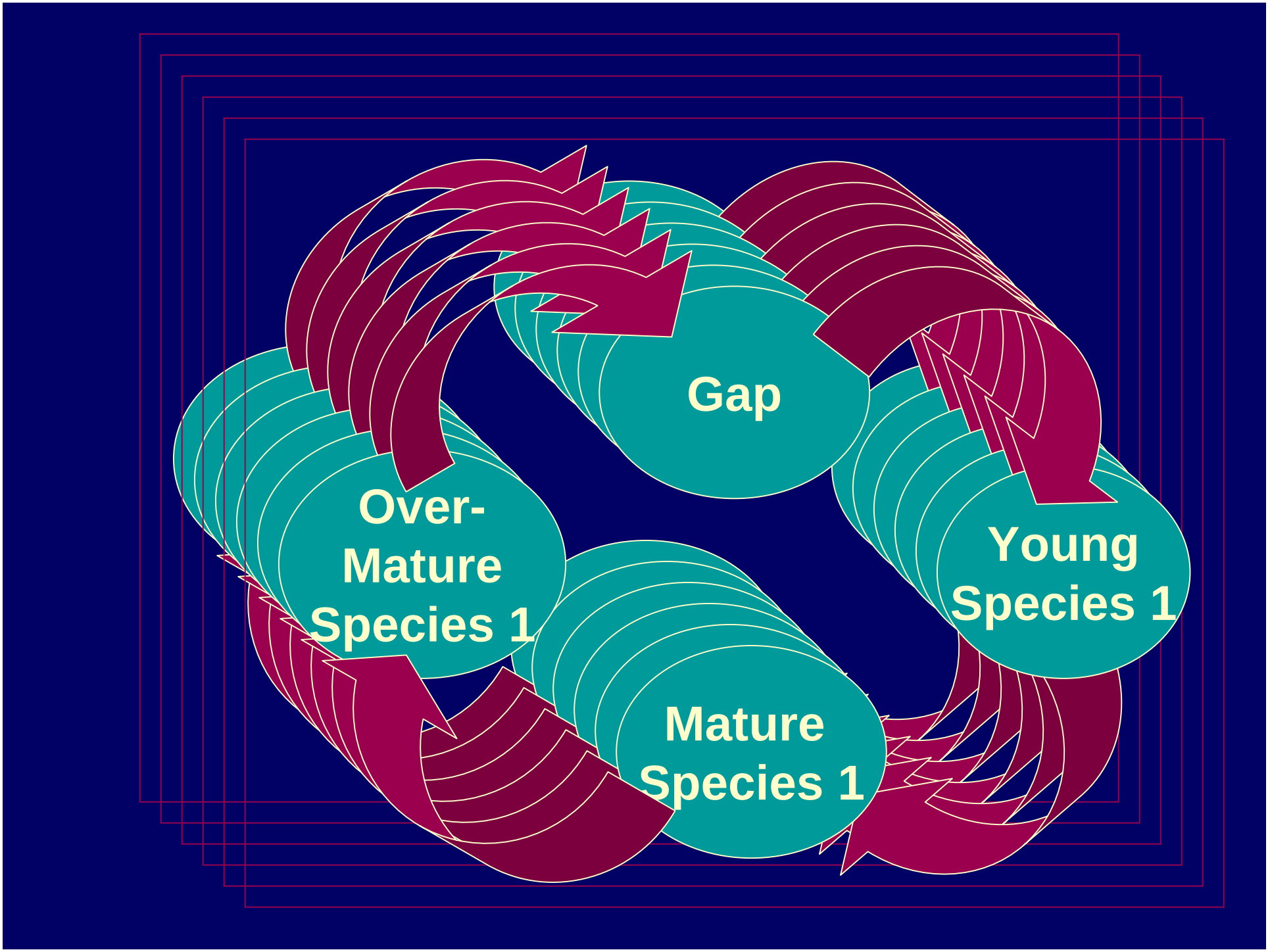
Longevity

Growth Rate

Tolerance to environmental factors

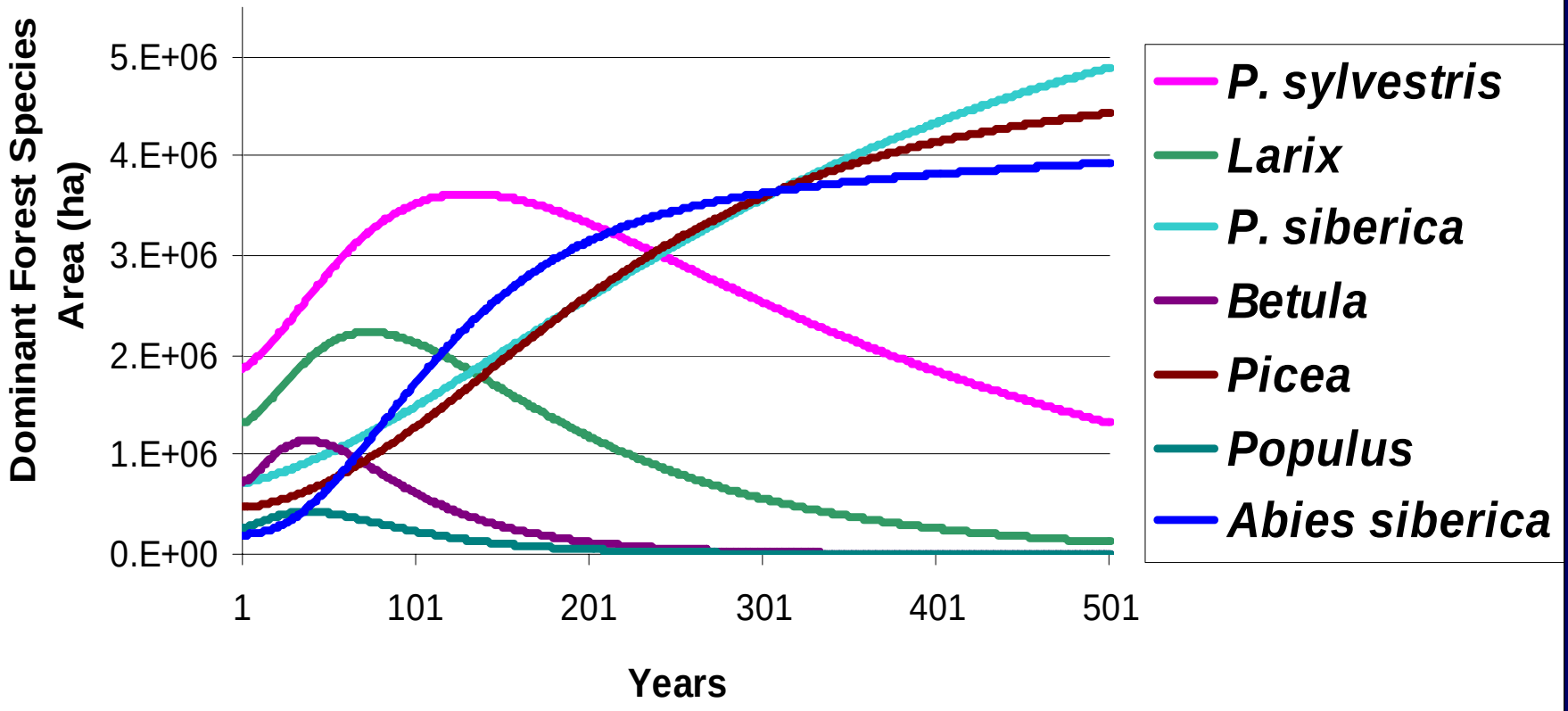
Table 2.15 (*cont.*)

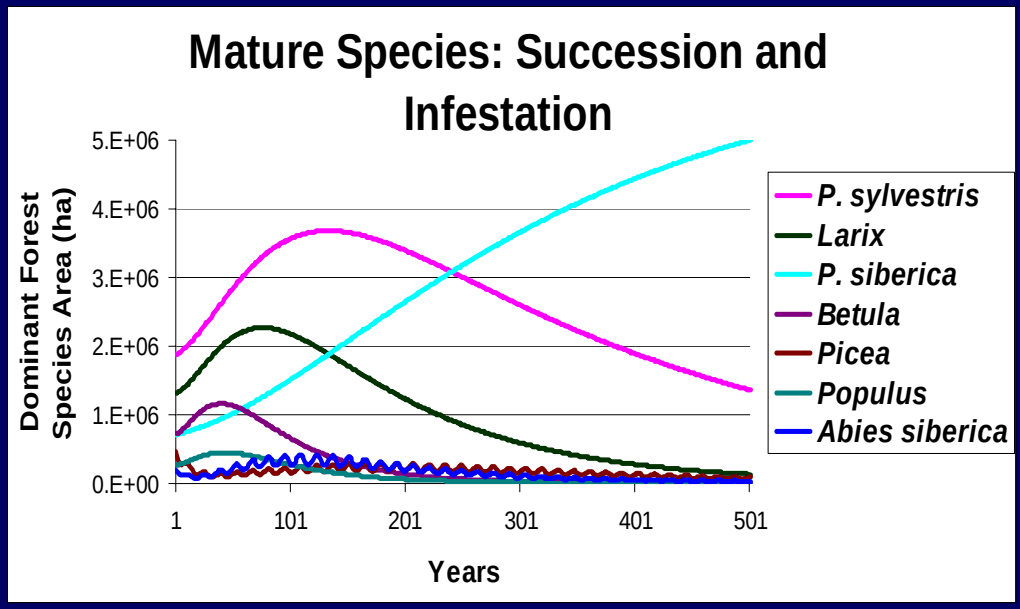
Species	*Hmax*	*Dmax*	*Imax*	*AGEmax*	*IS*	*B2*	*B3*	*S*	*Tl*	*Tdr*	*Tn*	*Tfr*	*Tfl*	*Bog*	*Ptol*
Abies sibirica	40 (42.4)	80	—	300	1.0329	91.18	0.5065	83.0	1	5	5	3	2	1	1
Betula pendula	30	60	100	150	1.0987	92.36	0.7448	235.0	4	1	1	1	1	1	2
Betula pubescens	30	60	—	100	1.0987	92.36	0.7448	235.0	4	5	1	2	2	2	2
Chosenia arbutifolia	37	80	—	130	—	89.06	0.5567	314.0	5	5	5	—	4	1	1
Larix gmelinii	40 (38.8)	140	120	400	1.0914	78.84	0.4022	164.0	5	2	2	1	3	2	3
Larix sibirica	45	180	—	450	1.4897	94.85	0.5155	165.0	5	1	2	1	3	2	2
Larix sukaczewii	40 (42.0)	120	—	350	1.4701	93.40	0.5368	161.0	5	3	2	1	2	2	1
Picea abies	63	170	70	570	1.0761	75.62	0.2320	152.0	2	5	3	3	2	2	1
Picea ajanensis	60	150	—	500	0.5649	57.20	0.1395	99.0	2	4	3	3	2	2	2
Picea obovata	40	50	—	500	1.0214	85.84	0.4769	97.0	2	5	3	3	3	2	2
Pinus pumila	7	—	4	200	0.5567	50.04	1.1121	13.5	3	4	1	3	3	2	3
Pinus sibirica	45	190	—	800	0.8955	69.81	0.2792	83.0	2	4	3	2	3	2	2
Pinus sylvestris	48	190	100	600	0.9772	81.81	0.3588	144.4	4	1	1	1	3	2	1
Populus tremula	42	100	150	150	1.3910	90.29	0.5016	225.0	4	2	3	3	3	1	1


Gap
Young Species 1
Mature Species 1
Over-Mature Species 1

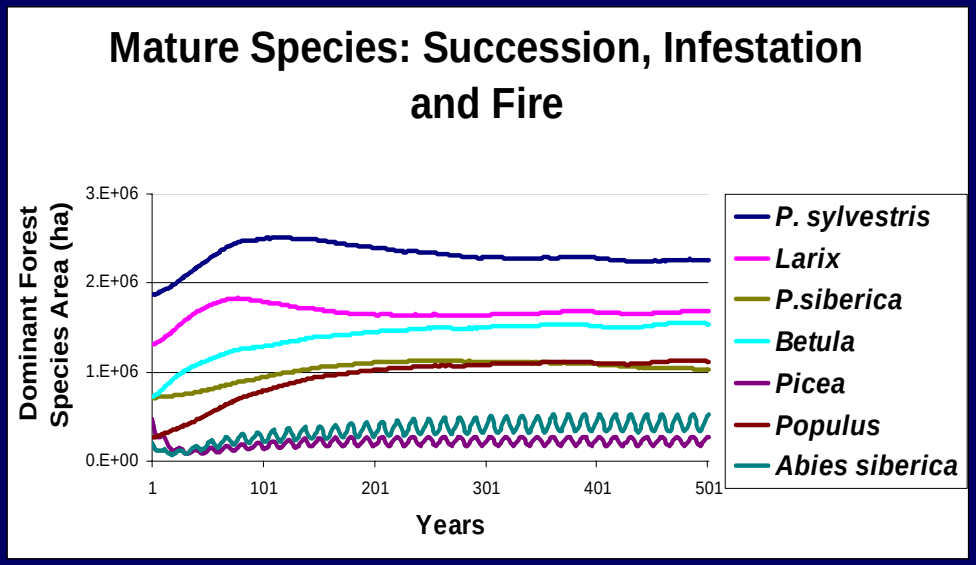
Results

Mature Species: Succession Only



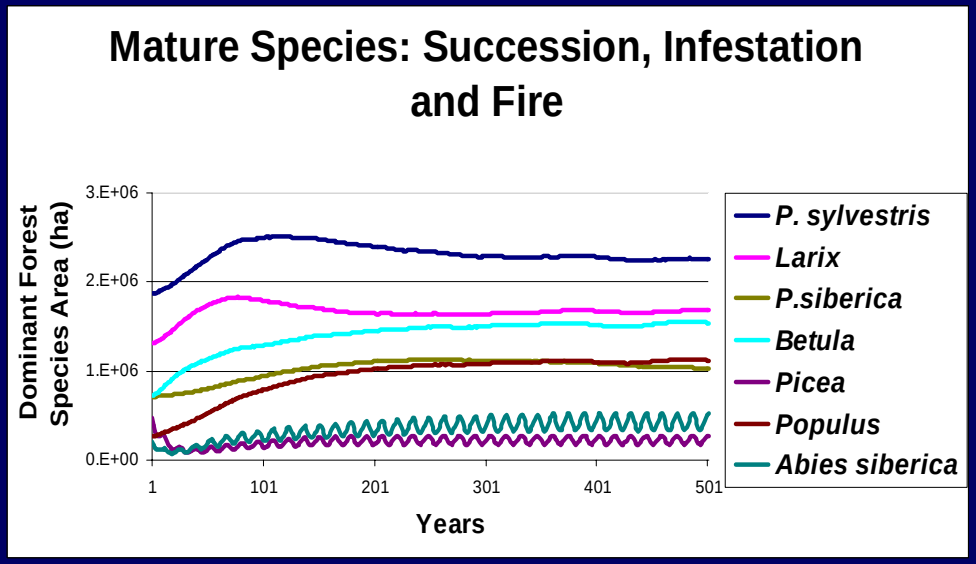


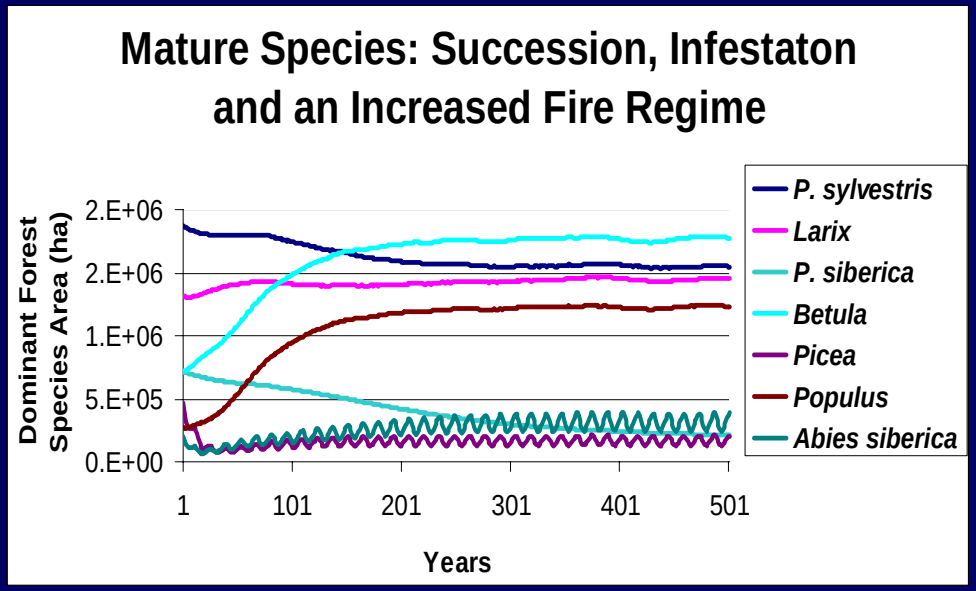
Infestation


Mature Species: Succession, Infestation and Fire
Dominant Forest Species Area (ha)
3.E+06
2.E+06
1.E+06
0.E+00
1
101
201
301
401
501
Years
P. sylvestris
Larix
P.siberica
Betula
Picea
Populus
Abies siberica

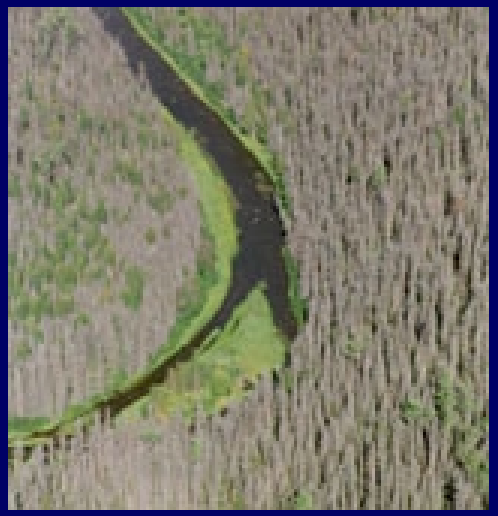
Fire

Fire

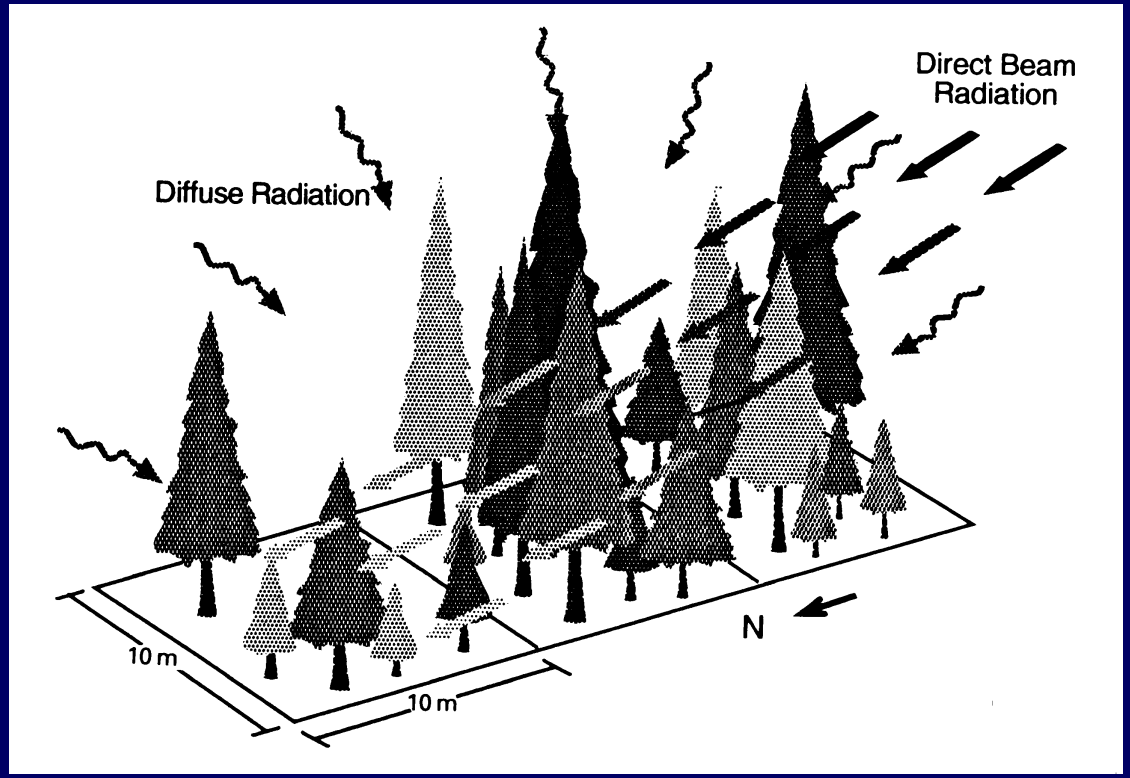

Mature Species: Succession, Infestation and Fire
Dominant Forest Species Area (ha)
3.E+06
2.E+06
1.E+06
0.E+00
1
101
201
301
401
501
Years
P. sylvestris
Larix
P.siberica
Betula
Picea
Populus
Abies siberica


Mature Species: Succession, Infestaton and an Increased Fire Regime
Dominant Forest Species Area (ha)
2.E+06
2.E+06
1.E+06
5.E+05
0.E+00
1
101
201
301
401
501
Years
P. sylvestris
Larix
P. siberica
Betula
Picea
Populus
Abies siberica

Current work involves the development of an individual-based model of forest dynamics that integrates directly with the landscape simulator.



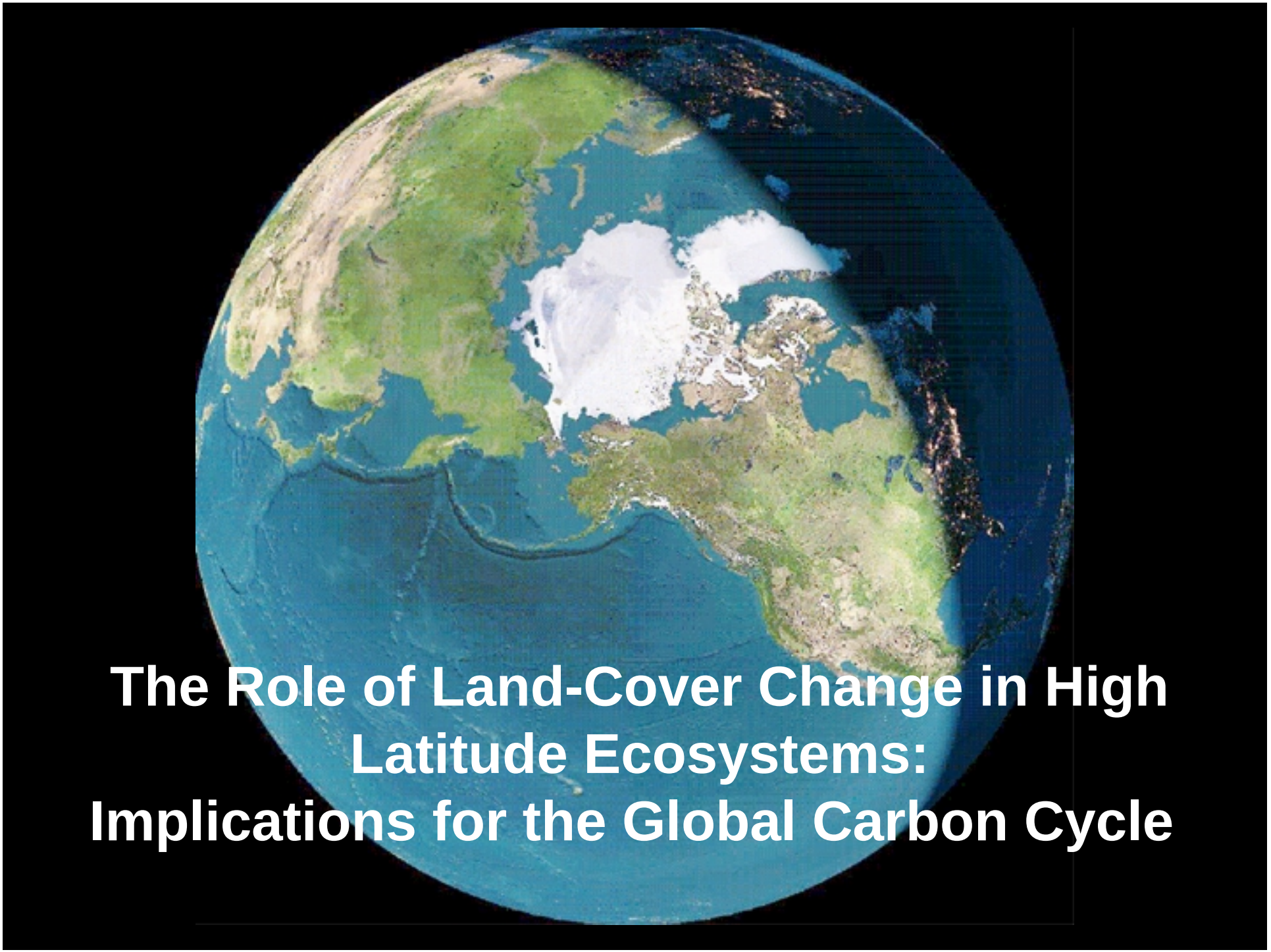
Individual-based Model



The 6-week visit of Slava Kharuk allowed us to reparameterize the land-cover change model. We have also developed an spatial individual based model for the central Siberian site.

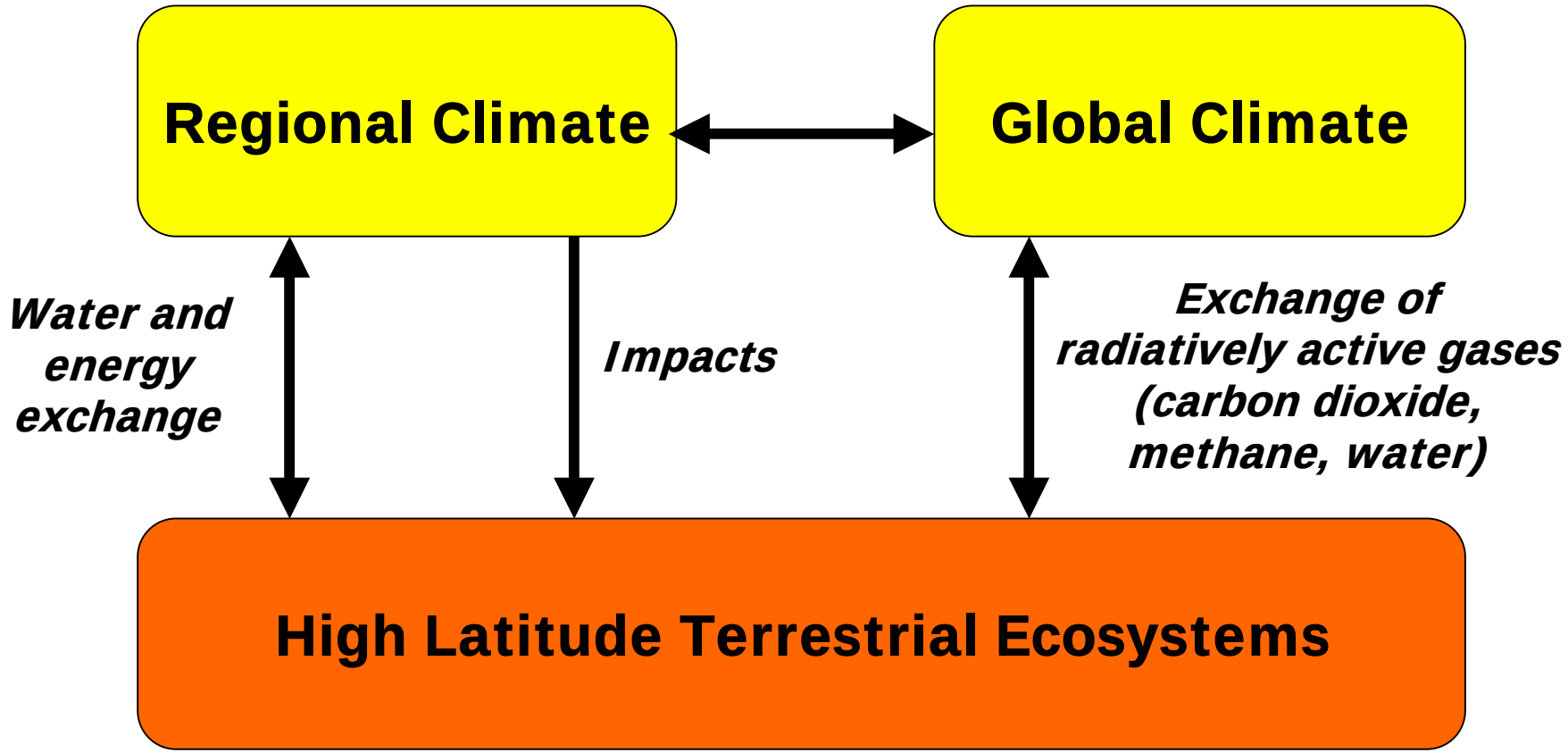
Alaska

Early Results- The role of land-cover change in high latitude ecosystems: implications for the global carbon cycle - D. McGuire



The Role of Land-Cover Change in High Latitude Ecosystems: Implications for the Global Carbon Cycle

Global Change in High Latitude Ecosystems



Participants

- A. David McGuire (PI, UAF)
- Dave Verbyla (Co-PI, UAF)
- Jerry Melillo (Co-PI, MBL)
- Rose Meier (UAF)
- Dave Kicklighter (MBL)
- Matt Macander, Cherie Silapaswan, Aaron Woods, Qianlai Zhuang, Dorte Dissing
- Scott Rupp, Terry Chapin, Tony Starfield

Project Goals

- **Develop prototype spatially explicit modeling framework to elucidate how land-cover change in high latitude ecosystems influences carbon storage**

- **Apply modeling framework to assess sensitivity and uncertainty of terrestrial carbon storage responses in high latitude ecosystems**
  - **Historical responses**
  - **Future responses**

Strategy

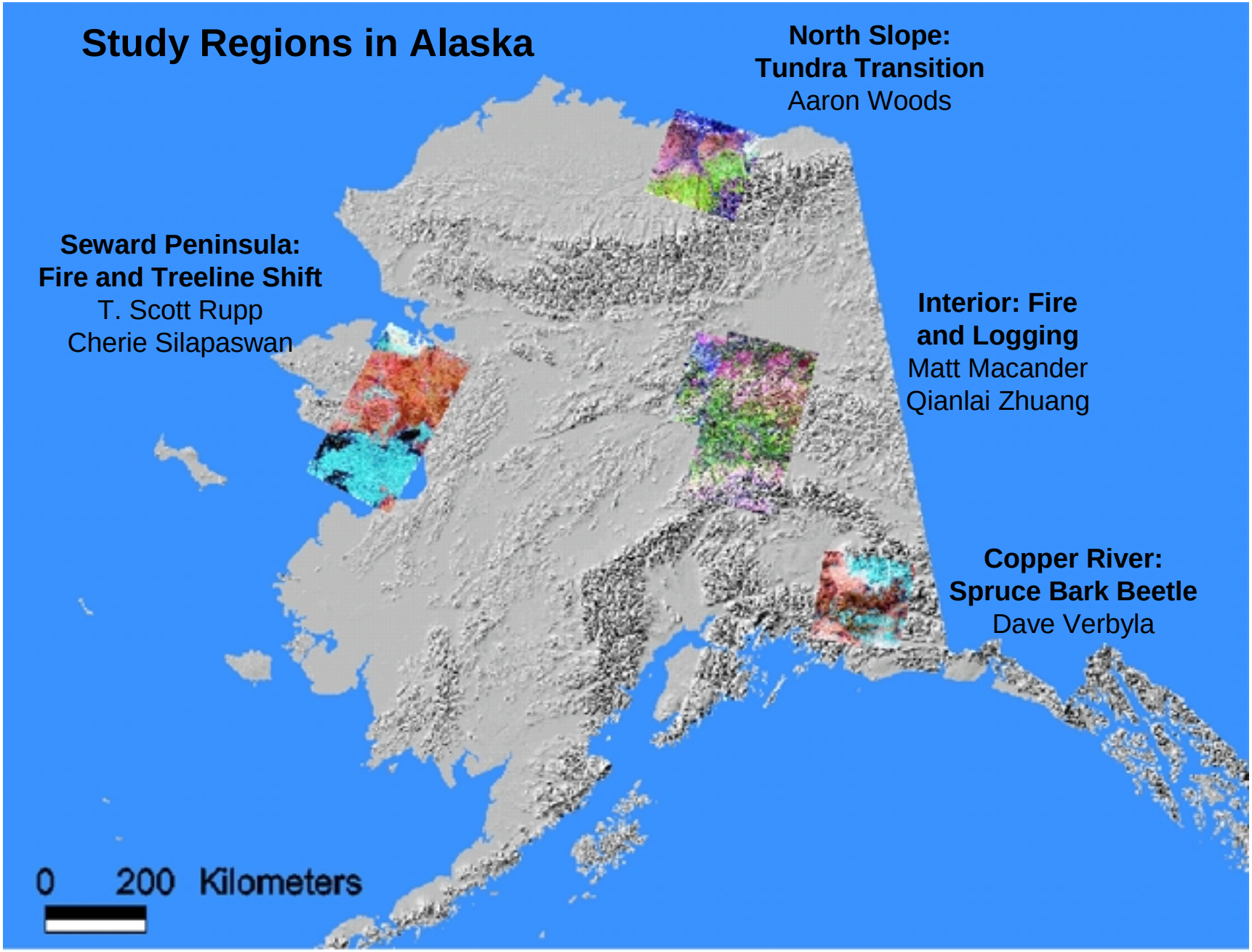
- **Focus on Alaska**
- **Develop historical transient land cover**
- **Develop components of modeling framework**
- **Application of modeling framework**
  - **Retrospective analyses**
  - **Prognostic analyses**

Why Alaska?

- **Substantial development over last 30 years**
- **Timing and extent of disturbances known**
- **Major disturbances include fire, logging, and insect infestation**
- **Vegetation replacement may be occurring**
- **Climate change may be affecting vegetation dynamics and the frequency and extent of disturbances**
- **Process-based research (taiga/tundra LTERs)**

Development of Transient Land Cover

- **Focus: 4 regions in Alaska plus Global**
  - **Tanana River Valley - fire and logging**
  - **Copper River Valley - insects and logging**
  - **Seward Peninsula - vegetation dynamics and fire**
  - **North Slope - vegetation dynamics**
  - **Global - agricultural land use**
- **Change detection**
  - **Aerial Photography**
  - **Landsat MSS, TM**
  - **AVHRR**
  - **Ancillary Data Sets**


Study Regions in Alaska
North Slope:
Tundra Transition
Aaron Woods
Seward Peninsula:
Fire and Treeline Shift
T. Scott Rupp
Cherie Silapaswan
Interior: Fire
and Logging
Matt Macander
Qianlai Zhuang
Copper River:
Spruce Bark Beetle
Dave Verbyla
0 200 Kilometers

Change Detection in Interior Alaska

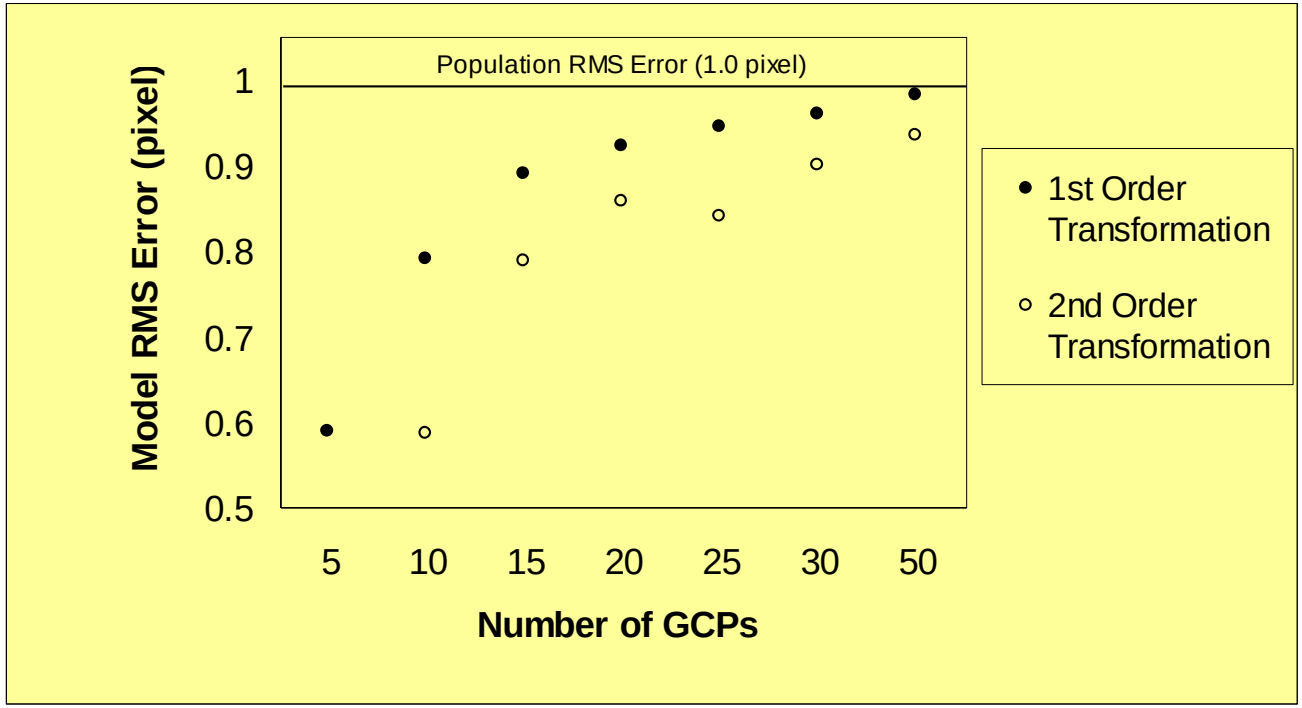
- **Theoretical Issues (GCP's, Grain Size, Classes)**
- **Firescar Database 1950-1997**
- **Comparisons with Landsat Imagery**
- **Detailed Analysis of Land-Cover Change:**

  1983 Rosie Creek Fire

  - **Pre-fire Air Photos and Landsat MSS Imagery**
  - **Immediate Post-fire Air Photos and Landsat TM Imagery**
  - **Decadal Post-fire Air Photos and Landsat TM imagery**

Potential Bias in Land Cover Change Estimates Due to Positional Errors

- Bias can occur at any spatial scale
- False change may exceed real landscape change



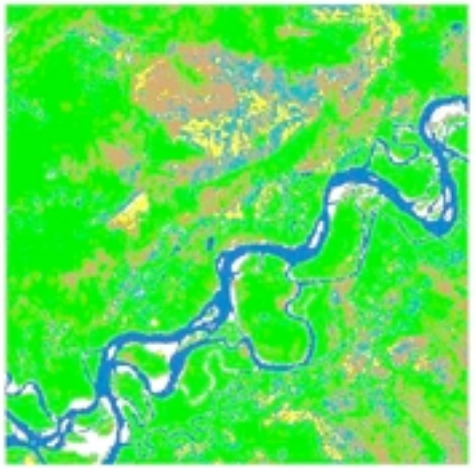
Subpixel rectification error may be optimistic:

- **model error varies with GCP sample size**
- **model error varies with transformation order**

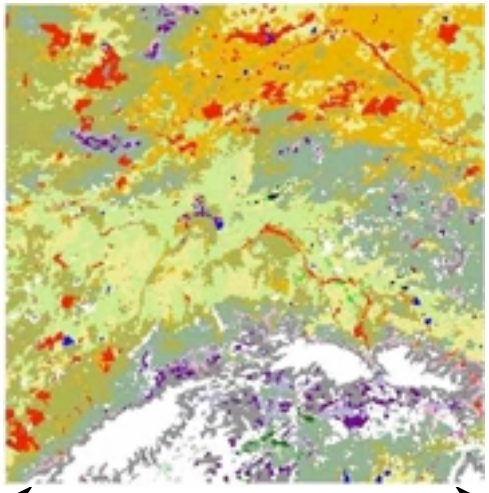
Landsat TM 20 Classes

10 KM

Landsat TM 6 General Classes

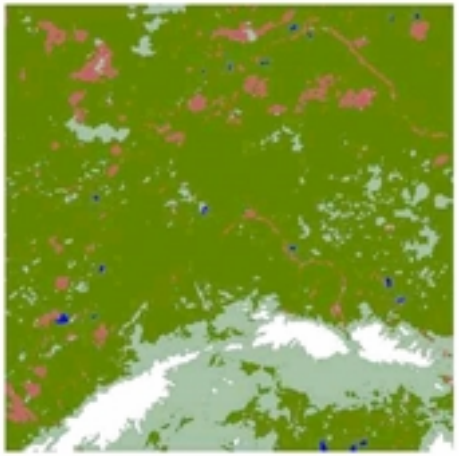


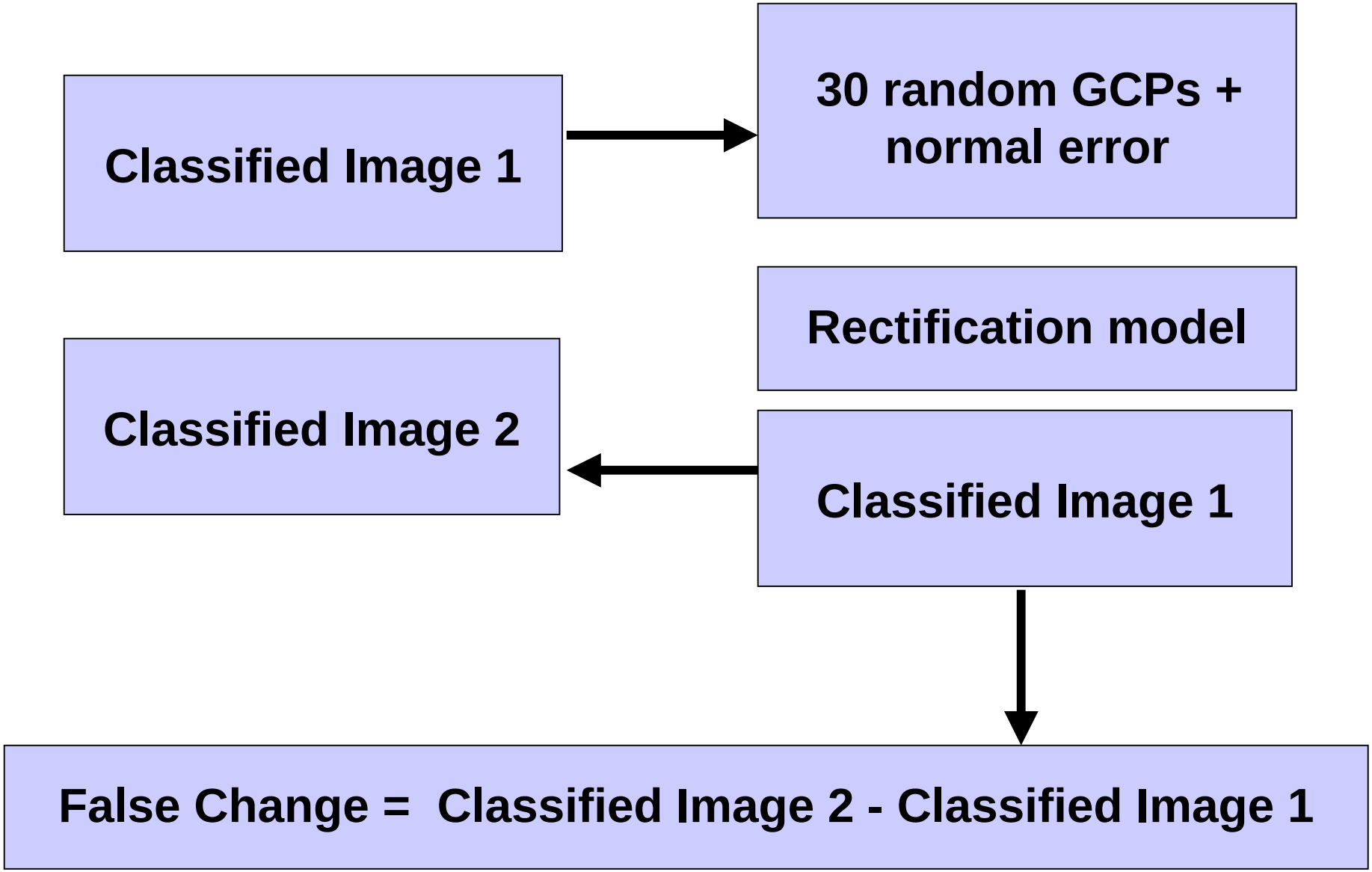
AVHRR 20 Classes



500 KM

AVHRR 5 General Classes




Classified Image 1
30 random GCPs + normal error
Rectification model
Classified Image 2
Classified Image 1
False Change = Classified Image 2 - Classified Image 1

	20 class, 25m pixel		20 class, 1km pixel		6 class, 25m pixel		5 class, 1km pixel	
	Co-registration RMS error	Percent Change	Co-registration RMS error	Percent Change	Co-registration RMS error	Percent Change	Co-registration RMS error	Percent Change
Trial#1	1.10	7.6	0.72	10.9	1.10	8.4	0.86	1.4
Trial#2	0.86	23.7	0.89	14.3	0.73	8.2	0.87	3.5
Trial#3	1.00	8.6	0.89	20.4	0.81	10.1	0.76	2.0
Trial#4	0.75	33.2	0.95	1.8	0.94	8.5	0.96	0.1
Trial#5	0.97	5.9	1.01	13.9	0.89	15.0	0.96	0.5
Trial#6	1.06	9.7	0.94	7.1	1.02	2.2	0.97	2.7
Trial#7	0.93	8.8	0.86	6.6	1.01	10.6	0.96	1.2
Trial#8	0.71	16.1	1.01	5.4	1.09	5.8	0.99	0.6
Trial#9	0.86	4.2	1.00	10.1	1.01	4.4	0.93	1.1
Trial#10	0.90	19.8	0.82	8.4	0.87	14.2	0.96	0.9

- **Landscape metric of heterogeneity not useful; bias in landscape change varied by trial**
- **Bias in landscape change was generally more significant with heterogeneous landscapes**
- **Subpixel co-registration may not solve the problem**

Change Detection in Interior Alaska

- Theoretical Issues (GCP's, Grain Size, Classes)
- **Firescar Database 1950-1997**
- Comparisons with Landsat Imagery
- Detailed Analysis of Land-Cover Change:

  1983 Rosie Creek Fire

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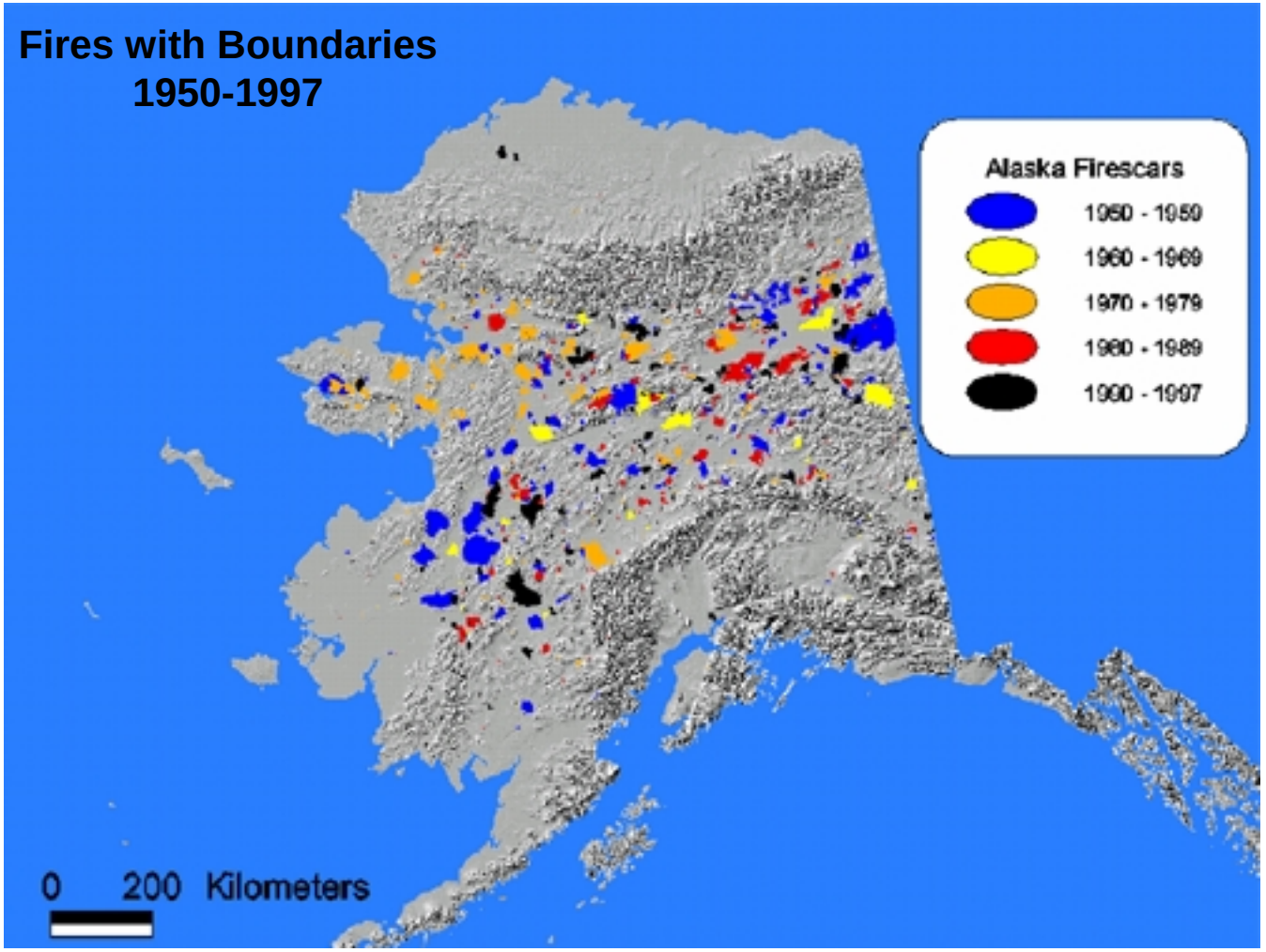
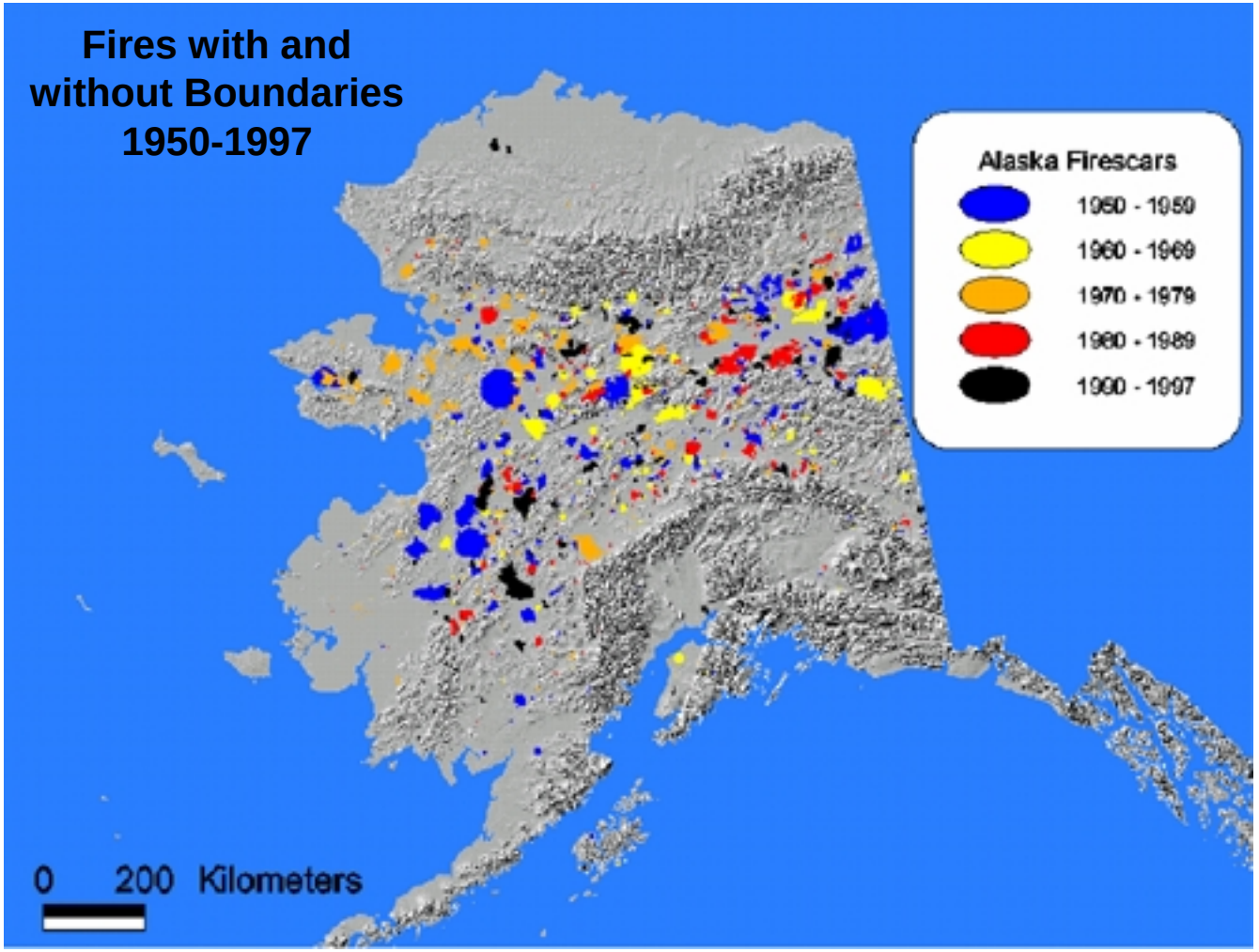

Fires with Boundaries
1950-1997
Alaska Firescars
1950 - 1959
1960 - 1969
1970 - 1979
1980 - 1989
1990 - 1997
0 200 Kilometers


Fires with and without Boundaries 1950-1997
Alaska Firescars
1950 - 1959
1960 - 1969
1970 - 1979
1980 - 1989
1990 - 1997
0 200 Kilometers

Change Detection in Interior Alaska

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- **Comparisons with Landsat Imagery**
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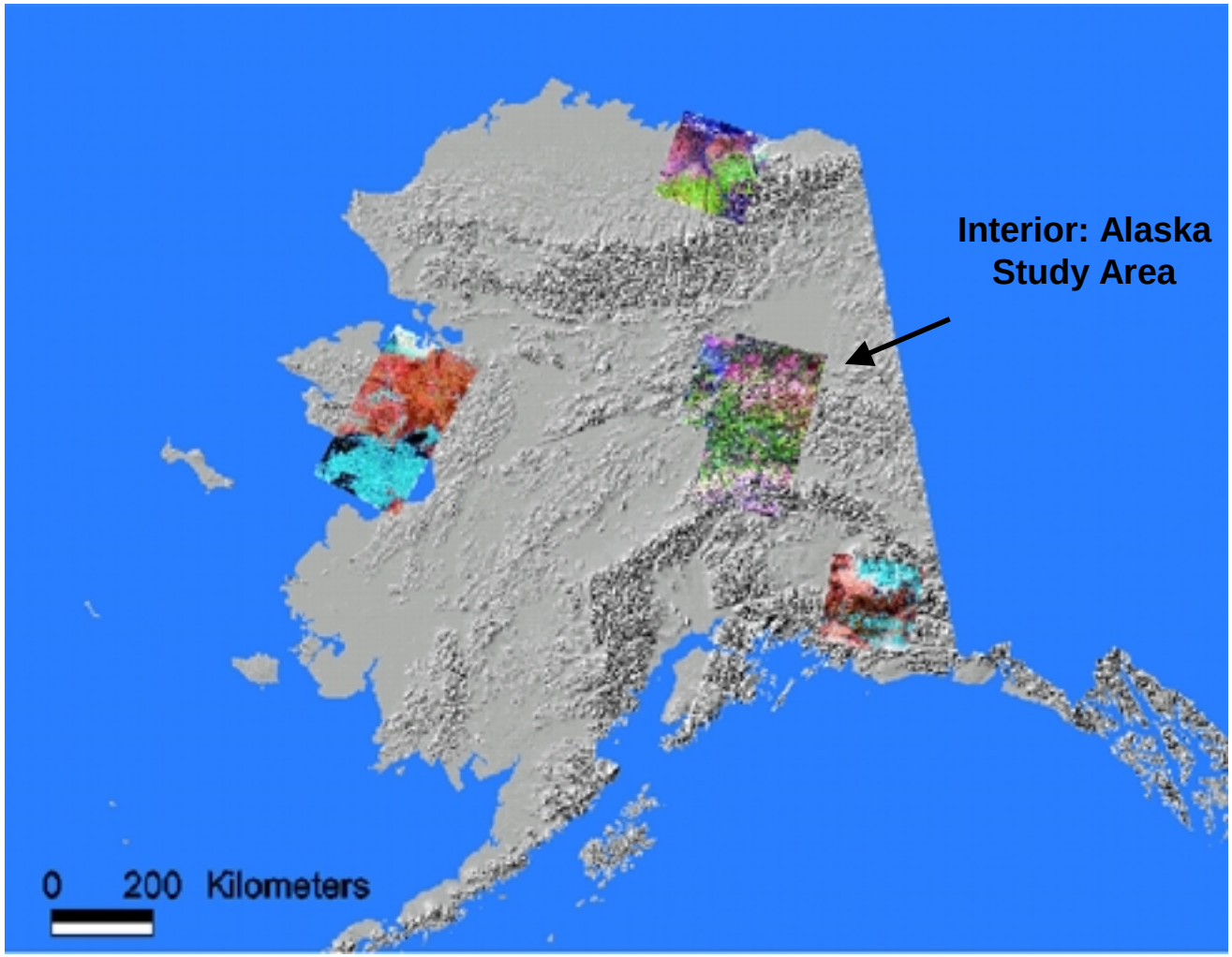
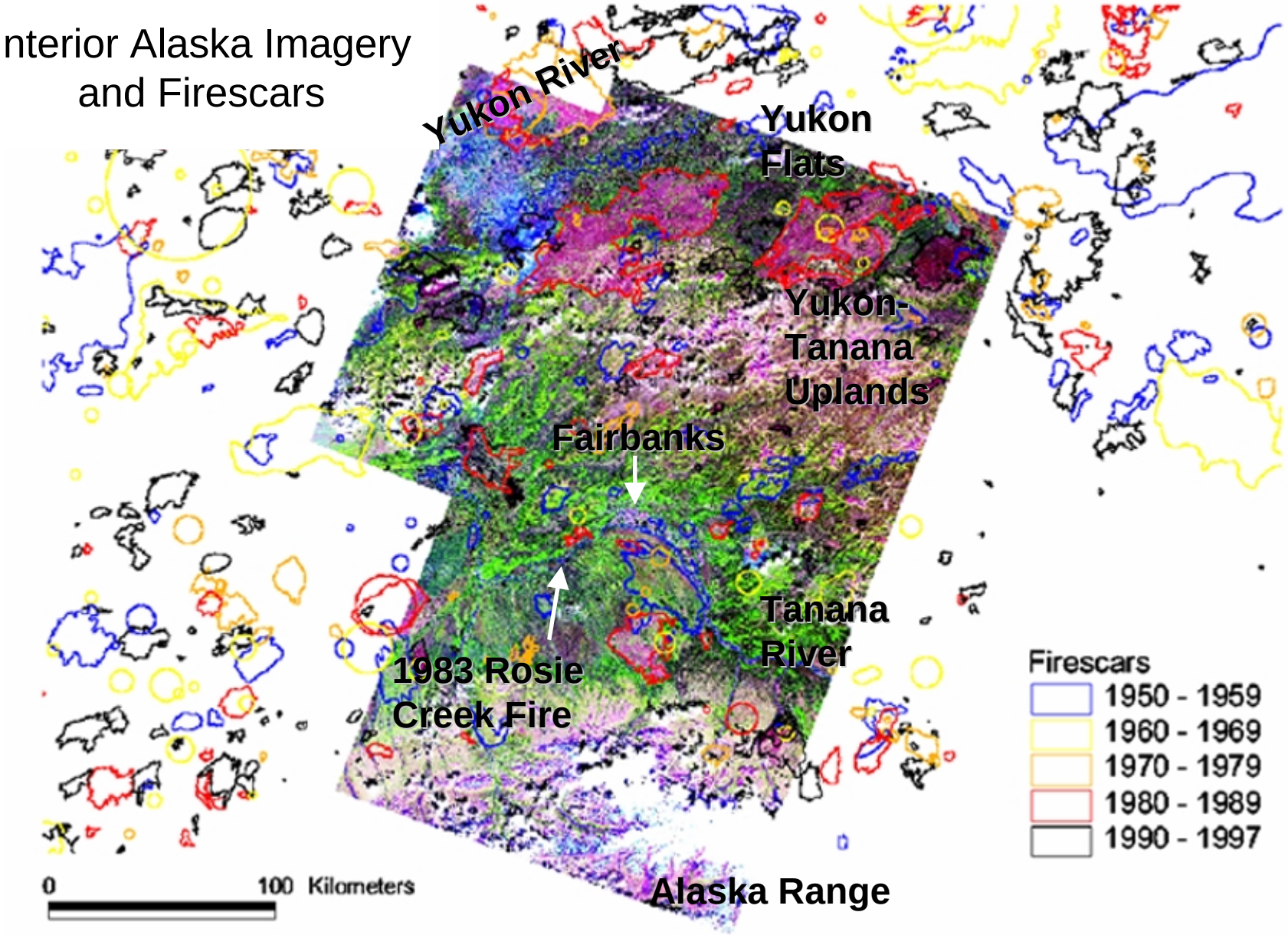

Interior: Alaska
Study Area
0 200 Kilometers

Interior Alaska Imagery and Firescars

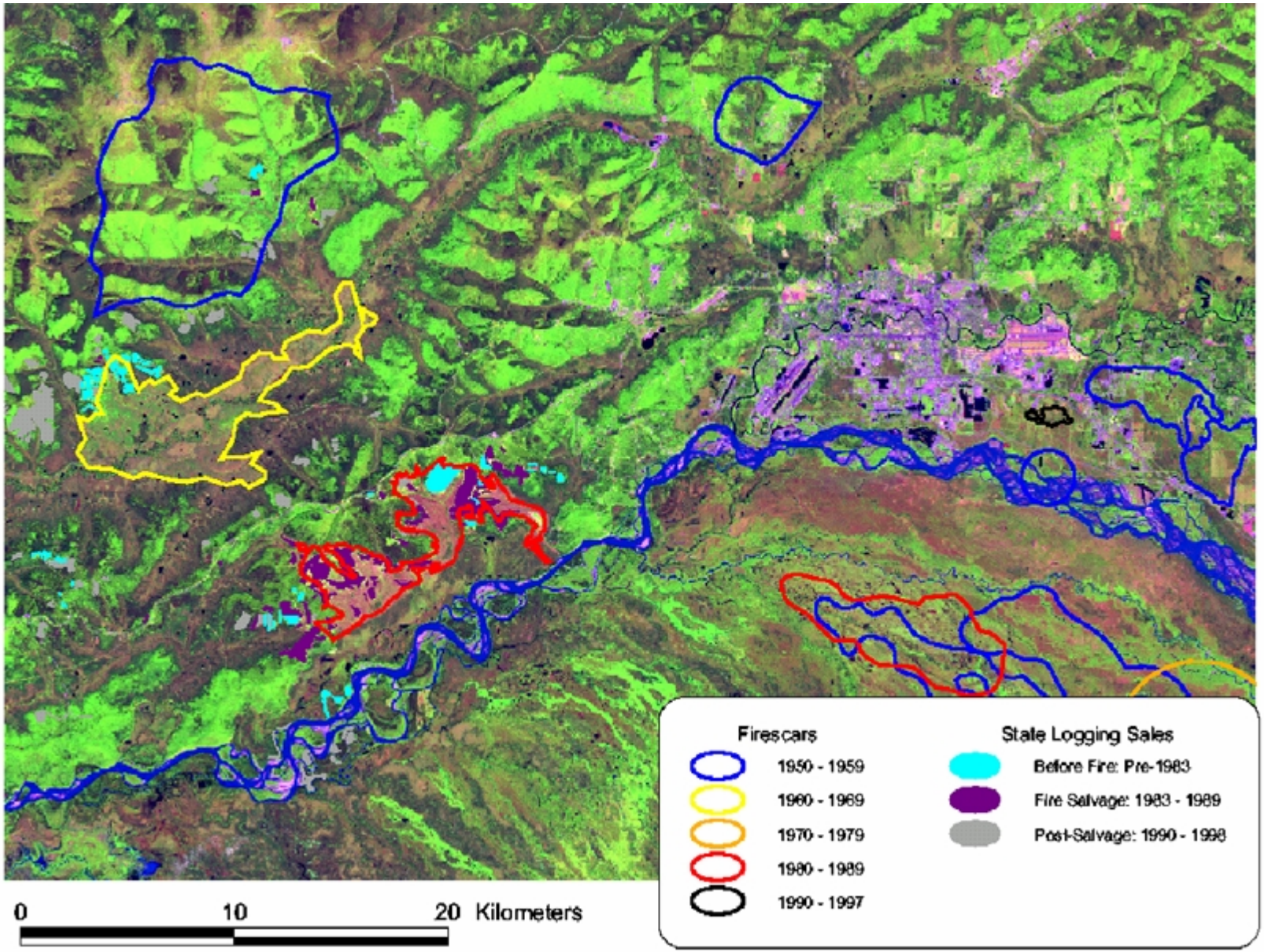


Change Detection in Interior Alaska

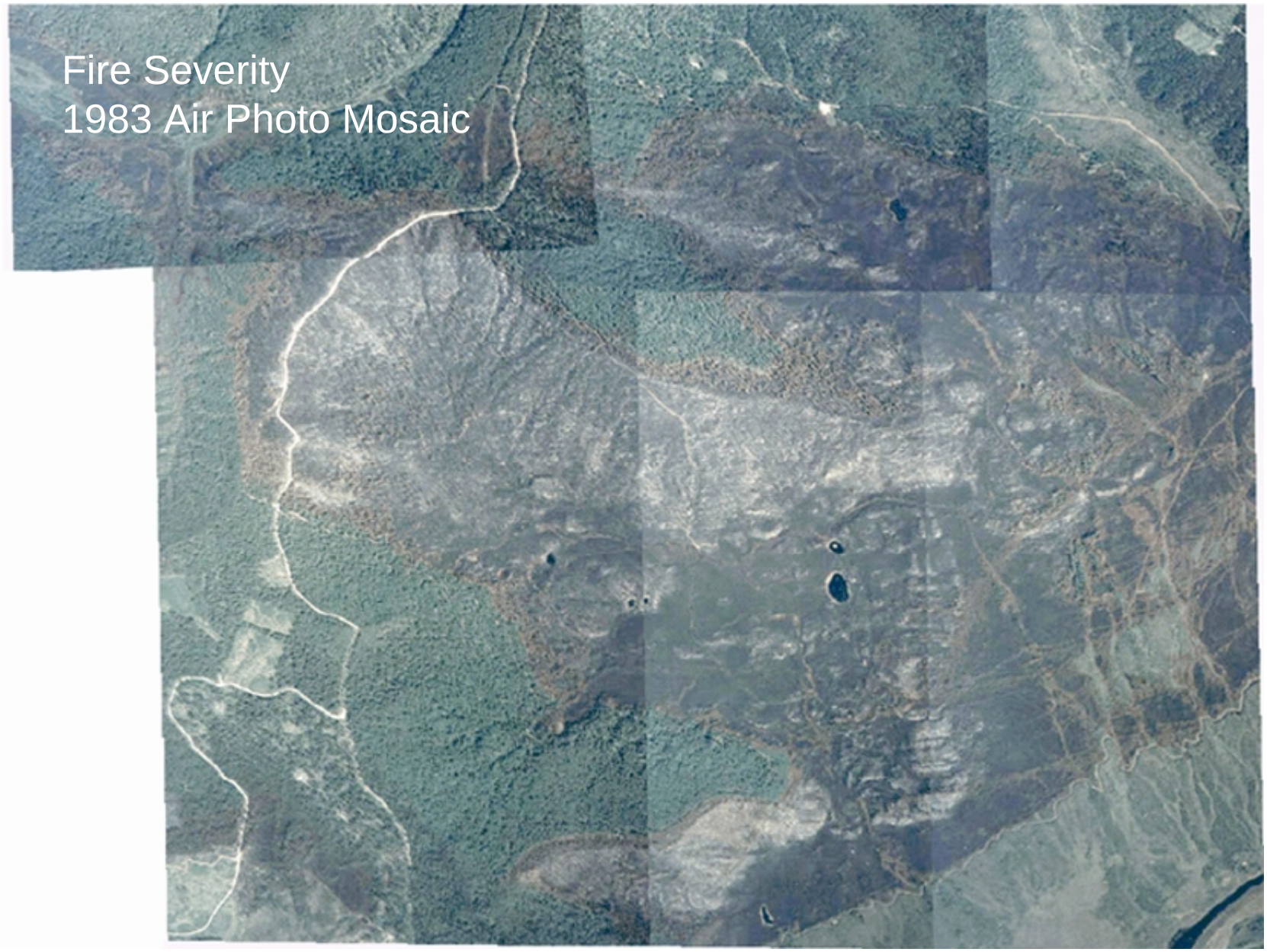
- Theoretical Issues (GCP's, Grain Size, Classes)
- Firescar Database 1950-1997
- Comparisons with Landsat Imagery
- **Detailed Analysis of Land-Cover Change:**

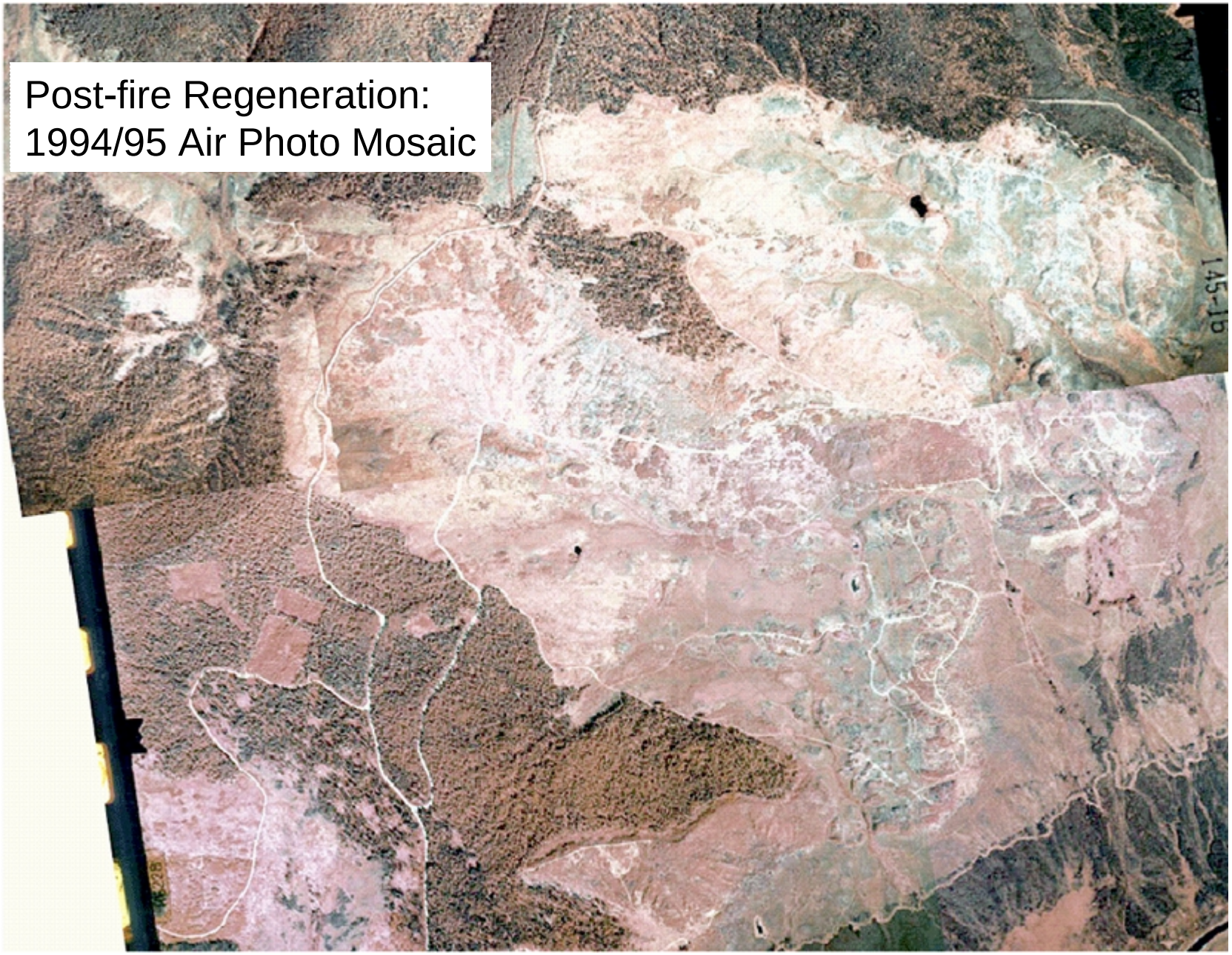
  1983 Rosie Creek Fire

  - Pre-fire Air Photos and Landsat MSS Imagery
  - Immediate Post-fire Air Photos and Landsat TM Imagery
  - Decadal Post-fire Air Photos and Landsat TM imagery

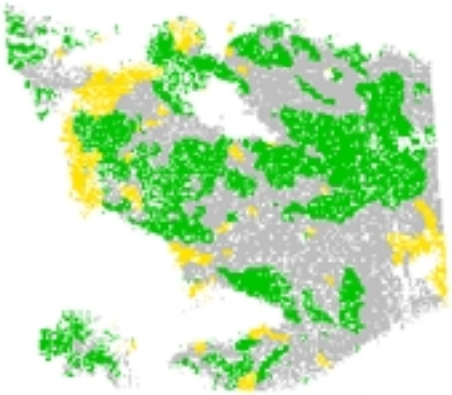

Firescars
1950 - 1959
1960 - 1969
1970 - 1979
1980 - 1989
1990 - 1997
State Logging Sales
Before Fire: Pre-1983
Fire Salvage: 1983 - 1989
Post-Salvage: 1990 - 1998
0
10
20 Kilometers

Pre-Fire Vegetation
1971 Air Photo Mosaic


Fire Severity
1983 Air Photo Mosaic

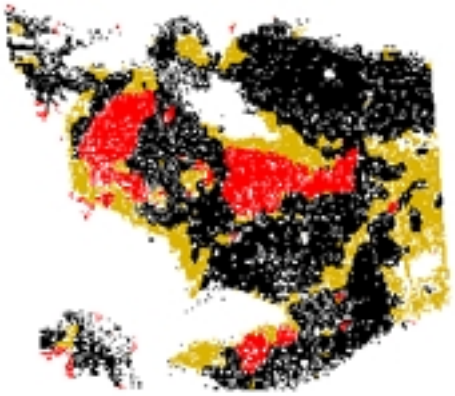

Post-fire Regeneration:
1994/95 Air Photo Mosaic

Predicting Post-fire Regeneration in the 1983 Rosie Creek Fire



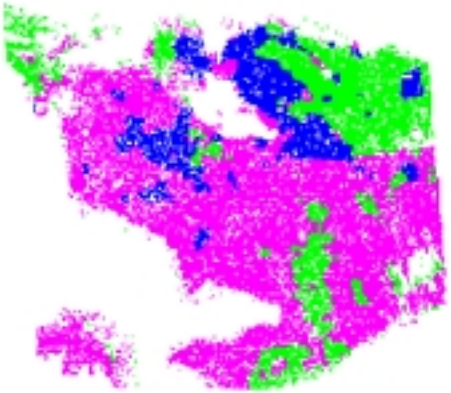
1971 Pre-fire Vegetation

- 0=Low Muskeg
- 1=Spruce Forest
- 2=Hardwood Forest



1983 Fire Severity

- 0=Unburned / Nonvegated
- 1=Light Severity
- 2=Moderate Severity
- 3=High Severity



1994/95 Dominant Post-Fire Vegetation

- 0=Unburned / Nonvegetated
- 1=Grass and Bare Ground
- 2=Spruce / Labrador Tea
- 3=Shrubs

Vegetation Regeneration after the 1983 Rosie Creek Fire (Bonanza Creek LTER)

Developing a Predictive Model of Post-fire Regeneration Classes

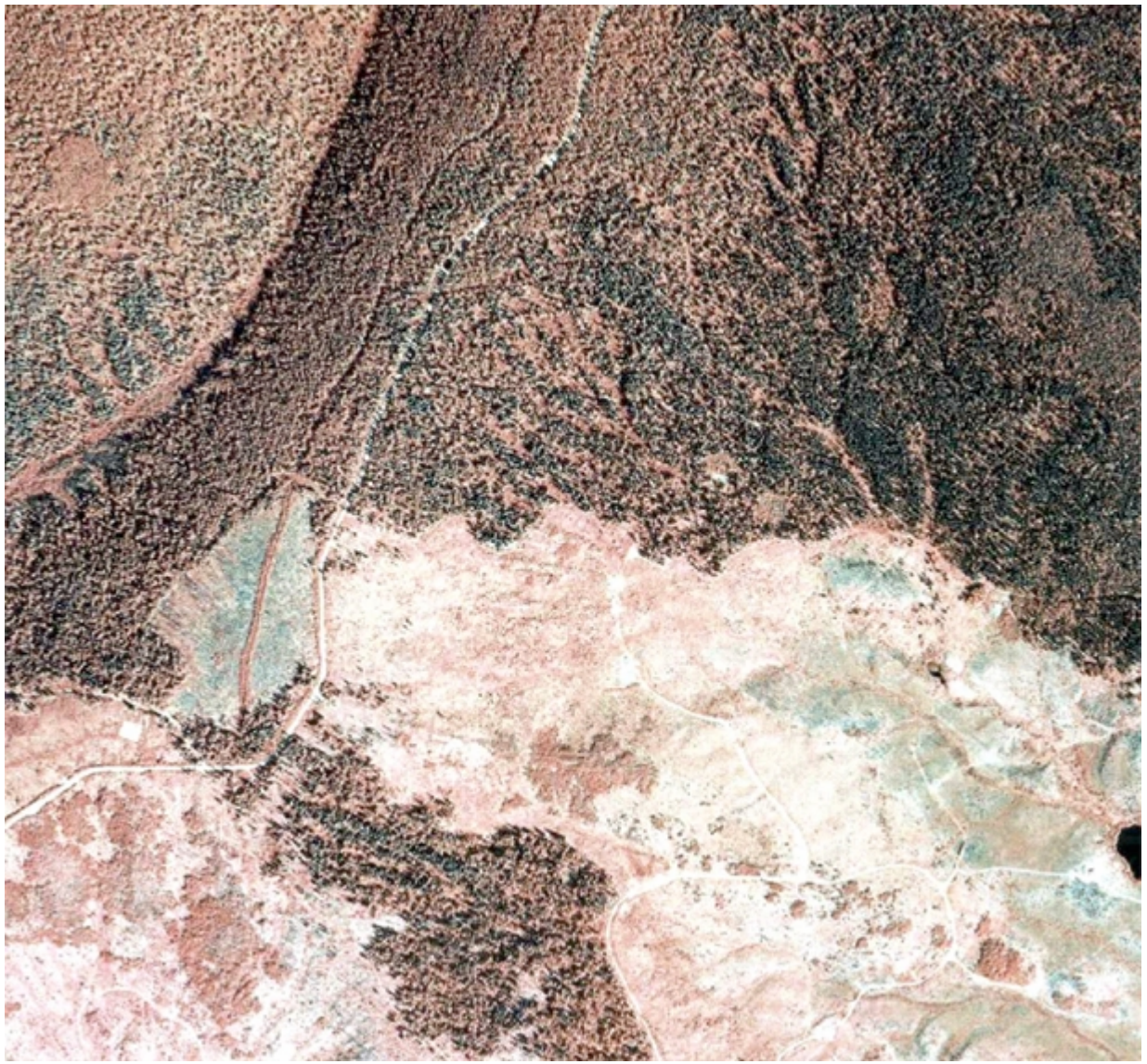
• Remote sensing as primary data source: aerial photography and satellite imagery obtained before and after the fire.

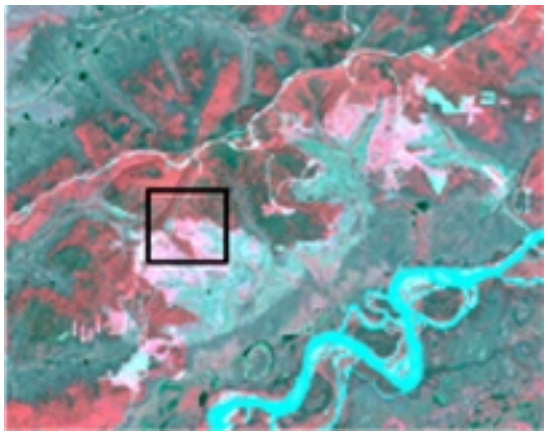
•On most burned forest sites in Interior Alaska, shrub regeneration dominates a decade after the fire. What conditions are most likely to lead to alternative successional trajectories?

Air Photo Class	Pixel Count	Shrub Regen. Proportion
Pre-fire Hardwood	967	0.903
Pre-fire Muskeg	5304	0.609
Pre-fire Spruce	4466	0.549
Light Burn	2262	0.743
Moderate Burn	6976	0.508
Severe Burn	1499	0.888

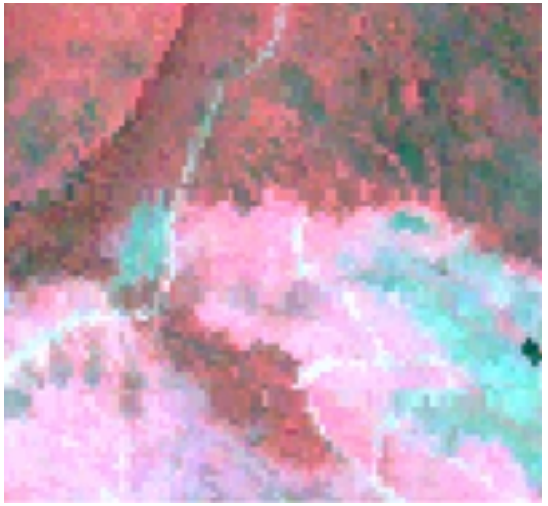
•Topographic position, salvage logging status, and field measurements of biomass, soil, and permafrost will be used as additional explanatory variables.

Bonanza Creek Experimental Forest (1983 Rosie Creek Fire)
Decadal Post-Fire: 1994 Air Photo and 1991 Landsat TM Imagery





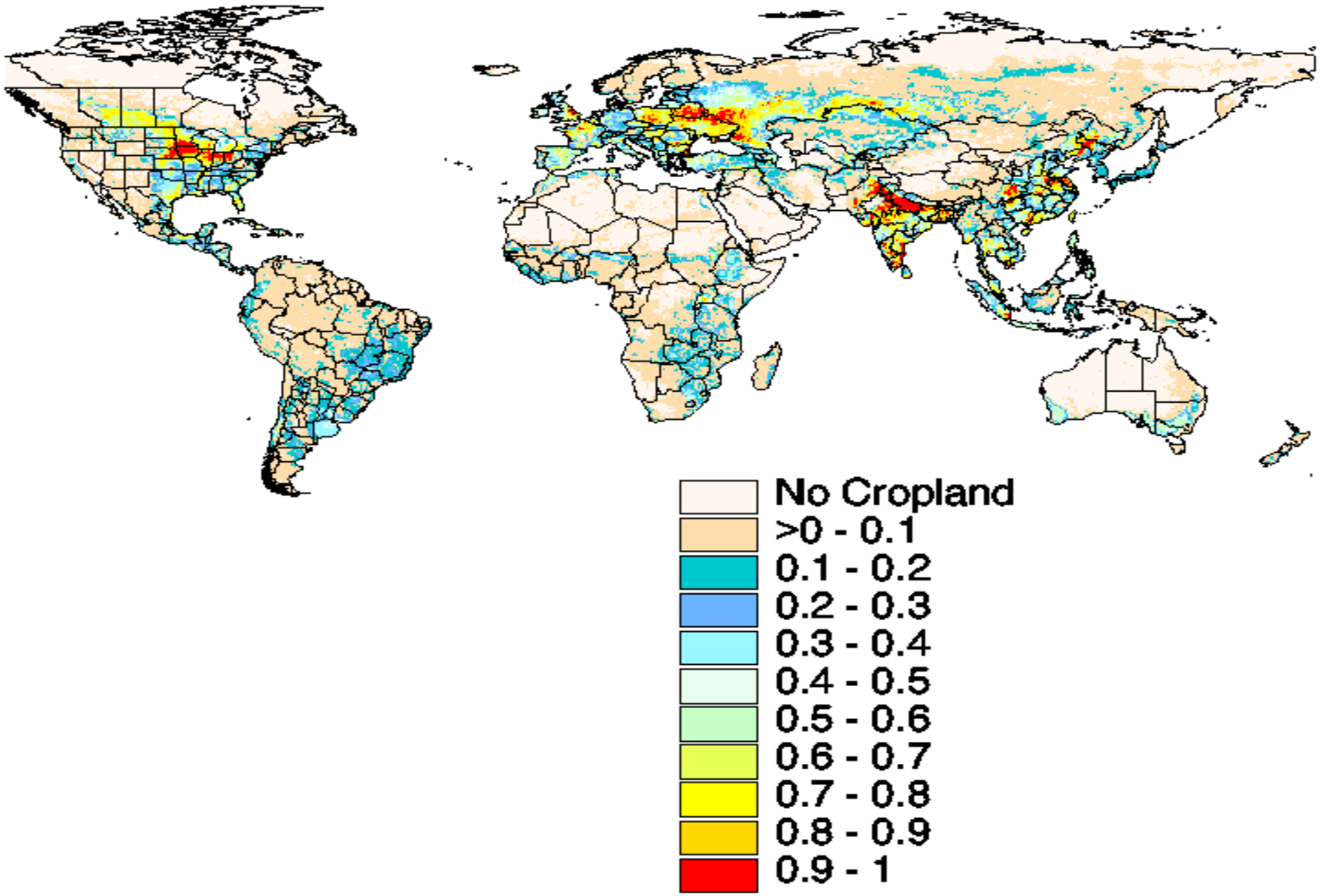
= 2x2 km



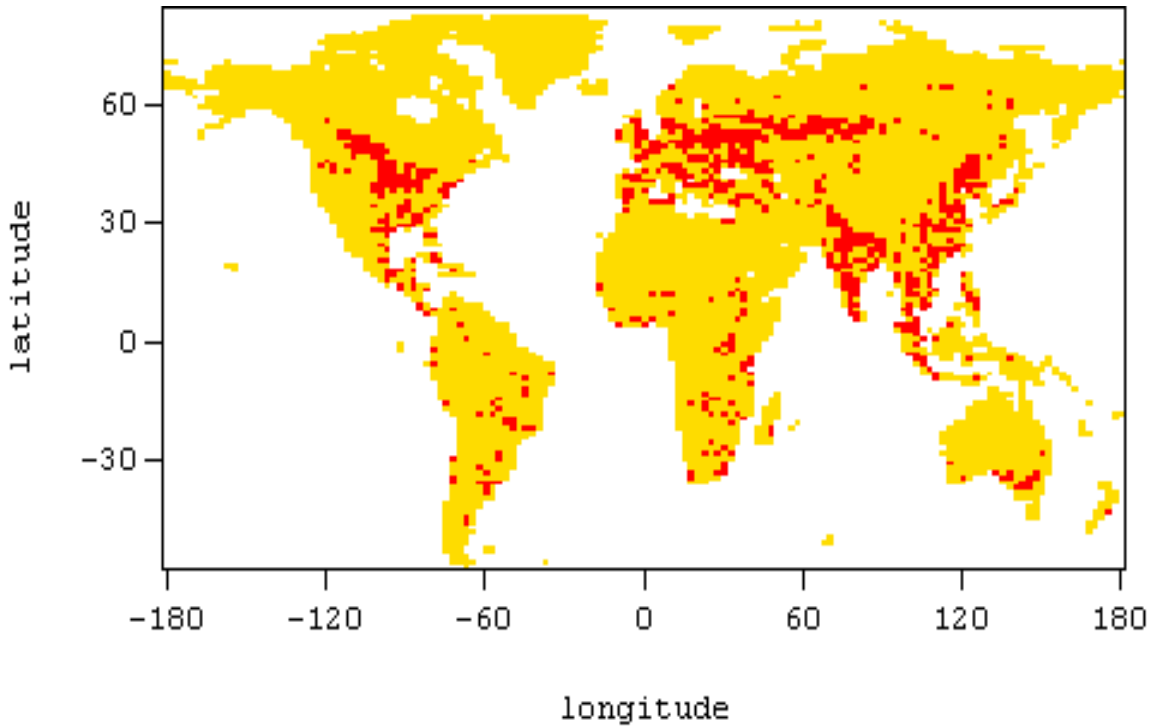
Global Historical Agricultural Land-Use: Development of a 0.5º Boolean Data Set

- Based on 1-km data set developed by Ramankutty and Foley (1998)
  - Based on version 1.2 DISCover data set
  - Based on 1992 crop cover inventory
  - Backcast to 1860 based on historical inventory
  - Aggregated to 0.5º as fractional crop cover
- Mixture at 5º to minimize bias
- Time-filtered (9-years) to minimize blinking

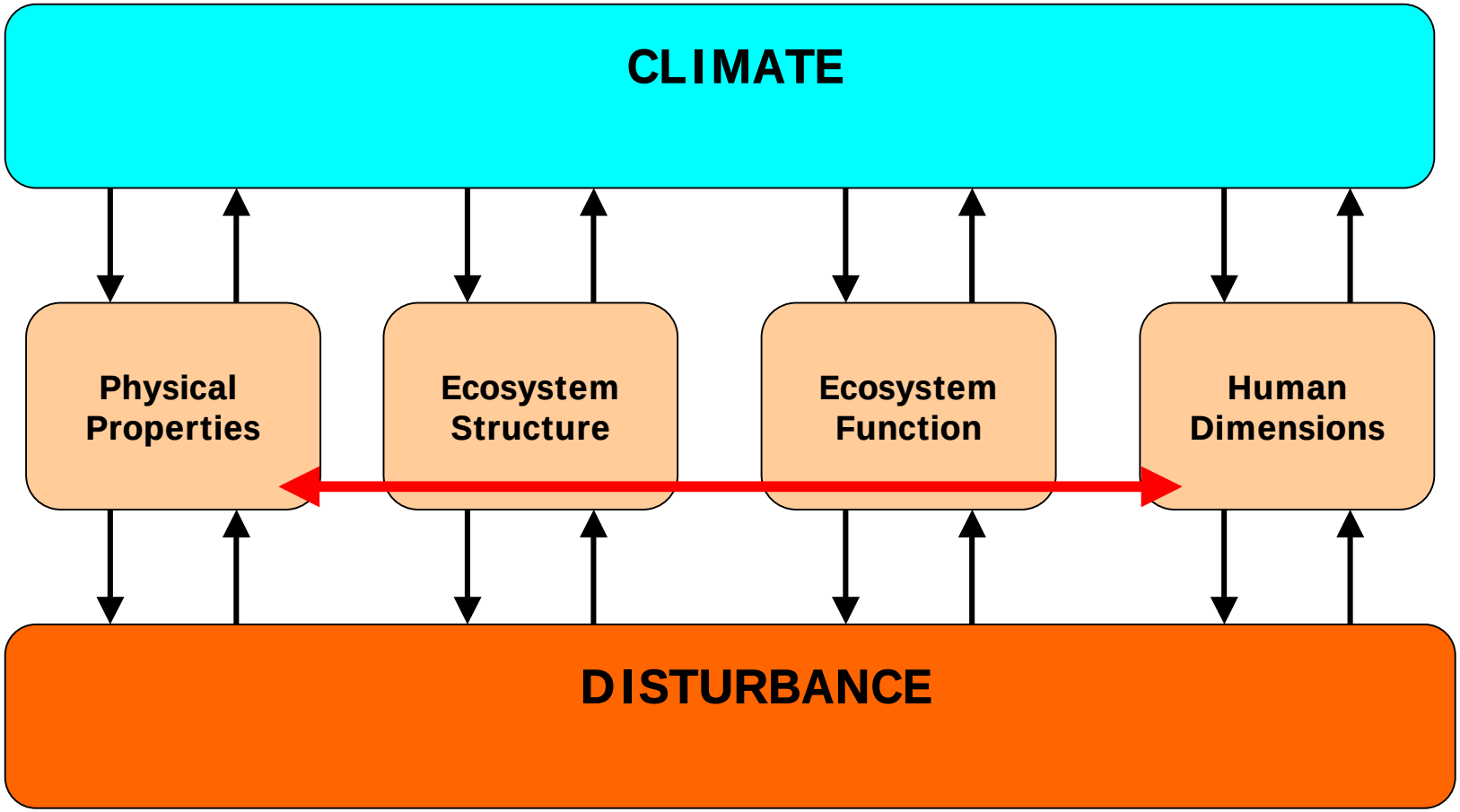
Global Crop Cover in 1992 (0.5 deg resolution)
(Ramankutty and Foley, 1998)



Global Crop Cover in 1992 (0.5 Degree Boolean Data Set)



Modeling Framework for Investigating Global Change in High Latitude Ecosystems



Components of the Modeling Framework

- **Physical Properties of Terrestrial Ecosystems:**
  Based on Goodrich model of permafrost dynamics
- **Physical Processes and Ecosystem Function:**
  Based on Terrestrial Ecosystem Model (TEM) - version 4.
- **Effects of Disturbance on Ecosystem Function:**
  Based on Terrestrial Ecosystem Model (TEM) - version 4.
- **Modeling the Disturbance Regime:**
  Based on physical and biological properties of ecosystems.
- **Ecosystem Structure and the Disturbance Regime:**
  Based on ALaska FRame-based EcoSystem Code (ALFRESCO)
  Starfield and Chapin. 1996. Ecol. Appl. 6:842-864
- **Modeling Vegetation Dynamics:**
  Development of Dynamic Arctic Vegetation Model (DAVM)
- **Human Dimensions:**
  Based on conceptual model of Chapin, Starfield, and Naylor

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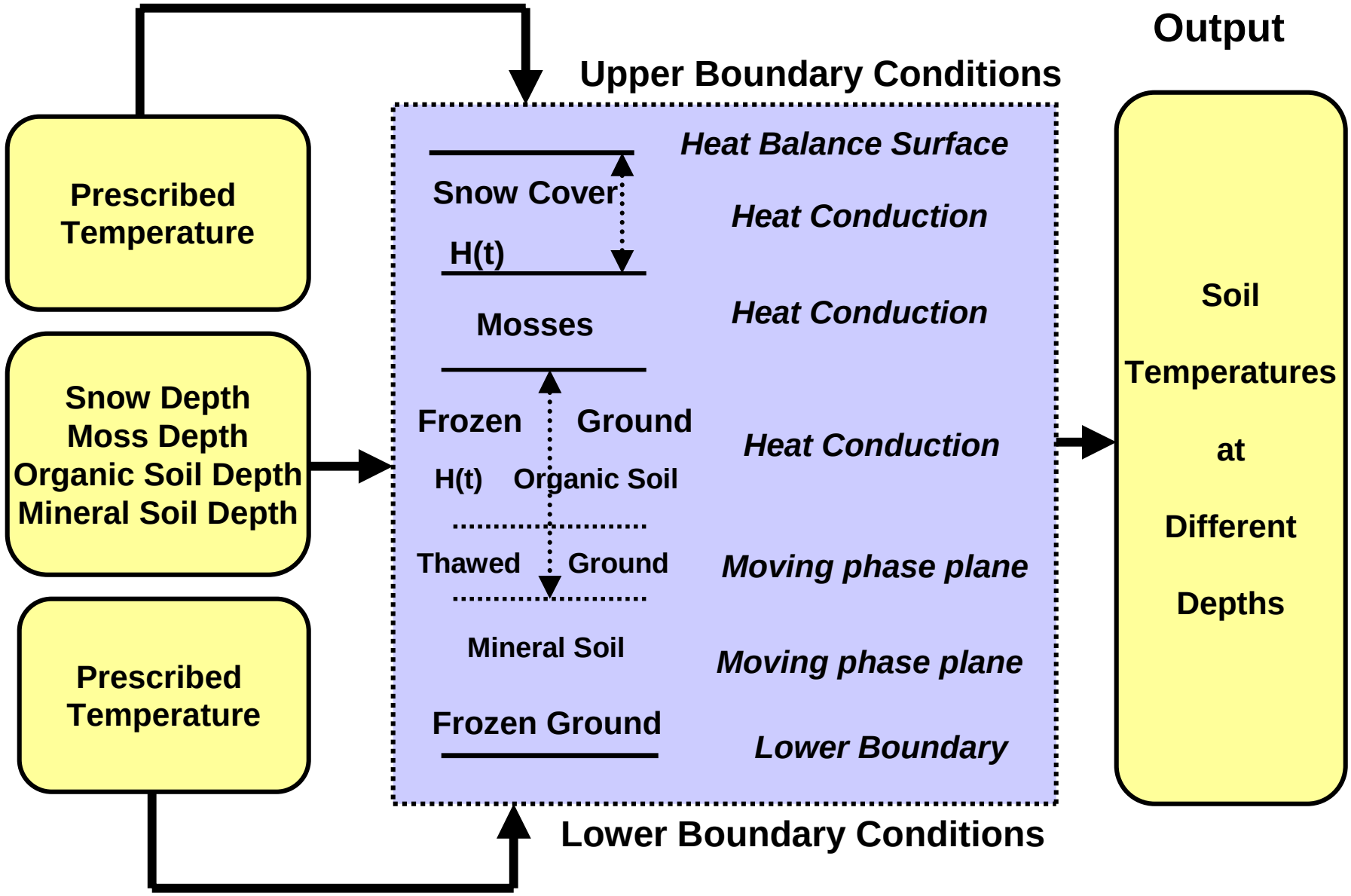
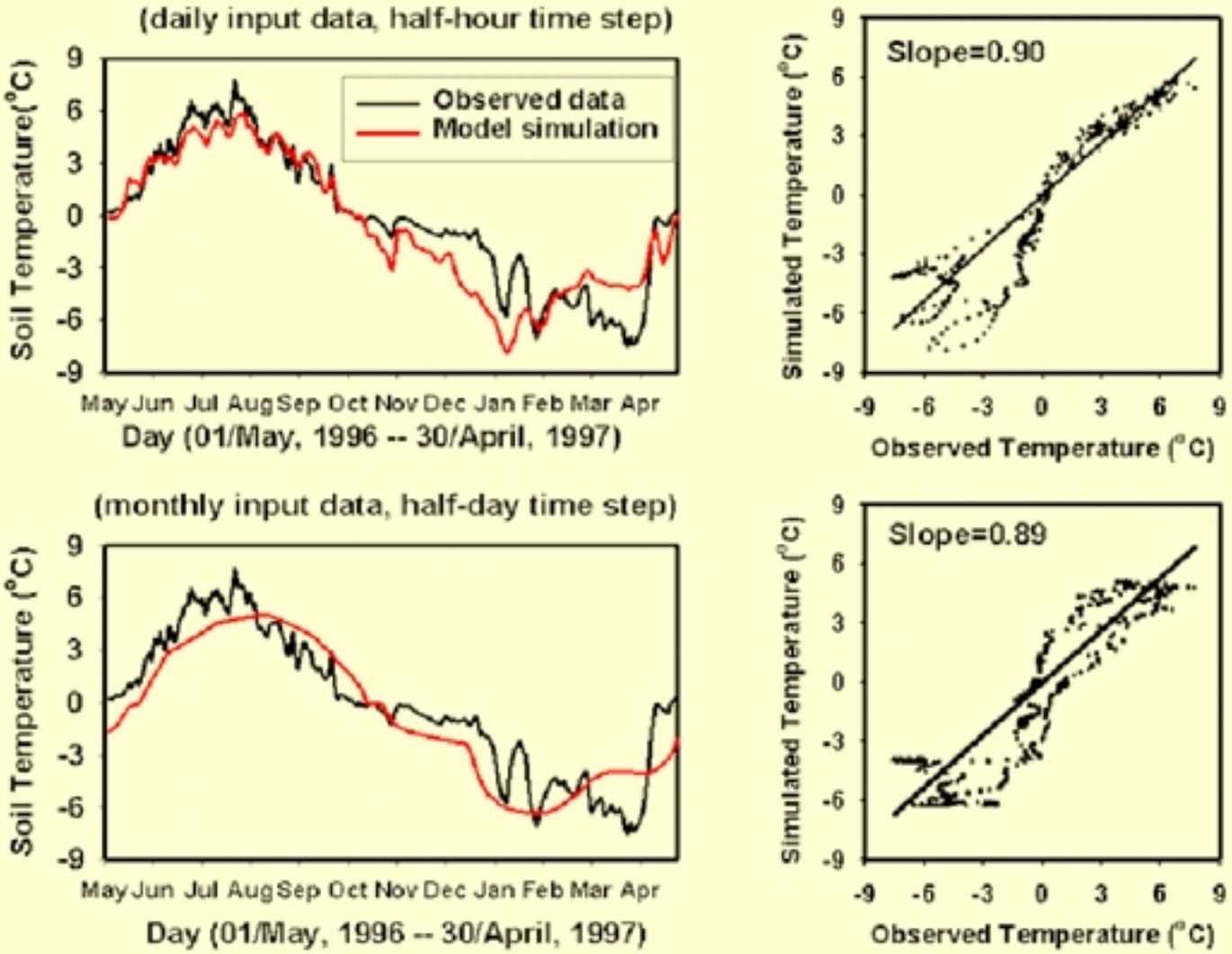
Why is Modeling Permafrost Dynamics Important?

- The dynamics of permafrost influences the physical environment, ecosystem function, ecosystem structure, and the disturbance regime
- The effects of disturbance on permafrost dynamics influences vegetation trajectories after disturbance
- Permafrost is warming in many high latitude regions
- Areas of discontinuous permafrost are most vulnerable to melting and are also regions of higher population density
- Thawing of permafrost has important impacts on humans in high latitude regions



Soil Temperature Model

Soil Temperature Comparison at 23 cm - Daily Output



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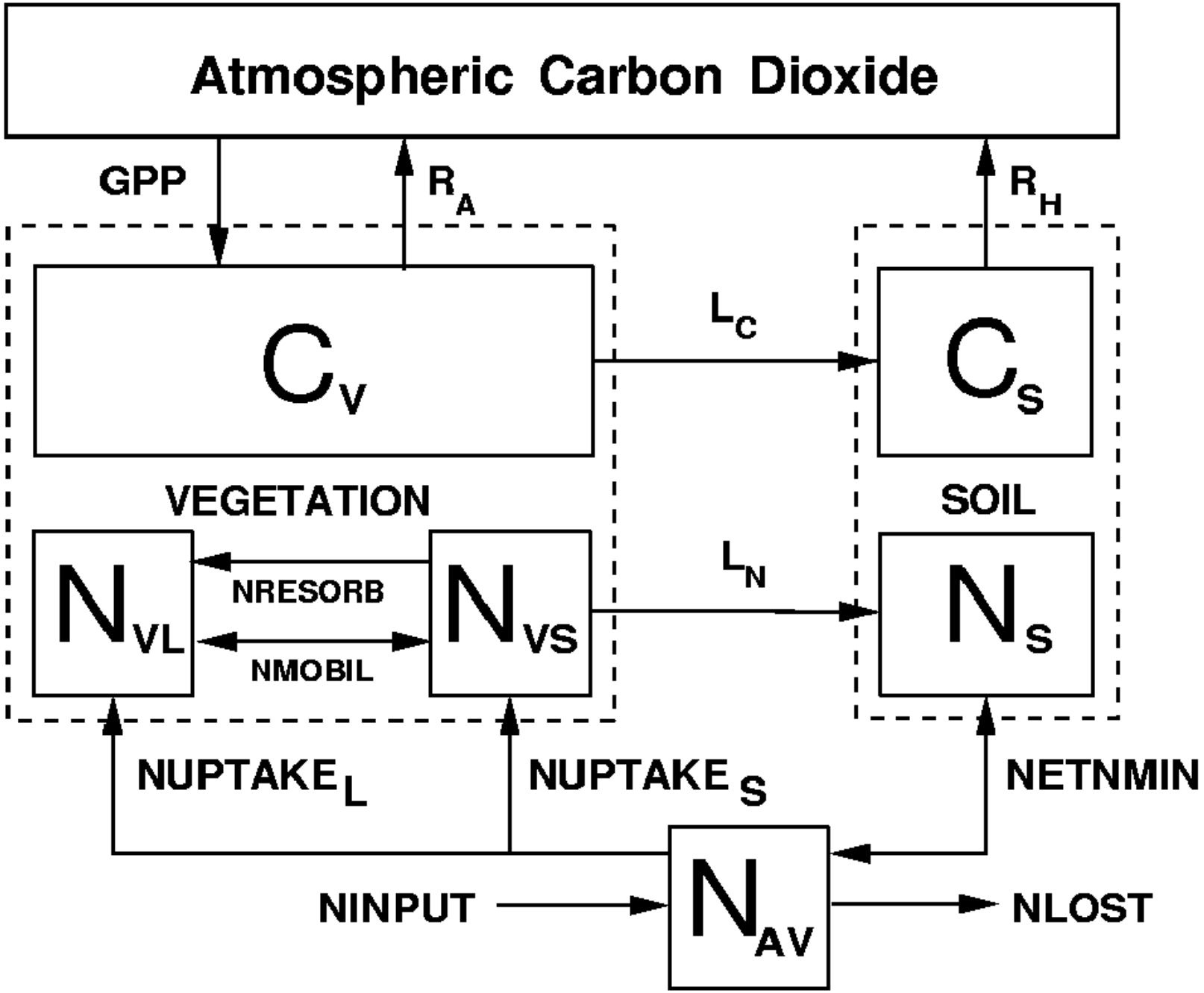
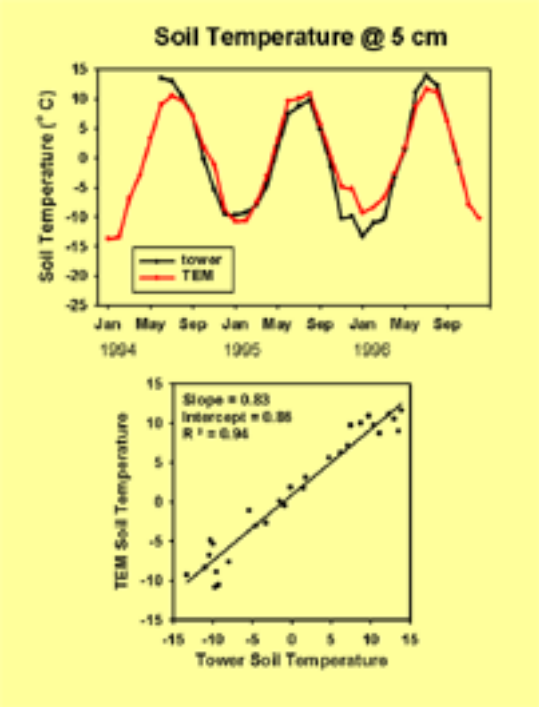
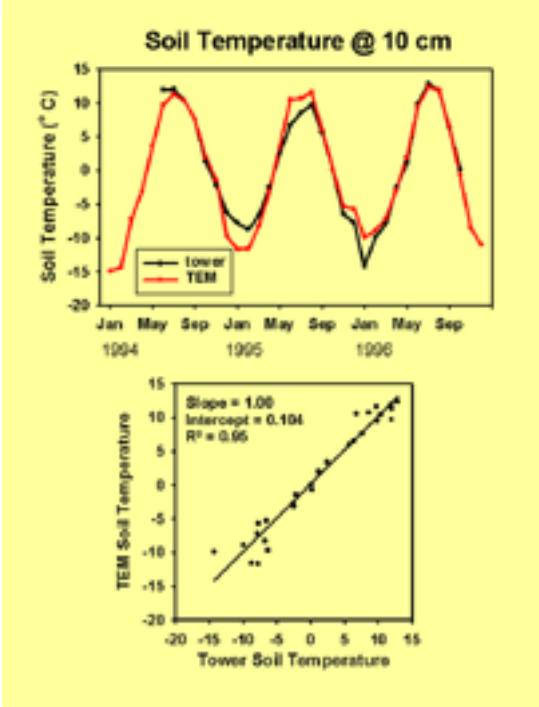
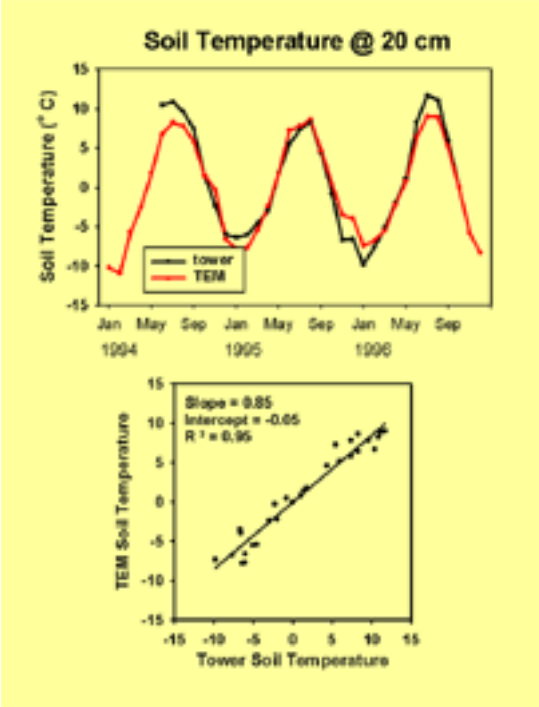

Atmospheric Carbon Dioxide
GPP
R_A
R_H
C_V
L_C
C_S
VEGETATION
SOIL
N_{VL}
NRESORB
NMOBIL
N_{VS}
L_N
N_S
$NUPTAKE_L$
$NUPTAKE_S$
NETNMIN
NINPUT
N_{AV}
NLOST

Simulated and Observed Soil Temperature at the Northern Study Area Old Black Spruce Site (BOREAS)

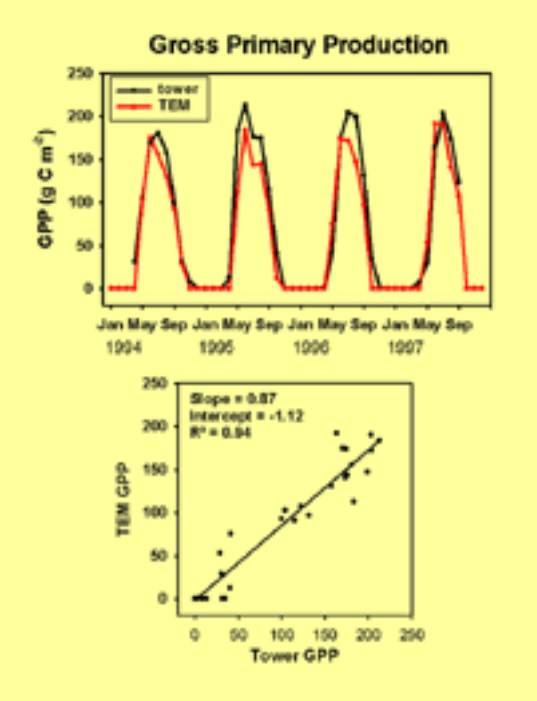


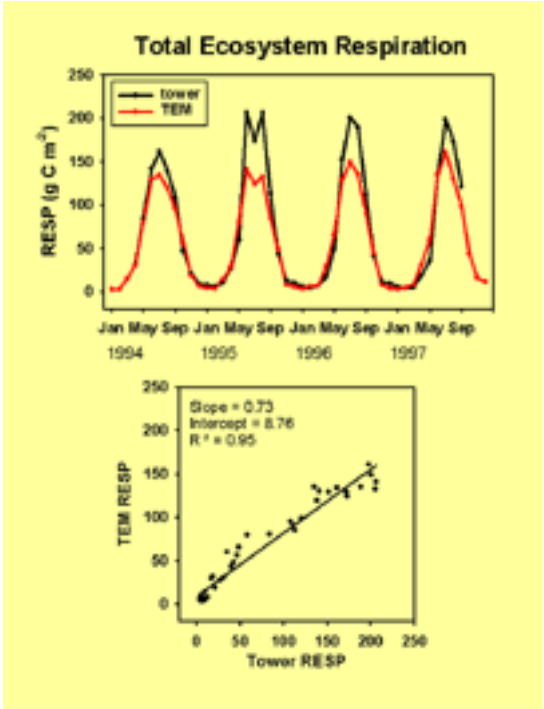


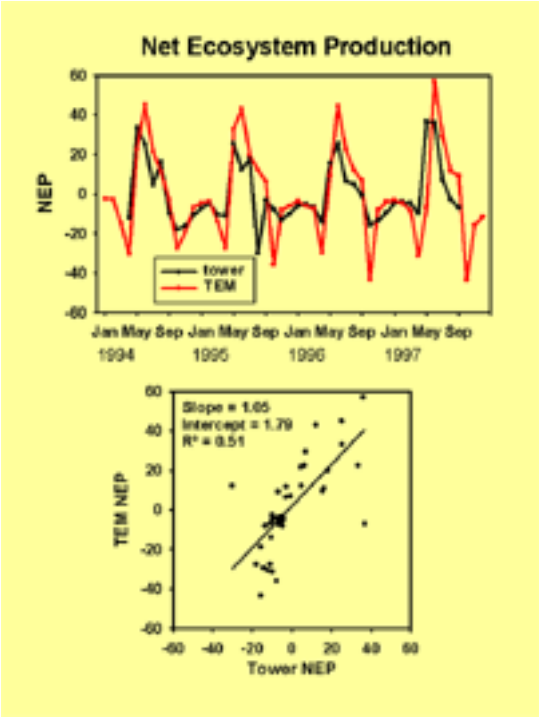


Regressions represent comparisons between simulated and observed soil temperature from June 1994 to Oct. 1996.

Simulated and Field-based Carbon Fluxes at the Northern Study Area Old Black Spruce Site (BOREAS)



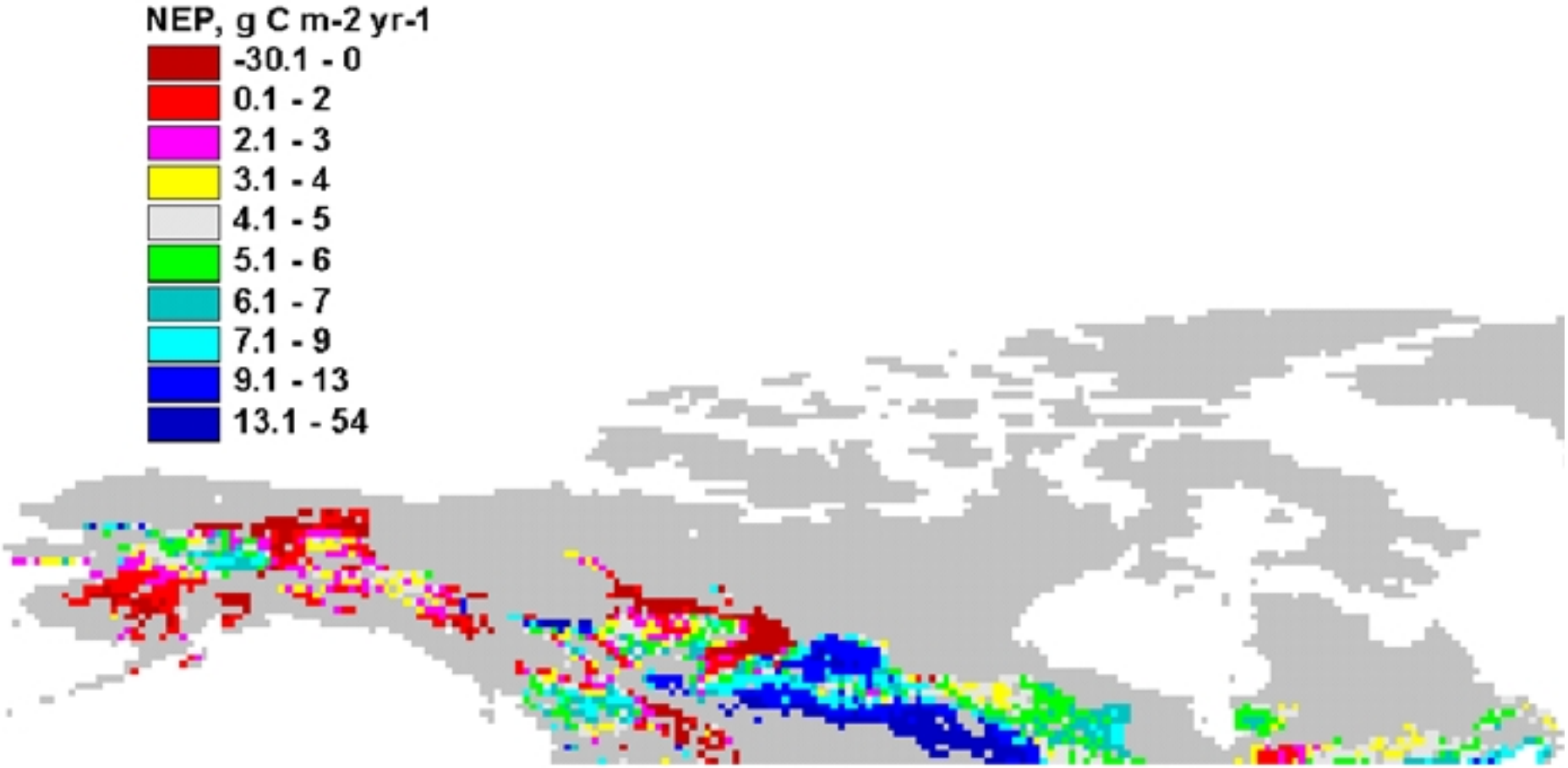




Regressions represent comparisons between simulated and field-based carbon fluxes from April 1994 to Sept 1997.

