The NASA LCLUC Program

LCLUC **NASA**

Land Cover Land Use Change

NASA's Land-Cover and Land-Use Change Program

The Land-Cover/Land-Use Change (LCLUC) Program is an interdisciplinary scientific program of the Science Mission Directorate at NASA Headquarters. Land-use and land-cover change research has become an important element of global change research programs at national as well as international levels. Land-use and land-cover change has also been established as a separate research element of the U.S. Climate Change Science Program and is currently being further developed through interagency coordination.

NASA's Earth Science programs study the Earth as an integrated system, analyzing observations made from space together with laboratory and field measurements, combined with numerical modeling. The goal of NASA Earth Science programs is to develop a scientific understanding of the Earth system in response to natural and human-induced changes and to improve predictive capabilities for climate, weather, and natural hazards. Understanding land-cover and land-use change is essential to meet this science goal. NASA's Earth Science strategic objective is to provide scientific answers to an overarching question: "How is the Earth changing and what are the consequences for life on Earth?" To address this question, five fundamental scientific components are identified:- variability, forcing, responses, consequences and prediction – (*http://science.hq.nasa.gov/strategy/researchPlan.pdf*).

LCLUC and the Key Science Questions

The LCLUC research program focuses on these components in addressing the following key land-use science questions:

- Where are land-cover and land-use changing, what is the extent and over what time scale and how do the changes vary from year to year? (Variability)
- What changes are occurring in global land-cover and land-use, and what are their causes? (Forcing)
- What are the impacts of climate variability and changes on LCLUC and what is the potential feedback? (Responses)
- What are the consequences of changing land-use activities for ecosystems and how do they respond to and affect global environmental change? (Consequences and Responses)
- What are the consequences of land-cover and land-use change for human societies and the sustainability of ecosystems? (Consequences)
- How will land-cover change on time scales from years to centuries? (Prediction)
- What are the projected changes in land-cover and their potential impacts? (Prediction)

LCLUC Program Focus and Goals

The LCLUC Program, through an interdisciplinary approach, is developing and using NASA remote sensing technologies to improve understanding of human interactions with the environment and, thus, provides a scientific foundation for understanding the sustainability, vulnerability and resilience of human land-use and terrestrial ecosystems. The major goal of the program is to further our understanding of the interactions of land-cover and land-use change with the carbon and water cycles, and the climate system, and how these interactions affect ecosystems, biodiversity, environmental goods and services, and the management of natural resources.

The longer-term objectives of the LCLUC program are to develop the capability to perform repeated global

inventories of land-use and land-cover from space, and the capability to predict land-use and land-cover changes and their direct and indirect impacts on the Earth's system and society.   The NASA LCLUC research contributes to the U.S. Climate Change Research Initiative by providing the scientific underpinning for the operational provision of land-use and land-cover data and information products, services, models and tools for multiple users including scientists, resource managers, decision makers and policy makers.

LCLUC Program Background

The LCLUC program was designed initially around a small number of regional land-use change case studies, complemented by method development and the production and validation of particularly important regional and global remote sensing land-use and land-cover related datasets. The LCLUC program is a component of the NASA Science Focus Area of Carbon, Biogeochemistry and Ecosystems. The program has quickly grown into a multifaceted, interdisciplinary science program, funding diverse research projects and forging partnerships with other NASA Focus Research Areas, such as Water and Energy Cycle, Climate Variability, and other NASA programs, such as Applications, Education and Data Systems, and NASA Missions such as the Earth Observing System (Terra and Aqua), Landsat and New Millennium (EO-1). The LCLUC program has developed strategic partnerships with other agencies such as U.S. Department of Agriculture (USDA), U.S. Geological Survey (USGS) and U.S. Agency for International Development (USAID) in the framework of the U.S. Climate Change Science Program (CCSP). The LCLUC program supports a number of regional initiatives and contributes to key international programs that are fostering international coordination and cooperation on aspects of science and space observations of land-cover and land-use.

LCLUC Science Components

The focus of LCLUC research is on quantifying the location, extent and variability of change, the causes or forcing factors of change, for example, climatic, ecological and socioeconomic drivers, the processes of change and the responses and consequences of change. NASA LCLUC research projects use a combination of space observations, in situ measurements, process studies and numerical modeling. As an interdisciplinary research program, LCLUC fosters strong partnerships between physical and social scientists to develop the integrated science necessary to understand why and how patterns of land-use and land-cover are changing, how they will change in the future and the implications of these changes. LCLUC research crosscuts several other research areas, e.g. climate change and variability, water cycle, carbon cycle, ecosystems and biodiversity, and human contributions and responses to environmental change.

Variability: The current spatial pattern of land-cover is a result of previous and current land-use. Quantifying the location, extent and trends of recent land-cover and land-use change is an important component of land-change science. Satellite systems often provide the only means to inventory land-cover and monitor land-cover change in a timely fashion. NASA has developed procedures for wall-to-wall mapping of land-cover and spatially explicit monitoring of land-cover change. Systematic long-term observations of land-cover are essential to enable scientists to quantify the rates of change and their variability over time. Establishing consistent long-term data records of land-cover is an important objective for the LCLUC Program.

Forcing: To make a projection of how land-cover will change in the future and to be able to better manage land-use it is important to understand the drivers of change. These include the local and proximate physical, socioeconomic and demographic causes of change, as well as the broader global and regional climatic or macroeconomic forces of change. Quantifying processes of land-use change is undertaken by combining in-

situ measurements and ground surveys with satellite data. This is often done through regional case studies.

Responses and Impacts: The impacts of land-use change can be biophysical and socio-economic and they can be positive and negative. Changes in forest cover can affect carbon sources and sinks, local water resources and biodiversity through landscape fragmentation. Changes in fire regimes can affect ecosystem structure, trace gasses, aerosol emissions and water quality. Overuse of marginal lands leads to degradation and impoverishment affecting human livelihood. Agricultural intensification through the use of fertilizers can improve crop production but may degrade water quality. Changes in land-use can affect human health by changing insect habitat or disease vectors. Agricultural abandonment leads to changes in land-cover, for example, by increasing woody vegetation. Urban expansion and suburban development can result in a loss of agricultural lands or wetlands. Changes in land-use can affect local and regional climate.

Prediction and Feedbacks: Modeling of land-use change provides a means to understand the consequences of different land management options and study the feedbacks. For example, coupled land-use and dynamic vegetation models are needed to understand the impacts of future land management on carbon budgets. Recent trends in land-use change and an understanding of the processes of change provide a point of departure for predictive modeling. Spatially explicit modeling of land-use is needed to study scenarios of land change under different land-uses for a large number of science applications. There are a number of approaches for modeling land-use that are currently being investigated, including statistical empirical models, cellular automata and agent-based modeling. Better understanding the impacts of land-use change on climate and the impacts of climate change on land-use is also needed.

Underpinning the Earth science research paradigm (variability-forcing-response-consequences-prediction) is an ongoing program of LCLUC research, which includes the development of new algorithms, methods and techniques for characterizing, monitoring and modeling land-cover and land-use change and validating derived products. This is achieved by combining the new methods and land-use models with remote sensing and GIS. Development of techniques for data management and analyses are needed to handle the large volumes of data needed for global and regional monitoring and analysis. Global and regional data sets of land-cover characteristics developed within this program support the NASA modeling activities and provide the long-term data records needed to study trends.

LCLUC Themes

The LCLUC projects presented in this brochure are organized into the following main LCLUC themes : LCLUC Detection and Monitoring, LCLUC Predictive Modeling, Carbon/Biogeochemical Cycle, Ecosystems and Biodiversity, Water and Energy Cycle, Climate Variability and Change.

This brochure provides a summary of the NASA Land-Cover and Land-Use Change research program at the beginning of 2006. Much of the research described is funded directly through the LCLUC program but the crosscutting nature of land-cover and land-use issues, means that some of the research is also funded by other parts of the NASA program, through various research announcements. For example, projects included in this brochure are also funded though such programs as Carbon Cycle, LBA, North American Carbon, Applications, Education, EOS, and IDS.

The LCLUC Book

Land Change Science: Observing, Monitoring and Understanding Trajectories of Change on the Earth's Surface

Series: <u>Remote Sensing and Digital Image Processing</u>, Vol. 6

Gutman, G.; Janetos, A.C.; Justice, C.O.; Moran, E.F.; Mustard, J.F.; Rindfuss, R.R.; Skole, D.; Turner II, B.L.; Cochrane, M.A. (Eds.)

2004, XXI, 461 p.

This volume is a synthesis of the NASA funded work from the initial phase of the Land-Cover and Land-Use Change Program. Hundreds of scientists have worked for the past eight years to understand one of the most important forces that is changing our planet-human impacts on land-cover, that is land-use. Its contributions span the natural and the social sciences, and apply state-of-the-art techniques for understanding the earth: satellite remote sensing, geographic information systems, modeling, and advanced computing. It brings together detailed case studies, regional analyses, and globally scaled mapping efforts.
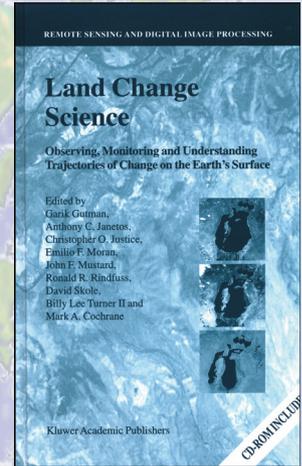
The LCLUC Science Team

The LCLUC Science Team consists of NASA P.I.'s undertaking land-use and land-cover change research, currently funded by the LCLUC program directly, or through other NASA funding opportunities. As the different aspects of land-cover and land-use change research cut across the NASA programs, the P.I.'s are funded through different programs and research announcements e.g. Carbon Cycle, Water Cycle, Data Systems and Applications. Since its inception the LCLUC program has held an annual Science Team Meeting. These meetings are organized by the Program Scientist, providing an opportunity for PI's to present their research findings, to learn about new NASA, USGCRP, ande international program developments, and to provide feedback to the program management on future missions and research directions. The meetings also provide an opportunity for networking between LCLUC scientists and new collaborations to be developed. Past collaborations have included the LCLUC Book, review articles, thematic workshops, special editions and team proposals. New investigators and graduate fellows are encouraged to attend these meetings and present posters. With the increasing interest,the broadening scope of the program, the clear benefit of open communication between the program managers and the science community, LCLUC is now holding two science team meetings in the Spring and Fall, focussing on different research themes.

LCLUC Science Team Meeting, January 2005

LCLUC Educational Component

The LCLUC Program is strengthened by the NASA Educational Program through its New Investigators Program and the NASA Earth System Science Fellowship Program (ESSFP). The New Investigator Program (NIP) in Earth Science was established in 1996 to encourage the integration of Earth system science research and education by scientists and engineers at the early stage of their professional careers. The program, designed for investigators in Earth system science and applications at academic institutions and non-profit organizations, emphasizes the early development of professional careers of these individuals as both researchers and educators. A number of new investigators have been supported in the area of land-cover and land-use change research.

The ESSFP was started in 1990. The purpose of the program is to ensure continued training of interdisciplinary scientists to support the study of the Earth as a system. Over 700 Ph.D. and M.Sc. fellowships have been awarded since the inception of the program. The graduates from these fellowships constitute a growing network of scholars endeavored to promote Earth system science. In recent years a number of PhD and Graduate Fellowships have been awarded in the area of Land-Cover and Land Use research.

More information on these programs can be found at:
www.nasa.gov/audience/foreducators/postsecondary/features/F_New_Investigator_Program.html
www.nyu.edu/pages/gsas/files/nasaessFellowship-ESS05/winners.html

Current NIP Projects

Brown de Colstoun, Eric Goddard Space Flight Center. *Consequences of Land Cover/Use Changes on National Parks: A Research/Educational Partnership in the Upper Delaware River Basin*

Cochrane, Mark South Dakota State University. T*he Synergism of Fire, Forest Fragmentation and Selective Logging in the Brazilian Amazon*

Csiszar, Ivan University of Maryland. *Intercalibration of Fire Products from the Advanced Very High Resolution Radiometer (AVHRR) and Moderate Resolution Imaging Spectroradiometer (MODIS) Towards a Consistent Long-Term Record of Biomass Burning in Northern Eurasia*

French, Nancy Altarum Institute. *Assessment of Biomass Consumption Variability in Forest Fires Using Satellite Remote Sensing*

O'Connell, Kari Oregon State University. *Effects of Fire Management on Fuels Along Fire Regime and Forest Productivity Gradients in Oregon: Implications for Long-Term Carbon Dynamics*

Messina, Joseph Michigan State University. *Simulating the Effects of "Plan Colombia" on Land Use and Land Cover in the Ecuadorian Amazon: A Complex Systems Approach*

Current ESSFP Projects

Anderson, Jeanne University of New Hampshire . *The Integration of AVIRIS and LIDAR Data for Remote Detection of Forest Structure, Species Composition, and Land-Use Legacies in the White Mountains of New Hampshire*

Dempewolf, Jan University of Maryland. *Impacts of Land-Cover Change on Wildebeest Migration and Abundance in the Serengeti-Mara Region*

Hayes, Daniel Oregon State University. *Mapping Regional Carbon Stocks and Monitoring Carbon Emissions from Land Cover and Land-Use Change Along the Mesoamerican Biological Corridor*

Kennedy, Christina University of Maryland. *Impacts of Land Cover and Land-Use Change on Bird* Communities of the Mayan Forests of the Southern Yucatan Peninsula

Liu, Desheng University of California at Berkeley. *Systematic Evaluation of Machine Learning Approaches for Remote Sensing Land Cover Classification*

Loboda , Tatiana University of Maryland. Impact of Climate and Land-Use Change on Wildland Fire Frequency and the Amur Tiger

McCarty , Jessica University of Maryland. *Seasonal and Interannual Variability of Greenhouse Gas Emissions from Crop Residue Burning in the Contiguous United States*

Morton, Douglas University of Maryland. *Savannization of a Tropical Forest Frontier: Carbon Consequences of Climate and Anthropogenic Fire from a Height-Structured Ecosystem Model***Van Holt, Tracy** University of Florida. *Twenty Years of Land-Cover and Land-Use Change Effects on Nearshore Marine Resources in Southern Chile*

Powers, Amy University of Michigan Ann Arbor . *Spatial and Temporal Patterns of Error in Land-Cover Change Analyses: Identifying and Propagating Uncertainty for Ecological Monitoring and Modeling***Schroeder, Wilfrid** University of Maryland. *Towards and Integrated System of Systems for Vegetation Fire Monitoring*

Xiao, Jingfeng University of North Carolina at Chapel Hill . *Carbon Sink Due to Woody Encroachment in Non-Forest Areas in the Western U.S. and Impacts of Fire and Climate*

Jessica McCarty on the perimeter of a sugarcane field in Iberia Parish, Louisiana. The cane farmer is setting fire to the crop in order to burn off the green 'trash' leaves to reduce transportation costs of moving the sugar to a local sugar mill. McCarty's research is focused on quantifying greenhouse gas emissions for crop residue burning in the contiguous United States.

Under the LBA experiment, Wilfrid Schroeder is studying the performance of satellite fire products and validating them in the Brazilian Amazon - with the highest interest in the MODIS products. This photo of an active fire, was taken from one of his field campaigns to validate the active fire products in the Brazilian Amazon. Active fire products from the NOAA AVHRR, GOES, and MODIS are being compared and validated, leading to the development of a multi-source fused data product.

Boreal Zone Forest Type and Structure From EOS Data Sets

Jon Ranson (Principal Investigator), NASA GSFC; Guoqing Sun, University of Maryland at College Park; Slava Kharuk, Sukachev Institute of Forest, Krasnoyark, Russia; Daniel S. Kimes, NASA GSFC

The boreal forest is an important component of the world's forests covering 12×10^6 km^2, nearly 30% of world's forest, and 73% of its coniferous forest area. General circulation models predict regions of Canada and Siberia, especially the northern and sub-arctic parts, will experience significant warming over the foreseeable future (Hansen et al 1996, Geophys. Res. Lett. 23:1665-1668). The magnitude of the boreal forest area suggests that it plays a critical role in the global climate system, e.g., as potential sink or source of atmospheric carbon (Stocks et al. 2002, http://www.igac.unh.edu/newsletter/15/boreal.php). Forest cover type and structure (e.g., height, biomass) are fundamental parameters for understanding the global carbon cycle and ecosystem dynamics in the face of changing climate. Objectives: the purpose of the project is to map boreal forest type and structure using Terra instrument data aided by point measurements of canopy height, density and biomass inferred from satellite lidar data. The primary objective is to improve forest identification and biomass estimation by combining MODIS, MISR, and Geoscience Laser Altimeter System (GLAS) data sets. Methods: the emphasis of this project is to map boreal forest structure parameters (i.e. age, coverage, height and biomass) using temporal, multi-angle, and vertical profile information

of MODIS, MISR and GLAS data. Field samples, GLAS point data, and MISR images will be used at test sites to develop training and testing datasets, which will be used in MODIS data classification and for further algorithm development. The relationships between MODIS data and forest structure parameters will be investigated using the datasets. The relationships will then be used to map forest structure parameters from MODIS data, and the results will be compared with the map produced from MODIS classification and GLAS samples. Expected results: methods for mapping boreal forest structure parameters from Terra and GLAS data, a validated biomass map for a portion Eurasia boreal forest. Other maps such as tree height, tree coverage, may also be produced. The results of this research will be applicable to answering several important questions posed by NASA's Earth Science Enterprise including: *How are global ecosystems changing*? and, *How is the Earth's surface being transformed and how can such information be used to predict future changes?* The results of this study will address these questions for a large portion of the Siberian boreal zone and help pave the way for future circumpolar boreal forest studies.

Human and Biophysical Dimensions of Land-Use/Cover Change in Amazonia: Towards a Multi-scale Synthesis and Sustainability

Emilio F. Moran (Principal Investigator), Indiana University; Mateus Batistella, EMBRAPA Satellite Monitoring, Brazil; Eduardo Brondizio, Ryan Jensen, Paul Mausel, Indiana State University; Lars Hedin, Princeton University

The goals of this project are to develop a multi-scale synthesis of LCLUC in 7 study areas over the past 25 years; develop a multi-sensor analysis of land-cover using artificial neural networks; understand landscape level controls by nitrogen and phosphorus dynamics in sustainability of forests in the Basin; and to identify trajectories of land-use most likely to be conducive to environmental and socially sustainable uses of the Amazonian tropical forest landscape.

Particular contribution of this project within LCLUC is through studies of demographic and institutional dimensions of environmental change i.e. human dimensions of global environmental change.

The project contributes to larger goals of NASA and the US Carbon Cycle Program by converting our vegetation biomass to carbon pool estimates at all seven sites and by calculating the carbon emissions from deforestation and the rates of carbon sequestration.

The project also examines the effects caused by export of nutrients; the patterns of dissolved nutrient losses from our research sites; characterize patterns of N and P losses across geographic gradient of soil fertility by sampling in both wet and dry seasons; and undertaking hydrologic mass balance calculations to translate measures into estimates of N and P losses from the forest ecosystem to assess sustainability.

