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Research Article

Evolving standards in land cover characterization

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Reliable observations of the terrestrial environment are of crucial importance to understanding climate change and its impacts, to sustainable economic development, natural resources management, conservation, biodiversity and a scientific understanding of ecosystems and biogeochemical cycling. GOF-C-GOLD (Global Observations of Forest Cover and Land Dynamics) as panel of GTOS (Global Terrestrial Observing System) and the Global Land Cover Network of FAO-UNEP (GLCN) brings together key participants and stake-holders involved in global land cover observations. The objective is to provide a platform for cooperation and communication on current and planned activities including developments on the political programs, international strategic frameworks as well as related implementation initiatives. Harmonization and validation of land cover datasets are central implementation issues.

Keywords: Land cover; Harmonization; LCCS; Standards; Validation; GOF-C-GOLD; GTOS

1. Introduction

The Earth's land cover characteristics and its use are key variables in global change. In such emphasis, the UNCED's Agenda 21, the World Summit on Sustainable Development (WSSD) in Johannesburg 2002, and existing UN conventions, most prominently the United Nations Framework Convention on Climate Change (UNFCCC), have further strengthened the importance of land cover in their implementation. The recently adopted implementation plan of the Group on Earth Observation (GEOSS 2005) particularly highlights the importance of 'land cover' for all areas of societal benefits. Despite such importance, it is to be recognized that land observations are not operational, at least not in a 'in a weather forecasting' sense. Two major reasons are particularly prominent for this limitation: The land surface is heterogeneous and the mapping standards to acquire, represent and generalize land characteristics are about as diverse as the land surface itself. Hence,

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fostering discussions, developments, and implementation of internationally agreed standards in land characterization is an essential task to overcome current limitations and fulfil the requirements posed by the international community.

In general, 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. On a fundamental level, land cover is the most important element for description and study of the environment. In situ and satellite land observations as well as different disciplines (geography, ecology, geology, forestry, land policy and planning etc.) use and refer to land cover as the most obvious and detectable indicator of land surface characteristics. Land cover provides the most useful indicator of human interventions on the land. Land cover changes quickly over time and is a good proxy for dynamics of the Earth surface resulting from a variety of drivers and factors. At a certain level, land cover provides the common ground for many actors and disciplines interested in land mapping and, thus, provides the platform to link information between them.

Land-mapping activities can be understood as process of information extraction governed by a process of generalization. This implicitly points to the loss of detail in the interpretation process to map specific land features. The degree of generalization and thus the efficiency of representing reality in two-dimensional form is directly 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 is reflected in the characteristics of the source data, the timing, interpretation procedures, skills of the interpreter etc. These factors affect the mapping products, its content, quality, flexibility and efficiency for applications.

In the past, each discipline was producing its own land cover map. The same geographic area was mapped several times, at different scales, for different purposes, with different types of data, and with varying accuracy. The associated legends were discipline-specific with sufficient detail for the specific applications but with poor information for others. The exchange and/or use of environmental data between disciplines, organizations and countries has proven to be complicated. Despite the fact that interoperability and the joint use of resources would be an essential step to enhance any decision making and planning of natural and human resources, discipline-specific mapping still is the common situation in the land observation domain today.

With the evolution of technology including satellite Earth observation, and digital data interpretation, analyses and integration has certainly started a new era in land mapping. Prominent results are a variety of global and regional land cover products and their use in studying land characteristics and dynamics. Technology has helped to overcome many previous limitations in land cover mapping on different scales. Today, it is quite easy to produce land cover maps with a rather low amount of effort. However, it is challenging to derive 'efficient' maps that are interoperable and satisfy the requirements of the end user community. Technology driven mapping often reflects technological capabilities rather than the needs of users.

Many global and regional land mapping products are tailored to serve a variety of potential applications. Their development was driven by different national or international initiatives; the subsequent mapping standards adopted reflect the varied interests, requirements and methodologies of the originating programs. Often they lack flexibility and interoperability with other information and exist as independent

datasets. Thus, this situation is similar to the one described for traditional discipline-specific mapping. There is a large heterogeneity of datasets that are limited their flexibility and efficiency considering the multitude of potential applications.

Technologies such as satellite Earth observation and geographical information systems (GIS) have vastly increased the suite of applications and users, the need and availability of land cover information, and the base for exchange and integration of such data. These technologies, however, do not solve the problem of standardization and interoperability. In fact, they have maximized the need for standards and the developments towards interoperability mechanisms. Land mapping has evolved with sophisticated technologies producing maps, but is still dominated by old mapping concepts developed before the age of GIS and advanced spatial analyses. New mapping concepts have to respect the needs and required flexibility resulting from a multi-user community and the interoperability among them.

