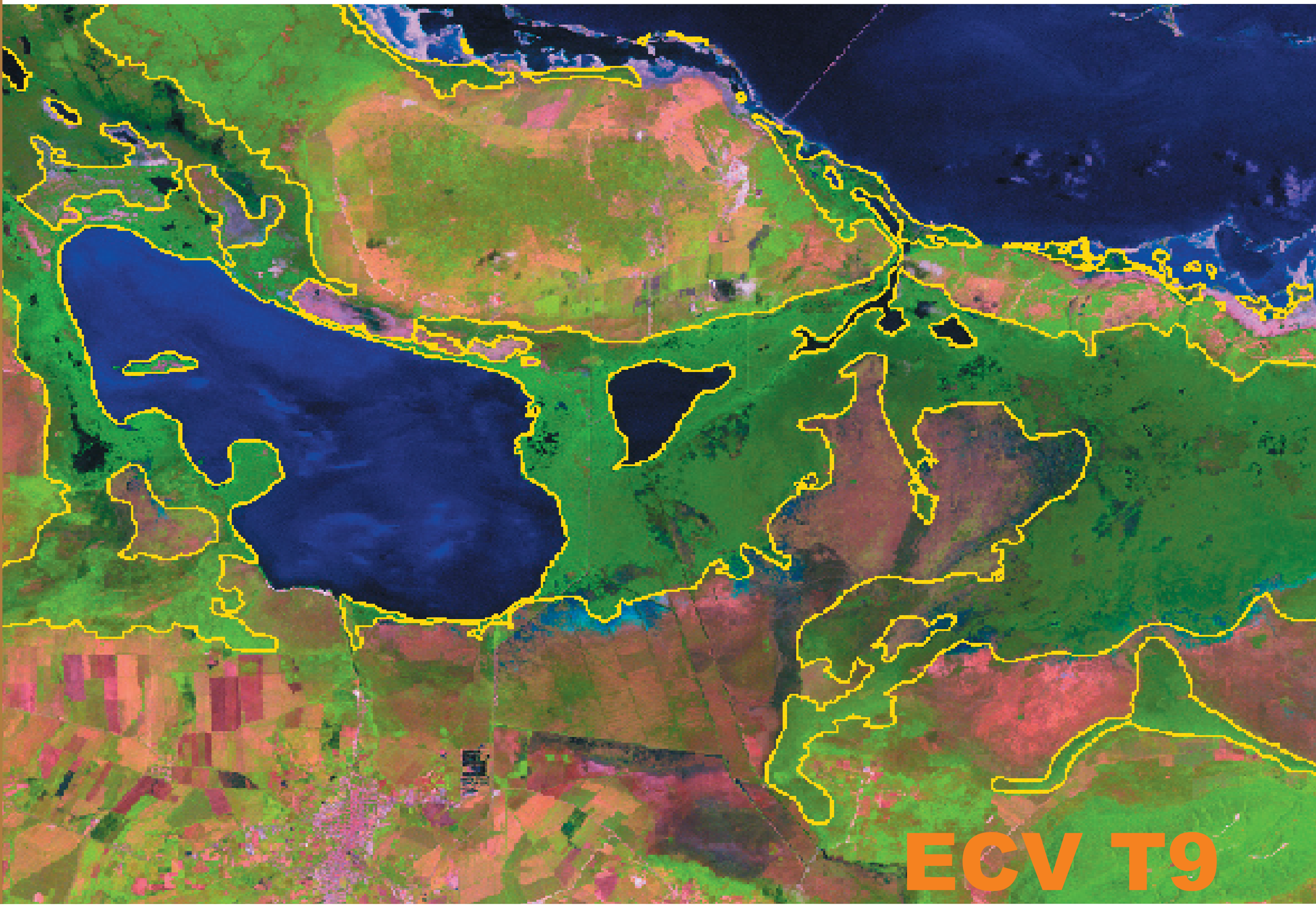
Essential Climate Variables



ECV T9
LAND COVER

GTOS 64

Assessment of the status of the development of standards for the Terrestrial Essential Climate Variables

ECV T9: Land Cover

Assessment of the status of the development of standards for the Terrestrial Essential Climate Variables

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PLEASE NOTE THAT THE CURRENT DOCUMENT IS A DRAFT WHICH IS UNDER REVIEW AND TO BE COMPLETED. A FINAL DOCUMENT WILL BE SUBMITTED AT SBSTA 30. FEEDBACK AND COMMENTS ARE ENCOURGAED.

Global Terrestrial Observing System, Rome, 2008

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Acronyms

CEOS	Committee for Earth Observation Satellite
EOS	Earth Observing System?
ESA	European Space Agency
EU	European Union
FAO	Food and Agriculture Organization of United Nations
FRA	Global Forest Resources Assessment of FAO
GLCF	Global Land Cover Facility
GLN	Global Land Cover?
GLP	Global Land Project
GOFC	Global Observations of Forest Cover
GOLD	Global observations of Land Cover Dynamics
IGBP	International Geosphere-Biosphere Programme?
IGOL	Integrated Observation of the Land
ILTER	International Long Term Ecological Research Sites
IPCC	Intergovernmental Panel on Climate Change
ISO	International Organization for Standardization
LCCS	Land Cover Classification System
LUCAS	Land Use/Cover Area Frame Statistical Survey
MMU	minimum mapping unit
NASA	National Aeronautics and Space Administration
RS	Remote Sensing
SAR	Synthetic Aperture Radar
TEMS	Terrestrial Ecosystem Monitoring Sites
UNFCCC	United Nations Framework Convention on Climate Change
VCF	Vegetation Continuous Fields?

Executive Summary

Land cover change is a pressing environmental issue, acting as both a cause and a consequence of climate change. Reliable observations are crucial to monitor and understand the ongoing processes of deforestation, desertification, urbanization, land degradation, loss of biodiversity and ecosystem functions, water and energy management, and the influence of land-cover changes on the physical climate system itself. A number of disciplines (i.e. geography, ecology, geology, forestry, land policy and planning, etc.) use and refer to land cover and land-cover change as one of the most obvious and detectable indicators of land surface characteristics and associated human induced and natural processes. Current and future IPCC Assessment Reports are based upon an uncertain understanding of the land surface and related processes. Applications of land cover and land dynamics in climate change related Earth System Models and Impact Assessment Models should be better linked and coordinated. The importance of these issues requires continuous monitoring systems and data.