The colonist footprint: Average deforestation trajectories across cohorts
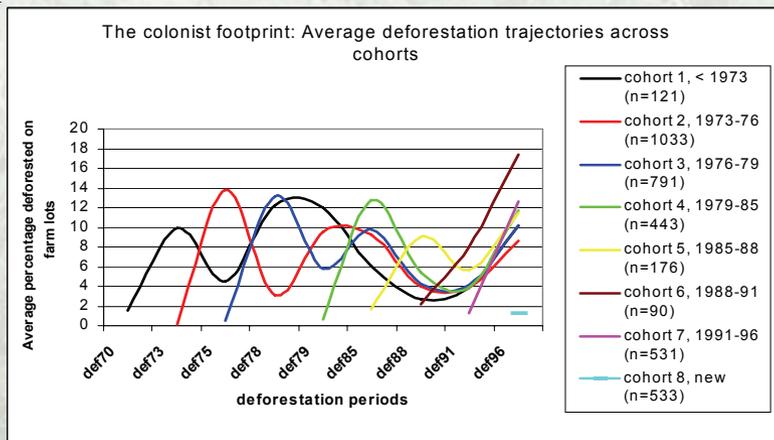
Global Rates and Extent of Tropical Deforestation, Forest Regeneration, Selective Logging and Fragmentation

David Skole, Michigan State University (Principal Investigator)

This project is aimed at reducing the uncertainty in the global estimates of tropical deforestation using massive-scale analysis of Landsat data. It takes advantage of key new global Landsat datasets that have been acquired in recent years, and which now provide a comprehensive baseline for continental scale measurements of deforestation, regeneration, and fragmentation rates. The project has spent considerable time accumulating the needed global databases. The combination of the NASA orthorectified dataset and the existing TRFIC dataset make the overall holdings the largest single Landsat archive in the world outside the US federal government, with unique data not found elsewhere. These data are available at *www.landsat.org*. The efficacy of a global sample approach to deforestation monitoring has been tested. The solution to this problem is to use a combination of complete "wall-to-wall" inventories in benchmark or census years (approximately every 5 years) and use these inventories to develop a low-density stratification on an annual basis between census years. Sampling alone without the advantage of a stratification based on inventories is inaccurate. The project has also been examining of the full suite of tropical forest disturbances, ranging from logging to outright deforestation. The story for the Amazon is now clear: early logging in the 1990s has not been as important as some studies suggest, but the rate has been increasing. Today the effect of logging and fragmentation is an important additional form of forest disturbance, but has yet to have a total area impact as important as deforestation.
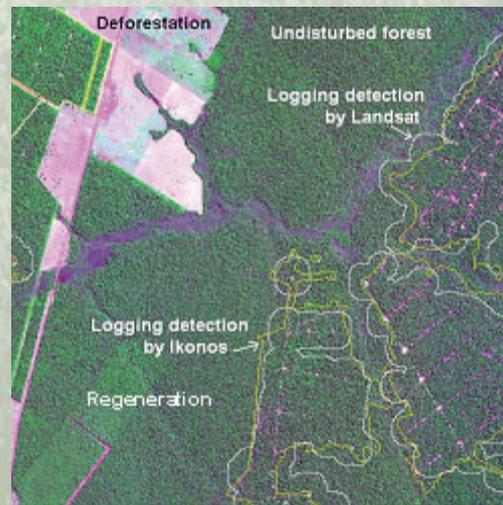
Mapping Height and Biomass of Mangrove Forests in Everglades National Park with SRTM Elevation Data

Marc Simard (Principal Investigator), **Caltech- Jet Propulsion Laboratory;** Keqi Zhang, **Florida International University;** Victor H. Rivera-Monroy, **Louisiana State University;** Michael S. Ross, Pablo L. Ruiz, **Florida International University;** Edward Castañeda-Moya, Robert R. Twilley, **Louisiana State University**

An interdisciplinary team from the Jet Propulsion Laboratory, the Louisiana State University and Florida International University, has been working on this project since 2004. Their efforts revealed, for the first time, the 3D complexity of the mangrove forests at the landscape scale in the Everglades National Park (ENP). A map was produced of tree height of mangrove forests in ENP using the elevation data from the Shuttle Radar Topography Mission (SRTM). The SRTM data were calibrated using airborne LIDAR data and a high resolution USGS Digital Elevation Model (DEM). The resulting mangrove height map has an error of 2.0m (RMSE) over a pixel of 30m. In addition, field data was collected to derive a relationship between mean forest stand height and biomass in order to map the spatial distribution of standing biomass of mangroves for the entire National Park. The total mangrove standing biomass in ENP was estimated to be 5.6Mt. These maps will serve as a base to evaluate landscape changes resulting from the ongoing Comprehensive Everglades Restoration Plan (CERP) as well as impacts of hurricanes and sea level rise. More details about this investigation are published in the SRTM Special Issue of Photogrammetric Engineering and Remote Sensing of March 2006.
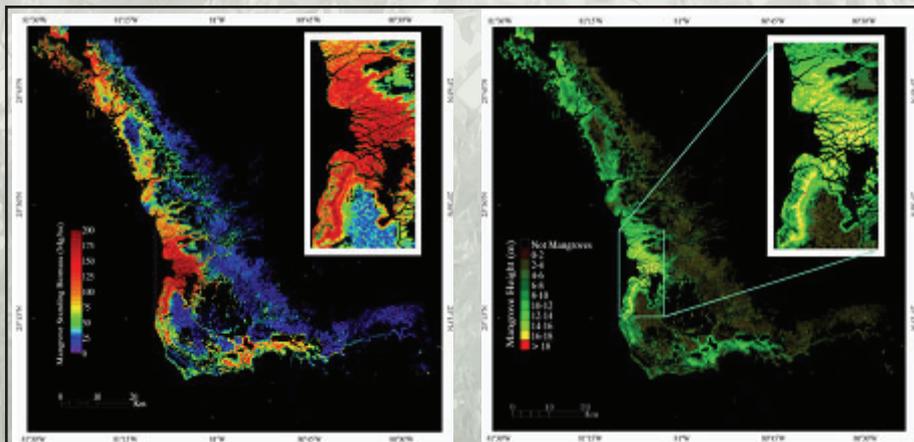
Figures: A) Map of tree height in the Everglades National Park produced with SRTM elevation data. This map only includes the mangrove forests and the mean tree height estimation over the 30m pixel has an error of 2m. The zoom shows the mouth of the Shark river where most tall forests are found. B) This map shows the spatial distribution of standing biomass contained in the mangrove forests of the ENP. The tallest forests

Other LCLUC Detection and Monitoring Projects:

Bowling Laura, Purdue University. *Multisensor/Multiscale Assessment of Urban Impacts in the Great Lakes Region*

Christensen Philip, Arizona State University. *Investigation of rapid urbanization processes using ASTER, MODIS and Landsat data*

French Nancy /Brown Dan, Altarum Institute/ University of Michigan. *Using Remote Sensing-Based Measures to Assess NRCS Impacts in Michigan*

Geerken, Roland Yale University. *Ecological Monitoring in Semi-Arid Central and West Asia: Drivers and Trajectories*

Hansen, Matthew Geographic Information Science Center of Excellence SDSU. *Establishing a global forest monitoring capability using multi-resolution and multi-temporal remotely sensed data sets*

Kling, Cathy Iowa State University of Science & Technology. *Interactive Drivers of Land-Use/Land-Cover Change in Agricultural Areas: Climate and Land-Manager Choices*

Ramankutty, Navin University of Wisconsin-Madison. *Land Use mapping*

Turner, Billie Clark University. *Landscape Vulnerability-Resilience in the Southern Yucatan Peninsular Region [SYPR]*
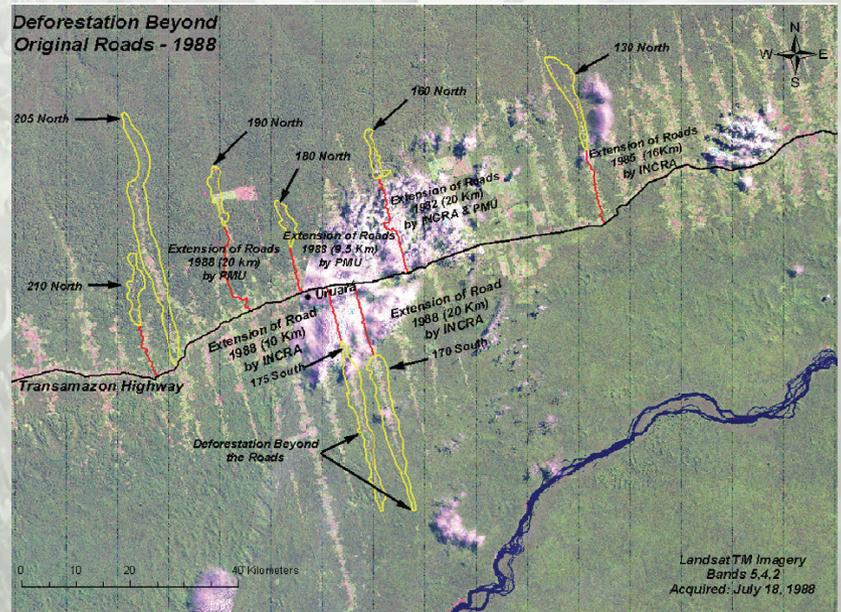
Walker, Skip University of Alaska Fairbanks. *Application of space-based technologies to examine land-cover/land-use change along a transect on the Yamal Peninsula and Novaya Zemlya, Russia*

A Basin-Scale Econometric Model for Projecting Future Amazonian Landscapes

Robert Walker (Principal Investigator) Michigan State University; Eustá quio Reis, Institute of Applied Economics Research (IPEA), Brazil

A Basin-Scale Econometric Model for Projecting Future Amazonian Landscapes was developed to predict forest loss associated with development scenarios in the Amazon basin. Given the scenarios, projections follow from results of econometric modeling based on economic theory and detailed local observation (led by Alexander Pfaff of Columbia University). The empirical analysis benefits from enhanced statistical "power" due to an expanded database using information for census tracts, not counties. This yields thousands of observations, enabling the use of fixed county effects to control for unobserved differences across space, as well as a partitioning of the sample to control for previous deforestation. Table 1 presents a subset of results for Amazonian deforestation between 1976 and 1987. Findings applicable

to most of the region show that new roads will raise deforestation rates. Further, contrary to a claim in the literature that road-building in highly cleared areas could lower deforestation rates, no results are significant and negative for any level of previous clearing. The project is extending this work based on understandings, new to such literature, about complex relationships between roads and deforestation. Project research has shown that road "endogeneity" can lead to mistaken statistical estimation of road effects, and is developing ways to minimize associated biases. Fieldwork documenting and addressing such interrelationships is led by Stephen Perz of the University of Florida. As an example, Figure 1 shows a situation in which deforestation precedes road-building. It depicts in red several settlement roads in 1988; deforested areas, as of 1988, are shown by the yellow polygons extending beyond the roads. Since the roads now pass through these old deforested areas, the figure suggests reverse causality, in which deforestation actually leads to road-building. This situation is probably common in areas of smallholder colonization. *http://marajo.geo.msu.edu/lba/*

Table 1. Regression Results for Deforestation: Four Treatments by Prior Clearing

Prior Deforestation: Explanatory Variables[1]	0 %	1-50 %	50-75 %	75-100 %
Paved Highways	11 (5.8)	10 (2.7)	21 (2.6)	3.6 (0.7)
Unpaved Roads	71 (9.1)	53 (2.8)	11 (0.3)	-1.7 (0.1)
Cleared % in 1976	—————	2.8 (6.2)	0.95 (0.5)	2.0 (1.3)
Distance to City	-0.001 (2.9)	0.001 (0.9)	0.004 (1.0)	0.01 (1.8)
Next To Big City	1.1 (0.9)	-0.14 (0.1)	1.9 (2.6)	-0.2 (0.4)
Adjusted R[2]	0.45	0.49	0.60	0.73
# Observations	5376	933	205	233

[1]*Coefficient value on left, t-statistic in parentheses. Results given for 5 of the 19 implemented.*

Mapping and Modeling Land Use/Land Cover Dynamics in the Northern Ecuadorian Amazon

Stephen Walsh, Richard Bilsborrow (Principal Investigators), University of North Carolina-Chapel Hill

This Ecuador Project uses longitudinal household survey data collected in 1990 and 1999, a 2000 community survey, a multi-resolution satellite imagery time-series, GIS coverages of resource potentials and endowments, and field verification and geodetic control data to analyze the determinants of changes in land cover/land-use (LCLU) change at the plot, sector, and regional levels in the Northern Ecuadorian Amazon. The fundamental research questions revolve around (a) the rates, patterns, and mechanisms of forest conversion to agricultural and urban uses; (b) the relative importance of exogenous and endogenous variables to these land uses; (c) the associated scale-dependent drivers of LCLU dynamics and pattern-process relations operating across socio-economic and demographic, biophysical, and geographical domains; (d) rate and pattern of land conversion from forest to agricultural crops, pasture, secondary plant succession, and urbanization, as well as the rate and pattern of land abandonment at the farm level; and (e) plausible scenarios of future LCLU change and the policy implications as assessed through multi-level models, spatial lag models, neutral models, cellular automata models, and agent based models. Recent cellular automata and agent based models integrate space-time scales as well as global, regional, and local effects to derive rules and weights of variable behavior, neighborhood conditions, initial conditions, feedback mechanisms, and critical threshold. The spatial simulations are space-time sensitive and policy relevant and address important scenarios of LCLU change. The graphics below show (a) the LCLU classification of a portion of a 1986 Landsat TM image that was used to set the initial model conditions and (b) predicted LCLU for 2010 using growth or transition rules implemented within a cellular automata environment. This scenario examined deforestation and agricultural extensification at the farm-level as a consequence of terrain conditions, road features, population at the household, community characteristics, regional level demographics, and a generated surface of household income. ***http://www.cpc.unc.edu/projects/ecuador***

Legend: Primary Forest | Succession | Pasture | Crops | Urban / Barren | Water
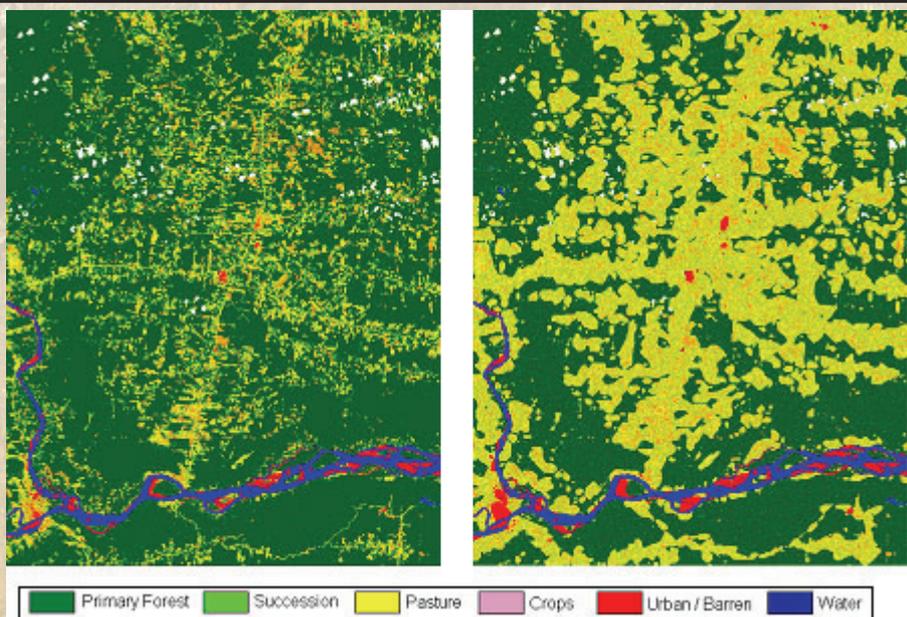
This graphic shows the initial landscape conditions and model outcomes of a generated cellular automata model: (a) Landsat TM LCLU classification for the year 1986 that sets the initial condition for the model, and (b) a predicted LCLU surface for 2010 relative to a defined scenario of LCLU dynamics.
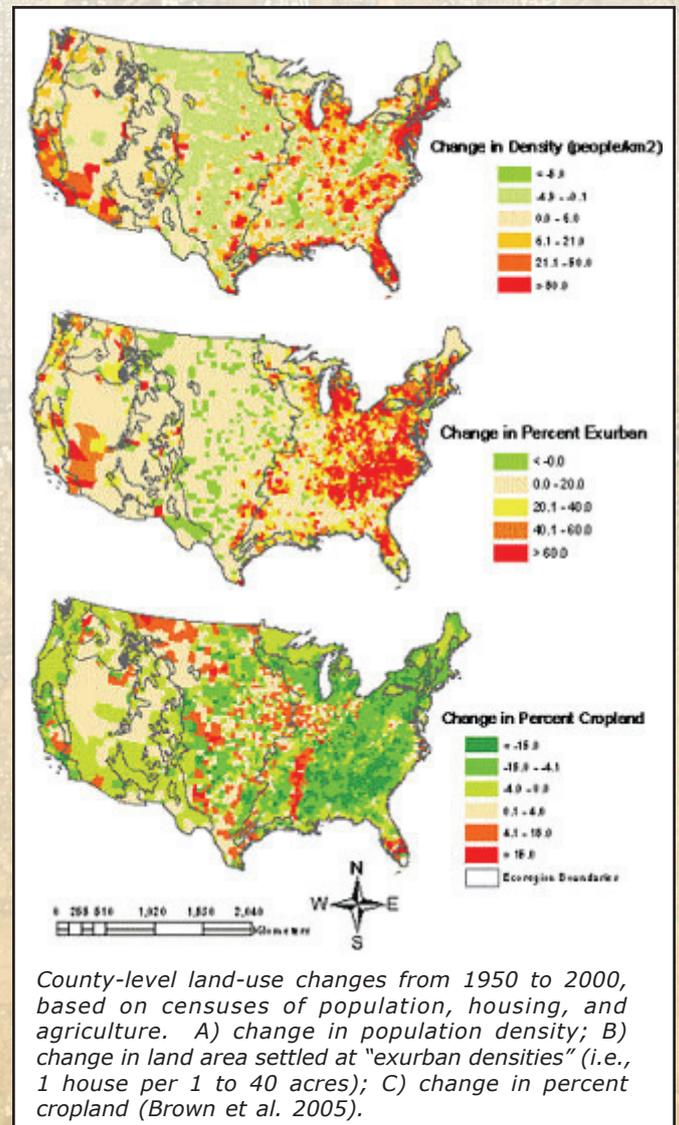
Rural land-use change in the conterminous U.S.

Dan Brown (Principal Investigator), University of Michigan; Pierre Goovaerts, BioMedware, Inc.; Kathleen Bergen, University of Michigan

This team of researchers at the University of Michigan, is investigating the land-cover consequences of land-use changes associated with "rural sprawl," or the widespread development of exurban areas (e.g., outside cities, towns and suburbs) for relatively low-density settlement (Figure; Brown et al. 2005). The work is also supported by related grants from the NSF and USDA Forest Service. The team is using remote sensing to (a) map changes in landscape productivity (i.e., gross primary production) at a coarse resolution (i.e., 1km) over the 1990s and evaluate the relationships between these observed changes and demographic changes over the same period, (b) classify land-cover for four dates during the period 1985 to 2001 from moderate resolution Landsat images, (c) classify land-use and land-cover for individual parcels mapped using plat maps and historical aerial photographs from the period 1950 to 2000, and (c) develop geostatistical models to describe and model the spatial patterns of these changes over time. With support from an Earth System Science Fellowship (ESSFP) PhD grant (Amy Powers) the team is also investigating the spatial and temporal patterns of classification errors, so that future land-cover change investigations might benefit from an understanding of how patterned errors affect the accuracy of land-cover change information and models and analyses that rely on this information.

The research provides a richer, multi-scale picture of how land-cover in exurban areas of the Eastern U.S. are changing in response to conversion of agricultural land-uses to low-density residential areas. Exurban areas are experiencing significant increases in productivity, resulting from the replacement of crops with perennial grasses and substantial amounts of increased tree cover. Data from U.S. censuses of housing and agriculture suggest that the changes are widespread and we can infer that the changes could play a significant role in forcing changes in regional scale ecosystem and atmospheric processes. This research is producing tools that take multiple approaches to modeling and that can be used in planning and policy applications associated with land-use and ecosystem impacts.

County-level land-use changes from 1950 to 2000, based on censuses of population, housing, and agriculture. A) change in population density; B) change in land area settled at "exurban densities" (i.e., 1 house per 1 to 40 acres); C) change in percent cropland (Brown et al. 2005).