2. Challenges for operational land characterization

The current limitations in land cover assessment point at several challenges to move towards operational land observations. ‘Continuity in observation’ for both fine and coarse resolution satellite data and *in situ* information is one essential issue that is to be addressed by the satellite and ground data providers. The derivation of land mapping products has to move from ‘research and technology driven’ approaches to flexible and efficient mapping ‘driven by applications’. Land cover information, as key land feature, 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). This requires a common ground, a ‘common language’ to communicate land information among the different domains. Each land mapping product should be accompanied by a ‘solid estimation of accuracy’. The adequacy of mapping products for applications implies ‘open access and exchange’ of data sets and information and that the user community is informed about their availability and ways of dissemination. Basically, an operational land observation system requires an integrated use of observations, their transformation into useful and flexible products, their assimilation into models, effective model design and their use in assessments, policy making and decision-support systems.

3. Harmonization and standardization

Harmonization is the process whereby similarities between existing definitions of land characterization are emphasized, and inconsistencies reduced. The ultimate goal is to bring various land cover datasets in ‘harmony’, thus allowing direct comparison between them. This process follows a ‘bottom up’ perspective. Beginning from a state of divergence in land cover datasets it seeks compatibility and comparability. Harmonization does not necessarily eliminate all differences, but should eliminate major inconsistencies. Standardization, in contrast, is a ‘top down’ process, and is therefore far more rigid. It requires common definitions and standards to derive land cover information and should eliminate all inconsistencies – and differences – between the datasets (Jansen 2004, Herold *et al.* 2006).

Harmonization essentially deals with existing definitions and attempts to harmonize the parameters used for description of land cover and their definitions. Then, if these are applied or adopted, it is possible to harmonize the individual criteria used to

create categories of whatever name in whatever language. Ideally, harmonization should be guided by existing or evolving standards. Standardization assumes that all requirements (standards) are present during the development phase of a mapping project. Given the multitude of users it is obvious that too much standardization reduces application, relevance and versatility of land mapping products and thus the approach in the land cover domain is to standardize terminology rather than categories (FAO/UNEP 1994). Basically, this is same approach adopted by soil science since the 1960s, where the FAO classification system was used as the standard classification system and common language to harmonize existing national and regional soil maps and their legends (FAO/ISRIC/ISSS 1998).

4. Evolving standards

4.1 *A common language for land cover characterization*

Previous consensus building efforts and experiences have resulted in general agreement that the UN Land Cover Classification System (LCCS Jansen and Di Gregorio 2004, Di Gregorio 2005) seems to provide a valuable universal land cover language for building land cover legends and comparing existing legends. LCCS evolved through a consensus building approach in response to a need for harmonized and standardized collection of land cover data, availability of land cover data for a wide range of applications and users, and comparison and correlation of land cover classes. LCCS is an *a priori* classification system. It represents a worldwide reference system for land cover able to combine high flexibility (ability to describe land cover features all over the world at any scale or level of detail) with an absolute level of standardization of class definitions between different users (Di Gregorio 2005). The first version of LCCS was available in 2000; a new updated and improved version (LCCS-2) is currently available for download (www.glc-lccs.org). LCCS has been explored and adopted by a number of international land assessment communities such as Land Use Cover Change (LUCC) programme element of the International Geosphere-Biosphere Programme (IGBP) (McConnell and Moran 2001) and GOF-C-GOLD (Herold and Schumliuss 2004).

LCCS allows a dynamic creation of classes via a dynamic combination of land cover diagnostic attributes called classifiers without obliging users to use a pre-defined list of names. In its basic dichotomous categorization levels, LCCS distinguishes eight major land cover groups. These classes can be further described in the modular-hierarchical phase where the set of classifiers and their hierarchical arrangement are tailored to the major land cover type. A resultant 200.000 different classes of land cover are potentially derivable using a combination of these classifiers. Further definition of a land cover class can be achieved by adding attributes. Two types of attributes that form separate levels in the classification are distinguished: environmental attributes (e.g. climate, land form, soils/lithology and erosion) and specific attributes (e.g. floristic composition and crop type). Through the addition of these environmental classifiers the resultant number of potential classes increases exponentially. A central component in creating land cover legends from LCCS-2 is the incorporation in the software of a standardized codified syntax to deal with the representation of mixed unit classes.

