APPENDIX 3: FINE RESOLUTION DESIGN TEAM REPORT

GLOBAL OBSERVATION OF FOREST COVER

FINE RESOLUTION DATA AND PRODUCT DESIGN STRATEGY

Report of a Workshop
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1.0 INTRODUCTION

Land cover change in forests may be the most significant agent of global change today: it has an important influence on hydrology, climate, and global biogeochemical cycles. Arguably, forest cover change will have a more significant and direct influence on human habitability than climate change over the next 20 to 50 years. It is an issue with far reaching policy implications, either internationally, nationally, or locally. Indeed, forest cover change is as inextricably linked to policy and sustainable development as it is to basic research issues.

This document provides an initial strategy for an program for a global forest cover change monitoring system based on fine resolution remote sensing. The strategy will link satellite measurements with models to make quantitative assessments of the effects of land cover changes on the global environment and forest inventory and management. The strategy has a three-tier focus which fulfills the needs of: (a) the global change research community, (b) international policy initiatives such as the Framework Convention on Climate Change (FCCC) and the Intergovernmental Panel on Climate Change (IPCC), and (c) national-level resource management and mitigation efforts.

2.0 FINE RESOLUTION DESIGN AND PRODUCT SPECIFICATIONS

A workshop to define the design for global forest monitoring using fine resolution earth observation satellites was held at the CNES Headquarters in Paris, France in September 1998 (see Annex 1 for list of participants and agenda). The workshop was convened to define a strategy for fine resolution observations, dataset compilation, and product definition to support GOFC objectives. This report details the conclusions and recommendations of the workshop, and serves as an input to the End-to-End Design for GOFC as a whole. The workshop emphasized satellite observations but recognized the importance of in-situ data. Workshop participants included representatives from a range of communities including: (a) space agencies, (b) the scientific research community, and (c) the user community.

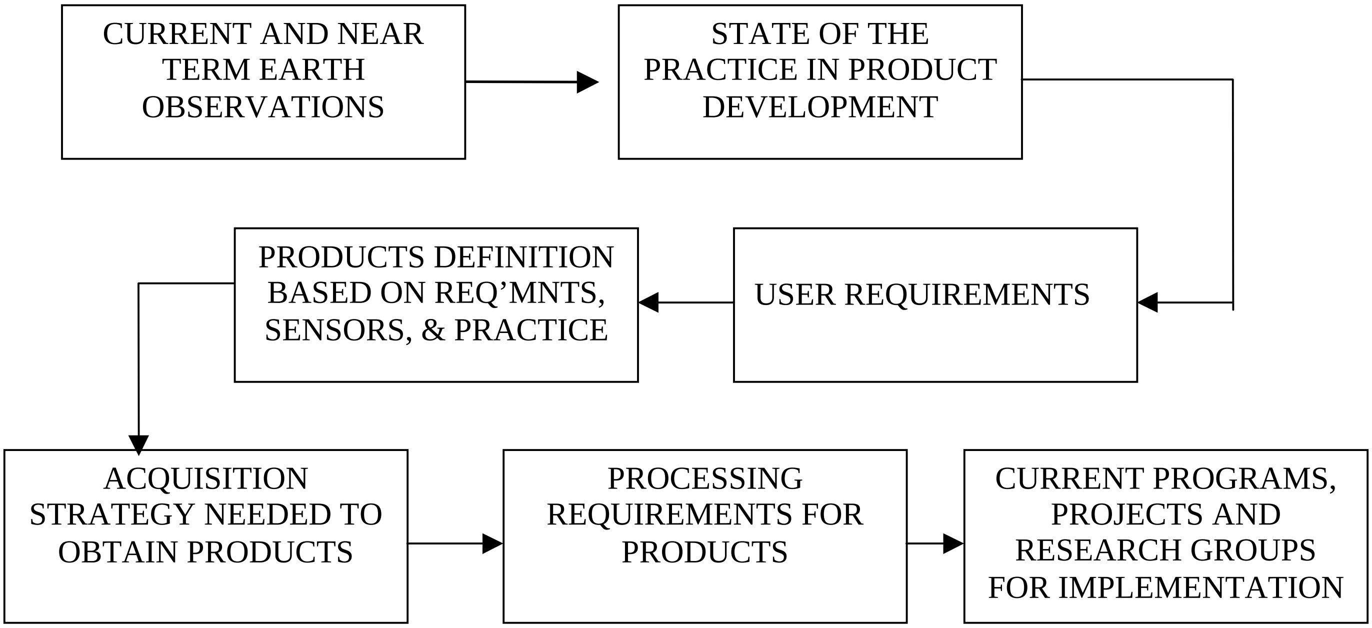
Although the participation was small – approximately 20 participants – there was representation from the national forest management users in North America, Asia, and Africa (See Annex 1). This workshop was also represented by the global change science community, particularly the carbon cycle and climate community, as well as key groups involved in the acquisition and processing large-area datasets from both optical and SAR data for forest monitoring at a global scale (e.g. Landsat Pathfinder, Landsat 7 Science Team, TREES, GRFM, GBFM, Siberia Project). This workshop and document represents an initial review of an observation strategy, which would be elaborated further through the GOFC program design and implementation.

2.1 Workshop Objectives

The objective of the workshop was to develop an initial strategy for utilizing existing and future high spatial resolution optical and microwave earth observation satellites for monitoring and mapping the forests of the world. The specific objectives were to:

- Review the current and future space-based systems deployed by the space agencies
- Identify current large-area forest monitoring projects or research/applications groups which could support and implement GOFC objectives
- Review the current state-of-the practice for analysis of satellite data for forest mapping and monitoring, with recommendations on potential methods and products, as well as their limits for global application
- Definition of the user communities for high resolution data products, and definition of the user requirements
- Define a reasonable and practical data acquisition model for products which meet the user community's needs
- Definition of products and product specifications
- Description of processing and data handling and analysis considerations

INFORMATION DERIVED FROM THE WORKSHOP AND PRESENTED IN THIS REPORT



2.2 General Design Considerations

The strategies recommended for the development of fine resolution products are based on some fundamental considerations, including:

- Products should be relevant to as broad an audience as is practical and feasible. There was particular emphasis on products at the global scale, with regional or national application. An emphasis is placed on forest cover and forest cover change data to support carbon cycle research, policy support to IPCC and the Kyoto protocol, and national forest inventories.

- Products and the overall design must be practical and lead to a reasonable operational concept, implemented using existing and near-term observational systems, with a straightforward and management level of effort.

- The Fine Resolution component should build on existing and near term programs, and should include proven or near-ready applications rather than propose approaches with high research and development aspects, although recognizing that research and development should be a critical component of the program

2.2 Design Requirements

The proposed strategy has been developed around the following requirements:

- The program must incorporate both global and national level objectives and be capable of providing results at national, regional and global scales.

- The information generated by the program must be useful for national level resource planning and management, as well as vulnerability studies and mitigation and adaptation planning.

- The program must include an operational monitoring system with the capability for permanent implementation.

- The monitoring system should utilize data from a variety of sources and allow for in-country analyses where appropriate.

- The information generated by the system should have a known and stated accuracy.

- Accuracy assessment must be an integral part of the program. Field validation must be an essential component of the accuracy assessment.

- The monitoring system should be coupled to, and support, an independent vetting of the proposed methodology and be subject to independent peer review.

- Data and information generated by the program must be made readily available in a timely fashion to a broad user community. A data system should be developed to serve the information management needs of the program and its data users.

3.0 CURRENT PROGRAMS AND STATE OF THE PRACTICE

Datasets from Landsat, SPOT and other fine resolution sensors with global and national coverage have created opportunities to exploit data in ways not possible just three or four years ago. Here we list some key projects for example, although the list is not complete. Annex 2 presents an overview of the EO sensors which could be used for the fine resolution data acquisition.

3.1 Global Scale Initiatives.

The NASA Landsat Pathfinder Humid Tropical Forest Inventory Project (HTFIP) is another high resolution satellite remote sensing dataset being developed through cooperative funding by NASA and the EPA. It will provide "wall-to-wall" coverage of the closed tropical forests of the world with Landsat MSS and TM at three points in time from the 1970s to the mid 1990s.

The Commission of the European Communities TREES project is compiling a 1 km tropical forest dataset in an effort to map the global distribution of tropical evergreen and seasonal forests, which is being made available as raw data and high level products, such as GIS-based forest maps, in an information system. This data provides a global stratification for detailed analyses with high resolution data. New initiatives with the TREES project involve the acquisition of large samples of high resolution satellite data to compliment the complete inventories provided by the Landsat Pathfinder Project. Combined, these two efforts would provide a prototype annual tropical forest assessment.

NASA is developing an acquisition plan for a global series of test sites using Landsat TM data. These data are to be used to calibrate global analyses from coarse resolution data such as AVHRR, and for development of site-specific models of ecological processes in places where detailed in-situ measurements have been made in conjunction with the satellite acquisitions. In a related effort, NASA is also compiling the Landsat Global Change Catalog, which is a worldwide catalog of Landsat data acquired in and outside the tropics for global change research. The data are available to the global change community at the cost of reproduction.

The High Resolution Data Exchange Project is a joint project of the Committee on Earth Observation Satellites (an international affiliation space agencies) and the International Geosphere Biosphere Program. This project is aimed at testing the utility of multi-sensor data acquisition, and a multi-agency international coordinated system of remote sensing observations. It is building a dataset containing several hundred SPOT, MOS, JERS-OPS, ERS-1, and IRS data at selected global change study sites around the world.

The Global Forest Mapping Program (GFMP) is a multinational effort led by the Earth Observation Research Center (EORC) of the National Space Development Agency of Japan (NASDA) in cooperation with, among others, NASA Headquarters – Earth Science Enterprise, NASA's Jet Propulsion Laboratory (JPL), the Alaska SAR Facility (ASF), the Space Applications Institute of the Joint Research Centre of the European Commission (JRC/SAI), Sweden's Swedish Space Corporation (SSC), Canadian Centre for Remote Sensing (CCRS), European Space Agency (ESA), German Space Agency (DLR), the University of California, Santa Barbara (UCSB), the Brazilian National Institute for Space Research (INPE) and the National Institute for Research of the Amazon (INPA). Several international research teams are also currently associated with the GFMP. Its goal is to acquire geographically and temporally contiguous Synthetic Aperture Radar (SAR) data sets of the Earth's major tropical and boreal forest systems by using the Japanese Earth Resources Satellite (JERS-1 or FUYO-1). The two mapping projects associated with this initiative are the Global Rain Forest Mapping Project (GRFM) and the Global Boreal Forest Mapping Project (GBFM). The GRFM has been in operation since 1995 whereas the GBFM has been operational since 1997. The Global Forest Mapping Program will continue to make use of Japanese remote sensing platforms such as the proposed JERS-2 and the Advanced Land Observing Satellite (ALOS) which will be launched in 2002.

3.2 Regional Initiatives

Currently, there are a number of projects underway in North America that are relevant to the High Resolution component of GOFC. For example, the North American Landscape Characterization (NALC) Project has been acquiring and processing complete coverage of the continental United States and Central America with Landsat MSS data at three points in time from the 1970s to the present. These include the following "wall-to-wall" mapping projects:

- Regional Multiresolution Land Characteristics (MRLC) – conterminous United States
- Earth Observation for Sustainable Development – Canada; *still in design phase
- Inventario Nacional Forestal Periodico – Mexico; conducted by "photo"-interpreting vintage 1993 Landsat Thematic Mapper data

Numerous other national inventories and projects which involve the establishment of statistical patterns and trends in forest conditions are relevant to GOFC, including: (i) FRA 2000 – international, (ii) Forest Inventory and Analysis (FIA) – United States, (iii) National Forestry Database Program (NFDP) – Canada, (iv) National Inventory for the Year 2000 – Mexico; proposed, (v) Mexican Deforestation Study – Mexico; proposed

Within the United States, the MRLC project is jointly funded by the United States Geological Survey (USGS) and the United States Environmental Protection Agency (EPA). The goal of this project is to generate a general, consistent, and seamless 30m land cover data set by the year 2000. 1991-1993 vintage “leaf-on” and “leaf-off” TM data are used in conjunction with multiple sources of ancillary data (e.g. digital elevation model data, available land user / land cover data, population census information) to accomplish this task. Currently, seven mapping teams representing both the government and private sector are conducting the project. Land cover products have been generated for most of the east coast of the United States and activities are currently focused on the US Midwest and Pacific Northwest. Accuracy assessment is conducted on completed sections- US Standard Federal Regions. A follow-on effort, MRLC 2000, is currently being planned.

Regional Activities have been initiated in recent years which could be coupled to the program outlined here for in-country work. Within the IGBP System for Analysis, Research and Training (START) a number of regional activities focusing on the land cover change question have begun. Most notable is the Southeast Asian regional activity which is directly linked to the EPA Pathfinder project in that region, as well as the aforementioned IGBP LUCC and High Resolution Data Exchange projects. START/Southeast Asia has initiated a Land Use and Cover Change (LUCC) program in two components: (a) a complete region-wide analysis of deforestation trends in the region, and (b) specific case studies established in four participating countries: Thailand, Malaysia, Indonesia, and the Philippines. The case studies, conducted primarily by local experts and scientists, provide a prototype example upon which to build in-country work. The Thailand Country Study is already a component of the START/LUCC activities in Southeast Asia.