Changes in Black Spruce Carbon Storage Between 1980 and 1989 in Boreal North America

Climate based on Jones temperature anomalies,
Hulme precipitation anomolies, and Cramer-Leeman's climatology



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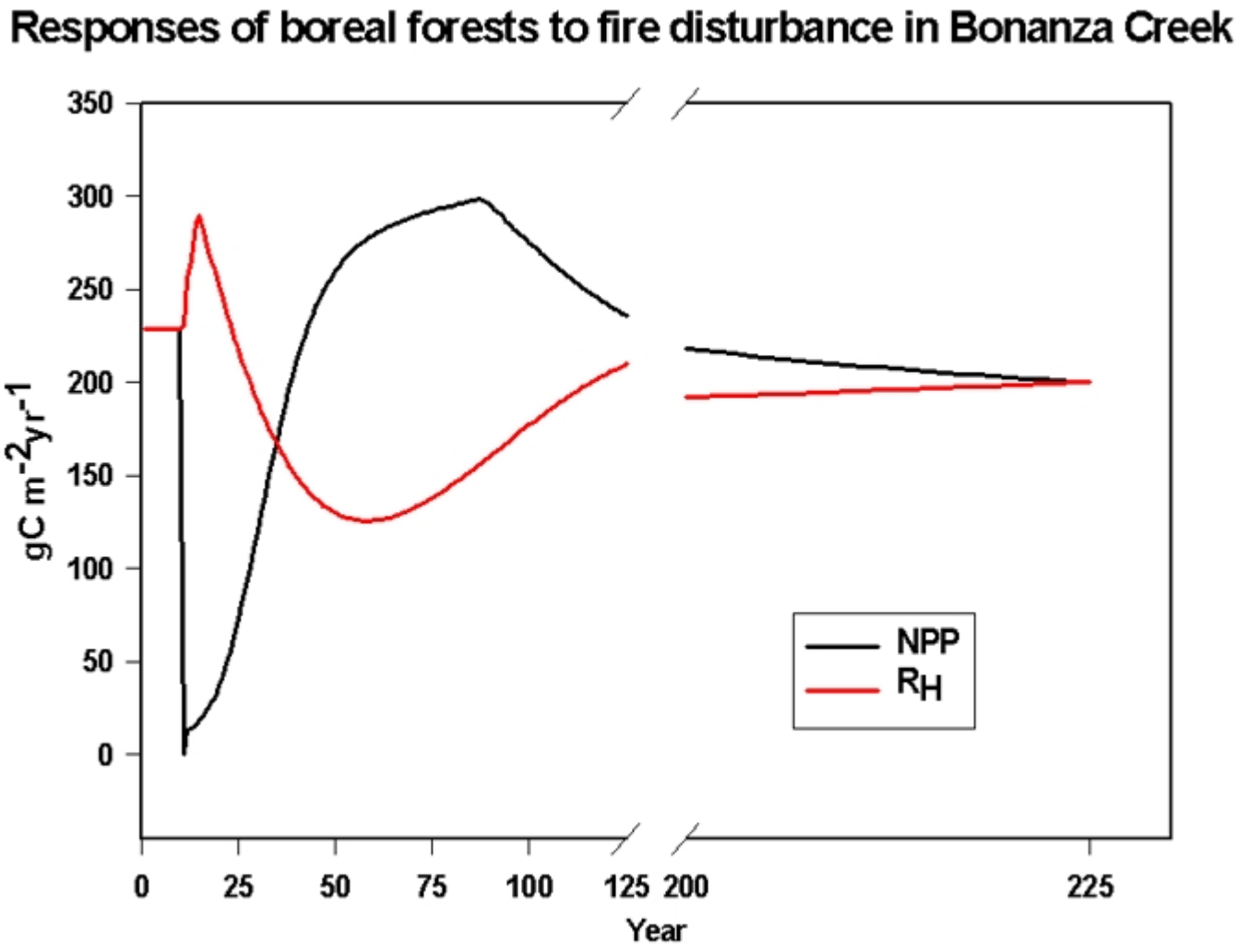
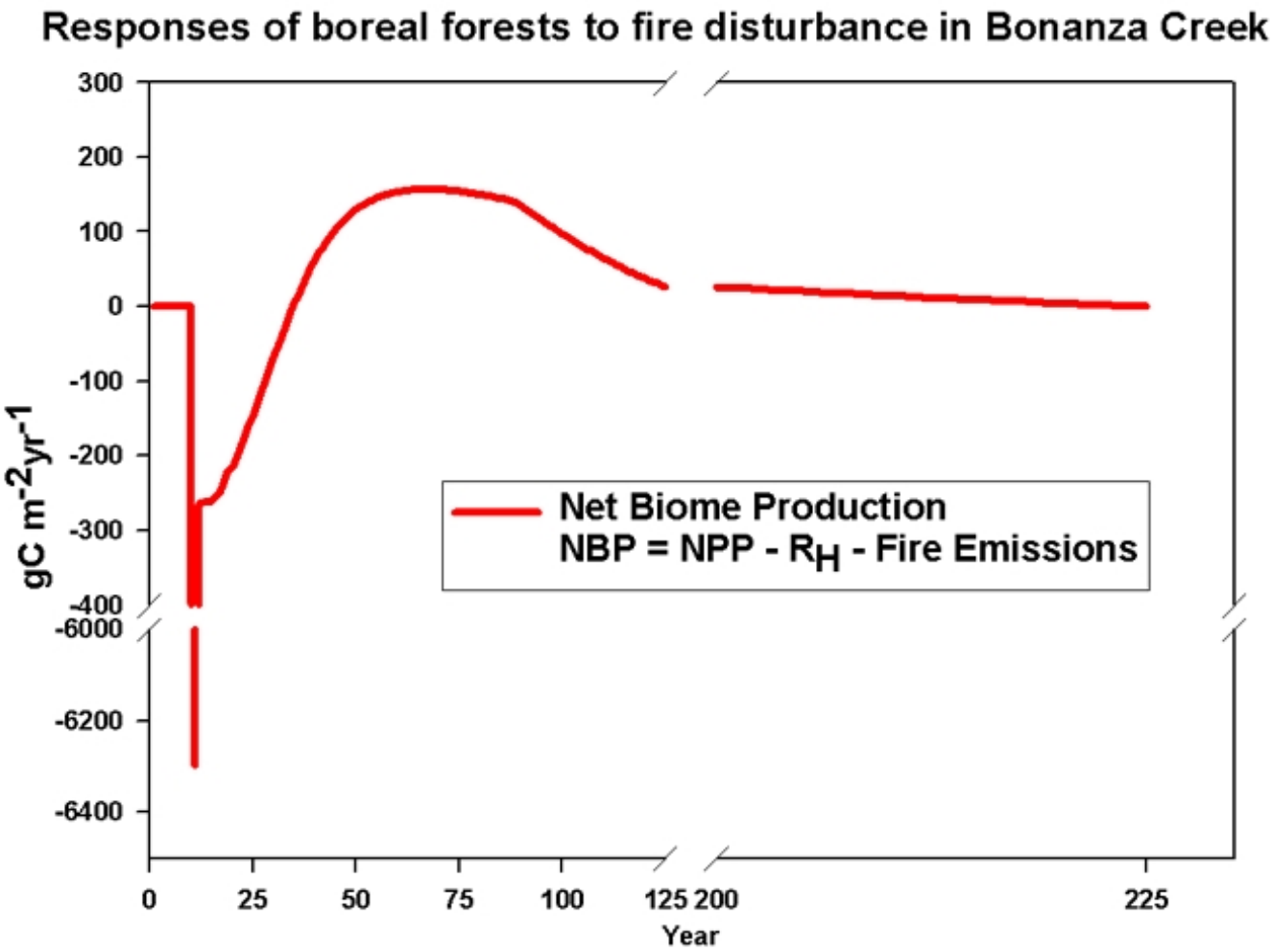
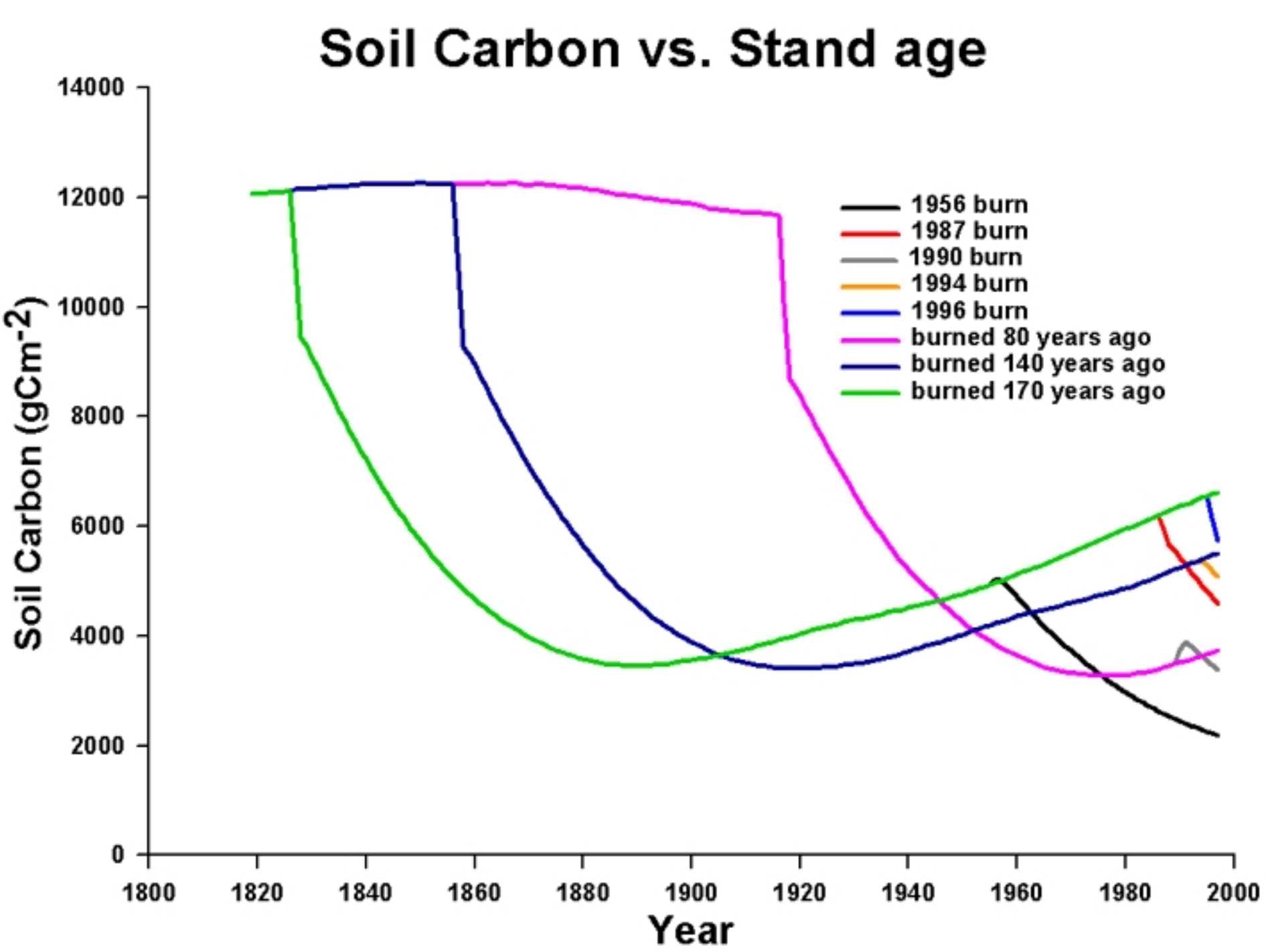
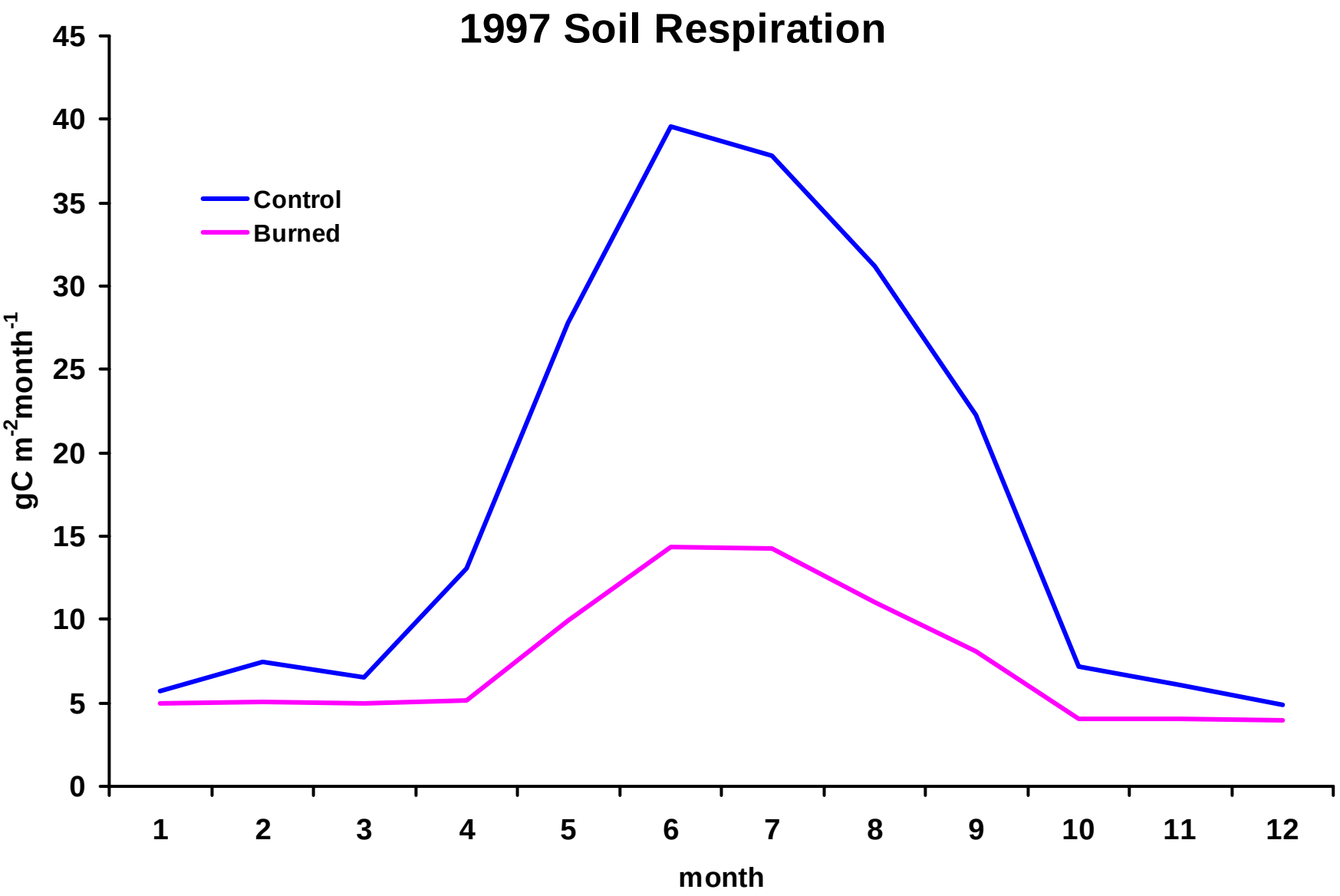
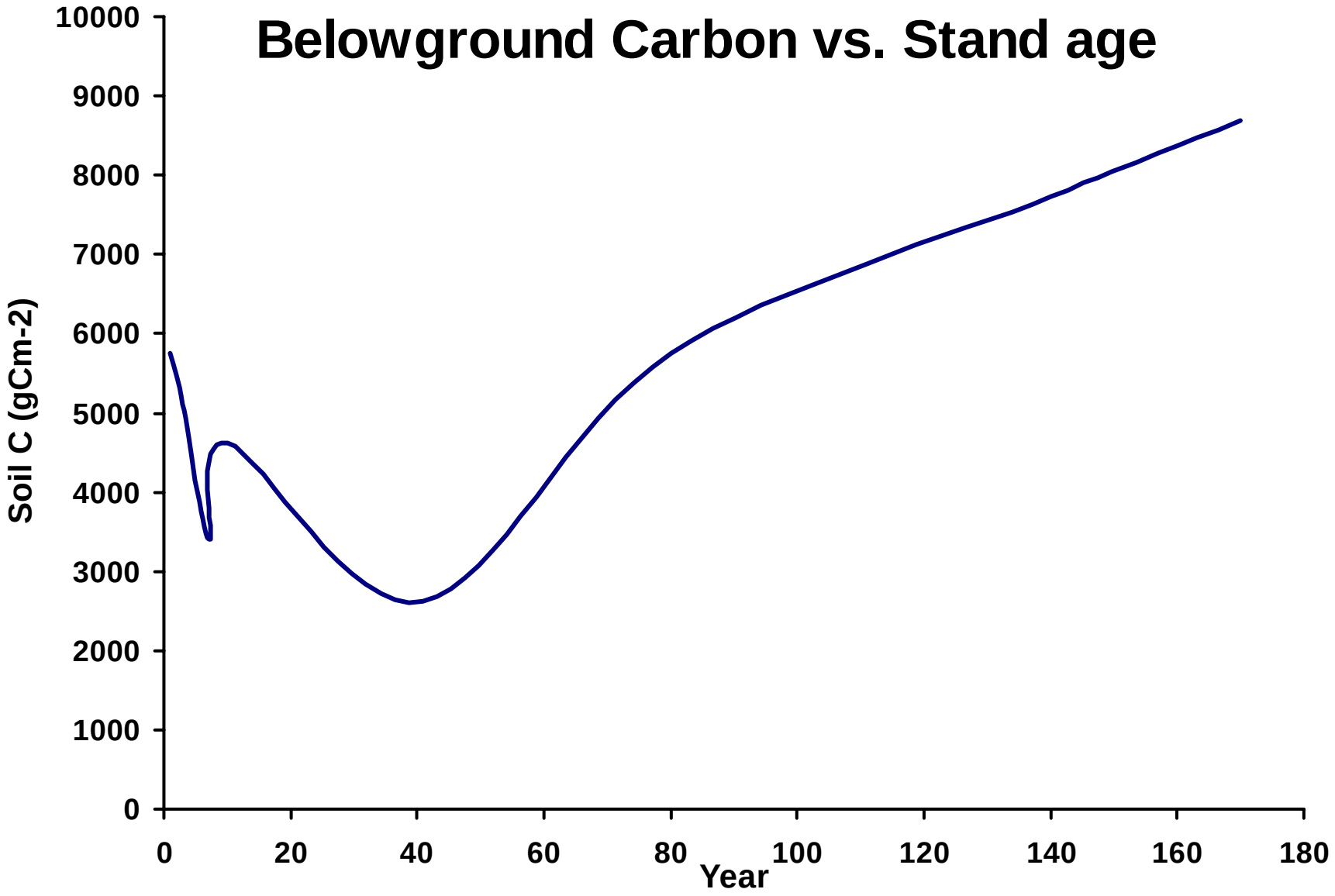

Responses of boreal forests to fire disturbance in Bonanza Creek
350
300
250
200
150
100
50
0
gC m-2yr-1
0
25
50
75
100
125
200
225
Year
NPP
RH


Responses of boreal forests to fire disturbance in Bonanza Creek
300
200
100
0
-100
-200
-300
-400
-6000
-6200
-6400
gC m-2yr-1
Net Biome Production
NBP = NPP - RH - Fire Emissions
0
25
50
75
100
125
200
225
Year

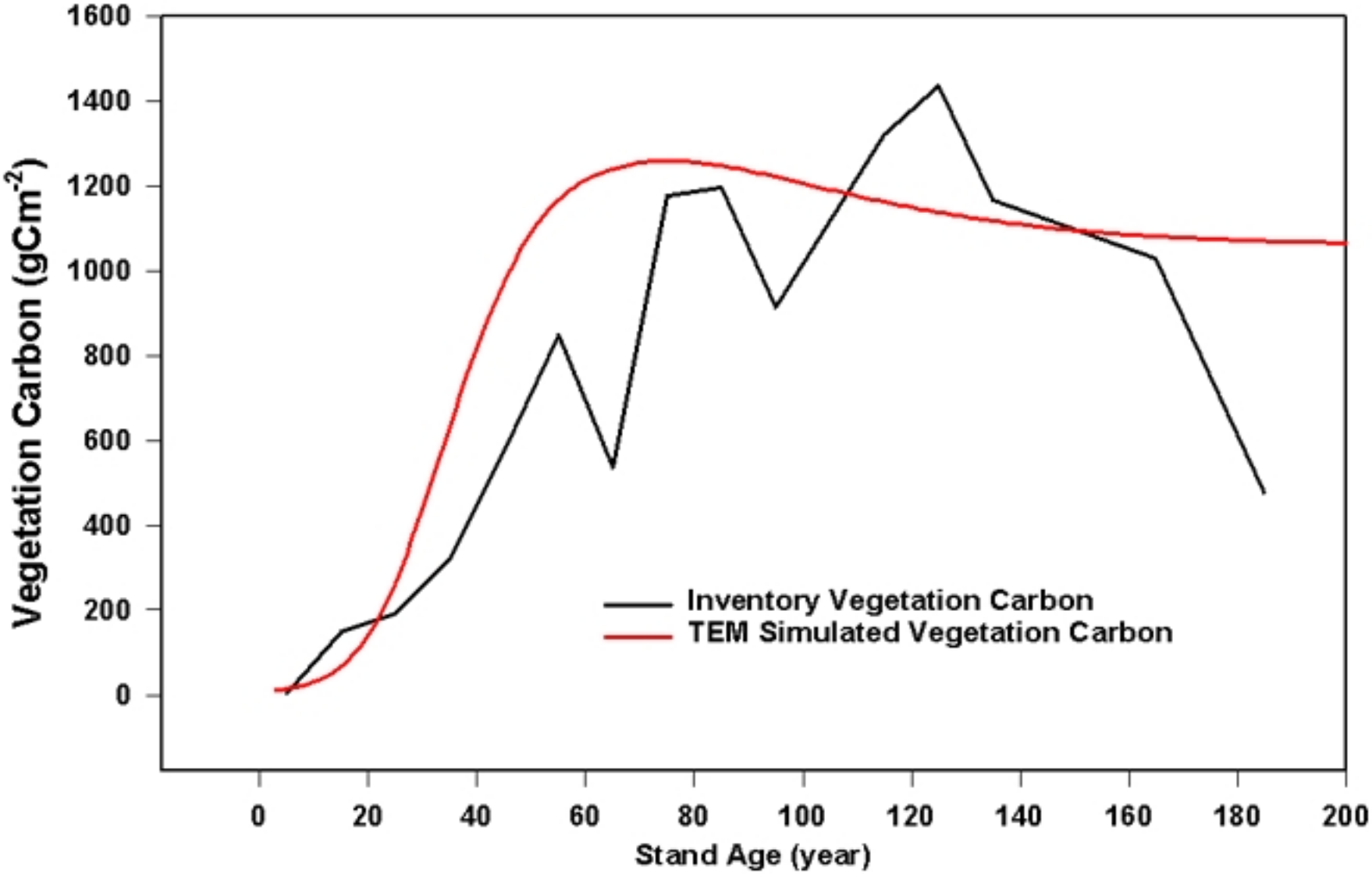

Soil Carbon vs. Stand age
Soil Carbon (gCm-2)
14000
12000
10000
8000
6000
4000
2000
0
1800
1820
1840
1860
1880
1900
1920
1940
1960
1980
2000
Year
1956 burn
1987 burn
1990 burn
1994 burn
1996 burn
burned 80 years ago
burned 140 years ago
burned 170 years ago


1997 Soil Respiration
Control
Burned
gC m-2month-1
45
40
35
30
25
20
15
10
5
0
1
2
3
4
5
6
7
8
9
10
11
12
month

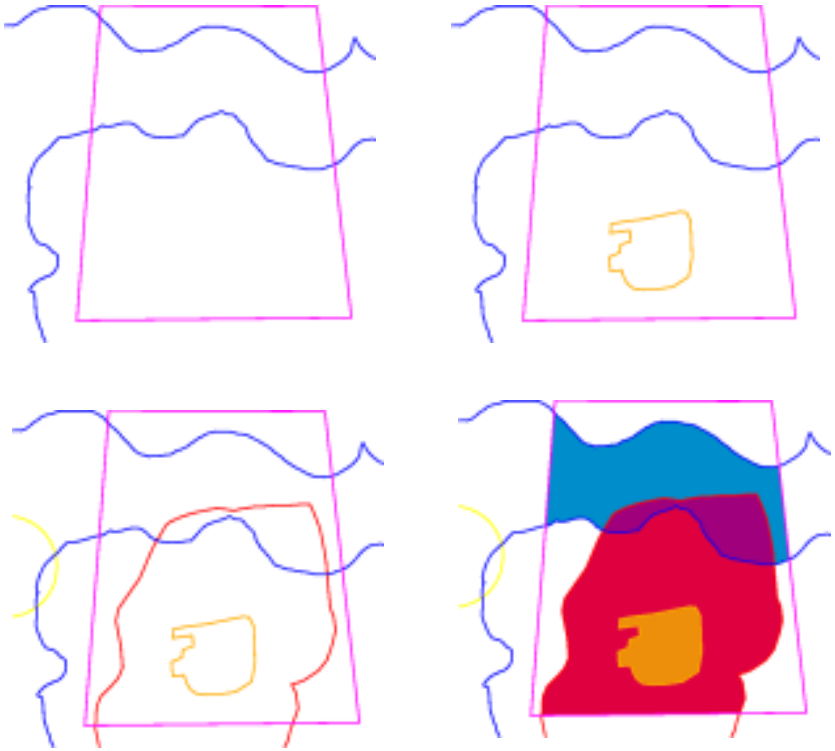

Belowground Carbon vs. Stand age
Soil C (gCm-2)
10000
9000
8000
7000
6000
5000
4000
3000
2000
1000
0
0
20
40
60
80
100
120
140
160
180
Year

Aboveground Vegetation Carbon:

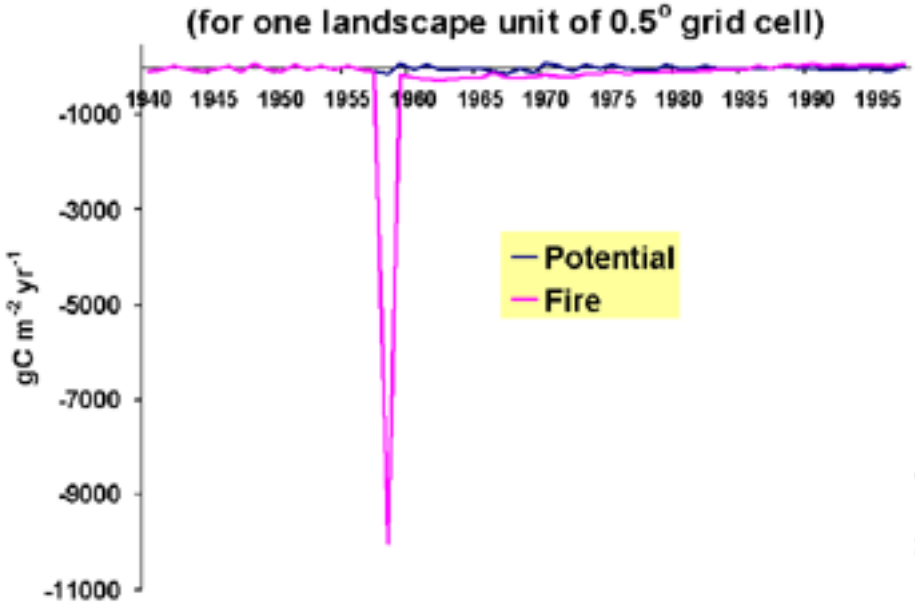
TEM Simulation vs. Inventory Data for Black Spruce Forests in Alaska

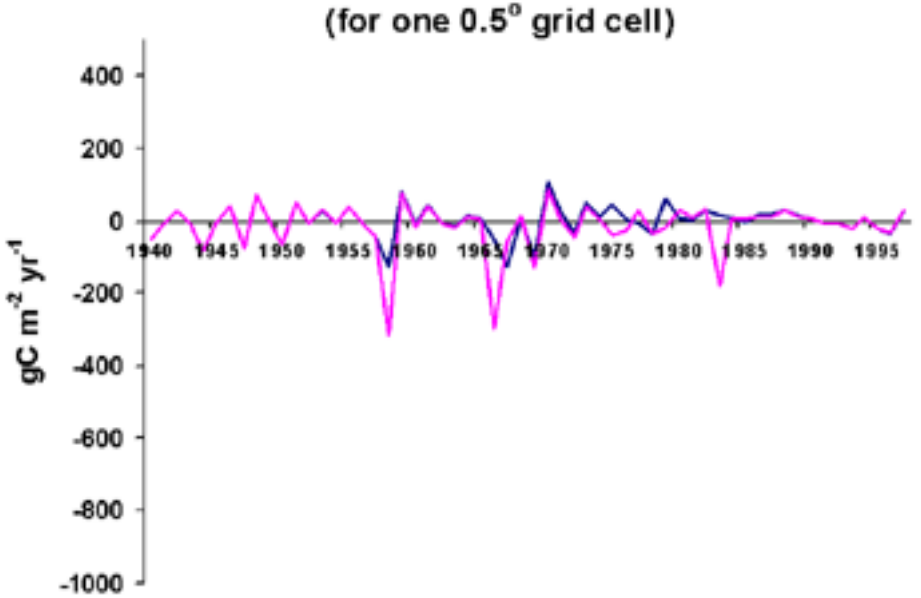


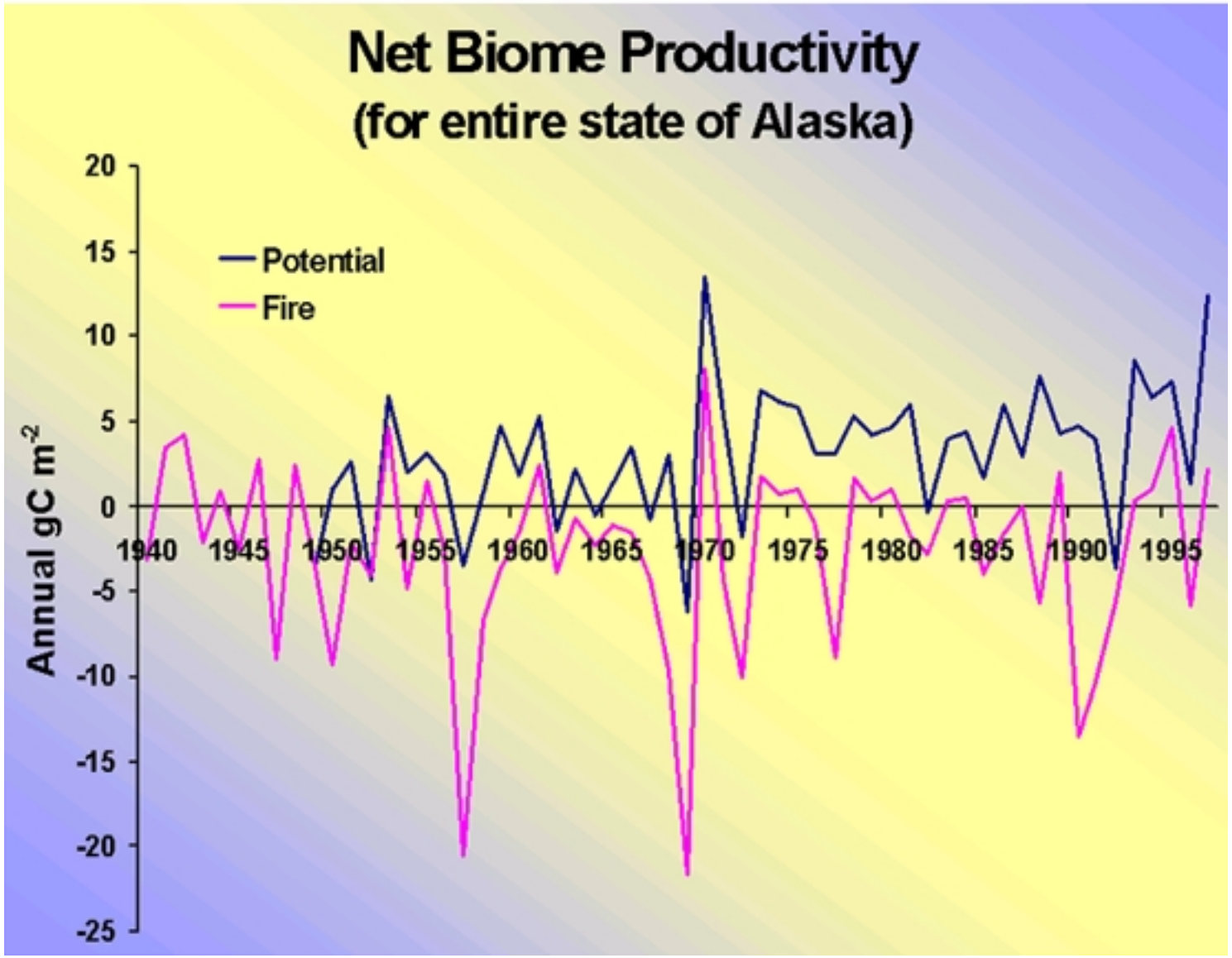
Firescars and Cohorts



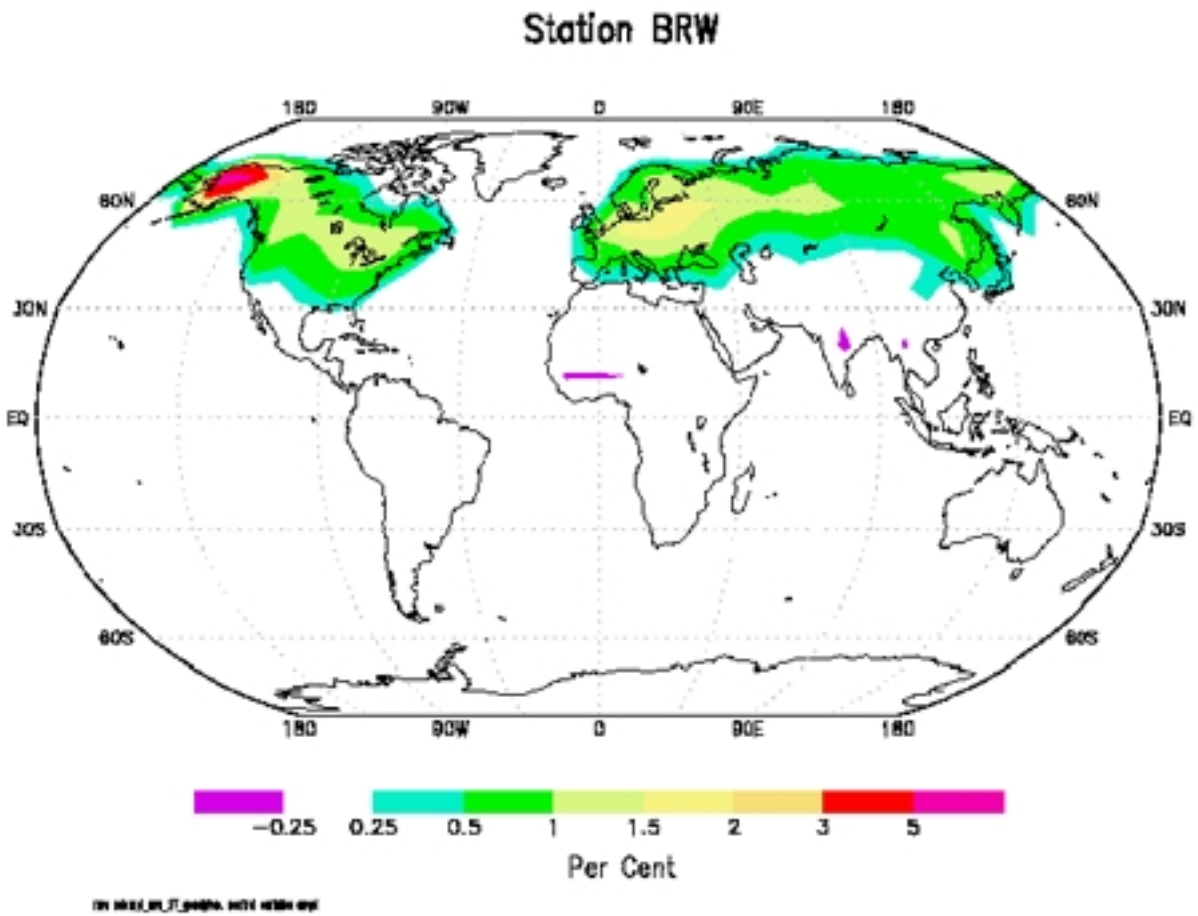
Net Biome Productivity





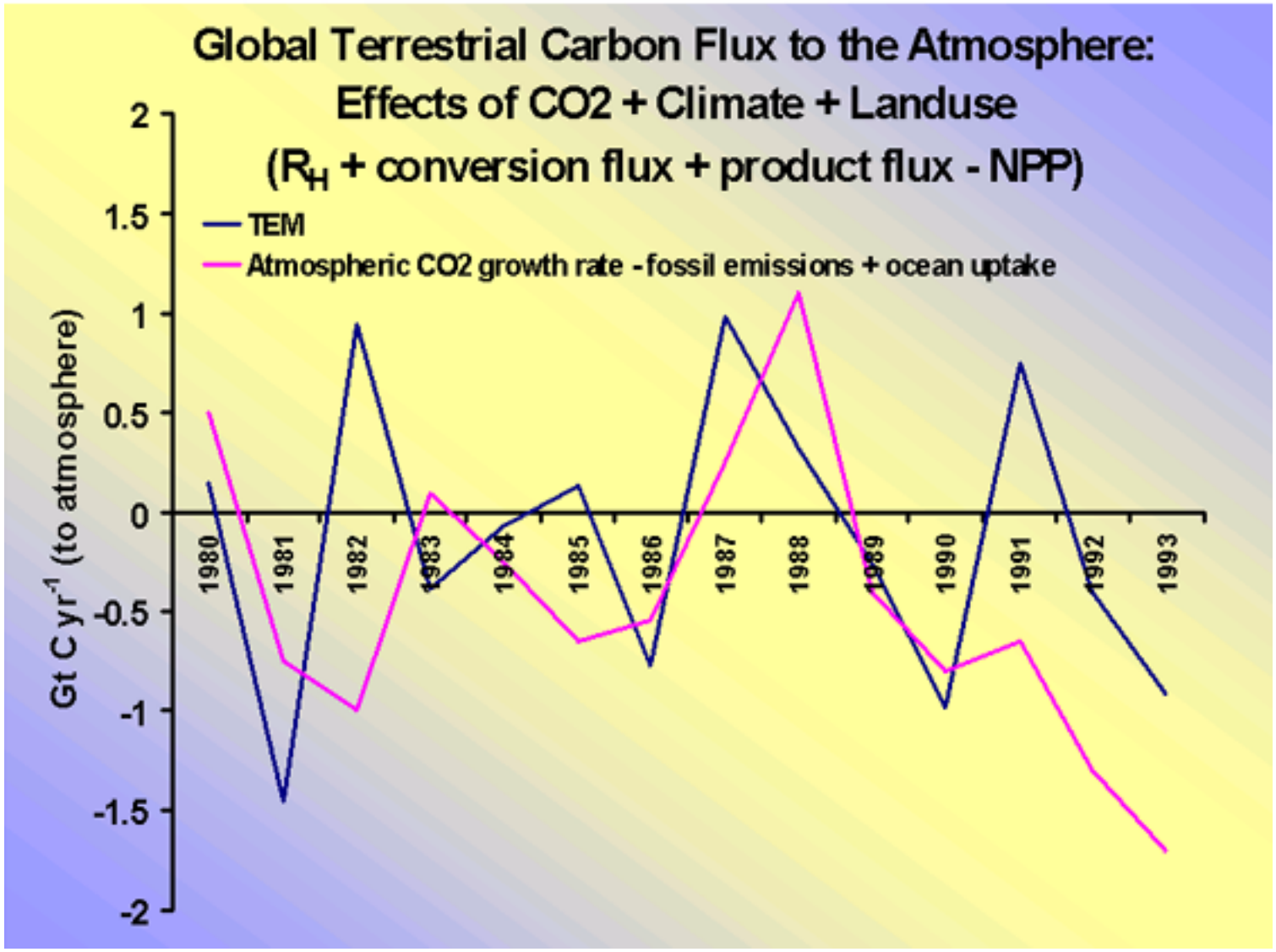

Net Biome Productivity
(for entire state of Alaska)
Potential
Fire
Annual gC m-2
20
15
10
5
0
-5
-10
-15
-20
-25
1940
1945
1950
1955
1960
1965
1970
1975
1980
1985
1990
1995

Simulated Carbon Flux in Alaska: Animation


Station BRW
180
90W
0
90E
180
60N
30N
EQ
30S
60S
−0.25
0.25
0.5
1
1.5
2
3
5
Per Cent

Modeling Historical Responses of Global Terrestrial Ecosystems to changes in Atmospheric Carbon Dioxide, Climate, and Agricultural Land Use

- Changes in atmospheric CO_2 based on Keeling record.
- Historical temperature based on Jones et al. anomalies.
- Historical precipitation based on Hulme et al. anomalies.
- Historical land use based on boolean data sets of (1) Esser and (2) Ramankutty et al.
- Fate of carbon on conversion based on Houghton.


Global Terrestrial Carbon Flux to the Atmosphere:
Effects of CO2 + Climate + Landuse
(R_H + conversion flux + product flux - NPP)
TEM
Atmospheric CO2 growth rate - fossil emissions + ocean uptake
Gt C yr-1 (to atmosphere)
2
1.5
1
0.5
0
-0.5
-1
-1.5
-2
1980
1981
1982
1983
1984
1985
1986
1987
1988
1989
1990
1991
1992
1993

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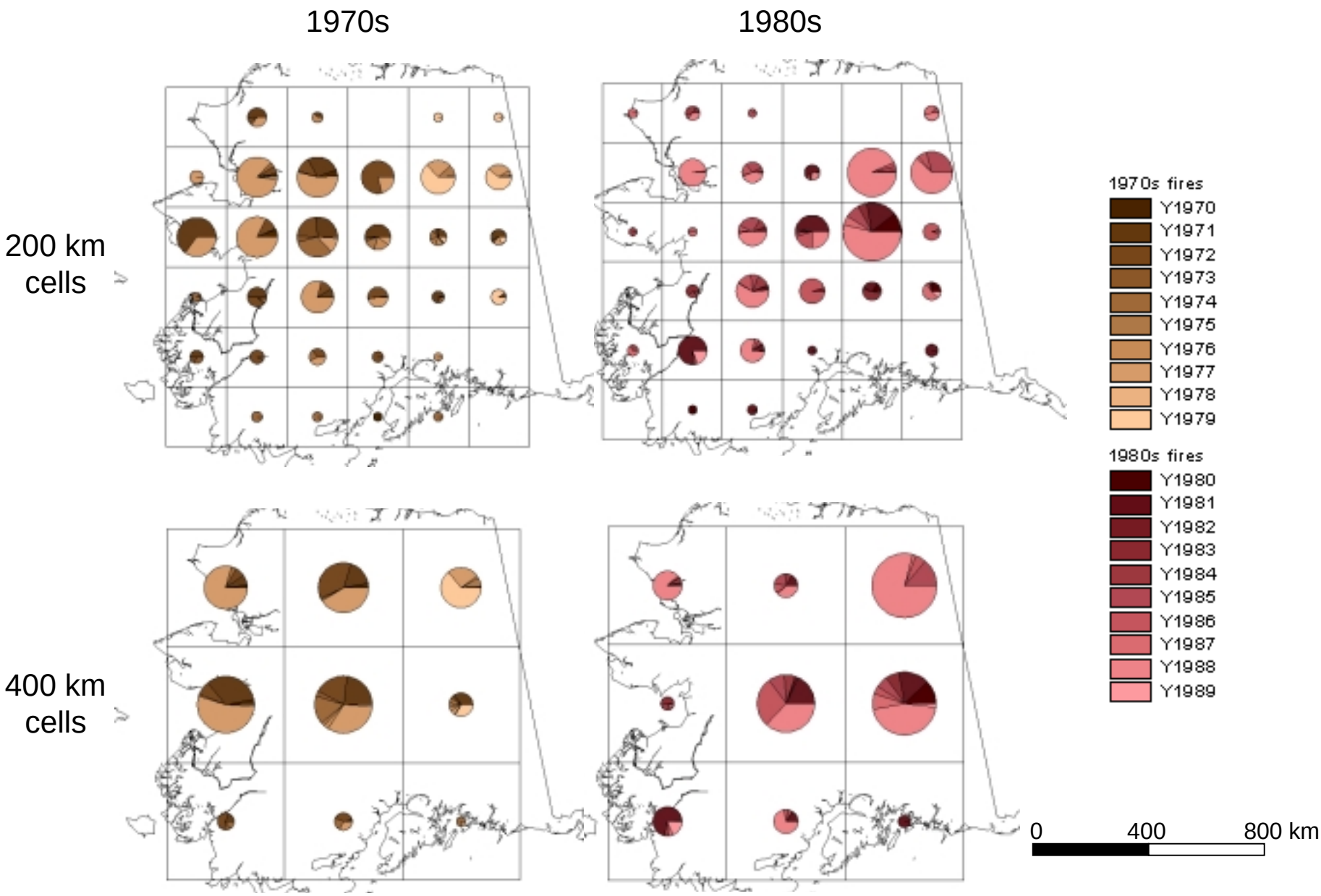
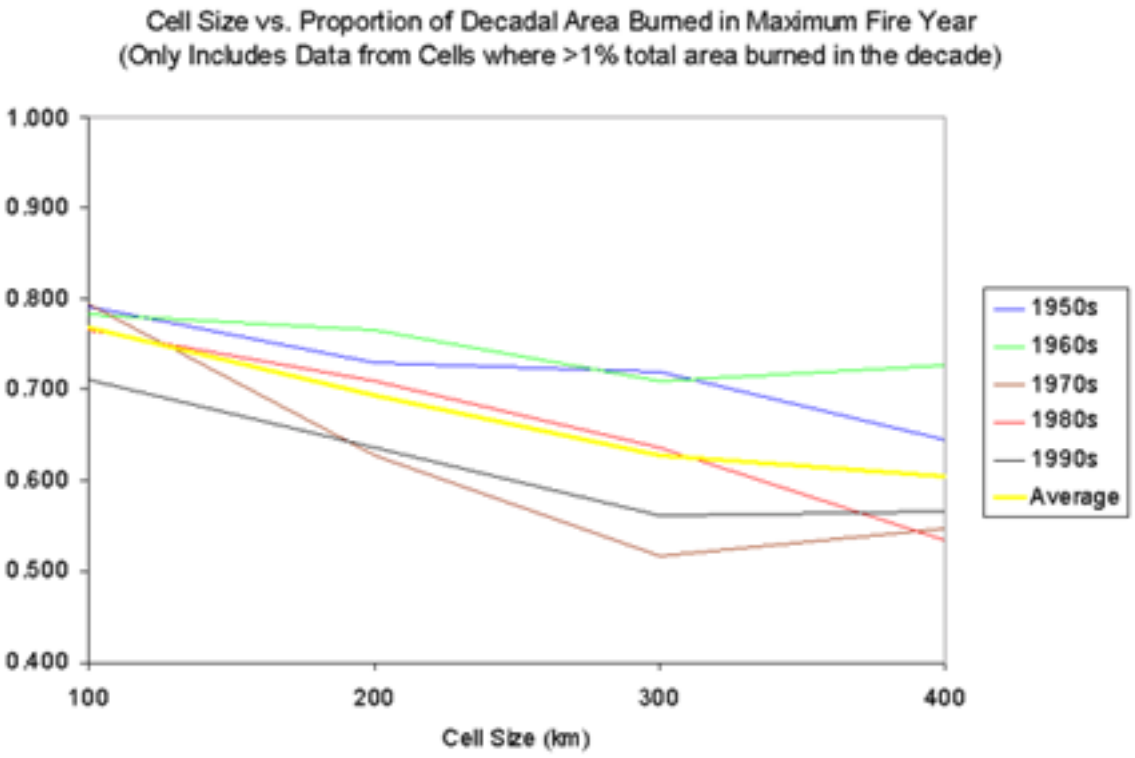
Annual Area Burned as a Proportion of Decadal Area Burned



Annual Area Burned as a Proportion of Decadal Area Burned at Regional Scales in Alaska



- On average, 50-80% of the area burned in a decade is burned in the maximum fire year.
- Within smaller regions, the impact of the largest fires and fire years is greatest.
- Fire regime dominated by very large fires and fire years.

Evaluating the role of interannual climate variation in proportion of area burned at half-degree resolution:

Logistic Regression Model:

$$\text{Proportion Burned} = e^{LP} / (1 + e^{LP}) \text{ where}$$

$$LP = -14.939 + 0.0896T_{MAY} + 0.6478T_{JUNE} - 0.00933\ SNOWPACK_{MAY}$$

- The model overestimates number of cells with small burns and underestimates number of cells with large burns
- Aggregating results to the state scale, the model explains 33.7% of the interannual variance in area burned across Alaska
- Over 47 years, the model predicts area burned within a few km^2

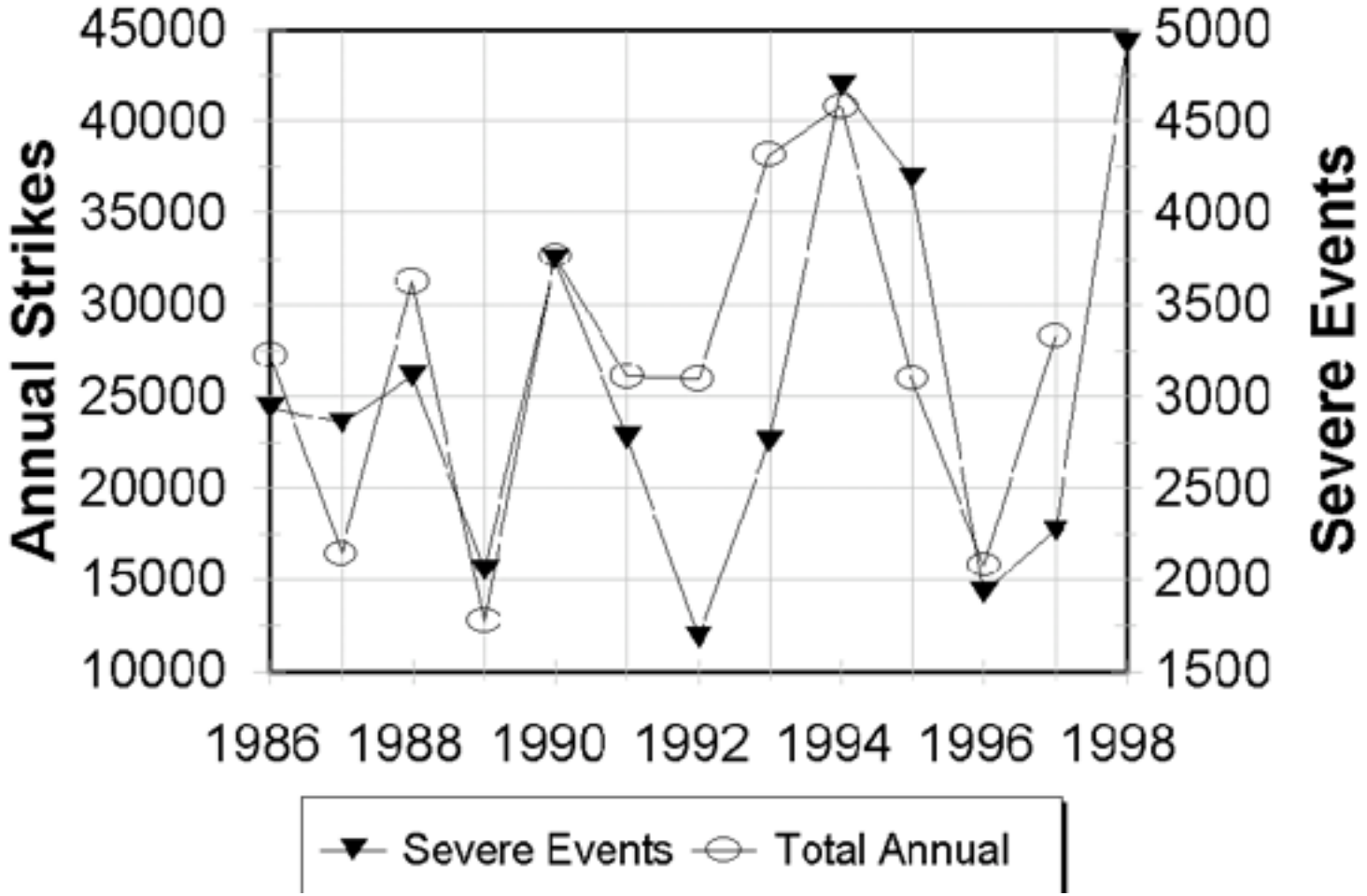
Evaluating the role of fire history:

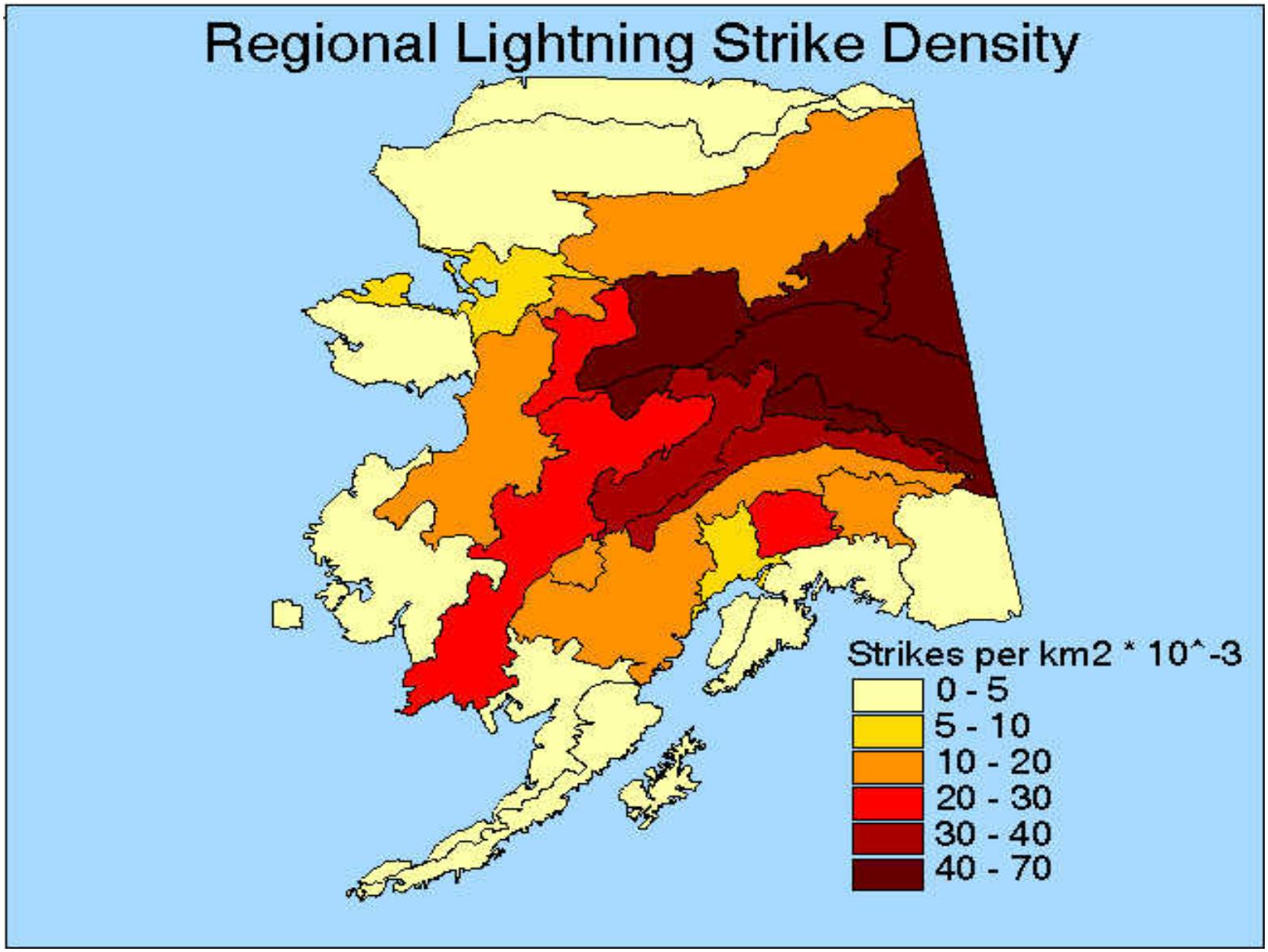
We examined the pattern of burning in fire-history cohorts that existed in 1990:

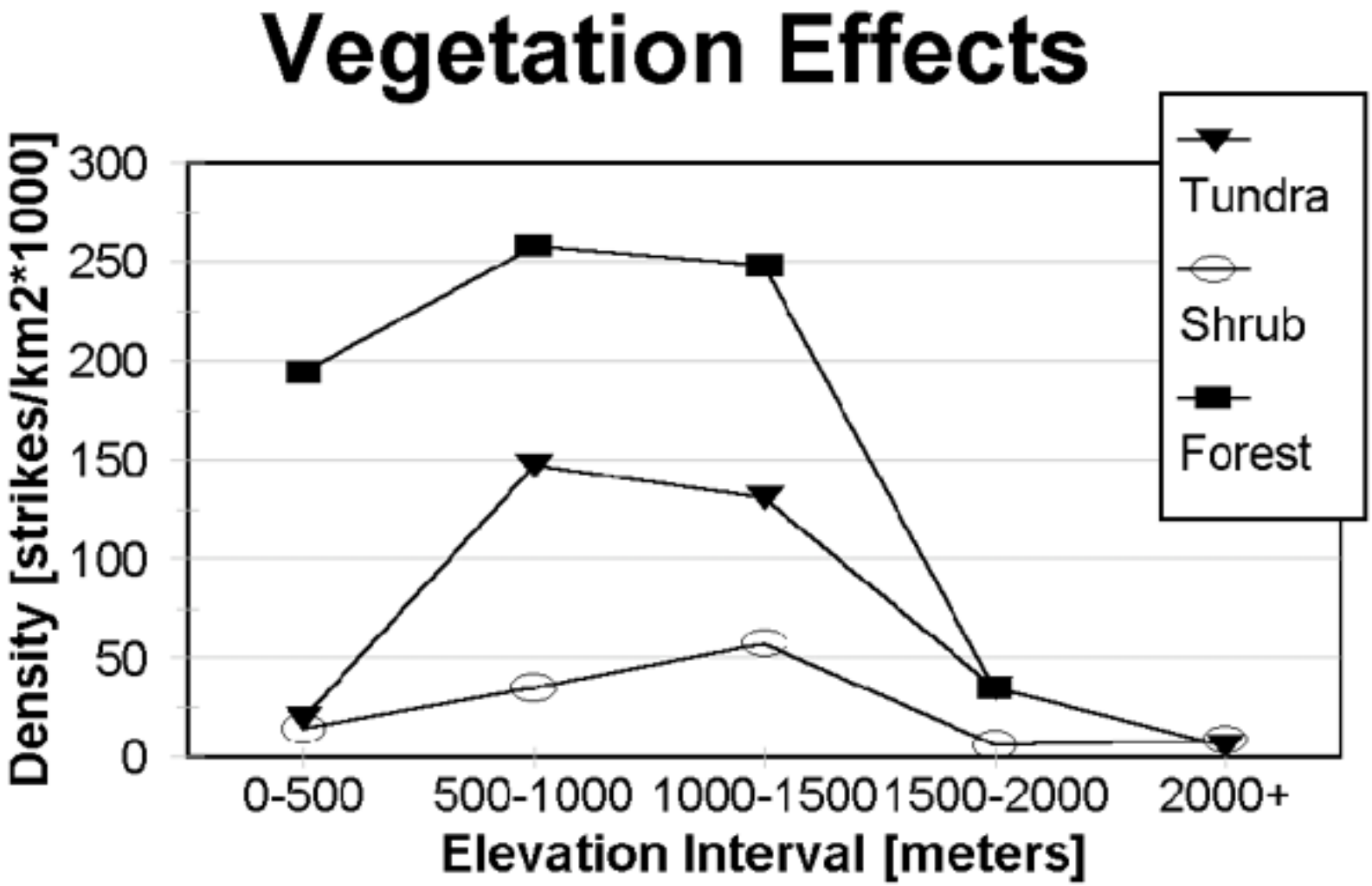
	Burned	Unburned
Previous Burn > 40 years ago	135	1675
Previous Burn <= 40 years ago	54	1115

- **Of 2979 cohorts in 1990, 60.8% had not burned in last 40 years**
- **Of cohorts burned in 1990, 71.4% had not burned in last 40 years**
- **Chi-square Test: P = 0.0025**

Lightning Variation




Regional Lightning Strike Density
Strikes per km2 * 10^-3
0 - 5
5 - 10
10 - 20
20 - 30
30 - 40
40 - 70


Vegetation Effects
Density [strikes/km2*1000]
300
250
200
150
100
50
0
0-500
500-1000
1000-1500
1500-2000
2000+
Elevation Interval [meters]
Tundra
Shrub
Forest

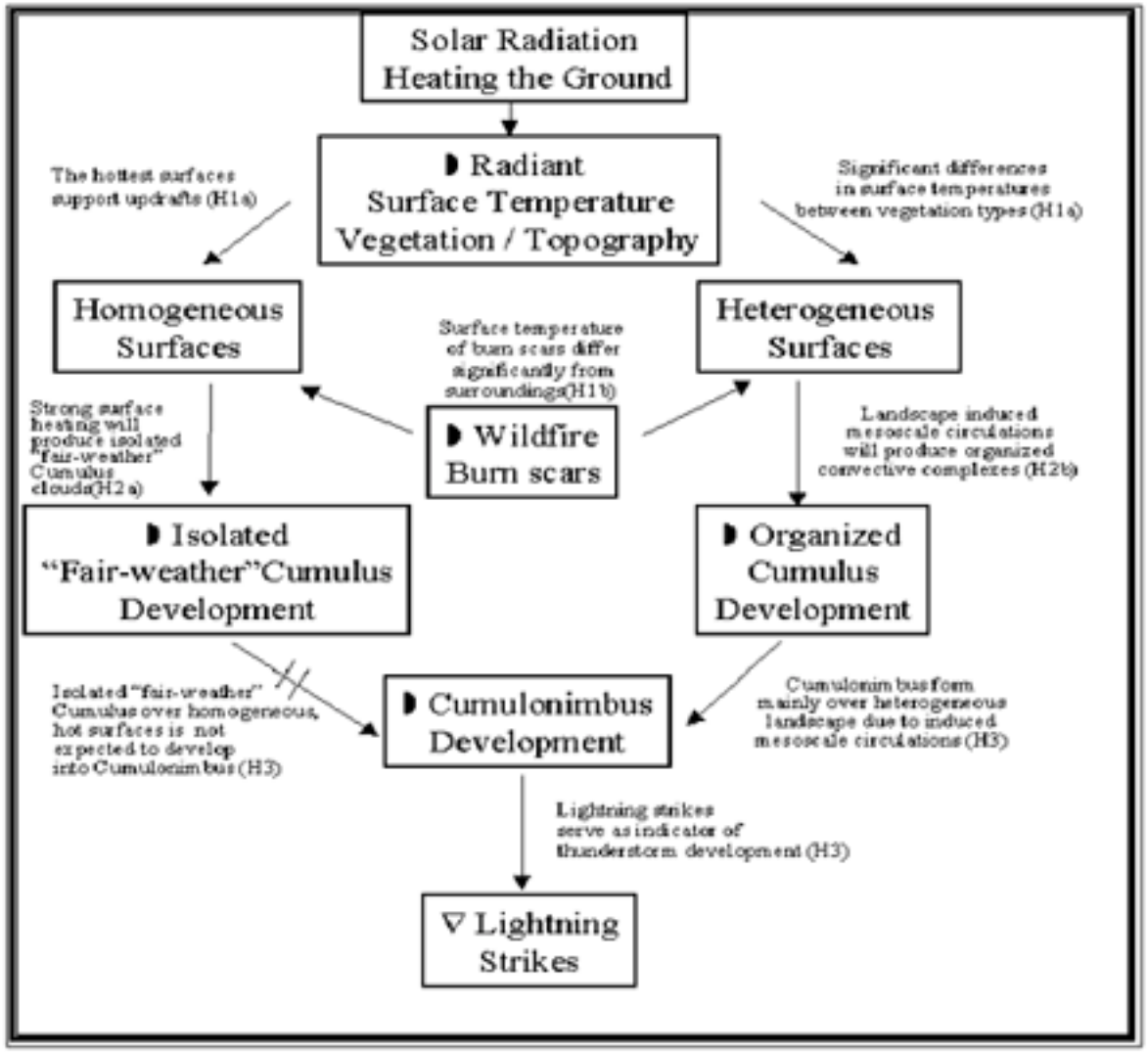


Figure 1: Flow Chart of Tested Hypotheses

Text explains the hypothesis tested. H-numbers refer to hypothesis.

◗ Detectable by remote sensing techniques

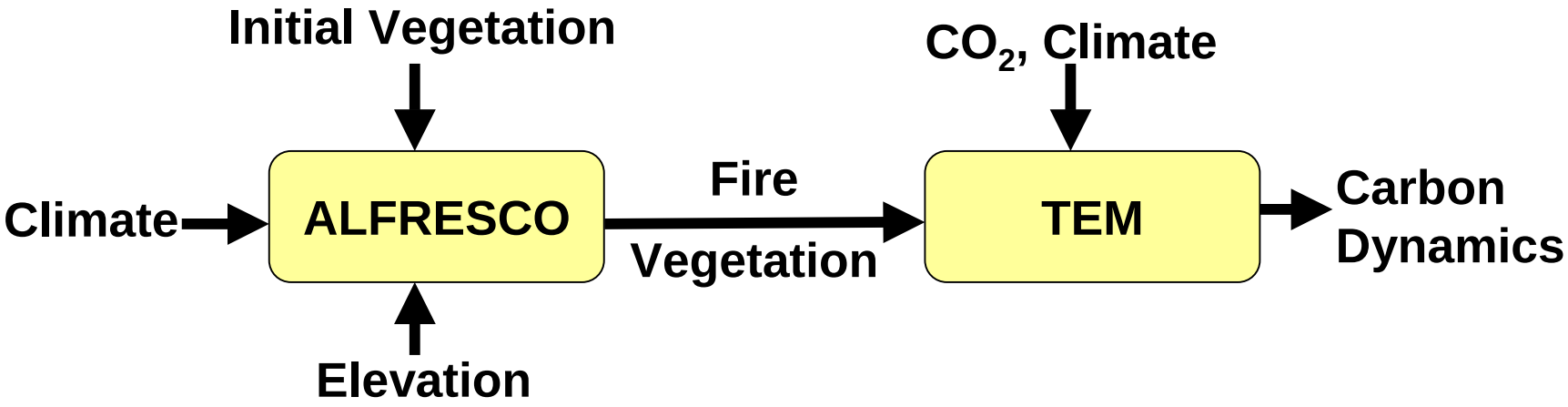
▽ BLM / ASF automated network data

Components of the Modeling Framework

- **Physical Properties of Terrestrial Ecosystems:**
  Based on Goodrich model of permafrost dynamics
- **Physical Processes and Ecosystem Function:**
  Based on Terrestrial Ecosystem Model (TEM) - version 4.
- **Effects of Disturbance on Ecosystem Function:**
  Based on Terrestrial Ecosystem Model (TEM) - version 4.
- **Modeling the Disturbance Regime:**
  Based on physical and biological properties of ecosystems.
- **Ecosystem Structure and the Disturbance Regime:**
  Based on ALaska FRame-based EcoSystem Code (ALFRESCO)
  Starfield and Chapin. 1996. Ecol. Appl. 6:842-864
- **Modeling Vegetation Dynamics:**
  Development of Dynamic Arctic Vegetation Model (DAVM)
- **Human Dimensions:**
  Based on conceptual model of Chapin, Starfield, and Naylor

Modeling the influence of climate variability on carbon dynamics through changes in disturbance regime and ecosystem structure and function:

Coupling of ALFRESCO with TEM

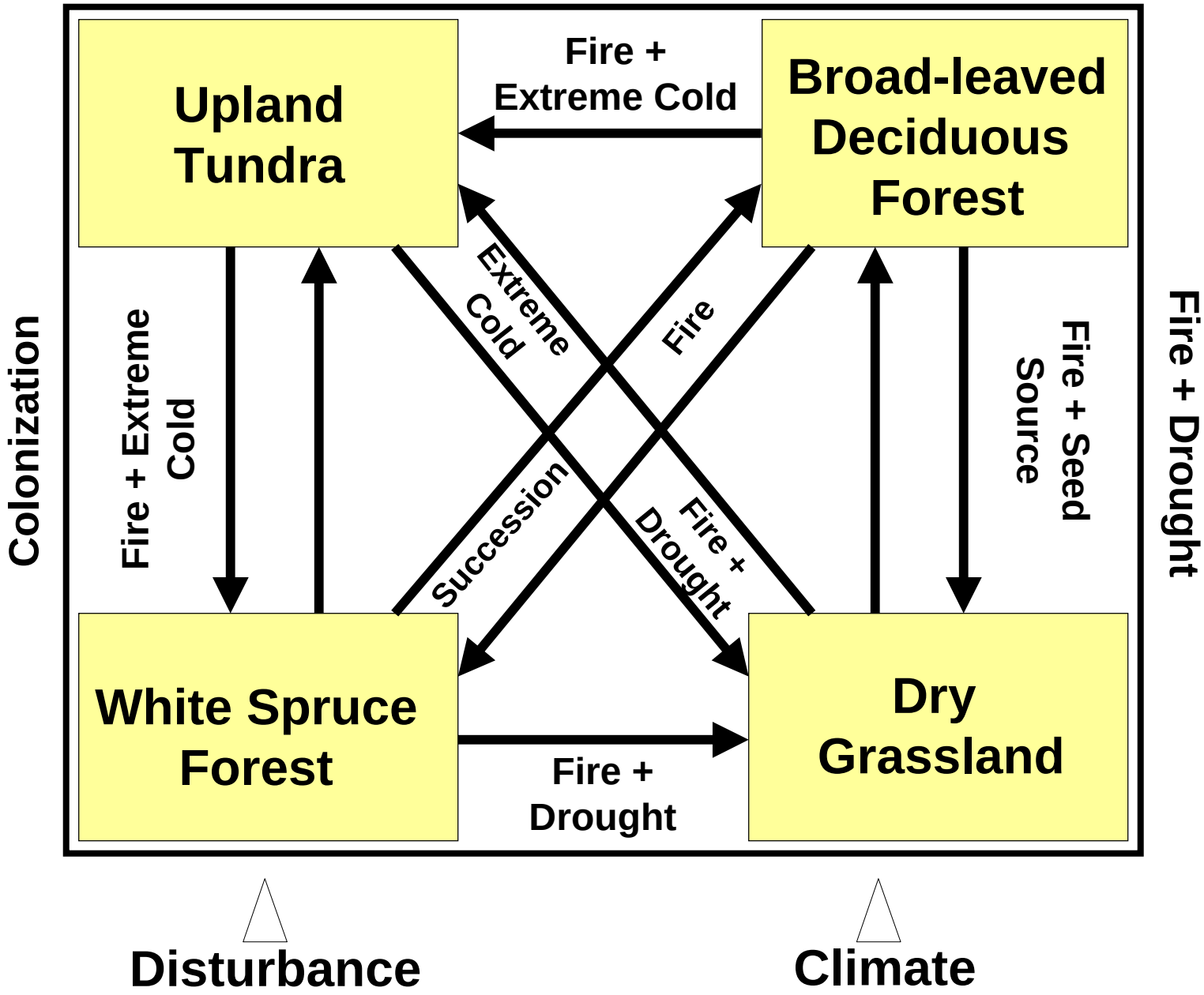


Simulation Specifications:

Spatial Scope: 200 km by 400 km region of the Seward Peninsula

Temporal Scope: 1950 to 2100

Climate Data: Max Planck historical connected with Hadley CM2 projected climate

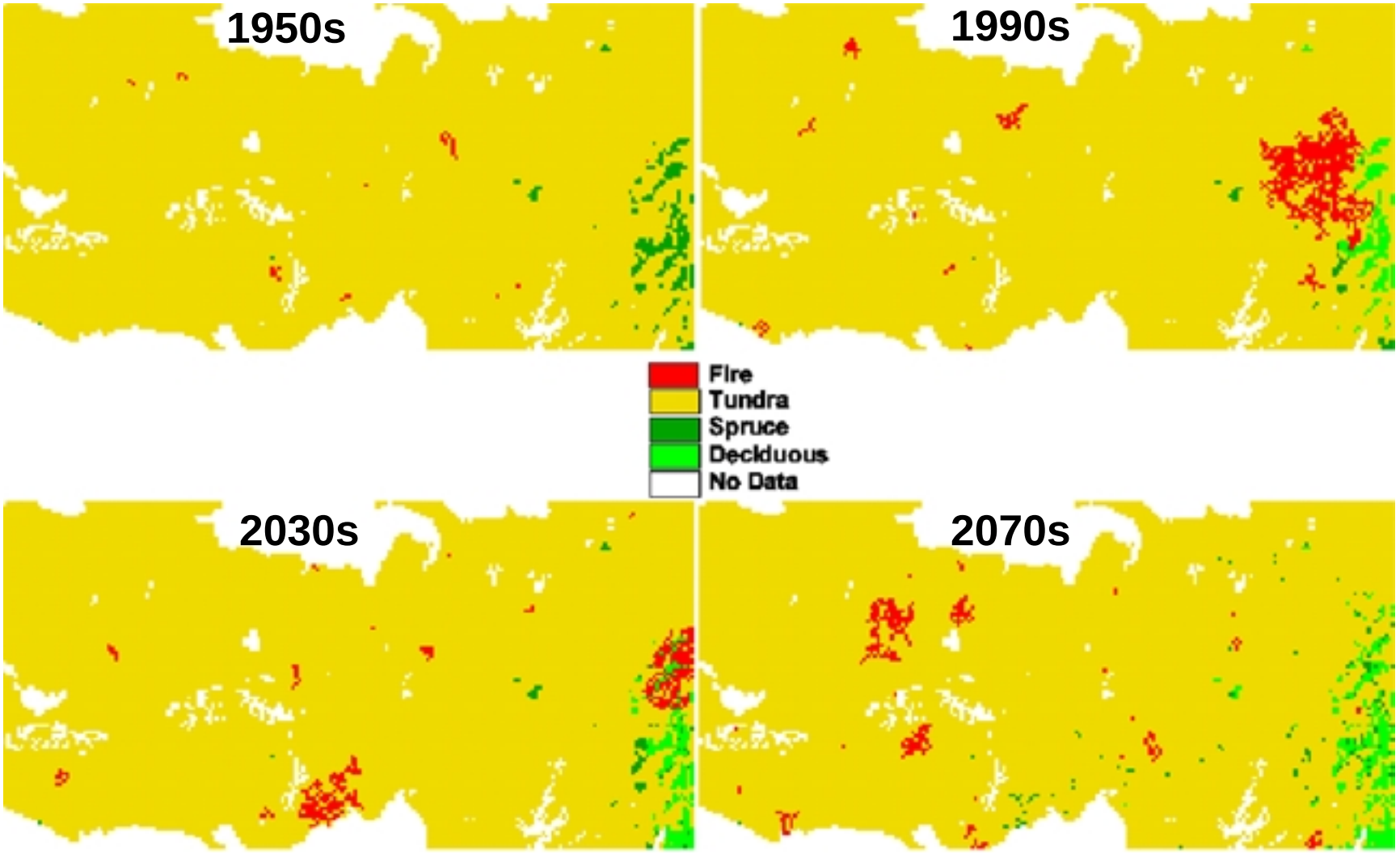

Upland Tundra
Fire + Extreme Cold
Broad-leaved Deciduous Forest
Colonization
Fire + Extreme Cold
Extreme Cold
Fire
Succession
Fire + Drought
Fire + Seed Source
Fire + Drought
White Spruce Forest
Fire + Drought
Dry Grassland
Disturbance
Climate

Fire History of the Seward Peninsula, Alaska Between 1950 and Present:

Number of Fires and Area Burned Per Decade

	Number	Area (km^2)
Observed	10	2212
Simulated by ALFRESCO	10	1552

ALFRESCO Simulated Fire and Vegetation
Seward Peninsula AK



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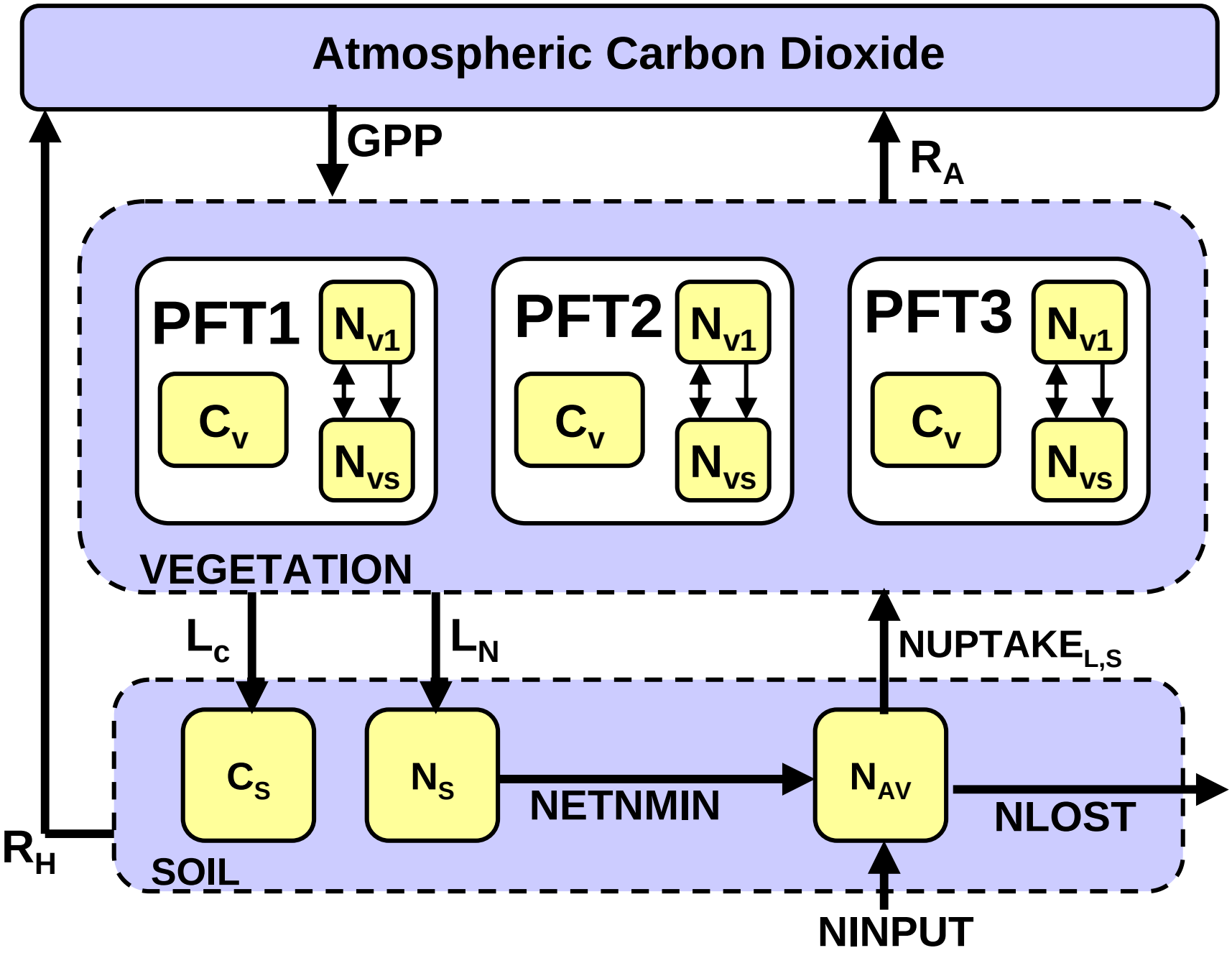
Atmospheric Carbon Dioxide
GPP
R_A
PFT1
N_{v1}
C_v
N_{vs}
PFT2
N_{v1}
C_v
N_{vs}
PFT3
N_{v1}
C_v
N_{vs}
VEGETATION
L_C
L_N
$NUPTAKE_{L,S}$
C_S
N_S
NETNMIN
N_{AV}
NLOST
R_H
SOIL
NINPUT

Components of the Modeling Framework

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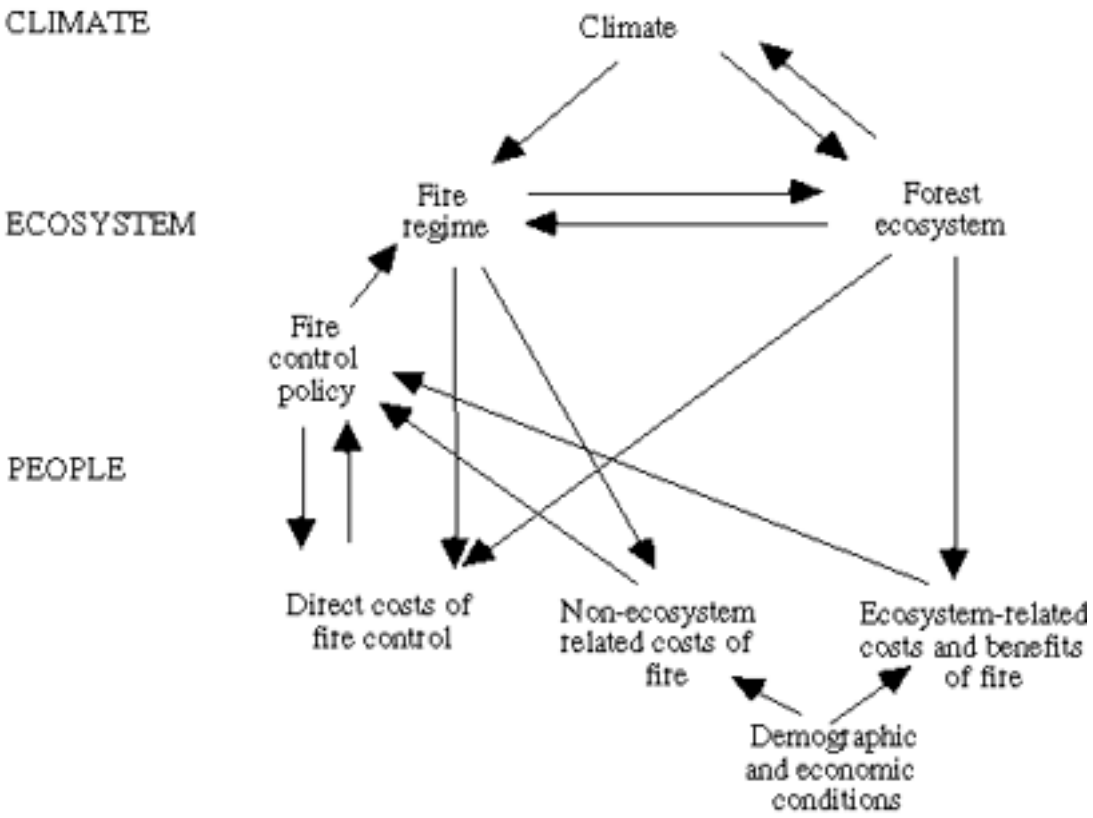

CLIMATE
ECOSYSTEM
PEOPLE
Climate
Fire regime
Forest ecosystem
Fire control policy
Direct costs of fire control
Non-ecosystem related costs of fire
Ecosystem-related costs and benefits of fire
Demographic and economic conditions

Significant Results

- **Theoretical exploration of factors that influence the level of false change detection in estimates of land cover change.**
- **Making progress in developing a methodology to estimate decadal scale land-cover change in high latitude ecosystems.**
- **Progress in modeling effects of climate on permafrost dynamics, ecosystem function, and aspects of the disturbance regime.**
- **Progress in coupling models of ecosystem structure and function in high latitude ecosystems.**
- **Progress in modeling the role of elevated atmospheric CO_2, climate, and agricultural land use in the global carbon cycle.**

Policy Implications

- **Relevant to international negotiations with respect to controlling the concentrations of radiatively active gases in the atmosphere.**
- **Providing support for the use of spatially explicit and temporally explicit vegetation, disturbance, and climate data in the Alaska Regional Assessment.**
- **Conducting pathfinding research for the application to Alaska of the models in the Vegetation/Ecosystem Modeling and Analysis Project (VEMAP), which is an important component of the National Assessment.**
- **Regional and global analyses will contribute to the IPCC assessment process.**

Manuscripts in Preparation
(Expect submission by end of project)

- **Verbyla et al. Potential bias in land cover change estimates associated with positional errors**
- **Macander et al. Vegetation dynamics after fire in interior Alaska.**
- **Zhuang et al. Modeling permafrost dynamics and carbon storage in fire-disturbed ecosystems of Alaska.**
- **McGuire et al. The role of fire disturbance, climate, and atmospheric carbon dioxide in the response of historical carbon dynamics in Alaska from 1950 to 1997: A process-based analysis with the Terrestrial Ecosystem Model.**
- **McGuire et al. The role of rising atmospheric carbon dioxide, climatic variation, and agricultural land use in terrestrial carbon storage: A forward modeling comparison among four terrestrial biosphere models.**
- **Macander/McGuire et al. An analysis of the temporal and spatial dynamics of fire across Alaska between 1950 and 1997.**

Manuscripts in Preparation, continued...
(Expect submission by end of project)

- **Dissing and Verbyla. Landscape interactions with thunderstorms in interior Alaska.**
- **Rupp et al. Historical and projected patterns of fire disturbance and vegetation dynamics on the Seward Peninsula, Alaska.**
- **McGuire et al. Historical and projected patterns of carbon storage on the Seward Peninsula, Alaska: The role of changes in atmospheric carbon dioxide, climate, simulated fire, and simulated vegetation dynamics.**
- **Rupp TS, Starfield AM, Chapin III FS (Submitted) A frame-based spatially explicit model of subarctic vegetation response to climatic change: comparison with a point model. Landscape Ecology.**
- **Rupp TS, Chapin III FS, Starfield AM (Submitted) Response of subarctic vegetation to transient climatic change on the Seward Peninsula in northwest Alaska. Global Change Biology.**

Next Steps

- **Remote Sensing and Spatial Data Sets**
- **Modeling**
- **Human Dimensions**

Next Steps

Remote Sensing and Spatial Data Sets:

- **Better automation of change-detection methodology**
- **Application of methodology to broader region (Alaska and beyond)**
- **Use of new technologies/data - MODIS, LANDSAT 7**

Next Steps

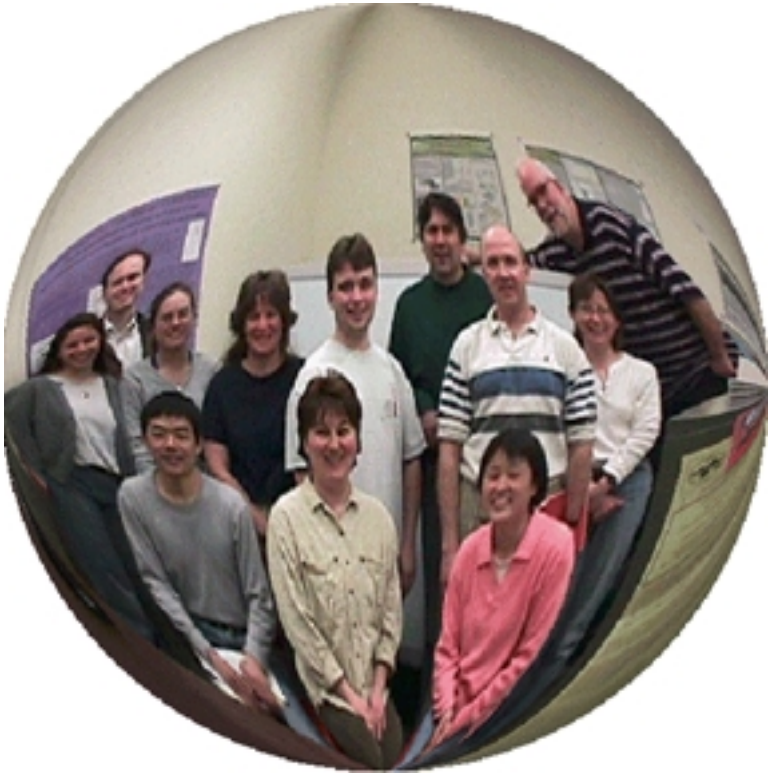
Modeling:

- **Continued development of individual modeling components**
- **Focused effort on a predictive model of the fire regime**
- **Vegetation dynamics based on both population processes and biogeochemistry**
- **Comparison between forward and inverse modeling approaches**
- **Incorporation of human dimensions**

Next Steps

Human Dimensions:

- **Fire control policy**
- **Direct costs of fire control**
- **Non-ecosystem related costs of fire**
- **Ecosystem-related costs and benefits of fire**
- **Demographic and economic conditions**



For more information look us up at

http//alces.sel.uaf.edu

China

Early Results- Modeling and forecasting effects of land use change in China based on socioeconomic drivers - R. Kaufmann

Modeling and Forecasting Effects of Land-Use Change in China Based on Socioeconomic Drivers

Boston University
Department of Geography
Principal Investigator: Robert K. Kaufmann

Co-Investigators: Curtis E. Woodcock
Dennis G. Dye
Karen C. Seto

Chinese Collaborators: Lu Jinfa
Li Xiaowen
Wang Tongsan
Huang Xiuhua
Liang Youcai

Summary of Talk

Project Overview

Remote Sensing Methodologies
- Atmospheric Correction
- Change Detection Methodologies
- Land-Use Change Map, Accuracy Assessment, & Area Estimates

Biophysical and Biogeochemical Effects

Time of Change

Economic Data

Research Findings to Date

Project Overview

Goals

- Quantify rate and amount of land conversion
- Quantify socioeconomic drivers of land-use change
- Quantify effects of land-use change on biophysical properties and biogeochemical processes

Steps

- Quantify land-use change from satellite images
- Model relation between land-use and socioeconomic variables
- Explore the effect of land-use change on biophysical attributes and biogeochemical processes
- Forecast land-use change under various scenarios for economic development

List of Atmospheric Correction Methods

DOS1:

Chavez, P.S. 1989.

DOS2:

Chavez, P.S. 1996.

DOS3:

Use Tz and Tv of Rayleigh atmosphere, Edown (downwelling diffuse irradiance) from 6S with Rayleigh atmospheric optical thickness and mid-latitude winter atmosphere model.

DOS4:

Image based estimate of Tz, Tv, and Edown

Liang et al. 1997.

rho (TM1) = 0.25*rho(TM7) rho (TM3) = 0.50*rho(TM7)

References:

Chavez, P.S. 1989. Radiometric Calibration of Landsat Thematic Mapper Multispectral Images. PE & RS. 55: 1285-1294.

Chavez, P.S. 1996. Image-Based Atmospheric Corrections -- Revisited and Improved. PE & RS. 62: 1025-1036.

Liang, et al. 1997. An Operational Atmospheric Correction Algorithm for Landsat Thematic Mapper Imagery over the Land. Journal of Geographical Research. 102:17, 173-17, 186.

Land-Use Categories (Stable)

Water

Natural Vegetation

- Eucalyptus, Pine, Fast Growing Trees, Shrubs

Agriculture

- Fish Ponds, Field Crops, Rice Fields, Orchards

Urban

- Old urban, transition to new urban

Land-Use Categories (Change)

Agriculture to Water
- new reservoirs

Natural Vegetation to Water
- new reservoirs

Water to agriculture
- water to fish ponds, rice fields, or bananas

Natural to Urban (non-economic use to developed)
- water or natural vegetation to urban/transition

Agriculture to Urban (some economic use to developed)
- fish ponds, rice fields, field crops, or orchards to urban/transition

Test Dataset

- 809 sites
- 7807 pixels
- 23 classes
- 9 classes
- Sites based on field visits and image interpretation
- Training and testing done on successive 80/20 splits
- No testing data ever seen in prior training

  (No cheating allowed!)

Econometric Techniques - Logit Models

Specification

- Dependent variable: Land cover type
- Independent variables: DN values for bands 1-5, 7, brightness, greenness, wetness

Diagnostic Statistics

- Independent variables generally significant
- In sample cases correct generally greater than 95%

Artificial Neural Networks

(Help from Gopal and Woodcock's NSF project)

Multiple ways of formulating Fuzzy Artmap
(Carpenter et al., 1991)

1. El-Gasim's Methods (Abuelgasim et al., in press at RSE)
   - Used to identify change due to Gulf War
   - Train on classes in initial date
   - Used trained net on second date
   - Allows identification of new land cover categories
   - Uses fuzzy membership values for multiple classes to determine change

Artificial Neural Networks (cont'd)

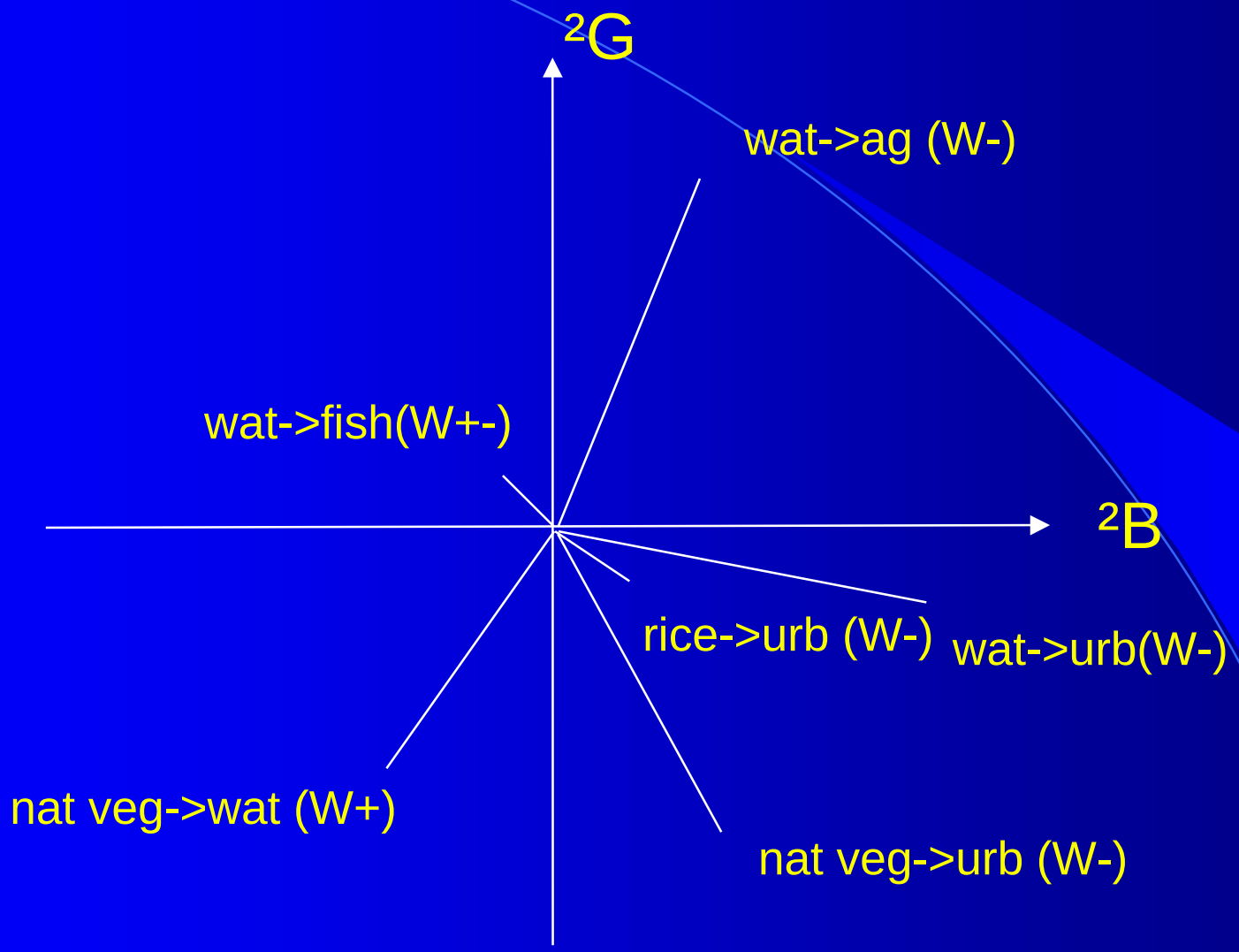
2. Two-date Classification
   - Input both dates of spectral data, including examples of change classes
   - Output is both stable and change classes
3. All-date classification
   - Input all 9 dates of imagery
   - Output is both stable and change classes

References

Abuelgasim, A.A., Ross, W. D., Gopal, S., and C. E. Woodcock, In Press. Change Detection using adaptive fuzzy neural networks: Environmental damage assessment after the Gulf War. RSE.

Carpenter, G. A., Grossberg, S. and J.H. Reynolds, 1991. A neural network architecture for object recognition by evidence accumulation, IEEE Transactions on Neural Networks, 6(4): 805-818.

BGW Change Vector



Inputs: Tasseled Cap BGW in 1988, and ²B, ²G, ²W
Output: Stable and Change Classes
Classification: Bayesian Maximum Likelihood

Preliminary Results on Test Data

Methodology	23 Categories	9 Categories
• Artificial Neural Nets	76 percent	N/A
• BGW Change Vector	74 percent	82 percent
• Logit Model	80 percent	86 percent

Time of Change

Problem

- Existing map identifies land-use categories in 1988 and 1996
- Need to know date at which land-use changes have occurred

Methodologies

- Neural Nets
- BGW change vector
- Time series techniques

Artificial Neural Networks for Time of Change

Multiple configurations of Fuzzy Artmap available

1. El-Gasim's Method
   - Could be sequentially applied to successive pairs of images to identify time of change
2. Two-date classification
   - Could be sequentially applied to successive pairs of images to identify time of change
3. All-date classification
   - To identify both type and time of change would require examples of all kinds of change at all possible times for training
   - Not viable option for this project

BGW Change Vector Time of Change

Approach:

- Once the 1988-1996 classification is trained, any pair of dates can be used
- Plan is to apply existing training statistics on images in a pair-wise fashion

Method of Atmospheric Correction:

- Ridge Method of DN Matching

Time Series Techniques

Estimate models for constant classes

- Dependent variables: DN value bands 1-5, 7, brightness, greenness, wetness, NDVI
- Independent variables: solar zenith angle, aerosol optical depth, minimum DN value, seasonal dummies

Estimation technique

- Stack as seemingly unrelated regressions
- Fixed effects estimators

Time Series Techniques (cont'd)

Predict pixel values

- Use classification technique to determine land-use categories
- Simulate all possible dates of change

Choose best model

- Pair-wise comparison of change dates
- Choice criterion – Predictive accuracy tests developed by Diebold and Mariano (1995)

Reference:

Diebold, F. X. and R. S. Mariano. 1995. Comparing Predictive Accuracy. Journal of Business and Economic Statistics. 13(3): 253-263.

Accuracy Assessment and Area Estimates

	Ground Truth										
Map Class	water	nat veg	ag	urban	ag>wat	nat>wat	wat>ag	nat>urb	ag>urb	total	map prop
water	**49**									49	7.82
nat veg		**85**	6							91	44.13
ag		1	**109**	1					2	113	37.68
urban			2	**53**				1		56	2.67
ag->wat	2		11		**15**	1				29	.06
nat->wat					8	**22**				30	.02
wat->ag							**24**			24	.56
nat->urb	1	2	4					**27**	17	51	1.96
ag->urb			5	2				5	**41**	53	5.10

Total # sites:496

Area Weighted Accuracy:93.50%

Class	Map Estimate (% of total area)	Corrected Estimate (% of total area)	Net Change (%)
water	7.76	7.82	.77
nat veg	46.80	44.13	-5.71
ag	35.06	37.68	7.47
urban	2.31	2.67	15.58
ag->water	.1	.06	-.4
nat->water	.03	.02	-.33
water->ag	.56	.56	0
nat->urban	2.78	1.96	-29.49
ag->urban	4.60	5.10	10.87

Biophysical Effects

- Albedo of urban areas is surprisingly low (previously observed in Egypt)
- The effect of a dramatic increase in albedo due to urbanization is only true for a limited number of years (less than a decade)
- Approach - tracking of albedos derived from Landsat TM imagery through time for urbanized sites

Biogeochemical Effects
Change in Surface Carbon Flux

- Intent is to include both the change in surface carbon flux due to land-use change and also emissions due to increased fossil fuel consumption
- Resources limit our abilities to do detailed estimates of surface carbon fluxes
- Expect fossil fuel consumption changes to swamp surface flux changes

County Level Socioeconomic Data

Sources:

Professor Lu Jinfa, Institute of Geography,
Chinese Academy of Science

Liang Youcai, Vice Director, Economic Forecasting
Department, State Information Center

Statistical Yearbook of Guangdong Province (1985–1998)

- Value added by sector
- Urban/Rural Population
- GDP
- Income
- Agricultural output
- Number of vehicles

Socioeconomic Data Compilation and Analysis

Dr. Lee Xinzhong, Institute of Quantitative and Technical Economics Chinese Academy of Social Science, World Bank Visiting Scholar, Boston University Summer of 1999

Research Findings to Date

- The degree of atmospheric correction required is related to the methods used for change detection and research question
- New modifications to dark-object-subtraction methods do not significantly improve change detection accuracies
- We have been able to map land-use change with high accuracy (93.5%), particularly with respect to the ultimate land-use classes
- The amount of developed land has tripled between 1988 and 1996

Research Findings to Date (cont'd)

- Application of innovations from time series econometrics and artificial neural networks improve monitoring of change and time of change in a series of images (relative to conventional methods)
- Effects of urbanization on albedo do not seem to follow expectations
- Spatially disaggregated socioeconomic data are available for the study period
- Period of analysis limited because Landsat images are unavailable 1982 – 1987

Central and South America

Early Results- Time series forest change, land cover/land use conversion and socio-economic driving forces in the Northern Peten District, Guatemala - D. Hayes

Early Results- Land cover and land use change in southern Yucatan Peninsular Region - B. Turner

Land use and land cover change in Sonara, Mexico:trajectories of agricultural intensification and consequences for non-agricultural systems - P. Matson

Time-series Forest Change, Land Cover/Land Use Conversion, and Socio-economic Driving Forces in the Petén, Guatemala

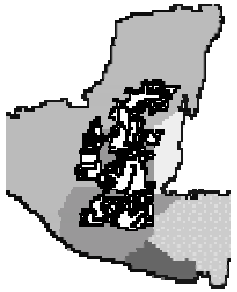
Steven A. Sader, Daniel J. Hayes
Maine Image Analysis Laboratory
University of Maine, Orono, USA

Introduction

With all the publicity given to deforestation in the Amazon Basin (and deservedly so, this region has the greatest area deforested each year), few people realize that Central America has the second highest deforestation rate in %/yr (1.5), behind only S.E. Asia (1.6%/yr) -- according to FAO statistics 1993.

Presentation Outline

- *The Maya Biosphere Reserve: Background*
- *Project Objectives*
- *Cooperators, Activities, Data and Products*
- *Project Development*
  - *Image Processing / Change Detection Methods*
- *Analysis and Early Results*
  - *The Land Cover / Land Use History Database*
- *Discussion / Future Research*



Guatemala
Geopolitical Context

- ***The Petén, Guatemala's largest department, is located in the lowland tropical moist forest at the southern extension of the Yucatan Peninsula…***
- ***The region has a low (but growing) population compared to the deforested and highly populated southern highlands***

The Maya Biosphere Reserve

Spanning 1.6 million hectares of northern Guatemala, the Maya Biosphere Reserve (MBR) is an area of lowland tropical forests and expansive wetlands. Together with adjacent forests in Mexico and Belize, the area known as the* Selva Maya *constitutes the largest contiguous tropical moist forest remaining in Central America.

The Maya Biosphere Reserve

The MBR was established in 1990 in order to preserve the remaining forest and the extensive biodiversity that it holds. The reserve is home to many rare and important plant and animal species including mahogany, Spanish cedar, chicle, jaguars, tapirs, white lipped peccaries, the scarlet macaw, harpy eagles, and various monkeys.

The Maya Biosphere Reserve

This region is also the heartland of the ancient Mayan civilization, vestiges of which remain today. Tikal National Park (next slide…) is a designated UNESCO World Heritage Site and serves as an important scientific window into Mayan history as well as a popular destination for visitors from around the world.

The Maya Biosphere Reserve

The Petén supports an expanding population that relies on the forest for its survival and well-being. Attention from international organizations (NGOs) and government agencies has aimed at fostering sustainable development and conservation programs.

The Maya Biosphere Reserve

The forests of the Petén, that for centuries rebuffed development attempts, are suddenly being destroyed at an alarming rate (next slide…). Serious threats include: slash & burn agriculture, cattle ranching, illegal logging, wildlife poaching, oil and gas development, road construction, and population growth (including refugee migration and immigration of landless peasants).

Land Cover / Land Use Change Pathways

- ***Pressure on the Petén, external factors:***
  - ***lower population density than the crowded and already deforested southern highlands***
  - ***availability of cheap land, lack of land tenure***
  - ***more stable political climate since end of civil conflict, migration more favorable***
  - ***government encouraging settlement of the "agricultural frontier" of the Petén***
  - ***external market incentives for oil development, logging, hunting, and wildlife poaching***
  - ***lax enforcement of protected areas***

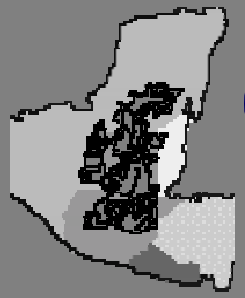
Land Cover / Land Use Change Pathways

- ***Typical progression of forest conversion:***
  - ***Access: oil development, logging road***
  - ***migration of landless farmers***
  - ***clear forest of valuable hardwoods***
  - ***slash and burn, clear forest for milpa***
  - ***squat on land, tend milpa for 2 years***
  - ***leave for fallow (how long? do they return?)***
  - ***without land tenure and following the loss of productivity in the milpa, the land may be acquired by wealthier families and often undergo permanent conversion to pasture***

Project Objectives

There is little systematic and reliable information on areas and rates of deforestation in the MBR. Because the expansive, remote and inaccessible nature of the reserve makes collecting ground data difficult and often infeasible, remote sensing data and image processing techniques have come to be relied upon for the generation and analysis of this information.

- ***Develop a land-cover/land-use database that spans more than twenty years (1974 to 1997);***
- ***Quantify forest clearing rates by time period and the proportion of land area converted to different land-cover types at each time period;***
- ***Determine the spatial distribution and abundance of second growth vegetation and estimate crop-fallow ratios in different management units and communities;***
- ***Determine the socio-economic factors that influence humans to make decisions that result in land-cover conversion;***
- ***Determine the spatial geometry of landscape disturbance through analysis of forest fragmentation and the relationships to socio-economic factors;***
- ***Other: Examine the relationship between radar backscatter and second growth age class canopy structure.***



Cooperators, Activities, Data and Products

Maine Image Analysis Laboratory
Department of Forest Management
University of Maine, Orono, USA

NASA-Marshall
Space Flight Center

CI-ProPetén
Flores, Guatemala

U.S. Agency for
International Development
Consejo Nacional de Areas
Protegidas, Guatemala

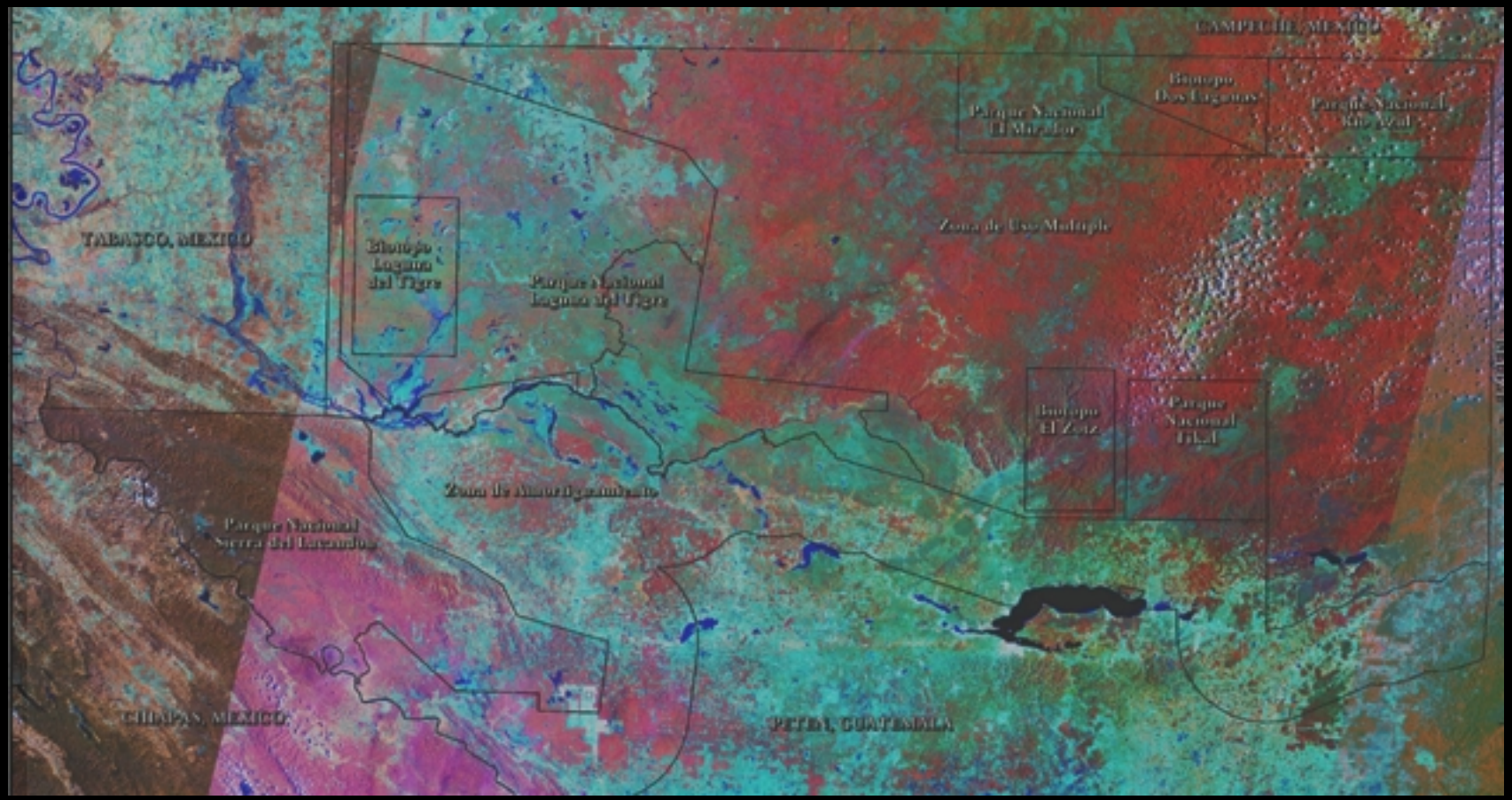
TNC- Guatemala
Program

Wildlife
Conservation Society

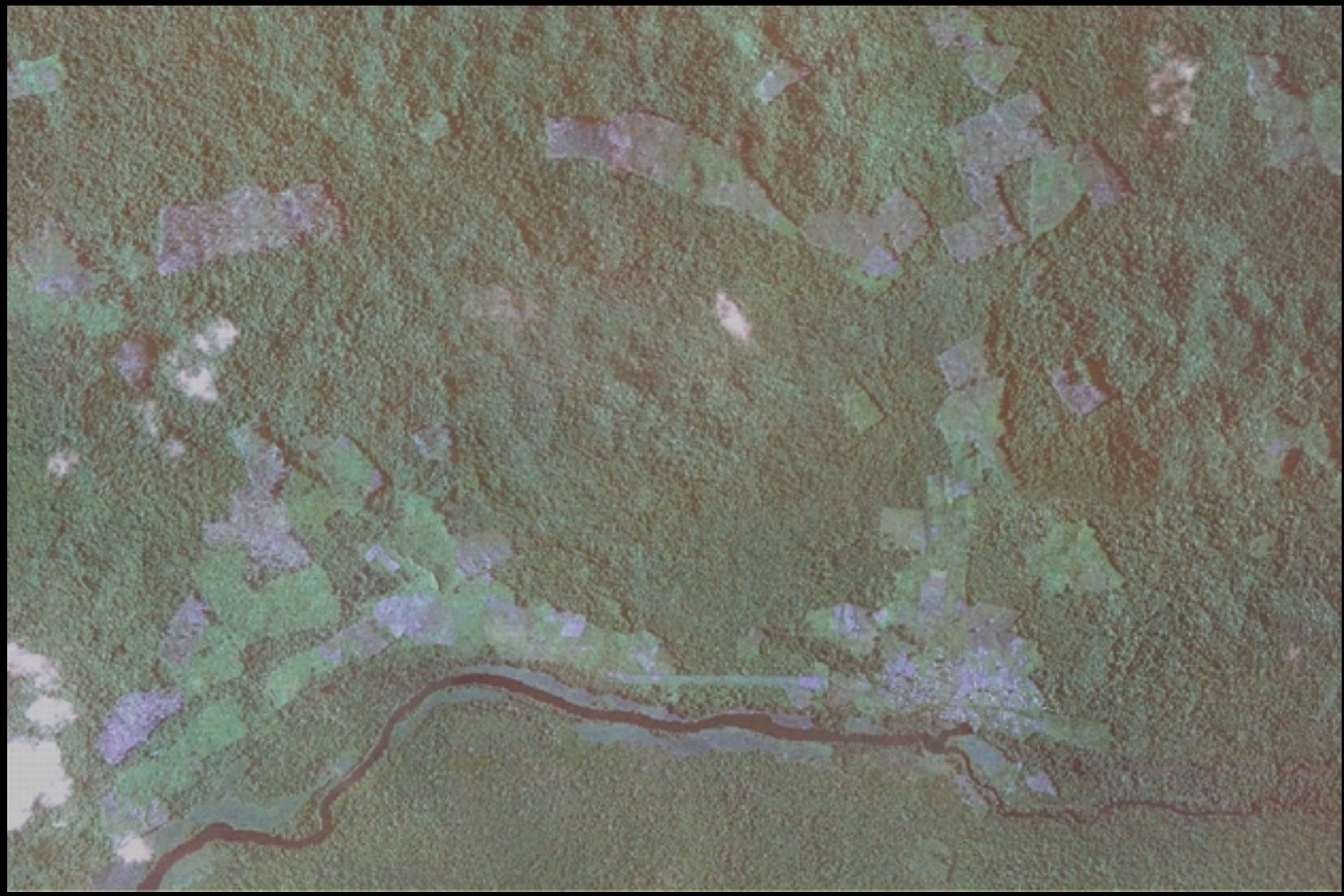
Cooperators, Activities, Data and Products

Satellite image change detection techniques were used to develop data on forest clearing rates in the MBR, to facilitate data transfer to local interests, and provide a base-line for future monitoring. Seven dates of Landsat Multispectral Scanner (MSS) and Thematic Mapper (TM) imagery covering the MBR were acquired, spanning 1974 to 1997.

1997 Landsat TM RGB 453 Satellite Image Color Composite of the Maya Biosphere Reserve, Petén, Guatemala



1997 1m Resolution Air Photo Mosaic, Village of Paso Caballos



Community Concession Boundaries / Socio-economic Study Areas

Study Area Profiles

- ***Carmelita***
  - ***Ladino***
  - ***Oldest, most stable (population and well-being) of the four community study areas***
  - ***mostly non-farmers, emphasis on non-timber forest products (NTFPs)***
  - ***smaller milpas (crops), longer fallow periods***
  - ***root and tuber crops; corn, beans, and squash in milpas; convert guamiles (second growth) instead of primary forest for milpas***

Study Area Profiles

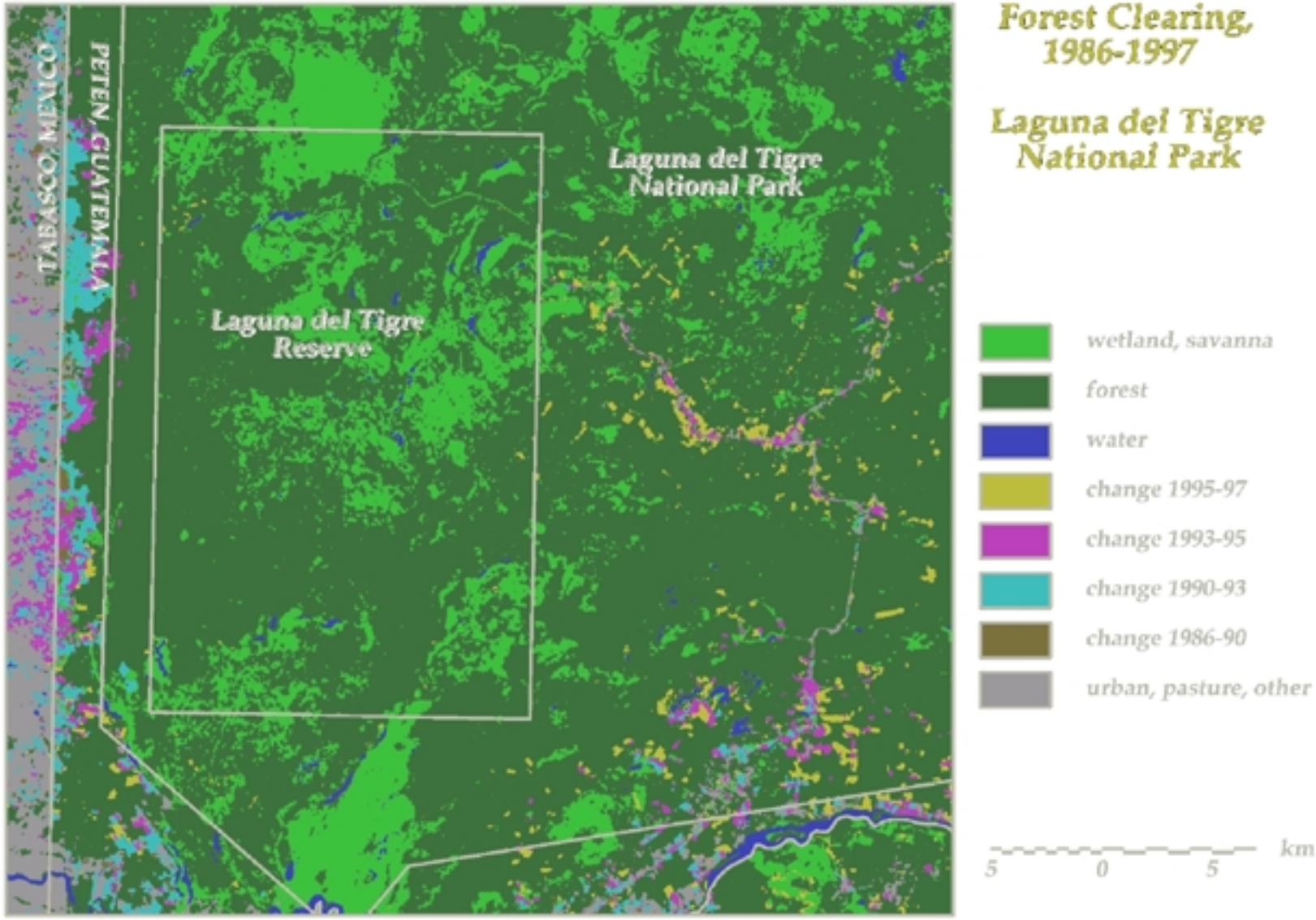
- *El Cruce Dos Aguadas*
  - *50% Ladino, 50% Q'eqchi relocated from southern Petén*
  - *largest community; stable*
  - *church, ethnicity important*
  - *larger than avg. milpas (esp. Q'eqchi)*
  - *Q'eqchi use velvet beans (frijol obono), a nitrogen fixer, in milpa: results in less herbicide, one crop per year but longer cropping period (7 years vs. 2 year average)*

Study Area Profiles

- *Paso Caballos and Buen Samaritano*
  - *Ladino / Q'eqchi; relocated from other regions of the Petén and the Guatemalan Highlands*
  - *newest communities, least stable*
  - *large milpas, corn mono-cropping*
- *The Petén, on average (Schwartz 1990):*
  - *1 ha of milpa to feed family of 6, depending on number of animals; average milpa 2.5 hectares*
  - *2 crops/year for 2 years (dry season has 50% yield of wet season); fallow 3-4 yrs, declining*

Products

The normalized difference vegetation index (NDVI) was used to detect changes in the forest canopy between dates. A change detection map was developed to show spatial and temporal trends in forest clearing. 100km^2 cells based on the Universal Transverse Mercator (UTM) grid system were used for landscape-level reporting and analysis of deforestation rates over time.


TABASCO, MEXICO
PETEN, GUATEMALA
Laguna del Tigre National Park
Laguna del Tigre Reserve
Forest Clearing, 1986-1997
Laguna del Tigre National Park
wetland, savanna
forest
water
change 1995-97
change 1993-95
change 1990-93
change 1986-90
urban, pasture, other
km
5
0
5

Project Development

- ***Land Cover / Land Use History Database***
  - ***develop and test methods to create a 7-date change detection database which identifies forest conversion pathways over a 20yr span;***
  - ***use satellite image change detection techniques to generate spatial data on forest clearing and regrowth, facilitate technology transfer to local agencies, and provide a base-line for future monitoring.***

Project Development

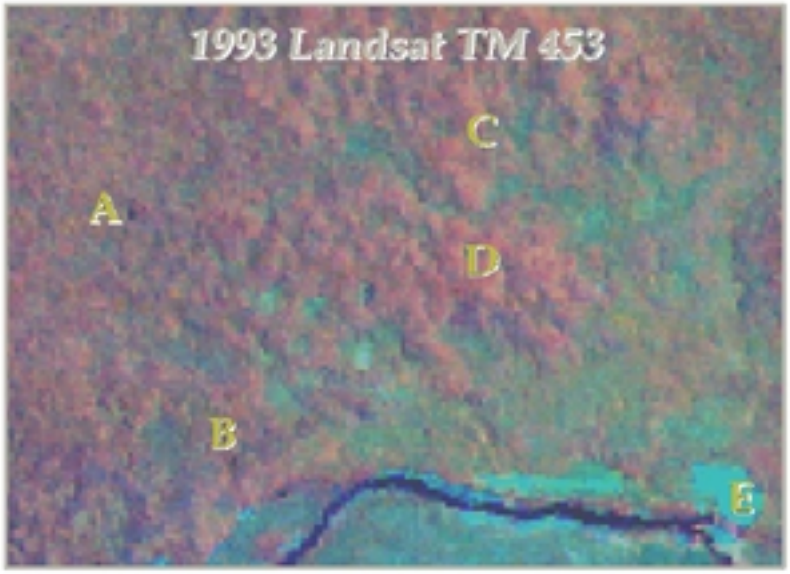
- ***Image Processing / Change Detection***
  - ***Radiometric calibration***
  - ***Image Differencing of Normalized Difference Vegetation Index (NDVI)***
  - ***Principal Components Analysis (PCA)***
  - ***3-Date RGB-NDVI Color Composites***
  - ***Threshold / Classify results of each method***
  - ***Assess the accuracy of and statistically compare the resulting error matrices***

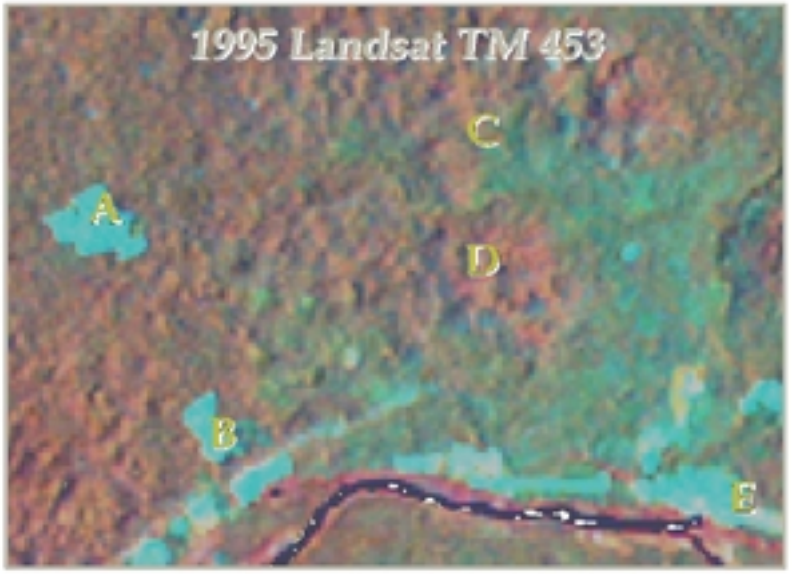
Image Processing / Change Detection Methods

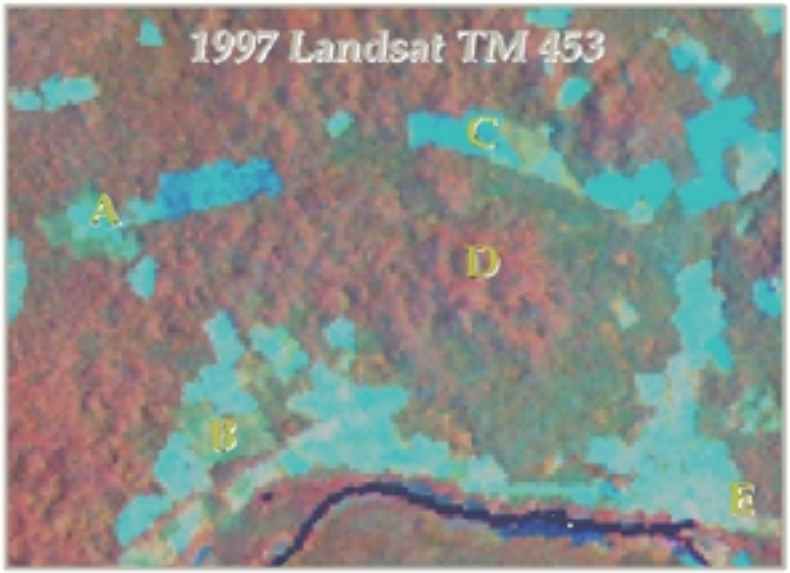
- ***Relative radiometric "normalization" (Eckhardt* et al. *1990, Hall* et al. *1991)***
  - *reference image: 1997 TM bands 3,4,5*
  - *subject images: 1995 TM 3,4,5 and 1993 TM bands 3,4,5*
  - *select "radiometric control sets", compute bright and dark control set means for each image*
  - *correct each subject image by regression against the reference image:* $Y' = m_i x + b_i$

$$m_i = (B_{ri} - D_{ri}) / (B_{si} - D_{si})$$

$$bi = (D_{ri}B_{si} - D_{si}B_{ri}) / (B_{si}-D_{si})$$


1993 Landsat TM 453
C
A
D
B
E


1995 Landsat TM 453
C
A
D
B
E


1997 Landsat TM 453
C
A
D
B
E

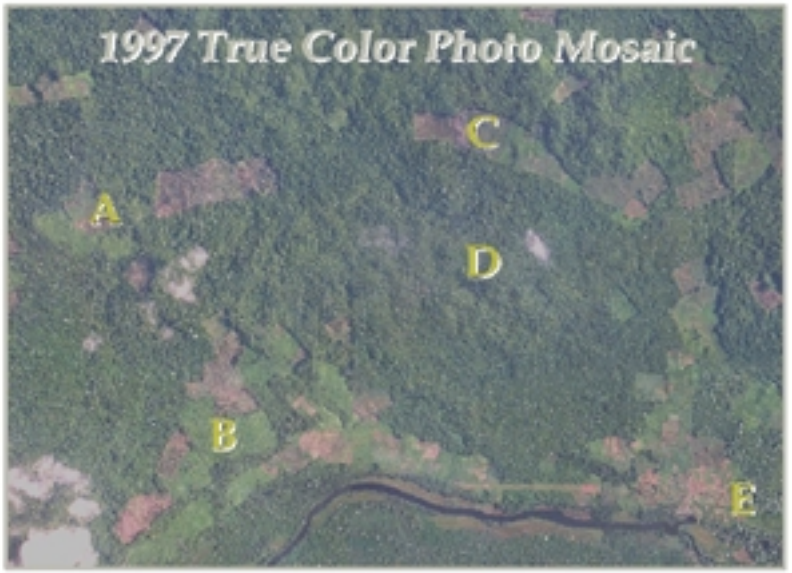
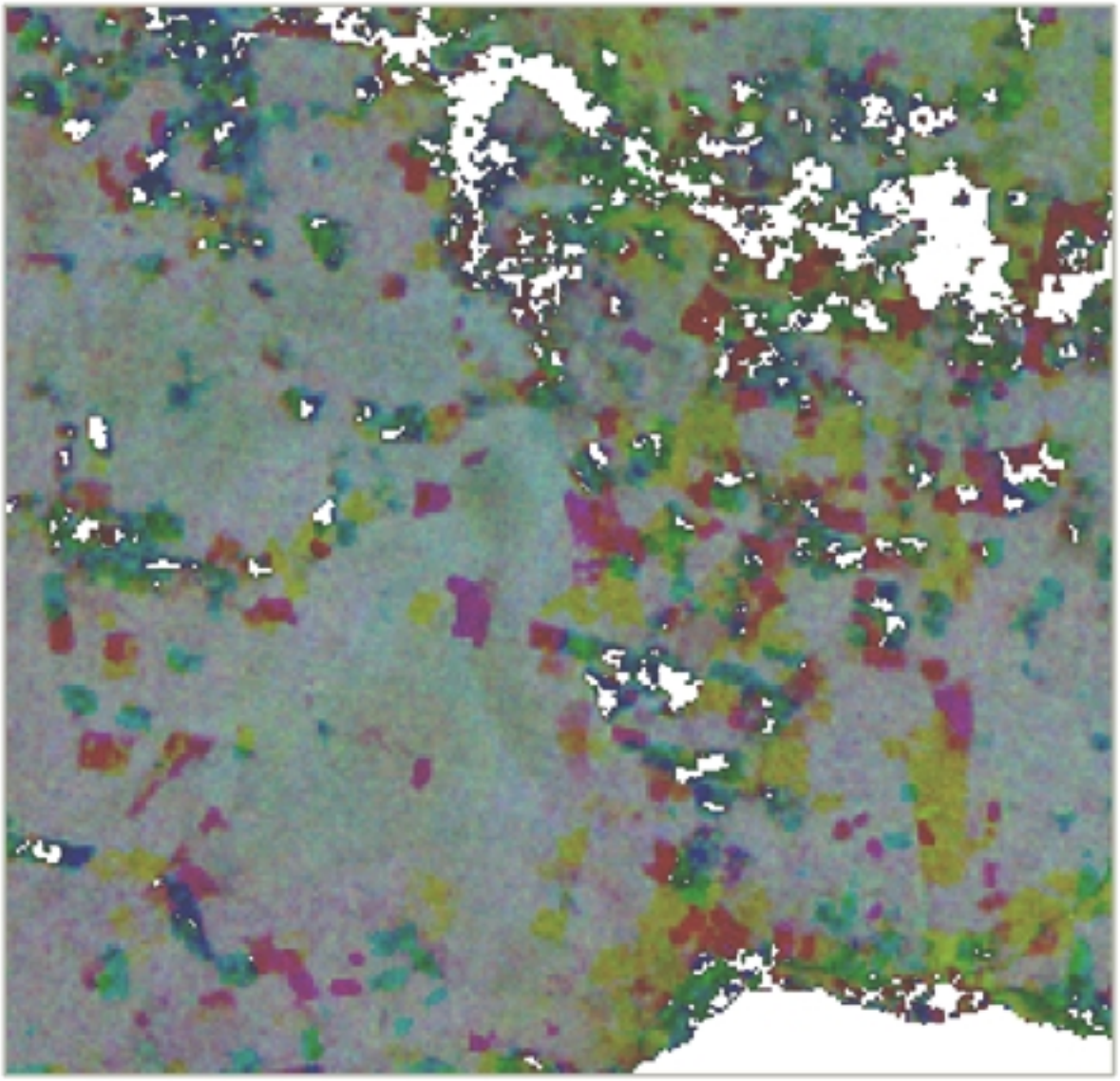

1997 True Color Photo Mosaic
C
A
D
B
E

Image Processing / Change Detection Methods

- ***3-date RGB-NDVI (Sader and Winne 1992)***
  - ***calculate NDVI for each date and stack them into a 3 layer image with the following color scheme:***

    1993 - RED 1995 - GREEN 1997 - BLUE
  - ***run unsupervised clustering on the 3 layer image (preserve color scheme in output clusters)***
  - ***interpret clusters based on signature statistics, color additive theory, TM RGB color composites, and comparison with visually interpreted sample points***
  - ***recode into 3-date time series change detection image***

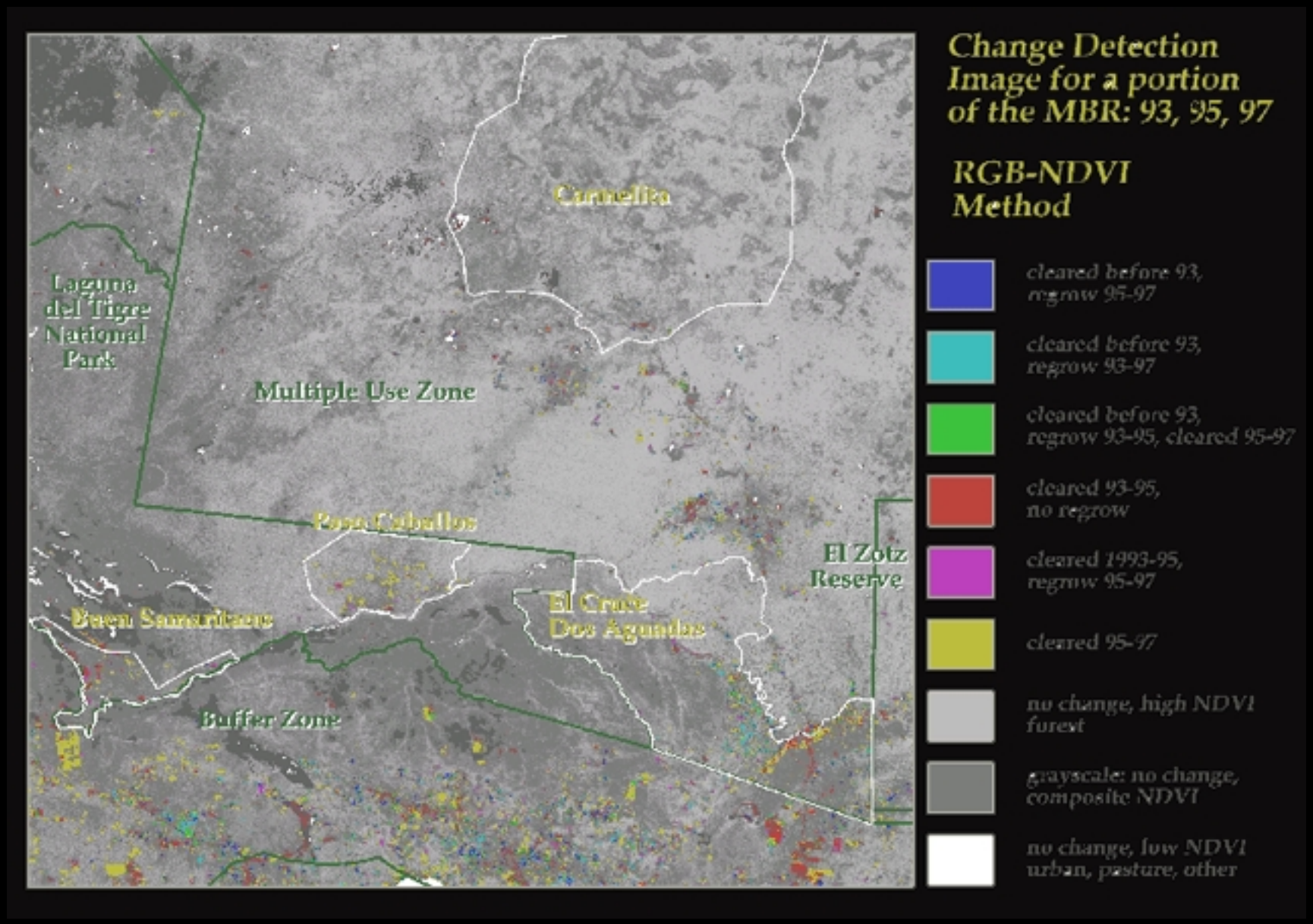


3-Date RGB-NDVI Image Interpretation

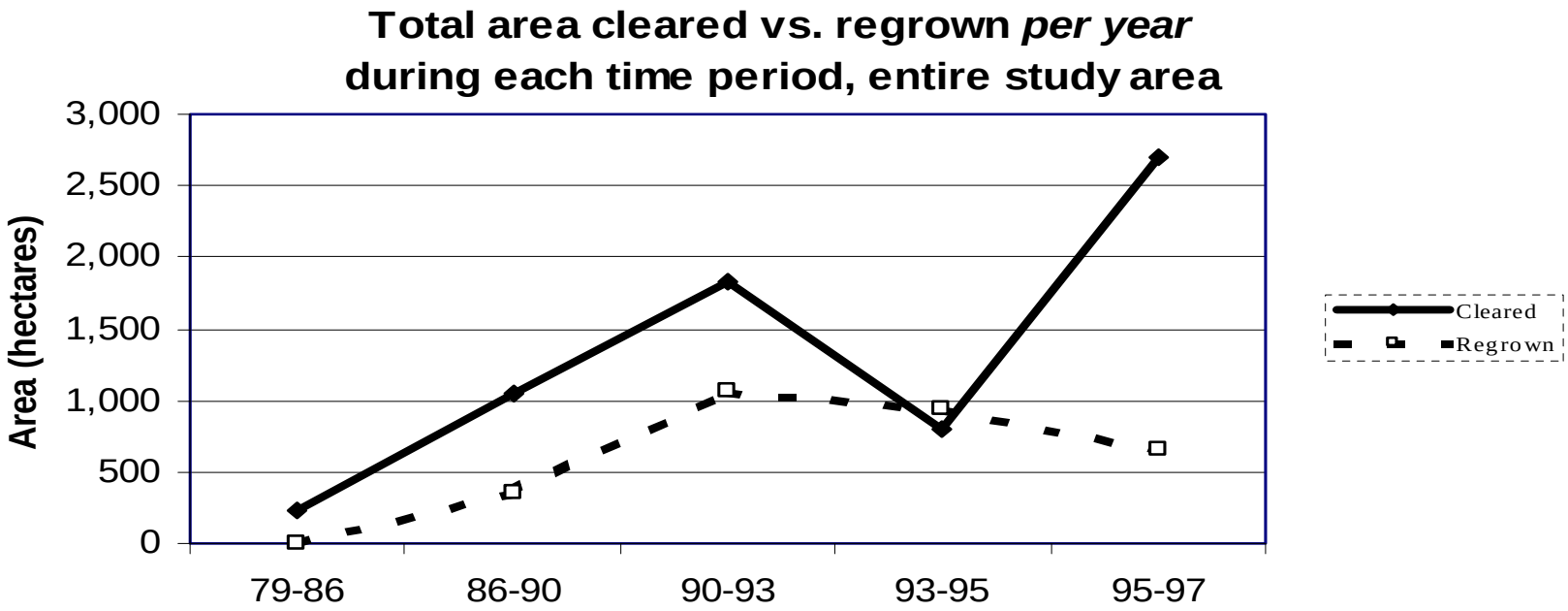
- cleared before 93, regrow 95-97
- cleared before 93, regrow 93-97
- cleared before 93, regrow 93-95, cleared 95-97
- cleared 93-95, no regrow
- cleared 1993-95, regrow 95-97
- cleared 95-97
- no change, high NDVI (forest)
- no change, low NDVI urban, pasture, other

Image Processing / Change Detection Methods

- ***Accuracy Assessment***
  - ***visually interpret a new set of reference points***
  - ***create error matrices for the results of each method against the reference points***
  - ***calculate user's and producer's accuracy, overall accuracy, and KAPPA statistic (Congalton and Green 1999) for each error matrix***
  - ***compare the independent error matrices with a Z-test***


Change Detection Image for a portion of the MBR: 93, 95, 97
RGB-NDVI Method
cleared before 93, regrow 95-97
cleared before 93, regrow 93-97
cleared before 93, regrow 93-95, cleared 95-97
cleared 93-95, no regrow
cleared 1993-95, regrow 95-97
cleared 95-97
no change, high NDVI forest
grayscale: no change, composite NDVI
no change, low NDVI urban, pasture, other
Carmelita
Laguna del Tigre National Park
Multiple Use Zone
Paso Caballos
El Zotz Reserve
Buen Samaritano
El Cruce Dos Aguadas
Buffer Zone

Analysis and Early Results



Total area cleared vs. regrown during each time period, study area

	79-86	86-90	90-93	93-95	95-97	Total
Cleared	1,631.46	4,198.26	5,484.95	1,611.31	5,385.46	18,306.44
Regrown	------	1,418.80	3,188.35	1,880.82	1,297.72	7,785.69

Average patch size cleared vs. regrown during each time period, study area

	79-86	86-90	90-93	93-95	95-97	Avg
Cleared	5.10	5.61	5.29	3.43	4.71	4.83
Regrown	------	3.06	3.92	3.03	2.61	3.16

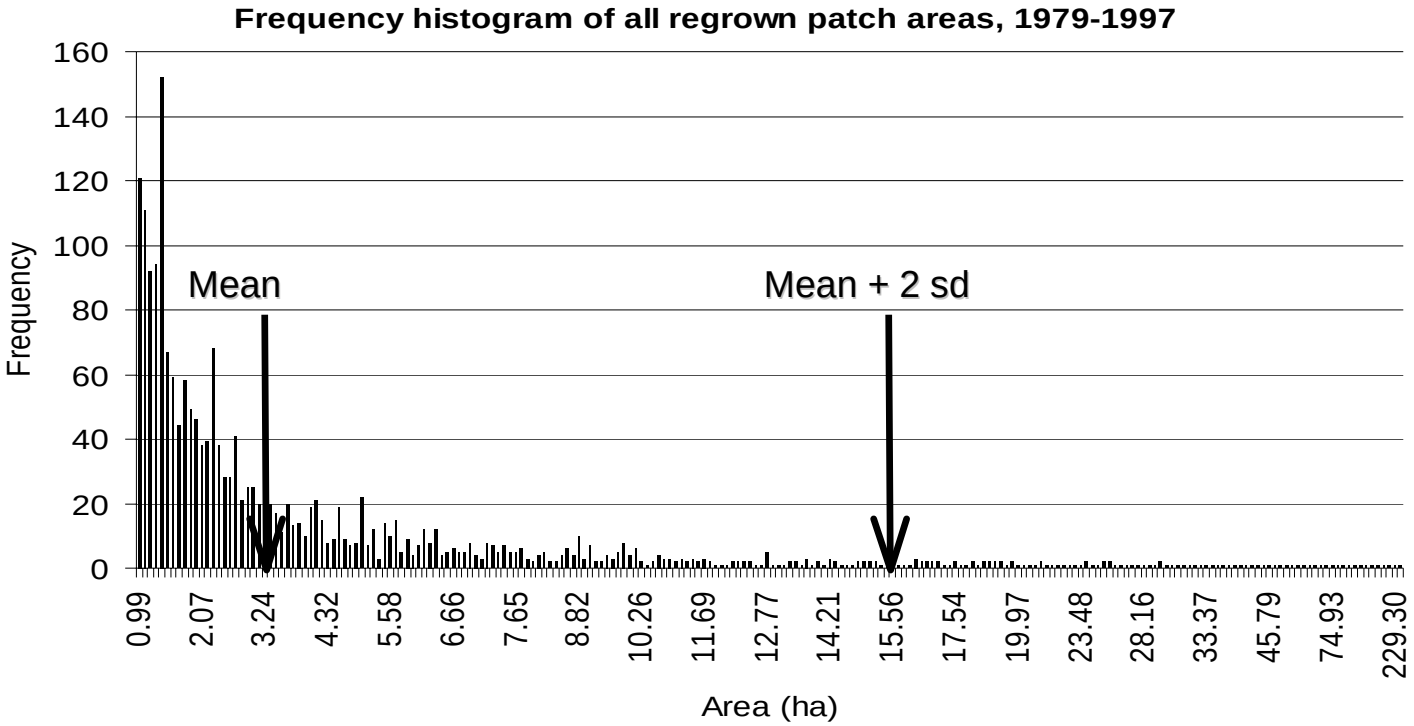
Land Cover / Land Use History Database

Percent of area cleared from fallow for each time period

Unit	90-93	93-95	95-97
Buen Samaritano	0.00	0.00	0.25
Carmelita	0.00	45.00	22.37
Cruce Dos Aguadas	0.88	18.79	12.49
Paso Caballos	0.00	0.00	0.00
Other: Buffer Zone	0.24	14.87	6.62
Other: Muli-use	0.68	27.34	8.57
Other: National Park	0.00	0.00	0.00
Other: Biotope	0.00	13.62	12.19
Entire Study Area	**0.07**	**15.66**	**6.93**

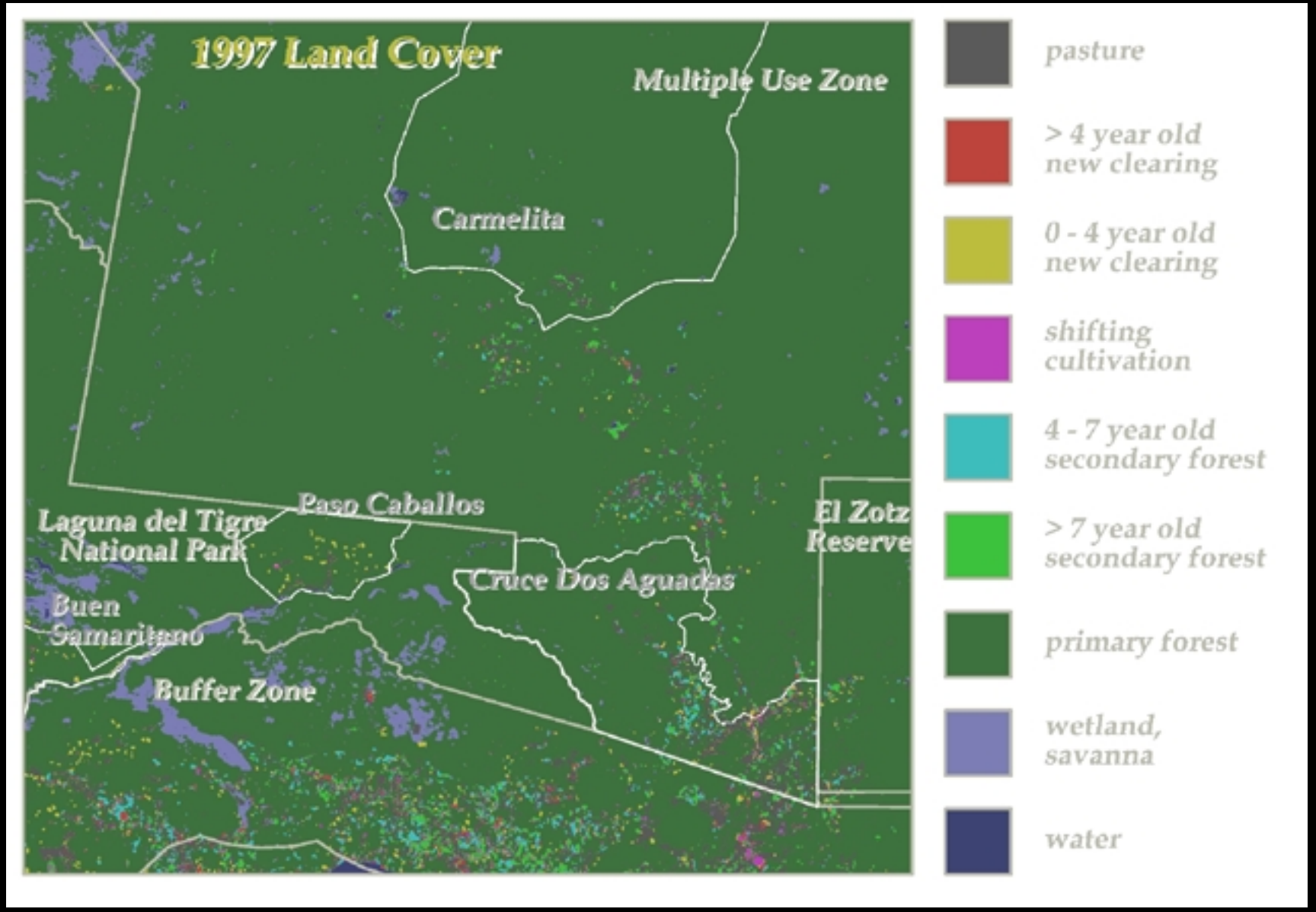
Area regrown to area cleared ratio during each time period

Unit	86-90	90-93	93-95	95-97	Avg.
Buen Samaritano	0.07	0.00	0.04	0.67	0.15
Carmelita	4.82	3.06	0.46	0.31	1.16
Cruce Dos Aguadas	0.85	0.67	1.35	0.16	0.54
Paso Caballos	3.08	0.00	0.00	0.10	0.09
Other: Buffer Zone	0.20	0.51	1.27	0.25	0.38
Other: Muli-use	0.76	1.00	1.24	0.27	0.59
Other: National Park	5.33	0.53	0.00	0.12	0.19
Other: Biotope	0.98	1.58	0.81	0.43	0.88
Entire Study Area	**0.34**	**0.58**	**1.17**	**0.24**	**0.43**



Cleared patches not regrown and >15 ha in size

Unit	Count	Total Area	Mean Size
Buen Samaritano	4	112.90	28.23
Carmelita	1	33.19	33.19
Cruce Dos Aguadas	10	386.19	36.82
Paso Caballos	5	108.49	21.70
Other: Buffer Zone	82	3,685.90	44.95
Other: Muli-use	8	210.41	26.30
Other: National Park	2	36.16	18.08
Other: Biotope	0	0.00	0.00
Entire Study Area	**112**	**4,555.24**	**40.67**


1997 Land Cover
Multiple Use Zone
Carmelita
Paso Caballos
Laguna del Tigre
National Park
El Zotz
Reserve
Cruce Dos Aguadas
Buen
Samaritano
Buffer Zone
pasture
> 4 year old
new clearing
0 - 4 year old
new clearing
shifting
cultivation
4 - 7 year old
secondary forest
> 7 year old
secondary forest
primary forest
wetland,
savanna
water

Discussion / Future Research

- ***Change Detection Methodology***
  - ***3-date RGB NDVI method preferred for its high accuracy, ability to process three dates at a time, ease in interpretation, and utility for future monitoring and technology transfer***
- ***Land Use / Land Cover History Database***
  - ***facilitates description of land cover change pathways, spatial analysis of forest clearing and regrowth, and development and testing of hypotheses related to socio-economic factors***

Discussion / Future Research

- ***Socio-economic drivers of LCLUC***
  - ***develop and test hypothesis related to the socio-economic factors that result in the spatial patterns of land use change observed in the satellite imagery and LCLUC database***
  - ***develop spatially explicit models to explain the trends in land cover conversion using socio-economic data, and use those models to predict LCLUC behavior in the region under different possible and relevant scenarios***

Literature Cited

Cohen, W.B., M. Fiorella, G. Gray, E. Helmer and K. Anderson. 1998. An efficient and accurate method for mapping forest clearcuts in the Pacific Northwest using Landsat imagery. *PE & RS*, 64:293-300.

Congalton, R.G. and K. Green. 1999. *Assessing the Accuracy of Remotely Sensed Data: Principles and Practices*. Boca Raton: CRC Press.

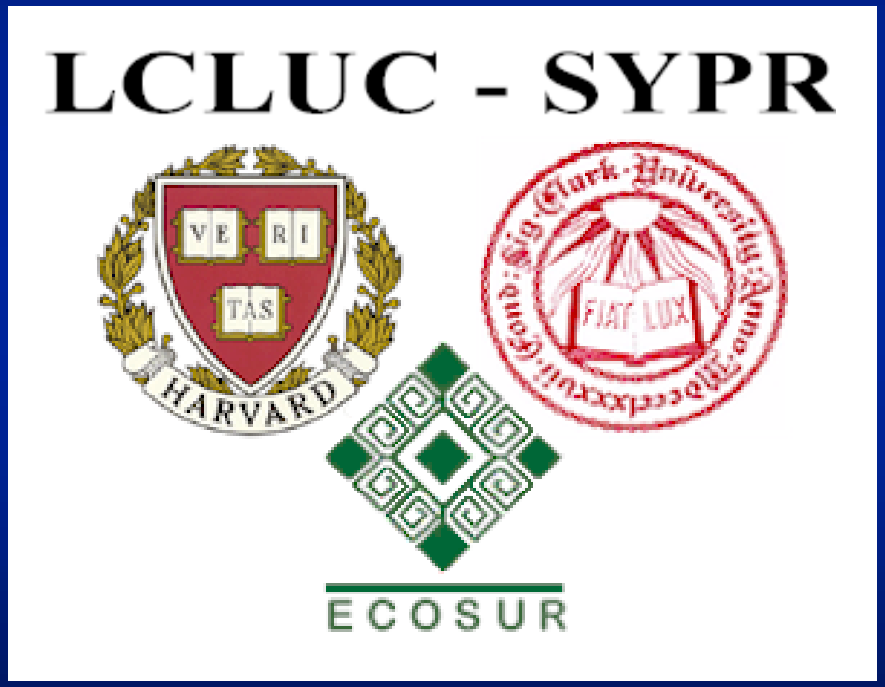
Eckhardt, D.W., J.P. Verdin, and G.R. Lyford. 1990. Automated update of an irrigated lands GIS using SPOT HRV imagery. *PE & RS*, 56:1515-1522.

Fung, T. and E. LeDrew. 1987. Application of principal components analysis to change detection. *PE & RS*, 53:1649-1658.

Fung, T. and E. LeDrew. 1988. The determination of optimal threshold levels for change detection using various accuracy indices. *PE & RS*, 54:1449-1454.

Sader, S.A. and J.C. Winne. 1992. RGB-NDVI colour composites for visualizing forest change dynamics. *Int. J. of Remote Sensing*, 13:3055-3067.

Land-Cover Land-Use Change
in the
Southern Yucatán Peninsular Region



Major Participants

- George Perkins Marsh Institute & Graduate School of Geography - Clark University
- Harvard Forest - Harvard University
- El Colegio de la Fronter Sur (ECOSUR)

[with cooperation of CIS-CMU]

For a list of individual researchers and their contributions to the project see the SYPR web page (earth.clarku.edu/lcluc)

Funding Sources

Overall Project

- NASA - LCLUC Program
- Higgins Professorship, Clark University
- ECOSUR

Ecological Research

- Harvard Forest
- Conservation Research Foundation
- National Science Foundation

Modeling Research

- Center for Integrated Studies, Carnegie Mellon University
- NASA Young Investigator Fellowship

Specific Dissertation Research

- Fulbright Fellowship (Garcia Robles)

Problem Overview

LCLUC-SYPR seeks

- to understand land changes in the region by bridging understanding gained from historical-empirical narratives, behavioral, structural, and ecological theory, and remote sensing and GIS analysis and
- to develop theory-based and empirical diagnostic models capable of explaining and projecting use and cover changes, and
- to advance models for integrative assessment relevant for policy analysis.

Specific Goals and Components of LCLUC-SYPR

Understand the dynamics of land-use/cover changes in SYPR, especially deforestation and agriculture since the 1960s

- History of land-use and land-cover changes
- Recent political economy
- Socio-economic inventory & econometric analysis
- Structure & function of forest types
- Successional dynamics from land-use
- Advanced classification from TM imagery
- Link socio-economic & ecological understanding to TM imagery

Specific Goals of LCLUC-SYPR

Develop and test the applicability of three types of spatially explicit models that explain and project land-use/cover changes, especially forests and agriculture

- Theory-based models built from the household survey to the remotely sensed imagery (pixelizing the social = Focus 1 research)
- Empirical diagnostic models built from the remotely sensed imagery but incorporating biophysical and social information (socializing the pixel = Focus 2 research)
- Integrative assessment models used to project land-use/cover changes under different scenarios (Focus 4 research)

Status of Components of the LCLUC-SYPR
[summer 1999]

- History & political economy: data collection [85%], interpretation begun
- Socio-economic inventory & econometric analysis: inventory [95%], data transformation [75%], analysis begins Summer 1999
- Structure-function forest: first yr. field study completed
- Successional dynamics from land uses: field study has begun
- Image classification & GIS data: class. [90%], GIS [50%]
- Theory-based modelling [econometric]: begin Fall 1999
- Empirical-based modelling [remote sensing]: begin Fall 1999
- Integrative modelling [projection-policy]: framework completed, construction begins Fall 1999

Focus 1: Historical Narrative and Household Surveys

leading to econometric analysis and theory-based models

The following slides illustrate [1] the kind of evidence being used to construct the history of land change in SYPR and the drivers and responses to this change. This information is used to inform the survey data and resulting analyses. The slides then illustrate [2] the kinds of questions explored in order to frame an econometric model of contemporary land change, and some of the initial results from the survey. Surveys of 210 households were undertaken in 10 ejidos throughout the SYPR.

