# CEOS Pilot Project: Global Observations of Forest Cover (GOFC)

## Ottawa, Ontario, Canada
## July 7 - 10, 1997

**Editors: Anthony C. Janetos, NASA HQ and Frank Ahern, CCRS**

## Version 3.3

## Executive Summary

The CEOS Pilot Project on Global Observations of Forest Cover (GOFC) is defined. Six goals are identified that satisfy the requirements of the CEOS Pilot Projects, as defined by the CEOS Strategic Implementation Team (SIT). The six goals are:

**(1) Produce high quality, multi-resolution, multi-temporal global data sets and derived products of forest cover and attributes;**

**(2) with particular attention to areas of rapid change and fragmentation;**

**(3) to be repeated for quantitative analysis of subdecadal variation;**

**(4) with associated regional applications and methodological investigations;**

**(5) for the benefit of multiple user communities;**

**(6) and ultimate transition to routine operational use.**

GOFC will make maximum use of existing capabilities within the CEOS partners and affiliates. It will require additional coordination among the CEOS partners for acquisition and analytical capabilities.

A suite of potential products is defined, ranging from the actual underlying satellite data to derived products that have been defined in publications from the potential user communities. Further consultations with a variety of potential user communities will be required, to ensure that a maximally efficient allocation of resources can be achieved.

Three phases of GOFC are proposed: (1) a Design Phase, in which specific technical details of acquisition, processing, and analysis are worked out, and in which further consultation with user and operational communities are pursued; (2) a Prototype Phase, in which implementation begins, regional experiments are pursued, and the first set of experimental products are produced; and (3) an Execution Phase, in which the production and distribution of final products is achieved with new acquisitions from Earth observation sensors.

These phases then are followed by an evaluation period. The ultimate transition to operational status is planned from the beginning of the project.

## Table of Contents

## I. Introduction

Two of the most crucial roles of the Committee on Earth Observation Satellites (CEOS) are to promote the use of Earth observation data to improve the quality of life on earth, and to increase coordination and reduce duplication of the satellite programs of the member states. At its 1995 plenary meeting in Montreal, Canada, CEOS recognized the need to establish a strategic framework to determine and assess the data and information requirements for satellite-based Earth observations, and to facilitate the transition to routine operation of those research systems which have proven most useful. The plenary also recognized the need to improve the coordination of the space-based and *in situ* components of Earth observations, and to increase the terrestrial benefits of the Earth-observation data already being collected (Shaffer, 1996). In response to the requirements identified at the Montreal plenary, a working group to discuss an Integrated Global Observing Strategy (IGOS) was convened in March, 1996. This group recognized that the most effective means to accomplish its mandated objectives would be to identify pilot projects dealing with key areas of earth observations, and recommended the establishment of a Strategic Implementation Team (SIT) to select pilot projects and an Analysis Group (AG) to coordinate the requirements of the pilot projects and to ensure good coordination between producers and users of earth-observation data (Shaffer, 1997). The general goals of the pilot projects have been identified by the SIT:

(1) Provide a framework for a coherent set of user requirements so that providers can respond to them.

(2) Reduce unnecessary duplication of observations.

(3) Assist in the improved allocation of resources among different types of observation systems.

(4) Make possible the creation of improved higher level products by facilitating the integration of multiple data sets from different agencies, national, and international organizations.

(5) Provide a framework for decisions on continuity and spatial comprehensiveness of key observations.

(6) Identify situations where existing international arrangements do not exist for the management and distribution of key global observations and products.

(7) Assist in the transitioning of systems from research to operational status through improved international cooperation.

(8) Provide improved understanding for Governments on the need for global observation through the presentation of an overarching view of their capabilities and limitations.

SIT held its first meeting in Irvine, California, in February, 1997. The attendees identified six pilot projects[1] of vital importance, whose execution is expected to advance the CEOS objectives stated above. The Canadian Space Agency (CSA) and the Canada Centre for Remote Sensing (CCRS) agreed to co-lead a pilot project on Global Observations of Forest Cover (GOFC), with the U.S. National Aeronautics and Space Administration (NASA) agreeing to play a strong supporting role (Guertin, 1997).

---

[1] Global Observations of Forest Cover, Ocean Data Assimilation, Upper Air Network and Tropospheric Winds from Space, Continuity of Stratospheric Ozone Observations from Space, Long-term Ocean Color Measurements, and Disaster Monitoring and Management Support.

Recognizing its potential importance to a wide spectrum of users, this program was subscribed to by numerous space agencies including CSA/CCRS, NASA, ESA, INPE, CNES, EUMETSAT, NASDA, and ASI. It has also been endorsed by representatives of GTOS, GCOS, TOPC, EC, and FAO. However, a program of global observations of forest cover is also recognized as very challenging, requiring coordination of acquisition and analysis of data from satellites from many nations operating in the visible, infrared, and microwave regions of the spectrum. It also requires considerable input of *in situ* data and local knowledge of land cover characteristics. Ultimately, the GOFC is envisioned to lead to a routine operational capability for the observation of changes in global forest cover and its attributes.

## II. Objectives of the Pilot Project on Global Observations of Forest Cover

As a contribution to the implementation of an ongoing global forest monitoring system that will meet specific needs of international conventions, global observing systems, national institutions, and supporting research, GOFC will

**(1) Produce high quality, multi-resolution, multi-temporal global data sets and derived products of forest cover and attributes;**

**(2) with particular attention to areas of rapid change[2] and fragmentation;**

**(3) to be repeated for quantitative analysis of variation on a three to ten year cycle;**

**(4) with associated regional applications and methodological investigations;**

**(5) for the benefit of multiple user communities;**

**(6) and ultimate transition to routine operational use.**

These six objectives will enable the Pilot Project to conduct an end-to-end test of many aspects of the space-based observational systems (including data systems) that will be required for an operational IGOS. It will also enable the CEOS partners to evaluate how their space-based observations can effectively be coupled to *in situ* data, and how data products can be provided effectively to several important user communities.

## III. Scientific, Policy, and Resource Management Needs

The potential user community is extremely diverse. In many ways, the GOFC must assist communities of users in extracting the maximum information available from remotely sensed data, and from its combination with *in situ* data. Likewise, the various communities of users themselves can provide essential guidance to the GOFC to focus on those products and data sets that are of the most benefit to them, in order to guide the efficient allocation of resources, and prepare most effectively for the transition to operational status. The ultimate success of this program will lie in the extent to which national, sub-national, and international organizations make routine, ongoing use of earth-observation data to satisfy their information needs. It will be critical in both

[2] In the context of this project, the types of rapid change of greatest relevance are those caused by forest fires and land clearing, generally for conversion to various non-forest land uses.

respects to build on those programs that already exist for the production and analysis of data on forest cover and attributes. There is an explicit desire to learn from the vast experience available in the remote sensing, *in situ*, research, and operational communities.

*A. Issues*

(1) Global Change. There are three pathways of relevance for global change and forest lands with implications for this CEOS project (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?

(2) Timber, fuel, and fibre. For centuries, human society has depended critically on the continued supply of wood and fiber from forest land. Many societies have declined after depleting their forest resources (Perlin, 1991). The twentieth century has produced substantial improvements in the efficiency of production of wood and fiber from forests. Increasing populations and increasing literacy and affluence in the twenty-first century will continue to put increasing demands on the forests of the world. Continued improvements in forest management will be necessary to meet these demands without depleting the forest resource (Nyland, 1996).

(3) Watershed Protection. Forested areas and other wooded lands play a crucial role for terrestrial hydrological systems (Nyland, 1996; Hammond 1991). These areas constitute the most important buffer zones for both run-off and infiltration to ground water reserves. The actual location and size of forests in relation to the watershed often determines the run-off fraction of the precipitation and becomes the dominant factor in flood and erosion prevention. A close monitoring of forests in relation to the hydrographic network thus becomes a critical issue in physical planning, landscape planning, and environmental protection in all regions of the world.

(4) Biodiversity. Concern over the rapid, human-driven loss of biodiversity worldwide is rapidly mounting, culminating in the International Convention on Biological Diversity (Interim Secretariat of the Convention on Biological Diversity, 1994). The extent and condition of forested lands are central issues to the preservation and sustainable use of biodiversity. Both forest loss and forest fragmentation have been implicated in losses of biodiversity by the scientific community. On the other hand, many national programs for sustainable forest management are now incorporating biodiversity as one of the attributes to be enhanced and maintained. (e.g. Canadian Council of Forest Ministers, 1995.)

(5) Recreation and Tourism. Forests provide habitat for wildlife, and opportunities for recreation and tourism. In many countries, the direct economic return from these activities approaches the return from extraction of wood and fibre. Many other countries want to increase the benefits they derive from recreation and tourism. Information obtained from Earth observation data can aid in the strategic planning for recreation and tourism in forested areas.