Since 1992, the Chinese Academy of Sciences (CAS), has conducted the National Land Use Mapping Project and Dynamic Monitoring Project through the use of Landsat TM data and established the National Land Use and Land Cover Database of China which includes National Land Use and Land Cover Maps interpreted and digitized from TM data at the scale of 1:1 000 000, 1:500 000, 1:250 000, and 1:100 000. CAS plans to update the database every five (5) years. Based on the LUC database, CAS and the Chinese Academy of Forestry (CAF) are leading a project which will produce a national forest type map and database. All of these databases are stored and managed in the Chinese Natural Resources and Environment Information System, a GIS system.

During 1994-1997, CAS and CAF took part in an international project of the Global Research Network System (GRNS). Through this project, the Chinese Vegetation Working Group and the Japanese Integrated Forest and Forestry Production Institute (IFFPI) conducted the field survey and produced the Forest Type Map of Changbai Mountain and Maoeb Mountain. This field survey was based on Landsat TM data.
This collaboration also produced the 1km forest and land use maps of northeast China by using AVHRR data integrated with DEM and regional climate datasets.

At present, CAS is continuing with mapping China’s vegetation using AVHRR data at 1km resolution for the entire country. Current plans are to update the results on an annual basis.

The CORINE Land Cover project is an initiative coordinated by the European Environment Agency (EEA) through its European Topic Centre on Land Cover (ETC-LC). The ETC-LC is led by the Environmental Satellite Data Centre in Kiruna, Sweden.

The CORINE Land Cover product has 44 land-cover classes and 25 ha map presentation units. The mandate of the EEA is the entire continent of Europe to the Ural Mountains, and CORINE Land Cover has or will be generated for most or all of the European countries. The first mapping of the EU is complete except for the UK, Finland and Sweden which will be completed early next century. In addition the mapping has also been completed for a number of central and eastern European states including Poland and the Baltic States.

The CORINE Land Cover product is generally derived from manual interpretation of TM imagery and complementary data. CORINE Land Cover in Sweden is being performed without any funding from the EU. Therefore the project has been forced to explicitly address national mapping needs and adopt different methods. To this end the Swedish Land Cover product has been defined with 52 thematic classes and a map presentation unit of 1 to 5 ha depending on the class (highest resolution achieved among others for the forest classes). The methodology is highly automated (but includes some interpretation work, particularly in urban areas) enabling future product updates at relatively low cost, and the generation of a range of different end-products from the same core processing system. The development and pilot production phases in Sweden have been led by Swedish Space Corporation (SSC). In the production of the forest classification extensive use is being made of the National Forest Inventory ground plot data.

The BALANS project is a land cover project for the whole of the Baltic Sea Drainage Basin part-funded by the European Commission. The project starts in October 1998 and runs for about 2½ years. It is planned that a sustainable activity will continue after the initial project period. The project is led by the Swedish Space Corporation. The collaborators are the Finnish Environment Institute, Finnish National Land Survey, Swedish Meteorological and Hydrological Institute, the Environmental Satellite Data Centre (Sweden), GRID-Arendal (Norway) and GRID-Warsaw (Poland).

The aim of the project is to develop the methods for the production of a 200m land cover database and generate an initial database by the end of the project. In addition, a number of ”confidence sites ” will be investigated in detail, partly for validation and also to test the usefulness of the land cover products for specific users. The database will be primarily based on medium-resolution optical imagery (e.g. RESURS, IRS-1C WiFS and Envisat MERIS). A JERS SAR mosaic of the whole area is also available.

The Pan-European Land Cover Monitoring project (PELCOM) is a Europe-wide land cover product from AVHRR. The project has been running since 1995 and will end early in 1999. The project includes teams from the JRC, SSC, MeteoFrance, RIVM (Belgium) and the Austrian Research Centre Seibersdorf.. The project aims to produce a land-cover product at 1 km resolution with a limited number of classes, including a single ”forest” class.

The Forest Monitoring in Europe with Remote Sensing projects (FMERS 1 and 2) are initiatives within the Joint Research Centre, Ispra. They are funded within the Centre for Earth Observation programme (CEO) and in terms of technical associations fall within the JRC’s FIRS project (Forest Information from Remote Sensing). Both projects are technical development and demonstration projects of possible methods for a future European forest monitoring system.

The FMERS-1 project began Autumn 1997 and will finish early in 1999. The project team is led by VTT (Finland), and includes SSC, Scot Conseil (France), European Forest Institute (Finland), CESBIO (France), SCEOS (UK), University of Bologna (Italy). It focuses on distinguishing forest from other land-cover classes and on further dividing the forest areas into different types (e.g. needleleaf, mixed, broadleaf, etc.). The target nomenclature is based on the FAO definitions for Forest and OtherWooded Land. The project is using medium-resolution (RESURS with 170m pixels and IRS-1C WiFS with 190m pixels) and high-resolution (TM and SPOT) optical imagery. The first part of the project was to do some testing and evaluation of different methods and data. Some work was also included to demonstrate the potential of current SAR data and methods in this area. Six test areas were looked at sampling the boreal, temperate and Mediterranean forest types – the first time (we believe) I this kind of project in Europe. The second phase is more oriented towards putting methods for the medium-resolution optical data to work. Forest maps from medium-resolution data will be generated over two large areas in Europe – one focussed on the southern Baltic Sea region, the other on western Europe from the British Isles to the Alps (excluding Spain and Portugal).

The FMERS-2 project is smaller in scale than FMERS-1 and is looking at forest biomass and volume estimations using a multi-phase approach. The model builds from the ground data upwards through aerial photography, TM data and medium-resolution imagery – there is no radar component in the project. Two relatively limited areas will be looked at, one covering Sweden and Finland around the Gulf of Bothnia, the other over the northern half of Portugal and Spain. The project kicks off in October and runs until April 1999. The team is led by SSC who are working with the Finish and Swedish National Forest Inventories and the Instituto Superior Agronomia of the University of Lisbon, Portugal.

The SIBERIA project (SAR Imaging for Boreal Ecology and Radar Interferometry Applications) is a European boreal forest mapping and classification project which makes use of data from different microwave sensors: JERS-1 L-band SAR and ERS C-band SAR tandem data to retrieve forest parameters (forest type, biomass) on a large scale. Collaborators in the project include DLR (Germany), IIASA (Austria), CESBIO (France), SCEOS (Great Britain), VTT (Finland), several other European agencies and companies, four Siberian forestry partners from Russia, and NASDA (Japan).

Comprising at least 21% of the world's growing stock and 11% of the world's live forest biomass, Russia's boreal forests are a natural resource of global importance, both from an economic and ecological perspective. SIBERIA therefore strives through the use of multitemporal ERS, ERS tandem and JERS-1 data to develop a methodology and to produce a forest map of central Siberia (89-111 deg. East; 52-60 deg. North) which will serve the development of sustainable management policies, Siberia's socio-economic development, and climate change research.

The classification and estimation of forest variables in the SAR data will be supported by reference data collected and compiled from several information sources such as:

- Forest maps with stand descriptions (1:10,000 to 1:50,000)
- Aerial photos (1:7,000 to 1:25,000)
- Field measurements from sample plots
- Landscape and soil maps
- Aggregated landform data of different scales
- Russian and Siberian forest maps at different scales
- Forest maps from separate regions (1:100,000 to 1:300,000)

Deliverables for the project include the following:

- A map covering an area of 2 million square kilometers of Siberia indicated the spatial distribution of boreal forests of different types and biomass densities.
- A large database containing the forest classification and the remotely sensed data from which the classification was derived.
- A proven methodology for building a multi-satellite SAR dataset and using the assembled remotely sensed data to derive a reference forestry map over a significant portion of the Earth's surface.

4.0 USER REQUIREMENTS FOR FINE RESOLUTION PRODUCTS

The requirements of the user community must be an essential element in the design for GOFC in general and for the fine resolution component in particular. Satellite remote sensing of forest cover and forest cover change at the global scale

4.1 Global Change Research: the carbon cycle

Human activities are largely responsible for the observed increases in atmospheric carbon dioxide. Fossil fuel burning is currently the most important source of carbon dioxide. However, biogenic sources are also important. Evidence from ice core data suggests atmospheric concentrations of CO2 began to rise even before major inputs from fossil fuels existed.

The current global net flux of carbon from land cover conversion is between 0.9 and 2.5 x 1015 g C (Houghton et al. 1985). This represents between 18% and 49% of the release from fossil fuel combustion (Marland et al. 1985, Marland and Rotty 1984). On a long term basis, from 1700 to 1980, the total release from the biota was approximately equal to the long term total release from fossil fuels (Houghton and Skole 1990). However, the role of the biota in the global carbon cycle is poorly understood. The current estimates of the net flux from the biota cannot be reconciled in a balanced global carbon budget when other terms are also considered.

By coupling estimates of biotic source terms, estimates of ocean uptake, a modeled atmosphere, and in-situ measurements of the latitudinal gradient of atmospheric carbon dioxide concentration, recent analyses suggest the possibility of sink for carbon in the mid to high latitudes. This conclusion depends in part on our knowledge of the tropical source term. The temperate zone sink is computed as a residual of several presumably known factors, one being geographical location and size of the net flux of carbon from land cover change.

Closing the carbon budget will require improved estimates of the biotic source and sink terms globally. This will require annual, geographically specific estimates of land cover change and its associated influence on carbon release an uptake. This will require consideration of highly detailed new assessments at sub national resolution of areas which are actively being cleared and those areas which are being released to secondary succession. However, recent analyses in the Brazilian Amazon under support from the Landsat Pathfinder Project suggest that an inventory of areas in secondary growth are not sufficient since many of these areas are rapidly re-cycled into active agriculture. Thus, the dynamic pattern of land cover change is a central issue which will require acquisition of new data and further analysis.

4.2 Forest Inventory, Classification, and Characterization

The current distribution of forest cover worldwide is not well known or characterized. Regional stratification of vegetation and land cover types is required for most emission models. The stratification provided by a land cover map at a high spatial resolution would enable a framework for assigning variables such as biomass. This kind of map does not now exist, but programs are underway to develop them. Nonetheless, the global change research community needs to have a better definition of land cover strata upon which to layer datasets on land cover conversion and land use.

Since existing maps and databases from traditional sources are inadequate for global change research, national forest assessments, and international policy, improved data and analyses must be put in place.

Beyond the classification or stratification of land cover, it is important to have a comprehensive assessment of vegetation and land cover as it relates to the structure of forests – density, canopy closure, age, height, etc. Information on actual changes of this type are important for development of improved forest assessments as well as policy and carbon budgets.

4.3 Policy

As poorly understood are the global estimates, country-level estimates are even more poorly developed. This presents major difficulties for developing policies and mitigation strategies. For most developing countries the major source of greenhouse emissions is biogenic, rather than from fossil fuel combustion. A major new effort must be mounted to develop country-level estimates of land cover change in support of the IPCC and FCCC initiatives. To do this at a country level uniformly worldwide, it will be necessary to develop of mutually agreed methodologies for measuring land cover change, and providing improved methods for assessments and compliance.

Yet, in spite of the growing need for precise estimates of forest cover change to support both international policy and basic research, an operational program of measurement, monitoring and mapping has yet to be developed. For example, comprehensive and systematic information on the extent of forest and forest loss is not available on a global basis. The latest IPCC report considers the rate of tropical deforestation to be one of the key unknowns in global climate change assessment. Any lasting and effective implementation of a global emission inventory to support the IPCC process will require a new, concerted effort to measure and map tropical deforestation and biomass burning.

At a national level, numerous reports point to the critical need for accurate forest monitoring to support national forest management programs, particularly in developing countries where forests are an increasingly important source of foreign exchange. An accurate and up-to-date assessment of forest area and rates of depletion is fundamental to the development of improved national forest management strategies. Moreover, issues such as soil fertility and erosion, water yield, water pollution, and land use planning are directly linked to forest resource development and its management, which could benefit from such an assessment.

4.4 Convergence of Requirements to a Single Set.

A review of the individual requirements of the global change, forest inventory, and policy communities reveal a striking convergence, or similarity in scope and definition. The most complex and stringent requirements are set by the forest inventory users, with the carbon cycle community and the policy users (particularly the emissions inventory requirements) having of subset of these needs. Thus, it is possible to define a single common requirements list which satisfies a very broad range of users and at the same time focuses on the requirements for the global carbon community, forest inventory community, and the policy community.

The requirements of these three primary users resolve in three general categories:

- Forest Composition and Inventory requirements: periodic monitoring of forest extent and its structural and functional characteristics

- Forest Change requirements: frequent monitoring of changes in forest characteristics, extent and specific patterns of disturbance and regrowth

- Requirements to Support to the RAD components of the Kyoto protocols: frequent quantification of changes specific to deforestation, regrowth, and afforestation rates.

4.5 Baseline Requirements for Fine Resolution Product Suite

The Fine Resolution approach is centered on a single specific set of requirements as described in Table below.

SUMMARY OF USER REQUIREMENTS

Group	Requirements
Composition/Inventory	
Forest Types	Classification of forests by leaf morphology and physiognomy: e.g. needle leaf/broadleaf; deciduous/evergreen; wet/dry/montane
Species Composition	Classification of forests by dominant species
Other Types Included	Classification of wetlands, shrubs, etc.
Forest Density	Classification based on % closure: <10%, 10-25%, 25-40%, 40-60%, >60%
Age	Three classes of young, immature, and old-growth forest, or classes derived from specific multi-temporal analyses
Volume	Biomass per forest type
Forest Change	
Fire	Measurement of area and number of fires; fire intensity; residuals after burning
Harvest	Measurement of area harvested and type of harvesting including clear-cut, partial cuts, and thinning
Insect and Disease	Measurement of area and severity
Regeneration	Measurement of areas regrowing and rates of regrowth
RAD	
Deforestation	Area and rate of deforestation annually
Reforestation	Area and extent of regrowth and age of regrowth
Biomass	Carbon Stocks in Forest and regrowth
Fragmentation	Spatial pattern of deforestation, regrowth, and fragments

Not all of the baseline requirements listed above can be met with earth observation satellites, and some are more complicated than others. It is recognized that Volume data will be difficult to obtain operationally and uniformly within the GOFC time-frame, and should be considered a significant R and D effort. As well, in some forest environments, particularly the tropics, age will be a significant R and D effort. Nonetheless the current state of the practice as described in section --- above suggests potential for meeting all other requirements.

