Land-Cover Observations as Part of a Global Earth Observation System of Systems (GEOSS): Progress, Activities, and Prospects

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Abstract—The international land-cover community has been working with GEO since 2005 to build the foundations for land-cover observations as an integral part of a Global Earth Observation System of Systems (GEOSS). The Group on Earth Observation (GEO) has provided the platform to elevate the societal relevance of land cover monitoring and helped to link a diverse set of global, regional, and national activities. A dedicated 2007–2009 GEO work plan task has resulted in achievements on the strategic and implementation levels. Integrated Global Observations of the Land (IGO\textsc{L}), the land theme of the Integrated Global Observation Strategy (IGOS), has been approved and is now in the process of transition into GEO implementation. New global land-cover maps at moderate spatial resolutions (i.e., GLOB\textsc{COVER}) are being produced using guidelines and standards of the international community. The Middecadal Global Landsat Survey for 2005–2006 is extending previous 1990 and 2000 efforts for global, high-quality Landsat data. Despite this progress, essential challenges for building a sustained global land-cover-observing system remain, including: international cooperation on the continuity of global observations; ensuring consistency in land monitoring approaches; community engagement and country participation in mapping activities; commitment to ongoing quality assurance and validation; and regional networking and capacity building.

Index Terms—Global Earth Observation (GEO), Global Earth Observation System of Systems (GEOSS), global, Integrated Global Observations of the Land (IGO\textsc{L}), land cover, remote sensing.

I. INTRODUCTION

In ITS 10-year reference document [1], the Group on Earth Observation (GEO) has highlighted the importance of land cover for all areas of societal benefits (Fig. 1). In addressing this importance, the aim of this paper is to demonstrate progress, describe approaches and activities, and show prospects of the international land-cover community working with GEO to develop global land cover observing as part of a Global Earth Observation System of Systems (GEOSS).

Land cover is one of the most important properties for observing, describing, and studying the environment. Reliable land-cover and land-cover-change observations are of crucial importance to: 1) understanding and mitigating climate change and its impacts; 2) sustainable development; 3) natural resource management; 4) conserving biodiversity; and 5) understanding of ecosystems and biogeochemical cycling. As an example, land-cover characteristics reveal ongoing processes of deforestation, desertification, urbanization, loss of biodiversity and ecosystem functions, changing boundary conditions for vector-borne diseases, and water and energy management. Agenda 21 of the United Nations Conference on Environment and Development (UNCED), the World Summit on Sustainable Development (WSSD) in Johannesburg 2002, and existing United Nations conventions, most prominently the United Nations Framework Convention on Climate Change (UNFCCC), have all highlighted the importance of land cover in their implementation [2], [3] and strengthened recognition within the international community of the necessity of timely and accurate land-cover information. In situ and satellite-based land-observation efforts as well as different disciplines (e.g., geography, ecology, geology, forestry, and land management and planning) use and refer to land cover as an obvious and detectable indicator of land-surface characteristics.

Despite the fundamental importance of land-cover information and other land-surface characteristics, it is important to recognize that land observations are not operational, as compared with other earth observation domains such as oceans and the atmosphere. Although numerous satellites acquire data suitable for land-cover monitoring, large-scale regional and global mapping and monitoring programs have not reached operational status for delivering internationally accepted land-cover and, in particular, land-cover-change data to serve the many uses and applications.

The field of land-cover observations is heterogeneous in many ways, i.e., in terms of the land surface itself, the approaches to acquire land-cover data, and the users of such information. Basically, each land surface worldwide has been mapped and characterized several times, and many countries...
have some kind of monitoring system in place (i.e., forest, agriculture, and cartographic information systems and inventories [4]). In addition, there are a number of global land-cover mapping activities [5]–[9, App. A]. They have evolved with the availability of continuous global moderate resolution satellite observations since the early 1990s. Related projects and programs have generally remained in the research domain and have just recently started to evolve into operational programs.