(6) Sustainable Forest Management. Sustainable forest management has become an extremely important philosophy, along with ecosystem management, to guide the plans of land-managers (both public and private) for the use of forested lands over the next several decades. Sustainable forest management recognizes the multiple benefits provided by forests, and strives to respond to the needs and wants of the multiple stakeholders who benefit from the forest, while conserving its resources so future generations can also benefit from the forest. Earth observation data, in conjunction with geographic information systems, provides exciting new opportunities to engage a broad spectrum of stakeholders in long-term forest management planning.

*B. User Communities*

The GOFC planning group has identified several policy-level issues and potential user communities that together provide the core set of requirements for data sets, derived products, and subsequent analyses. Table 1 illustrates those user communities that have clearly articulated their observational requirements for forest information. Table 2 shows with more specificity the type of products that each community requires.

**Table 1: Status of Requirements for Issues and User Communities**

| User Communities | Global Change | Timber, fibre, fuel | Watershed Protection | Biodiversity | Recreation and Tourism | Sustainable Forest Management |
|---|---|---|---|---|---|---|
| *International Environmental Conventions and Agreements* | (X) | | | (X) | | (Y) |
| *International Policy and Operational Institutions* | (X) | X | | (Y) | | X |
| *Nationaland sub-national institutions* | X | X | X | (X) | X | X |
| *Scientific Community* | X | Y | Y | (X) | Y | Y |

Key

X: Published requirement statements

(X): Relevance clear from published documentation of issues

Y: Requirements published at national and sub-national levels

(Y): Requirements in early stages of development

**Table 2: Core Requirements of Major Users**

| | GCOS and GTOS | International Conventions | Science | IPCC | Other International Users | National Users |
|---|---|---|---|---|---|---|
| Baseline land cover | X | X | X | | X | X |
| Land cover change | X | X | X | | X | X |
| Land cover coarse resolution | X | X | X | X | | |
| Net Primary Productivity | X | X | X | X | | X |
| Biomass | X | | X | X | X | X |
| Fires | X | X | X | X | X | X |
| Harvest | X | X | | X | X | X |

(1) International Environmental Conventions and Agreements. The major conventions concerned with global forests are the Convention on Biological Diversity (Interim Secretariat for the Convention on Biological Diversity), on Climate Change, and on Desertification. Their core information needs are those quantifying major changes in the distribution and function of forests over time. Some of these can be met with Earth observation data, and are in general consistent with those discussed below for the GxOS's. The Framework Convention for Climate Change, particularly the Kyoto Protocol, (Framework Convention for Climate Change Internet Website), the Biological Diversity Convention (Biological Diversity Convention Internet Website), the Forest Principles agreed to at UNCED, the Montreal, Helsinki, and Tarapoto processes (Canadian Forest Service, 1996; ISCI, 1996; World Forestry Congress, 1997), and others all have a shared need for information on global forests. This need is most explicit in the scientific assessments that are either part of the Conventions and other instruments themselves, as in IPCC, or have been commissioned independently of them, as in the Global Biodiversity Assessment. The specific national requirements of the FCCC for the development and monitoring of national emissions inventories, and the international discussions of carbon trading, will require accurate and replicable assessments of forest cover at both national and international levels. The reporting requirements of the Biodiversity Convention for assessing national biodiversity and habitat, likewise require accurate information on forest cover, fragmentation, and change. The Intergovernmental Forum on Forests meets to discuss an Internaltional Convention on Forests. It has emphasized the need for a correct assessment of forest resources.

(2) International Policy and Operational Institutions.
The Food and Agriculture Organization of the United Nations (UN/FAO) is mandated to produce a global forest resource assessment (FRA) every ten years. 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. FAO also carries out projects of capacity building for forest assessment at the national level in developing countries. The provision of standardized regional datasets could facilitate FAO activities at the national level.

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 centres (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. Information on forest harvest is also an important input in this process.

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.

The United Nations Environment Programme (UNEP) provides access to datasets and carries out projects in key areas of environmental concern. The satellite data and many of the derived products proposed by GOFC will be be of interest to UNEP.

<u>(3) Scientific Community</u>. 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. Individual national scientific programs, such as the US Global Change Research Program, and the Canadian Global Change Program share these requirements, and place a high priority on the production of such data sets.

<u>(4) National and Sub-National Institutions</u>. Countries are interested in their forests because of the value of the forests for their economies and because of the environmental values of forests, both nationally and internationally. Some countries are increasingly concerned about the impact of the environmental movement on the economic utilization of the forest resource. Following the UNCED conference in Rio de Janeiro in 1992, forest nations have been discussing draft forest principles, and developing criteria and indicators of sustainable forest development. For these and other reasons, nations have begun to pursue initiatives aimed at tracking and

reporting on the forest condition and changes in their countries. Land cover, cover change and biomass are fundamental ‘state’ attributes for this purpose. Forest conversion to agriculture, harvest and fires are the most ubiquitous change agents at the global level. Damage by insects and disease, and various forms of pollution are often important nationally and locally, and in several instances are severe enough that affected areas can be mapped using spaceborne data. In many countries forestland management falls within the jurisdiction of sub-national (e.g. state and provincial) agencies. Earth-observation data have been extensively used to provide general information at the national and sub-national level. 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.

It should be noted that the degree to which a global product meets the needs of individual countries will vary depending on the information sought. For example, the global products for fires, biomass, net primary productivity and land cover at coarse resolution are more likely to meet the needs of individual countries than those for detailed land cover or land cover change. This distinction suggests various possible mechanisms for collaboration between the global project and individual countries, including a contribution to product development and validation, the development of new, more detailed or tailored products to meet the specific national needs, and technology transfer and capacity building.

Many national-level forestry ministries and environmental ministries are in the midst of planning efforts to transition from management of forested lands with the primary goal of timber production to sustainable management of forest resources, combining production of forest products with watershed protection, tourism, recreation, and other non-exploitative uses. In addition, the proliferation of international agreements with implications for forests has created new pressures on national institutions to respond with accurate and timely information. Regionally, countries whose forests contribute substantially to the national economy are cooperating to develop criteria and indicators of sustainable forest management.

*C. Satisfying Requirements*

It is important to note that while the CEOS pilot project perceives that these issues and user communities will find the products to be important, it cannot expect to satisfy all the demands of all potential users. Instead, there is a core set of requirements that can be substantially fulfilled by the products we have outlined. Other requirements can be addressed, but may not be completely fulfilled by the first set of planned products. However, we leave open the option of further activities in a later phase to define new sets of products that might satisfy additional requirements.

All of the users identified above are generally non-commercial scientific and educational organizations, or governmental or intergovernmental organizations dedicated to the public good. We also clearly anticipate that there may be commercial interests in the Pilot Project outcomes as well. Therefore, it is important to emphasize the expectation that derived products from the Pilot Project will be widely accessible and available without discrimination.

It is also clear that many users may wish to derive their own, tailored products from the underlying data used in the Pilot Project. The existing CEOS principles for non-discriminatory access to data should enable all users to search well-organized Pilot Project archives. The Pilot Project will seek to work with data providers to ensure that all data used in the project are organized in such a fashion that they can be accessed and distributed according to the national policies that govern their use.

## IV. The Current Experience Base

Over the past ten years, the remote sensing community has developed an impressive array of projects dealing with global, regional, and local forest-related issues. Projects have been implemented in North America, Europe, Asia, and South America that have examined such issues as tropical deforestation, forest cover mapping, forest health and vigour, and the extent of inundated forest. As a result, there is a broad spectrum of lessons to be learned for the planning and implementation of the Pilot Project.

### *A. Existing Programs and Data Sets*

The approach adopted is to build on existing national and international programs and activities. Around the world, experts have been building the scientific, technical, and procedural underpinnings for a forest cover change monitoring system through joint space agency initiatives. The Ottawa workshop recognized that some of the components of the program already exist. Rather than duplicate such efforts, wherever possible, the approach would be to integrate these existing studies into a broader programmatic framework.

<u>(1) World Forest Watch</u>. The World Forest Watch Meeting held in São José dos Campos, Brazil (June 1992) provided an initial high-level international forum for the assessment of current approaches to satellite-based monitoring. This meeting also served as a basis for forwarding recommendations from the technical and scientific communities to the policy makers and government leaders at UNCED. A variety of international participants were represented at the World Forest Watch Conference. The conference concluded that significant technical and methodological advances have been made in recent years, and they are now sufficient to proceed with an observation system which could satisfy both scientific and national-level forest management requirements. One important outcome was the Panamazonia Project, in which Brazil shared its proven technology for mapping deforestation in the Amazon region with its neighbors who share the Amazon Basin. These countries were subsequently able to produce deforestation estimates (Martini, 19??).

<u>(2) Landsat Pathfinder.</u> 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 and re-growth. The project is now in the process of extending its initial proof-of-concept to a large-area experiment across Central Africa, Southeast Asia and the entire Amazon Basin. The project is acquiring several thousand Landsat scenes at three points in time -- mid 1970s, mid 1980s, and mid 1990s -- to compile a comprehensive inventory of deforestation and secondary growth to support global carbon cycle models. Methodology and procedures have been identified. Although this exercise is being implemented for most of the tropics, it is not an operational global program. In principle, it provides an initial large-scale prototype of an operation program.

