GOFC-GOLD GLOBAL OBSERVATION OF FOREST AND LAND COVER DYNAMICS

A Strategy for Global Observation of Forest Cover

Canadian Centre for Remote Sensing

Ottawa, Canada

1999

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GTOS

GOFC-GOLD Report No. 2

Global Observation of Forest and Land Cover Dynamics (GOFC-GOLD) is a coordinated international effort to ensure a continuous program of space-based and in situ forest and other land cover observations to better understand global change, to support international assessments and environmental treaties and to contribute to natural resources management.

GOFC-GOLD encourages countries to increase their ability to measure and track forest and land cover dynamics by promoting and supporting participation on implementation teams and in regional networks. Through these forums, data users and providers share information to improve understanding of user requirements and product quality.

GOFC-GOLD is a Panel of the Global Terrestrial Observing System (GTOS), sponsored by FAO, UNESCO, WMO, ICSU and UNEP. The GOFC-GOLD Secretariat is hosted by Canada and supported by the Canadian Space Agency and Natural Resources Canada. Other contributing agencies include NASA, ESA, START and JRC. Further information can be obtained at http://www.fao.org/gtos/gofc-gold

A Strategy for Global Observation of Forest Cover

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Executive Summary

1.1 GOFC as a CEOS response to global concerns

As the twentieth century draws to a close, there is an emerging global consensus that the cumulative effects of past and present human activities are having a global impact on the Earth's ecosystems, atmosphere, and climate, and that steps must be taken to improve our knowledge and change policies and management practices throughout a broad range of human activities.

The international support for the Kyoto Protocol of the Framework Convention on Climate Change, together with earlier support for the International Convention on Biological Diversity, represent the first steps down a long, difficult path toward a sustainable future on the Earth.

Forests play a central role in the issues of greenhouse gasses, climate change, and biodiversity. In a general sense, the role forests play in the carbon and water cycles, and in providing rich habitat for diverse plants and animals, is well known. However, much additional research is required to understand the detailed role of forests. Scientists working on many aspects in the field of global change require global, regional, and local observations of forests to develop a better understanding of the complex, inter-related processes involved. At the same time, policy makers realize that we cannot afford to wait until all of the scientific questions are solved; global observations of forests are needed to monitor changes in the Earth's forests and provide objective, quantitative information to assess progress toward long-term objectives. As a result of the Kyoto protocol, particular emphasis is placed on reforestation, afforestation, and deforestation,

Earth observation satellites have been providing data for natural resource management since 1972. The data from these satellites has been widely used to map and monitor forest resources. However, these efforts have generally been made as individual projects within individual jurisdictions, such as states, provinces, or forest management units.

More recently, the global change science community, the United Nations Food and Agriculture Organization, and a number of national and regional efforts have worked to use earth observation data to create a consistent regional and global pictures of the earth's forests, and to monitor changes in the forests worldwide. These efforts have shown the difficulties involved and the progress needed in assembling continental and global data sets to address the science and policy questions surrounding forests.

Recognizing the accomplishments to date, but also the shortcomings, the Committee on Earth Observation Satellites has initiated a program of Global Observation of Forest Cover as part of its Integrated Global Observing Strategy. The objectives are to increase international cooperation in the integration and use of data from multiple earth observation satellites, in conjunction with in-situ data, for mapping and monitoring the earth's forests, and to provide feedback to the space agencies to enable them to better coordinate future space missions. GOFC will develop the means to undertake operational inventories of forest cover, fire and forest biophysical characteristics using satellite data.

1.2 What GOFC has accomplished, and what can be expected from GOFC

Since July 1997, teams of scientists, remote sensing specialists, and knowledgeable representatives from user organizations have been meeting and planning a strategy to lead to ongoing global observation of forest cover. In this process, we have endeavored to reach out and obtain input from a broad spectrum of user groups, in addition to drawing heavily from persons with the greatest current experience in assembling and processing large regional and global datasets. We have held six international workshops, first to outline a GOFC concept, and then to produce this detailed strategy document. More than fifty specialists from fifteen countries and seven international organizations have participated in this design process. During this same period, the GOFC project leader held briefing meeting with twenty-six international organizations, scientific bodies, forest management agencies, non-governmental organizations, and earth-observation agencies to inform them about the GOFC concept and obtain their feedback.

As a consequence of these interactions, GOFC has already resulted in increased dialog with international organizations, science bodies, forest management agencies, and non-governmental organizations which require forest information.

This document presents our strategy. The essence of our strategy is to develop and demonstrate operational forest monitoring at regional and global scales by developing prototype projects along three primary themes:

- Forest Cover Characteristics and Changes
- Forest Fire Monitoring and Mapping
- Forest Biophysical Processes

As part of this process, we propose to assemble teams to execute prototype projects, develop consensus algorithms and standard methodologies for product generation and product validation in conjunction with in-situ measurements, and develop and demonstrate procedures for improved data access for the user community.

As a consequence, we will identify gaps and overlaps in earth observation data, ground systems, methods, and scientific knowledge from the experience gained in developing and executing GOFC prototype projects. The ultimate objective is to lead to sustained, on-going operation without the need for major funding by CEOS members. Additionally, GOFC will

- Create and strengthen partnerships between CEOS members and user agencies;
- Identify gaps and overlaps in CEOS member programs and make recommendations how these might be resolved;
- Lead to increased operational use of earth-observation data for policy decision making at national, regional, and global levels;
- Provide validated products which can be used to derive credible information concerning the forest component of the carbon budget for research and policy use;
- Promote common data processing standards and interpretation methods, which are necessary for inter-comparison of regional studies;
- Stimulate advances in the state of the art in the management and dissemination of large volume datasets and information from multiple sensors;
- Use data from multiple sensors, in combination with in-situ data, to produce validated prototype information products which satisfy clearly identified requirements of user agencies;
- Enhance the use of earth-observation information products for forest management and scientific research concerning forest biophysical processes.

1.3 CEOS Support Required

To succeed, GOFC will require support from CEOS as a whole, and from individual CEOS members who choose to become involved in GOFC projects. The IGOS partnership mechanism must help form meaningful partnerships with forest management, policy and science communities, and funding agencies. CEOS agencies will be requested to provide essential data for the pilot projects. This requirement will extend beyond the production of primary data products to the provision of support for the production of derived products. Just as important, it will be necessary for many organizations which produce earth observation data products from raw data to update their production systems to provide for increased automation and large volume processing, in order to reduce the costs of earth observation data so that global observation of forest cover becomes economically feasible. CEOS member agencies will also be asked to conduct and promote targeted R&D on science and technical issues identified by GOFC and its partners.

WGISS and WGCV have already played an important role in the development of GOFC. The support of individual WGISS and WGCV working groups will be essential for addressing and resolving further technical issues which arise in the development and execution of GOFC pilot projects.

1.4 Primary Themes

We believe that the best way to make demonstrable progress toward widespread operational use of earth observation technology to address forest issues is through a suite of well-considered pilot projects. Each must provide information of value to user communities with clearly stated requirements. Each must be achievable using proven technology, although an integrated system may not yet exist. Through the course of execution of the pilot projects, CEOS member agencies and participants will benefit from increased communication, and technological capabilities will be expanded. Strategies will be developed and funding sources will be identified to make the transition to on-going routine operation. GOFC has adopted the approach of involving the operational users in the design of these pilot activities so as to ensure adoption by the operational agencies at the completion of the pilot phase.

We identify three primary themes:

- Forest Cover Characteristics and Changes
- Forest Fire Monitoring and Mapping
- Forest Biophysical Processes

GOFC can make a key contribution to all of these by providing integrated datasets from multiple sensors.

Forest cover characteristics and changes: This is the most important but the most challenging of the proposed themes. The products have the greatest appeal to the widest spectrum of users including forest resource managers, policy makers, and scientists studying the global carbon cycle and biodiversity loss. We propose a systematic program for periodic mapping of land cover at coarse resolution (250 – 1000 m) on a five year cycle, combined with periodic mapping and monitoring of forested areas at fine (~25 m) resolution. Very large datasets must be acquired, assembled, processed, and analyzed from coarse resolution optical sensors, fixed and pointable fine resolution optical sensors, and SAR sensors. Most of the needed technology has been demonstrated, but assembling coordinated systems to generate the required products will be very challenging. The proposed approach is shown schematically in Figures 1 and 2.

Forest Fire Monitoring and Mapping: The global increase in wildfire following the 1997-98 el Niño event has served to emphasize the urgent need for improved information from CEOS members' space systems. Data from existing and near-term coarse resolution sensors can satisfy most of the information requirements, and automated algorithms for much of the information extraction have been demonstrated. A distributed network of low cost receiving and processing facilities could satisfy many of the requirements for operational fire monitoring and mapping. The proposed approach is shown schematically in Figure 3. At the same time there are clearly defined areas where additional research can improve and validate information extraction. Cross-linkages with the forest cover characteristics and changes theme and the forest biophysical processes theme will provide additional information on fuel consumption and gas and aerosol emission. At the same time, information from this theme will be a valuable input into the other two themes as an indicator of forest disturbance and gas and aerosol emissions. We continue to collaborate with the with the IGOS Disaster Management Support Project to harmonize our efforts.

Forest biophysical processes: This theme reflects a key component of the sizeable effort to use earth observation data to understand, and eventually balance, the earth's carbon budget. With the signing of the Kyoto protocol in 1997, information on the carbon cycle now has policy as well as scientific implications. The major goal for this objective is to quantify net primary productivity of forests, combining satellite data with ecosystem process models. The approach is shown schematically in Figure 4.

Figure 1: Forest Cover Characteristics
(Centrally coordinated/regionally executed)

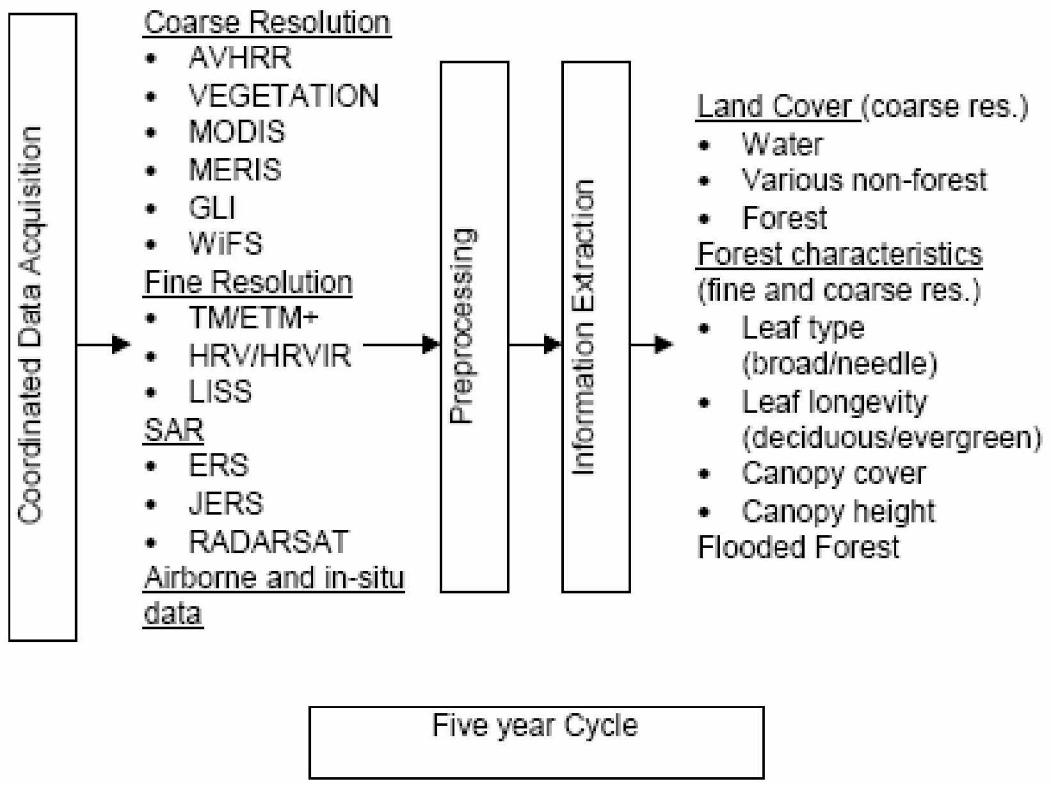


Figure 2: Forest Cover Changes
(Centrally coordinated/regionally executed)

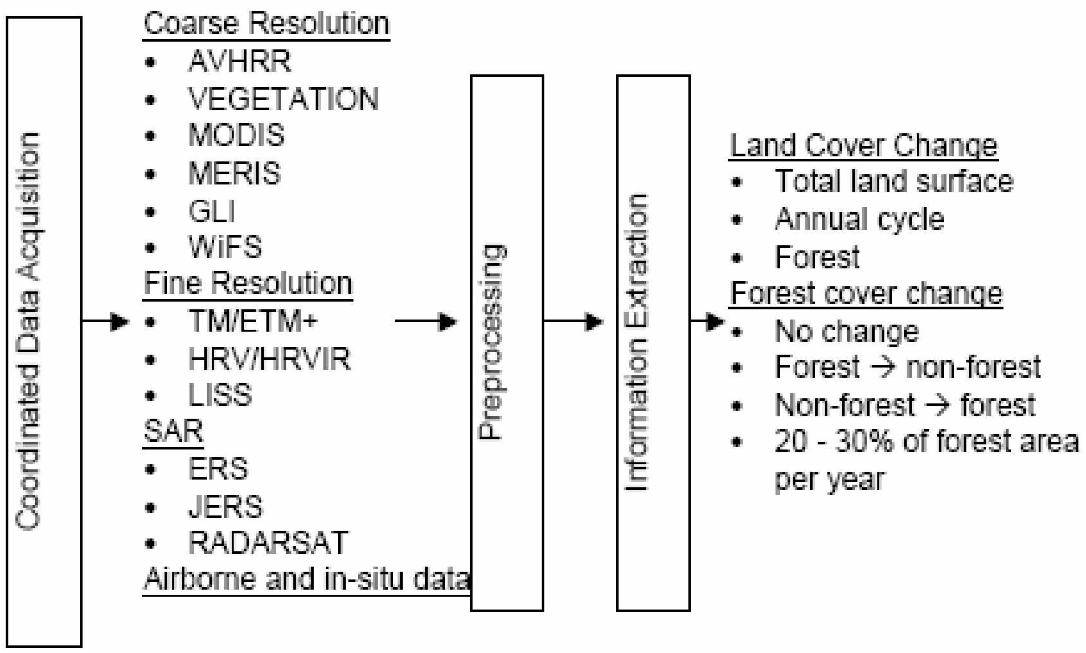


Figure 3:Forest Fire Monitoring and Mapping
(Centrally coordinated/regionally or nationally executed)