A global land-cover observing system requires long-term satellite and in situ observations, a sustained processing system to derive and disseminate land-cover information datasets, and an international coordinating mechanism to ensure relevance, acceptance, accuracy, and usability of such new global products. Suitable historic and recent satellite datasets exist at different scales, significantly reducing technical and logistical barriers associated with implementing a global land-cover monitoring [10]. The success of many recent land-cover mapping projects has demonstrated the feasibility of producing land-cover maps when sufficient resources are provided. Previous global, regional, and national land-cover assessment activities, however, have widely remained independent. The approaches and mapping standards to acquire and represent land characteristics have become as diverse as the land surface itself. While most mapping projects are developed for specific applications and purposes, the resulting inconsistency between the different land-cover map products or change accounting systems undermines our ability to successfully synthesize land assessments on regional and global scales. In addition, the user community for land-cover data is vast and complex and has been growing continuously with the evolution of the information age and progress in spatial data analysis and modeling. The various fields of application tend to have different perspectives on how they understand land cover and what they seek in terms of land-cover products. Land-cover data aiming to serve multiple applications must provide flexibility (in terms of data access and thematic and cartographic standards) not present in many existing environmental databases [11], [12].

Building a sustained global land-cover observing system requires international agreement and cooperation on: 1) the continuity of global observations; 2) the consistency in mapping and monitoring specifications and land-cover assessment approaches; and 3) sustained engagement and participation in mapping activities, regional networking, and capacity building. Thus, the objectives of this paper are to show how GEO can help to overcome some of the known issues and problems mentioned and help to evolve a sustained global land-cover observation system as part of a GEOSS. The paper addresses the following:

- GEO’s role in improving global land cover observations;
- the land-cover community’s experience working with GEO and its instruments;
- achievements on the strategic and implementation level;
- pathways toward operational global land cover observations.

Overall, the GEO contribution of the global land-cover community is to ensure that technical capabilities are understood and adopted by high-level political processes. This involves an advocacy role for participating in an international coordination and cooperation mechanisms (led by GEO) specifying land observation strategies from existing user requirements and putting them into operation.

II. ROLE FOR GEO

GEO is a result of three ministerial-level earth-observation summits. It aims to build and maintain a Global Earth Observation System of Systems (GEOSS) [13]. GEOSS will build on and add value to existing earth-observation systems by coordinating their efforts, addressing critical gaps, supporting their interoperability, sharing information, reaching a common understanding of user requirements, and improving delivery of information to users [1]. GEO, as a high-level political process (currently 66 member states and 46 participating organizations), has defined nine areas where society directly benefits from earth observations: disasters, energy, health, climate, water, weather, agriculture, ecosystems, and biodiversity (Fig. 1). Although being global in scope, GEO also seeks to stimulate national and regional implementation activities.

Fig. 2 puts GEO’s role in a schematic context. The needs of society for earth-observation information (and global land-cover observations) are reflected in requirements defined by the political and policy level. Examples are GEO and UN conventions. Comprehensive strategies are to be specified in implementation frameworks that develop technical consensus and help to put the strategies into operation. They specify what to observe when and where and, most importantly, why. Prominent examples are the Implementation Plan of the Global Climate Observing System [2], [3] and the land theme of Integrated Global Observation Strategy (IGOS), which is Integrated Global Observations of the Land (IGOL). For some observation domains, this link is well established in practice, with the best example being observations required to support weather forecasting. For land cover, practical progress on operational strategies has been limited. Such strategy definitions basically re-
reflect the interface between the domains of society and political discussions on the one hand (i.e., through multilateral environmental agreements), and the earth observation arena on the other. Following the circle in Fig. 2, the next stage refers to more detailed technical implementation guidelines based on scientific and technical consensus on suitable earth-observation data and methods for operational global and regional land-cover mapping and monitoring. Common issues discussed in this context relate to consistency and continuity in global satellite observations, harmonization, and standardization of land-cover information [14] validation protocols [15] and consensus technical protocols for global land cover and change monitoring. In essence, such guidelines provide internationally agreed technical specifications for implementing global land-cover observations. The resulting land-cover information products are then applied to support land policy and management for the benefits of society. Prominent examples are global environmental assessments, forest resources assessments, national carbon accounting systems, and others. Although GEO’s initial role is to link societal needs, political will, and land-cover observing strategies, it should and perhaps will have an impact on all activities downstream toward the benefits to society. This role requires the support and leadership of the technical land-cover community.