<u>(3) TREES.</u> 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 from earth observation sensors and other sources.

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

(4) IGBP 1 km Land Cover Mapping Project. In conjunction with NOAA and the USGS, NASA has been supporting an IGBP project to acquire global, daily coverage with the AVHRR sensor at 1 km resolution (Belward, 1996). This project is the first of its kind to acquire global, daily coverage. The resultant dataset is being processed at the EROS Data Center and provides the basis for mapping land cover, vegetation phenology, and fires. As part of a land-cover mapping exercise, this project will also develop a multi-level set of land cover maps ranging in spatial resolution from 1 degree down to 2 km.

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

Participation in international programs has been found to be a successful means for implementing international research and collaboration. Participation by scientists in the IGBP, WCRP and IHDP has proven to be effective in mobilizing the international research and monitoring community. The new joint core project of the IGBP and IHDP on Land Use and Land Cover Change (LUCC) could greatly benefit the proposed program (Turner *et al.*, 1995). Similarly, the IGBP Global Land Cover Program is a good example of potential international collaboration geared towards the generation of global land cover data. The NASA/ESA/USGS/IGBP Global 1km AVHRR data base is a good example of internationally coordinated data acquisition.

(6) FAO Forest Resource Assessment. The FAO Forest Resource Assessment for the 1990 period (FRA-90) used a combination of earth observation data and national statistics to derive statistics about forest cover for the 1990 datum, and forest cover change for the period 1980 to 1990 (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. Using training centres in Latin America, Africa, and Asia, FAO was able to train local interpreters and obtain consistent results. The resulting change classes also allowed FAO to estimate transitions between several woody biomass categories for Africa, Latin America, and Asia (FAO, 1996). The FAO Forest Resource Assessment Project provides an important interface to the national forest monitoring communities. Such projects can benefit from the proposed GOFC program as well as help the program.

(7) GAP Analysis Project. The GAP Analysis Project (Scott, Tear, and Davis, eds, 1996) is a land cover mapping project being carried by several consortia of U. S. federal and state agencies, led by the U.S. Geological Survey. The purpose is to infer wildlife habitat from land cover, and identify habitats in not adequately

represented in conservation lands. The project has obtained a large amount of valuable experience in catalyzing inter-institutional cooperation, and in processing and classifying large volumes of Landsat data according to varying standards developed by user agencies.

<u>(8) Multi-resolution Land Characterization.</u> A good example of a regional /continental scale land cover mapping study is the recently completed USFS /USGS US Forest Cover Map. This map was produced using the 1km AVHRR data set generated by Loveland *et al.* (1991). A similar effort is being undertaken in Mexico with the help of in-country collaborators. 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.

<u>(9) North American Landscape Characterization Project.</u> Datasets from Landsat, SPOT, AVHRR and other sensors with global and national coverage have created opportunities to exploit data in ways not possible just three or four years ago. For example, the North American Landscape Characterization (NALC) Project (North American Landscape Characterization Project Internet Website) is acquiring and processing complete coverage of the continental United States and Central America with Landsat MSS data at three points in time from the 1970s to the present.

<u>(10) The Global Rainforest Mapping Project.</u> Within the framework of NASDA's Global Forest Mapping Program, the Global Rain Forest Mapping 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 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 are being generated to cover the tropical region in all three continents, for distribution free of charge for research and educational purposes on CD-ROM and over the Internet. The mosaics are radiometrically and geometrically corrected (however not for topographical effects). Land cover classifications are also foreseen. A research program is being coordinated by NASDA for multi-temporal studies at local to continental scales.

Starting in 1997, the Global Boreal Forest Mapping Project (GBFM) forms a follow-on project to the GRFM. The GBFM project aims at covering the boreal forests in Siberia, Northern Europe and North America with JERS-1 SAR. Data acquisitions over the each region of interest have been completed once during the spring and summer of 1997. SAR mosaics at 100 m resolution will be generated and distributed free of charge for research and education. Also the GBFM project is a joint effort by NASDA, NASA/JPL/ASF and the JRC, with collaboration from DLR, the National Swedish Space Board, CCRS, and CSA.

<u>(11) Radarsat.</u> The Canadian Radarsat program has acquired complete global coverage in the ScanSAR mode during its initial phase of operations (Mahmood *et al.,* 1998) An associated PI research program was initiated to demonstrate applications, including applications to forest are research. Research to date has shown Radarsat to hold promise for mapping logging and deforestation in tropical and boreal forests (Shimabukuro, *et al.,* 1997; Kux, *et al.,* 1997; Ahern *et al.,* 1997) and for monitoring macrophyte growth in tropical reservoirs and floodplains (Costa *et al.,* 1997). The frequent, wide area coverage available, unaffected by cloud cover, makes Radarsat attractive for filling in gaps in optical data caused by persistent cloud cover.

<u>(12) Landsat - 7.</u> Landsat - 7 has become part of NASA’s Mission to Planet Earth, and will be launched in 1999. It will fly in formation with EOS AM-1, enabling researchers to obtain low and high resolution images of

the same area on the same day. MODIS data will enable atmospheric corrections of Landsat data to become operational for the first time in the program. The data price will be much lower than the previous commercial price, and there will be no copyright restrictions. A data acquisition strategy which incorporates data needs, local phenology, and local climate and weather, combined with an on-board solid state data recorder capable of recording 200 scenes per orbit are expected to provide global coverage which is more consistant and useful than in the past. These changes in policy and strategy will make it much easier to achieve the GOFC objectives.

(13) SPOT Vegetation The SPOT 4 mission will pioneer the simultaneous acquisition of wide area, low resolution data supplemented by pointable high resolution data, and stimulate the development of suitable data acquisition strategies (Phulpin and Gentet, 1993). The addition of a spectral band in the 1.6 to 1.8 µm region on both sensors will provide added sensitivity to damage from fire, insect attack, air pollution, and other causes (Vogelmann and Rock, 1988; Ahern et al, 1991).

(14) FIRS In 1994, the Joint Research Centre of the European Commission, in cooperation with the Commission's Directorate General 6 FII.2 and EUROSTAT, launched the FIRS (Forest Information from Remote Sensing) Project (Folving *et al.*, 1995). The objectives of the FIRS Project are:

1. To contribute to the development of a unified European forest information system;
2. To develop methods for providing both sectorial (i.e. production-related) and environmental (i.e. ecology-related) forestinformation, in the form of both statistical and mapped data;
3. To use remotely sensed data as a major source of information;
4. To use geographical information system (GIS) techniques to reduce the cost of data collection, data handling and data distribution;
5. To assist in the development of new methods for forest data collection and communication systems using space technology.

The project comprises two main parts. The first part consists of three Foundation Actions: 1) Regionalization and stratification of European forest ecosystems; 2) Design of a system of nomenclature for European forest mapping and 3) Compilation of a European geo-referenced forest data directory. The second part is divided into six major Application Themes: 1) European forest statistics; 2) European afforestation monitoring; 3) European forest mapping; 4) European forest monitoring; 5) European forest modelling and 6) Mapping and monitoring of European grassland and non-forest natural vegetation.

(15) Remote sensing use for forestland management at the national and sub-national level

Since the launch of Landsat 1 in 1972, numerous national and subnational agencies have experimented with and used earth-observation data for a variety of forestland mapping and monitoring activities. In most cases, the user agencies have been satisfied with the results as long as the work was competently performed and the user expectations did not exceed the the information content of the data. Nonetheless, it is generally agreed that earth-observation data has not fulfilled its expectations . Impediments to wider use include:

- High cost of earth-observation data. The new U.S. Landsat data policy is expected to help reduce this problem;
- The technology seems very complex and specialized to the un-initiated. Many consulting companies have sprung up to aid with the selection and use of the data, but this creates increased costs for the user;
- Earth-observation data provides less-detailed "top-down" information, while forest inventories have traditionally used a "bottom-up" approach with detailed information obtained from ground surveys and aerial photography. There has not been enough effort put into developing methodologies to incorporate the best features of both approaches;

- It is too difficult for unitiated users to know which E-O data sources are most suitable for their needs, and to locate and procure suitable data. The CEOS Working Group on Information Systems and Services (WGISS) is leading an international effort to address this problem.

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

*B. State of the Art*

(1) Technical Progress. Considerable technical progress has been made during the past five years in assembling large data sets from both high resolution and coarse resolution sensors, and in extracting information from these data sets. Increasing computer capability to move, store, and track massive amounts of data has been an essential enabling technology. Most of the coarse resolution studies have used AVHRR data. Researchers have developed methods for geometrically correcting the data and creating single-date mosaic images and multi-date composite images which are relatively free of geometric errors and radiometric artifacts. The TREES project and the IGBP 1 km Land Cover Mapping Project have both produced land cover classifications of large fractions of the world, while other efforts have produced land cover classifications at the national or continental level. Validation efforts are now underway for all of these products.