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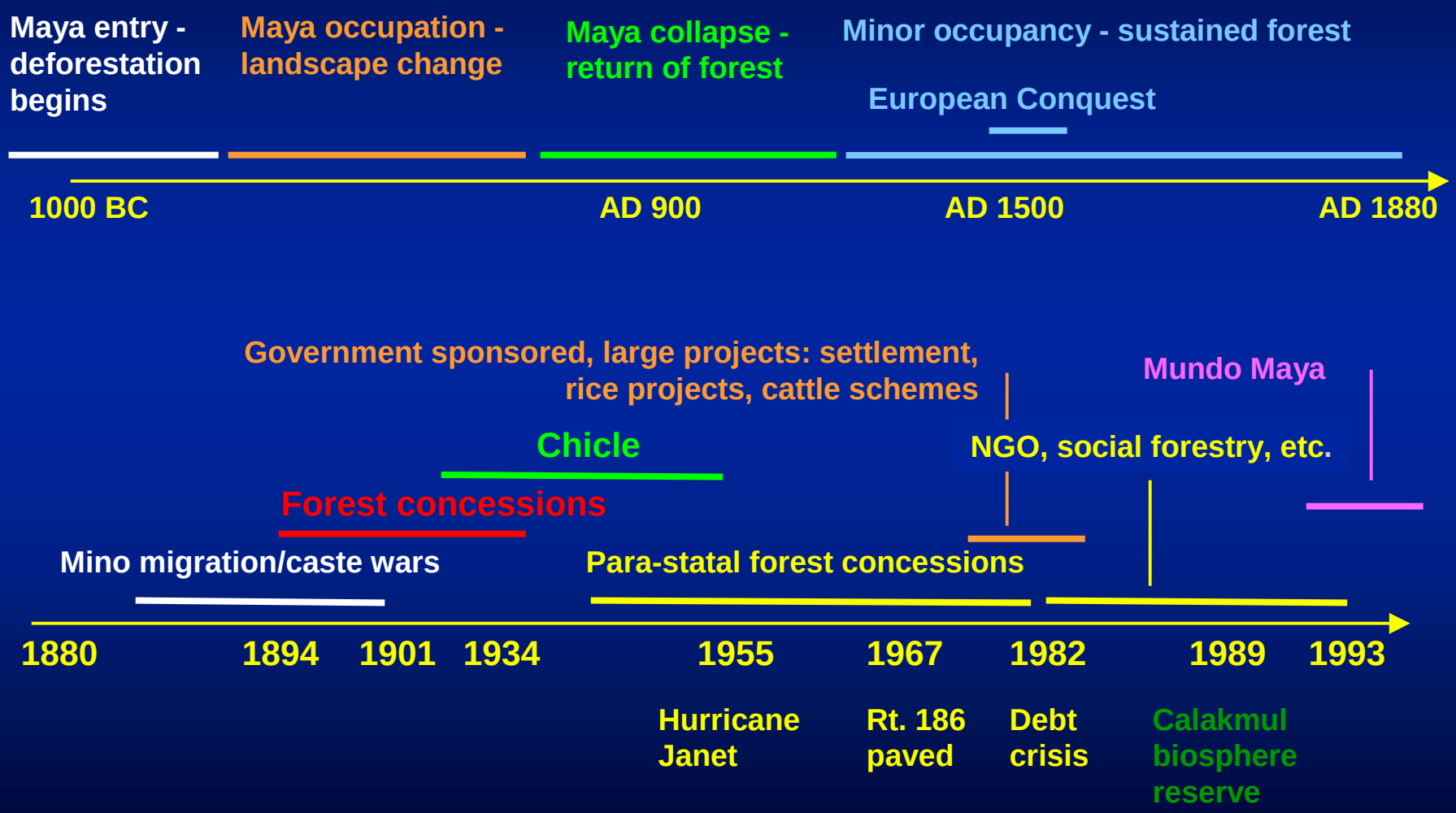
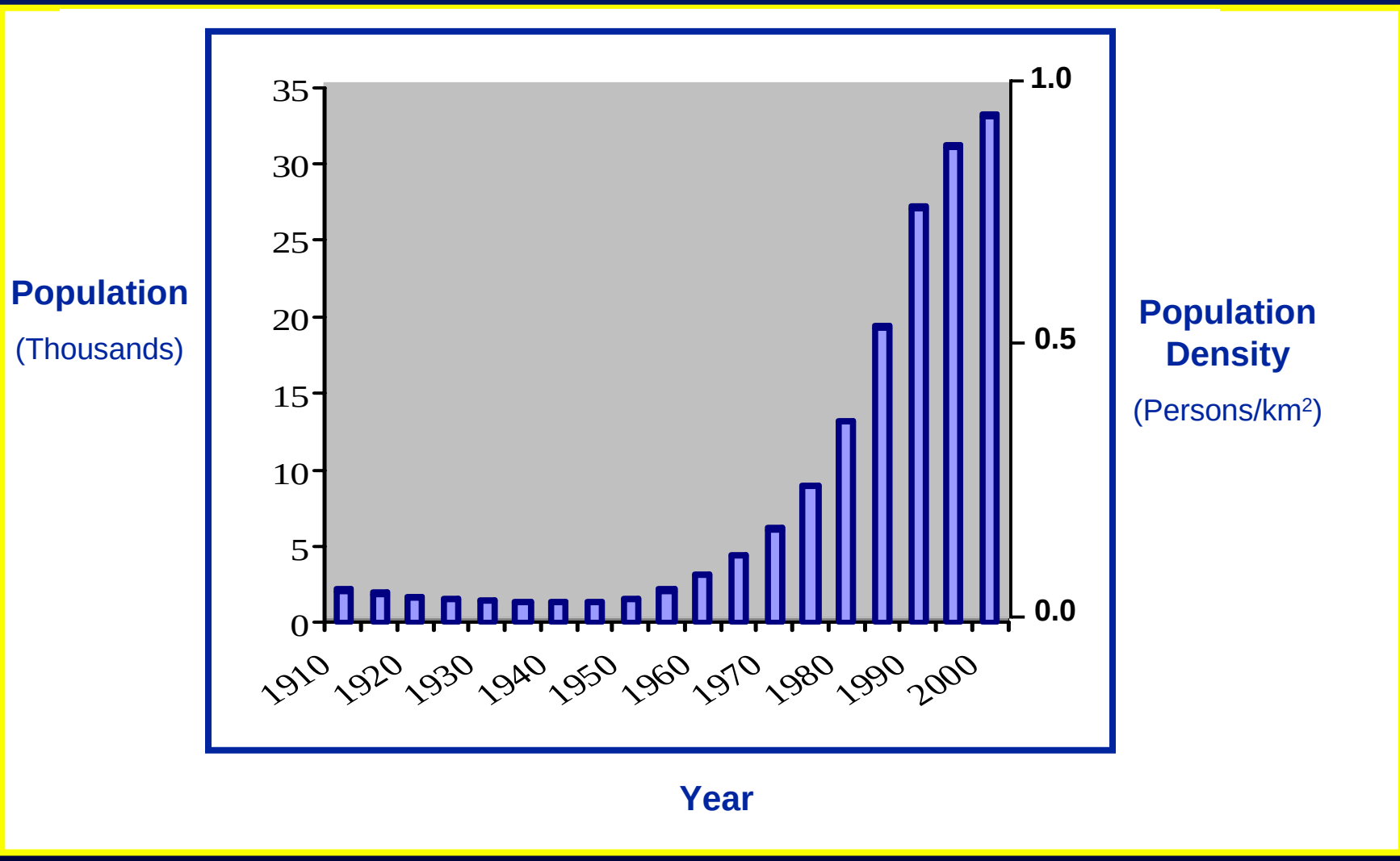
Human Impacts in SYPR*
(1000 BC - Present)



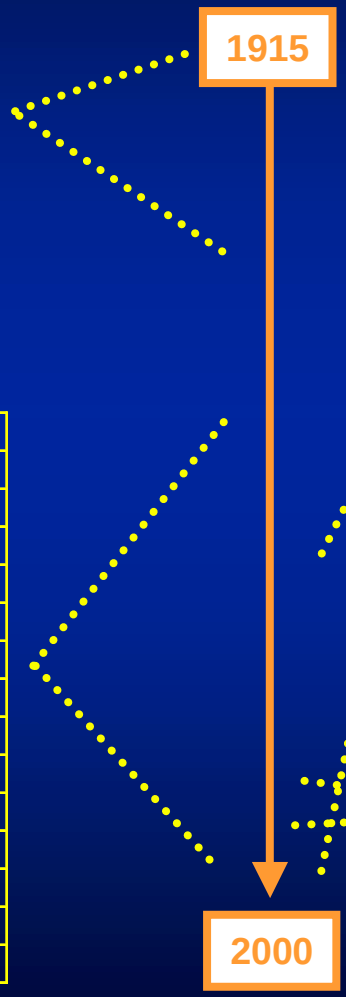
Initial findings suggest that large structural and policy changes link strongly to major shifts in rates of deforestation

Example Historical Data
SYPR Population (1910 - 2000)*



Ancient Maya population densities in SYPR previous of A.D. 900 was well over 100/km^2.
From that time until recently, the density was extremely low.

Example Historical Data
SYPR in Transition*



Laguna Corporation controls 760,460 ha in Campeche 1915-1935

Logging in Quintana Roo

Ejido	Year	Caoba (M^3)
Nicolas	1948	1200
Bravo	1967	400
	1991	300
	1992	300
	1993	300
	1994	400
	1995	400
	1996	400
	1997	400
Caobas	1958	830
	1962	812
	1963	829
	1964	830
	1967	830

Forest clearing for agriculture

Ejido	Year	Hectares	Use
Nicolas	1976-1979	2500 cleared	Rice
Bravo	1980	2500	Rice
	1997	1500	Cattle
	1997	700	Rice
Tomas	1973-1980	2000 cleared	Cattle
Garrido	1997	1600	Re-growth
	1997	400	Milpa

Eco-archeological tourism in the Calakmul zone

Year	Visitors
1993	3500
1994	4810
1995	11045

Spatially Explicit Land Models: Econometric Approach

Previous spatially-explicit econometric models

- **Aggregate socioeconomic data**
- **Profit maximizing behavior**

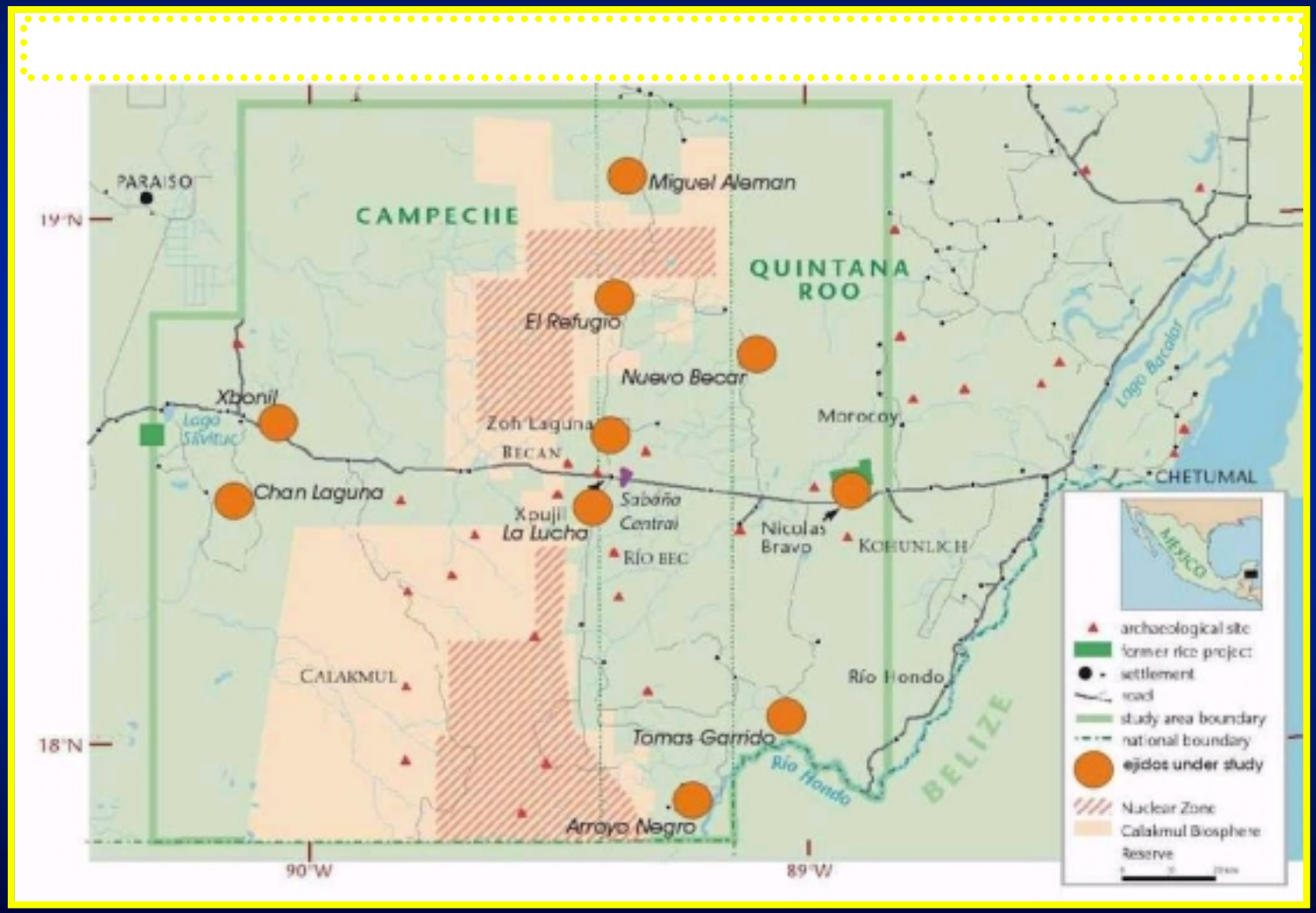
LCLUC-SYPR Project

- **Individual land manager linked to the pixel**
- **Test hypotheses concerning behavior linked to structural and infrasrtuctural changes**

Specific hypotheses will be selected once initial associations are identified but will include the role of transportation, land tenure, and subsistence-market changes.

SYPR Study Site and Ejidos Surveyed

[N households = 210]



LCLUC-SYPR: Example Question Guiding Theory Construction and Household Surveys

To what extent is the expansion of agriculture (i.e., forest to open land) propelled by:

[1] On-site demands for subsistence crops

or

[2] External markets for commercial crops?

Predominant Land Uses in SYPR: Tentative Survey Results*

Land Use	% sample	Mean plot size (ha)	S.D. plot size (ha)	Median plot size (ha)
Maize	100	4.65	4.34	4
Chili	52	1.34	1.36	1
Pasture [used]	28	25.9	28.9	15
Pasture [unused]	23	12.9	20.8	5.75

Indicators of Economic Links to Subsistence & Market Production*

Selling maize	41
Purchasing maize	27
Self sufficient in maize	31

% of households

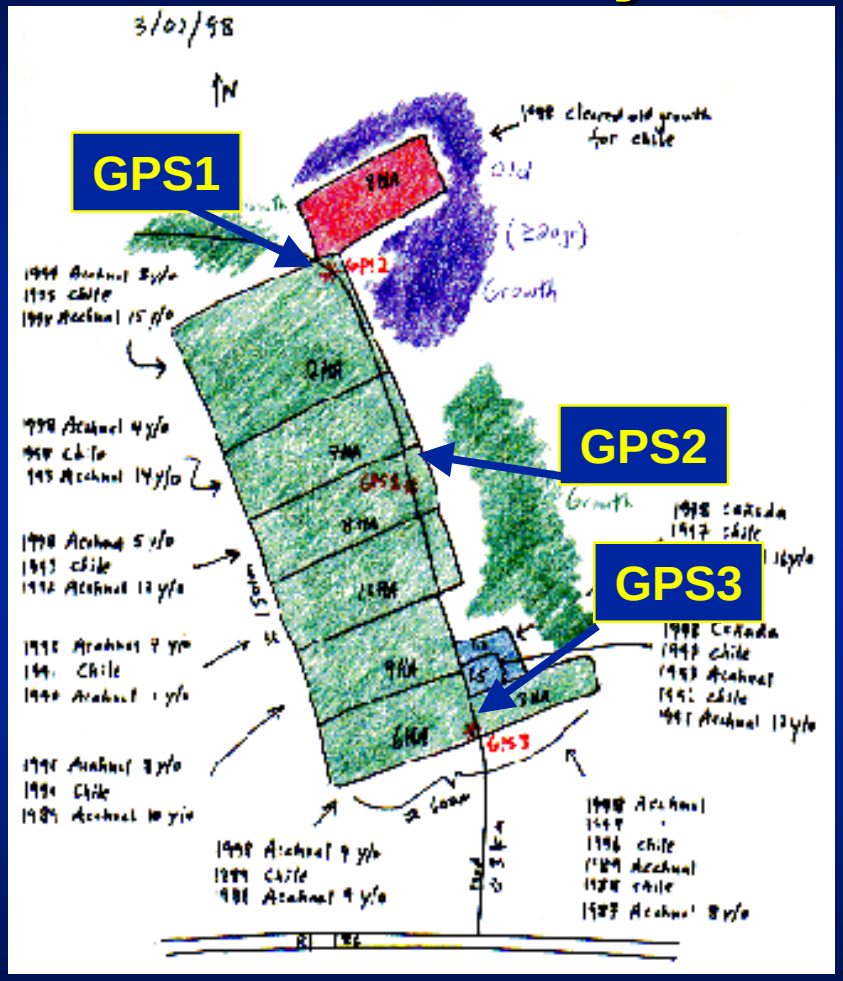
	Sell chili	No sell chili
Sell maize	27	15
No sell maize	24	34

	Sell labor	No sell labor
Hire labor	57	14
No hire labor	23	6

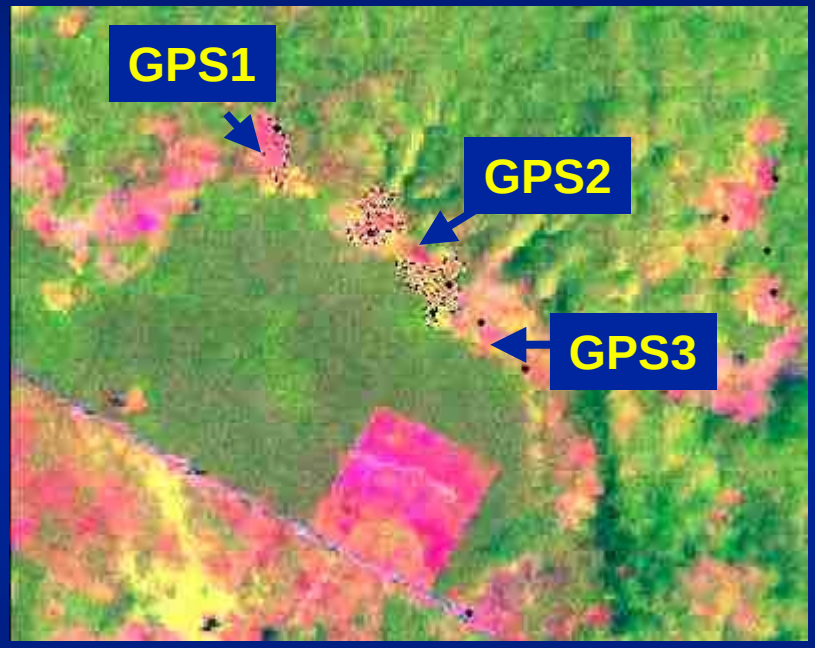
Initial Results via Regressions: Maize Production*

Ha-maize	Coef.	Std. Err.	t	p>|t|
All households [n = 180]				
Consumer-labor ratio	.340	.087	3.89	0.00
Total labor	.978	.230	4.24	0.00
Households not selling maize [n = 100]				
Consumer-labor ratio	.471	.096	4.90	0.00
Total labor	.949	.283	3.25	0.00

Signature Development & Sketch-Maps of Surveyed Household Fields*



Land Use History (>20 yrs) via sketch-map



Parcels linked to imagery by GPS

Sketch maps and GPS link the actions of the land managers with land-use/cover change. The maps not only aid in classification, they facilitate spatially explicit analysis of change and ultimately permit regional assessment.

Focus 2: Imagery-Based Approaches

leading to empirical diagnostic models

The following slides illustrate the approaches used to address land change from the use of TM imagery analysis, including the development of spatially explicit analysis of this change. [1] The first set of slides demonstrate the ability to push imagery classification to a level detailed required for the kind of analysis in question. [2] The second set demonstrates how the project intend to pursue model development from time series analyses of the changes detailed in the imagery and informed by GIS-based information.

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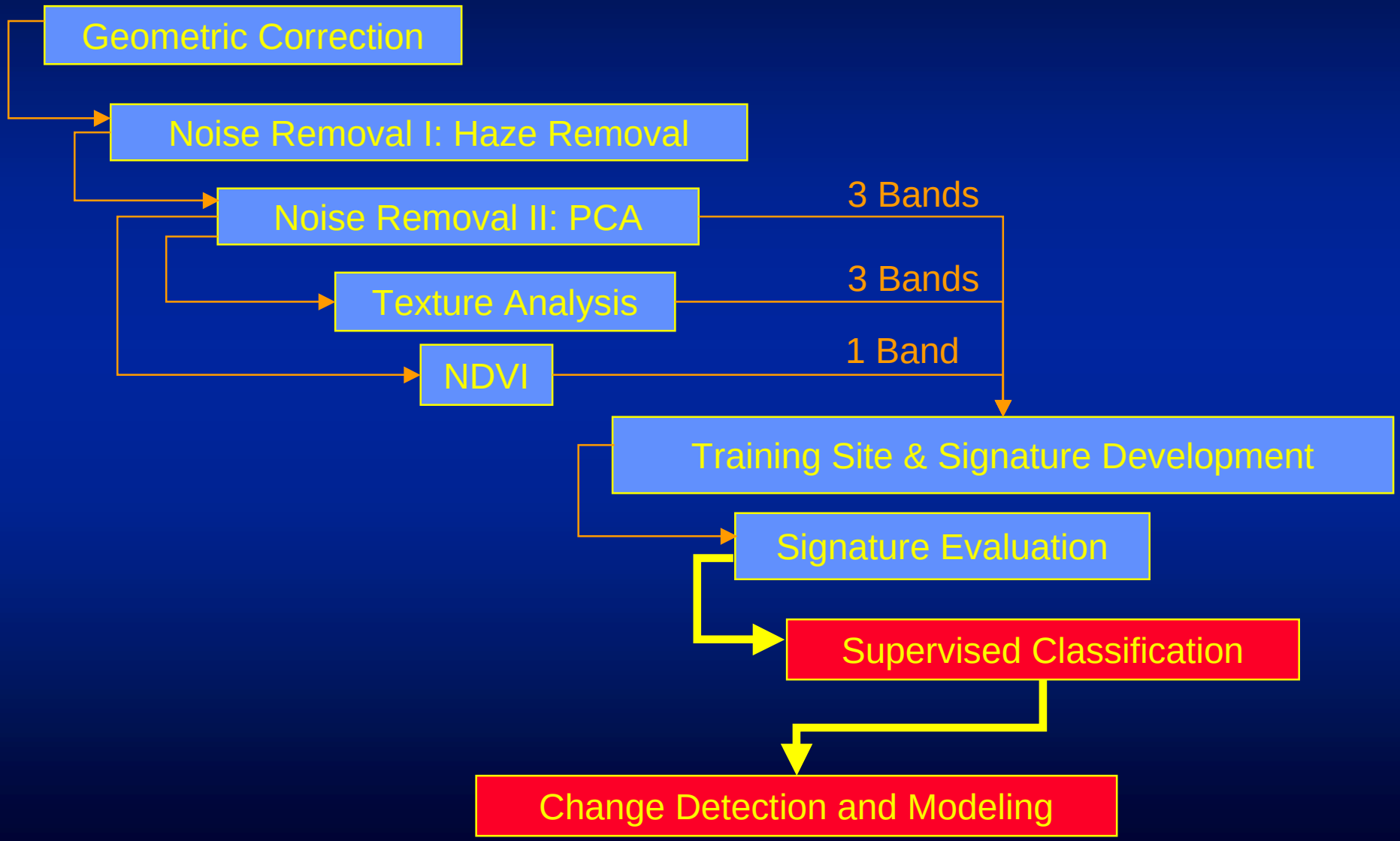
Target Classification Scheme

Clouds
Cloud Shadows
Urban, Roads and Quarries
Water
Savanna
Herbaceous Wetland Vegetation
Seasonally Inundated Lowland Forest
Well-drained Upland Forest
Cropland
Pasture
Successional Forests
- herbaceous
- shrub-dominated
- arboreal

Successional Pteridium (bracken fern)
Successional “Tahonal” (herbaceous species)

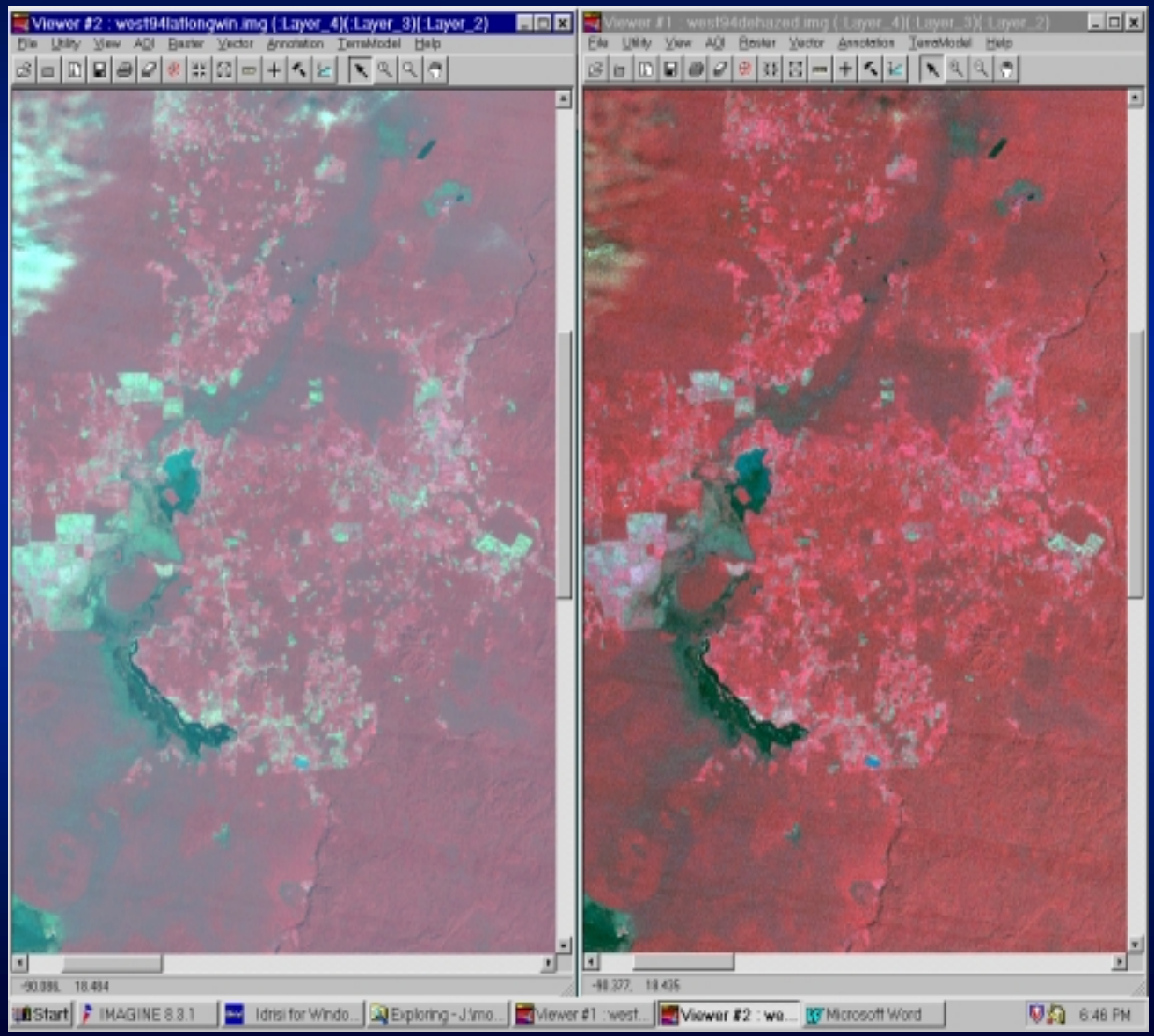
Image Processing Methodology: Overview



Noise Removal of Landsat TM: DEHAZING

ERDAS Imagine Dehazing algorithm, using Tasselled Cap Transformation

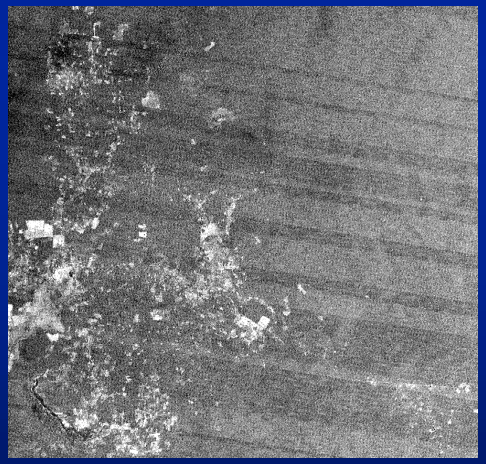
RGB False Color Composite: TM Bands 4,3,2



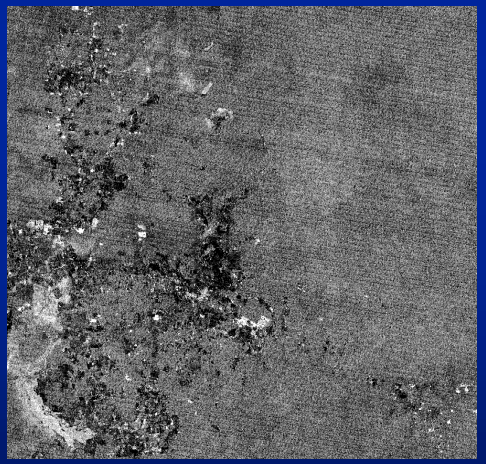
Noise Removal of Landsat TM: Principal Components Analysis

- Perform PCA on 6 of 7 Landsat TM bands (exclude thermal band)
- Results: striping and other noise eliminated, data redundancy greatly reduced

PC1, Visual bands



PC2, Visual bands



PC3, Visual bands

Incorporating Spatial Context: Texture Analysis*

- Image texture -- distinctive spatial and spectral relationships among neighboring pixels
- Focus on overall pattern of variation in each category, rather than spectral average
- Texture Analysis on PCA results: (1) greatly improved separability of upland and lowland forests, cropland and pasture, transitional edges, (2) allowed the detection and separation of 4 classes of secondary (successional) vegetation

RGB Composite: 3 PCA bands

3x3
variance

RGB Composite: 3 Texture bands

Compilation of PCA, Texture and NDVI Bands

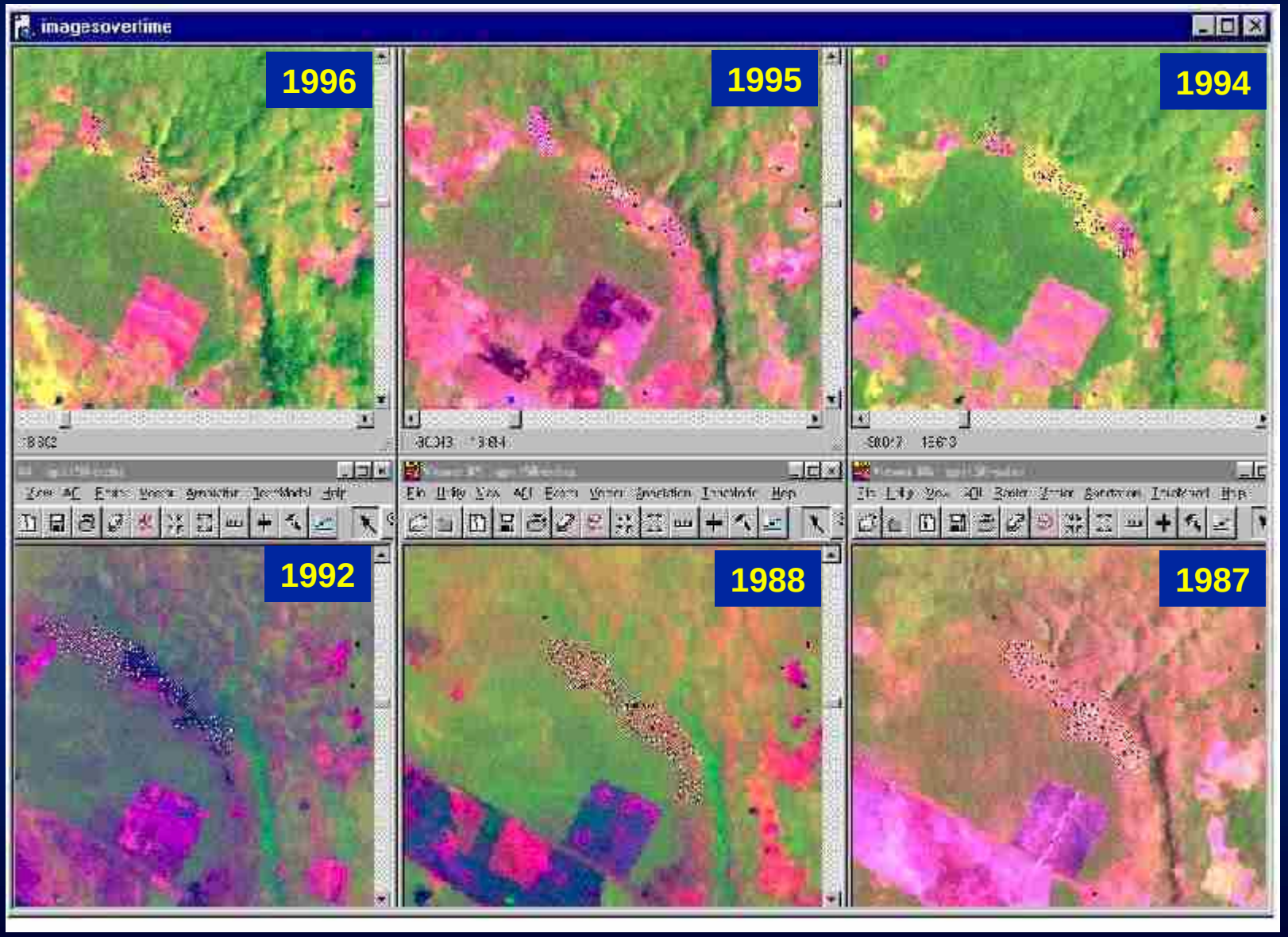
- Normalized Difference Vegetation Index (NDVI) is a measure of relative biomass

  NDVI = (IR-R)/(IR+R)

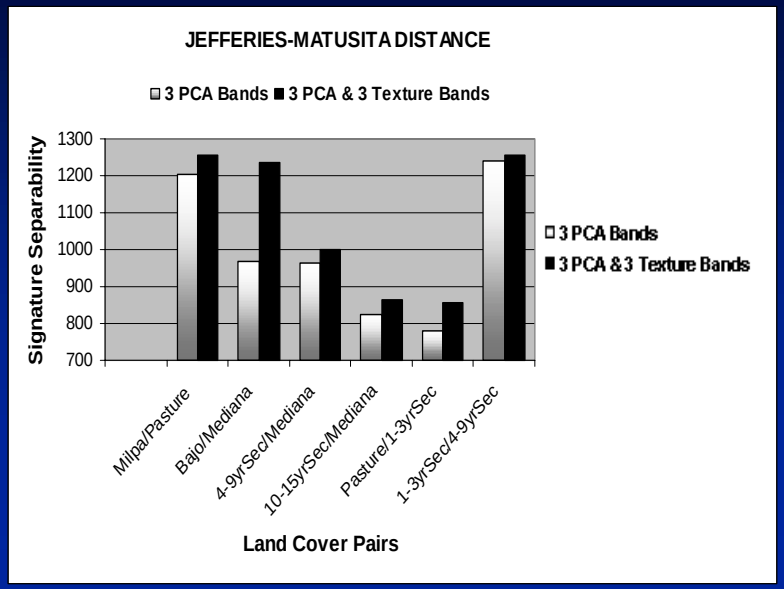
- 3 PCA bands, 3 Texture Bands, 1 NDVI band layer-stacked to produce final 7-band image for signature development and classification

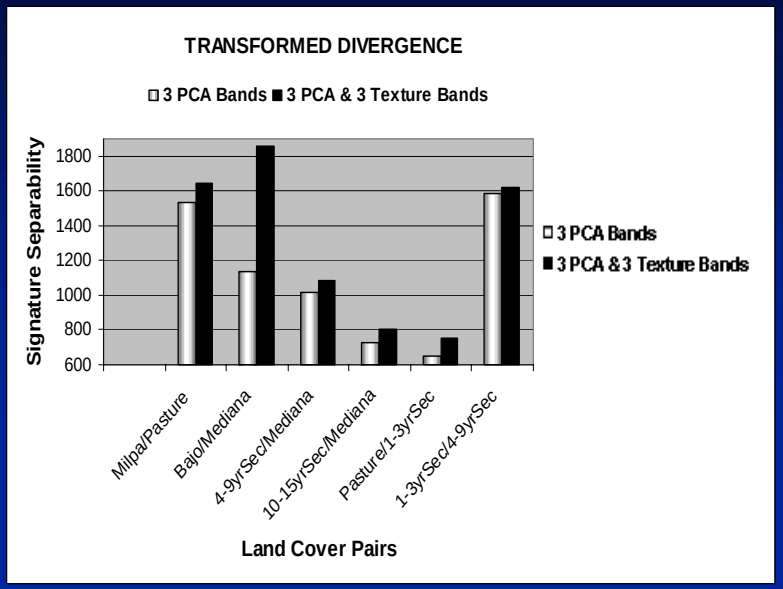
Training Sites for Signatures for Multiple Years

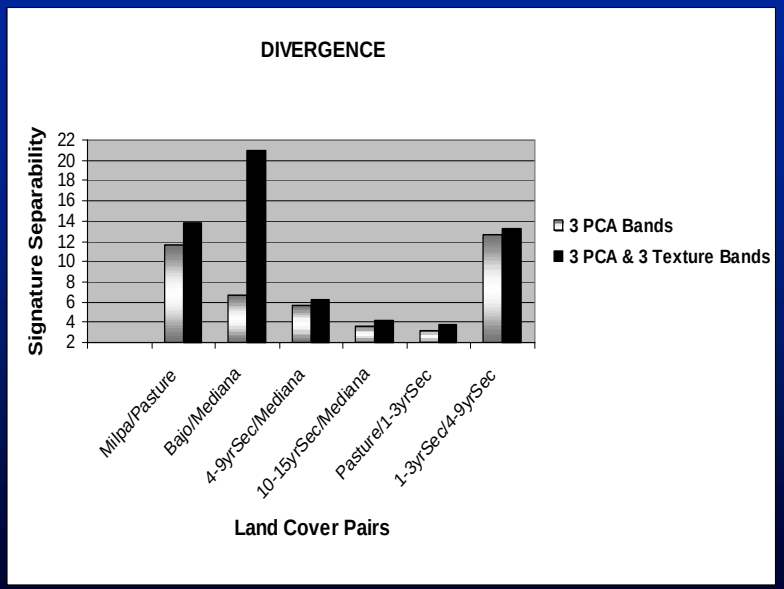
[see sketch map above]

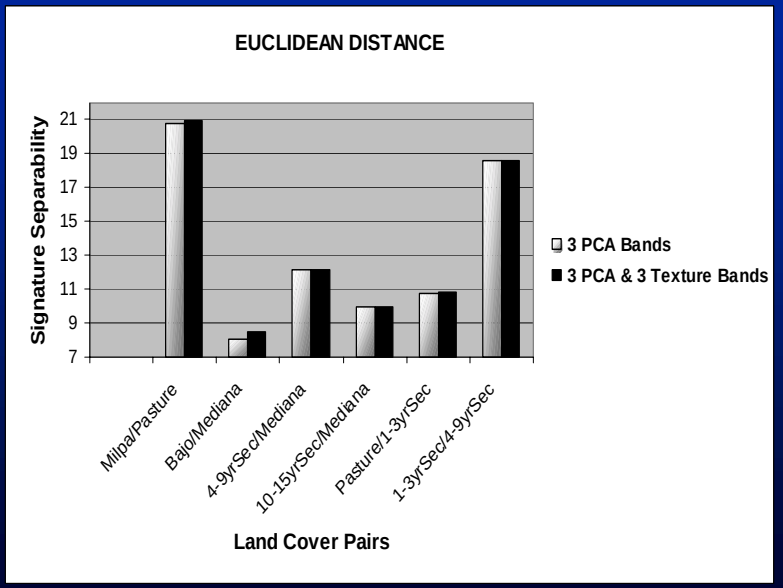


Improvements in Signature Separability using Texture*









Improvements in Classification Contingency using Texture & NDVI*

IMPROVED SIGNATURE SEPARABILITY IN SUCCESSIONAL FORESTS:
Experiments with Texture & NDVI Bands

3 PCA BANDS

		Reference		
		1-3yrs	4-9yrs	>10yrs
1996	Classified			
	1-3yrs	***89.26***	6.10	0.00
	4-9yrs	10.74	***75.82***	10.94
	>10yrs	0.00	18.08	***89.06***

		Reference		
		1-3yrs	4-9yrs	>10yrs
1992	Classified			
	1-3yrs	***66.47***	35.61	0.31
	4-9yrs	30.32	***63.19***	5.52
	>10yrs	3.21	1.20	***94.17***

		Reference		
		1-3yrs	4-9yrs	>10yrs
1988	Classified			
	1-3yrs	***66.37***	9.09	1.80
	4-9yrs	29.18	***80.52***	0.90
	>10yrs	4.45	10.39	***97.30***

3 PCA + 3 TEXTURE BANDS

		Reference		
		1-3yrs	4-9yrs	>10yrs
1996	Classified			
	1-3yrs	***89.42***	5.66	0.15
	4-9yrs	10.58	***83.44***	9.27
	>10yrs	0.00	10.89	***90.58***

		Reference		
		1-3yrs	4-9yrs	>10yrs
1992	Classified			
	1-3yrs	***68.85***	9.30	0.31
	4-9yrs	28.18	***89.06***	4.29
	>10yrs	2.97	1.64	***95.40***

		Reference		
		1-3yrs	4-9yrs	>10yrs
1988	Classified			
	1-3yrs	***70.21***	9.09	1.80
	4-9yrs	26.37	***81.17***	1.80
	>10yrs	3.42	9.74	***96.40***

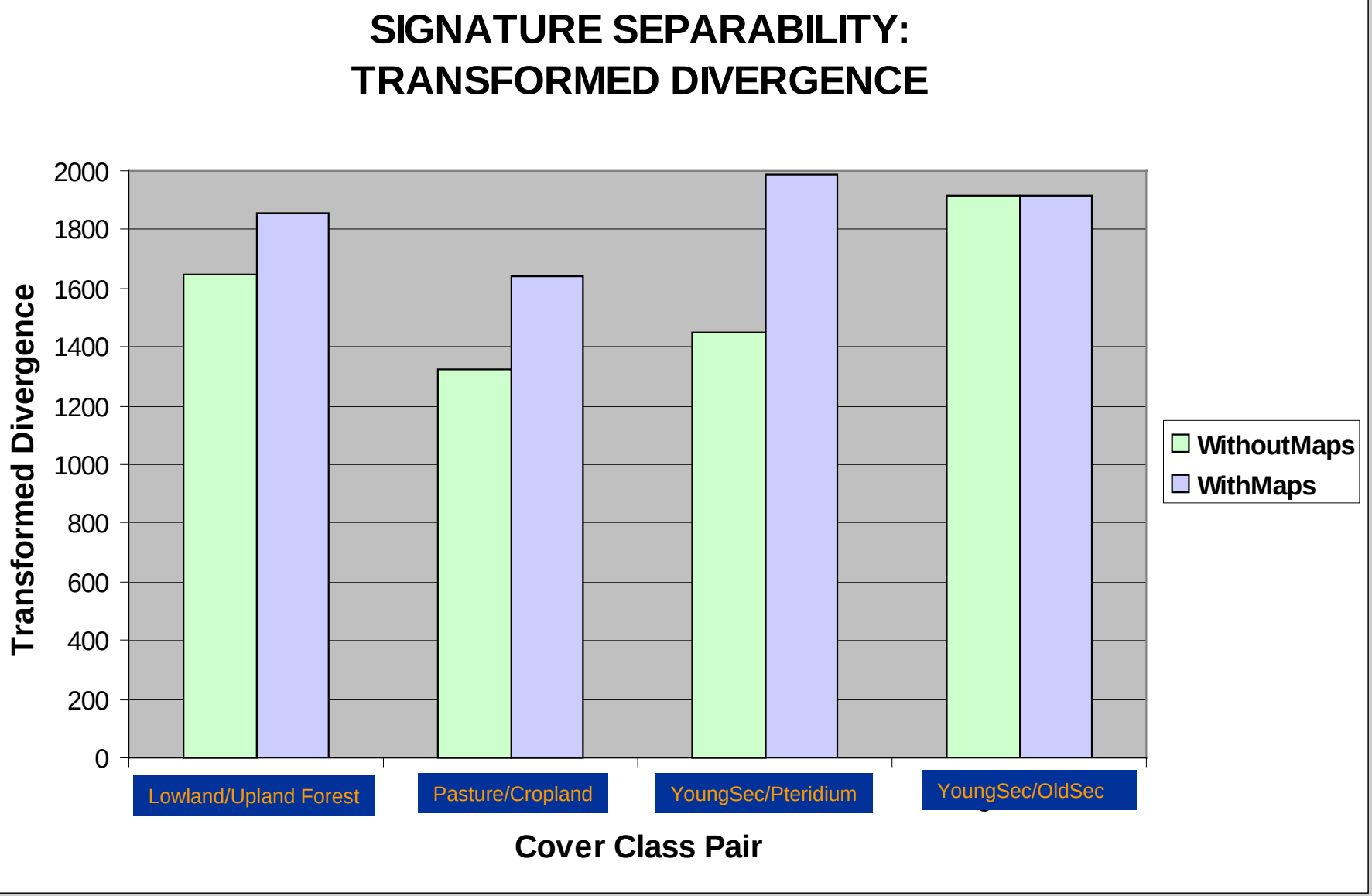
3 PCA + 3 TEXTURE + NDVI

		Reference		
		1-3yrs	4-9yrs	>10yrs
1996	Classified			
	1-3yrs	***90.25***	6.10	0.15
	4-9yrs	9.75	***84.31***	7.29
	>10yrs	0.00	9.59	***92.55***

		Reference		
		1-3yrs	4-9yrs	>10yrs
1992	Classified			
	1-3yrs	***80.62***	10.75	0.92
	4-9yrs	16.05	***85.83***	0.00
	>10yrs	3.33	3.42	***99.08***

		Reference		
		1-3yrs	4-9yrs	>10yrs
1988	Classified			
	1-3yrs	***71.99***	7.14	0.90
	4-9yrs	24.52	***82.47***	3.60
	>10yrs	3.49	10.39	***95.50***

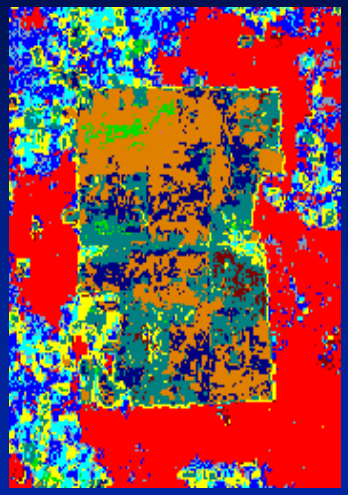
Improvements in Signature Separability Using Sketch-Maps*



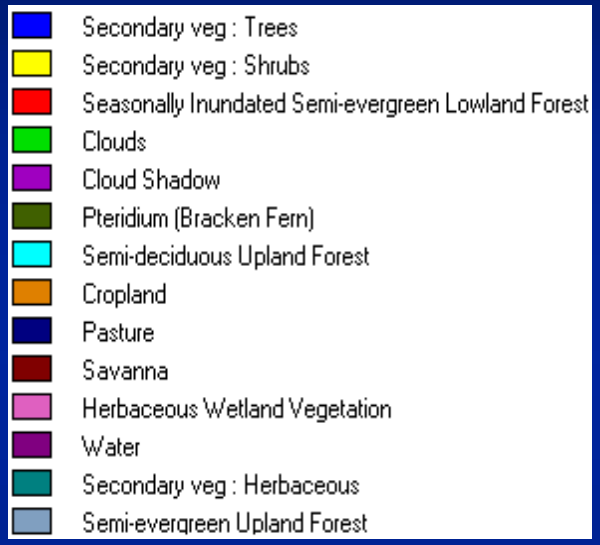
Characterizing Uncertainty: Soft Classifiers*

PCA Composite

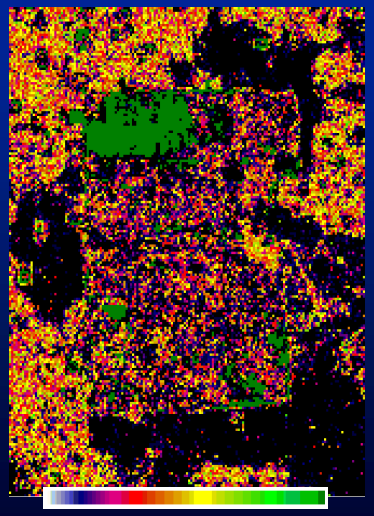
Bayesian Maximum Likelihood Classifier



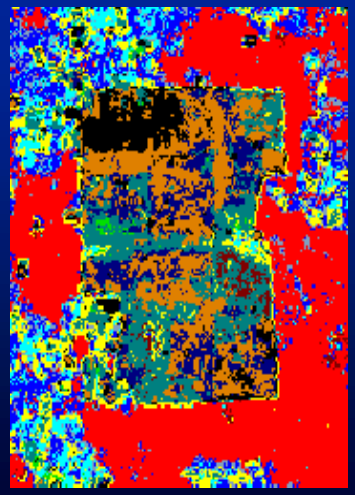
Land-cover Categories



Classification Uncertainty



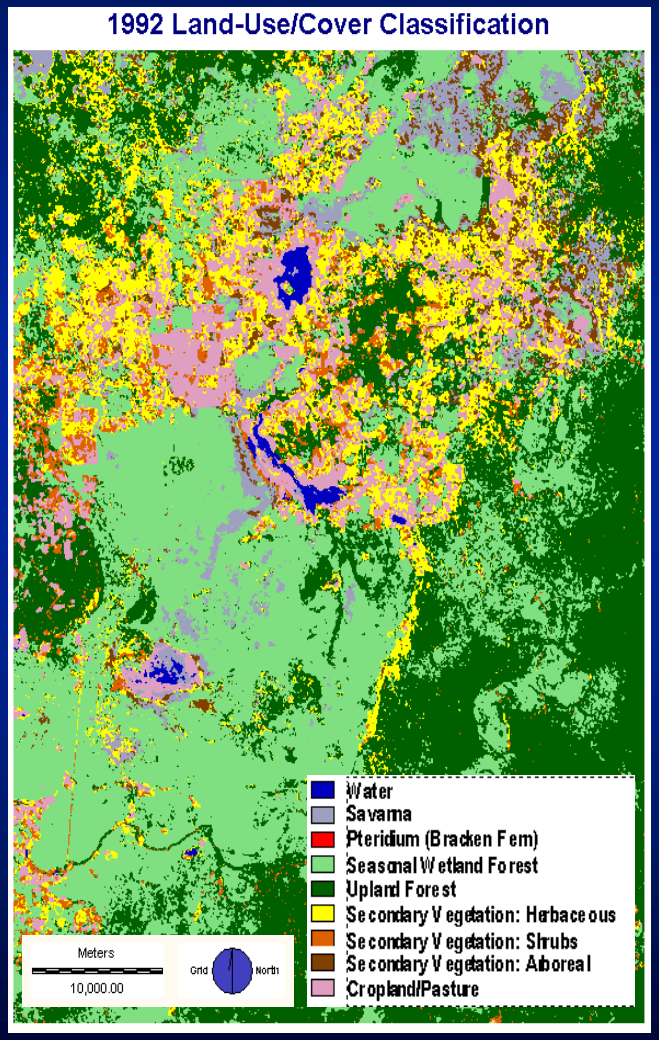
Bayesian Classifier w/ uncertain area unclassified

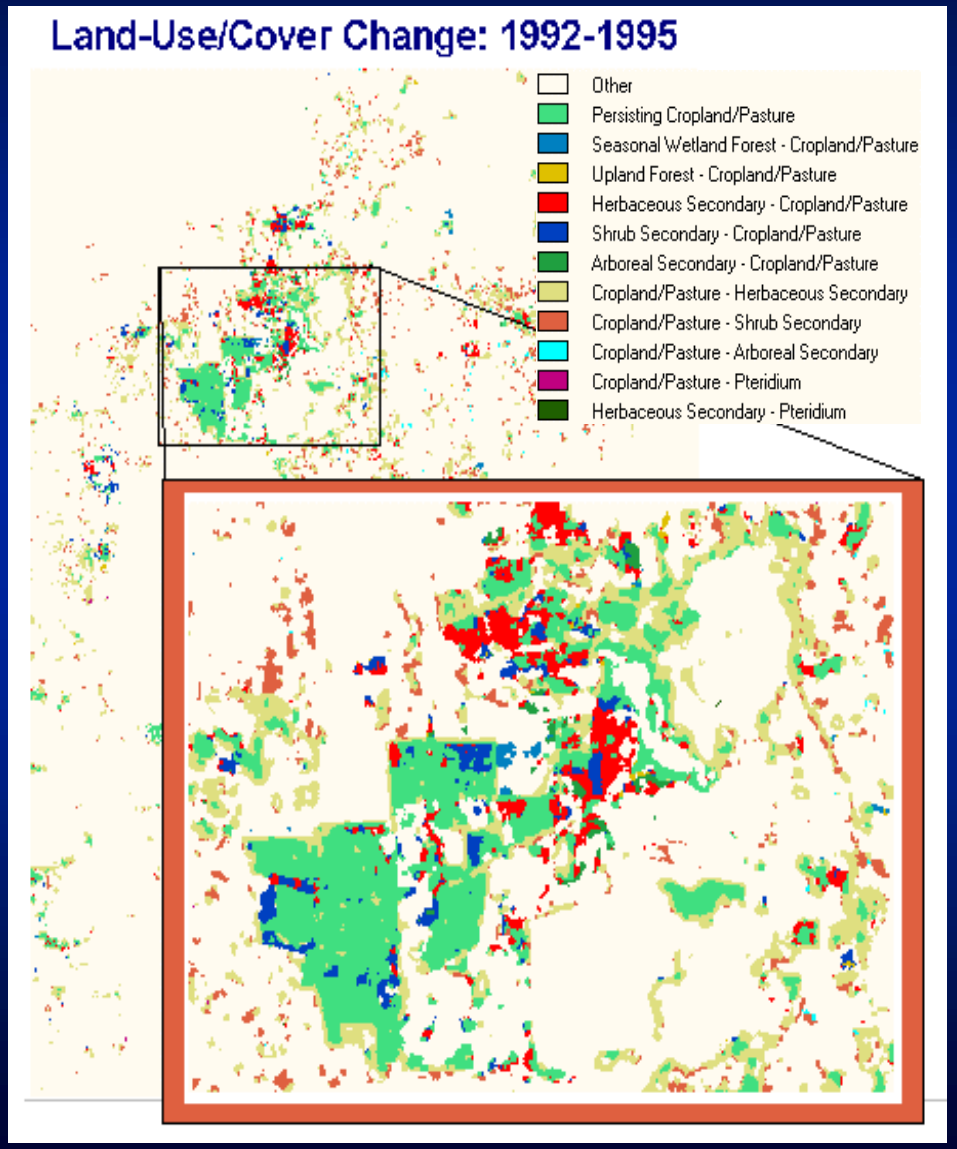


Average Uncertainty

0.37 Secondary Vegetation: Trees
0.29 Secondary Vegetation: Shrubs
0.19 Secondary Vegetation: Herbaceous
0.41 Upland Forest
0.13 Cropland
0.23 Pasture

Example Classification for Modeling Land-Use/Cover Change





Example Model of Land-Use/Cover Change

- Deforestation: Land-cover changes from Forest (mature and successional) to Cropland/Pasture
- Succession: Land-cover changes from Cropland/Pasture to young secondary vegetation
- Model 2 time periods: 1988-1992, 1992-1995

Explanatory Variables

- Biophysical: soils, topography, initial cover class
- Locational and infrastructure: distances to roads, village centers, markets, nearest other land cover
- Landscape pattern indices: fragmentation, diversity, richness, number of different classes (NDC)
- Socioeconomic: demographic, wealth indicators

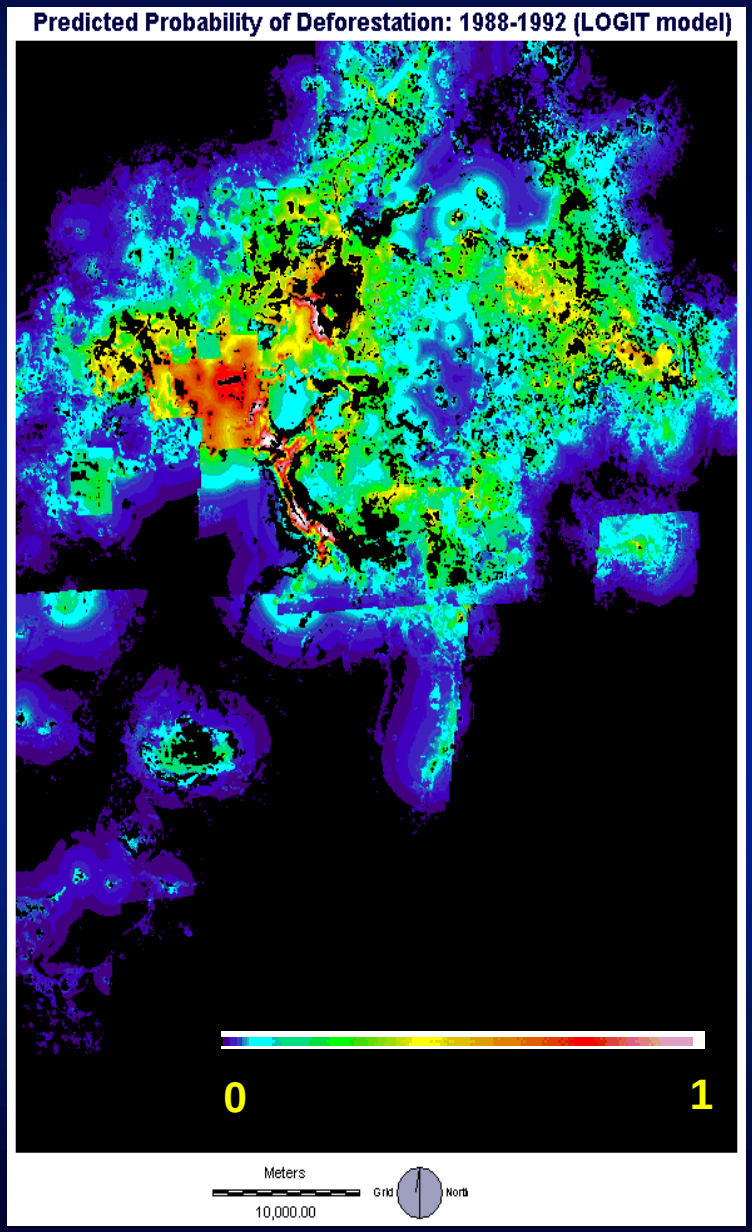
Model Estimation

- Binomial LOGIT model
  - Endogenous Variable: Forest Persistence vs. Deforestation
  - Exogenous Variables: GIS layers
- Base Case: Forest Persistence
- Estimate Parameters
  - evaluate significance of exogenous variables in model explanation
  - enable prediction of deforestation probability

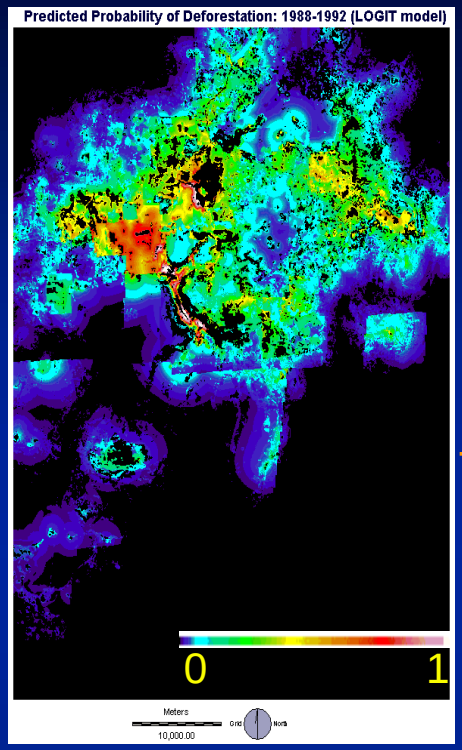
Spatially Explicit Probability Maps*

DEFORESTATION PROBABILITY: 1988-1992

$$\Pr(y_j \neq 0 \mid x_j) = \frac{e^{\beta_0 + \beta_1 x_1 + \beta_2 x_2 \cdots}}{1 + e^{\beta_0 + \beta_1 x_1 + \beta_2 x_2 \cdots}}$$

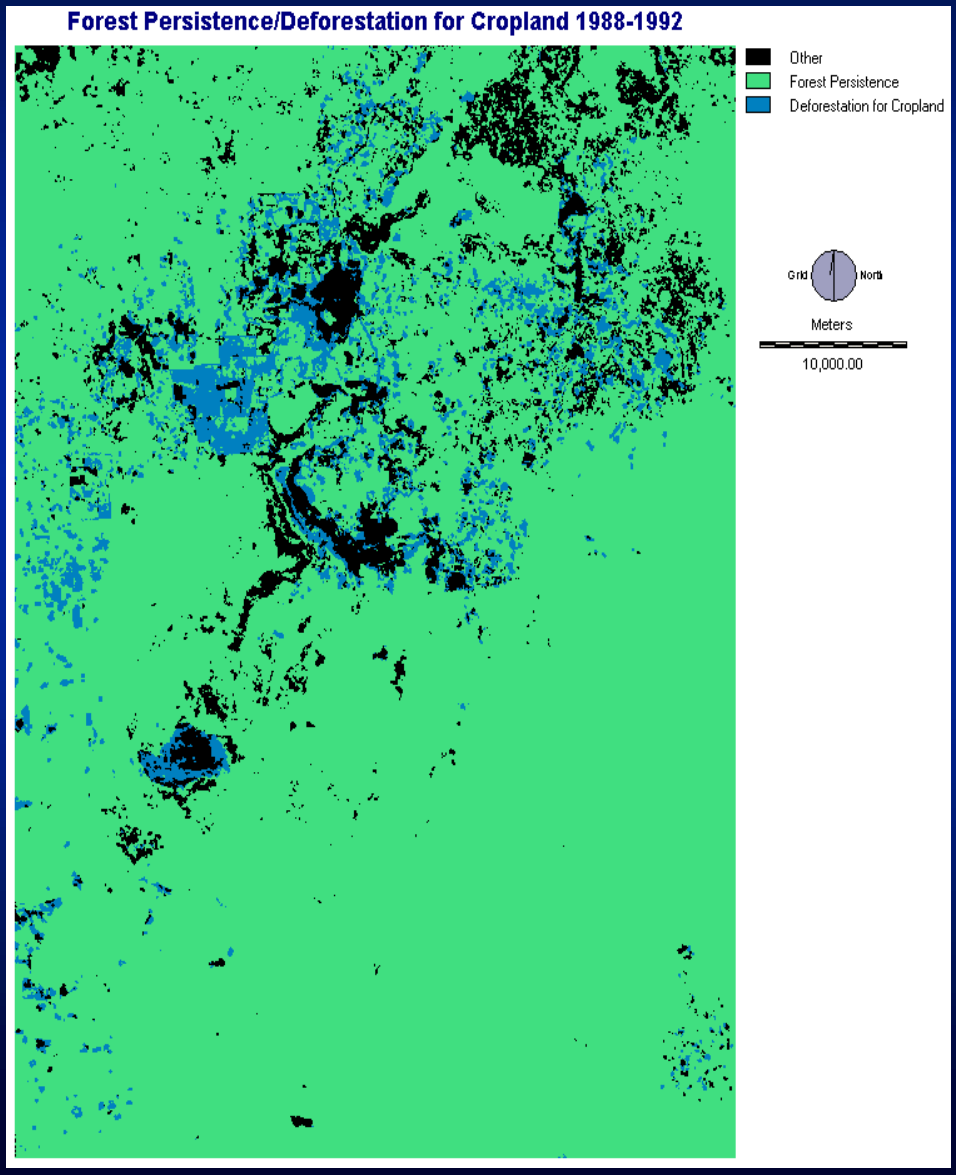


“Hardening” Predictions*



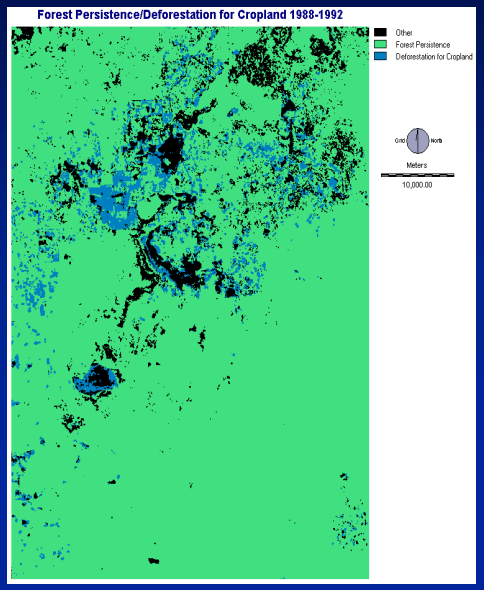
Threshold at p=0.5

FOREST PERSISTENCE/DEFORESTATION 1988-1992

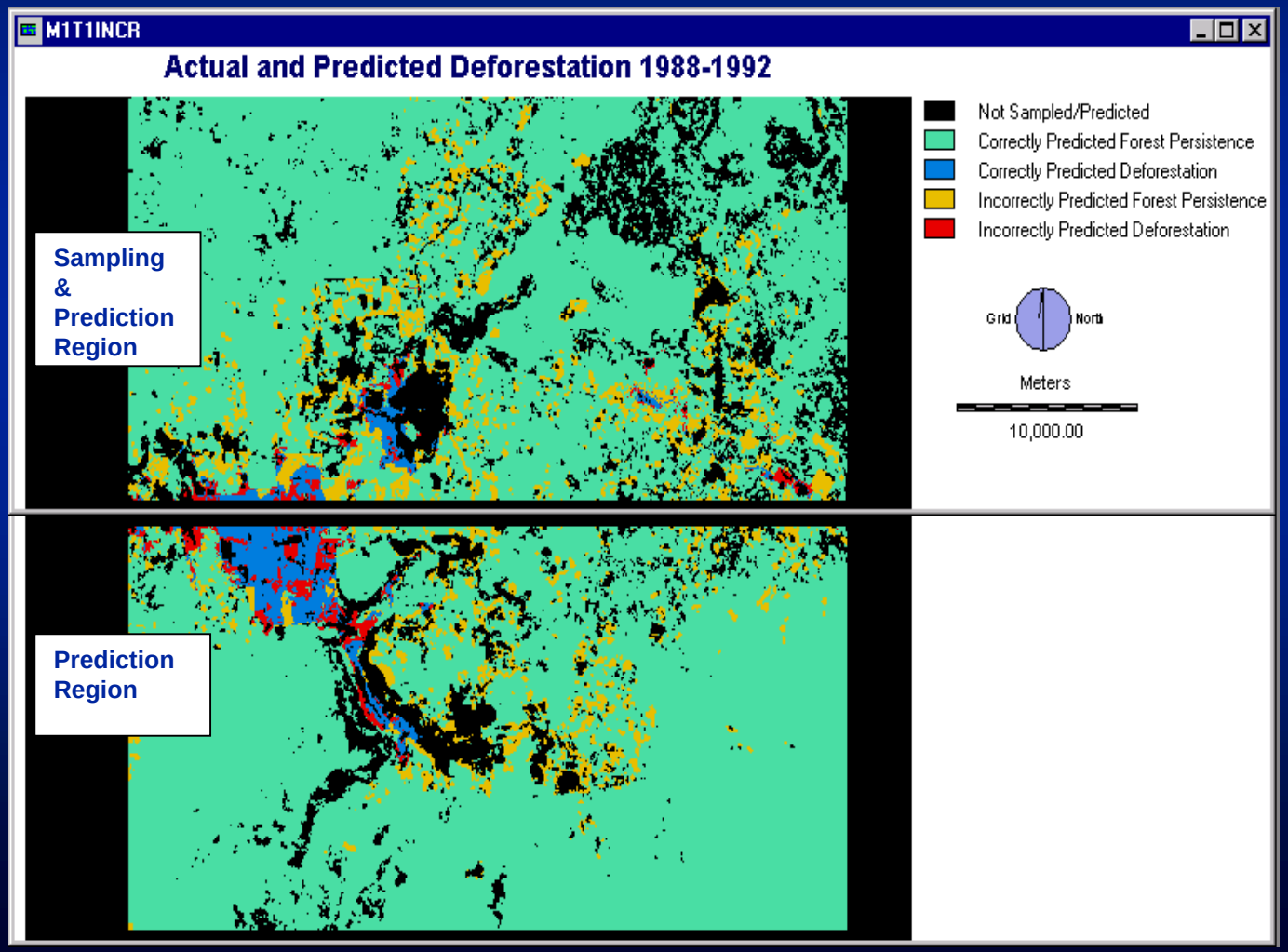


Comparing Predicted & Actual Change

Predicted Change



Crosstabulate Predicted Change with Actual Change



Kappa Index of Agreement Statistics*

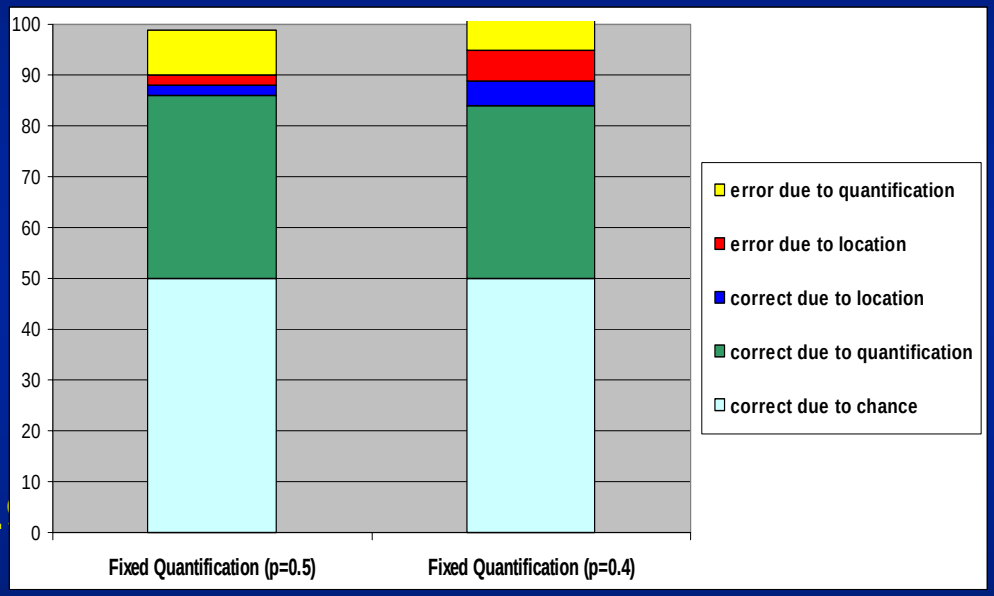
MODEL: FOREST PERSISTENCE/DEFORESTATION 1988-1992

Traditional Kappa (-1 ≤ K ≤ 1)

$$K = \frac{P_{RM} - P_R P_M}{P_R - P_R P_M}$$

Category	KIA (p=0.5)	KIA (p=0.4)
Forest Persistence	0.9873	0.
Deforestation	0.1224	0.2427
Overall	0.9310	0.9280

Modified Kappa (R. Pontius)



p=0.5	
Kappa standard	0.1775
Kappa No Information	0.7746
Kappa Location	0.5727
Kappa Quantity	0.9319

p=0.4	
Kappa standard	0.2792
Kappa No Information	0.7642
Kappa Location	0.4398
Kappa Quantity	0.9977

Focus 3: Ecological Approaches

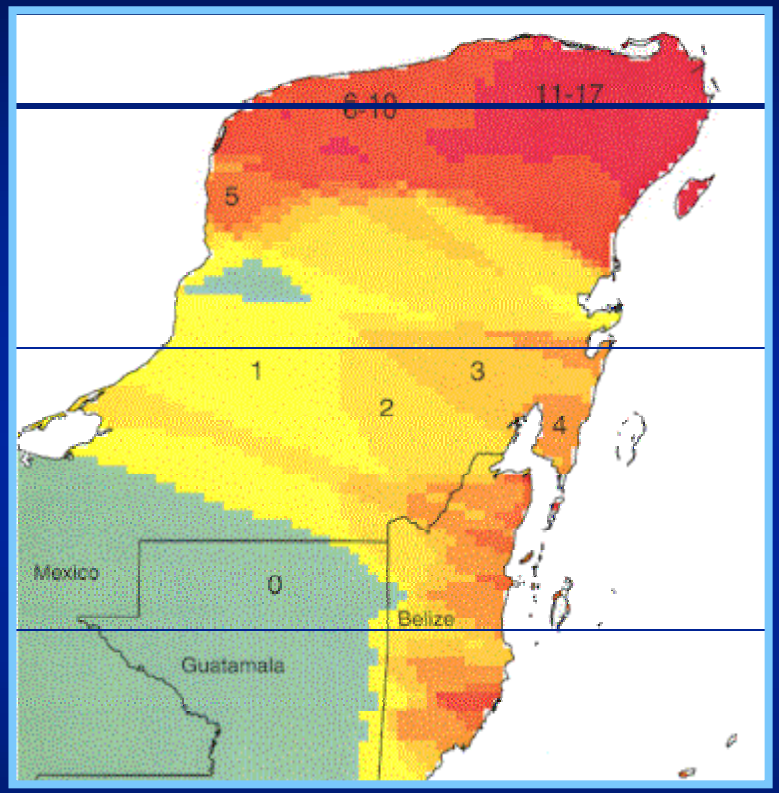
leading to the effects of and constraints on land change

This set of slides illustrates how the constraints on current and future ecological conditions and dynamics (disturbance and biophysical feedbacks) are determined and integrated with the other parts of the project. [1] Major environmental disturbances are reconstructed and [2] integrated with [2] studies of the structure and function of the dominant vegetation types (primarily upland and bajo forests, and secondary growth following cultivation, and [3] the processes of forest recovery, primarily ecosystem function and community.

ATTENTION: Slides marked by * are not be used or cited without permission of the project.

Hurricane Simulation*

a major historical disturbance

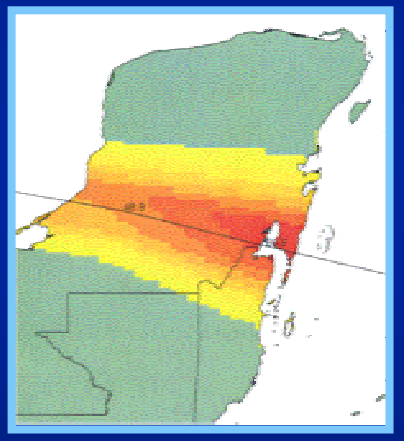


Hurricane frequency (1886-1996)

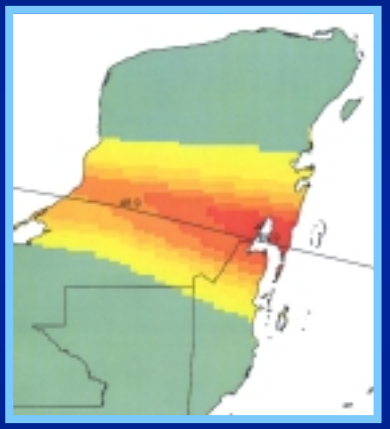
Modeled from wind speed, direction, and duration, producing estimates of potential damage.

Simulated hurricanes

Janet 1955



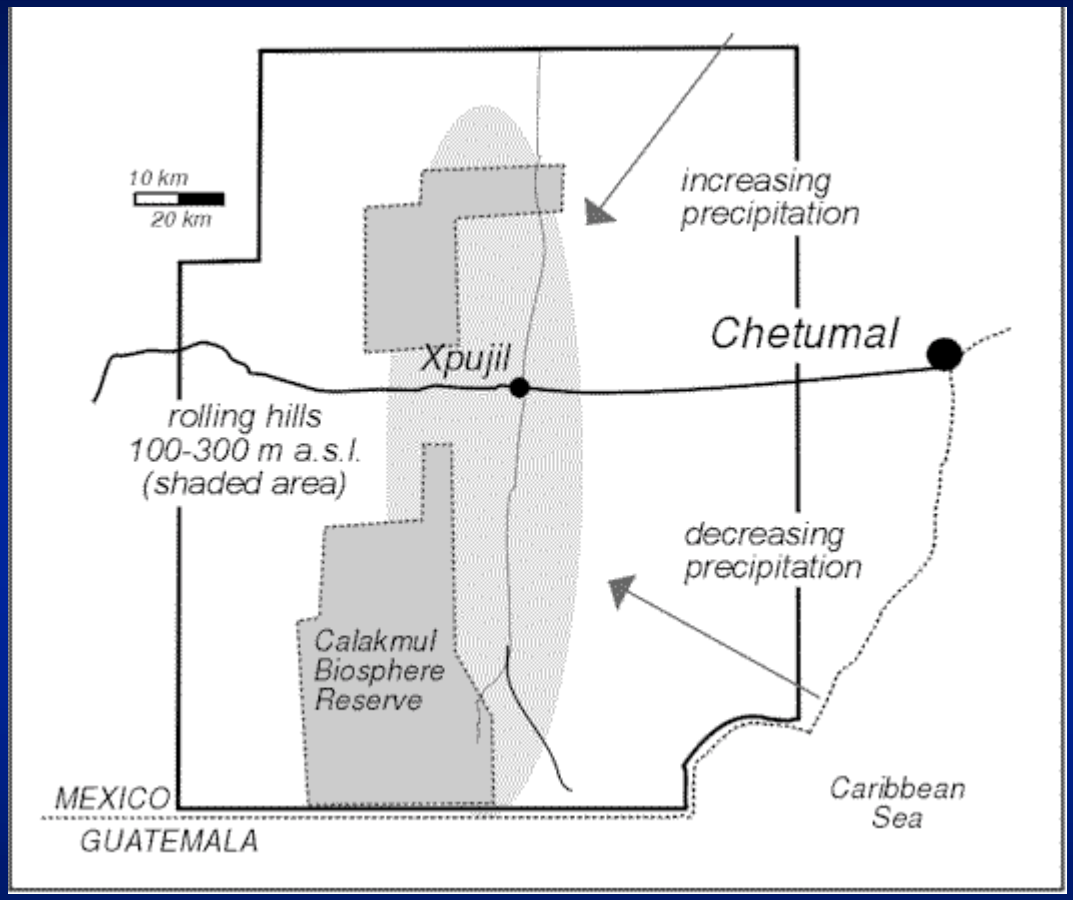
Gilbert 1988



Fujita damage

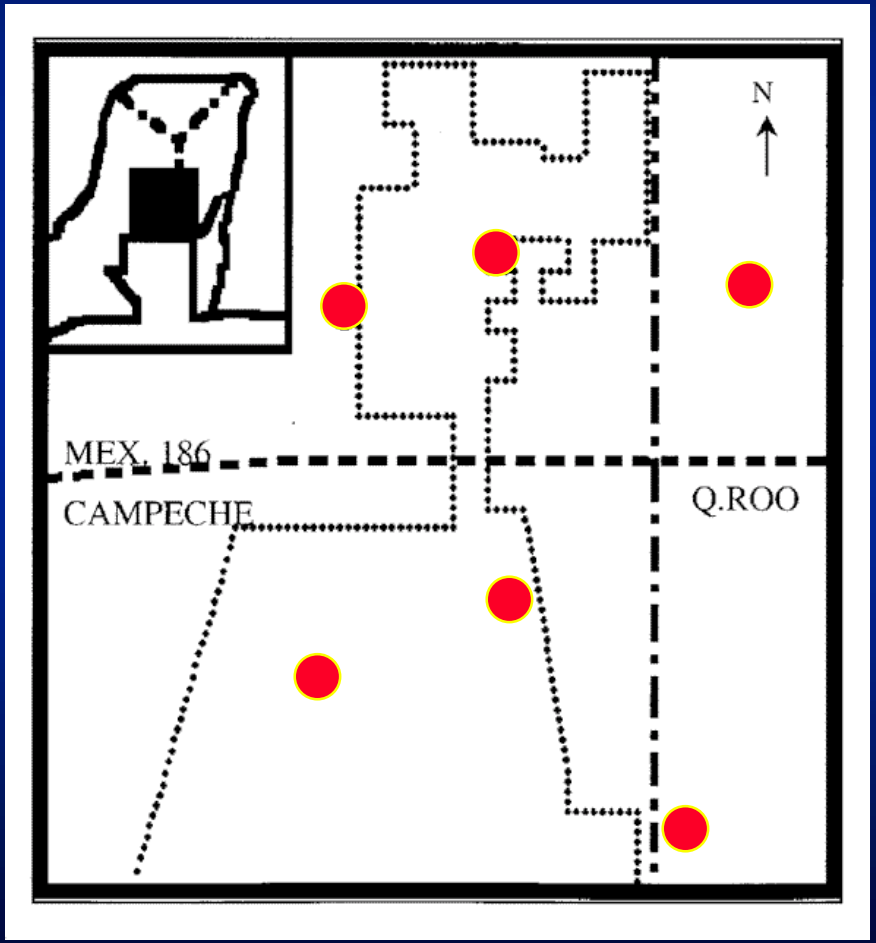
No Damage	F 2.0
F 0.0	F 2.5
F 0.5	F 3.0
F 1.0	F 3.5
F 1.5	

Environmental Schema of Region



The entire SYPR is karst with large, seasonally inundated poljes (*bajos*) dispersed throughout. These features increase in number and size on the low-lying eastern and western flanks of the region and support *bajo* forest. The center of region consists of rolling hills with moderate topography (100-300 m asml) dominated by *mediana* or upland forest and secondary forest. Poljes and uplands constitute the major soil distinction, with minor variation on uplands linked to depth of the limestone bedrock. A strong precipitation gradient exists: diminishing east to west and increasing north to south.

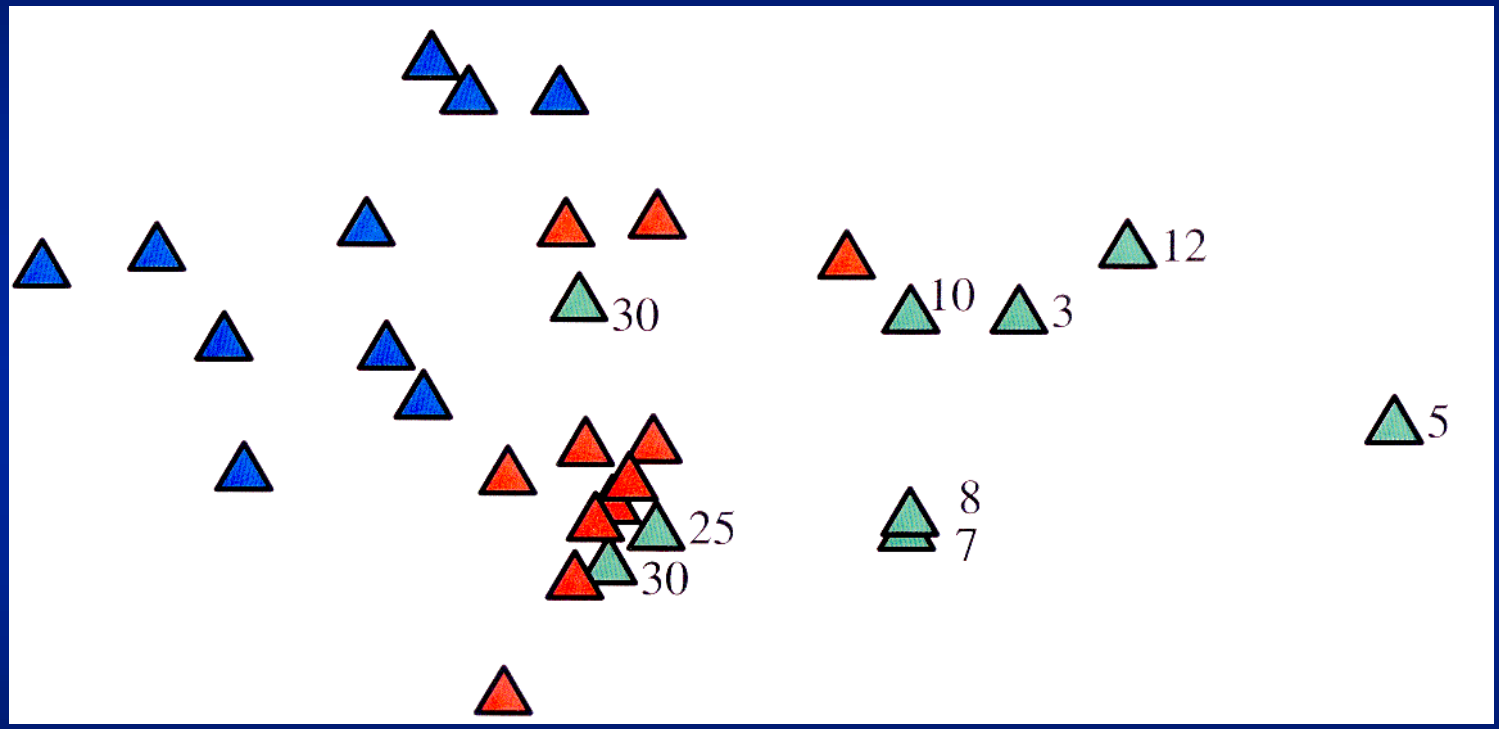
Composition, Structure, Dynamics, and Regeneration of Forests: SYPR study sites



Composition, Structure, Dynamics, and Regeneration of Vegetation

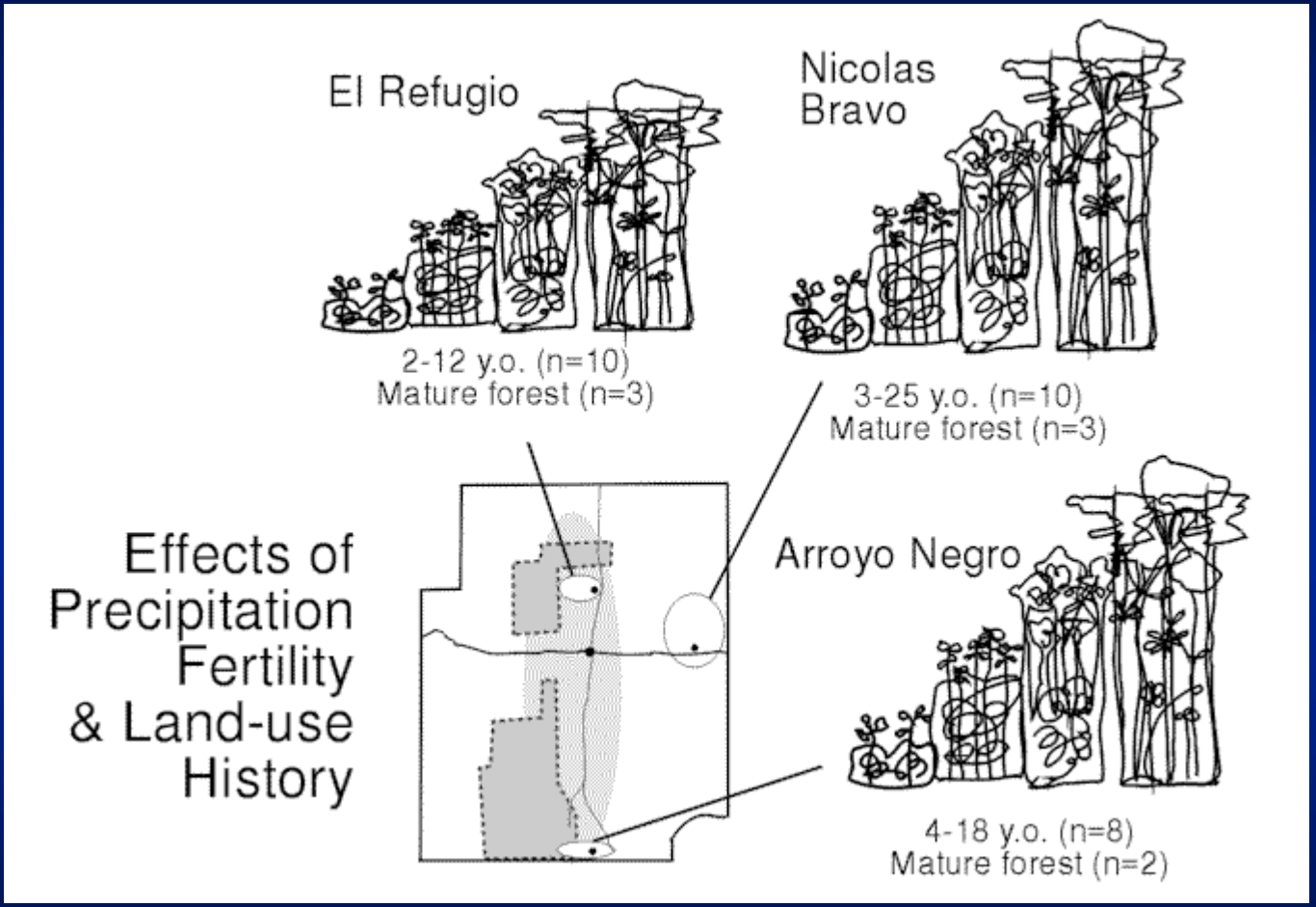
- Six vegetation sites established across the region representing gradient of precipitation, soil depth, topography, and hurricane exposure.
- Minimally 10 vegetation plots (circular 500 m^2 each) per forest type at each site.
- Tree (>10 cm dbh) and liana species composition and structural characteristics of forest record for each plot (as well as epiphyte load).
- In nested 100 m^2, stems >5 cm dbh or >2 m in height are recorded.
- Seedling layer to be investigated in future.

Primary Axes of Variation in Detrended Correspondence Analysis



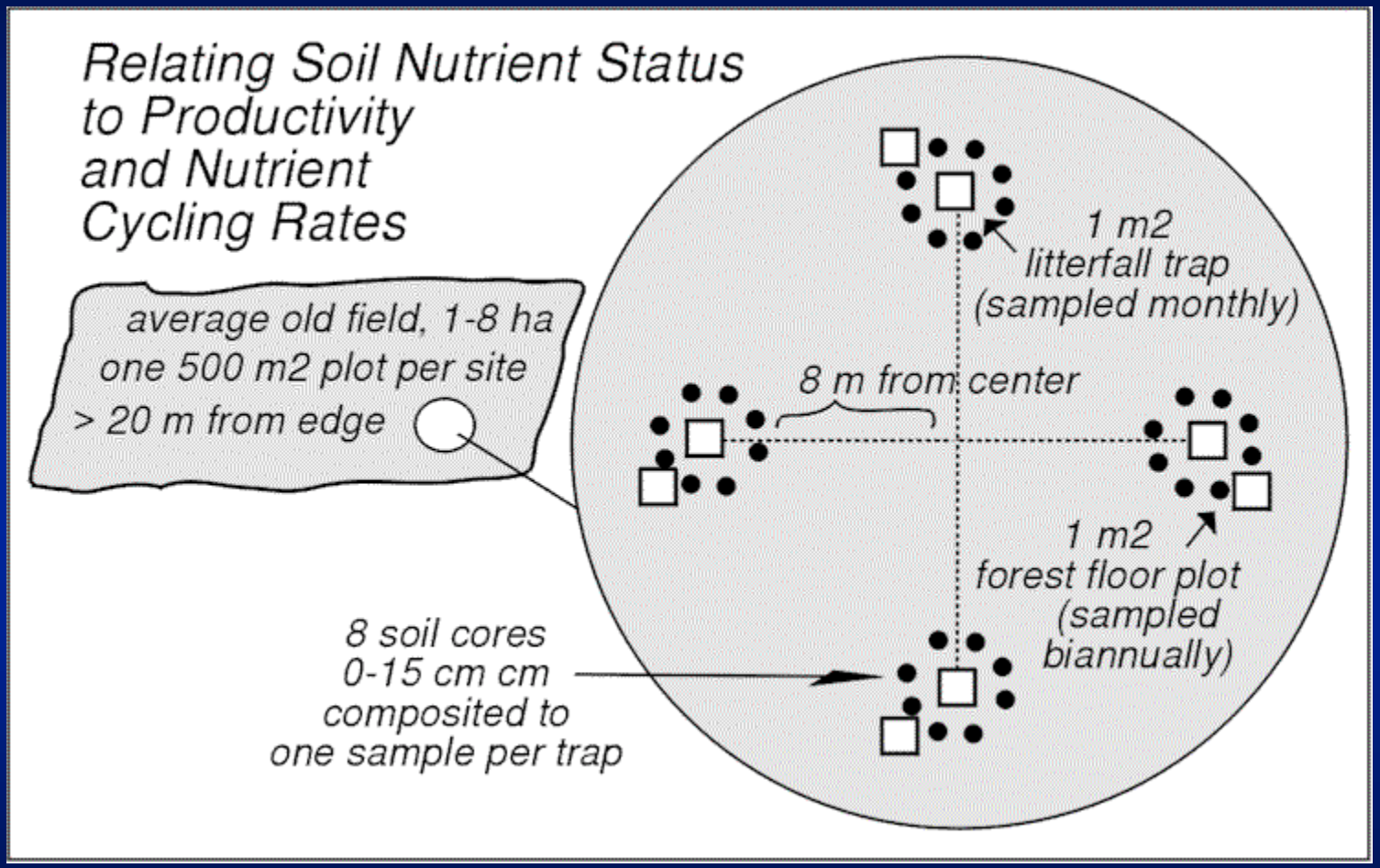
Initial results from northern site suggesting that tree communities are distinctive among bajos (blue) medianos (red), and young secondary forest (green).

Changes in Nutrient Cycling During Succession



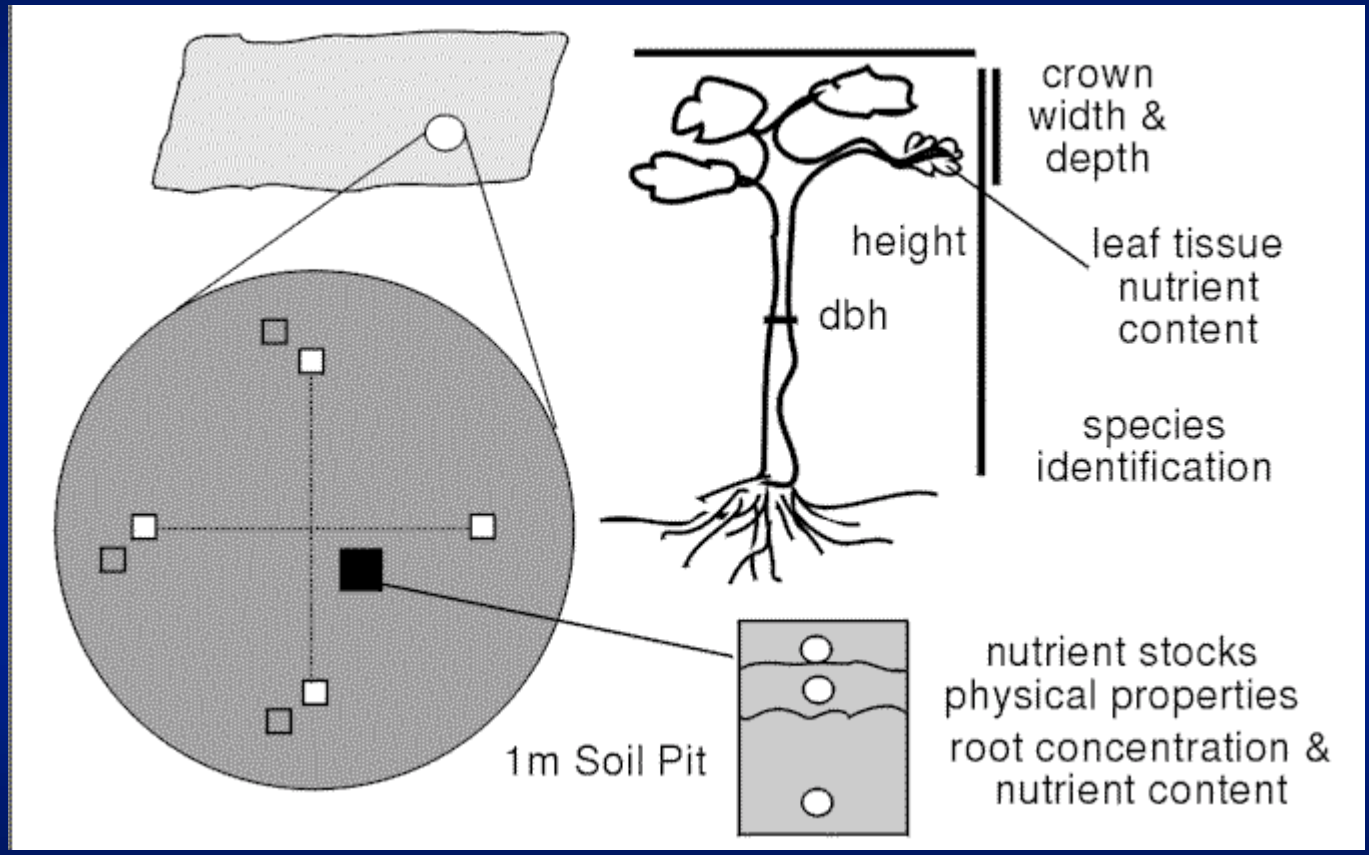
Three sites serve studies of nutrient stocks (biomass & soil) and cycling (production, turn over & constraints) as function of forest age under the dominant shifting or swidden cultivation in the region.

Relating Soil Nutrient Status to Productivity and Nutrient Cycling Rates



Successional sequence studied by way of 10-13 plots in each of three sites under growth ranging from 2 to 25 years since cultivation.

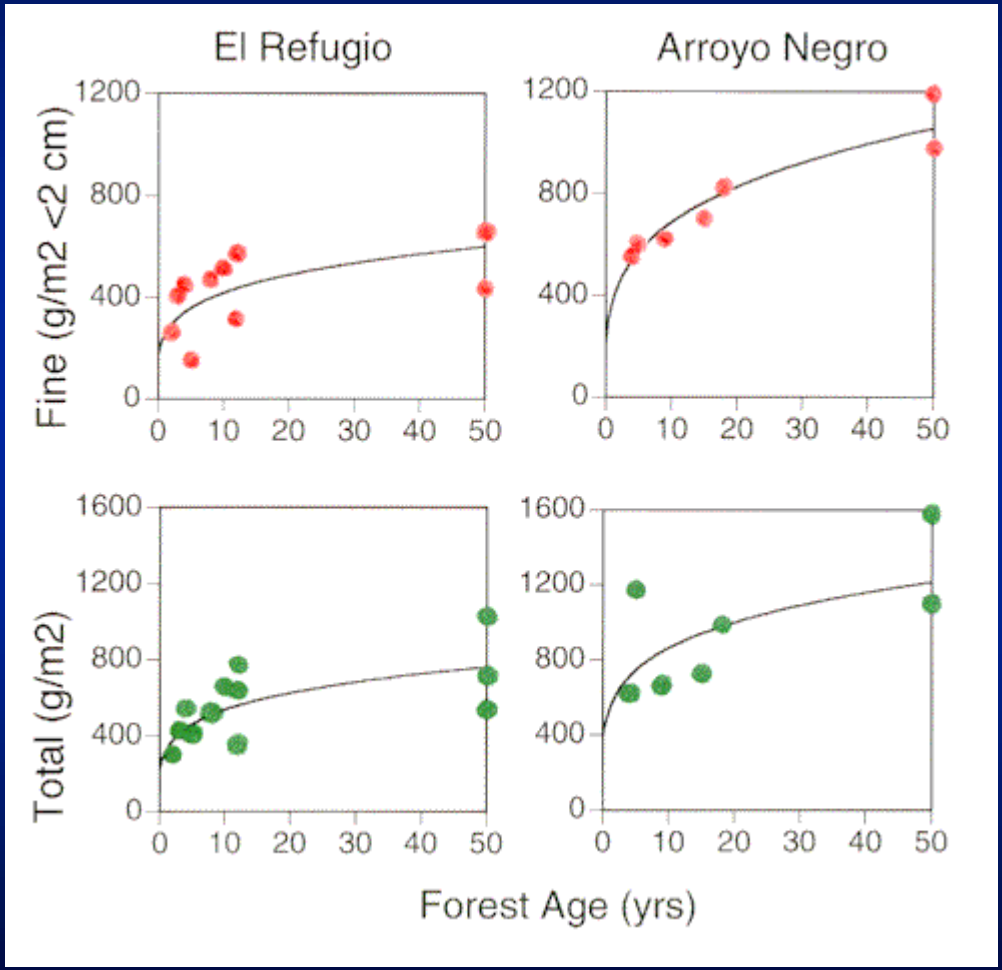
Linking Biomass and Species Composition to Nutrient Cycling Processes



Litter production as an index of productivity with links to soil nutrient status.

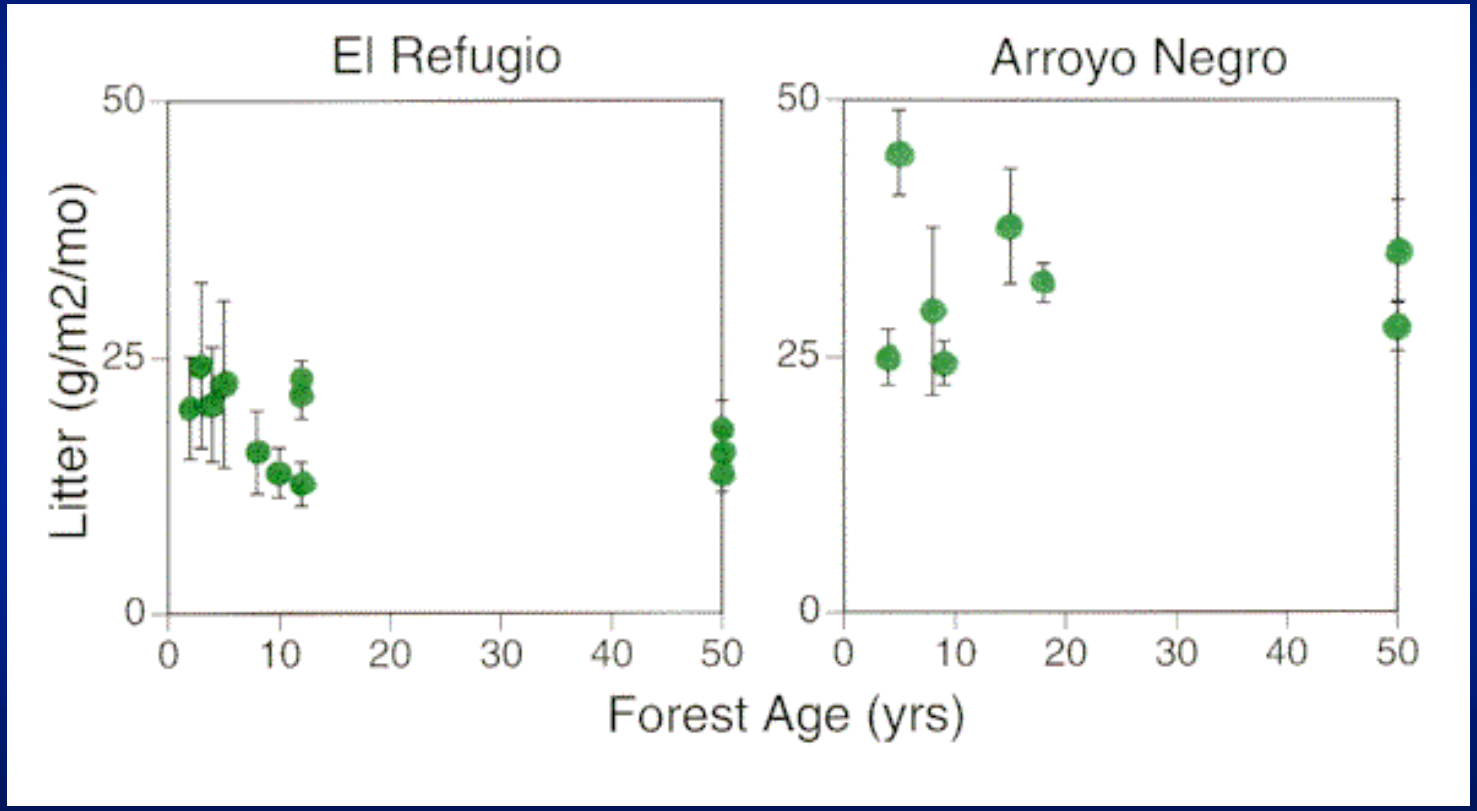
Variation in Forest Floor Mass vs. Age*

[Across Study Area]



Variation in Monthly Litter Fall vs. Age*

[Across Study Area]



Focus 4: Integrative Modeling

leading to scenario assessment for policy

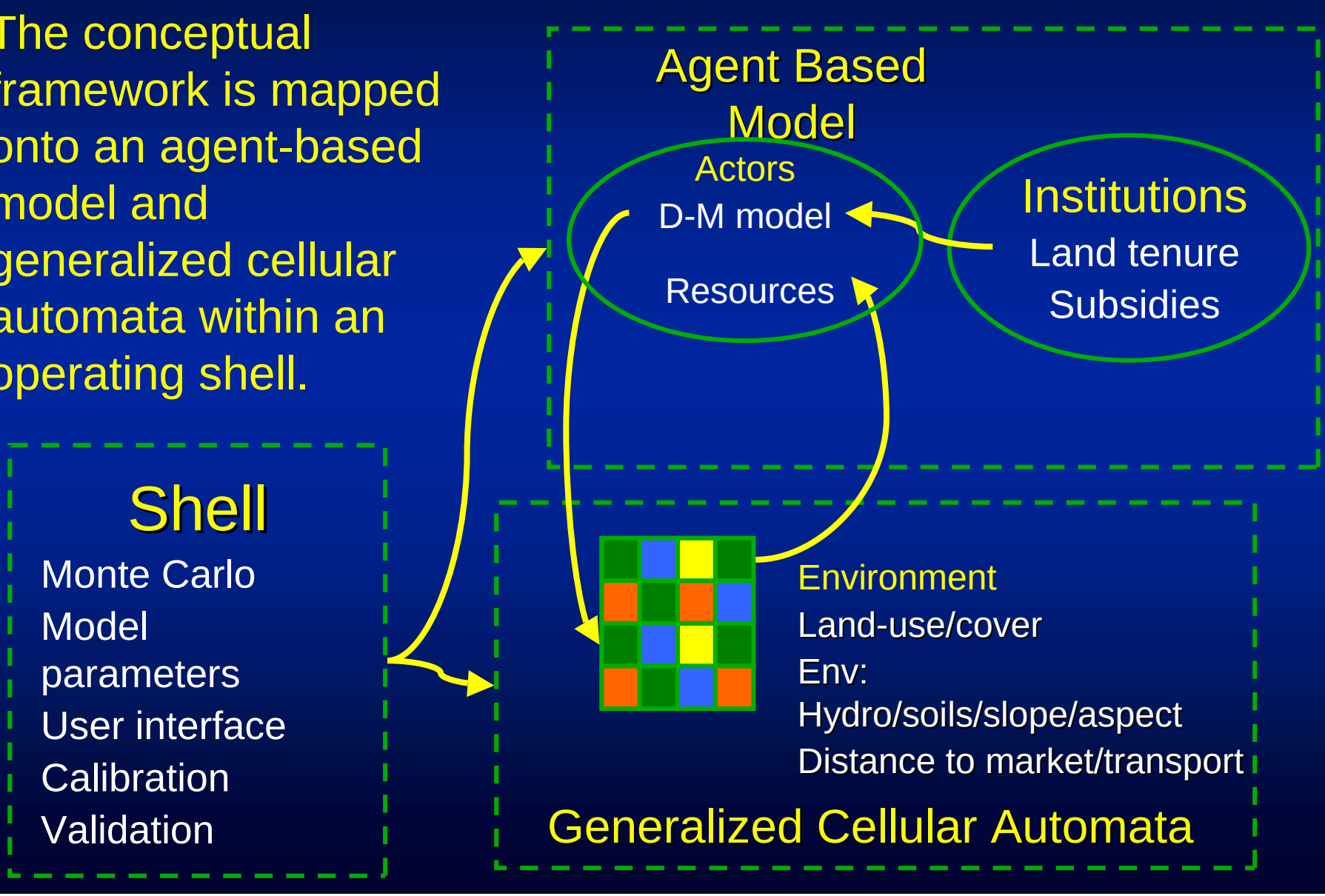
A conceptual actor-institution-environment framework is mapped onto a computer model to form an Agent-based Dynamic Spatial Simulation (ADSS).

The conceptual framework joins:

- Actors: agrarian decision making interpreted by bounded rationality & resource profiles
- Institutions: land tenure & subsidies
- Environment: simple ecological relationships

ADSS Implementation

The conceptual framework is mapped onto an agent-based model and generalized cellular automata within an operating shell.



Central and Southern Africa

Early Results- Deforestation and degradation in Southern and Central Africa Savannas - S. Prince

Coupling land use and land cover change and ecosystem processes in Miombo Woodlands - P. Desanker

Fire managment in African Savannas - P. Frost

Early Results- The process of land cover and land use change in Central Africa - D. Wilkie

Early Results- Study of land use and deforestation in Central African tropical forests using high resolution SAR satellite imagery - S. Saatchi

Deforestation and Degradation in Southern Central African savannas

Investigators:
Stephen D. Prince (PI), Geography, University of Maryland
Jon Ranson
Martha Geores
Ralph Dubayah
Dennis Lettenmaier

http://www.inform.umd.edu/geog/LGRSS/Projects/degradation.html

Deforestation and Degradation in Central and Southern African Savannas

Outline of proposal

– Integrated land degradation and deforestation detection system.

–Southern African Development Community (SADC) region plus southern Zaire.

–Move beyond classification of land cover to monitor the processes involved.

–Socio-economic drivers of land cover change and biophysical factors employed to identify degradation processes.

Deforestation and Degradation in Central and Southern African Savannas

Outline of proposal (continued)

– Radar and optical methods to measure biomass.

–Visible, near infrared and thermal remote sensing to monitor primary production.

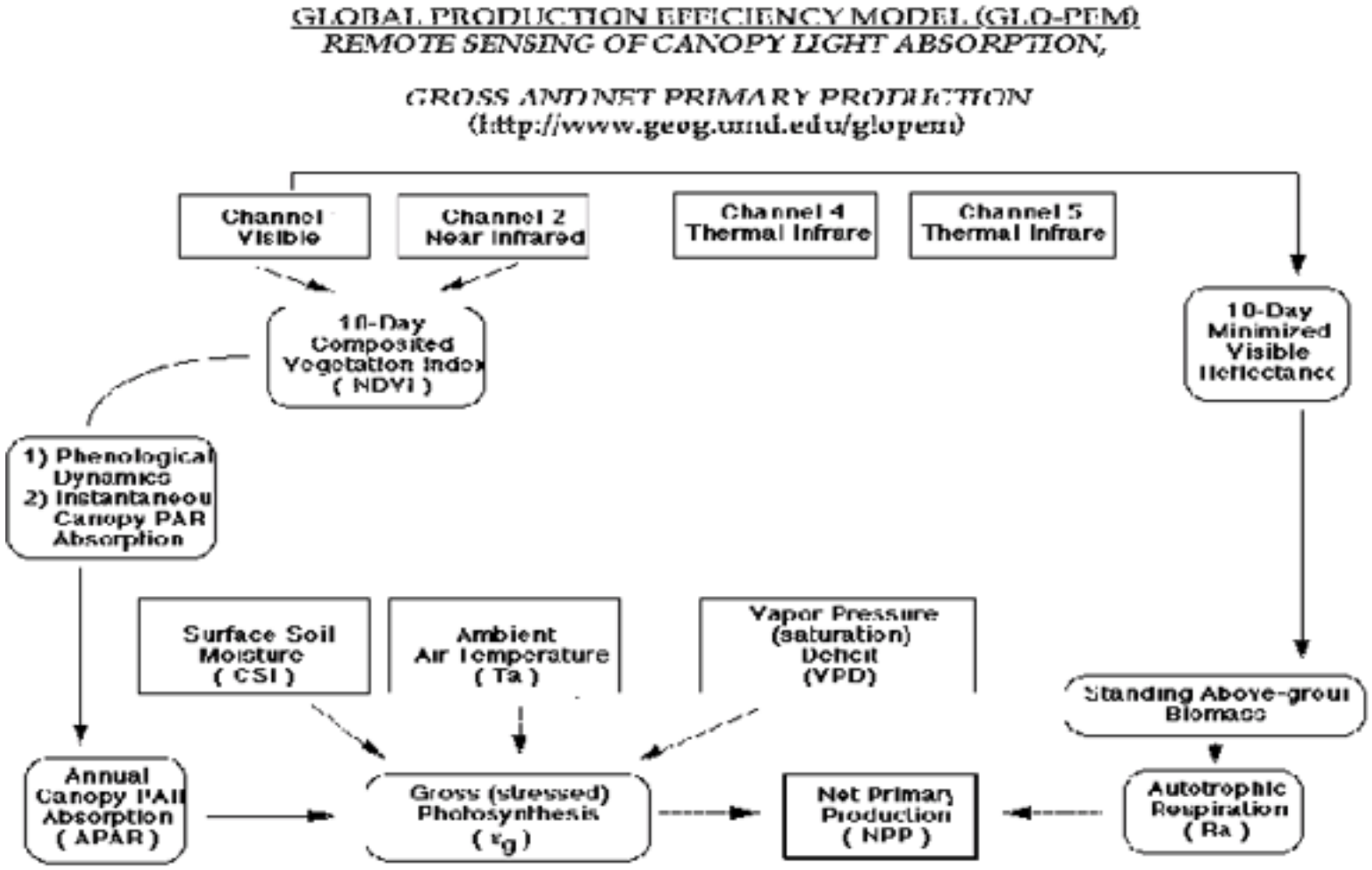
– Soil moisture and runoff modeled with surface water and energy balance models driven with remotely sensed data.

– Biophysical, socio-economic and cultural variables combined to create empirical models to identify leading indicators of environmental degradation.

–Prototype degradation early warning system (DEWS) for southern and central Africa and for similar areas worldwide.

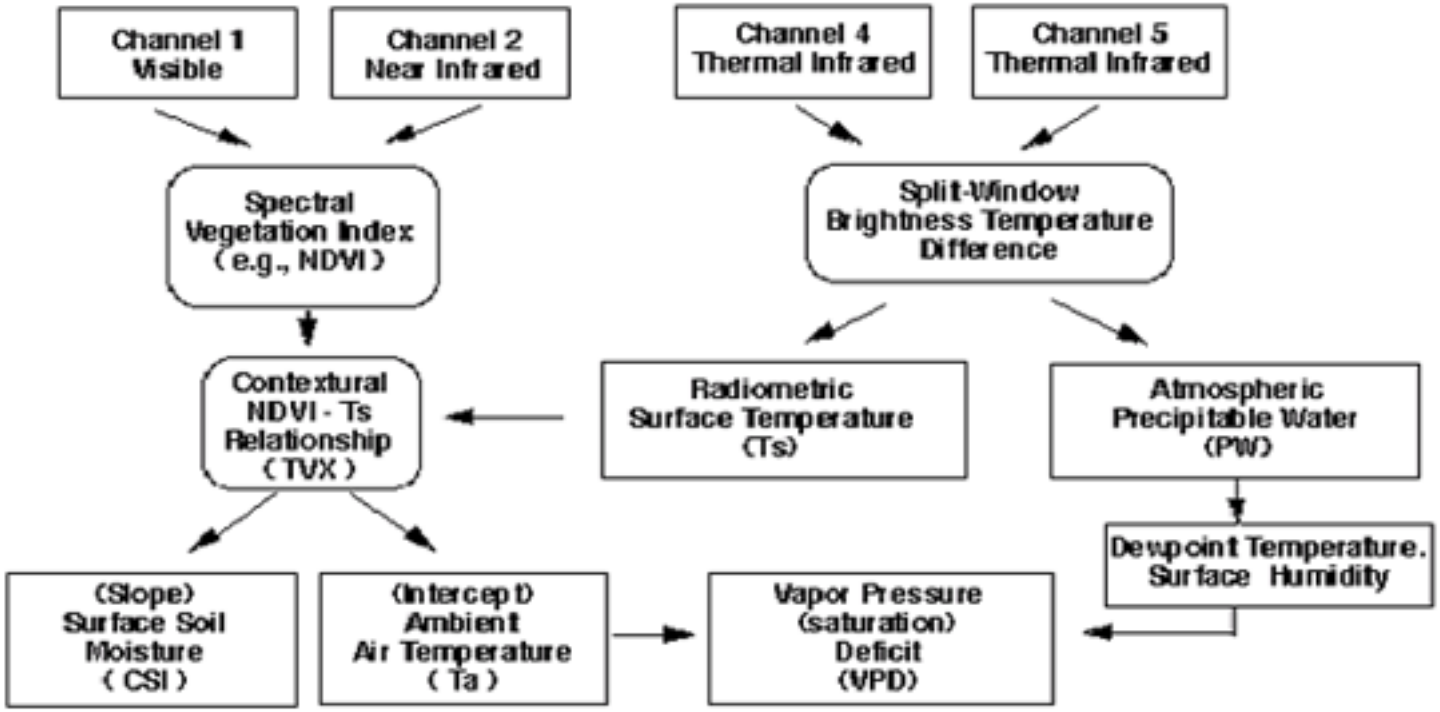
NPP monitoring using GLO-PEM model

Model Outline



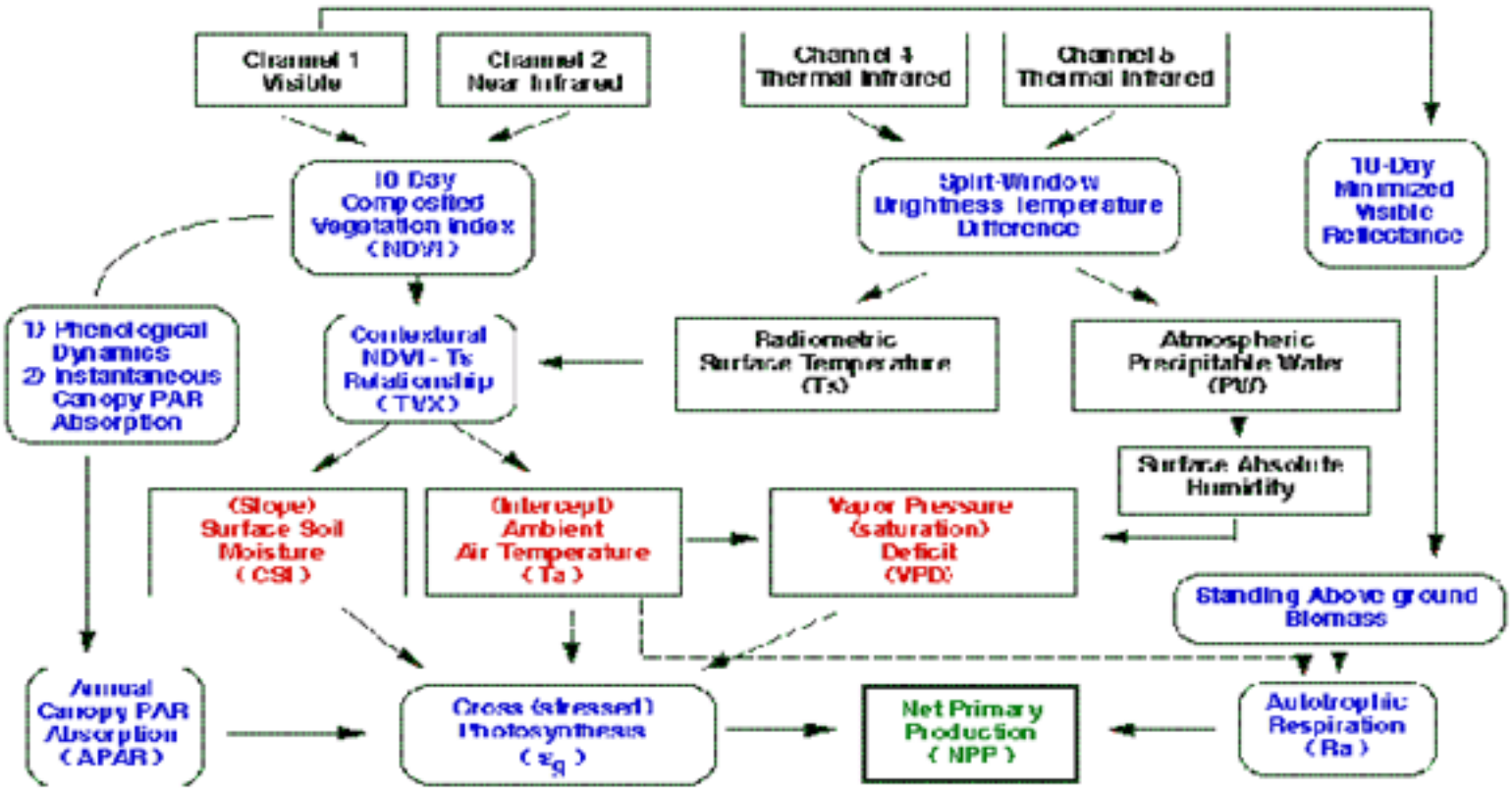
Model Outline

GLOBAL PRODUCTION EFFICIENCY MODEL (GLO-PEM)
REMOTE SENSING OF ENVIRONMENTAL VARIABLES..



Model Outline

GLOBAL PRODUCTION EFFICIENCY MODEL (GLO-PEM)
REMOTE SENSING OF CANOPY LIGHT ABSORPTION, SURFACE ENVIRONMENTAL VARIABLES, GROSS AND NET PRIMARY PRODUCTION
(http://www.geog.umd.edu/glopem)



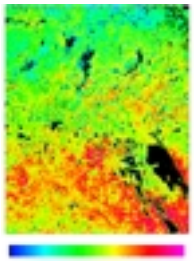
New developments

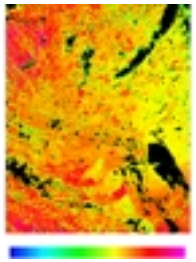
- Canopy respiration rates modeled exponentially using deviation from long-term air temperature (Ta)
- Ta inferred from TVX relationship, except where:
  - Slope is flat or positive: Ta = Ts-1stdev (or) Ts @ NDVI avg
  - $R^2 < 0.5$; small sample size or variance of Ts or NDVI low
  - Other conditions apply / thresholds are exceeded
    - (e.g., clouds, sparsely vegetated areas)
- Ts calculated with new LUT approach
  - Varies with emissivity (CERES), atmos water vapor
  - Coeffs specific to AVHRR instruments (NOAA-7 to 13)

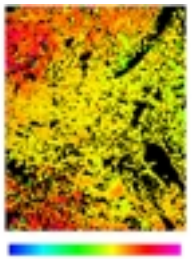
New developments

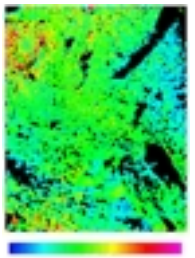
- Soil moisture stressor a continuous variable rather than a switch, ramps in below 30% (by volume).
- DAO atmospheric water vapor rather than DT4-T5 & LOWTRAN (avoids non-unique solution)
- Combined, these provide solutions for >80% land surface
- Methodology to compensate for AVHRR time drift devised.
  - SSiB simulations stratified by cover type, latitude
    - ISLSCP forcing variables
    - Diurnal Ta curves interpolated 3-hourly
  - LUT correction factors for overpass drift (~13:40 - 16:50 GMT)

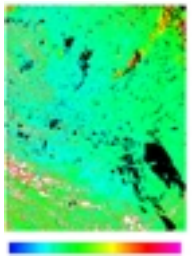
NPP monitoring using GLO-PEM model
Validation: BOREAS

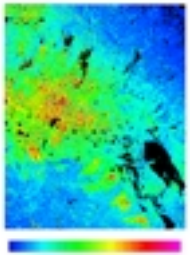
APAR 

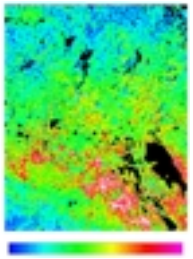
Ts 

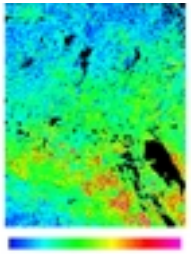
Ta 

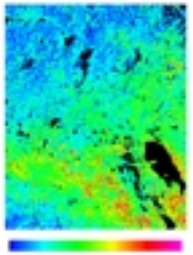
VPD 

CSI 

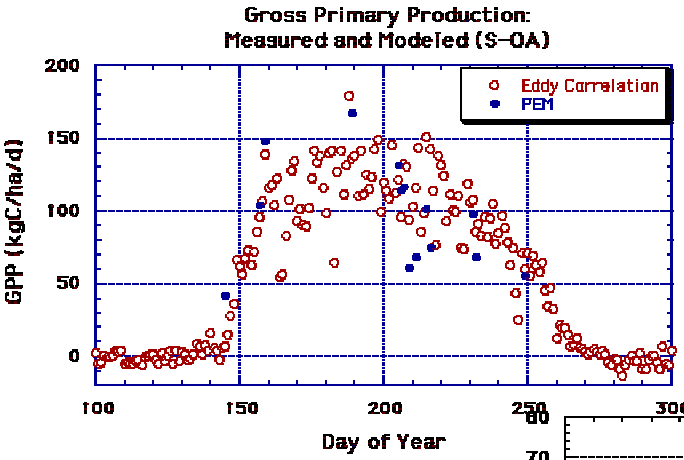
Biomass 

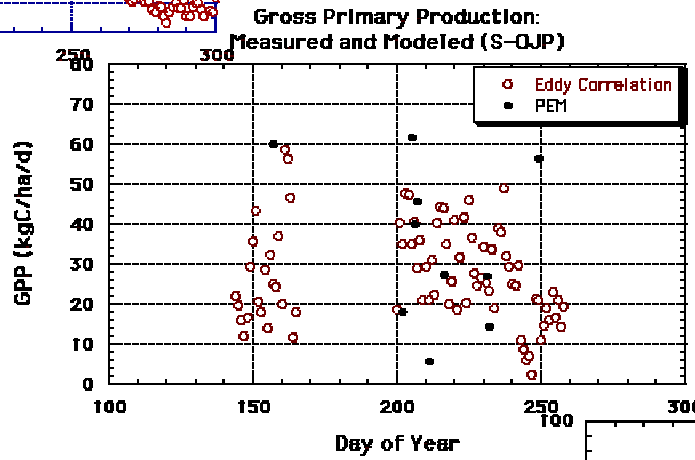
Respiration 

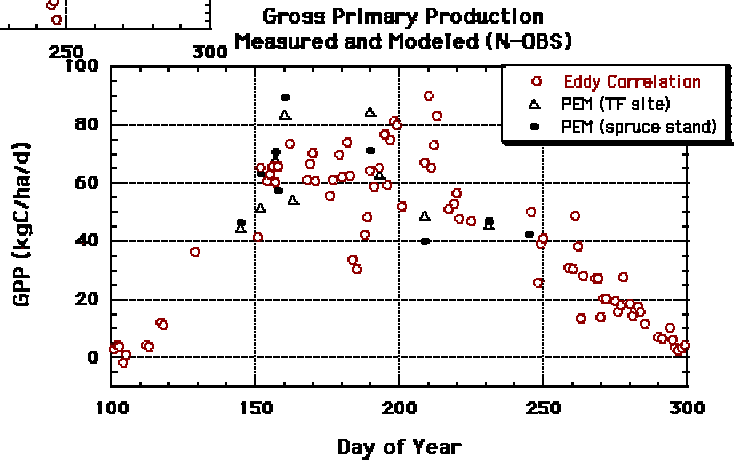
GPP 

NPP 

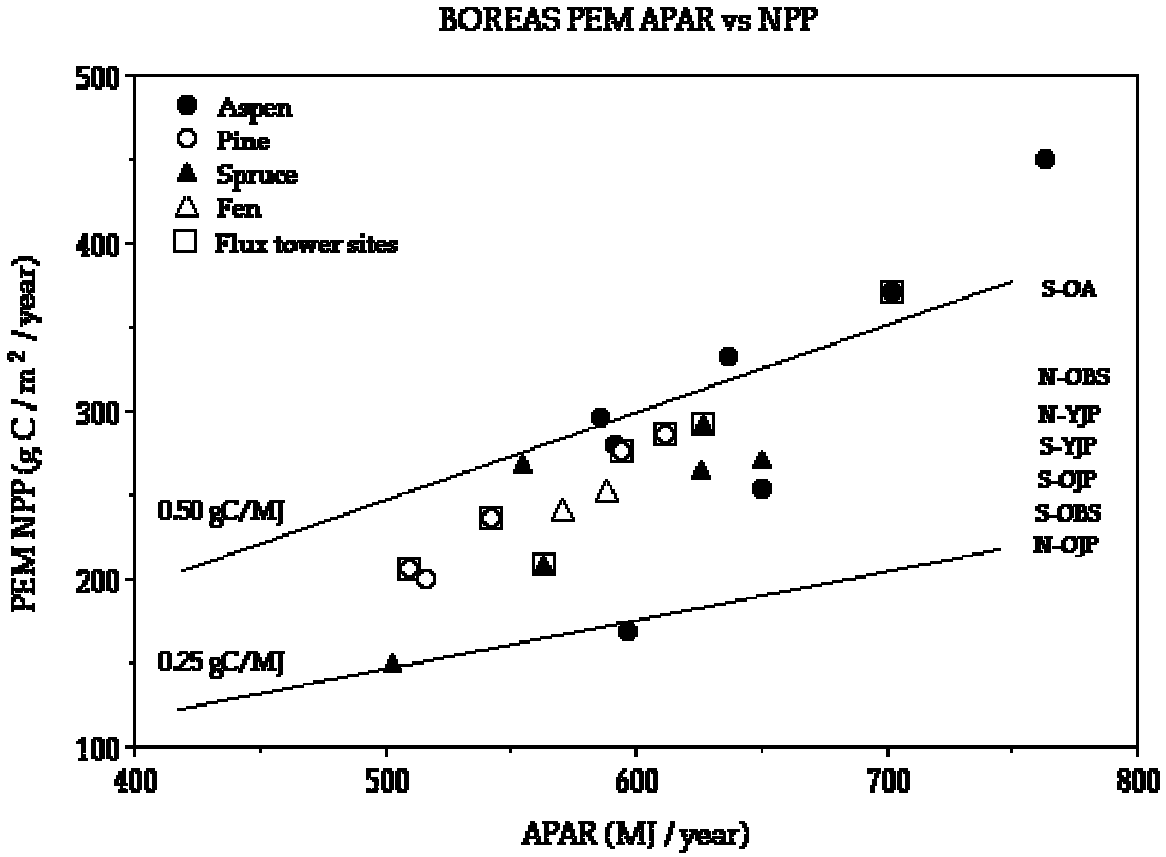
Validation of glo-pem npp model in boreas







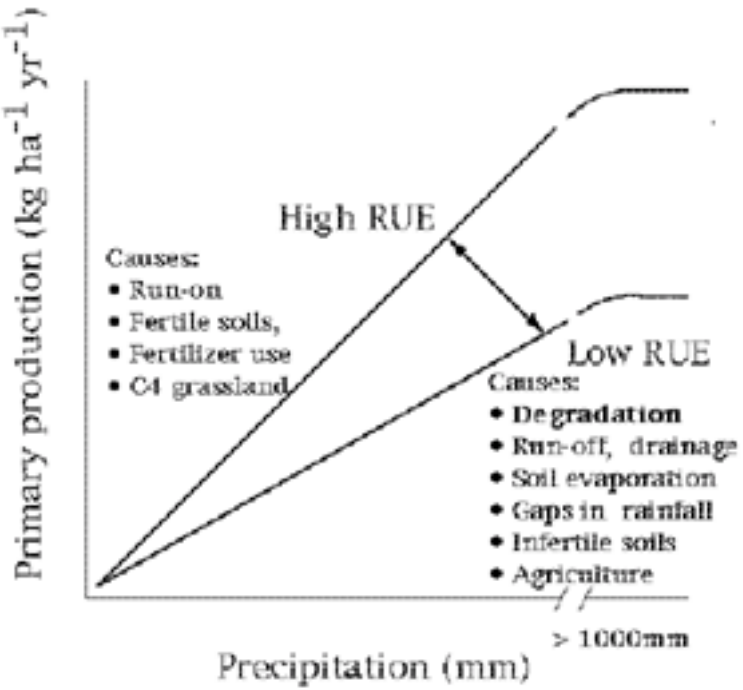
Glo-pem modeled
light use efficiency in boreas



PIK NPP Model Intercomparison

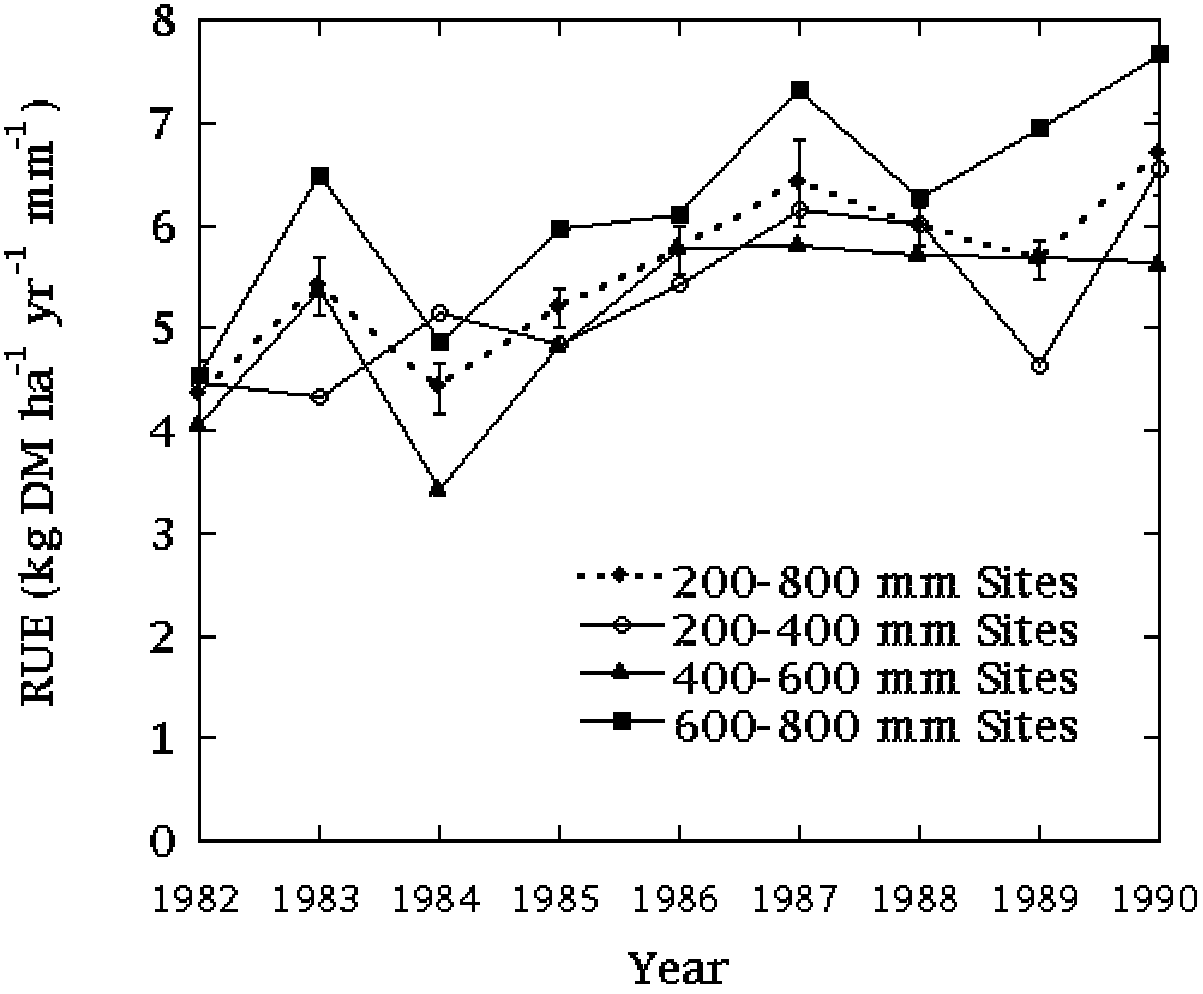
Rain Use Efficiency Theory

Outline of Theory



- **RUE = P_n / T = P_n / (T + E + I) + (D + R) + (ΔW + ΔWp)**
- **P_n = net primary production (NPP)**
- **P_r = precipitation** **All in volume water/time.**
- **T = transpiration**
- **E = soil evaporation**
- **I = evaporation from wet canopy**
- **D = drainage from the root zone**
- **R = run-off**
- **ΔW = change in water content of the soil**
- **ΔW_p = change in water content of the vegetation**

Sahelian multitemporal results



Significance of RUE as an objective index of degradation

Evidence from rain-use efficiencies does not indicate extensive Sahelian desertification

S. D. PRINCE, E. BROWN DE COLSTOUN and L. L. KRAVITZ

Abstract

Drawing a line in the desert sands

FOR decades the United Nations has campaigned to control desertification, the apparently inexorable advance of deserts, particularly the Sahara. But ecologists have never convinced that the process is happ- two recently published studies r scepticism.

images from an American satel- w that, in the past 15 years, the ahara has moved rapidly to and ng on rainfall. The movements as 300 kilometres in a few years ole period. "there is no progres- f the desert," says Dr Sharon Ni- lorida State Univer the land itself be not becoming des he greenness of t ith the amount of r here is no decline i th the plants use r d Dr Stephen Prin laryland concur in reports.