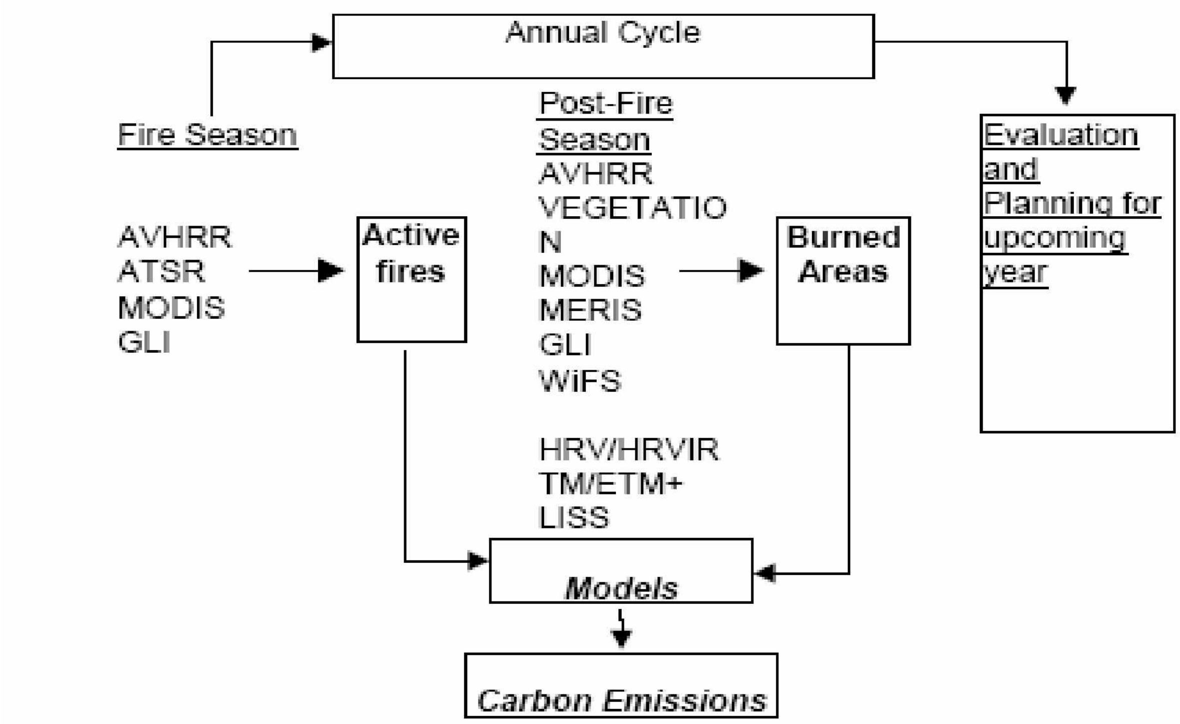
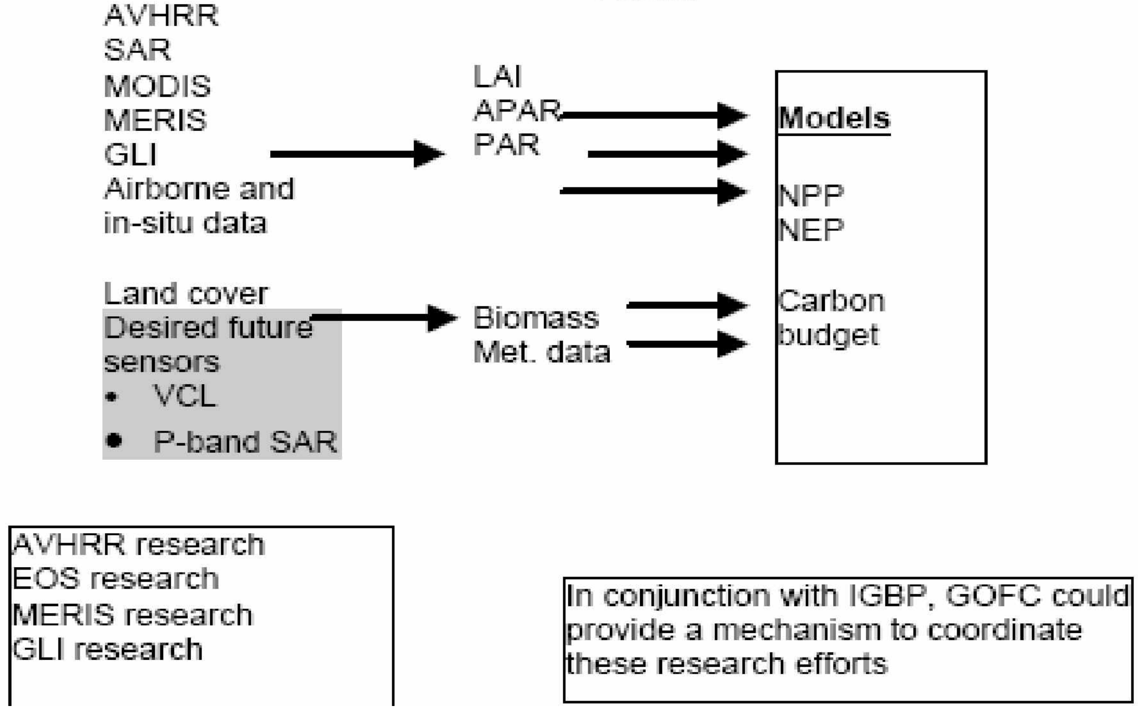


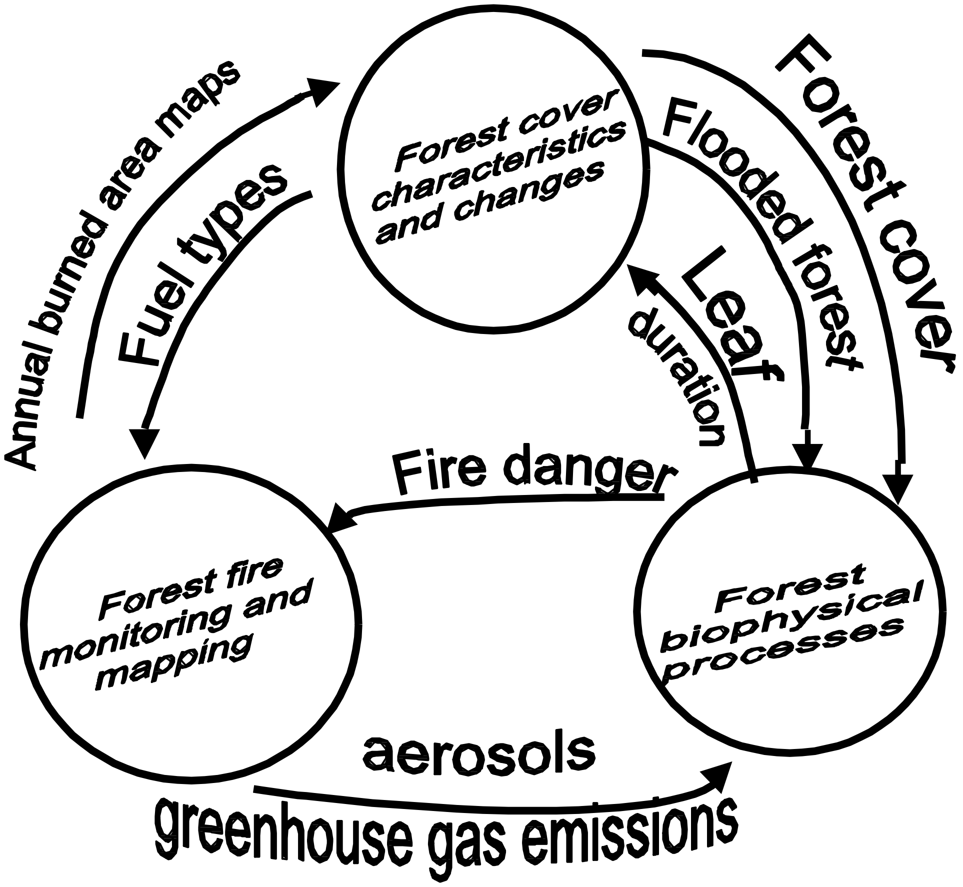
Figure 4: Forest Biophysical Processes
Confederation of Investigation Teams

- National/regional
- Global



Each of these themes of GOFC could be implemented as called for in this document and result in significant progress. But the natural interconnections (shown in Figure 5) make an implementation of all three components significantly stronger than simply the sum of the three parts.

Figure 5: Linkages between GOFC themes



While much progress in this area will take place independently of GOFC, GOFC can contribute to a more integrated global approach by:

- Providing opportunities to inter-compare results from different sensors and different algorithms;
- Providing linkages to organizations such as GTOS which can facilitate the sharing of in-situ observations.
- Promote ground observation networks and campaigns to validate forest biophysical process products.

1.5 Expanding the circle of consultation

This document provides a strategy, not a blueprint, to attain CEOS goals as defined by IGOS. A large number of representatives of producer and user agencies has participated in the development of this strategy, and many more have been consulted by the members of the GOFC design teams. Nonetheless, to achieve a broad consensus, wider consultation is needed. All organizations which have participated in the development of GOFC to date will be given an opportunity to comment. Subsequently, a revised draft will be circulated to organizations which may have an interest but which have not participated in this development. It will be particularly important to obtain feedback from foresters, forest managers, and forest policy makers from countries which have large areas of forests. We propose to hold one or more workshops in the first half of 1999 for this purpose.

Because of the comprehensive view we are taking of both earth observation technology and user requirements, the final document will serve as a reliable pointer to the way ahead. This strategy document will provide a basis for the CEOS agencies and partners to support and develop projects to meet the GOFC objectives. After the first year the complement of GOFC projects will be listed and evaluated to determine critical gaps in the strategy.

1.6 Initiating action

Even though this Strategy may be modified somewhat through wider circulation and comment, we are confident that the collective experience of the design team members, coupled with the additional consultations they have made during the course of the GOFC design phase, have produced a basis to initiate action. We propose to approach CEOS member agencies and user organizations to assemble teams of lead and participating agencies for each of the three primary themes, recognizing that the magnitude of the Forest Cover Characteristics and Changes theme may necessitate further discussion before initiating action in that particular area. The GOFC Executive must be formed, including representation from the lead agencies and participating users. The best way to move ahead is to begin working on specific pilot projects.

1.7 Schedule

Since GOFC is not a funded R&D effort but rather a partnership of voluntary participants, it is not possible to define a firm schedule as one might for an engineering project. Nevertheless, it is helpful to propose a possible schedule to examine how much progress could be made in the remaining four years of GOFC with rapid, enthusiastic participation. A schedule to achieve IGOS and GOFC objectives is proposed here to provide a starting point for further development.

Forest Cover Characteristics and Changes: We propose a two-phase approach. Each phase would be an end-to-end exercise of data acquisition, data analysis, and evaluation/validation of the resulting products. It is important to carry out an end-to-end exercise to ensure all the necessary components function properly, and to identify weak areas where remedial work is necessary. The first phase could be accomplished in as little as two years (1999-2000), although that is a very ambitious schedule. The first phase should cover one or two regions. The second phase (2001-2002) could cover several regions, expanding to all of the forested regions of the Earth if sufficient resources are available.

Forest Fire Monitoring and Mapping: There is a natural cycle time for this project: the annual seasonal cycle which normally includes one “fire season” in each region. The proposed GOFC initiative would also follow an annual cycle, with near-real-time fire monitoring during the fire season, followed by post-season fire mapping. The first two years (1999-2000) are proposed to be a testing phase, first for several countries, and then for many countries. By the third year (2001) the system could be in full operation for most countries. This would be a distributed effort, with an annual meeting at the end of each year to discuss accomplishments and difficulties, and to make plans for the following year.

Forest Biophysical Processes: The EOS-AM1 mission is expected to be launched in mid-1999, with validation campaigns taking place during the next few years. Research teams for the ADEOS-2 and ENVISAT missions are being selected. GOFC should facilitate communication and coordination among these groups, and should strive to promote regional and global pilot projects incorporating multiple teams and approaches working toward community consensus algorithms.

2 Introduction

Sustainable development of forests has emerged as one of the most difficult, serious, and pressing environmental issues of our time. Human-induced (direct and indirect) changes in Earth's forests have an impact on natural resource availability, biodiversity, atmospheric composition, and climate. Through feedback processes, it is likely that climate change will have adverse effects on forests, which may induce further climate change. Observation of forests by satellites provides the best hope of monitoring changes over extensive areas and understanding the complex processes involved. Observations from space can help policy makers document the current situation and judge long-term trends. Observations from space also provide forest managers with the information they need to assess the current state of the forests, weigh the requirements of multiple uses by multiple stakeholders, and manage forestland resources sustainably.