The Landsat Pathfinder program has enabled several organizations to develop methods to collect and assemble datasets of 30 m resolution data covering areas as large as the conterminous U.S. and the Amazon Basin. This experience has also pointed up the difficulties in collecting and correcting data from the existing Landsat data archive, and stimulated improvements for Landsat-7. The lack of accurate base maps to correct data of resolution below 100 m, coupled with the lack of high resolution DEM threatens to limit the accuracy with which high resolution data can be corrected and superimposed.

A significant number of researchers and operational users of both coarse and high spatial resolution data appear to be converging on a common approach to digital classification of multispectral/multitemporal optical data: numerical clustering of the data into a large number of data clusters (typically 50 – 100 clusters; sometimes called hyper-clustering), followed by merging and labeling the data clusters into desired thematic classes. The merging -labeling step is carried out by interpreters who are knowledgable about the land areas being studied, and seems to combine the best characteristics of digital and visual classification at the current time. This process is still very laborious, and digital image classification will be an important consideration for GOFC.

Research with L-band (JERS-1) and C-Band (ERS and Radarsat) SARs has built upon experience gained with airborne SAR missions and the SIR-C/XSAR mission to provide confidence in the use of SAR for GOFC. While the thematic content of single-band orbital SAR is not as great as that of optical sensors, the ability to cover large areas in a preplanned, systematic manner was recognized as a very important operational advantage at the

Ottawa workshop. Techniques for systematic geometric correction (except for terrain correction, where DEM data can be a problem) and radiometric calibration of SAR data are becoming highly automated. The Global Rainforest Mapping Project has gained considerable experience in assembling JERS-1 mosaics of large areas, and the routine radiometric calibration of the data is so good that no further radiometric processing of the mosaics is necessary.

(2) Institutional Progress. The IGBP and the Global Observing Systems have created well-functioning international bodies to ensure ongoing dialog between the producers of Earth observation data and the scientific community, addressing the very difficult global issues facing humanity. Most of the projects described in section IV A have created temporary or permanent inter-institutional linkages which have functioned well. The World Forest Watch, the FAO Forest Resource Assessment, and the GAP Analysis Project have demonstrated different ways to extend Earth observation technology to a multitude of users, particularly those involved in natural resource management planning. However, at a higher national and international level, the link between the information which can be obtained from Earth observation data and the formulation of policy has not been as well established.

*C. Gaps and Lessons*

Some common lessons have been learned from the above-described projects.

(1) Data Acquisition, Access, Pre-processing and Management. A systematic global data acquisition plan is necessary and requires the contribution of multiple ground receiving stations. Data have to been processed in standard format and well-documented in the catalogs. A comprehensive metadatabase including all the high spatial resolution sensors' images would be an important improvement for data access. Within the project, an automated information and archive management system is required. A high resolution DEM is needed in hilly and mountainous areas to orthorectify spaceborne data. This is particularly true for SAR data which is more severely affected by the effects of slopes and elevation variations.

(2) Product definition. Achievable products, not overly ambitious, must be defined. They must be explicitly targeted to specific user requirements. Legend definition and analysis design require the contribution of a large panel of experts, users, and potential users near the very beginning of the project. It is essential to document explicitly the forest classes and propose a correspondence between the sensor-based classes and the ecological classes.

(3) Data analysis. Operational data analysis must be based on existing and proven methods rather than relying too much on R&D. Data analysis methods can combine visual interpretation and digital classifications. For land cover change, a control mechanism is needed in order to check the consistency between the multi-date analyses and avoid excessive error propagation. Change information may be more reliably obtained by classifying two-date datasets than by comparing two single-date classification. A multi-resolution approach will allow the Project to exploit the complementarity between high and low resolution data: a sampling scheme of high resolution is optimized using low resolution data as a stratification, while high resolution data can correct the areas derived from low resolution data. Particular attention will be given to a validation schemes. Products' validation may be performed through comparison with immediate finer resolution data, i.e. fine resolution products can validate low resolution products, field observations can validate fine resolution products. National experts should contribute as soon as possible to the product validation.

(4) Product distribution. Open access to final products and validation sets is a key point for the success of the project. It can be achieved though WWW, CD-ROM or paper maps and reports. Continuing user support will be needed.

## V. Framework

*A. Strategy*

The Pilot Project is anticipated to have an overall lifetime of approximately five years, with initial test products being available within the first three. It anticipates several categories of outputs: basic scenes, specific time frame products, and change over time products.

(1) Raw data (Level 0) and corrected scenes (Level 1B). These represent composites of the basic raw data for all sensors covering all forest land areas of the globe. Data products at this level would enable users to undertake projects to contribute to preparation of global products identified in Table 3, as well as products that fulfill specific national and/or regional needs above and beyond those identified in Table 3. This level of product preparation is viewed as an absolute minimum in terms of project success. Optical sensors will provide high thematic resolution and temporal resolution at low spatial resolution, for wall-to-wall coverage, detection of drastic events, and forest seasonality monitoring.

(2) Specific Time Frame Products. This is the preparation of products of global forest cover and characteristics identified in Table 3 for specific years or time periods. These data sets essentially would represent the status of forest land cover and forest characteristics at specific points or windows in time (ie $T_{1990}$, $T_{1995}$ or $T_{1980-90}$ or $T_{1990-95}$).

(3) Change Products**.** This is the preparation of global forest cover and characteristic products identified in Table 4 that show the change in these parameters over time. (ie. $T_{1995}$-$T_{1990}$).

Most of the data acquisition issues follow directly from the primary project objective. Test products from the design and prototype phases (see Section VIII) are anticipated to be largely regional, and based on existing, available data sets. However, near the end of the prototype phase, the project will begin the production of derived products from new acquisitions. Thus, global and regional data sets are required from the present generation of spaceborne imaging optical and microwave sensors and their near-term successors, in conjuction with concurrent *in situ* data. The CEOS members will need to coordinate their respective strategies for the related future global-scale satellite acquisitions in order to acquire such data systematically and effectively. Particular organisational efforts may be required where an international network of ground receiving stations is involved.

For efficiency, the acquisition strategy should exploit the complementary capabilities and information content of optical and microwave sensors to address specific thematic issues on appropriate time scales:

Optical Sensors providing both high spatial and thematic resolution, based on well-established methodologies, under suitable acquisition conditions.

Microwave Sensors providing all-weather acquisition capability, at high spatial resolution and frequent revisit rates, but low thematic resolution, and utilising analysis methodologies which will necessarily evolve throughout the project.

Validation plans will be formulated and implemented as feasible so that users of both raw data and derived products will know their accuracy and limitations. Feedback will be solicited from users to refine derived products in order to maximize their utility.

*B. Simple Global and Detailed National Products*

It is anticipated that the global information needs in most cases are less detailed or specific than national or local needs. Hence, flexibility in data resolution and product specifications is both a requirement and a benefit of this project. Preparation of products at three levels provides this flexibility. Where specific user needs are more specific or detailed, the Level 1B (see Appendix 1) data should allow users to develop products at the level specific to their needs and requirements. At the same time using a common agreed upon global format or classification should allow more detailed national and regional information to be rolled up to meet the basic global requirement. Hence, the more simple global needs can be met while at the same time providing the flexibility to meet more detailed national and local needs and requirements. It is expected that this project will stimulate much activity at the national and sub-national level for practical forestland management, above and beyond that related to the global portion alone.

*C. Product Identification*

<u>(1) CEOS Level 0 and 1B Products</u>. The Appendix presents the lowest level products, characterized as level 0 and 1B CEOS products. These products are basically “raw” (level 0) data or data to which calibration and geometric processing are applied (level 1B). They will not be discussed further.

<u>(2) CEOS Level 2 Products</u>. Table 3 contains level 2 products that are obtained from level 1B data, but are based on more complex processing techniques, like classification algorithms or functional dependencies, and may require *in situ* or ancillary information to be developed. (Global Climate Observing System, 1997.)

*Fine Scale Land Cover:* Products derived from high spatial resolution data are georeferenced data sets describing the predominant forest types that can be used as a baseline inventory for long term studies of land cover and land cover change. The temporal coverage of this data will be less than that of mid-low spatial resolution land cover products. The total global number of classes could reach 50 or more. They will include various wooded ecosystems : temperate and tropical forests, savanna, and others. These products may be derived from various sensors.

*Coarse Scale Land Cover:* Products derived from low spatial resolution data can be updated more frequenty than the fine scale products due to the sensors’ data acquisition cycles and lower data volumes. The total global number of classes could reach 40 or more. However, observational constraint imposed by the coarser resolution will prevent the detection of changes affecting areas of less than several $km^2$. Areas affected by large wildfires will be type of change most suitable for frequent update using coarse resolution sensors.

*Fires:* Fire is a primary force of vegetation change/renewal in some ecosystems. It is important to monitor fires in the context of a forest monitoring program with respect to their role in global trace gas emissions, land conversion, ecological disturbance regimes, and land management. Data products will consist of fire occurrence and burned area, providing the location, timing, and areal extent of burning. A thermal channel product will provide hot spots which may indicate forest fires.