Land cover is defined as the observed (bio)-physical cover on the earth's surface. It includes vegetation and man-made features as well as bare rock, bare soil and inland water surfaces. The primary units for characterizing land cover are categories (i.e. forest or open water) or continuous variables classifiers (fraction of tree canopy cover). Secondary outcomes of land cover characterization include surface area of land cover types (ha), land cover change (area and change trajectories), or observation by-products such as field survey data or processed satellite imagery.

Land cover in different regions has been mapped and characterized several times and many countries have some kind of land monitoring system in place (i.e. forest, agriculture and cartographic information systems and inventories). In addition, there are a number of global land cover map products and activities. These activities have been building upon the availability of continuous global satellite observations since the 1980s.

With evolving technology, it has become increasingly efficient to derive land cover information from a combination of *in situ* surveys and earth observation satellite data at global, regional, and national scales. Inconsistencies exist between the different land cover map products or change monitoring systems complicating our ability to successfully synthesize land cover assessments on regional and global scales.

Current data, products, and capabilities:

- Quasi-operational global land cover monitoring integrate information from three common observation scales: moderate resolution satellite data (e.g. MODIS- or MERIS–type satellite sensor); fine resolution satellite data (from LANDSAT- and SPOT-type satellite sensors), and *in situ* observations (or very high resolution satellite data). Continuity of observations and consistency for land cover characterization is required for all these scales.

- The UN Land Cover Classification System (LCCS) currently provides a comprehensive, internationally accepted, and flexible framework for thematic land cover characterization. LCCS uses classifiers enabling compatibility between existing datasets and for future global monitoring systems.
- Global mapping efforts (i.e. MERIS-based GlobCover and those from MODIS) are ongoing to provide consistent and validated land cover data and land cover change indicators worldwide at moderate-resolutions.

- Land cover change estimates require multi-temporal fine resolution satellite observations. Archived image data (i.e. global Landsat mosaics) and methods are available to implement a global land cover change monitoring system. Regional and national programs (e.g. CORINE, PRODES) and international initiatives such as the Forest Resources Assessment for 2010 of the FAO use multiple data sources for regional and global assessment of historical forest change processes.

- An independent accuracy assessment using a sample of ground-reference data is an integral part of any land cover monitoring effort. Standard methods for land cover validation have been developed by the international community.

Recommendations

- Continuity and availability of data is required for all observations scales.
- Continuous monitoring of conditions is recommended through periodic mapping cycles.
- The collection of ground reference data should be continuous and national agencies are encouraged to supply ground reference data in support of calibration and validation requirements.
- Further international development and adoption of land cover and land cover change mapping standards have been initiated and this process should be further encouraged.
- The international land observation community should coordinate and cooperate to provide useful and flexible land cover validation protocols.
- Internally consistent and synoptic data sets are required to represent the global land cover ECV, requiring communication and cooperation between nations.
- Member nations are encouraged to support the continuity of existing measurement capabilities and to promote a broadening of monitoring abilities.

1. Introduction

Land cover is defined as the observed physical cover of the earth's surface. Reliable 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, land degradation, loss of biodiversity and ecosystem functions, and water and energy management. *In situ* and satellite-based land observation efforts as well as different disciplines (i.e. geography, ecology, geology, forestry, land policy and planning etc.) use and refer to land cover as one of the most obvious and detectable indicators of land surface characteristics and associated human induced and natural processes.

The land surface in different regions of the world has been mapped and characterized several times and many countries have some kind of land monitoring system in place (i.e. forest, agriculture and cartographic information systems and inventories). There are multiple examples of countries using satellite data for national land cover and change assessments, i.e. in the context of their UNFCCC reporting. In addition, there are a number of global land cover mapping activities. They have evolved with the availability of continuous global moderate resolution satellite observations since the early 1990s and resulted in number of products in the 300m – 1km resolution range. Because most mapping projects are developed for specific applications and purposes, inconsistency exists between the different land cover map products or change monitoring systems and undermines the ability to successfully synthesize land assessments on regional and global scales. It is only recently that the UN Land Cover Classification System (LCCS) has been recognized and used to provide a basic level of thematic land cover standardization.

2. Definition and units of measure

Land cover is defined as the observed (bio)-physical cover on the earth’s surface. It includes vegetation and man-made features as well as bare rock, bare soil and inland water surfaces (Di Gregorio, 2005). In current practice, many national and regional observation programs and research institutes do not distinguish between land cover and land use. Land use characterizes the arrangements, activities and inputs people have undertaken on a certain land cover type to produce, change or maintain it. It includes both space and time and should be considered separately from land cover type to ensure internal and external consistency and comparability.

The primary units for characterizing land cover are categories (i.e. forest or open water) or continuous variables classifiers (fraction of tree canopy cover). Secondary outcomes include surface area of land cover types (ha), land cover change (area and change trajectories), or observational biproducts such as field survey data or geometrically and radiometrically corrected satellite image products. Categories and classifiers must be defined consistently in order to identify land cover changes within time series. Often it is essential to maintain the original data sources to support re-analysis of land cover with evolving technologies or changing standards or user requirements. In applications using land cover maps, the original land cover categories are often associated with specific attributes (i.e. average carbon stocks, degree of artificiality, and function in the hydrological system).

Many land information systems and legends mix land cover and land use concepts. Though often not considered carefully, the distinction between land cover and land use is fundamental to prevention of confusion or ambiguity, in particular for more standardized concepts of land cover characterization. Though the meaning of land use varies among sectors, analysis of major existing class sets reveals that two parameters suffice: function that describes land use in an economic context and activity that is defined as the combination of actions resulting in a certain type of product (Jansen, 2005). Land cover and land use transitions may be interoperable (i.e. change from natural forests to crop agriculture or expansion of built up areas as part of urban development processes), but this relationship doesn’t hold for all circumstances as land use characterization includes considerations that go beyond land cover

3. Existing measurement methods, protocols and standards

3.1 Standardized land cover characterization

Land cover mapping activities can be understood as a process of information extraction governed by a process of generalization. The degree of generalization and thus the efficiency of representing realty in 2-dimensional form is linked to three major factors. The ‘thematic’ component refers to the land classification system and the adopted land cover legend. ‘Cartographic’ standards include the spatial reference system, and the minimum mapping unit (MMU) and the mapping scale. The ‘interpretation’ process reflects the characteristics of the source data, the interpretation procedures, and the skill of their use. These factors affect the map products, their content, quality, flexibility and efficiency for applications.