4.6 Coverage, Resolution, Frequency Requirements.

Inventory assessment can be accomplished at 50 meter resolution, but the change analyses will require very precise registration to earth coordinates and precise co-registration. This constraint will drive the resolution requirements for high resolution products to 30 meters. Global coverage is recommended, with capabilities for national and regional subsetting. The recommendation for global coverage at 30 meter resolution will drive a significant duty cycle for data acquisition, or a multi-sensor strategy. Forest inventory should be repeated every 5 years. This repeat cycle is consistent with national forest inventory needs in most countries, and is compatible with the FAO forest assessment schedule. It is appropriate for carbon cycle analyses and IPCC assessments, but more frequent – annual -- RAD measurements are required.

5.0 FINE RESOLUTION PRODUCT SUITE

In this section we outline a practical and manageable suite of products which meet the user requirements specified in section 3.

The highest priority is given to global scale applications and products, with regional and local (i.e. national) products subsetted from the global products. High resolution global monitoring has never been done before, although there have been several large area successful prototypes. The NASA Landsat Pathfinder project analyzed several thousand MSS and TM scenes to measure forest area and forest area change in the tropics. The NASA/EPS North American Landscape Characterization Project (NALC) acquired and processed co-registered triplicates of Landsat MSS data for the US and Mexico. NASDA, ESA, NASA and other partners have demonstrated the compilation of large area mosaics of JERS SAR data for the tropical and boreal forests, and ESA has demonstrated a large area multi-date mosaic for the African continent. Most experience to-date has been in image data product assembly rather than derived product production.

To maintain a global scope for the high resolution component of GOFC, it is essential that the product suite be as simple as possible, yet remaining useful and meeting the requirements of the user community. The product suite should also be built on proven techniques, methods and approaches.

The first proposed high resolution product is a Forest Cover Characterization product, produced on a wall-to-wall basis at 30 meters every five years. This product will support the requirements for forest composition and inventory with detailed classification forests based on methods which define classes based on functional characteristics. The second product is a Forest Change product which will be a global forest-non forest extent map reproduced on a wall-to-wall basis every five years. Image change detection will then be used between dates to define the specific transitions and changes: forest to non forest, and non forest to forest. In addition, forest change will be measured on an annual basis using stratified sampling between the semi-decadal complete inventories.

It must be noted that in order to produce a forward-looking stratified sampling scheme for change detection, an initial "wall-to-wall" assessment would have to made in the first 2-3 years. This initial change would define the first stratification until another assessment is made after 5 years. Thereafter the change stratification would be derived from the previous 5 year analysis. It is also important to note that the stratification scheme would be developed in coordination with the coarse resolution team, using important indicators of change as strata (e.g. fires).The product suite is specified in the Table below.

HIGH RESOLUTION PRODUCT SUITE

Product Type	Product	Description
Data Products	Geometrically Rectified Land Cover Data Product (FCGD)	Landsat, Spot, SAR image products which are referenced to earth coordinates (± 60m) by scene
	Geometrically and Atmospherically Corrected Data Products (FCGAD)	FCGD image products which have an atmospheric correction
	Mosaicked Data Product (FCMD) [optional]	Mosaiced FCGD image products (Note: precision in the FCGD products would amount to mosaicing without actually scene merging
	Co-registered Image Pairs for change detection analysis (FCCD)	Image to image registered pairs (± 30 m) at multiple dates for change detection analysis. A "wall-to-wall data product initially at t_0 and t_{+3}, then every five years.
Derived Products	Forest Cover Product (FCI)	Large area (i.e. "wall-to-wall) classification maps at 30 m resolution, repeated independently every five years
	Forest Cover Change Product (FCC)	Large area (i.e. "wall-to-wall) forest/non forest classification change product derived from change detection analysis of multi-date (initially every 3 years, then every 5 years)
	Forest Cover Change Sample Product (FCC-s)	Stratified sample change detection based on scene pairs at 30% sampling or less on an annual basis using the FCCD products

5.1 Forest Cover Product (FCI) Description

The products from high resolution observations take advantage of recent advances in developing functional classification of forest cover which are demonstrating the potential for classifications schemes with detailed classes. The Forest Cover Product classification scheme will be compatible with the coarse resolution classification scheme. This should permit a close linkage for calibration and validation, as well as inter-product and inter-scale compatibility. A general description of the product is provided in the table below.

GENERAL DESCRIPTION OF THE FOREST COVER PRODUCT

Resolution	30 meters
Frequency of update	5 years
Data sources	Mostly Landsat, with gap-filling by Spot and SAR
Mapping units	Preserve all pixels, no filters
Coverage	Global, wall-to-wall, in areas of forest identified by coarse resolution
Thematic classes	Based on 4-D matrix of leaf type, longevity, tree height, and age
Data acquisition strategy	Landsat 7 acquisitions every year, 4 times annually, focused on areas of forest cover and rapid changes, using Spot and other optical as gap filling, with SAR for gap filling.
Processing requirements	Registration to earth coordinates to $\pm$ 60 m, atmospheric correction required (coordinated with coarse resolution),

The classification scheme for this product will have to be elaborated in detail and specificity, but the recommendation is to follow the convention described in the table below in which forest types are classified based on functional and structural conventions. This proposed product is deemed both feasible and compatible with the coarse resolution team's recommendations.

SPECIFICATION FOR THE FOREST COVER PRODUCT

Leaf Type	Needle, broad, mixed
Leaf Longevity	Evergreen, deciduous, mixed
Canopy Cover %	>60, 40-60, 25-40, 10-25
Canopy Height	Trees > 2m, Tall shrubs 1-2m, low shrubs <1 m
Other Classes of Cover	Snow/ice, water, grassland, barren, built-up, agriculture, wetlands (orchards, plantations are optional)

5.2 Forest Cover Change Products (FCC and FCC-s) Description.

This product will measure and map the change in forest cover using precise image-to-image change detection methods. Unlike the Forest Cover product which will be independent classifications at different dates, this analysis will be focused on change detection. To keep the analysis simple and straightforward, the product will describe "that which is forest at t=1 and is no longer forest at t=1." The product will also report areas of non-forest which returned to forest This analysis will be conducted using change pairs 5 years apart, providing a change period of 5 years globally. The five-year period will be compatible with the 5 year period of the Forest Cover Product.

To support RAD requirements, and most of the carbon cycle requirements, an annual assessment will be completed using stratified sampling.

A forest-no-forest classification is implicit in this change product, but will be compatible with the Forest Cover Product at the five-year milestones, so changes on a semi decadal basis will be resolved into forest types, while the inter-milestone stratified samples will not (but could be inferred).

General Description of the Forest Cover Change (FCC) Product

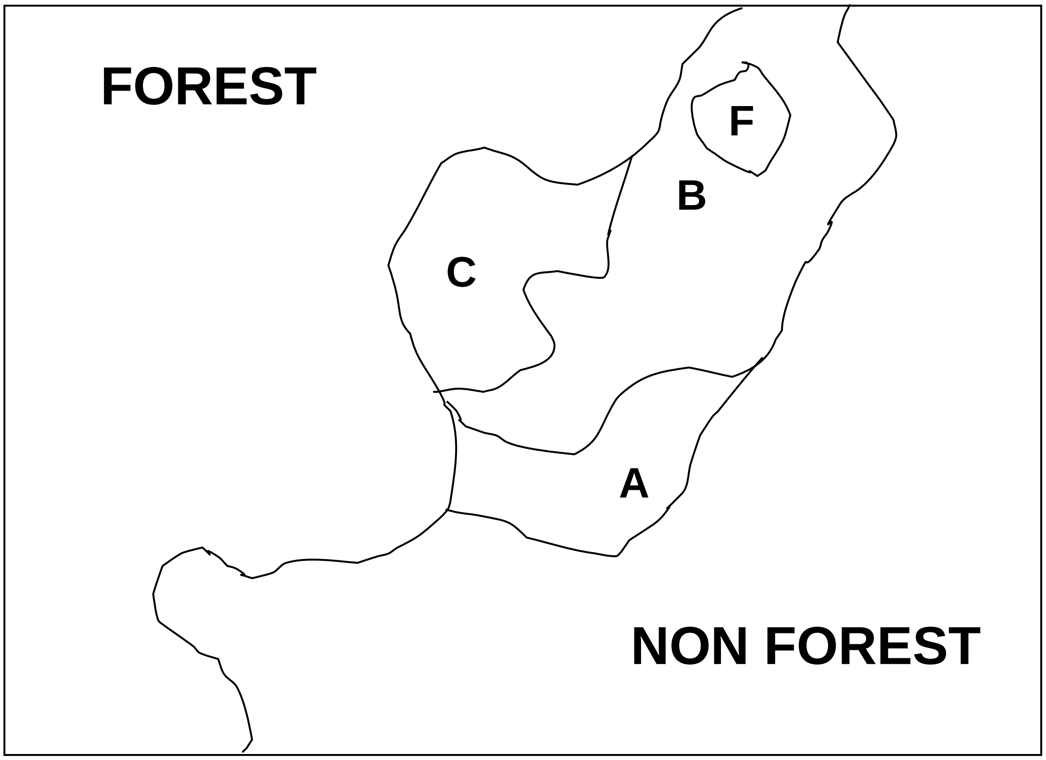
Resolution	50 meters
Frequency of update	5 years (with initial 3 year update to support the sampling product stratification
Data sources	Mostly Landsat, with gap-filling by Spot and SAR
Mapping Units	Preserve all pixels, no filters
Coverage	Global, wall-to-wall, in areas of forest identified by coarse resolution
Thematic classes	Forest, Non Forest
Data acquisition strategy	Landsat 7 acquisitions every year, 4 times annually, focused on areas of forest cover and rapid changes, using Spot and other optical as gap filling, with SAR for gap filling. *Change pairs must be of the same sensor type* .
Processing requirements	Registration to earth coordinates to ± 60 m, atmospheric correction required (coordinated with coarse resolution), *change detection using image co-registration to ± 15 m precision*

General Description of the Sample Forest Cover Change (FCC-s) Product

Resolution	50 meters
Frequency of update	Annually
Data sources	Mostly Landsat, with gap-filling by Spot and SAR
Mapping units	Preserve all pixels, no filters
Coverage	Global, based on stratification sampling scheme
Thematic classes	Forest, Non Forest
Data acquisition strategy	Landsat 7 acquisitions every year, 4 times annually, focused on areas with most of the area changes, using Spot and other optical as gap filling, with SAR for gap filling. *Change pairs must be of the same sensor type* .
Processing requirements	Registration to earth coordinates to ± 60 m, atmospheric correction required (coordinated with coarse resolution), *change detection using image co-registration to ± 15 m precision*

5.3 Special Products from the Forest Change Products

Two special products are defined: (i) a Forest Fragmentation product (FCF) which identifies patterns of fragments and calculates fragmentation statistics, and (ii) a Forest Change Occurrence (FCO) map, which would be produced annually in specific high priority locations, to be determined at a later date. Because co-registration change detection permits the development of maps of forest changes on an annual basis in which the individual increments of forest-to-nonforest or nonforest-to-forest changes occur, it is possible to define the specific “patches” of new clearings and compute such metrics as the deforestation event magnitude (DEM). The DEM is the statistical measure (mean, variance, etc) of the size of individual areas of forest converted to non forest between two years (see Figure below).



The Figure is an example of a Forest Change Occurrence product. The product depicts the forest and non forest extent in a particular year, t=5, along with the DEMs for t=4 (A), t=3 (B) and t=2 (C). The Fragment, F, is also shown.

6.0 FINE RESOLUTION DATA ACQUISITION STRATEGY

The GOFC High Resolution acquisition strategy should focus on meeting the following data needs for GOFC: wall to wall global coverage every five years, up to a 30% sample of forested areas annually, and a sufficient sample of Landsat 7 ETM+ and SPOT HR VIR data to test atmospheric correction based on the simultaneity with MODIS/MISR and VEGETATION instruments and for calibration and validation of GOFC coarse resolution products. Four scenes acquired once per season are required for the global coverage data and the samples. This design advocates an acquisition strategy based on multiple sensors to ensure optimal coverage and to provide redundancy and robustness for the data and derived products of GOFC (see Figure in Annex 3 for an overview of acquisition strategy). However, it is imperative that the sensors meet minimum standards TBD in terms of calibration and quality control.

The overall approach should focus on leveraging off of existing acquisition activities for current sensors (e.g. Landsat TM, SPOT HR VIR, JERS-1 SAR, ERS-1 SAR, Radarsat, etc.) and sensors that are funded and in development for launch in the near-term (e.g. Landsat 7 ETM+, ASTER, SRTM, ADEOS AVNIR, ALOS SAR, ENVISAT SAR, etc.). Given these goals and constraints, the acquisition strategy should rely on the global archive planned for Landsat 7 with SPOT, other visible-near infra-red (VIR), and active microwave SARs providing the critical role of gap filling and hot spot monitoring. This multi-sensor approach would utilize the strengths each sensor (e.g. planned systematic global acquisition of Landsat, SPOT HR VIR pointing capability for frequent imaging opportunities, and SARs all weather imaging capabilities).