2.1 Setting:

2.1.1 Global Forest Issues

The management of the forests of the Earth has become an issue of global concern. In addition to traditional anxiety over adequate supplies of wood for fuel, construction, and papermaking, more recent indirect but related concerns center on issues of soil erosion, watershed protection, biodiversity, recreation and tourism, equitable treatment of indigenous populations, and the buildup of greenhouse gases in the Earth's atmosphere. Stimulated especially by the Rio Earth Summit in 1992, the nations of the earth, through the United Nations and other bodies, are laying the groundwork to deal with these problems.

Several Agenda 21 initiatives, including the Convention on Biological Diversity, the Kyoto Protocol to the United Nations Framework Convention on Climate Change, the Montreal, Helsinki, and Tarapoto Processes leading to Criteria and Indicators of Sustainable Forest Management, and the Intergovernmental Panel of Forests all represent concrete steps forward by sovereign nations dealing with global problems. All of these initiatives require information about forests to assess progress, although some have progressed further in identifying specific information requirements.

Since 1972, the Earth has been under observation from space with satellites designed to provide information about earth resources, including forests. The data from these satellites has been widely used to map and monitor forest resources. However, these mapping and monitoring projects have generally been made within individual jurisdictions, such as states, provinces, or forest management units. Until recently, there has been little effort to use earth observation data, particularly data from the higher resolution natural resource satellites, to create a consistent global picture of the earth's forests, or to monitor changes in the forests worldwide.

2.1.2 GOFC Heritage

In response to concerns about the global impact of human activities on the earth's forests, researchers have begun to assemble national, continental, and global data sets from earth-observation satellites in an attempt to provide badly-needed information about the state of the earth's forests, and how they are changing. Examples of programs which have provided essential experience and positive results include the World Forest Watch (INPE, Brazil), Landsat Pathfinder (NASA, U.S.), TREES (Joint Research Centre, Europe), IGBP 1 km Land cover (NASA, NOAA, JRC, USGS/EDC), Forest Resource Assessment (FAO, UN), North American Landscape Characterization (U.S. Environmental Protection Agency), and Global Rainforest Mapping (NASDA, Japan, and JPL, U.S.).

(1) World Forest Watch. The World Forest Watch Program undertaken as part of the International Space Year in 1992 provided an international forum for developing satellite based forest monitoring. The summary meeting held in São José dos Campos, Brazil (June 1992) provided an initial high-level international forum for the assessment of current approaches to satellite-based monitoring. This meeting also served as a basis for forwarding recommendations from the technical and scientific communities to the policy makers and government leaders at UNCED. One important outcome was the PanAmazonia Project, in which Brazil shared its proven technology for mapping deforestation in the Amazon region with its neighbors who share the Amazon Basin. These countries were subsequently able to produce deforestation estimates. The PRODES project of INPE (Brazil) continues to be the largest systematic application of high resolution satellite data to monitor changes in forests.

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

This project has succeeded in demonstrating how to develop wall-to-wall maps of forest conversion area and re-growth. The project is now in the process of extending its initial proof-of-concept to a large-area experiment across Central Africa, Southeast Asia and the entire Amazon Basin. The project has acquired and processed several thousand Landsat scenes at three points in time -- mid 1970s, mid 1980s, and mid 1990s -- to compile an inventory of deforestation and secondary growth to support global carbon cycle models. Methodology and procedures have been identified. In principle, it provides an initial large-scale prototype of an operation program.

(3) TREES. The TRopical Ecosystem Environment Observations by Satellites (TREES) project is currently being implemented as a demonstration of the feasibility of applying space observation

techniques to monitoring of land cover and biomass burning (Malingreau *et al.*, 1993). This project, being sponsored by the European Commission and executed by the Space Applications Institute of the Joint Research Centre (Ispra, Italy), utilizes global coverage with a wide range of sensors including AVHRR, ERS-SAR, JERS-1 SAR, ATSR, Resurs, Landsat, and SPOT. It also focuses on the use of thermal sensors for the detection of fires, and incorporates other indicators of deforestation. The project has developed methods of data assimilation leading to an optimization of the multiple data sources. It has also developed a central repository for data on tropical forests called the Tropical Forest Information System (TFIS) which can serve as a model of a decision support system providing information derived from a variety of sources, only a few of which may be earth satellites.

(4) IGBP-DIS 1 km Land Cover Mapping Project. In conjunction with NOAA and the USGS, NASA has been supporting an IGBP project to acquire global, daily coverage with the AVHRR sensor at 1 km resolution (Belward, 1996). This project is the first of its kind to acquire and process global, daily coverage. Several complementary global land cover classifications have been produced and are now in the process of validation.

(5) IGBP-DIS High Resolution Data Set. The IGBP has also initiated a project to make high resolution data available to the global change research community through co-operation with CEOS. This project is being initiated as a pilot study to make available each year several hundred individual scenes from SPOT, Landsat , ERS-1, MOS-1, JERS-OPS, and IRS. The project is also preparing a centralized archive system in which users can mount an inquiry for data from all of the aforementioned platforms from one point.

(6) FAO Forest Resource Assessment. The FAO Forest Resource Assessment for the 1990 period (FRA-90) used a combination of earth observation data and national statistics to derive statistics about forest cover for the 1990 datum, and forest cover change for the period 1980 to 1990 (FAO, 1995). For tropical forests, FAO developed a technique called the Interdependent Interpretation Procedure, which relied primarily on a two-date interpretation of large-scale photographic prints of full Landsat scenes. The resulting change classes also allowed FAO to estimate transitions between several woody biomass categories for Africa, Latin America, and Asia (FAO, 1996). The year 2000 Forest Resource Assessment has been extended to include all forests. The FAO Forest Resource Assessment Project provides an important interface to the national forest monitoring communities.

(8) Multi-resolution Land Characterization. An Interagency Multi-Resolution Land Characterization (MRLC) project, implemented by the USGS on behalf of a number of federal agencies, is generating land cover data sets for the conterminous US. This data set includes products from coarse and high spatial resolution satellite sensors. This project also provides complete coverage of the United States with TM data.

(10) The Global Rainforest Mapping Project/Global Boreal Forest Mapping Project. Within the framework of NASDA's Global Forest Mapping Program, the GRFM/GBFM project is a collaboration between NASDA, ASA/JPL/ASF and the Joint Research Centre (SAI/MTV), with the aim of generating JERS-1 L-band SAR data sets of the global tropical and boreal forests. A complete SAR coverage over the tropical belt - in total some 13,000 scenes - was acquired in 1995-96, including multi-temporal coverages over the Amazon and Congo river basins to capture season effects and to map inundation in flooded forests. SAR mosaics at 100 m resolution have been generated to cover the tropical region in all

three continents. Data acquisition has been completed for the boreal forests and the production of mosaic products is underway.

11) IGBP-DIS Global Fire Working Group. The global fire working group has provided a forum for the discussion of existing satellite capabilities for fire monitoring. Global and regional fire data sets have been developed and distributed on CD, providing new data sets on fire distribution, timing and extent.

This base of experience and technological development provides a basis to move to a higher level of integration of data from multiple earth-observation sensors with in-situ observations, to satisfy the information requirements of a wide spectrum of user groups.

2.2 CEOS Response: IGOS, SIT, and AG

The Committee on Earth Observation Satellites (CEOS) is an organization composed of space agencies, affiliates, and observers linked by a common interest in the provision and use of earth observation data from space. Recognizing the accomplishments to date, but also the shortcomings, CEOS members have developed an Integrated Global Observing Strategy (IGOS) to coordinate earth observation programs in six critical areas, including Global Observations of Forest Cover (Shaffer, 1996 and 1997, Ahern *et al.*, 1998). The objectives are to increase international co-operation in the integration and use of data from several earth observation satellites for mapping and monitoring the earth's forests, to identify technical and non-technical barriers, to improve the integration of earth-observation and *in-situ* data, and to provide feedback to the space agencies to enable them to better coordinate future space missions.

Rather than creating a new institution, GOFC seeks to produce a networked international consortium of existing programs.

2.3 GOFC Origins and History

GOFC traces its origins to the first IGOS Strategic Implementation Team (SIT) meeting, which took place in February 1997 in Irvine, California. It was one of six pilot projects chosen to illustrate and develop the IGOS concept. Canada was chosen to take the lead in developing GOFC, through the Canada Centre for Remote Sensing and the Canadian Space Agency, with NASA agreeing to play a strong supporting role.

A workshop was convened in Ottawa, Canada, in July, 1997 to review user requirements and current capabilities, and create a draft plan to proceed (Janetos and Ahern, 1997).

In parallel, CEOS created an Analysis Group to review the joint requirements of the six pilot projects. This group met three times in 1997, and a GOFC representative participated in all three meetings. The GOFC concept was further developed through the participation in those meetings.

The GOFC concept was strongly endorsed by most of the space agency member of CEOS at a Strategic Implementation Team meeting in Oxford, UK, and GOFC was given a green light to proceed into its design phase at the CEOS plenary in Toulouse in November, 1997.

The design phase began with a meeting in Washington, D.C. in January, 1998. At that meeting five design teams were created, each with specific tasks to accomplish. Each design team was co-chaired by two or more persons who have been very active in continental to global scale projects dealing with forests. The design teams, their co-chairs, and tasks are shown in Table 2.3.1, while a complete list of GOFC participants is provided in Appendix 1. Table 2.3.2. documents the seven GOFC and related workshops which have led to this draft strategy. Table 2.3.2 and Appendix 1 show that the number of nations and international organizations has broadened significantly since the original GOFC planning meeting in Ottawa.

Table 2.3.1: GOFC Design Teams and their Tasks

Name	Task	Co-chairs
Data Acquisition, Preprocessing, and Access (DAPA)	confirm user requirements, design data acquisition strategy; detailed level 1 product definition; strategy to produce products and metadata; define system to catalog, store, and distribute all products	J. P. Malingreau (EC), Chris Justice (UVa), Martha Maiden(NASA), Peter Churchill(JRC)
Fine resolution products	confirm user requirements, detailed design of all fine resolution products; strategy to produce products and metadata	David Skole (MSU),Victor Taylor(NASDA/JPL)
Coarse resolution products	confirm user requirements, detailed design of all coarse resolution products; strategy to produce products and metadata.	Tom Loveland(EDC), Yoshifumi Yasuoka (National Institute for Environmental Studies of Japan)
Product validation	develop validation strategy for all products	Alan Belward(JRC), Zhiliang Zhu (EDC)
Communication and Coordination	Collect and document user requirements; define approaches to project communication; define organizational structure; strategy for ongoing operational production	Frank Ahern (CCRS) Robert Davis(FAO)

Table 2.3.2: GOFC and related workshops

Dates	Location	Host	Topic	No. of members*	No. of nations and int'l orgs.
1997					
July 7-10	Ottawa	CCRS	Develop GOFC concept	35	8
1998					
Jan. 29-30	Washington	NASA	Establish design teams and their tasks	17/1	7
Mar. 23-24	Ispra	JRC	IGOS pilot project requirements from WGISS and WGCV	N/A	N/A
June 23-24	Frascati	ESA/ESRIN	Communication and coordination	11/6	11

			Design Team		
June 23-24	Sioux Falls	USGS/EDC	Coarse Resolution Design Team	7/2	5
Sept. 23-25	Paris	CNES	Fine Resolution Design Team	24/7	14
Sept. 29 – Oct 1	Paris	ESA/HQ	End-to-End Design Review		

* First number indicates members present/second indicates members absent, most of whom provided input before or after the meeting.

In parallel to these development efforts, the GOFC project leader presented briefings to numerous potential user agencies and cooperating organizations to inform them of GOFC and obtain their feedback regarding interest, information requirements, and potential future co-operation. These meetings are summarized in Table 2.3.3.

Table 2.3.3. GOFC Briefing Meetings

International Organizations	Scientific Organizations	Forest management agencies	Non-governmental organizations	Earth observation organizations	Other
FAO September 97 and Mar. 98	GTOS September 97 and Mar. 98	Canadian Forest Service July 97, Nov. 97, Feb. 98	IISD July 98	NASDA, July 97	CIDA Dec. 97 and Feb. 98.
ESCAP Nov. 97	IGBP-DIS November 97	NAFC July 98	WCFSD July 98	CSA Sept. 97 and Mar 98.	Radarsat International Feb. 98
UNEP-Sioux Falls Feb. 98	Symposium on Agriculture and Forestry June 98.	Manitoba Department of Natural Resources July 98	WRI Aug. 98	JRC September 97, June 98	Biological Diversity Convention Secretariat, Mar. 98
	International Symposium on Remote Sensing of Environment June 98			CNES Nov. 97, Oct. 98	IIASA Mar. 98
				EDC, Feb. 98	
				WGISS/WGCV Mar. 98	
				Swedish Space Corp. June 98.	
				ESA/ESRIN June 98.	
				NASA Aug. 98	
				ESA Oct. 98	

2.4 Overarching Design Statement for the GOFC Strategy

In its five-year pilot phase, GOFC will work toward defining, developing implementing, and refining an ‘operational’ pilot, and will seek multiple research and development prototypes for methods and techniques to incorporate as they mature and will implement operational demonstrations with operational users. GOFC ‘operational pilots’ are viewed as projects developed with the view of ongoing operational implementation after four or five years, with a longer view towards serving a long term agenda e.g. FCCC (2008), FRA 2010

Previous “lessons learned” indicate that the pilot phase should engage the operational community from the beginning, to articulate the operational requirements, assist in the design and testing of methods and techniques, prototyping operational application. The process and pathways for transition from an operational pilot to a fully operational system should be built in to the project design.