It has become straightforward and efficient to derive land cover information from *in situ* surveys and earth observation satellite data. Thus, extensive information on land cover has been produced in many regions of the world. The varying purposes, data sources, accuracies, spatial resolutions, and thematic legends of these efforts have resulted in a suite of incompatible land cover datasets. Available global, regional, and national mapping products exist as independent datasets. For example, multiple definitions and thresholds for a particular land cover type, such as forests, result in different representations of forest class in the different land cover maps. The lack of consistency has triggered the need for harmonization and standardized land cover monitoring.

Land cover information has to be compatible and comparable for multi-temporal analysis and map updates, within and between countries, within and between applications, disciplines and agencies and among local to global scales (vertical and horizontal harmonization). In general, harmonization is a "bottom-up" process of emphasizing similarities and reducing inconsistencies between existing definitions of land cover to allow for better comparisons and compatibility between various land cover datasets (Herold 2006). Harmonization efforts should first harmonize the terminology, or classifiers, used for the description of land cover, and then, once applied to systems and legends, the individual criteria used for creating land cover categories should be harmonized and applied in operational observing programs.

The Land Cover Classification System (LCCS, Di Gregorio 2005) currently is the most comprehensive, internationally accepted, and flexible framework for land cover characterization. It defines a system of diagnostic criteria (land cover classifiers) that provides standardization of terminology and not categories. On this level, existing land cover data can be much better compared. The LCCS related Land Cover Data Macro Language is undergoing approval to become a standard of the International Standards Organization (ISO).

A translation of existing land cover legends and data in LCCS language usually provides the first step to develop understanding for applying the classifier concept, and many existing global, regional and national land cover legends have been developed or translated using LCCS (see www.glcn-lccs.org). An agreement on a set of recommended common LCCS classifiers provides the common ground for compatibility of land cover data. Current international consensus on classifiers that meet global mapping land cover requirements include:

- Vegetation life form: trees, shrubs, herbaceous vegetation (maybe separated into grasslands and agricultural crops), lichen and mosses, non-vegetated.
- Leaf type (needle-leaf, broad-leaf) and leaf longevity (deciduous, evergreen) for the different vegetation life forms.
- Non-vegetated cover types (bare soil or bare rock, built up areas, snow, ice, open water).
- Density of life form and leaf characteristics in percent cover.
- Terrestrial areas versus aquatic/regularly flooded.
- Artificiality of cover and land use.

The agreement and application of these classifiers have result in a number of generic land cover categories that should be considered in future mapping efforts:

- Trees (further separated by leaf type and leaf longevity).
- Shrubs (further separated by leaf type and leaf longevity).
- Herbaceous vegetation (further separated into grasslands and agricultural crops).
- Bare areas.
- Built up areas.
- Snow and/or Ice.
- Open water.

As a specific application of this concept, GOFC-GOLD in conjunction with the FAO will develop a globally exhaustive list of generic land cover classes, that conforms to LCCS classifiers, and can be regionally applied. This effort will provide a closed legend allowing mapping to be consistently categorized internationally or cross-walked to a known and globally meaningful scheme, while leaving the opportunity for provision of additional categorical detail to, i.e. accommodate regional specific characteristics or national monitoring requirements.

3.2 Observing land cover

Multispectral and multi-temporal global, regional and national land cover data sets are currently produced by a range of space agencies, research institutes, and national agencies at medium resolutions (250m-1km) for determining land cover type, and fine resolutions (10-50m) for determining type and detecting land cover change. Additionally, *in situ* data are acquired for monitoring of land cover, vegetation migration, and related phenomena, and is also used as reference for validation of land cover and land cover change measurements by satellites.

3.2.1 *In situ*

In situ or field observations are important and accurate source of land cover data. Depending on the scale and purpose a sampling design guides geo-referenced and GPS-guided *in situ* observations and description of land cover characteristics. Such surveys can provide statistical estimates of land cover area and, if repeated, changes for the sampled area. *In situ* observations easily provide measurements on both land cover and land use.

Ground-based observations are also a critical component of large-area land cover mapping and dynamics programmes to support the land cover interpretation of remotely sensed data and for the purpose of calibration and validation. For large-area projects, it is becoming increasingly common to use high spatial resolution airborne or satellite imagery. Samples derived from these image sources can be used to create datasets that allow for classification calibration and, if collected appropriately, robust and statistically validation. At minimum geo-located independent land cover classes are required to aid in the development of land cover maps based upon satellite imagery.

3.2.2 Satellite

In general, remote sensing data can be acquired from both airborne and satellite platforms and are based on a suite of measurements that can be used for land cover analysis. Spectral radiance is the primary variable used to determine land cover type from remote-sensing data. Spectral pattern recognition procedures provide pixel or object-based analysis based on varying responses of different land cover types in multispectral satellite observations such as Landsat or hyperspectral sensor with a large number of continuous and narrow spectral bands. Remote sensing data acquired on multiple dates (multi-temporal observations) recognize changes over time to assist in land cover characterization (i.e. phenology) or detection of changes.

Distance resolved measurements are based on time-delay measurements between sensor and land surface. Such measurements are provided by active sensors such as the Synthetic Aperture Radar (SAR), SAR interferometry or LiDAR sensors. Compared to optical multispectral data, such data are often more dependent on the three dimensional structures (i.e. roughness, topography, vegetation structure) on the earth surface, and, thus provide additional information for land cover interpretations. Spatial pattern in the image data provides information on the texture and relationship of neighbourhood pixels that can be useful for land cover interpretations.