*Harvest, regeneration, and afforestation:* It is important to distinguish between land cover change due to clear cutting and selective logging. Harvesting, regeneration, and afforestation are some of the most significant anthropogenic changes that occur in the forest. These often occurs in similar locations from year to year.

*Biomass:* This product will largely depend on *in-situ* field measurements and other ancillary data. Earth observation data cannot provide direct measurements of biomass, but may be used to extend local estimates to larger areas, with varying degrees of confidence.

*LAI, FPAR and PAR:* These products provide the necessary information to derive net primary productivity (NPP) using process models at the landscape level (Running *et al*, 1989; Liu *et al*.., 1997). NPP is an essential component of all carbon budgeting calculations.

FPAR, the fraction of photosynthetically active radiation absorbed by a vegetation canopy is readily measured from space on clear days from observations of the upwelling radiance above the canopy, since the downwelling radiance (PAR) can be readily estimated. Daily observations with polar-orbiting meteorological satellites are well suited to these observations. Progress has recently been reported in extending these techniques to cloudy days using frequent observations of upwelling radiance (Li and Moreau, 1996; Moreau and Li, 1996). Geostationary meteorological satellites provide the most suitable observations of PAR, which can exhibit rapid temporal variations under conditions of variable cloud cover.

Leaf Area Index (LAI) is required to calculate the efficiency with which APAR is converted into stored carbon. LAI can be estimated from observations of FPAR, but knowledge of land cover is also needed to produce estimates of adqueate accuracy.

**Table 3: Level 2 products**

| Product | Sensor | Accuracy/ Optimal/ (minimum) | Resolution(m) Optimal/ (minimum) | Cycle interval Optimal/ (minimum) | Delivery wait Optimal/ (minimum) |
|---|---|---|---|---|---|
| Fine Scale Land Cover | Optical high spatial res & Microwave | 50 classes (20 classes) | 10-30 (100 ? or 1:1.000.000) | 3 yr (10 yr) | 2 yr (5 yr) |
| Coarse Scale Land Cover | Optical mid-low spatial res & Microwave | 40 classes (20 classes) | 250-1000 (or 1:5.000.000) | 1 yr (3 yr) | 1 yr (3 yr) |
| Fire Scars | Optical mid-low spatial res & Microwave | 2 classes[3] (2 classes) | 250-1000 (4000) | 1 yr (1 yr) | 1 month (6 months) |
| Harvest | Optical high spatial res Microwave | 3 classes[4] (2 classes) | 10-30 (50) | 3 yr (10 yr) | 2 yr (5 yr) |
| Biomass | microwave and in-situ and ancillary data and mid-low spatial res | 10% of measured value (20%) | 100 (1000) | 10 yr (20 yr) | 2 yr (5 yr) |
| LAI | optical low-mid spatial res | 0.2 (1) absolute | 250 (2000) | 10d (1mo) | 10 d (10d) |
| FPAR | optical low-mid spatial res | 5% (10%) | 250 (2000) | 10d (1mo) | 10 d (10d) |
| PAR | optical low-mid spatial res | 10% (20%) | 1000 (4000) | 6 h (12 hr) | 1 d (2d) |

[3] (burned - not burned,+hot spots)

[4] (clearcut, selective logging, not logged/ (clearcut, not logged))

(3) CEOS Level 3 Products. Table 4 contains one level 3 product at the present stage, which consists of a land cover change product that requires multitemporal data and a more sophisticated classification scheme. We propose to limit the land cover change measurements to regions at high risk of disturbance, because land-cover change only affects part of the global forest. This stratification can be achieved by starting with coarse scale indicators (fires, population, logging concessions, etc.). The land cover change measurements can be based on sampling strategies or exhaustive mapping in sensitive regions.

**Table 4: Level 3 products**

Note: Classes for this product shall represent change. Sampling may apply. To be linked to low resolution land cover and fires.

| **Product** | **Sensor** | **Processing level/ Accuracy** | **Resolution (m) Opt (min req)** | **Cycle Opt (min req)** | **Delivery Optim (min req)** |
|---|---|---|---|---|---|
| Land Cover Change | Optical high spatial res + Microwave | 10 classes (4) | 10-50 | 1 yr (5 yr) | 1 yr (5 yr) |

*D. Data Bundles For Users.*

The Pilot Project will also undertake to enhance the value of derived products for particular user communities by providing them as part of a data bundle. These bundles are collections of data and derived products which particular programs or users can use most effectively to fill a particular need, thus cutting down on the provision of data that are non-essential to that need.

The example below shows how the data bundling might work to meet the requirements of the Framework convention user community. A bundle is proposed for emission inventories, which focuses on data for land-cover change and biomass burning. Multiple sensors are required to produce these complete packages, and CEOS can therefore play an important role by providing coordination and cooperation in acquiring and processing data from different sensors, platforms, and programs.

Here we provide an example as it might be done for emission inventories, and carbon cycle research. An Emission Inventory data bundle is shown below.

**TARGETED CEOS DATA BUNDLE**
**BUNDLE NAME: Emission Inventory**
**USER: Framework Convention on Climate Change, IPCC, IGBP**

| Dataset | Horiz. Res. | Cycle | Timeliness | Accuracy | etc... |
|---|---|---|---|---|---|
| L.C. 1 | - | - | | | |
| L.C. 2 | | | | | |
| Fires | | | | | |
| Biomass | | | | | |
| etc | | | | | |

**Input Data Sources from Archive**

| Input Data | Source/Sensor | Sp. Resolution | Temp. Res. | etc |
|---|---|---|---|---|
| Deforestation, decadal | SPOT, TM, IRS | 10-50 m | 5 yr | .... |
| deforestation, annual | SPOT, TM, JERS | 10-50 m | 1 yr | |
| Logging | JERS, Radarsat | 10 - 30 m | 5 yr | |

## Acquisition Strategy

An acquisition strategy must be developed to ensure the necessary data are acquired to produce each of the required products. This is particularly true for the data bundle products, where data from multiple sources must be combined to produce the required product. It will be necessary to create an organization to continuously monitor data acquistion and modify acquisition plans to ensure that complete coverage is obtained.

## Data Processing Bundle

This data bundle provides a package which includes the 5 data products necessary to make an emission inventory as well as the bundle of requisite satellite sensors; it provides a framework for plugging in datasets as objects, and provides a framework to define CEOS partners participation. It also couples the acquisition strategy directly to the products and the user/science requirements. Finally it couples a data processing bundle which include the algorithms, data distribution mechanisms, formats, and information systems necessary to produce the data archive and the products.

## VI. Methodologies

*A. Sensors*

A preliminary list of sensors relevant for the project has been identified. The focus of the Pilot Project is on those systems that are either currently in orbit, or are funded and in the development cycle for launch within the next several years. There are clearly many other missions that might become available within the next decade, but they are beyond the scope of the current Pilot Project.

<u>(1) Optical coarse resolution sensors (1km - 200m)</u>

These sensors provide high thematic information with high temporal sensitivity, but at coarse spatial resolution for seasonal evolution and monitoring studies.

Exisiting: AVHRR,ATSR, Resource MSU-SK, WiFS

Near-term : AATSR, SPOT Vegetation, MODIS, GLI, MERIS, MISR,POLDER,SEAWIFS, CEBRS WFI Camera

(2) Optical Fine resolution sensors (200m - 15m)

These sensors provide land cover and land cover change information with great spatial and thematic detail. However, the data volumes are very large, and it is not yet possible to automate the classification process completely. This necessitates a long interval between land cover updates. Best use of resources can be achieved by revisiting areas of rapid change more frequently.

Existing :SPOT/HRV, IRS/LISS II, Landsat 5/TM, MOS/MESSR

Near-term: SPOT4/HRVIR,Landsat 7 ETM+, ASTER, ADEOS AVNIR, CEBRS CCD Camera, Resource MSU-SK

(3) SARs (fine-resolution 150 - 20 m)

SAR (Synthetic Aperture Radar) sensors can acquire data through clouds and are needed in areas of nearly continuous cloud cover, such as tropical rainforests and some coastal areas. They can provide information on land cover change.

Existing: ERS1,ERS-2,JERS-1,RADARSAT

Near term: ASAR,ALOS,SRTM, Lightsar?

(4) Hyper-resolution Optical sensors (0-1m)

This data is expected to be available commercially during the course of the GOFC project. A very limited set of data from these sensors could contribute to validation.

*B. Data Access*

The procedural aspects of data access deal with metadata formats and data browsing and query systems on the one hand, and the delivery elements of timeliness, media and means on the other hand. The Pilot Project will investigate a unified system of metadata maintenance and integrated mechanism of cataloguing, querying and ordering. Integrated systems may be ensured by remote sensing data distribution and access networks such as EOSDIS and CEONet currently under development. Although a unified system of metadata maintenance may be sufficient to provide the first level of information on a data set, the availability of a quick-look facility at the browsing and query stage may be highly desirable to know the quality of the data before these can be ordered.