As an international project, GOFC will be federated, relying on multi-source data acquisition, distributed data processing, and distributed data access and archive.

GOFC will need to develop partnerships with the international ground stations and data providers to acquire the data needed for GOFC projects.

3 Requirements

3.1 Global Change Research

There are three pathways of relevance for global change and forest lands with implications for GOFC (Turner *et al*., 1995). The first is the interaction of forests and the atmosphere: regulation of the hydrologic cycle and energy budget, with implications for weather and climate prediction. Understanding these interactions is a crucial part of the global change science agenda. The second is both a scientific and policy issue: the implications of changes in forest land for the atmospheric carbon dioxide budget. Are forested lands net sources of carbon or net sinks of carbon? What are the rates of deforestation and reforestation? What are the implications of changes in fire frequency? The third pathway is the potential impacts of climate change: what effect will changes in temperature, precipitation, and concentrations of carbon dioxide and other radiatively active gases have on forest composition, productivity, health, and distribution, and therefore on the economic activities that are generated by forested lands? What feedbacks might these changes have to the climate system itself?

The International Geosphere-Biosphere Programme (IGBP) and World Climate Research Programme (WCRP) have each articulated clearly the urgent need for comprehensive, spatially explicit, global data sets on forest cover and attributes. Several projects in the International Geosphere-Biosphere Program (IGBP) and the World Climate Research Program (WCRP) require information on global forests. The IGBP Land Use and Cover Change (LUCC) project has critical needs for high-resolution information on land cover and change (Turner *et al.*, 1995). Information on biomass, fires, net primary productivity and land cover change is essential for the IGBP International Global Atmospheric Chemistry (IGAC) project (IGBP, 1994). The IGBP project on Global Change and Terrestrial Ecosystems has strong requirements for land cover, land cover change, leaf area index (LAI), and net primary productivity (NPP) data sets. The Biospheric Aspects of the Hydrological Cycle (BAHC) project has essential needs for land cover, biomass, LAI and NPP data sets (IGBP, 1993). The Global Energy and Water Cycle Experiment (GEWEX) has essential requirements for several forest data sets including land cover and cover change, LAI, biomass, and fires. Several Framework Activities (IGBP Global Analysis and Integrative Modeling, IGBP-Data and Information System, ISLSCP Initiative II) have especially strong scientific requirements for such forestry data. Furthermore, numerous regional programs such as the Amazon LBA, the European FIRS, and others have essential requirements for most of the above mentioned data sets.

3.2 United Nations

Member countries of the Food and Agriculture Organization of the United Nations (UN/FAO) have recognized FAO as the lead agency for conducting periodic global assessments of forest cover and have formally endorsed the Global Forest Resources Assessment 2000 (FRA 2000) agenda in the Committee on Forestry Meeting 1997 and in the United Nations Intergovernmental Panel on Forests (IPF) (1997).

Remote sensing observations were used for the tropical regions in 1990 and will be expanded to temperate and boreal forests in 2000. There is an obvious commonality of interest in access to data and land cover classifications between FAO and GOFC. Several meetings have been held to discuss information requirements and discuss co-operation between GOFC and UN/FAO. The most recent of was hosted by the North American Forest Commission and included representation from the forest services of Canada, the United States, and Mexico. The FAO information requirements and methodology are, by necessity, already prescribed and not satisfied by the classification scheme identified in Sections 4.1 and 4.2. Nonetheless, both organizations appreciate the benefits of co- operation: GOFC will facilitate the acquisition of data for the FAO FRA2000 exercise, and continuing involvement in the FRA2000 exercise may provide GOFC participants with greater insight into problems associated with the extraction of land cover and land cover change information at global scales. Both organizations benefit from increased dialog on sampling designs and densities needed to achieve reliable global and regional statistics on forest cover change. Continuing dialog and interaction will, ideally, lead to convergence on data and methods in time for the FRA2010 exercise.

FAO also carries out projects of capacity building for forest assessment at the national level in developing countries. Cooperation between FAO and GOFC will facilitate this process, and also provide increased dialog between GOFC participants and developing country foresters.

The United Nations Environment Programme (UNEP) provides access to datasets and carries out projects in key areas of environmental concern. UNEP’s Global Resource Information Database (GRID) has a mandate to keep the state of the world’s environment under review, provide early warning of environmental threats, and improve access to information. Particular emphasis has recently been placed on forest fires, as a result of the severe fire season in 1997-98. Many of the derived products proposed by GOFC, particularly those related to wildfires, will be be of interest to UNEP and GRID.

3.3 Global Observing Systems

The Global Observing Systems incorporate scientific, operational, and policy-level concerns at both international and national levels. They have already indicated their strong need for global forest cover information and information on forest attributes, primarily through the report of the Terrestrial Observations Panel for Climate (TOPC), a joint GCOS-GTOS activity (Terrestrial Observation Panel for Climate, 1997). The Global Terrestrial Observing System (GTOS) and the Global Climate Observing System (GCOS) are the major clients in this area. GTOS is an international organization co-sponsored by UNEP, UNESCO, FAO, ICSU, and WMO. GTOS promotes improved collection of and access to bio-physical and socio-economic georeferenced data, with an initial emphasis on existing research centers (Global Terrestrial Observing System, 1997). GTOS requires detailed land cover and land cover change information for many purposes, including the assessment of land use and its impact on the natural ecosystems. GTOS has recently given priority to the collection of global data on Net Primary Productivity (NPP). A strong interaction between GTOS and GOFC will benefit both organizations, since GTOS has many linkages to organizations with in-situ data, while GOFC facilitates access to earth-observation data.

GCOS is a partnership of WMO, IOC of UNESCO, UNEP and ICSU. The objectives of the Global Climate Observing System, GCOS, are to insure the acquisition of data for climate system monitoring, climate change detection and response monitoring, application of climate information to national economic development, and research. (Global Climate Observing System Internet Website, 1997). GCOS requires information on land cover (coarse resolution) for global circulation modeling and model validation; for carbon, water, and energy modeling; and for the assessment of climate impact. Both GCOS and GTOS require information on net primary productivity as a fundamental parameter linking the terrestrial and the atmospheric systems on the one hand, and the natural and economic systems on the other. Both also require knowledge of forest biomass and fires as major parameters that quantify the distribution of the carbon stocks and the effect of major disturbance agents.

3.4 International Conventions and Agreements

The major conventions and agreements concerned with global forests are the Framework Convention on Climate Change, the Convention on Biological Diversity, and the Montreal, Helsinki, and Tarapoto processes leading to Criteria and Indicators of Sustainable Forest (World Forestry Congress, 1997).

The Kyoto Protocol of the Framework Convention for Climate Change has established reporting requirements on reforestation, afforestation, and deforestation which must be met at the national level by signatories. The carbon trading and clean development mechanisms will need reporting on reforestation, afforestation, and deforestation by participating nations. The forest cover change information to result from the Forest Cover Characteristics and Changes theme is intended to be suitable for the RAD reporting requirements.

The IGBP Terrestrial Carbon Working Group (1998) has emphasized the shortcomings of carbon trading based on partial carbon budgets and recommends moving to a full carbon budget accounting system as quickly as possible. The forest biophysical processes theme identified in section 6 is an important step CEOS members and their partners can take toward a full carbon budget accounting system.

Canadian Forest Service researchers have indicated that many of the indicators of sustainable forest development resulting from the Montreal Process can be obtained in whole or in part using earth observation data, particularly the derived products proposed as part of the Forest Cover Characteristics and Changes theme. It is likely that the other Criteria and Indicators initiatives will be equally well served by these products.

The Convention on Biological Diversity will require accurate information on forest cover, fragmentation, and change. However, the discussions leading to the definition of reporting requirements and methods to satisfy these are moving slowly, and no binding requirements are yet in place.

It is important to distinguish between the science requirements and the reporting requirements with respect to international conventions and agreements. Whereas the science requirements will be satisfied by teams of scientists collaborating internationally, the reporting requirements are ultimately a national responsibility and must be satisfied by national forest ministries and other national agencies.

3.5 Non-Governmental Organizations

Many NGOs have interests in forests at local and regional levels. At a global level, two NGOs with particular interest in forests are the World Resources Institute, in Washington, D. C., and the World

Conservation Monitoring Centre, in Cambridge, UK. These organizations recently collaborated to produce a report which shows changes between historical and present forest and identifies the world' remaining large natural forest ecosystems. They have indicated that global forest datasets, as proposed here, would have been of great value in facilitating the production of this study. Since both organizations have an interest in following the changes to forests in the future, they can continue to benefit from the proposed products, particularly those from the Forest Cover Characteristics and Changes theme.

The WRI has recently initiated planning for a Global Forest Watch. This initiative will involve networks of organizations working at local and regional levels with emphasis on the collection of in-situ data. Current, objective information on current forest cover characteristics and recent changes has been identified as an important component of this initiative.

3.6 National forest agencies

Historically, forest information has been obtained locally by ground plots or aerial photography, with national information derived through statistical compilation and generalization of the local data. Earth observation data have generally been used to update the locally produced inventories for major changes caused by new roads, logging, fires, and severe insect and storm damage. This use is expected to increase as the cost of the data and related technology decreases, and with increasing pressure on national and sub-national governments to provide more information, more rapidly, with decreasing budgets.

National forest agencies are recognizing the value of the comprehensive overview provided by earth observation technology, which can provide nationally-consistent information over wide areas in a reasonably short time frame. A recent workshop of the North American Forest Commission provided an opportunity to see how Canada, the United States, and Mexico are moving in similar directions toward the implementation of national forest information system using a multi-tier approach which combines complete coverage with fine resolution satellite data with samples using data from aerial photography and ground plots.

These systems are intended to provide information at the national level which is needed for policy formulation and strategic forest management planning, as well as for international reporting.

The products proposed for the Forest Cover Characteristics and Changes and Forest Fire Monitoring and Mapping themes are expected to satisfy many national, as well as international, information requirements. The products proposed for the Forest Biophysical Processes theme will aid individual nations in addressing many aspects of their commitments under the Kyoto Protocol.

4 Three Themes for GOFC

As described above, we have collected the proposed GOFC activities under three themes, Forest Cover Characteristics and Changes, Forest Fire Monitoring and Mapping, and Forest Biophysical Processes. Each theme represents what is essentially a stand-alone activity which would produce global derived products containing information for multiple user groups. Cross-linkages exist which serve to strengthen the overall effort.

4.1 Forest Cover Characteristics and Changes

This theme is by far the most challenging, but also the most valuable, of GOFC. We propose below an end-to-end plan which uses data from coarse and fine resolution sensors in a well thought out, highly integrated approach to generate a relatively small number of products which provide essential information concerning land cover, forest cover characteristics, and forest cover changes. These products will provide most of the information which has been identified as needed at continental and global scales by a wide spectrum of user groups. They will also provide very useful, albeit incomplete, information for forest assessment, policy-making, and management at the national level.

The criteria used to design this part of the GOFC pilot project were:

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

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

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

Design Requirements

The proposed strategy has been developed around the following requirements:

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

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

- The program should result in an operational monitoring system with the capability for permanent implementation.

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

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

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

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

4.1.1 Land cover and forest cover information

The Coarse Resolution design team established a number of criteria to guide the development of land cover classes. The team then proposed a set of classes, which the Fine Resolution design team was able to follow, allowing a joint classification scheme to be proposed. This scheme can be applied to the entire land surface of the earth. In accordance with the needed emphasis on forest cover and forest cover change information, the number of classes is much greater in areas of forest and other woody vegetation.

The criteria which guided the development of the classification scheme were:

- The classes mapped must be relevant to carbon studies.

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

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

- A hierarchical system allowing multi-scale classification is desirable.

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

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

- Compatibility between GOFC coarse and fine resolution products is necessary.

Table 4.1.1 Land and Forest Cover Classification Scheme

Land Cover					
Water					
Snow and Ice					
Barren or sparsely vegetated					
Built-up					
Croplands					
Grasslands					
Forest	**Leaf type**	Needle	Broadleaf	Mixed	
	Leaf longevity	Evergreen	Deciduous	Mixed	
	Canopy cover	10-25%	25-40%	40-60%	60-100%
	Canopy height	0-1 m	1-2 m	>2m	
		(low shrub)	(tall shrub)	(trees)	
Forest special theme: flooded forest					
Spatial resolution: 1 km (coarse) and 25 m (fine)					
Update cycle: 5 years (coarse and fine)					

This scheme has a number of attractive features. All land cover types are included. The non-forest types are very simply defined, an approach which should avoid difficulty in agreeing on class definitions. The forest class is sub-classified according to four descriptors: leaf type, leaf longevity, canopy cover, and canopy height. This scheme is based on the biophysical characteristics of the area rather than ecological classes. Again, this should help avoid difficulty in agreeing on class definitions. Nonetheless, ecological classes can be derived from the forest biophysical classes, if agreement can be reached on a satisfactory definition. For example, a savannah could be defined as an area of forest with broadleaf deciduous foliage with canopy height > 2 m and canopy cover of 10 – 25%.

An additional special theme is proposed: flooded forest. This theme provides valuable additional information which can be related to hydrological and biogeochemical cycling. Flooded forest can be reliably mapped with SAR data. The existing GRFM/GBFM project is already mapping flooded forests for all of the tropical and boreal forests of the world. This effort could be expanded to all of the world's forests in a straightforward manner.