In consideration of Fig. 2 and GEO’s role to add value through coordination of existing earth-observation efforts, there are a number of resulting issues to overcome the current heterogeneity (i.e., in terms of data, mapping standards, and data access) and, given the current lack of coordinated land cover observations globally, GEO has provided a platform for improvement and has been driving progress on land cover observations through the following:

- highlighting the societal needs and relevance of land cover observations;
- advocating for global land cover mapping and monitoring;
- fostering integrated perspectives for continuity and consistency of land observations, in particular for coordinated international efforts to provide baseline observations and data suitable to monitor land cover globally;
- helping to evolve and apply international standards for land cover characterization and validation;
- advocating coordinated international participation in ongoing global mapping activities, as well as regional networking and capacity building in developing countries.

GEO has helped to further develop international partnerships involving producers, users, and the scientific community to improve use of existing databases and produce better new datasets.

### III. RELEVANT GEO WORK PLAN TASKS

GEO activities and its secretariat have evolved considerably since their initiation in 2005. The first GEO 2006 work plan involved a large number of individual tasks. Early GEO activities (in 2005 and 2006) focused on setting up appropriate instruments and committees, sorting of roles and responsibilities, and coordinating organizations leading or contributing to the GEO work plan. GEO itself is not a funding mechanism for many organizations involved, and activities had to be built upon efforts and organizations already active in this arena with an emphasis on where GEO could make a direct contribution.

Given the large number of tasks and topics GEO aims to address, it became obvious that GEO activities will have to become more focused and deliver distinct success stories. The 2007–2009 work plan was one important step to provide a consolidated plan for GEO implementation. As in the 2006 plan, a specific task in the GEO 2007–2009 work plan (DA-07-02) has been to advocate “global land cover.” The overall goal of the task is to provide a suite of global land-cover datasets, initially based on improved and validated moderate resolution land-cover maps and eventually including land-cover change at high resolution. The task is lead by the U.S. Geological Service (USGS) and the land-cover team of Global Observations of Forest Cover and Land Dynamics [16] and is under the auspices of the Architecture and Data Committee (ADC).

The detailed activities defined for this task are shown in Table I. The main objective is to initiate regular analysis and reporting on land-cover change and promulgate the use of the resulting mapping products and information, especially in developing countries. On the level of moderate-resolution land-cover observations, the activities range from efforts to provide a common basis for land-cover characterization and validation, exploring the synergy of existing products, and fostering the further processing and analysis of global satellite data (Work Items 1 and 2). Significant progress should be accomplished within the 2007–2009 work plan commitment for these two issues. Land-cover change observations at fine-resolution scales are required to fully achieve the societal benefits. Work Item 3 involves a number of related issues for evolving international agreement on land-cover dataset specifications, ensuring that appropriate Landsat-type data are available in sufficient quality and the land-cover-change data products are eventually produced. Such efforts require a close interaction with the countries and, thus, aims beyond 2009 to be completed.
Further work is advocated to improve access to existing datasets (Work Item 4), identify application examples demonstrating societal benefits (Work Item 5), and building national capacity (Work Item 6). On Work Item 5, one particular issue relates to the UNFCCC process (in particular, 2007–2009) of Reducing Emissions from Deforestation and Forest Degradation (REDD) and the role satellite observations have to play for related monitoring activities [23]. This task emphasizes the role of developing countries and their involvement in both producing and using national and global land-cover data [24, and see DA-07-02 work item 6].

A few other tasks in the 2007–2009 work plan are directly related to DA-07-02. They include the task AG-06-04 on global forest monitoring that aims to integrate international efforts on assessment and monitoring of forests and forest changes using a combination of ground and satellite information and internationally agreed upon standards. An additional task (US-06-02) is initiating pilot communities of practice for forest observations to identify and further refine users’ needs, in particular on cross-cutting areas, building upon the initial experience of community of practice and on information provided by national, regional, and project-level surveys. Additional common objectives exist with task DA 07-03 on the Land Surface Imaging Constellation to coordinate the efforts of member nations to collect, process, and make openly available Landsat-type imagery from a variety of earth-observation missions for the 2009–2011 time period.

### IV. EXAMPLES OF ACTIVITIES AND PROGRESS IN 2007

GEO Global Land Cover Task DA-07-02 aims to deliver a suite of results and the planned outputs including:

- a survey of existing land-cover datasets and a web site data base including technical specifications and access conditions;
- improved, validated, and up-to-date global moderate-resolution land-cover datasets available for specific societal benefits;
- specifications and implementation plan for production and validation of high-resolution land-cover and land-cover-change data products;
- global land-cover maps at high resolution repeated on a five-year cycle;
- global land-cover change maps at high resolution repeated initially on a five-year cycle and, where appropriate, eventually on an annual basis;
- operational and updated (“living”) reference database of land-cover validation test sites;
- capacity-building workshops.