The delivery elements that need to be taken into consideration are the turn around times covering the data ordering, data reception/archive retrieval, data processing and data transmission cycle. Agreements on standardization of delivery medium are important in view of the variety of strategies adopted at various output centres. The means of delivery are wide ranging, but need to be verified for each of the missions participating in the project.

*C. Data Pre-Processing and Management.*

All data provided for the Pilot Project should be pre-processed in a standardized way in order to maximize the amount of automation that is feasible.

Concerning the data management, the lessons learned with the CEOS initiative 'High Resolution Data for IGBP' show that it is crucial that there be clear responsibilities and accountability for data management and distribution. Tools will be required to compile the metadata to make up a Global Forest metadata base. A tool for inventory tracking has to be designed and implemented at the management level and probably also in each producing center. The project archive could be distributed among the various producers and consulted through a interoperable catalogue. A documentation system (web site, CD-ROM, etc.) must be created.

*D. Analysis*

The aim of the analysis is to produce global datasets of forest cover and attributes.This will involve integration of data from a number of satellite instruments to provide global coverage at appropriate resolution and timescales. A key issue to be addressed by this project is therefore harmonisation of methods and results to ensure global consistency and comparability.

The outputs desired are anticipated to require two forms of analysis. The first is direct production of a thematic classification of forested areas, while the second requires modelling of the data to derive information on forest functioning.

<u>(1) Thematic Classification</u>. Methodologies for thematic classification of forest from coarse resolution satellite information (eg TREES) and fine resolution (eg Landsat pathfinder) have been an active research area for many years. Results from microwave seonsors have also demonstrated distinguishing forest, inundated forest, and non/forest with high temporal coverage. The number of classes envisaged and the useful spatial resolution implies that considerable analysis of fine resolution satellite data will be employed. It is anticipated that data from a number of fine resolution sensors will be required in order to obtain adequate cloud-free coverage. A key issue to be resolved is how to combine the results of classifications resulting from different instruments, particularly with respect to analysis of change detection. The coarse resolution instruments have the capacity to provide information at higher temporal scale, giving more opportunity to use phenology in class seperation, and to optimise the acquisition strategy for data processing. For the production of thematic classes, ancilary data will be required in order to identify categories such as dominant tree species. An important contribution will be to direct and stimulate research leading to greater automation of image classification.

<u>(2) Derivation of information on function</u>. The estimation of the net primary productivity (NPP) requires a model of ecosystem function. Driving variables in addition to the classification information are LAI, FPAR as well as ancillary data on downwelling PAR, temperature etc. Information for forest functioning models is required at a much higher temporal resolution than the classification (at timescales of one hour to ten days). Accordingly, while an accurate classification of land cover is needed, these applications will mostly require coarse or moderate resolution data. Currently, a number of models exist specified for different ecosystems, and there is not a consensus on best methods to invert the necessary parameters from remote sensing observations. It is recommended that accuracies from different platforms are made comparable, and that assimilation techniques

are developed similar to those routinely employed in meteorology. Further ancillary data are required to both drive and validate model function, and to derive parameters such as biomass.

*E. Ancillary Data*

Several types of ancillary data will be needed for the pilot project both for data pre-processing, satellite data analysis and product validation. For example data processing of the coarse resolution data will involve the use of coarse digital terrain data to provide first order atmospheric correction and improved geolocation for coarse resolution data sets used in classification. The existing global 1km topographic data set will be adequate for meeting these needs. Similary a common land water classification and mask will be needed for the coarse resolution data products. An enhanced land water mask for use with coarse resolution systems, derived from a combination of microwave and moderate resolution sensing systems available in the near-term would provide a desirable improvement over the current data base derived from the best available map sources. The development of a standard ‘community’ land water mask derived from multiple sensing systems would be a useful CEOS contribution to this activity.

For the individual sensor products and the multi-resolution integration there will be the need for the data products to be presented in a common geographic coordinate scheme. This will have to be developed early in the project. For high resolution, the availability of a new high spatial resolution satellite derived digital terrain data towards the end of the project will provide the possibility of improving high resolution analyses in areas of complex terrain.

The use of information from non-satellite sources will play an important role in the development and evaluation of the satellite derived products. This information will be in the form of existing maps, air photos, and field data. In some cases these data will be used as part of the classification process to train the classifiers, in other cases they will be used to test the accuracy of the thematic products. For example as part of the high resolution accuracy assessment, sample geolocated field data will be needed. The development of the sampling strategy will need to be developed as part of the design phase of the project.

*In situ* data on biomass is part of the product suite. In this context it is seen as a primary data source rather than an ancillary set. The combination of satellite data and *in-situ* biomass data will provide the necessary spatialisation needed for the biomass product.

*F. Product Validation*

Product validation will be critical part of the project, providing the user community with a level of confidence concerning the results provided. It is important that the accuracy of the various products be stated quantitatively and explicity. A set of procedures for validating coarse resolution global land cover data sets is being piloted by the IGBP-DIS global land cover project. The procedures include a rigorous statistical core sample supplemented by a series of confidence sites where existing information are readily available. Regional scientists provide an important part of the product validation. High resolution products are used to validate the coarse resolution products.

Validation of high resolution data products will be performed by a combination of hyper-resolution data (3-5m) and precisely located field data collection. We expect that CEOS affiliates will play an important role in product validation.

The relationship of the global products and associated validation activities of this project to the GTOS/TOPC GHOST network of field sites and the relevant product validation activities of the different space agencies need to be established early in the project. For example forest test sites within the GHOST network could play an important role in the pilot project validation. The relationship of this pilot project validation activity with respect to the on going CEOS calibration/validation activities also need to be determined.

It is important that the validation data be packaged in a usable form and made available along with the products and their associated accuracy statements. A mechanism should be established to allow for users to provide feedback on product accuracy.

*G. Product Distribution*

Products should be distributed to user communities including scientists, policy makers and other operational users as promptly as possible in different ways and through different media. In particular, reporting to policy makers is of great importance. Several different scales and levels of data should be provided such as global, continental, national, and if possible sub-national so that policy makers can evaluate the state of the environment in their particular areas of interest, thus making informed decisions possible. In some cases products will be distributed with appropriate interpretation to policy makers so that they can understand the products in the context of the information that they require.

The Internet is a very efficient way to distribute derived products and information about products and data to users. However, other media will also be taken into account in order to satisfy users without reliable access to electronic networks. Alternative media includes CD-ROMs or other digital media, and paper prints, maps, and reports. Some users will require access to the actual underlying satellite data. In most cases, network delivery of such data is difficult, and tape or other media may be preferable. Table 5 illustrates several of the possible combinations of users and types of distribution.

**Table 5: Product Distribution**

| | Scale | | | Media | | |
|---|---|---|---|---|---|---|
| Users | *Global/ continental* | *National* | *Sub-national* | *WWW* | *Digital* | *Paper* |
| *Scientist*s | X | X | X | X | X | |
| *Policy makers* | X | X | X | | | X |
| *Operational users* | | X | X | X | X | X |

## VII. Implementation Issues

*A. Management*

(1) Oversight by CEOS. CEOS will provide programmatic and technical oversight to the Pilot Project. This function includes evaluation of Pilot Project performance, and an evaluation of the degree to which the Pilot has been successful in addressing the needs of targeted user communities.

(2) Project Team. The Project Team will come initially from the CEOS members and affiliates, using whatever national or programmatic mechanisms each institution has at its disposal. In addition, early in the life of the Pilot Project, a concerted effort will be made to identify and incorporate team members from national and international forestry and environmental organizations, so as to ensure that there is broad representation from both providers and users of data. The Canadian Forest Service has expressed an interest in developing a national forest inventory based on earth observation data, thereby serving as a challenging test case. The first tasks of the Project Team will be to form a Design Team to specify the technical details of implementation for the first phase of the project.

*B. Data Issues*

(1) Satellite Data Access and Redistribution. The participants at the Ottawa workshop agreed that GOFC will benefit from liberal data access policies, that is, data which are available at minimal cost and with minimal restrictions on re-distribution. However, they recognized that satellite data policies vary between CEOS members, and that members may insist that data made available for GOFC be subject to their established data policies. All scientific members of the project require access to the data for analysis and publication of results. The project team will also share satellite data for which additional processing has been performed.

(2) Ancillary and *In Situ* Data. All data will be calibrated. Ground calibration data will be made available within the project team. All products generated also require the inclusion of ancillary data for analysis, such as topographic data. For some regions there will be available additional geographic information layers. Each member of the project team will have full access to these additional ancillary data sets. The project team will maintain a catalog of all data acquired, and its distribution.

(3) Analytical Techniques. The products to be created from IGOS project activity should have clear statements on their accuracies. The products should be unbiased estimations of forest properties. The project team will fully document the analytical techniques used for each product. These analytical techniques will likely vary from region to region, and consistency of results on a global basis is an important goal of the project.