Spatial Predictive Modeling and Remote Sensing of Land Use Change in the Chesapeake Bay Watershed

Scott J. Goetz, Woods Hole Research Center; Nancy E. Bockstael, University of Maryland (Principal Investigators); Claire A. Jantz, Shippensburg University

This work addresses mapping and monitoring urbanization in the Chesapeake Bay Watershed, where the spatial patterns of "sprawl" represent a set of conditions generally prevalent in much of the nation. Using innovative remote sensing techniques and spatially modeling the land-use change decision at the pixel (cell) and the individual property owner level, scenario analyses of future land-use dynamics provide critical quantitative insight into the impact of alternative land management and policy decisions. These are specifically aimed at addressing the effectiveness of implemented and proposed growth control policies. The project generated both remote sensing and spatially explicit socio-economic data to estimate and calibrate the parameters for the two different types of land-use change models. One, a cellular automata model (CA), was driven largely by observations of past patterns of land-use change from satellite observations. The other, an economically-based model (EC), was driven by mechanisms of the land-use change decision at the parcel level. The CA model does not incorporate the immense detail of the EC model, and the spatial pattern of development predicted by the two models is quite different. Modifications to the CA model, and manipulation of 'parameter sets' by incorporating rules from the economic model, were found useful for improving CA model performance – especially in capturing low-density residential development. This project may be the first serious attempt at developing both types of models for the same area, using as much common data as possible. The strengths and weaknesses of the two approaches were identified and this team of researchers plan to continue to revise each model in the light of new data and new lessons learned through continued collaboration.
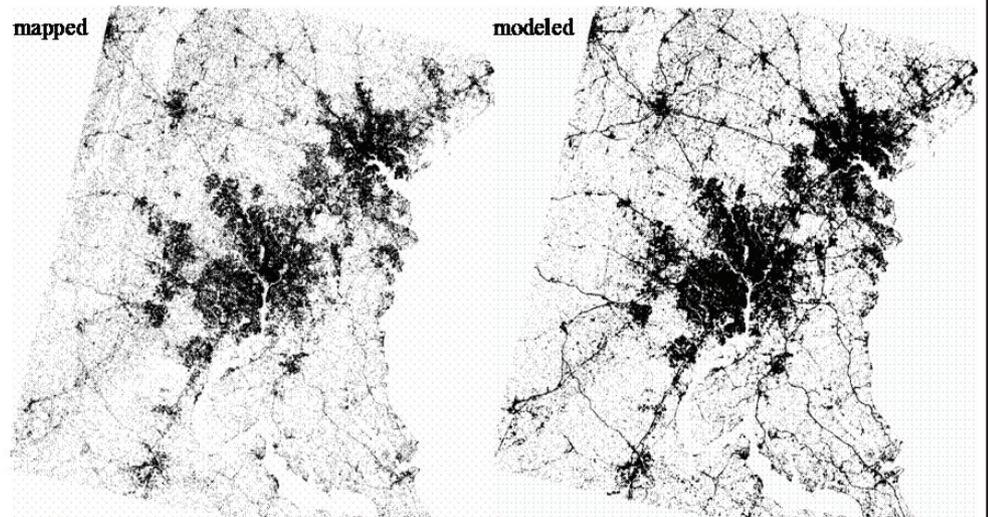
Urban extent as of the year 2000 in the greater Washington DC metropolitan area

Other Prediction and Modeling LCLUC Projects:

Small Christopher, Columbia University. *Development and Sensitivity Analysis of High Resolution Land Surface Parameters from Satellite Data and their Use in a Mesoscale Model - LDEO*
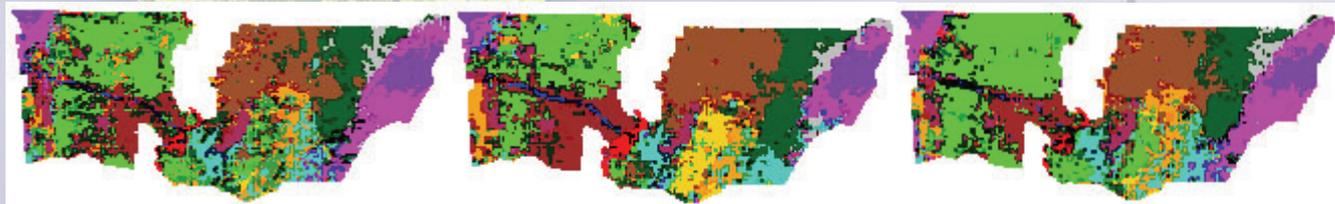
Quantifying Changes in Carbon Pools with Shrub Invasion of Desert Grasslands using Multi-Angle Data from EOS Terra and Aqua

Mark J. Chopping (Principal Investigator), Lihong Su, Montclair State University; John V. Martonchik, NASA/JPL; Albert Rango, Debra P. C. Peters, USDA, ARS Jornada Experimental Range

This work addresses new approaches to exploiting data from the Multi-angle Imaging Spectro-Radiometer (MISR) and Moderate Resolution Imaging Spectroradiometer (MODIS) for mapping desert grasslands. Significant progress has been made in geometric optical canopy modeling, with good simulations of 441 red band pixels in the 9 MISR views in a 5.25 km^2 area in the Jornada Experimental Range (N = 3969, r^2 =0.78). Regression of the four background sub-model parameters on the kernel weights of a LiSparse-RossThin bidirectional reflectance distribution function (BRDF) model and nadir camera multi-spectral reflectance provided accurate measures of the background contribution, allowing inversion of the model for fractional shrub cover, using numerical methods. Absolute root-mean square error between retrieved and measured values was 0.03 and ~90% of the estimates were within 0.05 of the true value for a wide range of canopy configurations. Research was also performed on the use of maximum likelihood and support vector machine (SVM) algorithms for classification of MISR and MODIS data sets to plant community types in the Jornada Experimental Range and the Sevilleta National Wildlife Refuge, New Mexico (19 classes). Half of the samples were randomly selected as the training set and the other half as the testing set. A total of 66 classifications were performed with various combinations of data sets: the $r0$, k, and b parameters of the MRPV BRDF model; the isotropic, geometric and volume scattering kernel weights of a Li-Ross BRDF model; the structural scattering index; and MISR and MODIS surface reflectance estimates. This research found that multi-angular observations, surface anisotropy patterns and SVM algorithms can improve desert vegetation type differentiation importantly. Using multi-angle data raised the overall classification accuracy from 45.4% for nadir observations to 60.9%, and with surface anisotropy patterns derived from MRPV and RossThick-LiSparse-Reciprocal BRDF models an overall accuracy of 67.5% can be obtained with a maximum likelihood classifier. Using a non-parametric SVM algorithm the classification accuracy was raised to 76.7%.

Community Type Classifications for the Sevilleta National Wildlife Refuge using MISR data and model-derived multi-angle metrics (a) 1998 NSF LTER Vegetation Map (b) Maximum Likelihood method (c) Support Vector Machine method.

a.   b.   c.

Legend	
Plains Grasslands	Water or Wet Ground
Chihuahuan or Gr. Basin Lowland Swale/Swale Grasslands	Barren or Sparsely Vegetated
Chihuahuan Desert Shrublands	Great Basin Grasslands
Great Basin Shrublands	Transition Chihuahuan and Great Basin Grasslands
Rocky Mountain Conifer Savanna	Chihuahuan Desert Grasslands
Rocky Mountain Conifer Woodlands	Transition Chihuahuan and Plains Grasslands
Rio Grande Riparian Woodlands	

N

5km

Effects of Logging, Plantation Conversion, Biomass Burning and Regrowth on Carbon Dynamics in Bornean Peat and Dipterocarp Forests: Implications for Global Carbon Cycle

Lisa Curran (Principal Investigator), Yale University; Simon Trigg, University of Maryland; Daniel Nepstad, Richard Houghton, Woods Hole Research Center

This research focuses on biodiversity-rich Indonesian Borneo (Kalimantan), a significant terrestrial reservoir for atmospheric carbon. With Kalimantan currently undergoing rapid forest conversion and habitat degradation, this research aims to develop carbon models based on: (1) a regional-scale database that can be used to quantify variations in terrestrial carbon storage as a function of forest cover and land-use type, and (2) new regionally-specific approaches to map the extent of peat forest, oil palm plantations, and areas burned, as well as assessments of the spatio-temporal patterns of degradation and land-cover change.

Cumulative forest loss within the Gunung Palung National Park (GPNP) 1998-2002
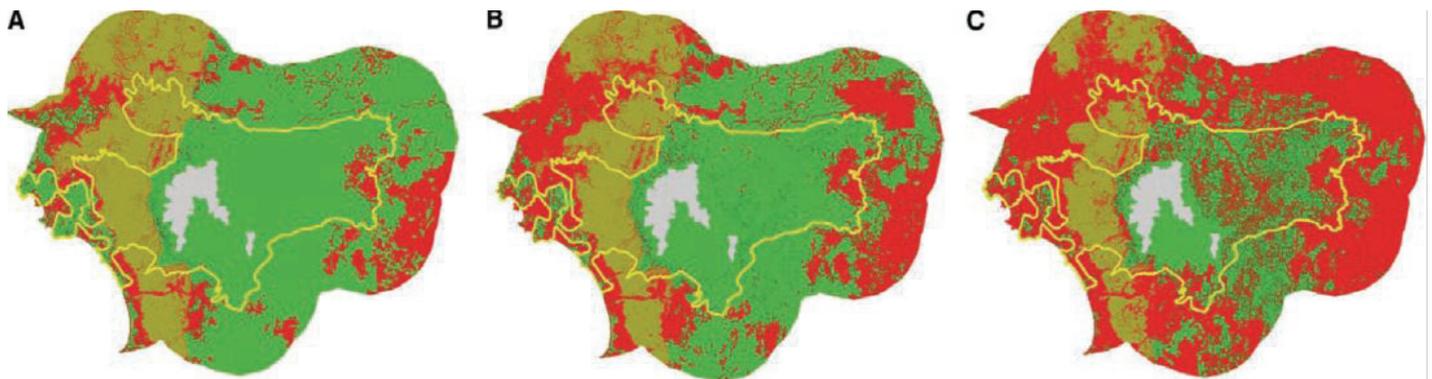
*Cumulative forest loss within the Gunung Palung National Park (GPNP) in West Kalimantan boundary (yellow) and its surrounding 10-km buffer. Forest and nonforest classification are based on a Landsat Thematic Mapper time series (1988, 1994, 1997, 1999, 2001, and 2002). Classifications are shown for (**A**) 1988, (**B**) 1994, and (**C**) 2002. Lowland (green) and peat (olive) forests were converted to nonforest (red), first predominantly in the buffer and later within the park. Grayareas are montane forest (66 km2 more than 500 m a.s.l.) and were excluded from analyses. The well-defined nonforest area that appears northeast of GPNP in (B) has been clear-felled for an oil palm plantation.*

Database development has been furthered by the compilation of essential data layers, such as district-level GIS census data, GIS lithology data, detailed GIS land system (cover) data, and Landsat-derived 1990-era roads, 2000-era roads, and oil palm plantation extent. The summer field campaign of 2005 yielded aerial surveys across many land cover types in western West Kalimantan, and field surveys that derived the key measures of peat depth and above and below-ground biomass. The above ground biomass estimates are being tested to derive empirical relationships that will permit the use of ETM+ and MODIS reflectance measurements to extrapolate above ground biomass across Borneo. The below-ground biomass estimates are being compared with peat phasic zones classified from ETM+ data (as illustrated) to test phasic zone information as a predictor of peat depth. A further project component is using ETM+ data coupled with field survey to assess the carbon implications of the widespread conversion of residual forest stands to oil palm plantations. Preparations are also underway for our experimental peat burn (planned for 2006). Relationships derived from

field parameters will assist time-series analysis of change and carbon model development; regional analyses will serve as the basis for scaling up mapping and modeling efforts.

Selective Logging in the Brazilian Amazon

Gregory Asner Principal Investigator), David Knapp, Eben Broadbent, Paulo Oliveira, Stanford University; Michael Keller, USDA Forest Service/University of New Hamshire; Jose Natalino Silva, Embrapa Amazonia Oriental
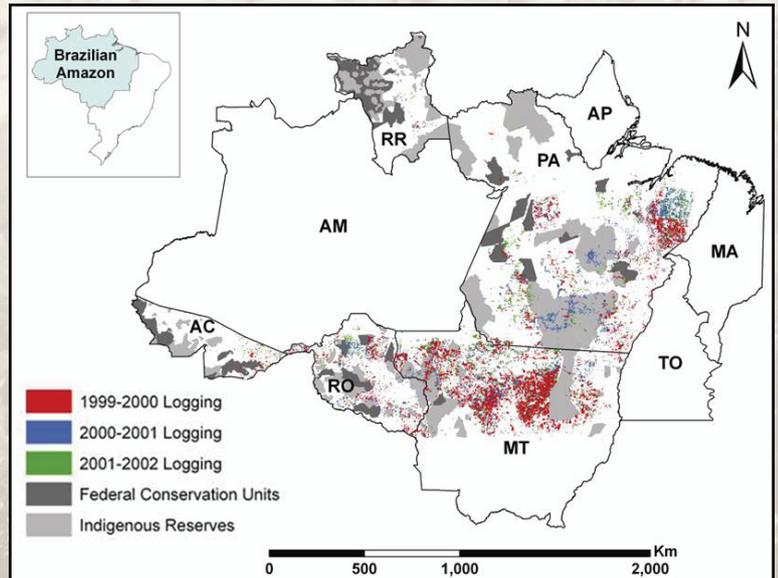
Amazon deforestation has been measured by remote sensing for three decades. In comparison, selective logging has been mostly invisible to satellites. This team developed the first large-scale, high-resolution, automated remote sensing analysis of selective logging in the top five timber producing states of the Brazilian Amazon. Data were combined from Landsat 7 ETM+, Terra MODIS, and EO-1 Hyperion sensors to achieve this goal. Selective logging areas in the Brazilian Amazon ranged from 12,075-19,823 km^2 yr^{-1} ($\pm$14%) between 1999 and 2002, equivalent to 60-123% of previously reported annual deforestation or "clear-cut" area. Up to 1,200 km^2 yr^{-1} of logging was observed on conservation lands. Each year 27-50 million m^3 of wood were extracted and a gross flux of up to 0.08 Gt C was destined for release to the atmosphere by logging. More information on this project can be found at:
http://asnerlab.stanford.edu/projects/ amazon_logging2/amazon_logging.shtml

*Spatial distribution of selective logging in five timber-production states of the Brazilian Amazon for the year intervals 1999–2000 (red), 2000–2001 (blue), and 2001–2002 (green). The states of Amazonas (AM), Amapa (AP), Tocantins (TO), Maranhao (MA), and the southern nonforested part of Mato Grosso were not included in the analysis. Light gray areas show the extent of indigenous reserves; dark gray areas delineate federal conservation lands as of 1999 (*Science vol. 310, p. 480-482, 21 October 2005)

Northern Eurasian C-land use-climate interactions in the semi-arid regions

Dennis Ojima (Principal Investigator), Colorado State University; Xiangming Xiao, University of New Hampshire; Chuluun Togtoghyn, Mongolian National University; Sayat Temirbekov, Kazakhstan National Institute of Botany; Svetlana Nikulina, UNEP; Muhtor Nasyrov, Mardonov Bakhtiyor, Samarkand State University; Kanat Akshalov, Research Institute of Grain Farming, Kazakhstan

The Northern Eurasian (from the Black Sea to the Mongolian Plateau) land use history and importance is unique within the global environmental science framework. The land-use systems are the most diverse among the temperate ecosystems due to the fertile soils, mountain fed rivers, and range of climate. The region is noted for the rapid increase in surface temperature, approximately a 1°C increase during the past 50 years. The recent changes in the climate and factors affecting land-use decision in the region have led to changes in cropland abandonment, destocking of certain rangelands and increased stocking of others, degradation of soils due to salinization and desertification, and damage to wetlands due to modifications of water regime.

Carbon stores and fluxes through out the region have been modified through land-use change over the past decades.

The objective of this study is to investigate the roles and consequences of changes in climate and land-use intensity on the land carbon stores and fluxes, water vapor exchange, and CO_2 exchange of the steppes of Eurasia during the past 100 years. Recent analysis of land-use changes indicate that socio-political changes driving land-use change have affected carbon dynamics more that mere climate changes in the region. However, the sensitivity of the rangeland and abandoned cropland ecosystems to changes in climate and land-use may alter the rate of carbon stored or emitted from these ecosystems.
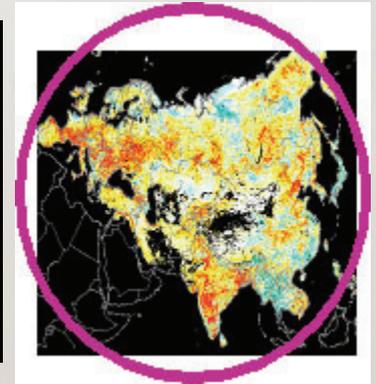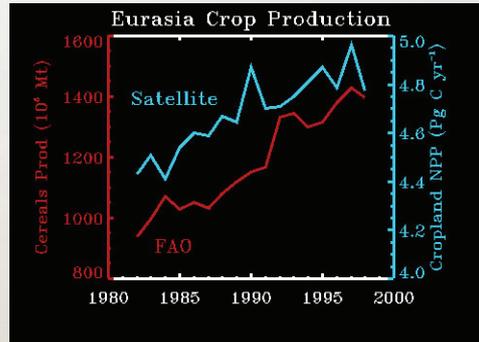
Analysis of NPP trends from remote sensing observations and FAO statistics indicate similar increase cropland NPP during the past 20 years. This result will enhance our analysis of land use impacts on NPP and ecosystem responses.

Detecting and characterizing fires in the Brazilian Amazon

Ivan Csiszar (Principal Investigator), University of Maryland; Jeff Morisette, GSFC; Douglas Morton, Wilfrid Schroeder University of Maryland; Joñ o Pereira IBAMA, Brazil; Louis Giglio SSAI/GSFC

As part of the Large-Scale Biosphere-Atmosphere Experiment in Amazonia (LBA) program, this project focuses on quantifying the uncertainty in satellite derived fire and burn scar products in the Brazilian Amazon, concentrating primarily on products derived from the Moderate Resolution Imaging Spectroradiometer (MODIS) sensors flown aboard the Terra and Aqua satellites. The project is a collaborative effort between the NASA Goddard Space Flight Center, the University of Maryland and the Instituto Brasileiro do Meio Ambiente e dos Recursos Naturais Renová veis (IBAMA). The team is building on previous efforts by quantifying the spatial extent of fire in the Amazon and characterizing fire types based on the nature of land-use changes. The project is producing data and tools to determine where fire leads to land-cover change and where it maintains land cover in a state of equilibrium. A series of field campaigns in the Brazilian Amazon are providing coincident field, airborne, and Advanced Spaceborne Thermal Emission and Reflection (ASTER) sensor data to evaluate the quality of the MODIS fire product. Ground temperature measurements and fire perimeters from field and airborne data are compared with coincident satellite images to refine the detection algorithms. Characteristics of fires from MODIS are combined with time series of the MODIS vegetation index (VI) product to differentiate between "conversion" fires, the result of recent deforestation, and "maintenance" fires, used to rehabilitate degraded pasture areas or to clear woody material from agricultural fields. Quantifying the timing and area of new clearing and maintenance fires provides critical insight into carbon fluxes from land-use change in Amazonia.