To meet user requirements, this classification should be carried out globally every five years. The entire land surface should be covered at coarse resolution. While global land cover with 250 to 500 m resolution will have the highest applications value, in the near term a 1000 m resolution data set is most practical and feasible. By means of information provided by the coarse resolution land cover classification and other information sources, the forested areas should be covered at fine resolution on a five year cycle as well. This is a very ambitious goal. It is likely that initially some areas where rapid change is not taking place will be covered less frequently.

4.1.2 Change information

Because of the importance of forest cover change information, a forest cover change product should be produced annually at coarse resolution, and on a sampled basis annually at fine resolution. The annual coarse resolution change detection will help target the fine resolution observations to areas of rapid change, with a goal of covering all of the forested areas on a five year cycle.

Table 4.1.2 Forest Change Classes

	Coarse	**Fine**
Resolution	1 km initially 250 m as soon as possible	25 m
Cycle	Annual wall-to-wall	5 year wall-to-wall 20% - 30% annual
Classes	No change Forest à non-forest Non-forest à forest	No change Forest à non-forest Non-forest à forest
Special Products	burned forest	Forest fragmentation Forest change occurrence

Annual mapping of burned areas is an important component of GOFC in its own right (see section 5). The annual coverage with coarse resolution sensors can provide annual mapping of burned areas.

Additional products can be derived from the fine resolution forest change, including a Forest Fragmentation product and a Forest Change Occurrence map. These are described in detail in the Fine Resolution design team report (Appendix 3).

Many methods have been used for change detection based on satellite data. Analysis of radiometric differences between dates generally provides more accurate results than analysis of difference between classification results because the latter compounds inaccuracies in the classification products. Hence this approach is recommended by both the Coarse and Fine design teams.

4.1.3 Data types and calibration

Products for Forest Cover Characteristics and Changes require a very large amount of data from all of the sensor types listed in Table 10.2.1 (Appendix 2). A tremendous amount of experience has been gained using data from existing sensors, particularly TM, HRV, AVHRR, and LISS, which will apply to next-generation sensors which have been recently launched (SPOT-4) or are soon to be launched. This experience provides confidence in the ability to achieve routine production of radiometrically and geometrically corrected products.

Orthorectification requires the use of digital elevation models (DEMs). This is particularly important for SAR data where large distortions can be induced by relatively minor elevation differences. DEMs are becoming more readily available for much of the world, so it will be possible initiate GOFC regional pilot projects. However, DEMs will not be available for all forested areas until the completion of the Shuttle Radar Topographic Mapping Mission. A standard data set from that mission will be a tremendous asset for GOFC and other projects. For GOFC, DEM data will be required at 25 m resolution or better, with a vertical accuracy of 5 – 10 m.

With the exception of AVHRR, sensors are designed and operated to produce top-of-atmosphere radiance measurements to an absolute accuracy around 5%. So-called vicarious calibration campaigns, where multiple sensors obtain measurements of calibrated ground targets, are providing accurate inter-calibration of sensors of the same type. SAR sensors can now routinely be calibrated to absolute backscatter values of 2dB or better. However, calibration is often under-funded. It is important for sensor sponsors to realize that excellent calibration pays major dividends in reducing the down-stream cost of processing earth observation data, particularly for studies of vegetation change.

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

4.1.4 Data acquisition strategy

Data from coarse resolution sensors will be routinely acquired and archived by the sensor sponsors. These sensors acquire data daily or every few days, thus providing ample data for the generation of Forest Cover Characteristics and Changes products.

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

Given these goals and constraints, the acquisition strategy should rely on the global archive planned for Landsat 7 with SPOT, other optical and active microwave SARs providing the critical role of gap filling and monitoring areas of rapid change. This multi-sensor approach would utilize the strengths each sensor (e.g. planned systematic global acquisition of Landsat, SPOT HR VIR pointing capability for frequent imaging opportunities, and SARs all weather imaging capabilities).

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

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

SAR sensors would also play an important role in GOFC. SAR data (e.g. JERS-1 LHH, ERS-1/2 CVV, and Radarsat CHH) will be used to image areas where there are gaps remaining after the VIR acquisitions due to persistent cloud cover conditions. These areas should be imaged with the SARs at least four times per year. SAR system will also provide some important baseline datasets for GOFC (e.g. NASDA GRFM mosaics in the tropics and SRTM global DEM with 30 meter pixel spacing and 8 meter vertical postings). Use of SAR alone and in fusion studies will be an important part of GOFC research and development activities in an effort to evolve GOFC processing to better meet the needs of the user community. It is noted that the absolute calibration of SAR data is ideal for operational applications.

A seasonally-sensitive global SAR coverage on a 5 year cycle is feasible and would provide forest baseline information complementary to that provided by the optical sensors. In particular, it would provide for monitoring of changes in flooded forests.

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

An acquisition status tracking system will be essential for this GOFC project.

Table 4.1.4 Summary of Acquisition Strategy and Tasking Requirements

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

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

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

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

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

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

4.1.5 Data volumes and data management

The coarse resolution data needed for Forest Cover Characteristics and Changes could be retained and processed at either several regional facilities or one central facility. The Coarse Design Team Report, Appendix 4, contains a good discussion of the relative merits of the two approaches, and can be summarized as follows: "The centralized production model, in which one organization developed the product, has advantages for scientific applications, offers greater chances of global consistency, can likely be completed at a lower cost, and may be completed in a shorter period of time. The decentralized approach is more relevant for policy applications in which it is essential that local to regional landscape conditions are most reliably represented. It also may lead to greater local and regional acceptance of GOFC coarse resolution products."

The massive volumes of fine resolution data identified in section 4.1.4 preclude central archiving and processing. It is likely that several regional facilities will have to cooperate to accomplish the GOFC objectives. However, it will be necessary to create a central metadata facility which can track the acquisition of fine resolution data and the production of products. The data acquisition task requires unprecedented coordination of the acquisition of data from multiple sensors. Because of the gap-filling role of the SAR and pointable optical sensors, as well as their sensitivity to phenological conditions, acquisitions with these must be dynamically tasked using up-to-date information available at the central metadata facility. Just as Landsat-7 acquisitions will be scheduled using the automated LTAP system, it will be necessary to produce an automated system to schedule acquisitions by the SAR and pointable optical sensors. It is recommended that any proposed acquisition strategy be tested manually or semi-automatically before attempting full automatic operation.

The same metadata facility which tracks and commands data acquisition can also be used, with suitable extensions, to track the production of products from the acquired data.

4.1.6 Production of Products

The experience gained through several global and regional projects using coarse resolution data can be used to establish production procedures for coarse resolution products. Projects of particular relevance include the IGBP DISCover 1 km global land cover mapping, TREES and TREES-II, and the IGBP global fire mapping project.

GOFC should utilize data processing and analysis methods that are well established and suitable for operational use. There are several considerations to address for the end-to-end operational processing stream.

The following figure illustrates a set of processing steps from data acquisition (described in detail in the previous section) through product distribution and use by the end users of GOFC data:

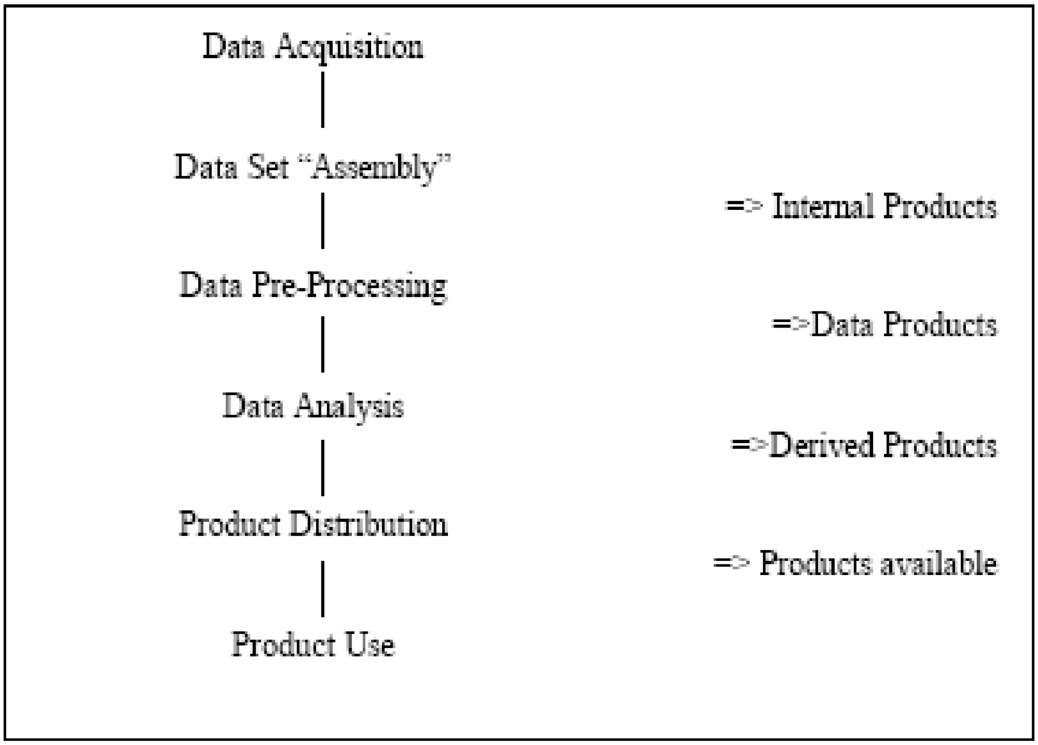


Figure 4.1.6: Processing Steps where

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

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

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

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

The data analysis step includes data classification and data fusion. The overall objective of the classification steps should be to simplify the data content into GOFC feature classes without losing land cover information. Considerable research and thought has gone into producing the feature classes, listed in products section of this document, with an emphasis of developing and automated system while providing critical information needed by the user community. Additional research is needed to demonstrate that classification procedures at the regional scale can handle spectral confusion due to large area coverage. There are two basic classification approaches to be considered by GOFC: supervised classification with a few very specialized classes (as was done in Boreas) or hyper-clustering approaches with knowledge based relabeling (Landsat Pathfinder HTF).

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

4.1.7 Product validation

Accuracy assessments of digital land cover classifications are typically based on contingency tables, or confusion matrices, where accuracy is expressed in terms of errors of omission and commission, or in terms of agreement analysis using the Kappa test statistic (Stehman 1996a, Congalton 1991, Rosenfeld and Fitzpatric-Lins 1986). The contingency table is created by comparing on a class by class basis the land cover classification with an independent data source - field observations, existing maps, higher resolution imagery - collected using a statistically valid sampling strategy (Robinson *et al*., 1983, Stehman 1996b, Rosenfeld 1986).

Such methods are widely accepted as a means to determine the accuracy of earth observation derived land cover classifications when derived from higher resolution data, such as from Landsat's TM sensor, or the SPOT HRVs. This approach may be quite suitable for validation of GOFC fine resolution products.

Validation for the fine resolution products can be derived from a combination of in-situ data, data from very high spatial resolution (1-3m) satellite imagery, aerial photography, and local knowledge. Several groups have recently demonstrated GPS-controlled aerial videography to be a very inexpensive means to validate fine resolution products over large areas. Nonetheless, the very large amounts of fine resolution products proposed here will require very large validation efforts, with very considerable support from persons with local knowledge.

Validation of the coarse resolution products will benefit tremendously from a database of co-registered, validated fine resolution products, especially since the same classification scheme is proposed for both coarse and fine resolution products. Additional fine resolution data will undoubtedly be needed in some cases. The experience gained in the validation exercise for the IGBP DISCover classification will be valuable in defining the exact validation approach for the coarse resolution products. It is already apparent that geometric errors can seriously reduce the classification accuracy. As such, the use of data from sensors with better geometric characteristics than AVHRR should improve results.

Validation activities are expensive and as such have often been accorded second place in mission planning and implementation programs. GOFC stresses to CEOS the importance of including cal/val programs in mission planning.

4.1.8 Research issues

In addition to operational processing, GOFC should have several research and development activities that focus on improving the current state of the art processing techniques so that GOFC evolves and produces improved products for the user community. These development activities should include, for example, improved atmospheric correction algorithms.

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

Some research and development would be necessary to adapt existing classification methods to the land cover and land cover change classes proposed here. Further research would be beneficial to increase the degree of automation so as to decrease the labor involved and thus lower the cost of producing products. It is recommended that these efforts concentrate on data near 1990 because of the need for baseline information for 1990 resulting from the Kyoto protocol.

Data fusion may be a necessary intermediate step in the classification process. However, it is currently unclear if fusion is required to product GOFC products. Therefore, there needs to be a research and development activity to assess the need and benefit of fused data products. Considerations for fusion should include: multiple high resolution optical data, high and coarse resolution optical data, and possibly most promising is the fusion of optical and microwave data.

4.1.9 Implementation strategy

Although the GOFC design teams have made considerable progress in defining the Forest Cover Characteristics and Changes theme, there are numerous technical details which remain to be resolved. More importantly, it is now appropriate to seek further comment and input from nations which have major forest resources. Many of these countries have sent representatives to GOFC design meetings, but other nations have not been represented. The current draft provides a sufficient level of detail to initiate a dialog with forest managers and policy makers.

The critical requirement for implementation of this ambitious theme is for a agency to take up the challenge of defining and implementing a pilot project. Here we provide a possible scenario.

4.1.9.1 Pilot projects

The initial pilot project(s) should be end-to-end exercises of data acquisition, data analysis, and evaluation/validation of the resulting products. It is important to carry out an end-to-end exercise to ensure all the necessary components function properly, and to identify weak areas where remedial work is necessary. The project could require as little 1.5 years, but this is a very short for such an endeavor. The project could cover one region (for example, one continent). At the conclusion, an evaluation would be held, and planning begun for a second cycle. The second cycle could cover several regions, including a repeat of the first region for comparison purposes. It is possible, but seems very ambitious, for the second cycle to cover the entire world at both coarse and fine resolution.