In the current IPCC guidance given to countries for developing their national Greenhouse Inventories, the sections "Remote sensing techniques" (2.4.4.1 of Penman *et al.*, 2003 and 3A.2.4 of Eggleston *et al.*, 2006) provide a synthetic outline of the type of RS data. These sections briefly discuss some of the strengths and problems of remote sensing techniques, including:

- the ability to provide spatially-explicit information and the possibility to cover large and/or remote areas that are otherwise difficult to access;
- the possibility of repeated coverage and the availability of archives of past remote sensing data that can be used to reconstruct past time-series of land cover;
- the challenge of interpretation, i.e. the images need to be translated into meaningful information on land cover and land use by visual or digital (computer based) analysis;
- the risk, depending on the satellite sensor, that acquisition of data is impaired by the presence of clouds and atmospheric haze;
- the need of ground reference data and of evaluation of mapping accuracy;
- the fact that a complete remote sensing system for tracking land cover change may require combinations of different types of remote sensing data at a variety of resolutions.

Table 1 provides an overview of satellite sensors commonly used for land cover mapping and monitoring. The spatial resolution of the satellite imagery determines the minimum detectable size of individual patches (which changing land cover between two dates) – also referred to as Minimum Mapping Unit: fine resolution (circa 30m) data allows detecting operationally over large regions (e.g. at country level) single patches of circa 0,5 - 1 ha. For detecting patches smaller than 0.1 ha very fine resolutions (< 5 m) are needed.

Wall-to-wall (an analysis that covers the full spatial extent of the study area) and sampling approaches are both suitable methods for producing estimates of land cover area change. The main criteria for the selection of wall-to-wall or sampling approaches are:

- wall-to-wall is a common approach if appropriate for national circumstances, in particular when a benchmark land cover map is needed;
- if resources are not sufficient to complete wall-to wall coverage, sampling is more efficient, in particular for large areas to produce accurate estimates of land cover and change. Recommended sampling approaches are systematic sampling and stratified sampling which can be combined.

Satellite imagery usually goes through three main pre-processing steps before interpretation: geometric corrections, cloud removal and radiometric corrections.

Sensor & resolution	Examples of current sensors	Common minimum mapping unit	Cost for data acquisition	Utility for land cover monitoring
Moderate optical (250-1000 m)	SPOT-VGT (1998-) Terra-MODIS (2000-) Envisat-MERIS (2004-)	~ 100 ha ~ 10-20 ha	Low or free	Consistent global annual monitoring to identify phonological pattern, basic land cover types, large changes and locate "hotspots" for further analysis with finer resolution data
Fine optical (10-60 m)	Landsat TM or ETM+, SPOT HRV IRS AWiFs or LISS CBERS HRCCD	0.5 - 5 ha	Some free, otherwise <$0.001/km² for historical data $0.02/km² to $0.5/km2 for recent data	Primary tool to map major land cover types and changes and associated estimate area estimates
Very fine optical (<5 m)	IKONOS QuickBird Aerial photos	< 0.1 ha	High to very high $2 -30 /km²	Detailed surveys and mapping, validation of results from coarser resolution analysis, and training of algorithms.
Synthetic Aperture Radar (SAR) (10-60 m)	ERS-1 and 2, ENVISAT ASAR, RADARSAT, ALOS/PALSAR TERRASAR-X	0.5 - 5 ha	Depending on sensor and distribution agency	Additional information for mapping specific land cover types and for covering consistently cloudy areas

Table 1: Utility of common remote sensors at multiple resolutions for land cover monitoring

Many methods exist to interpret satellite images (Franklin and Wulder 2002, GOFC-GOLD 2008). The selection of the method depends on available resources and whether image processing software is available. Visual scene interpretation can be simple and robust, although it is a time-consuming method. A combination of automated methods (segmentation or classification) and visual interpretation can reduce the work load. Automated methods are generally preferable where possible because the interpretation is repeatable and efficient. Even in a fully automated process, visual inspection of the result by an analyst familiar with the region should be carried out to ensure appropriate interpretation.

The use of ancillary variables or support spatial data layers is well established as a means to improve land cover classification outcomes and accuracy. For instance, digital elevation data can be used in the classification or as a stratification layer (to differentiate land cover types that have known landscape positions). Further, temporal and spatial information can also be gleaned from image data to aid in image classification. Temporal signatures can assist in the differentiation of cover types that appear spectrally similar in one season and different in another (e.g. deciduous forests). Spatial signatures, or additional contextual information, are also increasingly used to improve classification outcomes, with known pixels/class associations used to aid in the determination of final class. A single class does not need to be the sole outcome of the classification processes. Statistical information produced during the classification, such as distances in the statistical feature space, can be used to identify also the second most likely class, or the confidence a user should have in a given class. The production of continuous fields, whereby each pixel is composed of component classes, is a soft classification method that is highly flexible allowing for the production of a wide-range of classification outcomes. Vegetation continuous fields (VCF) are especially relevant to more coarse spatial resolution imagery that have an internal mixture of land cover types.

The capture of change, or dynamics, in land cover is important and may be considered by type, magnitude, or area, among others. For change assessment consistent methodologies need to be used between the repeated time intervals to obtain accurate results. Fine spatial resolution change can provide dynamics information that is relevant at the landscape or management level, although physical and technical limitations remain in the production of large area dynamics products. Coarse spatial resolution data, while conferring less detail on a pixel level, have the advantage of capturing large areas in short periods of time allowing for change products to be developed over shorter temporal intervals. The combination of this coarse and fine spatial resolution data provides opportunities for large area monitoring in a systematic and meaningful fashion.

Satellite remote sensing can provide accurate information on land cover. Land use is considered a secondary observation variable that may or may not have a distinct relationship with land cover. To move from primary land cover to land use observations additional information is usually required, i.e. local expert interpretations, higher resolution data or ground-based observations.