Certainly, most items defined in Table I are long-term goals that have evolved through GEO processes. The following two sections describe the global land-cover observation and monitoring progress achieved as part of the GEO global land-cover activities.


<table>
<thead>
<tr>
<th>GEO area of societal benefits</th>
<th>Key land cover observations and recommended products</th>
<th>Relevant observation needs and requirements from IGOL</th>
<th>Examples of documented global user requirements</th>
</tr>
</thead>
</table>
| DISASTERS: Reducing loss of life and property from natural and human-induced disasters | • Fire monitoring  
• Surface cover type changes and land degradations due to disasters | • Fire observations: early warning (i.e. fuel conditions), active fire, burned area/intensity  
• Location of population and infrastructure | • IGOS – Geohazards theme report  
• GEO Community of Practice for Disaster Monitoring  
• GOFC-GOLD strategy for fire observations |
| HEALTH: Understanding environmental factors affecting human health and well-being | • Land characteristics/change for disease vectors  
• Land cover/change affecting environmental boundary conditions  
• Demographic and socio-economic characteristics | • Location and extent of settlement patterns  
• Land use, socio-economic and demographic characteristics  
• Vegetation characteristics and riparian conditions | • GEO Community of Practice for Health  
• Requirements advocated by the World Health Organization |
| ENERGY: Improving management of energy resources. | • Bio-fuel production sustainability  
• Assessments for wind and hydro power generation and explorations | • Biomass yield estimates (forestry and agriculture)  
• Location and extent of energy consumption | • GEO Community of Practice for Energy |
| CLIMATE: Understanding, assessing, predicting, mitigating, and adapting to climate variability and change. | • Greenhouse gas emissions caused by land cover change  
• Land cover dynamics forcing water and energy exchanges | • Changes in natural vegetation distributions and land use  
• Terrestrial carbon stocks and fluxes, biophysical properties, and phenology | • GCOS implementation plan to the UNFCCC  
• IPCC LULUCF good practice guidance  
• IGOS Carbon theme report |
| WATER: Improving water resource management through better understanding of the water cycle. | • Land cover change affecting dynamics the hydrological system  
• Available water resources and quality | • Distribution of water bodies and wetlands  
• Water use pattern (i.e. irrigation, vegetation stress) and infrastructure quality | • Ramsar convention |
| WEATHER: Improving weather information, forecasting, and warning | • Land cover/change affecting radiation balance and sensible heat exchange  
• Land surface roughness | • Biophysical vegetation characteristics and phenology  
• Change of weather-relevant land cover characteristics | • Requirements advocated by the World Meteorological Organisation |
| ECOSYSTEMS: Improving the management and protection of terrestrial, coastal, and marine ecosystems. | • Human alterations in natural ecosystem development  
• Changes in environmental conditions and provision of ecosystem services  
• Monitoring ecosystem conservation | • Land cover and vegetation characteristics and changes  
• Land use dynamics and driving processes | • Millennium Ecosystem Assessment and Development goals + indicators  
• United Nation Environment Program (UNEP) and Global Environmental Outlook  
• GOFC-GOLD observation strategy |
| AGRICULTURE: Supporting sustainable agriculture and combating desertification. | • Distribution of cultivation practices and crop production  
• Land degradations and threats terrestrial resources and productivity | • Monitoring of food crops (type, rotations, conditions)  
• Forest types and changes (i.e. logging)  
• Land cover and use changes affecting agriculture and forestry | • FAO/UNEP requirements for global resources assessment  
• UNCDD requirements |
| BIODIVERSITY: Understanding, monitoring, and conserving biodiversity. | • Trends in extent of selected ecosystems, habitats, and species  
• Connectivity and fragmentation of ecosystems | • Ecosystem characterization and vegetation monitoring (types, species)  
• Habitat characteristics and fragmentation of invasive and protected species  
• Changes in land cover and use threatening biodiversity | • UNCBD 2010 target indicators  
• United Nation Environment Program (UNEP) |

A. Strategic Level

The IGOS partnership was established in 1998 to provide a comprehensive framework to harmonize the common interests of the major space-based and in situ systems for global earth observation. In 2004, the IGOS partnership started to develop an additional theme covering all land requirements outside of those covered by other established themes. The new theme, IGOL, defines detailed observations requirements for different application areas such as agriculture, forestry, land degradation, ecosystem goods and services, biodiversity and conservation, human health, water resource management, disasters, energy, urbanization, and climate change. An IGOL report was presented and approved at the 14th Plenary Meeting.
of the IGOS Partnership on 30 May 2007 in Paris. The IGOL report represents the first comprehensive and integrated global observation strategy for the land domain.