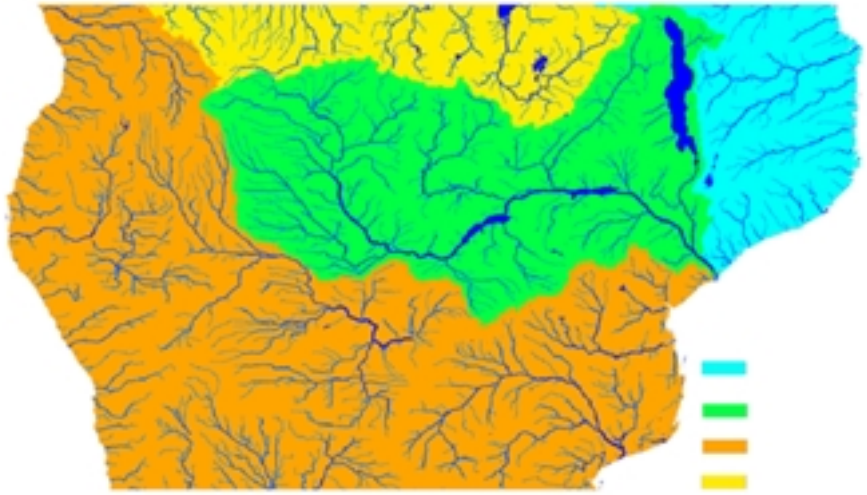
ECOLOGY

The Sahara Is Not Marching Southward

REMOTE SENSING

Study Shows No Long-Term Growth of Sahara Desert

Future Developments
Hydrological modeling to separate runoff and soil moisture components



River Catchments
Coastal Mozambique
Zambeze
Limpopo/Okavango
Zaire

- **RUE = P_n / T = P_n / (T + E + I) + (D + R) + (ΔW + ΔWp)**
- **P_n = net primary production (NPP)**
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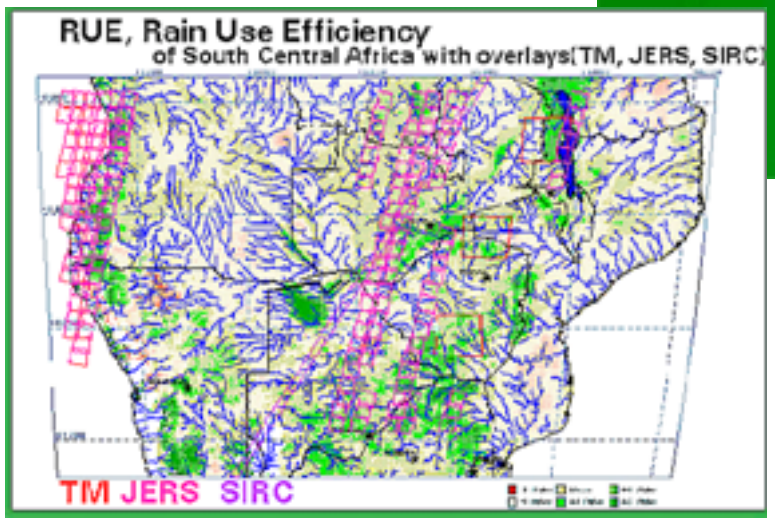
- **D = drainage from the root zone**
- **R = run-off**
- **ΔW = change in water content of the soil**
- **ΔW_p = change in water content of the vegetation**

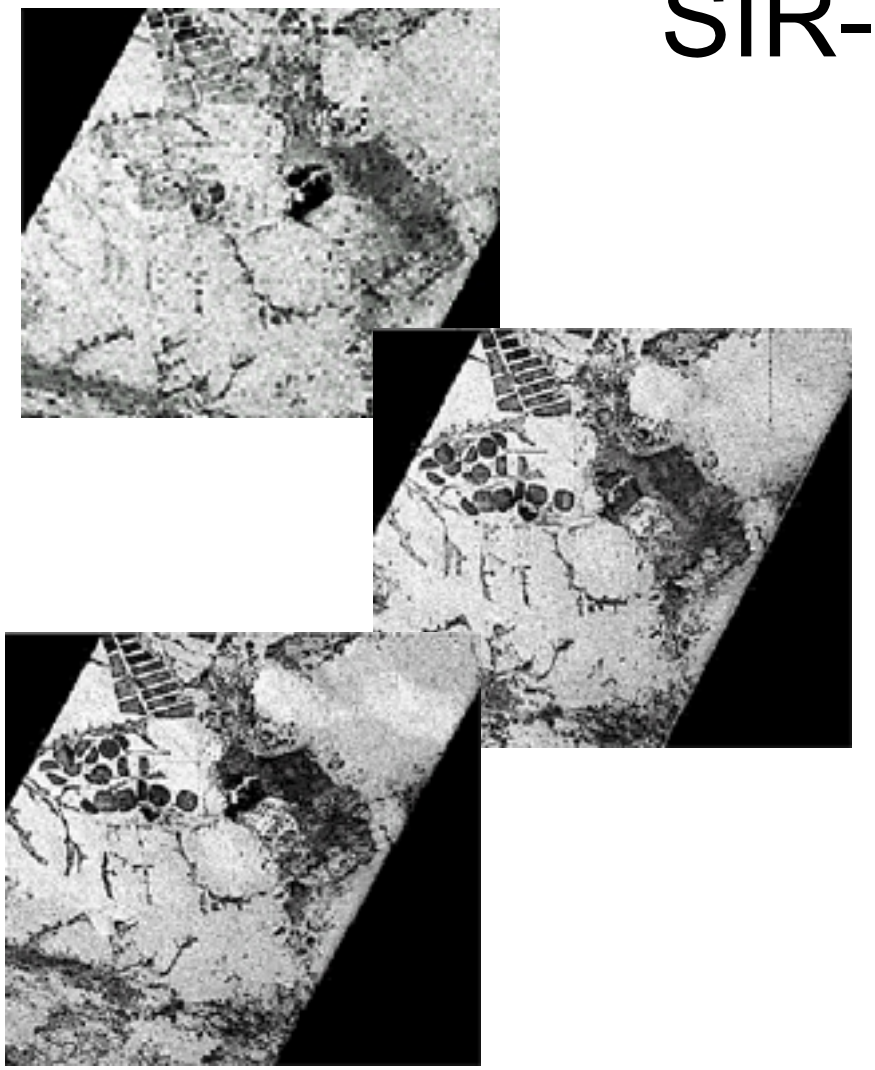
High Resolution Remote Sensing

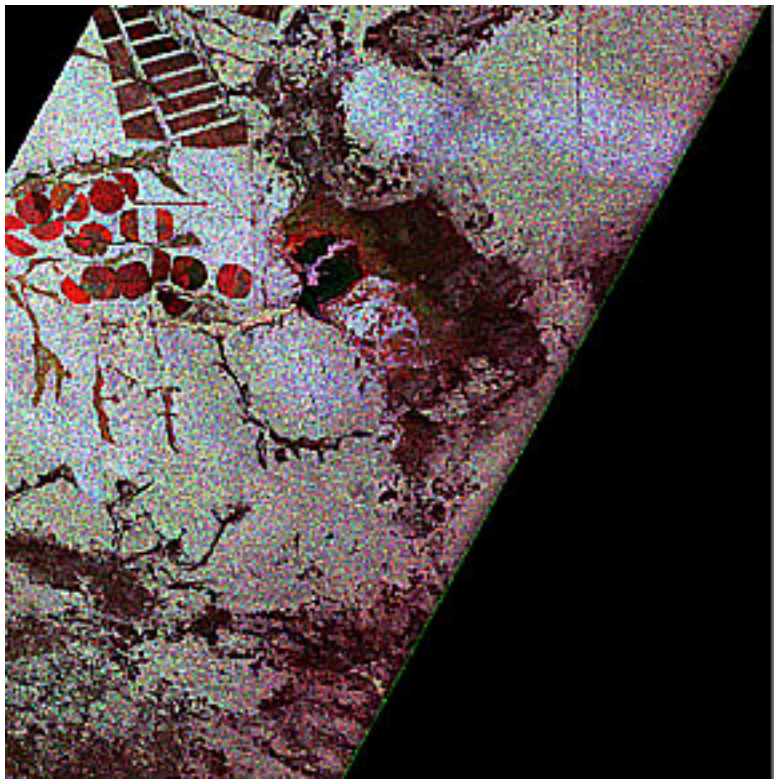
Database

Clickable Interactive Query of TM, JERS, and SIRC Data
Enter a name for map #:
October_94
Hit this button first
Draw Base Map
Choose a data Source:
TM
JERS
SIRC
Choose a Month(Required for TM and JERS):
all
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
Optional Fields:
Row
Path
SIRC Fields:
Flight
Path
Number 1
Number 2
Choose a color for polygons
red
magenta
dodgerblk
yellow
chartreuse
purple
Hit this Button to Draw Selected Data on Map
You can keep adding polygons with this button
Redraw Map
But if you want a new base map to draw on, click here
CLEAR and New Base Map
Dismiss Menu

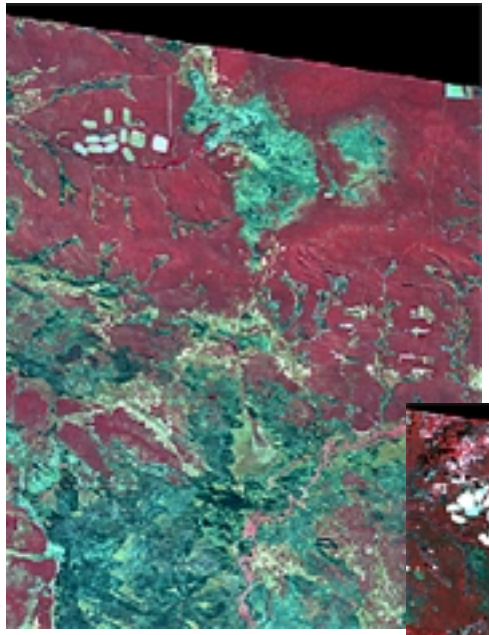

RUE, Rain Use Efficiency
of South Central Africa with overlays(TM, JERS, SIRC)
TM JERS SIRC

SIR-C

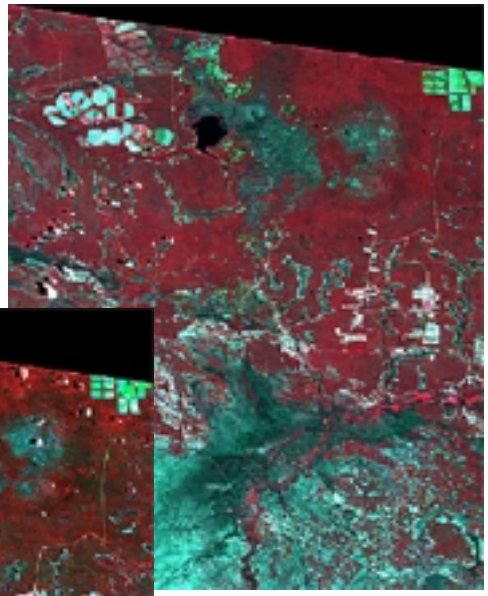




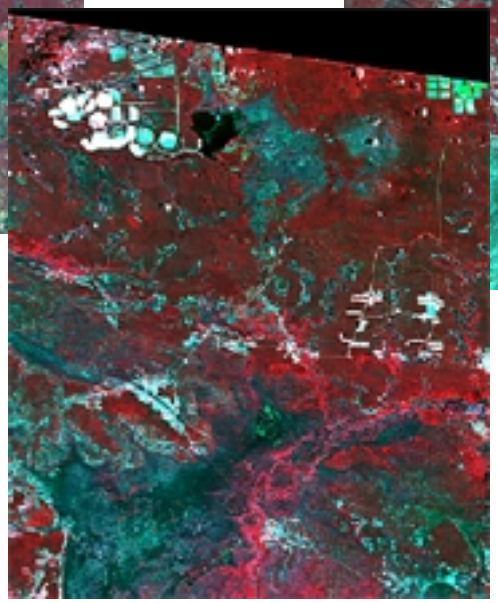
- 3 TM images & SIR-C 3-band image of Muncumpua, Zambia



1984

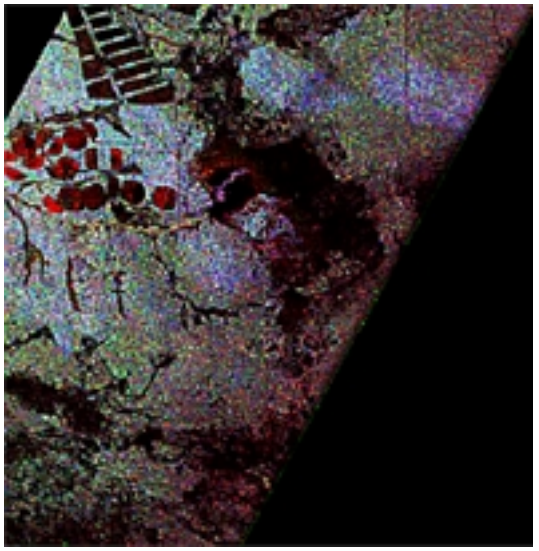


1994



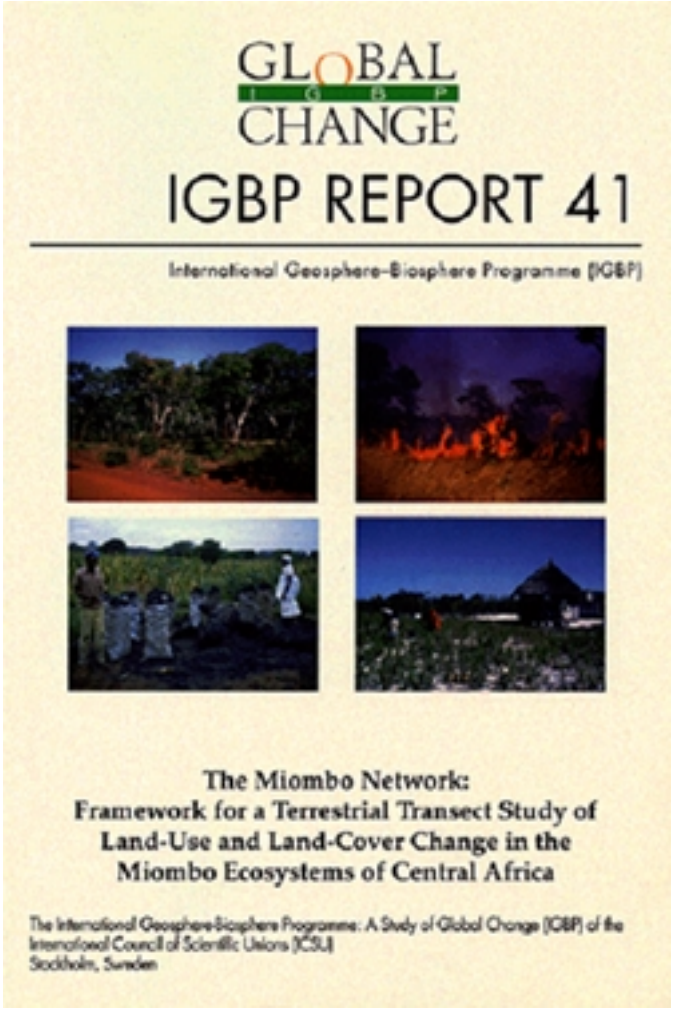
1986

SIR-C



Field Studies

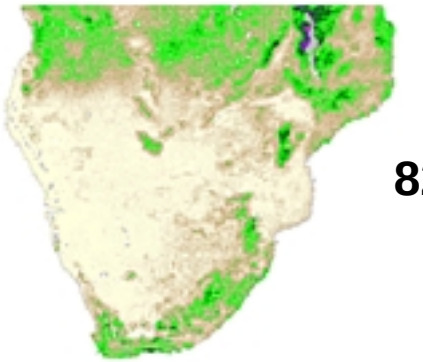
Miombo Network



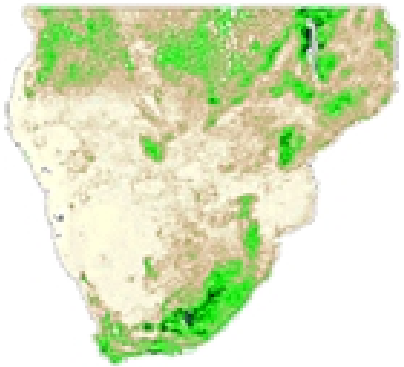
Net Primary Production

Results: NPP

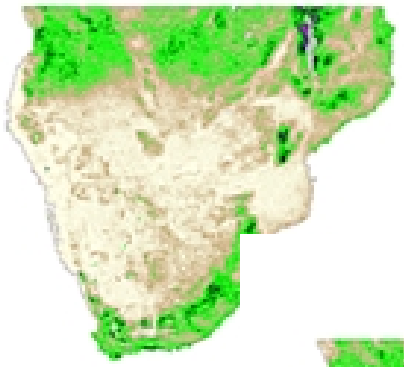
7 years NPP



82-83



88-89



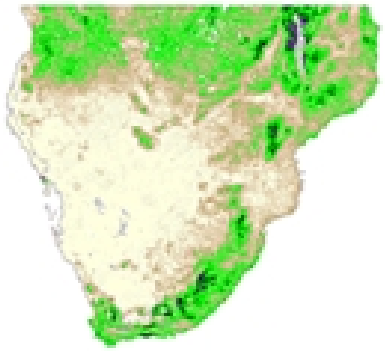
83-84

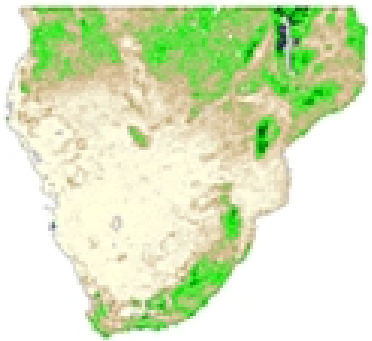
87-8_

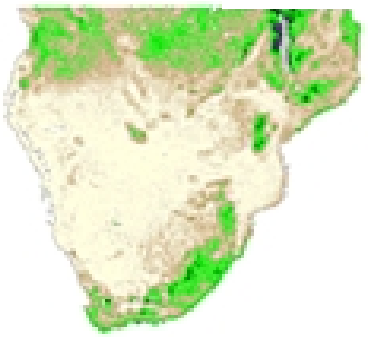
84-85

85-86

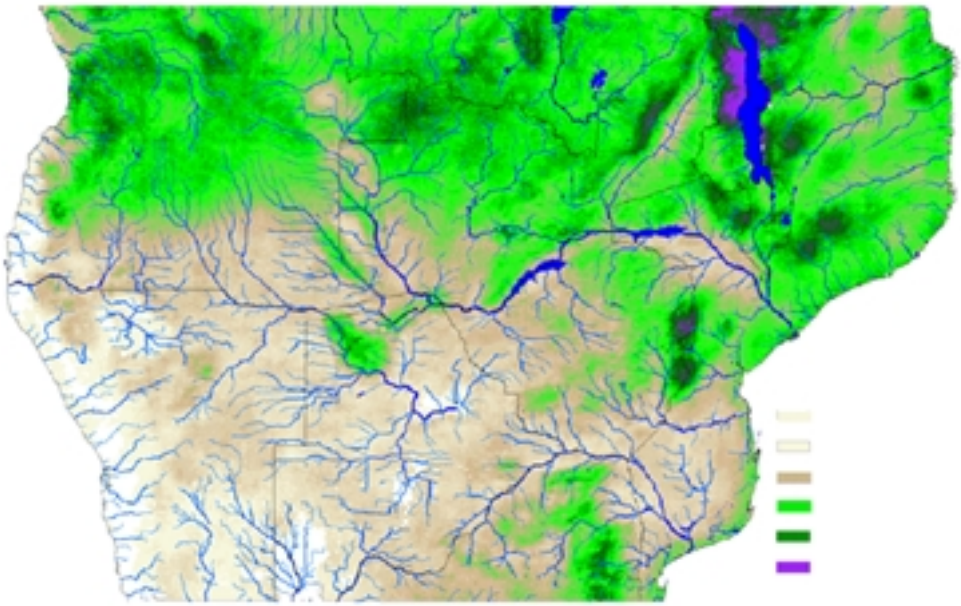
86-87







Mean NPP

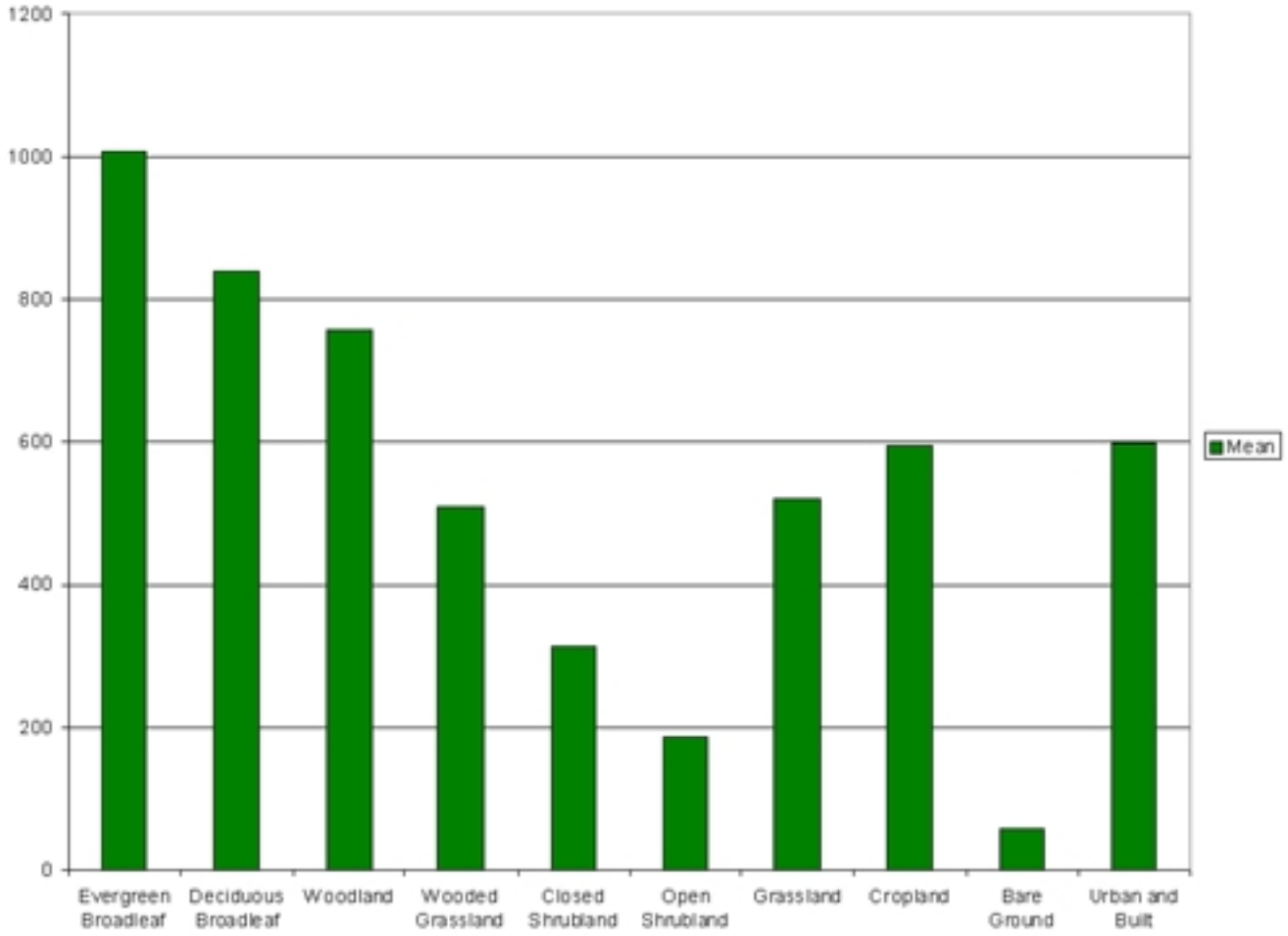


Mean NPP from 1982 to 1989

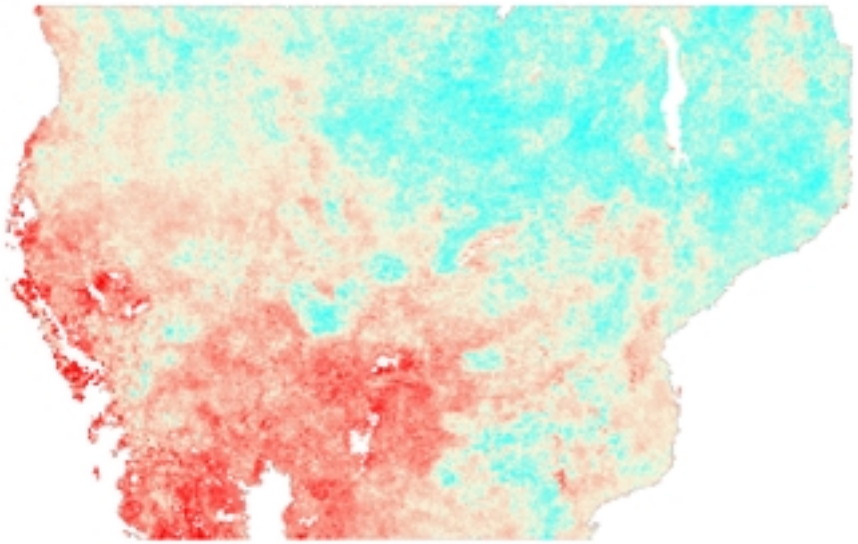
NPP g/m2/yr
7
118
452
780
1014
1500

Results: NPP

Mean npp by land cover class



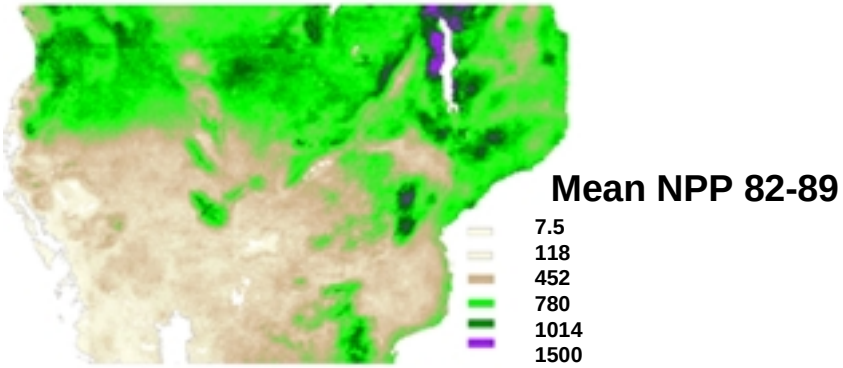
Coefficient of Variation of interannual NPP



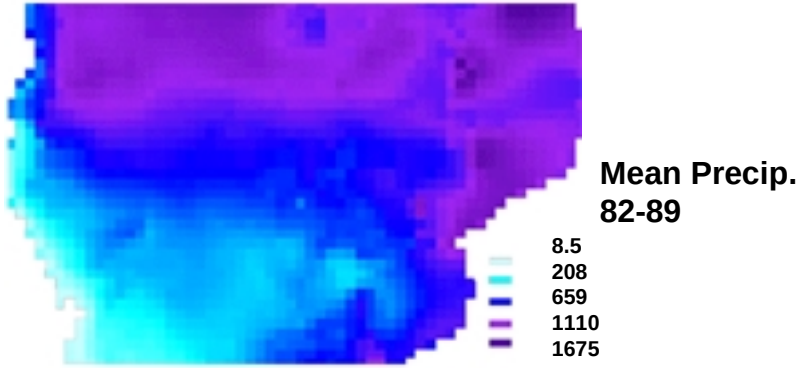
RUE- overall assessment of performance as a measure of degradation

Normalizing effect of rainfall on regional NPP

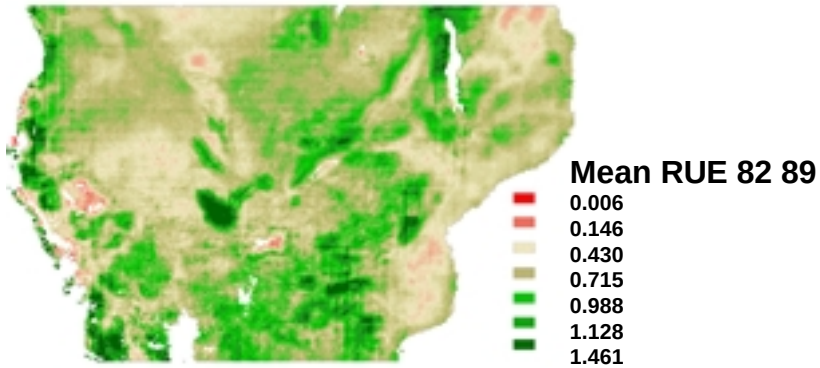
Mean NPP



Mean precipitation

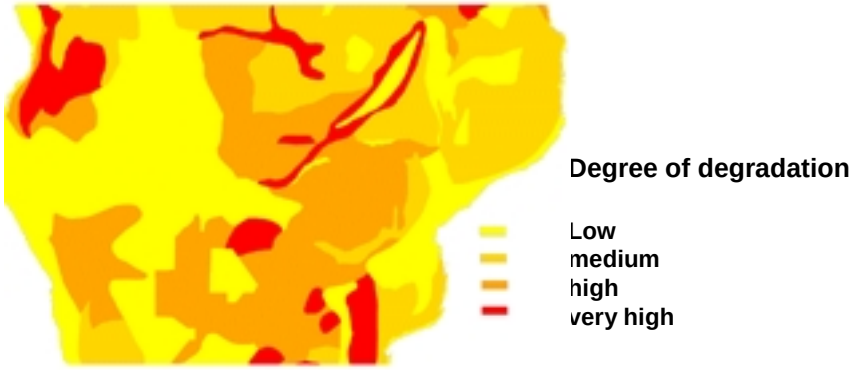


Mean RUE

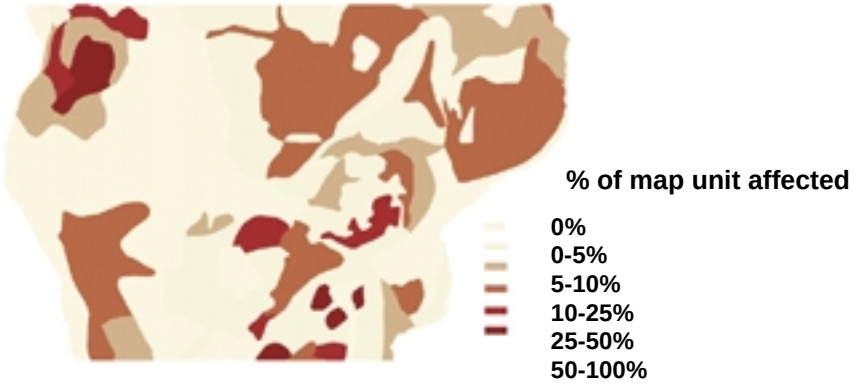


Areas of agreement, low RUE

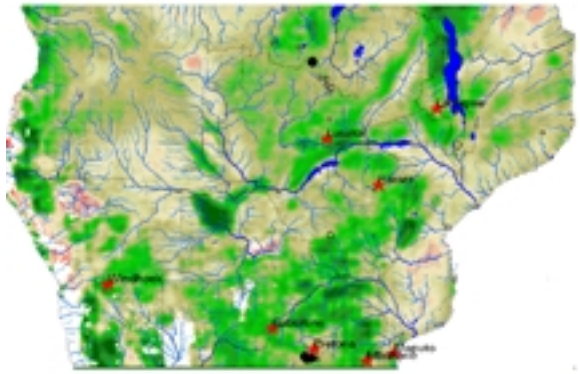
Degree of human induced soil degradation



Extent of human induced soil degradation

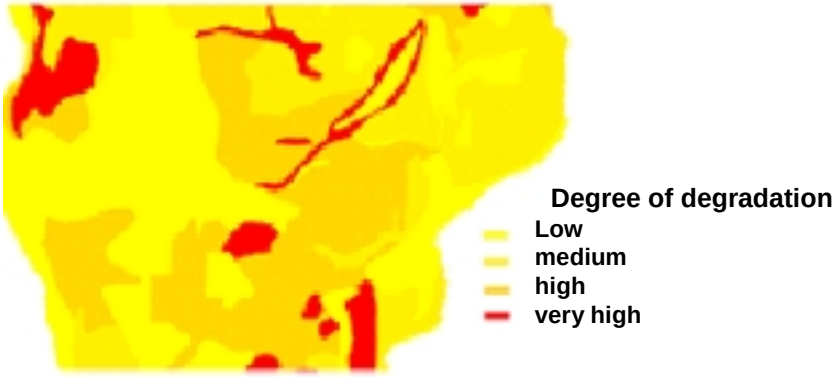


1. Congo Shaba Province
2. Zambia Copperbelt
3. Botswana NE, Mkgadikgadi
4. Nambia N Windhoek
5. RSA N of Mbabane, Pretoria
6. Zimbabwe N & E borders
7. Angola Huambo

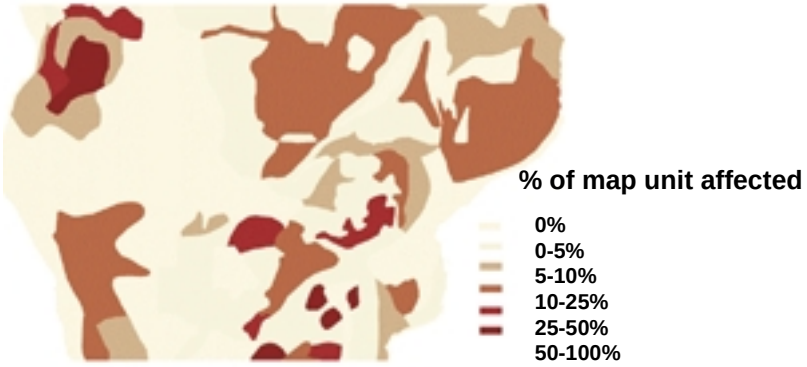


Areas of agreement, high RUE

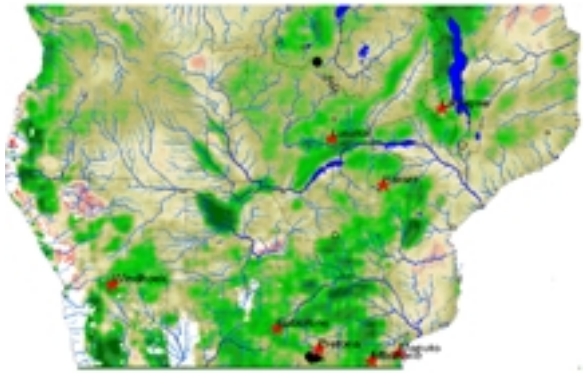
Degree of human induced soil degradation



Extent of human induced soil degradation

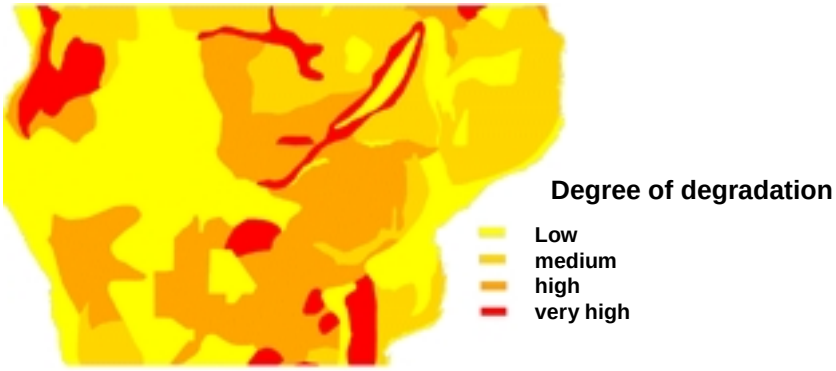


1. Malawi N Province
2. RSA Nylsstroom Transvaal, N Drakensberg
3. Zimbabwe Metabeleland
4. Namimia E of Windhoek

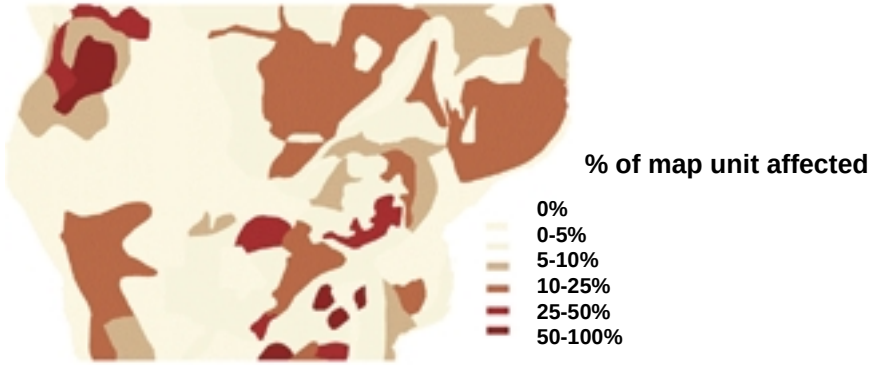


Areas of Disagreement
RUE low/GLASOD not degraded

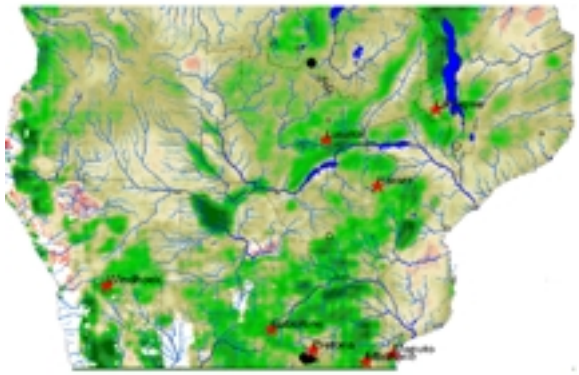
Degree of human induced soil degradation



Extent of human induced soil degradation

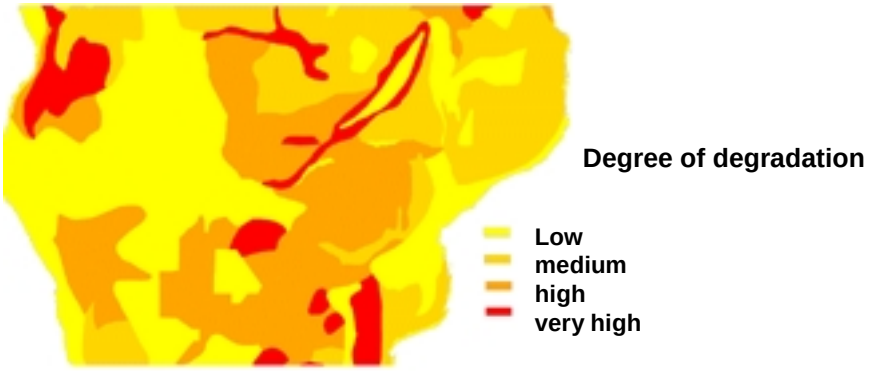


1. Zambia Luangwa Valley
2. Mozambique Tete Province
3. Botswana Chobe Province
4. Nambia/Angola Herero/Cubango
5. Mozambique Sofala-Imhambane

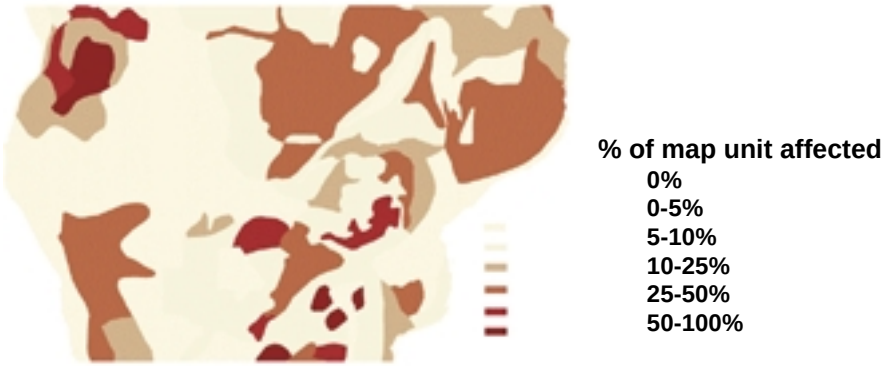


Areas of Disagreement
RUE high/GLASOD degraded

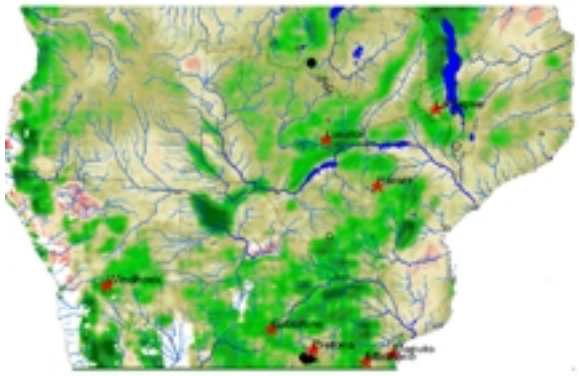
Degree of human induced soil degradation



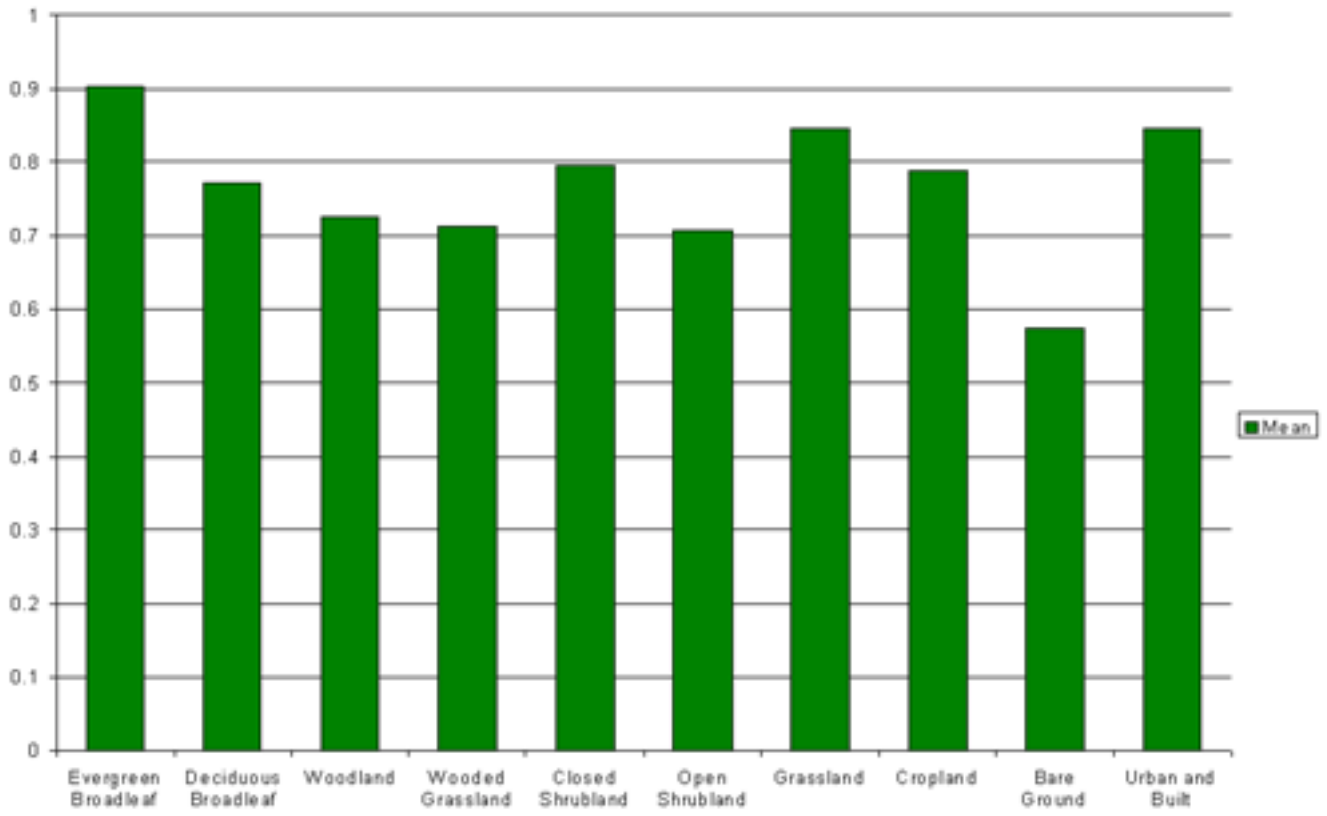
Extent of human induced soil degradation



1. Zambia, Luangwa Valley escarpments



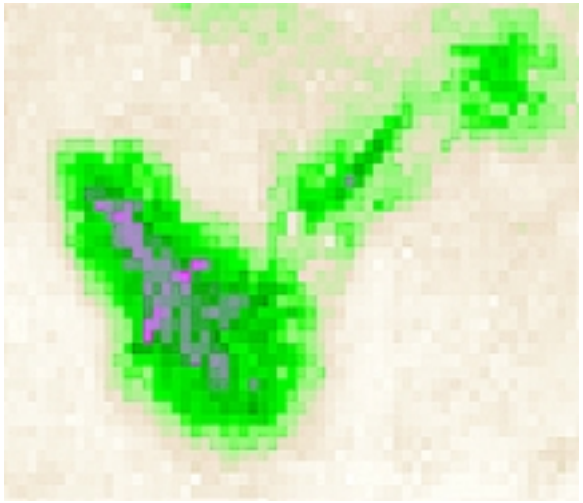
Mean rue by land cover class



Interpretation of rue in southern central Africa

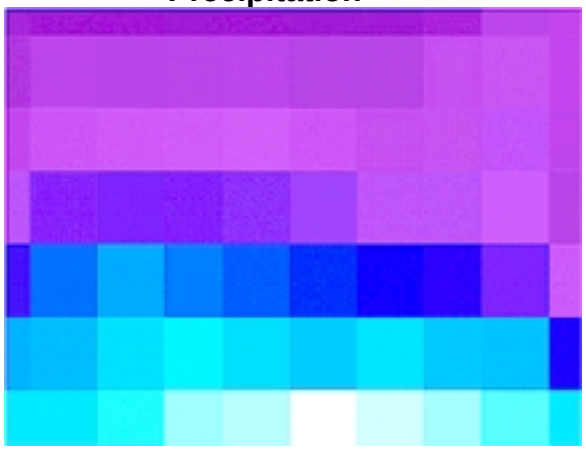
Results: RUE

Not degraded: high rue caused by run-on of water from elsewhere

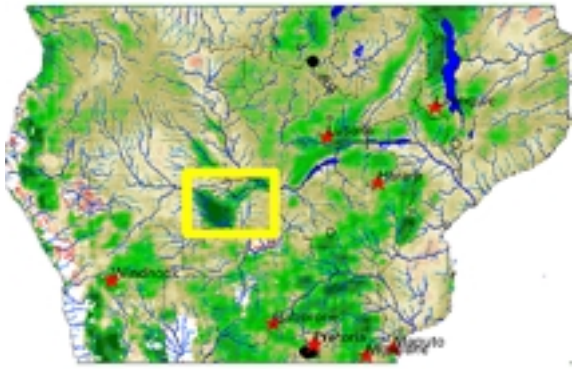


NPP

Precipitation

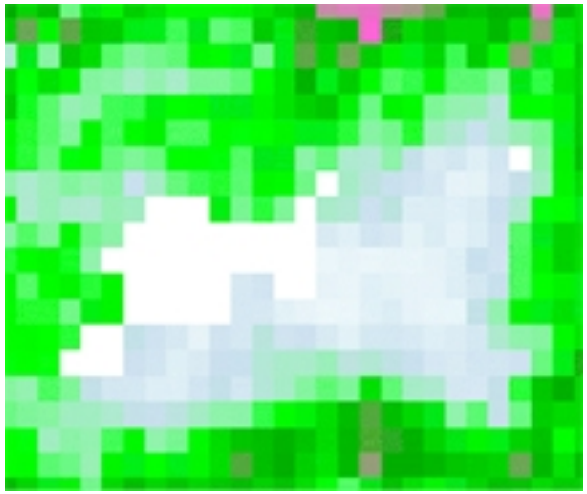


RUE



Results: RUE

Degraded: naturally susceptible regions Mkgadikgadi pans region



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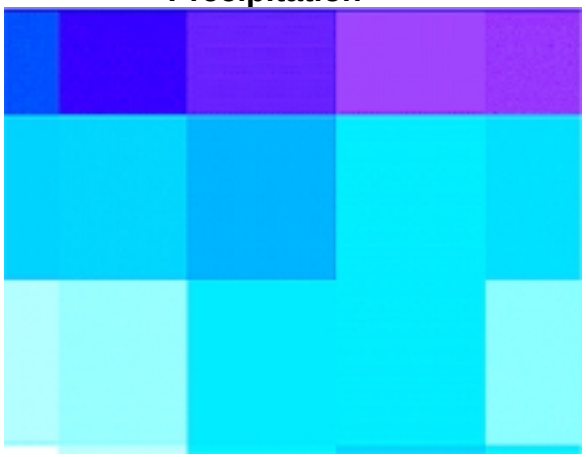
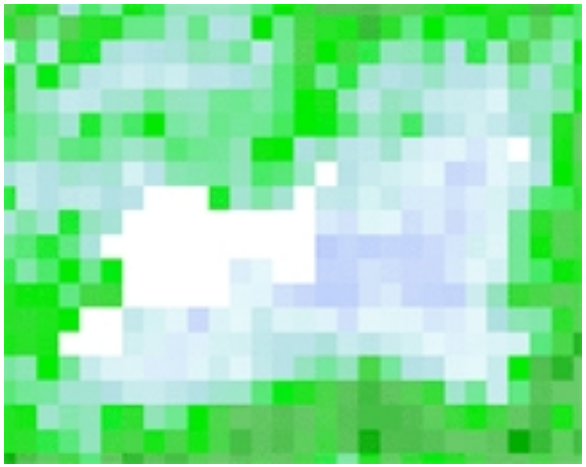
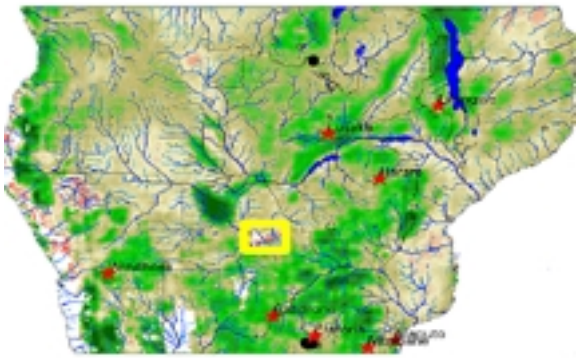
Precipitation





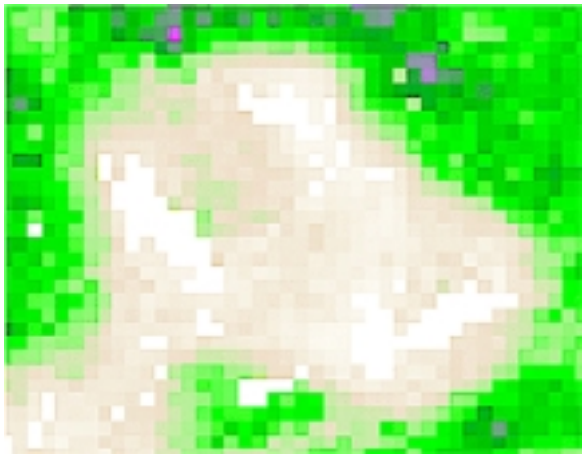
RUE

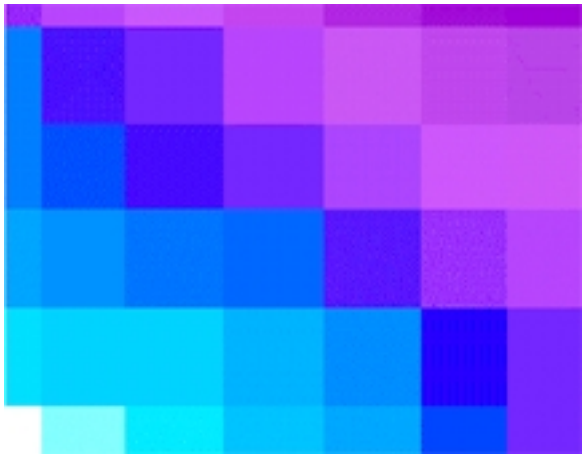


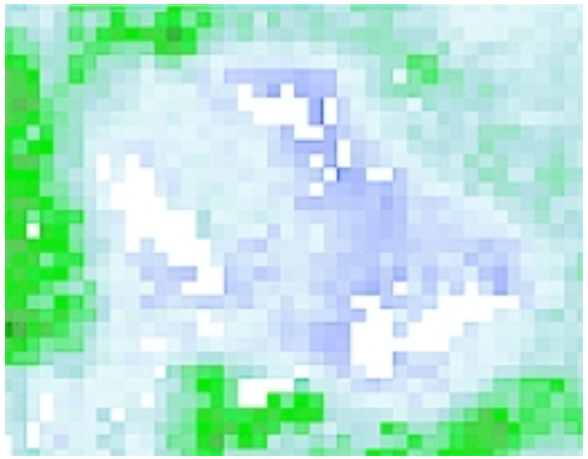
Results: RUE

Degraded: naturally susceptible regions Etosha pan region

Precipitation

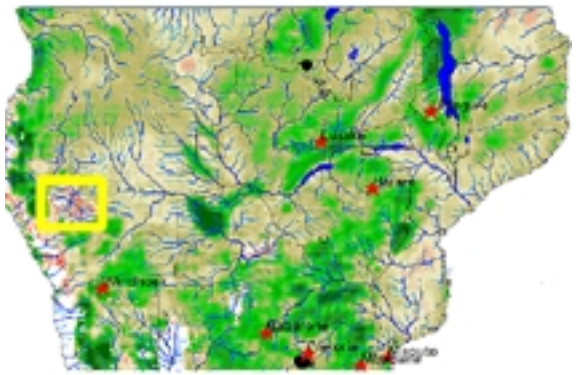






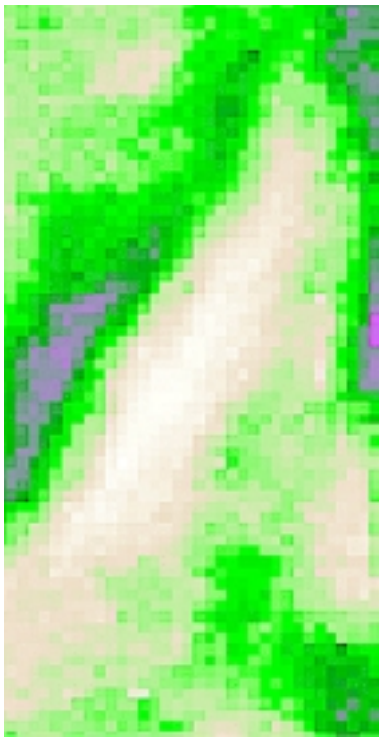
RUE

NPP



Results: RUE

Degraded: naturally susceptible regions Luangwa valley



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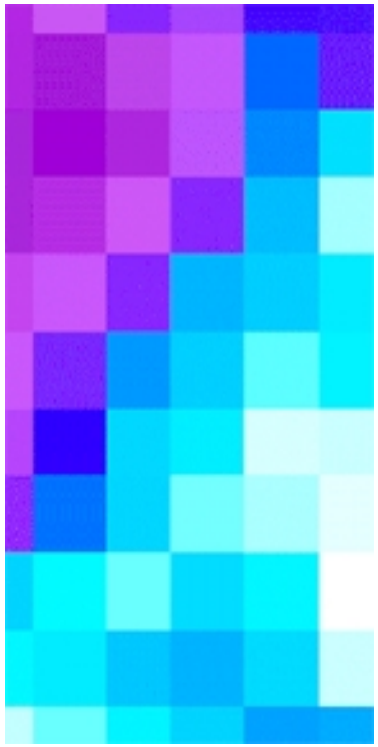
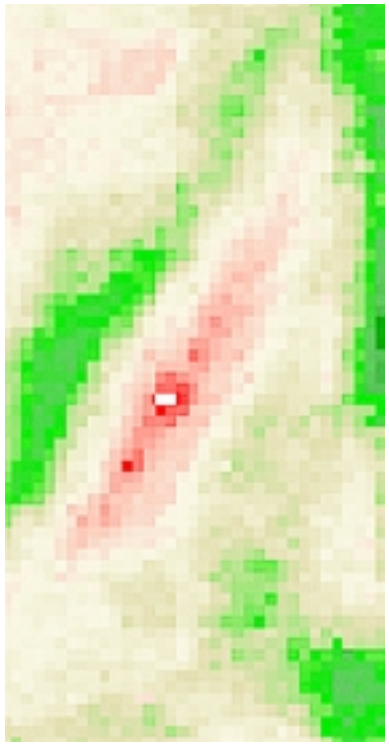


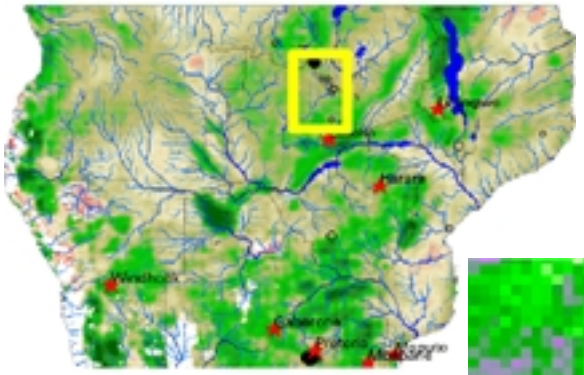
Precipitation

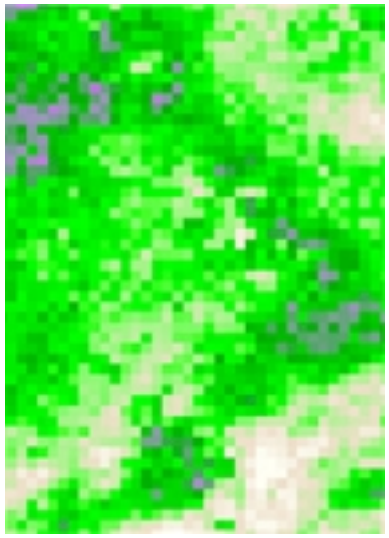


RUE

Results: RUE

Degraded: human induced Zambian Copperbelt





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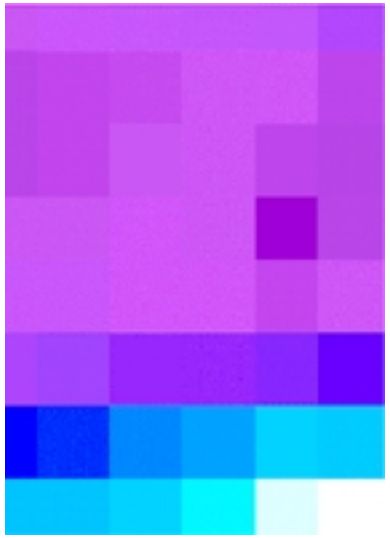

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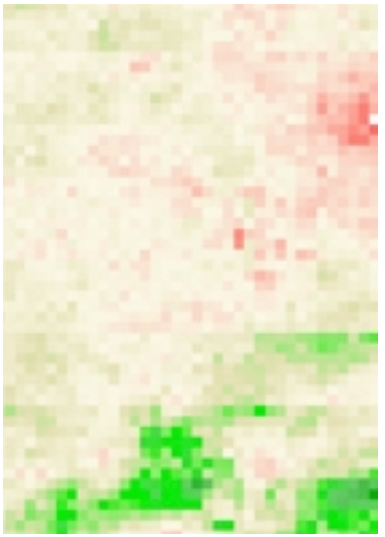
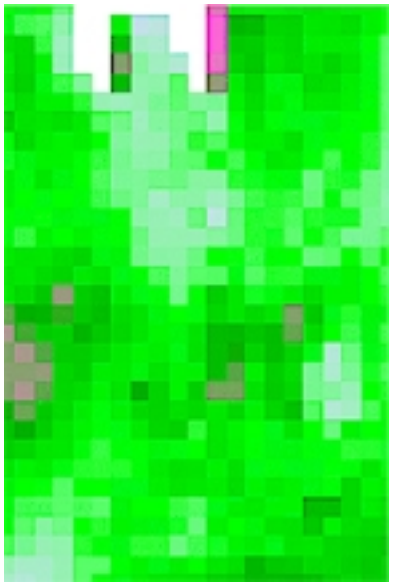


RUE

Results: RUE

Degraded: human induced Malawi Namwera highlands



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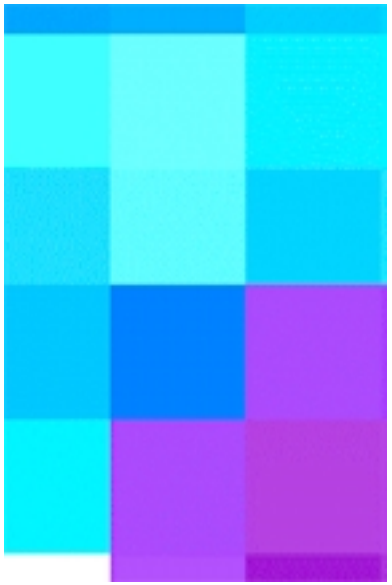

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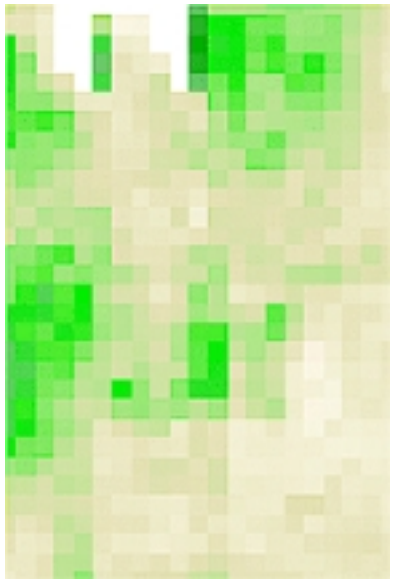
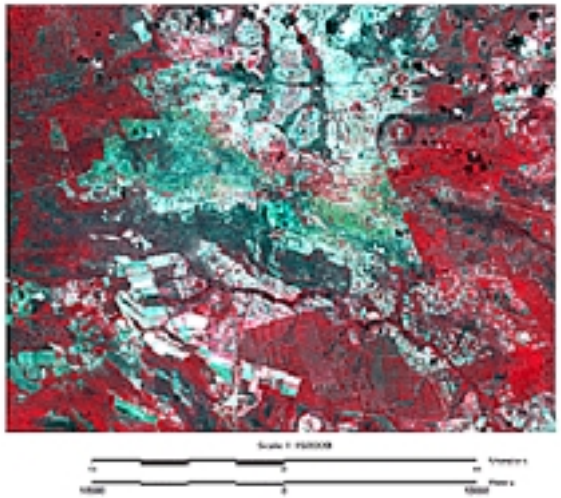


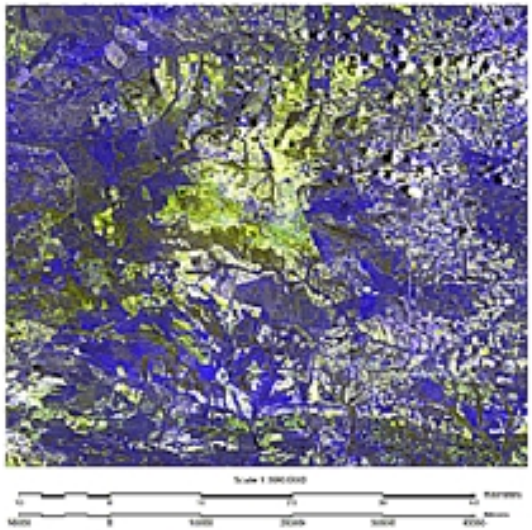
RUE

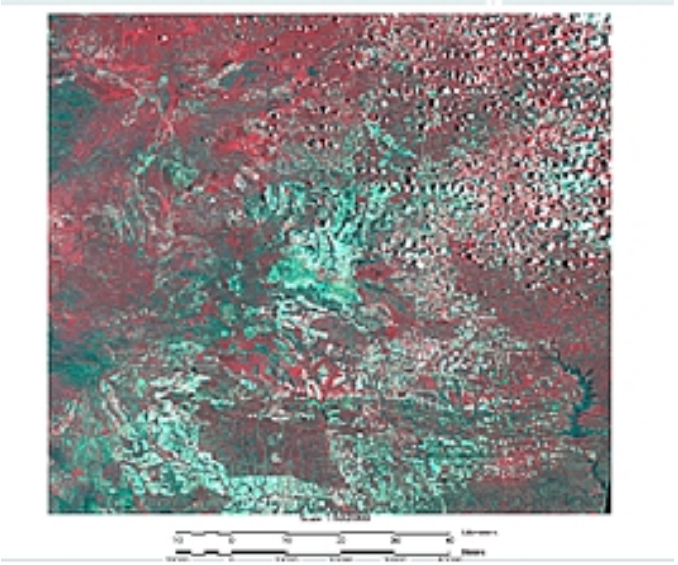
High Resolution Degradation Features

Degradation at Kabwe, Zambia

- 1986 17 Nov TM







Next Steps

Potential for local - Sub-national scale interpretation

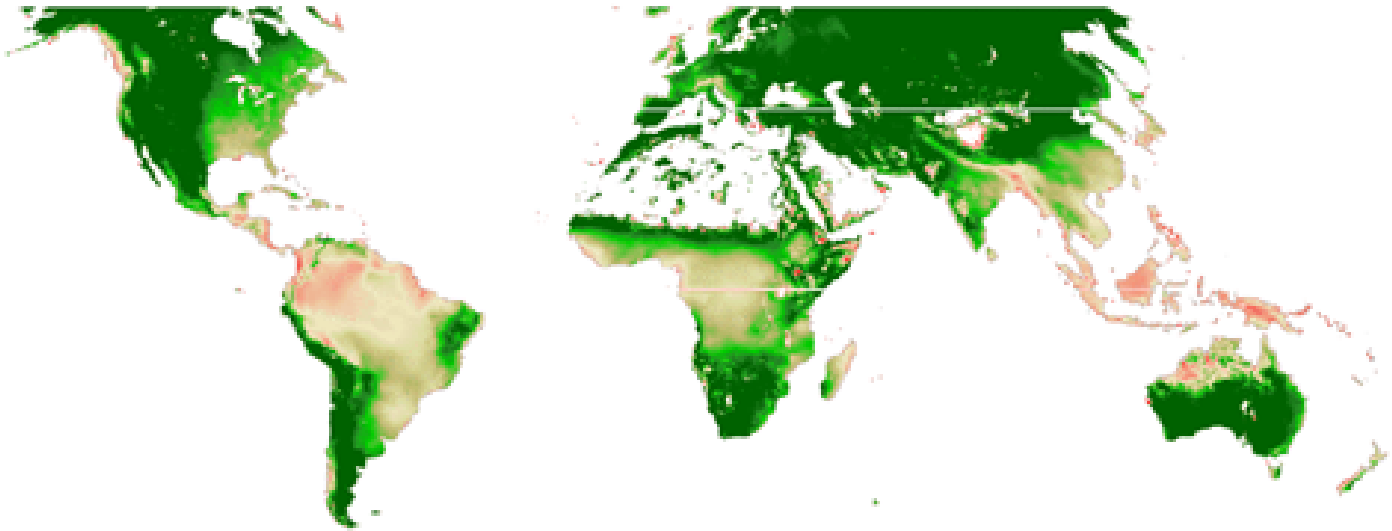
AIM FOR FINER SPATIAL RESOLUTION

- Rainfall data
  - Raingauge network
  - Geostationary meteorological satellite
  - Separate soil moisture and runoff from rainfall
- NPP
  - PAR 30-100 km multi-annual from METEOSAT
  - 1-8 km AVHRR or MODIS/ASTER data
- Air temperature
  - Diurnal Ta (METEOSAT)

Potential for field scale interpretation

- Comparisons with local degradation studies
  - Miombo network partners
  - Regional issues
    - e.g. Gwembe Valley, Botswana rangelands, Copperbelt
- Identify sources of site biophysical data
  - Local scale modeling
  - Comparison with coarse resolution satellite inferences
- Explore integrated assessments
  - Multiple resolution data sets for participants

Potential for global scale interpretation



Integrated assessment and degradation monitoring

Integrated Assessment

Strategy for addressing complex problems across scales

Land cover, land use in southern Africa

Integrated Assessment

Definition:

An interdisciplinary and participatory process
of combining, interpreting, and communicating
KNOWLEDGE from diverse scientific disciplines to
achieve a better understanding of complex phenomena

Integrated Assessment

Objective:
to arrive at an informed judgement

Relevant Information: physical, chemical, biological, psychological, socio-economic, and institutional phenomena

Integrated Assessment

Southern Africa

Example:

Gwembe Tonga - Lake Kariba region - Zambia
Building on work by Thayer Scudder and Elizabeth Colson

- Long historical record
- Focussed studies of agricultural traditions
- Forced migration
- Adjustment to new biophysical environment

Allocative Resources:
- Grazing Land
- Agricultural Land
- Livestock
- Crops

Authoritative Resources
- Decision-makers
- Land tenure
- Commercial crop vs subsistence

Integrated Assessment

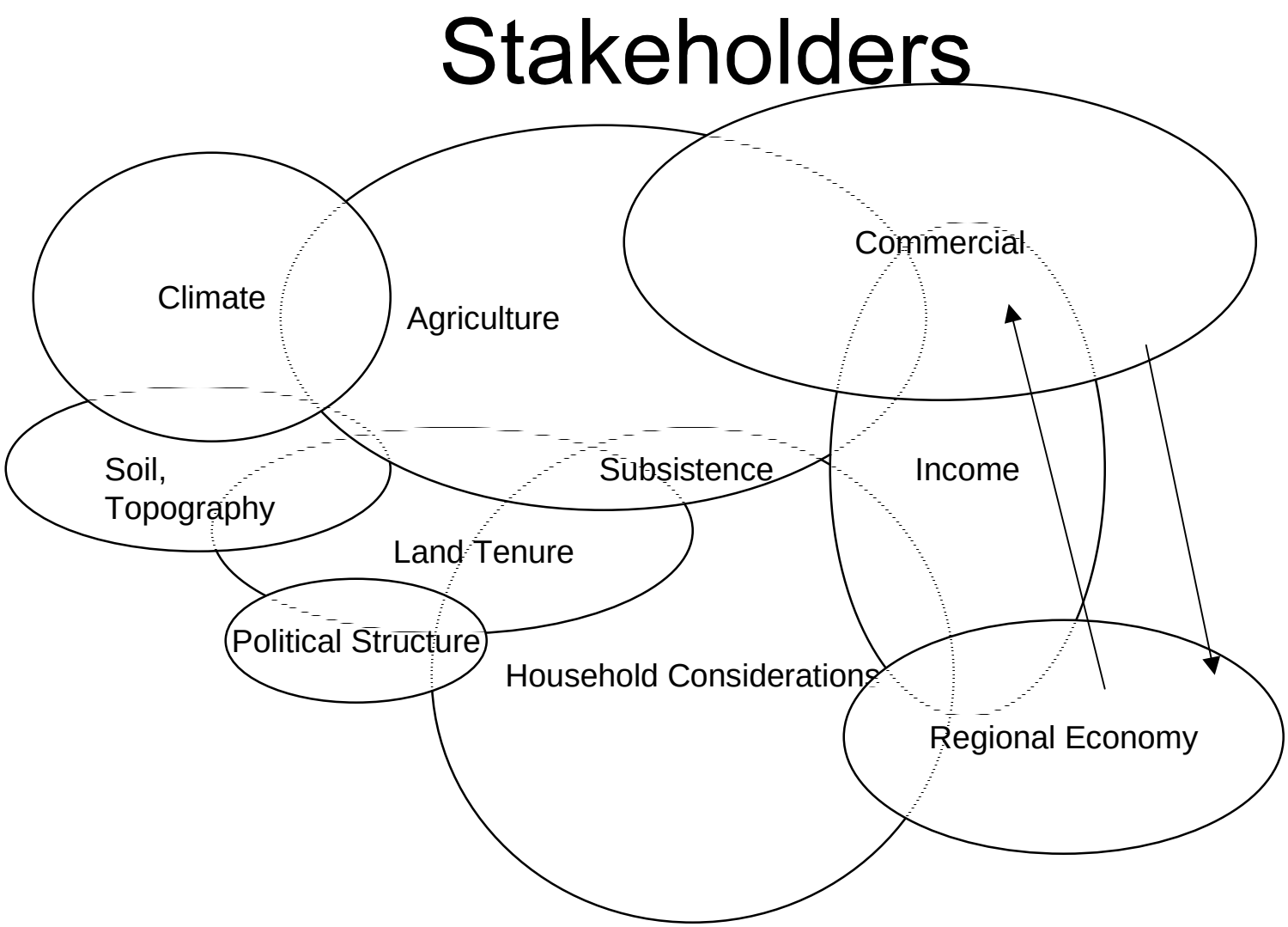
Methods

Existing Information or studies
Rapid Rural Appraisals
Participatory Rural Appraisals

Discussions with stakeholders in the local areas
•Focus on how they handle uncertainty and
•Issues of equity

Broad Categories
•regional economy
•conflict resolution
•government and NGO organizations
•Household interactions
•Agricultural networks

Integrated Assessment



Miombo LCLUC - LUC and Ecological Processes

Paul V. Desanker, PI; University of Virginia

Peter G.H. Frost, Co-PI; University of Zimbabwe

Collaborator:
Bryan Pijanwski, Michigan State Univ

Students:
Malanding Jaiteh, Michigan Tech Univ
Sarah Walker, Univiversity of Virginia
Daniel Semwayo, University of Zimbabwe

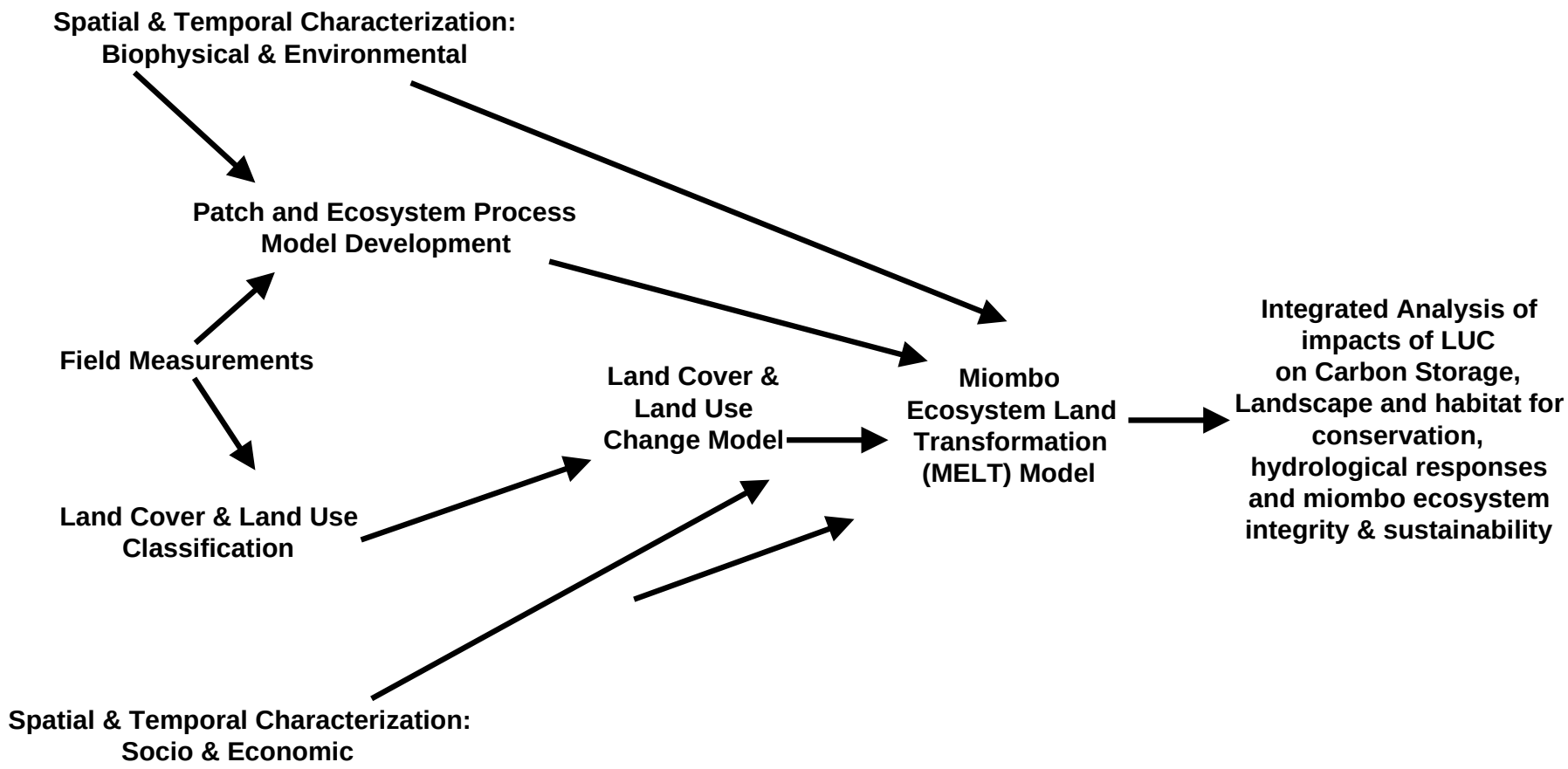
Miombo NASA LCLUC Project Objectives

- To analyze land cover changes as driven by land use change in miombo ecosystems by *integrating* analyses of remotely sensed data, field measurements of land cover and land use attributes, and socio-economic drivers, at selected study sites in southern Central Africa;

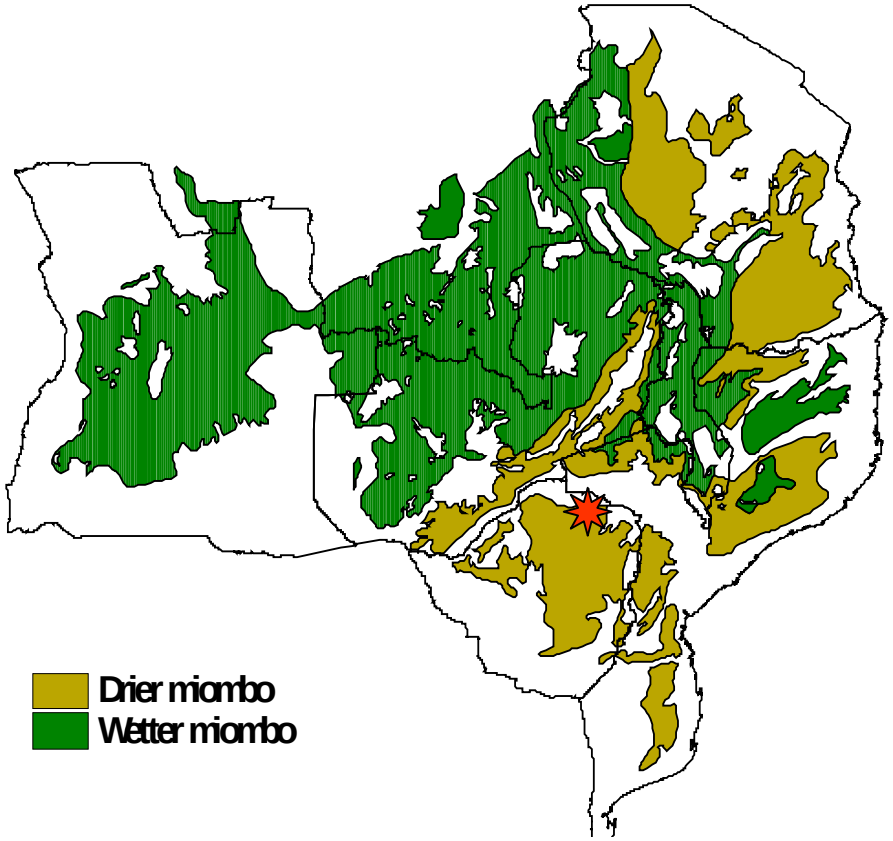
- To develop an ecological model for miombo to evaluate effects of disturbance on vegetation development (including human induced disturbance such as fire, and use; and

- To develop an integrated model that couples miombo ecosystem dynamics with land use and socio-economic drivers

The Miombo Ecosystem Land Transformation (MELT) Model: Linkages



The Miombo Region and White (1983) Vegetation Types



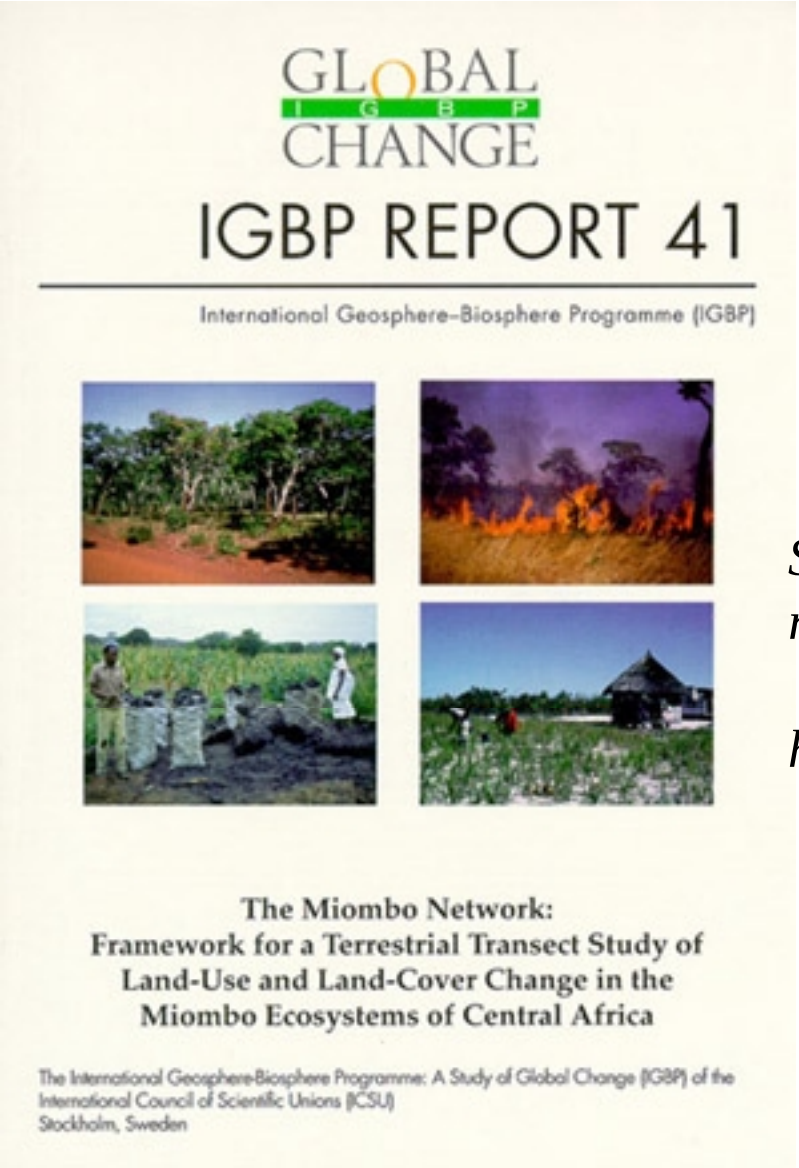
The Miombo Network

The Miombo Network is a regional alliance of researchers working on land use and land-use change in the miombo region of Central Africa, under the auspices of the IGBP/IHDP Land Use and Cover Change (LUCC) Project and the IHDP/IGBP/WCRP Global Change System for Analysis, research and Training (START)

Members in Africa include government, university and research institutions in DRC, Malawi, Mozambique, Tanzania, Zambia and Zimbabwe. Elsewhere, members include Universities, research institutions and NGOs in the U.S., Europe and Australia.

Main sponsors include NASA, WWF, START, LUCC and DIS.

A joint science agenda was developed under the central theme of *land use and land-use changes* and their consequences, and is available as IGBP Report 41.



edited by: Desanker, Frost, Scholes, Justice (1997), *Available from IGBP in Stockholm, START, or from the authors, can request via the Miombo Web Page at:*

http://miombo.gecp.virginia.edu

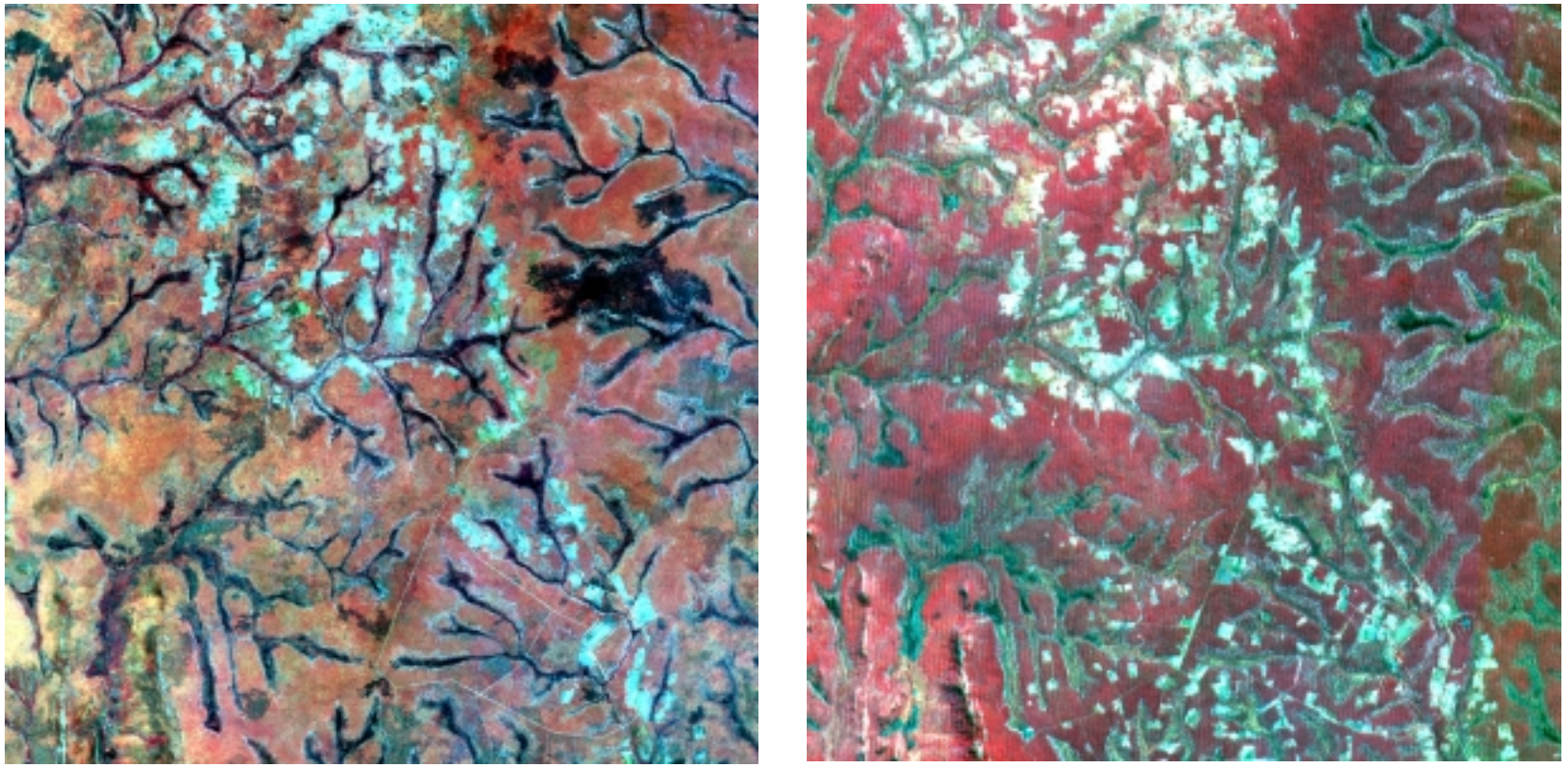
Different States of Miombo from intact woodland to tree-grass mixtures, in response to fire

Rural populations depend on miombo for wood and construction

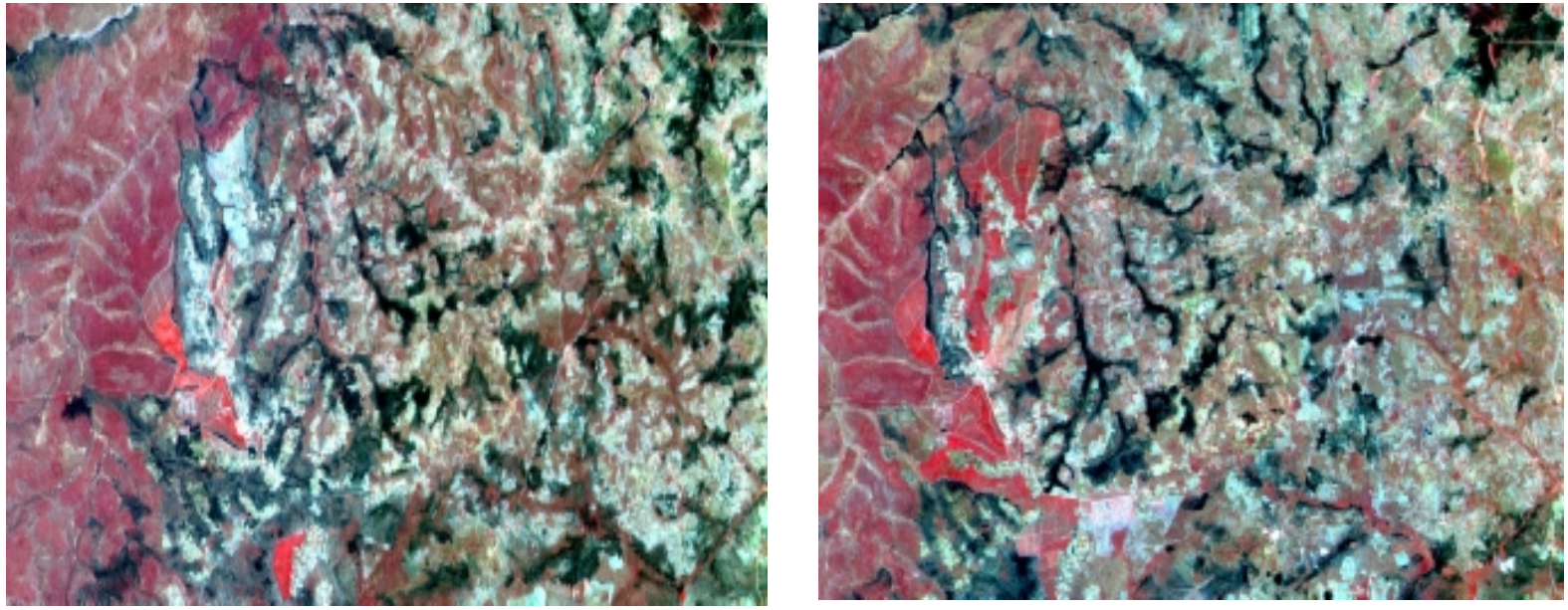
Miombo Wood Used to Make Charcoal, Charcoal Transported to City for Sale

Woodland is Slashed and Burnt for Agriculture, FieldsCoppice Profusely

Wood Sold for Firewood, Woodland Recovers if Abandoned

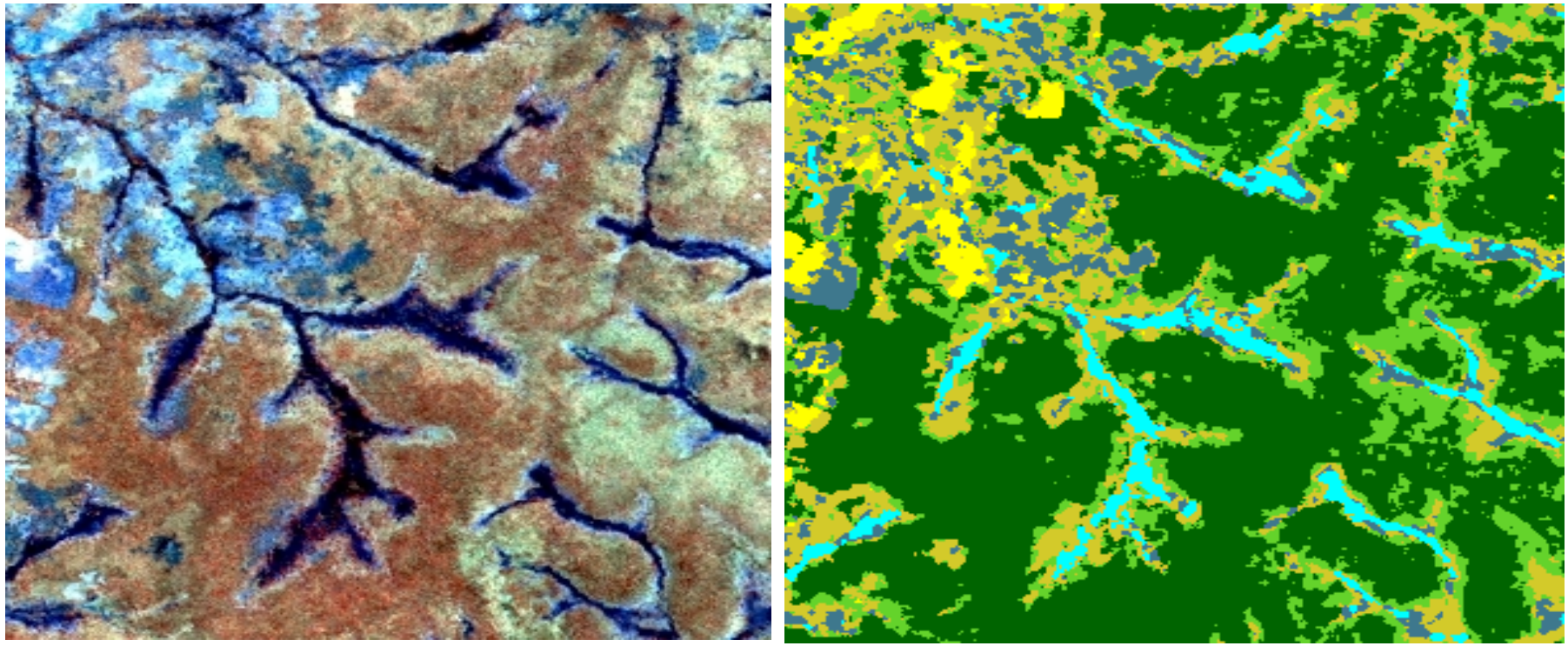


Land cover changes in north east Zambia (Kasungu National Park -KNP, Malawi is on right), based on SPOT XS from Oct 1987 (late dry season) and June 1994 (cool and dryish). Notice typical dambo landscape, fire scars, and agricultural expansion with time. Also note very little encroachment in the KNP.



Kasungu, Malawi, 1987 (left), 1992 (right) - dry season images - lots of fires. This is in fire-cured tobacco area, notice forest reserve area intact on left

Landsat TM False color composite of Miombo Landscape showing Dambos and Burn Scars on left, classified image on right (Jaiteh method): woodland, grassland, water/scars, cultivated/bare



Coppicing likely increases above ground biomass, below-ground components likely significant stores of biomass - regional impacts wrt Carbon stocks largely unknown

Baseline Land Cover/Land Use Maps - Historical - 1990/1 - Harmonize national products into regional map

Data Sources for Regional Mapping

Country	Data
Mozambique	**Visual classification of 1992-93 Landsat TM supplemented with low-level aerial sampling. Completed 1995**
Zimbabwe	**Visual classification of Landsat TM, 1992-93. Intensive field inventory in 1995. Mapping Completed 1996**
Malawi	**Visual classification of 1991-92 Landsat TM with field checks in 1993.**
Tanzania	**Visual classification of 1992-93 Landsat TM. Mapping completed 1996.**
Zambia, Angola	***In progress – partial coverage available, may use new L7 to develop new maps or use 1 km products***

Miombo Regional Classification System for Vegetated Land Covers (after Zimbabwe System)

		Height		
	>15m	15-5m	5-1m	<1m
Canopy Cover				
100-70%	Nat Forest			
100-70%	Forest Plantation	Forest Plantation	Forest Plantation	
70-20%		Woodland	Bushland	
20 - 2%	Wooded Grassland	Wooded Grassland	Bushland Savanna	
<2%	Grassland	Grassland	Grasland	

UMD (DeFries et al.) and Miombo Regional Legends

UMD Classes

0 WATER (and Goode's interrupted space)
1 EVERGREEN NEEDLELEAF FOREST
2 EVERGREEN BROADLEAF FOREST
3 DECIDUOUS NEEDLELEAF FOREST
4 DECIDUOUS BROADLEAF FOREST
5 MIXED FOREST
6 WOODLAND
7 WOODED GRASSLAND
8 CLOSED SHRUBLAND
9 OPEN SHRUBLAND
10 GRASSLAND
11 CROPLAND
12 BARE GROUND
14 URBAN AND BUILT-UP

Miombo Classes

1 Natural Forests
2. Plantations
3. Woodlands
4. Bushlands/thickets
5. Wooded grassland
6. Grassland/Dambos
7. Barren areas
8, Water
9. Swamps and Marshes
10. Cultivated Land
11 Builtup area

Land Use and Land Cover Map of Tanzania

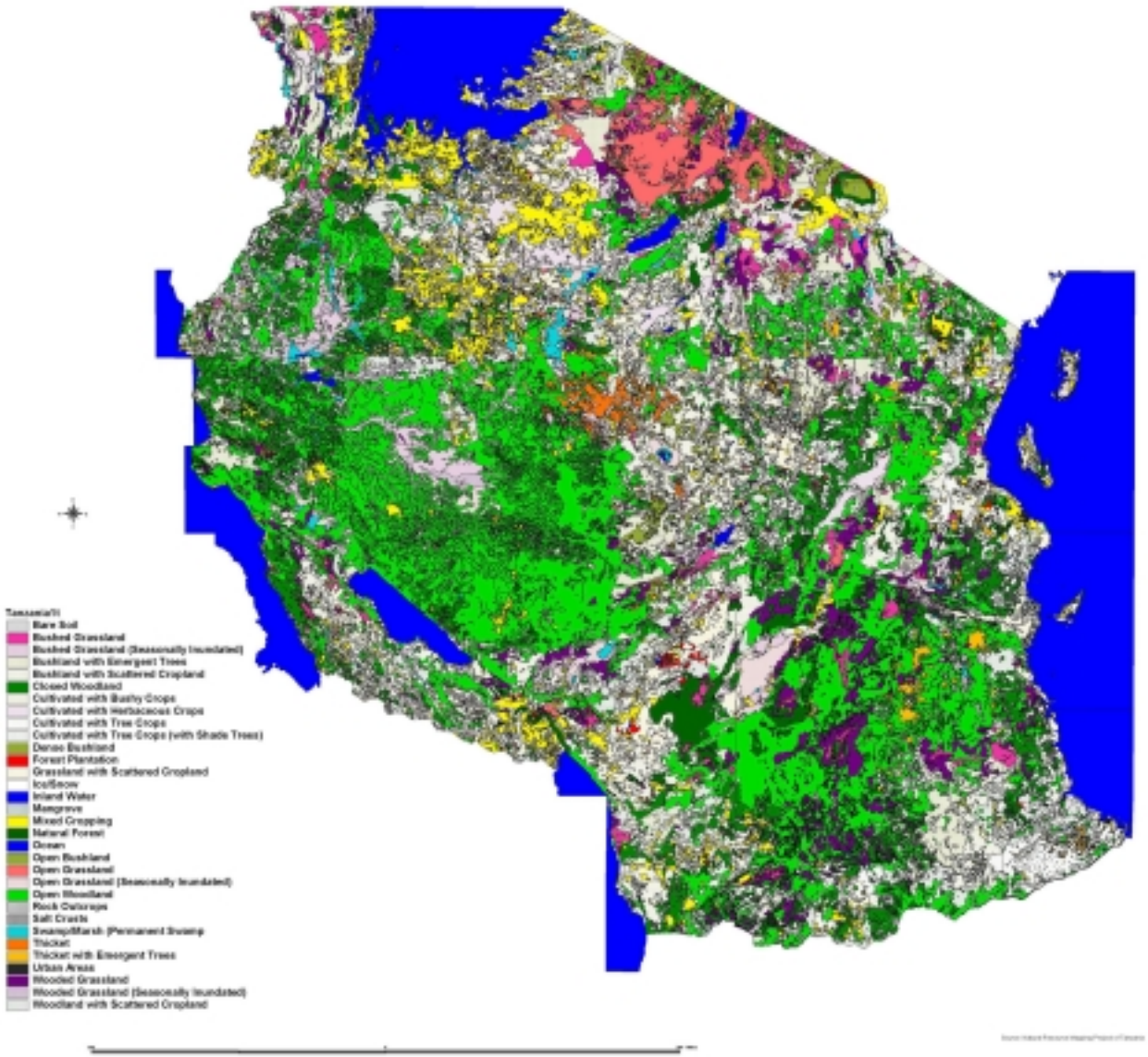
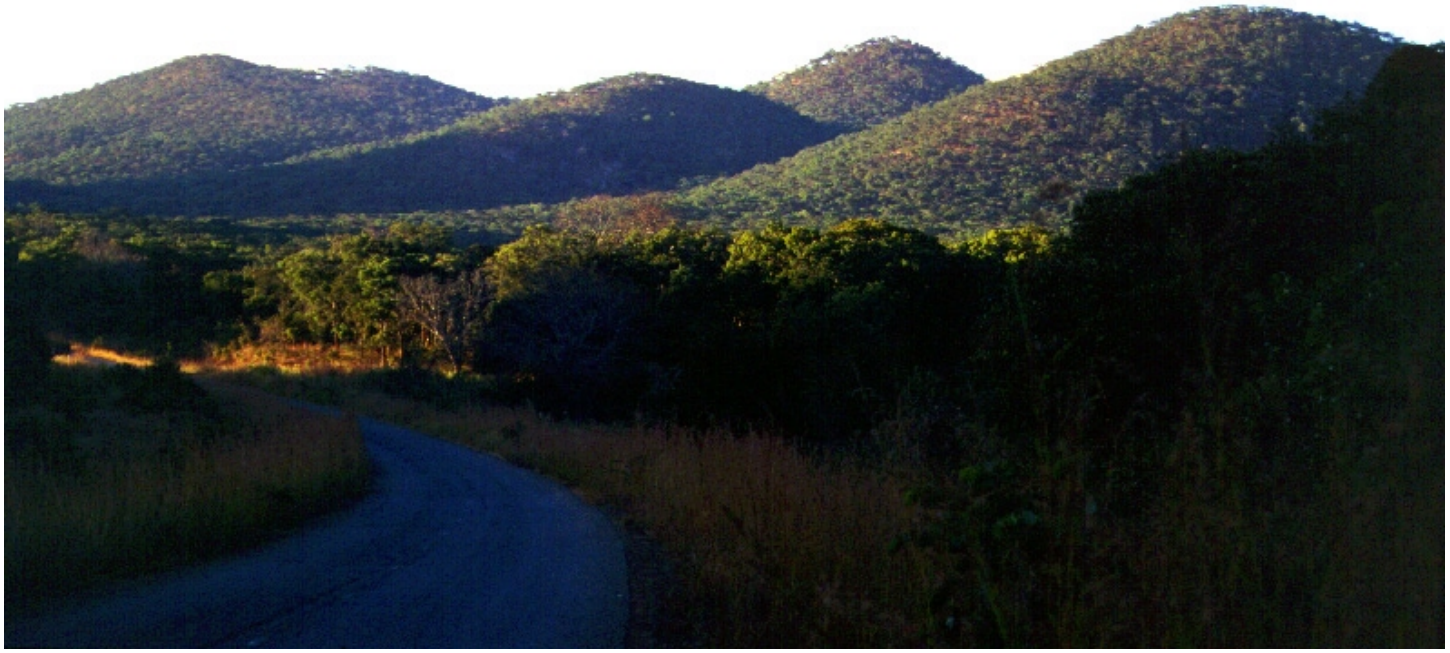
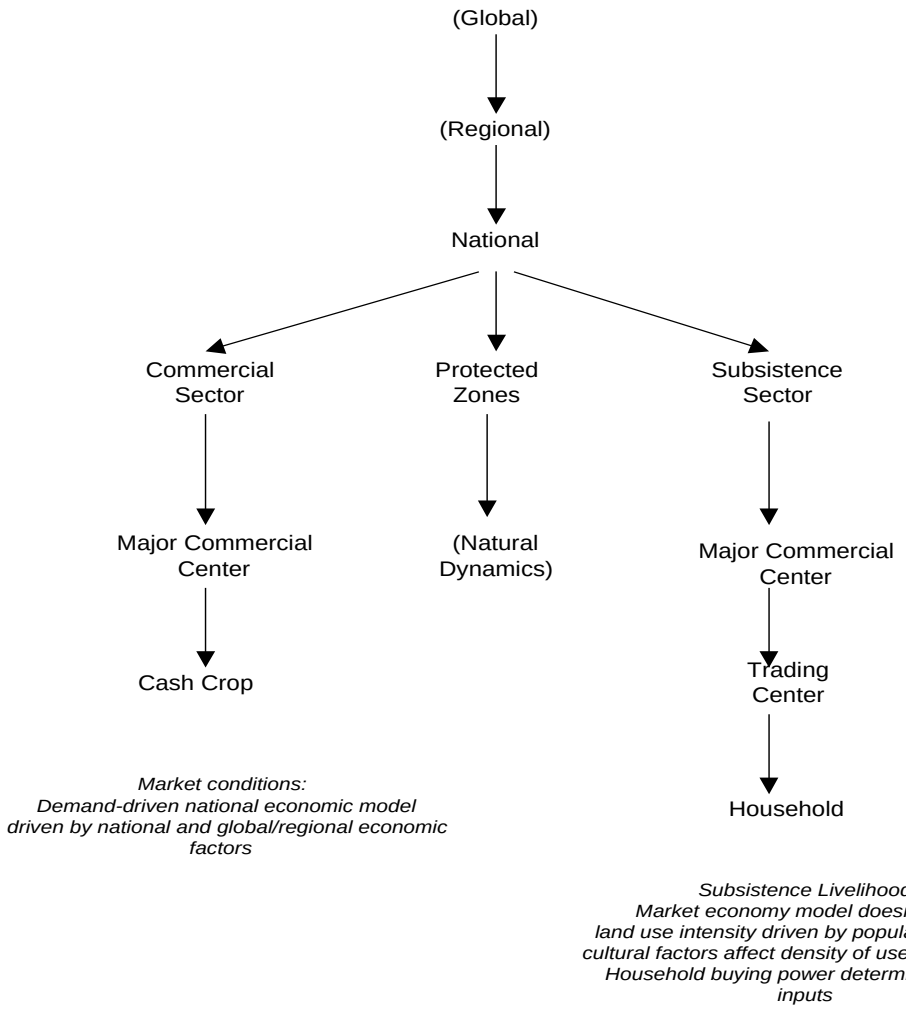


Image Classification and Patterns of Land Cover/Land Use

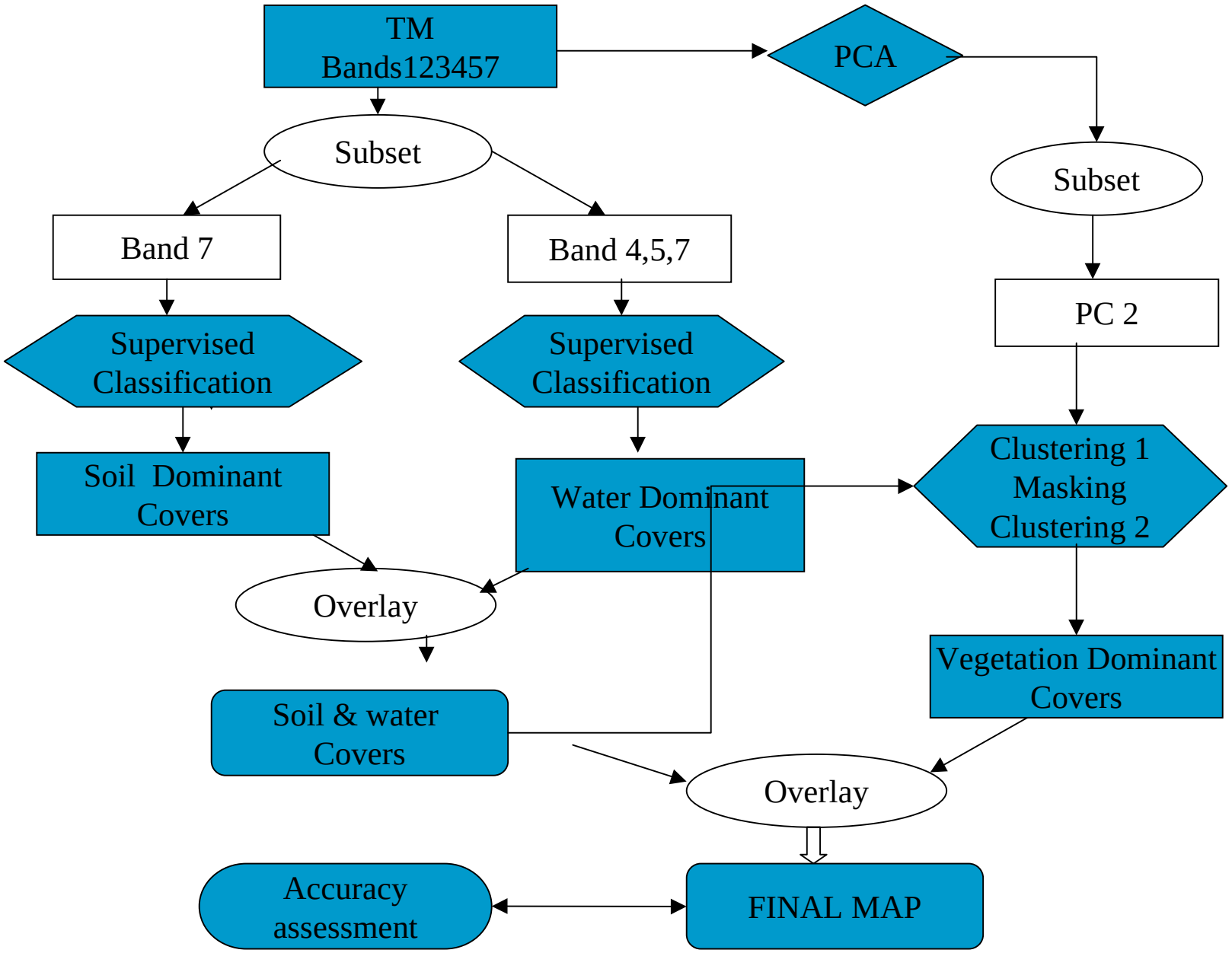


Typical rural scene - settlements with trees, sacred grounds covered in dense woodlands



Analyze LUC by these or more categories

Stratification of land use sectors: commercial, subsistence (communal) and protected areas



Flowchart of hybrid supervised-unsupervised classification method used (Jaiteh et al. Submitted)

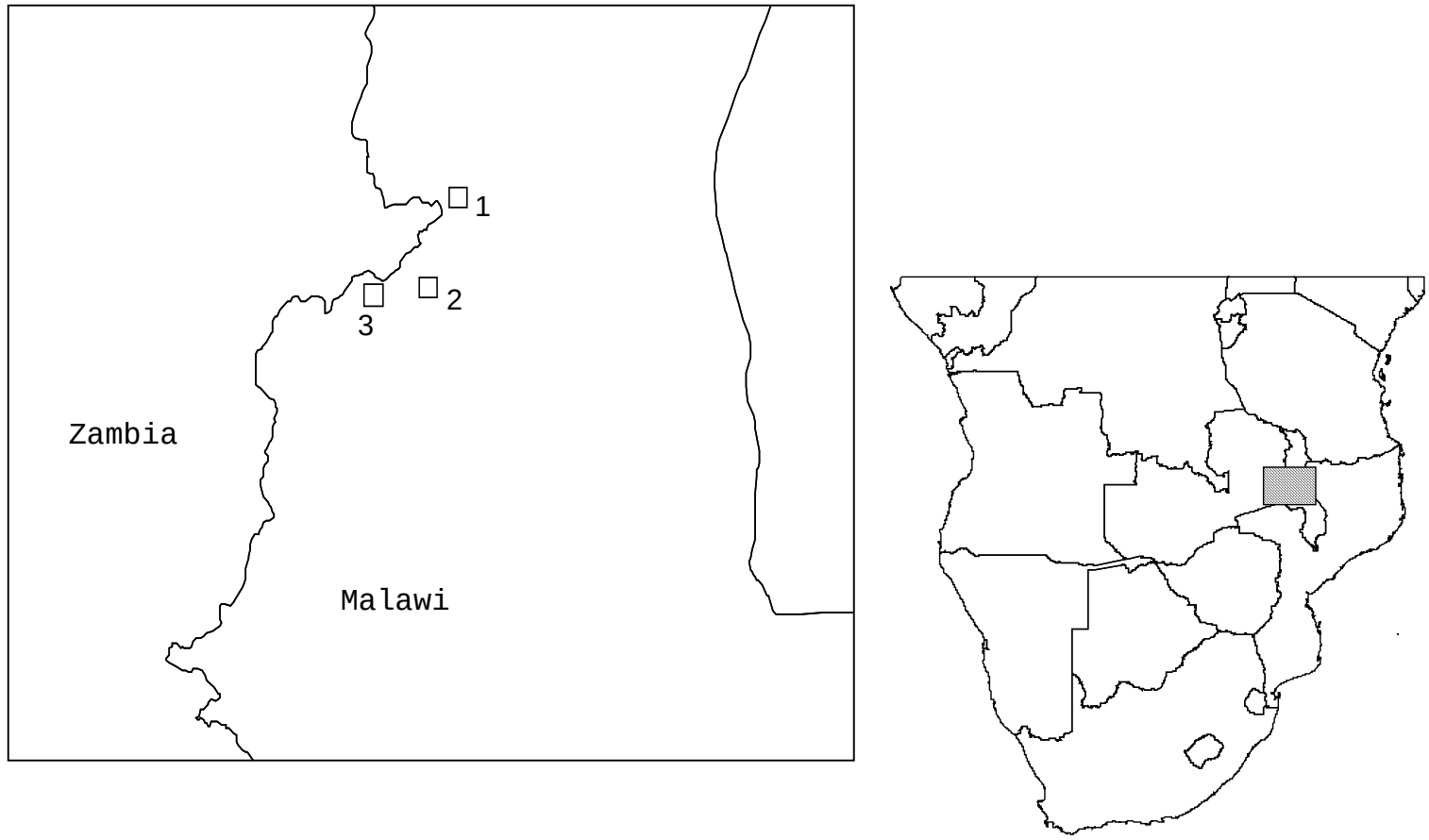


Figure 1. Map showing location of three landscapes in central Malawi, southern Africa. Extensive agriculture in forests (1), intensive agricultural matrix (2) and Brachystegia in flat areas (3).

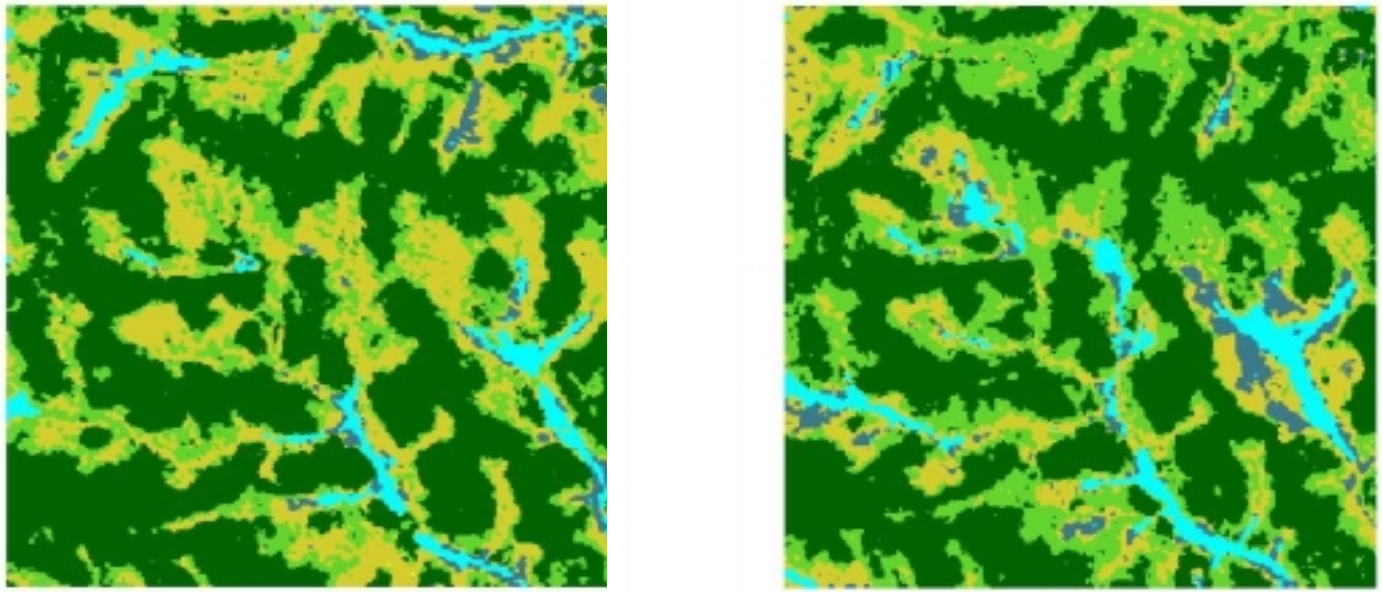
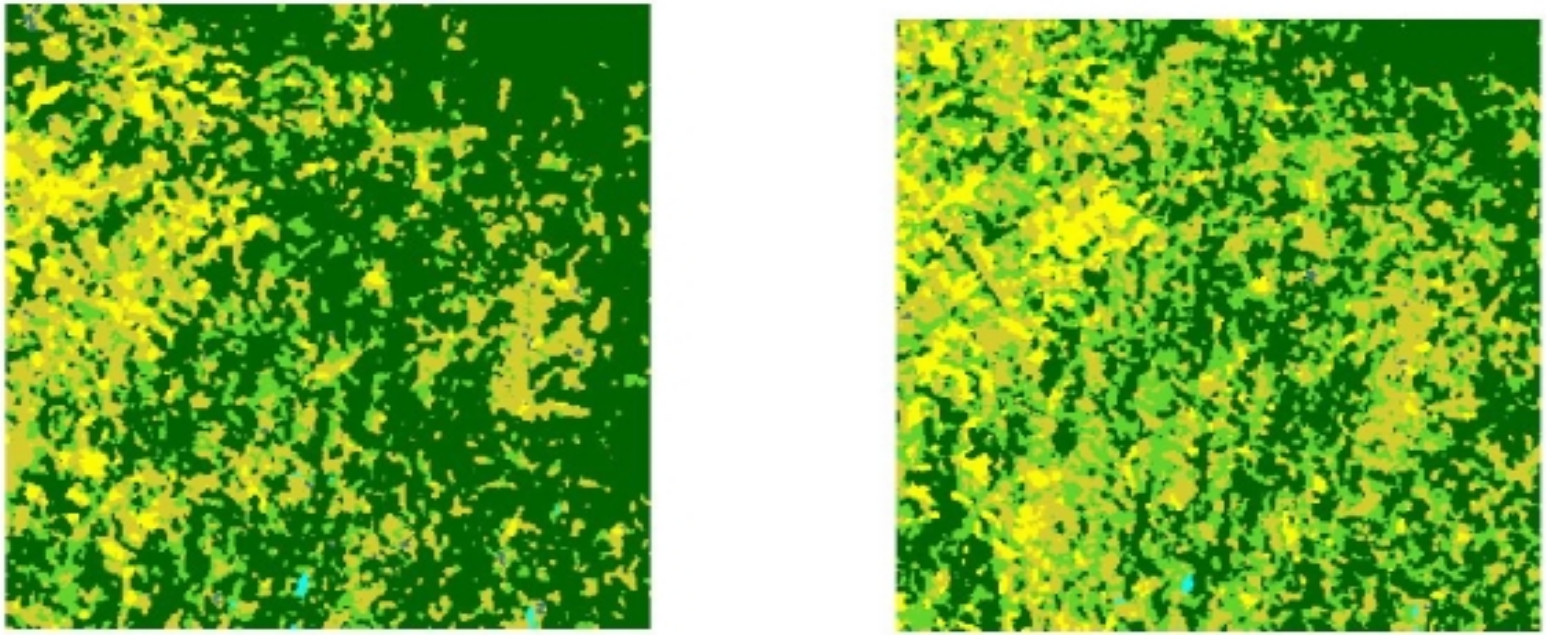


Figure 2c. Land cover map of Brachystegia in flat area (BFA) landscape. 1984 (top) 1995 (bottom). From Landsat TM data. ***Seasonal flooding in dambos and fire scars complicate change analysis***

Patterns of Land Cover



Land cover map of extensive agriculture in forest area landscape. 1984 (left) and 1995 (right). From Landsat TM, Kasungu, Malawi

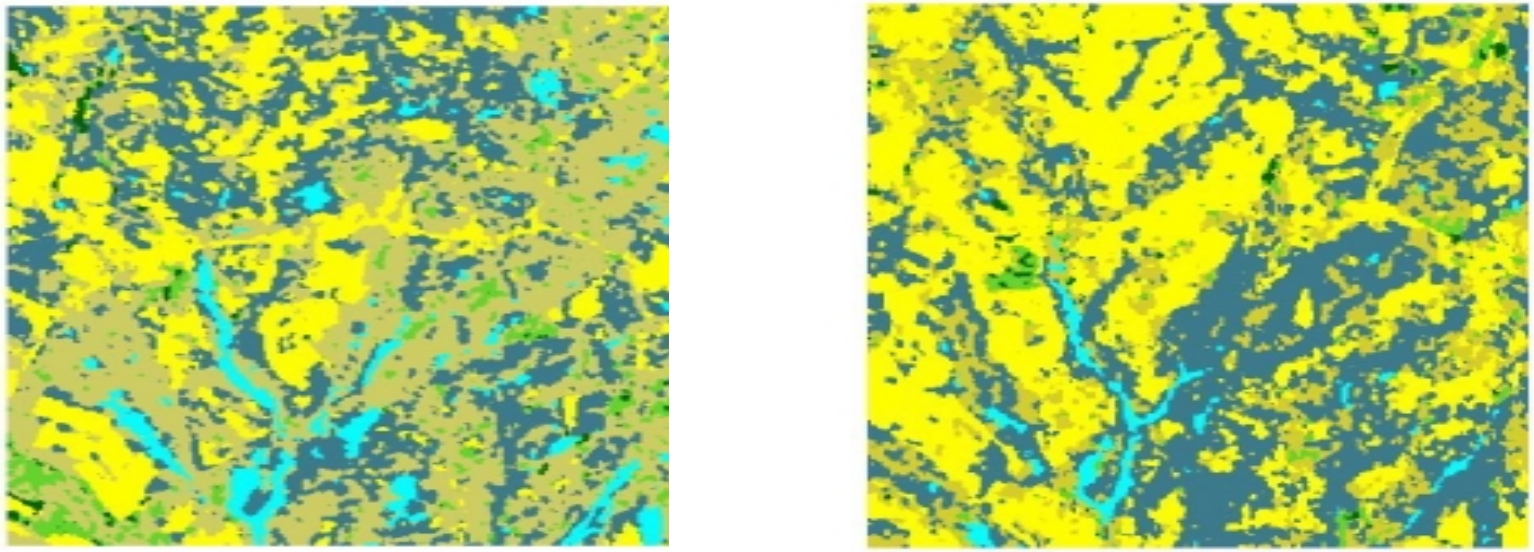
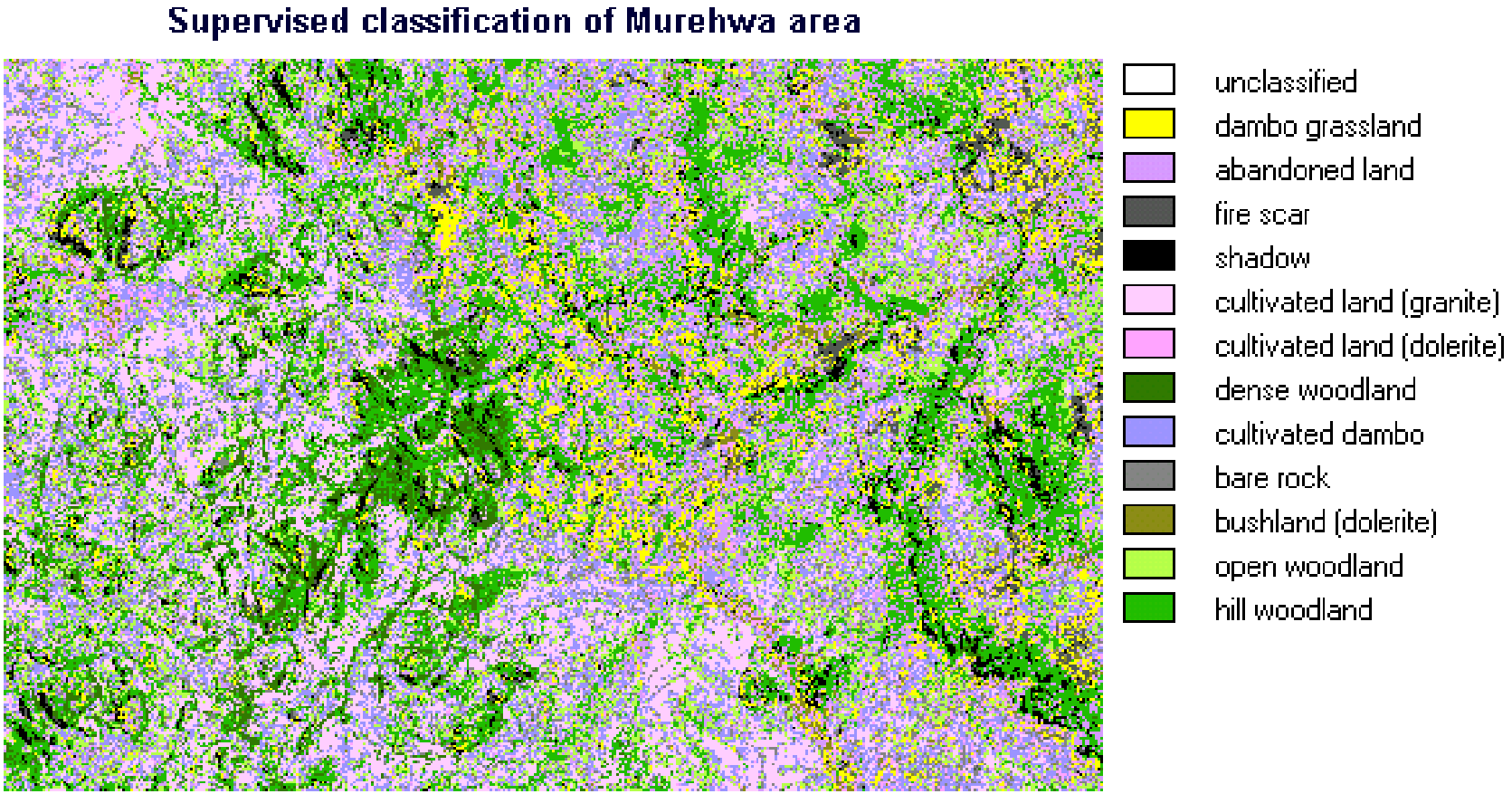


Figure 2b. Land cover map of *intensive agricultural matrix* (IAM) - (commercial farming) landscape. 1984 (left) and 1995 (right). From Landsat TM data for Kasungu, Malawi.

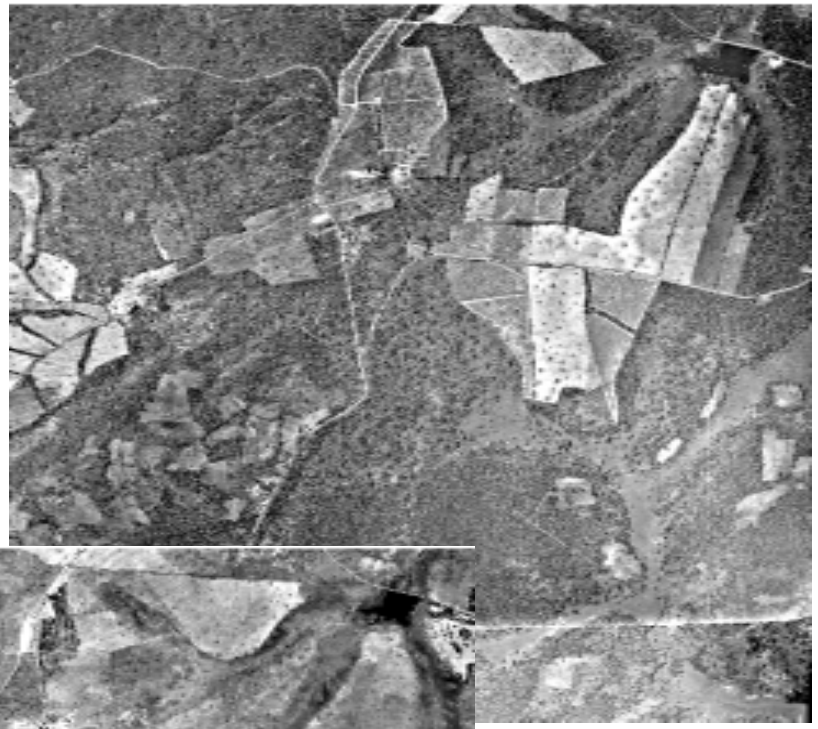
Table 1. Landscape spatial characteristics for extensive agriculture in forest areas (AFA), intensive agricultural matrix (IAM) and Brachystegia in flat areas (BFA) landscapes

	Agric. In forest areas		Intensive agric. matrix		Brachystegia in flat areas	
Landscape indices	1984	1995	1984	1995	1984	1995
No. Of patches	74000	86450	75253	74500	39399	35794
Mean patch size (stdev) (ha)	3.5(91)	3.0(24)	4.9(47)	5.0(47)	6.6(66)	7.1(77)
Patch density (#/100ha)	28.48	33.27	20	19.8	15.3	13.9
Largest Patch Index	41	33	37	31	31	32
Edge Density (m/ha)	116.5	156	114	108	91.6	89.5
No. of cover classes	7	7	7	7	7	7
Largest cover type	CW	WG	WG	WG	CW	CW
Percent of landscape area (%)	41	33	37	27	31	32
Percent of woodland cover (%)	52	43	8	11	62	62
Percent of cropland & settlement (%)	3	4	17	27	0	0



Communal farming area, Zimbabwe - *high levels of fragmentation*, hilly landscape (land less suitable for agriculture)

1964



1976

1995

Kasungu APs

How do we model all this Land Use, given multiple drivers and forcings acting at multiple temporal and spatial scales?

1. Design some structure to the landscape from people to higher levels of organization and spatial interaction

2. Assemble data to represent the relationships

3. Start with a minimal model given data and understanding of inherent scale of processes that are important

4. Complicate model even more

HIERARCHICAL LEVELS IN MIOMBO LAND USE MODEL

Global

Regional

National

‘Scale’

Major Urban Center

Urban Hierarchy: Minor Urban Center

Trading Center

Community

Household

Individual

BIOPHYSICAL SETTING - Soils, Geology, Climate, Slope, etc.

Spatial Interactions

- Policy: At National Level, implicit (sometimes explicit) is an implied development paradigm - whether diffusionist (trickle down economics), basic needs, etc.
- For example, Malawi's National Development Plan (1986) implies a diffusionist approach, later development phasing came in with Structural Adjustment Programs, now on to basic needs (poverty alleviation) - driven by global funding
- Other policies include land and trade control policies that have an effect on land use, directly on indirectly

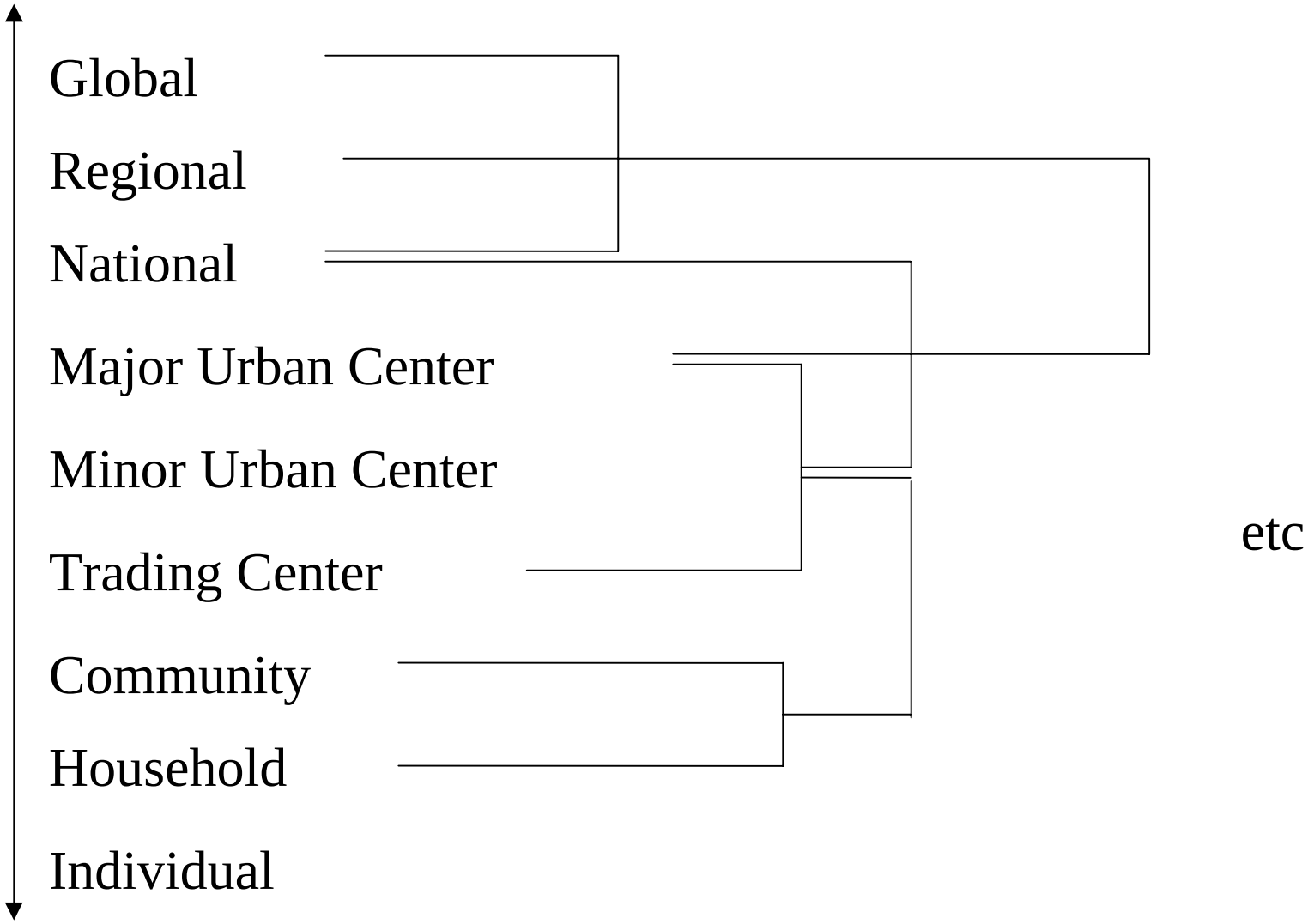
Between Communities/households and urban hierarchy

- Some mixture of basic needs at household level versus income generation capacity, and some opportunism to move up (function of education, plus other factors)
- Constrained by population density (family size), cultural factors (marriage), geography, etc
- For countries like Malawi, socio-economic data available by Agricultural Development Divisions (and districts) - large databases (one time, not continuous fields)

Exploratory Data Analysis - in progress

- Global to Regional and National - time series analysis (logit regression) to explore strong relationships - develop some distance weights
- ADD or district level - time series analysis (for subsistence and commercial farming systems)
- (Stratifying country into ownership/tenure types)
- For conservation and reserved areas, into managed versus unmanaged (people encroachment then becomes an issue (neighborhood interactions - CA type)

Linkages/Interactions to be Characterized - from the EDA and literature, other miombo case studies



Simple Model - Malawi Version

- 3 strata - subsistence, commercial, reserved
- Subsistence: Use trading areas or districts as basic units (these fit into agric develop divisions)
- Predict land use fractions under major land use types (versus pixel specific changes) - prediction function will be a logit function of socio-economic varies (yet to be fitted)
- Commercial: type of activity function of site suitability, national policy, world markets, access to markets/ports
- Unmanaged reserved areas - vegetation dynamics/succession with disturbance (account for bush and human encroachment, fire, herbivory)

For Zimbabwe ...

- Major strata along Land apportionment - Communinal, state land, parks and wildlife, forestry land, commercial (large and small scale)
- Time series of land distribution maps available, including latest resettlements
- Currently developing land cover change vectors for selected sites, and the community-level land use, in conjunction with other projects (CIFOR, etc).