A thorough consideration and independent accuracy assessment using a sample of higher quality data should be an integral part of any land cover monitoring system. If the sample for the higher quality data is statistically balanced (e.g. random, stratified, systematic), a calibration estimator (or similar) gives better results than the original survey. The accuracy assessment should lead to a quantitative description of the uncertainty of the land categories and the associated area or change observed. Different components of the monitoring system affect the quality of the outcomes. They include:

- the quality and suitability of the satellite data (i.e. in terms of spatial, spectral, and temporal resolution),
- the interoperability of different sensors or sensor generations,
- the radiometric and geometric preprocessing (i.e. correct geolocation),
- the cartographic and thematic standards (i.e. land category definitions and MMU),
- the interpretation procedure (i.e. classification algorithm or visual interpretation),
- the post-processing of the map products (i.e. dealing with no data values, conversions, integration with different data formats, e.g. vector versus raster), and

- the availability of reference data (e.g. ground truth data) for evaluation and calibration of the system.

Given the experiences from a variety of large-scale land cover monitoring systems, many of these error sources can be properly addressed during the monitoring process using widely accepted data and approaches:

- Suitable data characteristics: Using Landsat-type data, for example, have been proven useful for national-scale land cover and land cover change assessments for MMU's of about 1 ha. Temporal inconsistencies from seasonal variations that may lead to false change (phenology), and different illumination and atmospheric conditions can be reduced in the image selection process by using same-season images or, where available, applying two images for each time step.

- Data quality: Suitable preprocessing quality for most regions is provided by some satellite data provides (i.e. global Landsat Geocover mosaics). Geolocation and spectral quality should be checked with available datasets, and related corrections are mandatory when satellite sensors with no or low geometric and radiometric processing levels are used.

- Consistent and transparent mapping: The same cartographic and thematic standards (i. definitions), and accepted interpretation methods should be applied in a transparent manner using expert interpreters to derive the best national estimates. Providing the initial data, intermediate data products, a documentation of all processing steps interpretation keys and training data along with the final maps and estimates supports a transparent consideration of the monitoring framework applied. Consistent mapping also includes a proper treatment of areas with no data (i.e. from constraints due to cloud cover).

3.3 Summary of requirements and gaps

In summary of sections 3.1 and 3.2 the following important criteria should be considered for selecting land cover observation data and land cover product development:

- Adequate land categorization scheme;
- Appropriate spatial resolution;
- Appropriate temporal resolution for estimating of land conversions;
- Availability of accuracy assessment;
- Transparent methods applied in data acquisition and processing;
- Consistency and availability over time.

Integrated Observation of the Land (IGOL, Townshend *et al.* 2008) defines detailed land observations requirements for land cover and advocates existing requirements and gaps. IGOL advocates sustained and integrated observations on all three major scales of land cover observations: moderate and fine resolution satellite data, and in situ, (see Figure 1). An operational global observing system for land cover integrates information from these three different scales, i.e. MODIS or MERIS –type satellite sensor (moderate resolution), from Landsat and Spot-type satellite sensors (fine resolution satellite data), and in situ observations (or very high resolution satellite data). Measurements on these different scales have their strengths and weakness for monitoring in terms of spatial and thematic detail they provide, and for the efforts needed for regular temporal updates. An integrated system combines their advantages to provide world-wide consistency and link the local and global observation level.

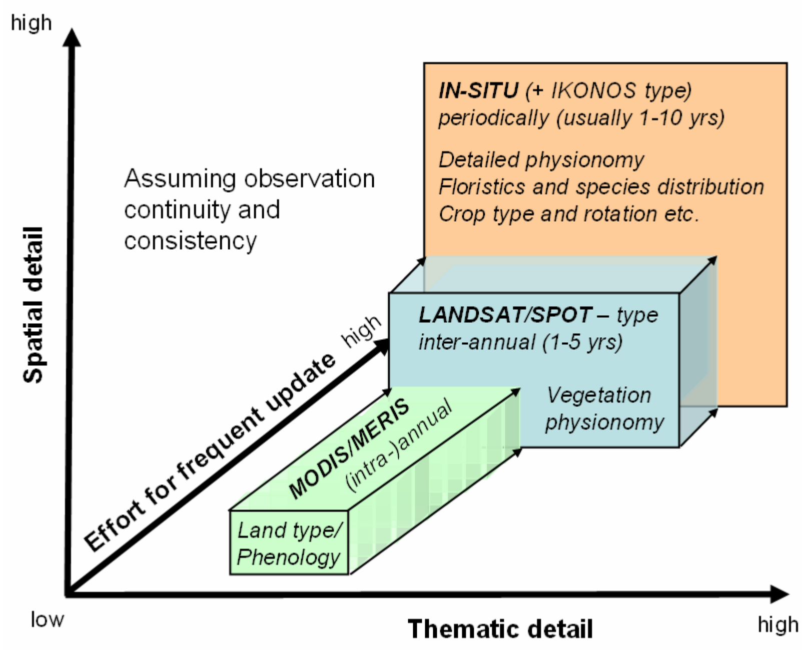

Figure 1: A framework for integrated global observations of land cover and vegetation (from Herold et al., 2008).

Based on the IGOL requirements and current consensus among the international land observation community the following requirements and gaps can be highlighted:

a. Availability of baseline observations

The implementation of the framework assumes that there is observation continuity on all scales. Existing and archived data sources are not yet fully explored for land cover monitoring. Basically there is difference in the usefulness of existing data sources depending on the following characteristics:

i. Observations datasets are being continuously acquired and archived by national or international agencies,
ii. There is general understanding on the availability (i.e. global cloud-free coverage), quality and accessibility of archived data,
iii. Observation data are being pre-processed (i.e. geometrically and radiometrically corrected) and are made accessible to the monitoring community,
iv. Pre-processed datasets are available in international or national mapping agencies for land cover and change interpretation,

v. Sustained capacities exists to produce and use land cover datasets within countries and for global assessments (i.e. in developing countries)

Ideally, all relevant land cover observations (satellite and in situ) should meet these requirements to be considered useful for the overall aim of UNFCCC. For example, the commitment to build and operate LANDSAT 8 (US) and Sentinel 2 (EU) are major achievements to ensure continuity beyond 2012. In particular the collection of ground and in-situ data should be continuous and national agencies are encouraged to supply data support of monitoring and to meet calibration and validation requirements.