The IGOS partnership will now be transitioned into GEO. All individual IGOS themes are asked to propose transition arrangements and, thus, the land community has initiated the process of integrating the IGOL observational requirements into GEO implementation. The IGOL requirements address a number of issues (e.g., land cover, land use, biodiversity, and fire), but here the focus will be on the land-cover domain as an example. The land-cover requirements of IGOL are reflected in the related GEO task DA-07-02. To emphasize this point, Table II links the land-cover map with global land-cover observations (or very high-resolution satellite data). All of these measurements have their strengths and weakness for global monitoring in terms of clouds, phenology, change, and validation) and assist in consistent and effective preprocessing of high-resolution datasets. Due to the coarse spatial resolution, observed land change may provide solid estimates for large and aggregate changes and indicate hot spots, however, they are not able to provide quantitative change information required to fully address societal benefits as defined by GEO.

Global availability of basic observations data at coarse resolution is less of a challenge than for the fine scales. NASA and USGS have been making progress acquiring fine-resolution imagery for the Middecadal Global Land Survey that will provide consistent, preprocessed, global, free-of-charge Landsat data for circa 2005. The effort extends the existing 1990 and 2000 Tri-Decadal Landsat global dataset [17]. There are challenges in constructing consistent global observations such as integration of different satellite observation sources [18]. This new dataset for circa 2005 provides a major contribution of basic data support for global and regional land-mapping activity at a time when nearly all user communities are asking for land change information at least every five years and many national programs already work with such data. For example, there is a suite of existing national and regional high-resolution land-cover mapping programs including CORINE and the Global Monitoring for Environment and Security (GMES) service, the U.S. National Land Cover Database, and new products. In essence, these requirements are congruent with objectives and the Work Items defined for GEO Task DA-07-02 and, thus, this task ensures that the IGOS land-cover requirements are considered in GEO implementation.

B. Implementation Activities

In addition to progress achieved on the strategic level, there are a number of activities on the implementation level contributing to GEO progress in global land-cover observations. Here, they are exemplified through some key developments in 2007. On the level of moderate-resolution observations, the ESA-funded GLOBCOVER project will provide global land maps based on 2005/06 ENVISAT MERIS data and provide the highest resolution (300 m) consistent global land-cover map [9]. The data products will be fully compliant with international standards for land-cover characterization [12], [14] and validation [15]. The preprocessed MERIS image data and the land-cover map will be available free of charge. The first global map product was delivered prior to the GEO ministerial summit in November 2007. Additional progress can be reported for the next-level global MODIS-based land-cover mapping.

The framework shown in Fig. 3 assumes that there is observation continuity on all of these scales and that the data and information products are consistent and compatible. This assumes the availability of coordinated operational global satellite and in situ observations and common approaches to characterize, describe, and compare land-cover information (harmonization and validation), and to facilitate the joint application of mapping products. In essence, these requirements are congruent with objectives and the Work Items defined for GEO Task DA-07-02 and, thus, this task ensures that the IGOS land-cover requirements are considered in GEO implementation.

![Fig. 3. Framework for integrated global observations of land cover and vegetation.](image-url)
TABLE III
SUMMARY OF MAIN CHARACTERISTICS OF NATIONAL LAND-COVER/USE CHANGE MAPPING PROGRAMS

