Update on

Land cover change

for use in global carbon observations

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1. Abstract

Land cover change is an Essential Carbon Cycle Variable (previously called Essential Carbon Variable) that should be measured with coarse (250 m – 1000 m, annually) and fine (25 m, every five years) spatial resolution. Land cover change is assessed from land cover products. Land cover products from satellite observations are generally available at 1 km resolution, and more recently 300 m resolution (GLOBCOVER). Few land cover products have been prepared in such a way that changes can be calculated without additional efforts for data harmonization. The only global product available for calculating land cover change at nearly the specified fine resolution is the Global Land Survey for the 1970s, 1990, 2000, 2005, and (in preparation) 2010. It is necessary to formally adjust the ECCV definitions and requirements for land cover and land cover change products so that they are in line with the specifications of land cover as an Essential Climate Variable. Furthermore, it is necessary to address also other land cover transitions than forest/non-forest as ECCV.

2. Introduction

Land cover and land cover change are Essential Carbon Cycle Variables[1] (ECCVs) according to the IGOS carbon theme report (Ciais et al. 2004). Land cover is also an Essential Climate Variable (ECV). The purpose of this document is to describe the current efforts to monitor land cover change at the global scale.

The current status of land cover as an ECV and necessary improvements has been described in the GOSC Implementation Plan (GCOS 2009).

ECV – Land Cover

Land cover and its changes modify the services provided to human society (e.g., provision of food, fibre, recreational opportunities, etc.), force climate by altering water and energy exchanges with the atmosphere, and change greenhouse gas and aerosol sources and sinks. Land-cover distribution is partly determined by regional climate, so changes in cover may indicate climate change.

Although land-cover change can be inferred using data from Earth observing satellites, currently available data sets vary in terms of data sources employed, spatial resolution and thematic content, have different types and patterns of thematic accuracy and many use different land-cover type classification systems, although improvement has been made in using common standards. It is necessary, and feasible with present-day technology, to provide satellite-based optical systems at 10-30 m resolution with temporal, spectral and data-acquisition characteristics that are consistent with previous systems. Commitments to short-term continuity of this class of observations, such as the Landsat Data Continuity Mission and Sentinel-2, are vital steps, though long-term commitments still need to be secured. The CEOS Land Surface Imaging Constellation has been instigated to promote the effective and comprehensive collection, distribution and application of space-acquired imagery of the land surface.

Data sets characterizing global land cover are currently produced at resolutions of between 250m and 1km by several space agencies in close cooperation with the research community (especially those research groups participating in the GTOS technical panel Global Observation of Forest and Land Cover Dynamics (GOFC-GOLD)). The lack of compatibility between these products makes it difficult to measure and monitor climate-induced or anthropogenic changes in land cover. A range of approaches is adopted, e.g., centralized processing using a single method of image classification (e.g., MODLAND, GlobCover), or a distributed approach using a network of experts applying regionally specific methods (e.g., GLC2000). Using a single source of satellite imagery and a uniform classification algorithm has benefits in terms of consistency, but may not yield optimum results for all regions and all land-cover types. Automated land-cover characterization and land-cover change monitoring thus remains a research priority.

[1] GCOS has suggested to rename Essential Carbon Variables (ECaV) 'Essential Carbon Cycle Variables (ECCV)' to avoid confusion (S. Bojinski, pers. comm., January 2010, supported by H. Dolman and Ph. Ciais).

It is necessary that land-cover classification systems and the associated map legends adhere to internationally-agreed standards[2]. Such standards should eventually be agreed upon by the UN/ISO Terrestrial Framework …. In the near term, however, full benefit should be taken of existing initiatives, e.g., the FAO's Land Cover Classification System for legend harmonization and translation, and the legends published by the IGBP and the GTOS GOFC-GOLD. The process of harmonization and translation of existing legends will be strengthened with the FAO's new Land Cover Meta Language (LCML). The LCML will be an operational tool to formalize the meaning of any existing land cover classification/legend according to the latest ISO standards.

As a minimum, new land-cover maps should be produced annually, documenting the spatial distribution of land-cover characteristics with attributes suitable for climate, carbon and ecosystem models, and using a common language for class definitions (e.g., include wetland information describing forest peat lands (boreal), mangroves, sedge grasslands, rush grasslands and seasonally-flooded forests, and area of land under irrigation), at moderate (250m–1km) resolution. Grid-scale information on the percentage of tree, grass and bare soil cover should ideally also be made available.