The Landsat 7 Project and Science Team has developed a Long Term Acquisition Plan (LTAP) for the Landsat 7 mission to acquire and periodically refresh a global archive of high quality (low cloud cover, sufficient solar zenith angle, with optimal gain settings) data for all land areas at least four times a year. LTAP has been designed based on a constraint of at most 250 scenes acquired per day (capacity of the on board recording and direct downlink to EDC receiving station). Given that Landsat 7 orbit would enable up to 850 acquisition of land areas per day, LTAP uses vegetation seasonality (based on 10yr AVHRR NDVI record), cloud climatology (ISCCP), and 24 hour NOAA weather predictions to prioritize scheduling in an effort to populate the archive with high quality data. Although LTAP stresses vegetation phenology and GOFC focuses on land cover and land cover change products, Landsat 7 coverage based on the LTAP should meet GOFC requirements for the initial GOFC acquisition. However, as GOFC evolves and the results of the LTAP are know, there may be a need for GOFC input into the LTAP.

Based on the historical archive of the Landsat program and ISCCP cloud climatology, there will likely be significant areas where low cloud cover data will not be available over the 5 year inventory periods for global coverage for GOFC. This is a result of Landsat's 16 day repeat cycle, periods of low solar illumination in the upper latitudes (e.g. Boreal forest where forest loss due to fire is high), and persistent cloud cover (most notably in the tropics where forest conversion rates are high). Therefore, additional VIR sensors are critically needed to provide additional coverage in these important forest zones. Given its unique pointing capability, SPOT HR VIR role in GOFC is very important. SPOT will need to be tasked to make routine acquisitions of critical areas that tend to be cloudy, thereby increasing the probability of a low cloud cover acquisition to be used in the global inventory every five years. In addition, SPOT will provide increase capability for programming targets of opportunity for hot spot monitoring. As with Landsat, the goal with these SPOT acquisitions would be to obtain at least 4 scenes acquired seasonally. Additional VIR sensors will be used to for gap filling to augment the SPOT and Landsat coverage, providing redundancy and robustness to the overall GOFC acquisition strategy.

Although SAR sensors have not been used for wide spread or routine land cover mapping/monitoring, these sensors would also play an important role in GOFC. SAR data (e.g. JERS-1 LHH, ERS-1/2 CVV, and Radarsat CHH) will be used to image areas where there are gaps remaining after the VIR acquisitions due to persistent cloud cover conditions. These areas should be imaged with the SARs at least four times per year. SAR system will also provide some important baseline datasets for GOFC (e.g. NASDA GRFM mosaics in the tropics and SRTM global DEM with 30 meter pixel spacing and 8 meter vertical postings). Use of SAR alone and in fusion studies will be an important part of GOFC research and development activities in an effort to evolve GOFC processing to better meet the needs of the user community. It is noted that the absolute calibration of SAR data is ideal for operational applications. Additional SAR data will be needed for these R&D activities.

Data from the suite of very high resolution (1-3 meter) sensors should also play an important role in GOFC. Systematic and statistically valid accuracy assessment of regional to global scale land cover and land cover change studies is extremely difficult and can be prohibitively expensive. Use of the very high resolution sensors for systematic validation should be incorporated into the GOFC validation strategy.

SUMMARY OF ACQUISITION STRATEGY AND TASKING REQUIREMENTS

Sensor	Product	Duty Cycle		Acquisition number of scenes
		Tasking	Frequency and # per yr	
Landsat 7	FCI	Global, routine acquisition	5yr, 4	28,000
	FCC	Global, routine acquisition	5yr, 1	7,000
	FCC-s	Global, routine acquisition	Annual, 1	2,100
Spot	FCI	Gap filling, targeted sites	5yr, 4	7,500
	FCC	Gap filling, targeted sites	5yr, 1	1,875
	FCC-s	Gap filling, targeted sites	Annual, 1	600
SARs	FCI	Complementary, targeted regions	5yr, 4	7,800
	FCC	Complementary, targeted regions	5yr, 1	1,950
	FCC-s	Complementary, targeted regions	Annual, 1	600
Other VIR	FCI	Gap filling, targeted sites	5yr, 4	TBD
	FCC	Gap filling, targeted sites	5yr, 1	TBD
	FCC-s	Gap filling, targeted sites	Annual, 1	TBD

Notes:

FCI=Global Forest Inventory/Classification, FCC=Global Forest Change,
FCC-s=Global Forest Change Sample

Acquisition strategy assumes that Landsat 7 will provide the backbone of acquisition by acquiring all areas on a routine and constant basis (i.e. globally, annually, season refresh), with areas of known persistent cloud cover being routinely imaged by SAR and Spot. Gaps at the end of one acquisition period (approx 1 yr) are then tasked as targets for Spot and SAR.

Acquisition estimates for Landsat 7 are based on an assumption of 14,000 Landsat scenes to cover the earth land mass, of which 50% has forest cover. For sampling, the estimate is based on an assumption of a 30% stratified sample

Acquisition estimates for Spot are based on an assumption that 10% of the areas imaged will have excess cloud cover and a success rate of 30% for these areas.

Acquisition estimates for SAR are based on the assumption that all remaining gaps (i.e. 70% of the 10%) are filled by SAR requests.

7.0 FINE RESOLUTION DATA PROCESSING PLAN

7.1 High Resolution Data Processing

GOFC should utilize data processing and analysis methods that are well established and suitable for operational use. There are several considerations to address for the end-to-end operational processing stream. The following figure illustrates a set of processing steps from data acquisition (described in detail in the previous section) through product distribution and use by the end users of GOFC data:

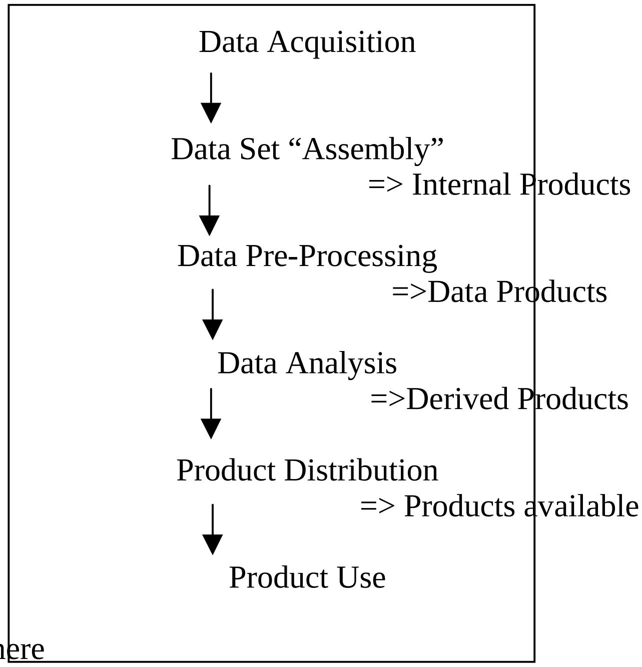


Figure: Processing Steps where

- Internal Products: interim products such as georeferenced imagery and atmospherically corrected data.
- Data Products: georeferenced, atmospherically corrected, image mosaics.
- Derived Products: forest cover and forest cover change maps and statistics.
- Products available: derived products in a standard format for distribution.

It is proposed that GOFC implement a processing model where a set of centralized facilities (e.g. DAACs, ESIPs, or Regional Data Providers) handle the bulk processing steps (including at least the data assembly and data pre-processing) and an expanded set of facilities handle the local level labeling of land cover classes and incorporation of *in situ* data. An advantage of this approach is that the computationally heavy steps of the processing stream are handled at facilities with adequate resources and where processing standardization can be assured, while fully utilizing the regional/local expertise and knowledge. The data product in itself is a very important and significant product for GOFC and is extremely useful for the GOFC user community.

In addition to operational processing, GOFC should have several research and development activities that focus on improving the current state of the art processing techniques so that GOFC evolves and produces improved products for the user community. These development activities should include, for example, improved atmospheric correction algorithms and direct parameterization of continuous variables that characterize forest function (e.g. biomass and LAI).

The objective of the data set assembly step is to bring together all high resolution data required GOFC. The guiding principle behind this step is to initially select appropriate processing centers and participants that are interested in GOFC and have sufficient technical expertise and capacity. Then develop mechanisms to ensure that each processing center receives all data needed to produce the products within their domain. This includes data from all suitable high resolution sensors and archives. For example, this step would focus on selecting the appropriate data from the Landsat 7 archive (existing level 1 data is ordered and if necessary requests to process level 0 data), SPOT global archive, and international Landsat ground stations.

The data pre-processing step should include geometric rectification, atmospheric correction, and mosaicing. Once again this step should utilize a network of centralized processing facilities where standard, proven and robust procedures are used. An effort to automate these procedures should be made. GOFC needs to maintain consistency and quality control across processing centers. Periodic intercomparisons are needed to monitor and ensure processing consistency. These pre-processing facilities need to accommodate evolution of the methods and techniques so GOFC can evolve and incorporate new pre-processing techniques (e.g. improved atmospheric correction algorithms).

Geometric rectification should focus on using automated image to image techniques with a base map/image set is the NASA sponsored Earth Satellite Corporation (EarthSat) TM data base. This EarthSat data base is being developed as part of an on going NASA data buy. The timeframe of the EarthSat activity parallels the initial GOFC timeframe, therefore, consideration of regions for initial prototypes should be made in concert with the EarthSat activity. The EarthSat data base will consist of global coverage of TM data that have been ortho-rectified (with a 60m RMS to true Earth coordinates) using NIMA DTED (3 arc seconds) data and an automated block triangulation method. The data will have 28.5 meter pixels in a UTM projection using WGS84 datum. GOFC image to image registration requires an RMS of less than 30m with a goal of less than 15m. GOFC should recognize the importance of this baseline data set and make a recommendation to EarthSat on scene selection process to improve its utility.

Several options for atmospheric correction of GOFC visible and infra-red (VIR) data exist. Two basic approaches are being considered. One method, considered the most promising and appropriate, is to utilize atmospheric correction capabilities of MODIS/MISR and VEGETATION to correct the Landsat 7 ETM+ and SPOT HR VIR data, respectively. Technical specifications for this technique will need to bet set and demonstrated to be feasible on a regional and global scale before it would be implemented in GOFC processing stream. The second method, considered as a back up, is to utilize relative radiance measurements in image overlaps to correct the data (.i.e. dark object subtraction method).

If adequate atmospheric corrections can be applied, then and only then will it be useful for GOFC to produce mosaiced data products. There are two options for mosaicing: actual or virtual (.i.e. tiling) mosaics. The most appropriate approach will depend on the derived products and capacity of the processing facilities. Since useful mosaics require high quality atmospheric corrections, which may not be always available, there needs to be some research and development to evaluate the best approach, utility and need for these mosaics. The bottom line of the pre-processing step is to produce the most viable products and processing scenario for GOFC success.

The data analysis step includes data classification and data fusion. The overall objective of the classification steps should be to simplify the data content into GOFC feature classes without losing land cover information. Considerable research and thought has gone into producing the feature classes, listed in products section of this document, for GOFC with an emphasis of developing and automated system while providing critical information needed by the user community. Additional research is need to demonstrate that classification procedures at the regional scale can handle spectral confusion due to large area coverage. There are two basic classification approaches to be considered by GOFC: supervised classification with a few very specialized classes (as was done in Boreas) or hyper-clustering approaches with knowledge based relabeling (Landsat Pathfinder HTF). Data fusion may be a necessary intermediate step in the classification process. However, it is currently unclear if fusion is required to product GOFC products. Therefore, there needs to be a research and development activity to assess the need and benefit of fused data products. Considerations for fusion should include: multiple high resolution optical data, high and coarse resolution optical data, and possibly most promising is the fusion of optical and microwave data. In addition, further research is need to develop algorithms for extracting continuous variables (biomass, LAI, leaf area duration, and others to be defined by user requirements) from the data. There is some support for developing a longer wavelength SAR (e.q. polarimetric P-band SAR) for biomass estimation.

For the data generation and distribution steps, GOFC should adopt a guiding principle of identifying experienced and currently active groups and assessing if together they provide global coverage (an overlap is desirable), In parallel, an effort is needed to involve additional groups, especially and the national and local levels, to ensure long term operation and maximum benefit from GOFC. The product generation and distribution systems need to be sufficient where results can be produced in a timely manner (forest cover products with 2-4 years and forest cover change products within 1-2 years). To this end, GOFC needs to learn from and take advantage off of other existing programs (e.g. GRFM, LPHTF, TREES, …). If the product generation and distribution system is complete and timely, then the success of GOFC will be the basis for an on going forest cover monitoring program.

8.0 PROGRAMMATIC CONSIDERATIONS

8.1 An International Focus.

There are a number of established and nascent international programs which could be strengthened to contribute to the high resolution program. The international nature of this global program necessitates collaboration with international structures, as well as the CEOS partners. The workshop recognized the pros and cons of working with the international agencies outside the CEOS system. The suggested approach is to focus international collaboration on areas of mutual benefit to GOFC and the international participants in question.

Participation in international programs has been found to be a successful means for implementing international research and collaboration. Participation by scientists in the IGBP, WCRP and IHDP has proven to be effective in mobilizing the international research and monitoring community. The IGBP Global Land Cover Program (IGBP 1992) is a good example of potential international collaboration geared towards the generation of global land cover data. The NASA/ESA/USGS/IGBP Global 1km AVHRR data base is a good example of internationally coordinated data acquisition.