- Tanzania and Mozambique - meetings planned to explore appropriate model structures

Database Development

1. Baseline - soils, slope, transportation networks (TS)
   land suitability (f{slope, soils, climate}, various
   boundaries - water bodies, etc (assembled in Miombo CD
   and in followup CD from many sources, e.g. SADC, national
   mapping agencies

2. Climate Data - Climate CD workshop to develop daily
   station time series for further spatial processing to drive
   various modeling - partial drafts available

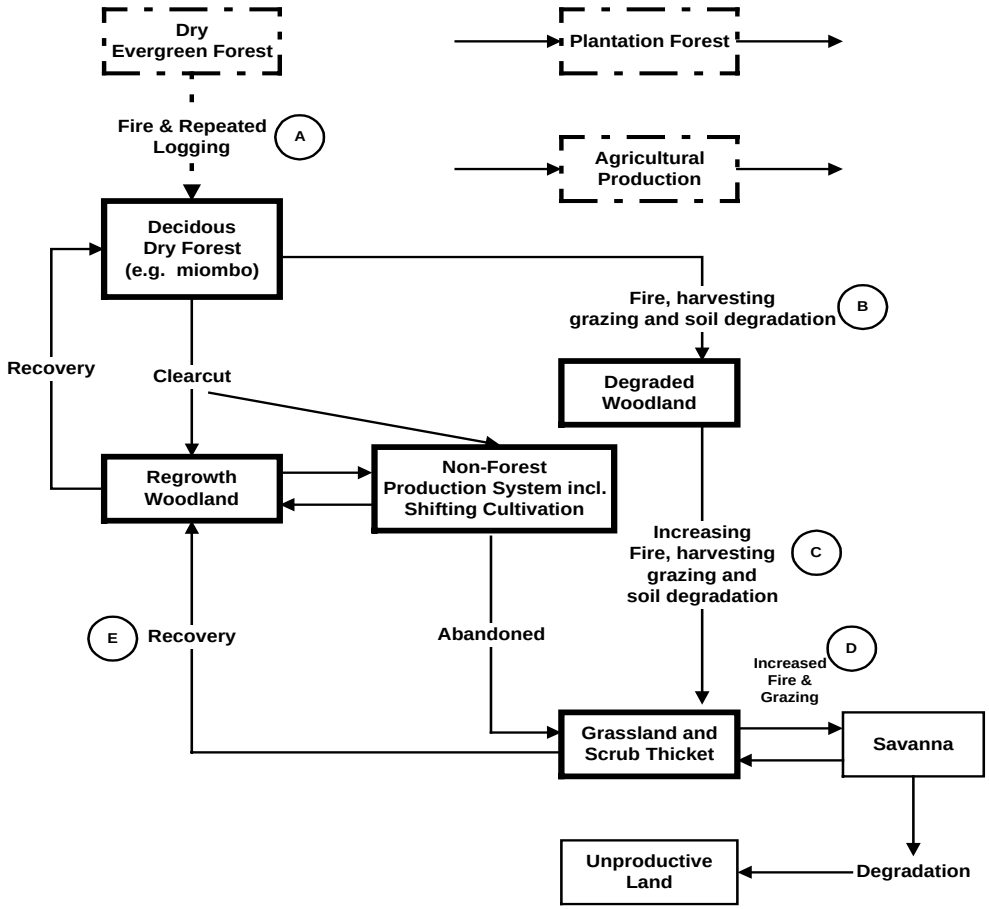
3. National to Global socio-economic variables - WRI, WB

4. Assembling subnational statistics

5. Baseline land cover/land use (1990/1), harmonizing older
   products as well, future monitoring using Landsat 7 (GOFC)

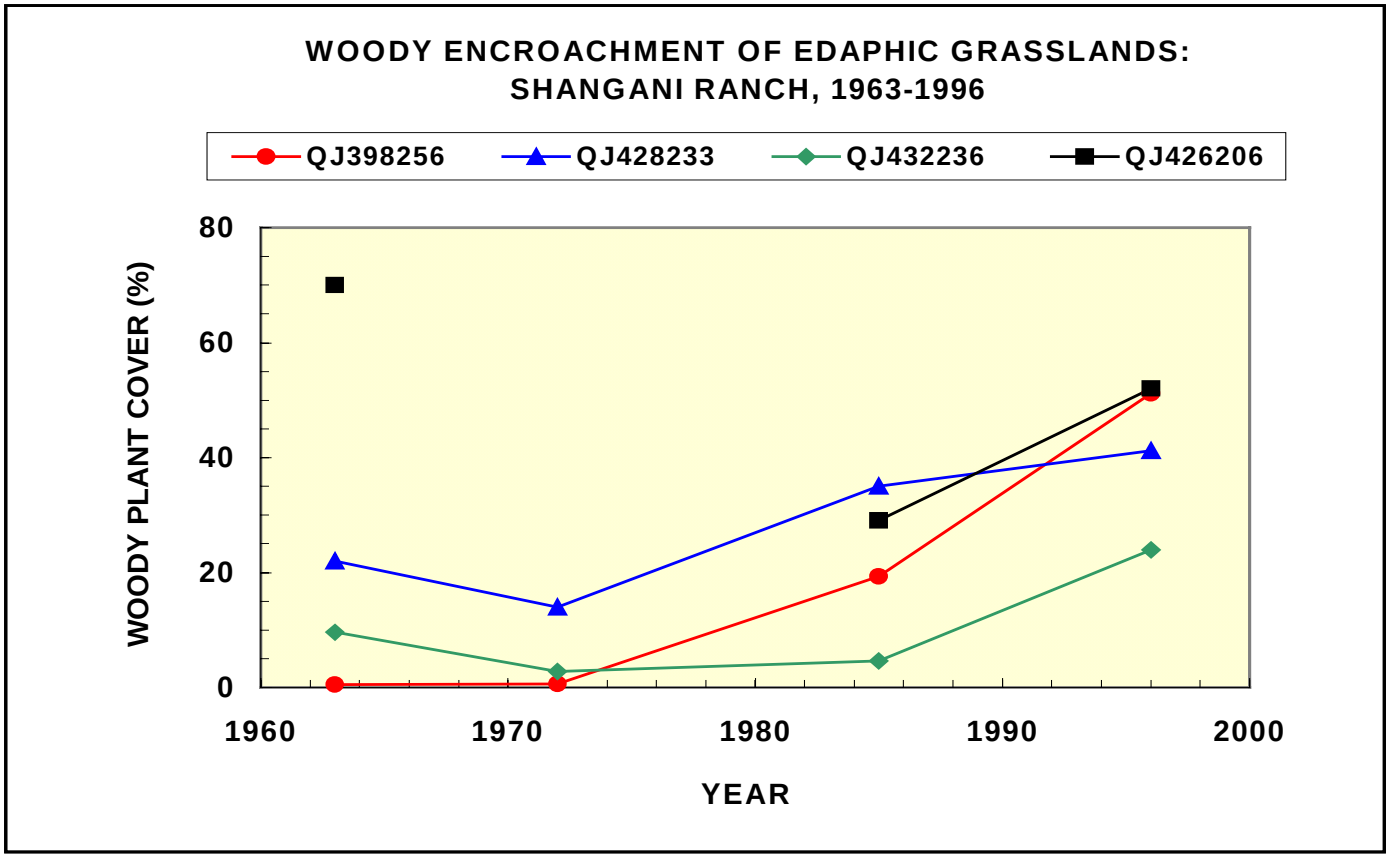
Ecological Studies

Dense Miombo Woodland, Degraded , then Converted to Grassland with Saplings Stunted by Frequent Fires

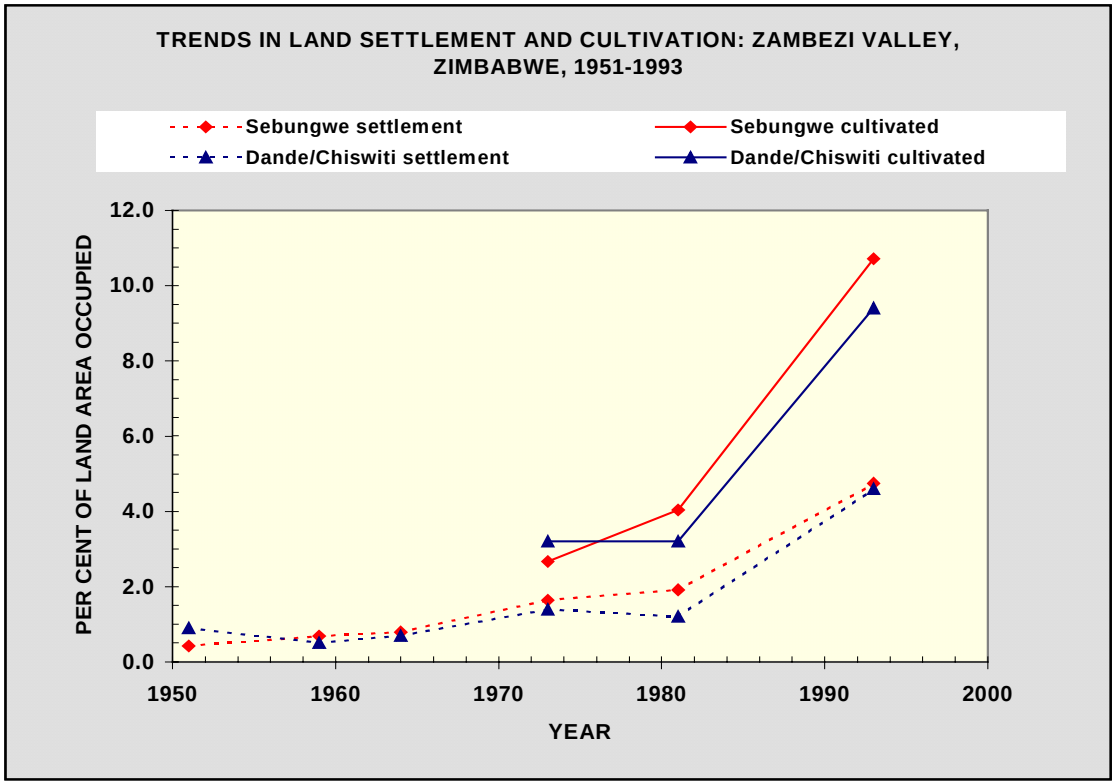


Conceptual model of the effects of disturbances (fire, harvesting/clearing, grazing, etc.) on land cover changes. Emphasis is on miombo woodlands and related transitions, conversions to plantation forest and agriculture are possible at every stage. Letters A-E are major hypotheses to be tested.

Encroachment of *Acacia nilotica* on an old field on Shangani Ranch, Zimbabwe. This field was abandoned in the latter part of the period 1963-1972



Changes in percentage woody plant cover on four edaphic grasslands on Shangani Ranch, 1963-1996, as estimated from aerial photographs. UTM co-ordinates of the approximate centre of each of the areas sampled are given. No estimate of tree canopy cover was made for location QJ426206 in 1972 as the available aerial photographs did not cover this site.

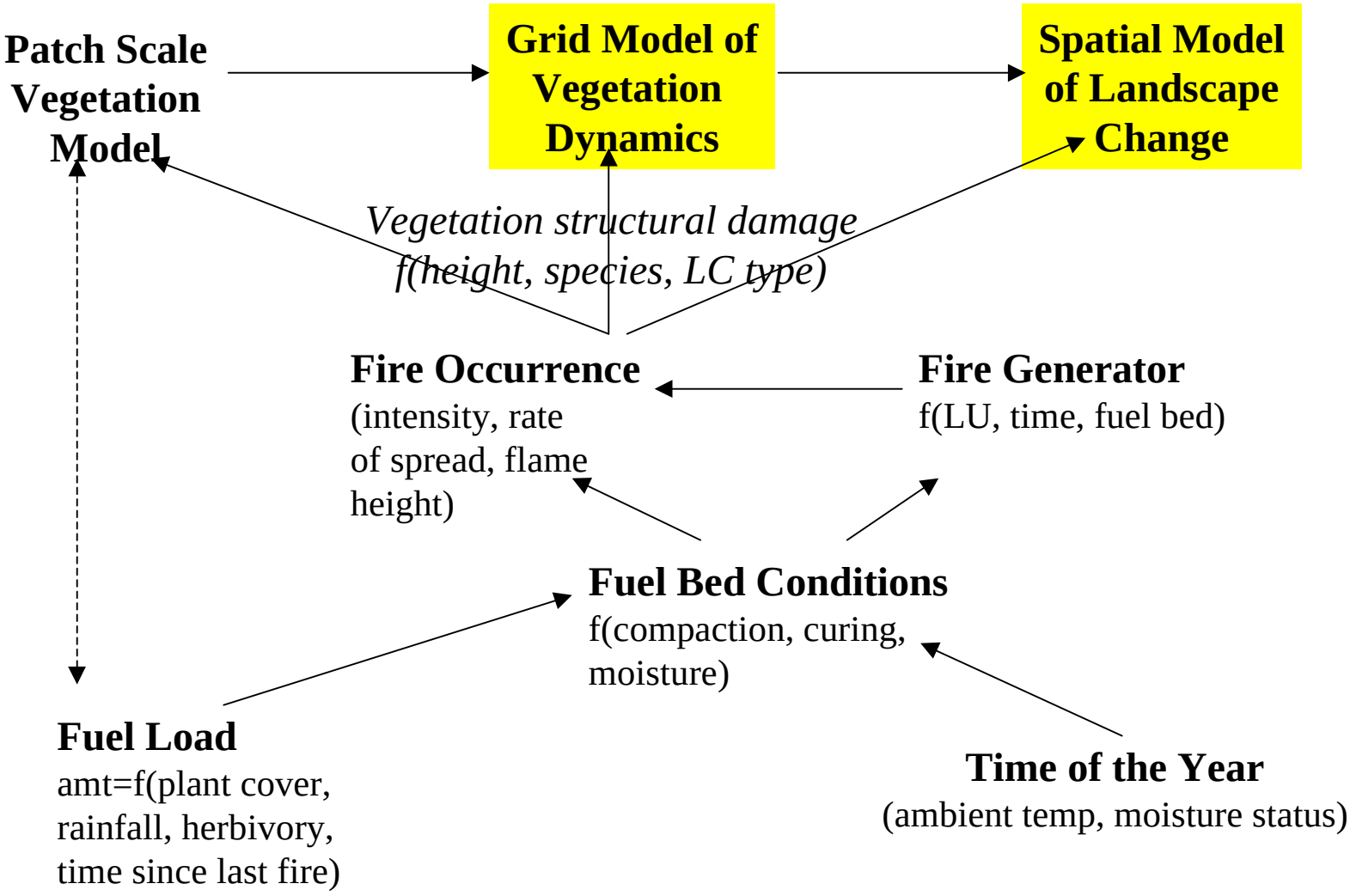


SOURCE: DAVID CUMMING, WWF ZIMBABWE

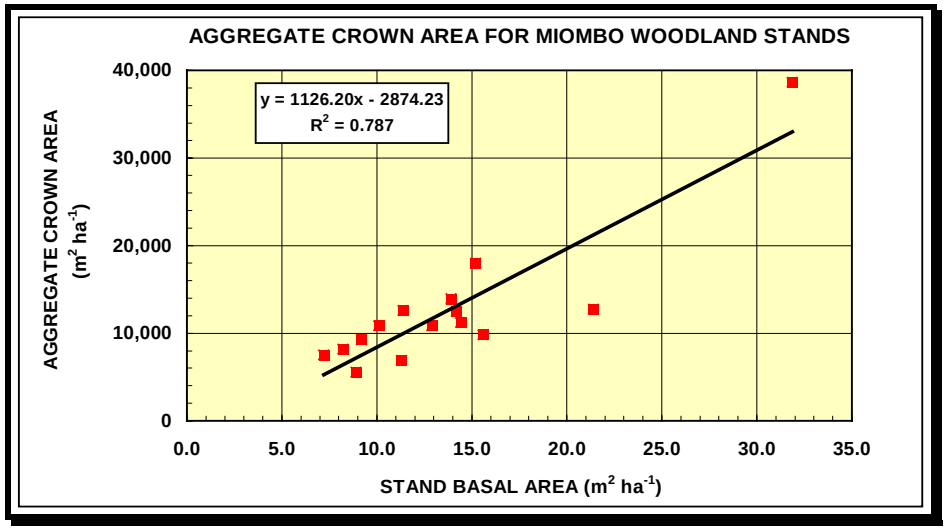
- CHANGES IN LAND USE AND LAND COVER ARE USUALLY NON-LINEAR AND SOMETIMES DISJUNCT
- THESE DATA MAY HIDE CONSIDERABLE TURNOVER IN THE AMOUNT OF LAND ACTUALLY USED IN THE INTERVALS BETWEEN SURVEYS
- THE LARGE INCREASE IN CULTIVATED AREA AFTER 1980 IS DUE TO A COMBINATION OF THE END OF WAR, GRADUAL ERADICATION OF TSETSE FLY, INCREASED SETTLEMENT THROUGH IN-MIGRATION, AND EXPANSION OF SMALL-SCALE COTTON PRODUCTION

Will link already developed patch models to landscape level disturbance processes - fire, human use, etc

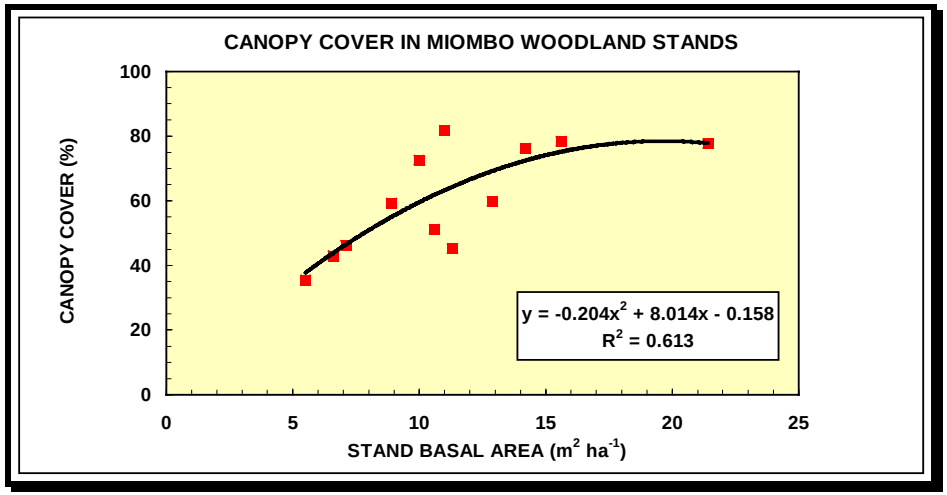
MIOMBO LU/FIRE MODEL



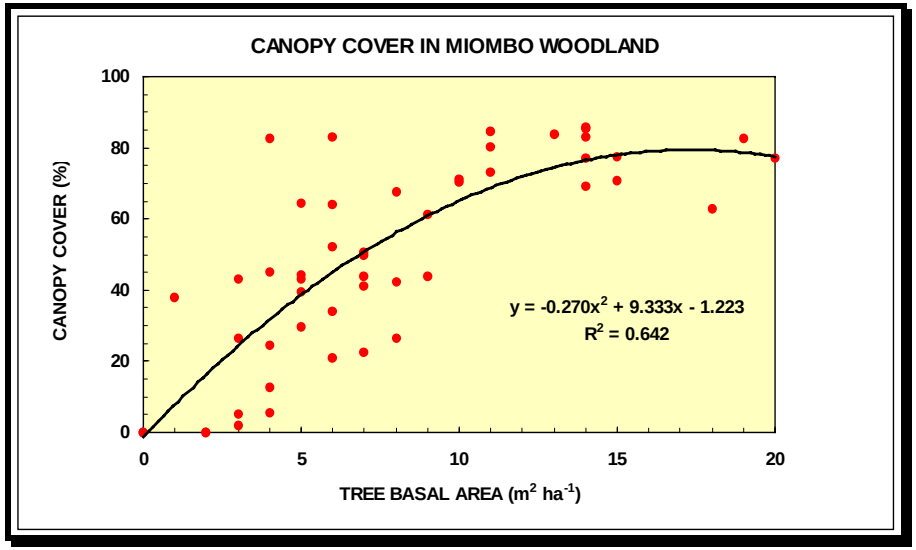
Examples of basic ecological relationships that will contribute to ecological modeling



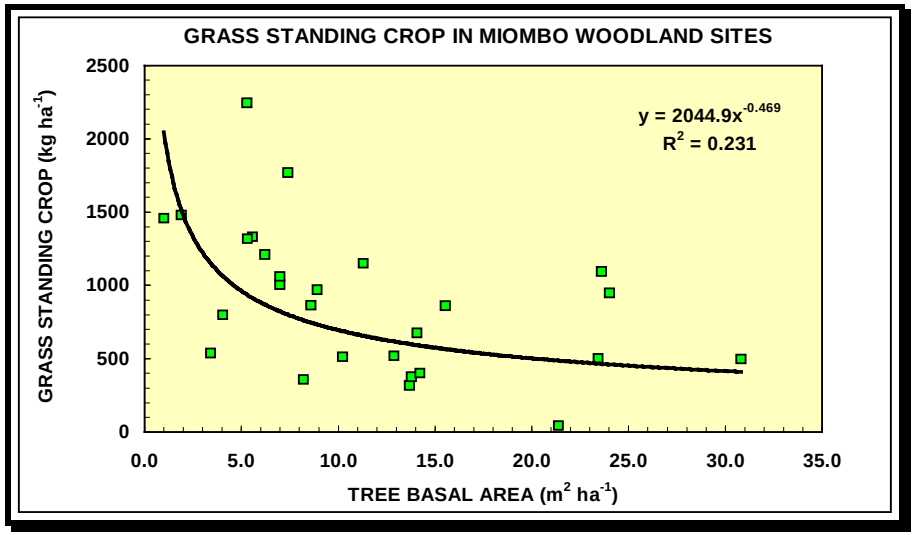
AGGREGATE CROWN AREA INCREASES LINEARLY WITH INCREASING BASAL AREA OF TREES IN THE STAND

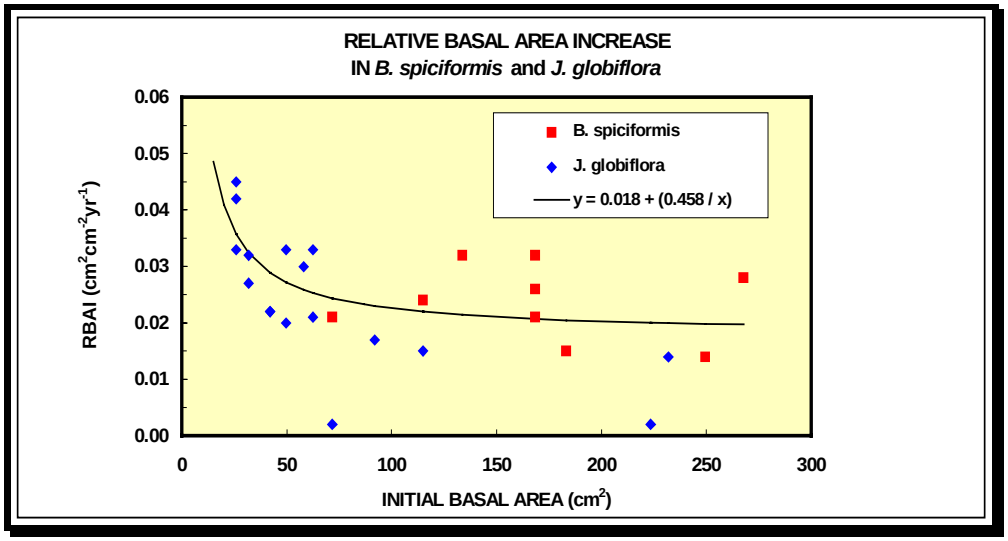


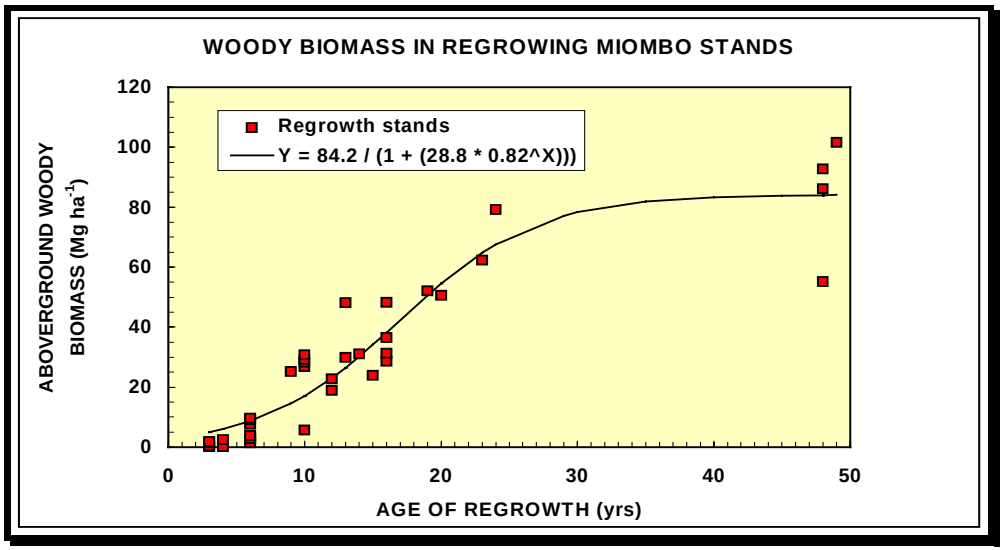
CANOPY COVER INCREASES WITH INCREASING BASAL AREA OF TREES BUT APPEARS TO REACH AN ASYMPTOTE AT ABOUT 15 m^2 ha^{-1} BASAL AREA

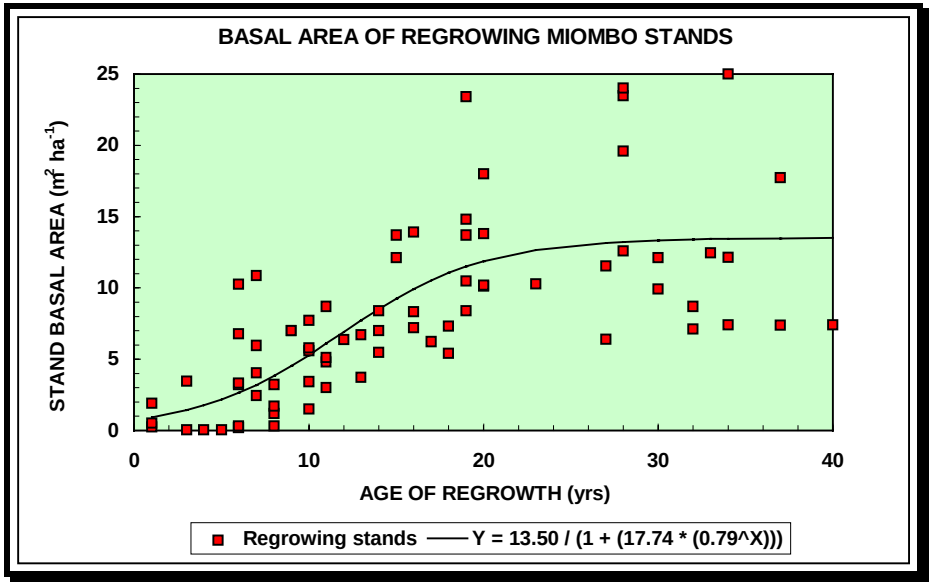


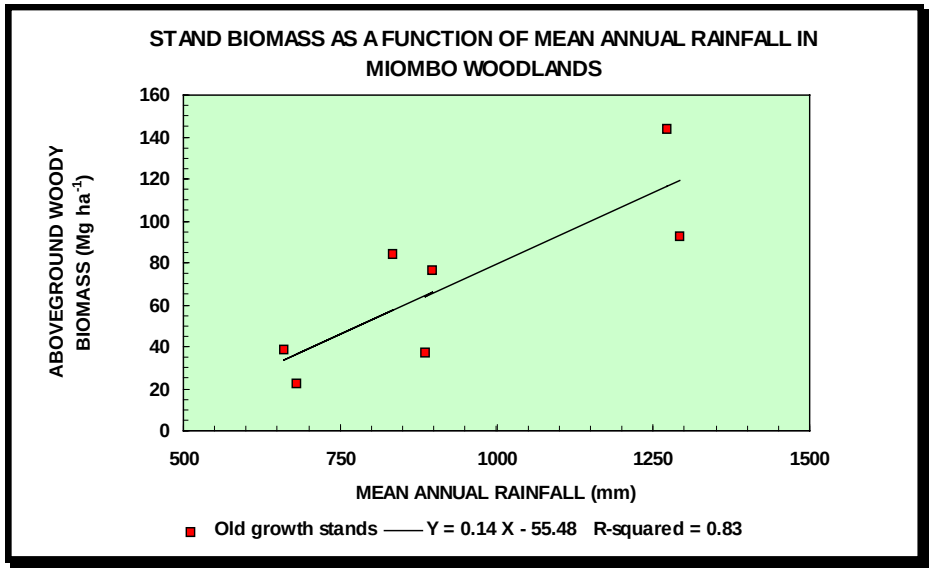
CANOPY COVER WITHIN A STAND IS NON-LINEARLY RELATED TO TREE BIOMASS (INDEXED HERE BY TREE BASAL AREA). AN ASYMPTOTE OF ABOUT 80 % CANOPY COVER IS REACHED AT ABOUT 10-15 m^2 ha^{-1}




RELATIVE BASAL AREA INCREASE
IN B. spiciformis and J. globiflora
RBAI (cm2cm-2yr-1)
0.06
0.05
0.04
0.03
0.02
0.01
0.00
0
50
100
150
200
250
300
INITIAL BASAL AREA (cm2)
B. spiciformis
J. globiflora
y = 0.018 + (0.458 / x)


WOODY BIOMASS IN REGROWING MIOMBO STANDS
ABOVERGROUND WOODY BIOMASS (Mg ha-1)
120
100
80
60
40
20
0
0
10
20
30
40
50
AGE OF REGROWTH (yrs)
Regrowth stands
Y = 84.2 / (1 + (28.8 * 0.82^X)))


BASAL AREA OF REGROWING MIOMBO STANDS
STAND BASAL AREA (m2 ha-1)
25
20
15
10
5
0
0
10
20
30
40
AGE OF REGROWTH (yrs)
Regrowing stands
Y = 13.50 / (1 + (17.74 * (0.79^X)))


STAND BIOMASS AS A FUNCTION OF MEAN ANNUAL RAINFALL IN MIOMBO WOODLANDS
ABOVEGROUND WOODY BIOMASS (Mg ha-1)
160
140
120
100
80
60
40
20
0
500
750
1000
1250
1500
MEAN ANNUAL RAINFALL (mm)
Old growth stands
Y = 0.14 X - 55.48
R-squared = 0.83

New Opportunities for Collaboration and Policy Interface

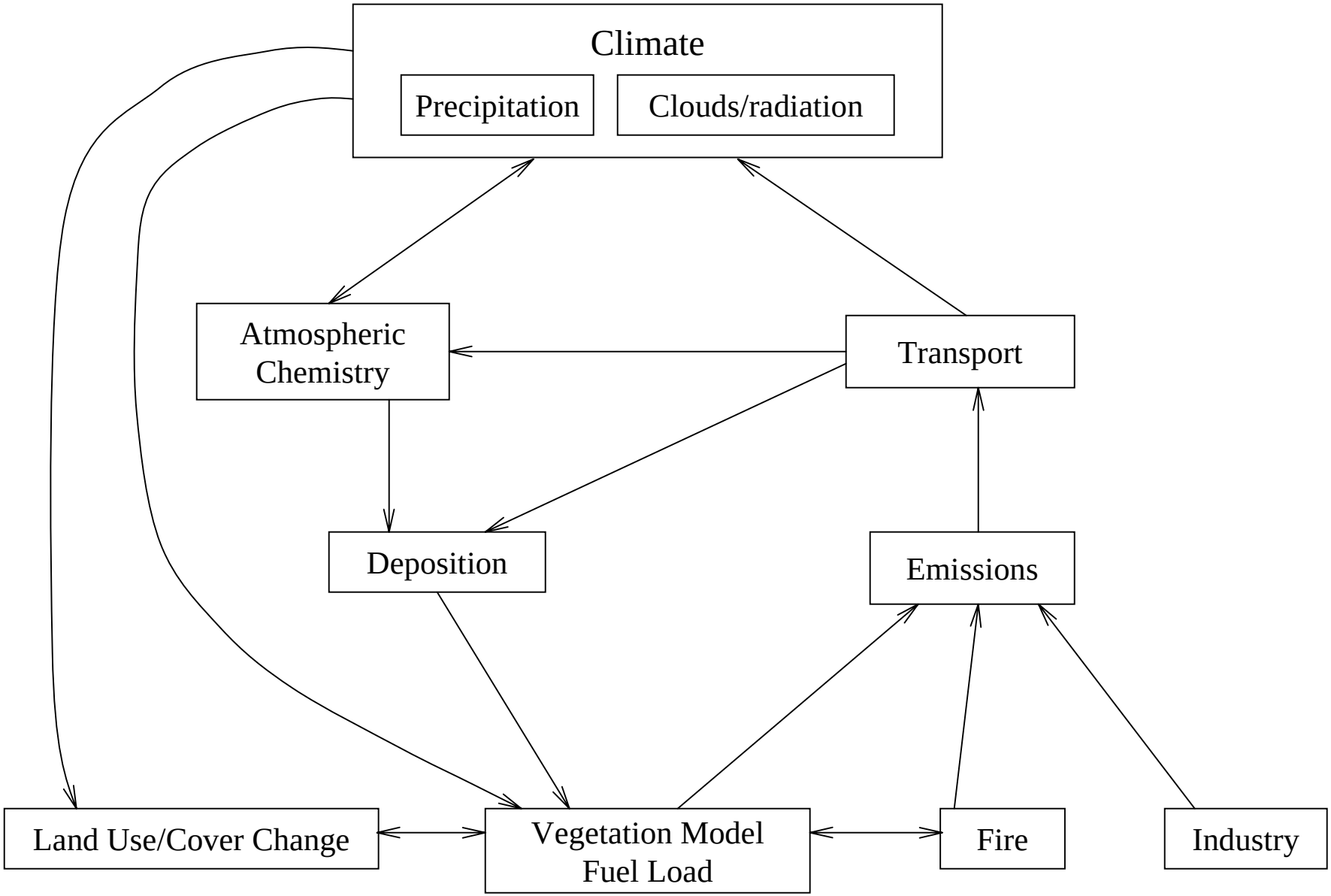
1. SAFARI 2000

2. IPCC - Integrated Assessment; Forestry and Land Use, Assessment Reporting

3. National Policy and Management/Sustainable Development

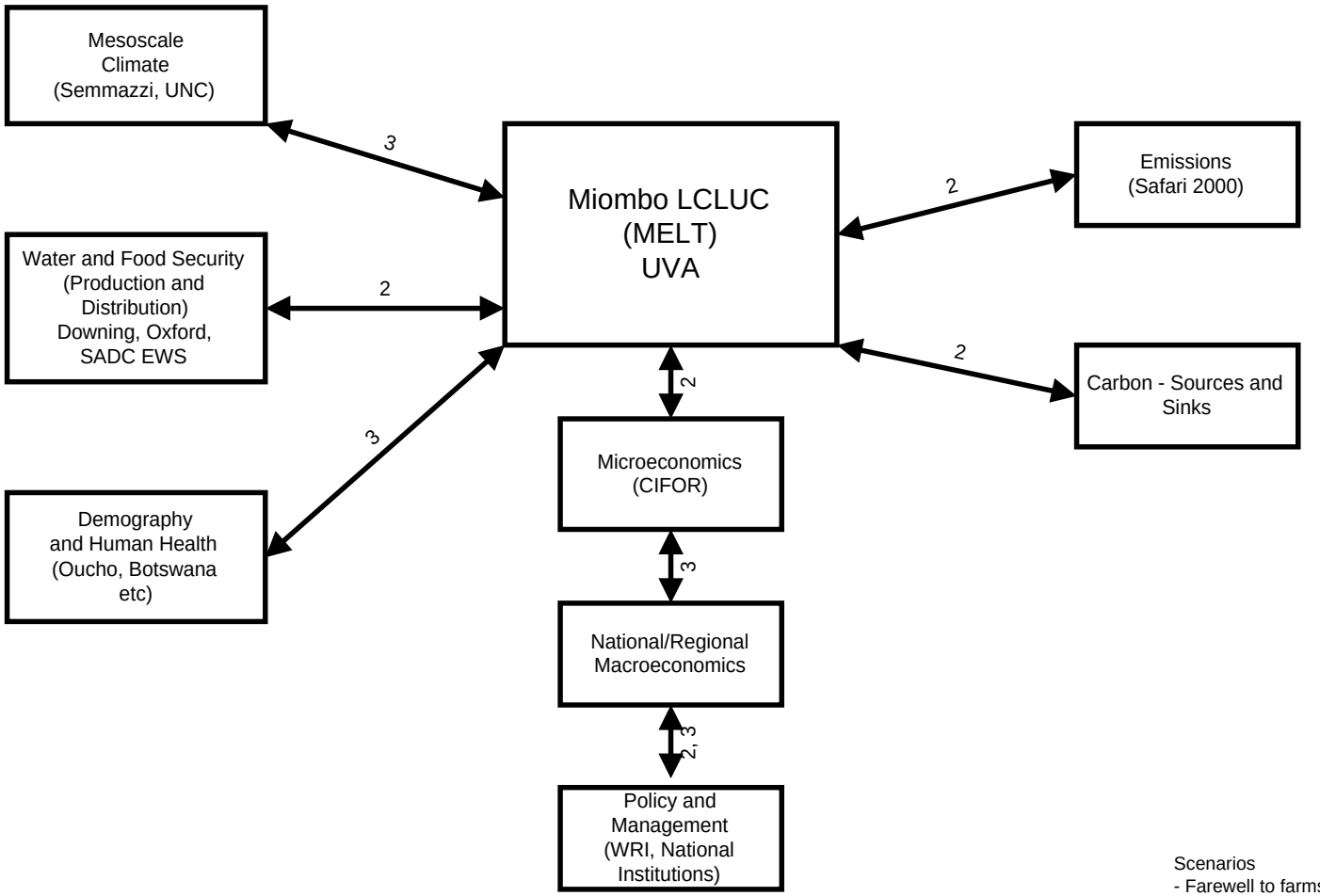
CORE ELEMENT 2: LAND COVER AND LAND USE CHANGE (LCLUC)

- *Activity 1:* Land Cover and Land Use Change Characterization and their Impacts
- *Activity 2:* Regional Fire Characterization, Emissions and Management
- *Activity 3:* Land Cover-Land Use, Carbon and Emissions
- *Activity 4:* Land Cover and Land Use Modeling
- *Activity 5:* Integrated Modeling of Southern African System - Coupling Land Use to Vegetation and Atmospheric Models


Climate
Precipitation
Clouds/radiation
Atmospheric Chemistry
Transport
Deposition
Emissions
Land Use/Cover Change
Vegetation Model Fuel Load
Fire
Industry

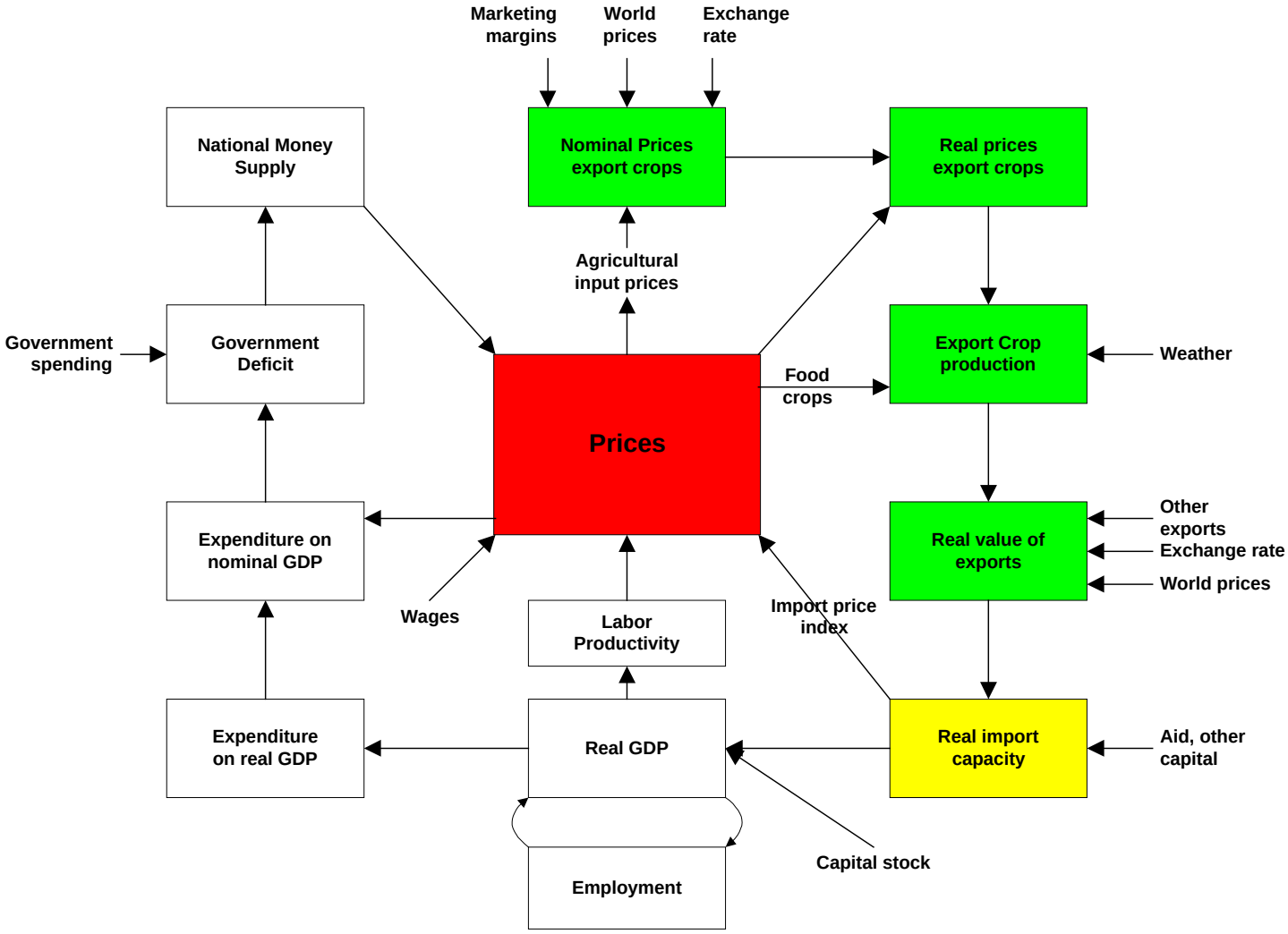
Proposed Integrated Modeling Activity - Building upon Existing Pieces

MIMOSA - Mesoscale Integrated Modeling of Southern Africa



Scenarios
- Farewell to farms
- Food for all
- Sustained Economic Growth
etc

National Level Econometrics



Main Relationships in a Supply Constrained Macroeconometric Model of Tanzanian (after Lipumba et al. 1988). Similar implementations exist for Kenya and Botswana.

Summary of Product Delivery

- Miombo CD - Regional Data
- Baseline data - regional land cover/land use map for 4 countries available using harmonized legend, for 1991;
- Rates of change for few study sites available, more image analysis in progress
- Baseline climate data - 3-6 months, partial drafts available
- First order carbon accounting in progress, ~4 months
- MELT Model (Land Use) - running version for 3/4 countries ~6 months
- Linked Vegetation-Fire-Land Use model ~1 year

The Miombo CD Project

The first Miombo Network meeting in Zomba, Malawi December 1995 identified data availability as a major constraint for development of a strong scientific agenda, and in general, for global environmental change research in Central and Southern Africa (funded by NSF, IGBP)

The Miombo CD project was then designed to make data widely available to Miombo Network Projects and more generally, to regional scientists (funded by NASA, START, IGBP DIS).

Data were collated from various international data archives and from individuals, and processed to be accessible using a web browser on a cd-rom.

The Miombo CD contains all the software required to access and manipulate the data, including a GIS, a Web Browser, Adobe Acrobat Reader and utilities for converting the GIS data commonly used Arc/Info export format and IDRISI image format.

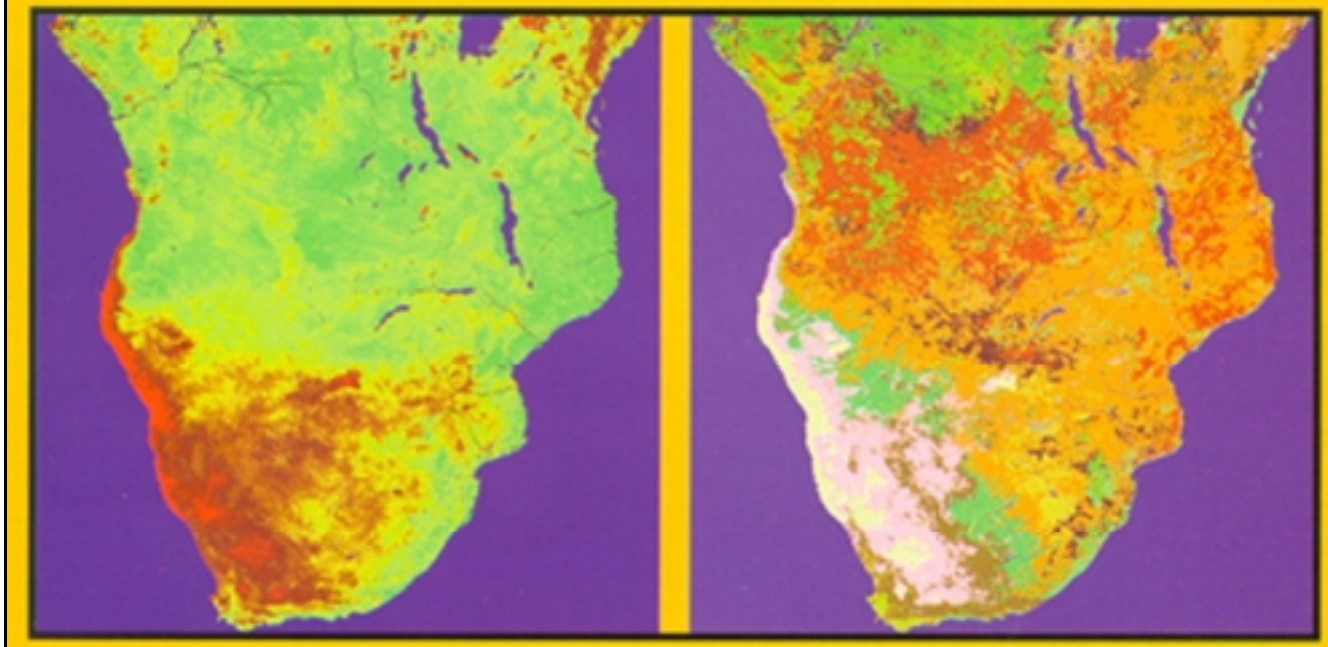
MIOMBO NETWORK

LUCC
LAND USE AND COVER CHANGE

IGBP DIS

START
IHDP • IGBP • WCRP

LUCC CD-ROM Series. Nº 1: MIOMBO



Also sponsored by:

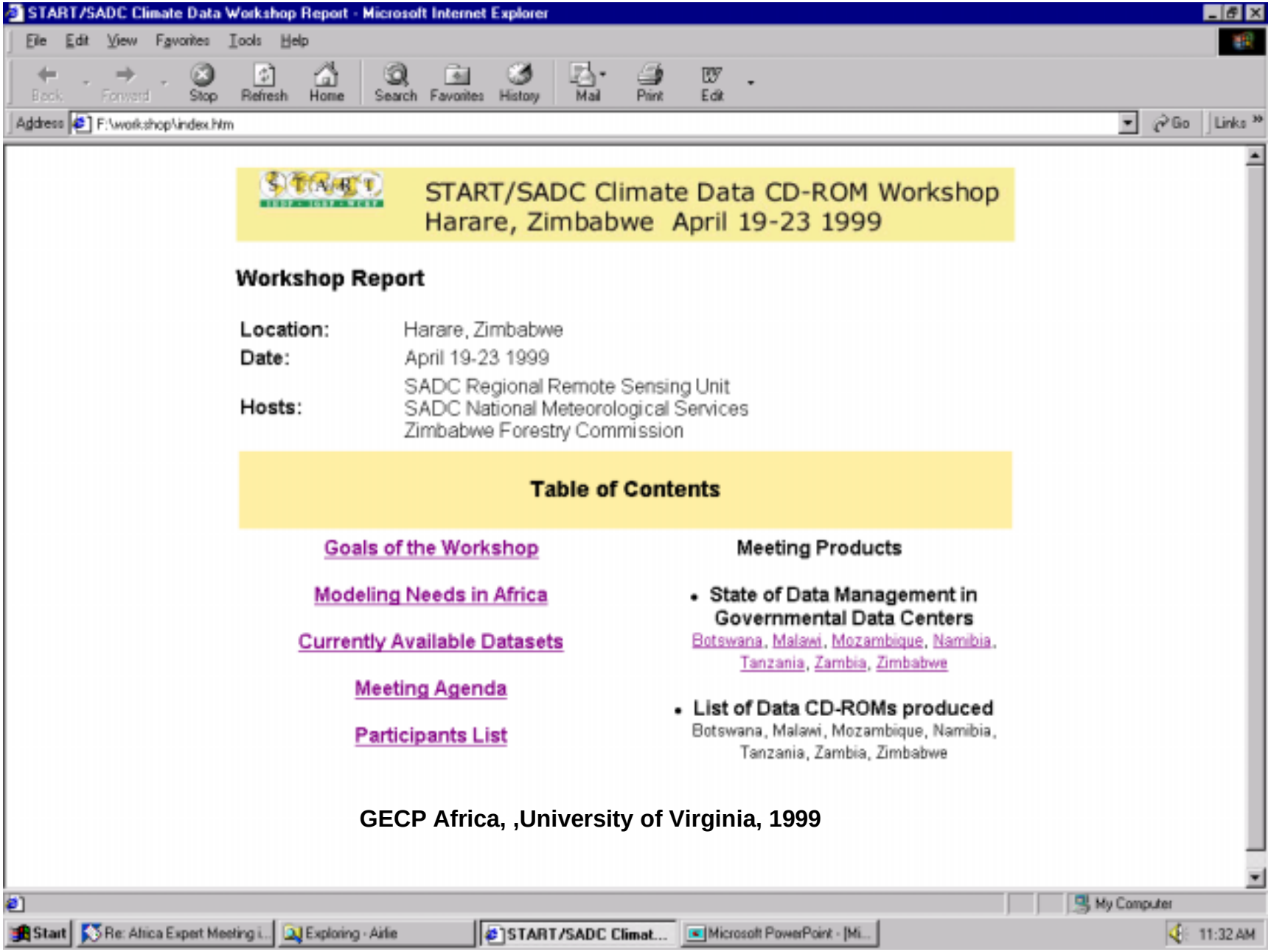
IHDP

NASA

Mission to Planet Earth

Generalitat de Catalunya
Institut Cartogràfic de Catalunya

GECP



GECP Africa, ,University of Virginia, 1999

Mid-life Crises or Project Course Corrections

- Fast track shift from case study sites to regional extent - in response to immediate needs for consistent baseline data (Safari 2000, IPCC IAM, etc); and large number of related ‘pieces’ from Miombo Network partners - need for integration and synthesis great
- Renewed emphasis on fire - Peter’s talk later
- Potential for very exciting new data sets through GOFC/Landsat 7 and other instruments, need to be ready to take full advantage

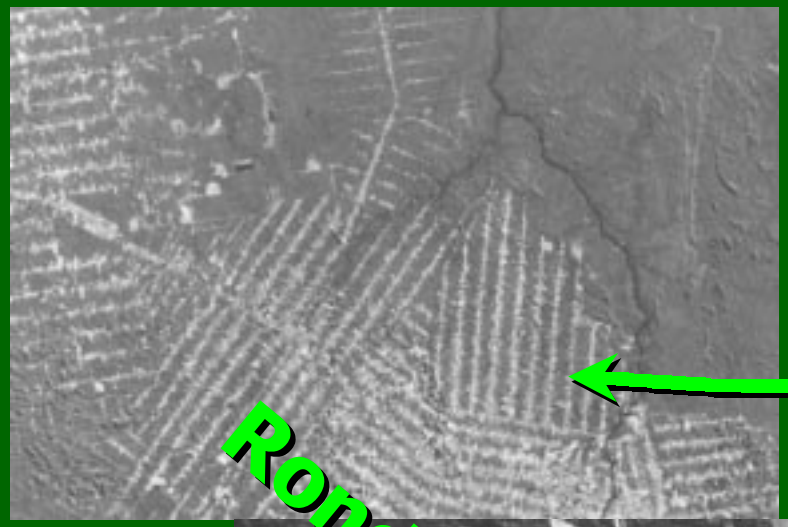
Integration into LCLUC model Challenging - broadening inputs to include diverse **experts** in attempting to develop a “good” LUCCy model (with socio-economic and ecological components)

The Process of Land Cover and Land Use Change in Central Africa

Historical over view and ongoing activities

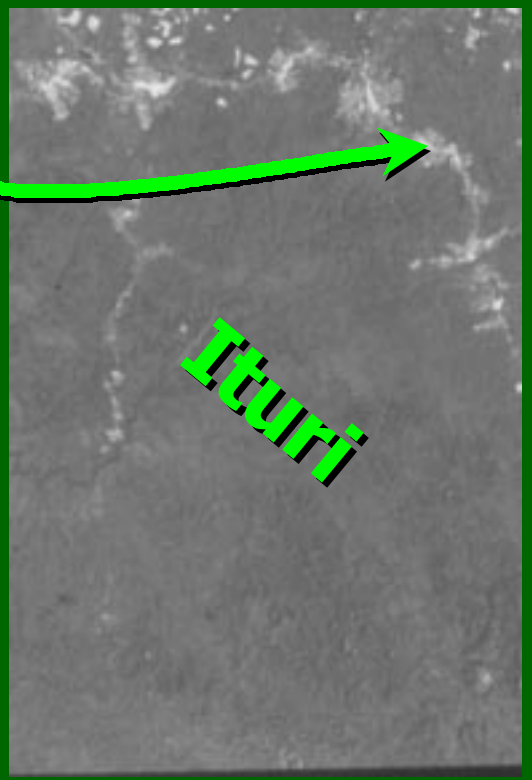
Dr. David S. Wilkie
Boston College
18 Clark Lane, Waltham MA 02451
dwilkie@email.msn.com

Congo Basin is different?



Roadside clearing

Rondonia

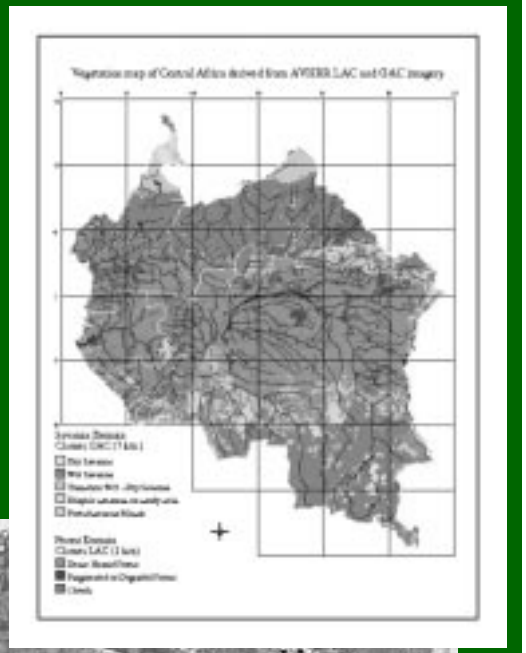


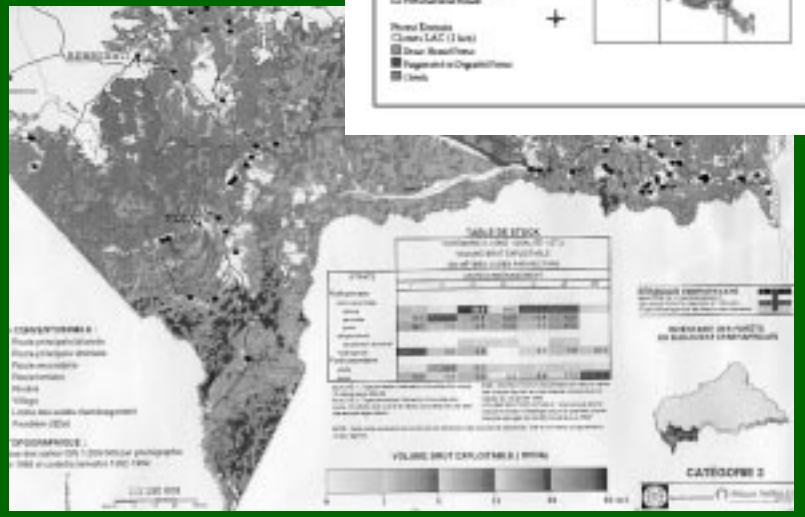
Ituri

Ongoing LCLUC research

CARPE - USAID

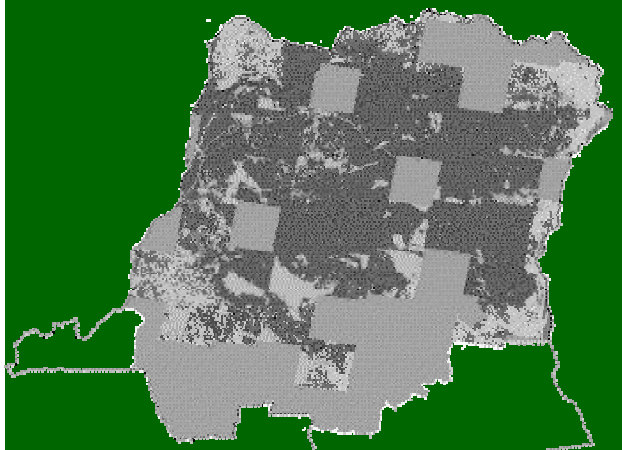
- low resolution forest cover and forest disturbance (NASA, TREES, UMd)
- logging concessions and protected areas (WRI, WWF, WCMC)
- determinants of deforestation in 7 forest management units in CAR (PARN)
- forest resource use intensity (WRI and Uwe Deichmann UN)
- future land cover scenarios (WRI, Boston College)
- agricultural land transformation in Cameroon derived from road density and travel times (UMd)



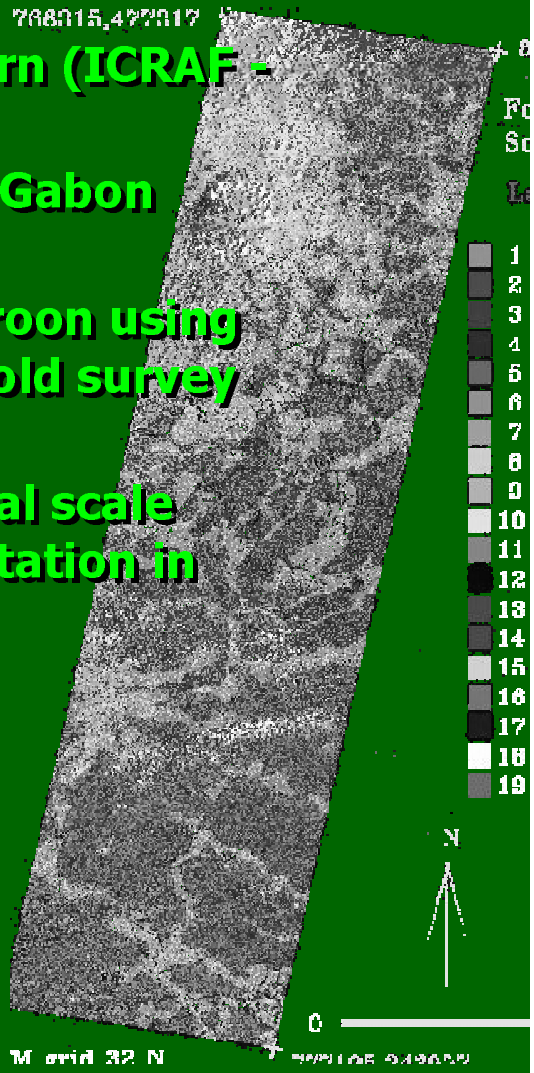


Ongoing LCLUC research

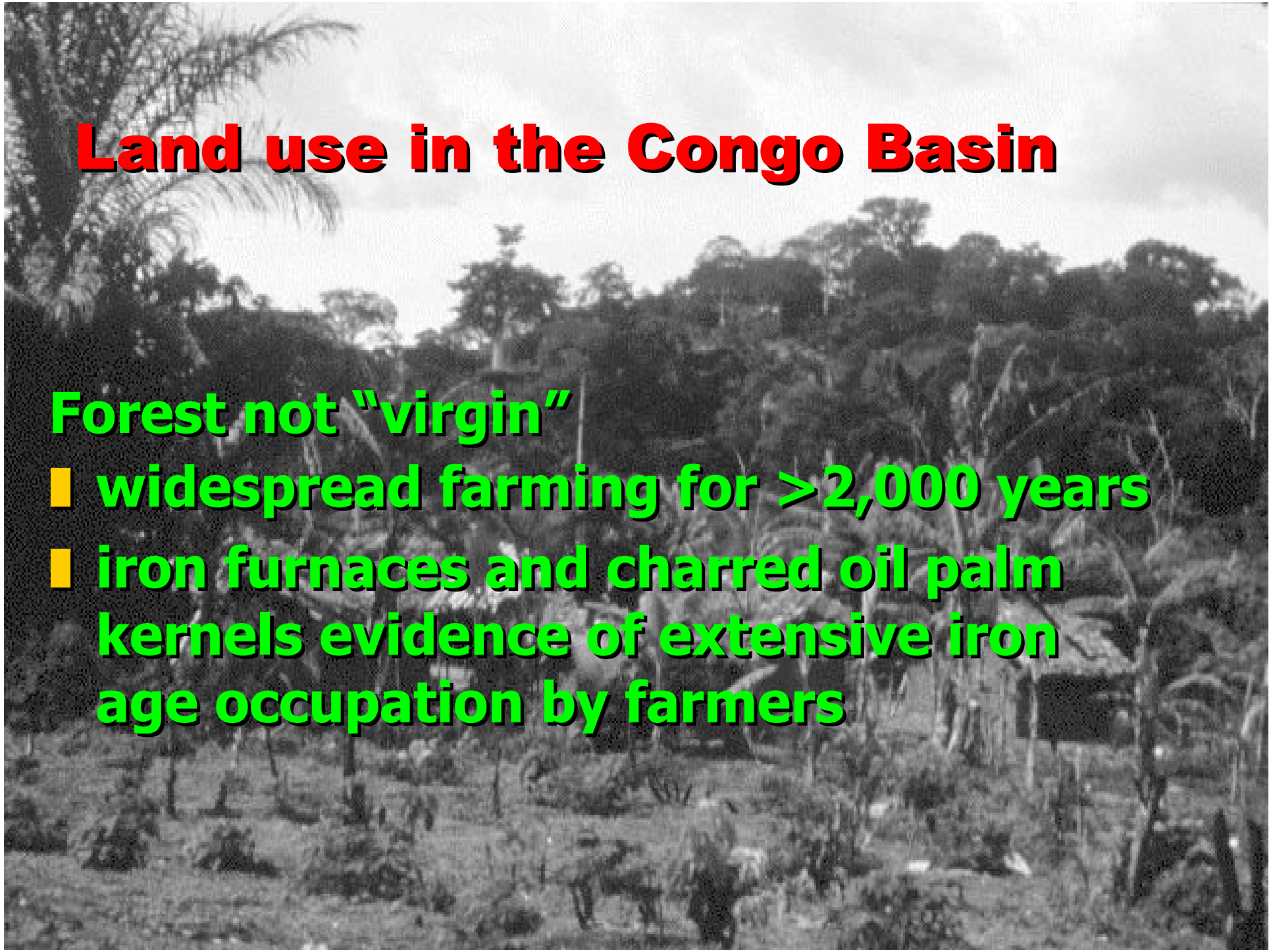
Others



- Alternatives to slash and burn (ICRAF - Cameroon)
- Peri-urban forest change in Gabon (APFT, ULB, UMd)
- Land cover change in Cameroon using remote sensing and household survey data (UMd, CIFOR)
- Rule-based modelling of local scale forest clearing and fragmentation in CAR (NASA, WWF)



- Landsat Pathfinder (NASA, UMd)
- Macro-economic dynamics and deforestation in southern Cameroon (University of Louvain and CIFOR)

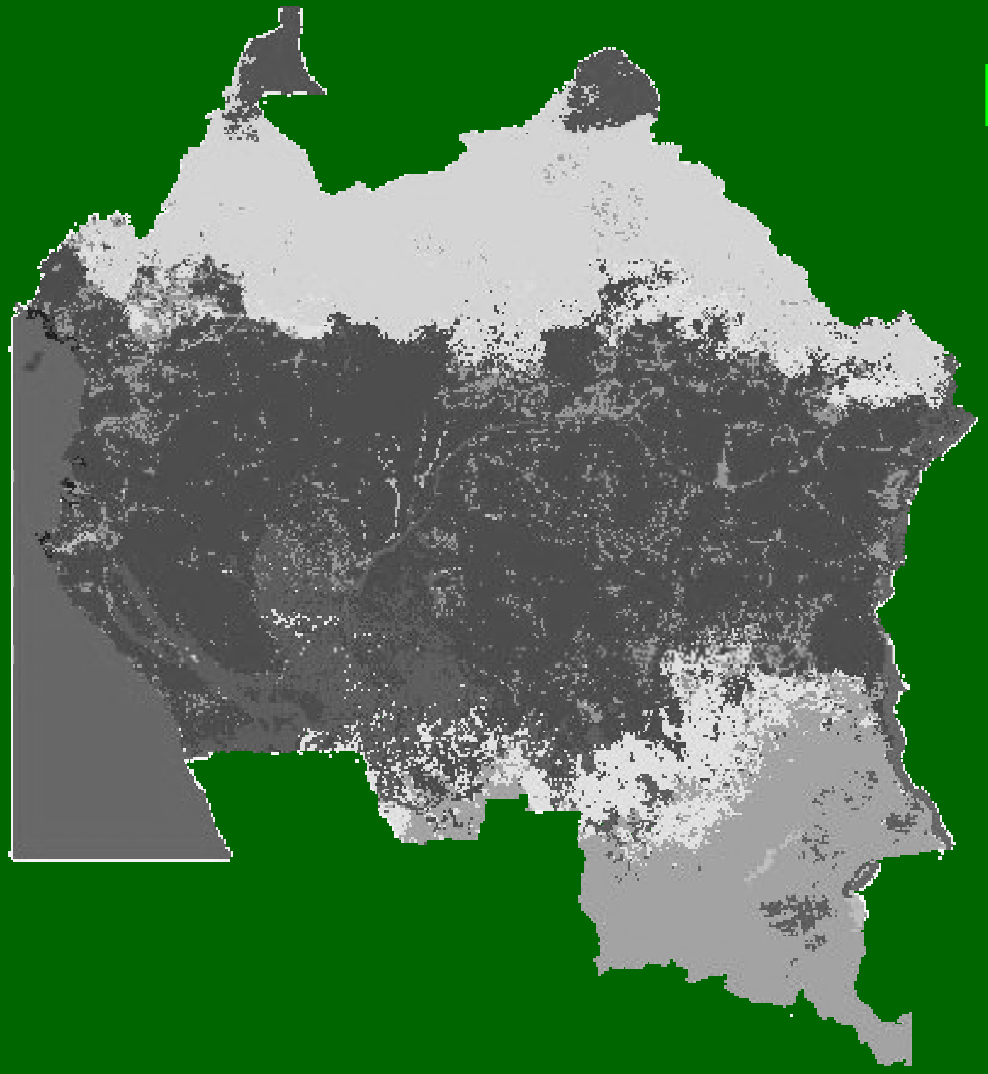

Land use in the Congo Basin
Forest not "virgin"
widespread farming for >2,000 years
iron furnaces and charred oil palm kernels evidence of extensive iron age occupation by farmers

Land use in the Congo Basin

Demographic Changes

- evidence of population crash in Gabon 400-700 years ago
- forest population reduced by 50% in first 20 years of this century
- demographic pressure varies across the basin
  - urban populations 40-60%
  - DRC and Cameroon 10-14 people/km^2
  - Gabon, Congo, Equatorial Guinea, CAR 2-3 people/km^2
  - growth rates 2.5%

Land use in the Congo Basin



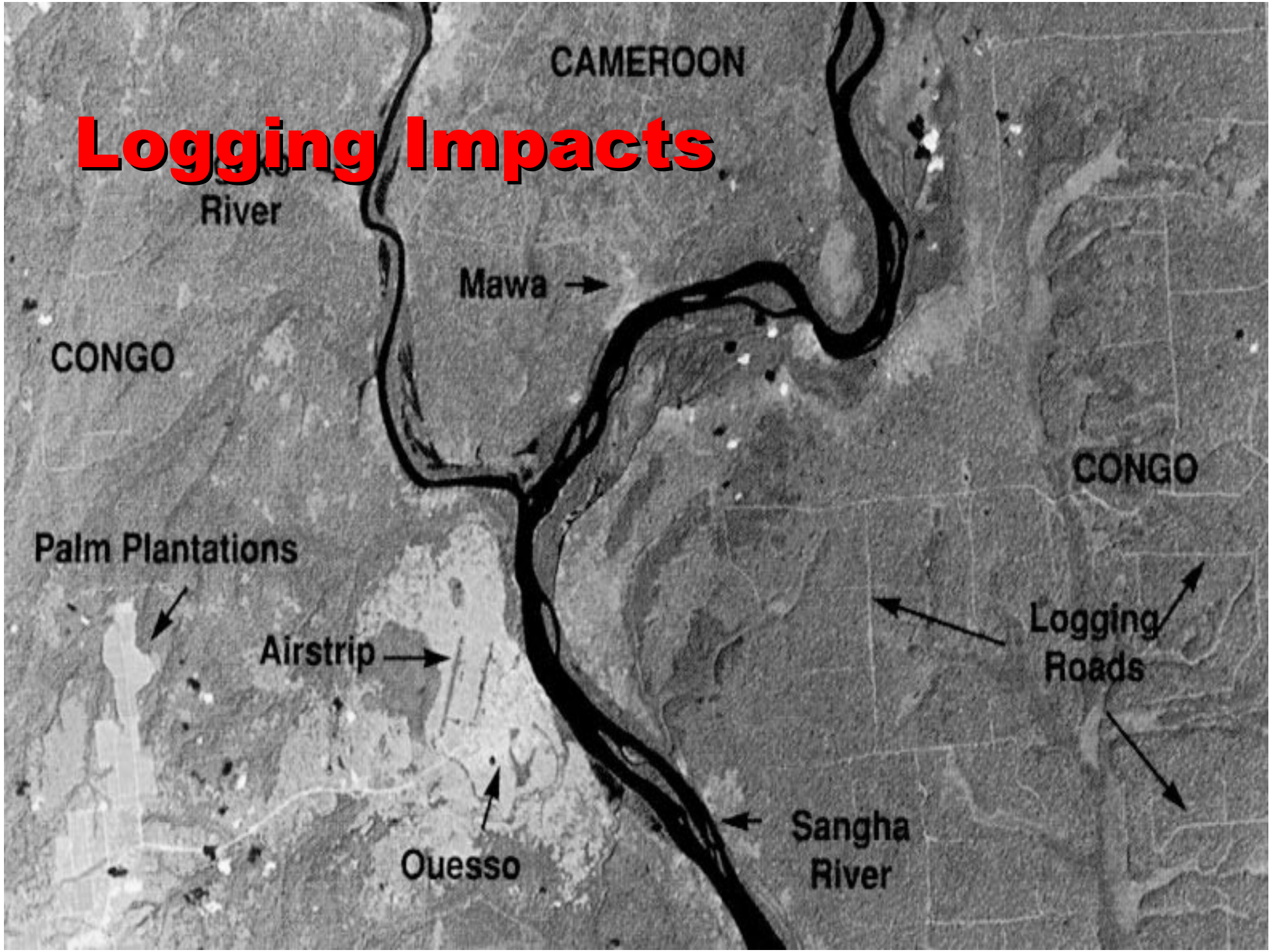
Economic factors

- Prior to 1850s little extra-regional trade
- Early colonial period - river transportation
- 1920-1950 - road building
- Logging - extensive old-growth mining

Land cover change

Logging

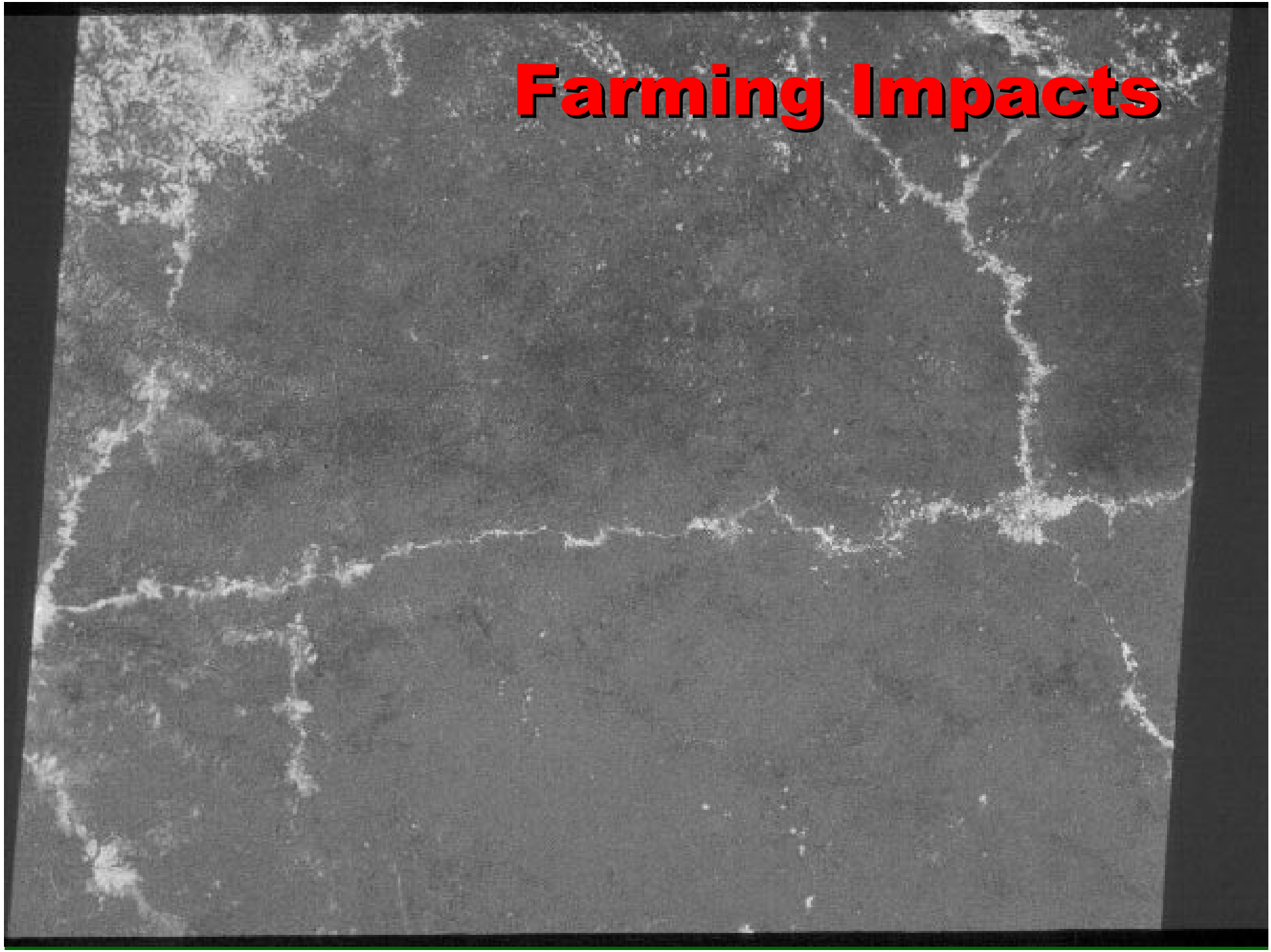
- markets for only a few species
- extensive not intensive harvesting
  - 1-2 trees per hectare
  - <10% of the canopy disturbed
- defaunation not deforestation
- habitat fragmentation not deforestation
  - extensive network of unpaved roads


Logging Impacts
CAMEROON
River
Mawa
CONGO
CONGO
Palm Plantations
Airstrip
Logging
Roads
Ouesso
Sangha
River

Land cover change

Agriculture

- little industrial scale farming
- extent of family farms based on demographic pressure, farm-gate prices, and market access


Farming Impacts

LCLUC modelling in Dzanga-Sangha protected area, CAR

Goals of the study

- Help WWF better understand the likely future extent and patterning of forest clearing for agriculture in the Dzanga-Sangha special reserve

LCLUC modelling in Dzanga-Sangha protected area, CAR

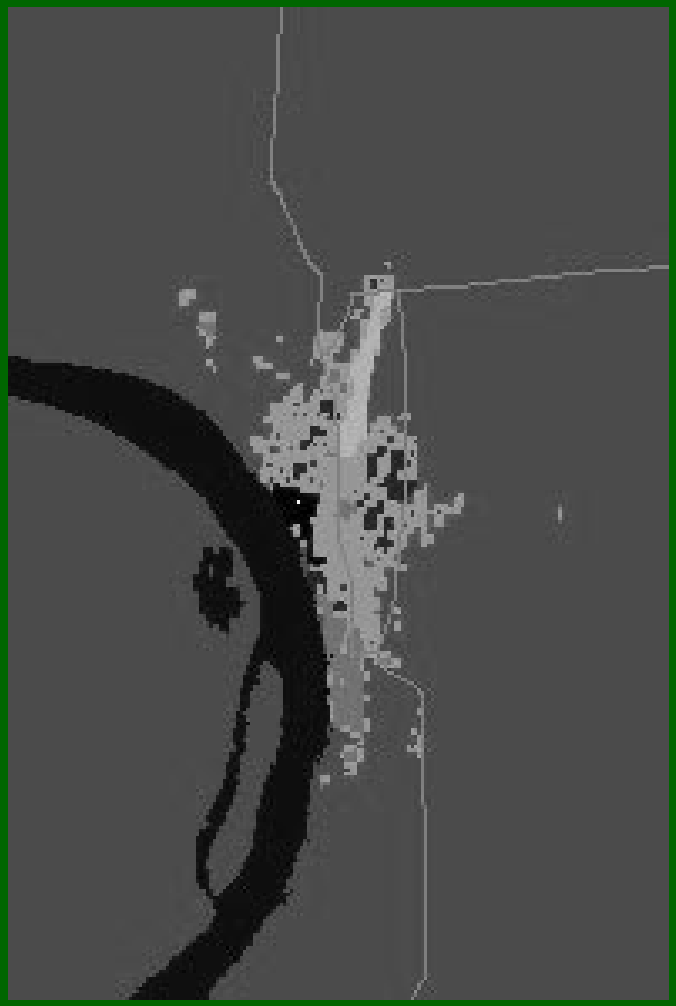
Value of spatially explicit, rule-based models

- based on actual land use decisions and behaviors of forest families
- characterizes both scale of land cover transformation and extent of habitat fragmentation
- allows creation of "what if" scenarios essential to effective management of protected area resources

LCLUC modelling in Dzanga-Sangha protected area, CAR

Parameters and rules

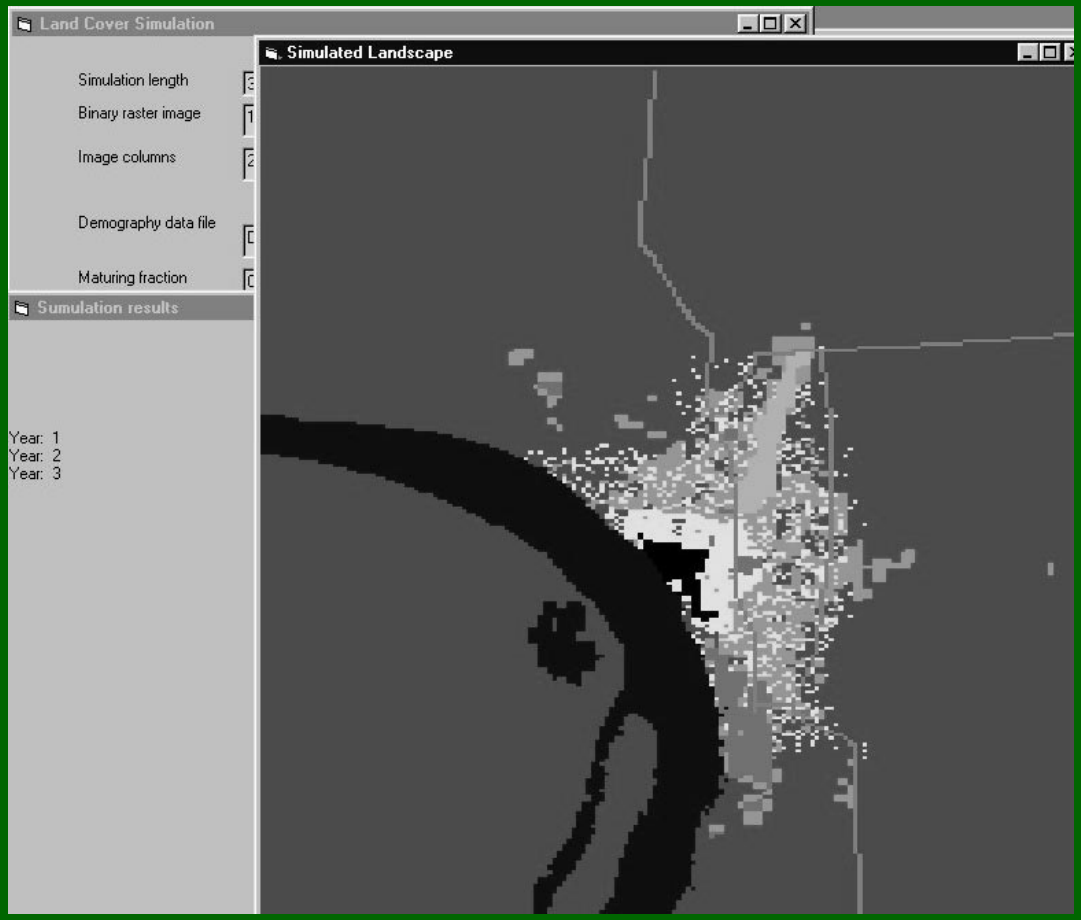
- Initial land cover based on classified Landsat TM imagery
- family size, nutritional requirements, and crop productivity determine field area needs
- fallow period, crop productivity, labor costs and labor allocation determine area of each forest cover type that can be converted to agriculture
- travel costs and proximity to active cropland determine field location



LCLUC modelling in Dzanga-Sangha protected area, CAR

Simulation scenarios

- status quo
- increased market access
- revitalization of the logging concession



Climate Change and Human Response in the Semi Arid Near East

Funding: NASA ESE/IDS (12/96 to 12/99)

Group: Yale Center for Earth Observation

Subprojects:

- Large scale climate, landscape** and hydrology (Smith et al.)
- Hyperspectral crop yield analysis (Thenkabail et al.)
- Farming systems (Hole et al.)
- Epidemiology and landscape change (Wilson et al.; U. Mich.)

(** This presentation)

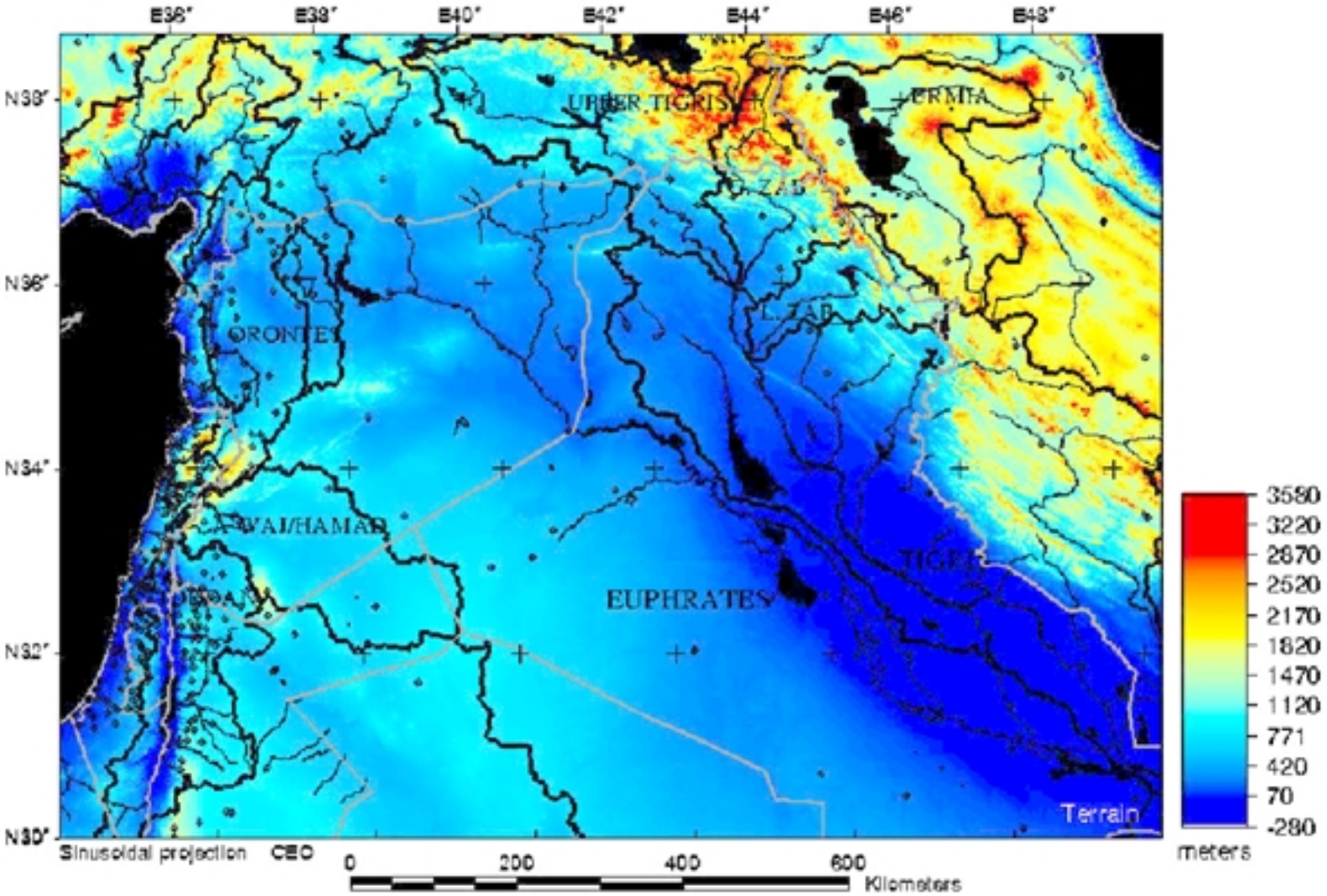
Characteristics of the Middle East Region

- Semi-arid climate; strong climate gradients
- Degraded landscape
- Rapid population growth
- Shifting economic/agricultural strategies

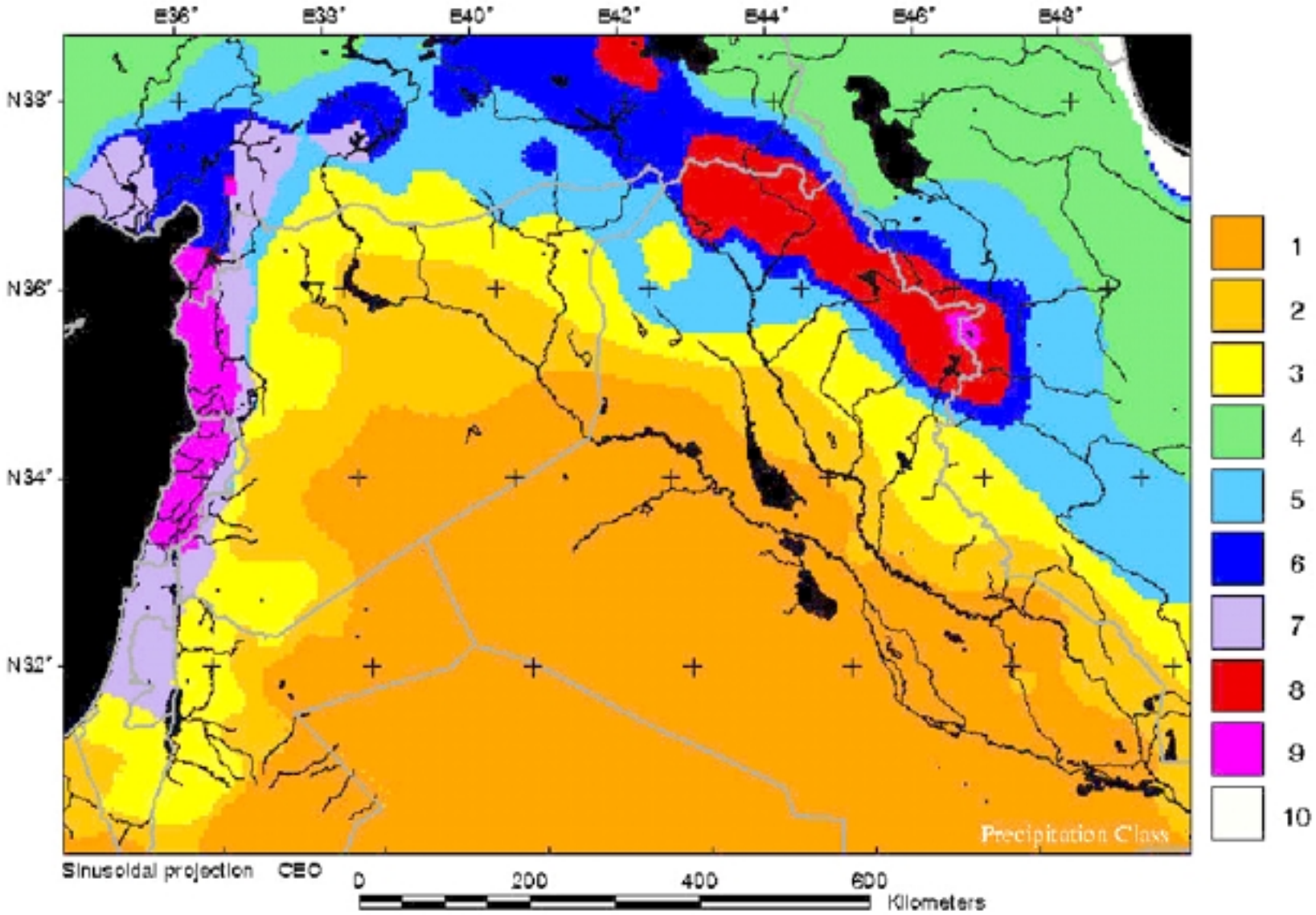
LC/LU in a dynamic arid landscape

Outline:

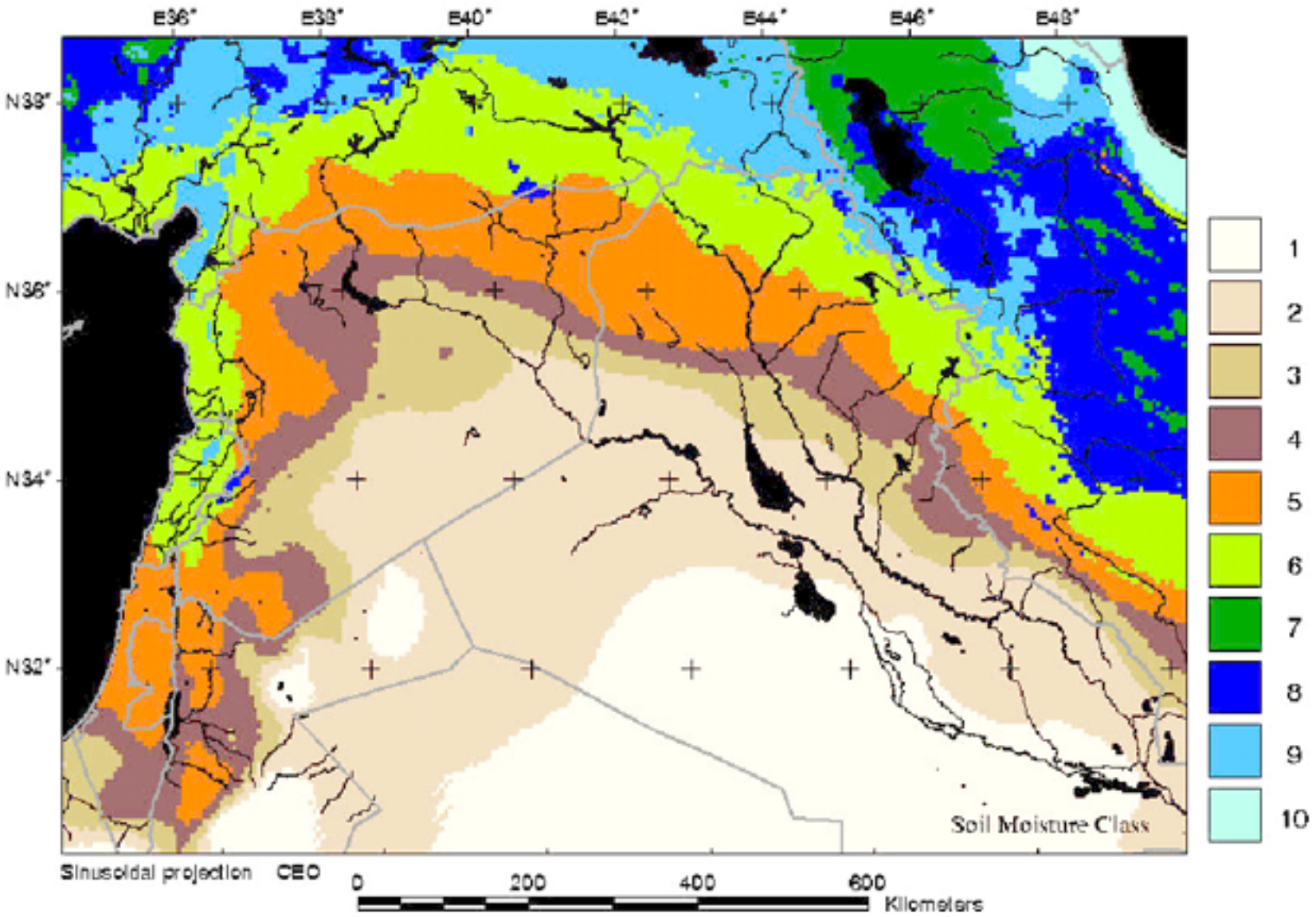
- Climate and Terrain
- Land cover classification
- Snow variability
- Irrigation variability
- Rainfed agriculture variability
- Discussion



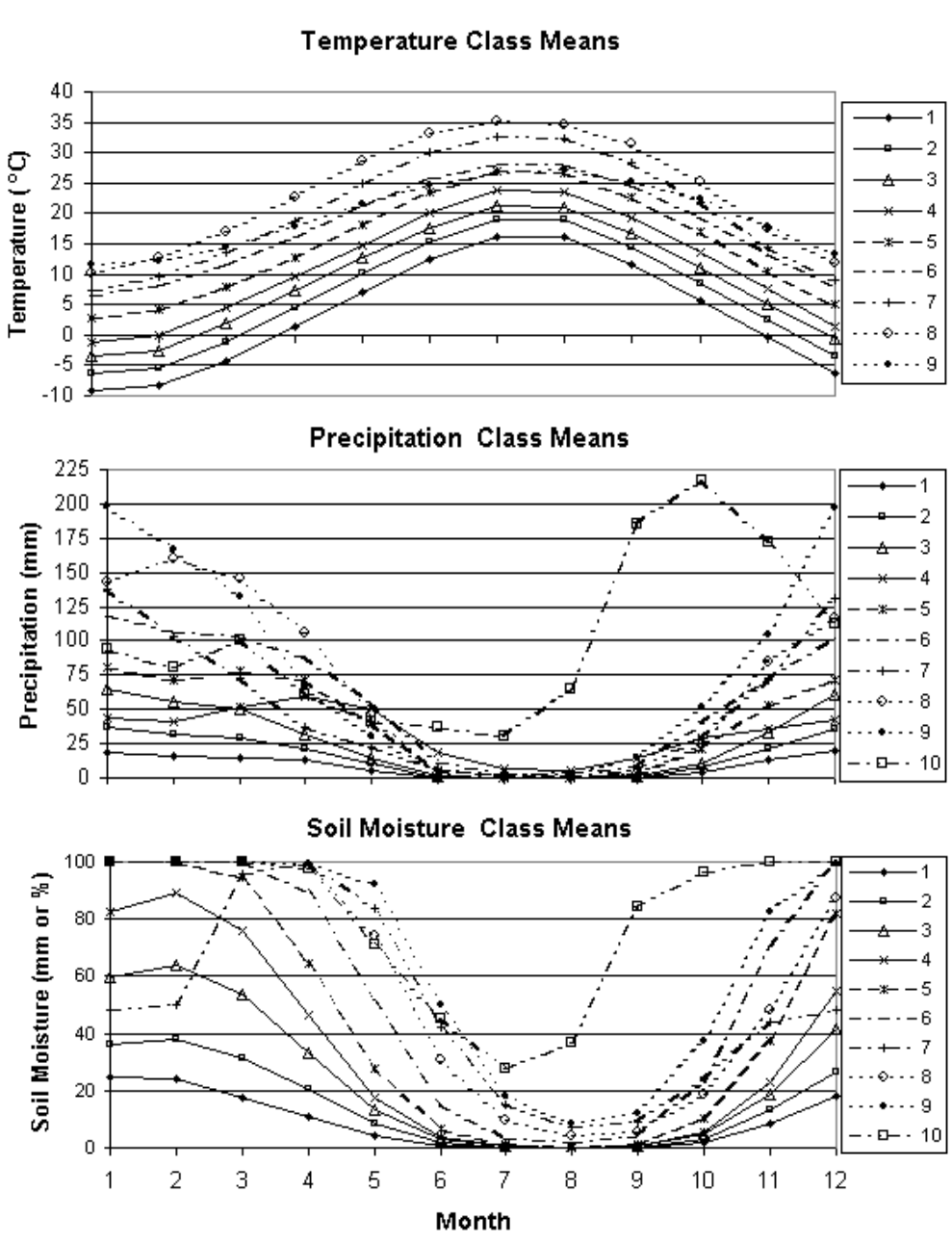
Digital Elevation Model with 30 Arc Second Resolution (black circles represent meteorological stations)

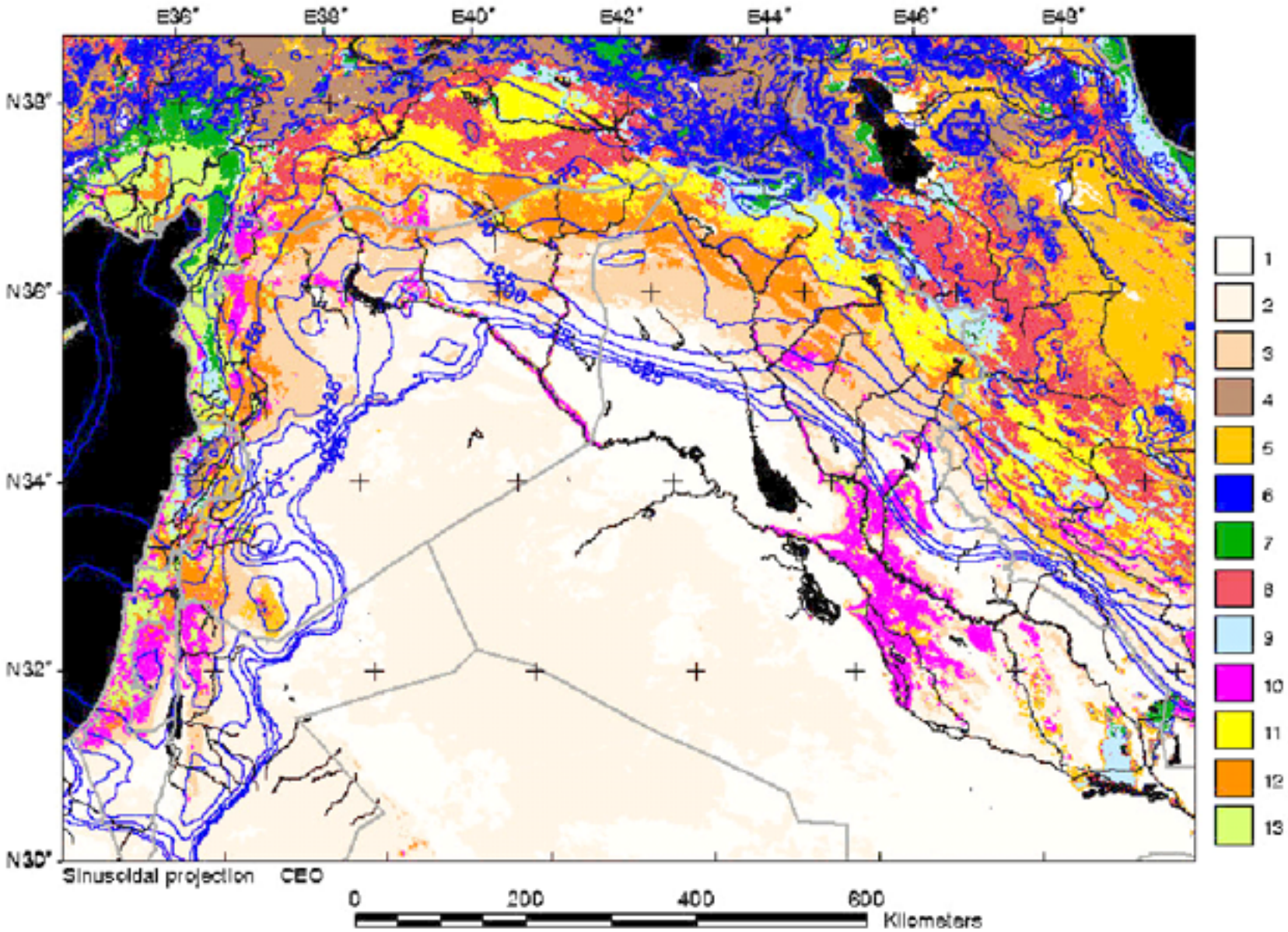


Multitemporal Unsupervised Classification of Monthly Precipitation Data



Multitemporal Unsupervised Classification of Monthly Soil Moisture Data


Temperature Class Means
Temperature (°C)
40
35
30
25
20
15
10
5
0
-5
-10
1
2
3
4
5
6
7
8
9
Precipitation Class Means
Precipitation (mm)
225
200
175
150
125
100
75
50
25
0
1
2
3
4
5
6
7
8
9
10
Soil Moisture Class Means
Soil Moisture (mm or %)
100
80
60
40
20
0
1
2
3
4
5
6
7
8
9
10
11
12
Month



SWAP13 Multitemporal Unsupervised Classification of 1km Composite NDVI (10/1992-09/1993)

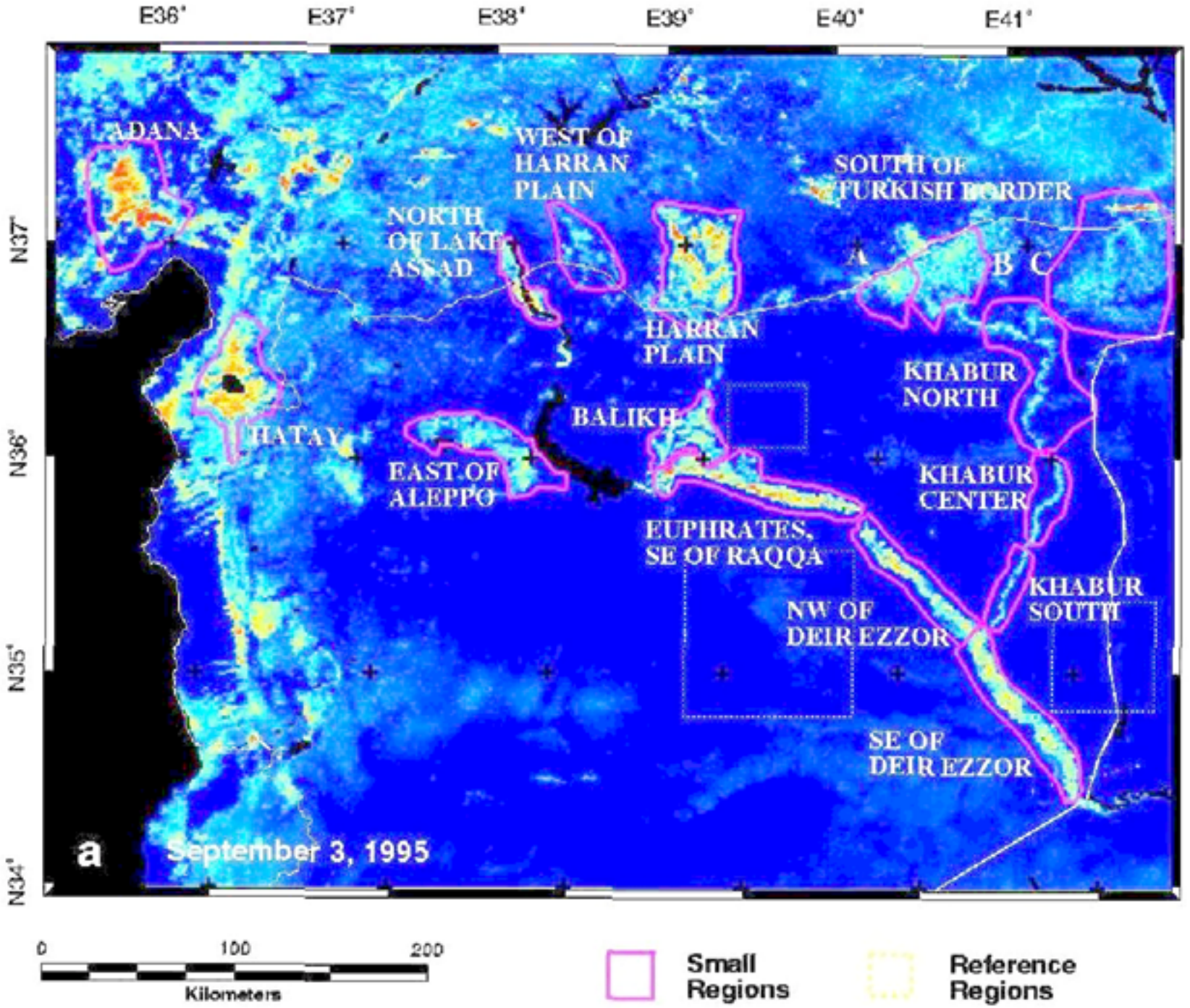
Problems in the satellite estimation of irrigated area

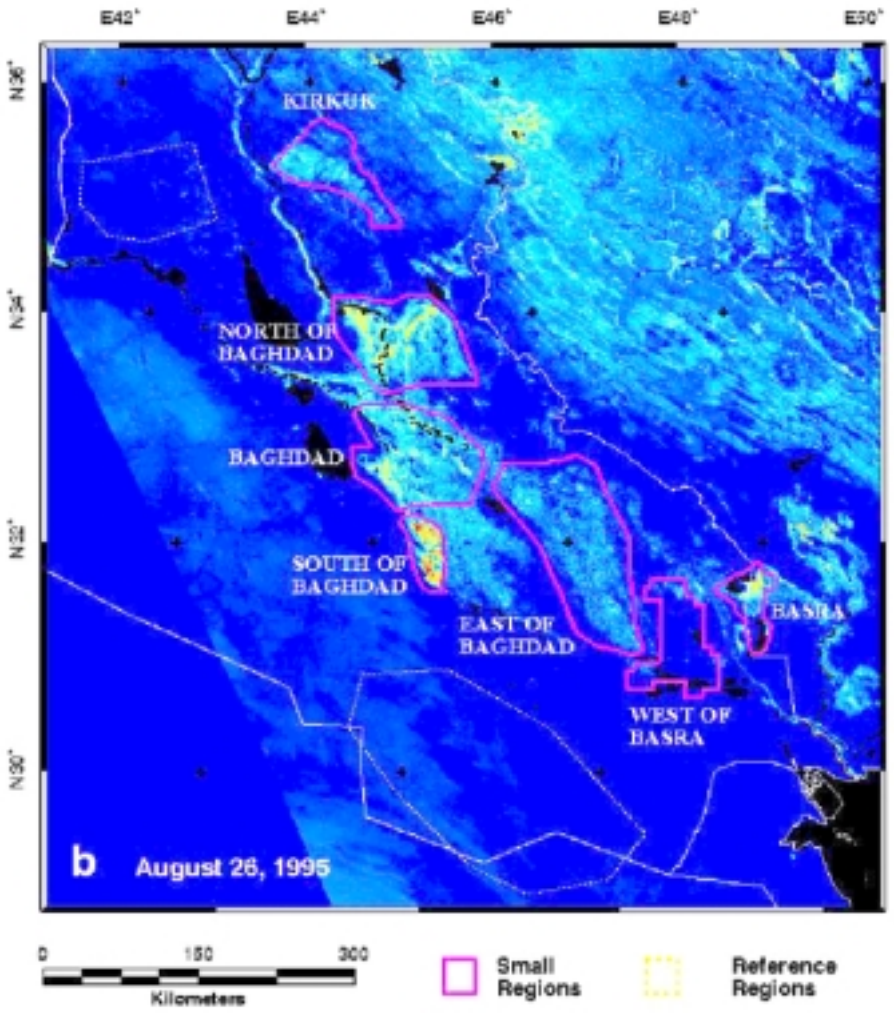
Detection of spring supplemental irrigation is difficult. We focus on summer crops.

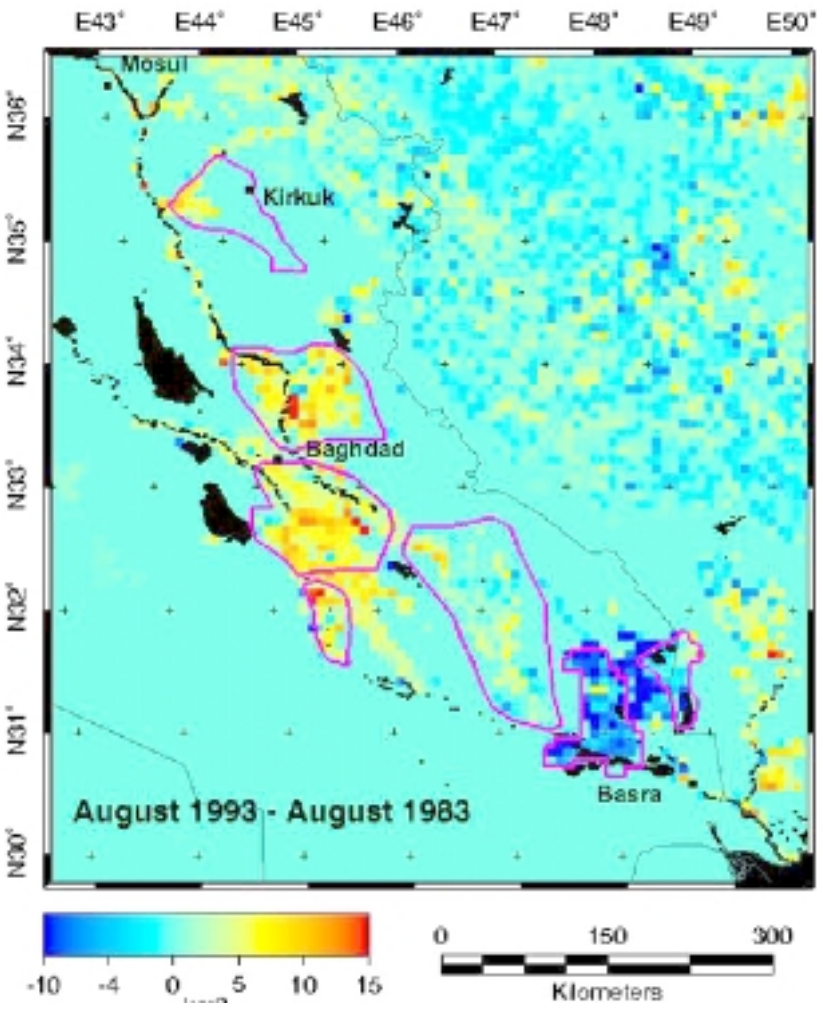
Phenology of irrigated crops mimics other landcovers. We use other factors such as terrain to reduce misidentification.

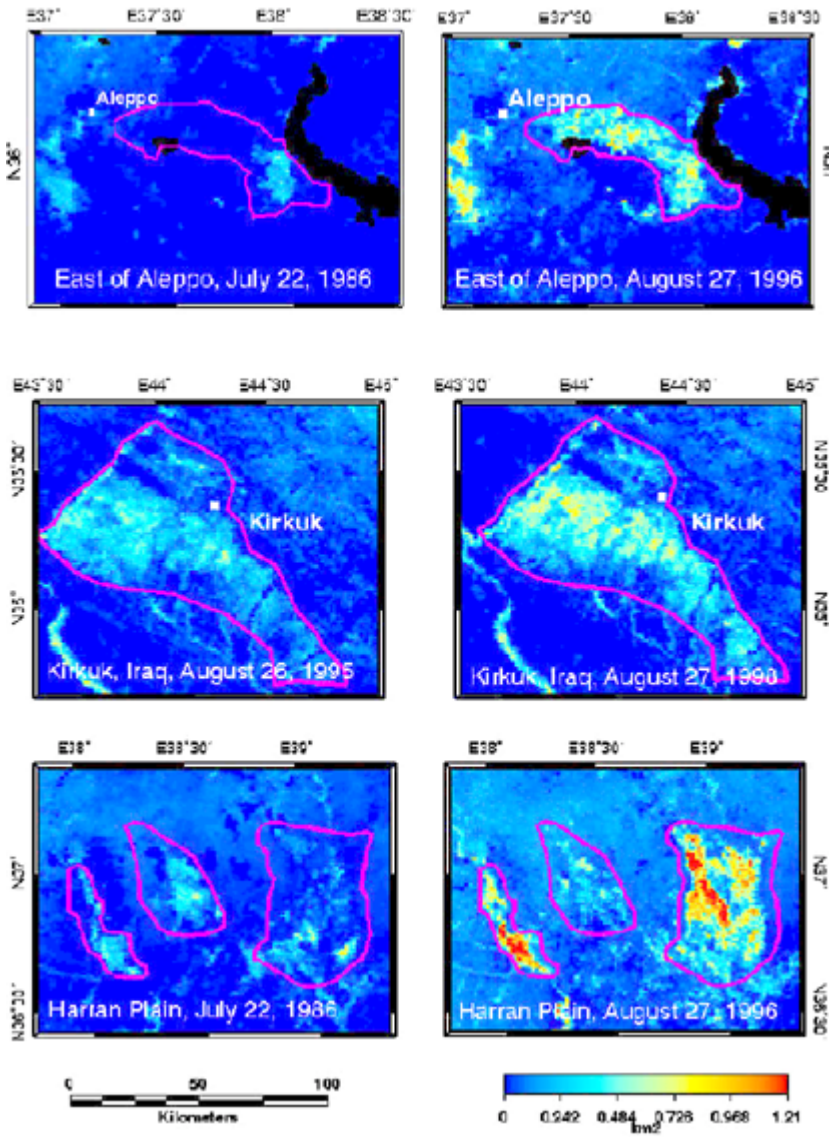
Broad size distribution of irrigated fields ($F(A)=C\ A^{m}$; m = -1.9). Small fields dominate. We combine Landsat and AVHRR data.

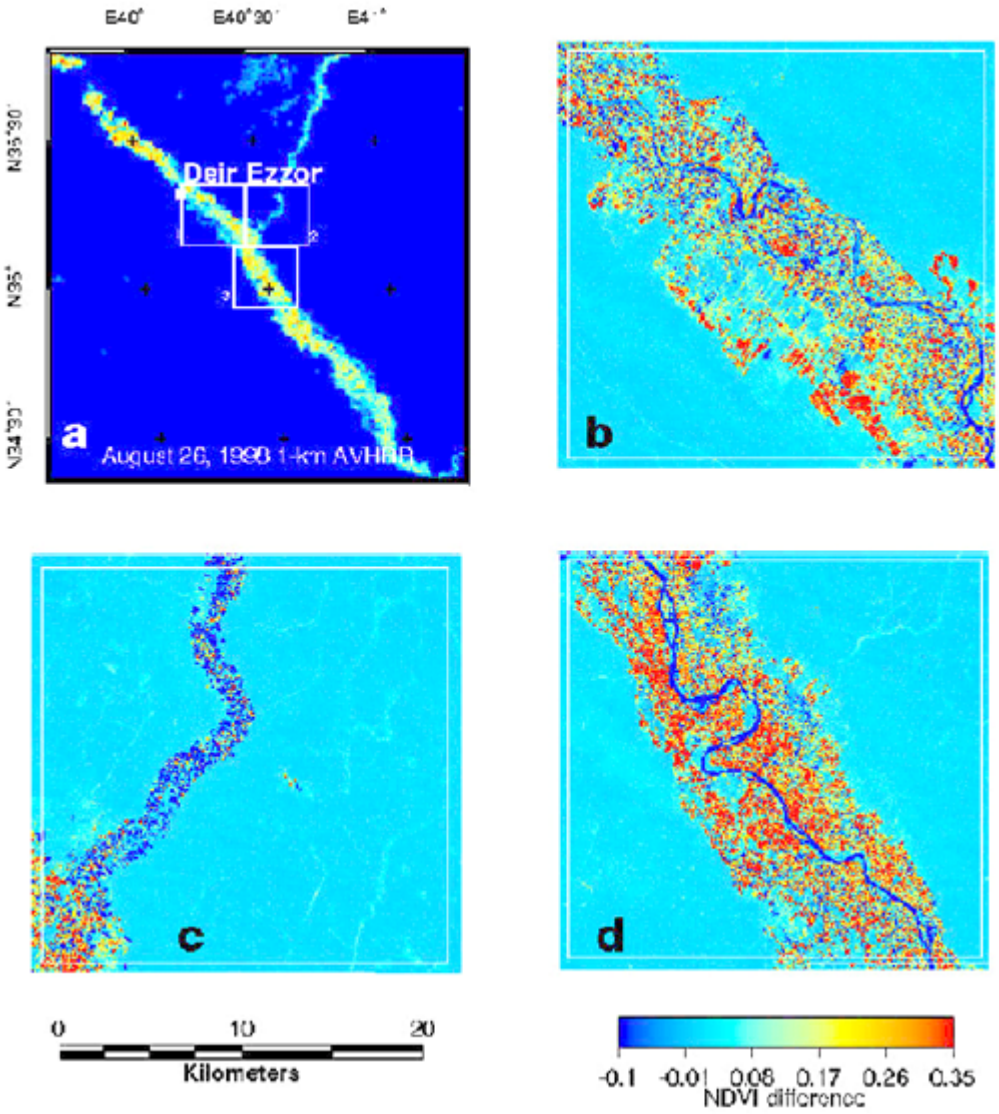
Sensor and orbit drift. We use a desert reference area.

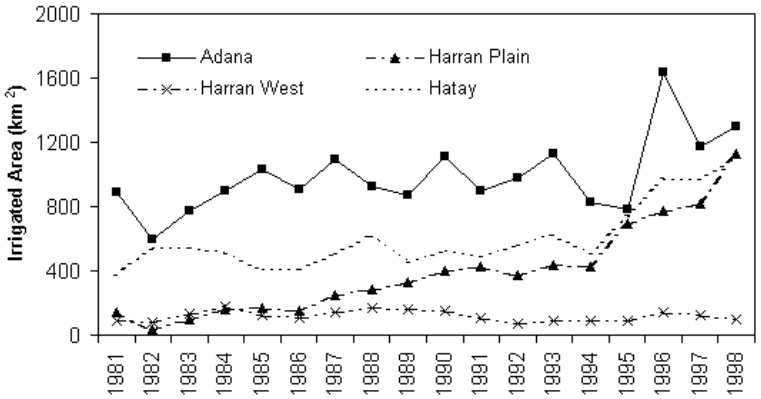

E36°
E37°
E38°
E39°
E40°
E41°
N37°
N36°
N35°
N34°
ADANA
WEST OF HARRAN PLAIN
NORTH OF LAKE ASSAD
SOUTH OF TURKISH BORDER
A
B
C
HARRAN PLAIN
KHABUR NORTH
BALIKH
HATAY
EAST OF ALEPPO
KHABUR CENTER
EUPHRATES, SE OF RAQQA
KHABUR SOUTH
NW OF DEIR EZZOR
SE OF DEIR EZZOR
a
September 3, 1995
0
100
200
Kilometers
Small Regions
Reference Regions

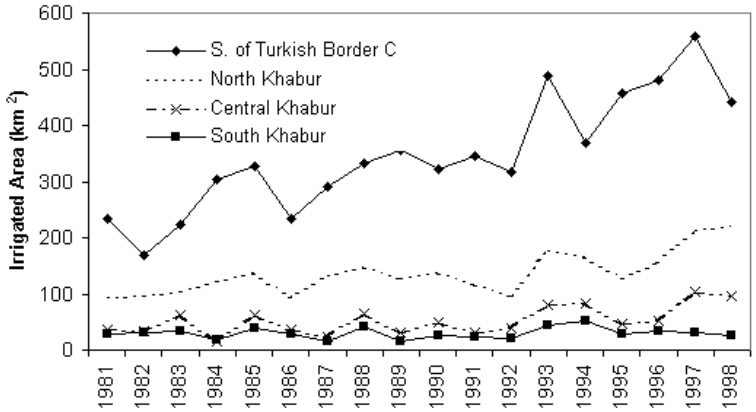

E42°
E44°
E46°
E48°
E50°
N36°
N34°
N32°
N30°
KIRKUK
NORTH OF BAGHDAD
BAGHDAD
SOUTH OF BAGHDAD
EAST OF BAGHDAD
BASRA
WEST OF BASRA
b
August 26, 1995
0
150
300
Kilometers
Small Regions
Reference Regions

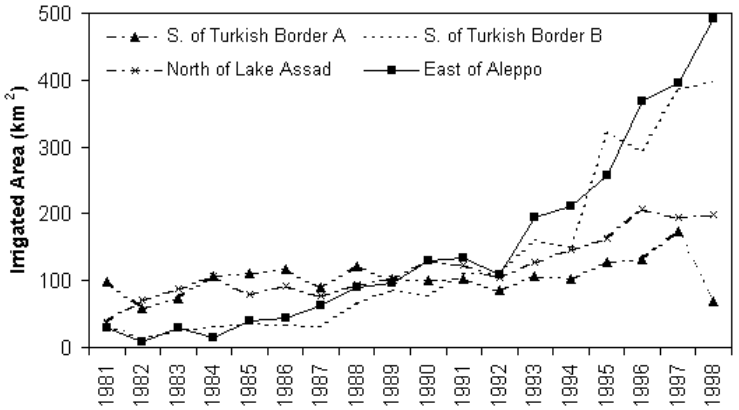

E43°
E44°
E45°
E46°
E47°
E48°
E49°
E50°
N36°
N35°
N34°
N33°
N32°
N31°
N30°
Mosul
Kirkuk
Baghdad
Basra
August 1993 - August 1983
-10
-4
0
5
10
15
0
150
300
Kilometers

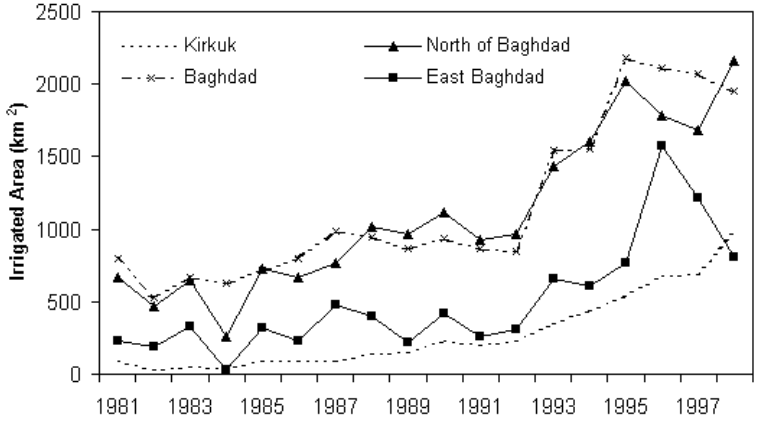

Aleppo
East of Aleppo, July 22, 1986
Aleppo
East of Aleppo, August 27, 1996
Kirkuk
Kirkuk, Iraq, August 26, 1995
Kirkuk
Kirkuk, Iraq, August 27, 1996
Harran Plain, July 22, 1986
Harran Plain, August 27, 1996
0
50
100
Kilometers
0
0.242
0.484
0.726
0.968
1.21

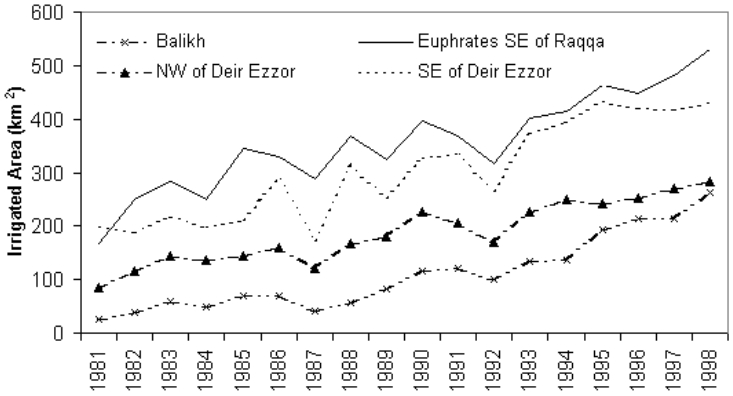

E40°
E40°30'
N35°30'
N35°
Deir Ezzor
a
August 26, 1998 1-km AVHRR
b
c
d
0
10
20
Kilometers
-0.1
-0.01
0.08
0.17
0.26
0.35
NDVI difference

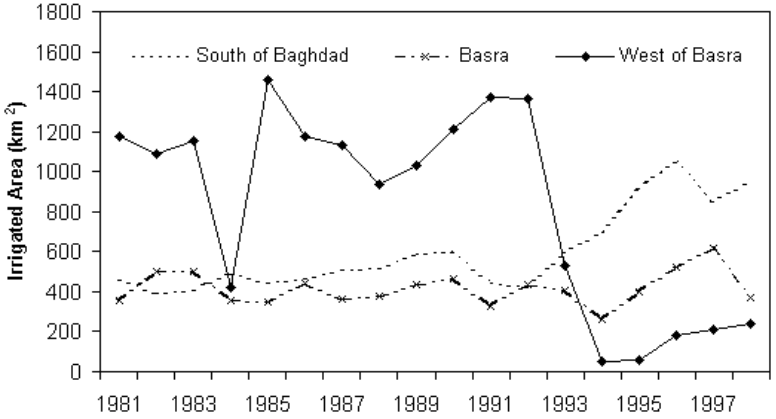

Adana
Harran Plain
Harran West
Hatay
Irrigated Area (km 2)
2000
1600
1200
800
400
0
1981
1982
1983
1984
1985
1986
1987
1988
1989
1990
1991
1992
1993
1994
1995
1996
1997
1998


S. of Turkish Border C
North Khabur
Central Khabur
South Khabur
Irrigated Area (km 2)
600
500
400
300
200
100
0
1981
1982
1983
1984
1985
1986
1987
1988
1989
1990
1991
1992
1993
1994
1995
1996
1997
1998


S. of Turkish Border A
S. of Turkish Border B
North of Lake Assad
East of Aleppo
Irrigated Area (km 2)
500
400
300
200
100
0
1981
1982
1983
1984
1985
1986
1987
1988
1989
1990
1991
1992
1993
1994
1995
1996
1997
1998


Kirkuk
North of Baghdad
Baghdad
East Baghdad
Irrigated Area (km 2)
2500
2000
1500
1000
500
0
1981
1983
1985
1987
1989
1991
1993
1995
1997


Balikh
Euphrates SE of Raqqa
NW of Deir Ezzor
SE of Deir Ezzor
Irrigated Area (km 2)
600
500
400
300
200
100
0
1981
1982
1983
1984
1985
1986
1987
1988
1989
1990
1991
1992
1993
1994
1995
1996
1997
1998


South of Baghdad
Basra
West of Basra
Irrigated Area (km 2)
1800
1600
1400
1200
1000
800
600
400
200
0
1981
1983
1985
1987
1989
1991
1993
1995
1997

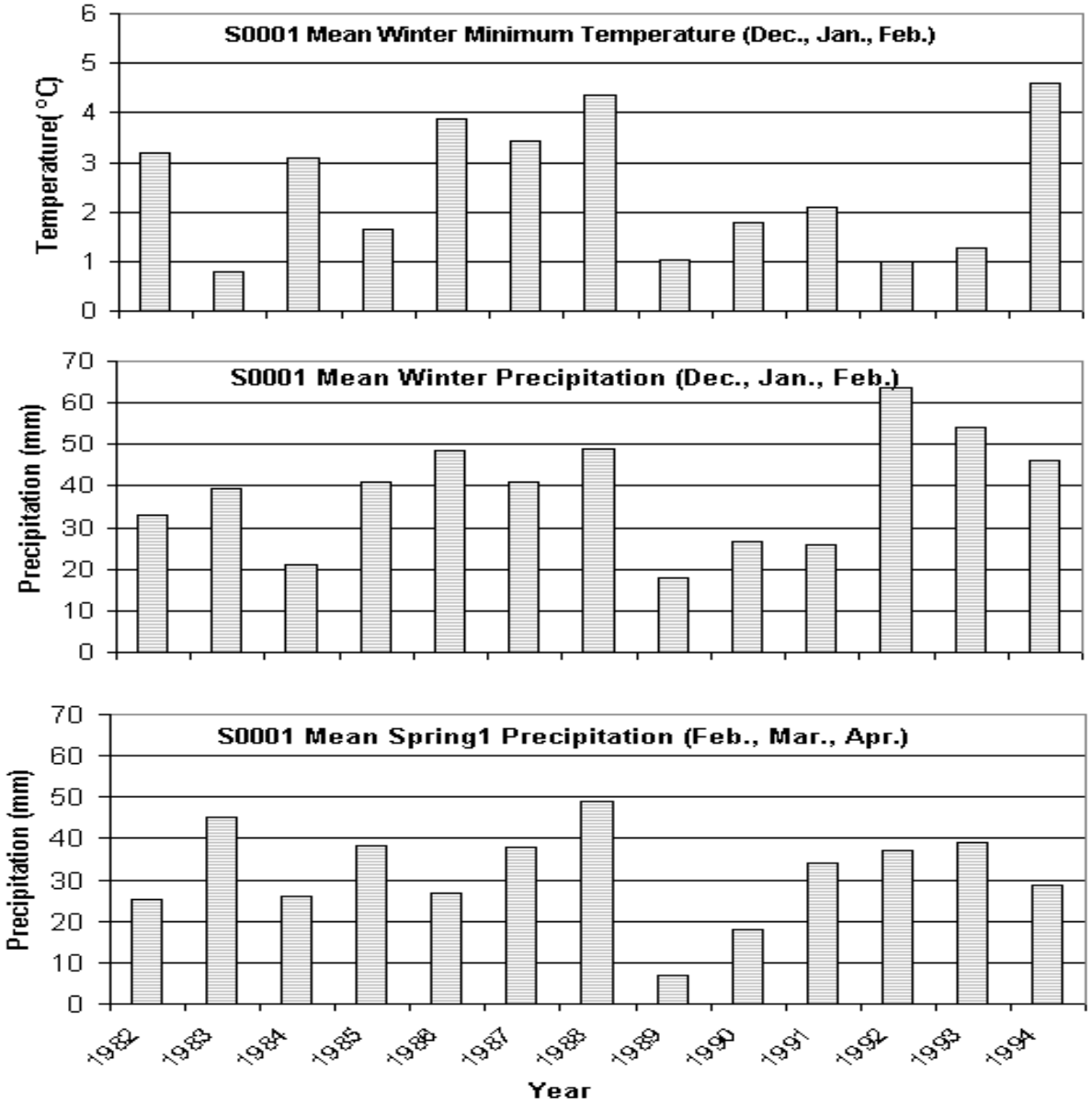
Correlation of Climate and Spring Vegetation

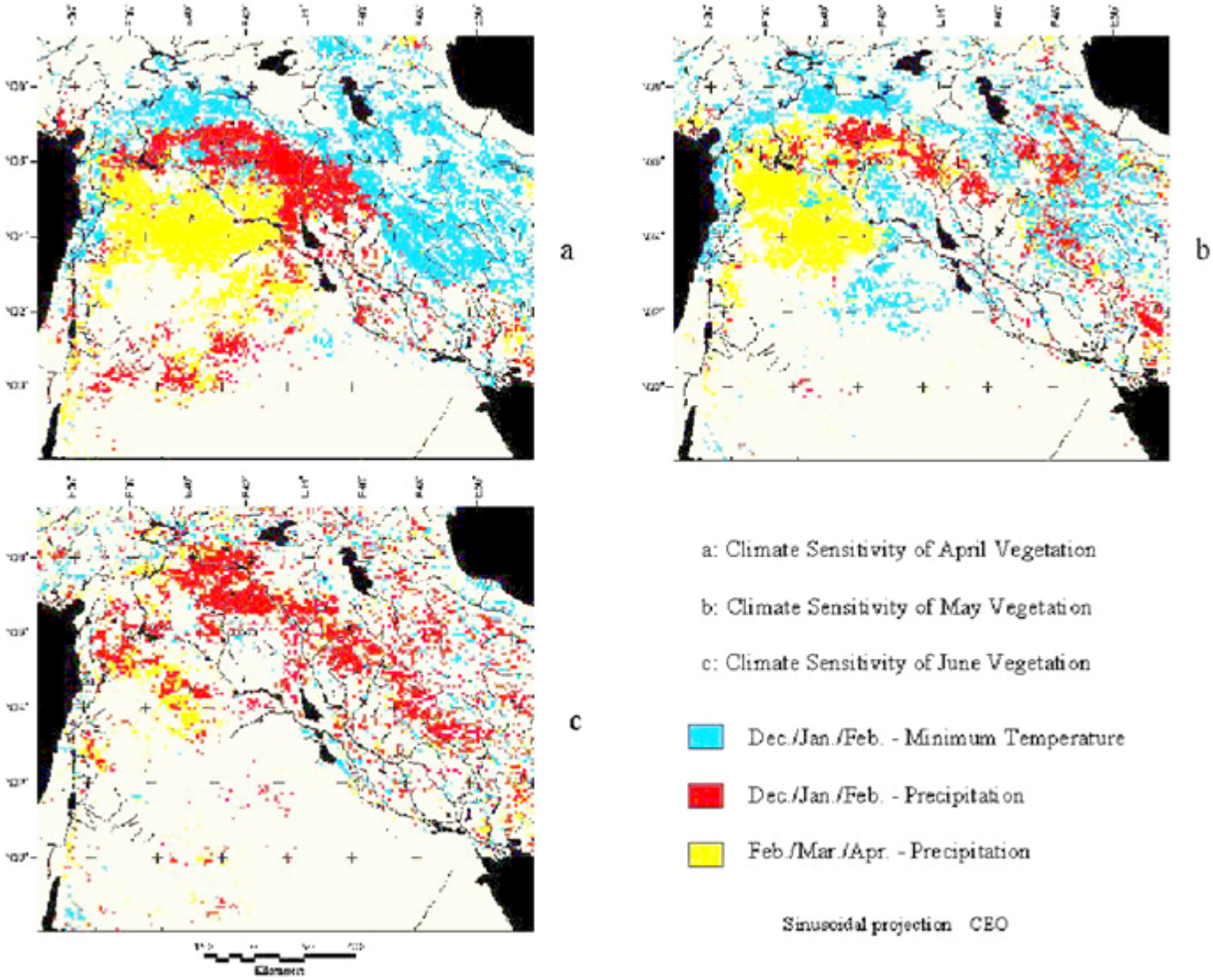
Datasets: 12 years (1983-1994) AVHRR NDVI and climate indices from a cluster of six WMO stations in NW Syria.

Methods: Compute the correlation coefficients (R) between April, May and June NDVI and 16 climate indices. Select the three most important climate indices.