b. Continuous monitoring

There are commitments of observing agencies for coordination of observations that should be further encouraged to provide continuity and availability of data for all observations scales. However, there is lack of using available data for continuous monitoring of conditions in periodic mapping cycles rather than single mapping efforts. For example, global mapping efforts, i.e. MERIS-based GlobCover (Arino et al., 2008) and those from MODIS need to move to operation to provide consistent land cover data and land cover change indicators worldwide at moderate-resolutions. An operational validation and verification system should be part of these efforts and the international land observation community should help to coordinate and cooperate to provide useful and flexible land cover validation protocols. Similarly national monitoring system

c. Land cover versus land use and land change

Observation strategies and methods vary for observing land cover, land use or associated changes. Standard procedures exist for observation of land cover. Further international technical consensus should be developed for the area of observing land cover change, land use, and land use change. I particular the requirements for estimating, accounting and reporting on land use change and forestry using the IPCC guidelines and guidance (Penman *et al.*, 2003, Eggleston *et al.*, 2006) and the global forest resources assessments by FAO rely on land cover and land use change information.

d. Towards more standardized land cover characterization

The observation framework described in Figure 1 assumes that measurements taken on all of these scales are comparable and compatible. A number steps should be taken to ensure consistency for future mapping and monitoring efforts:

- Further international consensus discussion on the adoption of evolving land cover mapping standards (LCCS classifiers and generic classes),
- Existing legends should be revisited in the context of evolving land cover standards.
- Any land cover legend should be developed using LCCS and the common set of classifiers. Based on these general descriptions more thematic detail can be specified that meet the mapping requirements without losing compatibility on a broader level.

- Explore how a harmonized land cover product can be link or can benefit from existing mapping initiatives on both finer and coarser scales (e.g. in situ and global) and vice versa.

e. Further technical guidance on remote sensing approaches

Several initiatives are currently ongoing to move towards operational land cover monitoring. The approaches used by the international community or by countries (i.e. for their GHG inventories) still seem diverse. This highlights that some basic level of consistency would be needed between the different methodologies and to ensure:

- Better description of characteristics of satellite imagery (e.g. spatial and temporal resolution, cost and availability) to be used in relation to the definition selected by the country (minimum land area). This has also implication on the accuracy.
- Existing standard image classification methodologies, with a special focus on land use identification (i.e. based on IPCC land use categories);
- Integration of different data, i.e. more info on potentialities and problems of methods for combining in situ observations with RS satellite data;
- Indication of cost of data processing and analysis;
- Better description of specific issues and problems related to the detection of active fire and burned areas with satellite remote sensing techniques;

There is need for more formalized technical guidance and support, and capacity development given the increasing role for evolving monitoring technologies and building upon established international networks. For example, dedicated technical input was provided to the negotiations of the UNFCCC on reducing greenhouse gas emissions from deforestation in developing countries (REDD) as key mitigation option for the post-Kyoto climate agreement. A sourcebook of methods and procedures to estimate and account for carbon emissions from forest loss in an operational, verifiable, transparent and efficient manner has been developed (GOFC-GOLD, 2008).

f. Assessment of accuracy of land area change

Despite a number of successful case studies, there are no uniform methods for the accuracy assessment of land cover / land use change and associated area estimates. The GOFC-GOLD community (who has developed consensus guidelines to validate single date land cover maps), has already started the process to develop such internationally agreed approaches for the case of land cover and use change.

g. Support modeling the earth system, and climate change and policy impacts

Applications of Earth System Models and Impact Assessment Models to understand and forcast climate change impacts, and potential mitigation and adaption strategies require improved land cover, land cover change and land use datasets. Further emphasis should better link and coordinate between the land observation and the modelling community to better address land use change issues to reduce uncertainties in understanding and modelling the global carbon cycle, and for related impact and policy assessments.

4. Contributing networks and agencies

The Global Terrestrial Observing System (GTOS, http://www.fao.org/gtos/) is a programme for observations, modelling, and analysis of terrestrial ecosystems to support sustainable development. GTOS facilitates access to information on terrestrial ecosystems so that researchers and policy makers can detect and manage global and regional environmental change. The main GTOS sponsor is FAO and which is also sponsored by UNEP, WMO and ICSU. GTOS has two sister organizations: the Global Ocean and Climate Observing Systems (GOOS and GCOS). GTOS is the mandated organization to coordinate ECV observations in the terrestrial domain and the development of reporting guidelines and standards.

Global Observations of Forest Cover and Land Dynamics (GOFC-GOLD initially named GOFC, http://www.fao.org/gtos/gofc-gold/) is a coordinated international effort working to provide ongoing space-based and in-situ observations of forests and other vegetation cover, for the sustainable management of terrestrial resources and to obtain an accurate, reliable, quantitative understanding of the terrestrial carbon budget. Originally developed as a pilot project by the Committee on Earth Observation Satellites (CEOS) as part of their Integrated Global Observing Strategy, GOFC-GOLD is now a panel of the Global Terrestrial Observing System (GTOS). GOFC-GOLD is working to accomplish its objectives by providing a forum for users of satellite data to discuss their needs and for producers to respond through improvements to their programs, providing regional and global land datasets, promoting globally consistent data processing and interpretation methods and promoting international networks for data access, data sharing, and international collaboration, and stimulating the production of improved products (Townshend and Brady, 2006).

The Group on Earth Observation (GEO) shaped as a result of three ministerial level earth observation summits. It aims to build and maintain a Global Earth Observation System of Systems (GEOSS). 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 (GEOSS, 2005). GEO as high-level political process (74 member states and 51 participating organizations in August 2008) has defined nine areas where society directly benefits from earth observations. These areas are related to Disasters, Energy, Health, Climate, Water, Weather, Agriculture, Ecosystems, and Biodiversity. According to the 10 year implementation plan, land cover observations are important for all of these areas (GEOSS, 2005). Although being global of scope, GEO seeks to stimulate national and regional implementation activities. GEO's main objective is better international coordination and a number of relevant forest and land cover monitoring related tasks a carried out by existing agencies and networks (Herold et al., 2008).