Programs of the international agencies such as the UNFAO and UNEP with the mandate for monitoring the global forest environment will certainly need to be considered with respect to international collaboration. For example the FAO Tropical Forest Resource Assessment Project provides an important interface to the national forest monitoring communities. Such projects can benefit from the proposed program as well as help the program. However in addition to the more traditional international agencies there are some emerging international initiatives which should be considered. For example START, IAI, ENRICH and GTOS are all addressing aspects of international networking and research and development with a focus on the global change research agenda. Such programs would provide a useful structure under which certain international aspects of this proposed land cover change program could be coordinated.

International funding agencies may also be interested in helping developing countries to participate in the high resolution component of GOFC. Alternatively funds to support the program might be routed through international agencies with the infrastructure to support in-country activities.

8.2 Building on Existing Programs and Expertise.

The approach proposed is to build on existing national and international programs and activities. Building on existing activities would enable the propose program to reduce the large expense associated with start-up, and would take advantage of a well-developed suite of methods and experience. A new program must move the knowledge and data base beyond the aggregate methods used in past decade. However, the development of such a system will not be a small undertaking, and therefor must build on, and where necessary expand upon, existing efforts.

In the United States, Europe and around the world experts have been building the scientific, technical, and procedural underpinnings for a land cover change monitoring system. The World Forest Watch Meeting held in Sao Jose dos Campos, Brazil (June 1992) provided a high-level international forum for the assessment of current approaches to satellite-based monitoring. This meeting also served as a basis for forwarding recommendations from the technical and scientific communities to the policy makers and government leaders at UNCED.

A variety of international participants were represented at the World Forest Watch Conference. The conference concluded that significant technical and methodological advancements have been made in recent years, and they are now sufficient for proceeding with an observation system which could satisfy both scientific and national-level forest management requirements.

In 1990 NASA began a prototype procedure for using large amounts of high resolution satellite imagery to map the rate of tropical deforestation, one of the most important land cover changes. This activity, called the Landsat Pathfinder Project builds on experience gained during a proof-of-concept exercise as part of NASA's contribution to the International Space Year/World Forest Watch Project. It focused initially on the Brazilian Amazon, and has been expanded as part of NASA's Earth Observing System activities to cover other regions of the humid tropical forests.

This project has succeeded in demonstrating how to develop wall-to-wall maps of forest conversion and re-growth. The project is now in the process of extending its initial proof-of-concept to a large-area experiment across Central Africa, Southeast Asia and the entire Amazon Basin. The project is acquiring several thousand Landsat scenes at three points in time -- mid 1970s, mid 1980s, and mid 1990s -- to compile a comprehensive inventory of deforestation and secondary growth to support global carbon cycle models. Methodology and procedures have been identified. Although this exercise is being implemented for most of the tropics, it is not an operational global program. In principle it will provide an initial large-scale prototype of an operation program. As its name implies, this project is exploratory, but it could readily be expanded to form the nucleus of a global scale operational program.

The TRopical Ecosystem Environment Observations by Satellites project (1991- 1998) is currently being implemented as a demonstration of the feasibility of applying space observation techniques to monitoring of land cover and biomass burning. This project, being sponsored by the European Commission, utilizes global coverage with coarse resolution sensor systems such as the AVHRR, which provide daily coverage over large areas. It also focuses on the use of thermal sensors for the detection of fires, and incorporates other indicators of deforestation. The project uses these data in conjunction with sample higher spatial resolution data from a range of space sensors (e.g. Landsat).

The Landsat Pathfinder Project and the TREES Project demonstrate the ready feasibility of developing a global land cover monitoring system for the tropical forests. Coverage of tropical forests must be a paramount objective of any program focused on obtaining improved estimates of emissions of carbon dioxide since 90% of the current emissions come from tropical forest regions.

The IGBP has also initiated a project to make high resolution data available to the global change research community through cooperation with the Committee on Earth Observation Satellites, the international organization of space agencies responsible for developing and coordinating policies and standards for all remote sensing satellites. This project is being initiated as a pilot study to make available each year several hundred individual scenes from Spot (the French multispectral, 20m resolution satellite), Landsat (the US multispectral 30m resolution satellite), ERS-1 (the European Space Agency's radar satellite), MOS-1 (the Japanese 50m multispectral satellite), JERS-OPS (the Japanese 18m multispectral satellite), and IRS (the Indian 30m multispectral satellite). The project is also preparing a centralized archive system in which users can mount an inquiry for data from all of the aforementioned platforms from one point.

8.3 Linkages With Other Programs

The high resolution component of GOFC would establish linkages to various organizations and communities that would be contributors to *and* recipients of data and information from the program. In addition, close linkages would be established with the user communities targeted by the program (e.g. global change research, the Framework Conventions, IPCC, national forest programs) to refine the required products from the program and to provide support in the utilization of the project output as an on going activity.

It is important that GOFC now develop a rationale organizational structure which extend outside CEOS to include user agencies, international global change research community and the global observing systems efforts.

It is also important that the high resolution component develop strong partnerships with the foreign ground stations, particularly those which have capabilities for Landsat 7 and SAR. The ground stations can serve as focal points for regional networks regional datasets which can significantly augment the on board acquisition capabilities.

8.4 Networks for Building Regional Support and Participation.

The high resolution design component recommends a strong linkage to regional networks of on-the-ground practitioners (remote sensing, forestry, global change science), through the IGBP START program and the FAO forest assessment efforts.

The most costly component of the program is likely to be the collection of ground based data and the validation of regional satellite data interpretations. These field-based activities will best be done in collaboration with national scientists and resource managers familiar with the local environment. For example the FAO Tropical Forest Assessment has successfully coordinated a network of national forest agencies to assist in the interpretation of satellite data and their validation. Similarly successful collaborations have been developed by the NASA Landsat Pathfinder Humid Tropical Forest Project. The recent START initiatives of IGBP/WCRP/IHDP also provide a means for involving foreign scientists in regional global change projects. To fully engage the scientists and organizations from developing countries it is often necessary to build capacity at the institutional level. Clearly all the resources required for such a critical activity cannot be found within the budget of this program. A more appropriate approach would be to form partnerships and linkages to those agencies with the responsibility for national level capacity building such as national and international development agencies and organizations.

9. RESEARCH AND DEVELOPMENT AS AN INTEGRAL COMPONENT

There is great promise that remote sensing techniques can be applied globally, but more research is needed to fully develop the techniques and approaches employed by existing forest cover change monitoring efforts, particularly for new regions outside the tropics, seasonal forests in the tropics, savannas, and other land cover types. The methodological issues include: development of classification techniques, objective boundary /class definitions, best means for change detection, registration and orbit navigation, and scene processing. The specific method employed may vary from region to region. It is therefore necessary to define appropriate methods for each region of interest.

The program strategy we describe calls for a combination of complete census and stratified sampling. The scheme seems to work in selected regions, but has not been fully developed for all regions of interest. A complete methodology for sampling and complete census needs to be work through for a variety of regions.

The degradation of forests is becoming an important issue, yet more research needs to be done before it will be possible to incorporate this approach into remote sensing techniques. It is feasible that satellite data can be used to quantify the areas of forest which have been degraded for selective logging. More research needs to be done in this are.

To employ several sensors in an internationally coordinated of data acquisition, it will be necessary to know the significance of using the different sensors for land cover change analysis. An inter-comparison R and D effort in which the various sensors are acquired and analyzed at common test sites would make an important contribution to the program. Initial work is now underway with the IGBP/CEOS High Resolution Data Exchange Pilot project; EPA could support and expand this effort. A clear quantitative understanding of the differences between sensors for specific applications of land cover change analysis would improve an multi-sensor acquisition and analysis program.

New remote sensing and data management technologies and methods are continually being developed. To maintain a state-of-the-art system, a program of research and development must be incorporated directly with the remote sensing activities mentioned here. In particular, development of microwave technologies could be emphasized since it has great potential as a data source which will eliminate the cloud cover problem. The strategy proposed here utilizes considerable SAR data, yet there does not exists a demonstration of large area forest/non forest mapping with SAR data in the same vein as previous demonstrations with optical data. More research is required to demonstrate SAR applications; a proof-of-concept demonstration project has yet to come.

Annex 1: List of Participants

Participant	Representing
Victor Taylor, co-chair	NASDA, Japan
David Skole, co-chair	Michigan State University, USA
William Salas	University of New Hampshire, USA
Ake Rosenqvist	JRC, Sweden
Bruce Chapman	NASA/JPL, USA
Ian Spence	Swedish Space Corp, Sweden
Liu Jiyan	Chinese Academy of Sciences, China
Rodgers Malimbwi	Sokoine University, Tanzania
Manuel Ferrao	National Remote Sensing Center, Mozambique
Jean Louis Fellous	CNES, France
Ichtiaque Rasool	IGBP
Don Leckie	Canadian Forest Service, Canada
Joe Cihlar	CCRS, Canada
Alain Podaire	CNES, France
Herve Jeanjean	Spot Image/Scot Conseil, France
Curtis Woodcock	Boston University, USA
Jim Vogelmann	USGS/EDC, USA
Jiaguo Qi	Michigan State University, USA
Diogenes Alves*	INPE, Brazil
Thuy LeTaon*	CESBIO, France
Tony Janetos*	NASA, USA
Chris Schmullius*	DLR, Germany
Dominic Kwehsa*	Forestry Commission of Zimbabwe
Eric Lambin*	IGBP
Suvit Ongsomwang*	Royal Thai Forestry, Thailand
* Could not attend, but express willingness to participate	

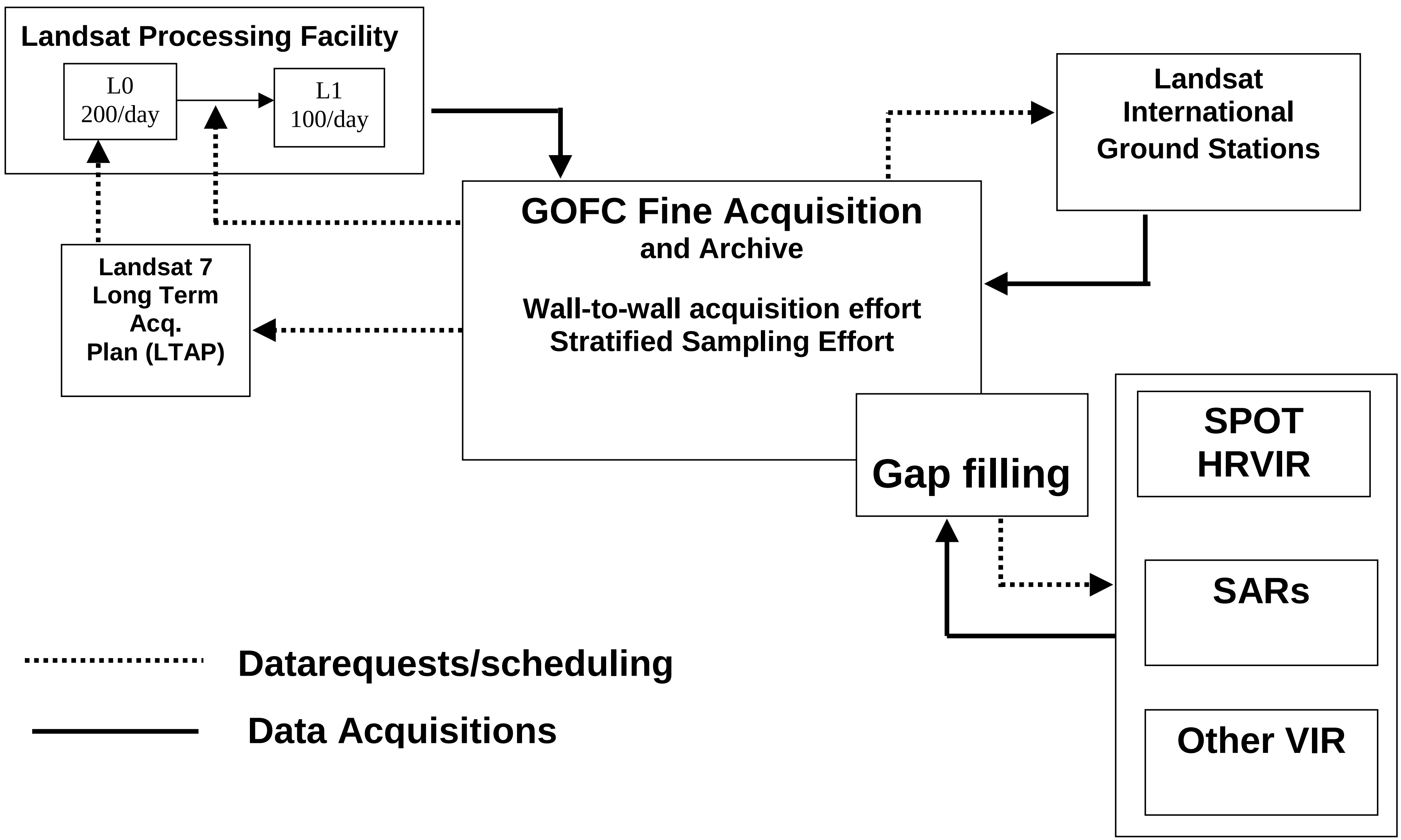
Annex 2: Sensor Suite for Fine Resolution GOFC