Results: Winter (DJF) precipitation and minimum temperature and Spring (FMA) precipitation influence specific vegetation zones in different months

$$R = \sum_{i=1}^{12}(N_i - \overline{N})(C_i - \overline{C}) \times (\sum_{i=1}^{12}(N_i - N)^2 \times \sum_{i=1}^{12}(C_i - \overline{C})^2)^{-1/2}$$


S0001 Mean Winter Minimum Temperature (Dec., Jan., Feb.)
Temperature(°C)
0
1
2
3
4
5
6
S0001 Mean Winter Precipitation (Dec., Jan., Feb.)
Precipitation (mm)
0
10
20
30
40
50
60
70
S0001 Mean Spring1 Precipitation (Feb., Mar., Apr.)
Precipitation (mm)
0
10
20
30
40
50
60
70
1982
1983
1984
1985
1986
1987
1988
1989
1990
1991
1992
1993
1994
Year


a
b
c
a: Climate Sensitivity of April Vegetation
b: Climate Sensitivity of May Vegetation
c: Climate Sensitivity of June Vegetation
Dec./Jan./Feb. - Minimum Temperature
Dec./Jan./Feb. - Precipitation
Feb./Mar./Apr. - Precipitation
Sinusoidal projection CEO

Landscape Issues in the Middle East

- Degraded land + restoration
- Water Resources
- Sensitivity to Climate Change
- Changing Agricultural Strategies
- Landscape "drivers"

--Government decisions

--Globalization / Population

--Oil money / end of oil

--Gulf war / embargo

--Peace process

--Upstream water consumption

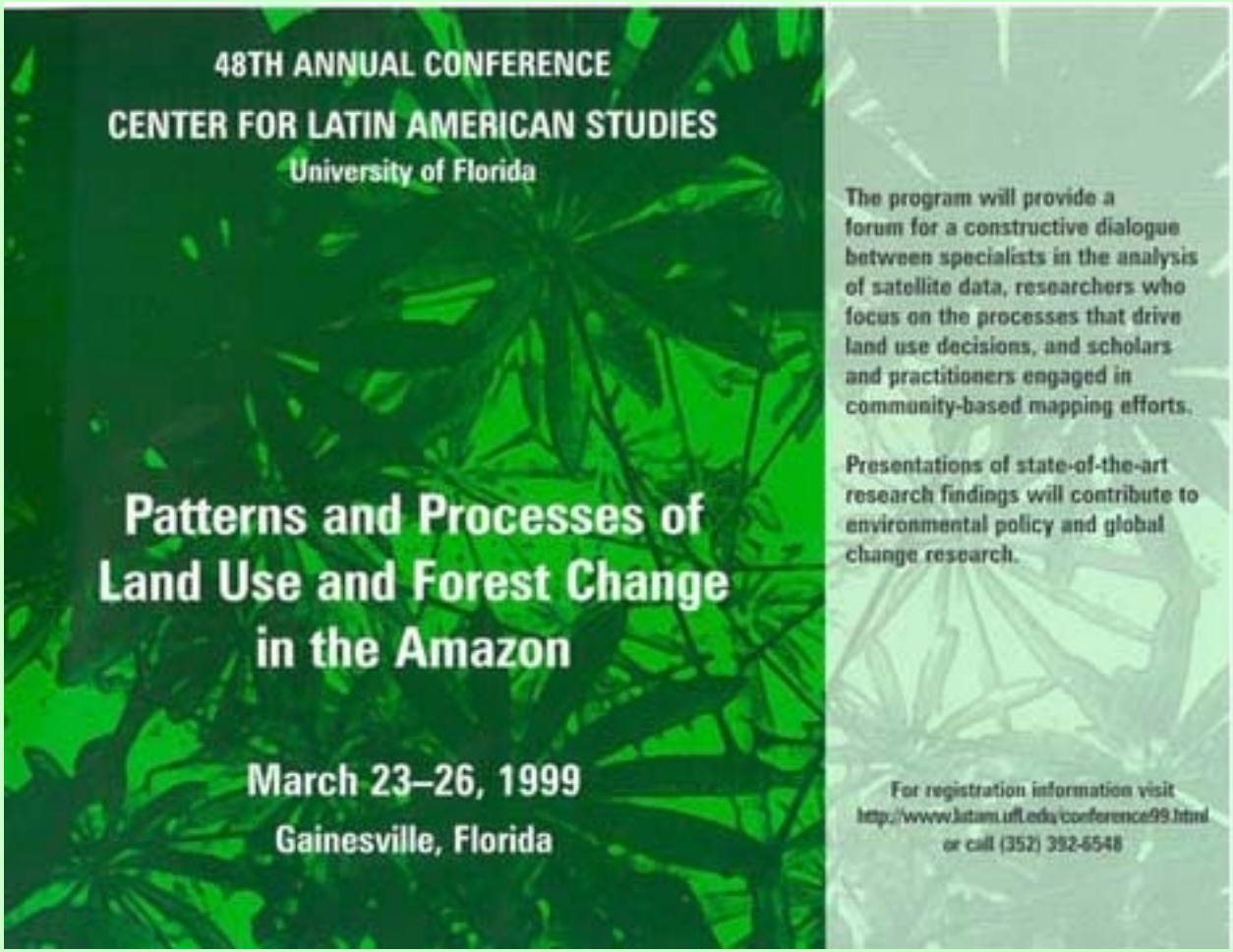
--Bedouin family structure

Overcoming Technical Limits

- Improved ET (L-7)
- Crop Yield (L-7, EO-1)
- LC/LU (L-7, Modis)
- Saline Soils (Aster)
- Soil Moisture (Light SAR)
- Climate Sensitivity (MODIS)
- Rangeland (L-7, MODIS)

Amazon Basin

Amazon LCLUC pattern to process - C. Wood


48TH ANNUAL CONFERENCE
CENTER FOR LATIN AMERICAN STUDIES
University of Florida
Patterns and Processes of Land Use and Forest Change in the Amazon
March 23–26, 1999
Gainesville, Florida
The program will provide a forum for a constructive dialogue between specialists in the analysis of satellite data, researchers who focus on the processes that drive land use decisions, and scholars and practitioners engaged in community-based mapping efforts.
Presentations of state-of-the-art research findings will contribute to environmental policy and global change research.
For registration information visit
http://www.latam.ufl.edu/conference99.html
or call (352) 392-6548

Patterns and Processes of Land Use and Forest Change in the Amazon

Charles H. Wood

Roberto Porro

Stephen G. Perz

Funded by:

- NASA project at UF
- NASA project at MSU
- Center for Latin American Studies at UF
- Tropical Conservation and Development program (TCD) at UF
- Conservation and Development Forum (CDF) at UF

Patterns and Processes of Land Use and Forest Change in the Amazon

Objective: Promote a dialogue between research communities that focus on:

1. Remote sensing
2. Land use decision-making
3. Participatory community mapping

Keynote Address and Special Presentations

- Carlos Nobre, INPE (Brazil)
  "Regional and Global Impacts of Land Use Change in Amazonia"

- Steven Sanderson, Emory
  "Land Use and Cover Change: Past and Future"

- Diane Wickland, NASA
  "NASA and the LUCC Agenda"

Handouts

1. List of Participants
2. Abstracts of Papers and Presentations

http://www.latam.ufl.edu/conference99.html

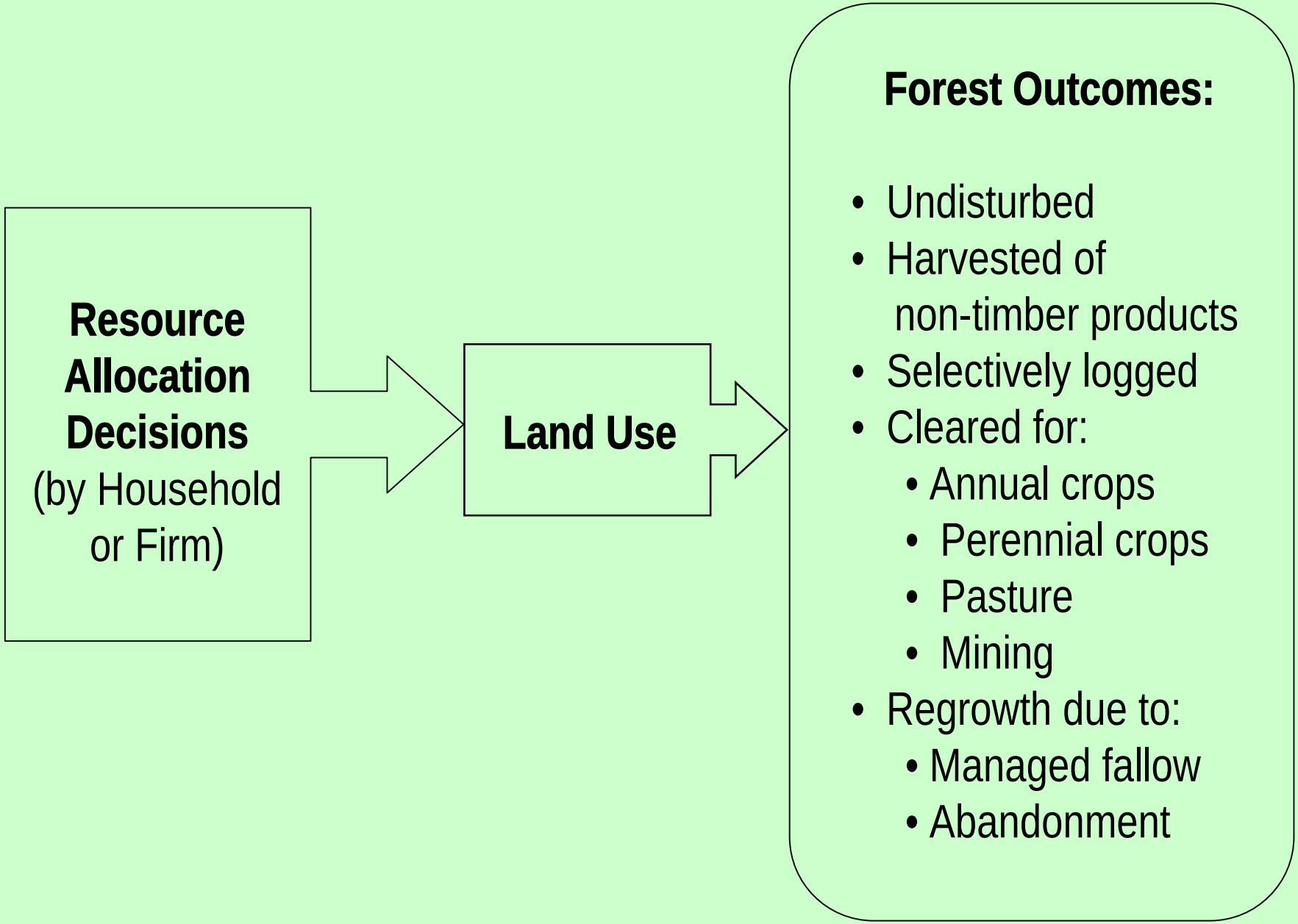
Final Session

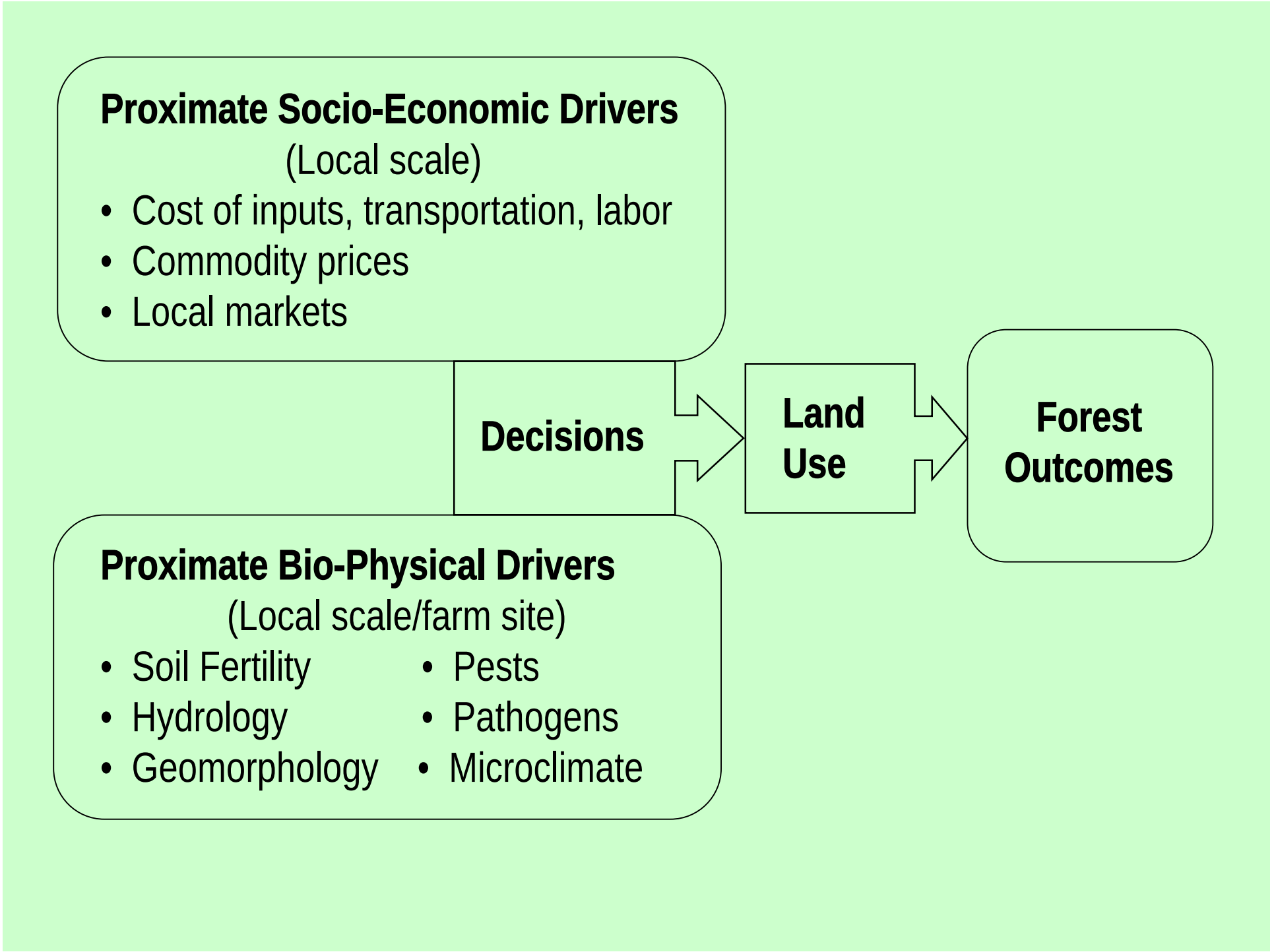
- Open-ended discussion among participants from the three communities

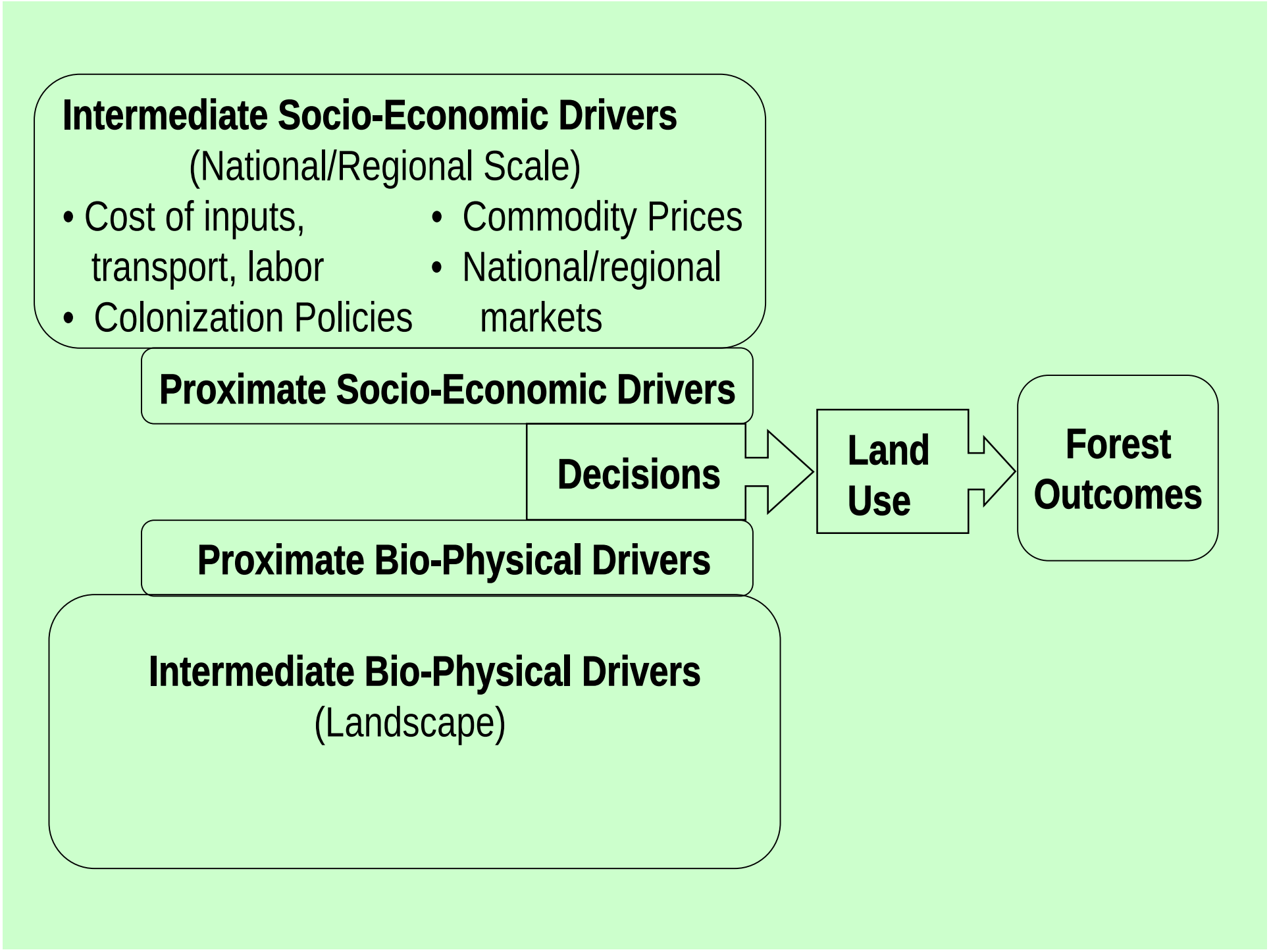
Final Session: Recommendations

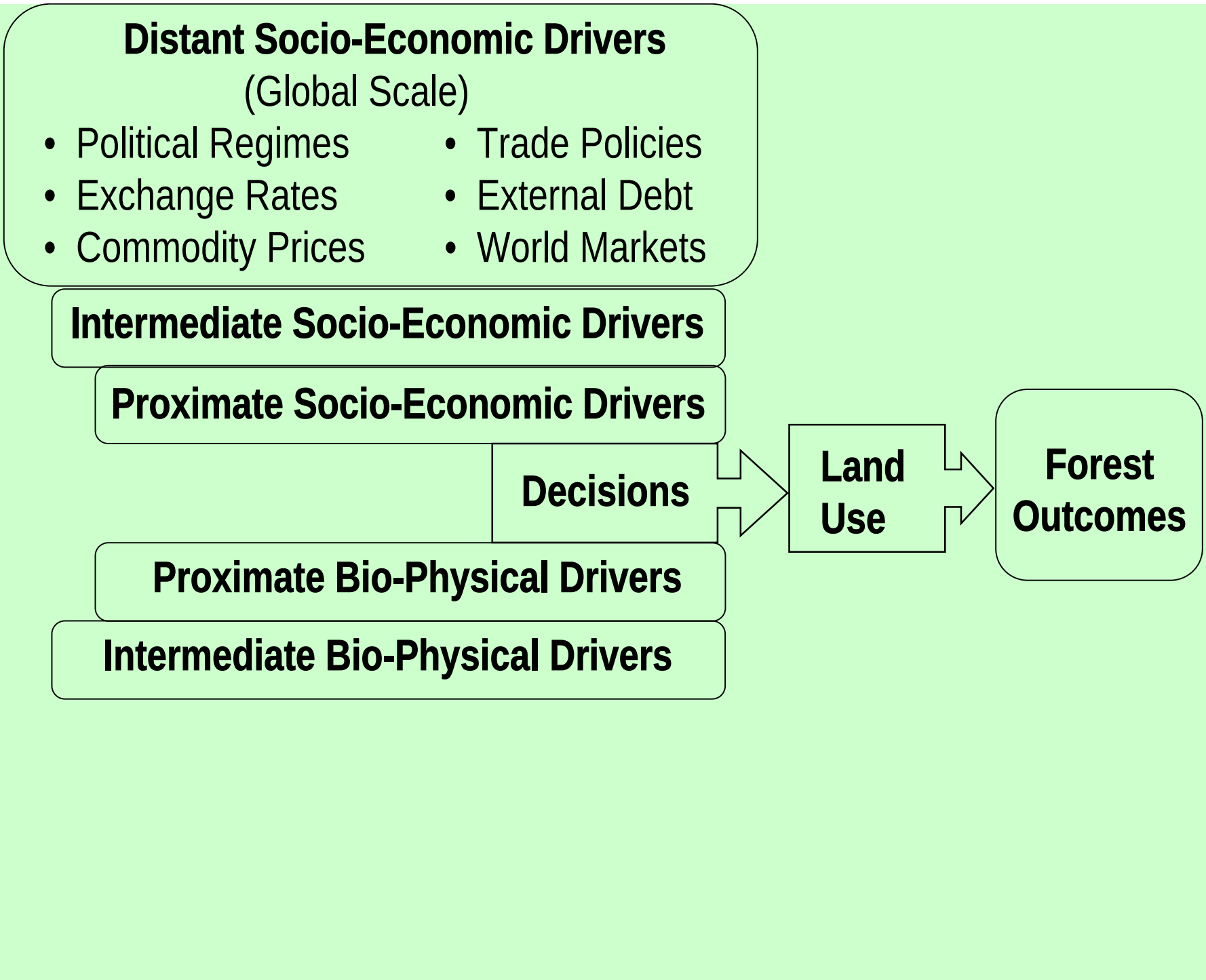
- More fully integrate social sciences
- Broaden scope to include:
  1. Policy makers; policy analysts
  2. Conservation and wildlife ecologists
  3. Forestry and agricultural scientists
  4. Communities living in Amazonia
- Advance conceptual underpinnings of the LUCC agenda

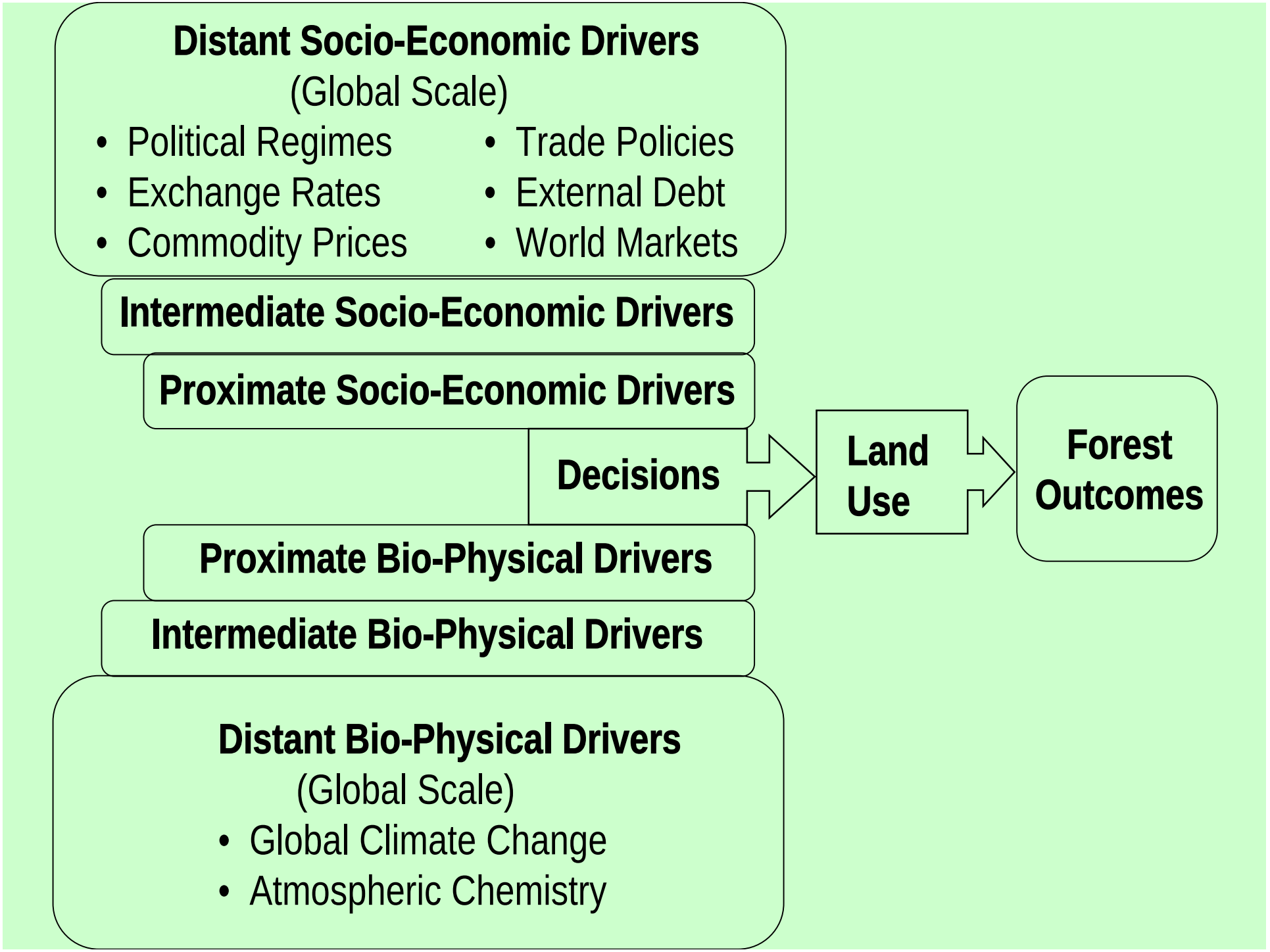
Conceptual Framework: Amazon Forest Change


Resource Allocation Decisions (by Household or Firm)
Land Use
Forest Outcomes:
• Undisturbed
• Harvested of non-timber products
• Selectively logged
• Cleared for:
• Annual crops
• Perennial crops
• Pasture
• Mining
• Regrowth due to:
• Managed fallow
• Abandonment


Proximate Socio-Economic Drivers
(Local scale)
• Cost of inputs, transportation, labor
• Commodity prices
• Local markets
Decisions
Land Use
Forest Outcomes
Proximate Bio-Physical Drivers
(Local scale/farm site)
• Soil Fertility
• Hydrology
• Geomorphology
• Pests
• Pathogens
• Microclimate


Intermediate Socio-Economic Drivers
(National/Regional Scale)
• Cost of inputs, transport, labor
• Colonization Policies
• Commodity Prices
• National/regional markets
Proximate Socio-Economic Drivers
Decisions
Proximate Bio-Physical Drivers
Intermediate Bio-Physical Drivers
(Landscape)
Land Use
Forest Outcomes


Distant Socio-Economic Drivers
(Global Scale)
• Political Regimes
• Exchange Rates
• Commodity Prices
• Trade Policies
• External Debt
• World Markets
Intermediate Socio-Economic Drivers
Proximate Socio-Economic Drivers
Decisions
Land Use
Forest Outcomes
Proximate Bio-Physical Drivers
Intermediate Bio-Physical Drivers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Decisions
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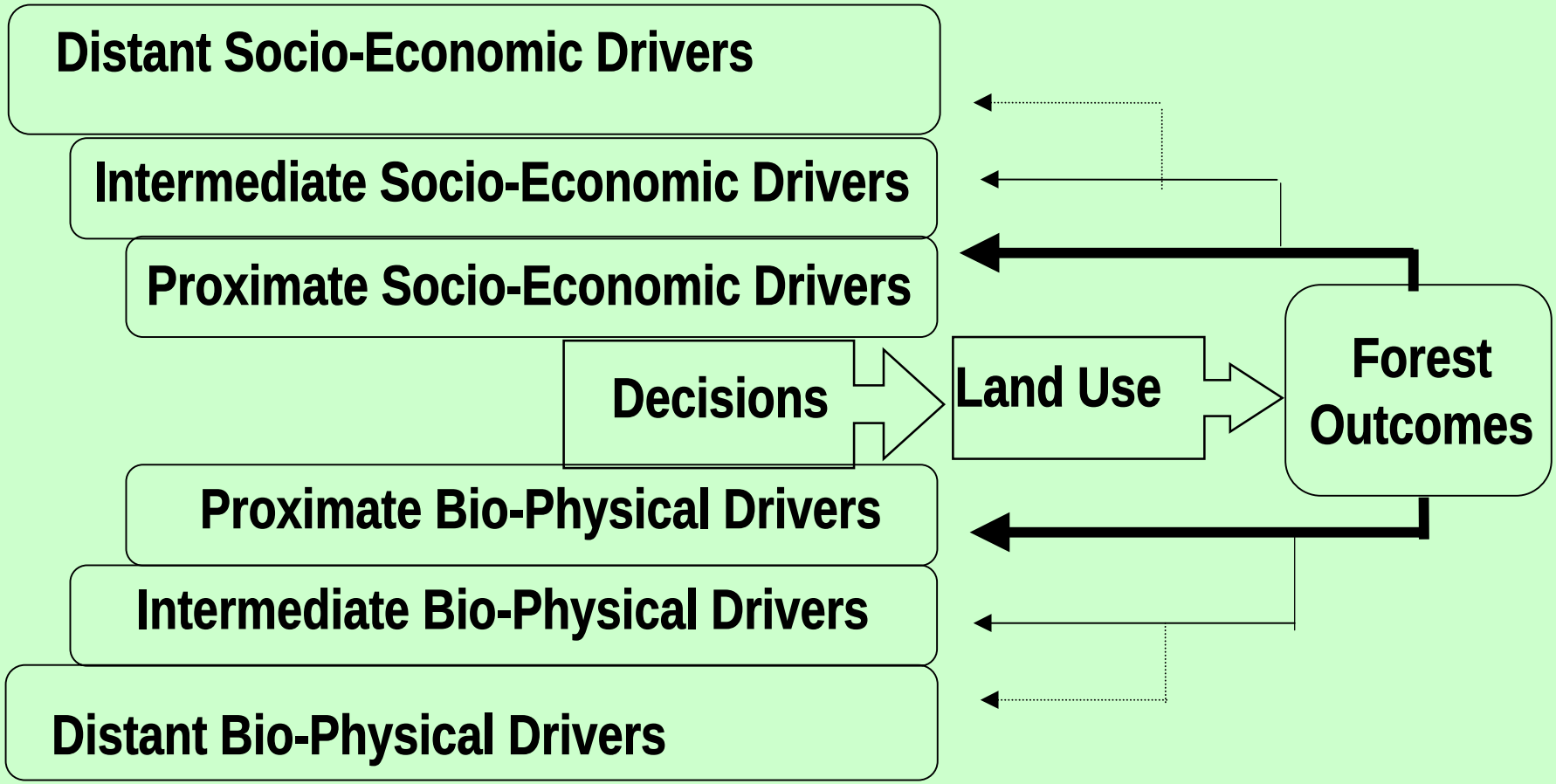
Forest Outcomes
Proximate Bio-Physical Drivers
Intermediate Bio-Physical Drivers
Distant Bio-Physical Drivers
(Global Scale)
• Global Climate Change
• Atmospheric Chemistry


Distant Socio-Economic Drivers
Intermediate Socio-Economic Drivers
Proximate Socio-Economic Drivers
Decisions
Land Use
Forest Outcomes
Proximate Bio-Physical Drivers
Intermediate Bio-Physical Drivers
Distant Bio-Physical Drivers

Conceptual Challenges

- Conceptualizing complex systems
- Relevance of hierarchy theory

1. Spatial-temporal scales
2. Levels of organization
3. Levels of observation
4. Levels of explanation
5. Relationships between levels

Conceptual Challenges: Final observations

- Hierarchy Theory as an organizing “point of view”
- Testing the applicability of the proposed conceptual framework

Anticipating the Future

- “Scale, scale, scale” D. Skole
- Spatial-temporal “levels” and the relationships between them
- Targeted workshop
  - social sciences
  - remote sensing

Southeast Asia

Early Results- Case studies and diagnostic models of the interannual dynamics of deforestations in Southeast Asia - D. Skole

Early Results- Soils, water, people and pixels: a study of Nang Rong - R. Rindfuss

Case Studies & Diagnostic Models of the Inter-annual Dynamics of Deforestation in Southeast Asia

Dave Skole

Basic Science & Remote Sensing Initiative

Department of Geography

Michigan State University

LC LUC Dynamics and Secondary Growth

- Global Carbon Budget: Tropics (Ciais *et al. 1995)*
  - Northern Tropics - source
  - Southern Tropics - small sink
- Explanations:
  - Increase in Tropical NEP offsets deforestation source
  - Reduced rate of deforestation w/increased secondary growth of previously cleared land
- Inconsistent with inter-decadal deforestation data derived from satellite imagery

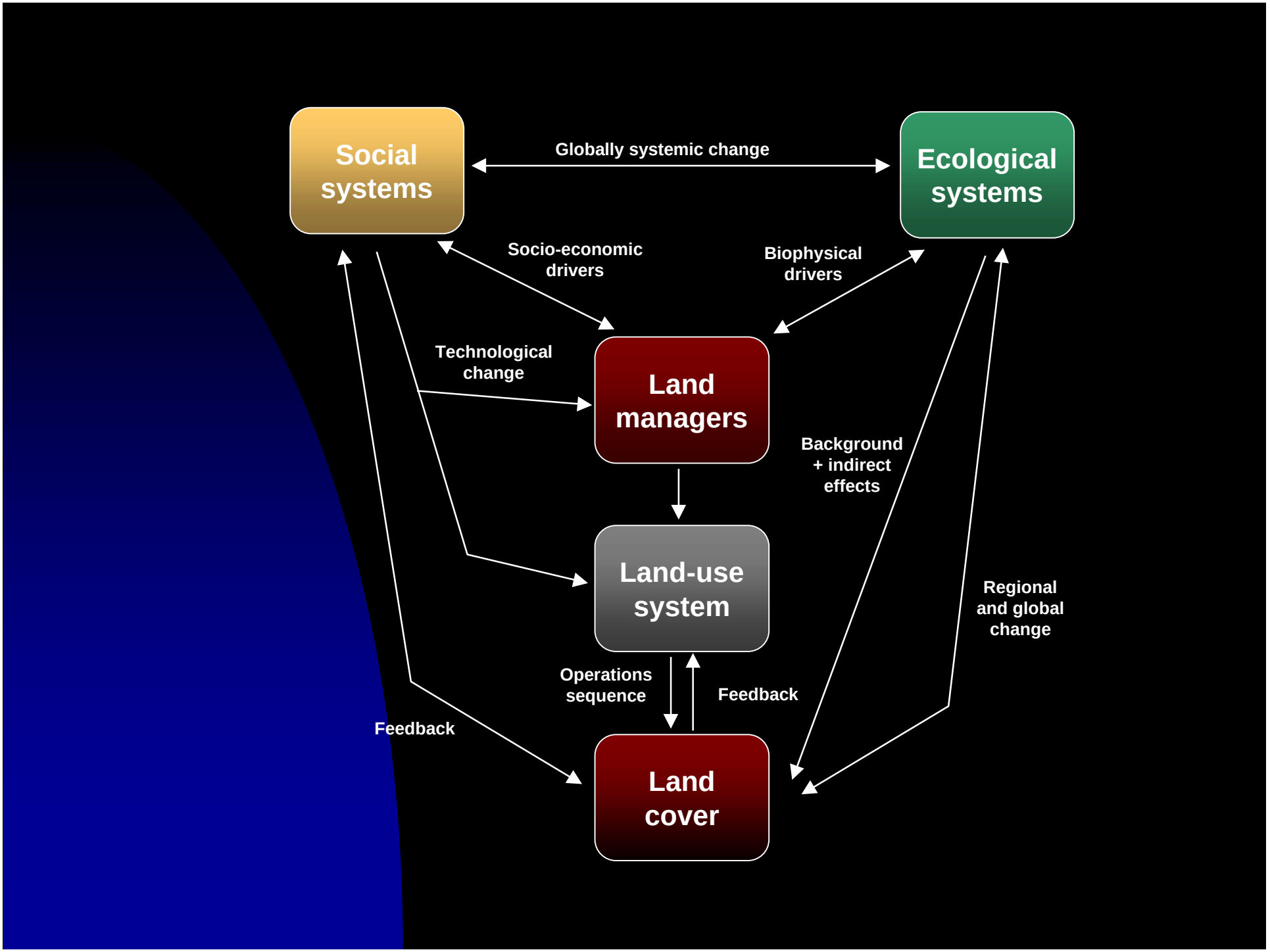
LC LUC Dynamics and Sec. Growth, Cont.

- Significant Inter-annual Differences in Rates of Deforestation asynchrony in relative contribution of the net flux from clearing and re-growth
  - Inter-annual departures in rates of deforestation from decadal mean
  - Significant abandonment of land to secondary growth

Biophysical & Socio-economic Factors Contributing to LC LUC Dynamics

- Dynamic Processes
  - clearing abandonment re-clearing
- Active Land Management
- Population Displacement

Land Use Strategies ⇔ Ecological Conditions


Social systems
Globally systemic change
Ecological systems
Socio-economic drivers
Biophysical drivers
Technological change
Land managers
Background + indirect effects
Land-use system
Regional and global change
Operations sequence
Feedback
Feedback
Land cover

Family structure
Division of labor
Values
Wage rate

Development work
Community organization
Property regime
Technology

Commodity prices
Infrastructure development
Colonization, migration
Commercialization

Unit of Production
Farms Households
Clearing Burning
Enhancement
Hunting/fishing Soil exhaustion

Landscape
Cultural Ecological
(Village) (Watershed)
Location
Irrigation Ditching
Erosion

Region
Urban/rural network
(processing, markers, services)
Infrastructure
Intensification Extensification
Groundwater depletion

Micriclimate
Soil moisture
Season
Small-scale geomorphic processes

Altitude
Topography
Drainage pattern
Soil type

Annual rainfall
annual temperature
Seasonality
landform
Crop potential

Research Questions

- Are the inter-annual dynamics and rates of deforestation and abandonment to secondary forest significantly different than the decadal mean in Southeast Asia…
- ...and can this account for a dampening of the biogenic source of carbon apparent in annual observations of atmospheric carbon dioxide and oxygen?

Research Questions, cont...

- Through the integration of socio-economic and satellite data and the development of dynamic deforestation models, can we improve our understanding of the dynamics of deforestation in the tropics…
- ... and the various controls on rates of deforestation and re-growth and land use transition sequences?

Research Activities

- 1. Develop case studies to determine deforestation dynamics: is secondary growth important and does land use change dynamically on an annual basis; what are the land use transition probabilities?
- 2. Determine if the annual rates of deforestation have been significantly different from the decadal mean rate over large areas and the region as a whole
- 3. Develop diagnostic models of the deforestation process to better understand and quantify the different controls on rates of deforestation and abandonment

Southeast Asia Science Network

- Thailand
  - National Resource Council of Thailand
  - Land Development Department
  - Royal Forestry Department of Thailand
  - Kesetsart University
  - Mahidol University
  - Chiang Mai University
- Malaysia
  - University Kebangsaan Malaysia
  - Department of Agriculture Malaysia
  - Forestry Department Malaysia
  - Malaysian Center for Remote Sensing (MACRES)

- Philippines
  - National Mapping and Resource Information Authority (NAMRIA)
  - National Research Council of the Philippines
  - National Economic Development Authority (NEDA)
  - Philippine Atmospheric, Geophysical and Astronomical Services Administration (PAGASA)
- Indonesia
  - Agency for Assessment and Application of Technology (BPPT)
  - National Institute of Aeronautics and Space (LAPAN)
  - National Coordinating Agency for Surveys and Mapping (BAKOSURTANAL)
  - Center for Development Studies, Bogor Agricultural University (BSP-IBP)

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Mr. Chetphong Butthep, National Research Council of Thailand
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- **Vietnam**

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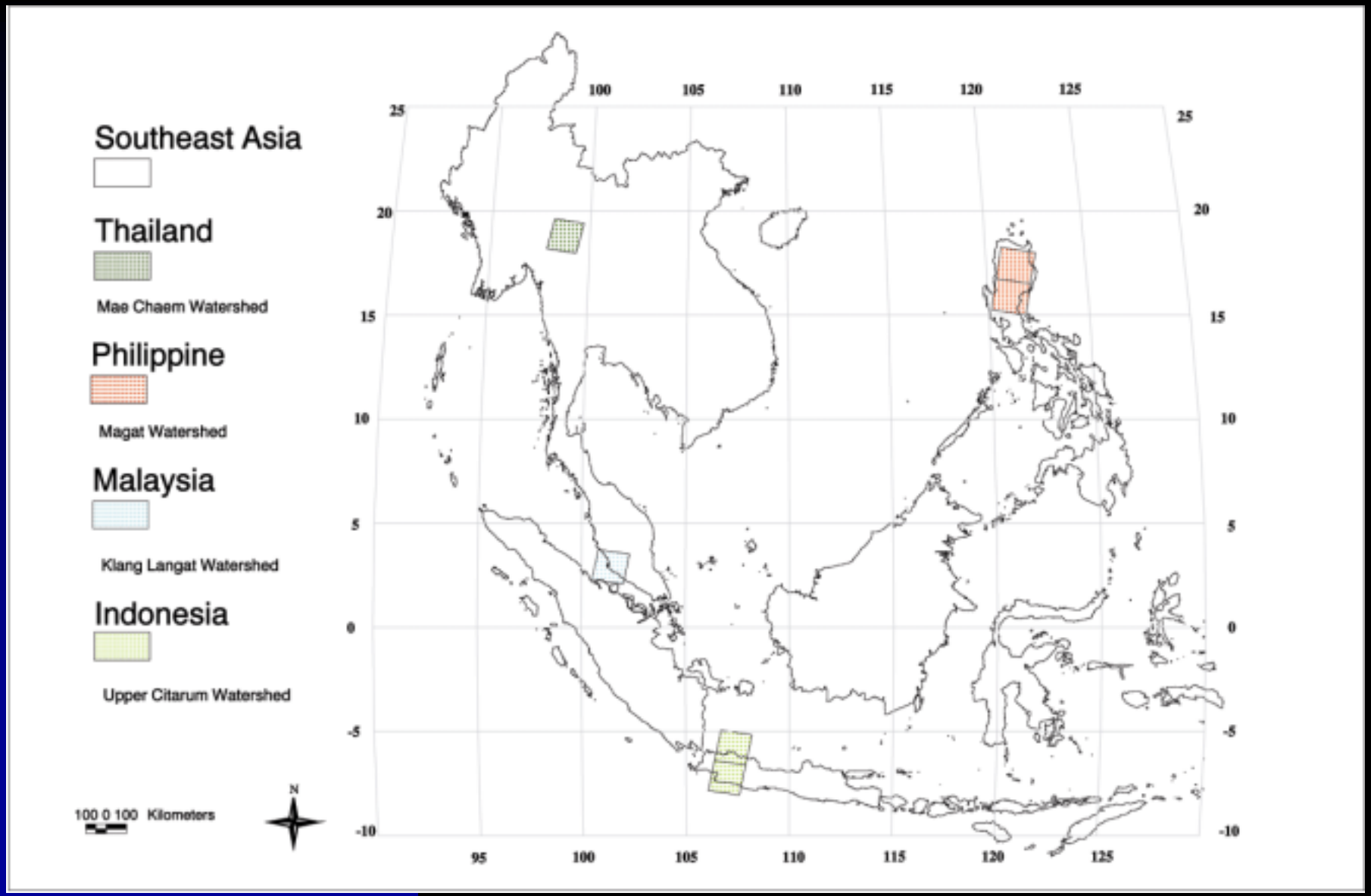
Ms. Tran Thi Bang Tam, Hanoi Agricultural University

Southeast Asia Case Studies

Building on Phase 1 under IGBP LUCC SARCS

- Multi-date Analysis of Landsat Imagery at 4 study sites
  - Land Cover / Land Use Change Detection
- Sites:
  - Thailand: Mae Chaem Watershed, Chiang Mai
  - Malaysia: Klang Langat Watershed, Selangor
  - Philippines: Magat Watershed, Nueva Viscaya, Luzon
  - Indonesia: Upper Citarum Watershed, Java
- Quantitative analysis of socio-economic factors and LC LUC analysis

Phase 1 Southeast Asia Sites



Land Use and Land Cover Change, sample watersheds in Southeast Asia, SARCS Case Studies: 1974-1996.

Land Use / Land Cover	Indonesia		Malaysia		Philippines		Thailand	
	(ha)	(%)	(ha)	(%)	(ha)	(%)	(ha)	(%)
Forest	**-20,994**	**-21.2**	**-37,610**	**-21.8**	**-25,453**	**-35.5**	**-56,894**	**-10.1**
Agriculture	-41,036	-44.0	+14,880	+7.7	-31,694	-62.3	+12,397	+35.6
Urban/Settlement	+51,068	+148.6	+34,664	+161.0	*	*	+3,400	+593.2
Grassland	+8,452	+87.2	-4,509	-56.7	-21,213	-17.9	+1,083	+3.4
Bare/openland	+10,789	+242.0	-7,175	-78.8	*	*	+214	+151.6
Water Body	+3,532	+994.9	+52	+0.5	*	*	+37,800	+110.4
Sample Watershed	Upper Citarum		Klang Langat		Magat		Mae Chaem, Mae Khan and Mae Klang	
Watershed Area, (ha)	259,505		415,409		240,868		669,242	
Time Covered, (yr.)	1984 -1996		1974 -1990		1983 -1993		1985 -1995	

* Remotely-sensed data did not clearly capture these types of land use and land cover.

-, + Denotes decrease or increase in land use and land cover, respectively.

Moving to Phase 2

- Year 1 of NASA LCLUC project is focused on expanding the initial Phase 1 effort: *emphasis on forests and initially Thailand*
- Collaboration between LUCC and START to develop the project with comparable results to other regions,
- Utilizes the IGBP-IHDP framework for linking physical and social science.

Phase 2, continued

- Initial emphasis on LUCC Focus 2, *Direct Observations and Empirical Models*.
- Emphasis now shifting toward integration of LUCC Focus 1, *Land Use Dynamics*, which incorporates socioeconomic data.
- The project takes an interdisciplinary look at the driving forces of land use and cover change in the region.
- To do this, the project has developed a common protocol for methods and datasets, aimed at providing a framework for intercomparison.
- Although isolated studies have been done in specific locales, there are virtually none which provide a region-wide perspective built from case studies with common protocols.

Phase 2, continued

- The project has also aimed at developing a network of practicing scientists in the region.
- This network has been centered on the case studies countries, *with additional participation* from other countries even though they are not currently hosting a case study (e.g. Vietnam).
- This network could and should be expanded over the course of the next phase.

Phase 2, continued

Phase 1

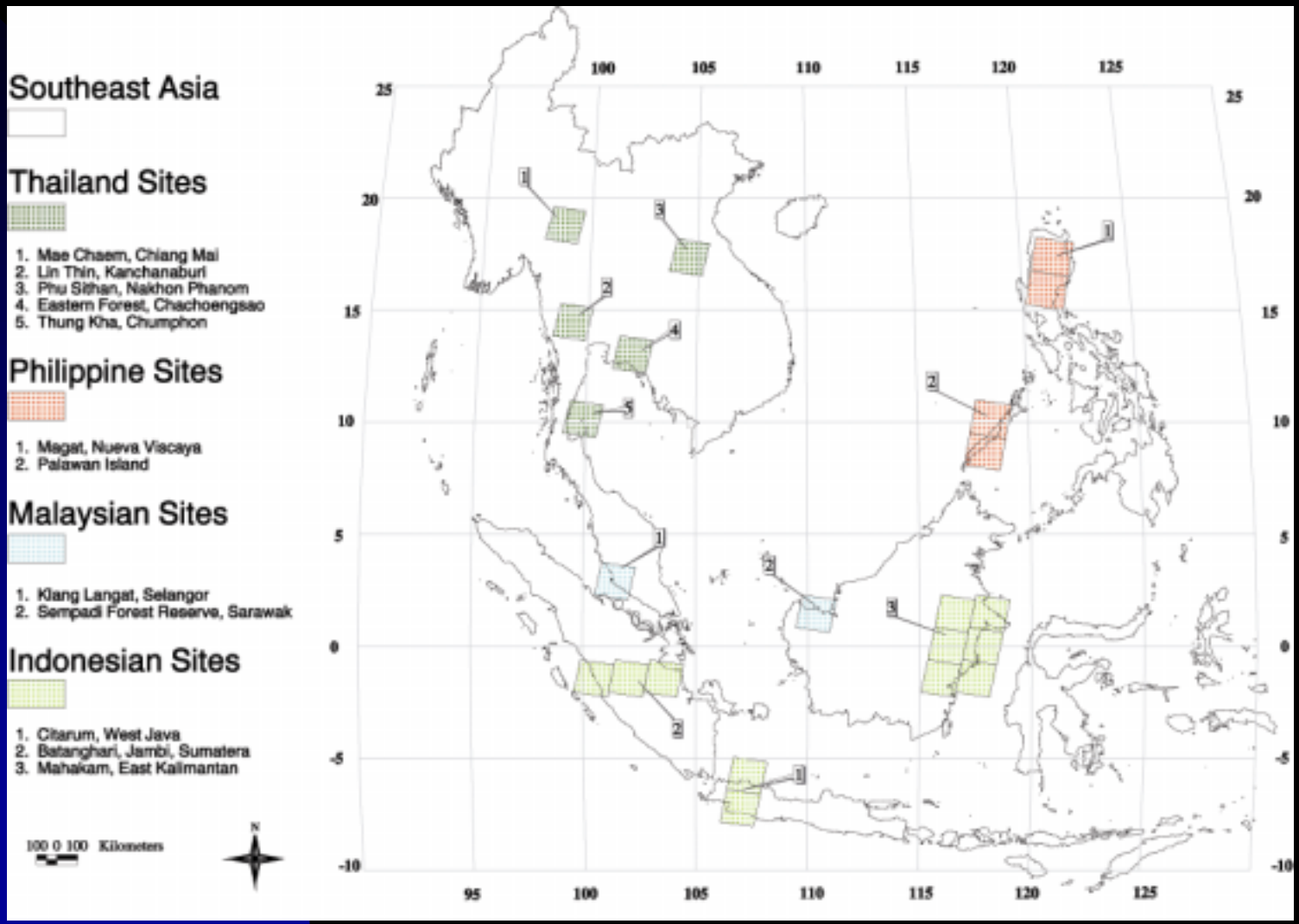
transition

Phase 2

- Case Studies: LUCC Focus 2
- Common methods, Site selection
- Team network
- Field and data analysis
- 2-date change probability model
- initial socio-economic analysis
- Results in Synthesis Workshop

- LUCC Focus 1 - 2 links
- Socio-economic methods
- Expand the network
- Focus on Forests
- Development of models
- Multi-date analysis
- Data set organization
- Regional analysis
- Links to GHG & IGAC

LCLUC phase 2 case studies sites



Phase II Site Description

A Suite of Geographic Gradients

- Geographic: range in latitude & longitude
- Climatic: seasonal dry to persistent wet
- Topographic
  - Inland & Coastal
  - Lowland & Mountainous
- Affected Forest Environments
  - *Dipterocarp* forests
  - Mangrove forests
  - Upland and lowland watersheds
  - Coastal areas (reefs)
- Land Use Characteristics (“drivers”)

Land Use Characteristics
(Human“Drivers” of Land Use Land Cover Change)

- Shifting Agriculture
- Temporary Agriculture (annuals)
- Permanent Agriculture (perennials)
- Logging
- Wet Agriculture (paddy rice)
- Wet Agriculture (aqua-culture)
- Urban
- Plantations
- Industry

Variation in Land Use by Case Study

Land Use	Thailand	Indonesia	Malaysia	Philippines
Shifting Agriculture	T1 & T2	I1 & I3		P1 & P2
Temporary Agriculture (annuals)	T1-T5	I1-I3	M1 & M2	P1 & P2
Permanent Ag. (perennials)	T1	I2	M1 & M2	P2
Logging	T1 & T4	I1 & I3	(M1) & M2	P1 & P2
Wet Agriculture (paddy rice)	T1, T4 & T5	I1 & I2	M1 & M2	P1 & P2
Wet Agriculture (aqua-culture)	T5	I1-I3	M1	P2
Urban	T1, T3-T5	I2	M1	P2
Plantation	T1-T5	I1, I3	M1 & M2	P1 & P2
Industry	T5	I2 & I3	M1	

Phase II Case Study Sites

Thailand:

T1 = Mae Chaem
T2 = Lin Thin
T3 = Phu Sithan
T4 = Eastern Forest
T5 = Thung Kha

Indonesia:

I1 = Citarum
I2 = Batanghari
I3 = Mahakam

Malaysia:

M1 = Klang Langat
M2 = Sarawak

Philippines:

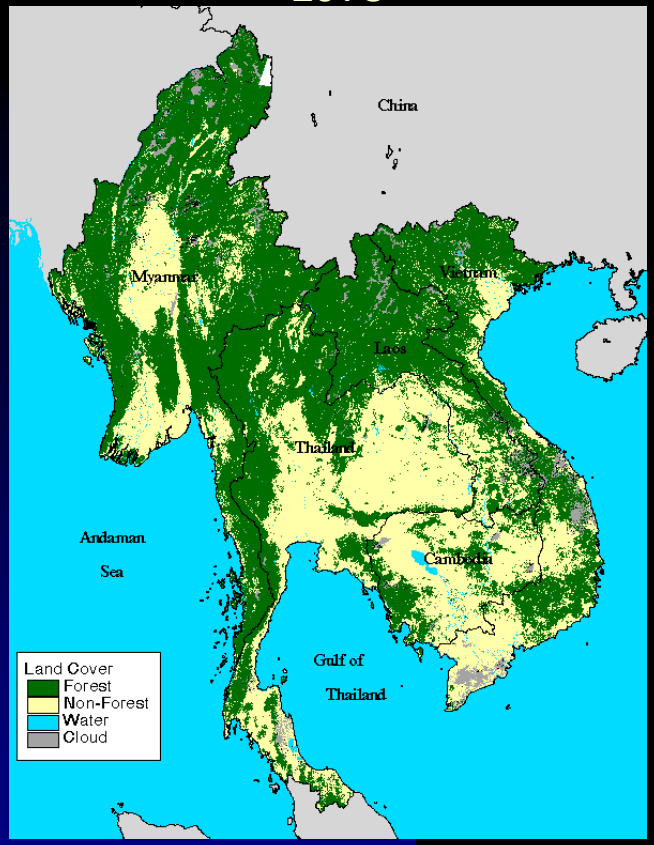
P1 = Magat
P2 = Palawan Island

Expansion of the Network

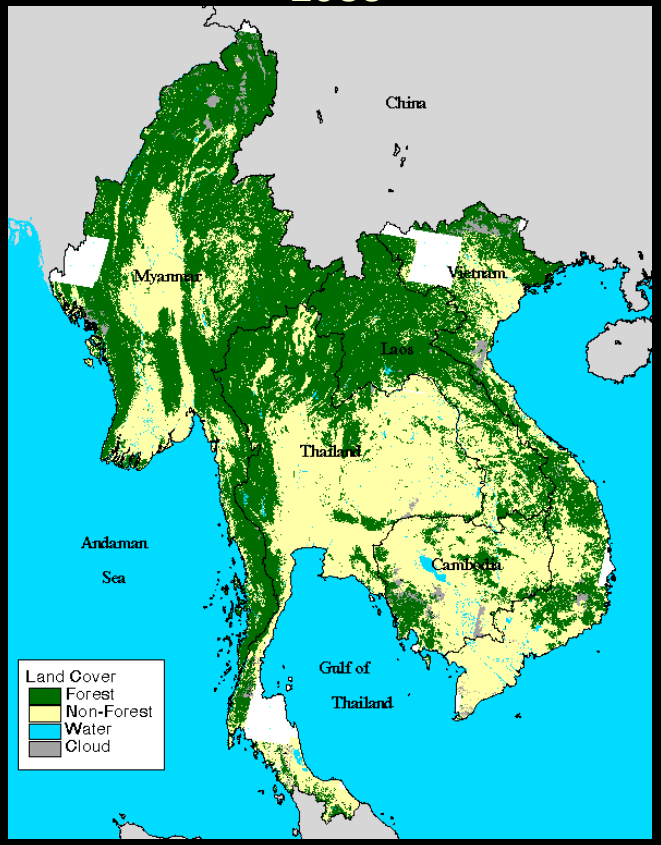
- Vietnam
- Laos
- Cambodia
- Myanmar

Regional Forest Cover in Southeast Asia

1973



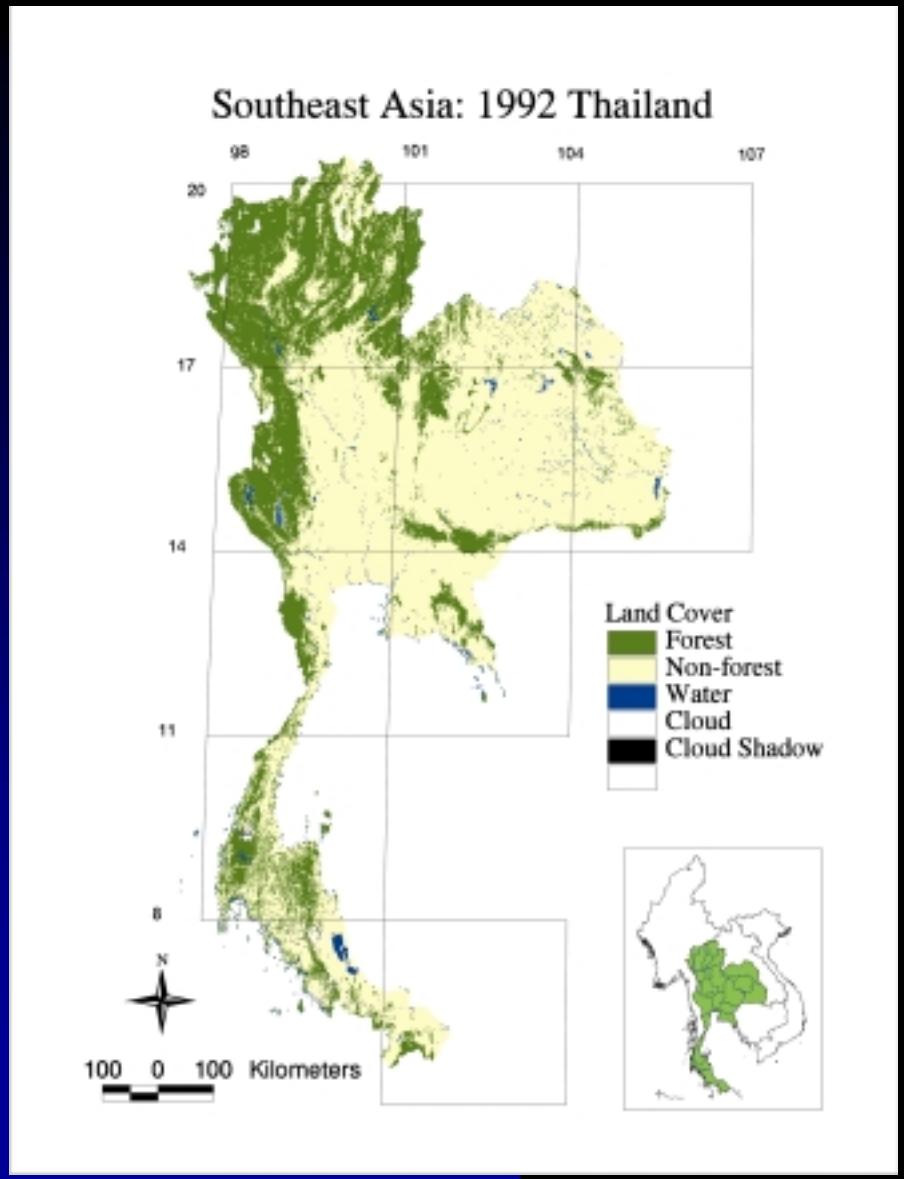
1985



Country	Forest Area in 1973	Forest Area in 1985	Change in Forest	% Change	Defor. Rate/Year
Cambodia	5.25	3.98	1.27	24	0.11
Laos	18.28	16.52	1.76	10	0.15
Thailand	22.56	16.74	5.81	26	0.49
Vietnam	19.92	16.15	3.77	19	0.31
Myanmar	48.71	44.82	3.88	8	0.32
Total	114.70	98.21	16.49	14	1.37

Units: 10^6 ha or 10^6 ha per year^{-1}

Recent Updates: 1992 Thailand



Synoptic Forest Cover Change in Thailand

Forest Cover 1973	22.56
Forest Cover 1985	16.74
Forest Cover 1992	16.54
▲ 1973 – 1985	5.82
▲ 1985 – 1992	0.20
▲ 1973 – 1992	6.02
Rate of Deforestation	0.32

Units: 10^6 ha or 10^6 ha per $year^{-1}$

Thailand case study

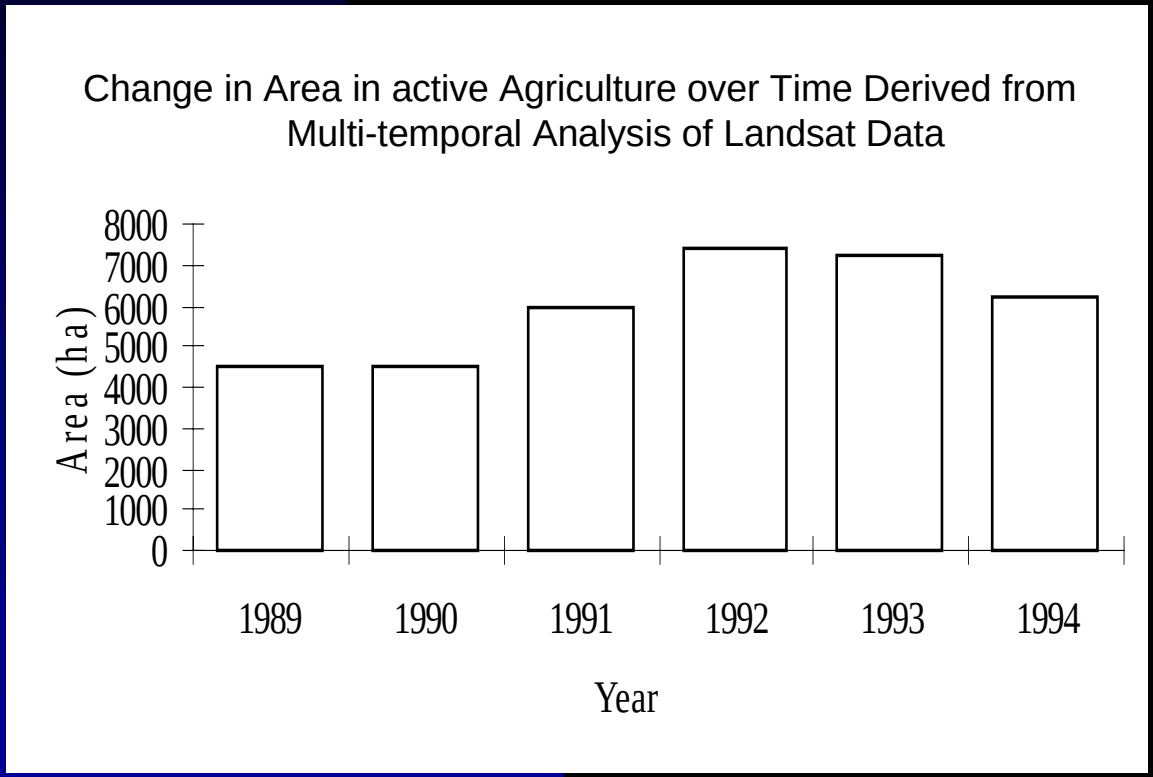
- Importance:
  - Deforested area in Northern Thailand has increased by 36 % between 1980-90.
  - Largest absolute amount of deforestation amongst all regions

Causes of deforestation

- **Logging**
  - Thailand has been a net exporter of wood since the early seventies
  - Contribution to GDP has been negligible
  - Thailand banned logging in 1986
- **Agriculture: Main reason**
  - pushing forward the extensive margin of cultivation (Intensification either not economically possible or is unsustainable)

Multi-temporal Analysis of Co-registered, Annual Data 1989-1994, Chiang Mai, Thailand

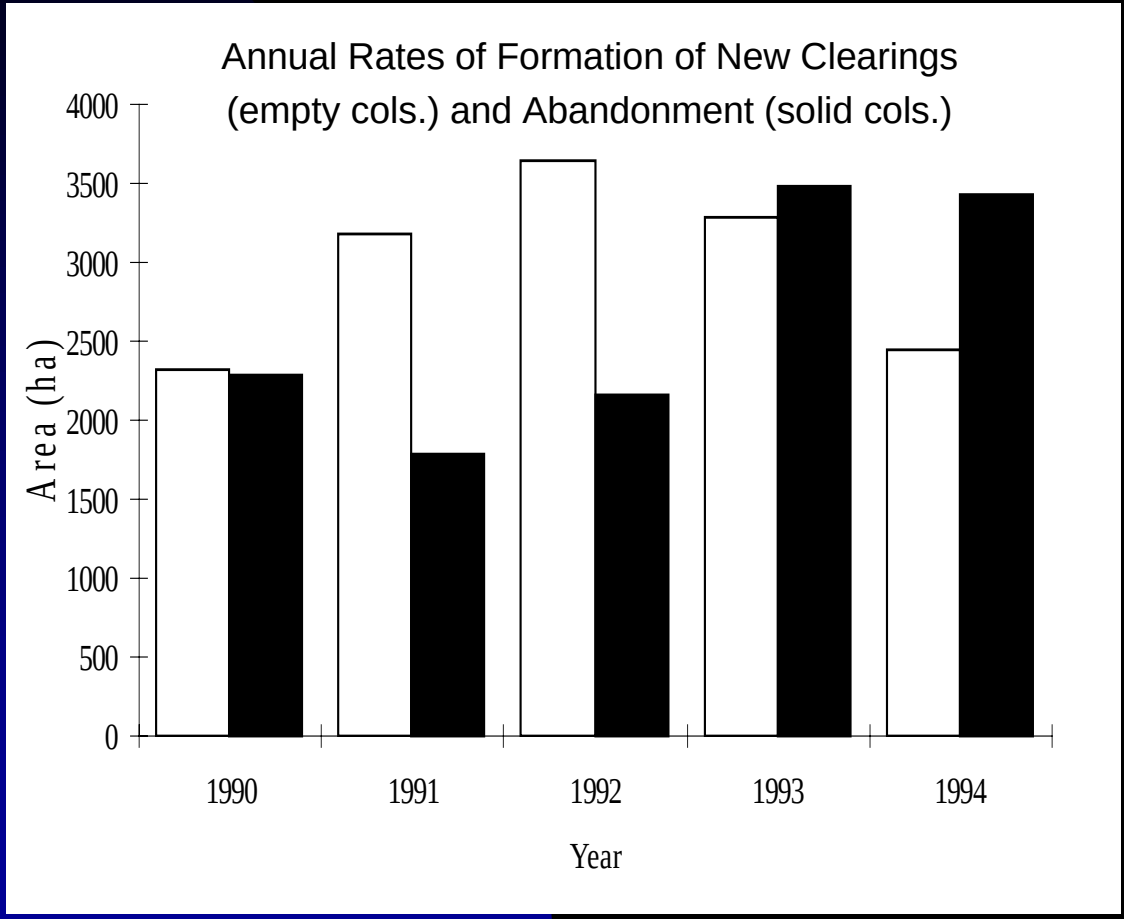
- Change in areas under cultivation



- Area in cultivation increased 38% from 1989 to 1994
- Long cultivation cycles (<6 years) over period from 1989 to 1994 varied from 14% to 23% of total area cultivated
- 81% of area during this period in long fallow, secondary forest or undisturbed primary forest

Inter-annual Analysis Chiang Mai, Thailand

- Annual Extent of New Clearings and Abandonment



- Clearings Varied: low of 2.3 x 10^3 ha in 1990 to peak of 3.7 x 10^3 ha in 1992
- Decline to 2.4 x 10^3 ha in 1994
- In 1990 and 1991 over 50% of cultivated area was on areas just cleared
- Decrease in newly cleared cultivated lands to 38% in 1994
- Smallest amount of abandonment (1991) 1.8 x 10^3 ha
- Largest amount of abandonment 1993 and 1994 3.5 x 10^3 ha and 3.4 x 10^3 ha respectively

Inter-annual Analysis
Chiang Mai,Thailand

- Conclusions
  - Annual deforestation rates highly variable
  - Rate of abandonment highly variable and asynchronous with clearing
  - Carbon-accumulating re-growth a predominant feature of the Chiang Mai landscape
  - Pulse of deforestation in the late 1980s slowing down in the 1990s

New LCLUC Models

- Regional Analysis
  - von Thünen Equilibrium Land Use Model; one date
  - Markov Model of Land Use Change; three dates
  - Fixed Effects Logit Model of Land Use Change; three dates
- Case Study Analysis
  - Markov Model; annual analysis (change matrix)
  - Fixed Effects Model; annual analysis

Approach to modeling

- **Two Types of Models**
  - Explain land use at a point of time
  - Explain change in land use between two points of time
- **Two Levels of Spatial Disaggregation**
  - Landscape (pixel) level
  - District or provincial level

Purpose of Models

- **Understand Patterns of Land Use**
- **Predict Patterns of Land Use**
  - Local level – e.g., for natural resource management
  - Regional level – e.g. to forecast carbon emissions
- **Predict Impacts of Policy Levers**
  - Agricultural policies
  - Employment policies
  - Road building

Types of Land Use Models

- ***Long Run Equilibrium Models***
  - Explain land use at a point of time, ***independently*** of past land use
  - Predict P(Plot i is in use k at time t)
  - Can be estimated using a single cross section of data or multiple cross sections
  - Can be used to predict land use change if future values of explanatory variables can be predicted

Types of Land Use Models, cont.

- ***Markov Models of Land Use Change***
  - Explain probability of land use at *t*+1 given land use at *t*
  - Predict ***P***(Plot ***i*** in use ***k*** at t| Plot ***i*** in use ***j*** at ***t***-1)
  - Allows for state dependence
  - Estimation requires observations on land use at 2 or more points of time
  - Can be used to predict land use change if future values of explanatory variables can be predicted

A Landsat-based deforestation model

- We hypothesize that the farm creation process unfolds in two sequential phases:
  - the initial, ***deforestation*** phase,
  - and the ***regrowth*** **clearance** phase.
- The timing of these phases depends on the number (m) and interval between deforestation events,
- which in turn is related to the shift time for annual plots (Δt), or the number of years a field producing annuals is used before abandonment (to regrowth) or allocation to pasture or perennials

Deforestation model, cont.

- Consider the three decisions faced by farmers:
  - *(1) deforestation decision,*
  - *(2) field decision,*
  - *(3) regrowth decision.*
- Each of these decisions determines how a particular piece of land will be used, as defined by its groundcover.
- In the deforestation decision, the farmer decides, in the wake of deforesting old forest, the proportions to allocate to annuals production (a), pasture (pa), and perennials (pe).
- With the field decision, the farmer reallocates land used in annuals production to pasture, perennials, or to regrowth (r).
- The regrowth decision involves clearance for annuals, pasture, or perennials.

Deforestation model, cont.

- During the deforestation phase, both deforestation and field decisions are made, although the first field decision occurs with the second deforestation event,
- Thus, the first deforestation event occurs at t= 0, and the first field decision, at t = Δt. The final deforestation event, with decision, takes place at year, t = (m-1)Δt.
- After this, regrowth is cleared to annuals, pasture, and perennials in a cycle similar to that of old forest.

Deforestation model, cont.

- Consider the land area cleared in a deforestation event; call this the deforestation event magnitude, or DEM. DEM is a function of the human resources (h), natural resources, i.e. the physical environment (n), and location (l), or

$$DEM_t = DEM\ (h_t, n_t, l).$$

- Similarly, consider the probability of transitions between the land cover classes old forest (o), regrowth (r), annuals (a), pasture (pa), and perennials (pe), or

$$p^t_{i,j} = p^t_{i,j}\ (h_t, n_t, l)., \text{ where}$$

$$l \in (o, a, r),\ j \in (a, pa, pe, r).$$

Deforestation model, cont.

- Stocks of land cover type I at time t are given, in areal terms, as x^t_l ; stock change at time ?t is $?x^t_i$. Hence, the transitions in land cover classes in the deforestation phase are at t = 0, conversion of primary forest, with initial land cover stocks:

$\Delta x^0_{o,a} = p^0_{o,a}\ DEM_0$ and $x^0_a = \Delta x^0_{o,a}$ (= x^1_a)

$\Delta x^0_{o,pa} = p^0_{o,pa}\ DEM_0$ and $x^0_{pa} = \Delta x^0_{o,pa}$ (= x^1_{pa})

$\Delta x^0_{o,pe} = p^0_{o,pe}\ DEM_0$ and $x^0_{pe} = \Delta x^0_{o,pe}$ (= x^1_{pe})

- At t = 2, conversion of plots under annuals production:

$\Delta x^2_{a,pa} = p^2_{a,pa}\ x^0_a$

$\Delta x^2_{a,pe} = p^2_{a,pe}\ x^0_a$

$\Delta x^2_{a,r} = p^2_{a,r}\ x^0_a$

Deforestation model, cont.

- in addition to the conversion of primary forest:

$$\Delta x^2_{o,\,a} = p^2_{o,\,a}\ DEM_2$$

$$\Delta x^2_{o,\,pa} = p^2_{o,\,pa}\ DEM_2$$

$$\Delta x^2_{o,\,pe} = p^2_{o,\,pe}\ DEM_2$$

- yields the land cover stocks in time period 2:

$$x^2_{a} = x^0_{a} + \Delta x^2_{o,\,a} - S\,\Delta x^2_{a,\,j}\ ,\quad j \in (pa, pe, r)$$

$$x^2_{pa} = x^0_{pa} + \Delta x^2_{o,\,pa} + \Delta x^2_{a,\,pa}$$

$$x^2_{pe} = x^0_{pe} + \Delta x^2_{o,\,pe} + \Delta x^2_{a,\,pe}$$

$$x^2_{r} = \Delta x^2_{a,r}$$

The Second LCLUC Science Meeting was held at the Airlie Conference Center, Warrenton, Virginia from March 29 to April 1, 1998

The objectives of the meeting were to:

1. Present the NASA LCLUC program status
2. Provide summary presentations of the proposed LBA / LCLUC research projects
3. Discuss, plan and coordinate the role of NASA LCLUC research in Assessments :
   - contributing to the IPCC Third Assessment (2001)
   - contributing to the national regional assessments
   - contributing to emerging international regional assessments
4. Provide status reports on selected LCLUC data initiatives, related projects and programs.
5. Enable the P.I.'s to contribute to the development of the NASA LCLUC Science Implementation Plan - in terms of science, observation and monitoring needs

Breakout groups were established to develop the Science Team's input on LCLUC Science Priorities, Immediate Data Needs, and Long Term Information Needs.

GROUP PHOTO!

REPORT OF THE SCIENCE PRIORITIES BREAKOUT GROUP

LCLUC Second Science Team Meeting
Warrenton, Virginia
30 March - 1 April 1998

C.A. Wessman & B. L. Turner II

Premise:

The global environmental change community, from science to policy, is expanding from a primary focus on global warming to a broader environmental agenda captured in the "sustainability transition". The central question of this transition, as articulated by the NRC's Board on Sustainability, is: "How do we provide employment and improved standards of living for a world of 10 billion without threatening the earth's life support system?" The support system is the biosphere and its critical resources. Thus the environmental problem is expanded to the structure and functioning of the biosphere, including climate warming, to critical resources for humanity, from biotic diversity to water quality.

Role of NASA's Land-Cover and Land-Use Change program:

Study of changes in land cover and land use are pivotal to the sustainability transition because the terrestrial biomes of earth provide the essential food, water, and mineral resources on which the 10 billion will exist. The transformations of these biomes are unprecedented in human history - in magnitude, spatial scale, and pace. The sustainability transition focuses on the implications of this transformation for a warmer, wetter, more crowded, stressed, and demanding world, requiring improved understanding of them in order to reduce threats to our life support systems.

NASA's participation in science at the human-ecosystem interface is critical for the advancement of interdisciplinary collaborations. NASA has been important to "big science" and can uniquely contribute to the data requirements needed for these syntheses. Temporal and spatial measurements of landscape and regional heterogeneity are fundamental to understanding land-cover/land-use change trajectories and implications for sustainability. New and upcoming quantitative capabilities in remote sensing, stand-alone and coupled with ecosystem simulation models, can better define environmental constraints on land use and cover change. Similarly, patterns and rates of land-cover change can strengthen understanding of social and economic controls.

General and Specific Issues Requiring Special Attention:

The sustainability transition opens LCLUC to a plethora of unresolved questions, both substantive and methodological, that are linked to but go beyond that of the carbon cycle in a global warming vision of LCLUC. All of these questions, however, are anchored on two basic themes: (i) how do changes in land use affect the dynamics of land cover properties (e.g., biomass, productivity, soil nutrients, hydrologic cycle); and (ii) how do changes in land

cover and associated biophysical/biogeochemical processes affect land use. The focus of LCLUC, then, is on the land-use/land-cover change interface with terrestrial ecosystem dynamics, with underlying forcing from climate variability and atmospheric compositional change (Figure 1). Understanding these questions, of course, requires improved understanding of the explanatory dynamics of use and cover change as well as of the means of modeling these dynamics.

The two general questions of this research are:

1. What are the relative roles of biophysical, biogeochemical, and anthropogenic drivers of LCLUC, and their temporal and spatial variability?

2. How can explanatory and integrated models of LCLUC be improved that incorporate the scalar capacity to link the local, regional, and global?

Specific questions are:

1. At what scales do biophysical, biogeochemical and human processes most closely overlap and match one another, and are these scales the optimal entries for LCLUC understanding?

2. How can complexity, uncertainty, surprise, and path dependency be used to improve LCLUC understanding and vice versa?

3. How can LCLUC be used to refine the concept of vulnerability and identify vulnerable ecosystems, peoples, and human-environment relationships?

4. How can LCLUC be used to address mitigation and adaptation strategies?

These questions, issues, and themes raise a number of points about sensors and data which NASA should seriously consider.

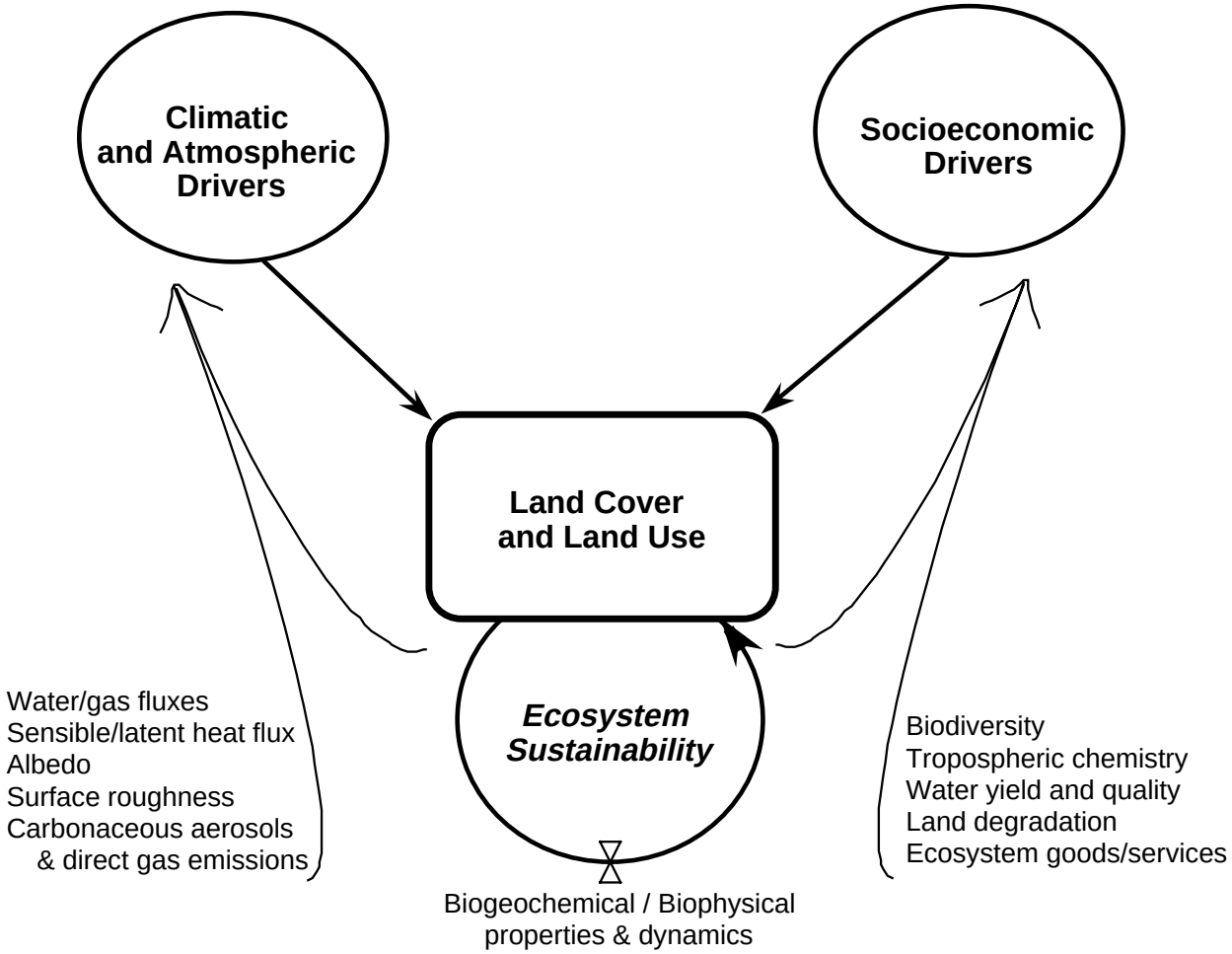
A. Spatially explicit information and observations of the roles and impacts of human agency and social structures are desperately needed.

B. Land-cover and land-use change histories require documentation.

C. Quantification of biophysical and biogeochemical interactions and feedbacks on land cover and land-use at landscape and regional scales is required.

D. Continuity and increased frequency in measurements of landscape structural and functional change are absolutely critical. (This not only applies to current measurements, but to improved metrics evolving from algorithm development and improved instrumentation.)

Figure 1. Regional impacts of climate variability, atmospheric composition change, and socioeconomic factors are integrated within the landscape through land cover (i.e. vegetation type and distribution) and the management strategies employed to maintain, manipulate, or convert that cover (i.e. land use). Ecosystem sustainability will be determined by immediate and longer-term biogeochemical and biophysical processes and their feedbacks on climate and land-use systems.



LCLUC- Breakout Group #2 Summary Report

Charge: Assessment of Immediate Data Needs

Chairs: Ronald Rindfuss & Mark Harmon

Our working group focused on general issues concerning data rather than specific data needs. For the most part the remote sensing needs of the group were being met, but there were problems related to linking the remotely sensed data to biophysical and social science data. The key challenge facing the LCLUC community was seen as linkage across different types of data sets. Finally, there was a consensus that the LCLUC community must be involved in the discussion of the sensors being planned and the acquisition strategies used for remote sensing data.

Our discussion was driven by three assumptions:

1. Significant progress in this arena depends on how well land cover is linked to land use. This indicates that, while improvements in remote sensing technology are welcome, significant steps need to be made to move from an assessment of land cover (provided by remote sensing) to exactly how that land cover functions biophysically and in a social context. Specifically we need to be able to link existing and planned biophysical and social data sets to the land cover data derived from satellite data. This will involve coordination between the remote sensing community and those who collect the other data sets. This will be difficult because many of the critical actors are not part of the USGCRP.

2. Carbon dynamics of ecosystems is a very important issue for the LCLUC community, however, it is part of the larger issue of use of land. The latter can be viewed very broadly to include not only human uses, but also use by plants, animals, and microbes. It is therefore essential that LCLUC not be converted into a carbon assessment program- maintaining a diversity of issues is very important.

3. An important step has been made by introducing land cover and land use into the global change discussion. In the next few years, however, we must move beyond this to a consideration of how land use and climate interact to control ecosystem function (sensu latu). Several of the briefing sessions contained examples of how land use coupled with climate dramatically changed ecosystem function. For example, clearing in tropical forests lead to increased drying, which lead to increased deforestation as fires set in pastures spread into normally fire proof forests. An example from the Middle East was the spread of barley farming onto marginal lands in years when abundant water is expected. These interactions are clearly not unidirectional; causality runs both ways. General themes that might drive the examination of land use-climate interaction might be why, when, and where these interactions occur. Another might be the degree to which current land use strategies (recall the African example) are dislocated spatially as climate change proceeds.

Problems and Issues Concerning Data Use

While collection of new data is crucial, our group found that key data may already exist, but is not being effectively used. Although this data may eventually be used by the LCLUC community, specific problems and issues are limiting their use in the short-term. A concerted effort should be made to eliminate or reduce these barriers to progress as soon as possible. One reason they may be difficult to eliminate entirely is that they often involve lapses of inter- agency, institutional, or disciplinary coordination. Given the limits on budgets, groups are going to have to learn dual use of data. Specific examples include:

1. Georeferencing of traditionally non-spatial data. There is a need to be able to match what has been traditionally viewed as non-spatial data to as specific a location as possible. Problems include confidentiality (i.e., promises made to respondents during the data collection process), matching ownership to land, and convincing data gathers that location is an important data attribute. This issue exists for social and biophysical data. An issue more specific to the social sciences is an understanding of how to match people to the land they control. This will require methodological development as the solution is dependent on the region and owner (cluster villages versus systematic dispersion, resident versus absentee owners).

2. Temporal referencing of data. This is really the temporal analog of georeferencing of data. It is not clear the degree to which this problem exists given that many human and natural resources are censused or inventoried on 10 year cycles.

3. Historical data recovery. Given that historical perspective on LCLUC is essential to interpreting the consequences of current pattern and process, more attention must be placed on recovering historical data. In particular, NASA needs to continue to focus on recovering old missions as well as planning new ones. This is probably the one area where current research needs are not being met; essential data exist at foreign ground stations, but can not currently be used because of cost, lack of equipment, or other problems.

4. Image quality and consistency. Given that the main task of LCLUC in a remote sensing context is often change detection, it is essential that as much extraneous noise as possible be removed from the data. Atmospheric corrections remain a major problem. Another problem is the lack of georeferencing of historical data. The latter may also be a problem for LANDSAT 7 as registration to earth coordinates may not have been addressed adequately. A major question that needs to be reconsidered is the degree to which it is NASA's job to make these corrections versus the user communities. Passing on these costs to the users makes a good deal of sense given that one may not always be able to predict how the data will be used. On the other hand it also introduces a lack of consistency that may ultimately limit the degree results can be compared.

5. Developing a strategy of remote sensing data collection that meets the needs of the LCLUC community. The current refresh or sampling strategy of LANDSAT 7 is based on a 4 month interval. While this may be ideal for phenological sampling, it may not be appropriate for LCLUC questions. In the latter context it may be better to have wall to wall coverage at certain specified time intervals. More frequent sampling could be done within certain regions expected to undergo high rates of change. Stratification of the sampling could be driven by other remote sensing data (e.g., use AVHRR to set up an ecosystem type screen) or non-remote sensing data on records of fire, land clearing, logging, or economic activity.

6. Development of comparable metadata. It is one thing to provide access to data. It is quite another to provide it in an understandable format. The LCLUC community needs to start thinking about this issue and take advantage of the work other communities (e.g., NSF's Long Term Ecological Research Network has developed a policy on data sharing). One challenge is to develop similar policy and metadata standards for spatial databases. Another is to compile and inventory existing data in a way that helps provide general access. The latter activity should certainly be done for each LCLUC study, but regional compilations would also be extremely valuable.

7. Software issues. The cost, ease of use, and access to algorithms can be the limiting factor in using data effectively. This is going to become more and more an issue as remote sensing passes from the domain of specialists to generalists. On the other hand, there is a real danger of providing access to the untrained (or unwashed). A more problematic issue is providing usable software to scientists in underdeveloped regions where budgets are limited. The involvement of these individuals may be critical to provide truly global coverage of LCLUC analysis.

Immediate Date Needs

Although few immediate data needs were described, there was a need to consider certain types of data in the near term. Two questions need to be considered in selecting data priorities:

1. Are the data required to ask new questions or seek more detail within a region? Or

2. Are the data required to move the results from a singular case study to a global level? The latter data could be primary data describing pattern or process, or could be secondary data that allow extrapolation of results to new regions. For example, if excellent relationships between temperature and decomposition rates exist, then it should be possible to predict the latter from a spatial database of the former.

Examples of the data needed to improve LCLUC studies are:

1. Temporally harmonized data at the global or local levels. Many census data and resource inventory data are collected periodically. It would be extremely helpful if

the period that these data were collected were synchronized and if they would match global level remote sensing products.

2. Cross-scale products. It is essential that information gathered at the finer spatial scale be incorporated into broader scales. Currently these efforts are not well connected and are proceeding on separate fronts. Two alternative strategies were discussed:
   1) synthesis of local and regional information/processes into the broader-scale
   2) provide global coverage of local or regional information or processes. These two approaches need not be mutually exclusive.

   An example of the former approach might be the development of regimes of land use and/or disturbances.

3. Data that adds a historical dimension to LCLUC analysis.There are several cases where historical perspectives may be essential to understand/or predict current processes or patterns. For example, human activity on most landscapes predates the availability of satellite data. A historical perspective may also be essential to understanding the function of certain ecosystem components. The flux of carbon from soil and detritus has a strong historical component (e.g., a 1 year-old pasture does not behave the same as a 100 year-old one). Development of a 25 year old history of land cover will depend on recovery of achieved MSS and TM data. Development of a longer-term historical record will involve a synthesis of many sources of data including maps, historical and management records, event history data (in essence, retrospectively asking about various events, a procedure widely used in the social sciences), and other data. Efficient development of the latter requires that a sensible strategy be developed (i.e., what level of detail is sufficient to answer questions) and how far back does the history extend? The latter question might be driven by an event (e.g., the onset of the industrial revolution) or the time required for the impact of an event to diminish.

4. A one time global database of forest location based on AVHRR data. This database would provide a consistent reference point for studies at many spatial scales and could serve as the basis for stratifying finer resolution sampling.

5. Wall to wall fine resolution data on land cover at a preset temporal sampling interval. This would be based on TM and or ETM. For many natural disturbances and regions with "normal" rates of land use change a 5 year interval should prove adequate. Although the group discussion centered on future data products, there is no reason this 5 year data product could not be made retroactive.

6. Location of fires to indicate location of deforestation events. Night time data may be of real use here, if the location of fixed cities and towns could be factored out. Probably would need to be TM or ETM data.

7. Climate data. While there has been great progress in synthesizing historical climate data at the global level, the resolution of this data is of marginal value to more local studies. A database that allowed access of daily data from specific climatic stations

would allow users to develop regional databases at the appropriate time and spatial scales for their analyzes.

8. Urban sites. The projects funded by NASA-LCLUC are focusing on rural areas. There is a need to include urban sites into the present mix of studies. One question raised was the degree to which the new Urban-LTER sites (Baltimore and Phoenix) are including remote sensing into their projects.

9. Vegetation Canopy Lidar. Access to VCL data needs to be prioritized for LCLUC use. It is anticipated the these data can be used to corroborate ecosystem model predictions or to initialize models themselves.

10. The group thought thermal data of all types would be important, but there was no time to develop any specifics on this issue.

Break-Out Group on Long Term Data Needs

The breakout group on long term data pursued issues related to the availability of satellite and in situ data needed for land cover and land use change studies. In particular, the discussion dealt with data needs in the post-Landsat and post-EOS era.

Land cover and land use change data were viewed in a broad context that includes a broad range of attributes and measurements. In addition to their multi-dimensional information content, land cover and land use change data must have a strong temporal component. All attributes of land cover and land use vary over time. Both baseline measurements, change vectors, and continuous monitoring data sets are essential. Examples of land cover and land use measurements include:

Land Cover

Physiognomic characteristics (e.g., vegetation density, height, longevity, form)
Floristic characteristics (e.g., community composition, species)
Biophysical characteristics (e.g., phenology, trace gas fluxes, net primary productivity)
Successional stage, disturbance history
Land cover types

Land Use

Management intensity practices
Soil condition
Economic activity
Land use types

While there are currently both geographic and thematic gaps in both land cover and land use data coverage, many of the land cover gaps will be reduced or eliminated when data products that will be generated through the Earth Observing System become available. However, land use data gaps will remain and must be addressed.

There are some general trends in land cover and land use data that are relevant when considering the specifications of the future satellite and sensor configurations from which these data will be derived. They include:

X Land cover and land use data requirements arel becoming increasingly quantitative.

X Monitoring will always be a multi-resolution activity, and the importance and dimensions of multi-resolution analysis will continue to increase.

X The data spatial and spectral resolutions that will be used will need to increase incrementally over time. In addition, the repeat frequency of intermediate resolution data

collection systems, such as Landsat, should be narrowed.

X There is currently a void between 30m and 1000m observations. Regional monitoring (i.e., national to continental scales) require data resolutions inbetween current capabilties.

X There is an urgent need to monitor certain regions (i.e., tropical landscapes) and resources (i.e., agriculture, forestry) at higher resolutions and with greater temporal frequency and spatial resolutions. Tropical landscapes are an example.

X Inter- and intra sensor calibration and atmospheric corrections are mandatory. Measurements must be comparable over time.

X Validation must be an essential element of all data production programs.

Significant attention must be given to future satellite programs that collect the remotely sensed data from which land cover and land use data will be derived. While the near term is well-defined with the continuation of an enhanced Landsat program, new data from sensors onboard the EOS-AM platform, and innovative missions such as the Vegetation Canopy Lidar, the future is quite unclear. Because of the uncertainty concerning future missions, a series of general statements concerning the characteristics of the future generations of earth observation satellites were developed. They are:

X Environmental data and environmental monitoring are everybody=s business (science community, government, industry). The same data used for scientific purposes are important for resource management and planning, and econonmic development. Thus, all sectors should work together to ensure viable long-term monitoring programs.

X Decisions on future operational satellite capabilities (e.g., NPOESS) are being made before research and development results are available. For example, the transition from AVHRR to NPOESS will be based on decisions that are made without the benefit of lessons learned from the MODIS experience. It is important that the successful capabilties of MODIS and other satellites be included in future satellite configurations.

X Related to the previous issue, it is essential that there be continuity in the successful and useful data products between missions. In addition, the characteristics of products must be planned in an evolutionary context. New missions should include the beneficial characteristics of previous missions, while making incremental improvements in observation and measurement products. In other words, products must get better over the long term.

X An unbroken temporal record, wihout reduced capabilties, is essential so that there is a consistent and reliable long-term time series with no gaps. In the case of the transition between AVHRR, MODIS, and NPOESS, it is important that the time series be unbroken and that there be no reduction in observation data quality. This suggests that MODIS be continued for an additional cycle so that there is no gap between the planned MODIS

sensors on EOS-AM and -PM and NPOESS.

X New data products must have links to past products. This means that issues of inter- and intra-sensor calibration and data set reprocessing must be planned, funded, and completed.

X Access to data should be direct, and ideally, seamless. The challenges in dealing with foreign ground stations must be addressed so that past problems in obtaining data over foreign areas are reduced or eliminated.

X Geographic gaps in data coverage must be reduced, either through advances in recording and downlinking, or through improved network of cooperating ground receiving stations. There is a need for a long term strategy to work in partnership with foreign ground stations.

X Private sector and government cooperation must be used to the advantage of all parties. With the increasing involvement of the private sector in satellite missions, it is important that scientific interests be weighted and negotiated with commercial interests. This suggests that a long-term strategy is needed to "acquire" acquisition time in order to ensure that the data needed for monitoring and validation be available.

X Hyper-spatial data (< 3m resolution) are important for a variety of scientific purposes. However, there is some concern that data that will become available in the near future are not designed for scientific purposes, and may be two expensive for scientific activities. The ideal system should have narrow-band multispectral channels and have data calibration capabilities. The data must be affordable and available to the scientific community. Data acquisition strategies must be sensitive to the needs for data within narrow temporal windows and coincident with other satellite overpasses. The science community needs a voice and a mechanism for influencing acquisition plans so the required data are available.

X NASA must play a lead role in stimulating new research and development missions. Candidates include multi-frequency, multi-polarization SAR, hyperspectral, and lidar missions. In addition, NASA should sponsor a viable research program on remote sensing methods that leads to new products. Finally, there is a need for proof-of-concept studies that provide the applied research that bridges basic research and operational applications.

X In situ measurements are essential complements to the long-term satellite record. It is important that an organization come forward and take the lead in advocating for a long-term in situ data collection network. One possible organization is the Global Terrestrial Observing System (GTOS).

Finally, it is important to reiterate the importance of ensuring that successful missions that have produced or led to important new monitoring capabilities and products be continued

without reduction of critical characteristics. Because of the need for long-term continuity without decay in capabilities or gaps in coverage, continuation of missions such as Landsat and EOS (especially the MODIS sensor) are mandatory if long-term monitoring are to meet the diverse national needs.

EXIT

The First NASA LCLUC Science Meeting, April 8-10, 1997, Airlie Conference Center, Warrenton, Virginia.

The objectives of the meeting were to:

1. Present to the LCLUC science team the program objectives and its role within the NASA ESE program.
2. Present the initial round LCLUC research projects, identify potential synergy's and foster collaboration between the LCLUC regional projects.
3. Examine the potential role and relationships to on-going LUCC activities within NASA, other US Agencies and internationally.

The meeting consisted of presentations on the selected LCLUC research projects, presentations from LCLUC related, NASA funded research projects and programmatic presentations on LCLUC related programs. The newly selected LCLUC investigators were asked to prepare a short presentation outlining the goals and planned deliverables of their research, the methodology to be adopted, a work schedule, a data management plan and the principle points of contact for the different aspects of the study. The presentations identified changes to the proposals made in response to reviewers recommendations.

Patterns and Processes of Land Use and Forest Change in the Amazon: 48th Annual Conference Sponsored by the Center for Latin American Studies

March 23 – March 26, 1999
University of Florida
Gainesville, Florida

The Center for Latin American Studies at the University of Florida convened an international conference to review state-of-the-art research projects on environmental change in the Amazon region of South America.

The conference focused on the use of remote sensing techniques to estimate the pace and pattern of forest change in Amazonia, as well as on-the-ground analyses of the land use decisions made by rural producers.

The agenda included community-level activists who increasingly turn to satellite images, Global Positioning Systems and Geographic Information Systems to address an array of conservation and land tenure issues.

The objective is to contribute to environmental policy and global change research by providing a forum for a constructive dialogue between specialists in the analysis of satellite data, researchers who focus on the processes that drive land use decisions, and scholars and practitioners engaged in community-based mapping efforts.

Special sessions will identify future research topics, and will explore ways to harmonize the compatibility of different data sources.

Presentations will be in English, Spanish and Portuguese on all countries whose national borders encompass significant portions of the Amazon basin.

Earth's Changing Land GCTE-LUCC Open Science Conference was held in Barcelona, Spain from March 14-18, 1998.

The Global Change and Terrestrial Ecosystems (GCTE) and Land-Use/Cover Change (LUCC) Core Projects held an open Science Conference in 1998. GCTE studies the effects of changes in climate, atmospheric composition, and land use on terrestrial ecosystems, and the consequent feedback to climate and atmosphere. LUCC aims to document and understand global land-use and land-cover change, the forces that drive it, its relationship to climate and biogeochemistry, and the links between sustainability and land use.

The LUCC Data Requirements Workshop, organized by IGBP/IHDP LUCC and IGBP-DIS, was held in Barcelona, Spain from November 11-14, 1997.

The title of the workshop was: Survey of Needs, Gaps and Priorities on Data for Land Use and Land Cover Change Research. It provided a forum of relevant LUCC researchers aimed at identifying major situations where the progress in LUCC research is inhibited because of the lack or unsuitability of data, and assessing the nature and significance of these gaps.
The main objectives of the workshop were to:

1. Convene scientists to articulate their specific data needs for research.
2. Identify major common data needs.
3. Determine data priorities.
4. Identify monitoring system needs.

START/NAFCOM Workshop on Land Use and Land Cover Change (LUCC) in West/Central Africa, November 3-5, 1997 in Accra, Ghana.

The main objectives of this workshop were to:

1. Review the state-of-science in regional land use and land cover change (LUCC) research and to identify issues and challenges for consideration at the workshop.
2. Develop a LUCC-related research plan for Sub-Sahelian West and Central Africa.
3. Identify core groups of scientists to collaborate in the preperation and development of research proposal(s) for submission to various national, regional and international scientific research foundations.

View/Download Meeting Report

LUCC/START/DIS Workshop on Land Uses and Land-Cover Change in Miombo Ecosystems, Oct. 26-Nov. 1st, 1997, Lusaka, Zambia .

The main objectives of this workshop were to:

1. Establish the current state of knowledge of the patterns, trends and rates of change in land use and land cover in Miombo;
2. Identify known and potential drivers of such changes;
3. Identify known and potential consequences of such changes;
4. Develop a framework of key questions and hypotheses that will stimulate research aimed at improving our understanding of the patterns, causes and consequences of such changes;
5. Consider how best to mesh observations, analyses and models of land-use and land-cover change; and,
6. Initiate a process of collaborative and supportive research aimed at producing a regional assessment of the impacts of land-use and land-cover change.

For more information, contact Peter Frost or Paul Desanker .

Land Cover Land Use Change

STRATEGIES AND PLANNING PAPERS

As the LCLUC program develops, so will a number of strategies and planning papers. These papers will be listed here and will be accessible through this site.

- A Strategy for Global Observation of Forest Cover- Draft for Comments, version 1.2 GOFC Design Team
- A Strategy for Global Observation of Forest Cover Executive Summary - Draft for comments, version 1.2, GOFC Design Team.
- GOFC Fine Resolution Data and Product Design Strategy- Report of Workshop 23-25 September 1998, Paris France, Fine Resolution Design Team Report.
- A Land Cover Change Monitoring Program: A Proposed Federal Agency Initiative (Skole and Justice, 1994: as pat of the precursor activities to this program, a strategy document for Globla Carbon Monitoring was developed in conjunction with the EPA
- IGBP/IHDP Land-Use and Land-Cover Change Science/Research Plan 1995: this is the science plan that was developed fro the joint IGBP/IHDP Land Use and Land Cover Change program
- CEOS Pilot Project: Global Observations of Forest Cover (GOFC) 1997: this is the proposal to CEOS to develop an operational pilot for global forest monitoring
- Summary of GOFC Design Team Meeting, Washington D.C. 1998/01/29-30

A Strategy for

Global Observation of Forest Cover

A Strategy for Global Observation of Forest Cover

Draft for comments, Version 1.2

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Executive Summary

1.1 GOFC as a CEOS response to global concerns

As the twentieth century draws to a close, there is an emerging global consensus that the cumulative effects of past and present human activities are having a global impact on the Earth's ecosystems, atmosphere, and climate, and that steps must be taken to improve our knowledge and change policies and management practices throughout a broad range of human activities.

The international support for the Kyoto Protocol of the Framework Convention on Climate Change, together with earlier support for the International Convention on Biological Diversity, represent the first steps down a long, difficult path toward a sustainable future on the Earth.

Forests play a central role in the issues of greenhouse gasses, climate change, and biodiversity. In a general sense, the role forests play in the carbon and water cycles, and in providing rich habitat for diverse plants and animals, is well known. However, much additional research is required to understand the detailed role of forests. Scientists working on many aspects in the field of global change require global, regional, and local observations of forests to develop a better understanding of the complex, inter-related processes involved. At the same time, policy makers realize that we cannot afford to wait until all of the scientific questions are solved; global observations of forests are needed to monitor changes in the Earth's forests and provide objective, quantitative information to assess progress toward long-term objectives. As a result of the Kyoto protocol, particular emphasis is placed on reforestation, afforestation, and deforestation,

Earth observation satellites have been providing data for natural resource management since 1972. The data from these satellites has been widely used to map and monitor forest resources. However, these efforts have generally been made as individual projects within individual jurisdictions, such as states, provinces, or forest management units.

More recently, the global change science community, the United Nations Food and Agriculture Organization, and a number of national and regional efforts have worked to use earth observation data

to create a consistent regional and global pictures of the earth's forests, and to monitor changes in the forests worldwide. These efforts have shown the difficulties involved and the progress needed in assembling continental and global data sets to address the science and policy questions surrounding forests.

Recognizing the accomplishments to date, but also the shortcomings, the Committee on Earth Observation Satellites has initiated a program of Global Observation of Forest Cover as part of its Integrated Global Observing Strategy. The objectives are to increase international cooperation in the integration and use of data from multiple earth observation satellites, in conjunction with in-situ data, for mapping and monitoring the earth's forests, and to provide feedback to the space agencies to enable them to better coordinate future space missions. GOFC will develop the means to undertake operational inventories of forest cover, fire and forest biophysical characteristics using satellite data.

1.2 What GOFC has accomplished, and what can be expected from GOFC

Since July 1997, teams of scientists, remote sensing specialists, and knowledgeable representatives from user organizations have been meeting and planning a strategy to lead to ongoing global observation of forest cover. In this process, we have endeavored to reach out and obtain input from a broad spectrum of user groups, in addition to drawing heavily from persons with the greatest current experience in assembling and processing large regional and global datasets. We have held six international workshops, first to outline a GOFC concept, and then to produce this detailed strategy document. More than fifty specialists from fifteen countries and seven international organizations have participated in this design process. During this same period, the GOFC project leader held briefing meeting with twenty-six international organizations, scientific bodies, forest management agencies, non-governmental organizations, and earth-observation agencies to inform them about the GOFC concept and obtain their feedback.

As a consequence of these interactions, GOFC has already resulted in increased dialog with international organizations, science bodies, forest management agencies, and non-governmental organizations which require forest information.

This document presents our strategy. The essence of our strategy is to develop and demonstrate operational forest monitoring at regional and global scales by developing prototype projects along three primary themes:

- Forest Cover Characteristics and Changes
- Forest Fire Monitoring and Mapping
- Forest Biophysical Processes

As part of this process, we propose to assemble teams to execute prototype projects, develop consensus algorithms and standard methodologies for product generation and product validation in conjunction with in-situ measurements, and develop and demonstrate procedures for improved data access for the user community.

As a consequence, we will identify gaps and overlaps in earth observation data, ground systems, methods, and scientific knowledge from the experience gained in developing and executing GOFC prototype projects. The ultimate objective is to lead to sustained, on-going operation without the need for major funding by CEOS members. Additionally, GOFC will

- Create and strengthen partnerships between CEOS members and user agencies;
- Identify gaps and overlaps in CEOS member programs and make recommendations how these might be resolved;
- Lead to increased operational use of earth-observation data for policy decision making at national, regional, and global levels;
- Provide validated products which can be used to derive credible information concerning the forest component of the carbon budget for research and policy use;
- Promote common data processing standards and interpretation methods, which are necessary for inter-comparison of regional studies;
- Stimulate advances in the state of the art in the management and dissemination of large volume datasets and information from multiple sensors;
- Use data from multiple sensors, in combination with in-situ data, to produce validated prototype information products which satisfy clearly identified requirements of user agencies;
- Enhance the use of earth-observation information products for forest management and scientific research concerning forest biophysical processes.

1.3 CEOS Support Required

To succeed, GOFC will require support from CEOS as a whole, and from individual CEOS members who choose to become involved in GOFC projects. The IGOS partnership mechanism must help form meaningful partnerships with forest management, policy and science communities, and funding agencies. CEOS agencies will be requested to provide essential data for the pilot projects. This requirement will extend beyond the production of primary data products to the provision of support for the production of derived products. Just as important, it will be necessary for many organizations which produce earth observation data products from raw data to update their production systems to provide for increased automation and large volume processing, in order to reduce the costs of earth observation data so that global observation of forest cover becomes economically feasible. CEOS member agencies will also be asked to conduct and promote targeted R&D on science and technical issues identified by GOFC and its partners.

WGISS and WGCV have already played an important role in the development of GOFC. The support of individual WGISS and WGCV working groups will be essential for addressing and resolving further technical issues which arise in the development and execution of GOFC pilot projects.

1.4 Primary Themes

We believe that the best way to make demonstrable progress toward widespread operational use of earth observation technology to address forest issues is through a suite of well-considered pilot projects. Each must provide information of value to user communities with clearly stated requirements. Each must be achievable using proven technology, although an integrated system may not yet exist. Through the course of execution of the pilot projects, CEOS member agencies and participants will benefit from increased communication, and technological capabilities will be expanded. Strategies will be developed and funding sources will be identified to make the transition to on-going routine operation. GOFC has adopted the approach of involving the operational users in the design of these pilot activities so as to ensure adoption by the operational agencies at the completion of the pilot phase.

We identify three primary themes:

- Forest Cover Characteristics and Changes
- Forest Fire Monitoring and Mapping
- Forest Biophysical Processes

GOFC can make a key contribution to all of these by providing integrated datasets from multiple sensors.

Forest cover characteristics and changes: This is the most important but the most challenging of the proposed themes. The products have the greatest appeal to the widest spectrum of users including forest resource managers, policy makers, and scientists studying the global carbon cycle and biodiversity loss. We propose a systematic program for periodic mapping of land cover at coarse resolution (250 – 1000 m) on a five year cycle, combined with periodic mapping and monitoring of forested areas at fine (~25 m) resolution. Very large datasets must be acquired, assembled, processed, and analyzed from coarse resolution optical sensors, fixed and pointable fine resolution optical sensors, and SAR sensors. Most of the needed technology has been demonstrated, but assembling coordinated systems to generate the required products will be very challenging. The proposed approach is shown schematically in Figures 1 and 2.

Forest Fire Monitoring and Mapping: The global increase in wildfire following the 1997-98 el Niño event has served to emphasize the urgent need for improved information from CEOS members' space systems. Data from existing and near-term coarse resolution sensors can satisfy most of the information requirements, and automated algorithms for much of the information extraction have been demonstrated. A distributed network of low cost receiving and processing facilities could satisfy many of the requirements for operational fire monitoring and mapping. The proposed approach is shown schematically in Figure 3. At the same time there are clearly defined areas where additional research can improve and validate information extraction. Cross-linkages with the forest cover characteristics and changes theme and the forest biophysical processes theme will provide additional information on fuel consumption and gas and aerosol emission. At the same time, information from this theme will be a valuable input into the other two themes as an indicator of forest disturbance and gas and aerosol emissions. We continue to collaborate with the with the IGOS Disaster Management Support Project to harmonize our efforts.

Forest biophysical processes: This theme reflects a key component of the sizeable effort to use earth observation data to understand, and eventually balance, the earth's carbon budget. With the signing of the Kyoto protocol in 1997, information on the carbon cycle now has policy as well as scientific implications. The major goal for this objective is to quantify net primary productivity of forests, combining satellite data with ecosystem process models. The approach is shown schematically in Figure 4.

Figure 1: Forest Cover Characteristics
(Centrally coordinated/regionally executed)

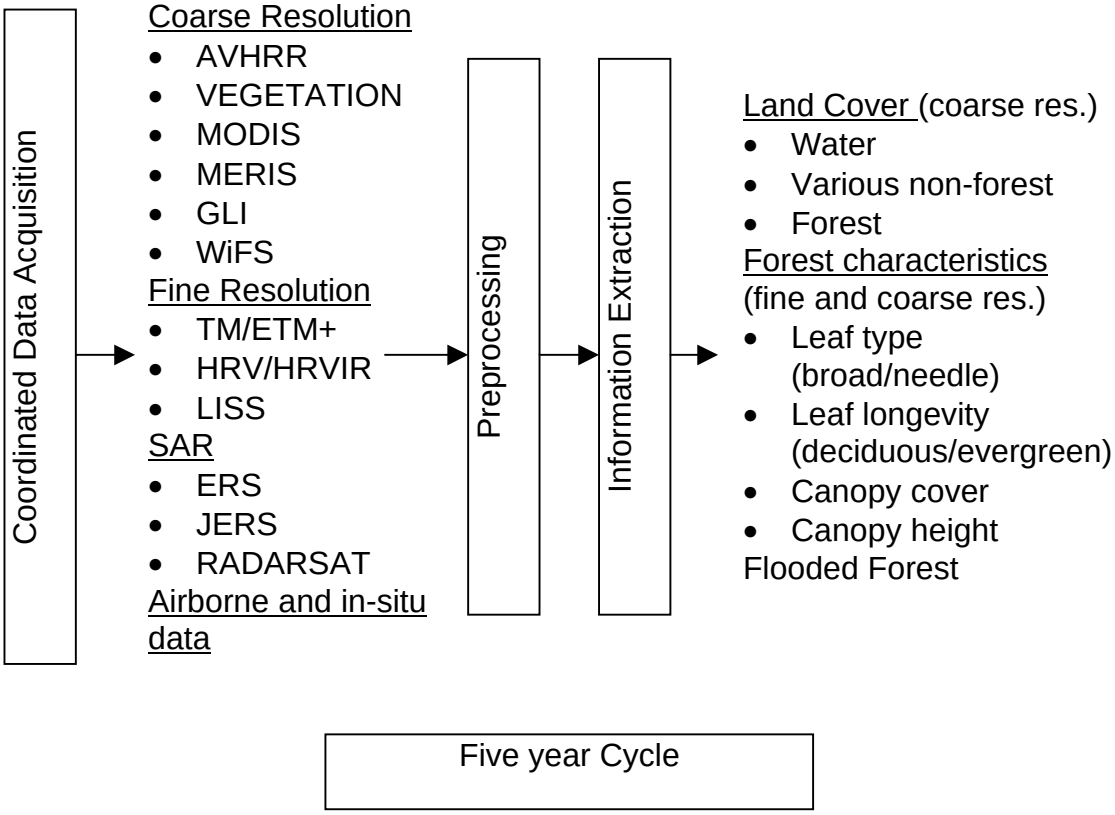


Figure 2: Forest Cover Changes
(Centrally coordinated/regionally executed)

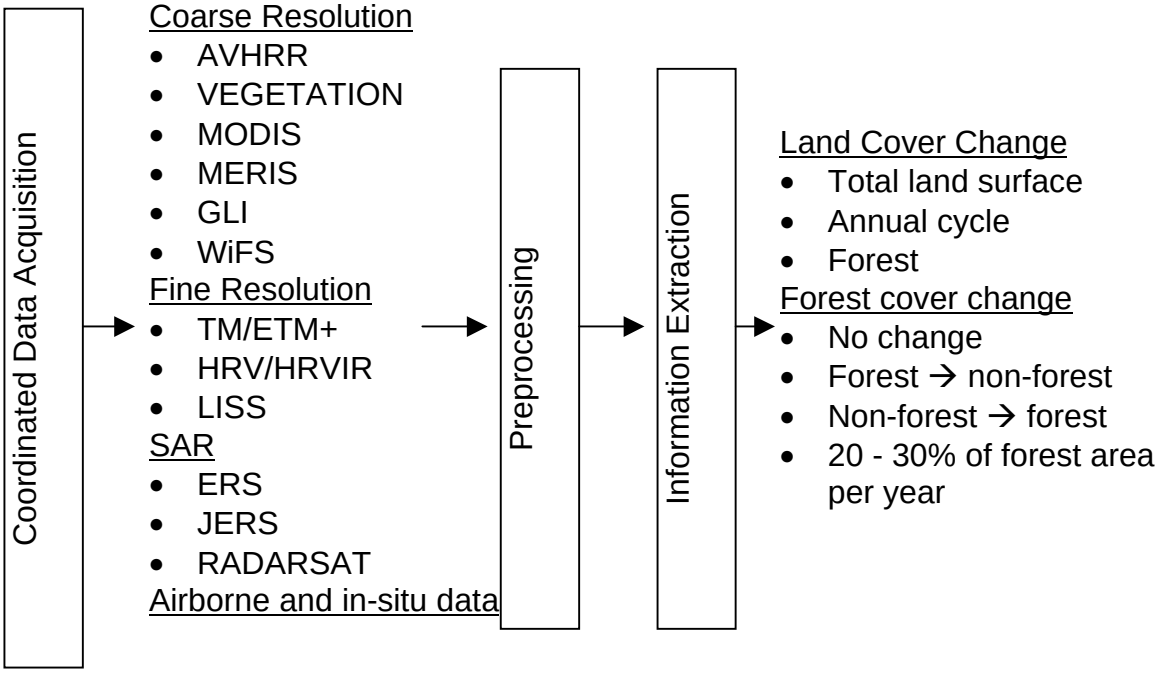


Figure 3:Forest Fire Monitoring and Mapping
(Centrally coordinated/regionally or nationally executed)

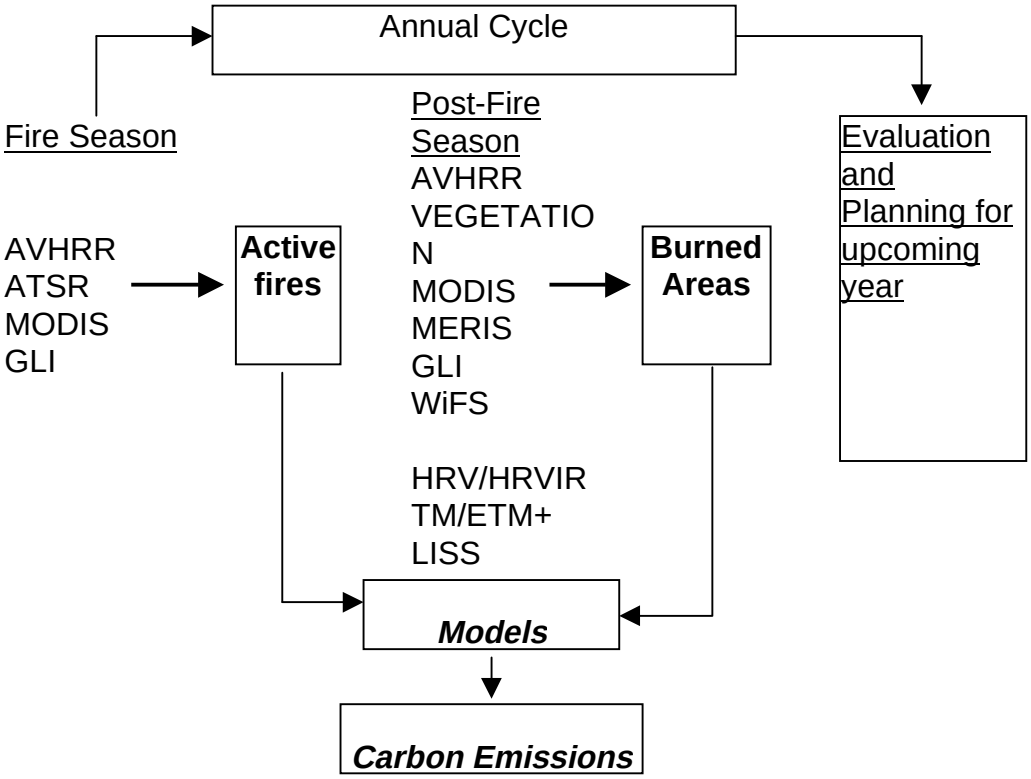
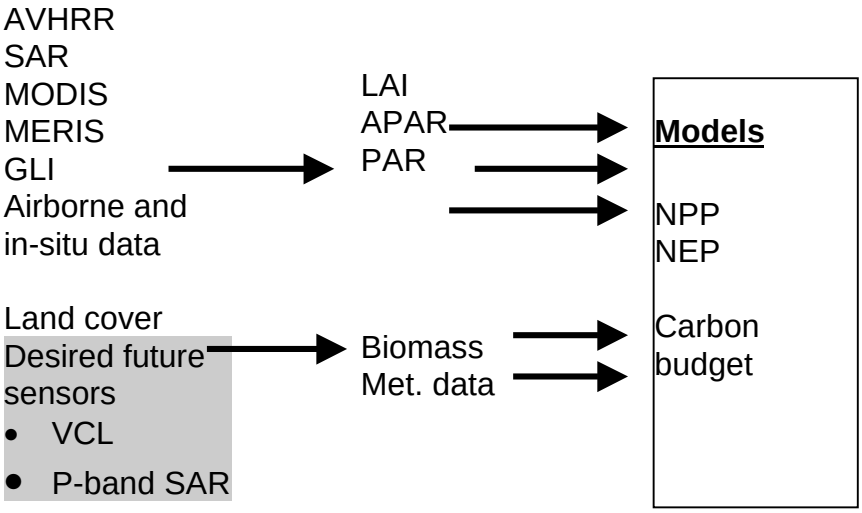


Figure 4: Forest Biophysical Processes
Confederation of Investigation Teams

- National/regional
- Global

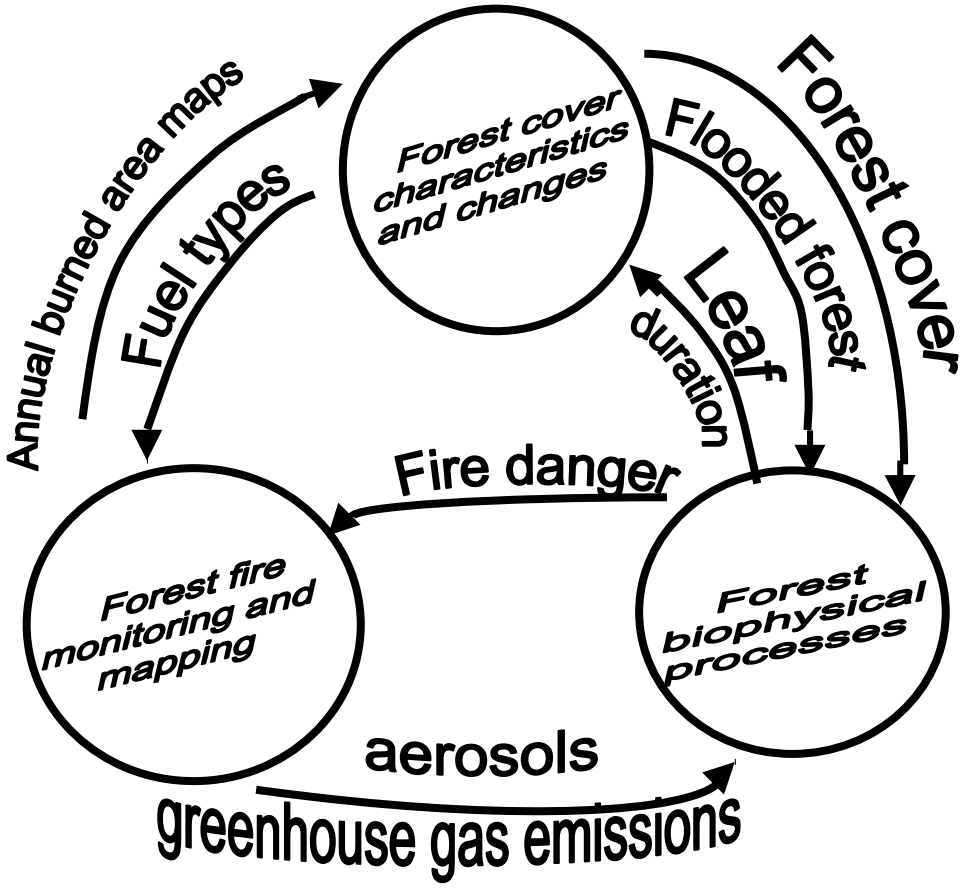


AVHRR research
EOS research
MERIS research
GLI research

In conjunction with IGBP, GOFC could provide a mechanism to coordinate

Each of these themes of GOFC could be implemented as called for in this document and result in significant progress. But the natural interconnections (shown in Figure 5) make an implementation of all three components significantly stronger than simply the sum of the three parts.

Figure 5: Linkages between GOFC themes



While much progress in this area will take place independently of GOFC, GOFC can contribute to a more integrated global approach by:

- Providing opportunities to inter-compare results from different sensors and different algorithms;
- Providing linkages to organizations such as GTOS which can facilitate the sharing of in-situ observations.
- Promote ground observation networks and campaigns to validate forest biophysical process products.

1.5 Expanding the circle of consultation

This document provides a strategy, not a blueprint, to attain CEOS goals as defined by IGOS. A large number of representatives of producer and user agencies has participated in the development of this

strategy, and many more have been consulted by the members of the GOFC design teams. Nonetheless, to achieve a broad consensus, wider consultation is needed. All organizations which have participated in the development of GOFC to date will be given an opportunity to comment. Subsequently, a revised draft will be circulated to organizations which may have an interest but which have not participated in this development. It will be particularly important to obtain feedback from foresters, forest managers, and forest policy makers from countries which have large areas of forests. We propose to hold one or more workshops in the first half of 1999 for this purpose.

Because of the comprehensive view we are taking of both earth observation technology and user requirements, the final document will serve as a reliable pointer to the way ahead. This strategy document will provide a basis for the CEOS agencies and partners to support and develop projects to meet the GOFC objectives. After the first year the complement of GOFC projects will be listed and evaluated to determine critical gaps in the strategy.

1.6 Initiating action

Even though this Strategy may be modified somewhat through wider circulation and comment, we are confident that the collective experience of the design team members, coupled with the additional consultations they have made during the course of the GOFC design phase, have produced a basis to initiate action. We propose to approach CEOS member agencies and user organizations to assemble teams of lead and participating agencies for each of the three primary themes, recognizing that the magnitude of the Forest Cover Characteristics and Changes theme may necessitate further discussion before initiating action in that particular area. The GOFC Executive must be formed, including representation from the lead agencies and participating users. The best way to move ahead is to begin working on specific pilot projects.

1.7 Schedule

Since GOFC is not a funded R&D effort but rather a partnership of voluntary participants, it is not possible to define a firm schedule as one might for an engineering project. Nevertheless, it is helpful to propose a possible schedule to examine how much progress could be made in the remaining four years of GOFC with rapid, enthusiastic participation. A schedule to achieve IGOS and GOFC objectives is proposed here to provide a starting point for further development.

Forest Cover Characteristics and Changes: We propose a two-phase approach. Each phase would be an end-to-end exercise of data acquisition, data analysis, and evaluation/validation of the resulting products. It is important to carry out an end-to-end exercise to ensure all the necessary components function properly, and to identify weak areas where remedial work is necessary. The first phase could be accomplished in as little as two years (1999-2000), although that is a very ambitious schedule. The first phase should cover one or two regions. The second phase (2001-2002) could cover several regions, expanding to all of the forested regions of the Earth if sufficient resources are available.

Forest Fire Monitoring and Mapping: There is a natural cycle time for this project: the annual seasonal cycle which normally includes one “fire season” in each region. The proposed GOFC initiative would also follow an annual cycle, with near-real-time fire monitoring during the fire season, followed by post-season fire mapping. The first two years (1999-2000) are proposed to be a testing phase, first for several countries, and then for many countries. By the third year (2001) the system could be in full

operation for most countries. This would be a distributed effort, with an annual meeting at the end of each year to discuss accomplishments and difficulties, and to make plans for the following year.

Forest Biophysical Processes: The EOS-AM1 mission is expected to be launched in mid-1999, with validation campaigns taking place during the next few years. Research teams for the ADEOS-2 and ENVISAT missions are being selected. GOFC should facilitate communication and coordination among these groups, and should strive to promote regional and global pilot projects incorporating multiple teams and approaches working toward community consensus algorithms.

2 Introduction

Sustainable development of forests has emerged as one of the most difficult, serious, and pressing environmental issues of our time. Human-induced (direct and indirect) changes in Earth's forests have an impact on natural resource availability, biodiversity, atmospheric composition, and climate. Through feedback processes, it is likely that climate change will have adverse effects on forests, which may induce further climate change. Observation of forests by satellites provides the best hope of monitoring changes over extensive areas and understanding the complex processes involved. Observations from space can help policy makers document the current situation and judge long-term trends. Observations from space also provide forest managers with the information they need to assess the current state of the forests, weigh the requirements of multiple uses by multiple stakeholders, and manage forestland resources sustainably.

2.1 Setting:

2.1.1 Global Forest Issues

The management of the forests of the Earth has become an issue of global concern. In addition to traditional anxiety over adequate supplies of wood for fuel, construction, and papermaking, more recent indirect but related concerns center on issues of soil erosion, watershed protection, biodiversity, recreation and tourism, equitable treatment of indigenous populations, and the buildup of greenhouse gases in the Earth's atmosphere. Stimulated especially by the Rio Earth Summit in 1992, the nations of the earth, through the United Nations and other bodies, are laying the groundwork to deal with these problems.

Several Agenda 21 initiatives, including the Convention on Biological Diversity, the Kyoto Protocol to the United Nations Framework Convention on Climate Change, the Montreal, Helsinki, and Tarapoto Processes leading to Criteria and Indicators of Sustainable Forest Management, and the Intergovernmental Panel of Forests all represent concrete steps forward by sovereign nations dealing with global problems. All of these initiatives require information about forests to assess progress, although some have progressed further in identifying specific information requirements.

Since 1972, the Earth has been under observation from space with satellites designed to provide information about earth resources, including forests. The data from these satellites has been widely used to map and monitor forest resources. However, these mapping and monitoring projects have generally been made within individual jurisdictions, such as states, provinces, or forest management units. Until recently, there has been little effort to use earth observation data, particularly data from the

higher resolution natural resource satellites, to create a consistent global picture of the earth's forests, or to monitor changes in the forests worldwide.

2.1.2 GOFC Heritage

In response to concerns about the global impact of human activities on the earth's forests, researchers have begun to assemble national, continental, and global data sets from earth-observation satellites in an attempt to provide badly-needed information about the state of the earth's forests, and how they are changing. Examples of programs which have provided essential experience and positive results include the World Forest Watch (INPE, Brazil), Landsat Pathfinder (NASA, U.S.), TREES (Joint Research Centre, Europe), IGBP 1 km Land cover (NASA, NOAA, JRC, USGS/EDC), Forest Resource Assessment (FAO, UN), North American Landscape Characterization (U.S. Environmental Protection Agency), and Global Rainforest Mapping (NASDA, Japan, and JPL, U.S.).

(1) World Forest Watch. The World Forest Watch Program undertaken as part of the International Space Year in 1992 provided an international forum for developing satellite based forest monitoring. The summary meeting held in São José dos Campos, Brazil (June 1992) provided an initial high-level international forum for the assessment of current approaches to satellite-based monitoring. This meeting also served as a basis for forwarding recommendations from the technical and scientific communities to the policy makers and government leaders at UNCED. One important outcome was the PanAmazonia Project, in which Brazil shared its proven technology for mapping deforestation in the Amazon region with its neighbors who share the Amazon Basin. These countries were subsequently able to produce deforestation estimates. The PRODES project of INPE (Brazil) continues to be the largest systematic application of high resolution satellite data to monitor changes in forests.

(2) Landsat Pathfinder. NASA, in conjunction with the EPA and USGS, began a prototype procedure for using large amounts of high resolution satellite imagery to map the rate of tropical deforestation, one of the most important land cover changes. This activity, called the Landsat Pathfinder Project (Landsat Pathfinder Project Internet Website), builds on experience gained during a proof-of-concept exercise as part of NASA's contribution to the International Space Year/World Forest Watch Project. It focused initially on the Brazilian Amazon, and has been expanded as part of NASA's Earth Observing System activities to cover other regions of the humid tropical forests.

This project has succeeded in demonstrating how to develop wall-to-wall maps of forest conversion area and re-growth. The project is now in the process of extending its initial proof-of-concept to a large-area experiment across Central Africa, Southeast Asia and the entire Amazon Basin. The project has acquired and processed several thousand Landsat scenes at three points in time -- mid 1970s, mid 1980s, and mid 1990s -- to compile an inventory of deforestation and secondary growth to support global carbon cycle models. Methodology and procedures have been identified. In principle, it provides an initial large-scale prototype of an operation program.

(3) TREES. The TRopical Ecosystem Environment Observations by Satellites (TREES) project is currently being implemented as a demonstration of the feasibility of applying space observation techniques to monitoring of land cover and biomass burning (Malingreau *et al.*, 1993). This project, being sponsored by the European Commission and executed by the Space Applications Institute of the Joint Research Centre (Ispra, Italy), utilizes global coverage with a wide range of sensors including

AVHRR, ERS-SAR, JERS-1 SAR, ATSR, Resurs, Landsat, and SPOT. It also focuses on the use of thermal sensors for the detection of fires, and incorporates other indicators of deforestation. The project has developed methods of data assimilation leading to an optimization of the multiple data sources. It has also developed a central repository for data on tropical forests called the Tropical Forest Information System (TFIS) which can serve as a model of a decision support system providing information derived from a variety of sources, only a few of which may be earth satellites.

(4) IGBP-DIS 1 km Land Cover Mapping Project. In conjunction with NOAA and the USGS, NASA has been supporting an IGBP project to acquire global, daily coverage with the AVHRR sensor at 1 km resolution (Belward, 1996). This project is the first of its kind to acquire and process global, daily coverage. Several complementary global land cover classifications have been produced and are now in the process of validation.

(5) IGBP-DIS High Resolution Data Set. The IGBP has also initiated a project to make high resolution data available to the global change research community through co-operation with CEOS. This project is being initiated as a pilot study to make available each year several hundred individual scenes from SPOT, Landsat , ERS-1, MOS-1, JERS-OPS, and IRS. The project is also preparing a centralized archive system in which users can mount an inquiry for data from all of the aforementioned platforms from one point.

(6) FAO Forest Resource Assessment. The FAO Forest Resource Assessment for the 1990 period (FRA-90) used a combination of earth observation data and national statistics to derive statistics about forest cover for the 1990 datum, and forest cover change for the period 1980 to 1990 (FAO, 1995). For tropical forests, FAO developed a technique called the Interdependent Interpretation Procedure, which relied primarily on a two-date interpretation of large-scale photographic prints of full Landsat scenes. The resulting change classes also allowed FAO to estimate transitions between several woody biomass categories for Africa, Latin America, and Asia (FAO, 1996). The year 2000 Forest Resource Assessment has been extended to include all forests. The FAO Forest Resource Assessment Project provides an important interface to the national forest monitoring communities.

(8) Multi-resolution Land Characterization. An Interagency Multi-Resolution Land Characterization (MRLC) project, implemented by the USGS on behalf of a number of federal agencies, is generating land cover data sets for the conterminous US. This data set includes products from coarse and high spatial resolution satellite sensors. This project also provides complete coverage of the United States with TM data.

(10) The Global Rainforest Mapping Project/Global Boreal Forest Mapping Project. Within the framework of NASDA's Global Forest Mapping Program, the GRFM/GBFM project is a collaboration between NASDA, ASA/JPL/ASF and the Joint Research Centre (SAI/MTV), with the aim of generating JERS-1 L-band SAR data sets of the global tropical and boreal forests. A complete SAR coverage over the tropical belt - in total some 13,000 scenes - was acquired in 1995-96, including multi-temporal coverages over the Amazon and Congo river basins to capture season effects and to map inundation in flooded forests. SAR mosaics at 100 m resolution have been generated to cover the tropical region in all three continents. Data acquisition has been completed for the boreal forests and the production of mosaic products is underway.

11) IGBP-DIS Global Fire Working Group. The global fire working group has provided a forum for the discussion of existing satellite capabilities for fire monitoring. Global and regional fire data sets have been developed and distributed on CD, providing new data sets on fire distribution, timing and extent.

This base of experience and technological development provides a basis to move to a higher level of integration of data from multiple earth-observation sensors with in-situ observations, to satisfy the information requirements of a wide spectrum of user groups.

2.2 CEOS Response: IGOS, SIT, and AG

The Committee on Earth Observation Satellites (CEOS) is an organization composed of space agencies, affiliates, and observers linked by a common interest in the provision and use of earth observation data from space. Recognizing the accomplishments to date, but also the shortcomings, CEOS members have developed an Integrated Global Observing Strategy (IGOS) to coordinate earth observation programs in six critical areas, including Global Observations of Forest Cover (Shaffer, 1996 and 1997, Ahern *et al.*, 1998). The objectives are to increase international co-operation in the integration and use of data from several earth observation satellites for mapping and monitoring the earth's forests, to identify technical and non-technical barriers, to improve the integration of earth-observation and *in-situ* data, and to provide feedback to the space agencies to enable them to better coordinate future space missions.

Rather than creating a new institution, GOFC seeks to produce a networked international consortium of existing programs.

2.3 GOFC Origins and History

GOFC traces its origins to the first IGOS Strategic Implementation Team (SIT) meeting, which took place in February 1997 in Irvine, California. It was one of six pilot projects chosen to illustrate and develop the IGOS concept. Canada was chosen to take the lead in developing GOFC, through the Canada Centre for Remote Sensing and the Canadian Space Agency, with NASA agreeing to play a strong supporting role.

A workshop was convened in Ottawa, Canada, in July, 1997 to review user requirements and current capabilities, and create a draft plan to proceed (Janetos and Ahern, 1997).

In parallel, CEOS created an Analysis Group to review the joint requirements of the six pilot projects. This group met three times in 1997, and a GOFC representative participated in all three meetings. The GOFC concept was further developed through the participation in those meetings.

The GOFC concept was strongly endorsed by most of the space agency member of CEOS at a Strategic Implementation Team meeting in Oxford, UK, and GOFC was given a green light to proceed into its design phase at the CEOS plenary in Toulouse in November, 1997.

The design phase began with a meeting in Washington, D.C. in January, 1998. At that meeting five design teams were created, each with specific tasks to accomplish. Each design team was co-chaired

by two or more persons who have been very active in continental to global scale projects dealing with forests. The design teams, their co-chairs, and tasks are shown in Table 2.3.1, while a complete list of GOFC participants is provided in Appendix 1. Table 2.3.2. documents the seven GOFC and related workshops which have led to this draft strategy. Table 2.3.2 and Appendix 1 show that the number of nations and international organizations has broadened significantly since the original GOFC planning meeting in Ottawa.

Table 2.3.1: GOFC Design Teams and their Tasks

Name	Task	Co-chairs
Data Acquisition, Preprocessing, and Access (DAPA)	confirm user requirements, design data acquisition strategy; detailed level 1 product definition; strategy to produce products and metadata; define system to catalog, store, and distribute all products	J. P. Malingreau (EC), Chris Justice (UVa), Martha Maiden(NASA), Peter Churchill(JRC)
Fine resolution products	confirm user requirements, detailed design of all fine resolution products; strategy to produce products and metadata	David Skole (MSU),Victor Taylor(NASDA/JPL)
Coarse resolution products	confirm user requirements, detailed design of all coarse resolution products; strategy to produce products and metadata.	Tom Loveland(EDC), Yoshifumi Yasuoka (National Institute for Environmental Studies of Japan)
Product validation	develop validation strategy for all products	Alan Belward(JRC), Zhiliang Zhu (EDC)
Communication and Coordination	Collect and document user requirements; define approaches to project communication; define organizational structure; strategy for ongoing operational production	Frank Ahern (CCRS) Robert Davis(FAO)

Table 2.3.2: GOFC and related workshops

Dates	Location	Host	Topic	No. of members*	No. of nations and int'l orgs.
1997					
July 7-10	Ottawa	CCRS	Develop GOFC concept	35	8
1998					
Jan. 29-30	Washington	NASA	Establish design teams and their tasks	17/1	7
Mar. 23-24	Ispra	JRC	IGOS pilot project requirements from WGISS and WGCV	N/A	N/A
June 23-24	Frascati	ESA/ESRIN	Communication and coordination Design Team	11/6	11
June 23-24	Sioux Falls	USGS/EDC	Coarse Resolution Design Team	7/2	5

Sept. 23-25	Paris	CNES	Fine Resolution Design Team	24/7	14
Sept. 29 – Oct 1	Paris	ESA/HQ	End-to-End Design Review		

* First number indicates members present/second indicates members absent, most of whom provided input before or after the meeting.

In parallel to these development efforts, the GOFC project leader presented briefings to numerous potential user agencies and cooperating organizations to inform them of GOFC and obtain their feedback regarding interest, information requirements, and potential future co-operation. These meetings are summarized in Table 2.3.3.

Table 2.3.3. GOFC Briefing Meetings

International Organizations	Scientific Organizations	Forest management agencies	Non-governmental organizations	Earth observation organizations	Other
FAO September 97 and Mar. 98	GTOS September 97 and Mar. 98	Canadian Forest Service July 97, Nov. 97, Feb. 98	IISD July 98	NASDA, July 97	CIDA Dec. 97 and Feb. 98.
ESCAP Nov. 97	IGBP-DIS November 97	NAFC July 98	WCFSD July 98	CSA Sept. 97 and Mar 98.	Radarsat International Feb. 98
UNEP-Sioux Falls Feb. 98	Symposium on Agriculture and Forestry June 98.	Manitoba Department of Natural Resources July 98	WRI Aug. 98	JRC September 97, June 98	Biological Diversity Convention Secretariat, Mar. 98
	International Symposium on Remote Sensing of Environment June 98			CNES Nov. 97, Oct. 98	IIASA Mar. 98
				EDC, Feb. 98	
				WGISS/WGCV Mar. 98	
				Swedish Space Corp. June 98.	
				ESA/ESRIN June 98.	
				NASA Aug. 98	
				ESA Oct. 98	

2.4 Overarching Design Statement for the GOFC Strategy

In its five-year pilot phase, GOFC will work toward defining, developing implementing, and refining an ‘operational’ pilot, and will seek multiple research and development prototypes for methods and techniques to incorporate as they mature and will implement operational demonstrations with operational users. GOFC ‘operational pilots’ are viewed as projects developed with the view of ongoing operational implementation after four or five years, with a longer view towards serving a long term agenda e.g. FCCC (2008), FRA 2010

Previous “lessons learned” indicate that the pilot phase should engage the operational community from the beginning, to articulate the operational requirements, assist in the design and testing of methods and techniques, prototyping operational application. The process and pathways for transition from an operational pilot to a fully operational system should be built in to the project design.

As an international project, GOFC will be federated, relying on multi-source data acquisition, distributed data processing, and distributed data access and archive.

GOFC will need to develop partnerships with the international ground stations and data providers to acquire the data needed for GOFC projects.

3 Requirements

3.1 Global Change Research

There are three pathways of relevance for global change and forest lands with implications for GOFC (Turner *et al*., 1995). The first is the interaction of forests and the atmosphere: regulation of the hydrologic cycle and energy budget, with implications for weather and climate prediction. Understanding these interactions is a crucial part of the global change science agenda. The second is both a scientific and policy issue: the implications of changes in forest land for the atmospheric carbon dioxide budget. Are forested lands net sources of carbon or net sinks of carbon? What are the rates of deforestation and reforestation? What are the implications of changes in fire frequency? The third pathway is the potential impacts of climate change: what effect will changes in temperature, precipitation, and concentrations of carbon dioxide and other radiatively active gases have on forest composition, productivity, health, and distribution, and therefore on the economic activities that are generated by forested lands? What feedbacks might these changes have to the climate system itself?

The International Geosphere-Biosphere Programme (IGBP) and World Climate Research Programme (WCRP) have each articulated clearly the urgent need for comprehensive, spatially explicit, global data sets on forest cover and attributes. Several projects in the International Geosphere-Biosphere Program (IGBP) and the World Climate Research Program (WCRP) require information on global forests. The IGBP Land Use and Cover Change (LUCC) project has critical needs for high-resolution information on land cover and change (Turner *et al.*, 1995). Information on biomass, fires, net primary productivity and land cover change is essential for the IGBP International Global Atmospheric Chemistry (IGAC) project (IGBP, 1994). The IGBP project on Global Change and Terrestrial Ecosystems has strong requirements for land cover, land cover change, leaf area index (LAI), and net primary productivity (NPP) data sets. The Biospheric Aspects of the Hydrological Cycle (BAHC) project has essential needs for land cover, biomass, LAI and NPP data sets (IGBP, 1993). The Global Energy and Water Cycle Experiment (GEWEX) has essential requirements for several forest data sets including land cover and cover change, LAI, biomass, and fires. Several Framework Activities (IGBP Global Analysis and Integrative Modeling, IGBP-Data and Information System, ISLSCP Initiative II) have especially strong scientific requirements for such forestry data. Furthermore, numerous regional programs such as the Amazon LBA, the European FIRS, and others have essential requirements for most of the above mentioned data sets.

3.2 United Nations

Member countries of the Food and Agriculture Organization of the United Nations (UN/FAO) have recognized FAO as the lead agency for conducting periodic global assessments of forest cover and have formally endorsed the Global Forest Resources Assessment 2000 (FRA 2000) agenda in the Committee on Forestry Meeting 1997 and in the United Nations Intergovernmental Panel on Forests (IPF) (1997).