Reducing Uncertainties of Carbon Emissions from Land Use-Related Fires with MODIS Data: From Local to Global Scale

Ruth DeFries (Principal Investigator), Simon Trigg, Doug Morton, University of Maryland College Park; G.J. Collatz, NASA GSFC; J. Randerson, University of California Irvine; G. Van der Werf, USDA-FAS, NASA GSFC; Louis Giglio, SSAI, NASA/GSFC; Lisa Curran, Yale University

Tropical deforestation is a major source of carbon to the atmosphere, primarily through fire used to clear forests for cropland or pasture. Previous estimates of carbon emissions from fire are based on coarse resolution satellite data and do not account for varying fire regimes associated with different land uses or for variations in biomass. This project uses MODIS data and the CASA biogeochemical model at the MODIS 250m resolution in two test areas, each covering the extent of a MODIS tile (approximately 1000 x 1000 km). The test areas are the southern Amazon and Kalimantan, two regions of rapid land-use change where fire is used extensively for land management. Detailed analyses of these two test areas allows for assessment of sources of uncertainties in the coarser scale estimates. It also provides a means of partitioning carbon emissions from different land-use types, i.e. initial forest clearing vs. maintenance of previously cleared pasture or oil palm plantations. Using the high-resolution model results, it will be feasible to develop approaches to realistically scale up estimates of carbon emissions from land use-related fires to regional and global scales. The high-resolution model results also provide a basis for assessing emissions from possible future land-use trajectories in the rapidly-changing tropics.

Other Carbon/Biogeochemical Cycle LCLUC Projects:

Conard Susan, USDA Forest Service. *Wildfire Impacts on Carbon Stocks and Exchanges in Forests of Central Siberia: Quantifying Effects of Fire Intensity, Fire Severity, and Burning Conditions*

Lettenmaier Dennis, University of Washington/JPL. *Diagnosis and Prognosis of Changes in Lake and Wetland Extent on the Regional Carbon Balance of Northern Eurasia*

Li Changsheng, University of New Hampshire. *Quantifying CO2 Fluxes from Boreal Forests in Northern Eurasia: An Integrated Analysis of Flux Tower Data, Remote Sensing Data and Biogeochemical Modeling*

Nepstad Daniel, Woods Hole Research Center. *Integration of land use, fire, and carbon flux in critical Amazon landscapes: the Xingu River headwaters and the BR163 highway corridor*

Qi Jiaguo, Michigan State University. *Land Use and Land Cover Dynamics of China in Support of GOFC/GOLD and NEESPI Sciences*

Saatchi Sassan, JPL//BU/USDA. *Forest woody biomass carbon estimates of N. America from synergistic analysis of MODIS, MISR and JERS data in support of NACP*

Shugart Herman, University of Virginia. *Modeling the carbon dynamics of the Eurasian Boreal Forest*

Soja Amber, NASA Langley Research Center. *Wildfire, ecosystems, and climate in Siberia*

Sun Guoqing/Masek Jeff, UMD/NASA. *Comparative Studies on Carbon Dynamics in Disturbed Forest Ecosystems: Eastern Russia and Northeastern China*

Tubiello Francesco, Columbia University. *Carbon, Climate and Managed Land in Ukraine: Integrating Data and Models of Land Use for NEESPI*

Woodcock Curtis, Boston University. *Quantifying the Effects of Land-Use Change on Carbon Budgets in the Black Sea Region and China*

Evaluating Impact of Climate and Land Use change on Wildland Fire and the Amur Tiger

Tatiana Loboda, University of Maryland, ESS Fellow 2004

This project is aimed at developing quantitative methodologies for assessment, monitoring, and predicting the impact of wildland fire on a highly endangered species – the Amur tiger. The only known tiger habitat is under pressure from growing demand for natural resources which is further amplified by the rising threat of large and catastrophic fire occurrence. The remotely sensed data driven Fire Threat Model (FTM) developed within this project provides a basis for spatially explicit quantitative assessment of likelihood of wildland fire occurrence, its impact and recovery potential for a given resource. This model is intended for use by resource managers to assist them in assessing current levels of fire threat to a given resource, projecting the changes in fire threat under the changing climate and land-use and evaluating the efficiency of various management approaches aimed at minimizing the fire impact. During its first phase, the project focused on evaluating the risk of ignition using MODIS active fire product. Unlike fire behavior, fire ignition is often connected with economic and cultural aspects of human presence as well as climatic conditions. The risk of ignition in the Russian Far East is highly variable in spatial and temporal domains and is strongly linked to anthropogenic activity (transportation routes, settlements and land use). However, there is also an indication that during the largest fire seasons natural sources of ignition also contribute to increased fire occurrence. In the next phases analyses leading to proper parameterization for the FTM will be undertaken to evaluate potential fire behavior, fire impact on the tiger, and the area's rehabilitation potential through remotely sensed data. A set of potential scenarios of changes in fire threat associated with climate and land-use change will provide a basis for long-term planning of the Amur tiger habitat protection.
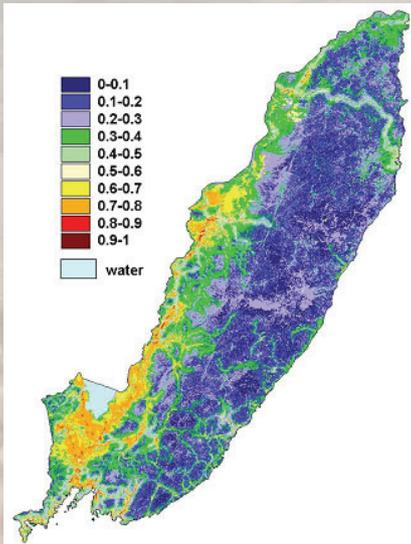
The spatial patterns and the levels of the Risk of Ignition vary throughout the year. The majority of fire ignitions during years of high and low fire activity occur in April. April map of the Risk of Ignition (left) shows the concentration of fire ignitions along roads and particularly in lowlands in the western part which are primarily occupied by croplands. In contrast forest covered mountainous regions have very low levels of the Risk of Ignition during that time.

Land Use Change Around Protected Areas in LCLUC Sites: Synthesis of Rates, Consequences for Biodiversity, and Monitoring Strategies

Andrew Hansen (Principal Investigator), Montana State University; Lisa Curran, Yale University ;Emilio Moran, Indiana University; Jack Liu, Michigan State University; Ruth DeFries, University of Maryland; Robin Reid, International Livestock Research Institute; Billie Turner, Clark University

Many nature reserves are loosing species despite being well protected within their boundaries; land-use change in the surrounding landscape may strongly impact reserves. This study examined land use effects on nature reserves by synthesis across six regions: Borneo, Indonesia; Maasailand, East Africa; Santerem, Brazil; Wolong, China; Yellowstone, USA; and Yucatan, Central America. Objectives were to: quantify rates of change in land use around reserves; examine consequences for biodiversity within the context of specific ecological mechanisms; and draw implications for regional management. Within each of the regions, semi-natural habitats around reserves have been converted to human land uses. Rates vary from 0.2-0.4%/yr for swidden farming in Yucatan, to 9.5%/yr for logging in Borneo. Ecological mechanisms that connect biodiversity

to these land-use changes include habitat size, ecological flows, crucial habitats, and edge effects. For example, the effective size of the East African study area has been reduced by 45% by human activities. Based on the species area relationship, this reduction in habitat area will lead to a loss of 14% of bird and mammal species. While land conversion rates have been less in Yucatan, habitat destruction has been biased towards the productive, old-growth habitat that is crucial habitat to many species. In a portion of East Africa, loss of seasonal habitats contributed to significant population declines of 10 of 13 large mammal species. In Greater Yellowstone, low elevation population source habitats for birds have been converted to population sink areas due to rural home development. Consequently subpopulations in Yellowstone National Park are at increased risk of extinction. A major conclusion is that the viability of nature reserves can best be ensured by managing them in the context of the surrounding region.
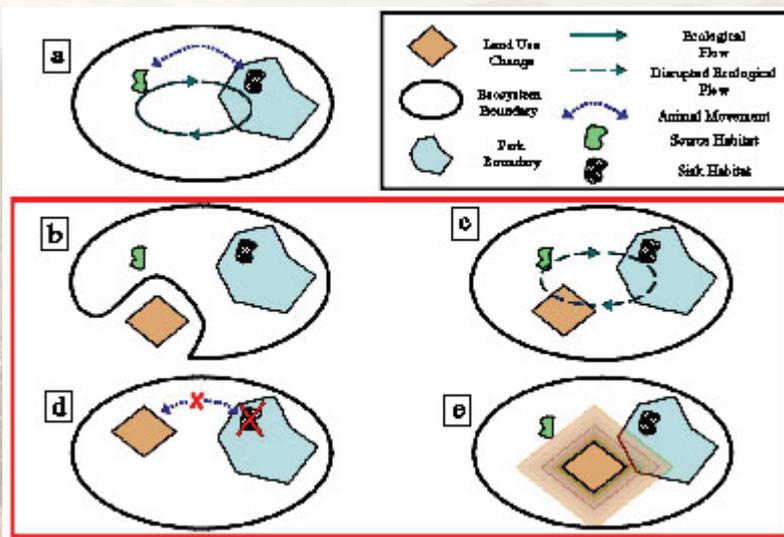

Figure 1. Conceptual model illustrating the effects of land-use change on ecosystem function. (a) Protected areas as part of a larger ecosystem with energy, materials, and/or organisms flowing through the ecosystem. (b) Land-use change reduces effective size of ecosystem. (c) Land-use change alters ecological flows. (d) Land-use change eliminates unique habitats and disrupts source-sink dynamics. (e) Edge effects from land use negatively influence park

Fire and Vegetation Dynamics in the Serengeti-Mara Region

Jan Dempewolf, University of Maryland, College Park, ESS Fellow 2003

This project investigates fire and vegetation dynamics in the savanna environment of the Serengeti-Masai Mara region in Tanzania and Kenya and its impact on wildebeest migratory behavior. The most important factors defining ecosystem dynamics of the study region include the migratory wildebeest herds as the key species and dominant grazing animal, the distribution of structural vegetation types, the temporal distribution of vegetation greenness as a proxy for food resources, and fire dynamics. The objective of this study is to quantify these factors, and determine the interaction between them. Three data sets were developed for this purpose, using a combination of field and satellite data. Spatial and temporal distribution of food resources was derived from a MODIS vegetation indices time series. Structural vegetation types and changes over time were derived from Landsat scenes, and a time series of SPOT4 Vegetation, and MODIS data. Fire dynamics was derived from a MODIS time series. Wildebeest migratory behavior was collected in the field by use of collars equipped with Global Positioning System receivers and simulated in an agent based model. The vegetation type analysis showed increasing woody cover for the Serengeti National Park (SNP) and Maswa Game Reserve (MGR), while the Masai Mara National
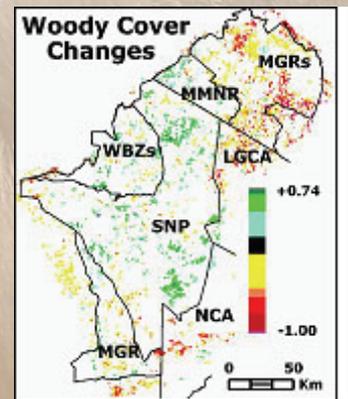
Relative changes of woody cover density 1998 to 2004 from SPOT4-Vegetation and MODIS time series, significant at p=0.10.
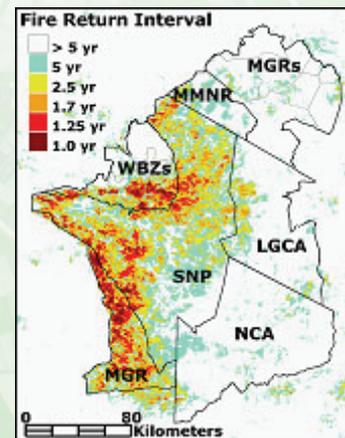
Reserve (MMNR) and Mara Group Ranches (MGRs) had stable or decreasing woody cover (Figure 1). Burned areas in the study region have been mapped implementing a newly designed, fully automatic algorithm based on daily MODIS imagery at 250 m resolution. Fire return interval differed considerably within the study area. SNP and adjacent Western Buffer Zones (WBZs) and the MGR showed the shortest average fire return interval with 4.0 years or less and MMNR and the MGRs 12.7 years or more (Figure 2). Further analysis is focused on the relation between fire dynamics and woody cover trends, fire management, and wildebeest movements.

Fire return interval 2000-2004

Fire Return Interval
- > 5 yr
- 5 yr
- 2.5 yr
- 1.7 yr
- 1.25 yr
- 1.0 yr

Other LCLUC Ecosystem and Biodiversity Projects

Radeloff Volker, University of Wisconsin. Post-USSR land-cover change in Eastern Europe – socioeconomic forcings, effects on biodiversity, and future scenarios

Liu Jack, Michigan State University. Multi-scale Impacts of Land-Use/Land-Cover Change on Giant Panda Habitats

Consequences of Institutional Change: Land-Cover Dynamics in Kazakhstan 1960-2000

Anatoly Gitelson, Geoffrey Henebry (Principal Investigators), University of Nebraska

This project explores the biogeophysical consequences of the collapse of the Soviet Union in the early 1990s, with a particular emphasis on Kazakhstan, the second largest country to emerge from the Soviet Union (after Russia) and the ninth largest country on the planet. The disintegration of the institutions of centralized control over the agricultural sector triggered a rapid, widespread LCLUC event. Without planting schedules or crop energy subsidies in the form of fertilizers, pesticides, and fuel, or access to markets, the agricultural sector contracted sharply during the 1990s throughout the former Soviet Union and its client states. There were significant consequent changes in biogeophysical processes, including the onset and timing of *land surface phenology* (LSP) that links the ecological dynamics of the vegetated surface with the atmospheric dynamics of the planetary boundary layer. To establish that significant changes had occurred, the project developed a new statistical framework for the analysis of image time series (that included robust tests for step changes, trends, and seasonal functional responses) and techniques sensitive to changes in moderate-to-high vegetation density (http://calmit.unl.edu/kz). Analyzing the Pathfinder AVHRR Land (PAL) NDVI dataset as a function of accumulated growing degree-day using two different spatial partitionings, only three significant patterns of change in LSP, shown bellow, were observed across Kazakhstan out of 14 possible patterns: (1) increased NDVI throughout the growing season; (2) higher NDVI earlier in the growing season; and (3) earlier green-up with increased seasonal integral of NDVI. The principal mechanism behind these changes in LSP was *widespread agricultural deintensification* in the forms of increased proportions of fallow fields in the rain-fed grain belt and decreased grazing intensities in pastures due to declines in livestock herds. This quantitative change analysis framework has been successfully extended to different ecoregions and biomes in Eurasia, including tundra, taiga, and desert.
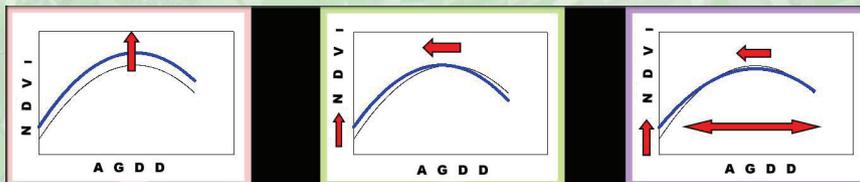
Responses of coastal waters to terrestrial inputs of elemental CNP in urbanizing coastal regions

Thomas R. Fisher, Horn Point Laboratory, University of Maryland; Anatoly A. Gitelson, University of Nebraska-Lincoln (Principal Investigators); Michael Williams, EPA, Chesapeake Bay Program Office; Donald C. Rundquist, School of Natural Resources, CALMIT, UNL

The US coastal zone has long been impacted by human populations. Many coastal areas were converted from forests to agriculture in the 18th and 19th centuries, and in the second half of the 20th century widespread application of fertilizers increased crop yields to feed human populations. This more intensive agriculture also resulted in greater export of nitrogen and phosphorus, and the chemistry of non-tidal waters is now determined by upstream agriculture in rural areas.

Human populations grew rapidly during the second half of the 20th century, particularly in coastal areas. Urbanization resulted in increasing imports of food and export of human waste. The Chesapeake Bay and the Mississippi plume are regions which have received large quantities of N and P from agriculture and human wastes and which have developed symptoms of eutrophication such as algal blooms, loss of transparency, and hypoxia. However, other coastal regions such as the Delaware Bay and the Hudson estuary receive equally large inputs (scaled to area or volume), but these exhibit little enhanced turbidity, phytoplankton biomass, and hypoxia.

Figure 1. Annual average total nitrogen (TN) concentrations in non-tidal streams of the Choptank River basin.

The focus of this research is the spatial variation in sensitivity to nutrient loading from urbanization and agriculture. This team of researchers is testing the hypothesis that the water-residence time determines the sensitivity of estuarine systems to terrestrial nutrient inputs in three Mid-Atlantic estuarine systems: Chesapeake Bay, Delaware Bay, and the Hudson River estuary. MODIS imagery is used to derive spatial estuarine patterns of turbidity and chlorophyll a in response to nutrient loading from surrounding basins. The hypothesis will be tested by (1) estimating urbanization in coastal areas using historical and current AVHRR, Landsat TM, and MODIS imagery, (2) calculating nutrient inputs to these estuarine systems using USGS measurements, municipal wastewater records, and hydrochemical modeling of ungauged areas; (3) applying MODIS and SeaWiFS data to estimate turbidity and chlorophyll-a in turbid productive waters of estuaries; and (4) estimating water residence times using bathymetry, tides, salinity distributions, and stratification. This approach will be used to distinguish between nutrient-sensitive and insensitive coastal regions in order to provide a method for classifying coastal waters into regions in which urbanization and agriculture have negative consequences for water quality.
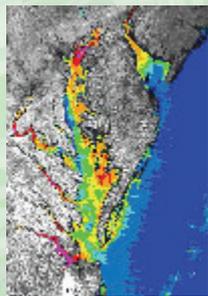

Figure 2. Spatial estuarine patterns of turbidity in Chesapeake Bay (center) and Delaware Bay (upper right) derived from a 250 m resolution MODIS image obtained in June 2002.

Agriculture and the Transformation of Planet Earth

Jon Foley (Principal Investigator), Mike Coe, Chris Kucharik, Navin Ramankutty, Carol Barford, Center for Sustainability and the Global Environment, University of Wisconsin, Madison

The rise of modern agriculture, coupled with the massive population increases and technological developments of recent decades, has transformed about one-third of the Earths land surface into croplands and pastures.
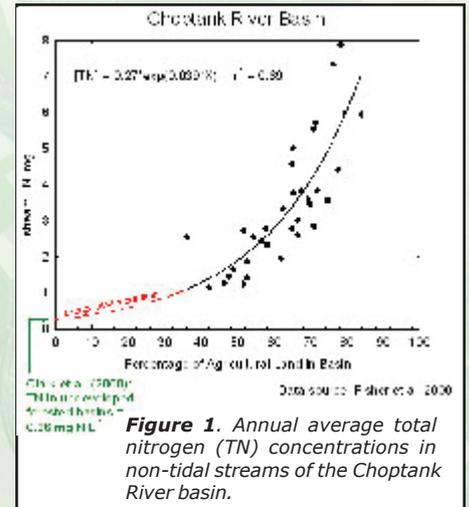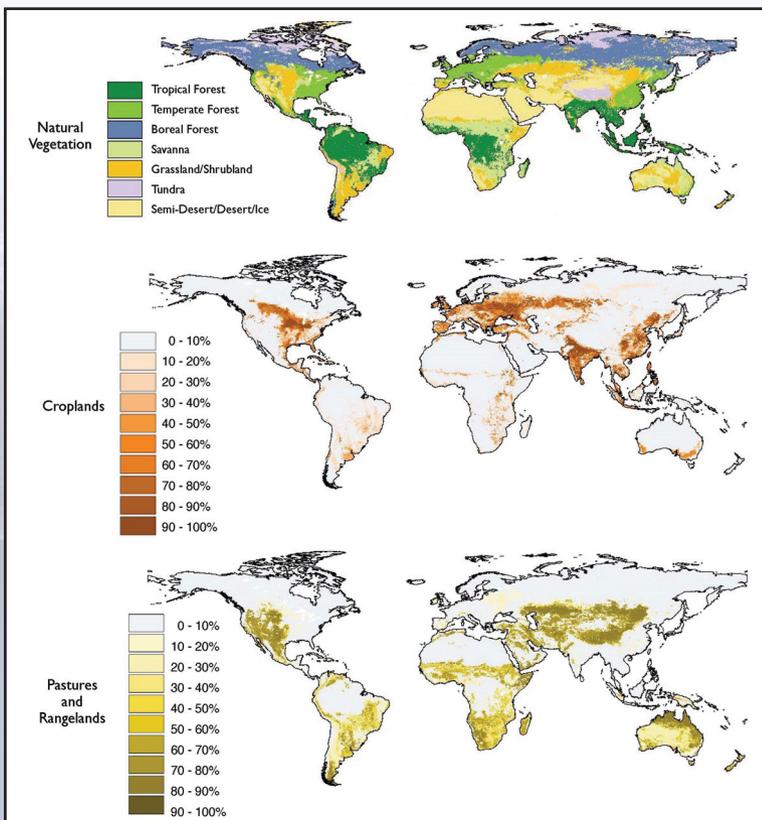
In addition, the widespread use of fertilizers and irrigation has drastically affected water and nutrient balances across large regions of the globe. Such changes to the land have driven fundamental shifts in the ecological, biogeochemical and hydrological systems of the planet. Even the effects of future climate change may not have such a major transformative effect on the environment and on human society. However, despite the importance of agriculture on environmental systems, we still know relatively little about how these domains interact across local, regional and global scales.