Potential Optical EO Sensors to Support High Resolution GOFC

Sensor	Data Coverage	Data Policy	Products
Landsat MSS - 4 bands - 57 m pixels - 185 km X 185 km	Global	Access to full-res data based on USGAU restrictions	Imagery
Landsat TM - 7 bands - 28.5 m pixels - 185 km X 185 km	Global	Access to full-res data based on USGAU	Imagery Image GCP databank restrictions
SPOTS XS	Global		Imagery
SPOT Pan	Global		Imagery
IRS LISS, I, II, III	Global		Imagery
MOS MESSR	SE Asia		Imagery
JERS-1 OPS	1992-Present: Global	Open	Imagery
JERS-2 OPS (proposed)	2000: Global	Open	Imagery
Landsat 7 (Future) - 7 XS bands - 1 Pan band - 28.5 m XS and 15 m Pan pixels - 185 km swath	1999: Global		Imagery
Spot 5 (Future)	1998: Global on demand	Open	Imagery
ASTER (Future)	1999: Global	Open	Imagery
AVNIR (Future)	2000: Global	Open	Imagery
LISS/IRS (Future)	TBD	TBD	Imagery
ALOS AVNIR-2 (future) - multichannel - 10 m resolution	2002: Global	Open	Imagery
ALOS PRISM (future) - optical scanner - 2.5 m resolution	2002: Global	Open	DEM

Potential Microwave EO Sensors to Support High Resolution GOFC

Sensor	Data Coverage	Data Policy	Products
JERS-1 - L-band; single pol - 75 km swath - 44-day repeat cycle	- 1992- Present Global	- Unrestricted access to low-res byte data over Web - Restricted access to high-res data; formal request	- Imagery
SIR-C - L, C bands; Multi-pol - 10-70 km swath - Variable repeat cycle	- April and October 1994: Global	- Unrestricted access to low-res (100 m) and high-res (20 m) data from EROS data center	- Imagery
ERS-1/2 - C-band; Single pol - 100 km swath - 35-day repeat cycle	Global - ERS-1 1991 - Present - ERS-2 1995 - Present	- Unrestricted access to low-res byte images and mosaic - Restricted access to high-res digital data; request through ESA/TREES	- Imagery
Radarsat - C-band; Single pol - Variable swath - 24-day repeat cycle	1996 – Present: Global	- Restricted access to derived data products - Digital data may be purchased from Radarsat International	- Imagery
SRTM (Future) - C-band; Single pol - Topography	1999: Global	- Restricted access to 30 m posting DEM data - Unrestricted access to 90 m data	- Imagery - DEM data
Envisat (Future) - C-band; Dual pol	2000: Global	- Researchers only	- Imagery
ALOS (Future) L-band; Quad-pol	2002: Global	- Open	- Imagery
JERS-2 (Proposed) - Copy of JERS-1 for 2000 launch	2000: Global	-Open	- Imagery
Lightsar/Echo (Proposed) - L-band; quad pol - 15-280 km swath - 20-52 deg. incidence angle	2002: Global	-TBD	-Imagery
BIOMASS (Proposed) - P-band; quad pol - 100-200 km swath - 60 day repeat cycle	?: Global	-TBD	-Imagery - Biomass density and types


Landsat Processing Facility
L0
200/day
L1
100/day
Landsat
International
Ground Stations
GOFC Fine Acquisition
and Archive
Wall-to-wall acquisition effort
Stratified Sampling Effort
Landsat 7
Long Term
Acq.
Plan (LTAP)
Gap filling
SPOT
HRVIR
SARs
Other VIR
Datarequests/scheduling
Data Acquisitions

APPENDIX 4: COARSE RESOLUTION DESIGN TEAM REPORT

GLOBAL OBSERVATION OF FOREST COVER
Coarse Resolution Products Design Strategy

September 21, 1998

1.0 GOFC Coarse Resolution Products

The Coarse Resolution Products Design Team met in Sioux Falls, SD in July 1998 to develop a strategy for generating a set of Global Observation of Forest Cover (GOFC) coarse resolution data sets. The team, listed in the report Appendix, built on the general specifications that were developed during the 1997 Ottawa GOFC meeting. During the Sioux Falls workshop, we reviewed and prioritized all products identified during the Ottawa meeting. In addition, three additional products were recommended: tree cover density, forest cover change, and active fires. The coarse resolution products, prioritized based on their relevance for science, policy, forest management, and other values, are listed in Table 1.

The discussion of priorities focused on user requirements rather than feasibility. Clearly, land cover products (global land cover, forest density, and forest cover change) and fire products (active fires, burned areas) are the highest priority and have the widest applicability. In addition, the state of processing is sufficiently advanced to permit immediate development of quality products. The other products, such as biomass and PAR, have significant research elements that must be resolved before products with the desired accuracy and precision can be developed. The rankings, therefore, strictly reflect the broader issue of user relevance.

After finalizing and prioritizing the list of GOFC coarse resolution products, the group developed specifications and processing strategies for each product. A brief summary of product characteristics is found in Table 2. The following are descriptions of the nine products recommended to represent the core set of coarse resolution products.

2.0 General Design Considerations

The strategies recommended for the development of the coarse resolution products are based on some fundamental considerations, such as:

- Products should be relevant to as broad an audience as is practical and feasible. It is particularly important that the products be designed to be relevant for carbon assessment and carbon crediting applications. In addition, relevance to national and international forestry organizations is also important.

- Product specifications should be achievable, whenever possible, with current technology (i.e., using data from sensors either currently operational, or scheduled to be operating in the coming year). The specifications, however, should also include definitions of optimal characteristics that may be achievable with advancements in future remote sensing systems.

- Research will be a necessary component in most product development strategies.

- Product specifications should be periodically reviewed and improved so that advances in methods and source data characteristics can be incorporated to improve overall data quality.

- Validation of data products is necessary to evaluate product quality, and also to identify new research priorities.

3.0 Global Land Cover Product Summaries Definitions

Three global land cover products were identified as high priority coarse resolution data sets. They are: (1) land cover; (2) forest density; and (3) forest cover change. The following sections present the definitions of each of the three land cover products.

3.1 Land Cover

The global land cover product should have two components: (1) a detailed thematic map of land cover; and (2) forest canopy density. While they are defined separately in this document, they should be viewed as linked products. The density data layer is considered to be a key part of the land cover product and it can provide information that will improve the consistency of the thematic map definitions, and will contribute directly to both scientific and international forestry applications.

The land cover product should be produced every five years, with completion of the product 12-24 months following the end of the baseline period. A separate annual forest cover change product is needed for monitoring global forest change. The highest possible spatial resolution is desirable. While global land cover with 250m to 500m resolution will have the highest applications value, in the near term a 1000m resolution data set is most practical and feasible. However, it is important to recognize the long-term requirement for higher resolution global land cover products.

The global land cover product must cover the entire global land surface and be relevant for carbon studies. The level of thematic detail should be greatest for woody vegetation (i.e., trees, shrubs) and only general land cover types are necessary for the other landscapes. This means that there will be uneven categorical detail, with 40-50 classes representing woody vegetation, and approximately 5-10 additional categories representing all other cover types. A draft land cover legend is presented for discussion in Table 3. However, before a land cover legend is adopted, it will be necessary to conduct a thorough review of user requirements. The following is a set of guiding principles that can be used in the land cover legend development process:

- The classes mapped must be relevant to carbon studies.

- Cover is based on actual rather than potential land cover.

- Compatibility with exiting legends is desirable, especially those used by national and international forestry organizations.

- A hierarchical system is desirable.

- The system must be sufficiently flexible to permit generation of forest cover products based on different canopy closure criteria.

- Mapping units must consider physiognomic characteristics. Floristic elements are less important, and biome types may be used to imply possible community composition.

- Compatibility with definitions used for the GOFC fine resolution products is necessary.

The development, testing, and evaluation of the actual land cover legend is an appropriate pilot project activity. It is necessary to test legends in an applications context in order to ensure that the product has the highest possible utility.

The methods used to develop the product are perhaps less of an issue than is the issue of source remotely sensed data. While several training procedures and classifiers have recently been used to develop global land cover data sets (i.e., Defries, et al., 1995; Loveland, et al., submitted), there is currently no clear evidence to suggest that one approach is superior to another. The selection of a methodology must therefore be based on applications issues, including degree of required flexibility and tailoring of the GOFC global land cover product, frequency of updates, and implementation considerations.

An understanding of the advantages and disadvantages of a centralized versus decentralized global land cover production model is needed before the operational strategy of the GOFC coarse resolution data set generation activity is finalized. The centralized production model, in which one organization developed the product, has advantages for scientific applications, offers greater chances of global consistency, can likely be completed at a lower cost, and may be completed in a shorter period of time. The decentralized approach is more relevant for policy applications in which it is essential that local to regional landscape conditions are most reliably represented. It also may lead to greater local and regional acceptance of GOFC coarse resolution products. However, is could be less efficient. When considering the intended applications of the global land cover product, it may be appropriate to consider implementation based on the decentralized strategy. However, this issue requires debate within a larger GOFC forum.

The decentralized strategy could consist of a series of mapping organizations with responsibility for mapping a particular continent (i.e., Africa, Asia, Australia, Europe, North America, and South America), and a strong central office with coordination, quality control, validation, data management, and other functions. The mapping organizations must be able to provide long-term operational continuity.

Because of the decentralized model, it is necessary to standardize inputs, and definitions of results. Rather than rigidly standardize methods, the group concluded that it was more realistic to establish a set of criteria that any method used in the land cover classification must meet. It will also be necessary to identify validation strategies that deal with the different error structures associated with each regional data set.

The accuracy requirements for the product must be established based on the state-of-the-practice in global land cover mapping. While past global land cover mapping initiatives such as the IGBP DISCover activity (Loveland and Belward, 1997) call for 85% accuracy, this figure is not practical for the GOFC global land cover product. The results of accuracy assessments of global land cover data sets that will be completed later in 1998 should provide an indication of reasonable accuracy targets. Regardless of the target accuracy statements, validation results should include overall and per class statements of accuracy as well as regional area estimates for each category.

3.2 Forest Density

An integral part of the global land cover product is a forest canopy density product that provides estimates of percent tree canopy for each pixel. The density would be described in terms of percent forest cover within the pixel, varying from 0 in locations with no woody cover to 100 for locations with full canopy cover. The resolution of this product should be the same as that used in the global land cover product. This data set can also be produced in a decentralized structure, but the arguments are less compelling. Regardless, this data set must be based on a standardized methodology. This data set should be produced every five years, but will be needed within 3 months following the end of the baseline period so that it can be used in the global land cover classification process.

The land cover classification will provide information about forest type stratified according to threshold values for canopy closure. Additional information on forest density will allow comparison with other classification systems using alternate definitions and thresholds for canopy cover. A forest density layer will also allow the identification of locations undergoing changes in forest density that would not be detectable if only considering the land cover type. This information is required to monitor changes in canopy density and to assess the condition of forests. From the point of view of the scientific user, this information permits the modeling of carbon and other biospheric properties that would not be possible with the land cover layer alone.

Processing of the forest density layer, though requiring alternate algorithms, would be done in parallel to the generation of the land cover map with a 5 year frequency. Processing for the forest density layer would be done for those pixels classified as woody vegetation in the land cover map. We recommend a pilot project to compare methods for generating a forest density layer and to carry out validation of pilot products.

Several algorithms have been developed and applied to generate forest density maps on regional and global scales. These methods generally fall into three categories:

- Endmember linear unmixing. In this approach the proportion of vegetation types are deconvolved based on the assumption that the spectral signature is a linear combination of reflectances from the components within the pixel. Implementation of this method requires knowledge of reflectances of “pure pixels” from spectral libraries, field measurements, or high resolution data. This approach has been applied at regional and global scales (i.e., Adams et al., 1995; Bierwirth, 1990; DeFries et al., submitted; Pech et al., 1986; Quarmby et al., 1992; Settle and Drake, 1993). Recently methods have been applied to incorporate nonlinear mixtures (Foody et al., 1997) and multiple endmembers (Roberts et al., in press).

- Spectral regressions. This approach is based on empirical relationships derived from coregistration between fine resolution (e.g., Landsat TM) and coarse resolution (e.g. AVHRR) data. The empirical relationships are then extrapolated over larger regions to estimate percent forest density (DeFries et al., 1997; Iverson et al., 1989; Iverson et al., 1994; Zhu and Evans, 1992; Zhu and Evans, 1994).

- Calibration of areal estimates from spatial aggregation of classifications derived from coarse resolution data. These methods can be used to derive areal estimates of forest cover based on classification of coarse resolution data. The method adjusts the areal estimates taking into account the spatial arrangement of land covers at fine resolution (Mayaux and Lambin, 1995; Moody, 1998).

These methods have all been successfully applied. A comparison of these methods for selected area needs to be carried out to determine which is the most feasible in an operational context.

The forest density product should be produced in parallel to the land cover map product. Coregistration with the fine resolution product will be needed to assure consistency in results. The post-launch MODIS product generating continuous fields of vegetation characteristics provides an additional link that might useful in the implementation of GOFC.

The forest density product requires validation to provide information on the reliability of the continuum of density values. The validation of the density product may be done using methods similar to those used for the biophysical products. The forest density validation could use high resolution data and ground studies to assure accuracy. This should be carried out for a small number of selected locations.

A pilot project to test existing algorithms for deriving a forest density layer is needed to determine the methodology that provides the most accurate results and is most feasible for operational implementation. This pilot project would select a few globally distributed regions where high resolution data are available for testing.

3.3 Forest Cover Change

The forest cover change product would identify on an annual basis locations where changes in forest condition are occurring. This product would be linked with the fine resolution product so that more in-depth analysis at higher resolution could be carried out for these locations. The forest cover change product would serve as a flag for detecting change in forest cover.

A forest cover change product is needed for monitoring changes in forest extent and condition to support implementation of emission inventories related to climate convention agreements. This information is also critical for NGOs and other institutions assessing biodiversity and identifying “hot spots”. From the science user perspective, the identification of areas undergoing harvesting, deforestation, and burning are critical for assessing the carbon budget. A separate forest cover change product is needed, as opposed to comparison of classification products, because: 1) change detection methods that do not rely on successive comparison of land cover classifications are known to be more accurate; and 2) changes in forest cover need to be detected on a more frequent basis than the five years recommended for the global land cover classification product.