4.1.9.2 Evolving toward on-going operation

A coordinated, distributed operational system of regional nodes seems most likely to succeed. For example, nodes could exist in North America, South America, Europe, Africa, East Asia, West Asia, and Australia. Each node would be led by an organization with established capabilities to process massive data volumes, with common or comparable software being used at each node.

The pilot projects would focus on technical issues, but organizations having information requirements would be involved at all stages, to ensure that their requirements will be met. At the same time, planning would take place to identify sources of long-term funding, to facilitate the transition to on-going operation.

4.2 Forest Fire monitoring and mapping

Wildfires and biomass burning are significant agents of change in forest ecosystems, can cause serious disruption to communities which are economically dependent on forest resources, result in air quality degradation with serious health implications, and sometimes result in loss of human life. Burning of forests also accounts for a substantial fraction of the atmospheric increase in carbon dioxide and other greenhouse gasses.

The development of a global fire information system represents an objective which would provide many benefits at national, regional, and global scales and enable CEOS to provide an early demonstration of the concept of an integrated global observing strategy. This theme consists of two components: monitoring of fires during the fire season, and mapping of burned areas during or after the end of the fire season. A modeling component to estimate burn intensity, fuel load and consumption, and emissions of gasses and aerosols is an additional option.

The monitoring and mapping components can be implemented using data from coarse resolution optical (including mid IR and thermal) sensors alone, while the modeling component would require input from the two other GOFC themes: forest cover and forest biophysical processes. The Forest Fire Monitoring and Mapping theme would provide valuable input into the other two themes: annual maps of burned areas are an important input into forest cover change mapping, and estimates of area burned, burn intensity, and fuel consumption provide important input for understanding forest biophysical processes, particularly loss of biomass and release of carbon to the atmosphere.

It is important to note that the forest fire monitoring and mapping theme proposed by GOFC complements but does not overlap the information on forest fires which forms a component of the CEOS Disaster Management Pilot Project. The latter project addresses the provision of fire detection information to aid fire suppression. Effective fire suppression requires rapid attack, which necessitates continuous monitoring and the provision of information to response teams in timeframes as short as 15 minutes. The fire monitoring component of this GOFC pilot project foresees observations by polar orbiting systems with a repeat cycle of 12 hours, and a similar time delay for the provision of information. In the development of both GOFC and the Disaster Management Project there has been a deliberate sharing of personnel to ensure good communication and coordination between these two IGOS Pilot Projects.

4.2.1 Information requirements

The proposed information products are outlined in Table 4.2.1. Each of these products addresses the specific needs of one or more user communities. They are described in more detail below.

Table 4.2.1 Forest Fire Information Products

	Spatial resolution	**Revisit cycle**	**Data delivery**	**Source(s) of data**
Fire monitoring	250 m – 1 km	12 h	12 hours	Coarse resolution optical (thermal)
Mapping burned area	25 m – 1 km	Annual	3 months	Coarse and fine resolution optical with SAR backup
Modeling	250 m – 1 km	Annual	6 months	Coarse resolution optical plus land cover plus biomass, emission factors, etc.

As a minimum, the proposed fire monitoring product consists of hotspot locations which are produced from thermal sensors operating in the 3 – 5 and 8 –12 micrometer bands, using algorithms which have been validated to produce a minimum of false alarms while detecting most fires. Because of the very small data volumes involved, these hotspot locations can be transmitted widely using Internet facilities. When larger bandwidth exists, it is valuable to transmit portions of the image surrounding the fire (about 300 x 300 km) to provide additional visual information on the geographic context and the location of the smoke plume.

Fire monitoring information is needed nationally, regionally, and globally. At the national level, this information should benefit countries that have limited fire detection resources or countries that have fires which occur in remote, sparsely-populated areas. In the latter case, if there is no initial effort at fire suppression, it is important for authorities to monitor the progress of the fire in case it begins to threaten settlements or other resources. With smoke plume imagery, authorities can also make informed decisions about closing highways or evacuating communities which are affected.

As was the case in 1997-98, during a severe fire season, trans-boundary air pollution becomes a serious regional issue. An operational fire monitoring system would provide all nations in the region with rapid, consistent information concerning the location of fires and the direction of smoke transport. In a very severe fire year, the location of fires and consequent air pollution becomes an issue of global concern. The proposed fire monitoring system would be able to provide a consistent global picture of the current situation on a daily basis.

Although not required in near-real-time, fire monitoring products will provide valuable data on the location and inter- and intra-annual variability of wildfires for researchers studying the causes and consequences of wildfires. When summarized statistically, the information can be used for policy decision making at national and international levels.

The burned area mapping product would be produced annually at 1 km resolution, improving to 500 m or 250 m as technology permits. Since most of the area burned results from a relatively small number of large fires, annual mapping with coarse resolution sensors would provide reliable information on the location and areal extent for most of the significant fires. Acquisition of coarse resolution data for fire mapping can be targeted using the output from the fire monitoring component. Data from fine resolution optical sensors can be acquired for those fires where additional spatial detail is needed, and will permit reliable, accurate validation of the results from the coarse resolution sensors.

At the national level, end-of-season fire maps would support updating of national forest inventories, annual fire statistics reporting, and serve as indicators for monitoring sustainable forest management under most of the Agenda 21 Criteria and Indicators of Sustainable Forest Management initiatives. This type of information is also required by many countries for strategic fire management planning.

For the science community, annual mapping of burned areas provides an important indication of rapid land cover change. The data also have scientific value for studies on the interaction of climate change and forest fire trends.

Annual mapping of burned areas will aid nations in responding to the United Nations Framework Convention on Climate Change and the Convention on Biological Diversity.

The modeling component would provide combined information on hotspots, burned areas, land cover, and forest biomass. This would enable researchers to investigate the emissions of gasses and aerosols to the atmosphere, and estimate the amount of biomass converted to atmospheric carbon dioxide. In areas where digital information on topography, forest fuels, and meteorological information can be added, fire behavior models have been developed which can provide information on the fire intensity, rate of spread, and fuel consumption. These models can provide information for strategic allocation of fire fighting resources and sometimes for tactical decision making for fire suppression.

4.2.2 Data types and calibration

Daily fire monitoring can be provided using existing hotspot detection algorithms working on thermal channel data from the NOAA AVHRR and ESA ATSR sensors. Future sensors which will carry suitable thermal bands include MODIS, MERIS, AATSR, and GLI. Accurate calibration can be provided for thermal sensors using hot and cold reference targets, so algorithms which work in units of absolute temperature (K) can be readily adapted to use data from a variety of sensors. Accurate geometric correction is also an important requirement.

Burned area mapping is most readily performed using data from the near infrared (0.7 to 1.1 micrometer) and short-wave infrared (1.1 to 2.5) micrometer bands, although satisfactory results can often be obtained using red (0.6 to 0.7 micrometer) and near infrared bands.

Several groups have demonstrated satisfactory fire mapping algorithms with AVHRR data. The Vegetation sensor on SPOT-4 has improved radiometric and geometric performance, and carries a spectral band at 1.5, as do the ATSR and AVHRR on NOAA-15.

Fine resolution mapping of selected burned areas can be accomplished with data from Landsat, SPOT, and IRS satellites. All of the satellites carry high performance, well-calibrated sensors which include red, near infrared and short-wave infrared bands.

Numerous attempts to use SAR data intensity data for mapping burned areas in real time or shortly after the fire have proven unsuccessful more often than not. In the weeks and months following the fire however, the radar backscatter of the burned area becomes much more variable than that of the surrounding forest, enabling burned areas to be detected using multi-temporal SAR data.

Promising results have been obtained at the ESA/ESRIN facility in Frascati using SAR coherence from multi-temporal data obtained with ERS-1/2 satellites operating in tandem mode. A permanent tandem-mode SAR capability would make operational near-real-time burn mapping much more feasible.

Accurate on-board radiance calibration facilitates the development of automated algorithms for burn mapping. Accurate atmospheric correction would be a further asset, but the bands in the near and short-wave infrared are less affected by variable atmospheric aerosols, so a first-order correction would probably suffice.

4.2.3 Data acquisition, production, and dissemination strategy

Global, daily acquisition and processing of AVHRR data or any other global dataset at 1 km resolution is an enormous task. Therefore a decentralized regional model is more appropriate for the development of these products, at least initially. Considering current capabilities, the on-board recorders of the AVHRR sensor cannot store the data required to obtain global daily coverage at 1 km resolution. AVHRR data would have to be captured by a network of ground stations. A coordinated global network of real-time receiving stations is required. Each receiving station would have to be able to run the fire detection algorithm on site in order to reduce the amount of data that needs to be transferred to assemble the global fire product.

Several initiatives have demonstrated algorithms to detect active fires and reject false alarms using AVHRR satellite data (1 km resolution) as input. Algorithms have been developed by: 1) NASA/GSFC, by a team of researchers collaborating under the IGBP (Kaufman, et al., 1997), 2) Space Applications

Institute of JRC (Pereira, 1998); and 3) Canada Centre for Remote Sensing (Li et al,1997a, b, and c). Similarly, ESA researchers have developed successful fire detection algorithms using data from the ATSR instrument. Inter-comparison of these algorithms is needed to understand their strengths and weaknesses, leading to the identification of a global approach. The IGBP-DIS fire project could provide valuable assistance in facilitating this activity.

Likewise, several groups are testing algorithms to map burned areas from AVHRR, TM, SPOT-Vegetation, and SPOT-HRV and HRVIR data. As mentioned above, the high contrast of burned areas and the good radiometric performance of recent sensors provide confidence that these efforts will lead to robust, effective algorithms.

Many nations and international agencies currently monitor active fires using data from geostationary meteorological satellites. However, only large fires can be monitored from geostationary altitude, particularly at high latitudes. The JRC World Fire Web project proposes to build a network of regional centers using the same to extract active fire locations from real-time AVHRR data. Burned area mapping is proposed to be carried out at six-month intervals. The resulting products (hotspots and burned area boundaries) require very modest data volumes to store and transmit. Exchange of final products using existing Internet technology is very feasible.

4.2.4 Validation

Fire detection algorithms are usually validated by comparison with reliable post-season burned area maps. Hotspot pixels form clusters which should be confined to the interior of the burned area. Burned areas with no hotspot pixels may represent errors of omission, which can be caused by setting detection thresholds too high, or by cloud cover. Hotspot pixels outside known burned areas can represent errors of commission, which can be caused by setting detection thresholds too low. Even the best algorithms available today produce errors of omission and commission; they must be adjusted to achieve a suitable balance of the two types of errors.

Validation of the coarse resolution burned area maps can be accomplished using fine resolution data. Validation of burned area maps produced from fine resolution data will require the cooperation of national and sub-national fire management agencies.

4.2.5 Implementation strategy

4.2.5.1 Initial pilot projects

A number of national and regional initiatives are already underway to incorporate current knowledge into operational fire monitoring and mapping systems, while continuing research to improve algorithms. The most comprehensive of these is the JRC World Fire Web. We propose that GOFC, in cooperation with the IGBP-DIS Fire Working Group, facilitate discussions aimed at defining a unified approach which would lead to an early regional trial. Specific areas where such a coordinating and facilitating role will be valuable include:

- Development of technology needed to produce operational active fire products on a daily basis, with products available within 12 hours of satellite data reception;

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

- Development and testing of automated algorithms for burned area classification, including evaluation of fire mapping accuracy using finer satellite data and field observations;

- Refinement of fire detection and burned area mapping algorithms based on the results of field trials;

- Development of methods for using the data to produce higher order products such as daily fuel consumption and fire emissions products.

- In co-operation with international agencies, provide assistance to nations wishing to incorporate forest fire information derived from earth-observation data into their forest management and fire suppression activities.

4.2.5.2 Evolving toward on-going operation

This theme represents the best opportunity for an early transition toward on-going operation. There are well-defined users with well-defined requirements. Suitable sensors are currently available and will continue to be provided on operational satellites. The earth observation data volumes and data rates are relatively modest, especially with distributed reception and processing. The resulting information products have small data volumes, enabling current Internet technology to be used for product dissemination. We expect that the networks established during the initial pilot project stage can be readily expanded to a global system.

4.3 Forest biophysical processes

A suite of related products which describe forest biophysical processes is needed to provide estimates of annual forest ecosystem dynamics and productivity and measures of forest structure. An additional product, above-ground biomass, is needed to provide an indication of overall forest carbon stocks and sequestration potential, as well as provide land use implications. The ultimate goal is to understand, and eventually balance, the earth's carbon budget.

While this area of investigation and technology development has been viewed in the past as primarily a scientific endeavor, the international participation in the Kyoto protocol since December 1997 has brought the need for reliable estimates of forest biophysical processes to the center of the policy arena. It is expected that as soon as reliable estimates of forest biophysical processes are available, the resulting knowledge will become incorporated into international policy decisions and subsequently into national forest management decisions. Non-governmental organizations will also be interested in the results.

4.3.1 Products

The products required for reliable estimates of forest biophysical processes are:

- Leaf area index (LAI): one half of the total leaf area in the forest canopy per unit flat ground surface area (m^2/m^2)
- PAR: the total photosynthetic active radiation incident on a horizontal surface on the top of a plant canopy (W/m^2).
- FPAR: the fraction of incident photosynthetic radiation (PAR) absorbed by green leaves in the forest canopy (dimensionless).
- Above-ground biomass: the total amount of above-ground dry organic matter existing in a unit area at one instance (g/m^2).
- NPP: the mass of new carbon stored in vegetation (leaves, stems and roots) per unit space and time. It is the difference between gross photosynthesis and autotrophic respiration ($gC/m^2/yr$).