With NASA IDS funding, this research team is investigating how a variety of human and environmental drivers affect the condition of agroecosystems and freshwater systems on regional and global scales. This work is done at the global scale to identify and better document agricultural land cover and land use practices, and their consequences on large-scale water, carbon and nitrogen budgets. We also conduct more detailed regional-scale studies in the Mississippi basin to improve our understanding of the linkages between atmospheric, ecological, biogeochemical and hydrological processes in agriculturally dominated regions.

Worldwide extent of human land use and land-cover change. The maps illustrate the geographic distribution of "potential vegetation" (top panel, vegetation that would probably exist in the absence of human land use) and the extent of agricultural land cover (including croplands and pastures, middle and bottom panels) across the world in the 1990s (Foley et al. 2005. Science 309:570-574)

Regional Hydrological Response of Semi-Arid Mediterranean Climate Watersheds to Land-Cover/Land-Use Variability

Allen Hope (Principal Investigator), San Diego State University; Douglas Stow, South Dakota State University; Terence Newby, Agricultural Research Council, South Africa

This project was launched in October 2005. It has two broad components, the first being to relate watershed land-cover/land-use (LCLUC) and physiographic variables to the parameters of a parsimonious, lumped-parameter, conceptual model (such as the IHACRES model). The LCLUC variables will be derived from MODIS products and physiographic variables will be calculated from Shuttle Radar Topography Mission (SRTM) terrain data. Hydrographic and meteorological data for all gauged watersheds (area range 100 - 4,000 km^2) in the Mediterranean-climate regions of California and the Western Cape Province of South Africa (fynbos biome) will be used in this regionalization study. The objectives of this study are consistent with the International Association of Hydrological Sciences (IAHS) Decade on Predictions in Ungauged Basins (PUB) initiative, which calls for a specific focus on predictive uncertainty, regional analyses based on available gauged data and the assimilation of new data (remote sensing). A major outcome of this project is expected to be a regional
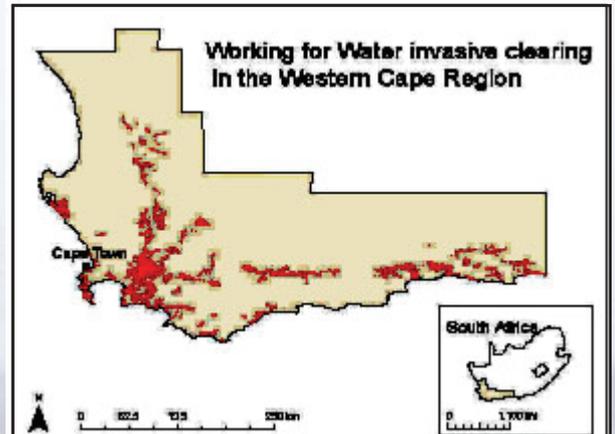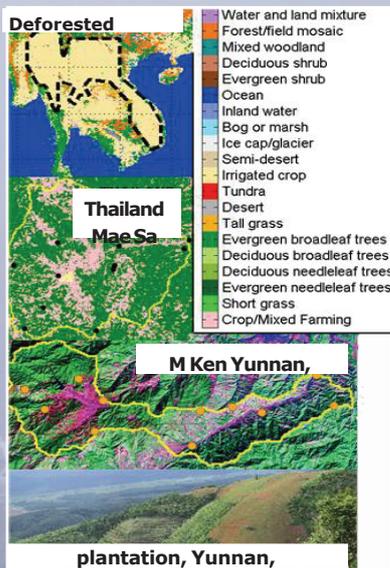
hydrological modeling system for simulating river flows in ungauged watersheds accompanied by quantitative indicators of predictive uncertainty.

The second component of the project will exploit recent rapid and large scale transformations of ecosystems in California (fire) and South Africa (invasive vegetation removal) to quantify their effects on river flow regimes. Both modeling and paired watershed analyses will be used in this component of the project. MODIS products of LCLUC will be used to quantify changes in the study watersheds.

The Working for Water Program was initiated in 1995 to clear invasive vegetation from watersheds in South Africa. Close to 300,000 Ha are undergoing clearing in the Western Cape Region (red polygons).

The Role of Land-Cover Change in Montane Mainland Southeast Asia in Altering Regional Hydrological Processes under a Changing Climate

Jefferson Fox, Tom Giambelluca (Principal Investigators), University of Hawaii

Montane mainland Southeast Asia (MMSEA), situated within the Greater Mekong Subregion, is an area of great biological and cultural diversity that has come under close scrutiny because of deforestation, land degradation, road development, and the conversion of traditional agricultural land uses to more permanent agriculture driven by regional and global markets. These changes have important implications for biodiversity, watershed hydrology, local and regional meteorological processes and climate change. This project seeks to understand, characterize and explore the relationships between LCLUC in MMSEA and local and regional moisture and energy fluxes and regional changes in atmospheric circulation. A

multi-scale, historical geospatial database has been acquired for the region and information regarding drivers of LCLUC is being collected and analyzed via Analytical Hierarchy Process and Fuzzy Cognitive Mapping methods. These data and interrelated future scenarios of agricultural, infrastructure and market changes guide the development of a portfolio of LCLUC models at watershed to regional scales using cellular automata, agent-based, and fuzzy cognitive simulation techniques. The team has installed and begun collecting data from a network of 22 hydrological and climate instruments across two representative, intensive study watersheds in southern Yunnan, China and northern Thailand, each around 100km^2. These field observations together with additional biophysical data and LCLUC projections will be used to parameterize and calibrate the distributed hydrological model (DHSVM) for the watersheds. Regional climate simulations are running under present climate conditions (European Centre for Medium-Range Weather Forecasts) with present LCLU and extreme deforestation, and additional experiments are planned using control and projected climate (Parallel Climate Model) with present LCLU and LCLUC projections. More information on this project can be found at: *http:/research.eastwestcenter.org/mmsea/*

Other Energy and Water-Cycle LCLUC Projects:

Aizen Vladimir, University of Idaho. *Estimation of seasonal snow cover and glacial area changes in central Asia (Tien Shan) during the last 50 years using NASA ESE products and in-situ data*

Anderson Martha, University of Wisconsin-Madison. *Multi-scale remote assessment of land-surface hydrologic response to natural and anthropogenic stressors: a case study in the Florida Evergaldes*

Brown Dan, University of Michigan. *Changing Responses of Land Dynamics and Vulnerability to Flooding Under Policy and Environmental Change near Poyang Lake, China*

Chen Jiquan, The University of Toledo. *Effects of land-use change on the energy and water balance of the semi-arid region of inner Mongolia*

Davidson Eric, Woods Hole Research Center. *Interactions of Edaphic and Land Use Factors on Water Budgets in Cerrado and Semi-Arid Caatinga Region of Brazil*

Eshleman Keith, University of Maryland. *Exacerbation of Flooding Responses Due to Land Cover/Land-Use Change: A Comparative Study*

Gitelson Anatoly, University of Nebraska-Lincoln. *Land-cover land-use change effects on surface water quality: Integrated MODIS and SeaWiFS assessment of the Dnieper and Don River basins and their reservoirs*

Marc Imhoff, Goddard Space Flight Center. *Global Distribution of Human Appropriation of Fresh Water: An Earth Observation-supported Strategy Linking Biophysics and Socio-economics for Addressing Water Vulnerability*

Munroe Darla, Ohio State University. *A Comprehensive Statistical Analysis System to Associate Local Land-Cover/Land-Use Change and Regional Aerosol Composition and Concentration*

Townsend Phil, University of Wisconsin. *Spatial Patterns of Forest Disturbance and Consequences for Regional Water Quality*

Vorosmarty Charles, University of New Hampshire. *Role of land cover and land-use change in hydrology of Eurasian pan-Arctic*

Zeng Xubin, University of Arizona. Relationship between Land Cover/Land-Use Change and Surface Hydrology over Arid and Semiarid Regions

Using MODIS Data to Characterize Climate Model Land Surface Processes and the Impacts of Land Use/Cover Change on Surface Hydrological Processes

Robert Dickinson (Principal Investigator), Georgia Institute of Technology

This project is being undertaken by a multidisciplinary multi-institutional team with considerable experience in both climate modeling and remote sensing algorithms. This team is developing a quantitative basis for the assessment of consequences of land-use/cover change in terms of climate and hydrological changes. It is building on a climatology of spectral albedos related to the plant functional types (PFTs) of the Community Land Model (CLM3), a component of the Community Climate System Model (CCSM3), hosted at NCAR. The first part of this investigation is focused on establishing more realistic radiative models for these PFTs and using MODIS data to improve descriptions of land surface parameters such as leaf area index, fractional vegetation cover, fractional snow cover, and emissivity/skin temperature in CLM3. Relevant model processes are also reformulated to ensure their consistency with the MODIS observations. Major progress achieved so far includes (a) derivation of new land surface datasets from MODIS (more accurate and consistent) for use in climate models and (b) development of new land-surface parameterizations of snow fraction for the melting season, albedo for arid and semi-arid regions, and characterization of urban surfaces. These new datasets and schemes significantly improve land surface climate and energy balance simulations
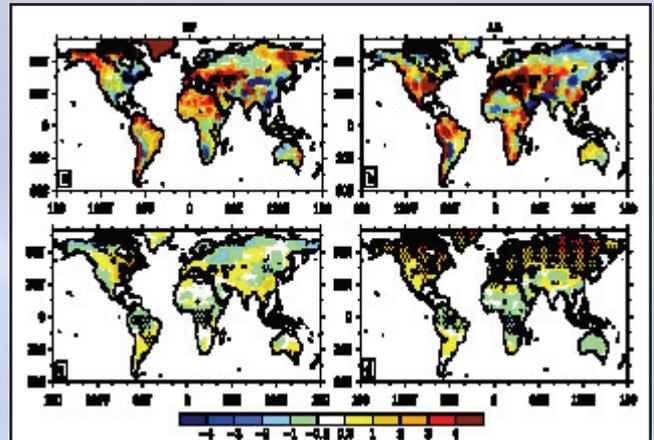
Improvements in CLM3 land surface air temperature due to the use of a new land surface dataset created from MODIS. The upper panel (a,b) shows initial temperature bias compared to observations in winter (DJF) and summer (JJA). The lower panel (c,d) shows temperature differences after the MODIS dataset was used. The red color represents positive change while blue color represents negative change. Stippling shows regions where the difference is statistically significant. Color contrasts between the upper and lower panels shows where improvements are made. For example, the model cold bias over northern high latitudes in summer and the warm bias over northern high latitude America in winter are significantly reduced.

in the NCAR CLM3/CAM3 models. The second part of this research will investigate regions of change identified by MODIS land cover dynamic algorithms and will characterize such changes in terms of changes of spectral albedos and hence in terms of some combination of changes of PFTs or of the other properties connected to a particular PFT. This study will provide a basis for including year-to-year changes of land-use/cover in climate prediction models and for establishing the hydrological consequences of past and future land-cover change. More information on this project can be found at: ***http://climate.eas.gatech.edu/dickinson***.

Integrated Regional Climate Study with a Focus on the Land-Use Land-Cover Change and Associated Changes in Hydrological Cycles in the Southeastern United States

Roger A. Pielke (Principal Investigator), Colorado State University

The land and atmospheric modeling system for this study has been developed. The land model (GEMTM-LEAF2) was integrated with NCAR's Community Land Model (CLM) 2, and an explicit sun/shaded big-leaf scheme was introduced to account for diffuse/direct solar radiation. This new Unified Land Model (ULM) is currently implemented in the NASA's Land Information System (LIS). The ULM-LIS system allows regional/
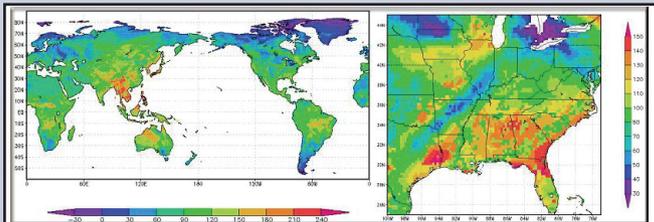

Figure 1. ULM-simulated daily net surface radiation (W/m^2) on April 8th 2001 on a) global, and b) regional-scale (eastern U.S.) with grid spacing of 25 km in the Land Information System.
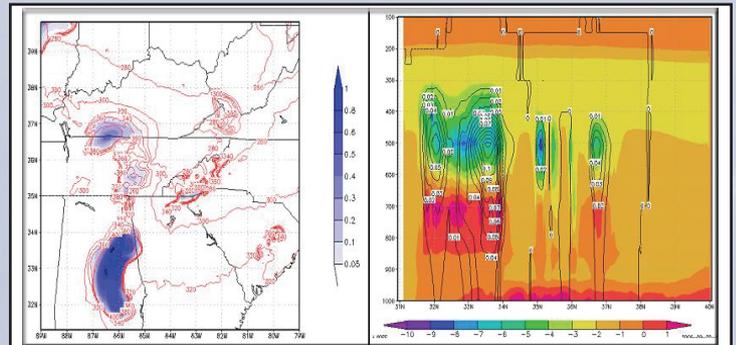
global offline simulation of land-surface processes at 1 km~25 km grid spacing, and will be applied to examine the change in the energy and water budget due to anthropogenic land-cover/land-use (LCLU) perturbations (Figure 1). Simultaneously, Terra/Aqua MODIS global surface albedo products, the LCLU map, and surface skin temperature were compiled for the

2a. **2 b.**

Figure 2. RAMS-simulated total condensate and longwave radiation fields at 03Z, June 1st 2001 over the southeast U.S. a) Vertically integrated total condensate mixing ratio (g/kg, blue shaded) and downwelling longwave flux at surface (W/m^2, red contour). b) Vertical profile of longwave heating rate (K/day, color shaded) and total condensate mixing ratio (g/kg, contour) in the pressure coordinate.

calibration and initialization of the ULM. This research is testing the North American Regional Reanalysis (NARR) for the lateral boundary conditions of the Regional Atmospheric Modeling System (RAMS). The use of NARR allows for implementation of RAMS at 5 km grid spacing with the explicit microphysics, while turning off the deep cumulus parameterization. This cloud-resolving regional climate model will considerably improve the

Other LCLUC Climate Variability and Change Projects:

Bounoua Lahouari, GSFC. Development and Validation of Process Algorithms of Urbanization for Water Cycle, Data Assimilation and Climate studies

Loveland Tom, USGS. *The Influence of Historical and Projected Land Use and Land-Cover Changes on Land Surface Hydrology and Regional Weather and Climate Variability*

Sokolik Irina, Georgia Institute of Technology. *Understanding the role of changes in land-use/land-cover and atmospheric dust loading and their coupling on climate change in the NEESPI study domain drylands*

LCLUC Regional Initiatives

Important land-use questions related to global food supply, regional water resources, carbon sources and sinks, biodiversity loss and population growth, and the regional impacts of climate change, necessitate working in a number of different regions and results in a strong international flavor to the LCLUC program. The program emphasizes studies where land-use change is rapid or where there are significant regional or global implications. The program promotes collaboration with in-country scientists and regional science networks, increasing their accessibility to NASA spaceborne assets and helping NASA scientists analyze and understand the often complex local and regional issues and conditions.

In addition to individual regional research projects, LCLUC supports several large regional science campaigns and programs with an emphasis on land-use/cover change:

• **NEESPI** - The Northern Eurasia Earth Science Partnership Initiative
• **GOFC/GOLD** - Global Observation for Forest and Land Cover Dynamics
• **LBA** - The Large Scale Biosphere Atmosphere Experiment in Amazonia
• **NACP** - North American Carbon Program
• **CARPE** - The Central Africa Regional Program for the Environment

NEESPI

## The Northern Eurasia Earth Science Partnership Initiative

NEESPI, is an active and strategically evolving program of internationally-supported Earth systems science research, which has as its foci issues in northern Eurasia that are relevant to regional and global scientific and decision-making communities.

Mission: The Northern Eurasia Earth Science Partnership Initiative (NEESPI) will identify the critical science questions and establish an international program of coordinated research on the state and dynamics of terrestrial ecosystems, land-use in northern Eurasia and their interactions with the Earth's Climate system to enhance scientific knowledge and develop predictive capabilities to support informed decision-making communities concerned for example with carbon accounting, water resources and the impacts of changes in permafrost. and practical applications.

NEESPI Goals: To conduct a large-scale, interdisciplinary program of funded research aimed at developing a better understanding of the interactions between the terrestrial ecosystem and the atmosphere, with a special emphasis on the human impacts and feedbacks in northern Eurasia in support of international Earth science programs with particular relevance to global climate change research interests (including carbon) and international sponsoring agency funding priorities.

NEESPI Study Area: The NEESPI study area is loosely defined as the region lying between 15 E Longitude in the west, the Pacific Coast in the east, 40 N Latitude in the south, and the Arctic Ocean coastal zone in the north. Territory of the former USSR, Fennoscandia, Eastern Europe, Mongolia, and North China are all included in this area. All landscapes and components of the terrestrial biosphere, including the hydrology and atmosphere, that are interactive for purposes of Earth science investigation (to include the human impacts) are considered a part of NEESPI study area.

The NEESPI Study Area
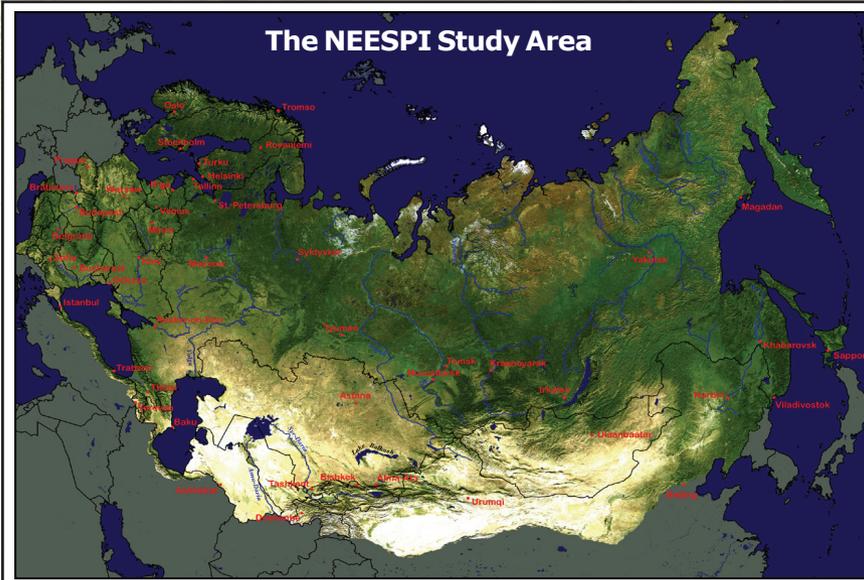
Shades of green correspond to vegetated land. Light brown and yellow indicate sparse vegetation and arid areas. Water bodies are shown in blue. Grey areas correspond to land surfaces outside the NEESPI study area.