We recommend that the forest cover change product be generated at a spatial resolution of 250m, the resolution necessary to detect clearings and modifications of forests by human activities (Townshend and Justice, 1988). The product would be produced annually and would be compared to a baseline extent of forest cover as well as to the previous 5 years. We propose that a standardized method for deriving this product, including source data and methodology, be established by a coordinating group and that the product be generated on a continental or regional basis by various organizations. Strong oversight is required to assure a consistent product both though time and between regions. The coordinating group would be responsible for disseminating the results.

Many methods have been used for change detection based on satellite data. Analysis of radiometric differences between dates generally provides more accurate results than analysis of difference between classification results because the latter compounds inaccuracies in the classification products. Radiometric analysis includes band differencing, band ratioing, transformed band differencing, principal component analysis, and multispectral or multitemporal change vector analysis (Singh (1989) provides a review of these methods). A key requirement for a methodology to be operational in GOFC is that the process be automated as much as possible with realistic computing resources.

A coordinating group is needed to develop a standardized method for deriving this product. The method would be implemented on a continental or regional basis by various institutions.   In the initial phases of GOFC, we recommend that the change detection product focus on changes in forest extent. In the future, this would be expanded to cover other types of land cover conversion such as agricultural expansion.

The forest cover change product would be strongly linked to the fine resolution products. Identification of areas undergoing change would be flagged for more in-depth analysis with finer resolution data.   It will also require linkages with the land cover map and fire scar product to assure consistency. The MODIS 250m and 1km land cover change products might serve as a useful linkage for GOFC.

A strong verification process will need to be an integral component of the method. This will involve high resolution data and a sampling strategy on the ground.

A pilot project should be carried out to select from existing change detection methods that can be operationally applied in the context of GOFC. Criteria for selecting a method include accuracy, feasibility to automate the process, and feasibility of implementing with a realistic computing resources. The pilot project would be carried out in sample areas where changes are known to occur and where satellite data are available. The pilot project would establish confidence intervals that could be obtained with change detectable algorithms.   During the first year, the focus should be on the selection of the most feasible algorithms. In the second year, this would be applied to sample areas where satellite data are available and changes are known to have occurred.

4.0 Active Fire Products

The recommended GOFC coarse resolution products include the development of a global fire monitoring and fire mapping system. Two capabilities are needed. First, the system would provide the capabilities to automatically detect fires on a daily basis using 1 km (250 m to 1 km in the future) resolution satellite data. Second, 1 km (250m in the future) data would also be used to map large (> 200 ha) fire burn boundaries on a seasonal basis.

Wildfires and biomass burning are significant agents of change in forest ecosystems, can cause major perturbations of atmospheric chemistry, often result in economic upsets, and some even result in the loss of human life. There are three main contributors to global fire:

- Land use change where forests are burned to convert forests to cleared land for agricultural crops or for pasture.

- Shifting agriculture or savanna burning where grasslands are burned to improve the soil for agricultural crops or for animal forage.

- Wildfires in woodlands (e.g., temperate forests, savannas, grasslands and shrub lands, conifer plantations, and eucalypt forests) around the world.

This product should benefit countries that do not have fire detection resources or countries that have fires that occur in remote areas. It will also benefit countries that cannot mount traditional forms of fire detection using aircraft or fire towers. The product will greatly shorten the time required to map large forest fires and it will provide a mechanism for inventorying fires on an international scale.

This type of information is also required by many countries for strategic fire management planning. Fire monitoring and end-of-season fire maps would also support updating of national and regional forest inventories, annual fire statistics reporting, criteria and indicators for monitoring sustainable forest management, and fire and global change research. In addition, the data have scientific value in studies on the interaction of climate change and forest fire trends. Information on fires and related emissions is the key to address this critical issue and will have a significant impact on forest policy.

Several initiatives have demonstrated algorithms to detect active fires and reject false alarms using AVHRR satellite data (1 km resolution) as input. Algorithms have been developed by: 1) NASA/GSFC, by a team of researchers collaborating under the IGBP (Kaufman, et al., 1997), 2) Space Applications Institute of JRC (Pereira, 1998); and 3) Canada Centre for Remote Sensing (Li et al.,1997a, b, and c). With several proven fire detection algorithms that are considered to be robust and that provide similar results when applied to the same satellite data, it is possible to use more than one methodology. However, for purposes of consistency, a single methodology should be used. Rather than suggest a method, selection criteria should be developed. Then the group should consult with members of the IGBP-DIS fire project for assistance in defining this product.

Detailed post-fire burn boundary mapping would also use coarse resolution satellite data but finer resolution data sources could be used as dictated by requirements and budgets. This could be accomplished through close cooperation with the GOFC fine resolution products team.

Global, daily processing of AVHRR data is an enormous task, therefore a decentralized regional model may be appropriate for the development of these products. Considering current capabilities, the on-board recorders of the AVHRR sensor cannot store the data required to obtain global daily coverage at 1 km resolution. In order to acquire global coverage at 1 km resolution, AVHRR data would have to be captured by a network of ground stations. The JRC Fire Web project calls for various regional centers using the same software to extract active fire locations from real-time AVHRR data. In addition, the IGBP-DIS global 1 km AVHRR project currently uses a network of over 30 AVHRR ground stations (Eidenshink and Faundeen, 1994). The IGBP-DIS network, however, does not deliver data in real-time. A co-ordinated global network of real-time receiving stations is required. Each receiving station would have to be able to run the fire detection algorithm on site in order to reduce the amount of data that needs to be transferred to assemble the global fire product.

It is important to recognize that another CEOS initiative, the Disaster Management Support Project, has the primary concern for detection of active forest fires. In addition, there are several other organizations working toward operational fire products, including the IGBP, NASA’s Earth Science

Enterprise, and the European Commission Joint Research Centre's Space Applications Institute. Close collaboration with these organizations is essential. Even with the activities already underway, there are still several important development issues that need to be resolved, including:

- Development of technology needed to produce operational active fire products on a daily basis. For operational fire management programs, satellite data received as late as 3:00 pm must be analyzed to produce active fire hotspots 9:00 a.m. the following day. These data must be available internationally within 2-3 days of the regional analysis.

- Development and testing of automated algorithms for burned area classification must continue.

- Evaluation of fire mapping accuracy using finer satellite data and field observations. During the pilot phase, specific fire management organizations could provide support for verification assessments.

- Refinement of fire detection algorithms based on the results of the evaluation.

- Methods for using the data in key applications, such as producing daily fuel consumption and fire emissions products.

- Development of Internet processes and security procedures to manage and distribute products to test-clients through a world wide web.

The coarse resolution fire product must be closely linked to the land cover and biomass products. Both land cover and biomass mapping must be able to account for losses of forest cover and transitional changes (vegetation recovery) in biomass following disturbance. Although this strategy proposes to deal with fire detection, monitoring and mapping using coarse resolution satellite data, it will not be practical or desirable to completely separate coarse resolution products from fine resolution products.

As stated in the Implementation Strategy, fine resolution products may be required as a means of validating the coarse resolution mapping. Validation of the fire products has an advantage over validating other GOFC products (land cover, biomass, etc.) because most countries that experience wildfires also have agencies that have a clear mandate to manage fire. Validation will require the cooperation of these national and sub-national fire management agencies. Inconsistencies between the data and regional fire management agency statistics will have to be mitigated by a program of random data checks.

Three to four pilot projects should be undertaken. These pilot studies should include areas where there is a keen international interest such as South America and Indonesia. Natural Resources Canada (the Canadian Forest Service with the Canada Centre for Remote Sensing) is about to undertake a pilot project for monitoring and mapping fires in Canada over the next two years. Australia could be a candidate for a pilot project because the fire season there is often associated with large high pressure systems that are associated with clear skies over much of the country. Another candidate for a pilot project is the USA where some effort has already been expended on this problem at home and internationally. The USA has the advantage of mounting considerable resources to address this issue and they possess one of the most advanced telecommunication networks in the world.

5.0 Biophysical Product Summaries

A suite of related biophysical products, namely Leaf Area Index (LAI), Fraction of Photosynthetically Active Radiation (FPAR), Photosynthetically Active Radiation (PAR), and Net Primary Productivity (NPP) are needed to collectively provide estimates of annual forest ecosystem dynamics and productivity. An additional product, biomass, is needed to provide an indication of overall forest carbon stocks and sequestration potential, as well as provide land use implications.

The general strategy for LAI, FPAR, PAR, and NPP is similar, as these products are all related and needed to produce NPP. Because the MODIS product generation plans will become operational during the early years of GOFC, it is logical that they be used. However, it was also recognized that there are a variety of methods being used (e.g., model inversion, look-up tables, vegetation index-based), and other potential data sources (e.g., AVHRR, VEGETATION, GLI, MISR, MERIS, POLDER) so it is practical that other approaches be monitored and investigated.

5.1 Leaf Area Index

LAI is the basic input to process-based models of net primary productivity and carbon budget. Spatially explicit LAI data can also be used to improve other models, which involve land surface processes and parameterizations (Bonan et al., 1993). It is feasible to derive LAI from satellite imagery with a reasonable accuracy (Badhwar et al., 1986; Peterson et al., 1987; Nemani et al., 1994; Spanner et al., 1994; Chen and Cihlar, 1996), and thus this parameter is the critical step toward operational remote sensing applications in areas related to weather, climate and land surface processes, as well as modeling net primary productivity.

We recommend that the functional definition of LAI used to product GOFC coarse resolution products is “one half of the total leaf area per unit flat ground surface area (m^2/m^2)”. The use of one half the total leaf area rather than the projected leaf area can unify the effects of different leaf shapes on optical measurements of LAI. The ground area should be projected to the horizontal surface to consider topographical effects on the detection of LAI it nadir and other angles. The LAI product should have a resolution of 1000m. The products are needed for weekly periods and should be available within a week following the production period.

The state of LAI estimation research suggests that LAI be derived from optical data. Methods used for LAI retrieval from multi-spectral optical imagery include: (1) model inversion; (2) look-up table (LUT); and (3) algorithms based on vegetation indices (VI). Model inversion approaches can be quite accurate if detailed radiative transfer processes are considered. However, the computation demand is much higher than other methods. There is also a tradeoff between model complexity and invertibility that makes operational use of this method difficult. The LUT strategy is regarded as a simplified form of model inversion, and may be most desirable for both efficiency and accuracy of computation. VI-based approaches are empirical but can also be efficient and accurate, provided sufficient data for validation are available. All these methods depend on land cover maps with the same projection and resolution. Thus, the land cover product must include classes needed for LAI estimation.

Ground-based measurements of LAI in various biomes in different locations are needed for validation. There are several techniques of measuring LAI on the ground: destructive sampling, allometry and optical instruments. Destructive sampling is labor intensive and time consuming, and is obviously not suitable for collecting data for a large number of sites. Allometry is often species and location specific (Gower, et al., 1997). It is also difficult to establish a suitable set of allometry of a large range of site conditions. Optical instruments hold the best promise for fast and accurate measurements of LAI and are recommended taking measurements needed for LAI validation.

Pilot projects should be conducted for a least one area in each forest biome. Possible sites include: (1) Smithsonian test sites in South America and Southeast Asia could represent the tropical biome; (2) U.S. Long Term Ecological Research (LTER) sites be considered for the temperate biome; and (3) the LAI/FPAR validation program in Canada led by Canada Centre for Remote Sensing be a candidate for boreal biome validation work. This is the minimum set of validation requirement, and multiple test sites for the same biome would be beneficial.

5.2 Fraction of Photosynthetically Active Radiation

FPAR is defined as the fraction of incident photosynthetic radiation (PAR) absorbed by green leaves in plant canopies. It is non-dimensional, and it excludes the fraction of PAR reflected back to space and the fraction absorbed by the underlying surface and non-green materials in the canopy. There is a difference between instantaneous FPAR and daily FPAR (Goward and Huemmrich, 1992). FPAR times incident PAR gives the absorbed PAR (APAR), and APAR is useful for many semi-empirical models of net primary productivity, although in process-based models, FPAR can be calculated from LAI on a cover type basis (Liu, et al., 1997). We suggest that daily FPAR be produced as standard product for the convenience of obtaining daily total PAR absorbed by plant canopies. FPAR products should correspond to weekly baseline periods and should be available within a week following production. The estimates should be 5-10% of actual PAR.

FPAR can be retrieved from multi-spectral optical imagery using the same methods listed for LAI estimation. The accuracy in retrieving FPAR is potentially higher than that in retrieving LAI because FPAR can be more accurately measured on the ground and has more direct effects on remote sensing signals than LAI. FPAR products therefore have advantages in modeling applications, although many process models prefer LAI over FPAR as input.

Consistent FPAR data sets from different biomes are needed for validation purposes. Field estimates can be obtained for a variety of portable instruments and mobile sensors. Pilot validation projects should be carried out in conjunction with LAI validation projects discussed .

5.3 Photosynthetically Active Radiation

The PAR product is also needed to calculate NPP. It is the total photosynthetic active radiation incident on a horizontal surface on the top of a plant canopy. It is in unit of either micromol/m^2/s or W/m^2. Solar radiation is the main driving force affecting all biological and physical processes in plant canopies. PAR is the main control on photosynthesis of plants. NPP is basically proportional to PAR (Monteith and Unsworth, 1990), although temperature, moisture, nutrients, etc. can considerably modify the proportionality. It is therefore crucial to improve the accuracy of this product. PAR products are to be used with FPAR products to obtain APAR (absorbed PAR), i.e. APAR=FPAR*PAR. For regional and global NPP estimation, daily total PAR is the recommended product. The spatial resolution can be considerably coarser than the associated LAI and NPP products; 0.5-1.0 degree resolution may be adequate. The products should be available within a week following the production period. The estimates should be 2-5% of actual PAR.