<table>
<thead>
<tr>
<th>Program / Country</th>
<th>Main Data Source</th>
<th>Change period</th>
<th>Scale / MMU</th>
<th>Thematic focus</th>
</tr>
</thead>
<tbody>
<tr>
<td>CORINE (EU)</td>
<td>Landsat TM /ETM+</td>
<td>1990-2000(2006)</td>
<td>5 ha change detection MMU</td>
<td>All 44 land cover/use classes of CORINE nomenclature</td>
</tr>
<tr>
<td>EODS/Canada (pilots)</td>
<td>Landsat TM /ETM+</td>
<td>Varying by case 5-10 years interval</td>
<td>Landsat pixel</td>
<td>Major forest changes</td>
</tr>
<tr>
<td>NLCD / USA (prototype)</td>
<td>Landsat TM /ETM+</td>
<td>1992 - 2001</td>
<td>Landsat pixel</td>
<td>Modified Anderson level classes</td>
</tr>
<tr>
<td>NCAS-LCCP / Australia</td>
<td>Landsat MSS, TM, ETM+ since 1972; NOAA NDVI</td>
<td>1972 – 2000, several time steps</td>
<td>50m (1979-88), 25m (since 1989)</td>
<td>Deforestation or forest conversion and regrowth</td>
</tr>
<tr>
<td>LCDB2 / New Zealand (GHG Inv.)</td>
<td>Spot and Landsat 7 ETM+</td>
<td>1996/97 – 2001/02</td>
<td>Landsat pixel</td>
<td>IPCC-LULUCF categories: Forest, Grassland, Agriculture, Wetlands, Settlements, other</td>
</tr>
<tr>
<td>ESA Kyoto Inventory / Switzerland, Netherlands, Spain, Italy (in progress)</td>
<td>Landsat TM /ETM+</td>
<td>1990-2000 (varying)</td>
<td>Landsat pixel</td>
<td>Change for forest categories (ARD)</td>
</tr>
</tbody>
</table>

consensus on the specifications for a high-resolution land-cover change dataset.

Several encouraging efforts are underway that improve the ability to monitor land cover at a global scale. The Indian Space Agency and the China-Brazil CBERS collaboration are committed to fine-scale earth-observation missions in the coming years. The NASA-USGS partnership is working toward a mid-2011 launch of the Landsat Data Continuity Mission (LDCM). It is also important to note that the continuity of Landsat-class earth observations is an important component of the recent U.S. Government decision to establish a National Land Imaging Program. Upcoming changes in global Landsat 7 pricing will also stimulate fine-scale global land-cover assessments.

In addition, the GOFC/GOLD land-cover team working with GEO has started to produce a “best available” global land-cover dataset that could become the “GEO global land cover product.” Starting with existing moderate-resolution global land-cover datasets (Table IV), the aim is to validate and harmonize existing data from global, regional, and national mapping efforts based on a robust and comparative accuracy assessment to derive the best land-cover estimate for each location worldwide. The idea is to further develop this product including regional high-resolution products until a new high-resolution (change) product is being produced (the final goal of DA-07-02).

V. CONCLUSION

Recent GEO activities to improve land-cover observations for sustained worldwide monitoring have evolved as one part of the terrestrial component of a GEOSS. The activities build upon positive experiences for truly global land-cover mapping efforts on moderate resolution (where satellite observations and land cover products are primarily generated through research funding), quasi-operational national and regional land monitoring systems, scientific advances in image processing and analysis, and efforts of the international community to increase the degree of harmonization and interoperability of land-cover information. GEO, as a platform and through its dedicated Task in the 2007–2009 workplan (DA-07-02), is trying to bring these efforts together. GEO has helped to raise awareness for terrestrial monitoring and advance the specifications and strategic considerations towards operational land-cover observations. The completion of IGOL and its transition into GEO is one prominent achievement.

The GEO progress so far has been widely driven by commitment and a coherent vision from the international land-cover community. As shown in this paper, integrated global observations will require coordinated efforts on different scales. Linking land-cover monitoring on national and regional scales on the one hand and global activities on the other hand is a key issue for further GEO implementation. It is hoped that, by emphasizing the progress made so far, more countries will be encouraged to get engaged and support this process. This should lead to more cooperation in continuous and consistent global land-cover observations. To mention an example, global land-cover issues are increasingly becoming an issue as part of the European Commission’s GMES activities [19]. GMES emphasizes a user-driven focus to provide services supporting EU applications and policy, thus, GEO can provide the appropriate platform to link such activities to the global level.