Moderate Resolution Imaging Spectroradiometer (MODIS) 1km true color composite from August 20-28 2004. Shaded relief adjustment using the Shuttle Radar Topography Mission (SRTM) GTOPO30 elevation dataset compiled by USGS EROS Data Center.

contact Pasha Groisman (NEESPI Project Scientist, NOAA/UCAR) or check: ***http://neespi.org/***

Example NEESPI Project: Northern Eurasia Landcover Dynamics Analysis (NELDA) Project

Principal Investigator: Olga Krankina, Oregon State University

Dr. Olga Krankina, with a team of collaborators in the US and in Russia is completing the analysis of carbon dynamics in forest ecosystems of the St. Petersburg region of Russia. Landsat-based mapping of land-cover and forest biomass *(http://www.fsl.orst.edu/larse/carbon/lcluc.html)* agreed well with the results of ground-based forest inventory. Change detection was performed using the Disturbance Index and the archive of 42 Landsat images covering the period 1977-2000. Clearcut harvest was detected on 7.1% of the total forest area (6.7 million ha) and reflected the known patterns of variation within the region and over time. Regionally calibrated StandCarb model (***http://www.fsl.orst.edu/lter/pubs/webdocs/models/standcarb2.html***) indicates net carbon sink of 2.27 TgC in year 2000 with regrowing forest offsetting carbon source of 0.45TgC in forests harvested within the prior 14 years. The project attracted renewed attention in Russia after the country ratified the Kyoto protocol in 2005 and started to explore the potential for using remotely sensed data to assess carbon sources and sinks in its vast forests.

LBA
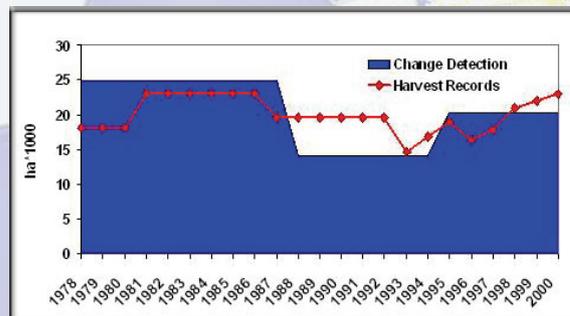
The Large Scale Biosphere-Atmosphere Experiment in Amazonia

The Large Scale Biosphere-Atmosphere Experiment in Amazonia (LBA) is an international research initiative led by Brazil. LBA is designed to create the new knowledge needed to understand the climatological, ecological, biogeochemical, and hydrological functioning of Amazonia, the impact of land-use change on these functions, and the interactions between Amazonia and the Earth system. LBA is centered on two general key questions that are addressed through multi-disciplinary research, integrating studies in the physical, chemical, biological, and human sciences:

• How does Amazonia currently function as a regional entity?

• How will changes in land use and climate affect the biological, chemical, and physical functions of Amazonia, including the sustainability of development in the region and the influence of Amazonia on global climate?

The LBA Land Cover and Land-Use change studies focus on the documentation of past and current land cover and land-use changes throughout Amazonia and development of a capability to predict the location and magnitude of future land cover and land-use changes in the region. Land cover and land use are key to documenting, understanding, and predicting ecosystem responses in Amazonia. LBA cannot succeed without adequate land cover data, nor can it succeed without an adequate understanding of the dynamics of change in land cover and land use. The specific LCLUC science questions are:

• What are the rates and mechanisms of forest conversion to agricultural land uses, and what is the relative importance of these land uses?

• At what rate are converted lands abandoned to secondary forests; what is the fate of these converted lands, and what are the overall dynamic patterns of land conversion and abandonment?

• What is the area of forest that is affected by selective logging each year? How does the intensity of selective logging influence forest ecosystem function, thus altering forest regrowth and flammability?

• What are plausible scenarios for future land-cover change in Amazonia?

For more information on LBA activities please contact Michael Keller (LBA Project Scientist US Forest Service) or check the LBA website: *http://www-eosdis.ornl.gov/lba_cptec* of the LBA-ECO Project Office website *http://lba-ecology.gsfc.nasa.gov/lbaeco*.

Example LBA Project: Integrating Coarse and Fine Resolution Satellite Data to Monitor Land Cover Change throughout Amazñnia

Ruth DeFries (Principal Investigator), University of Maryland; Yosio Shimabukuro, Brazilian National Space Research Institute INPE

The LBA LC-22 team is working to integrate coarse and fine resolution satellite data to monitor land-cover change in the Brazilian Amazon. The team has developed and validated several methods for near-real time monitoring of deforestation using 250 m resolution MODIS data. Building on the research findings, INPE launched the DETER deforestation detection project in May 2004 (*www.obt.inpe.br/deter*). The locations of new clearings larger than 25 hectares are posted to the DETER web GIS system approximately every two

weeks. DETER data and annual Landsat-based deforestation mapping products (PRODES project, *www.obt.inpe.br/prodes*) are available for download at no cost. The second aspect of the project has been to work with time series of MODIS data to characterize the nature of land use conversions. Recent expansion of cropland agriculture into the southern Amazon is altering the timing, size, and fate of deforested areas.

Phenological information from biweekly MODIS composites enables agricultural areas to be separated from other land cover types. Frequent MODIS observations help to minimize cloud contamination, especially since the growing season coincides with persistent cloud cover over the Amazon. Results from this aspect of the project include MODIS-based land cover classifications, characterization of the dynamics of cropland agriculture expansion versus deforestation for cattle ranching, and predictive modeling of the potential for the additional agricultural expansion. Finally, the team has worked with the MODIS Vegetation Continuous Fields (VCF)tree-cover product to generate training and validation data for various vegetation structures across the gradient from Amazon forest to cerrado savanna-woodland physiognomies. These training data are an integral part of calibration and validation for the VCF product.

Deforestation Year
2002 (yellow)
2003 (blue)
2004 (red)
NDVI 2004-129
Hgh : 10000
Low : -3000
50 km
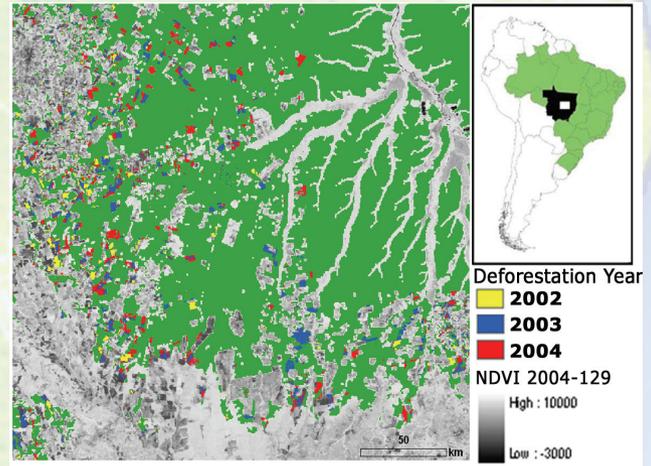
NACP

The North American Carbon Program

The central objective of the North American Carbon Program is to measure and understand carbon stocks and the sources and sinks of carbon dioxide (CO_2), methane (CH_4), and carbon monoxide (CO) in North America and in adjacent ocean regions. The NACP addresses several basic questions:

• What is the carbon balance of North America and adjacent ocean basins, and how is the balance changing over time? What are the sources and sinks, and the geographic patterns of carbon fluxes?

• What factors control the sources and sinks, and how do they change with time?

• Are there potential "surprises", where sources could increase or sinks disappear?

• How can we enhance and manage long-lived carbon sinks to sequester carbon?

There are two major program elements that related to the theme of land-use and land-cover changes. These are: 1) development of the infrastructure of long-term observations of the atmosphere, including exchange fluxes with vegetation and soils, and of the capability to measure net uptake or emissions from the land (forests, agriculture, urban and suburban areas, and wild lands) of North America, and 2) enhancement of forest, crop, wetland, and soil inventories, and process studies. The goal for NACP ecosystem measurements and models are to quantify, and reduce uncertainty in, spatial patterns and mechanisms accounting for changes in carbon stocks and methane release and uptake. The list of LCLUC-related NACP projects can be found at *http://lcluc.hq.nasa.gov.* Additional information on the NACP can be found at: *http://www.nacarbon.org/nacp* and at *http://www-radar.jpl.nasa.gov/carbon*
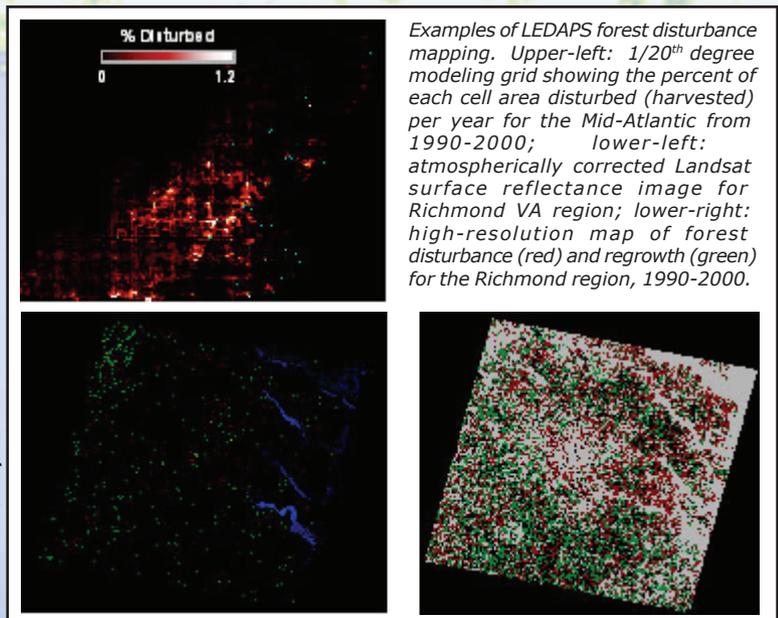
Example NACP Project: LEDAPS - A North American Forest Disturbance Record from Landsat

Jeffrey G. Masek (Principal Investigator), Biospheric Sciences, NASA GSFC

Forest-cover conversion, disturbance, and recovery have been proposed as primary mechanisms for transferring carbon between the land surface and the atmosphere, but the area and timing of these processes is still poorly quantified. Our project (LEDAPS – Landsat Ecosystem Disturbance Adaptive Processing System) has been funded to "mine" the 33+ year Landsat observational record in order to assess forest disturbance across North America, in support of the USGCRP North American Carbon Program. Specifically, we have the following objectives:

- Create surface reflectance (SR) products for North America from the Landsat GeoCover archive, a global orthorectified dataset of Landsat imagery centered on 1975, 1990, and 2000 epochs.
- Generate decadal, wall-to-wall maps of North American forest disturbance (fire, harvest, insect damage), recovery, and conversion from these reflectance products
- Develop automated approaches for processing and analyzing Landsat data that can be re-used across the remote sensing community
- Work with representatives of the US Forest Service to assess the utility of Landsat reflectance and forest-cover change products for carbon and forest monitoring.

Landsat TM and ETM+ data are being atmospherically corrected using algorithms and processing approaches derived from MODIS. To date, some 2200 Landsat images covering North America have been atmospherically corrected, and can be downloaded from the LEDAPS web site (***http://ledaps.nascom.nasa.gov/ledaps/ledaps_NorthAmerica.html***). Disturbance and recovery are being mapped using a multi-spectral "Disturbance Index". By early 2006, scientists will be able to download maps of forest change for the interval 1990-2000, both at full resolution (30-meter) and coarse-resolution suitable for carbon modeling (500-m and 1/20th degree). Later releases will cover the period 1975-1990. Funded by NASA, the LEDAPS project includes researchers from NASA GSFC, the US Forest Service, and University of Maryland.

Examples of LEDAPS forest disturbance mapping. Upper-left: 1/20th degree modeling grid showing the percent of each cell area disturbed (harvested) per year for the Mid-Atlantic from 1990-2000; lower-left: atmospherically corrected Landsat surface reflectance image for Richmond VA region; lower-right: high-resolution map of forest disturbance (red) and regrowth (green) for the Richmond region, 1990-2000.

GOFC/GOLD Regional Networks

The NASA LCLUC program is contributing to the Global Observation of Forest Cover/Global Observation of Landcover Dynamics (GOFC/GOLD), a Global Terrestrial Observation System (GTOS) program. Land cover and fire are two focus areas for the program. The goal of the program is to help ensure that the international

science and applications requirements for satellite data are met and that proven satellite systems and analysis methods are transitioned from research to the operational domain. Such a transition would for example enable the periodic assessment of global land cover. One of the aims of the program is to improve the use of and access to current satellite observations and facilitate their integration with other data types. To achieve this, GOFC/GOLD has developed a number of regional networks of scientists, data users and data providers, which are benefiting from improved access to NASA data and research collaboration with NASA scientists. Regional network activities exist in Southern Africa (the Miombo Network- *http://www.geog.psu.edu/geclab/miombo/* and SAFNET- *http://safnet.umd.edu/*), Northern Eurasia (NERIN- *http://www.fao. org/gtos/gofc-gold/networks.html*), Central Africa (OSFAC- *http://www.osfac.org/*), Southeast Asia (SEARIN- *http://www.eoc.ukm.my/searrin/*), South America (REDLATIF- *http://mob.conae.gov.ar/redlatif/*) and Australia.

Additional information can be found at the GOFC/GOLD website - *http://www.fao.org/gtos/gofc-gold/* and at the GOFC-Fire website at - *http://gofc-fire.umd.edu/index.asp*

Example GOFC/GOLD Project: Fire product development and evaluation in Northern Eurasia

Ivan Csiszar, Tatiana Loboda (UMD/Geography), Dimitry Ershov (CFEP), Alexey Mazurov (SRI), Vladimir Belov (IAO), Anatoly Sukhinin (SFI) and Sergei Tashchilin (ISTP)

Scientists at the University of Maryland (UMD) are working together with Russian collaborators to improve the quality and spatio-temporal coverage of biomass burning data in Northern Eurasia. Major partner institutions in Russia include the Center for Forest Ecology and Productivity (CFEP; Moscow), the Space Research Institute (SRI; Moscow), the Institute of Atmospheric Optics (IAO; Tomsk), the Sukachev Forest Institute (SFI; Krasnoyarsk) and the Institute of Solar and Terrestrial Physics (ISTP; Irkutsk). This partnership represents the core of the Northern Eurasian regional GOFC/GOLD (Global Observation of Forest Cover / Global Observation of Land Cover Dynamics) fire network.

In a NASA New Investigator in Earth Science project, fire products from AVHRR (Advanced Very High Resolution Radiometer) and MODIS (Moderate Resolution Imaging Spectroradiometer) are compared to ensure the continuity of a long-term, multi-sensor historical fire record. An *a posteriori* analysis of burned area and active fire products is carried out to ensure proper quality assessment. The product evaluation is primarily based on high resolution ETM+ (Enhanced Thematic Mapper) and ASTER (Advanced Spaceborne Thermal Emission and Reflection Radiometer) imagery.

The key effort of this NASA Land-Cover Land-Use Change project is to facilitate the development of an integrated regional fire monitoring system that will provide various user communities with data of known accuracy in a long-term, sustained manner. The UMd fire group is providing MODIS active fire products and processing software. MODIS fire data, together with active fire products generated at the Russian partner institutions from the precursor AVHRR are collected into an integrated database, which is evaluated for science quality and used to analyze fire dynamics at various spatial and temporal scales in Northern Eurasia.
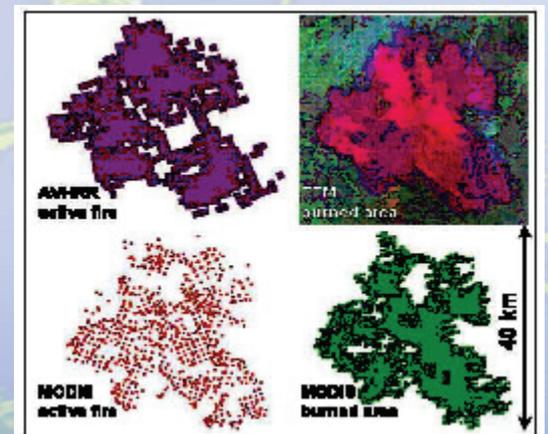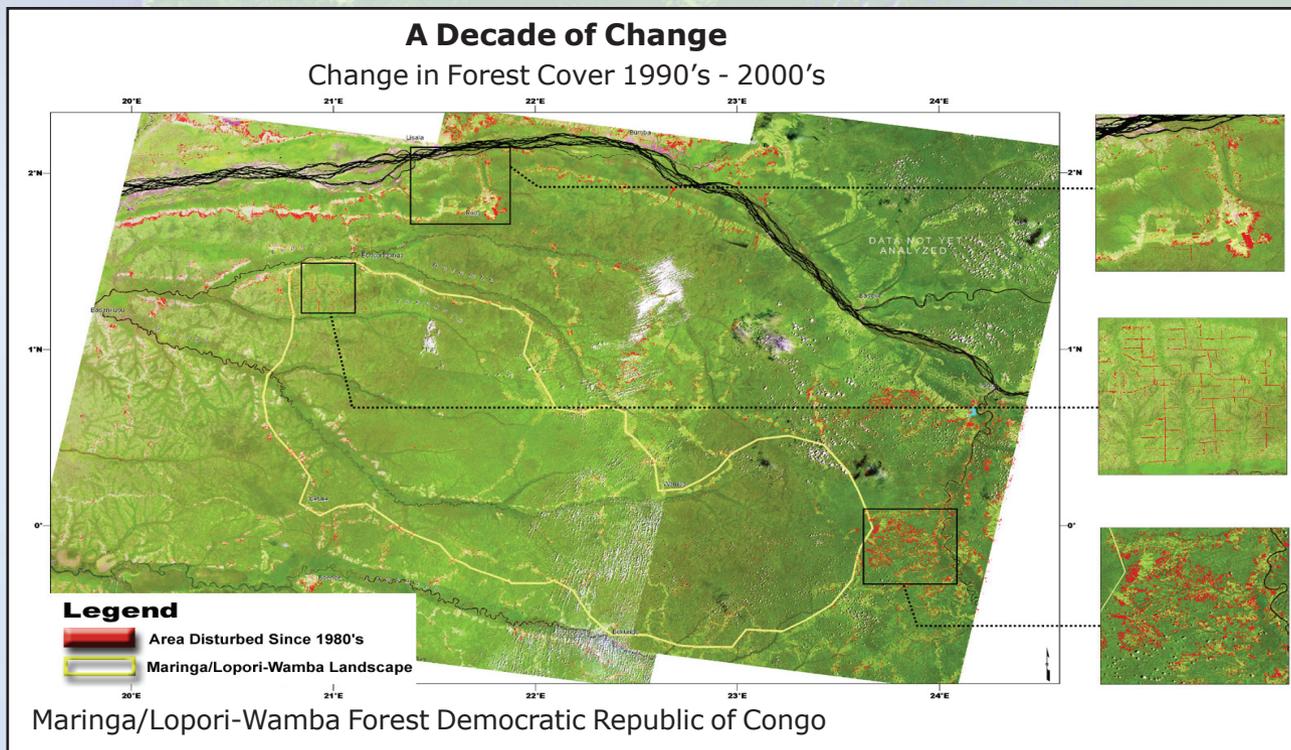
CARPE

The Central Africa Regional Program for the Environment

The tropical forests of the Congo Basin represent one of the world's great remnant blocks of closed canopy habitat. This forest is under increasing pressure from population growth, unsustainable resource use, poor management, and other problems related to poverty and political instability. CARPE is a long-term initiative by USAID to address the issues of deforestation and biodiversity loss in the Congo Basin forest zone, in the middle of the African continent. CARPE's partners include conservation organizations and appropriate federal agencies. NASA is the CARPE partner responsible for satellite monitoring land-cover and land-use change in the Basin. Landsat and MODIS data are combined to monitor changes in the forest canopy. One of the least developed regions of the world, the Congo Basin holds massive expanses of closed canopy tropical forest, second only to the Amazon Basin in area. Much of this forest remains relatively intact, yet unsustainable timber exploitation, shifting cultivation, urban expansion, and other human themes are posing increasing threats to this globally-significant tropical forest resource. Loss of forest cover on this scale imposes serious risks of loss of biodiversity, and emission into the atmosphere of carbon dioxide previously locked up in forest biomass. CARPE's strategic objective is to reduce the rate of forest degradation and loss of biodiversity through increased local, national, and regional natural resource management capacity. Intermediate Results (IRs) to be achieved in order to reach this objective will involve implementing sustainable forest and biodiversity management practices, strengthening environmental governance, and monitoring forests and other natural resources throughout the region. **CARPE website:** *http://carpe.umd.edu/index.*

A Decade of Change
Change in Forest Cover 1990's - 2000's

Maringa/Lopori-Wamba Forest Democratic Republic of Congo

Central Africa Example Project: Forest Biomass and Land-Use Change in Central Africa: Reducing Regional Carbon Cycle Uncertainty

Principal Investigator: Nadine Laporte

Scientists at the Woods Hole Research Center are working to quantify and map above ground forest biomass over Africa. The research uses state-of-the-art statistical techniques to integrate remotely sensed data, climate and forest inventory measurements. Forest inventory data (dbh(m^3/ha) collected from different regions by collaborators are converted into biomass (tons/ha) and used to calibrate an empirical relationship with MODIS 1km spectral reflectance. The derived empirical model will provide the amount of forest biomass at each MODIS pixels, showing the spatial distribution of forest biomass over the entire region.