The Integrated Global Observation Strategy-Partnership (IGOS-P) is organized through a series of themes, including Oceans, Carbon, Water Cycle Coasts and

Natural Hazards. In 2004 it was decided that IGOS-P should have an additional theme so that international agreement could be reached concerning all land requirements outside of those covered by other established themes. This new theme is known as Integrated Global Observations of the Land (IGOL). Following the requirements laid out by GEO, IGOL defines detailed observations requirements for the land domain (Townshend et al., 2007). At the present time while GEO is evolving, there is clearly considerable overlap between IGOS-P and GEOSS and many IGOS themes are in transition into to GEO tasks and activities.

The Committee on Earth Observing Satellites (CEOS) was set up to coordinate global earth observing activities among the space agencies. CEOS implementation is organized in working groups. The Working Group on Calibration and Validation's Land Product Validation sub-group (CEOS WGCV) is of particular importance for the land cover observation domain.

With the UN system the Food and Agriculture Organization (FAO) and United Nations Environment Program (UNEP) are primarily involved in land cover observations. For example, FAO, at the request of its member countries, regularly monitors the world's forests and their management and uses through the Forest Resources Assessment Programme (FRA). Every five to ten years since 1946, FAO provides a periodic global picture on existing forests, derived trends and statistics. The Global Forest Resources Assessment 2005 is the most comprehensive assessment to date. Although FRA has been primarily using national statistics, the FRA 1990 and 2000 used a combination of earth observation data and national data to estimate transitions between several woody biomass categories for Africa, Latin America and Asia. For FRA 2010 a comprehensive global remote sensing survey is intended (FAO, 2006).

The United Nations Global Land Cover Network (GLCN) has been driving the national implementation of the evolving land cover standards and its implementation. GLCN developed from FAO's Africover and Asiacover initiatives. The approach is to bring all national land mapping entities together and develop strategies on how the standards can be implemented on a national level. As one of its main activities, GLCN is leading the development and implementation of UN Land Cover Classification System (LCCS, Di Gregorio, 2005).

Several space agencies are leading global efforts to land cover observations. Activities include US sponsored initiatives like NASA's land cover and land use change program (http://lcluc.umd.edu/), the US Geological Survey (http://edc2.usgs.gov/glcc/), and Global Land Cover Facility based at the University of Maryland (glcf.umiacs.umd.edu). They develop and distribute satellite data and land cover information with a focus on determining the location, extent, and drivers of land cover changes around the world. The European Space Agency, and in particular its Data User Element (dup.esrin.esa.it) are providing continuous global land cover observations (i.e. through GLOBCOVER, Arino et al., 2008). The EU lead initiative Kopernicus is developing earth observation based services for Europe and is evolving more engagement and support to the global land cover observation domain.

5. Available data

5.1 In Situ

An example is LUCAS, the European Land Use/Cover Area Frame Statistical Survey. LUCAS is based on an area frame survey (sample of geo-referenced points surveyed in situ by surveyors) carried out in 2001, 2003, and 2006. Several countries also have sample plot based national forest inventories that might be used as in situ information.

However, it is acknowledged that for many parts of the globe these types of data may not exist. Options for alternate acceptable or useful data sources will be developed, resulting in a prioritization of information to be used. When considered spatially, this prioritization will indicate locations / regions most in need of the collection of data to support land cover mapping. The temporal element of the field observations must also be considered. Ideally continuous collection of field observations of some sort will occur from before mapping is initiated and continue through the mapping effort. This enables gathering of field observations for calibration of a given map product, but through the continued data collection facilitates the validation of mapping outcomes and for assessment of change products that may be developed.

The following are among the global and regional networks that collect in situ land cover data that might also be used for validation purposes:
- International Long Term Ecological Research Sites (ILTER) - 195 T.Sites
- Terrestrial Ecosystem Monitoring Sites (TEMS) - 146 T.Sites
- IGBP Land Cover Validation Confidence Sites - 413 T.Sites
- EOS Land Validation Core Sites - 31 T.Sites
- SAFARI 2000 Validation Sites - 20 T.Sites
- FLUXNET Network - 266 T.Sites
- BIGFOOT Network - 19 T.Sites
- GLC 2000 Validation Sites - 1253 T-Sites

5.2 Satellite

Global, 1-km Annual Land Cover Type

Data requirements:
1. A repeatable classification algorithm that can be applied uniformly across all regions of the Earth.
2. Use of the highest spatial resolution achievable for global land cover maps.
3. Annually updated maps to identify land cover change. Since the classification error rate is much higher than the annual rate of land cover change (and consequently changes observed are often due to algorithm errors or changes in training), a consistent and repeatable classification system is needed.
4. The highest classification accuracy possible. Accuracies associated with specific classes should not be less than 65 percent correctly classified, and classification accuracies shouldn’t vary widely due to geographic location.

5. A statistically rigorous validation strategy that assesses overall classification accuracy and accuracy within classes.

Technical Approach:

- Input data algorithms must be processed to minimize variations between and within sensors.
- To support of supervised classifications, high-resolution training data sets are needed; creation of such datasets requires protocols for geographic and ecological sampling, minimum patch size, quality assessment, and procedures for detecting land cover change in any given patch.
- Use of a validation strategy that uses a probability-based sample design with adequate samples to estimate overall accuracy and class-specific accuracy at continental, or if feasible, regional scales.

Global, Decadal, mid-Decadal, 30m Land Cover Type

Data requirements:

1. Based on a flexible and hierarchical land cover classification scheme with categories relevant for assessing a wide range of environmental applications. In particular, attention should be devoted to classes that are poorly represented in coarse-resolution representations, and those classes reflecting human land use (e.g. urban types, agricultural types, impervious surfaces).
2. A spatial resolution of 30m with temporal updates every 5 or 10 years.
3. Overall and regional accuracies exceeding 90 percent at the highest level of aggregation.
4. Validation should be based on the use of a probability-based sampling strategy.

Technical approach:

- The use of computer-assisted methods enables a cost-effective approach to creating accurate, high-resolution imagery.
- Validation must be statistically rigorous. Finding suitable sources of validation can be problematic; high resolution satellite imagery and aerial photography may be costly but are useful.