Following the overall goal of GEO Task DA-07-02 to develop global high-resolution land change products, it is important to emphasize that an operational land-cover observation and validation system is needed to fully achieve the societal benefits. Certainly, these are ambitious and long-term goals, but progress can be reported. Current efforts like the MidDecadal Global Landsat Survey [18] ensure that basic global observations for circa 2005–2006 are available in sufficient quality and with free access. By 2010, however, Landsat 5 and 7 may not be functional, and so the community is seeking help from GEO to ensure that the 2010 global fine-resolution satellite observations
TABLE IV
CHARACTERISTICS OF MAIN GLOBAL FOREST COVER AND LAND-COVER DATABASES DERIVED FROM SATELLITE DATA

<table>
<thead>
<tr>
<th>Dataset</th>
<th>Objective</th>
<th>Data</th>
<th>Classification system</th>
<th>Interpretation/map production approach</th>
<th>Validation</th>
<th>Data release policy</th>
</tr>
</thead>
<tbody>
<tr>
<td>IGBP DISCover part of the Global Land Cover Characterization Program (GLCC)</td>
<td>• Goal was to provide a global status-quo land cover map to improve the reliability of global-scale environmental assessments • No land cover change mapping was intended</td>
<td>AVHRR (1992-93), 1km</td>
<td>• IGBP-based land cover classification (17 classes) Additional legends: • Global Ecosystems (96 classes) • USGS Land Use/Land Cover (24 classes) • Simple Biosphere Model (20 classes) • Simple Biosphere Model 2 (11 classes) • Biosphere Atmosphere Transfer Scheme (20 classes) • Vegetation LifeForm (8 classes)</td>
<td>• Global land cover database: developed on a continent-by-continent basis • Continental database: unique elements based on the specific geographic aspects of each continent, there are a common set of derived thematic maps produced through the aggregation of seasonal land cover regions. • Computer-assisted image processing interpretation, multitemporal unsupervised classification of NDVI data • Classification process is not automated but more similar a traditional manual image interpretation. Human interpreter make the final decisions regarding the relationship between spectral classes defined using unsupervised and landscape characteristics that are used to make land cover definitions</td>
<td>Probability-based sampling with interpretation of Landsat TM or SPOT Application of two methods: “Core sample” of single pixels at each site (random stratified sampling of 13 classes, with a target of 25 samples per class “Confidence sample” consisting of an area of about 20 by 20 km, positioned with the core sample pixel at one corner, which was delineated into land cover polygons on the fine resolution imagery by a photointerpreter</td>
<td>Open access, data for free</td>
</tr>
<tr>
<td>Continuous Fields Tree Cover Project (AVHRR)</td>
<td>• To develop methodologies for global representation of vegetation characteristics and • To produce continuous fields of vegetation characteristics at 1 km which are accessible to the global change research community</td>
<td>AVHRR (1992-93), 1km</td>
<td>Proportional cover scale</td>
<td>• Automated classification procedure • Using training data and phenological metrics with a regression tree to derive global percent cover • Using Landsat MS images to train the linear mixture models for vegetation characteristics permitting estimation of endmember values • The spectral response of the AVHRR data is then unmixed using the endmembers and estimates of leaf longevity, leaf type and percent tree cover are identified</td>
<td>No information available</td>
<td>Open access, data for free</td>
</tr>
<tr>
<td>University of Maryland global Land Cover Product</td>
<td>• To develop methodologies for global land cover classifications that are objective, reproducible, and feasible to implement on data from additional years and • To produce a global land cover classification at 1 km spatial resolution accessible to the global change research community</td>
<td>AVHRR (1992-93), 1km, 8km, 1 deg.</td>
<td>• eleven major land cover types based on interannual variations in NDVI • These types were selected primarily to conform with the cover types required as input to climate models</td>
<td>• Developed on a continent-by-continent basis Automated unsupervised classification procedure • Training data and phenological metrics that describe the temporal dynamics of vegetation over an annual cycle • The metrics have the potential to be used as input variables to a global land cover classification</td>
<td>The data set has not been systematically validated.</td>
<td>Open access, data for free</td>
</tr>
<tr>
<td>MODIS Land Cover Products (MCD12)</td>
<td>• To provide a suite of land cover types useful to global system science models by exploiting the spectral, temporal, spatial, and directional information content of MODIS data</td>
<td>MODIS/Terra conc 2000), 1km</td>
<td>Application of following classification schemes: • IGBP based land cover classification (17 classes) • UMD (14 classes) • LAIAPPAR (9 classes) • PFT (12 classes)</td>
<td>• Supervised classification approach using a decision tree classification algorithm in conjunction with boosting • Top-down approach: image classification for the whole globe • Using a global suite of training sites interpreted primarily from Landsat Thematic Mapper (TM) data</td>
<td>• No probability-based sampling • Utilizing confusion matrices based on cross-validation using unseen training sites • Using IGBP confidence sites</td>
<td>Open access, data for free</td>
</tr>
<tr>
<td>Continuous Fields Tree Cover Project MODIS</td>
<td>• To support change detection studies at the global scale • To continue with and improve the continental fields product series, formerly retrieved from AVHRR data now using more detailed spatial/spectral characteristics of the MODIS data</td>
<td>MODIS/Terra. (2000-2005), 500m</td>
<td>Proportional cover scale</td>
<td>• Automated classification procedure using a regression tree algorithm • Using high-resolution imagery (Landsat ETM+, IKONOS) to derive global training data • Using training data as dependent variable, predicted by independent variables in form of annual MODIS metrics • Employing these data and phenological metrics and a regression tree to derive global percent cover • Outputs from the regression tree are further modified by stepwise regression and bias adjustment</td>
<td>Initial validation efforts Interpretation of field data along with IKONOS and Landsat ETM+ data Establishment of test areas with size of an ETM+ image • Crown cover maps of IKONOS images are binned to ETM+ cells to map percentage crown cover for 30m pixel • The retrieved ETM+ crown cover map is averaged to a 300-m resolution to validate the MODIS map</td>
<td>Open access, data for free</td>
</tr>
</tbody>
</table>