The detailed spatial estimates of biomass will enable more accurate estimates of carbon flux to be calculated from deforestation, logging, and other human activities.

Preliminary results show that remotely sensed data are able to characterize the general spatial distribution of forest biomass over the region. African forest biomass is poorly known relative to biomass in other regions, and this project will provide information integral for a better understanding of the carbon cycle. The methods used in this research are flexible and easily applicable to other tropical regions.

The work has also supported, in part, an analysis of carbon emissions from land-use change in all of sub-Saharan Africa. Previous estimates were based on highly aggregated data and ignored important categories of land use. The new analysis reconstructed rates of land-use change and rates of wood harvest from country-level statistics and used a bookkeeping model to calculate the annual flux of carbon associated with these changes. Results indicate that changes in land use were responsible for an annual net release of 0.287 PgC/yr during the 1990s. According to the study, sub-Saharan Africa accounted for 17% of the global flux of carbon from land-use change.

For more information on this project please contact N. Laporte or R. Houghton or check:

http://www.whrc.org/africa   http://www.whrc.org/carbon

As part of CARPE, the University of Maryland supports OSFAC (Observatoire Satellital de la Forê t d'Afrique Centrale) a GOFC/GOLD Network which promotes in-country capacity building for the use of satellite imagery in studying the forests of Central Africa.

Satellite Remote Sensing and LCLUC

Satellite data provide an important source of information for characterizing and monitoring land-cover and land-use change. In some regions it is the only feasible way to provide timely and reliable land-cover assessments and identify areas of rapid change. Recent land-cover history also provides a point of departure for modeling land-cover change.

NASA currently has sensing systems at high, medium and low resolution, which meet the LCLUC program observation needs. NASA satellite systems supplement operational satellites providing systematic measurements to study long-term trends. For example, the Moderate Resolution Imaging Spectroradiometer (MODIS) instruments on the EOS Terra (am) and Aqua (pm) platforms have significantly improved on the capabilities of the operational NOAA Advanced Very High Resolution Radiometer (AVHRR). These moderate resolution data are used to classify and characterize land-cover at the global scale and to detect land-cover change at the regional scale. They also provide daily monitoring of fire activity which is often an indicator of land-cover change. The operational Defense Meteorological Satellite Program provides a capability to map the extent of night time lights and has been used by LCLUC scientists to document the extent and growth of urban areas.

Landcover Classification from MODIS

From MODIS observations we map global distribution of vegetation types and unvegetated areas at 1x1 km^2 spatial resolution. This figure of North America, with zoomed in windows for Louisiana, Florida, and Maritime Provinces, is for the year 2004 primary labels for the International Geosphere-Biosphere Programme (IGBP) class scheme, (MOD12Q1 V004 2004001 SDS01). Additional data layers, not depicted, include confidence in the primary label, a second IGBP label with the next highest confidence, and four alternative class schemes (UMD, LAI/fPAR, BGC, and PFT). Maps are also available for 2001, 2002, and 2003. Data available at **http://edcimswww.cr.usgs.gov/pub/imswelcome/** *(search for MOD12Q1). Data user guide available at* **http://geography.bu.edu/landcover/userguidelc/.**

IGBP Landcover Classes

 0 Water
1 Evergreen Needleleaf Forest
2 Evergreen Broadleaf Forest
3 Deciduous Needleleaf Forest
4 Deciduous Broadleaf Forest
5 Mixed Forests
6 Closed Shrublands
7 Open Shrublands
8 Woody Savannas

9 Savannas
10 Grasslands
11 Permanent Wetlands
12 Croplands
13 Urban and Built-Up
14 Cropland/Natural Vegetation Mosaic
15 Permanent Snow and Ice
16 Barren or Sparsely Vegetated
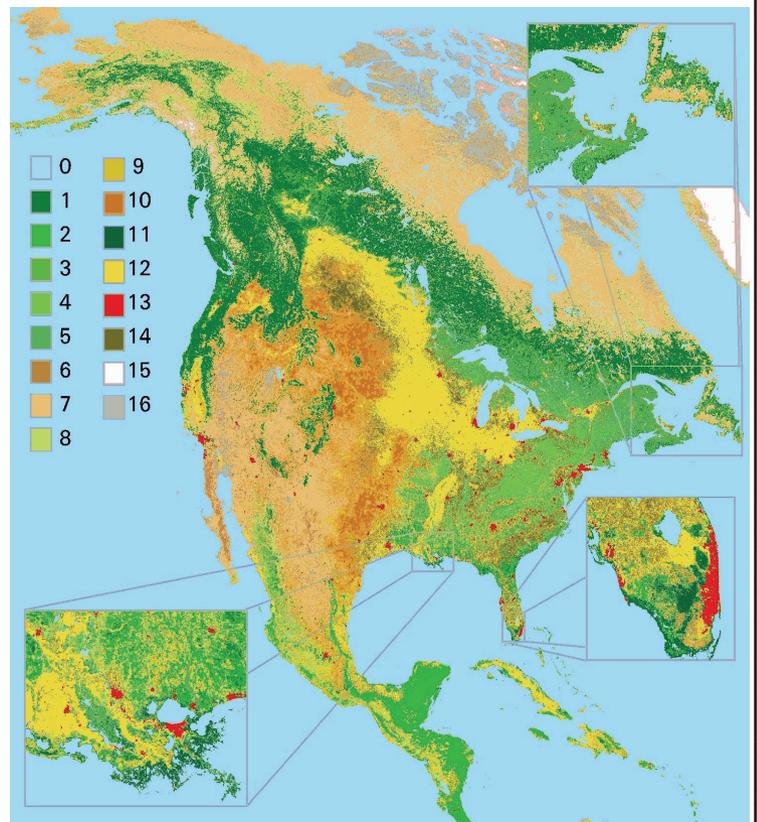
Landsat 7 has provided the systematic high resolution observations necessary to map and quantify land-cover changes at the local to regional scale. The Landsat class observations are a critical underpinning for LCLUC research. The Landsat 7 global acquisition strategy providing multiple cloud-free scenes each year, has facilitated land-cover studies around the World (*http://landsat7.usgs.gov/*). The LCLUC program has been pioneering methods for regional analysis of Landsat class observations setting the stage for periodic continental and global assessments of land-cover change. In this regard, the combination of systematic moderate and high resolution satellite remote sensing provides the opportunity for global scale studies and forms the basis for a global land observing system. Similarly, the NASA science programs are moving from Missions to Measurements with the aim of utilizing data from different instruments to address science questions.


ASTER August 2001

Iguazu Falls along the border between Argentina and Brazil, and near Paraguay, is one of the wonders of the world. The immediate surrounding area was once native forest and grasslands. Both Argentina and Brazil have set aside land near the Falls as National Parks. The effect of differing land use policies can be clearly seen on the August 2001 ASTER scene. Paraguay has permitted complete development of the land at the expense of the forests. In Argentina, development is considerably more modest; and Brazil shows a contrast between the National Park, and developed land. http://asterweb.jpl.nasa.gov/gallery-detail.asp?name=Iguazu

Experimental measurements of limited duration are needed to better understand processes and to test new sensor technologies. For example, the Earth Observer 1 (EO1) system (*http://eo1.gsfc.nasa.gov/*) has provided a test-bed for new sensor technology and spaceborne hyper-spectral remote sensing. Similarly the Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER) sensor has provided new high resolution thermal data collocated with MODIS data for improved surface characterization and validation of coarser MODIS thermal products. In the past experimental microwave satellite sensors operated by Europe and Japan have been used for mapping the extent of wetland areas. NASA LCLUC research in this part of the spectrum has been limited by the absence of a current US microwave sensing system.

NASA has also been exploring partnerships with industry for the commercial provision of data to meet the needs of its science community. In particular, hyperspatial data with 1-3m resolution from sensors such as IKONOS and Quickbird have been used to provide detailed validation of high resolution products.

The Global Mid-decadal Land Survey (GMDLS)

In partnership with the private sector, NASA purchased a global data set of cloud-free Landsat imagery for 1990 and 2000. These data were orthorectified and are easily accessible and freely available. They have greatly increased the use of Landsat data for LCLUC studies worldwide. In May 2003 the Landsat 7 scan line corrector failed and although the instrument continues to receive data, the imagery are of limited use. With no Landsat instrument ready to replace Landsat 7, there is an increasing data gap, posing a critical impediment to LCLUC science. The LCLUC program, working with the USGS is developing a mid-decadal (2004-2006) high

resolution global cloud-free data set to extend the previous global data sets. The data set will include data from Landsat 5, ASTER, EO1 and Landsat 7 temporal composites. This data set will include data provided by foreign ground stations and possibly foreign high resolution satellites. It is hoped that International cooperation concerning this data set could provide a prototype for future international efforts to coordinate high resolution global data acquisition from the increasing number of high resolution assets in the framework of GEOSS.

Data Systems for LCLUC Research

The unprecedented large volumes of data for land use research have necessitated the development of innovative data processing, delivery and analysis systems. The evolving EOS Data and Information System and a number of competed research opportunities such as REASON and ACCESS, have provided support for data systems research and development. The MODIS Advanced Data Processing System (MODAPS) at the Goddard Space Flight Center (GSFC) is generating land-cover related products from the daily MODIS instruments on board the Terra and Aqua platforms. Data products at 250m -1km are being reprocessed as the algorithms are improved to provide consistent data records. This system is currently being enhanced to provide MODIS land product distribution co apabilities (*https://modaps.nascom.nasa.gov:8499/*) to augment the services provided by the NASA Distributed Active Archive Center at the Eros Data Center (*http://edcdaac.usgs.gov/main.asp*) to meet the needs of the MODIS science community.
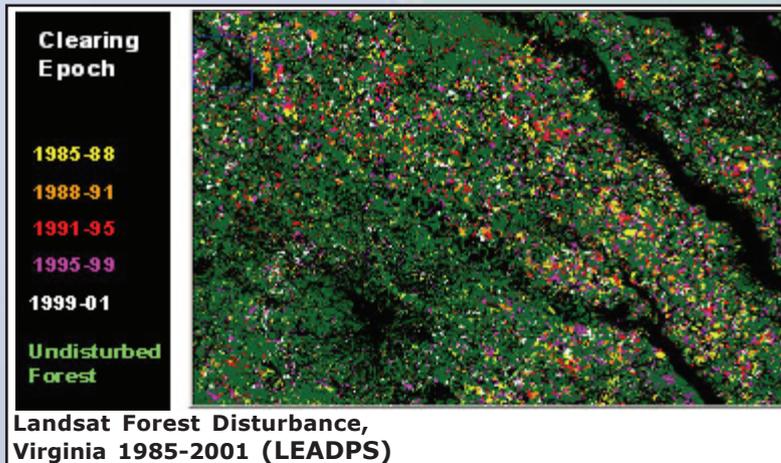
The Landsat Ecosystem Disturbance Adaptive processing system (*http://ledaps.nascom.nasa.gov/ledaps/ledaps_NorthAmerica.html*) is developing procedures for automated atmospheric correction and mosaicing of Landsat data and the generation of high resolution disturbance

Landsat Forest Disturbance, Virginia 1985-2001 (LEADPS)

time series. The Global Land Cover Facility (GLCF) at the University of Maryland (***http://glcf.umiacs.umd.edu/***) has developed a low cost system for processing and distribution of large volumes of land-cover data and enhanced data sets. Similarly, the Landsat.org project developed at Michigan State University (MSU) has developed a platform independent user interface and search engine for on-line purchasing, ordering and sharing of Landsat data worldwide (***http://landsat.org/***). Associated with this latter project is the development of a peer to peer data sharing system for Landsat data (SAXTA, ***http://saxta.geog.umd.edu***) offering an alternative mechanism for community data sharing. The Tropical Rain Forest Information Center at MSU is also providing Landsat derived data sets associated with monitoring tropical deforestation (***http://www.trfic.msu.edu***).

NASA Future Missions for LCLUC Research

NASA as part of the Integrated Program Office is contributing to the NPOESS Preparatory Project (NPP). The Visible Infrared Imaging Radiometer Suite (VIIRS) instrument is planned to transition MODIS class observations into the operational domain. The VIIRS instrument for launch in 2009 will continue the long term data records of vegetation indices, land-cover and fire. The NASA NPP Science Team is contributing to and evaluating the operational algorithms which will provide VIIRS Environmental Data Records (EDR's). The science team is determining whether these operational products will meet the needs of the science community and which additional or enhanced products will be needed

NASA has been charged with providing a continuity mission for the Landsat class of observations. As the major science driver for this mission, the LCLUC program is concerned that the mission be launched as soon as possible to minimize the Landsat 7 data gap. There are a number of possible solutions to securing rapid high resolution data continuity including a micro satellite imaging constellation. Clearly, as part of this mission, it will be important to establish the pathway for operational provision of Landsat class observations. Additional mission requirements for LCLUC research are being developed through a NRC Decadal Survey for NASA.

LCLUC Applications

LCLUC science research projects at NASA often have practical applications which are further developed under the NASA Applications Program. The focus of the Applications Program is to provide direct societal benefits from NASA research. The program addresses applications of national priority emphasizing partnerships with agencies with an operational mandate e.g. USDA, USFS, EPA, NPS, UNFAO and UNEP. The twelve applications include aspects of agricultural efficiency, carbon management, disaster management, coastal management, water management, ecological forecasting and public health. The approach is to enable the assimilation of remote sensing data and Earth Science model outputs to serve as *inputs* to decision support systems. Through a process of benchmarking, verification and validation the enhancement to the decision support system is documented and a pathway developed for the operational transition. Current projects include the use of remote in forest management, fire risk mapping, fire and invasive species monitoring, flood inundation, crop yield forecasting and famine early warning.
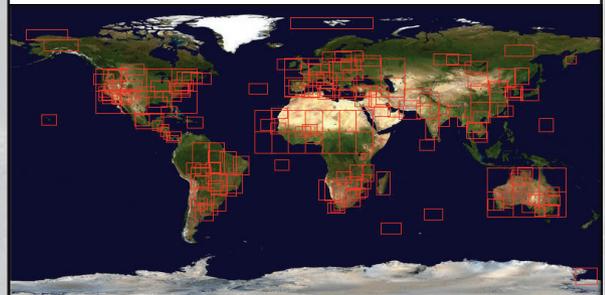
The MODIS Rapid Response System

Two hours after the National Hurricane Center issued their warning for hurricane Katrina on Aug. 28th 2005, MODIS captured this image from NASA's Terra satellite at 1:00 p.m. The massive storm covers much of the Gulf of Mexico, spanning from the U.S. coast to the Yucatan Peninsula.

The MODIS Rapid Response (RR) system was developed at NASA GSFC to provide near real time delivery of MODIS data for fire monitoring by the USFS. More recently the NASA Applications program has enhanced the RR system to support agricultural, flood and air quality and monitoring with USDA and EPA. Imagery from the RR system are used extensively for disaster monitoring, for example during the 2005 hurricane season. With a focus on rapid data delivery, the algorithms developed for the RR System and the associated web-based mapping have been made available to direct broadcast stations, leading to a large number of regional fire data distribution systems e.g.: CONABIO, Hot Spot Detection System , Mexico - *http://www.conabio.gob.mx/conocimiento/hotspots/doctos/puntos_calor.html*; AFIS, Advanced Fire Information Service, Africa- *http://divenos.meraka.csir.co.za/afis/afis.html*; and Sentinel Fire Mapping, Australia - *http://www.sentinel.csiro.au/sentinel.html*.

Rapid Response near-real-time subsets

The NASA Direct Readout Program: Providing a Bridge between NASA Direct Broadcast Earth Science Missions and the Direct Readout User Community

NASA's Direct Readout Laboratory (DRL) at Goddard Space Flight Center (GSFC) is the implementation arm of NASA's Direct Readout Program. The DRL acts as the bridge between Earth science remote sensing missions such as Terra, Aqua, and the NPOESS Preparatory Project (NPP), and the Direct Readout (DR) community. The DRL encourages communication and maintains an open-door policy with the commercial and research and development sectors. This process provides the DRL with critical information on DR systems currently in use,

technologies being developed commercially, and the needs of the DR community. The DRL's close relationship to all of the stakeholders is critical to the promotion of standardization in DR pre-processing sub-systems; DR Science Processing Algorithms (SPAs); visualization and data processing systems; and real-t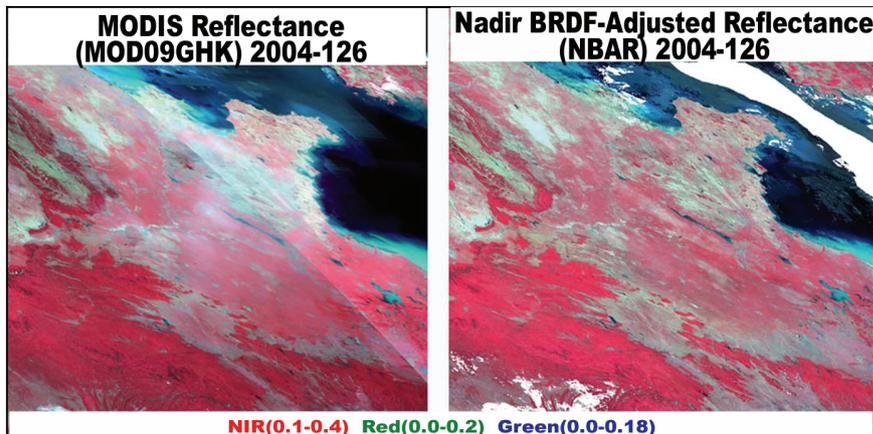ime data/product transport methods and mechanisms. The DRL is able to report the "state-of-the-community" to the NASA mission, while providing the community with a two-way dialogue between the mission objectives and the user needs.

DIRECT READOUT PROGRAM ROADMAP

| L-Band, S-Band 665 - 2 Mbps BPSK | X-Band 13.1 Mbps Convolutional UOQPSK NRZ-M | X-Band 15 Mbps OQPSK NRZ-M | X-Band • X-Band, L-Band 15 Mbps • 20, 3.8 Mbps Convolutional QPSK • OQPSK NRZ-M Compression | |

The DRL's understanding of both mission objectives and user needs guides the development of real-time DB data management and instrument-specific pre-processing tools. In order to maximize the utility of DB data, the DRL has been developing DR technology tools that will provide end users ready access to instrument data and derivative products from the legacy EOS Terra and Aqua missions, as well as the future NPP mission, thereby enabling real-time local and regional data processing and product generation that benefits and supports environmental, commercial, and public interests and the decision-making infrastructure. The tools have been designed to be scalable, extensible, portable and, most importantly, easy to use.