It is worth noting that several additional products can be derived from the above. For example, the length of the green period of deciduous vegetation can be derived from seasonal measurements of LAI or FPAR. This information is valuable for long term climate change studies. Such a product could also help determine the leaf longevity class for forest cover class products.

Table 6.1 Products for forest biophysical processes.

Product	Units	Accuracy Needed	Spatial Resolution	Temporal Cycle	Source of Data
LAI	m^2/m^2	± 0.2-1.0	1 km	7 days	Coarse resolution optical
PAR	W/m^2	± 2 – 5 %	> 1 km	30 min - 1 day	Geostationary optical (low and mid latitudes); Coarse optical (high latitudes).
FPAR	dimension-less	± 5 – 10 %	1 km	7 days	Coarse resolution optical
Above-ground Biomass	g/m^2	± 10–25 %	1 km	5 years	Inferred from land cover until spaceborne measurements are available
NPP	$gC/m^2/yr$	± 20-30 %	1 km	1 year	Above products plus ground and spaceborne meteorological data

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

4.3.2 Data sources and calibration requirements

Until now, almost all of the work being carried out to develop capabilities for earth observation of forest biophysical processes has used data from the NOAA AVHRR sensor. This sensor has well-known shortcomings, since it was originally designed for atmospheric rather than land surface observations. Nonetheless, the experience gained by teams who have addressed many aspects of the forest biophysical processes problem area have provided invaluable knowledge which has been incorporated into the design of next generation sensors and processing systems.

The CNES SPOT-4 satellite, launched in March, 1998, carries a four-band sensor, named VEGETATION, for monitoring the Earth's vegetation. The spectral bands, radiometric calibration, and radiometric resolution are all greatly improved over the AVHRR. Although this sensor has the same geometric resolution as AVHRR, the size of the resolution does not degrade away from nadir, as does the AVHRR resolution. The geometric accuracy is also improved, increasing the effective resolution of multi-date products. There are a number of investigations currently being carried out with early data from the VEGETATION sensor. These may lead to the ability to produce products related to forest biophysical processes routinely.

Under NASA's Earth Science Enterprise, the MODIS sensor will be flown on the Earth Observation Satellites AM-1 and PM-1. This sensor has been designed to address all of the forest biophysical processes requirements stated above. It has a suite of spectral bands much better suited to satisfy forest biophysical process requirements, as well as provisions for radiometric and geometric calibration standards which should permit the production of output products with the required accuracy.

ESA and NASDA are developing complementary sensors, MERIS and GLI, which could also be used to produce products related to forest biophysical processes.

Two additional sensors, NASA's MISR, and ESA's POLDER, have been developed to investigate particular aspects of the interaction of radiation with the vegetation canopy structure. The information gained from studies with these sensors can improve the algorithms used to derive forest biophysical process information from MODIS, MERIS, and GLI.

For all of the sensors which follow after AVHRR, teams of research scientists have played a central role in specifying the sensor characteristics, with particular attention to calibration and validation. It is expected that the ability to monitor the Earth's forest biophysical processes could improve dramatically as data from these sensors begins to be used for product generation and validation. To achieve this goal will require sponsorship of validation exercises by the CEOS agencies which have produced the new sensors.

4.3.3 Current capabilities including validation

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

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

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

Both satellite derived and gridded weather data need validation using ground measurements. Surface measurement data sets have been assembled and analyzed by the International Satellite Cloud Climatology Project, and these could be used by GOFC.

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

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

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

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

- Direct observation of leaf and stem density (fresh biomass): Many investigations have indicated that there is a correlation between microwave backscattering coefficients derived from SAR data and biomass (fresh biomass) in leaves and stems of vegetation. However, correlation is usually vegetation types specific. It has been observed to saturate at relatively low biomass levels for C- and L- bands, the only SAR bands which are currently available.

We recommend that the first approach be used initially to produce the coarse resolution biomass product. In this case biomass product generation is reduced to the generation of coarse resolution land cover product. A unit biomass database for vegetation types should be developed based on the ground observation and high spatial observation from satellite. The second approach can be implemented as a tool to determine a unit biomass for each vegetation type in a local scale.

The planned Vegetation Canopy Lidar mission (NASA), and proposed P-band SAR systems have the potential to improve biomass estimates from space, but considerable research and development will be required before these can be incorporated into operational systems.

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

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

4.3.4 Follow-on research and validation

We recommend that CEOS, through GOFC and GTOS, promote ground observation campaigns to validate forest biophysical process products and to establish a unit biomass database for vegetation types. In this campaign in-situ data relevant to biomass, LAI, APAR and NPP are collected together with the high spatial satellite data and their relations are investigated. Validation and verification processes are essential and should be carried out as a part of the ground observation campaign. The BOREAS project of 1993 – 1997, and the planned LBA and SAFARI campaigns, are examples of such an approach, carried out in boreal and tropical forests, respectively. Additional validation data should become available through co-operation between GOFC and GTOS.

It is also recommended that CEOS promotes parallel research initiatives to develop in-situ observation methods and to develop models relating biomass to remotely sensed data. It should be also noted that this product would be linked with high resolution products on land cover classification and vegetation density.

Efforts are needed to have operational production of PAR products using satellite measurements so that the current reliance on weather prediction data can be phased out. Pilot projects could be established to achieve this goal.

4.3.5 Implementation strategy

4.3.5.1 Initial pilot projects

A number of groups in the Americas, Europe, and Japan are carrying out research and development efforts in the area of forest biophysical processes, sponsored by the various opportunities engendered by the EOS, ENVISAT, and ADEOS-2 missions and other sponsors. Some groups are pioneering the assembly of global datasets, while others are undertaking more detailed investigations at regional scales. If successful, these efforts should provide a sound scientific and technical basis for an ultimate transition to routing operation. In co-operation with IGBP, GOFC can play a coordinating role to facilitate the interaction between the various groups active in this area, maintain current information on best practices, and provide advice to CEOS members.

Joint experiments should be conducted for several areas in each forest biome to focus on refining algorithms for forest areas, carrying out experimental research and development with emphasis on product validation relating in situ and satellite measurements.

Possible sites include: (1) the EOS core test sites; (2) Smithsonian test sites in South America and Southeast Asia representing the tropical biome; (3) U.S. Long Term Ecological Research (LTER) sites for the temperate biome; and (4) the LAI/FPAR validation program in Canada, with extension to Siberia, as a candidate for boreal biome validation work. This is the minimum set of validation requirements, and multiple test sites for each biome would be beneficial.

GTOS has recently initiated a demonstration project concentrating on net primary productivity. A common effort linking GTOS and GOFC is an attractive option.

4.3.5.2 Evolving toward on-going operation

NASA's Earth Science Enterprise plans for a minimum of 15 year data continuity for MODIS and MODIS-like products. If the NASA strategy succeeds, the suite of products related to forest biophysical processes can be generated in an ongoing basis during that period. Additionally, NOAA and NASA have a long term strategy to replace the NOAA satellite series with NPOESS satellites, which would move the production of key MODIS products into a production environment. The most valuable role the GOFC user community can play under this scenario is to use MODIS, MERIS, and GLI products to estimate forest biophysical processes as outlined here, to participate in validation exercises, to carry out research leading to improved information extraction algorithms, and to participate in the planning process leading to operational production through the NPOESS system.

5 Data principles

GOFC will adhere to the spirit of CEOS Data Policy . Wherever possible, input data and products will be also openly available to GOFC participants. Fine resolution, and hyperspectral commercial data, when purchased as part of GOFC, in principle will be negotiated so they can be accessed with no restrictions
to GOFC participants. However, we recognize that satellite data policies vary between CEOS members, and that members may insist that data made available for GOFC be subject to their established data policies. GOFC derived products will be placed in the public domain, in principle "free" but in any case not more than the cost of filling user requests. Responsibility for archiving original data and derived products will remain with the producer.

GOFC projects will need product availability via internet and hardcopy forms to meet a range of user capabilities and needs.

GOFC will implement project data and information access connections, for instance through GOFC WWW pointers. GOFC users should be able to access or link to all GOFC metadata through the GOFC WWW site. Full project interoperability is a strong goal. There should be no period of exclusive use after product validation. Where appropriate early release of un-validated products with the associated caveats will be encouraged. Documentation should specify product applicabilities for users, to assure products are not incorrectly used (e.g. global versus regional reliability). Data products should be available in clearly identified, readily-accessible archives ie. historical data remain available in the archive. The need for a GOFC directory of data products will be evaluated.

6 GOFC Implementation

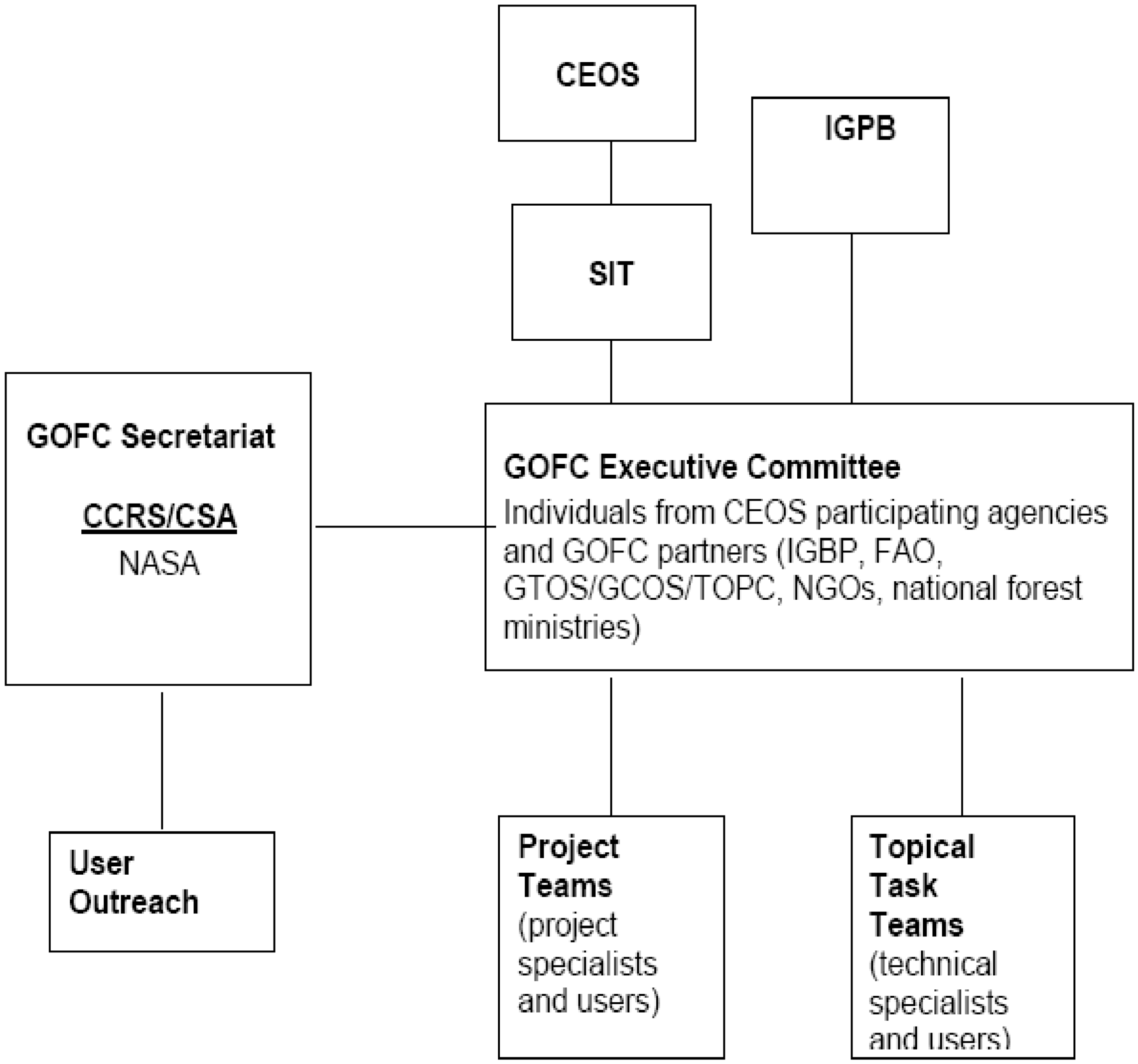
The goals of IGOS, as expressed by the SIT meeting February 6-7 in Irvine California, "are to provide on one level a strategic framework within which agencies can work to develop specific systems embracing both in-situ and space-based observations, and the need to ensure that value [is] added, being mindful to avoid increased bureaucracy and complex processes." (CEOS, 1997).

In keeping with IGOS' intent, the management structure of GOFC must be as simple as possible to avoid increased bureaucracy, while producing tangible benefits within the five-year time frame established by SIT.

6.1 Management structure

Our guiding principal in designing an appropriate organization for GOFC is to take maximum advantage of existing organizations and capabilities and create a minimum of new bureaucracy to meet IGOS and GOFC objectives during the five year lifetime of GOFC. The proposed management structure is shown in Figure 6.1.