(4) Communication. The project team members will communicate electronically on a free basis. A variety of methods for electronic communication with CEOS, the user communities, and the public will be developed. In addition, there are expected to be many major publications in the open, reviewed literature, and internal publications and reports for the CEOS members and affiliates themselves.

(5) Public Communications. Given the high public interest in the state of the forests and environment, it is essential that results of forest observation be widely communicated. Press releases should be prepared for

publications which are widely distributed, and to television and radio networks. The high visual content of our information is appealing to the public. The project team should also create CD-ROMs with integrated data and products which can be provided to the public and to educational institutions. The project team should give consideration to the creation of videos about regional and global forest cover and changes in forest cover.

*C. Additional Research Opportunities*

The Pilot Project is not perceived as a primarily research-oriented exercise. It is an experiment in operational capabilities. At the same time, it is clear that there are many research opportunities which may benefit project planning and execution. Some of these are outlined below.

<u>(1) Hyperspectral</u>. Optical sensors with large numbers of channels will shortly be launched. Sample data sets from space and airborne platforms will be available.

<u>(2) Very High Spatial Resolution</u>. Several commercial spacecraft are planned which will have resolutions of the order of one meter. There are methods for recognizing individual trees from such data. Such data can also be used to assess selective harvesting, partial cuts, and regeneration, and provide information on site characteristics.

<u>(3) Polarimetric and Interferometric SAR</u>. An important advance in microwave sensors is the creation of SARs with multiple frequencies and full polarization. Polarimetric SAR data sets and interferometric SAR data sets are available for sample areas.

<u>(4) Lidars</u>. In addition to their contribution to atmospheric measurement, lidars can be used for measuring tree heights and for creating DEMs. During the lifetime of the Pilot Project, sample lidar data sets are expected to be available.

*D. Recommendations from the FAO representative with respect to the workshop process and resolutions.*

Although the need for a global integrated (source) data set specifically designed for the observation of forest resources is fully endorsable, in view of the potential benefits to all user groups and on-going forest monitoring programs, the specifications of <u>derived global products</u> should be the result of a wider consultation process that includes representatives of all user communities identified under section III B of the Workshop Report. This is particularly important for the product based on high resolution data which would provide crucial information on land cover/forest cover state and change at national and sub-national level with consequent important strategic contribution to national planning operations.

The initial phase of the proposed pilot project will include a mechanism of thorough user consultation in order to define their priorities, propose suitable mechanisms of participation/consultation and better define product specifications. Such consultation should include, as a minimum, forest management/planning institutions' representatives from major "forest" countries (Russian Federation, U.S.A., Brazil, Indonesia, Democratic Republic of Congo [former Zaire], etc.), and International Policy and Operational Institutions (FAO, UNEP, UNDP, World Bank, etc.).

## VIII. Schedule of Activities

### *A. Overview*

The Ottawa workshop in July 1997 has provided the first kick-off for the GOFC project. Participants in the meeting represented a wide spectrum of international experiences with forest-related programs. There were also representatives of several potential user communities. However, all participants recognized that this was only a beginning. There are many strategic and technical issues that remain to be worked out before the GOFC can be regarded as fully implemented.

### *B. Project Phases*

There are three main phases that have been identified, with several follow-up activities.

<u>(1) Design Phase (1 year)</u>. The first year of the GOFC, beginning with project approval, will be devoted to a series of detailed design studies. These would include workshops on specific technical issues, e.g. to analyze the acquisition strategies for existing and planned remote sensing missions. Design studies might also include paper studies by selected study teams, or comprehensive literature reviews, and specific methodological intercomparison studies, e.g. studies comparing different classification methodologies using identical data sets. A specific need during the Design Phase will be a broader outreach effort to potential user communities, and specific planning for an eventual transition from the pilot phase to routine operational status for the GOFC. The ultimate goal of the Design Phase is to produce a detailed implementation plan that incorporates all the design issues. Deliverables will include a series of publications, project reports, and the data sets from intercomparison studies.

<u>(2) Prototype Phase (2 years)</u>. This phase can be regarded as the initial implementation phase. This is the period during which the details of preprocessing, data handling, analytical procedures, etc., which have been planned during the Design Phase, will actually be tested for their operational practicality. Current experience shows clearly that design studies, while necessary, cannot anticipate all the eventualities of having to cope with large data sets in a routine manner. The Prototype Phase anticipates this difficulty, and provides the opportunity to work with large data sets in a mode analogous to what will be necessary with new global acquisitions. During the Prototype Phase, a series of regional pilot studies will be performed with existing data sets, which will be expected to produce the first sets of products and product bundles identified in previously, but for periods from the late 1980's and early 1990's. During the latter part of the Prototype Phase, new data from remote sensing systems should begin to become available (e.g. the first few months of MODIS data). These data could then be used to ensure that all the data handling systems for GOFC are operational.

<u>(3) Execution Phase (2 years)</u>. The Execution Phase builds on the experience gained through the Prototype Phase. During this last phase of the GOFC, new data acquisitions are incorporated into the GOFC analytical system, analyses performed by the project team, and new products generated and distributed. The acquisitions for the Execution Phase will likely begin during the Prototype Phase, because of the time necessary for processing and analysis. Products and product bundles will be generated for the late 1990's and early 2000's. Validation studies will also be begun during the Execution Phase, although it is not clear that all of them can be completed during this time. However, the conduct of validation studies will be part of the overall evaluation follow-up activities. The full suite of evaluation activities will then prepare the stage for transition activities so that GOFC can become part of routine operational scenarios.

## IX. References


Ahern, F. J., T. Erdle, D. A. Maclean, and I. D. Kneppeck, 1991. A quantitative relationship between forest growth rates and Thematic Mapper reflectance measurements, Internatinational Journal of Remote Sensing, 12: 387-400.

Ahern, F. J., R. Landry, I. McKirdy, V. Janusauskas, A. Banner, J. Russell, and T. Balce, 1997. Factors affecting clearcut mapping accuracy from single-date RADARSAT images, Proceedings of Geomatics in the Era of RADARSAT, Canadian Aeronautics and Space Institute, Ottawa, Canada, May 26 - 30.

BAHC, 1993, Bioshperic Aspects of the Hydrological Cycle (BAHC): The Operational Plan. IGBP Report No. 27. BAHC Core project office, Berlin.

Belward, A.S., 1996, The IGBP-DIS Global 1 km Land Cover Data Set "DISCover": Proposal and Implementations plans, Report of the Land Cover Working Group of IGBP-DIS, (International Geosphere-Biosphere Programme - Data and Information System Office, Toulouse), 66 pp.

Biological Diversity Convention Internet Website http://www.biodiv.org/

Canadian Council of Forest Ministers, 1995. Defining Sustainable Forest Management, A Canadian Approach to Criteria and Indicators, (Canadian Forest Service, Ottawa), 22 pp.

Canadian Forest Service, 1995, Criteria and Indicators for the Conservation and Sustainable Management of Temperate and Boreal Forests: The Montreal Process. (Canadian Forest Service, Ottawa), 27 pp.

Costa, M. P. de F., E. M. L. de M. Novo, F. Mitsuo II, J. E. Mantovani, M. V. Ballester, and F. J. Ahern, 1997. Classification of floodplain habitats (Lago Grande, Brazilian Amazon) with RADARSAT and JERS-1 data. Proceedings of Geomatics in the Era of RADARSAT, Canadian Aeronautics and Space Institute, Ottawa, Canada, May 26 - 30.

FAO, 1995. Forest Resources Assessment 1990: Global Synthesis, FAO Forestry Paper 124, Food and Agriculture Organization of the United Nations, Rome, 44 pp.

FAO, 1996. Forest Resources Assessment 1990: Survey of tropical forest cover andstudy of change processes, FAO Forestry Paper 130, Food and Agriculture Organization of the United Nations, Rome, 152 pp.

Folving, S., P. Kennedy, and T. Häme, 1995. The FIRS project. Progress report and the first results from the foundation actions and themes. XX World Congress, International Union of Forestry Research Organizations, 6 - 12 August, 1995, Tampere, Finland. IUFRO News, Vol. 23, Issue 4 (CD-ROM).

Framework Convention for Climate Change Internet Website, http://www.unfccc.de/

Global Climate Observing System Internet Website, http://www.wmo.ch/

Global Climate Observing System, 1997. GTOS-GCOS plan for terrestrial climate-related observations, Version 2.0, World Meteorological Organization, Geneva.

Global Terrestrial Observing System, 1997. Annual Report, GTOS Secretariat, c/o FAO, SDRN, Viale delle Terme di Caracalla, Rome 00100, Italy.

Guertin, F., 1997. CEOS-IGOS-SIT Meeting, Irvine, California, unpublished memorandum, Canada Centre for Remote Sensing.

Hammond, H., 1991. Seeing the forest among the trees: The case for wholistic forest use (Polestar Book Publishers, Vancouver), 309 pp.