Remote sensing observations were used for the tropical regions in 1990 and will be expanded to temperate and boreal forests in 2000. There is an obvious commonality of interest in access to data and

land cover classifications between FAO and GOFC. Several meetings have been held to discuss information requirements and discuss co-operation between GOFC and UN/FAO. The most recent of was hosted by the North American Forest Commission and included representation from the forest services of Canada, the United States, and Mexico. The FAO information requirements and methodology are, by necessity, already prescribed and not satisfied by the classification scheme identified in Sections 4.1 and 4.2. Nonetheless, both organizations appreciate the benefits of co-operation: GOFC will facilitate the acquisition of data for the FAO FRA2000 exercise, and continuing involvement in the FRA2000 exercise may provide GOFC participants with greater insight into problems associated with the extraction of land cover and land cover change information at global scales. Both organizations benefit from increased dialog on sampling designs and densities needed to achieve reliable global and regional statistics on forest cover change. Continuing dialog and interaction will, ideally, lead to convergence on data and methods in time for the FRA2010 exercise.

FAO also carries out projects of capacity building for forest assessment at the national level in developing countries. Cooperation between FAO and GOFC will facilitate this process, and also provide increased dialog between GOFC participants and developing country foresters.

The United Nations Environment Programme (UNEP) provides access to datasets and carries out projects in key areas of environmental concern. UNEP's Global Resource Information Database (GRID) has a mandate to keep the state of the world's environment under review, provide early warning of environmental threats, and improve access to information. Particular emphasis has recently been placed on forest fires, as a result of the severe fire season in 1997-98. Many of the derived products proposed by GOFC, particularly those related to wildfires, will be of interest to UNEP and GRID.

3.3 Global Observing Systems

The Global Observing Systems incorporate scientific, operational, and policy-level concerns at both international and national levels. They have already indicated their strong need for global forest cover information and information on forest attributes, primarily through the report of the Terrestrial Observations Panel for Climate (TOPC), a joint GCOS-GTOS activity (Terrestrial Observation Panel for Climate, 1997). The Global Terrestrial Observing System (GTOS) and the Global Climate Observing System (GCOS) are the major clients in this area. GTOS is an international organization co-sponsored by UNEP, UNESCO, FAO, ICSU, and WMO. GTOS promotes improved collection of and access to bio-physical and socio-economic georeferenced data, with an initial emphasis on existing research centers (Global Terrestrial Observing System, 1997). GTOS requires detailed land cover and land cover change information for many purposes, including the assessment of land use and its impact on the natural ecosystems. GTOS has recently given priority to the collection of global data on Net Primary Productivity (NPP). A strong interaction between GTOS and GOFC will benefit both organizations, since GTOS has many linkages to organizations with in-situ data, while GOFC facilitates access to earth-observation data.

GCOS is a partnership of WMO, IOC of UNESCO, UNEP and ICSU. The objectives of the Global Climate Observing System, GCOS, are to insure the acquisition of data for climate system monitoring, climate change detection and response monitoring, application of climate information to national economic development, and research. (Global Climate Observing System Internet Website, 1997). GCOS requires information on land cover (coarse resolution) for global circulation modeling and

model validation; for carbon, water, and energy modeling; and for the assessment of climate impact. Both GCOS and GTOS require information on net primary productivity as a fundamental parameter linking the terrestrial and the atmospheric systems on the one hand, and the natural and economic systems on the other. Both also require knowledge of forest biomass and fires as major parameters that quantify the distribution of the carbon stocks and the effect of major disturbance agents.

3.4 International Conventions and Agreements

The major conventions and agreements concerned with global forests are the Framework Convention on Climate Change, the Convention on Biological Diversity, and the Montreal, Helsinki, and Tarapoto processes leading to Criteria and Indicators of Sustainable Forest (World Forestry Congress, 1997).

The Kyoto Protocol of the Framework Convention for Climate Change has established reporting requirements on reforestation, afforestation, and deforestation which must be met at the national level by signatories. The carbon trading and clean development mechanisms will need reporting on reforestation, afforestation, and deforestation by participating nations. The forest cover change information to result from the Forest Cover Characteristics and Changes theme is intended to be suitable for the RAD reporting requirements.

The IGBP Terrestrial Carbon Working Group (1998) has emphasized the shortcomings of carbon trading based on partial carbon budgets and recommends moving to a full carbon budget accounting system as quickly as possible. The forest biophysical processes theme identified in section 6 is an important step CEOS members and their partners can take toward a full carbon budget accounting system.

Canadian Forest Service researchers have indicated that many of the indicators of sustainable forest development resulting from the Montreal Process can be obtained in whole or in part using earth observation data, particularly the derived products proposed as part of the Forest Cover Characteristics and Changes theme. It is likely that the other Criteria and Indicators initiatives will be equally well served by these products.

The Convention on Biological Diversity will require accurate information on forest cover, fragmentation, and change. However, the discussions leading to the definition of reporting requirements and methods to satisfy these are moving slowly, and no binding requirements are yet in place.

It is important to distinguish between the science requirements and the reporting requirements with respect to international conventions and agreements. Whereas the science requirements will be satisfied by teams of scientists collaborating internationally, the reporting requirements are ultimately a national responsibility and must be satisfied by national forest ministries and other national agencies.

3.5 Non-Governmental Organizations

Many NGOs have interests in forests at local and regional levels. At a global level, two NGOs with particular interest in forests are the World Resources Institute, in Washington, D. C., and the World Conservation Monitoring Centre, in Cambridge, UK. These organizations recently collaborated to produce a report which shows changes between historical and present forest and identifies the world'

remaining large natural forest ecosystems. They have indicated that global forest datasets, as proposed here, would have been of great value in facilitating the production of this study. Since both organizations have an interest in following the changes to forests in the future, they can continue to benefit from the proposed products, particularly those from the Forest Cover Characteristics and Changes theme.

The WRI has recently initiated planning for a Global Forest Watch. This initiative will involve networks of organizations working at local and regional levels with emphasis on the collection of in-situ data. Current, objective information on current forest cover characteristics and recent changes has been identified as an important component of this initiative.

3.6 National forest agencies

Historically, forest information has been obtained locally by ground plots or aerial photography, with national information derived through statistical compilation and generalization of the local data. Earth observation data have generally been used to update the locally produced inventories for major changes caused by new roads, logging, fires, and severe insect and storm damage. This use is expected to increase as the cost of the data and related technology decreases, and with increasing pressure on national and sub-national governments to provide more information, more rapidly, with decreasing budgets.

National forest agencies are recognizing the value of the comprehensive overview provided by earth observation technology, which can provide nationally-consistent information over wide areas in a reasonably short time frame. A recent workshop of the North American Forest Commission provided an opportunity to see how Canada, the United States, and Mexico are moving in similar directions toward the implementation of national forest information system using a multi-tier approach which combines complete coverage with fine resolution satellite data with samples using data from aerial photography and ground plots.

These systems are intended to provide information at the national level which is needed for policy formulation and strategic forest management planning, as well as for international reporting.

The products proposed for the Forest Cover Characteristics and Changes and Forest Fire Monitoring and Mapping themes are expected to satisfy many national, as well as international, information requirements. The products proposed for the Forest Biophysical Processes theme will aid individual nations in addressing many aspects of their commitments under the Kyoto Protocol.

4 Three Themes for GOFC

As described above, we have collected the proposed GOFC activities under three themes, Forest Cover Characteristics and Changes, Forest Fire Monitoring and Mapping, and Forest Biophysical Processes. Each theme represents what is essentially a stand-alone activity which would produce global derived products containing information for multiple user groups. Cross-linkages exist which serve to strengthen the overall effort.

4.1 Forest Cover Characteristics and Changes

This theme is by far the most challenging, but also the most valuable, of GOFC. We propose below an end-to-end plan which uses data from coarse and fine resolution sensors in a well thought out, highly integrated approach to generate a relatively small number of products which provide essential information concerning land cover, forest cover characteristics, and forest cover changes. These products will provide most of the information which has been identified as needed at continental and global scales by a wide spectrum of user groups. They will also provide very useful, albeit incomplete, information for forest assessment, policy-making, and management at the national level.

The criteria used to design this part of the GOFC pilot project were:

- Products should be relevant to as broad an audience as is practical and feasible. There was particular emphasis on products at the global scale, with regional or national application. An emphasis is placed on forest cover and forest cover change data to support carbon cycle research, policy support to IPCC and the Kyoto protocol, and national forest inventories.

- Products and the overall design must be practical and lead to a reasonable operational concept, implemented using existing and near-term observational systems, with a straightforward and manageable level of effort.

- The Fine Resolution component should build on existing and near term programs, and should include proven or near-ready applications rather than propose approaches with high research and development aspects, although recognizing that research and development should be a critical component of the program

Design Requirements

The proposed strategy has been developed around the following requirements:

- The program must incorporate both global and national level objectives and be capable of providing results at national, regional and global scales.

- Some of the information generated by the program should be useful for national level resource planning and management, as well as vulnerability studies and mitigation and adaptation planning.

- The program should result in an operational monitoring system with the capability for permanent implementation.

- The monitoring systems should utilize data from a variety of sources and allow for in-country analyses where appropriate.

- The information generated by the system should have a known and stated accuracy.

- Accuracy assessment must be an integral part of the program. Field validation will be an important component of the accuracy assessment.

- Data and information generated by the program must be made readily available in a timely fashion to a broad user community. A data system should be developed to serve the information management needs of the program and its data users.

4.1.1 Land cover and forest cover information

The Coarse Resolution design team established a number of criteria to guide the development of land cover classes. The team then proposed a set of classes, which the Fine Resolution design team was able to follow, allowing a joint classification scheme to be proposed. This scheme can be applied to the entire land surface of the earth. In accordance with the needed emphasis on forest cover and forest cover change information, the number of classes is much greater in areas of forest and other woody vegetation.

The criteria which guided the development of the classification scheme were:

- The classes mapped must be relevant to carbon studies.
- Cover is based on actual rather than potential land cover.
- Compatibility with exiting legends is desirable, especially those used by national and international forestry organizations.
- A hierarchical system allowing multi-scale classification is desirable.
- The system must be sufficiently flexible to permit generation of forest cover products based on different canopy closure criteria.
- Mapping units must consider physiognomic characteristics. Floristic elements are less important, and ancillary ecosystem information may be used to imply possible community composition.
- Compatibility between GOFC coarse and fine resolution products is necessary.

Table 4.1.1 Land and Forest Cover Classification Scheme

Land Cover					
Water					
Snow and Ice					
Barren or sparsely vegetated					
Built-up					
Croplands					
Grasslands					
Forest	**Leaf type**	Needle	Broadleaf	Mixed	
	Leaf longevity	Evergreen	Deciduous	Mixed	
	Canopy cover	10-25%	25-40%	40-60%	60-100%
	Canopy height	0-1 m	1-2 m	>2m	
		(low shrub)	(tall shrub)	(trees)	
Forest special theme: flooded forest					
Spatial resolution: 1 km (coarse) and 25 m (fine)					
Update cycle: 5 years (coarse and fine)					

This scheme has a number of attractive features. All land cover types are included. The non-forest types are very simply defined, an approach which should avoid difficulty in agreeing on class definitions. The forest class is sub-classified according to four descriptors: leaf type, leaf longevity, canopy cover, and canopy height. This scheme is based on the biophysical characteristics of the area rather than ecological classes. Again, this should help avoid difficulty in agreeing on class definitions. Nonetheless, ecological classes can be derived from the forest biophysical classes, if agreement can be reached on a satisfactory definition. For example, a savannah could be defined as an area of forest with broadleaf deciduous foliage with canopy height > 2 m and canopy cover of 10 – 25%.

An additional special theme is proposed: flooded forest. This theme provides valuable additional information which can be related to hydrological and biogeochemical cycling. Flooded forest can be reliably mapped with SAR data. The existing GRFM/GBFM project is already mapping flooded forests for all of the tropical and boreal forests of the world. This effort could be expanded to all of the world's forests in a straightforward manner.

To meet user requirements, this classification should be carried out globally every five years. The entire land surface should be covered at coarse resolution. While global land cover with 250 to 500 m resolution will have the highest applications value, in the near term a 1000 m resolution data set is most practical and feasible. By means of information provided by the coarse resolution land cover classification and other information sources, the forested areas should be covered at fine resolution on a five year cycle as well. This is a very ambitious goal. It is likely that initially some areas where rapid change is not taking place will be covered less frequently.

4.1.2 Change information

Because of the importance of forest cover change information, a forest cover change product should be produced annually at coarse resolution, and on a sampled basis annually at fine resolution. The annual coarse resolution change detection will help target the fine resolution observations to areas of rapid change, with a goal of covering all of the forested areas on a five year cycle.

Table 4.1.2 Forest Change Classes

	Coarse	Fine
Resolution	1 km initially 250 m as soon as possible	25 m
Cycle	Annual wall-to-wall	5 year wall-to-wall 20% - 30% annual
Classes	No change Forest → non-forest Non-forest → forest	No change Forest → non-forest Non-forest → forest
Special Products	burned forest	Forest fragmentation Forest change occurrence

Annual mapping of burned areas is an important component of GOFC in its own right (see section 5). The annual coverage with coarse resolution sensors can provide annual mapping of burned areas.

Additional products can be derived from the fine resolution forest change, including a Forest Fragmentation product and a Forest Change Occurrence map. These are described in detail in the Fine Resolution design team report (Appendix 3).

Many methods have been used for change detection based on satellite data. Analysis of radiometric differences between dates generally provides more accurate results than analysis of difference between classification results because the latter compounds inaccuracies in the classification products. Hence this approach is recommended by both the Coarse and Fine design teams.

4.1.3 Data types and calibration

Products for Forest Cover Characteristics and Changes require a very large amount of data from all of the sensor types listed in Table 10.2.1 (Appendix 2). A tremendous amount of experience has been gained using data from existing sensors, particularly TM, HRV, AVHRR, and LISS, which will apply to next-generation sensors which have been recently launched (SPOT-4) or are soon to be launched. This experience provides confidence in the ability to achieve routine production of radiometrically and geometrically corrected products.

Orthorectification requires the use of digital elevation models (DEMs). This is particularly important for SAR data where large distortions can be induced by relatively minor elevation differences. DEMs

are becoming more readily available for much of the world, so it will be possible initiate GOFC regional pilot projects. However, DEMs will not be available for all forested areas until the completion of the Shuttle Radar Topographic Mapping Mission. A standard data set from that mission will be a tremendous asset for GOFC and other projects. For GOFC, DEM data will be required at 25 m resolution or better, with a vertical accuracy of 5 – 10 m.

With the exception of AVHRR, sensors are designed and operated to produce top-of-atmosphere radiance measurements to an absolute accuracy around 5%. So-called vicarious calibration campaigns, where multiple sensors obtain measurements of calibrated ground targets, are providing accurate inter-calibration of sensors of the same type. SAR sensors can now routinely be calibrated to absolute backscatter values of 2dB or better. However, calibration is often under-funded. It is important for sensor sponsors to realize that excellent calibration pays major dividends in reducing the down-stream cost of processing earth observation data, particularly for studies of vegetation change.

Several options for atmospheric correction of GOFC visible and infra-red (VIR) data exist. Two basic approaches are being considered. One method, considered the most promising and appropriate, is to utilize atmospheric correction capabilities of MODIS/MISR and VEGETATION to correct the Landsat 7 ETM+ and SPOT HR VIR data, respectively. Technical specifications for this technique will need to bet set and demonstrated to be feasible on a regional and global scale before it would be implemented in the GOFC processing stream. The second method, considered as a back up, is to utilize relative radiance measurements in image overlaps to correct the data to a master scene for which atmospheric correction has been applied using, for example, dark targets to characterize the atmosphere.

4.1.4 Data acquisition strategy

Data from coarse resolution sensors will be routinely acquired and archived by the sensor sponsors. These sensors acquire data daily or every few days, thus providing ample data for the generation of Forest Cover Characteristics and Changes products.

The GOFC Fine Resolution acquisition strategy should focus on meeting the following data needs for GOFC: wall to wall global coverage every five years, up to a 30% sample of forested areas annually, and a sufficient sample of Landsat 7 ETM+ and SPOT HR VIR data to test atmospheric correction based on the simultaneity with MODIS/MISR and VEGETATION instruments and for calibration and validation of GOFC coarse resolution products. Four scenes acquired once per season are required for the global coverage data and the samples. This design advocates an acquisition strategy based on multiple sensors to ensure optimal coverage and to provide redundancy and robustness for the data and derived products of GOFC. However, it is imperative that the sensors meet minimum standards (TBD) in terms of calibration and quality control.

Given these goals and constraints, the acquisition strategy should rely on the global archive planned for Landsat 7 with SPOT, other optical and active microwave SARs providing the critical role of gap filling and monitoring areas of rapid change. This multi-sensor approach would utilize the strengths each sensor (e.g. planned systematic global acquisition of Landsat, SPOT HR VIR pointing capability for frequent imaging opportunities, and SARs all weather imaging capabilities).

The Landsat 7 Project and Science Team has developed a Long Term Acquisition Plan (LTAP) for the Landsat 7 mission to acquire and periodically refresh a global archive of high quality (low cloud cover,

sufficient solar zenith angle, with optimal gain settings) data for all land areas at least four times a year. LTAP has been designed based on a constraint of up to 250 scenes acquired per day (capacity of the on board recording and direct downlink to EDC receiving station). Given that the Landsat 7 orbit would enable up to 850 scenes of land areas per day, LTAP uses vegetation seasonality (based on 10yr AVHRR NDVI record), cloud climatology (ISCCP), and 24 hour NOAA weather predictions to prioritize scheduling in an effort to populate the archive with high quality data. Although LTAP stresses vegetation phenology and GOFC focuses on land cover and land cover change products, Landsat 7 coverage based on the LTAP should meet GOFC requirements for the initial GOFC acquisition. However, as GOFC evolves and the results of the LTAP are better known, there may be a need for GOFC input into the LTAP.

Based on the historical archive of the Landsat program and ISCCP cloud climatology, there will likely be significant areas where low cloud cover data will not be available over the 5 year inventory periods for global coverage for GOFC. This is a result of Landsat's 16 day repeat cycle, periods of low solar illumination in the upper latitudes (e.g. Boreal forest where forest loss due to fire is high), and persistent cloud cover (most notably in the tropics where forest conversion rates are high). Therefore, additional VIR sensors are critically needed to provide additional coverage in these important forest zones. Given its unique pointing capability, SPOT HR VIR role in GOFC is very important. SPOT will need to be tasked to make routine acquisitions of critical areas that tend to be cloudy, thereby increasing the probability of a low cloud cover acquisition to be used in the global inventory every five years. In addition, SPOT will provide increase capability for programming targets of opportunity for hot spot monitoring. As with Landsat, the goal with these SPOT acquisitions would be to obtain at least 4 scenes acquired seasonally. Additional VIR sensors will be used to for gap filling to augment the SPOT and Landsat coverage, providing redundancy and robustness to the overall GOFC acquisition strategy.

SAR sensors would also play an important role in GOFC. SAR data (e.g. JERS-1 LHH, ERS-1/2 CVV, and Radarsat CHH) will be used to image areas where there are gaps remaining after the VIR acquisitions due to persistent cloud cover conditions. These areas should be imaged with the SARs at least four times per year. SAR system will also provide some important baseline datasets for GOFC (e.g. NASDA GRFM mosaics in the tropics and SRTM global DEM with 30 meter pixel spacing and 8 meter vertical postings). Use of SAR alone and in fusion studies will be an important part of GOFC research and development activities in an effort to evolve GOFC processing to better meet the needs of the user community. It is noted that the absolute calibration of SAR data is ideal for operational applications.

A seasonally-sensitive global SAR coverage on a 5 year cycle is feasible and would provide forest baseline information complementary to that provided by the optical sensors. In particular, it would provide for monitoring of changes in flooded forests.

Data from the suite of very high resolution (1-3 meter) sensors should also play an important role in GOFC. Systematic and statistically valid accuracy assessment of regional to global scale land cover and land cover change studies is extremely difficult and can be prohibitively expensive. Use of the very high resolution sensors for systematic validation should be incorporated into the GOFC validation strategy.

An acquisition status tracking system will be essential for this GOFC project.

Table 4.1.4 Summary of Acquisition Strategy and Tasking Requirements

Sensor	Product	Duty Cycle		Acquisition number of scenes
		Tasking	Frequency and # per yr	
Landsat 7	FCI	Global, routine acquisition	5yr, 4	28,000
	FCC	Global, routine acquisition	5yr, 1	7,000
	FCC-s	Global, routine acquisition	Annual, 1	2,100
Spot	FCI	Gap filling, targeted sites	5yr, 4	7,500
	FCC	Gap filling, targeted sites	5yr, 1	1,875
	FCC-s	Gap filling, targeted sites	Annual, 1	600
SARs	FCI	Complementary, targeted regions	5yr, 4	7,800
	FCC	Complementary, targeted regions	5yr, 1	1,950
	FCC-s	Complementary, targeted regions	Annual, 1	600
Other VIR	FCI	Gap filling, targeted sites	5yr, 4	TBD
	FCC	Gap filling, targeted sites	5yr, 1	TBD
	FCC-s	Gap filling, targeted sites	Annual, 1	TBD

Notes:
FCI=Global Forest Inventory/Classification, FCC=Global Forest Change,
FCC-s=Global Forest Change Sample

Acquisition strategy assumes that Landsat 7 will provide the backbone of acquisition by acquiring all areas on a routine and constant basis (i.e. globally, annually, season refresh), with areas of known persistent cloud cover being routinely imaged by SAR and SPOT. Gaps at the end of one acquisition period (approx. 1 yr) are then tasked as targets for SPOT and SAR.

Acquisition estimates for Landsat 7 are based on an assumption of 14,000 Landsat scenes to cover the earth land mass, of which 50% has forest cover. For sampling, the estimate is based on an assumption of a 30% stratified sample

Acquisition estimates for SPOT are based on an assumption that 10% of the areas imaged will have excess cloud cover and a success rate of 30% for these areas.

Acquisition estimates for SAR are based on the assumption that all remaining gaps (i.e. 70% of the 10%) are filled by SAR requests.

4.1.5 Data volumes and data management

The coarse resolution data needed for Forest Cover Characteristics and Changes could be retained and processed at either several regional facilities or one central facility. The Coarse Design Team Report,

Appendix 4, contains a good discussion of the relative merits of the two approaches, and can be summarized as follows: “The centralized production model, in which one organization developed the product, has advantages for scientific applications, offers greater chances of global consistency, can likely be completed at a lower cost, and may be completed in a shorter period of time. The decentralized approach is more relevant for policy applications in which it is essential that local to regional landscape conditions are most reliably represented. It also may lead to greater local and regional acceptance of GOFC coarse resolution products.”

The massive volumes of fine resolution data identified in section 4.1.4 preclude central archiving and processing. It is likely that several regional facilities will have to cooperate to accomplish the GOFC objectives. However, it will be necessary to create a central metadata facility which can track the acquisition of fine resolution data and the production of products. The data acquisition task requires unprecedented coordination of the acquisition of data from multiple sensors. Because of the gap-filling role of the SAR and pointable optical sensors, as well as their sensitivity to phenological conditions, acquisitions with these must be dynamically tasked using up-to-date information available at the central metadata facility. Just as Landsat-7 acquisitions will be scheduled using the automated LTAP system, it will be necessary to produce an automated system to schedule acquisitions by the SAR and pointable optical sensors. It is recommended that any proposed acquisition strategy be tested manually or semi-automatically before attempting full automatic operation.

The same metadata facility which tracks and commands data acquisition can also be used, with suitable extensions, to track the production of products from the acquired data.

4.1.6 Production of Products

The experience gained through several global and regional projects using coarse resolution data can be used to establish production procedures for coarse resolution products. Projects of particular relevance include the IGBP DISCover 1 km global land cover mapping, TREES and TREES-II, and the IGBP global fire mapping project.

GOFC should utilize data processing and analysis methods that are well established and suitable for operational use. There are several considerations to address for the end-to-end operational processing stream.
The following figure illustrates a set of processing steps from data acquisition (described in detail in the previous section) through product distribution and use by the end users of GOFC data:

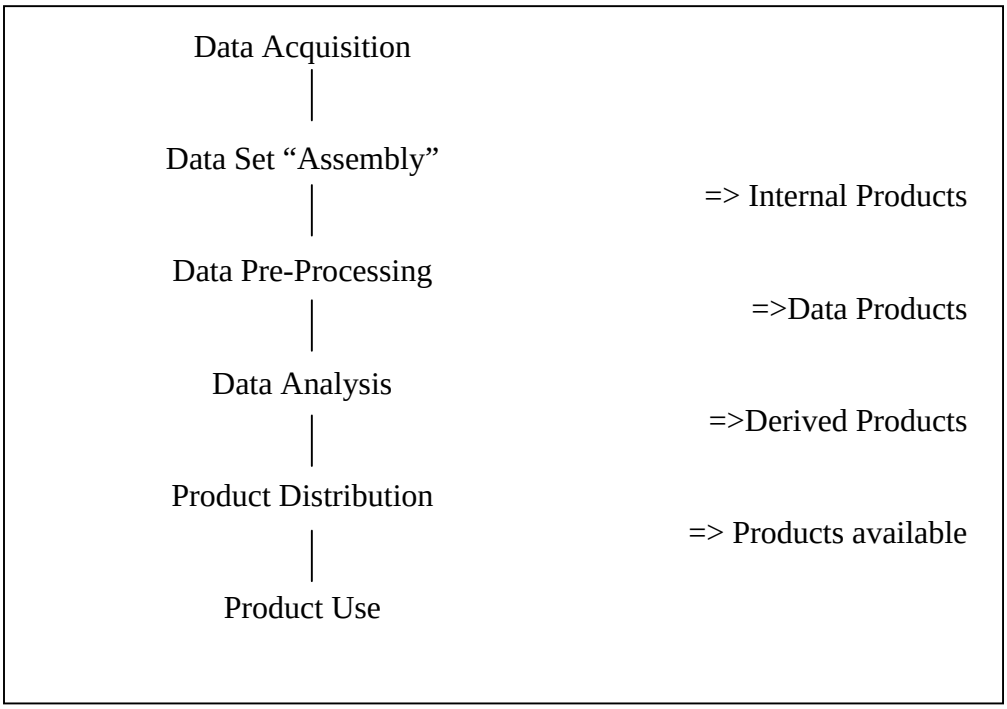


Figure 4.1.6: Processing Steps where

- Internal Products: interim products such as georeferenced imagery and atmospherically corrected data.
- Data Products: georeferenced, atmospherically corrected, image mosaics.
- Derived Products: forest cover and forest cover change maps and statistics.
- Products available: derived products in a standard format for distribution.

It is proposed that GOFC implement a processing model where a set of centralized facilities or regional data providers handle the bulk processing steps (including at least the data assembly and data pre-processing) and an expanded set of facilities handle the local level labeling of land cover classes and incorporation of *in situ* data. An advantage of this approach is that the computationally heavy steps of the processing stream are handled at facilities with adequate resources and where processing standardization can be assured, while fully utilizing the regional/local expertise and knowledge. The data product in itself is a very important and significant product for GOFC and is extremely useful for the GOFC user community.

The objective of the data set assembly step is to bring together all high resolution data required GOFC. The guiding principle behind this step is to initially select appropriate processing centers and participants that are interested in GOFC and have sufficient technical expertise and capacity. Then develop mechanisms to ensure that each processing center receives all data needed to produce the products within their domain. This includes data from all suitable high resolution sensors and archives. For example, this step would focus on selecting the appropriate data from the Landsat 7 archive (existing level 1 data is ordered and if necessary requests to process level 0 data), SPOT global archive, and international Landsat ground stations.

The data pre-processing step should include geometric rectification, atmospheric correction, and mosaicing. Once again this step should utilize a network of centralized processing facilities where standard, proven and robust procedures are used. Because of the large amounts of data to be processed, it will be necessary to automate these procedures. GOFC needs to maintain consistency and quality control across processing centers. Periodic inter-comparisons are needed to monitor and ensure processing consistency. These pre-processing facilities need to accommodate evolution of the methods and techniques so GOFC can evolve and incorporate new pre-processing techniques (e.g. improved atmospheric correction algorithms).

The data analysis step includes data classification and data fusion. The overall objective of the classification steps should be to simplify the data content into GOFC feature classes without losing land cover information. Considerable research and thought has gone into producing the feature classes, listed in products section of this document, with an emphasis of developing and automated system while providing critical information needed by the user community. Additional research is needed to demonstrate that classification procedures at the regional scale can handle spectral confusion due to large area coverage. There are two basic classification approaches to be considered by GOFC: supervised classification with a few very specialized classes (as was done in Boreas) or hyper-clustering approaches with knowledge based relabeling (Landsat Pathfinder HTF).

For the data generation and distribution steps, GOFC should adopt a guiding principle of identifying experienced and currently active groups and assessing if together they provide global coverage (an overlap is desirable). In parallel, an effort is needed to involve additional groups, especially and the national and local levels, to ensure long term operation and maximum benefit from GOFC. The product generation and distribution systems need to be sufficient such that results can be produced in a timely manner (forest cover products with 2-4 years and forest cover change products within 1-2 years). To this end, GOFC needs to learn from and take advantage off of other existing programs (e.g. GRFM, LPHTF, TREES). If the product generation and distribution system is complete and timely, then the success of GOFC will be the basis for an on going forest cover monitoring program.

4.1.7 Product validation

Accuracy assessments of digital land cover classifications are typically based on contingency tables, or confusion matrices, where accuracy is expressed in terms of errors of omission and commission, or in terms of agreement analysis using the Kappa test statistic (Stehman 1996a, Congalton 1991, Rosenfeld and Fitzpatric-Lins 1986). The contingency table is created by comparing on a class by class basis the land cover classification with an independent data source - field observations, existing maps, higher resolution imagery - collected using a statistically valid sampling strategy (Robinson *et al*., 1983, Stehman 1996b, Rosenfeld 1986).

Such methods are widely accepted as a means to determine the accuracy of earth observation derived land cover classifications when derived from higher resolution data, such as from Landsat's TM sensor, or the SPOT HRVs. This approach may be quite suitable for validation of GOFC fine resolution products.

Validation for the fine resolution products can be derived from a combination of in-situ data, data from very high spatial resolution (1-3m) satellite imagery, aerial photography, and local knowledge. Several groups have recently demonstrated GPS-controlled aerial videography to be a very inexpensive means

to validate fine resolution products over large areas. Nonetheless, the very large amounts of fine resolution products proposed here will require very large validation efforts, with very considerable support from persons with local knowledge.

Validation of the coarse resolution products will benefit tremendously from a database of co-registered, validated fine resolution products, especially since the same classification scheme is proposed for both coarse and fine resolution products. Additional fine resolution data will undoubtedly be needed in some cases. The experience gained in the validation exercise for the IGBP DISCover classification will be valuable in defining the exact validation approach for the coarse resolution products. It is already apparent that geometric errors can seriously reduce the classification accuracy. As such, the use of data from sensors with better geometric characteristics than AVHRR should improve results.

Validation activities are expensive and as such have often been accorded second place in mission planning and implementation programs. GOFC stresses to CEOS the importance of including cal/val programs in mission planning.

4.1.8 Research issues

In addition to operational processing, GOFC should have several research and development activities that focus on improving the current state of the art processing techniques so that GOFC evolves and produces improved products for the user community. These development activities should include, for example, improved atmospheric correction algorithms.

If adequate atmospheric corrections can be applied, then and only then will it be useful for GOFC to produce mosaiced data products. There are two options for mosaicing: actual or virtual (i.e. tiling) mosaics. The most appropriate approach will depend on the derived products and capacity of the processing facilities. Since useful mosaics require high quality atmospheric corrections, which may not be always available, there needs to be some research and development to evaluate the best approach, utility and need for these mosaics. The bottom line of the pre-processing step is to produce the most viable products and processing scenario for GOFC success.

Some research and development would be necessary to adapt existing classification methods to the land cover and land cover change classes proposed here. Further research would be beneficial to increase the degree of automation so as to decrease the labor involved and thus lower the cost of producing products. It is recommended that these efforts concentrate on data near 1990 because of the need for baseline information for 1990 resulting from the Kyoto protocol.

Data fusion may be a necessary intermediate step in the classification process. However, it is currently unclear if fusion is required to product GOFC products. Therefore, there needs to be a research and development activity to assess the need and benefit of fused data products. Considerations for fusion should include: multiple high resolution optical data, high and coarse resolution optical data, and possibly most promising is the fusion of optical and microwave data.

4.1.9 Implementation strategy

Although the GOFC design teams have made considerable progress in defining the Forest Cover Characteristics and Changes theme, there are numerous technical details which remain to be resolved. More importantly, it is now appropriate to seek further comment and input from nations which have

major forest resources. Many of these countries have sent representatives to GOFC design meetings, but other nations have not been represented. The current draft provides a sufficient level of detail to initiate a dialog with forest managers and policy makers.

The critical requirement for implementation of this ambitious theme is for a agency to take up the challenge of defining and implementing a pilot project. Here we provide a possible scenario.

4.1.9.1 Pilot projects

The initial pilot project(s) should be end-to-end exercises of data acquisition, data analysis, and evaluation/validation of the resulting products. It is important to carry out an end-to-end exercise to ensure all the necessary components function properly, and to identify weak areas where remedial work is necessary. The project could require as little 1.5 years, but this is a very short for such an endeavor. The project could cover one region (for example, one continent). At the conclusion, an evaluation would be held, and planning begun for a second cycle. The second cycle could cover several regions, including a repeat of the first region for comparison purposes. It is possible, but seems very ambitious, for the second cycle to cover the entire world at both coarse and fine resolution.

4.1.9.2 Evolving toward on-going operation

A coordinated, distributed operational system of regional nodes seems most likely to succeed. For example, nodes could exist in North America, South America, Europe, Africa, East Asia, West Asia, and Australia. Each node would be led by an organization with established capabilities to process massive data volumes, with common or comparable software being used at each node.

The pilot projects would focus on technical issues, but organizations having information requirements would be involved at all stages, to ensure that their requirements will be met. At the same time, planning would take place to identify sources of long-term funding, to facilitate the transition to on-going operation.

4.2 Forest Fire monitoring and mapping

Wildfires and biomass burning are significant agents of change in forest ecosystems, can cause serious disruption to communities which are economically dependent on forest resources, result in air quality degradation with serious health implications, and sometimes result in loss of human life. Burning of forests also accounts for a substantial fraction of the atmospheric increase in carbon dioxide and other greenhouse gasses.

The development of a global fire information system represents an objective which would provide many benefits at national, regional, and global scales and enable CEOS to provide an early demonstration of the concept of an integrated global observing strategy. This theme consists of two components: monitoring of fires during the fire season, and mapping of burned areas during or after the end of the fire season. A modeling component to estimate burn intensity, fuel load and consumption, and emissions of gasses and aerosols is an additional option.

The monitoring and mapping components can be implemented using data from coarse resolution optical (including mid IR and thermal) sensors alone, while the modeling component would require

input from the two other GOFC themes: forest cover and forest biophysical processes. The Forest Fire Monitoring and Mapping theme would provide valuable input into the other two themes: annual maps of burned areas are an important input into forest cover change mapping, and estimates of area burned, burn intensity, and fuel consumption provide important input for understanding forest biophysical processes, particularly loss of biomass and release of carbon to the atmosphere.

It is important to note that the forest fire monitoring and mapping theme proposed by GOFC complements but does not overlap the information on forest fires which forms a component of the CEOS Disaster Management Pilot Project. The latter project addresses the provision of fire detection information to aid fire suppression. Effective fire suppression requires rapid attack, which necessitates continuous monitoring and the provision of information to response teams in timeframes as short as 15 minutes. The fire monitoring component of this GOFC pilot project foresees observations by polar orbiting systems with a repeat cycle of 12 hours, and a similar time delay for the provision of information. In the development of both GOFC and the Disaster Management Project there has been a deliberate sharing of personnel to ensure good communication and coordination between these two IGOS Pilot Projects.

4.2.1 Information requirements

The proposed information products are outlined in Table 4.2.1. Each of these products addresses the specific needs of one or more user communities. They are described in more detail below.

Table 4.2.1 Forest Fire Information Products

	Spatial resolution	**Revisit cycle**	**Data delivery**	**Source(s) of data**
Fire monitoring	250 m – 1 km	12 h	12 hours	Coarse resolution optical (thermal)
Mapping burned area	25 m – 1 km	Annual	3 months	Coarse and fine resolution optical with SAR backup
Modeling	250 m – 1 km	Annual	6 months	Coarse resolution optical plus land cover plus biomass, emission factors, etc.

As a minimum, the proposed fire monitoring product consists of hotspot locations which are produced from thermal sensors operating in the 3 – 5 and 8 –12 micrometer bands, using algorithms which have been validated to produce a minimum of false alarms while detecting most fires. Because of the very small data volumes involved, these hotspot locations can be transmitted widely using Internet facilities. When larger bandwidth exists, it is valuable to transmit portions of the image surrounding the fire (about 300 x 300 km) to provide additional visual information on the geographic context and the location of the smoke plume.

Fire monitoring information is needed nationally, regionally, and globally. At the national level, this information should benefit countries that have limited fire detection resources or countries that have fires which occur in remote, sparsely-populated areas. In the latter case, if there is no initial effort at fire suppression, it is important for authorities to monitor the progress of the fire in case it begins to threaten settlements or other resources. With smoke plume imagery, authorities can also make informed decisions about closing highways or evacuating communities which are affected.

As was the case in 1997-98, during a severe fire season, trans-boundary air pollution becomes a serious regional issue. An operational fire monitoring system would provide all nations in the region with rapid, consistent information concerning the location of fires and the direction of smoke transport. In a very severe fire year, the location of fires and consequent air pollution becomes an issue of global concern. The proposed fire monitoring system would be able to provide a consistent global picture of the current situation on a daily basis.

Although not required in near-real-time, fire monitoring products will provide valuable data on the location and inter- and intra-annual variability of wildfires for researchers studying the causes and consequences of wildfires. When summarized statistically, the information can be used for policy decision making at national and international levels.

The burned area mapping product would be produced annually at 1 km resolution, improving to 500 m or 250 m as technology permits. Since most of the area burned results from a relatively small number of large fires, annual mapping with coarse resolution sensors would provide reliable information on the location and areal extent for most of the significant fires. Acquisition of coarse resolution data for fire mapping can be targeted using the output from the fire monitoring component. Data from fine resolution optical sensors can be acquired for those fires where additional spatial detail is needed, and will permit reliable, accurate validation of the results from the coarse resolution sensors.

At the national level, end-of-season fire maps would support updating of national forest inventories, annual fire statistics reporting, and serve as indicators for monitoring sustainable forest management under most of the Agenda 21 Criteria and Indicators of Sustainable Forest Management initiatives. This type of information is also required by many countries for strategic fire management planning.

For the science community, annual mapping of burned areas provides an important indication of rapid land cover change. The data also have scientific value for studies on the interaction of climate change and forest fire trends.

Annual mapping of burned areas will aid nations in responding to the United Nations Framework Convention on Climate Change and the Convention on Biological Diversity.

The modeling component would provide combined information on hotspots, burned areas, land cover, and forest biomass. This would enable researchers to investigate the emissions of gasses and aerosols to the atmosphere, and estimate the amount of biomass converted to atmospheric carbon dioxide. In areas where digital information on topography, forest fuels, and meteorological information can be added, fire behavior models have been developed which can provide information on the fire intensity, rate of spread, and fuel consumption. These models can provide information for strategic allocation of fire fighting resources and sometimes for tactical decision making for fire suppression.

4.2.2 Data types and calibration

Daily fire monitoring can be provided using existing hotspot detection algorithms working on thermal channel data from the NOAA AVHRR and ESA ATSR sensors. Future sensors which will carry suitable thermal bands include MODIS, MERIS, AATSR, and GLI. Accurate calibration can be provided for thermal sensors using hot and cold reference targets, so algorithms which work in units of

absolute temperature (K) can be readily adapted to use data from a variety of sensors. Accurate geometric correction is also an important requirement.

Burned area mapping is most readily performed using data from the near infrared (0.7 to 1.1 micrometer) and short-wave infrared (1.1 to 2.5) micrometer bands, although satisfactory results can often be obtained using red (0.6 to 0.7 micrometer) and near infrared bands.

Several groups have demonstrated satisfactory fire mapping algorithms with AVHRR data. The Vegetation sensor on SPOT-4 has improved radiometric and geometric performance, and carries a spectral band at 1.5, as do the ATSR and AVHRR on NOAA-15.

Fine resolution mapping of selected burned areas can be accomplished with data from Landsat, SPOT, and IRS satellites. All of the satellites carry high performance, well-calibrated sensors which include red, near infrared and short-wave infrared bands.

Numerous attempts to use SAR data intensity data for mapping burned areas in real time or shortly after the fire have proven unsuccessful more often than not. In the weeks and months following the fire however, the radar backscatter of the burned area becomes much more variable than that of the surrounding forest, enabling burned areas to be detected using multi-temporal SAR data.

Promising results have been obtained at the ESA/ESRIN facility in Frascati using SAR coherence from multi-temporal data obtained with ERS-1/2 satellites operating in tandem mode. A permanent tandem-mode SAR capability would make operational near-real-time burn mapping much more feasible.

Accurate on-board radiance calibration facilitates the development of automated algorithms for burn mapping. Accurate atmospheric correction would be a further asset, but the bands in the near and short-wave infrared are less affected by variable atmospheric aerosols, so a first-order correction would probably suffice.

4.2.3 Data acquisition, production, and dissemination strategy

Global, daily acquisition and processing of AVHRR data or any other global dataset at 1 km resolution is an enormous task. Therefore a decentralized regional model is more appropriate for the development of these products, at least initially. Considering current capabilities, the on-board recorders of the AVHRR sensor cannot store the data required to obtain global daily coverage at 1 km resolution. AVHRR data would have to be captured by a network of ground stations. A co-ordinated global network of real-time receiving stations is required. Each receiving station would have to be able to run the fire detection algorithm on site in order to reduce the amount of data that needs to be transferred to assemble the global fire product.

Several initiatives have demonstrated algorithms to detect active fires and reject false alarms using AVHRR satellite data (1 km resolution) as input. Algorithms have been developed by: 1) NASA/GSFC, by a team of researchers collaborating under the IGBP (Kaufman, et al., 1997), 2) Space Applications Institute of JRC (Pereira, 1998); and 3) Canada Centre for Remote Sensing (Li et al,1997a, b, and c). Similarly, ESA researchers have developed successful fire detection algorithms using data from the ATSR instrument. Inter-comparison of these algorithms is needed to understand their strengths and weaknesses, leading to the identification of a global approach. The IGBP-DIS fire project could provide valuable assistance in facilitating this activity.

Likewise, several groups are testing algorithms to map burned areas from AVHRR, TM, SPOT-Vegetation, and SPOT-HRV and HRVIR data. As mentioned above, the high contrast of burned areas and the good radiometric performance of recent sensors provide confidence that these efforts will lead to robust, effective algorithms.

Many nations and international agencies currently monitor active fires using data from geostationary meteorological satellites. However, only large fires can be monitored from geostationary altitude, particularly at high latitudes. The JRC World Fire Web project proposes to build a network of regional centers using the same to extract active fire locations from real-time AVHRR data. Burned area mapping is proposed to be carried out at six-month intervals. The resulting products (hotspots and burned area boundaries) require very modest data volumes to store and transmit. Exchange of final products using existing Internet technology is very feasible.

4.2.4 Validation

Fire detection algorithms are usually validated by comparison with reliable post-season burned area maps. Hotspot pixels form clusters which should be confined to the interior of the burned area. Burned areas with no hotspot pixels may represent errors of omission, which can be caused by setting detection thresholds too high, or by cloud cover. Hotspot pixels outside known burned areas can represent errors of commission, which can be caused by setting detection thresholds too low. Even the best algorithms available today produce errors of omission and commission; they must be adjusted to achieve a suitable balance of the two types of errors.

Validation of the coarse resolution burned area maps can be accomplished using fine resolution data. Validation of burned area maps produced from fine resolution data will require the cooperation of national and sub-national fire management agencies.

4.2.5 Implementation strategy

4.2.5.1 Initial pilot projects

A number of national and regional initiatives are already underway to incorporate current knowledge into operational fire monitoring and mapping systems, while continuing research to improve algorithms. The most comprehensive of these is the JRC World Fire Web. We propose that GOFC, in cooperation with the IGBP-DIS Fire Working Group, facilitate discussions aimed at defining a unified approach which would lead to an early regional trial. Specific areas where such a coordinating and facilitating role will be valuable include:

•Development of technology needed to produce operational active fire products on a daily basis, with products available within 12 hours of satellite data reception;

•Development of Internet processes and security procedures to manage and distribute products to test-clients through a world wide web.

•Development and testing of automated algorithms for burned area classification, including evaluation of fire mapping accuracy using finer satellite data and field observations;

•Refinement of fire detection and burned area mapping algorithms based on the results of field trials;

•Development of methods for using the data to produce higher order products such as daily fuel consumption and fire emissions products.

•In co-operation with international agencies, provide assistance to nations wishing to incorporate forest fire information derived from earth-observation data into their forest management and fire suppression activities.

4.2.5.2 Evolving toward on-going operation

This theme represents the best opportunity for an early transition toward on-going operation. There are well-defined users with well-defined requirements. Suitable sensors are currently available and will continue to be provided on operational satellites. The earth observation data volumes and data rates are relatively modest, especially with distributed reception and processing. The resulting information products have small data volumes, enabling current Internet technology to be used for product dissemination. We expect that the networks established during the initial pilot project stage can be readily expanded to a global system.

4.3 Forest biophysical processes

A suite of related products which describe forest biophysical processes is needed to provide estimates of annual forest ecosystem dynamics and productivity and measures of forest structure. An additional product, above-ground biomass, is needed to provide an indication of overall forest carbon stocks and sequestration potential, as well as provide land use implications. The ultimate goal is to understand, and eventually balance, the earth's carbon budget.

While this area of investigation and technology development has been viewed in the past as primarily a scientific endeavor, the international participation in the Kyoto protocol since December 1997 has brought the need for reliable estimates of forest biophysical processes to the center of the policy arena. It is expected that as soon as reliable estimates of forest biophysical processes are available, the resulting knowledge will become incorporated into international policy decisions and subsequently into national forest management decisions. Non-governmental organizations will also be interested in the results.

4.3.1 Products

The products required for reliable estimates of forest biophysical processes are:

- Leaf area index (LAI): one half of the total leaf area in the forest canopy per unit flat ground surface area (m^2/m^2)
- PAR: the total photosynthetic active radiation incident on a horizontal surface on the top of a plant canopy (W/m^2).

- FPAR: the fraction of incident photosynthetic radiation (PAR) absorbed by green leaves in the forest canopy (dimensionless).
- Above-ground biomass: the total amount of above-ground dry organic matter existing in a unit area at one instance (g/m^2).
- NPP: the mass of new carbon stored in vegetation (leaves, stems and roots) per unit space and time. It is the difference between gross photosynthesis and autotrophic respiration ($gC/m^2/yr$).

It is worth noting that several additional products can be derived from the above. For example, the length of the green period of deciduous vegetation can be derived from seasonal measurements of LAI or FPAR. This information is valuable for long term climate change studies. Such a product could also help determine the leaf longevity class for forest cover class products.

Table 6.1 Products for forest biophysical processes.

Product	Units	Accuracy Needed	Spatial Resolution	Temporal Cycle	Source of Data
LAI	m^2/m^2	± 0.2-1.0	1 km	7 days	Coarse resolution optical
PAR	W/m^2	± 2 – 5 %	> 1 km	30 min - 1 day	Geostationary optical (low and mid latitudes); Coarse optical (high latitudes).
FPAR	dimension -less	± 5 – 10 %	1 km	7 days	Coarse resolution optical
Above-ground Biomass	g/m^2	± 10–25 %	1 km	5 years	Inferred from land cover until spaceborne measurements are available
NPP	$gC/m^2/yr$	± 20-30 %	1 km	1 year	Above products plus ground and spaceborne meteorological data

The general strategy for LAI, FPAR, PAR, and NPP is similar, as these products are all related and needed to produce NPP. Because the MODIS product generation plans will become operational during the early years of GOFC, it is logical that they be used. However, it was also recognized that there are a variety of methods being used (e.g., model inversion, look-up tables, vegetation index-based), and other potential data sources (e.g., AVHRR, VEGETATION, GLI, MISR, MERIS, POLDER) so it is recommended that other approaches be monitored and investigated.

4.3.2 Data sources and calibration requirements

Until now, almost all of the work being carried out to develop capabilities for earth observation of forest biophysical processes has used data from the NOAA AVHRR sensor. This sensor has well-known shortcomings, since it was originally designed for atmospheric rather than land surface

observations. Nonetheless, the experience gained by teams who have addressed many aspects of the forest biophysical processes problem area have provided invaluable knowledge which has been incorporated into the design of next generation sensors and processing systems.

The CNES SPOT-4 satellite, launched in March, 1998, carries a four-band sensor, named VEGETATION, for monitoring the Earth's vegetation. The spectral bands, radiometric calibration, and radiometric resolution are all greatly improved over the AVHRR. Although this sensor has the same geometric resolution as AVHRR, the size of the resolution does not degrade away from nadir, as does the AVHRR resolution. The geometric accuracy is also improved, increasing the effective resolution of multi-date products. There are a number of investigations currently being carried out with early data from the VEGETATION sensor. These may lead to the ability to produce products related to forest biophysical processes routinely.

Under NASA's Earth Science Enterprise, the MODIS sensor will be flown on the Earth Observation Satellites AM-1 and PM-1. This sensor has been designed to address all of the forest biophysical processes requirements stated above. It has a suite of spectral bands much better suited to satisfy forest biophysical process requirements, as well as provisions for radiometric and geometric calibration standards which should permit the production of output products with the required accuracy.

ESA and NASDA are developing complementary sensors, MERIS and GLI, which could also be used to produce products related to forest biophysical processes.

Two additional sensors, NASA's MISR, and ESA's POLDER, have been developed to investigate particular aspects of the interaction of radiation with the vegetation canopy structure. The information gained from studies with these sensors can improve the algorithms used to derive forest biophysical process information from MODIS, MERIS, and GLI.

For all of the sensors which follow after AVHRR, teams of research scientists have played a central role in specifying the sensor characteristics, with particular attention to calibration and validation. It is expected that the ability to monitor the Earth's forest biophysical processes could improve dramatically as data from these sensors begins to be used for product generation and validation. To achieve this goal will require sponsorship of validation exercises by the CEOS agencies which have produced the new sensors.

4.3.3 Current capabilities including validation

The state of LAI estimation research suggests that LAI be derived from optical data. Methods used for LAI retrieval from multi-spectral optical imagery include: (1) model inversion; (2) look-up table (LUT); and (3) algorithms based on vegetation indices (VI). Model inversion approaches can be quite accurate if detailed radiative transfer processes are considered. The LUT strategy is regarded as a simplified form of model inversion, and may be most desirable for both efficiency and accuracy of computation. VI-based approaches are empirical but can also be efficient and accurate, provided sufficient data for validation are available. All these methods depend on land cover maps with the same projection and resolution. Thus, the land cover product must include classes needed for LAI estimation.

Ground-based measurements of LAI in various biomes in different locations are needed for validation. There are several techniques of measuring LAI on the ground: destructive sampling, allometry and

optical instruments. Destructive sampling is labor intensive and time consuming, and is obviously not suitable for collecting data for a large number of sites. Allometry is often species and location specific (Gower, et al., 1997). It is also difficult to establish a suitable set of allometry of a large range of site conditions. Optical instruments hold the best promise for fast and accurate measurements of LAI and are recommended taking measurements needed for LAI validation.

Spatial distribution of PAR, either instantaneous or daily total, can be obtained from either satellite measurements or from weather prediction models. Geostationary satellites provide frequent PAR measurements for low and middle latitudes (Gu and Smith 1997), and polar orbiting satellites are useful for high latitudes but need temporal scaling methods to obtain the daily total of PAR (Li et al., 1993). Satellite-based products are generally more accurate than gridded weather forecast or reanalysis data, but programs for operational production of daily PAR at the global or continental scale have not been identified. The short-term solution would be pilot projects to validate gridded weather data using satellite imagery for selected areas and seasons.

Both satellite derived and gridded weather data need validation using ground measurements. Surface measurement data sets have been assembled and analyzed by the International Satellite Cloud Climatology Project, and these could be used by GOFC.

FPAR can be retrieved from multi-spectral optical imagery using the same methods listed for LAI estimation. The accuracy in retrieving FPAR is potentially higher than that in retrieving LAI because FPAR can be more accurately measured on the ground and has more direct effects on remote sensing signals than LAI. FPAR products therefore have advantages in modeling applications, although many process models prefer LAI over FPAR as input.

Consistent FPAR data sets from different biomes are needed for validation purposes. Field estimates can be obtained for a variety of portable instruments and mobile sensors. Pilot validation projects should be carried out in conjunction with LAI validation projects discussed above.

There have been two potential methods to estimate biomass from satellite data:

- Vegetation classification based method: In this approach biomass is estimated based on vegetation type classification and on the unit biomass value predetermined for each vegetation type which is basically obtained from the ground observation. Multiplication between the area extent of each vegetation type and the predetermined unit biomass for each type would give the estimate of total biomass. Information on vegetation age or height and vegetation density would increase estimation accuracy.

- Direct observation of leaf and stem density (fresh biomass): Many investigations have indicated that there is a correlation between microwave backscattering coefficients derived from SAR data and biomass (fresh biomass) in leaves and stems of vegetation. However, correlation is usually vegetation types specific. It has been observed to saturate at relatively low biomass levels for C- and L- bands, the only SAR bands which are currently available.

We recommend that the first approach be used initially to produce the coarse resolution biomass product. In this case biomass product generation is reduced to the generation of coarse resolution land cover product. A unit biomass database for vegetation types should be developed based on the ground

observation and high spatial observation from satellite. The second approach can be implemented as a tool to determine a unit biomass for each vegetation type in a local scale.

The planned Vegetation Canopy Lidar mission (NASA), and proposed P-band SAR systems have the potential to improve biomass estimates from space, but considerable research and development will be required before these can be incorporated into operational systems.

Process-based model estimation of NPP is potentially most accurate, provided satellite and ancillary data are available. Satellite imagery provides the critical spatial distributions of land cover and LAI (Running et al., 1994). Ancillary data required are soil texture (for available water holding capacity), meteorological variables (radiation, temperature, precipitation and humidity), and above-ground and below-ground biomass. The preferred data interval is daily for NPP estimation (Hunt and Running, 1992, Liu et al., 1997). Process-models use either LAI or FPAR as input, but corresponding land cover map at the same projection and resolution as the LAI or FPAR is always needed. LAI and FPAR can be converted from each other for the same land cover types. Semi-empirical methods usually relate NPP to absorbed PAR (APAR) in plant canopies, estimated as the product of FPAR and PAR. Other variables are used to modify to relationship between APAR and NPP (Prince and Goward, 1995). Autotrophic respiration in forest stands usually consumes more than 50% of the gross photosynthesis (Ryan, 1991) and is sensitive to both temperature and biomass. Biomass is therefore an important input to NPP models. As accurate biomass maps derived using remote sensing techniques are not yet available for large areas, a short term solution is to estimate biomass from land cover types with density classes.

The ideal strategy for NPP validation is to have coincident NPP measurements with LAI/FPAR measurements. In this way, not only NPP results but also NPP models can be validated. However, NPP data available for validation are sparse, especially for forest ecosystems. Published measurements for various biomes and different time scales are very limited. NPP also vary considerably between years. Global NPP distributions from various models are often very different (Potter et al., 1993; Melillo et al., 1993; Foley, 1994; Woodward et al., 1995). In recent years, efforts have been made to obtain these measurements on small and large scales.

4.3.4 Follow-on research and validation

We recommend that CEOS, through GOFC and GTOS, promote ground observation campaigns to validate forest biophysical process products and to establish a unit biomass database for vegetation types. In this campaign in-situ data relevant to biomass, LAI, APAR and NPP are collected together with the high spatial satellite data and their relations are investigated. Validation and verification processes are essential and should be carried out as a part of the ground observation campaign. The BOREAS project of 1993 – 1997, and the planned LBA and SAFARI campaigns, are examples of such an approach, carried out in boreal and tropical forests, respectively. Additional validation data should become available through co-operation between GOFC and GTOS.

It is also recommended that CEOS promotes parallel research initiatives to develop in-situ observation methods and to develop models relating biomass to remotely sensed data. It should be also noted that

this product would be linked with high resolution products on land cover classification and vegetation density.

Efforts are needed to have operational production of PAR products using satellite measurements so that the current reliance on weather prediction data can be phased out. Pilot projects could be established to achieve this goal.

4.3.5 Implementation strategy

4.3.5.1 Initial pilot projects

A number of groups in the Americas, Europe, and Japan are carrying out research and development efforts in the area of forest biophysical processes, sponsored by the various opportunities engendered by the EOS, ENVISAT, and ADEOS-2 missions and other sponsors. Some groups are pioneering the assembly of global datasets, while others are undertaking more detailed investigations at regional scales. If successful, these efforts should provide a sound scientific and technical basis for an ultimate transition to routing operation. In co-operation with IGBP, GOFC can play a coordinating role to facilitate the interaction between the various groups active in this area, maintain current information on best practices, and provide advice to CEOS members.

Joint experiments should be conducted for several areas in each forest biome to focus on refining algorithms for forest areas, carrying out experimental research and development with emphasis on product validation relating in situ and satellite measurements.

Possible sites include: (1) the EOS core test sites; (2) Smithsonian test sites in South America and Southeast Asia representing the tropical biome; (3) U.S. Long Term Ecological Research (LTER) sites for the temperate biome; and (4) the LAI/FPAR validation program in Canada, with extension to Siberia, as a candidate for boreal biome validation work. This is the minimum set of validation requirements, and multiple test sites for each biome would be beneficial.

GTOS has recently initiated a demonstration project concentrating on net primary productivity. A common effort linking GTOS and GOFC is an attractive option.

4.3.5.2 Evolving toward on-going operation

NASA’s Earth Science Enterprise plans for a minimum of 15 year data continuity for MODIS and MODIS-like products. If the NASA strategy succeeds, the suite of products related to forest biophysical processes can be generated in an ongoing basis during that period. Additionally, NOAA and NASA have a long term strategy to replace the NOAA satellite series with NPOESS satellites, which would move the production of key MODIS products into a production environment. The most valuable role the GOFC user community can play under this scenario is to use MODIS, MERIS, and GLI products to estimate forest biophysical processes as outlined here, to participate in validation exercises, to carry out research leading to improved information extraction algorithms, and to participate in the planning process leading to operational production through the NPOESS system.

5 Data principles

GOFC will adhere to the spirit of CEOS Data Policy . Wherever possible, input data and products will be also openly available to GOFC participants. Fine resolution, and hyperspectral commercial data, when purchased as part of GOFC, in principle will be negotiated so they can be accessed with no restrictions to GOFC participants. However, we recognize that satellite data policies vary between CEOS members, and that members may insist that data made available for GOFC be subject to their established data policies. GOFC derived products will be placed in the public domain, in principle "free" but in any case not more than the cost of filling user requests. Responsibility for archiving original data and derived products will remain with the producer.

GOFC projects will need product availability via internet and hardcopy forms to meet a range of user capabilities and needs.

GOFC will implement project data and information access connections, for instance through GOFC WWW pointers. GOFC users should be able to access or link to all GOFC metadata through the GOFC WWW site. Full project interoperability is a strong goal. There should be no period of exclusive use after product validation. Where appropriate early release of un-validated products with the associated caveats will be encouraged. Documentation should specify product applicabilities for users, to assure products are not incorrectly used (e.g. global versus regional reliability). Data products should be available in clearly identified, readily-accessible archives i.e. historical data remain available in the archive. The need for a GOFC directory of data products will be evaluated.

6 GOFC Implementation

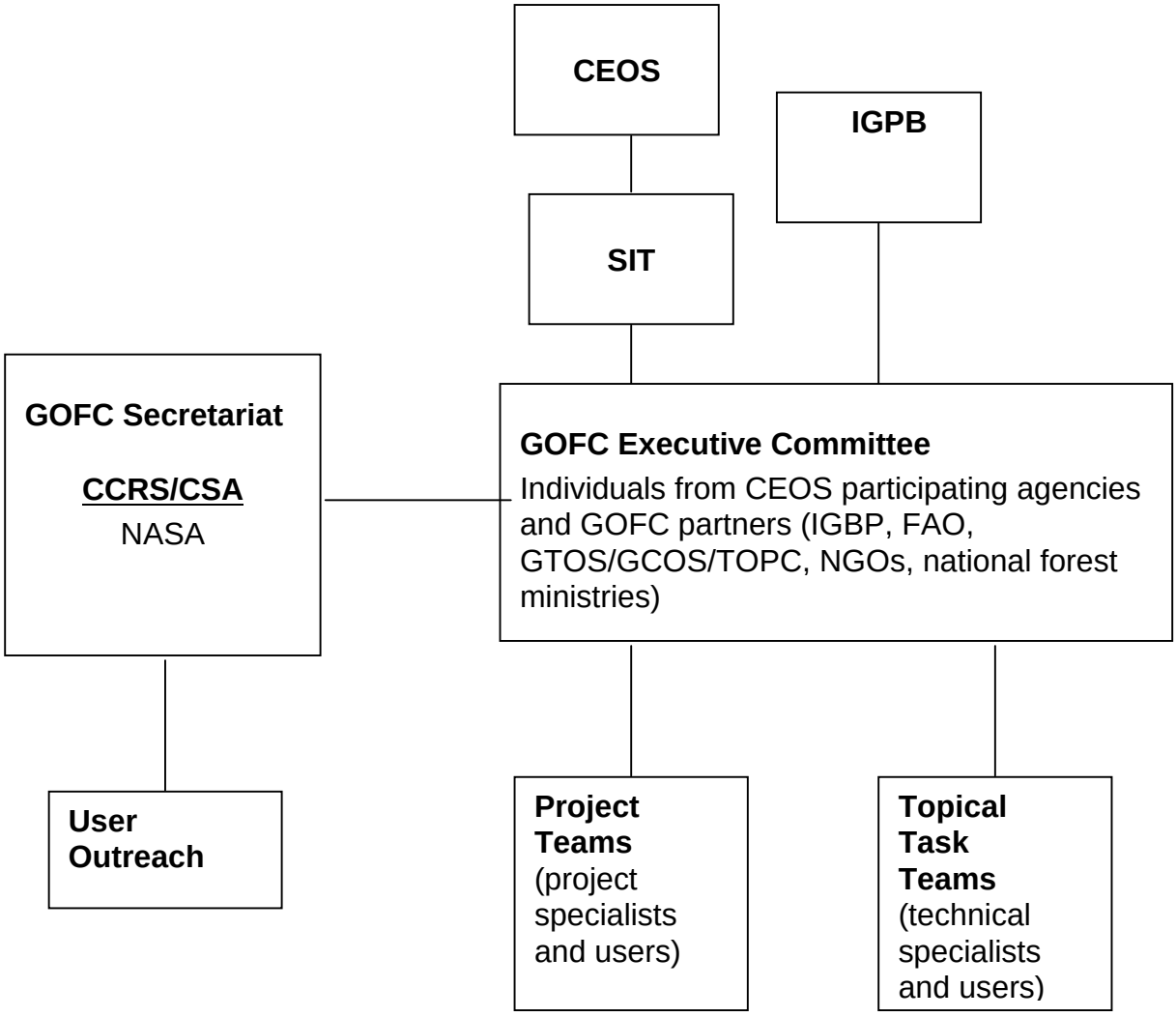
The goals of IGOS, as expressed by the SIT meeting February 6-7 in Irvine California, "are to provide on one level a strategic framework within which agencies can work to develop specific systems embracing both in-situ and space-based observations, and the need to ensure that value [is] added, being mindful to avoid increased bureaucracy and complex processes." (CEOS, 1997).

In keeping with IGOS' intent, the management structure of GOFC must be as simple as possible to avoid increased bureaucracy, while producing tangible benefits within the five-year time frame established by SIT.

6.1 Management structure

Our guiding principal in designing an appropriate organization for GOFC is to take maximum advantage of existing organizations and capabilities and create a minimum of new bureaucracy to meet IGOS and GOFC objectives during the five year lifetime of GOFC. The proposed management structure is shown in Figure 6.1.

Figure 6.1 GOFC Management Structure



6.1.1 Connection to CEOS and IGBP

In accordance with CEOS' intent under the IGOS concept, we propose for GOFC to have a dual affiliation. GOFC will report to CEOS through SIT, as in the past. It will also be attached to IGBP through IGBP-DIS. CEOS is the original "parent organization" of GOFC. CEOS members remain those most committed to making GOFC a success and control resources which are essential to implement the ambitious projects which GOFC is recommending. The objective of IGBP-DIS is data set development and distribution. IGBP-DIS provides a valuable knowledge base to GOFC through its experience in a number of projects including global 1 km land-surface data base from AVHRR, the global 1km land cover project, the global fire data base, areal extent of global wetlands, estimation of

terrestrial primary productivity, global topographic data sets, and a global land biomass data base. It will provide GOFC with the benefit of its experience in the assembly of, and access to large data bases. It can also provide linkages to related IGBP core projects including LUCC, BAHC, GCTE, and GAIM.

6.1.2 Executive Committee

The Executive Committee should be a small, active group which takes the important actions necessary to ensure that GOFC continues to make progress toward its objectives. Membership consists of individuals from CEOS participating agencies and GOFC partners (IGBP, FAO, GTOS/GCOS/TOPC, NGOs, national forest ministries) which are contributing to the implementation of GOFC. The initial membership can be drawn from the design teams, but a mechanism is needed to provide turnover. The committee would meet twice per year, once at the annual CEOS plenary meetings, and approximately 6 months in between. Between meetings, members would maintain frequent contact by listserver, email, and phone.

The Executive Committee:

- Works to form partnerships which lead to the initiation of project activity
- Helps to arrange sponsorship of projects;
- Monitors program and project implementation and progress;
- Ensures availability of project outputs and results;
- Reviews proposals for inclusion in GOFC against clearly stated criteria;
- Creates short term teams to address specific issues.

6.1.3 Secretariat

The Secretariat for GOFC is sponsored by CCRS and CSA. At the Irvine SIT meeting, NASA offered to play a strong supporting role. The support by NASA has been essential for the success of GOFC, and it should continue. The Secretariat provides a Project Leader for GOFC as an IGOS prototype project. It hosts the GOFC website, and provides an office which can be contacted at any time for information about GOFC. It manages day-to-day communications, and provides planning support for GOFC activities, particularly Executive Committee and other meetings. The GOFC Secretariat will develop and test approaches for policy and science outreach, and conduct outreach to organizations which share common interests with GOFC.

6.1.4 Project Teams

GOFC depends on the voluntary contributions of organizations to carry out project work. Therefore, project teams will be formed by participating organizations to accomplish specific tasks. Under the desired scenario, GOFC will recommend products which should be produced, and encourage suitable organizations to take the lead to form projects to produce them.

Following the strategy outlined in this document, a project team should be formed to address each of the three primary themes, Forest Cover Characteristics and Changes, Forest Fire Monitoring and Mapping, and Forest Biophysical Processes.

It is proposed that in each such case, the leader of the project becomes the point of contact between the project and GOFC, and communicates through the Executive Committee.

6.1.5 Task Teams

From time to time the GOFC Executive Committee will identify specific topics where recommendations are urgently needed to enable GOFC to meet its objectives. The Executive Committee will have a mandate to form Task Teams which will be given a specific task, and requested to report back to the Executive Committee within a relatively short time period. As such, they will be very similar to the current Design Teams. In many cases existing WGISS or WGCV working groups, or subsets of these, might be able to address topical tasks identified by the GOFC Executive Committee.

6.2 Communications strategy

An Internet website, together with email, provide an ideal mechanism for internal and external communications. The website will have a public portion for everyone, and an internal portion for GOFC participants. The general public will be the primary target audience for the public portion, recognizing that the public portion must also appeal to specialists in earth-observations and forest management. In the introductory pages the website should include a statement about the objectives of GOFC and its rationale for existence, as well as a balanced treatment of the role of satellite observations as a source of information on forests at the national and global levels. It will also include brief descriptions of participating organizations and links to their home pages. The public portion will also provide access to GOFC documents, and a mechanism for readers to provide comments to the GOFC Secretariat via email.

Eventually the website should provide access to project output, either directly or through links to agencies holding the derived data products. This may be a sensitive area. GOFC can act as an advocate of liberal rather than restrictive access to data and derived products.

Together with email, the website will provide an easy mechanism for internal project communications and enable organizations to achieve greater participation in GOFC even when they cannot send a delegate to a meeting.

We recognize that we cannot depend entirely on electronic communications. The GOFC Secretariat must be prepared to communicate using mechanisms suitable for participants if they do not have access to electronic communications. During the development phase GOFC will explore options for data packaging for different user communities.

7 Recommendations to CEOS

This document represents a strategy for CEOS and other agencies to consider. As mentioned before, actual implementation will depend on lead and participating organizations "stepping forward" to take up the challenge of assembling a team to work in one of the proposed theme areas. Following the GOFC design, it is possible to make several more general recommendations to CEOS.

GOFC objectives cannot be accomplished without data. We request that CEOS space agencies:

- Acquire and process the data needed to accomplish GOFC objectives, and work cooperatively to ensure long-term continuity of essential data. The data requirements have been specified in conjunction with each of the three primary themes.
- Promote the development and implementation of efficient data management and production systems to lower the cost of large-volume earth-observation datasets. This is a critical requirement, not only for GOFC but for the success of operational implementation of forest cover observations. In order for the needed information to be affordable to users, much larger volumes of data must be processed quickly, efficiently and nearly automatically than has been the case to date.

A number of recommendations call for enhancements in the areas of technology and documentation:

- Encourage CEOS members to provide user-friendly on-line facilities to access metadata and quicklook images for archival imagery (with WGISS);
- Promote the standardization and documentation of data products from optical and SAR satellites (with WGISS);
- Develop and document calibration/validation protocols for earth-observation data and derived products generated for GOFC (with WGCV);
- Support R and D to develop a capability to estimate forest biomass from space. We have identified the Vegetation Canopy Lidar and P-band SAR as two promising technologies which should be developed further.

We support and encourage the IGOS partnership process. CEOS can help GOFC by promoting increased co-operation:

- In co-operation with GTOS and TOPC, help expand, establish, and maintain a network of test sites to validate GOFC experimental products (WGCV);
- Develop a relationship with research, forest management, and policy, agencies to facilitate dissemination of derived information, for example, reporting for international protocols and treaties;
- Facilitate a constructive relationship with vendors of hyperspatial resolution (1-3m) data, to be used for forest characterization and assist in the validation of derived products.

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9 Appendices

9.1 Appendix 1: GOFC Design Participants

Participants at Ottawa Workshhop, July 7 – 10, 1997

Name		**Organization**
Ahern	Frank	Canada Centre for Remote Sensing (Canada)
Alves	Diogenes Salas	Instituto Nacional de Pesquisas Espaciais (Brazil)
Beaubien	Jean	Centre de recherche forestieres des Laurentides (Canada)
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Doherty	Marc	ESA ESRIN (Italy)
Drigo	Rudi	FAO - Viale delle Terme di Caracalla (Italy)
Fisher	Terry	Canada Centre for Remote Sensing (Canada)
Folving	Sten	Joint Research Centre - European Commission (Italy)
Goodenough	David	Pacific Forestry Centre (Canada)
Guertin	Florian	Canada Centre for Remote Sensing (Canada)
Gutman	Garik	NOAA (US)
Janetos	Anthony	NASA Headquarters (US)
Jennings	Michael	GAP Analysis Programme (US)
Justice	Chris	University of Virginia (US)
Lynham	Tim	Great Lakes Forestry Centre (Canada)
Leckie	Don	Pacific Forestry Centre (Canada)
Mahmood	Ahmed	Canadian Space Agency (Canada)
Mamen	Rolf	Canadian Space Agency (Canada)
Mayaux	Philippe	Joint Research Centre - European Commission (Italy)
Myre	Pauline	Canada Centre for Remote Sensing (Canada)
Nemani	Rama	University of Montana School of Forestry/NTSG (US)
North	Peter	Institute of Terrestrial Ecology (UK)
Ottens	Hans	Canadian Forest Service (Canada)
Phulpin	Thierry	CNES SH/QTIS/VP (France)
Shaw	Edryd	Canada Centre for Remote Sensing (Canada)
Skole	David	Univeristy of New Hampshire (US)
Stewart	Robert	Canadian Forest Service (Canada)
Taylor	Victor	NASDA (Japan)
Teillet	Philippe	Canada Centre for Remote Sensing (Canada)
Townshend	John	University of Maryland (US)
Trencia	Jacques	Canadian Forest Service (Canada)
Williams	Darrel	NASA/GSFC (US)
Yasuoka	Yoshifumi	National Institute for Environmental Studies (Japan)
Zhu	Zhiliang	U S Department of Interior Geological Survey (US)

Members of GOFC Design Teams, 1998

Name		Organization
Achard	Fréderic	European Commission Joint Research Centre
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Chapman	Bruce	Jet Propulsion Laboratory – California Institute of Technology
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Davis	Robert	Food and Agriculture Organization of the United Nations
Doherty	Marc	ESA ESRIN (Italy)
Dull	Charles	U. S. Depatment of Agriculture Forest Service
Fellous	Jean-Louis	CNES, France
Ferrão	Manuel	National Remote Sensing Center, Mozambique
Fisher	Terry	Canada Centre for Remote Sensing (Canada)
Hendrickson	Ole	Canadian Forest Service
Janetos	Anthony	NASA Headquarters (US)
Jayaraman	V.	Indian Space Research Organization
Jeanjean	Hervé	Spot Image/Scot Conseil, France
Justice	Chris	University of Virginia (US)
Kamibayashi	Norihisa	Remote Sensing Technology Center of Japan
Kwesha	Dominic	Forestry Commission of Zimbabwe
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Tschirley	Jeff	Executive Secretary, Global Terrestrial Observing System
Vogelman	Jim	USGS/EDC (USA)
Woodcock	Curtis	Boston University (USA)
Yasuoka	Yoshifumi	National Institute for Environmental Studies (Japan)
Zhu	Zhiliang	U S Department of Interior Geological Survey (US)

9.2 Appendix 2: Sensor Types needed for GOFC

Table 10.2.1 Generic sensor types

Sensor Type	Resolution (m)	Swath (km)	Repeat (days)	Fixed/pointable targeting	Spectral Bands									
					B	G	R	NIR	1.5-1.7	3-5	8-10	L	C	
Fine-F	~25	~200	~14	Fixed		*	*	*	*					
Fine-P	~25	~75	~4	Pointable		*	*	*	*					
Coarse	~1000	~2000	1	Fixed	*	*	*	*	*	*	*			
SAR	~25 (min 4 looks)	100-200	~4	Pointable								*	*	

Table 10.2.2 Specific Sensors

Fine – Fixed		Fine – Pointable		Coarse		SAR	
Name	**Agency**	**Name**	**Agency**	**Name**	**Agency**	**Name**	**Agency**
TM	NASA	HRV	CNES	AVHRR	NOAA	JERS SAR	NASDA
ETM+	NASA	HRVIR	CNES	Vege-tation	CNES	Radarsat SAR	CSA
LISS III	ISRO			MODIS	NASA	ERS SAR	ESA
				MERIS	ESA	ASAR	ESA
				GLI	NASDA	PALSAR	NASDA
				ATSR	ESA		
				AATSR	ESA		

9.3 Appendix 3 Fine Resolution Design Team Report: Separate Attachment

9.4 Appendix 4 Coarse Resolution Design Team Report: Separate Attachment

9.5 Appendix 5 Characteristics of GOFC Website

* (Items with asterisks will be implemented first)

* Cover page has pleasing appearance and has brief table of contents. Includes
- Logo
- Acronym and name
- Imagery – montage of little pieces, or IGBP 1 km product
- Brief table of contents to establish links to
  - Overview/Introduction/Rationale
  - Clients
  - Supporting organizations
  - Documents
  - Means to contact GOFC

* Second page is a well designed site map

Website will have a public portion for everyone, and an internal portion for GOFC participants. At least three levels of "confidentiality are possible:

- confidential URL supplied to participants
- confidential URL checked against IP adress of authorized visitors
- password protection

Contents

* Simple explanation of "the GOFC concept"
* Links to participating agencies

* GOFC documents available
- in Adobe for external users
- in WORD and WordPerfect for internal users during drafting stages

Project Plans including frequently updated graphical display of project progress

Project output (likely to be provided through links to agencies holding the data; GOFC may provide mirror sites).
- data products
- GIS products

* Feedback mechanism

Internal Communications

* Calendar
tools to facilitate development of plans and documents
tools to monitor progress of projects

A Strategy for Global Observation of Forest Cover

Executive Summary

Draft for comments, Version 1.2

GOFC Design Team

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Executive Summary

1.1 GOFC as a CEOS response to global concerns

As the twentieth century draws to a close, there is an emerging global consensus that the cumulative effects of past and present human activities are having a global impact on the Earth's ecosystems, atmosphere, and climate, and that steps must be taken to improve our knowledge and change policies and management practices throughout a broad range of human activities.

The international support for the Kyoto Protocol of the Framework Convention on Climate Change, together with earlier support for the International Convention on Biological Diversity, represent the first steps down a long, difficult path toward a sustainable future on the Earth.

Forests play a central role in the issues of greenhouse gasses, climate change, and biodiversity. In a general sense, the role forests play in the carbon and water cycles, and in providing rich habitat for diverse plants and animals, is well known. However, much additional research is required to understand the detailed role of forests. Scientists working on many aspects in the field of global change require global, regional, and local observations of forests to develop a better understanding of the complex, inter-related processes involved. At the same time, policy makers realize that we cannot afford to wait until all of the scientific questions are solved; global observations of forests are needed to monitor changes in the Earth's forests and provide objective, quantitative information to assess progress toward long-term objectives. As a result of the Kyoto protocol, particular emphasis is placed on reforestation, afforestation, and deforestation,

Earth observation satellites have been providing data for natural resource management since 1972. The data from these satellites has been widely used to map and monitor forest resources. However, these efforts have generally been made as individual projects within individual jurisdictions, such as states, provinces, or forest management units.

More recently, the global change science community, the United Nations Food and Agriculture Organization, and a number of national and regional efforts have worked to use earth observation data to create a consistent regional and global pictures of the earth's forests, and to monitor changes in the forests worldwide. These efforts have shown the difficulties involved and the progress needed in assembling continental and global data sets to address the science and policy questions surrounding forests.

Recognizing the accomplishments to date, but also the shortcomings, the Committee on Earth Observation Satellites has initiated a program of Global Observation of Forest Cover as part of its Integrated Global Observing Strategy. The objectives are to increase international cooperation in the integration and use of data from multiple earth observation satellites, in conjunction with in-situ data, for mapping and monitoring the earth's forests, and to provide feedback to the space agencies to enable them to better coordinate future space missions. GOFC will develop the means to undertake operational inventories of forest cover, fire and forest biophysical characteristics using satellite data.

1.2 What GOFC has accomplished, and what can be expected from GOFC

Since July 1997, teams of scientists, remote sensing specialists, and knowledgeable representatives from user organizations have been meeting and planning a strategy to lead to ongoing global observation of forest cover. In this process, we have endeavored to reach out and obtain input from a broad spectrum of user groups, in addition to drawing heavily from persons with the greatest current experience in assembling and processing large regional and global datasets. We have held six international workshops, first to outline a GOFC concept, and then to produce this detailed strategy document. More than fifty specialists from fifteen countries and seven international organizations have participated in this design process. During this same period, the GOFC project leader held briefing meeting with twenty-six international organizations, scientific bodies, forest management agencies, non-governmental organizations, and earth-observation agencies to inform them about the GOFC concept and obtain their feedback.

As a consequence of these interactions, GOFC has already resulted in increased dialog with international organizations, science bodies, forest management agencies, and non-governmental organizations which require forest information.

This document presents our strategy. The essence of our strategy is to develop and demonstrate operational forest monitoring at regional and global scales by developing prototype projects along three primary themes:

- Forest Cover Characteristics and Changes
- Forest Fire Monitoring and Mapping
- Forest Biophysical Processes

As part of this process, we propose to assemble teams to execute prototype projects, develop consensus algorithms and standard methodologies for product generation and product validation in conjunction with in-situ measurements, and develop and demonstrate procedures for improved data access for the user community.

As a consequence, we will identify gaps and overlaps in earth observation data, ground systems, methods, and scientific knowledge from the experience gained in developing and executing GOFC prototype projects. The ultimate objective is to lead to sustained, on-going operation without the need for major funding by CEOS members. Additionally, GOFC will

- Create and strengthen partnerships between CEOS members and user agencies;
- Identify gaps and overlaps in CEOS member programs and make recommendations how these might be resolved;
- Lead to increased operational use of earth-observation data for policy decision making at national, regional, and global levels;
- Provide validated products which can be used to derive credible information concerning the forest component of the carbon budget for research and policy use;
- Promote common data processing standards and interpretation methods, which are necessary for inter-comparison of regional studies;
- Stimulate advances in the state of the art in the management and dissemination of large volume datasets and information from multiple sensors;

- Use data from multiple sensors, in combination with in-situ data, to produce validated prototype information products which satisfy clearly identified requirements of user agencies;
- Enhance the use of earth-observation information products for forest management and scientific research concerning forest biophysical processes.

1.3 CEOS Support Required

To succeed, GOFC will require support from CEOS as a whole, and from individual CEOS members who choose to become involved in GOFC projects. The IGOS partnership mechanism must help form meaningful partnerships with forest management, policy and science communities, and funding agencies. CEOS agencies will be requested to provide essential data for the pilot projects. This requirement will extend beyond the production of primary data products to the provision of support for the production of derived products. Just as important, it will be necessary for many organizations which produce earth observation data products from raw data to update their production systems to provide for increased automation and large volume processing, in order to reduce the costs of earth observation data so that global observation of forest cover becomes economically feasible. CEOS member agencies will also be asked to conduct and promote targeted R&D on science and technical issues identified by GOFC and its partners.

WGISS and WGCV have already played an important role in the development of GOFC. The support of individual WGISS and WGCV working groups will be essential for addressing and resolving further technical issues which arise in the development and execution of GOFC pilot projects.

1.4 Primary Themes

We believe that the best way to make demonstrable progress toward widespread operational use of earth observation technology to address forest issues is through a suite of well-considered pilot projects. Each must provide information of value to user communities with clearly stated requirements. Each must be achievable using proven technology, although an integrated system may not yet exist. Through the course of execution of the pilot projects, CEOS member agencies and participants will benefit from increased communication, and technological capabilities will be expanded. Strategies will be developed and funding sources will be identified to make the transition to on-going routine operation. GOFC has adopted the approach of involving the operational users in the design of these pilot activities so as to ensure adoption by the operational agencies at the completion of the pilot phase.

We identify three primary themes:

- Forest Cover Characteristics and Changes
- Forest Fire Monitoring and Mapping
- Forest Biophysical Processes

GOFC can make a key contribution to all of these by providing integrated datasets from multiple sensors.

Forest cover characteristics and changes: This is the most important but the most challenging of the proposed themes. The products have the greatest appeal to the widest spectrum of users including forest resource managers, policy makers, and scientists studying the global carbon cycle and

biodiversity loss. We propose a systematic program for periodic mapping of land cover at coarse resolution (250 – 1000 m) on a five year cycle, combined with periodic mapping and monitoring of forested areas at fine (~25 m) resolution. Very large datasets must be acquired, assembled, processed, and analyzed from coarse resolution optical sensors, fixed and pointable fine resolution optical sensors, and SAR sensors. Most of the needed technology has been demonstrated, but assembling coordinated systems to generate the required products will be very challenging. The proposed approach is shown schematically in Figures 1 and 2.

Forest Fire Monitoring and Mapping: The global increase in wildfire following the 1997-98 el Niño event has served to emphasize the urgent need for improved information from CEOS members' space systems. Data from existing and near-term coarse resolution sensors can satisfy most of the information requirements, and automated algorithms for much of the information extraction have been demonstrated. A distributed network of low cost receiving and processing facilities could satisfy many of the requirements for operational fire monitoring and mapping. The proposed approach is shown schematically in Figure 3. At the same time there are clearly defined areas where additional research can improve and validate information extraction. Cross-linkages with the forest cover characteristics and changes theme and the forest biophysical processes theme will provide additional information on fuel consumption and gas and aerosol emission. At the same time, information from this theme will be a valuable input into the other two themes as an indicator of forest disturbance and gas and aerosol emissions. We continue to collaborate with the with the IGOS Disaster Management Support Project to harmonize our efforts.

Forest biophysical processes: This theme reflects a key component of the sizeable effort to use earth observation data to understand, and eventually balance, the earth's carbon budget. With the signing of the Kyoto protocol in 1997, information on the carbon cycle now has policy as well as scientific implications. The major goal for this objective is to quantify net primary productivity of forests, combining satellite data with ecosystem process models. The approach is shown schematically in Figure 4.

Figure 1: Forest Cover Characteristics
(Centrally coordinated/regionally executed)

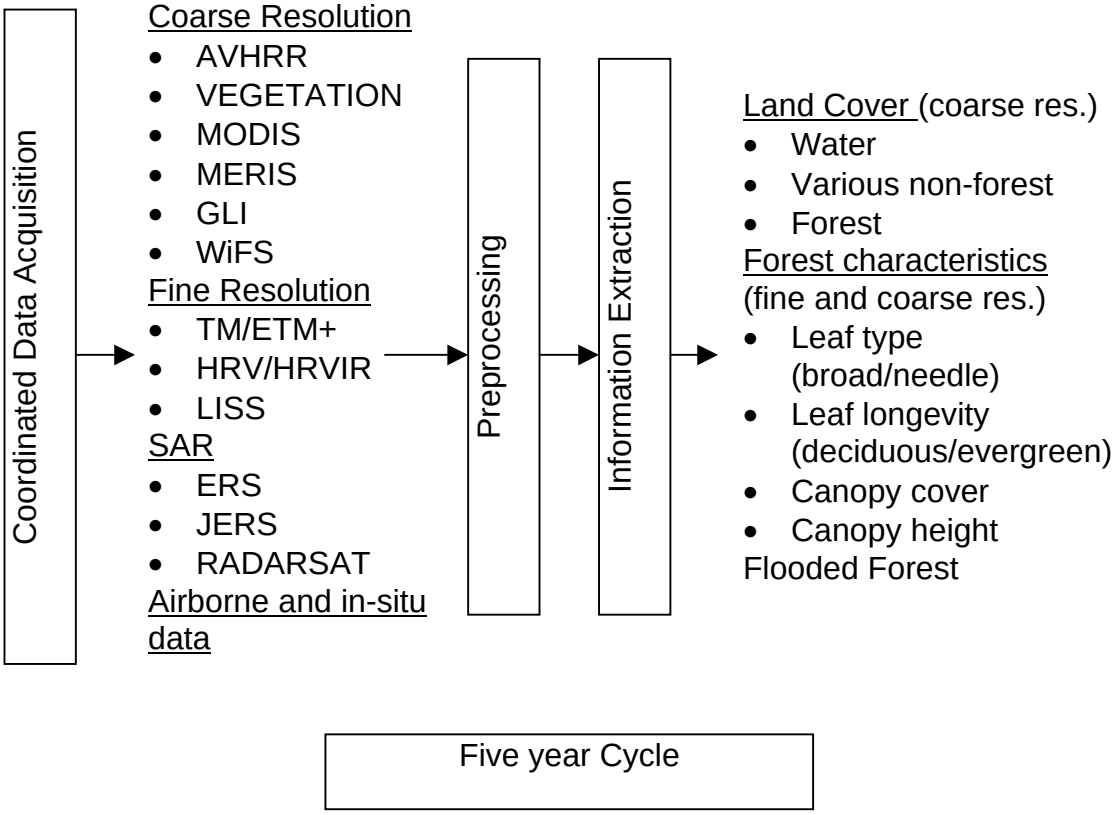


Figure 2: Forest Cover Changes
(Centrally coordinated/regionally executed)

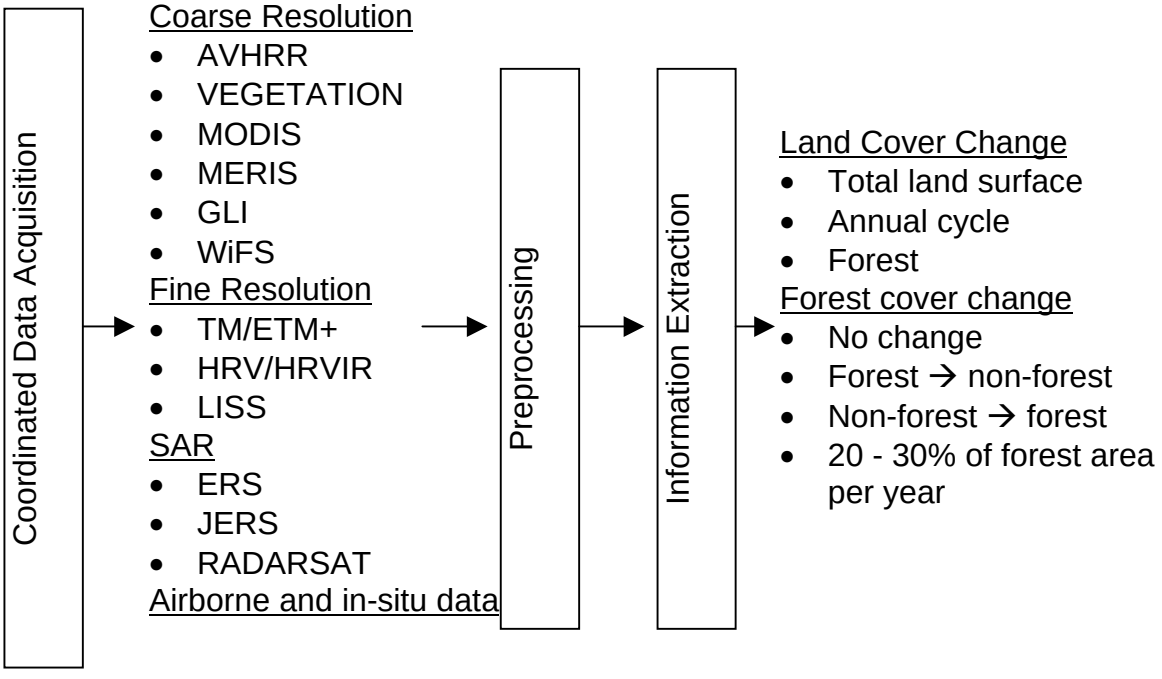


Figure 3:Forest Fire Monitoring and Mapping
(Centrally coordinated/regionally or nationally executed)

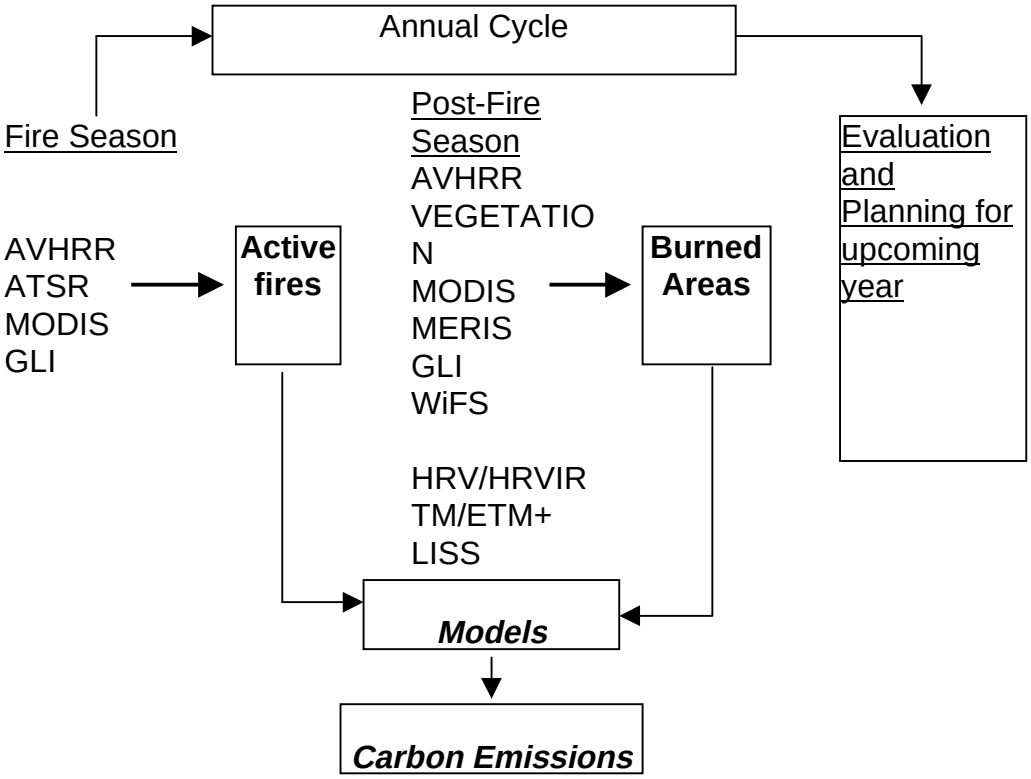
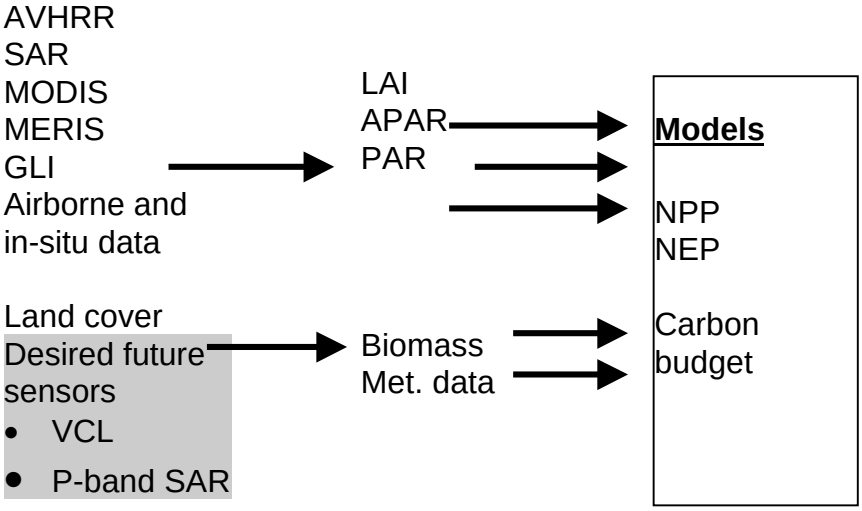


Figure 4: Forest Biophysical Processes
Confederation of Investigation Teams

- National/regional
- Global

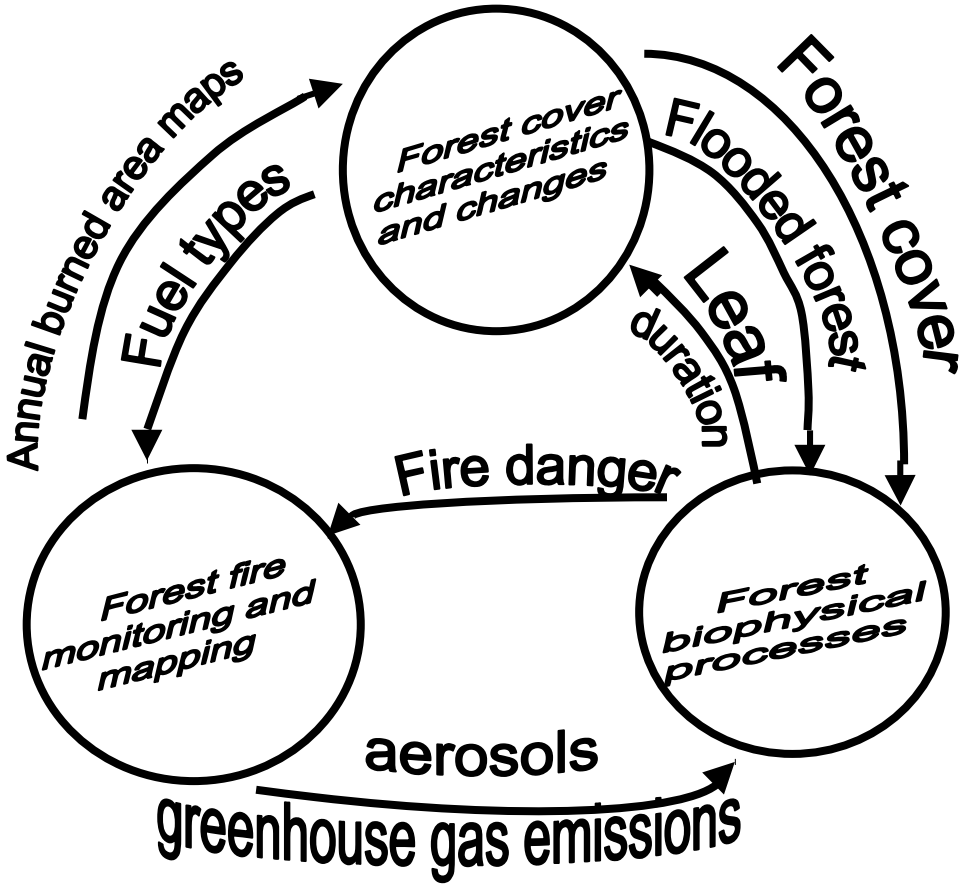


AVHRR research
EOS research
MERIS research
GLI research

In conjunction with IGBP, GOFC could provide a mechanism to coordinate

Each of these themes of GOFC could be implemented as called for in this document and result in significant progress. But the natural interconnections (shown in Figure 5) make an implementation of all three components significantly stronger than simply the sum of the three parts.

Figure 5: Linkages between GOFC themes



While much progress in this area will take place independently of GOFC, GOFC can contribute to a more integrated global approach by:

- Providing opportunities to inter-compare results from different sensors and different algorithms;
- Providing linkages to organizations such as GTOS which can facilitate the sharing of in-situ observations.
- Promote ground observation networks and campaigns to validate forest biophysical process products.

1.5 Expanding the circle of consultation

This document provides a strategy, not a blueprint, to attain CEOS goals as defined by IGOS. A large number of representatives of producer and user agencies has participated in the development of this

strategy, and many more have been consulted by the members of the GOFC design teams. Nonetheless, to achieve a broad consensus, wider consultation is needed. All organizations which have participated in the development of GOFC to date will be given an opportunity to comment. Subsequently, a revised draft will be circulated to organizations which may have an interest but which have not participated in this development. It will be particularly important to obtain feedback from foresters, forest managers, and forest policy makers from countries which have large areas of forests. We propose to hold one or more workshops in the first half of 1999 for this purpose.

Because of the comprehensive view we are taking of both earth observation technology and user requirements, the final document will serve as a reliable pointer to the way ahead. This strategy document will provide a basis for the CEOS agencies and partners to support and develop projects to meet the GOFC objectives. After the first year the complement of GOFC projects will be listed and evaluated to determine critical gaps in the strategy.

1.6 Initiating action

Even though this Strategy may be modified somewhat through wider circulation and comment, we are confident that the collective experience of the design team members, coupled with the additional consultations they have made during the course of the GOFC design phase, have produced a basis to initiate action. We propose to approach CEOS member agencies and user organizations to assemble teams of lead and participating agencies for each of the three primary themes, recognizing that the magnitude of the Forest Cover Characteristics and Changes theme may necessitate further discussion before initiating action in that particular area. The GOFC Executive must be formed, including representation from the lead agencies and participating users. The best way to move ahead is to begin working on specific pilot projects.

1.7 Schedule

Since GOFC is not a funded R&D effort but rather a partnership of voluntary participants, it is not possible to define a firm schedule as one might for an engineering project. Nevertheless, it is helpful to propose a possible schedule to examine how much progress could be made in the remaining four years of GOFC with rapid, enthusiastic participation. A schedule to achieve IGOS and GOFC objectives is proposed here to provide a starting point for further development.

Forest Cover Characteristics and Changes: We propose a two-phase approach. Each phase would be an end-to-end exercise of data acquisition, data analysis, and evaluation/validation of the resulting products. It is important to carry out an end-to-end exercise to ensure all the necessary components function properly, and to identify weak areas where remedial work is necessary. The first phase could be accomplished in as little as two years (1999-2000), although that is a very ambitious schedule. The first phase should cover one or two regions. The second phase (2001-2002) could cover several regions, expanding to all of the forested regions of the Earth if sufficient resources are available.

Forest Fire Monitoring and Mapping: There is a natural cycle time for this project: the annual seasonal cycle which normally includes one “fire season” in each region. The proposed GOFC initiative would also follow an annual cycle, with near-real-time fire monitoring during the fire season, followed by post-season fire mapping. The first two years (1999-2000) are proposed to be a testing phase, first for several countries, and then for many countries. By the third year (2001) the system could be in full

operation for most countries. This would be a distributed effort, with an annual meeting at the end of each year to discuss accomplishments and difficulties, and to make plans for the following year.

Forest Biophysical Processes: The EOS-AM1 mission is expected to be launched in mid-1999, with validation campaigns taking place during the next few years. Research teams for the ADEOS-2 and ENVISAT missions are being selected. GOFC should facilitate communication and coordination among these groups, and should strive to promote regional and global pilot projects incorporating multiple teams and approaches working toward community consensus algorithms.

APPENDIX 3: FINE RESOLUTION DESIGN TEAM REPORT

GLOBAL OBSERVATION OF FOREST COVER

FINE RESOLUTION DATA AND PRODUCT DESIGN STRATEGY

Report of a Workshop
23-25 September 1998
CNES Headquarters, Paris, France

Edited by
D.L. Skole, W.A. Salas, V. Taylor

DRAFT FOR DISCUSION
26 September 1998

1.0 INTRODUCTION

Land cover change in forests may be the most significant agent of global change today: it has an important influence on hydrology, climate, and global biogeochemical cycles. Arguably, forest cover change will have a more significant and direct influence on human habitability than climate change over the next 20 to 50 years. It is an issue with far reaching policy implications, either internationally, nationally, or locally. Indeed, forest cover change is as inextricably linked to policy and sustainable development as it is to basic research issues.

This document provides an initial strategy for an program for a global forest cover change monitoring system based on fine resolution remote sensing. The strategy will link satellite measurements with models to make quantitative assessments of the effects of land cover changes on the global environment and forest inventory and management. The strategy has a three-tier focus which fulfills the needs of: (a) the global change research community, (b) international policy initiatives such as the Framework Convention on Climate Change (FCCC) and the Intergovernmental Panel on Climate Change (IPCC), and (c) national-level resource management and mitigation efforts.

2.0 FINE RESOLUTION DESIGN AND PRODUCT SPECIFICATIONS

A workshop to define the design for global forest monitoring using fine resolution earth observation satellites was held at the CNES Headquarters in Paris, France in September 1998 (see Annex 1 for list of participants and agenda). The workshop was convened to define a strategy for fine resolution observations, dataset compilation, and product definition to support GOFC objectives. This report details the conclusions and recommendations of the workshop, and serves as an input to the End-to-End Design for GOFC as a whole. The workshop emphasized satellite observations but recognized the importance of in-situ data. Workshop participants included representatives from a range of communities including: (a) space agencies, (b) the scientific research community, and (c) the user community.

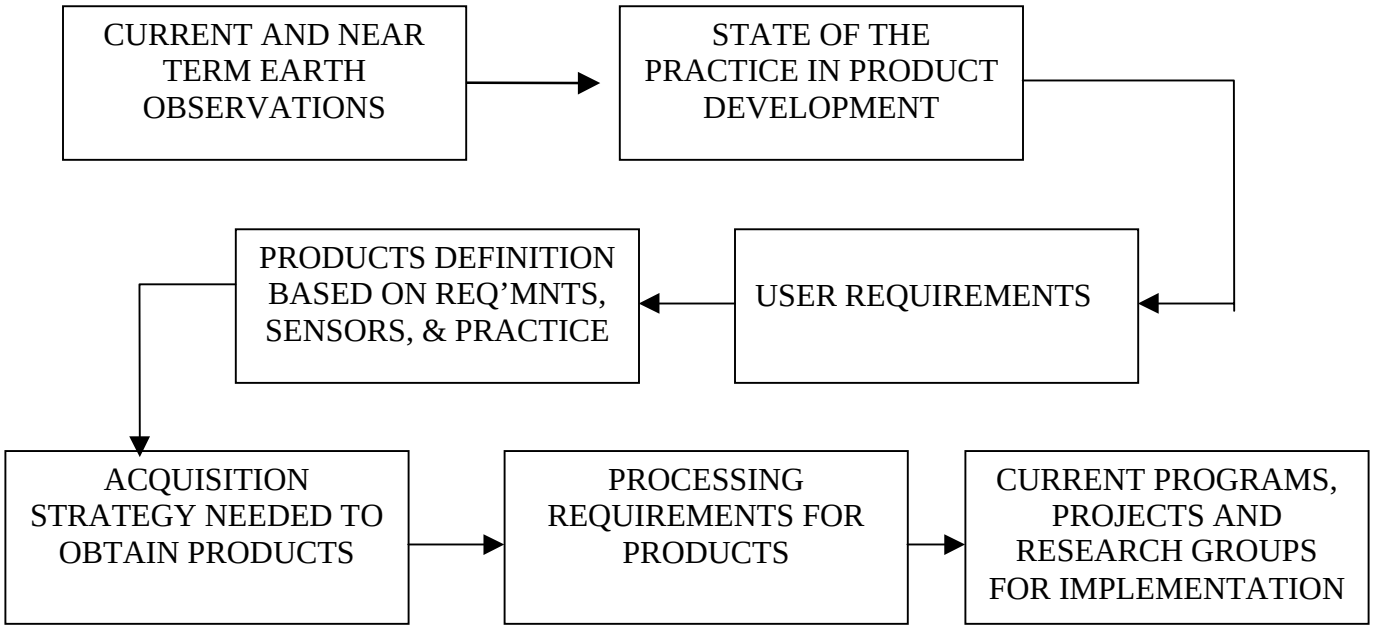
Although the participation was small – approximately 20 participants – there was representation from the national forest management users in North America, Asia, and Africa (See Annex 1). This workshop was also represented by the global change science community, particularly the carbon cycle and climate community, as well as key groups involved in the acquisition and processing large-area datasets from both optical and SAR data for forest monitoring at a global scale (e.g. Landsat Pathfinder, Landsat 7 Science Team, TREES, GRFM, GBFM, Siberia Project). This workshop and document represents an initial review of an observation strategy, which would be elaborated further through the GOFC program design and implementation.

2.1 Workshop Objectives

The objective of the workshop was to develop an initial strategy for utilizing existing and future high spatial resolution optical and microwave earth observation satellites for monitoring and mapping the forests of the world. The specific objectives were to:

- Review the current and future space-based systems deployed by the space agencies
- Identify current large-area forest monitoring projects or research/applications groups which could support and implement GOFC objectives
- Review the current state-of-the practice for analysis of satellite data for forest mapping and monitoring, with recommendations on potential methods and products, as well as their limits for global application
- Definition of the user communities for high resolution data products, and definition of the user requirements
- Define a reasonable and practical data acquisition model for products which meet the user community's needs
- Definition of products and product specifications
- Description of processing and data handling and analysis considerations

INFORMATION DERIVED FROM THE WORKSHOP AND PRESENTED IN THIS REPORT



2.2 General Design Considerations

The strategies recommended for the development of fine resolution products are based on some fundamental considerations, including:

- Products should be relevant to as broad an audience as is practical and feasible. There was particular emphasis on products at the global scale, with regional or national application. An emphasis is placed on forest cover and forest cover change data to support carbon cycle research, policy support to IPCC and the Kyoto protocol, and national forest inventories.

- Products and the overall design must be practical and lead to a reasonable operational concept, implemented using existing and near-term observational systems, with a straightforward and management level of effort.

- The Fine Resolution component should build on existing and near term programs, and should include proven or near-ready applications rather than propose approaches with high research and development aspects, although recognizing that research and development should be a critical component of the program

2.2 Design Requirements

The proposed strategy has been developed around the following requirements:

- The program must incorporate both global and national level objectives and be capable of providing results at national, regional and global scales.

- The information generated by the program must be useful for national level resource planning and management, as well as vulnerability studies and mitigation and adaptation planning.

- The program must include an operational monitoring system with the capability for permanent implementation.

- The monitoring system should utilize data from a variety of sources and allow for in-country analyses where appropriate.

- The information generated by the system should have a known and stated accuracy.

- Accuracy assessment must be an integral part of the program. Field validation must be an essential component of the accuracy assessment.

- The monitoring system should be coupled to, and support, an independent vetting of the proposed methodology and be subject to independent peer review.

- Data and information generated by the program must be made readily available in a timely fashion to a broad user community. A data system should be developed to serve the information management needs of the program and its data users.

3.0 CURRENT PROGRAMS AND STATE OF THE PRACTICE

Datasets from Landsat, SPOT and other fine resolution sensors with global and national coverage have created opportunities to exploit data in ways not possible just three or four years ago. Here we list some key projects for example, although the list is not complete. Annex 2 presents an overview of the EO sensors which could be used for the fine resolution data acquisition.

3.1 Global Scale Initiatives.

The NASA Landsat Pathfinder Humid Tropical Forest Inventory Project (HTFIP) is another high resolution satellite remote sensing dataset being developed through cooperative funding by NASA and the EPA. It will provide "wall-to-wall" coverage of the closed tropical forests of the world with Landsat MSS and TM at three points in time from the 1970s to the mid 1990s.

The Commission of the European Communities TREES project is compiling a 1 km tropical forest dataset in an effort to map the global distribution of tropical evergreen and seasonal forests, which is being made available as raw data and high level products, such as GIS-based forest maps, in an information system. This data provides a global stratification for detailed analyses with high resolution data. New initiatives with the TREES project involve the acquisition of large samples of high resolution satellite data to compliment the complete inventories provided by the Landsat Pathfinder Project. Combined, these two efforts would provide a prototype annual tropical forest assessment.

NASA is developing an acquisition plan for a global series of test sites using Landsat TM data. These data are to be used to calibrate global analyses from coarse resolution data such as AVHRR, and for development of site-specific models of ecological processes in places where detailed in-situ measurements have been made in conjunction with the satellite acquisitions. In a related effort, NASA is also compiling the Landsat Global Change Catalog, which is a worldwide catalog of Landsat data

acquired in and outside the tropics for global change research. The data are available to the global change community at the cost of reproduction.

The High Resolution Data Exchange Project is a joint project of the Committee on Earth Observation Satellites (an international affiliation space agencies) and the International Geosphere Biosphere Program. This project is aimed at testing the utility of multi-sensor data acquisition, and a multi-agency international coordinated system of remote sensing observations. It is building a dataset containing several hundred SPOT, MOS, JERS-OPS, ERS-1, and IRS data at selected global change study sites around the world.

The Global Forest Mapping Program (GFMP) is a multinational effort led by the Earth Observation Research Center (EORC) of the National Space Development Agency of Japan (NASDA) in cooperation with, among others, NASA Headquarters – Earth Science Enterprise, NASA's Jet Propulsion Laboratory (JPL), the Alaska SAR Facility (ASF), the Space Applications Institute of the Joint Research Centre of the European Commission (JRC/SAI), Sweden's Swedish Space Corporation (SSC), Canadian Centre for Remote Sensing (CCRS), European Space Agency (ESA), German Space Agency (DLR), the University of California, Santa Barbara (UCSB), the Brazilian National Institute for Space Research (INPE) and the National Institute for Research of the Amazon (INPA). Several international research teams are also currently associated with the GFMP. Its goal is to acquire geographically and temporally contiguous Synthetic Aperture Radar (SAR) data sets of the Earth's major tropical and boreal forest systems by using the Japanese Earth Resources Satellite (JERS-1 or FUYO-1). The two mapping projects associated with this initiative are the Global Rain Forest Mapping Project (GRFM) and the Global Boreal Forest Mapping Project (GBFM). The GRFM has been in operation since 1995 whereas the GBFM has been operational since 1997. The Global Forest Mapping Program will continue to make use of Japanese remote sensing platforms such as the proposed JERS-2 and the Advanced Land Observing Satellite (ALOS) which will be launched in 2002.

3.2 Regional Initiatives

Currently, there are a number of projects underway in North America that are relevant to the High Resolution component of GOFC. For example, the North American Landscape Characterization (NALC) Project has been acquiring and processing complete coverage of the continental United States and Central America with Landsat MSS data at three points in time from the 1970s to the present. These include the following “wall-to-wall” mapping projects:

- Regional Multiresolution Land Characteristics (MRLC) – conterminous United States
- Earth Observation for Sustainable Development – Canada; *still in design phase
- Inventario Nacional Forestal Periodico – Mexico; conducted by “photo”-interpreting vintage 1993 Landsat Thematic Mapper data

Numerous other national inventories and projects which involve the establishment of statistical patterns and trends in forest conditions are relevant to GOFC, including: (i) FRA 2000 – international, (ii) Forest Inventory and Analysis (FIA) – United States, (iii) National Forestry Database Program (NFDP) – Canada, (iv) National Inventory for the Year 2000 – Mexico; proposed, (v) Mexican Deforestation Study – Mexico; proposed

Within the United States, the MRLC project is jointly funded by the United States Geological Survey (USGS) and the United States Environmental Protection Agency (EPA). The goal of this project is to generate a general, consistent, and seamless 30m land cover data set by the year 2000. 1991-1993 vintage "leaf-on" and "leaf-off" TM data are used in conjunction with multiple sources of ancillary data (e.g. digital elevation model data, available land user / land cover data, population census information) to accomplish this task. Currently, seven mapping teams representing both the government and private sector are conducting the project. Land cover products have been generated for most of the east coast of the United States and activities are currently focused on the US Midwest and Pacific Northwest. Accuracy assessment is conducted on completed sections- US Standard Federal Regions. A follow-on effort, MRLC 2000, is currently being planned.

Regional Activities have been initiated in recent years which could be coupled to the program outlined here for in-country work. Within the IGBP System for Analysis, Research and Training (START) a number of regional activities focusing on the land cover change question have begun. Most notable is the Southeast Asian regional activity which is directly linked to the EPA Pathfinder project in that region, as well as the aforementioned IGBP LUCC and High Resolution Data Exchange projects. START/Southeast Asia has initiated a Land Use and Cover Change (LUCC) program in two components: (a) a complete region-wide analysis of deforestation trends in the region, and (b) specific case studies established in four participating countries: Thailand, Malaysia, Indonesia, and the Philippines. The case studies, conducted primarily by local experts and scientists, provide a prototype example upon which to build in-country work. The Thailand Country Study is already a component of the START/LUCC activities in Southeast Asia.

Since 1992, the Chinese Academy of Sciences (CAS), has conducted the National Land Use Mapping Project and Dynamic Monitoring Project through the use of Landsat TM data and established the National Land Use and Land Cover Database of China which includes National Land Use and Land Cover Maps interpreted and digitized from TM data at the scale of 1:1 000 000, 1:500 000, 1:250 000, and 1:100 000. CAS plans to update the database every five (5) years. Based on the LUC database, CAS and the Chinese Academy of Forestry (CAF) are leading a project which will produce a national forest type map and database. All of these databases are stored and managed in the Chinese Natural Resources and Environment Information System, a GIS system.

During 1994-1997, CAS and CAF took part in an international project of the Global Research Network System (GRNS). Through this project, the Chinese Vegetation Working Group and the Japanese Integrated Forest and Forestry Production Institute (IFFPI) conducted the field survey and produced the Forest Type Map of Changbai Mountain and Maoeb Mountain. This field survey was based on Landsat TM data.
This collaboration also produced the 1km forest and land use maps of northeast China by using AVHRR data integrated with DEM and regional climate datasets.

At present, CAS is continuing with mapping China's vegetation using AVHRR data at 1km resolution for the entire country. Current plans are to update the results on an annual basis.

The CORINE Land Cover project is an initiative coordinated by the European Environment Agency (EEA) through its European Topic Centre on Land Cover (ETC-LC). The ETC-LC is led by the Environmental Satellite Data Centre in Kiruna, Sweden.

The CORINE Land Cover product has 44 land-cover classes and 25 ha map presentation units. The mandate of the EEA is the entire continent of Europe to the Ural Mountains, and CORINE Land Cover has or will be generated for most or all of the European countries. The first mapping of the EU is

complete except for the UK, Finland and Sweden which will be completed early next century. In addition the mapping has also been completed for a number of central and eastern European states including Poland and the Baltic States.

The CORINE Land Cover product is generally derived from manual interpretation of TM imagery and complementary data. CORINE Land Cover in Sweden is being performed without any funding from the EU. Therefore the project has been forced to explicitly address national mapping needs and adopt different methods. To this end the Swedish Land Cover product has been defined with 52 thematic classes and a map presentation unit of 1 to 5 ha depending on the class (highest resolution achieved among others for the forest classes). The methodology is highly automated (but includes some interpretation work, particularly in urban areas) enabling future product updates at relatively low cost, and the generation of a range of different end-products from the same core processing system. The development and pilot production phases in Sweden have been led by Swedish Space Corporation (SSC). In the production of the forest classification extensive use is being made of the National Forest Inventory ground plot data.

The BALANS project is a land cover project for the whole of the Baltic Sea Drainage Basin part-funded by the European Commission. The project starts in October 1998 and runs for about 2½ years. It is planned that a sustainable activity will continue after the initial project period. The project is led by the Swedish Space Corporation. The collaborators are the Finnish Environment Institute, Finnish National Land Survey, Swedish Meteorological and Hydrological Institute, the Environmental Satellite Data Centre (Sweden), GRID-Arendal (Norway) and GRID-Warsaw (Poland).

The aim of the project is to develop the methods for the production of a 200m land cover database and generate an initial database by the end of the project. In addition, a number of ”confidence sites ” will be investigated in detail, partly for validation and also to test the usefulness of the land cover products for specific users. The database will be primarily based on medium-resolution optical imagery (e.g. RESURS, IRS-1C WiFS and Envisat MERIS). A JERS SAR mosaic of the whole area is also available.

The Pan-European Land Cover Monitoring project (PELCOM) is a Europe-wide land cover product from AVHRR. The project has been running since 1995 and will end early in 1999. The project includes teams from the JRC, SSC, MeteoFrance, RIVM (Belgium) and the Austrian Research Centre Seibersdorf.. The project aims to produce a land-cover product at 1 km resolution with a limited number of classes, including a single ”forest” class.

The Forest Monitoring in Europe with Remote Sensing projects (FMERS 1 and 2) are initiatives within the Joint Research Centre, Ispra. They are funded within the Centre for Earth Observation programme (CEO) and in terms of technical associations fall within the JRC’s FIRS project (Forest Information from Remote Sensing). Both projects are technical development and demonstration projects of possible methods for a future European forest monitoring system.

The FMERS-1 project began Autumn 1997 and will finish early in 1999. The project team is led by VTT (Finland), and includes SSC, Scot Conseil (France), European Forest Institute (Finland), CESBIO (France), SCEOS (UK), University of Bologna (Italy). It focuses on distinguishing forest from other land-cover classes and on further dividing the forest areas into different types (e.g. needleleaf, mixed, broadleaf, etc.). The target nomenclature is based on the FAO definitions for Forest and OtherWooded Land. The project is using medium-resolution (RESURS with 170m pixels and IRS-1C WiFS with 190m pixels) and high-resolution (TM and SPOT) optical imagery. The first part of the project was to do some testing and evaluation of different methods and data. Some work was also included to demonstrate the potential of current SAR data and methods in this area. Six test areas were looked at

sampling the boreal, temperate and Mediterranean forest types – the first time (we believe) I this kind of project in Europe. The second phase is more oriented towards putting methods for the medium-resolution optical data to work. Forest maps from medium-resolution data will be generated over two large areas in Europe – one focussed on the southern Baltic Sea region, the other on western Europe from the British Isles to the Alps (excluding Spain and Portugal).

The FMERS-2 project is smaller in scale than FMERS-1 and is looking at forest biomass and volume estimations using a multi-phase approach. The model builds from the ground data upwards through aerial photography, TM data and medium-resolution imagery – there is no radar component in the project. Two relatively limited areas will be looked at, one covering Sweden and Finland around the Gulf of Bothnia, the other over the northern half of Portugal and Spain. The project kicks off in October and runs until April 1999. The team is led by SSC who are working with the Finish and Swedish National Forest Inventories and the Instituto Superior Agronomia of the University of Lisbon, Portugal.

The SIBERIA project (SAR Imaging for Boreal Ecology and Radar Interferometry Applications) is a European boreal forest mapping and classification project which makes use of data from different microwave sensors: JERS-1 L-band SAR and ERS C-band SAR tandem data to retrieve forest parameters (forest type, biomass) on a large scale. Collaborators in the project include DLR (Germany), IIASA (Austria), CESBIO (France), SCEOS (Great Britain), VTT (Finland), several other European agencies and companies, four Siberian forestry partners from Russia, and NASDA (Japan).

Comprising at least 21% of the world's growing stock and 11% of the world's live forest biomass, Russia's boreal forests are a natural resource of global importance, both from an economic and ecological perspective. SIBERIA therefore strives through the use of multitemporal ERS, ERS tandem and JERS-1 data to develop a methodology and to produce a forest map of central Siberia (89-111 deg. East; 52-60 deg. North) which will serve the development of sustainable management policies, Siberia's socio-economic development, and climate change research.

The classification and estimation of forest variables in the SAR data will be supported by reference data collected and compiled from several information sources such as:

- Forest maps with stand descriptions (1:10,000 to 1:50,000)
- Aerial photos (1:7,000 to 1:25,000)
- Field measurements from sample plots
- Landscape and soil maps
- Aggregated landform data of different scales
- Russian and Siberian forest maps at different scales
- Forest maps from separate regions (1:100,000 to 1:300,000)

Deliverables for the project include the following:

- A map covering an area of 2 million square kilometers of Siberia indicated the spatial distribution of boreal forests of different types and biomass densities.
- A large database containing the forest classification and the remotely sensed data from which the classification was derived.
- A proven methodology for building a multi-satellite SAR dataset and using the assembled remotely sensed data to derive a reference forestry map over a significant portion of the Earth's surface.

4.0 USER REQUIREMENTS FOR FINE RESOLUTION PRODUCTS

The requirements of the user community must be an essential element in the design for GOFC in general and for the fine resolution component in particular. Satellite remote sensing of forest cover and forest cover change at the global scale

4.1 Global Change Research: the carbon cycle

Human activities are largely responsible for the observed increases in atmospheric carbon dioxide. Fossil fuel burning is currently the most important source of carbon dioxide. However, biogenic sources are also important. Evidence from ice core data suggests atmospheric concentrations of CO2 began to rise even before major inputs from fossil fuels existed.

The current global net flux of carbon from land cover conversion is between 0.9 and 2.5 x 1015 g C (Houghton et al. 1985). This represents between 18% and 49% of the release from fossil fuel combustion (Marland et al. 1985, Marland and Rotty 1984). On a long term basis, from 1700 to 1980, the total release from the biota was approximately equal to the long term total release from fossil fuels (Houghton and Skole 1990). However, the role of the biota in the global carbon cycle is poorly understood. The current estimates of the net flux from the biota cannot be reconciled in a balanced global carbon budget when other terms are also considered.

By coupling estimates of biotic source terms, estimates of ocean uptake, a modeled atmosphere, and in-situ measurements of the latitudinal gradient of atmospheric carbon dioxide concentration, recent analyses suggest the possibility of sink for carbon in the mid to high latitudes. This conclusion depends in part on our knowledge of the tropical source term. The temperate zone sink is computed as a residual of several presumably known factors, one being geographical location and size of the net flux of carbon from land cover change.

Closing the carbon budget will require improved estimates of the biotic source and sink terms globally. This will require annual, geographically specific estimates of land cover change and its associated influence on carbon release an uptake. This will require consideration of highly detailed new assessments at sub national resolution of areas which are actively being cleared and those areas which are being released to secondary succession. However, recent analyses in the Brazilian Amazon under support from the Landsat Pathfinder Project suggest that an inventory of areas in secondary growth are not sufficient since many of these areas are rapidly re-cycled into active agriculture. Thus, the dynamic pattern of land cover change is a central issue which will require acquisition of new data and further analysis.

4.2 Forest Inventory, Classification, and Characterization

The current distribution of forest cover worldwide is not well known or characterized. Regional stratification of vegetation and land cover types is required for most emission models. The stratification provided by a land cover map at a high spatial resolution would enable a framework for assigning variables such as biomass. This kind of map does not now exist, but programs are underway to develop them. Nonetheless, the global change research community needs to have a better definition of land cover strata upon which to layer datasets on land cover conversion and land use.

Since existing maps and databases from traditional sources are inadequate for global change research, national forest assessments, and international policy, improved data and analyses must be put in place.

Beyond the classification or stratification of land cover, it is important to have a comprehensive assessment of vegetation and land cover as it relates to the structure of forests – density, canopy closure, age, height, etc. Information on actual changes of this type are important for development of improved forest assessments as well as policy and carbon budgets.

4.3 Policy

As poorly understood are the global estimates, country-level estimates are even more poorly developed. This presents major difficulties for developing policies and mitigation strategies. For most developing countries the major source of greenhouse emissions is biogenic, rather than from fossil fuel combustion. A major new effort must be mounted to develop country-level estimates of land cover change in support of the IPCC and FCCC initiatives. To do this at a country level uniformly worldwide, it will be necessary to develop of mutually agreed methodologies for measuring land cover change, and providing improved methods for assessments and compliance.

Yet, in spite of the growing need for precise estimates of forest cover change to support both international policy and basic research, an operational program of measurement, monitoring and mapping has yet to be developed. For example, comprehensive and systematic information on the extent of forest and forest loss is not available on a global basis. The latest IPCC report considers the rate of tropical deforestation to be one of the key unknowns in global climate change assessment. Any lasting and effective implementation of a global emission inventory to support the IPCC process will require a new, concerted effort to measure and map tropical deforestation and biomass burning.

At a national level, numerous reports point to the critical need for accurate forest monitoring to support national forest management programs, particularly in developing countries where forests are an increasingly important source of foreign exchange. An accurate and up-to-date assessment of forest area and rates of depletion is fundamental to the development of improved national forest management strategies. Moreover, issues such as soil fertility and erosion, water yield, water pollution, and land use planning are directly linked to forest resource development and its management, which could benefit from such an assessment.

4.4 Convergence of Requirements to a Single Set.

A review of the individual requirements of the global change, forest inventory, and policy communities reveal a striking convergence, or similarity in scope and definition. The most complex and stringent requirements are set by the forest inventory users, with the carbon cycle community and the policy users (particularly the emissions inventory requirements) having of subset of these needs. Thus, it is possible to define a single common requirements list which satisfies a very broad range of users and at the same time focuses on the requirements for the global carbon community, forest inventory community, and the policy community.

The requirements of these three primary users resolve in three general categories:

- Forest Composition and Inventory requirements: periodic monitoring of forest extent and its structural and functional characteristics

- Forest Change requirements: frequent monitoring of changes in forest characteristics, extent and specific patterns of disturbance and regrowth

- Requirements to Support to the RAD components of the Kyoto protocols: frequent quantification of changes specific to deforestation, regrowth, and afforestation rates.

4.5 Baseline Requirements for Fine Resolution Product Suite

The Fine Resolution approach is centered on a single specific set of requirements as described in Table below.

SUMMARY OF USER REQUIREMENTS

Group	**Requirements**
Composition/Inventory	
Forest Types	Classification of forests by leaf morphology and physiognomy: e.g. needle leaf/broadleaf; deciduous/evergreen; wet/dry/montane
Species Composition	Classification of forests by dominant species
Other Types Included	Classification of wetlands, shrubs, etc.
Forest Density	Classification based on % closure: <10%, 10-25%, 25-40%, 40-60%, >60%
Age	Three classes of young, immature, and old-growth forest, or classes derived from specific multi-temporal analyses
Volume	Biomass per forest type
Forest Change	
Fire	Measurement of area and number of fires; fire intensity; residuals after burning
Harvest	Measurement of area harvested and type of harvesting including clear-cut, partial cuts, and thinning
Insect and Disease	Measurement of area and severity
Regeneration	Measurement of areas regrowing and rates of regrowth
RAD	
Deforestation	Area and rate of deforestation annually
Reforestation	Area and extent of regrowth and age of regrowth
Biomass	Carbon Stocks in Forest and regrowth
Fragmentation	Spatial pattern of deforestation, regrowth, and fragments

Not all of the baseline requirements listed above can be met with earth observation satellites, and some are more complicated than others. It is recognized that Volume data will be difficult to obtain operationally and uniformly within the GOFC time-frame, and should be considered a significant R and D effort. As well, in some forest environments, particularly the tropics, age will be a significant R and D effort. Nonetheless the current state of the practice as described in section --- above suggests potential for meeting all other requirements.

4.6 Coverage, Resolution, Frequency Requirements.

Inventory assessment can be accomplished at 50 meter resolution, but the change analyses will require very precise registration to earth coordinates and precise co-registration. This constraint will drive the resolution requirements for high resolution products to 30 meters. Global coverage is recommended, with capabilities for national and regional subsetting. The recommendation for global coverage at 30 meter resolution will drive a significant duty cycle for data acquisition, or a multi-sensor strategy. Forest inventory should be repeated every 5 years. This repeat cycle is consistent with national forest inventory needs in most countries, and is compatible with the FAO forest assessment schedule. It is appropriate for carbon cycle analyses and IPCC assessments, but more frequent – annual -- RAD measurements are required.

5.0 FINE RESOLUTION PRODUCT SUITE

In this section we outline a practical and manageable suite of products which meet the user requirements specified in section 3.

The highest priority is given to global scale applications and products, with regional and local (i.e. national) products subsetted from the global products. High resolution global monitoring has never been done before, although there have been several large area successful prototypes. The NASA Landsat Pathfinder project analyzed several thousand MSS and TM scenes to measure forest area and forest area change in the tropics. The NASA/EPS North American Landscape Characterization Project (NALC) acquired and processed co-registered triplicates of Landsat MSS data for the US and Mexico. NASDA, ESA, NASA and other partners have demonstrated the compilation of large area mosaics of JERS SAR data for the tropical and boreal forests, and ESA has demonstrated a large area multi-date mosaic for the African continent. Most experience to-date has been in image data product assembly rather than derived product production.

To maintain a global scope for the high resolution component of GOFC, it is essential that the product suite be as simple as possible, yet remaining useful and meeting the requirements of the user community. The product suite should also be built on proven techniques, methods and approaches.

The first proposed high resolution product is a Forest Cover Characterization product, produced on a wall-to-wall basis at 30 meters every five years. This product will support the requirements for forest composition and inventory with detailed classification forests based on methods which define classes based on functional characteristics. The second product is a Forest Change product which will be a global forest-non forest extent map reproduced on a wall-to-wall basis every five years. Image change detection will then be used between dates to define the specific transitions and changes: forest to non forest, and non forest to forest. In addition, forest change will be measured on an annual basis using stratified sampling between the semi-decadal complete inventories.

It must be noted that in order to produce a forward-looking stratified sampling scheme for change detection, an initial “wall-to-wall” assessment would have to made in the first 2-3 years. This initial change would define the first stratification until another assessment is made after 5 years. Thereafter the change stratification would be derived from the previous 5 year analysis. It is also important to note that the stratification scheme would be developed in coordination with the coarse resolution team, using important indicators of change as strata (e.g. fires).The product suite is specified in the Table below.

HIGH RESOLUTION PRODUCT SUITE

Product Type	Product	Description
Data Products	Geometrically Rectified Land Cover Data Product (FCGD)	Landsat, Spot, SAR image products which are referenced to earth coordinates (± 60m) by scene
	Geometrically and Atmospherically Corrected Data Products (FCGAD)	FCGD image products which have an atmospheric correction
	Mosaicked Data Product (FCMD) [optional]	Mosaiced FCGD image products (Note: precision in the FCGD products would amount to mosaicing without actually scene merging
	Co-registered Image Pairs for change detection analysis (FCCD)	Image to image registered pairs (± 30 m) at multiple dates for change detection analysis. A "wall-to-wall data product initially at t_0 and t_{+3}, then every five years.
Derived Products	Forest Cover Product (FCI)	Large area (i.e. "wall-to-wall) classification maps at 30 m resolution, repeated independently every five years
	Forest Cover Change Product (FCC)	Large area (i.e. "wall-to-wall) forest/non forest classification change product derived from change detection analysis of multi-date (initially every 3 years, then every 5 years)
	Forest Cover Change Sample Product (FCC-s)	Stratified sample change detection based on scene pairs at 30% sampling or less on an annual basis using the FCCD products

5.1 Forest Cover Product (FCI) Description

The products from high resolution observations take advantage of recent advances in developing functional classification of forest cover which are demonstrating the potential for classifications schemes with detailed classes. The Forest Cover Product classification scheme will be compatible with the coarse resolution classification scheme. This should permit a close linkage for calibration and validation, as well as inter-product and inter-scale compatibility. A general description of the product is provided in the table below.

GENERAL DESCRIPTION OF THE FOREST COVER PRODUCT

Resolution	30 meters
Frequency of update	5 years
Data sources	Mostly Landsat, with gap-filling by Spot and SAR
Mapping units	Preserve all pixels, no filters
Coverage	Global, wall-to-wall, in areas of forest identified by coarse resolution
Thematic classes	Based on 4-D matrix of leaf type, longevity, tree height, and age
Data acquisition strategy	Landsat 7 acquisitions every year, 4 times annually, focused on areas of forest cover and rapid changes, using Spot and other optical as gap filling, with SAR for gap filling.
Processing requirements	Registration to earth coordinates to $\pm$ 60 m, atmospheric correction required (coordinated with coarse resolution),

The classification scheme for this product will have to be elaborated in detail and specificity, but the recommendation is to follow the convention described in the table below in which forest types are classified based on functional and structural conventions. This proposed product is deemed both feasible and compatible with the coarse resolution team's recommendations.

SPECIFICATION FOR THE FOREST COVER PRODUCT

Leaf Type	Needle, broad, mixed
Leaf Longevity	Evergreen, deciduous, mixed
Canopy Cover %	>60, 40-60, 25-40, 10-25
Canopy Height	Trees > 2m, Tall shrubs 1-2m, low shrubs <1 m
Other Classes of Cover	Snow/ice, water, grassland, barren, built-up, agriculture, wetlands (orchards, plantations are optional)

5.2 Forest Cover Change Products (FCC and FCC-s) Description.

This product will measure and map the change in forest cover using precise image-to-image change detection methods. Unlike the Forest Cover product which will be independent classifications at different dates, this analysis will be focused on change detection. To keep the analysis simple and straightforward, the product will describe "that which is forest at t=1 and is no longer forest at t=1." The product will also report areas of non-forest which returned to forest This analysis will be conducted using change pairs 5 years apart, providing a change period of 5 years globally. The five-year period will be compatible with the 5 year period of the Forest Cover Product.

To support RAD requirements, and most of the carbon cycle requirements, an annual assessment will be completed using stratified sampling.

A forest-no-forest classification is implicit in this change product, but will be compatible with the Forest Cover Product at the five-year milestones, so changes on a semi decadal basis will be resolved into forest types, while the inter-milestone stratified samples will not (but could be inferred).

GENERAL DESCRIPTION OF THE FOREST COVER CHANGE (FCC) PRODUCT

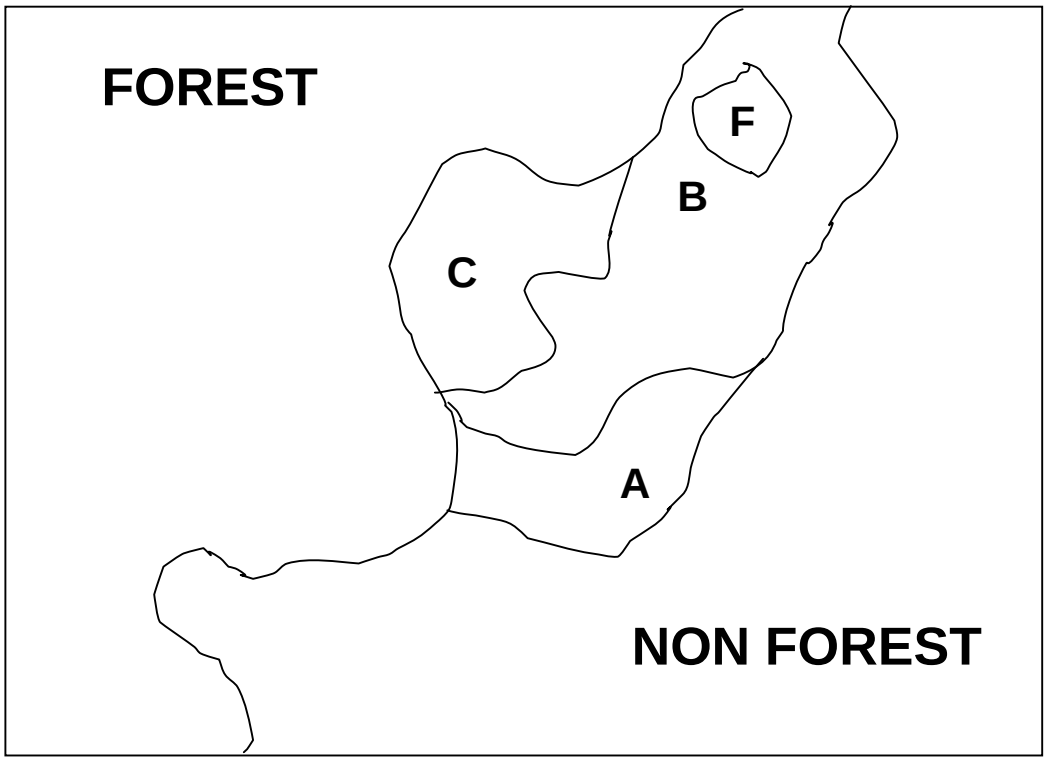
Resolution	50 meters
Frequency of update	5 years (with initial 3 year update to support the sampling product stratification
Data sources	Mostly Landsat, with gap-filling by Spot and SAR
Mapping Units	Preserve all pixels, no filters
Coverage	Global, wall-to-wall, in areas of forest identified by coarse resolution
Thematic classes	Forest, Non Forest
Data acquisition strategy	Landsat 7 acquisitions every year, 4 times annually, focused on areas of forest cover and rapid changes, using Spot and other optical as gap filling, with SAR for gap filling. *Change pairs must be of the same sensor type* .
Processing requirements	Registration to earth coordinates to $\pm$ 60 m, atmospheric correction required (coordinated with coarse resolution), *change detection using image co-registration to $\pm$ 15 m precision*

GENERAL DESCRIPTION OF THE SAMPLE FOREST COVER CHANGE (FCC-S) PRODUCT

Resolution	50 meters
Frequency of update	Annually
Data sources	Mostly Landsat, with gap-filling by Spot and SAR
Mapping units	Preserve all pixels, no filters
Coverage	Global, based on stratification sampling scheme
Thematic classes	Forest, Non Forest
Data acquisition strategy	Landsat 7 acquisitions every year, 4 times annually, focused on areas with most of the area changes, using Spot and other optical as gap filling, with SAR for gap filling. *Change pairs must be of the same sensor type* .
Processing requirements	Registration to earth coordinates to $\pm$ 60 m, atmospheric correction required (coordinated with coarse resolution), *change detection using image co-registration to $\pm$ 15 m precision*

5.3 Special Products from the Forest Change Products

Two special products are defined: (i) a Forest Fragmentation product (FCF) which identifies patterns of fragments and calculates fragmentation statistics, and (ii) a Forest Change Occurrence (FCO) map, which would be produced annually in specific high priority locations, to be determined at a later date. Because co-registration change detection permits the development of maps of forest changes on an annual basis in which the individual increments of forest-to-nonforest or nonforest-to-forest changes occur, it is possible to define the specific "patches" of new clearings and compute such metrics as the deforestation event magnitude (DEM). The DEM is the statistical measure (mean, variance, etc) of the size of individual areas of forest converted to non forest between two years (see Figure below).