will be available and appropriately assembled. Thus, continuity of observations is not ensured at this point, and basic data supply remains one of the current challenges to sustaining land monitoring. Worldwide monitoring may not rely on one national asset alone [20]. Luckily, many countries have Landsat-type satellite assets. However, their viability for use in coordinated global land-cover monitoring efforts has yet to be demonstrated. International coordination is required to ensure that appropriate data products and mosaics are created from existing observational assets [21]. GEO has dedicated a task to the concept of CEOS constellations that involves a land-surface imager designed to ensure the relevant synergy among different satellite data sources [22].

From a more general point of view, GEO should influence the way we do earth observation and, thus, its level of societal support, use, and acceptance, which is an issue of particular relevance for terrestrial observations. GEO provides the opportunity to specify how to best achieve sustained satellite-based land-cover monitoring of global relevance and to stimulate countries to support its operational implementation. With consistency and continuity in observations, it is possible to engage user communities previously not, or less, involved in earth observation. The experiences and progress reported here demonstrate initial GEO success that should evolve and be extended to related issues that currently are effectively addressed by GEO (i.e., fire observations). Some activities, however, would need further GEO engagement, i.e., land use observations, the monitoring of human settlements, and joint acquisition strategies for optical and radar data (as advocated by IGOL). In addition, GEO should use its unique role to further strengthen the relationships between ef-
forts of the global community and national activities that, in perhaps five years’ time, could lead to achieving the ultimate goal of task DA-07-02 of accomplishing a global land-cover-change assessment at Landsat-scale. Suitable global land-cover mapping requires agreement among countries on how to produce such datasets and how to use such datasets. This involves current GEO members and non-GEO member nations with particular emphasis for engaging developing countries.

REFERENCES


### TABLE IV (CONTINUED)

|----------------|----------|----------|----------|----------|------------------------|------------------------|

GLCC2000: A new approach to GLCC2000, developed a processing system to derive moderate-resolution global land cover map for 2005-2006. Set up an international partnership to produce and use such products in continuous manner for multiple global and regional applications.  

A global land cover service with MERIS, presented at the ESA ENVISAT Symp., Montreux, Switzerland, 2007.
Martin Herold (A’07) was born in Leipzig, Germany, in 1975. He received the Diploma in geography from both the Friedrich Schiller University, Jena, Germany, and from the Technical University of Berlin, Germany, in 2000, and the Ph.D. degree in geography from the University of California, Santa Barbara, in 2004.

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He is currently with the Canadian Forest Service, Edmonton, AB, Canada. There, he leads the Wildland Fire Information Systems group and co-manages an International Polar Year study on climate change effects on vegetation and peat dynamics in the Northwest Territories. He also acts as the GOFC-GOLD Executive Director and manages the Project Office based at the Canadian Forest Service. He is actively contributing to a forest observation community of practice, which is part of the GEO User Interface Committee.

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