Global Continuous Fields

Data requirements:

1. The use of explicit physiognomic-structural definition sets that are easily incorporated into FAO Land Cover Classification System and that enable the derivation of a mutually exclusive and exhaustive land cover classification.
2. (Modular) vegetation trait definitions that allow for their direct incorporation into global, continental and regional scale biogeochemical, hydrological and other natural resource and ecological modeling exercises.
3. An algorithm that yields the highest accuracy possible.
4. Annual or more frequent monitoring for those VCF layers suitable for change monitoring, and five year intervals for layers not likely to exhibit change.
6. Spatial resolution of at minimum 500 meters to permit large area monitoring of key vegetation change dynamics (e.g. deforestation).

7. Quality assessment mechanisms for each observation or pixel.
8. Validation protocols for both VCF layers and derived change products.
9. The temporal frequency of the VCF layers and change products are envisioned as x and y, respectively.

Technological approach:

- A supervised algorithm to ensure repeatability. Tree-based algorithms meet key criteria of repeatability, transparency, and a high level of accuracy.
- Training data should be derived from high-resolution data sets (5-50 meters) for calibrating the algorithm.
- Vegetation train definitions used should be compatible with FAO's Land Cover Classification System.
- Probability-based sample designs for assessing product accuracy should be based on the direct observation or measurement of the respective vegetation trait.

Inter-annual Land Cover Change and Disturbance

Data requirements:

1. High resolution data (less than ~50 meters) are required to create accurate maps of land cover conversion and many types of ecosystem disturbance, including anthropogenic changes.
2. Land cover change should be monitored according to two separate temporal resolutions: updates on intervals of five years or less to assess long-term trends in land-cover change; and annual updates to detect major annual variations at the regional scale in terms of deforestation and regrowth (these changes strongly impact carbon sinks and sources).
3. Land cover change products for this purpose should collect information on three themes: (1) *conversion* of land-cover from one type to another; (2) ecosystem *disturbance* events without change in land cover type; and (3) quantitative data on *changes in vegetation cover* due to land cover conversion, disturbance, recovery, or long-term ecological trends.

Technical approach:

- Algorithms should explicitly account for atmospheric and seasonal variability among images. Atmospheric correction to surface reflectance may reduce atmospheric variability, and provide a physical basis for further analyses.
- Spectral unmixing algorithms have proven to be effective for assessing changes in land cover, as long as sufficient training data exist. Mapping land-cover conversion requires algorithms that use direct radiometric comparison across time. Multi-date supervised classification has been effective for this purpose.
- Different algorithms for specific regions, processes, or parameters, rather than a single algorithm for all land cover change, should be considered.

6. Other issues

Other issues of concern can be raised in this section, for example issues of lack of funding, problems of data access, lack of government support (e.g. research sites not becoming part of the networks or data not being realised), continuity of technologies, etc.

7. Conclusions

A general summary of the finding of the report in regards to available standards, methods, validation, etc. and their adoption should be placed here. To be added once bulk of text is edited and reviewed.

8. Recommendations

8.1 Standards and methods

More activities are needed to move towards more standardized land cover characterization and to ensure that land cover measurements taken on all of these scales are comparable and compatible. A number of steps should be taken to ensure consistency for future mapping and monitoring efforts:

- Further international consensus discussions on the adoption of evolving land cover mapping standards (LCCS classifiers and generic classes),
- Existing legends should be revisited in the context of evolving land cover standards,
- Land cover legends should be developed using LCCS and the common set of classifiers. Based on these general descriptions more thematic detail can be specified that meet the mapping requirements without losing compatibility on a broader level,
- Explore how a harmonized land cover product can link to, or benefit from existing mapping initiatives on both finer and coarser scales (e.g. in situ and global) and vice versa.

The international land observation community should further coordinate and cooperate towards useful, flexible and validated global land cover information. Particular effort should be focused on the implementation of an operational global land cover validation system, and to formulate specifications for a global high-resolution land cover product and land change monitoring and accuracy assessment.

8.2 other recommendations

- The interaction between the observation community and the political community needs to be established as continuous process to ensure the achievement of the long-term observation goals and the further development of saliency. The current priorities and prominent processes mainly focus on issues of forest observation. Future attention may be required for the observation of other domains, i.e. related to agriculture or urban areas.

- Continuity and availability of data is required for all observation scales. Current shortcomings include limited access to available observation data in existing archives, the lack of coordinated global observations for both satellite and in situ data. National and international space agencies are urged to make long-term commitments to acquire and ensure availability of baseline datasets. Priority should be given to the development of the 2005 and 2010 consistent, pre-processed, global, and free-of charge LANDSAT data that extends the existing 1990 and 2000 datasets. In the future, better synergistic use of optical and active remote sensing (i.e Radar and Lidar) data sources will improve land cover characterization.
- There are gaps (both geographic and thematic) in the collection of in situ and reference data necessary for land cover/use surveys, and the calibration and validation of satellite data analysis that should be addressed in future efforts to reduce them.
- Based on availability of baseline data, continuous monitoring of conditions is recommended through periodic mapping cycles.
- Although some countries maintain operational, satellite-based land cover monitoring systems (i.e. India, Brazil, Australia, EU, US, Australia), the capacities in many countries to produce and use land cover datasets are limited. Significant efforts should aim to build and strengthen existing capacities, with an emphasis given to the stronger involvement of developing countries in the anticipated post 2012 climate agreement.
- While standard procedures exist for the monitoring of land cover and to some extent for land cover change, monitoring strategies and methods vary for observing land cover changes and land use. The technical community is asked for a better description of satellite imagery characteristics, existing standard interpretation methodologies, and integration of different data sources for such purposes.
- Further emphasis should be given to better link and coordinate the land observation and modeling communities, to better address land change issues to reduce uncertainties in understanding and modeling the global carbon cycle, and for related impact and policy assessments. Among the requirements is the need for better conceptual and thematic treatment of land cover and land use concepts, and its heterogeneity and uncertainty in Earth system models; in particular assuming that in the near future global land cover data will provide even more spatial detail (i.e. GLOBCOVER), and all new maps will be accompanied by robust accuracy measures. This may entail modeling meteorological and land surface processes on different scales, and is of particular relevance for the incorporation of often small-scale and spatially clustered land change processes.

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