The Figure is an example of a Forest Change Occurrence product. The product depicts the forest and non forest extent in a particular year, t=5, along with the DEMs for t=4 (A), t=3 (B) and t=2 (C). The Fragment, F, is also shown.

6.0 FINE RESOLUTION DATA ACQUISITION STRATEGY

The GOFC High Resolution acquisition strategy should focus on meeting the following data needs for GOFC: wall to wall global coverage every five years, up to a 30% sample of forested areas annually, and a sufficient sample of Landsat 7 ETM+ and SPOT HR VIR data to test atmospheric correction based on the simultaneity with MODIS/MISR and VEGETATION instruments and for calibration and validation of GOFC coarse resolution products. Four scenes acquired once per season are required for the global coverage data and the samples. This design advocates an acquisition strategy based on multiple sensors to ensure optimal coverage and to provide redundancy and robustness for the data and derived products of GOFC (see Figure in Annex 3 for an overview of acquisition strategy). However, it is imperative that the sensors meet minimum standards TBD in terms of calibration and quality control.

The overall approach should focus on leveraging off of existing acquisition activities for current sensors (e.g. Landsat TM, SPOT HR VIR, JERS-1 SAR, ERS-1 SAR, Radarsat, etc.) and sensors that are funded and in development for launch in the near-term (e.g. Landsat 7 ETM+, ASTER, SRTM, ADEOS AVNIR, ALOS SAR, ENVISAT SAR, etc.). Given these goals and constraints, the acquisition strategy should rely on the global archive planned for Landsat 7 with SPOT, other visible-near infra-red (VIR), and active microwave SARs providing the critical role of gap filling and hot spot monitoring. This multi-sensor approach would utilize the strengths each sensor (e.g. planned systematic global acquisition of Landsat, SPOT HR VIR pointing capability for frequent imaging opportunities, and SARs all weather imaging capabilities).

The Landsat 7 Project and Science Team has developed a Long Term Acquisition Plan (LTAP) for the Landsat 7 mission to acquire and periodically refresh a global archive of high quality (low cloud cover, sufficient solar zenith angle, with optimal gain settings) data for all land areas at least four times a year. LTAP has been designed based on a constraint of at most 250 scenes acquired per day (capacity of the on board recording and direct downlink to EDC receiving station). Given that Landsat 7 orbit would enable up to 850 acquisition of land areas per day, LTAP uses vegetation seasonality (based on 10yr AVHRR NDVI record), cloud climatology (ISCCP), and 24 hour NOAA weather predictions to prioritize scheduling in an effort to populate the archive with high quality data. Although LTAP stresses vegetation phenology and GOFC focuses on land cover and land cover change products, Landsat 7 coverage based on the LTAP should meet GOFC requirements for the initial GOFC acquisition. However, as GOFC evolves and the results of the LTAP are know, there may be a need for GOFC input into the LTAP.

Based on the historical archive of the Landsat program and ISCCP cloud climatology, there will likely be significant areas where low cloud cover data will not be available over the 5 year inventory periods for global coverage for GOFC. This is a result of Landsat's 16 day repeat cycle, periods of low solar illumination in the upper latitudes (e.g. Boreal forest where forest loss due to fire is high), and persistent cloud cover (most notably in the tropics where forest conversion rates are high). Therefore, additional VIR sensors are critically needed to provide additional coverage in these important forest zones. Given its unique pointing capability, SPOT HR VIR role in GOFC is very important. SPOT will need to be tasked to make routine acquisitions of critical areas that tend to be cloudy, thereby increasing the probability of a low cloud cover acquisition to be used in the global inventory every five years. In addition, SPOT will provide increase capability for programming targets of opportunity for hot spot monitoring. As with Landsat, the goal with these SPOT acquisitions would be to obtain at least 4 scenes acquired seasonally. Additional VIR sensors will be used to for gap filling to augment the SPOT and Landsat coverage, providing redundancy and robustness to the overall GOFC acquisition strategy.

Although SAR sensors have not been used for wide spread or routine land cover mapping/monitoring, these sensors would also play an important role in GOFC. SAR data (e.g. JERS-1 LHH, ERS-1/2 CVV, and Radarsat CHH) will be used to image areas where there are gaps remaining after the VIR acquisitions due to persistent cloud cover conditions. These areas should be imaged with the SARs at least four times per year. SAR system will also provide some important baseline datasets for GOFC (e.g. NASDA GRFM mosaics in the tropics and SRTM global DEM with 30 meter pixel spacing and 8 meter vertical postings). Use of SAR alone and in fusion studies will be an important part of GOFC research and development activities in an effort to evolve GOFC processing to better meet the needs of the user community. It is noted that the absolute calibration of SAR data is ideal for operational applications. Additional SAR data will be needed for these R&D activities.

Data from the suite of very high resolution (1-3 meter) sensors should also play an important role in GOFC. Systematic and statistically valid accuracy assessment of regional to global scale land cover and land cover change studies is extremely difficult and can be prohibitively expensive. Use of the very high resolution sensors for systematic validation should be incorporated into the GOFC validation strategy.

SUMMARY OF ACQUISITION STRATEGY AND TASKING REQUIREMENTS

Sensor	Product	Duty Cycle		Acquisition number of scenes
		Tasking	Frequency and # per yr	
Landsat 7	FCI	Global, routine acquisition	5yr, 4	28,000
	FCC	Global, routine acquisition	5yr, 1	7,000
	FCC-s	Global, routine acquisition	Annual, 1	2,100
Spot	FCI	Gap filling, targeted sites	5yr, 4	7,500
	FCC	Gap filling, targeted sites	5yr, 1	1,875
	FCC-s	Gap filling, targeted sites	Annual, 1	600
SARs	FCI	Complementary, targeted regions	5yr, 4	7,800
	FCC	Complementary, targeted regions	5yr, 1	1,950
	FCC-s	Complementary, targeted regions	Annual, 1	600
Other VIR	FCI	Gap filling, targeted sites	5yr, 4	TBD
	FCC	Gap filling, targeted sites	5yr, 1	TBD
	FCC-s	Gap filling, targeted sites	Annual, 1	TBD

Notes:
FCI=Global Forest Inventory/Classification, FCC=Global Forest Change,
FCC-s=Global Forest Change Sample

Acquisition strategy assumes that Landsat 7 will provide the backbone of acquisition by acquiring all areas on a routine and constant basis (i.e. globally, annually, season refresh), with areas of known persistent cloud cover being routinely imaged by SAR and Spot. Gaps at the end of one acquisition period (approx 1 yr) are then tasked as targets for Spot and SAR.

Acquisition estimates for Landsat 7 are based on an assumption of 14,000 Landsat scenes to cover the earth land mass, of which 50% has forest cover. For sampling, the estimate is based on an assumption of a 30% stratified sample

Acquisition estimates for Spot are based on an assumption that 10% of the areas imaged will have excess cloud cover and a success rate of 30% for these areas.

Acquisition estimates for SAR are based on the assumption that all remaining gaps (i.e. 70% of the 10%) are filled by SAR requests.

7.0 FINE RESOLUTION DATA PROCESSING PLAN

7.1 High Resolution Data Processing

GOFC should utilize data processing and analysis methods that are well established and suitable for operational use. There are several considerations to address for the end-to-end operational processing stream. The following figure illustrates a set of processing steps from data acquisition (described in detail in the previous section) through product distribution and use by the end users of GOFC data:

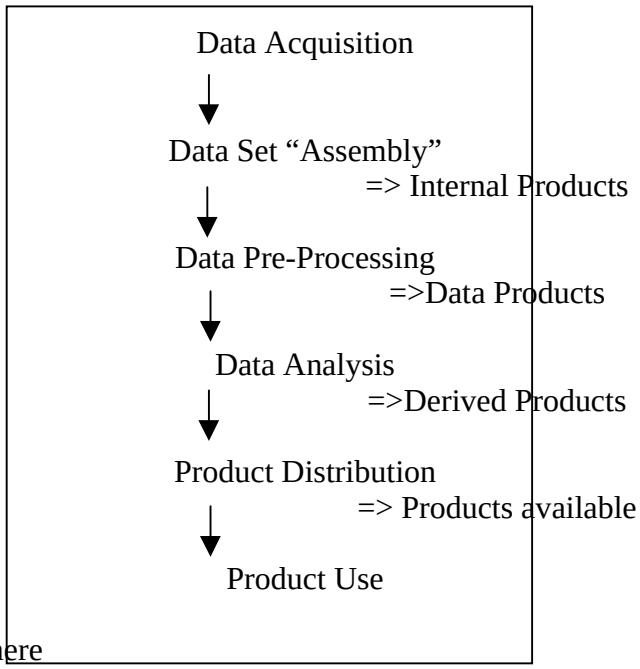


Figure: Processing Steps where

- Internal Products: interim products such as georeferenced imagery and atmospherically corrected data.
- Data Products: georeferenced, atmospherically corrected, image mosaics.
- Derived Products: forest cover and forest cover change maps and statistics.
- Products available: derived products in a standard format for distribution.

It is proposed that GOFC implement a processing model where a set of centralized facilities (e.g. DAACs, ESIPs, or Regional Data Providers) handle the bulk processing steps (including at least the data assembly and data pre-processing) and an expanded set of facilities handle the local level labeling of land cover classes and incorporation of *in situ* data. An advantage of this approach is that the computationally heavy steps of the processing stream are handled at facilities with adequate resources and where processing standardization can be assured, while fully utilizing the regional/local expertise and knowledge. The data product in itself is a very important and significant product for GOFC and is extremely useful for the GOFC user community.

In addition to operational processing, GOFC should have several research and development activities that focus on improving the current state of the art processing techniques so that GOFC evolves and produces improved products for the user community. These development activities should include, for example, improved atmospheric correction algorithms and direct parameterization of continuous variables that characterize forest function (e.g. biomass and LAI).

The objective of the data set assembly step is to bring together all high resolution data required GOFC. The guiding principle behind this step is to initially select appropriate processing centers and participants that are interested in GOFC and have sufficient technical expertise and capacity. Then develop mechanisms to ensure that each processing center receives all data needed to produce the products within their domain. This includes data from all suitable high resolution sensors and archives. For example, this step would focus on selecting the appropriate data from the Landsat 7 archive (existing level 1 data is ordered and if necessary requests to process level 0 data), SPOT global archive, and international Landsat ground stations.

The data pre-processing step should include geometric rectification, atmospheric correction, and mosaicing. Once again this step should utilize a network of centralized processing facilities where standard, proven and robust procedures are used. An effort to automate these procedures should be made. GOFC needs to maintain consistency and quality control across processing centers. Periodic intercomparisons are needed to monitor and ensure processing consistency. These pre-processing facilities need to accommodate evolution of the methods and techniques so GOFC can evolve and incorporate new pre-processing techniques (e.g. improved atmospheric correction algorithms).

Geometric rectification should focus on using automated image to image techniques with a base map/image set is the NASA sponsored Earth Satellite Corporation (EarthSat) TM data base. This EarthSat data base is being developed as part of an on going NASA data buy. The timeframe of the EarthSat activity parallels the initial GOFC timeframe, therefore, consideration of regions for initial prototypes should be made in concert with the EarthSat activity. The EarthSat data base will consist of global coverage of TM data that have been ortho-rectified (with a 60m RMS to true Earth coordinates) using NIMA DTED (3 arc seconds) data and an automated block triangulation method. The data will have 28.5 meter pixels in a UTM projection using WGS84 datum. GOFC image to image registration requires an RMS of less than 30m with a goal of less than 15m. GOFC should recognize the importance of this baseline data set and make a recommendation to EarthSat on scene selection process to improve its utility.

Several options for atmospheric correction of GOFC visible and infra-red (VIR) data exist. Two basic approaches are being considered. One method, considered the most promising and appropriate, is to utilize atmospheric correction capabilities of MODIS/MISR and VEGETATION to correct the Landsat 7 ETM+ and SPOT HR VIR data, respectively. Technical specifications for this technique will need to bet set and demonstrated to be feasible on a regional and global scale before it would be implemented in GOFC processing stream. The second method, considered as a back up, is to utilize relative radiance measurements in image overlaps to correct the data (.i.e. dark object subtraction method).

If adequate atmospheric corrections can be applied, then and only then will it be useful for GOFC to produce mosaiced data products. There are two options for mosaicing: actual or virtual (.i.e. tiling) mosaics. The most appropriate approach will depend on the derived products and capacity of the processing facilities. Since useful mosaics require high quality atmospheric corrections, which may not be always available, there needs to be some research and development to evaluate the best approach, utility and need for these mosaics. The bottom line of the pre-processing step is to produce the most viable products and processing scenario for GOFC success.

The data analysis step includes data classification and data fusion. The overall objective of the classification steps should be to simplify the data content into GOFC feature classes without losing land cover information. Considerable research and thought has gone into producing the feature classes, listed in products section of this document, for GOFC with an emphasis of developing and automated system while providing critical information needed by the user community. Additional research is need to demonstrate that classification procedures at the regional scale can handle spectral confusion due to large area coverage. There are two basic classification approaches to be considered by GOFC: supervised classification with a few very specialized classes (as was done in Boreas) or hyper-clustering approaches with knowledge based relabeling (Landsat Pathfinder HTF). Data fusion may be a necessary intermediate step in the classification process. However, it is currently unclear if fusion is required to product GOFC products. Therefore, there needs to be a research and development activity to assess the need and benefit of fused data products. Considerations for fusion should include: multiple high resolution optical data, high and coarse resolution optical data, and possibly most promising is the fusion of optical and microwave data. In addition, further research is need to develop algorithms for

extracting continuous variables (biomass, LAI, leaf area duration, and others to be defined by user requirements) from the data. There is some support for developing a longer wavelength SAR (e.q. polarimetric P-band SAR) for biomass estimation.

For the data generation and distribution steps, GOFC should adopt a guiding principle of identifying experienced and currently active groups and assessing if together they provide global coverage (an overlap is desirable), In parallel, an effort is needed to involve additional groups, especially and the national and local levels, to ensure long term operation and maximum benefit from GOFC. The product generation and distribution systems need to be sufficient where results can be produced in a timely manner (forest cover products with 2-4 years and forest cover change products within 1-2 years). To this end, GOFC needs to learn from and take advantage off of other existing programs (e.g. GRFM, LPHTF, TREES, …). If the product generation and distribution system is complete and timely, then the success of GOFC will be the basis for an on going forest cover monitoring program.

8.0 PROGRAMMATIC CONSIDERATIONS

8.1 An International Focus.

There are a number of established and nascent international programs which could be strengthened to contribute to the high resolution program. The international nature of this global program necessitates collaboration with international structures, as well as the CEOS partners. The workshop recognized the pros and cons of working with the international agencies outside the CEOS system. The suggested approach is to focus international collaboration on areas of mutual benefit to GOFC and the international participants in question.

Participation in international programs has been found to be a successful means for implementing international research and collaboration. Participation by scientists in the IGBP, WCRP and IHDP has proven to be effective in mobilizing the international research and monitoring community. The IGBP Global Land Cover Program (IGBP 1992) is a good example of potential international collaboration geared towards the generation of global land cover data. The NASA/ESA/USGS/IGBP Global 1km AVHRR data base is a good example of internationally coordinated data acquisition.

Programs of the international agencies such as the UNFAO and UNEP with the mandate for monitoring the global forest environment will certainly need to be considered with respect to international collaboration. For example the FAO Tropical Forest Resource Assessment Project provides an important interface to the national forest monitoring communities. Such projects can benefit from the proposed program as well as help the program. However in addition to the more traditional international agencies there are some emerging international initiatives which should be considered. For example START, IAI, ENRICH and GTOS are all addressing aspects of international networking and research and development with a focus on the global change research agenda. Such programs would provide a useful structure under which certain international aspects of this proposed land cover change program could be coordinated.

International funding agencies may also be interested in helping developing countries to participate in the high resolution component of GOFC. Alternatively funds to support the program might be routed through international agencies with the infrastructure to support in-country activities.

8.2 Building on Existing Programs and Expertise.

The approach proposed is to build on existing national and international programs and activities. Building on existing activities would enable the propose program to reduce the large expense associated with start-up, and would take advantage of a well-developed suite of methods and experience. A new program must move the knowledge and data base beyond the aggregate methods used in past decade. However, the development of such a system will not be a small undertaking, and therefor must build on, and where necessary expand upon, existing efforts.

In the United States, Europe and around the world experts have been building the scientific, technical, and procedural underpinnings for a land cover change monitoring system. The World Forest Watch Meeting held in Sao Jose dos Campos, Brazil (June 1992) provided a high-level international forum for the assessment of current approaches to satellite-based monitoring. This meeting also served as a basis for forwarding recommendations from the technical and scientific communities to the policy makers and government leaders at UNCED.

A variety of international participants were represented at the World Forest Watch Conference. The conference concluded that significant technical and methodological advancements have been made in recent years, and they are now sufficient for proceeding with an observation system which could satisfy both scientific and national-level forest management requirements.

In 1990 NASA began a prototype procedure for using large amounts of high resolution satellite imagery to map the rate of tropical deforestation, one of the most important land cover changes. This activity, called the Landsat Pathfinder Project builds on experience gained during a proof-of-concept exercise as part of NASA's contribution to the International Space Year/World Forest Watch Project. It focused initially on the Brazilian Amazon, and has been expanded as part of NASA's Earth Observing System activities to cover other regions of the humid tropical forests.

This project has succeeded in demonstrating how to develop wall-to-wall maps of forest conversion and re-growth. The project is now in the process of extending its initial proof-of-concept to a large-area experiment across Central Africa, Southeast Asia and the entire Amazon Basin. The project is acquiring several thousand Landsat scenes at three points in time -- mid 1970s, mid 1980s, and mid 1990s -- to compile a comprehensive inventory of deforestation and secondary growth to support global carbon cycle models. Methodology and procedures have been identified. Although this exercise is being implemented for most of the tropics, it is not an operational global program. In principle it will provide an initial large-scale prototype of an operation program. As its name implies, this project is exploratory, but it could readily be expanded to form the nucleus of a global scale operational program.

The TRopical Ecosystem Environment Observations by Satellites project (1991- 1998) is currently being implemented as a demonstration of the feasibility of applying space observation techniques to monitoring of land cover and biomass burning. This project, being sponsored by the European Commission, utilizes global coverage with coarse resolution sensor systems such as the AVHRR, which provide daily coverage over large areas. It also focuses on the use of thermal sensors for the detection of fires, and incorporates other indicators of deforestation. The project uses these data in conjunction with sample higher spatial resolution data from a range of space sensors (e.g. Landsat).

The Landsat Pathfinder Project and the TREES Project demonstrate the ready feasibility of developing a global land cover monitoring system for the tropical forests. Coverage of tropical forests must be a paramount objective of any program focused on obtaining improved estimates of emissions of carbon dioxide since 90% of the current emissions come from tropical forest regions.

The IGBP has also initiated a project to make high resolution data available to the global change research community through cooperation with the Committee on Earth Observation Satellites, the international organization of space agencies responsible for developing and coordinating policies and standards for all remote sensing satellites. This project is being initiated as a pilot study to make available each year several hundred individual scenes from Spot (the French multispectral, 20m resolution satellite), Landsat (the US multispectral 30m resolution satellite), ERS-1 (the European Space Agency's radar satellite), MOS-1 (the Japanese 50m multispectral satellite), JERS-OPS (the Japanese 18m multispectral satellite), and IRS (the Indian 30m multispectral satellite). The project is also preparing a centralized archive system in which users can mount an inquiry for data from all of the aforementioned platforms from one point.

8.3 Linkages With Other Programs

The high resolution component of GOFC would establish linkages to various organizations and communities that would be contributors to *and* recipients of data and information from the program. In addition, close linkages would be established with the user communities targeted by the program (e.g. global change research, the Framework Conventions, IPCC, national forest programs) to refine the required products from the program and to provide support in the utilization of the project output as an on going activity.

It is important that GOFC now develop a rationale organizational structure which extend outside CEOS to include user agencies, international global change research community and the global observing systems efforts.

It is also important that the high resolution component develop strong partnerships with the foreign ground stations, particularly those which have capabilities for Landsat 7 and SAR. The ground stations can serve as focal points for regional networks regional datasets which can significantly augment the on board acquisition capabilities.

8.4 Networks for Building Regional Support and Participation.

The high resolution design component recommends a strong linkage to regional networks of on-the-ground practitioners (remote sensing, forestry, global change science), through the IGBP START program and the FAO forest assessment efforts.

The most costly component of the program is likely to be the collection of ground based data and the validation of regional satellite data interpretations. These field-based activities will best be done in collaboration with national scientists and resource managers familiar with the local environment. For example the FAO Tropical Forest Assessment has successfully coordinated a network of national forest agencies to assist in the interpretation of satellite data and their validation. Similarly successful collaborations have been developed by the NASA Landsat Pathfinder Humid Tropical Forest Project. The recent START initiatives of IGBP/WCRP/IHDP also provide a means for involving foreign scientists in regional global change projects. To fully engage the scientists and organizations from developing countries it is often necessary to build capacity at the institutional level. Clearly all the resources required for such a critical activity cannot be found within the budget of this program. A more appropriate approach would be to form partnerships and linkages to those agencies with the responsibility for national level capacity building such as national and international development agencies and organizations.

9. RESEARCH AND DEVELOPMENT AS AN INTEGRAL COMPONENT

There is great promise that remote sensing techniques can be applied globally, but more research is needed to fully develop the techniques and approaches employed by existing forest cover change monitoring efforts, particularly for new regions outside the tropics, seasonal forests in the tropics, savannas, and other land cover types. The methodological issues include: development of classification techniques, objective boundary /class definitions, best means for change detection, registration and orbit navigation, and scene processing. The specific method employed may vary from region to region. It is therefore necessary to define appropriate methods for each region of interest.

The program strategy we describe calls for a combination of complete census and stratified sampling. The scheme seems to work in selected regions, but has not been fully developed for all regions of interest. A complete methodology for sampling and complete census needs to be work through for a variety of regions.

The degradation of forests is becoming an important issue, yet more research needs to be done before it will be possible to incorporate this approach into remote sensing techniques. It is feasible that satellite data can be used to quantify the areas of forest which have been degraded for selective logging. More research needs to be done in this are.

To employ several sensors in an internationally coordinated of data acquisition, it will be necessary to know the significance of using the different sensors for land cover change analysis. An inter-comparison R and D effort in which the various sensors are acquired and analyzed at common test sites would make an important contribution to the program. Initial work is now underway with the IGBP/CEOS High Resolution Data Exchange Pilot project; EPA could support and expand this effort. A clear quantitative understanding of the differences between sensors for specific applications of land cover change analysis would improve an multi-sensor acquisition and analysis program.

New remote sensing and data management technologies and methods are continually being developed. To maintain a state-of-the-art system, a program of research and development must be incorporated directly with the remote sensing activities mentioned here. In particular, development of microwave technologies could be emphasized since it has great potential as a data source which will eliminate the cloud cover problem. The strategy proposed here utilizes considerable SAR data, yet there does not exists a demonstration of large area forest/non forest mapping with SAR data in the same vein as previous demonstrations with optical data. More research is required to demonstrate SAR applications; a proof-of-concept demonstration project has yet to come.

Annex 1: List of Participants

Participant	Representing
Victor Taylor, co-chair	NASDA, Japan
David Skole, co-chair	Michigan State University, USA
William Salas	University of New Hampshire, USA
Ake Rosenqvist	JRC, Sweden
Bruce Chapman	NASA/JPL, USA
Ian Spence	Swedish Space Corp, Sweden
Liu Jiyan	Chinese Academy of Sciences, China
Rodgers Malimbwi	Sokoine University, Tanzania
Manuel Ferrao	National Remote Sensing Center, Mozambique
Jean Louis Fellous	CNES, France
Ichtiaque Rasool	IGBP
Don Leckie	Canadian Forest Service, Canada
Joe Cihlar	CCRS, Canada
Alain Podaire	CNES, France
Herve Jeanjean	Spot Image/Scot Conseil, France
Curtis Woodcock	Boston University, USA
Jim Vogelmann	USGS/EDC, USA
Jiaguo Qi	Michigan State University, USA
Diogenes Alves*	INPE, Brazil
Thuy LeTaon*	CESBIO, France
Tony Janetos*	NASA, USA
Chris Schmullius*	DLR, Germany
Dominic Kwehsa*	Forestry Commission of Zimbabwe
Eric Lambin*	IGBP
Suvit Ongsomwang*	Royal Thai Forestry, Thailand
* Could not attend, but express willingness to participate	

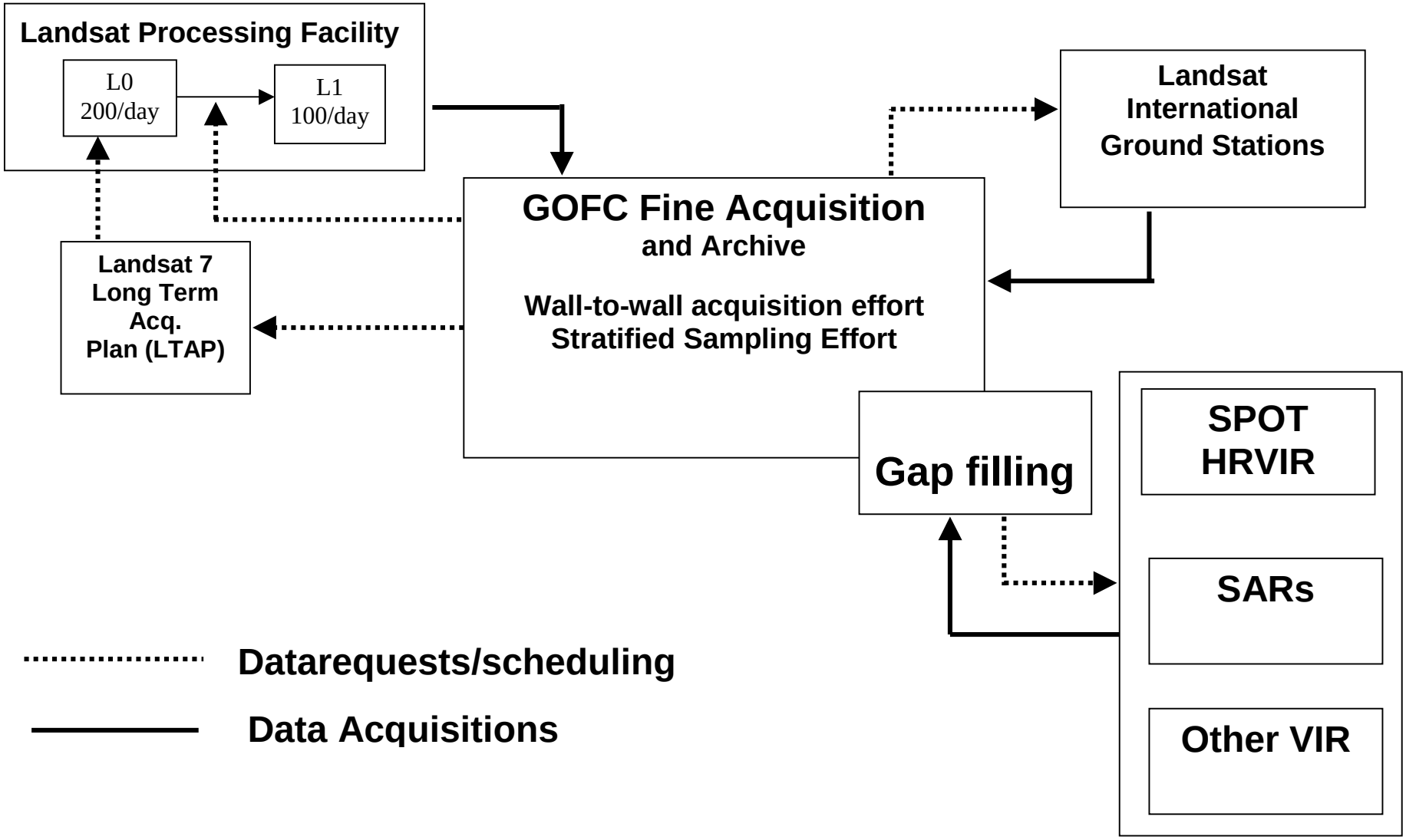
Annex 2: Sensor Suite for Fine Resolution GOFC

Potential Optical EO Sensors to Support High Resolution GOFC

Sensor	Data Coverage		Data Policy	Products
Landsat MSS - 4 bands - 57 m pixels - 185 km X 185 km	Global		Access to full-res data based on USGAU restrictions	Imagery
Landsat TM - 7 bands - 28.5 m pixels - 185 km X 185 km	Global		Access to full-res data based on USGAU	Imagery Image GCP databank restrictions
SPOTS XS	Global			Imagery
SPOT Pan	Global			Imagery
IRS LISS, I, II, III	Global			Imagery
MOS MESSR	SE Asia			Imagery
JERS-1 OPS	1992-Present: Global	Open		Imagery
JERS-2 OPS (proposed)	2000: Global	Open		Imagery
Landsat 7 (Future) - 7 XS bands - 1 Pan band - 28.5 m XS and 15 m Pan pixels - 185 km swath	1999: Global			Imagery
Spot 5 (Future)	1998: Global on demand		Open	Imagery
ASTER (Future)	1999: Global		Open	Imagery
AVNIR (Future)	2000: Global		Open	Imagery
LISS/IRS (Future)	TBD		TBD	Imagery
ALOS AVNIR-2 (future) - multichannel - 10 m resolution	2002: Global		Open	Imagery
ALOS PRISM (future) - optical scanner - 2.5 m resolution	2002: Global		Open	DEM

Potential Microwave EO Sensors to Support High Resolution GOFC

Sensor	Data Coverage	Data Policy	Products
JERS-1 - L-band; single pol - 75 km swath - 44-day repeat cycle	- 1992- Present Global	- Unrestricted access to low-res byte data over Web - Restricted access to high-res data; formal request	- Imagery
SIR-C - L, C bands; Multi-pol - 10-70 km swath - Variable repeat cycle	- April and October 1994: Global	- Unrestricted access to low-res (100 m) and high-res (20 m) data from EROS data center	- Imagery
ERS-1/2 - C-band; Single pol - 100 km swath - 35-day repeat cycle	Global - ERS-1 1991 - Present - ERS-2 1995 - Present	- Unrestricted access to low-res byte images and mosaic - Restricted access to high-res digital data; request through ESA/TREES	- Imagery
Radarsat - C-band; Single pol - Variable swath - 24-day repeat cycle	1996 – Present: Global	- Restricted access to derived data products - Digital data may be purchased from Radarsat International	- Imagery
SRTM (Future) - C-band; Single pol - Topography	1999: Global	- Restricted access to 30 m posting DEM data - Unrestricted access to 90 m data	- Imagery - DEM data
Envisat (Future) - C-band; Dual pol	2000: Global	- Researchers only	- Imagery
ALOS (Future) L-band; Quad-pol	2002: Global	- Open	- Imagery
JERS-2 (Proposed) - Copy of JERS-1 for 2000 launch	2000: Global	-Open	- Imagery
Lightsar/Echo (Proposed) - L-band; quad pol - 15-280 km swath - 20-52 deg. incidence angle	2002: Global	-TBD	-Imagery
BIOMASS (Proposed) - P-band; quad pol - 100-200 km swath - 60 day repeat cycle	?: Global	-TBD	-Imagery - Biomass density and types


Landsat Processing Facility
L0
200/day
L1
100/day
Landsat
International
Ground Stations
GOFC Fine Acquisition
and Archive
Wall-to-wall acquisition effort
Stratified Sampling Effort
Landsat 7
Long Term
Acq.
Plan (LTAP)
Gap filling
SPOT
HRVIR
SARs
Other VIR
Datarequests/scheduling
Data Acquisitions

APPENDIX 4: COARSE RESOLUTION DESIGN TEAM REPORT

GLOBAL OBSERVATION OF FOREST COVER
Coarse Resolution Products Design Strategy

September 21, 1998

1.0 GOFC Coarse Resolution Products

The Coarse Resolution Products Design Team met in Sioux Falls, SD in July 1998 to develop a strategy for generating a set of Global Observation of Forest Cover (GOFC) coarse resolution data sets. The team, listed in the report Appendix, built on the general specifications that were developed during the 1997 Ottawa GOFC meeting. During the Sioux Falls workshop, we reviewed and prioritized all products identified during the Ottawa meeting. In addition, three additional products were recommended: tree cover density, forest cover change, and active fires. The coarse resolution products, prioritized based on their relevance for science, policy, forest management, and other values, are listed in Table 1.

The discussion of priorities focused on user requirements rather than feasibility. Clearly, land cover products (global land cover, forest density, and forest cover change) and fire products (active fires, burned areas) are the highest priority and have the widest applicability. In addition, the state of processing is sufficiently advanced to permit immediate development of quality products. The other products, such as biomass and PAR, have significant research elements that must be resolved before products with the desired accuracy and precision can be developed. The rankings, therefore, strictly reflect the broader issue of user relevance.

After finalizing and prioritizing the list of GOFC coarse resolution products, the group developed specifications and processing strategies for each product. A brief summary of product characteristics is found in Table 2. The following are descriptions of the nine products recommended to represent the core set of coarse resolution products.

2.0 General Design Considerations

The strategies recommended for the development of the coarse resolution products are based on some fundamental considerations, such as:

- Products should be relevant to as broad an audience as is practical and feasible. It is particularly important that the products be designed to be relevant for carbon assessment and carbon crediting applications. In addition, relevance to national and international forestry organizations is also important.

- Product specifications should be achievable, whenever possible, with current technology (i.e., using data from sensors either currently operational, or scheduled to be operating in the coming year). The specifications, however, should also include definitions of optimal characteristics that may be achievable with advancements in future remote sensing systems.

- Research will be a necessary component in most product development strategies.

- Product specifications should be periodically reviewed and improved so that advances in methods and source data characteristics can be incorporated to improve overall data quality.

- Validation of data products is necessary to evaluate product quality, and also to identify new research priorities.

3.0 Global Land Cover Product Summaries Definitions

Three global land cover products were identified as high priority coarse resolution data sets. They are: (1) land cover; (2) forest density; and (3) forest cover change. The following sections present the definitions of each of the three land cover products.

3.1 Land Cover

The global land cover product should have two components: (1) a detailed thematic map of land cover; and (2) forest canopy density. While they are defined separately in this document, they should be viewed as linked products. The density data layer is considered to be a key part of the land cover product and it can provide information that will improve the consistency of the thematic map definitions, and will contribute directly to both scientific and international forestry applications.

The land cover product should be produced every five years, with completion of the product 12-24 months following the end of the baseline period. A separate annual forest cover change product is needed for monitoring global forest change. The highest possible spatial resolution is desirable. While global land cover with 250m to 500m resolution will have the highest applications value, in the near term a 1000m resolution data set is most practical and feasible. However, it is important to recognize the long-term requirement for higher resolution global land cover products.

The global land cover product must cover the entire global land surface and be relevant for carbon studies. The level of thematic detail should be greatest for woody vegetation (i.e., trees, shrubs) and only general land cover types are necessary for the other landscapes. This means that there will be uneven categorical detail, with 40-50 classes representing woody vegetation, and approximately 5-10 additional categories representing all other cover types. A draft land cover legend is presented for discussion in Table 3. However, before a land cover legend is adopted, it will be necessary to conduct a thorough review of user requirements. The following is a set of guiding principles that can be used in the land cover legend development process:

- The classes mapped must be relevant to carbon studies.

- Cover is based on actual rather than potential land cover.

- Compatibility with exiting legends is desirable, especially those used by national and international forestry organizations.

- A hierarchical system is desirable.

- The system must be sufficiently flexible to permit generation of forest cover products based on different canopy closure criteria.

- Mapping units must consider physiognomic characteristics. Floristic elements are less important, and biome types may be used to imply possible community composition.

- Compatibility with definitions used for the GOFC fine resolution products is necessary.

The development, testing, and evaluation of the actual land cover legend is an appropriate pilot project activity. It is necessary to test legends in an applications context in order to ensure that the product has the highest possible utility.

The methods used to develop the product are perhaps less of an issue than is the issue of source remotely sensed data. While several training procedures and classifiers have recently been used to develop global land cover data sets (i.e., Defries, et al., 1995; Loveland, et al., submitted), there is currently no clear evidence to suggest that one approach is superior to another. The selection of a methodology must therefore be based on applications issues, including degree of required flexibility and tailoring of the GOFC global land cover product, frequency of updates, and implementation considerations.

An understanding of the advantages and disadvantages of a centralized versus decentralized global land cover production model is needed before the operational strategy of the GOFC coarse resolution data set generation activity is finalized. The centralized production model, in which one organization developed the product, has advantages for scientific applications, offers greater chances of global consistency, can likely be completed at a lower cost, and may be completed in a shorter period of time. The decentralized approach is more relevant for policy applications in which it is essential that local to regional landscape conditions are most reliably represented. It also may lead to greater local and regional acceptance of GOFC coarse resolution products. However, is could be less efficient. When considering the intended applications of the global land cover product, it may be appropriate to consider implementation based on the decentralized strategy. However, this issue requires debate within a larger GOFC forum.

The decentralized strategy could consist of a series of mapping organizations with responsibility for mapping a particular continent (i.e., Africa, Asia, Australia, Europe, North America, and South America), and a strong central office with coordination, quality control, validation, data management, and other functions. The mapping organizations must be able to provide long-term operational continuity.

Because of the decentralized model, it is necessary to standardize inputs, and definitions of results. Rather than rigidly standardize methods, the group concluded that it was more realistic to establish a set of criteria that any method used in the land cover classification must meet. It will also be necessary to identify validation strategies that deal with the different error structures associated with each regional data set.

The accuracy requirements for the product must be established based on the state-of-the-practice in global land cover mapping. While past global land cover mapping initiatives such as the IGBP DISCover activity (Loveland and Belward, 1997) call for 85% accuracy, this figure is not practical for the GOFC global land cover product. The results of accuracy assessments of global land cover data sets that will be completed later in 1998 should provide an indication of reasonable accuracy

targets. Regardless of the target accuracy statements, validation results should include overall and per class statements of accuracy as well as regional area estimates for each category.

3.2 Forest Density

An integral part of the global land cover product is a forest canopy density product that provides estimates of percent tree canopy for each pixel. The density would be described in terms of percent forest cover within the pixel, varying from 0 in locations with no woody cover to 100 for locations with full canopy cover. The resolution of this product should be the same as that used in the global land cover product. This data set can also be produced in a decentralized structure, but the arguments are less compelling. Regardless, this data set must be based on a standardized methodology. This data set should be produced every five years, but will be needed within 3 months following the end of the baseline period so that it can be used in the global land cover classification process.

The land cover classification will provide information about forest type stratified according to threshold values for canopy closure. Additional information on forest density will allow comparison with other classification systems using alternate definitions and thresholds for canopy cover. A forest density layer will also allow the identification of locations undergoing changes in forest density that would not be detectable if only considering the land cover type. This information is required to monitor changes in canopy density and to assess the condition of forests. From the point of view of the scientific user, this information permits the modeling of carbon and other biospheric properties that would not be possible with the land cover layer alone.

Processing of the forest density layer, though requiring alternate algorithms, would be done in parallel to the generation of the land cover map with a 5 year frequency. Processing for the forest density layer would be done for those pixels classified as woody vegetation in the land cover map. We recommend a pilot project to compare methods for generating a forest density layer and to carry out validation of pilot products.

Several algorithms have been developed and applied to generate forest density maps on regional and global scales. These methods generally fall into three categories:

- Endmember linear unmixing. In this approach the proportion of vegetation types are deconvolved based on the assumption that the spectral signature is a linear combination of reflectances from the components within the pixel. Implementation of this method requires knowledge of reflectances of "pure pixels" from spectral libraries, field measurements, or high resolution data. This approach has been applied at regional and global scales (i.e., Adams et al., 1995; Bierwirth, 1990; DeFries et al., submitted; Pech et al., 1986; Quarmby et al., 1992; Settle and Drake, 1993). Recently methods have been applied to incorporate nonlinear mixtures (Foody et al., 1997) and multiple endmembers (Roberts et al., in press).

- Spectral regressions. This approach is based on empirical relationships derived from coregistration between fine resolution (e.g., Landsat TM) and coarse resolution (e.g. AVHRR) data. The empirical relationships are then extrapolated over larger regions to estimate percent forest density (DeFries et al., 1997; Iverson et al., 1989; Iverson et al., 1994; Zhu and Evans, 1992; Zhu and Evans, 1994).

- Calibration of areal estimates from spatial aggregation of classifications derived from coarse resolution data. These methods can be used to derive areal estimates of forest cover based on classification of coarse resolution data. The method adjusts the areal estimates taking into account the spatial arrangement of land covers at fine resolution (Mayaux and Lambin, 1995; Moody, 1998).

These methods have all been successfully applied. A comparison of these methods for selected area needs to be carried out to determine which is the most feasible in an operational context.

The forest density product should be produced in parallel to the land cover map product. Coregistration with the fine resolution product will be needed to assure consistency in results. The post-launch MODIS product generating continuous fields of vegetation characteristics provides an additional link that might useful in the implementation of GOFC.

The forest density product requires validation to provide information on the reliability of the continuum of density values. The validation of the density product may be done using methods similar to those used for the biophysical products. The forest density validation could use high resolution data and ground studies to assure accuracy. This should be carried out for a small number of selected locations.

A pilot project to test existing algorithms for deriving a forest density layer is needed to determine the methodology that provides the most accurate results and is most feasible for operational implementation. This pilot project would select a few globally distributed regions where high resolution data are available for testing.

3.3 Forest Cover Change

The forest cover change product would identify on an annual basis locations where changes in forest condition are occurring. This product would be linked with the fine resolution product so that more in-depth analysis at higher resolution could be carried out for these locations. The forest cover change product would serve as a flag for detecting change in forest cover.

A forest cover change product is needed for monitoring changes in forest extent and condition to support implementation of emission inventories related to climate convention agreements. This information is also critical for NGOs and other institutions assessing biodiversity and identifying “hot spots”. From the science user perspective, the identification of areas undergoing harvesting, deforestation, and burning are critical for assessing the carbon budget. A separate forest cover change product is needed, as opposed to comparison of classification products, because: 1) change detection methods that do not rely on successive comparison of land cover classifications are known to be more accurate; and 2) changes in forest cover need to be detected on a more frequent basis than the five years recommended for the global land cover classification product.

We recommend that the forest cover change product be generated at a spatial resolution of 250m, the resolution necessary to detect clearings and modifications of forests by human activities (Townshend and Justice, 1988). The product would be produced annually and would be compared to a baseline extent of forest cover as well as to the previous 5 years. We propose that a standardized method for deriving this product, including source data and methodology, be established by a coordinating group and that the product be generated on a continental or regional basis by various

organizations. Strong oversight is required to assure a consistent product both though time and between regions. The coordinating group would be responsible for disseminating the results.

Many methods have been used for change detection based on satellite data. Analysis of radiometric differences between dates generally provides more accurate results than analysis of difference between classification results because the latter compounds inaccuracies in the classification products. Radiometric analysis includes band differencing, band ratioing, transformed band differencing, principal component analysis, and multispectral or multitemporal change vector analysis (Singh (1989) provides a review of these methods). A key requirement for a methodology to be operational in GOFC is that the process be automated as much as possible with realistic computing resources.

A coordinating group is needed to develop a standardized method for deriving this product. The method would be implemented on a continental or regional basis by various institutions. In the initial phases of GOFC, we recommend that the change detection product focus on changes in forest extent. In the future, this would be expanded to cover other types of land cover conversion such as agricultural expansion.

The forest cover change product would be strongly linked to the fine resolution products. Identification of areas undergoing change would be flagged for more in-depth analysis with finer resolution data. It will also require linkages with the land cover map and fire scar product to assure consistency. The MODIS 250m and 1km land cover change products might serve as a useful linkage for GOFC.

A strong verification process will need to be an integral component of the method. This will involve high resolution data and a sampling strategy on the ground.

A pilot project should be carried out to select from existing change detection methods that can be operationally applied in the context of GOFC. Criteria for selecting a method include accuracy, feasibility to automate the process, and feasibility of implementing with a realistic computing resources. The pilot project would be carried out in sample areas where changes are known to occur and where satellite data are available. The pilot project would establish confidence intervals that could be obtained with change detectable algorithms. During the first year, the focus should be on the selection of the most feasible algorithms. In the second year, this would be applied to sample areas where satellite data are available and changes are known to have occurred.

4.0 Active Fire Products

The recommended GOFC coarse resolution products include the development of a global fire monitoring and fire mapping system. Two capabilities are needed. First, the system would provide the capabilities to automatically detect fires on a daily basis using 1 km (250 m to 1 km in the future) resolution satellite data. Second, 1 km (250m in the future) data would also be used to map large (> 200 ha) fire burn boundaries on a seasonal basis.

Wildfires and biomass burning are significant agents of change in forest ecosystems, can cause major perturbations of atmospheric chemistry, often result in economic upsets, and some even result in the loss of human life. There are three main contributors to global fire:

- Land use change where forests are burned to convert forests to cleared land for agricultural crops or for pasture.

- Shifting agriculture or savanna burning where grasslands are burned to improve the soil for agricultural crops or for animal forage.

- Wildfires in woodlands (e.g., temperate forests, savannas, grasslands and shrub lands, conifer plantations, and eucalypt forests) around the world.

This product should benefit countries that do not have fire detection resources or countries that have fires that occur in remote areas. It will also benefit countries that cannot mount traditional forms of fire detection using aircraft or fire towers. The product will greatly shorten the time required to map large forest fires and it will provide a mechanism for inventorying fires on an international scale.

This type of information is also required by many countries for strategic fire management planning. Fire monitoring and end-of-season fire maps would also support updating of national and regional forest inventories, annual fire statistics reporting, criteria and indicators for monitoring sustainable forest management, and fire and global change research. In addition, the data have scientific value in studies on the interaction of climate change and forest fire trends. Information on fires and related emissions is the key to address this critical issue and will have a significant impact on forest policy.

Several initiatives have demonstrated algorithms to detect active fires and reject false alarms using AVHRR satellite data (1 km resolution) as input. Algorithms have been developed by: 1) NASA/GSFC, by a team of researchers collaborating under the IGBP (Kaufman, et al., 1997), 2) Space Applications Institute of JRC (Pereira, 1998); and 3) Canada Centre for Remote Sensing (Li et al.,1997a, b, and c). With several proven fire detection algorithms that are considered to be robust and that provide similar results when applied to the same satellite data, it is possible to use more than one methodology. However, for purposes of consistency, a single methodology should be used. Rather than suggest a method, selection criteria should be developed. Then the group should consult with members of the IGBP-DIS fire project for assistance in defining this product.

Detailed post-fire burn boundary mapping would also use coarse resolution satellite data but finer resolution data sources could be used as dictated by requirements and budgets. This could be accomplished through close cooperation with the GOFC fine resolution products team.

Global, daily processing of AVHRR data is an enormous task, therefore a decentralized regional model may be appropriate for the development of these products. Considering current capabilities, the on-board recorders of the AVHRR sensor cannot store the data required to obtain global daily coverage at 1 km resolution. In order to acquire global coverage at 1 km resolution, AVHRR data would have to be captured by a network of ground stations. The JRC Fire Web project calls for various regional centers using the same software to extract active fire locations from real-time AVHRR data. In addition, the IGBP-DIS global 1 km AVHRR project currently uses a network of over 30 AVHRR ground stations (Eidenshink and Faundeen, 1994). The IGBP-DIS network, however, does not deliver data in real-time. A co-ordinated global network of real-time receiving stations is required. Each receiving station would have to be able to run the fire detection algorithm on site in order to reduce the amount of data that needs to be transferred to assemble the global fire product.

It is important to recognize that another CEOS initiative, the Disaster Management Support Project, has the primary concern for detection of active forest fires. In addition, there are several other organizations working toward operational fire products, including the IGBP, NASA's Earth Science

Enterprise, and the European Commission Joint Research Centre's Space Applications Institute. Close collaboration with these organizations is essential. Even with the activities already underway, there are still several important development issues that need to be resolved, including:

- Development of technology needed to produce operational active fire products on a daily basis. For operational fire management programs, satellite data received as late as 3:00 pm must be analyzed to produce active fire hotspots 9:00 a.m. the following day. These data must be available internationally within 2-3 days of the regional analysis.

- Development and testing of automated algorithms for burned area classification must continue.

- Evaluation of fire mapping accuracy using finer satellite data and field observations. During the pilot phase, specific fire management organizations could provide support for verification assessments.

- Refinement of fire detection algorithms based on the results of the evaluation.

- Methods for using the data in key applications, such as producing daily fuel consumption and fire emissions products.

- Development of Internet processes and security procedures to manage and distribute products to test-clients through a world wide web.

The coarse resolution fire product must be closely linked to the land cover and biomass products. Both land cover and biomass mapping must be able to account for losses of forest cover and transitional changes (vegetation recovery) in biomass following disturbance. Although this strategy proposes to deal with fire detection, monitoring and mapping using coarse resolution satellite data, it will not be practical or desirable to completely separate coarse resolution products from fine resolution products.

As stated in the Implementation Strategy, fine resolution products may be required as a means of validating the coarse resolution mapping. Validation of the fire products has an advantage over validating other GOFC products (land cover, biomass, etc.) because most countries that experience wildfires also have agencies that have a clear mandate to manage fire. Validation will require the cooperation of these national and sub-national fire management agencies. Inconsistencies between the data and regional fire management agency statistics will have to be mitigated by a program of random data checks.

Three to four pilot projects should be undertaken. These pilot studies should include areas where there is a keen international interest such as South America and Indonesia. Natural Resources Canada (the Canadian Forest Service with the Canada Centre for Remote Sensing) is about to undertake a pilot project for monitoring and mapping fires in Canada over the next two years. Australia could be a candidate for a pilot project because the fire season there is often associated with large high pressure systems that are associated with clear skies over much of the country. Another candidate for a pilot project is the USA where some effort has already been expended on this problem at home and internationally. The USA has the advantage of mounting considerable resources to address this issue and they possess one of the most advanced telecommunication networks in the world.

5.0 Biophysical Product Summaries

A suite of related biophysical products, namely Leaf Area Index (LAI), Fraction of Photosynthetically Active Radiation (FPAR), Photosynthetically Active Radiation (PAR), and Net Primary Productivity (NPP) are needed to collectively provide estimates of annual forest ecosystem dynamics and productivity. An additional product, biomass, is needed to provide an indication of overall forest carbon stocks and sequestration potential, as well as provide land use implications.

The general strategy for LAI, FPAR, PAR, and NPP is similar, as these products are all related and needed to produce NPP. Because the MODIS product generation plans will become operational during the early years of GOFC, it is logical that they be used. However, it was also recognized that there are a variety of methods being used (e.g., model inversion, look-up tables, vegetation index-based), and other potential data sources (e.g., AVHRR, VEGETATION, GLI, MISR, MERIS, POLDER) so it is practical that other approaches be monitored and investigated.

5.1 Leaf Area Index

LAI is the basic input to process-based models of net primary productivity and carbon budget. Spatially explicit LAI data can also be used to improve other models, which involve land surface processes and parameterizations (Bonan et al., 1993). It is feasible to derive LAI from satellite imagery with a reasonable accuracy (Badhwar et al., 1986; Peterson et al., 1987; Nemani et al., 1994; Spanner et al., 1994; Chen and Cihlar, 1996), and thus this parameter is the critical step toward operational remote sensing applications in areas related to weather, climate and land surface processes, as well as modeling net primary productivity.

We recommend that the functional definition of LAI used to product GOFC coarse resolution products is "one half of the total leaf area per unit flat ground surface area (m^2/m^2)". The use of one half the total leaf area rather than the projected leaf area can unify the effects of different leaf shapes on optical measurements of LAI. The ground area should be projected to the horizontal surface to consider topographical effects on the detection of LAI it nadir and other angles. The LAI product should have a resolution of 1000m. The products are needed for weekly periods and should be available within a week following the production period.

The state of LAI estimation research suggests that LAI be derived from optical data. Methods used for LAI retrieval from multi-spectral optical imagery include: (1) model inversion; (2) look-up table (LUT); and (3) algorithms based on vegetation indices (VI). Model inversion approaches can be quite accurate if detailed radiative transfer processes are considered. However, the computation demand is much higher than other methods. There is also a tradeoff between model complexity and invertibility that makes operational use of this method difficult. The LUT strategy is regarded as a simplified form of model inversion, and may be most desirable for both efficiency and accuracy of computation. VI-based approaches are empirical but can also be efficient and accurate, provided sufficient data for validation are available. All these methods depend on land cover maps with the same projection and resolution. Thus, the land cover product must include classes needed for LAI estimation.

Ground-based measurements of LAI in various biomes in different locations are needed for validation. There are several techniques of measuring LAI on the ground: destructive sampling, allometry and optical instruments. Destructive sampling is labor intensive and time consuming, and is obviously not suitable for collecting data for a large number of sites. Allometry is often species and

location specific (Gower, et al., 1997). It is also difficult to establish a suitable set of allometry of a large range of site conditions. Optical instruments hold the best promise for fast and accurate measurements of LAI and are recommended taking measurements needed for LAI validation.

Pilot projects should be conducted for a least one area in each forest biome. Possible sites include: (1) Smithsonian test sites in South America and Southeast Asia could represent the tropical biome; (2) U.S. Long Term Ecological Research (LTER) sites be considered for the temperate biome; and (3) the LAI/FPAR validation program in Canada led by Canada Centre for Remote Sensing be a candidate for boreal biome validation work. This is the minimum set of validation requirement, and multiple test sites for the same biome would be beneficial.

5.2 Fraction of Photosynthetically Active Radiation

FPAR is defined as the fraction of incident photosynthetic radiation (PAR) absorbed by green leaves in plant canopies. It is non-dimensional, and it excludes the fraction of PAR reflected back to space and the fraction absorbed by the underlying surface and non-green materials in the canopy. There is a difference between instantaneous FPAR and daily FPAR (Goward and Huemmrich, 1992). FPAR times incident PAR gives the absorbed PAR (APAR), and APAR is useful for many semi-empirical models of net primary productivity, although in process-based models, FPAR can be calculated from LAI on a cover type basis (Liu, et al., 1997). We suggest that daily FPAR be produced as standard product for the convenience of obtaining daily total PAR absorbed by plant canopies. FPAR products should correspond to weekly baseline periods and should be available within a week following production. The estimates should be 5-10% of actual PAR.

FPAR can be retrieved from multi-spectral optical imagery using the same methods listed for LAI estimation. The accuracy in retrieving FPAR is potentially higher than that in retrieving LAI because FPAR can be more accurately measured on the ground and has more direct effects on remote sensing signals than LAI. FPAR products therefore have advantages in modeling applications, although many process models prefer LAI over FPAR as input.

Consistent FPAR data sets from different biomes are needed for validation purposes. Field estimates can be obtained for a variety of portable instruments and mobile sensors. Pilot validation projects should be carried out in conjunction with LAI validation projects discussed .

5.3 Photosynthetically Active Radiation

The PAR product is also needed to calculate NPP. It is the total photosynthetic active radiation incident on a horizontal surface on the top of a plant canopy. It is in unit of either micromol/m^2/s or W/m^2. Solar radiation is the main driving force affecting all biological and physical processes in plant canopies. PAR is the main control on photosynthesis of plants. NPP is basically proportional to PAR (Monteith and Unsworth, 1990), although temperature, moisture, nutrients, etc. can considerably modify the proportionality. It is therefore crucial to improve the accuracy of this product. PAR products are to be used with FPAR products to obtain APAR (absorbed PAR), i.e. APAR=FPAR*PAR. For regional and global NPP estimation, daily total PAR is the recommended product. The spatial resolution can be considerably coarser than the associated LAI and NPP products; 0.5-1.0 degree

resolution may be adequate. The products should be available within a week following the production period. The estimates should be 2-5% of actual PAR.

Spatial distribution of PAR, either instantaneous or daily total, can be obtained from either satellite measurements or from weather prediction models. Geostationary satellites provide frequent PAR measurements for low and middle latitudes (Gu and Smith 1997), and polar orbiting satellites are useful for high latitudes but need temporal scaling methods to obtain the daily total of PAR (Li et al., 1993). Satellite-based products are generally more accurate than gridded weather forecast or reanalysis data, but programs for operational production of daily PAR at the global or continental scale have not been identified. The short-term solution would be pilot projects to validate gridded weather data using satellite imagery for selected areas and seasons.

Both satellite derived and gridded weather data need validation using ground measurements. Surface measurement data sets have been assembled and analyzed by the International Satellite Cloud Climatology Project, and these could be used by GOFC. Efforts are needed to have operational production of PAR products using satellite measurements so that the current reliance on weather prediction data can be phased out. Pilot projects could be established to achieve this goal.

5.4 Net Primary Production

Net primary productivity (NPP) is defined as the new carbon stored in vegetation (leaves, stems and roots) per unit space and time. It is the difference between gross photosynthesis and autotrophic respiration. Annual total NPP is usually reported in unit of $gC/m^2/yr$ or tC/ha/yr. NPP provides a highly synthesized measure for ecosystem performance. It is useful for both sustainable forest management and biotic carbon budget estimation. NPP is an important component in the global carbon cycle, affecting not only the carbon stored in vegetation but also the heterotrophic respiration since most of the new carbon is turned over to soils in a short time period. To understand the role of vegetation in global carbon budget and the impact of climate changes as well as vegetation feedback to the climate system, NPP is urgently needed at regional and global scales.

Both weekly and annual estimates of NPP are needed, with the products corresponding to weekly baseline periods, available within a week following this period, and having 1000m resolution. Daily calculation steps should be apparent in the products. At this point, both empirical and process-based models should be considered.

Process-based model estimation of NPP is potentially most accurate, provided satellite and ancillary data are available. Satellite imagery provides the critical spatial distributions of land cover and LAI (Running et al., 1994). Ancillary data required are soil texture (for available water holding capacity), meteorological variables (radiation, temperature, precipitation and humidity), and above-ground and below-ground biomass. The preferred data interval is daily for NPP estimation (Hunt and Running, 1992, Liu et al., 1997). Process-models use either LAI or FPAR as input, but corresponding land cover map at the same projection and resolution as the LAI or FPAR is always needed. LAI and FPAR can be converted from each other for the same land cover types. Semi-empirical methods usually relate NPP to absorbed PAR (APAR) in plant canopies, estimated as the product of FPAR and PAR. Other variables are used to modify to relationship between APAR and NPP (Prince and Goward, 1995). Autotrophic respiration in forest stands usually consumes more than 50% of the gross photosynthesis (Ryan, 1991) and is sensitive to both temperature and biomass. Biomass is therefore an important input to NPP models. As accurate biomass maps derived using remote sensing techniques

are not yet available for large areas, a short term solution is to estimate biomass from land cover types with density classes.

The ideal strategy for NPP validation is to have coincident NPP measurements with LAI/FPAR measurements. In this way, not only NPP results but also NPP models can be validated. However, NPP data available for validation are sparse, especially for forest ecosystems. Published measurements for various biomes and different time scales are very limited. NPP also vary considerably between years. Global NPP distributions from various models are often very different (Potter et al., 1993; Melillo et al., 1993; Foley, 1994; Woodward et al., 1995). In recent years, efforts have been made to obtain these measurements on small and large scales.

5.5 Biomass

The forest biomass product has a strong research component and should be viewed as evolutionary. Biomass is defined as total amount of organic matters existing in a unit area at one instance, and described by a weight of organic matters in dry condition. The unit of biomass is, therefore, g/m^2, kg/m^2 or ton/ha. Vegetation biomass includes leaf, stem, root, fruit and flower. However, the product would be limited to providing total above-ground biomass.

Biomass is one of the most important biophysical parameters which defines the carbon budget in a terrestrial ecosystem. Basically, biomass is a parameter defined at the ground level, and is measured only at the ground by cutting trees or grasses and by measuring their dry weight. Satellite observation data cannot provide direct measurement of biomass but can provide indirect estimation based on in-situ field data and on models. Biomass estimation by satellite observation is still in the research phase and the biomass product in this project has a strong research component. It is, therefore, strongly recommended that CEOS promotes parallel research initiatives to develop in-situ observation methods and to develop models relating biomass with remotely sensed data. It should be also noted that this product would be linked with high resolution products on land cover classification and vegetation density.

There have been two potential methods to estimate biomass from satellite data:

- Vegetation classification based method: In this approach biomass is estimated based on vegetation type classification and on the unit biomass value predetermined for each vegetation type which is basically obtained from the ground observation. Multiplication between the area extent of each vegetation type and the predetermined unit biomass for each type would give the estimate of total biomass. Information on vegetation age or height and vegetation density would increase estimation accuracy. High resolution SAR data may provide the parameters for each vegetation type.

- Direct observation of leaf and stem density (fresh biomass): Many investigations have indicated that there is a correlation between microwave backscattering coefficients derived from SAR data and biomass (fresh biomass) in leaves and stems of vegetation. However, correlation is usually vegetation types specific, and we need to investigate the relation between them for all of the vegetation types. The spatial scale of this approach is local at the moment and can not cover country or continental spatial scale.

We recommend that the first approach be used initially to produce the coarse resolution biomass product. In this case biomass product generation is reduced to the generation of coarse resolution land

cover product. A unit biomass database for vegetation types should be developed based on the ground observation and high spatial observation from satellite. The second approach can be implemented as a tool to determine a unit biomass for each vegetation type in a local scale. Vegetation density and vegetation height or age may be estimated from high spatial resolution data (multi-polarization and multi-frequency SAR), and be used to increase the accuracy of biomass estimates for each vegetation type. We expect accuracy within10-20%.

The spatial resolution of the product would be 250m-1000m, and cycle interval should be 5 years which corresponds to the baseline period for global land cover product.

We recommend that CEOS promote ground observation campaigns to investigate biomass estimation models and to establish a unit biomass database for vegetation types. In this campaign in-situ data relevant to biomass, LAI, APAR and NPP are collected together with the high spatial satellite data and their relations are investigated. Validation and verification processes are essential and should be carried out as a part of the ground observation campaign.

The biomass product would be strongly linked with the land cover and the forest density products at both fine and coarse resolutions. Also the basic part of biomass product generation is common with that of NPP, LAI and other relevant products, therefore, they should be linked together. It also requires the linkage between the current on-going projects such as the MODIS project and the GLI project which are going to produce similar products.

A pilot project, linked with the ground observation campaign, should be carried out at several test sites representing typical vegetation types covering different ages and different vegetation densities. The sites should be selected from the different zones including American continent, Eurasian continent and Europe-African continent. Candidate sites include the BOREAS sites, Smithsonian sites, and LTER sites. The pilot project should be jointly organized with groups on other biophysical products.

A pilot project should be two years in total, and in the first year appropriate sites are selected based on the previous works and available data for the sites are collected. In parallel to it, inventories for biomass are investigated and a biomass database is developed. In the second year biomass estimation models are developed. Also a preliminary biomass map is produced for the selected regions including the test sites.

6.0 Data Format Considerations

Data formats, including metadata, must be both compliant with appropriate national and international standards. Technical elements of data sets, such as projections and datum, must be usable within most commercial image processing and geographic information systems.

With regard to data formats, the coarse resolution design team discussed the issue of map projections for the coarse resolution products. This issue can benefit from the experience of both the Pathfinder products and the plans for MODIS product generation. After considerable discussion, the group determined that projection specialists should be consulted for advice on map projections. While a solution was not reached, several areas of consensus were reached:

- Two or more projections will likely be needed. An archive projection will be needed for product generation and archiving, and “user” projections will be needed for applications.

- The archive projection should have equal-area characteristics with minimal distortions of areas. Ideally, there should be capabilities in commercial-off-the-shelf image processing and geographic information software to reproject from the archive format. The archive projection should also provide for efficient data storage.

- User projections should be conveniently and universally handled by commercial-off-the-shelf image processing and geographic information software.

- There must be some level of compatibility between the fine and coarse resolution product projections.

The MODIS projection and the Pathfinder projections were both recognized as candidates for the archive projection. Data in latitude/longitude grids and the Mercator projection are possible strategies for the user projections. Adequate warning to caution users about the decay in data quality associated with conversions to some projections.

7.0 Other Considerations

In order to successful produce coarse resolution forest products, several critical issues must be addressed. Perhaps the most serious issue affecting the design of the coarse resolution products is the uncertainty of the availability and specifications of monitoring data (i.e., 250-1000m) from earth observations satellites. While there are some excellent candidates for the first 5-10 years, the picture becomes uncertain beyond that time. GOFC should urge CEOS members to work toward a long-term commitment for space-based environmental monitoring data. Because of this, the following recommendations should be posed to CEOS, IGBP, and their supporters:

- Continued collection of daily global AVHRR data and generation of science-quality 1-km composites, for at least two years following the successful launch of MODIS or similar coarse resolution instruments.

- A long-term commitment to 250m and 500m daily global imagery is essential for the operational success of GOFC. There is clearly a need for global data at this resolution. This resolution is especially important when considering the uses of the coarse resolution products for forest management and sustainable forestry applications, but is also central to improving the value of global forest observations for scientific studies.

Finally, to the extent technically possible, both fine and coarse resolution data should be acquired at the same times so that radiometric cross calibration and correction for atmospheric contamination can be done using similar inputs.

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Table 1. Product priorities.

Product	Science	Policy	Forest Manage-ment	Other	Overall Rank
Global Land Cover with Canopy Density	High	High	High	High	High
Forest Cover Change	High	High	High	High	High
Active Fires	High	High	High	High	High
Fire Scars	High	High	Medium	Medium	High
Biomass	High	High	High	Low	High
Leaf Area Index	High	High	Medium	Low	Medium
FPAR	High	High	Medium	Low	Medium
PAR	High	High	Medium	Low	Medium
Net Primary Productivity	High	High	Medium	Low	Medium

Table 2. Summary of Product Characteristics

Product	Information Content	Spatial Resolution	Temporal Cycle	Availability after Cycle
Global Land Cover with Canopy Density	40-60 classes of cover, with 50-60 describing forests; canopy density in percent cover	500 m	5 years	1 year
Forest Cover Change	Change, No-Change	250 m	Annual	1 month
Active Fires	Fire, No-Fire	1000 m	Daily	3 Days
Fire Scars	Burned, Not Burned	500 m	Annual	2 months
Biomass	Tons C/ha, g C/m^2	1000 m	5 years	3 years
Leaf Area Index	m^2/m^2, within 0.2-1 of actual	1000 m	Weekly	7 days
FPAR	Within 5-10% of actual	1000 m	Weekly	7 days
PAR	Within 2-5% of actual	>1000 m	Daily	7 days
Net Primary Productivity	Within 20-30% of actual	1000 m	Weekly, Annual	14 days

Table 3. Optimal classification legend for a global land cover product.

Canopy Longevity	Leaf Type	Canopy Density	Canopy Height
Evergreen	Needleleaf	Closed	Trees
Evergreen	Broadleaf	Closed	Trees
Deciduous	Needleleaf	Closed	Trees
Deciduous	Broadleaf	Closed	Trees
Mixed		Closed	Trees
Evergreen	Needleleaf	Open	Trees
Evergreen	Broadleaf	Open	Trees
Deciduous	Needleleaf	Open	Trees
Deciduous	Broadleaf	Open	Trees
Mixed		Open	Trees
Evergreen	Needleleaf	Woodland	Trees
Evergreen	Broadleaf	Woodland	Trees
Deciduous	Needleleaf	Woodland	Trees
Deciduous	Broadleaf	Woodland	Trees
Mixed		Woodland	Trees
Evergreen	Needleleaf	Closed	Tall Shrubs
Evergreen	Broadleaf	Closed	Tall Shrubs
Deciduous	Broadleaf	Closed	Tall Shrubs
Mixed		Closed	Tall Shrubs
Evergreen	Needleleaf	Open	Tall Shrubs
Evergreen	Broadleaf	Open	Tall Shrubs
Deciduous	Broadleaf	Open	Tall Shrubs
Mixed		Open	Tall Shrubs
Evergreen	Needleleaf	Closed	Low Shrubs
Evergreen	Broadleaf	Closed	Low Shrubs
Deciduous	Broadleaf	Closed	Low Shrubs
Mixed		Closed	Low Shrubs
Evergreen	Needleleaf	Open	Low Shrubs
Evergreen	Broadleaf	Open	Low Shrubs
Deciduous	Broadleaf	Open	Low Shrubs
Mixed		Open	Low Shrubs
Evergreen	Needleleaf	Closed	Dwarf Shrubs
Evergreen	Broadleaf	Closed	Dwarf Shrubs
Deciduous	Broadleaf	Closed	Dwarf Shrubs
Mixed		Closed	Dwarf Shrubs
Evergreen	Needleleaf	Open	Dwarf Shrubs
Evergreen	Broadleaf	Open	Dwarf Shrubs
Deciduous	Broadleaf	Open	Dwarf Shrubs
Mixed		Open	Dwarf Shrubs
Grasslands			
Croplands			
Built-Up			
Barren or Sparsely Vegetated			
Snow and Ice			
Water			

Appendix – List of Participants in the July 1998 GOFC Coarse Resolution Design Team Workshop

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19 August 1997

Dear Colleagues:

In February of this year, the Committee of Earth Observation Satellites (CEOS) instituted a process to plan six pilot projects that have the potential to form a foundation for an International Global Observing Strategy. The accompanying document is a framework for one of those projects, Global Observations of Forest Cover (GOFC). It is a result of a workshop held in Ottawa, Canada, on July 7-10, and subsequently revised and edited according to comments received from workshop participants. The report accompanies this email in two attachments, one in Word for Windows format and the other in Word for the Macintosh.

We are sending this report out for broad review by key representatives of potential scientific, operational, and policy users of forest cover information. We would greatly appreciate your and your colleagues' feedback with respect to the overall goals and objectives of GOFC, the proposed data products, the potential user communities, and the technical feasibility and realism of achieving the goals within our five-year window. Comments related to the potential uses that you and your organization may have for GOFC data and products are as important to us at this stage as comments on technical matters.

The next stage for the GOFC pilot project will be to respond to any reviews received within the next month, and to be presented to the CEOS Strategic Implementation Team (SIT) in Oxford, UK, at the end of September. Assuming that GOFC is viewed to be on target, final approval of the pilot project will be considered by the CEOS Plenary in Toulouse in November.

Please feel free to redistribute this letter and the GOFC document to colleagues whose insights might be useful to the project team, and who might find the concept interesting. Comments received before mid-September will be most useful in preparing for the SIT meeting. Comments received afterwards can be considered in preparing for the CEOS Plenary, and in subsequent GOFC plans. The GOFC report and this letter have also been posted on the NASA Land-Cover and Land-Use Change Program home page (http://lcluc.gecp.virginia.edu/).

Comments may be returned directly to the editors of the Workshop Report, Dr. Anthony C. Janetos of NASA and Dr. Frank Ahern of CCRS. Please be so kind as to copy both. We thank you in advance for your time and interest.

Sincerely,

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CEOS Global Observation of Forest Cover Ottawa Workshop Participants

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REVIEW DRAFT

CEOS Pilot Project: Global Observations of Forest Cover (GOFC)

Ottawa, Ontario, Canada

July 7 - 10, 1997

Editors: Anthony C. Janetos, NASA HQ and Frank Ahern, CCRS

Executive Summary

The CEOS Pilot Project on Global Observations of Forest Cover (GOFC) is defined. Six objectives are identified that satisfy the goals of the CEOS Pilot Projects, as defined by the CEOS Strategic Implementation Team (SIT). The six goals are:

(1) Produce high quality, multi-resolution, multi-temporal global data sets and derived products of forest cover and attributes;

(2) with particular attention to areas of rapid change and fragmentation;

(3) to be repeated for quantitative analysis of subdecadal variation;

(4) with associated regional applications and methodological investigations;

(5) for the benefit of multiple user communities;

(6) and ultimate transition to routine operational use.

GOFC will make maximum use of existing capabilities within the CEOS partners and affiliates. It will require additional coordination among the CEOS partners for acquisition and analytical capabilities.

A suite of potential products is defined, ranging from the actual underlying satellite data to derived products that have been defined in publications from the potential user communities. Further consultations with a variety of potential user communities will be required, to ensure that a maximally efficient allocation of resources can be achieved.

Three phases of GOFC are proposed: (1) a Design Phase, in which specific technical details of acquisition, processing, and analysis are worked out, and in which further consultation with user and operational communities are pursued; (2) a Prototype Phase, in which implementation begins, regional experiments are pursued, and the first set of experimental products are produced; and (3) an Execution Phase, in which the production and distribution of final products is achieved with new acquisitions from Earth observation sensors.

These phases then are followed by an evaluation period. The ultimate transition to operational status is planned from the beginning of the project.

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I. Introduction

Two of the most crucial roles of the Committee on Earth Observation Satellites (CEOS) are promoting the use of Earth observation data to improve the quality of life on earth, and increasing coordination and reducing duplication of the satellite programs of the member states. At its 1995 plenary meeting in Montreal, Canada, CEOS recognized the need to establish a strategic framework to determine and assess the data and information requirements for satellite-based Earth observations, and for facilitating the transition to routine operation of those research systems which have proven most useful. The plenary also recognized the need to improve the coordination of the space-based and in situ components of Earth observations, and to increase the terrestrial benefits of the Earth-observation data already being collected (Shaffer, 1996). In response to the requirements identified at the Montreal plenary, a working group to discuss an Integrated Global Observing Strategy (IGOS) was convened in March, 1996. This group recognized that the most effective means to accomplish its mandated objectives would be to identify pilot projects dealing with key areas of earth observations, and recommended the establishment of a Strategic Implementation Team (SIT) to select pilot projects and an Analysis Group (AG) to coordinate the requirements of the pilot projects and to ensure good coordination between producers and users of earth-observation data (Shaffer, 1997). The general goals of the pilot projects have been identified by the SIT:

(1)Provide a framework for a coherent set of user requirements so that providers can respond to them.

(2) Reduce unnecessary duplication of observations.

(3) Assist in the improved allocation of resources among different types of observation systems.

(4) Make possible the creation of improved higher level products by facilitating the integration of multiple data sets from different agencies, national, and international organizations.

(5) Provide a framework for decisions on continuity and spatial comprehensiveness of key observations.

(6) Identify situations where existing international arrangements do not exist for the management and distribution of key global observations and products.

(7) Assist in the transitioning of systems from research to operational status through improved international cooperation.

(8) Provide improved understanding for Governments on the need for global observation through the presentation of an overarching view of their capabilities and limitations.

SIT held its first meeting in Irvine, California, in February, 1997. The attendees identified six pilot projects of vital importance, whose execution is expected to advance the CEOS objectives stated above. The Canadian Space Agency (CSA) and the Canada Centre for Remote Sensing (CCRS) agreed to co-lead a pilot project on Global Observations of Forest Cover (GOFC), with the U.S. National Aeronautics and Space Administration (NASA) agreeing to play a strong supporting role (Guertin, 1997).

Recognizing its potential importance to a wide spectrum of users, this program was subscribed to by numerous space agencies including CSA/CCRS, NASA, ESA, INPE, CNES, EUMETSAT, NASDA, and ASI. It has also been endorsed by representatives of GTOS, GCOS, TOPC, EC, and FAO. However, a program of global observations of forest cover is also recognized as very challenging, requiring coordination of acquisition and analysis of data from satellites from many nations operating in the visible, infrared, and microwave regions of the spectrum. It also requires considerable input of in situ data and local knowledge of land cover characteristics. Ultimately, the GOFC is envisioned to lead to a routine operational capability for the observation of changes in global forest cover and its attributes.

II. Objectives of the Pilot Project on Global Observations of Forest Cover

As a contribution to the implementation of an ongoing global forest monitoring system that will meet specific needs of international conventions, global observing systems, national institutions, and supporting research, GOFC will

(1) Produce high quality, multi-resolution, multi-temporal global data sets and derived products of forest cover and attributes;

(2) with particular attention to areas of rapid change and fragmentation;

(3) to be repeated for quantitative analysis of subdecadal variation;

(4) with associated regional applications and methodological investigations;

(5) for the benefit of multiple user communities;

(6) and ultimate transition to routine operational use.

These six objectives will enable the Pilot Project to conduct an end-to-end test of many aspects of the space-based observational systems (including data systems) that will be required for an operational IGOS. It will also enable the CEOS partners to evaluate how their space-based observations can effectively be coupled to in situ data, and how data products can be provided effectively to several important user communities.

III. Scientific, Policy, and Resource Management Needs

The potential user community is extremely diverse. In many ways, the GOFC must assist communities of users in extracting the maximum information available from remotely sensed data, and from its combination with in situ data. Likewise, the various communities of users

themselves can provide essential guidance to the GOFC to focus on those products and data sets that are of the most benefit to them, in order to guide the efficient allocation of resources, and prepare most effectively for the transition to operational status. It will be critical in both respects to build on those programs that already exist for the production and analysis of data on forest cover and attributes. There is an explicit desire to learn from the vast experience available in the remote sensing, in situ, research, and operational communities.

A. Issues

(1) Global Change. There are three pathways of relevance for global change and forest lands with implications for the CEOS project. The first is the interaction of forests and the atmosphere: regulation of the hydrologic cycle and energy budget, with implications for weather and climate prediction. Understanding these interactions is a crucial part of the global change science agenda. The second is both a scientific and policy issue: the implications of changes in forest land for the atmospheric carbon dioxide budget. Are forested lands net sources of carbon or net sinks of carbon? What are the rates of deforestation and reforestation? What are the implications of changes in fire frequency? The third pathway is the potential impacts of climate change: what effect will changes in temperature, precipitation, and concentrations of carbon dioxide and other radiatively active gases have on forest composition, health, and distribution, and therefore on the economic activity that are generated by forested lands? What feedbacks might these changes have to the climate system itself?

(2) Biodiversity. Concern over the rapid, human-driven loss of biodiversity worldwide is rapidly mounting. The extent and condition of forested lands are central issues to the preservation and sustainable use of biodiversity. Both forest loss and forest fragmentation have been implicated in losses of biodiversity by the scientific community. On the other hand, many national programs for sustainable forest management are now incorporating biodiversity as one of the attributes to be enhanced and maintained.

(3) Timber, fuel, and fibre. For centuries, human society has depended critically on the continued supply of wood and fiber (primarily for making paper) from forest land. Many societies have declined after depleting their forest resources. The twentieth century has produced substantial improvements in the efficiency of production of wood and fiber from forests. Increasing populations and increasing literacy and affluence in the twenty-first century will continue to put increasing demands on the forests of the world. Continued improvements in management will be necessary to meet these demands without depleting the forest resource.

(4) Watershed Protection. Forested areas and other wooded lands play a crucial role for terrestrial hydrological systems. These areas constitute the most important buffer zones for both run-off and infiltration to ground water reserves. The actual location and size of forests in relation to the watershed often determines the run-off fraction of the precipitation and becomes the dominant factor in flood and erosion prevention. A close monitoring of forests in relation to the hydrographic network thus becomes a critical issue in physical planning, landscape planning, and environmental protection in all regions of the world.

(5) Recreation and Tourism. Forests provide habitat for wildlife, and opportunities for recreation and tourism. In many countries, the direct economic return from these activities approaches the return from extraction of wood and fibre. Many other countries want to increase the benefits they derive from recreation and tourism. Information obtained from Earth observation data can aid in the strategic planning for recreation and tourism in forested areas.

(6) Sustainable Forest Management. Sustainable forest management has become an extremely important philosophy, along with ecosystem management, to guide the plans of land-managers (both public and private) for the use of forested lands over the next several decades. Sustainable forest management recognizes the multiple benefits provided by forests, and strives to respond to the needs and wants of the multiple stakeholders who benefit from the forest, while conserving its resources so future generations can also benefit from the forest. Earth

observation data, in conjunction with geographic information systems, provides exciting new opportunities to engage a broad spectrum of stakeholders in long-term forest management planning.

B. User Communities

TheGOFC planning group has identified several policy-level issues and potential user communities that together provide the core set of requirements for data sets, derived products, and subsequent analyses. Table 1 illustrates those user communities that have clearly articulated their observational requirements for forest information. Table 2 shows with more specificity the type of products that each community requires.

Table 1: Status of Requirements for Issues and User Communities

Issues

Global Change and Resources Management | *Biodiversity* | *Forest Health* | *Sustainable Forest*

User Communities

Scientific Community X (X) Y Y

International Environmental Conventions and Agreements (X) (X) (Y) (Y)

International Policy and Operational Institutions X (Y) X X

National Institutions X (X) X X

Key

X: Published requirement statements

(X): Relevance clear from published documentation of issues

Y: Requirements published on national and regional levels

(Y): Requirements in early stages of development

Table 2: Core Requirements of Major Users

.	GCOS and GTOS	International Conventions	Science	IPCC	Other International Users	National Users
Baseline land cover	X	X	X	.	X	X

Land cover change	X	X	X	.	X	X
Land cover coarse resolution	X	X	X	X	.	.
Net Primary Productivity	X	X	X	X	TBD	X
Biomass	X	.	X	X	X	X
Fires	X	X	X	X	TBD	X
Harvest	X	X	.	X	X	X

(1) Scientific Community. The International Geosphere-Biosphere Programme (IGBP) and World Climate Research Programme (WCRP) have each articulated clearly the urgent need for comprehensive, spatially explicit, global data sets on forest cover and attributes. Several projects in the International Geosphere-Biosphere Program (IGBP) and the World Climate Research Program (WCRP) require information on global forests. The IGBP Land Use and Cover Change (LUCC) project has critical needs for high-resolution information on land cover and change. Information on biomass, fires, net primary productivity and land cover change is essential for the the IGBP International Global Atmospheric Chemistry (IGAC) project . The IGBP project on Global Change and Terrestrial Ecosystems has strong requirements for land cover, land cover change, leaf area index (LAI), and net primary productivity (NPP) data sets. The Biospheric Aspects of the Hydrological Cycle (BAHC) project has essential needs for land cover, biomass, LAI and NPP data sets. The Global Eenrgy and Water Cycle Experiment (GEWEX) has essential requirements for several forest data sets including land cover and cover change, LAI, biomass, and fires. Several Framework Activities (IGBP Global Analysis and Integrative Modeling, IGBP-Data and Information System, ISLSCP Initiative II) have especially strong scientific requirements for such forestry data. Furthermore, numerous regional programs such as the Amazon LBA, the European FIRS, and others have essential requirements for most of the above mentioned data sets. Individual national scientific programs, such as the US Global Change Research Program, and the Canadian Global Change Program share these requirements, and place a high priority on the production of such data sets.

(2) International Environmental Conventions and Agreements. The major conventions concerned with global forests are the Convention on Biodiversity, on Climate Change, and on Desertification. Their core information needs are those quantifying major changes in the distribution and function of forests over time. Some of these can be met with Earth observation data, and are in general consistent with those discussed below for the GxOS's. The Framework Convention for Climate Change, the Biodiversity Convention, the Forest Principles agreed to at UNCED, the Helsinki process, and many others all have a shared need for information on global forests. This need is most explicit in the scientific assessments that are either part of the Conventions and other instruments themselves, as in IPCC, or have been commissioned independently of them, as in the Global Biodiversity Assessment. The specific national requirements of the FCCC for the development and monitoring of national emissions inventories, and the international discussions of carbon trading, will require accurate and replicable assessments of forest cover at both national and international levels. The reporting requirements of the Biodiversity Convention for assessing national biodiversity and habitat, likewise require accurate information on forest cover, fragmentation, and change.

(3) International Policy and Operational Institutions. The Global Observing Systems incorporate scientific, operational, and policy-level concerns at both international and national levels. They have already indicated their strong need for global forest cover information and information on forest attributes, primarily through the report of the Terrestrial Observations Panel for Climate

(TOPC), a joint GCOS-GTOS activity. The Global Terrestrial Observing System (GTOS) and the Global Climate Observing System (GCOS) are the major clients in this area (GCOS 32). GTOS requires detailed land cover and land cover change information for many purposes, including the assessment of land use and its impact on the natural ecosystems. Information on forest harvest is also an important input in this process. GCOS requires information on land cover (coarse resolution) for GCM modeling and model validation; for carbon, water, and energy modeling; and for the assessment of climate impact. Both GCOS and GTOS require information on net primary productivity as a fundamental parameter linking the terrestrial and the atmospheric systems on the one hand, and the natural and economic systems on the other. Both also require knowledge of forest biomass and fires as major parameters that quantify the distribution of the economically valuable timber and the effect of major disturbance agents.

In addition, organizations such as FAO, UNEP, and UNDP each have strong requirements for global, regional and national-level information on forests and forest resources that the CEOS pilot project can help provide.

(4) National Institutions. Countries are interested in their forests because of the value of the forests for their economies and because of the environmental values of forests, both nationally and internationally. Some countries are increasingly concerned about the impact of the environmental movement on the economic utilization of the forest resource, and for this and other reasons have begun to actively pursue initiatives aimed at tacking and reporting on the forest condition and changes in their countries. Land cover, cover change and biomass are fundamental ‘state’ attributes for this purpose. Net primary productivity, harvest and fires are the most ubiquitous change agents at the global level. Damage by insects and disease, and various forms of pollution are often important nationally and locally. It should be noted that the degree to which a global product meets the needs of individual countries will vary depending on the information sought. For example, the global products for fires, biomass, net primary productivity and land cover at coarse resolution are more likely to meet the needs of individual countries than those for detailed land cover or land cover change. This distinction suggests various possible mechanisms for collaboration between the global project and individual countries, including a contribution to product development and validation, the development of new, more detailed or tailored products to meet the specific national needs, and technology transfer and capacity building.

Many national-level forestry ministries and environmental ministries are in the midst of planning efforts to transition from management of forested lands with the primary goal of timber production to sustainable management of forest resources, combining production of forest products with watershed protection, tourism, recreation, and other non-exploitative uses. In addition, the proliferation of international agreements with implications for forests has created new pressures on national institutions to respond with accurate and timely information. Regionally, countries whose forests contribute substantially to the national economy are cooperating to develop criteria and indicators of sustainable forest management.

C. Satisfying Requirements

It is important to note that while the CEOS pilot project perceives that these issues and user communities will find the products to be important, it cannot expect to satisfy all the demands of all potential users. Instead, there is a core set of requirements that can be substantially fulfilled by the products we have outlined. Other requirements can be addressed, but may not be completely fulfilled by the first set of planned products. However, we leave open the option of further activities in a later phase to define new sets of products that might satisfy additional requirements.

All of the users identified above are generally non-commercial scientific and educational organizations, or governmental or intergovernmental organizations dedicated to the public good. We also clearly anticipate that there may be commercial interests in the Pilot Project outcomes as well. Therefore, it is important to emphasize the expectation that derived products from the

Pilot Project will be widely accessible and available without discrimination.

It is also clear that many users may wish to derive their own, tailored products from the underlying data used in the Pilot Project. The existing CEOS principles for non-discriminatory access to data should enable all users to search well-organized Pilot Project archives. The Pilot Project will seek to work with data providers to ensure that all data used in the project are organized in such a fashion that they can be accessed and distributed according to the national policies that govern their use.

IV. The Current Experience Base

Over the past ten years, the remote sensing community has developed an impressive array of projects dealing with global, regional, and local forest-related issues. Projects have been implemented in North America, Europe, Asia, and South America that have examined such issues as tropical deforestation, forest cover mapping, forest health and vigour, and the extent of inundated forest. As a result, there is a broad spectrum of lessons to be learned for the planning and implementation of the Pilot Project.

A. Existing Programs and Data Sets

The approach adopted is to build on existing national and international programs and activities. Around the world, experts have been building the scientific, technical, and procedural underpinnings for a forest cover change monitoring system through joint space agency initiatives. The Ottawa workshop recognized that some of the components of the program already exist. Rather than duplicate such efforts, wherever possible, the approach would be to integrate these existing studies into a broader programmatic framework.

(1) World Forest Watch. The World Forest Watch Meeting held in São José dos Campos, Brazil (June 1992) provided an initial high-level international forum for the assessment of current approaches to satellite-based monitoring. This meeting also served as a basis for forwarding recommendations from the technical and scientific communities to the policy makers and government leaders at UNCED. A variety of international participants were represented at the World Forest Watch Conference. The conference concluded that significant technical and methodological advancements have been made in recent years, and they are now sufficient for proceeding with an observation system which could satisfy both scientific and national-level forest management requirements. One important outcome was the Panamazonia Project, in which Brazil shared its proven technology for mapping deforestation in the Amazon region with its neighbors who share the Amazon Basin. These countries were subsequently able to produce deforestation (Martini, 19??).

(2) Landsat Pathfinder. NASA, in conjunction with the EPA and USGS, began a prototype procedure for using large amounts of high resolution satellite imagery to map the rate of tropical deforestation, one of the most important land cover changes. This activity, called the Landsat Pathfinder Project, builds on experience gained during a proof-of-concept exercise as part of NASA's contribution to the International Space Year/World Forest Watch Project. It focused initially on the Brazilian Amazon, and has been expanded as part of NASA's Earth Observing System activities to cover other regions of the humid tropical forests.

This project has succeeded in demonstrating how to develop wall-to-wall maps of forest conversion and re-growth. The project is now in the process of extending its initial proof-of-concept to a large-area experiment across Central Africa, Southeast Asia and the entire Amazon Basin. The project is acquiring several thousand Landsat scenes at three points in time -- mid 1970s, mid 1980s, and mid 1990s -- to compile a comprehensive inventory of deforestation and secondary growth to support global carbon cycle models. Methodology and procedures have been identified. Although this exercise is being implemented for most of the tropics, it is not an operational global program. In principle, it provides an initial large-scale prototype of an operation program.

(3) TREES. The TRopical Ecosystem Environment Observations by Satellites (TREES) project is currently being implemented as a demonstration of the feasibility of applying space observation techniques to monitoring of land cover and biomass burning. This project, being sponsored by the European Commission and executed by the Space Applications Institute of the Joint Research Centre (Ispra, Italy), utilizes global coverage with coarse resolution sensor systems such as the AVHRR, supplemented with data from the ERS-1 SAR. It also focuses on the use of thermal sensors for the detection of fires, and incorporates other indicators of deforestation. The project uses these data in conjunction with sample higher spatial resolution data from a range of space sensors.

The Landsat Pathfinder Project and the TREES Project demonstrate the ready feasibility of developing a global land cover monitoring system for the tropical forests. Coverage of tropical forests must be a paramount objective of any program focused on obtaining improved estimates of emissions of carbon dioxide since 90% of the current biogenic emissions come from tropical forest regions.

(4) IGBP 1 km Land Cover Mapping Project. In conjunction with NOAA and the USGS, NASA has been supporting an IGBP project to acquire global, daily coverage with the AVHRR sensor at 1 km resolution. This project is the first of its kind to acquire global, daily coverage. The resultant dataset is being processed at the EROS Data Center and provides the basis for mapping land cover, vegetation phenology, and fires. As part of a land-cover mapping exercise, this project will also develop a multi-level set of land cover maps ranging in spatial resolution from 1 degree down to 2 km.

(5) IGBP High Resolution Data Set. The IGBP has also initiated a project to make high resolution data available to the global change research community through cooperation with CEOS. This project is being initiated as a pilot study to make available each year several hundred individual scenes from SPOT, Landsat , ERS-1, MOS-1, JERS-OPS, and IRS. The project is also preparing a centralized archive system in which users can mount an inquiry for data from all of the aforementioned platforms from one point.

Participation in international programs has been found to be a successful means for implementing international research and collaboration. Participation by scientists in the IGBP, WCRP and IHDP has proven to be effective in mobilizing the international research and monitoring community. The new joint core project of the IGBP and IHDP on Land Use and Land Cover Change (LUCC) could greatly benefit the proposed program (IGBP 1993). Similarly, the IGBP Global Land Cover Program (IGBP 1992) is a good example of potential international collaboration geared towards the generation of global land cover data. The NASA/ESA/USGS/IGBP Global 1km AVHRR data base is a good example of internationally coordinated data acquisition.

(6) FAO Forest Resource Assessment. The FAO Forest Resource Assessment for the 1990 period (FRA-90) used a combination of earth observation data and national statistics to derive statistics about forest cover for the 1990 datum, and forest cover change for the period 1980 to 1990. For tropical forests, FAO developed a technique called the Interdependent Interpretation Procedure, which relied primarily on a two-date interpretation of large scale photographic prints of full Landsat scenes. Using training centres in Latin America, Africa, and Asia, FAO was able to train local interpreters and obtain consistent results. The resulting change classes also allowed FAO to estimate transitions between several woody biomass categories for Africa, Latin America, and Asia (FAO, 1996). The FAO Forest Resource Assessment Project provides an important interface to the national forest monitoring communities. Such projects can benefit from the proposed program as well as help the program.

(7) GAP Analysis Project. The GAP Analysis Project is a land cover mapping project being carried by several consortia of U. S. federal and state agencies, led by the U.S. Geological Survey. The purpose is to infer wildlife habitat from land cover, and identify habitats in not adequately represented in conservation lands. The project has obtained a large amount of

valuable experience in catalyzing inter-institutional cooperation, and in processing and classifying large volumes of Landsat data according to varying standards developed by user agencies.

(8) Multi-resolution Land Cover Characterization. A good example of a regional /continental scale land cover mapping study is the recently completed USFS /USGS US Forest Cover Map. This map was produced using the 1km AVHRR data set generated by Loveland (1992). A similar effort is being undertaken in Mexico with the help of in-country collaborators. An Interagency Multi-Resolution Land Cover Characterization (MRLC) project, implemented by the USGS on behalf of a number of federal agencies, is generating land cover data sets for the conterminous US. This data set includes products from coarse and high spatial resolution satellite sensors. This project also provides complete coverage of the United States with TM data.

(9) North American Landscape Characterization Project. Datasets from Landsat, SPOT, AVHRR and other sensors with global and national coverage have created opportunities to exploit data in ways not possible just three or four years ago. For example, the North American Landscape Characterization (NALC) Project is acquiring and processing complete coverage of the continental United States and Central America with Landsat MSS data at three points in time from the 1970s to the present.

(10) The Global Rainforest Mapping Project. The Global Rainforest Mapping project is being developed jointly with NASDA, EU/ESA, and NASA/JPL to utilize JERS1 coverage of the tropical forests. The project is acquiring complete coverage over the tropical belt, as well as several repeat coverages to capture season effects. It has focused on data acquisition for mapping forest change and flood area inundation in flooded forests. This mission is now being extended to cover the boreal forests as well in collaboration with CSA.

(11) Radarsat. The Canadian Radarsat program has acquired complete global coverage in the ScanSAR mode during its initial phase of operations. An associated PI research program was initiated to demonstrate applications, including applications to forest are research. Research to date has shown Radarsat to hold promise for mapping logging and deforestation in tropical and boreal forests, and for monitoring macrophyte growth in tropical reservoirs and floodplains.

(12) Landsat - 7. Landsat - 7 has become part of NASA’s Mission to Planet Earth, and will fly in formation with EOS AM-1, enabling researchers to obtain low and high resolution images of the same area on the same day. MODIS data will enable atmospheric corrections of Landsat data to become operational for the first time in the program. The data price will be much lower than the previous commercial price, and there will be no copyright restrictions. A data acquisition strategy which incorporates data needs, local phenology, and local climate and weather, combined with an on-board solid state data recorder capable of recording 200 scenes per orbit are expected to provide global coverage which is more consistant and useful than in the past. These changes in policy and strategy will make it much easier to achieve the GOFC objectives.

(13) Regional Activities. Regional Activities have been initiated in recent years which could be coupled to the program outlined here for in-country work. Within the IGBP System for Analysis, Research and Training (START) a number of regional activities focusing on the land cover change question have begun. Most notable is the Southeast Asian regional activity which is directly linked to the EPA Pathfinder project in that region, as well as the aforementioned IGBP LUCC and High Resolution Data Exchange projects. START/Southeast Asia has initiated a Land Use and Cover Change (LUCC) program in two components: (a) a complete region-wide analysis of deforestation trends in the region, and (b) specific case studies established in four participating countries: Thailand, Malaysia, Indonesia, and the Philippines. The case studies, conducted primarily by local experts and scientists, provide a prototype example upon which to build in-country work. The Thailand Country Study is already a component of the START/LUCC activities in Southeast Asia.

B. State of the Art

(1) Technical Progress. Considerable technical progress has been made during the past five years in assembling large data sets from both high resolution and coarse resolution sensors, and in extracting information from these data sets. Increasing computer capability to move, store, and track massive amounts of data has been an essential enabling technology. Most of the coarse resolution studies have used AVHRR data. Researchers have developed methods for geometrically correcting the data and creating single-date mosaic images and multi-date composite images which are relatively free of geometric errors and radiometric artifacts. The TREES project and the IGBP 1 km Land Cover Mapping Project have both produced land cover classifications of large fractions of the world, while other efforts have produced land cover classifications at the national or continental level. Validation efforts are now underway for all of these products.

The Landsat Pathfinder program has enabled several organizations to develop methods to collect and assemble datasets of 30 m resolution data covering areas as large as the conterminous U.S. and the Amazon Basin. This experience has also pointed up the difficulties in collecting and correcting data from the existing Landsat data archive, and stimulated improvements for Landsat-7. The lack of accurate base maps to correct data of resolution below 100 m, coupled with the lack of high resolution DEM threatens to limit the accuracy with which high resolution data can be corrected and superimposed.

A significant number of researchers and operational users of both coarse and high spatial resolution data appear to be converging on a common approach to digital classification of multispectral/multitemporal optical data: numerical clustering of the data into a large number of data clusters (typically 50 - 100), followed by merging and labeling the data clusters into desired thematic classes. The merging -labeling step is carried out by interpreters who are knowledgable about the land areas being studied, and seems to combine the best characteristics of digital and visual classification at the current time. This process is still very laborious, and digital image classification will be an important consideration for GOFC.

Research with L-band (JERS-1) and C-Band (ERS and Radarsat) SARs has build upon experience gained with airborne SAR missions and the SIR-C/XSAR mission to provide confidence in the use of SAR for GOFC. While the thematic content of single-band orbital SAR is not as great as that of optical sensors, the ability to cover large areas in a preplanned, systematic manner was recognized as a very important operational advantage at the Ottawa workshop. Techniques for systematic geometric correction (except for terrain correction, where DEM data can be a problem) and radiometric calibration of SAR data are becoming highly automated. The Global Rainforest Mapping Project has gained considerable experience in assembling JERS-1 mosaics of large areas, and the routine radiometric calibration of the data is so good that no further radiometric processing of the mosaics is necessary.

(2) Institutional Progress. The IGBP and the Global Observing Systems have created well-functioning international bodies to ensure ongoing dialog between the producers of Earth observation data and the scientific community addressing the very difficult global issues facing humanity. Most of the projects described in section IV A. have created temporary or permanent inter-institutional linkages which have functioned well. The World Forest Watch, the FAO Forest Resource Assessment, and the GAP Analysis Project have demonstrated different ways to extend Earth observation technology to a multitude of users, particularly those involved in natural resource management planning. However, at a higher national and international level, the link between the information which can be obtained from Earth observation data and the formulation of policy has not been as well established.

C. Gaps and Lessons

Some common lessons have been learned from the above-described projects.

(1) Data Acquisition, Access, Pre-processing and Management. A systematic global data acquisition plan is necessary and requires the contribution of multiple ground receiving stations. Data have to been processed in standard format and well-documented in the catalogs. A comprehensive metadatabase including all the high spatial resolution sensors' images would be an important improvement for data access. Within the project, an automated information and archive management is required.

(2) Product definition. Achievable products, not overly ambitious, must be defined. They must be explicitly targeted to specific user requirements. Legend definition and analysis design require the contribution of a large panel of experts near the very beginning of the project. It is essential to document explicitly the forest classes and propose a correspondence between the sensor-based classes and the ecological classes.

(3) Data analysis. Operational data analysis must be based on existing and proven methods rather than relying too much on R&D. Data analysis methods can combine visual interpretation and digital classifications. For land cover change, a control mechanism is needed in order to check the consistency between the multi-date analyses and avoid excessive error propagation. Change information may be more reliably obtained by classifying two-date datasets than by comparing two single-date classification. A multi-resolution approach will allow the Project to exploit the complementarity between high and low resolution data: a sampling scheme of high resolution is optimized using low resolution data as a stratification, while high resolution data can correct the areas derived from low resolution data. Particular attention will be given to a validation schemes. Products' validation may be performed through comparison with immediate finer resolution data, i.e. fine resolution products can validate low resolution products, field observations can validate fine resolution products. National experts should contribute as soon as possible to the product validation.

(4) Product distribution. Open access to final products and validation sets is a key point for the success of the project. It can be achieved though WWW, CD-ROM or paper maps and reports. Continuing user support will be needed.

V. Framework

A. Strategy

The Pilot Project is anticipated to have an overall lifetime of approximately five years, with initial test products being available within the first three. It anticipates several categories of outputs: basic scenes, specific time frame products, and change over time products.

(1) Raw data (Level 0) and corrected scenes (Level 1B). These represent composites of the basic raw data for all sensors covering all forest land areas of the globe. Data products at this level would enable users to undertake projects to contribute to preparation of global products identified in Table 3, as well as products that fulfill specific national and/or regional needs above and beyond those identified in Table 3. This level of product preparation is viewed as an absolute minimum in terms of project success.

(2) Specific Time Frame Products. This is the preparation of products of global forest cover and characteristics identified in Table 3 for specific years or time periods. These data sets essentially would represent the status of forest land cover and forest characteristics at specific points or windows in time (ie T1990, T1995 or T1980-90 or T1990-95).

(3) Change Products. This is the preparation of global forest cover and characteristic products identified in Table 4 that show the change in these parameters over time. (ie. T1995-T1990).

Most of the data acquisition issues follow directly from the primary project objective. Test products from the design and prototype phases (see Section VIII) are anticipated to be largely regional, and based on existing, available data sets. However, near the end of the prototype phase, the project will begin the production of derived products from new acquisitions. Thus,

global and regional data sets are required from the present generation of spaceborne imaging optical and microwave sensors and their near-term successors, in conjuction with concurrent in situ data. The CEOS members will need to coordinate their respective strategies for the related future global-scale satellite acquisitions in order to acquire such data systematically and effectively. Particular organisational efforts may be required where an international network of ground receiving stations is involved.

For efficiency, the acquisition strategy should exploit the complementary capabilities and information content of optical and microwave sensors to address specific thematic issues on appropriate time scales:

Optical Sensors providing both high spatial and thematic resolution, based on well-established methodologies, under suitable acquisition conditions.

Microwave Sensors providing all-weather acquisition capability, at high spatial resolution and frequent revisit rates, but low thematic resolution, and utilising analysis methodologies which will necessarily evolve throughout the project.

Validation plans will be formulated and implemented as feasible so that users of both raw data and derived products will know their accuracy. Feedback will be solicited from users to refine derived products in order to maximize their utility.

B. Simple Global and Detailed National Products

It is anticipated that the global information needs in most cases are less detailed or specific than national or local needs. Hence, flexibility in data resolution and product specifications is both a requirement and a benefit of this project. Preparation of products at three levels provides this flexibility. Where specific user needs are more specific or detailed, the Level 1B data should allow users to develop products at the level specific to their needs and requirements. At the same time using a common agreed upon global format or classification should allow more detailed national and regional information to be rolled up to meet the basic global requirement. Hence, the more simple global needs can be met while at the same time providing the flexibility to meet more detailed national and local needs and requirements.

C. Product Identification

(1) CEOS Level 0 and 1B Products. The Appendix presents the lowest level products, characterized as level 0 and 1B CEOS products. These products are basically “raw” (level 0) data or data to which calibration and geometric processing are applied (level 1B). They will not be discussed further.

(2) CEOS Level 2 Products. Table 3 contains level 2 products that are obtained from level 1B data, but are based on more complex processing techniques, like classification algorithms or functional dependencies, and may require in situ or ancillary information to be developed. (Global Climate Observing System, 1997.)

High Spatial Resolution Land Cover: These high spatial resolution derived products are georeferenced data sets describing the predominant forest types that can be used as a baseline inventory for long term evolution studies. The temporal coverage of this data will be less than that of mid-low spatial resolution land cover products. The total global number of classes could reach 50 or more. They will include various wooded ecosystems : temperate and tropical forests, savanna, and others. These products may be derived from various sensors.

Mid-Low spatial Resolution Land Cover: These mid to low spatial resolution derived products can be updated more frequenty than the high spatial resolution land cover products due to the sensors data acquisition cycles. The total global number of classes could reach 40 or more.

Fires: Fire is a primary force of vegetation change/renewal in some ecosystems. It is important

to monitor fires in the context of a forest monitoring program with respect to their role in global trace gas emissions, land conversion, ecological disturbance regimes, and land management. Data products will consist of fire occurrence and burned area, providing the location, timing, and areal extent of burning.

Harvest, regeneration, and afforestation: It is important to distinguish between land cover change due to clear cutting and selective logging. Harvesting, regeneration, and afforestation are some of the most significant anthropogenic changes that occur in the forest. These often occurs in similar locations from year to year.

Biomass: This product will largely depend on in-situ field measurements and other ancillary data. Earth observation data cannot provide direct measurements of biomass, but may be used to extend local estimates to larger areas, with varying degrees of confidence.

LAI, FPAR and PAR : NPP can be derived from these products.

Table 3: Level 2 Products

Product	**Sensor**	**Accuracy/ Optimal/ (minimum)**	**Resolution(m) Optimal/ (minimum)**	**Cycle interval Optimal/ (minimum)**	**Delivery wait Optimal/ (minimum)**	**NOTE**
Fine Scale Land Cover	Optical high spatial res & Microwave	50 classes (20 classes)	10-30 (100 ? or 1:1.000.000)	3yr (10yr)	2 yr (5 yr)	Classes TBD according to region MW mostly in gaps
Coarse Scale Land Cover	Optical mid-low spatial res & Microwave	40 classes (20classes)	250-1000 (or 1:5.000.000)	1 yr (3 yr)	1 yr (3 yr)	Idem May be used as a component of hte "coarse" Changes assess
Fire Scars	Optical mid-low spatial res & Microwave	2 classes[2] (2 classes)	250-1000 (4000)	1 yr (1yr)	1 month (6 months)	Not an active fire monitoring product
Harvest	Optical high spatial res Microwave	3 classes[3] (2 classes)	10-30 (50)	3 yr (10yr)	2 yr (5 yr)	needs ancillary data and in-situ observations

Biomass	microwave and insitu and ancillary data and mid-low spatial res	10%of measured value (20%)	100 (1000)	10 yr (20 yr)	2 yr (5 yr)	requires ancillary data and in-situ observations; very difficult product
LAI FPAR PAR	optical low-mid spatial res	0.2 (1) absolute 5% (10%) 10% (20%)	250 (2000) 250 (2000) 1000 (4000)	10d (1mo) 10d (1mo) 6 h (12hr)	10d (10d) 10d (10d) 1d (2d)	NPP is generated from these parameters

(3) CEOS Level 3 Products. Table 4 contains the proposed Level 3 products. Table 4 contains one level 3 product at the present stage, which consists of a land cover change product that requires multitemporal data and a more sophisticated classification scheme. We propose to limit the land cover change measurements to regions at high risk of disturbance, because land-cover change only affects part of the global forest. This stratification can be achieved by starting with coarse scale indicators (fires, population, logging concessions, etc.). The land cover change measurements can be based on sampling strategies or exhaustive mapping in sensitive regions.

Table 4: Level 3 products

Note: Classes for this product shall represent change. Sampling may apply. To be linked to low resolution land cover and fires.

Product	Sensor	Processing level/Accuracy	Resolution (m) Opt (min req)	Cycle Opt (min req)	Delivery Optim (min req)
Land Cover Change	Optical high spatial res + Microwave	10 classes (among Use-use, Use-Regr, Regr-regr, For-Use) (4)	10-50	1 yr (5 yr)	1 yr (5 yr)

(*) future mission

D. Data Bundles For Users.

The Pilot Project will also undertake to enhance the value of derived products for particular user communities by providing them as part of a data bundle. These bundles are collections of data and derived products which particular programs or users can use most effectively to fill a particular need, thus cutting down on the provision of data that are non-essential to that need.

The example below shows how the data bundling might work to meet the requirements of the Framework convention user community. A bundles is proposed for emission inventories, which focuses on data for land-cover change and biomass burning. Multiple sensors are required to produce these complete packages, and CEOS can therefore play an important role by providing coordination and cooperation in acquiring and processing data from different sensors, platforms, and programs.

Here we provide an example as it might be done for emission inventories, and carbon cycle

research. An Emission Inventory data bundle is shown below.

TARGETED CEOS DATA BUNDLE
BUNDLE NAME: Emission Inventory
USER: Framework Convention on Climate Change, IPCC, IGBP

Dataset	Horiz. Res.	Cycle	Tmeliness	Accuracy	Etc...
L.C. 1	---	---	.	.	.
L.C. 2	.	.	.	.	.
Fires	.	.	.	.	.
Biomass	.	.	.	.	.
etc	.	.	.	.	.

Input Data Sources from Archive

Input Data	Source/Sensor	Sp. Resolution	Temp. Res.	etc
Deforestation, decadal	Spot, TM, IRS	10-50 m	5 yr	.....
deforestation, annual	spot, TM, JERS	10-50 m	1 yr	_
Logging	JERS, Radarsat	10-30 m	5 yr	_

Acquisition Strategy
Data Processing Bundle

This data bundle provides a package which includes the 5 data products necessary to make an emission inventory as well as the bundle of requisite satellite sensors; it provides a framework for plugging in datasets as objects, and provides a framework to define CEOS partners participation. It also couples the acquisition strategy directly to the products and the user/science requirements. Finally it couples a data processing bundle which include the algorithms, data distribution mechanisms, formats, and information systems necessary to produce the data archive and the products.

VI. Methodologies

A. Sensors

A preliminary list of sensors relevant for the project has been identified. The focus of the Pilot Project is on those systems that are either currently in orbit, or are funded and in the development cycle for launch within the next several years. There are clearly many other missions that might become available within the next decade, but they are beyond the scope of the current Pilot Project.

(1) Optical coarse resolution sensors (1km - 200m)

Exisiting: AVHRR,ATSR, Resource MSU-SK, WiFS

Near-term : AATSR, SPOT Vegetation, MODIS, GLI, MERIS, MISR,POLDER,SEAWIFS, CEBRS WFI Camera

(2) Optical Fine resolution sensors (200m - 15m)

Existing :SPOT/HRV, IRS/LISS II, Landsat 5/TM, MOS/MESSR

Near-term: SPOT4/HRVIR,Landsat 7 ETM+, ASTER, ADEOS AVNIR, CEBRS CCD Camera, Resource MSU-SK

(3) SARs (fine-resolution 150 - 20 m)

Existing: ERS1,ERS-2,JERS-1,RADARSAT

Near term: ASAR,ALOS,SRTM, Lightsar?

(4) Hyper-resolution Optical sensors (0-1m)

A very limited set of data from these sensors could contribute to validation.

B. Data Access

The procedural aspects of data access deal with metadata formats and data browsing and query systems on the one hand, and the delivery elements of timeliness, medium and means on the other hand. The Pilot Project will investigate a unified system of metadata maintenance and integrated mechanism of cataloguing, querying and ordering. Integrated systems may be ensured by remote sensing data distribution and access networks such as EOSDIS and CEONet currently under development. Although a unified system of metadata maintenance may be sufficient to provide the first level of information on a data set, the availability of a quick-look facility at the browsing and query stage may be highly desirable to know the quality of the data before these can be ordered.

The delivery elements that need to be taken into consideration are the turn around times covering the data ordering, data reception/archive retrieval, data processing and data transmission cycle. Agreements on standardization of delivery medium are important in view of the variety of strategies adopted at various output centres. The means of delivery are wide ranging, but need to be verified for each of the mission participating in the project.

C. Data Pre-Processing and Management.

All data provided for the Pilot Project should be pre-processed in a standardized way in order to maximize the amount of automation that is feasible.

Concerning the data management, the lessons learned with the CEOS initiative ‘High Resolution Data for IGBP’ show that it is crucial that there be clear responsibilities and accountability for data management and distribution within the Core Project. Tools will be required to compile the metadata to make up a Global Forest metadata base. A tool for inventory tracking has to be designed and implemented at this management level and probably also in each producing center. The project archive could be distributed among the various producers and consulted through a interoperable catalogue. A documentation system (web site, CD-ROM, etc.) will be created.

D. Analysis

The aim of the analysis is to produce global datasets of forest cover and attributes.This will involve integration of data from a number of satellite instruments to provide global coverage at appropriate resolution and timescales. A key issue to be addressed by this project is therefore harmonisation of methods and results to ensure global consistency and comparability.

The outputs desired are anticipated to require two forms of analysis. The first is direct production of a thematic classification of forested areas, while the second requires modelling of the data to

derive information on forest functioning.

(1) Thematic Classification. Methodologies for thematic classification of forest from coarse resolution satellite information (eg TREES) and fine resolution (eg Landsat pathfinder) have been an active research area for many years. Results from microwave seonsors have also demonstrated distinguishing forest, inundated forest, and non/forest with high temporal coverage. The number of classes envisaged and the useful spatial resolution implies that considerable analysis of fine resolution satellite data will be employed. It is anticipated that data from a number of fine resolution sensors will be required in order to obtain adequate cloud-free coverage. A key issue to be resolved is how to combine the results of classifications resulting from different instruments, particularly with respect to analysis of change detection. The coarse resolution instruments have the capacity to provide information at higher temporal scale, giving more opportunity to use phenology in class seperation, and to optimise the acquisition strategy for data processing. For the production of thematic classes, ancilary data will be required in order to identify categories such as dominant tree species.

(2) Derivation of information on function. The estimation of the net primary productivity (NPP) requires a model of ecosystem function. Driving variables in addition to the classification information are LAI, fPAR as well as ancillary data on downwelling PAR, temperature etc. Information for forest functioning models is required at a much higher temporal resolution than the classification (at timescales of one hour to ten days). Accordingly, while an accurate classification of land cover is needed, these applications will mostly require coarse or moderate resolution data. Currently, a number of models exist specified for different ecosystems, and there is not a consensus on best methods to invert the necessary parameters from remote sensing observations. It is recommended that accuracies from different platforms are made comparable, and that assimilation techniques are developed similar to those routinely employed in meteorology. Further ancillary data are required to both drive and validate model function, and to derive parameters such as biomass.

E. Ancillary Data

Several types of ancillary data will be needed for the pilot project both for data pre-processing, satellite data analysis and product validation. For example data processing of the coarse resolution data will involve the use of coarse digital terrain data to provide first order atmospheric correction and improved geolocation for coarse resolution data sets used in classification. The existing global 1km topographic data set will be adequate for meeting these needs. Similary a common land water classification and mask will be needed for the coarse resolution data products. An enhanced land water mask for use with coarse resolution systems, derived from a combination of microwave and moderate resolution sensing systems available in the near-term would provide a desirable improvement over the current data base derived from the best available map sources. The development of a standard ‘community’ land water mask derived from multiple sensing systems would be a useful CEOS contribution to this activity.

For the individual sensor products and the multi-resolution integration there will be the need for the data products to be presented in a common geographic coordinate scheme. This will have to be developed early in the project. For high resolution, the availability of a new high spatial resolution satellite derived digital terrain data towards the end of the project will provide the possibility of improving high resolution analyses in areas of complex terrain.

The use of information from non-satellite sources will play an important role in the development and evaluation of the satellite derived products. This information will be for example in the form of existing maps, air photos, and field data. In some cases these data will be used as part of the classification process to train the classifiers, in other cases they will be used to test the accuracy of the thematic products. For example as part of the high resolution accuracy assessment, sample geolocated field data will be needed. The development of the sampling strategy will need to be developed as part of the design phase of the project.

In situ data on biomass is part of the product suite. In this context it is seen as a primary data source rather than an ancillary set. The combination of satellite data and in-situ biomass data will provide the necessary spatialisation needed for the biomass product.

F. Product Validation

Product validation will be critical part of the project, providing the user community with a level of confidence concerning the results provided. It is important that the accuracy of the various products be stated quantitatively and explicity. A set of procedures for validating coarse resolution global land cover data sets is being piloted by the IGBP-DIS global land cover project. The procedures include a rigorous statistical core sample supplemented by a series of confidence sites where existing information are readily available. Regional scientists provide an important part of the product validation. High resolution products are used to validate the coarse resolution products.

Validation of high resolution data products will be performed by a combination of hyper-resolution data (3-5m) and precisely located field data collection. We expect that CEOS affiliates will play an important role in product validation.

The relationship of the global products and associated validation activities of this project to the GTOS/TOPC GHOST network of field sites and the relevant product validation activities of the different space agencies need to be established early in the project. For example forest test sites within the GHOST network could play an important role in the pilot project validation. The relationship of this pilot project validation activity with respect to the on going CEOS calibration/validation activities also need to be determined.

It is important that the validation data be packaged in a usable form and made available along with the products and their associated accuracy statements. A mechanism should be established to allow for users to provide feedback on product accuracy.

G. Product Distribution

Products should be distributed to user communities including scientists, policy makers and other operational users as promptly as possible in different ways and through different media. In particular, reporting to policy makers is of great importance. Several different scales and levels of data should be provided such as global, continental, national, and if possible sub-national so that policy makers can evaluate the state of the environment in their particular areas of interest, thus making informed decisions possible. In some cases products will be distributed with appropriate interpretation to policy makers so that they can understand the products in the context of the information that they require.

The Internet is a very efficient way to distribute derived products and information about products and data to users. However, other media will also be taken into account in order to satisfy users without reliable access to electronic networks. Alternative media includes CD-ROMs or other digital media, and paper prints, maps, and reports. Some users will require access to the actual underlying satellite data. In most cases, network delivery of such data is difficult, and tape or other media may be preferable. Table 5 illustrates several of the possible combinations of users and types of distribution.

Table 5: Product Distribution

Scale	Media			
Global/ continental	*National*	*Sub-national*	*WWW*	*Digital*	*Paper*
Users					
Scientists	X	X	X	X	X

Policy X X X X
makers

Operational X X X X X
users

VII. Implementation Issues

A. Management

(1) Oversight by CEOS. CEOS will provide programmatic and technical oversight to the Pilot Project. This function includes evaluation of Pilot Project performance, and an evaluation of the degree to which the Pilot has been successful in addressing the needs of targeted user communities.

(2) Project Team. The Project Team will come initially from the CEOS members and affiliates, using whatever national or programmatic mechanisms each institution has at its disposal. In addition, early in the life of the Pilot Project, a concerted effort will be made to identify and incorporate team members from national and international forestry and environmental organizations, so as to ensure that there is broad representation from both providers and users of data. The first tasks of the Project Team will be to form a Design Team to specify the technical details of implementation for the first phase of the project.

B. Data Issues

(1) Satellite Data Access and Redistribution. The participants at the Ottawa workshop agreed that GOFC will benefit from liberal data access policies, that is, data which are available at minimal cost and with minimal restrictions on re-distribution. However, they recognized that satellite data policies vary between CEOS members, and that members may insist that data made available for GOFC be subject to their established data policies. All scientific members of the project require access to the data for analysis and publication of results. The project team will also share satellite data for which additional processing has been performed.

(2) Ancillary and In Situ Data. All data will be calibrated. Ground calibration data will be made available within the project team. All products generated also require the inclusion of ancillary data for analysis, such as topographic data. For some regions there will be available additional geographic information layers. Each member of the project team will have full access to these additional ancillary data sets. The project team will maintain a catalog of all data acquired, and its distribution.

(3) Analytical Techniques. The products to be created from IGOS project activity should have clear statements on their accuracies. The products should be unbiased estimations of forest properties. The project team will fully document the analytical techniques used for each product. These analytical techniques will likely vary from region to region, and consistency of results on a global basis is an important goal of the project.

(4) Communication. The project team members will communicate electronically on a free basis. A variety of methods for electronic communication with CEOS, the user communities, and the public will be developed. In addition, there are expected to be many major publications in the open, reviewed literature, and internal publications and reports for the CEOS members and affiliates themselves.

(5) Public Communications. Given the high public interest in the state of the forests and environment, it is essential that results of forest observation be widely communicated. Press releases should be prepared for publications which are widely distributed, and to television and radio networks. The high visual content of our public information is appealing to the public. The project team should also create CD-ROMs with integrated data and products which can be provided to the public and to educational institutions. The project team should give consideration

to the creation of videos about regional and global forest cover and changes in forest cover.

C. Additional Research Opportunities

The Pilot Project is not perceived as a primarily research-oriented exercise. It is an experiment in operational capabilities. At the same time, it is clear that there are many research opportunities which may benefit project planning and execution. Some of these are outlined below.

(1) Hyperspectral. Optical sensors with large numbers of channels will shortly be launched. Sample data sets from space and airborne platforms will be available.

(2) Very High Spatial Resolution. Several commercial spacecraft are planned which will have resolutions of the order of one meter. There are methods for recognizing individual trees from such data. Such data can also be used to assess selective harvesting, partial cuts, and regeneration, and provide information on site characteristics.

(3) Polarimetric and Interferometric SAR. An important advance in microwave sensors is the creation of SARs with multiple frequencies and full polarization. Polarimetric SAR data sets and interferometric SAR data sets are available for sample areas.

(4) Lidars. In addition to their contribution to atmospheric measurement, lidars can be used for measuring tree heights and for creating DEMs. During the lifetime of the Pilot Project, sample lidar data sets are planned to be available.

D. Recommendations from the FAO representative with respect to the workshop process and resolutions.

Although the need for a global integrated (source) data set specifically designed for the observation of forest resources is fully endorsable, in view of the potential benefits to all user groups and on-going forest monitoring programs, the specifications of derived global products should be the result of a wider consultation process that includes representatives of all user communities identified under section III B of the Workshop Report. This is particularly important for the product based on high resolution data which would provide crucial information on land cover/forest cover state and change at national and sub-national level with consequent important strategic contribution to national planning operations.

The initial phase of the proposed pilot project will include a mechanism of thorough user consultation in order to define their priorities, propose suitable mechanisms of participation/consultation and better define product specifications. Such consultation should include, as a minimum, forest management/planning institutions' representatives from major "forest" countries (Russian Federation, U.S.A., Brazil, Indonesia, Democratic Republic of Congo [former Zaire], etc.), and International Policy and Operational Institutions (FAO, UNEP, UNDP, World Bank, etc.).

VIII. Schedule of Activities

A. Overview

The Ottawa workshop in July 1997 has provided the first kick-off for the GOFC project. Participants in the meeting represented a wide spectrum of international experiences with forest-related programs. There were also representatives of several potential user communities. However, all participants recognized that this was only a beginning. There are many strategic and technical issues that remain to be worked out before the GOFC can be regarded as fully implemented.

B. Project Phases

There are three main phases that have been identified, with several follow-up activities.

(1) Design Phase (1 year). The first year of the GOFC, beginning with project approval, will be devoted to a series of detailed design studies. These would include workshops on specific technical issues, e.g. to analyze the acquisition strategies for existing and planned remote sensing missions. Design studies might also include paper studies by selected study teams, or comprehensive literature reviews, and specific methodological intercomparison studies, e.g. studies comparing different classification methodologies using identical data sets. A specific need during the Design Phase will be a broader outreach effort to potential user communities, and specific planning for an eventual transition from the pilot phase to routine operational status for the GOFC. The ultimate goal of the Design Phase is to produce a detailed implementation plan that incorporates all the design issues. Deliverables will include a series of publications, project reports, and the data sets from intercomparison studies.

(2) Prototype Phase (2 years). This phase can be regarded as the initial implementation phase. This is the period during which the details of preprocessing, data handling, analytical procedures, etc., which have been planned during the Design Phase, will actually be tested for their operational practicality. Current experience shows clearly that design studies, while necessary, cannot anticipate all the eventualities of having to cope with large data sets in a routine manner. The Prototype Phase anticipates this difficulty, and provides the opportunity to work with large data sets in a mode analogous to what will be necessary with new global acquisitions. During the Prototype Phase, a series of regional pilot studies will be performed with existing data sets, which will be expected to produce the first sets of products and product bundles identified in previously, but for periods from the late 1980's and early 1990's. During the latter part of the Prototype Phase, new data from remote sensing systems should begin to become available (e.g. the first few months of MODIS data). These data could then be used to ensure that all the data handling systems for GOFC are operational.

(3) Execution Phase (2 years). The Execution Phase builds on the experience gained through the Prototype Phase. During this last phase of the GOFC, new data acquisitions are incorporated into the GOFC analytical system, analyses performed by the project team, and new products generated and distributed. The acquisitions for the Execution Phase will likely begin during the Prototype Phase, because of the time necessary for processing and analysis. Products and product bundles will be generated for the late 1990's and early 2000's. Validation studies will also be begun during the Execution Phase, although it is not clear that all of them can be completed during this time. However, the conduct of validation studies will be part of the overall evaluation follow-up activities. The full suite of evaluation activities will then prepare the stage for transition activities so that GOFC can become part of routine operational scenarios.

IX. References (to be completed)

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Shaffer, L. R. 1996. "CEOS Holds Meeting on Integrated Global Observing Strategy", CEOS Newsletter No. 7, September, 1996.

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Appendix: Level 0 and Level 1B Products

Product	**Sensor**	**Processing level/ Accurarcy**	**Resolution (m)** (as provided by sensors)	**Cycle** Optimal (min req)	**Delivery** Optimal (min req)	**NOTES**
Level 0 Optical High Spatial resolution	TM/SPOT/ IRS/CBERS (*)	No processing	10-30	0.25 yr (3yr)	1 w (1 m)	–
Level 1B Optical High Spatial res	TM/SPOT/ IRS/CBERS (*)	Radiom. corr "System" corr.	10-30	3 yr (10 yr)	30 d (1 yr)	Cycle TBD in acc. w Microwave
Level 1B Optical Mid-Low spatial res	AVHRR ATSR RESURS DMSP MODIS/MI SR (*) SPOT Vegetation (*)	Radiom corr First order geometry corr	250-4000	1 d (2 w)	1 d (1 m)	–
Level 1B Microwave	ERS JERS RADARSA T SRTM (*) Light SAR (*) ASAR (*)	Radiometric and geometric Calibration	10-100	0.5 yr(2yr)	6 m (2yr)	Cycle TBD in w Optical High - may be mosaicked or tiled - may be terrain corrected

Optical High spatial Resolution: In order to generate and archive complete global coverage of the world’s forests will require systematic acquisition of data year-round. Data acquisition strategies will require coordination with microwave data acquisition plans to insure complete coverage. Data access strategy and formats should be defined. Small swath widths and cloud coverage may pose problems to acquire complete coverage within limited time.

Optical mid-low spatial Resolution: This dataset will contain areas covered by clouds. It is envisaged that a low cost processing system could be put into place that could make radiometric and first-order geometric corrections within a day. Large swath can assure global coverage

everyday.

Microwave: For the microwave level 1B data, we recommend that the data be 1) either seamlessly mosaicked or tiled, and 2) be calibrated. Whether or not the data are mosaicked or tiled will depend on the sensor and available resources for performing that task. If feasible, the data should be terrain corrected for geometric and possibly radiometric distortions. Terrain correction will require a DEM of sufficient resolution, accurate knowledge of the imaging geometry, and the processing capability to perform the correction. Data that are not terrain corrected will be geometrically and radiometrically distorted in regions of varying topography. SRTM, planned for launch in 1999, will produce a map of the world's topography between +57 and -57 degrees latitude that could be used for this purpose. Observations should be coordinated with optical high res data acquisitions to permit data fusion and synergy between these sensors. Since microwave sensors are not affected by cloud cover, they will play an important role by filling in gaps in coverage by optical sensors. However, current single-channel microwave sensors do not provide as much spatial detail and thematic content as high resolution optical sensors.

Summary of GOFC Design Team Meeting, Washington, DC, 1998/01/29-30
Overall Strategy, Design Team Tasks, and Schedule

Overall Strategy

1. Engage users to define/confirm requirements
    1.1. Maximize use of existing contacts
    1.2. Look for commonalities in classes of users
        1.2.1. Science community
        1.2.2. International organizations (FAO, UNEP)
        1.2.3. National and regional forest agencies
        1.2.4. International treaties and conventions
    1.3. Ensure good user representation on design teams
    1.4. Coordinate user contacts and user requirements through Communication and Coordination (C&C) design team
2. Design team tasks to be established by conclusion of this meeting
3. Detailed design to be completed by November CEOS plenary
    3.1. Consider potential demonstration products for November CEOS plenary
4. Pilot Projects in 1999/2000
5. Execution phase in 2001/2002

The following design team tasks and schedule were drafted and agreed to at the GOFC Design Team meeting in Washington, January 29 and 30, 1998. This is a draft document subject to revision by the design team co-chairs.

Data acquisition, processing, and access (DT/DAPA)
(Co-chairs Peter Churchill, Chris Justice, Martha Maiden, Jean-Paul Malingreau)

"Plan to secure thematic (TBD) coverage of forests of the world to a time to be decided with resolutions to be decided"

10-yr strategy until 2010 (which is the date of the next FAO assessment)
5-yr plan
Magnet drivers (e.g. legislation) => Information requirement => Product information => Processing requirement => Identify actors and operational players , e.g. commercial providers, stakeholders, users => Identify data supply and requirements.

- Identify information that is required (Ottawa workshop, users/stakeholders, and DT5 [Communication and Coordination])
- Create data flows from acquisition to products and information, in collaboration with Coarse and Fine Resolution product design teams
- (acquisition <=> product) (prototype / operational)
- Detailed design needed for
    - A system and organization to coordinate data acquisition
    - A prioritized list of data sources, including price and access for each
    - Processing facilities to produce geocoded products overlaid on a common grid
    - Archive, catalog, and access system for all data and thematic products (probably a distributed system)

- Identify gaps and potential gaps in data product creation and provision
- Analyse process for prototype operational constituents of push/pull system
- Involve prototype stakeholders (a few large stakeholders who have an important requirement)
- Provide access to catalogue system and distribution of data
- Provide information to CEOS plenary on new requirements
- Determine players (by type) for each step in the data flow and involve them for each data flow
- Identify actors – research, operational, commercial, value-added, stakeholders, users
- Look for synergy in requirements of coarse and fine resolution products
- Define strategy for graceful transition to routine operation

Calibration-Validation (DT/Cal-Val)

(Co chairs Alan Belward and someone to be identified to replace Diogenes Alves who has asked to become a member of DT/Fine)

- Specify Instrumental calibration requirements (accuracy and precision)
- Specify algorithm validation procedures
- Determine user product requirements for reliability and precision
- Prioritize validation efforts, considering criteria such as existing efforts, areas of greatest international interest, and important forest nations
- Define a validation strategy for each product, building on existing work
- Consider if these should be multi-level
- Confidence-building approaches
- Statistically-based approaches
    - Those requiring ground access
    - Those which can be performed with aircraft
    - Those which can be performed with high resolution satellite data
- Determine optimum and possible levels of validation; ensure that products will still have value if minimum levels of validation are possible
- Define which organizations will actually carry out the validation work, recognizing that the "world is too big for one organization", and that validation is a good opportunity for national involvement. This should be defined for the GOFC (5-year) timeframe, and for ultimate operational implementation by "a neutral body"

Fine Resolution Products (DT/Fine)

(Co chairs David Skole and Victor Taylor)

Goal: To develop reasonable and feasible prototypes and tests of an end to end product generation system for forest cover products from high resolution sources of data which could be operationalized for a range of applications and user requirements.

Charge to design team: to identify the scope of key applications/communities (global and regional), for example:

- International global change research community for land cover (IGBP);
- International forest policy and assessment agreements (G-8 talks look particularly promising) and key user groups (e.g. FAO)

- Land Quality Indicators (LQI), Criteria and Indicators of Sustainable Forest Management
- National needs
- Regional or ecosystem applications (cross-border)

Identify key windows of opportunity for achieving integrated applications (e.g. Miobo woodlands)

Objective: Specify and design a system which will produce a suite of testbed level 2 and level 3 products for targeted users over a five-year timeframe, with an infrastructure to support this beyond five years.

Need:

- Facilities (e.g. EDC, Frascati)
- Talent and capabilities
- Network to provide the interaction and cohesion

Design must include both engineering and institutional/programmatic considerations

Identify

- current and near-term technical and non-technical gaps and obstacles (e.g. data policy)
- points of collaboration and contribution with ongoing programs for leverage (e.g. data collection and analysis, FAO Needs Assessment Project, etc.)

Issues to consider:

1. Acquisition
    1. where? (prototype coverage and a real extent)
    2. need acquisition model
2. How to engage foreign ground stations? - want to see coherent/solid participation in GOFC by foreign ground stations.
3. Preprocessing: product level requirements and issues
4. Level 1 data
5. ancillary data requirements
6. multi-sensor needs
7. need strategy for design team support
8. specify algorithms to meet Level 2 product specifications
9. Thematic product generation: create a few “sell-off” demos
    1. classification legend(s)
    2. classification algorithm
    3. cross-resolution issues

It was proposed in the sub-group, and discussed and endorsed by the main group, that the majority of the effort of the Fine Resolution design team be directed toward the production of high quality “ready-to-classify” data products, rather than toward a global land cover classification. A few “sell-off” demonstration classification products would be produced for key users, but large-scale classification efforts would be left to the end user groups.

Coarse Resolution Products (DT/Coarse)
(Co-chairs Tom Loveland and Yashifumi Yasuoka)

1. Design Questions

1. What is a forest?
2. Classification legends (relate to fine resolution products)?
3. All land cover, or just forests?
4. Balance of top-down versus bottom-up approaches?
5. Global versus regional prototypes?
6. Potential for inter-sensor analysis?
7. Appropriate consistency between fine resolution and coarse scale products?
8. Appropriate scales for applying coarse scale products?

2. Design Objectives
3. User requirements
    1. Canvas user requirements for coarse resolution products
    2. Verify completeness of tentative slate of products
    3. Finalize and prioritize user requirements
    4. Recommend products to GOFC (should anything be added or dropped?)
4. Product development
    1. Develop specifications for each product
    2. Identify potential methods, data sources, and exiting product generation activities
    3. Define technical strategy for each product
    4. Identify potential participants
5. Strategic Process
    1. Pilot project requirements, activities, and participants
    2. Implementation requirements, activities, and participants
    3. Summary of milestones and measures of success
6. Linkages to other design teams
    1. Identify validation requirements
    2. summarize and data processing requirements
    3. identify interactions between fine and coarse resolution products
    4. determine special data management issues

Communication and Coordination (DT/C&C)
(Co-chairs Frank Ahern and Robert Davis)

1. **Collect, refine, and define user requirements**
    - **Agenda 21**
    - **Criteria and Indicators of Sustainable Forest Management**
    - **FAO**
    - **CFS**
1. **Make the information collected readily available**
2. **Provide within-project communication**
    - **Executive level: list server or list server plus web page**
    - **Nuts and bolts level: massive data transfers between locations**
        - **remember that not all parties will have the latest technology**
        - **draw on world expertise such Gap Analysis Project**
    - **Limited-access newsgroup on WWW**

1. **External communications:**
    - **Web Site**
    - **Strategy to communicate needs to CEOS**
    - **Engage user communities over the long term**
    - **funding/fundraising**
        - **core**
        - **project specific**
    - **Public Relations**
1. **Develop "global antennae"**
    - **track and assimilate what is coming**
        - **space programs**
        - **user programs**
1. **Develop strategy for on-going operational implementation of GOFC**

GOFC Design Teams

Name	Task	Co-chairs
Data Acquisition, Preprocessing, and Access (DAPA)	confirm user requirements, design data acquisition strategy and office; detailed level 1 product definition; strategy to achieve; define system to catalog, store, and distribute all products	J. P. Malingreau (EC), Chris Justice (UVa), Martha Maiden(NASA), Peter Churchill(JRC)
Fine resolution products	confirm user requirements, detailed design of all fine resolution products; strategy to achieve	David Skole (MSU),Victor Taylor(NASDA/JPL)
Coarse resolution products	confirm user requirements, detailed design of all coarse resolution products; strategy to achieve	Tom Loveland(EDC), Yoshifumi Yasuoka(National Institute for Environmental Studies of Japan)
Product validation	develop validation strategy for all products	Alan Belward(JRC), Zhiliang Zhu (EDC)
Communication and Coordination	Collect and document user requirements, define approaches to project communication, monitor developments in technology and user requirements, liason with users, eventual operational implementation	Frank Ahern (CCRS) Robert Davis(FAO)

Schedule for 1998

Date	Team	Activity or milestone
Now	All	Populate design teams (Frank to indicate key volunteers)
Mar. 1	All	Circulate names, funding needs, and potential sponsors for travel
March	Cal-Val	Meet in Ispra with WGISS
May "31"	All	Confirm product specifications in consultation with user reps.
September	All	End to end design review, define areas where clarification needed
September	C&C	Circulate draft design document for CEOS
October	All	Meet if necessary to finalize design document
November	C&C	Present design to CEOS

Land Cover Land Use Change

PROJECT MANAGEMENT AND FUNDING

- **Management**
- **The LCLUC Science Team**
- **Funding Opportunities**

Management

The LCLUC Program falls within NASA's Earth Science Enterprise. The Program Manager for LCLUC is Dr. Garik Gutman. The LCLUC program will be implemented through peer- reviewed individual research grants, which will phase in through a series of targeted research solicitations. It is the management's intention to have annual solicitations, bringing new projects and talent into the LCLUC program. All of the LCLUC funded research will go through the NASA Peer Review Process. The LCLUC Project Scientist, Dr. Chris Justice, will assist in the coordination of the science team activities, assisting with communication amongst the team and with external programs. NASA graduate and post doctoral fellows supported to undertake LCLUC related science will be asked to participate in the Science Team meetings.

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The LCLUC Science Team

The LCLUC Science Team is formed from the winners of the annual solicitations, combined with other investigators from ESE-supported programs whose projects are judged to be closely related to LCLUC objectives. The Science Team will meet at least once a year as a whole to review progress, report results, and advise Earth Science Enterprise on new research directions. In addition, the Science Team will advise NASA on a variety of research topics related to land-cover and land-use change. In some cases LCLUC will sponsor the development of strategy documents and reviews.

A specific charge to the Science Team will be to develop a series of reports and assessments on the consequences of land-use change in different parts of the globe. These reports will go beyond the expected high number of scientific refereed papers from this program and will be targeted at high-level decision-makers and the public. The reports will be along the lines of integrated assessments closely tying the observations and science to improved resource and environmental management. The regional projects will be asked to communicate amongst themselves and to

develop the basis for regional assessments, initiating or joining on-going regional initiatives involving scientists outside of this program. It is anticipated that NASA will contribute to a series of regional meetings to provide the basis for developing regional LCLUC assessments in the context of the IPCC.

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Funding Opportunities

The NASA LCLUC Research Announcement released July29, 1999 can be downloaded from http://earth.nasa.gov/nra/current/nra99oes06/index.html.

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