In addition to their use in Earth system models, these global products will help identify areas of rapid change, although the development of automated detection of changes in land-cover characteristics remains high on the research agenda. The production of such land-cover data sets will involve space agencies for processing the satellite data used in the database production, the FAO/science panels to ensure legend relevance and standards and the research community for optimizing image classification approaches. Mechanisms to fund such partnerships are emerging (e.g., the EU global monitoring for environment and security initiative) but are not yet guaranteed on a sustained basis.

Global land-cover databases must also be accompanied by a description of by-class thematic/spatial accuracy. The CEOS/WGCV, working with GOFC-GOLD and GLCN has published agreed validation protocols, which should be used. The current protocols base accuracy assessment on a sample of high-resolution (1-30m) satellite imagery, itself validated by *in situ* observations wherever possible. To better quantify changes in land-cover characteristics, these high-resolution data should also be used for wall-to-wall global mapping at resolutions of 10–30m. Maps at this resolution are needed at least every 5 years over long time periods (several decades) to assess land cover change. Global data sets of satellite imagery at 30m resolution have been assembled for selected years (e.g., 1990, 2000 and 2005) and some regional land-cover maps have been generated from these. The technologies have been developed and tested (e.g., Landsat, Sentinel-2 and the Satellite Probatoire d'Observation de la Terre High Resolution (SPOT HRV)), and suitable methods for land-cover characterization on these scales exist. Space agencies should assure that suitable optical sensors with 10–30m resolution are available for operational monitoring using data acquisition strategies comparable to systems in current operation.

[2] http://www.fao.org/gtos/ECV-T09.html

While, at the time of writing, it was not yet clear what methodology would be put in place under the UNFCCC in connection with the proposed implementation of Reducing Emissions from Deforestation and forest Degradation in developing countries (REDD), relevant space agencies under CEOS have agreed to supply, on a regular basis, the high-resolution data necessary for the generation of fine-resolution land cover maps to support such a methodology. … .

Samples of high-resolution satellite imagery have also been used to estimate change and are proposed for example by the FAO's Global Land Cover Network and the FAO Forest Resource Assessment. Initiatives such as these will provide much needed capacity-building and offer a framework for acquisition of *in situ* observations to support the satellite image-based monitoring. Such *in situ* networks will also provide information on how land is being used (as opposed to what is covering it). Land use cannot always be inferred from cover.

A more detailed report is available from GTOS (Herold 2009). A harmonized land cover classification system (LCCS) has been developed by FAO and UNEP (di Gregorio and Jansen 2005) and submitted to ISO for incorporation as a standard.

The specifications for land cover observations by satellite mostly agree between ECVs and ECCVs with notable exception of the classification detail (Tab. 1).

Table 1. Specifications for land use observations by satellites

Land Use	ECV	ECCV
Horizontal resolution: goal	0.25 km	0.25 km
Horizontal resolution: breakthrough	0.4 km	
Horizontal resolution: maximum	1.0 km	1.0 km
Observation cycle: goal	1.0 yr	weekly[3]
Observation cycle: breakthrough	1.5 yr	
Observation cycle: maximum	5.0 yr	5.0 yr
Categories: goal	50	221
Categories: breakthrough	25	
Categories: minimum	5	6 water, snow and ice, barren or sparsely vegetated, built-up, croplands, forest

The high number of categories for land cover as an ECCV (Table 1) results from the fine subclassification of forests according to leaf type (needle, broadleaf, mixed), leaf longevity (evergreen, deciduous,

[3] Ciais et al. (2004) Tables 9.1, 9.3.

mixed), canopy cover (10–25%, 25–40%, 40–60%, 60–100%), canopy height (0– 1 m [low shrubs], 1–2 m [tall shrubs], >2 m [trees], and flooding [flooded, non-flooded]). This classification corresponds to the original scheme of the Global Observation of Forest Cover (GOFC, Cihlar et al. 2002). The proposed shift from forest subcategories to continuous variables (Cihlar et al. 2002) has not been adopted (Ahern 2002). It is necessary to keep the ECCV specifications of land cover in line with those of ECV and to adopt the emerging ISO definitions.