Direct Broadcast Land Products
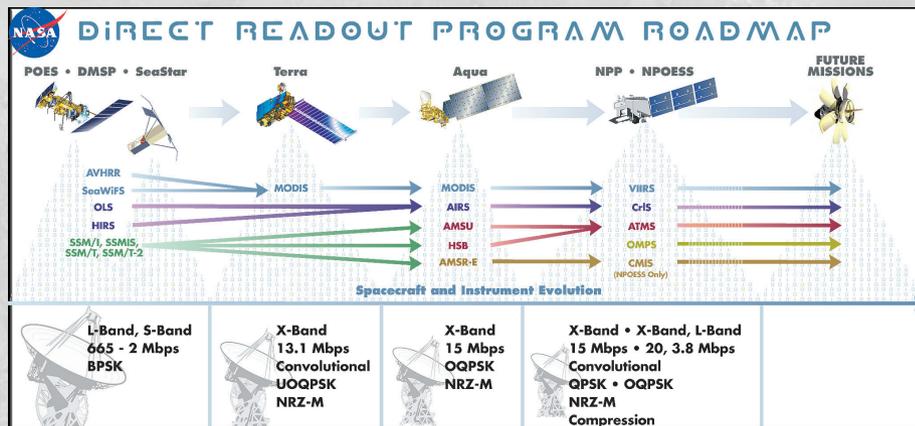
NASA is supporting Crystal Schaaf (Boston University) to convert selected MODIS data products codes to be compatible with direct broadcast product generation. One such example is the Nadir BRDF adjusted reflectance product. The MODIS instruments on board the Terra and Aqua platforms view the entire Earth at least once a day. However these acquisitions are necessarily made at varying view angles and thus some swaths may appear brighter or darker than adjoining swaths merely because the sensor sees varying degrees of sunlit or shadowed canopy and background. These view angle changes can add another source of variability to imagery that is being classified into land-cover and use categories. The MODIS BRDF/Albedo retrieves a measure of this surface anisotropy by fitting a bidirectional reflectance distribution function (BRDF) model to daily cloud-free, atmospherically-corrected surface reflectances acquired over a 16-day period. This BRDF measure can then be used to correct subsequent images to a single (usually nadir) view angle.

MODIS Reflectance (MOD09GHK) 2004-126

Nadir BRDF-Adjusted Reflectance (NBAR) 2004-126

NIR(0.1-0.4)   Red(0.0-0.2)   Green(0.0-0.18)

MOD09GHK View Angular effects between two swaths (North China Plain)

Nadir BRDF-Adjusted Relectance (NBAR) Angular effect is removed (North China Plain)

The difference in adjoining swaths of surface reflectance of agricultural regions of the North China Plain is clearly visible. By applying the MODIS-derived BRDFs, these view angle effects can be removed and nadir surface reflectances of the entire region can be produced.

Global Fire Information for Resource Management: Transitioning from a research to an operational system with an emphasis on Protected Areas

The Fire Information for Resource Management System (FIRMS) aims to transition NASA funded research results and observations to operational partners to support decision making for management of Protected Areas (PAs) worldwide. Specifically, a Web GIS developed by researchers at the University of Maryland (UMd) will provide active fire, burned areas and NASA imagery to protected area managers around the World in easy to use formats for decision making. The information will be delivered through web based interactive maps and email and text message alerts.

The operational partners in this project are the United Nations Food and Agriculture Organization (FAO), the United Nations Environment Program (UNEP) and Conservation International (CI). FAO and UNEP are natural hosts for such an operational system as they are the international operational agencies within the UN system that provide global environmental land information. At FAO, FIRMS will be housed in the Department of Sustainable Development and Natural Resources (SDRN) and will compliment their existing suite of projects that deliver near real time information to ongoing monitoring and emergency projects, as well as providing information to the general public. FAO will also provide a direct feed of data to the UNEP-GRID Global Wildfires monitoring site. UNEP-GRID will use the system to enhance the Division of Early Warning and Assessment website which seeks to provide real time information on global fires. The fire data will also be served over the internet by CI's Center for Applied Biodiversity Science, a US based NGO to both its regional projects and the broader NGO community.
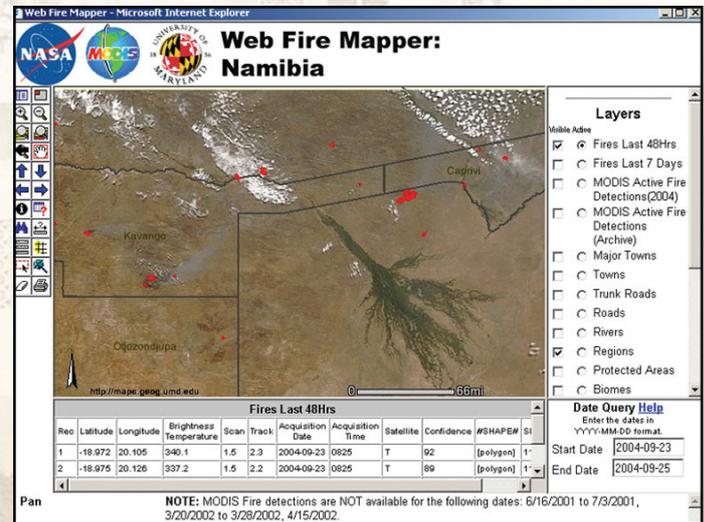
Obtaining satellite derived fire information in a user-friendly format, and in time to use it for operational fire management, has not been easy for park managers working in remote locations and with limited access to the internet. Protected area managers are usually interested in relatively small areas – generally their park and its surroundings. They also require fire information delivered with minimal file sizes that can be accessed by anyone with internet connectivity. FIRMS will meet these requirements in three main ways: by providing MODIS active fire information via an interactive Web Mapping interface, by providing subsets of true color MODIS images and also by delivering fire alerts through emails and cell phone text messages.

Additional information can be found at: ***http://maps.geog.umd.edu/default.asp***

A p p l i c a t i o n s

Global Agricultural Monitoring: Enhancing the agricultural monitoring and crop forecasting capabilities of the Foreign Agricultural Service using MODIS

The Global Agriculture Monitoring (GLAM) Project aims to enhance the agricultural monitoring and crop production estimation capabilities of the USDA Foreign Agricultural Service (USDA/FAS) using NASA's moderate resolution satellite data. The project is a collaboration between NASA/GSFC, USDA/FAS, SSAI, South Dakota State University (SDSU), and University of Maryland College Park (UMD) Department of Geography.

The primary mission of the FAS is to provide agricultural information for global food security through delivery of objective, timely and regular assessments of global agricultural production outlook and the conditions affecting it. To monitor crop conditions, the FAS analysts are provided with multiple remotely sensed products from moderate resolution sensors for target agricultural regions worldwide. This includes providing USDA crop analysts with a sophisticated web interface for analyzing MODIS temporal composites of vegetation index (VI) data, at 250-meter resolution. The web interface provides analysis tools which allow the crop analysts to drill down to the pixel level of detail. Using these data and tools, FAS analysts track the evolution of the growing season and make inter-annual comparisons of season dynamics between individual years as well as relative to reference long-term mean conditions. These comparisons yield anomaly images and plots highlighting regions that have undergone a change in productivity indicative of land-use/cover change. These changes may be due to direct anthropogenic factors such as deforestation and land conversion from forest to croplands and expansion of urban areas; or change due to weather factors such as heat stress, drought, and storms.

Iberian Peninsula drought in 2004-05 depicted by database GUI
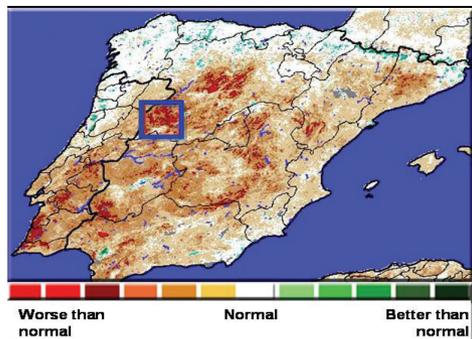
NDVI anomaly image created using MODIS data collected between May 25 and June 9 2005 compared to the mean NDVI for this time-step between 2000 and 2004. The entire Iberian Peninsula was clearly stressed due to the drought in 2005. Reds/Brown represent the regions where vegetation is thin and less dense than average, while tiny flecks of green show where vegetation is healthier than average.
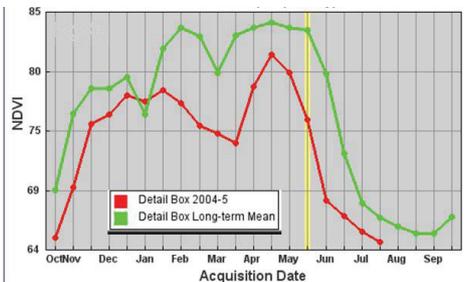
NDVI graph comparing the 2004-05 season with mean conditions for the highlighted crop region in the blue box. The red line, consistently below the green line indicates highly reduced NDVI values throughout the season, due to the severe drought.

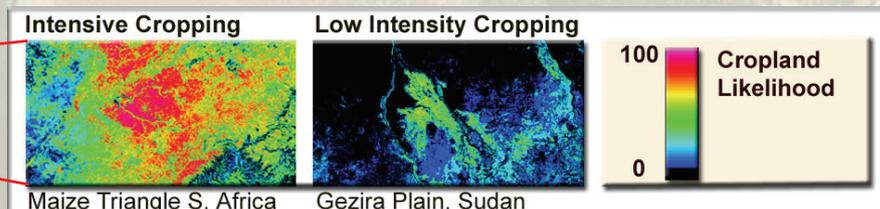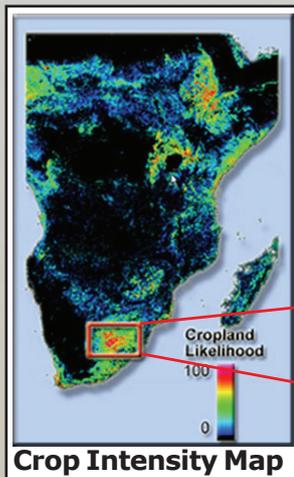## A Dynamic Continuous Cropland Mask for use with MODIS time-series web interface

To successfully monitor worldwide agricultural regions and provide accurate agricultural production assessments, it is important to understand the spatial distribution of croplands. To do this, Matthew Hansen at SDSU, has developed a global croplands mask to identify all sites used for crop production. Croplands are highly variable

both temporally and spatially. Croplands vary from year to year due to events such as drought and fallow periods, and they vastly differ across the globe in accordance with characteristics such as cropping intensity and field size. A flexible crop likelihood mask is used to help depict these varying characteristics of global crop cover. This flexible croplands mask which is in currently being validated, is generated by analysis of 4 years of MODIS data (2001-2004). Rather than the traditional static yes/no crop mask, the new map depicts crop likelihood allowing users, to threshold cropland membership according to their needs. Regions featuring intensive agro-industrial farming practices such as the Maize Triangle in South Africa will have higher confidence values in the crop mask as compared to less intensively farmed regions in parts of Sub-Saharan Africa where cropland identification is partly confounded with natural background vegetation phenologies. Thus, a customized threshold can be employed to examine areas of varying cropping intensification.

Crop Intensity Map

Intensive Cropping — Maize Triangle S. Africa
Low Intensity Cropping — Gezira Plain, Sudan
Cropland Likelihood 0–100

NASA LCLUC Program Partnerships

The LCLUC program has developed a number of strategic partnerships at the national and international level. These partnerships have been developed with programs which complement the NASA LCLUC program activities or help achieve the program goals.

National Partnerships

U.S. Global Change Research Program (**USGCRP**) supports research on the interactions of natural and human-induced changes in the global environment and their implications for society. The USGCRP began as a presidential initiative in 1989 and was codified by Congress in the Global Change Research Act of 1990 (P.L. 101-606), which mandates development of a coordinated interagency research program. The Climate Change Science Program (**CCSP**) was established in 2002 to empower the Nation and the global community with the science-based knowledge to manage risks and opportunities of change in the climate and related environmental systems. CCSP incorporates and integrates the USGCRP with the Administration's U.S. Climate Change Research Initiative (CCRI). The CCSP has several elements including Land Use and Land-Cover Change (**LULCC-** *http://www.usgcrp.gov/usgcrp/ProgramElements/land.htm*). The NASA LCLUC Program has been closely involved in the development and implementation of this research element, co-chairing the Land Use Interagency Working Group (**LUIWG**). Agency partners in the LUIWG include NASA, USDA, USFS, USGS, EPA and the NPS. These agencies support external and in-house research on aspects of land use and land-cover change. The LUIWG identifies opportunities for

Partnerships

coordination and cooperation between programs and identifies program deliverables associated with the goals of the research element. The LUIWG is guided by a LULCC Steering Group consisting of leaders in land use science. Current areas being addressed by the LUIWG include the requirements for Landsat data continuity, and an NRC review of land use models leading to the development of a community land use model. The LUIWG fosters joint research announcements between agencies, the most recent being between NASA and USDA focused on Land Use and Carbon Cycle research.

International

At the international level there has been increased attention to earth observations. The Global Earth Observation System of Systems (GEOSS) has received international ministerial level support to achieve comprehensive, coordinated and sustained observations of the Earth system, to improve monitoring of the state of the Earth, increase understanding of Earth processes, and enhance prediction of the behavior of the Earth system (*http://www.epa.gov/geoss/index.html*). GEOSS is focused primarily on applications with a strong emphasis on societal benefit for example in the areas of agriculture, disasters, biodiversity, ecosystems and water. The NASA Applications Program is contributing to GEOSS through the US Interagency Working Group on Earth Observations (US IWGEO).

The Integrated Global Observing Strategy (**IGOS**) provides a comprehensive framework to harmonize the common interests of the major space-based and in-situ systems for global observation of the Earth (*http://ioc.unesco.org/igospartners/over.htm*). The Integrated Global Observation of Land (**IGOL**) theme of IGOS is focused on identifying and gaps in current observations and the requirements for future land observations. The Global Terrestrial Observing System (GTOS - *http://www.fao.org/gtos/*) is part of the International Global Observing System (IGOS) focused on terrestrial observations, with a Secretariat at UN FAO, Rome. The Global Observation of Forest Cover – Global Observation of Landcover Dynamics (**GOFC/GOLD**) program (*www.fao.org/gtos/gofc-gold/*) is the part of GTOS focused on developing the requirements and coordinating observations and data sets for land-cover and land-cover change and fire. By bringing together data producers and users, GOFC/GOLD promotes improved access to and enhanced use of satellite and ground based data. The NASA LCLUC program actively contributes to the GOFC/GOLD program through funded research and support of the GOFC/GOLD regional networks and their associated workshops. The Committee on Earth Observation Satellites, Land Product Validation (CEOS LPV) working group encourages the international coordination of the validation of global land data sets. Determining the accuracy of land-cover products is important for both science and applications users. CEOS LPV is assisting in the development of protocols for the validation of land-cover products and continuous fields, albedo, leaf area index, fire and burned area products (*http://lpvs.gsfc.nasa.gov/*).

The international land use cover change (LUCC) program developed by the IGBP/IHDP program in the 1990's provided much of the ground work for land use research. The recently proposed Global Land Project (GLP) defined by scientists from IGBP and IHDP is designed as part of IGBP II, to better integrate the understanding of the coupled human-environment systems. The Global Land Project is focused on the dynamics of land systems, the consequences of land system change and integrating an analysis and modeling for land sustainability. The LCLUC program provides support to the GLP office (*http://www.glp.colostate.edu/*).

Future Directions for the NASA LCLUC Program

With the ongoing and sometimes dramatic changes in global and regional economies, demographics, extreme weather events and climate, land-cover and land-use change will coninue to be an important topic for global environmental change research. The LCLUC program will continue to develop a unique role for NASA in utilizing its satellite assets for the study of LCLUC. The program will endeavor to maintain a balance between understanding the processes and determining the impacts of land-use change. The role of the satellite-data record and process studies in projecting future LCLUC will need further investment and the integration of land-use models with climate and ecosystem models will need to be developed. The procedures that the program develops for periodic inventory of land cover and the detection, characterization and quantification of land-cover change will need to be standardized and transitioned to the operational domain. In the immediate absence of an operational agency providing regular global monitoring of LCLUC, the NASA LCLUC program will need to provide the LCLUC data sets necessary to answer NASA's earth science questions. In addition to generating science quality land data products, and a consistent data record, it will be equally important for the accuracy of these data sets to be quantified and the data sets to be easily accessible by the science community. Emphasis will be given to studying areas of the planet where rapid change is taking place or where the impacts of the changes are most serious.

The LCLUC program will remain an important component of the NASA Carbon, Biogeochemistry and Ecosystems Focus Area and will continue to look for opportunities to fund LCLUC research through various upcoming NASA earth science research opportunities. The NASA LCLUC program will continue to be an integral part of the US Global Change Research program and the US Climate Change Science Program, contributing actively to the Land Use Interagency Working Group. The NASA LCLUC program will continue to explore partnerships with U.S. government agencies whose programs complement the LCLUC science agenda. As an interdisciplinary crosscutting program, LCLUC will continue to partner with other NASA focus areas and CCSP elements, for example in the areas of Carbon Cycle, Water Cycle, Climate Variability and Biodiversity research. LCLUC will support the new international Global Land Project being developed under the auspices of the IGBP and IHDP. The LCLUC program will continue research in the framework of various regional initiatives supported by NASA, such as the LBA, NACP, the NEESPI and USAID's CARPE program.

In the next few years the LCLUC program will play an important role in securing the continuity of the Landsat class observations needed for LCLUC science. In the near term, this will involve providing the scientific guidance and support for the rapid development of the Mid Decadal Land Survey. High priority will also be given to ensuring that the Landsat Data Continuity Mission meets the program's scientific objectives and expediting the mission to close the widening Landsat data gap. In the mid term, the attention will need to be given to the continuous provision of the Landsat class data and products to the LCLUC researchers. The LCLUC program will continue to work with the international efforts to better coordinate satellite observations of land cover through programs such as GOFC/GOLD and IGOL and to broaden the use of NASA data. The program will continue to promote international standards for land cover product accuracy through the CEOS Land Product Validation Working Group. The NASA LCLUC program will continue to explore the development and application of new remote sensing systems to better characterize land cover and new techniques and methods to extract information from remotely sensed data. Emphasis will be given to data fusion and synergistic use of different types of satellite measurements, including passive and active remote sensing. Incorporation of the remote sensing data products in models which incorporate climate process interactions and feedbacks

Directions

with LCLUC will be given high priority during the next few years. The NASA LCLUC program will continue to foster the incorporation of social processes in LCLUC models and closer interaction between social and physical scientists.

A closer partnership will be sought with the NASA Applications program to further demonstrate the societal benefits of LCLUC research in practical applications in partnership with operational natural resource agencies such as the USDA, USGS, USAID, UN FAO and UNEP. Practical land-use related topics such as urban and suburban development, agricultural expansion and abandonment, fire and flood management, water quality and wetlands and human health require a better scientific understanding and are important both nationally and internationally in the context of economic development, sustainability and vulnerability. It is envisioned that LCLUC research and the various NASA land-cover related products and applications initiatives will contribute to the international Global Earth Observing System of Systems (GEOSS) leading to direct and tangible societal benefits.

Contact Information

Program Manager
Dr. Garik Gutman
NASA Headquarters
ggutman@hq.nasa.gov

Program Scientist
Dr. Christopher Justice
University of Maryland
justice@hermes.geog.umd.edu

Earth-Sun System Science Website:
http://science.hq.nasa.gov/earth-sun/science/carbon.html

LCLUC Website:
http://lcluc.hq.nasa.gov