Spatial distribution of PAR, either instantaneous or daily total, can be obtained from either satellite measurements or from weather prediction models. Geostationary satellites provide frequent PAR measurements for low and middle latitudes (Gu and Smith 1997), and polar orbiting satellites are useful for high latitudes but need temporal scaling methods to obtain the daily total of PAR (Li et al., 1993). Satellite-based products are generally more accurate than gridded weather forecast or reanalysis data, but programs for operational production of daily PAR at the global or continental scale have not been identified. The short-term solution would be pilot projects to validate gridded weather data using satellite imagery for selected areas and seasons.

Both satellite derived and gridded weather data need validation using ground measurements. Surface measurement data sets have been assembled and analyzed by the International Satellite Cloud Climatology Project, and these could be used by GOFC. Efforts are needed to have operational production of PAR products using satellite measurements so that the current reliance on weather prediction data can be phased out. Pilot projects could be established to achieve this goal.

5.4 Net Primary Production

Net primary productivity (NPP) is defined as the new carbon stored in vegetation (leaves, stems and roots) per unit space and time. It is the difference between gross photosynthesis and autotrophic respiration. Annual total NPP is usually reported in unit of $gC/m^2/yr$ or tC/ha/yr. NPP provides a highly synthesized measure for ecosystem performance. It is useful for both sustainable forest management and biotic carbon budget estimation. NPP is an important component in the global carbon cycle, affecting not only the carbon stored in vegetation but also the heterotrophic respiration since most of the new carbon is turned over to soils in a short time period. To understand the role of vegetation in global carbon budget and the impact of climate changes as well as vegetation feedback to the climate system, NPP is urgently needed at regional and global scales.

Both weekly and annual estimates of NPP are needed, with the products corresponding to weekly baseline periods, available within a week following this period, and having 1000m resolution. Daily calculation steps should be apparent in the products. At this point, both empirical and process-based models should be considered.

Process-based model estimation of NPP is potentially most accurate, provided satellite and ancillary data are available. Satellite imagery provides the critical spatial distributions of land cover and LAI (Running et al., 1994). Ancillary data required are soil texture (for available water holding capacity), meteorological variables (radiation, temperature, precipitation and humidity), and above-ground and below-ground biomass. The preferred data interval is daily for NPP estimation (Hunt and Running, 1992, Liu et al., 1997). Process-models use either LAI or FPAR as input, but corresponding land cover map at the same projection and resolution as the LAI or FPAR is always needed. LAI and FPAR can be converted from each other for the same land cover types. Semi-empirical methods usually relate NPP to absorbed PAR (APAR) in plant canopies, estimated as the product of FPAR and PAR. Other variables are used to modify to relationship between APAR and NPP (Prince and Goward, 1995). Autotrophic respiration in forest stands usually consumes more than 50% of the gross photosynthesis (Ryan, 1991) and is sensitive to both temperature and biomass. Biomass is therefore an important input to NPP models. As accurate biomass maps derived using remote sensing techniques are not yet available for large areas, a short term solution is to estimate biomass from land cover types with density classes.

The ideal strategy for NPP validation is to have coincident NPP measurements with LAI/FPAR measurements. In this way, not only NPP results but also NPP models can be validated. However, NPP data available for validation are sparse, especially for forest ecosystems. Published measurements for various biomes and different time scales are very limited. NPP also vary considerably between years. Global NPP distributions from various models are often very different (Potter et al., 1993; Melillo et al., 1993; Foley, 1994; Woodward et al., 1995). In recent years, efforts have been made to obtain these measurements on small and large scales.

5.5 Biomass

The forest biomass product has a strong research component and should be viewed as evolutionary. Biomass is defined as total amount of organic matters existing in a unit area at one instance, and described by a weight of organic matters in dry condition. The unit of biomass is, therefore, g/m^2, kg/m^2 or ton/ha. Vegetation biomass includes leaf, stem, root, fruit and flower. However, the product would be limited to providing total above-ground biomass.

Biomass is one of the most important biophysical parameters which defines the carbon budget in a terrestrial ecosystem. Basically, biomass is a parameter defined at the ground level, and is measured only at the ground by cutting trees or grasses and by measuring their dry weight. Satellite observation data cannot provide direct measurement of biomass but can provide indirect estimation based on in-situ field data and on models. Biomass estimation by satellite observation is still in the research phase and the biomass product in this project has a strong research component. It is, therefore, strongly recommended that CEOS promotes parallel research initiatives to develop in-situ observation methods and to develop models relating biomass with remotely sensed data. It should be also noted that this product would be linked with high resolution products on land cover classification and vegetation density.

There have been two potential methods to estimate biomass from satellite data:

- Vegetation classification based method: In this approach biomass is estimated based on vegetation type classification and on the unit biomass value predetermined for each vegetation type which is basically obtained from the ground observation. Multiplication between the area extent of each vegetation type and the predetermined unit biomass for each type would give the estimate of total biomass. Information on vegetation age or height and vegetation density would increase estimation accuracy. High resolution SAR data may provide the parameters for each vegetation type.

- Direct observation of leaf and stem density (fresh biomass): Many investigations have indicated that there is a correlation between microwave backscattering coefficients derived from SAR data and biomass (fresh biomass) in leaves and stems of vegetation. However, correlation is usually vegetation types specific, and we need to investigate the relation between them for all of the vegetation types. The spatial scale of this approach is local at the moment and can not cover country or continental spatial scale.

We recommend that the first approach be used initially to produce the coarse resolution biomass product. In this case biomass product generation is reduced to the generation of coarse resolution land cover product. A unit biomass database for vegetation types should be developed based on the ground observation and high spatial observation from satellite. The second approach can be implemented as a tool to determine a unit biomass for each vegetation type in a local scale. Vegetation density and vegetation height or age may be estimated from high spatial resolution data (multi-polarization and multi-frequency SAR), and be used to increase the accuracy of biomass estimates for each vegetation type. We expect accuracy within10-20%.

The spatial resolution of the product would be 250m-1000m, and cycle interval should be 5 years which corresponds to the baseline period for global land cover product.

We recommend that CEOS promote ground observation campaigns to investigate biomass estimation models and to establish a unit biomass database for vegetation types. In this campaign in-situ data relevant to biomass, LAI, APAR and NPP are collected together with the high spatial satellite data and their relations are investigated. Validation and verification processes are essential and should be carried out as a part of the ground observation campaign.

The biomass product would be strongly linked with the land cover and the forest density products at both fine and coarse resolutions. Also the basic part of biomass product generation is common with that of NPP, LAI and other relevant products, therefore, they should be linked together. It also requires the linkage between the current on-going projects such as the MODIS project and the GLI project which are going to produce similar products.

A pilot project, linked with the ground observation campaign, should be carried out at several test sites representing typical vegetation types covering different ages and different vegetation densities. The sites should be selected from the different zones including American continent, Eurasian continent and Europe-African continent. Candidate sites include the BOREAS sites, Smithsonian sites, and LTER sites. The pilot project should be jointly organized with groups on other biophysical products.

A pilot project should be two years in total, and in the first year appropriate sites are selected based on the previous works and available data for the sites are collected. In parallel to it, inventories for biomass are investigated and a biomass database is developed. In the second year biomass estimation models are developed. Also a preliminary biomass map is produced for the selected regions including the test sites.

6.0 Data Format Considerations

Data formats, including metadata, must be both compliant with appropriate national and international standards. Technical elements of data sets, such as projections and datum, must be usable within most commercial image processing and geographic information systems.

With regard to data formats, the coarse resolution design team discussed the issue of map projections for the coarse resolution products. This issue can benefit from the experience of both the Pathfinder products and the plans for MODIS product generation. After considerable discussion, the group determined that projection specialists should be consulted for advice on map projections. While a solution was not reached, several areas of consensus were reached:

- Two or more projections will likely be needed. An archive projection will be needed for product generation and archiving, and “user” projections will be needed for applications.

- The archive projection should have equal-area characteristics with minimal distortions of areas. Ideally, there should be capabilities in commercial-off-the-shelf image processing and geographic information software to reproject from the archive format. The archive projection should also provide for efficient data storage.

- User projections should be conveniently and universally handled by commercial-off-the-shelf image processing and geographic information software.

- There must be some level of compatibility between the fine and coarse resolution product projections.

The MODIS projection and the Pathfinder projections were both recognized as candidates for the archive projection. Data in latitude/longitude grids and the Mercator projection are possible strategies for the user projections. Adequate warning to caution users about the decay in data quality associated with conversions to some projections.

7.0 Other Considerations

In order to successful produce coarse resolution forest products, several critical issues must be addressed. Perhaps the most serious issue affecting the design of the coarse resolution products is the uncertainty of the availability and specifications of monitoring data (i.e., 250-1000m) from earth observations satellites. While there are some excellent candidates for the first 5-10 years, the picture becomes uncertain beyond that time. GOFC should urge CEOS members to work toward a long-term commitment for space-based environmental monitoring data. Because of this, the following recommendations should be posed to CEOS, IGBP, and their supporters:

- Continued collection of daily global AVHRR data and generation of science-quality 1-km composites, for at least two years following the successful launch of MODIS or similar coarse resolution instruments.

- A long-term commitment to 250m and 500m daily global imagery is essential for the operational success of GOFC. There is clearly a need for global data at this resolution. This resolution is especially important when considering the uses of the coarse resolution products for forest management and sustainable forestry applications, but is also central to improving the value of global forest observations for scientific studies.

Finally, to the extent technically possible, both fine and coarse resolution data should be acquired at the same times so that radiometric cross calibration and correction for atmospheric contamination can be done using similar inputs.

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Table 1. Product priorities.

Product	Science	Policy	Forest Manage-ment	Other	Overall Rank
Global Land Cover with Canopy Density	High	High	High	High	High
Forest Cover Change	High	High	High	High	High
Active Fires	High	High	High	High	High
Fire Scars	High	High	Medium	Medium	High
Biomass	High	High	High	Low	High
Leaf Area Index	High	High	Medium	Low	Medium
FPAR	High	High	Medium	Low	Medium
PAR	High	High	Medium	Low	Medium
Net Primary Productivity	High	High	Medium	Low	Medium

Table 2. Summary of Product Characteristics

Product	Information Content	Spatial Resolution	Temporal Cycle	Availability after Cycle
Global Land Cover with Canopy Density	40-60 classes of cover, with 50-60 describing forests; canopy density in percent cover	500 m	5 years	1 year
Forest Cover Change	Change, No-Change	250 m	Annual	1 month
Active Fires	Fire, No-Fire	1000 m	Daily	3 Days
Fire Scars	Burned, Not Burned	500 m	Annual	2 months
Biomass	Tons C/ha, g C/m^2	1000 m	5 years	3 years
Leaf Area Index	m^2/m^2, within 0.2-1 of actual	1000 m	Weekly	7 days
FPAR	Within 5-10% of actual	1000 m	Weekly	7 days
PAR	Within 2-5% of actual	>1000 m	Daily	7 days
Net Primary Productivity	Within 20-30% of actual	1000 m	Weekly, Annual	14 days

Table 3. Optimal classification legend for a global land cover product.

Canopy Longevity	Leaf Type	Canopy Density	Canopy Height
Evergreen	Needleleaf	Closed	Trees
Evergreen	Broadleaf	Closed	Trees
Deciduous	Needleleaf	Closed	Trees
Deciduous	Broadleaf	Closed	Trees
Mixed		Closed	Trees
Evergreen	Needleleaf	Open	Trees
Evergreen	Broadleaf	Open	Trees
Deciduous	Needleleaf	Open	Trees
Deciduous	Broadleaf	Open	Trees
Mixed		Open	Trees
Evergreen	Needleleaf	Woodland	Trees
Evergreen	Broadleaf	Woodland	Trees
Deciduous	Needleleaf	Woodland	Trees
Deciduous	Broadleaf	Woodland	Trees
Mixed		Woodland	Trees
Evergreen	Needleleaf	Closed	Tall Shrubs
Evergreen	Broadleaf	Closed	Tall Shrubs
Deciduous	Broadleaf	Closed	Tall Shrubs
Mixed		Closed	Tall Shrubs
Evergreen	Needleleaf	Open	Tall Shrubs
Evergreen	Broadleaf	Open	Tall Shrubs
Deciduous	Broadleaf	Open	Tall Shrubs
Mixed		Open	Tall Shrubs
Evergreen	Needleleaf	Closed	Low Shrubs
Evergreen	Broadleaf	Closed	Low Shrubs
Deciduous	Broadleaf	Closed	Low Shrubs
Mixed		Closed	Low Shrubs
Evergreen	Needleleaf	Open	Low Shrubs
Evergreen	Broadleaf	Open	Low Shrubs
Deciduous	Broadleaf	Open	Low Shrubs
Mixed		Open	Low Shrubs
Evergreen	Needleleaf	Closed	Dwarf Shrubs
Evergreen	Broadleaf	Closed	Dwarf Shrubs
Deciduous	Broadleaf	Closed	Dwarf Shrubs
Mixed		Closed	Dwarf Shrubs
Evergreen	Needleleaf	Open	Dwarf Shrubs
Evergreen	Broadleaf	Open	Dwarf Shrubs
Deciduous	Broadleaf	Open	Dwarf Shrubs
Mixed		Open	Dwarf Shrubs
Grasslands			
Croplands			
Built-Up			
Barren or Sparsely Vegetated			
Snow and Ice			
Water			

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