Hoffmann, C., 1996. Mapping European Land Cover with NOAA-AVHRR Data, Space Applications Institute, Environmental Mapping and Modelling Unit., 24 pp.

IGBP 1993. Biospheric Aspects of the Hydrological Cycle: the Operational Plan, IGBP Global Change Report no. 27, (International Geosphere-Biosphere Program, Stockholm).

IGBP 1994. International Global Atmospheric Chemistry (IGAC): the Operational Plan, IGBP Global Change Report no. 32, (International Geosphere-Biosphere Program, Stockholm).

ISCI, 1996, Intergovernmental Seminar on Criteria and Indicators for Sustainable Forest Management: Background Document. August 19-22, 1996, Helsinki, Finland.

Interim Secretariat for the Convention on Biological Diversity, (United Nations, Geneva) 1994. Convention on Biological Diversity: Text and Annexes, 34 pp.

Kux, H. J. H., J. R. Dos Santos, M. S. P. Lacruz, F. J. Ahern, and R. W. Pietsch, 1997. Capabilities of RADARSAT data for land use/land cover analysis in S.W. Amazonia, Proceedings of Geomatics in the Era of RADARSAT, Canadian Aeronautics and Space Institute, Ottawa, Canada, May 26 - 30.

Landsat Pathfinder Project Internet Website http://pathfinderwww.sr.unh.edu/pathfinder1/information/overview/index.html

Li, Z. And L. Moreau, 1996. A new approach for remote sensing of canopy-absorbed photosynthetically active radiation. I: total surface absorption, Remote Sensing of Environment, 55, pp175 - 191.

Liu, J., J. M. Chen, J. Cihlar, and W. M. Park, 1997. A process-based boreal ecosystem productivity simulator using remote sensing inputs, Remote Sensing of Environment, 62, pp158-175.

Loveland, T., J. Merchant, D. Ohlen, J. Brown, 1991. Development of a land-cover characteristics database for the conterminous U.S., Photogrammetric Engineering and Remote Sensing, 57:1453-1463.

Mahmood, A., et al, 1998, Mapping the World with Remote Sensing , EOS: Transactions of the American Geophysical Union, (American Geophysical Union, Washington) 79: pp. 1 and 23.

Malingreau, J.P., F. Achard, G. D'Souza, H. Stibig, J. D'Souza, C. Estreguil, H. Eva, 1993, AVHRR for global tropical monitoring: the lessons of the TREES project, proceedings of the 6th AVHRR European Data Users Meeting, Belgirate, Italy, 28 June - 2 July 1993. (Darmstadt: EUMETSAT), pp 323-332.

Martini, P. R., 1992, Panamazonia Project: An Executive Report. Revista SELPER 8, 26-30.

Moreau, L, and Z. Li., 1996. A new approach for remote sensing of canopy-absorbed photosynthetically active radiation. I: proportion of canopy absorption, Remote Sensing of Environment, 55, pp 192 - 204.

North American Landscape Characterization Project, Internet Website, http://www.epa.gov/crdlvweb/land-sci/north-am.htm

Nyland, Ralph D., 1996. Silviculture: Concepts and Applications (McGraw-Hill, New York) 633 pp.

Olson, R.J., J.M.O. Scurlock, W. Cramer, S.D. Prince, W.J. Parton, 1997, From sparse field observations to a consistent global dataset on net primary production. IGBP-DIS Working Paper #16, pp. 1-22.

Perlin, J. 1991. A forest journey. The role of wood in the development of civilization. Harvard University Press, Cambridge, MA, 445pp.

Phulpin, T., T. Gentet, 1993, Vegetation on-board SPOT 4: A mission for global study of the biosphere, Proceedings of the 6th AVHRR European Data Users Meeting, Belgirate, Italy, 28 June - 2 July 1993 (Darmstadt: EUMETSAT), pp. 334-351.

Running, S. W., R. R. Nemani, D. L. Peterson, L. E. Band, D. F. Potts, L. L. Pierce, and M. A. Spanner, 1989. Mapping regional forest evapotranspiration and photosynthesis by coupling satellite data with ecosystem simulation, Ecology, 70, pp 1090-1101.

Scott, J. M, T. H. Tear, and F. W. Davis (eds.), 1996. GAP Analysis: A Landscape Approach to Biodiversity Planning, Proceedings of the ASPRS/GAP Symposium, Charlotte, North Carolina, National Biological Service, Mosco, Idaho, pp. 83-89.

Shaffer, L. R. 1996. “CEOS Holds Meeting on Integrated Global Observing Strategy”, CEOS Newsletter No. 7, September, 1996.

Shaffer, L. R. 1997. “CEOS and IGOS - The Way Forward”, CEOS Newsletter No. 8, February, 1997.

Terrestrial Observation Panel for Climate, 1997. Global Climate Observing System: GCOS/GTOS Plan for Terrestrial Climate-Related Observations, WMO/TD-No. 796, UNEP/DEIA/TR.97-7, (World Meteorological Organization, Geneva), 130 pp.

Shimabukuro, Y. E., S. Amaral, F. J. Ahern, and R. W. Pietsch, 1997. Classification and monitoring the Tapajós National Forest region using SAR (RADARSAT Standard Mode and SAREX Wide Swath Mode) and Landsat Thematic Mapper data, Proceedings of Geomatics in the Era of RADARSAT, Canadian Aeronautics and Space Institute, Ottawa, Canada, May 26 - 30.

Turner, B.L., et al, 1995. Land-Use and Land-Cover Change Science/Research Plan, IGBP Report No. 35, HDP Report No. 7.

Vogelmann, J. E., and B. N. Rock, 1988. Assessing forest damage in high-elevation coniferous forests in Vermont and New Hampshire using Thematic Mapper data, Remote Sensing of Environment, 24:227-246.

World Commission on Environment and Development, 1987. Our Common Future (Oxford University Press, New York), 400 pp.

World Forestry Congress, 1997. Policies, Institutions, and Means for Sustainable Forestry Development, *in* Proceedings of the World Forestry Congress, Antalya, Turkey, 13 to 22 October 1997, Food and Agriculture Organization of the United Nations, Rome, Italy.

**Appendix 1: Level 0 and Level 1B Products**

| **Product** | **Sensor** | **Processing level/ Accuracy** | **Resolution (m)** (as provided by sensors) | **Cycle** Optimal (min req) | **Delivery** Optimal (min req) | **NOTES** |
|---|---|---|---|---|---|---|
| Level 0 Optical High spatial resolution | TM / SPOT / IRS / CBERS (*) | No processing | 10-30 | 0.25 yr (3 yr) | 1 w (1 m) | |
| Level 1B Optical High spatial res | TM / SPOT / IRS / CBERS (*) | Radiom. corr "System" corr. | 10-30 | 3 yr (10 yr) | 30 d (1 yr) | Cycle TBD in acc. w Microwave |
| Level 1B Optical Mid-Low spatial res | AVHRR ATSR RESURS MODIS/MISR (*) SPOT Vegetation (*) | Radiom corr First order geometry corr | 250-4000 | 1 d (2 w) | 1d (1 m) | |
| Level 1B Microwave | ERS - SAR JERS-SAR RADARSAT SRTM (*) Light SAR (*) ASAR (*) ALOS-PALSAR | Radiometric and geometric Calibration | 10-100 | 0.5 yr (2 yr) | 6 m (1 yr) | - Cycle TBD in w Optical High - may be mosaicked or tiled - may be terrain corrected |

* future mission

<u>Optical High spatial Resolution</u>: In order to generate and archive complete global coverage of the world's forests will require systematic acquisition of data year-round. Data acquisition strategies will require coordination with microwave data acquisition plans to insure complete coverage. Data access strategy and formats should be defined. Small swath widths and cloud coverage may pose problems to acquire complete coverage within limited time.

<u>Optical mid-low spatial Resolution</u>: This dataset will contain areas covered by clouds. It is envisaged that a low cost processing system could be put into place that could make radiometric and first-order geometric corrections within a day. Large swath can assure global coverage everyday.

<u>Microwave:</u> For the microwave level 1B data, we recommend that the data be 1) either seamlessly mosaicked or tiled, and 2) be calibrated. Whether or not the data are mosaicked or tiled will depend on the sensor and available resources for performing that task. If feasible, the data should be terrain corrected for geometric and possibly radiometric distortions. Terrain correction will require a DEM of sufficient resolution, accurate knowledge of the imaging geometry, and the processing capability to perform the correction. Data that are not terrain corrected will be geometrically and radiometrically

distorted in regions of varying topography. SRTM, planned for launch in 1999, will produce a map of the world's topography between +57 and -57 degrees latitude that could be used for this purpose. Observations should be coordinated with optical high res data acquisitions to permit data fusion and synergy between these sensors. Since microwave sensors are not affected by cloud cover, they will play an important role by filling in gaps in coverage by optical sensors. However, current single-channel microwave sensors do not provide as much spatial detail and thematic content as high resolution optical sensors.

## Appendix 2: Participants at Ottawa Workshhop

| Last Name | First 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) |