Figure 6.1 GOFC Management Structure



6.1.1 Connection to CEOS and IGBP

In accordance with CEOS' intent under the IGOS concept, we propose for GOFC to have a dual affiliation. GOFC will report to CEOS through SIT, as in the past. It will also be attached to IGBP through IGBP-DIS. CEOS is the original "parent organization" of GOFC. CEOS members remain those most committed to making GOFC a success and control resources which are essential to implement the ambitious projects which GOFC is recommending. The objective of IGBP-DIS is data set development and distribution. IGBP-DIS provides a valuable knowledge base to GOFC through its experience in a number of projects including global 1 km land-surface data base from AVHRR, the global 1km land cover project, the global fire data base, areal extent of global wetlands, estimation of terrestrial primary productivity, global topographic data sets, and a global land biomass data base. It will provide GOFC with the benefit of its experience in the assembly of, and access to large data bases. It can also provide linkages to related IGBP core projects including LUCC, BAHC, GCTE, and GAIM.

6.1.2 Executive Committee

The Executive Committee should be a small, active group which takes the important actions necessary to ensure that GOFC continues to make progress toward its objectives. Membership consists of individuals from CEOS participating agencies and GOFC partners (IGBP, FAO, GTOS/GCOS/TOPC, NGOs, national forest ministries) which are contributing to the implementation of GOFC. The initial membership can be drawn from the design teams, but a mechanism is needed to provide turnover. The committee would meet twice per year, once at the annual CEOS plenary meetings, and approximately 6 months in between. Between meetings, members would maintain frequent contact by listserver, email, and phone.

The Executive Committee:

- Works to form partnerships which lead to the initiation of project activity
- Helps to arrange sponsorship of projects;
- Monitors program and project implementation and progress;
- Ensures availability of project outputs and results;
- Reviews proposals for inclusion in GOFC against clearly stated criteria;
- Creates short term teams to address specific issues.

6.1.3 Secretariat

The Secretariat for GOFC is sponsored by CCRS and CSA. At the Irvine SIT meeting, NASA offered to play a strong supporting role. The support by NASA has been essential for the success of GOFC, and it should continue. The Secretariat provides a Project Leader for GOFC as an IGOS prototype project. It hosts the GOFC website, and provides an office which can be contacted at any time for information about GOFC. It manages day-to-day communications, and provides planning support for GOFC activities, particularly Executive Committee and other meetings. The GOFC Secretariat will develop and test approaches for policy and science outreach, and conduct outreach to organizations which share common interests with GOFC.

6.1.4 Project Teams

GOFC depends on the voluntary contributions of organizations to carry out project work. Therefore, project teams will be formed by participating organizations to accomplish specific tasks.

Under the desired scenario, GOFC will recommend products which should be produced, and encourage suitable organizations to take the lead to form projects to produce them.

Following the strategy outlined in this document, a project team should be formed to address each of the three primary themes, Forest Cover Characteristics and Changes, Forest Fire Monitoring and Mapping, and Forest Biophysical Processes.

It is proposed that in each such case, the leader of the project becomes the point of contact between the project and GOFC, and communicates through the Executive Committee.

6.1.5 Task Teams

From time to time the GOFC Executive Committee will identify specific topics where recommendations are urgently needed to enable GOFC to meet its objectives. The Executive Committee will have a mandate to form Task Teams which will be given a specific task, and requested to report back to the Executive Committee within a relatively short time period. As such, they will be very similar to the current Design Teams. In many cases existing WGISS or WGCV working groups, or subsets of these, might be able to address topical tasks identified by the GOFC Executive Committee.

6.2 Communications strategy

An Internet website, together with email, provide an ideal mechanism for internal and external communications. The website will have a public portion for everyone, and an internal portion for GOFC participants. The general public will be the primary target audience for the public portion, recognizing that the public portion must also appeal to specialists in earth-observations and forest management. In the introductory pages the website should include a statement about the objectives of GOFC and its rationale for existence, as well as a balanced treatment of the role of satellite observations as a source of information on forests at the national and global levels. It will also include brief descriptions of participating organizations and links to their home pages. The public portion will also provide access to GOFC documents, and a mechanism for readers to provide comments to the GOFC Secretariat via email.

Eventually the website should provide access to project output, either directly or through links to agencies holding the derived data products. This may be a sensitive area. GOFC can act as an advocate of liberal rather than restrictive access to data and derived products.

Together with email, the website will provide an easy mechanism for internal project communications and enable organizations to achieve greater participation in GOFC even when they cannot send a delegate to a meeting.

We recognize that we cannot depend entirely on electronic communications. The GOFC Secretariat must be prepared to communicate using mechanisms suitable for participants if they do not have access to electronic communications. During the development phase GOFC will explore options for data packaging for different user communities.

7 Recommendations to CEOS

This document represents a strategy for CEOS and other agencies to consider. As mentioned before, actual implementation will depend on lead and participating organizations "stepping forward" to take up the challenge of assembling a team to work in one of the proposed theme areas. Following the GOFC design, it is possible to make several more general recommendations to CEOS.

GOFC objectives cannot be accomplished without data. We request that CEOS space agencies:

- Acquire and process the data needed to accomplish GOFC objectives, and work cooperatively to ensure long-term continuity of essential data. The data requirements have been specified in conjunction with each of the three primary themes.
- Promote the development and implementation of efficient data management and production systems to lower the cost of large-volume earth-observation datasets. This is a critical requirement, not only for GOFC but for the success of operational implementation of forest cover observations. In order for the needed information to be affordable to users, much larger volumes of data must be processed quickly, efficiently and nearly automatically than has been the case to date.

A number of recommendations call for enhancements in the areas of technology and documentation:

- Encourage CEOS members to provide user-friendly on-line facilities to access metadata and quicklook images for archival imagery (with WGISS);
- Promote the standardization and documentation of data products from optical and SAR satellites (with WGISS);
- Develop and document calibration/validation protocols for earth-observation data and derived products generated for GOFC (with WGCV);
- Support R and D to develop a capability to estimate forest biomass from space. We have identified the Vegetation Canopy Lidar and P-band SAR as two promising technologies which should be developed further.

We support and encourage the IGOS partnership process. CEOS can help GOFC by promoting increased co-operation:

- In co-operation with GTOS and TOPC, help expand, establish, and maintain a network of test sites to validate GOFC experimental products (WGCV);
- Develop a relationship with research, forest management, and policy, agencies to facilitate dissemination of derived information, for example, reporting for international protocols and treaties;
- Facilitate a constructive relationship with vendors of hyperspatial resolution (1-3m) data, to be used for forest characterization and assist in the validation of derived products.

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9 Appendices

9.1 Appendix 1: GOFC Design Participants

Participants at Ottawa Workshhop, July 7 – 10, 1997

Name		Organization
Ahern	Frank	Canada Centre for Remote Sensing (Canada)
Alves	Diogenes Salas	Instituto Nacional de Pesquisas Espaciais (Brazil)
Beaubien	Jean	Centre de recherche forestieres des Laurentides (Canada)
Chapman	Bruce	Jet Propulsion Laboratory (USA)
Cihlar	Josef	Canada Centre for Remote Sensing (Canada)
Doherty	Marc	ESA ESRIN (Italy)
Drigo	Rudi	FAO - Viale delle Terme di Caracalla (Italy)
Fisher	Terry	Canada Centre for Remote Sensing (Canada)
Folving	Sten	Joint Research Centre - European Commission (Italy)
Goodenough	David	Pacific Forestry Centre (Canada)
Guertin	Florian	Canada Centre for Remote Sensing (Canada)
Gutman	Garik	NOAA (US)
Janetos	Anthony	NASA Headquarters (US)
Jennings	Michael	GAP Analysis Programme (US)
Justice	Chris	University of Virginia (US)
Lynham	Tim	Great Lakes Forestry Centre (Canada)
Leckie	Don	Pacific Forestry Centre (Canada)
Mahmood	Ahmed	Canadian Space Agency (Canada)
Mamen	Rolf	Canadian Space Agency (Canada)
Mayaux	Philippe	Joint Research Centre - European Commission (Italy)
Myre	Pauline	Canada Centre for Remote Sensing (Canada)
Nemani	Rama	University of Montana School of Forestry/NTSG (US)
North	Peter	Institute of Terrestrial Ecology (UK)
Ottens	Hans	Canadian Forest Service (Canada)
Phulpin	Thierry	CNES SH/QTIS/VP (France)
Shaw	Edryd	Canada Centre for Remote Sensing (Canada)
Skole	David	Univeristy of New Hampshire (US)
Stewart	Robert	Canadian Forest Service (Canada)
Taylor	Victor	NASDA (Japan)
Teillet	Philippe	Canada Centre for Remote Sensing (Canada)
Townshend	John	University of Maryland (US)
Trencia	Jacques	Canadian Forest Service (Canada)
Williams	Darrel	NASA/GSFC (US)
Yasuoka	Yoshifumi	National Institute for Environmental Studies (Japan)

Zhu	Zhiliang	U S Department of Interior Geological Survey (US)

Members of GOFC Design Teams, 1998

Name		Organization
Achard	Fréderic	European Commission Joint Research Centre
Ahern	Frank	Canada Centre for Remote Sensing (Canada)
Alves	Diogenes Salas	Instituto Nacional de Pesquisas Espaciais (Brazil)
Chapman	Bruce	Jet Propulsion Laboratory – California Institute of Technology
Cihlar	Josef	Canada Centre for Remote Sensing (Canada)
Coops	Nicholas	CSIRO (Australia)
Davis	Robert	Food and Agriculture Organization of the United Nations
Doherty	Marc	ESA ESRIN (Italy)
Dull	Charles	U. S. Depatment of Agriculture Forest Service
Fellous	Jean-Louis	CNES, France
Ferrão	Manuel	National Remote Sensing Center, Mozambique
Fisher	Terry	Canada Centre for Remote Sensing (Canada)
Hendrickson	Ole	Canadian Forest Service
Janetos	Anthony	NASA Headquarters (US)
Jayaraman	V.	Indian Space Research Organization
Jeanjean	Hervé	Spot Image/Scot Conseil, France
Justice	Chris	University of Virginia (US)
Kamibayashi	Norihisa	Remote Sensing Technology Center of Japan
Kwesha	Dominic	Forestry Commission of Zimbabwe
Lambin	Eric	Universite Catholique de Louvain
Li	Zengyuan	Chinese Academy of Forestry
Liu	Jiyan	Remote Sensing Application/ Chinese Academy of Science
Lynham	Tim	Great Lakes Forestry Centre (Canada)
Leckie	Don	Pacific Forestry Centre (Canada)
Malimbwi	Rodgers	Sokoine University, Tanzania
Mayaux	Philippe	Joint Research Centre - European Commission (EC)
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Ongsomwang	Suvit	Royal Thai Forestry, Thailand
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Singh	Ashbindu	United Nations Environment Program
Skole	David	Univeristy of New Hampshire (US)
Spence	Ian	Swedish Space Corporation
Taylor	Victor	NASDA (Japan)
Teillet	Philippe	Canada Centre for Remote Sensing (Canada)
Thormodsgard	June	EROS Data Center
Townshend	John	University of Maryland (US)
Tschirley	Jeff	Executive Secretary, Global Terrestrial Observing System
Vogelman	Jim	USGS/EDC (USA)
Woodcock	Curtis	Boston University (USA)
Yasuoka	Yoshifumi	National Institute for Environmental Studies (Japan)
Zhu	Zhiliang	U S Department of Interior Geological Survey (US)

9.2 Appendix 2: Sensor Types needed for GOFC

Table 10.2.1 Generic sensor types

Sensor Type	Resolution (m)	Swath (km)	Repeat (days)	Fixed/pointable targeting	Spectral Bands									
					B	G	R	NIR	1.5-1.7	3-5	8-10	L	C	
Fine-F	~25	~200	~14	Fixed		*	*	*	*					
Fine-P	~25	~75	~4	Pointable		*	*	*	*					
Coarse	~1000	~2000	1	Fixed	*	*	*	*	*	*	*			
SAR	~25 (min 4 looks)	100-200	~4	Pointable								*	*	

Table 10.2.2 Specific Sensors

Fine – Fixed		Fine – Pointable		Coarse		SAR	
Name	**Agency**	**Name**	**Agency**	**Name**	**Agency**	**Name**	**Agency**
TM	NASA	HRV	CNES	AVHRR	NOAA	JERS SAR	NASDA
ETM+	NASA	HRVIR	CNES	Vege-tation	CNES	Radarsat SAR	CSA
LISS III	ISRO			MODIS	NASA	ERS SAR	ESA
				MERIS	ESA	ASAR	ESA
				GLI	NASDA	PALSAR	NASDA
				ATSR	ESA		
				AATSR	ESA		

9.3 Appendix 3 Fine Resolution Design Team Report:GOFC-GOLD Report No. 4 Separate Attachment

9.4 Appendix 4 Coarse Resolution Design Team Report GOFC-GOLD Report No. 3: Separate Attachment

9.5 Appendix 5 Characteristics of GOFC Website

* (Items with asterisks will be implemented first)

* Cover page has pleasing appearance and has brief table of contents. Includes
- Logo
- Acronym and name
- Imagery – montage of little pieces, or IGBP 1 km product
- Brief table of contents to establish links to
  - Overview/Introduction/Rationale
  - Clients
  - Supporting organizations
  - Documents
  - Means to contact GOFC

* Second page is a well designed site map

Website will have a public portion for everyone, and an internal portion for GOFC participants. At least three levels of "confidentiality are possible:

- confidential URL supplied to participants
- confidential URL checked against IP adress of authorized visitors
- password protection

<u>Contents</u>

* Simple explanation of "the GOFC concept"
* Links to participating agencies

* GOFC documents available
- in Adobe for external users
- in WORD and WordPerfect for internal users during drafting stages

Project Plans including frequently updated graphical display of project progress

Project output (likely to be provided through links to agencies holding the data; GOFC may provide mirror sites).
- data products
- GIS products

* Feedback mechanism

<u>Internal Communications</u>

* Calendar
tools to facilitate development of plans and documents
tools to monitor progress of projects