3. Land cover change

Land cover change as an ECCV should be assessed annually with coarse resolution from the available land cover observations (Ciais et al. 2004). Only three change categories are listed in the current definition (no change, forest to non-forest, non-forest to forest). For a calculation of carbon budget changes it is clearly necessary to consider also other transitions (Don et al., in prep.). In addition, the change of forest cover is an ECCV. Change of forest cover (no change, forest to non-forest, non-forest to forest) should be monitored every five years at 25 m resolution with about 20 – 30% of the land surface annually (Ciais et al. 2004). Derived variables of this observation are forest fragmentation and forest change occurrence. Suggested revisions of the forest change classes (Cihlar et al. 2002) to continuous variables have not been adopted for the ECCV definition.

At the time of writing, land cover change is calculated from available land cover products. The calculations are made difficult by incompatibilities among the products (see box above). A list of global and regional products is available at http://www.gofc-gold.uni-jena.de/sites/data/gofc.htm. Most products have a spatial resolution of 1 km (Table 2). A global land cover map with 300 m resolution for 2005 has been produced by the GLOBCOVER project. A product with fine resolution (30 m) and spanning four periods is the Global Land Survey (Gutman et al. 2008). In Europe, the CORINE Land Cover products for 1990, 2000, and 2006 at 100 m resolution are available.

Table 2. List of available land cover products based on the lists of GTOS-GOFC-GOLD (http://www.gofc-gold.uni-jena.de/sites/data/gofc.htm).

	finest resolution	represented years
Global Forest/Land Cover Datasets and Projects		
AVHRR Global Potential Land Cover Products	1 km	1981–1994
Continuous Fields Tree Cover Project AVHRR	1 km	2000
Continuous Fields Tree Cover Project MODIS	0.5 km	2000–2001
GISS Global Vegetation Data Set	1°	1971–1983
Global Land Cover Map for the Year 2000 (GLC 2000)	1 km	2000
Global Land Cover Characterization Program (GLCCP including IGBP DISCover)	1 km	1992–1993
Global Forest Resources Assessment (FRA 2000)	1 km	1995
Global Forest Mapping Project (GRFM/GBFM)	0.1 km	1993–1998
Global Land Survey (GLS) 1970, 1990, 2000, 2005 (2010 in	30 m (60 m for	1972–1987, 1984–

preparation)	GLS1970)	1997, ≈2000, 2005±3, 2010±1
GLOBCOVER	0.3 km	2004–2005
International Satellite Land Surface Climatology Project (ISLSCP)	0.5°	1986–1995
ISCGM Global Mapping Project	1 km	
MODIS Land Cover Products	1 km	since 2000
MURAI & HONDA World Vegetation Map from UNEP/GRID	16 km	1985-1987
NASA Landsat Pathfinder Humid Tropical Forest Inventory Project (HTFIP)	1:250'000	mid 1970s, mid 1980s, and early 1990s
USGS Global Land Cover Characterization Program	1 km	since 1992
WCMC Global Forest Cover Data Set	variable	variable
Regional/Continental Land Cover Datasets and Projects		
AFRICOVER Project	1:100'000	1994–2002
BALANS Project	0.2 km	1998–2001
BOREAS Land Cover Data Sets	1 km	1993-1996
CORINE Land Cover 1990, 2000, 2006	100 m	1986–1996, 2000±1, 2006±1
European Remote Sensing Forest/Non-Forest Digital Map from UNEP/GRID	4 km^2	1990–1992
LACOAST - Land Cover Change in Coastal Zones		1975–1979
Land Cover Mapping of Temperate Asia	1 km	1981–1994
North American Landscape Characterization Project (NALC)	1:24'000	1970s–1995
Pan-European Land Cover Monitoring Project (PELCOM)	1 km	1995–1999
SEI Europe Land Cover Map	1:500'000	variable
SIBERIA 1/2 Project	1:10'000	
USGS Multiresolution Land Characteristics (MRLC)	0.03 km	1992, 2000

4. Conclusions

Few land cover products have been prepared in such a way that changes can be calculated without additional efforts for data harmonization. The only global product available for calculating land cover change at nearly the specified fine resolution is the Global Land Survey for the 1970s, 1990, 2000, 2005, and (in preparation) 2010. It is necessary to formally adjust the ECCV definitions and requirements for land cover and land cover change products to be in line with the specifications of land cover as an Essential Climate Variable.

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