4.2 *Validation standards*

Validation is important both during the production and after the completion of land cover maps. Map uncertainty is a critical quality indicator of map products and

fosters an informed user community, forms the base for good science, interoperability, and resource management. User communities, e.g. responsible for implementation of international environmental protocols and agreements imply that land cover products are independently evaluated and possibly challenged.

To ensure transparent, robust, and independent accuracy reporting, a set of core analysis and requirements exist which should be routinely adopted as a baseline for reporting map accuracy. They have been recently documented and published by the CEOS Group on Calibration and Validation in the context of global datasets (Strahler *et al.* 2006). This 'best practice' guideline emerged from an international consensus on the issues involved in land cover validation including required approaches, techniques and accuracy reporting requirements.

4.3 ISO TC211 and GSDI standards

The International Organization for Standardization (ISO) and its Technical Committee 211 (TC211) host the standards for geographic information and geomatics. 50 countries are member of this ISO-TC. There are further liaisons with 25 international professional and scientific organizations and liaisons with 12 other ISO standards committees. TC211 host a large variety of standards for digital geographic information, e.g. on spatial reference information, geodetic codes and parameters, data quality, imagery and gridded data etc. (<http://www.isotc211.org>). TC211 promotes their awareness, adoption, and advocacy. It is recognized that awareness of ISO/TC 211 standards is known within many but not all global geographic communities, however, awareness is absent among most potential user communities. Thus, full realization of the benefits of ISO/TC 211 standards will only occur when they are adopted for all forms of human endeavour when using geographic information. LCCS has been submitted to the ISO/TC 211 Secretariat. It is now undergoing standard procedures to be accepted as an international standard. A UML model for LCCS is also being created to facilitate the mutual technical integration between LCCS and ISO/TC 211 standards for geographic information. This also provides an additional cascading integration to other technical specifications and de facto industry standards already linked to these ISO/TC 211 standards.

In a similar context, the Global Spatial Data Infrastructure (GSDI) association is an inclusive organization of organizations, agencies, firms, and individuals from around the world (www.gsdi.org). The purpose of the organization is to promote international cooperation and collaboration in support of local, national and international spatial data infrastructure developments that will allow nations to better address social, economic and environmental issues of pressing importance, and as part of their activities provide guidelines for spatial data characteristics.

4.4 Further developments

Existing and evolving standards discussed above have to be accompanied by a set of further developments for standards in land cover assessment and beyond. Basically, processes have to start to discuss and explore these issues in an international, consensus-oriented framework. Ultimately, they should evolve to a status of an internationally agreed standard for land characterization and assessment. The UNFCCC recognizes the need for such a terrestrial framework and has requested the GTOS to develop a framework for the preparation of guidance materials, standards and reporting guidelines for terrestrial observing systems for climate. It also called on

the GTOS secretariat to assess the status of the development of standards for each of the essential climate variables in the terrestrial domain. The SBSTA invited the GTOS secretariat to report on its progress by SBSTA 26 (May 2007).

4.4.1 Mapping standards. LCCS touches on the semantic aspects in land cover mapping. However, there are other factors affecting the mapping product and their interoperability like cartographic standards or data interpretation processes. Some of these are already represented in existing ISO TC211 standards and should be adopted accordingly. In addition, the development of land cover maps has to follow specific guidelines that are congruent with the set of common classifiers (LCCS), validation procedures, and user requirements. Evolving land characterization standards imply that the whole map production process is affected to derive flexible, efficient, and interoperable products. Experiences in this domain exist for the FAO-AFRICOVER and the GLCN projects but should be further recognized and explored.

4.4.2 Standards for land assessment, ecosystems and modelling. Land cover provides the common ground for different focus areas in land assessment. Next steps should aim at developing a common language for 'land use'. In its fundamental concept land use is rather different than land cover (Cihlar *et al.* 2001). It characterizes the arrangements, activities and inputs people have undertaken on a certain land cover type to produce, change or maintain it and thus have to consider both space and time (Jansen 2005). Land use deals with the socio-economic inputs to land and, thus, describes an activity with an input, a process, and an output. It is essential to base a common system for land use classification on existing land cover standards to ensure full compatibility between them. This becomes particularly important for the assessment of land cover and land use changes. Land cover and land use transitions have to be interoperable to start discussions on standardization developments in this domain including a common language on processes, drivers, factors and indicators of change. To think even further, modelling of land characteristics and changes requires the consideration of a common ground to derive interoperable, flexible and efficient results. Again, such developments have to start from existing or evolving standards in land characterization. Issues of model definitions, model input parameters, and modeling output reporting, as well as, open source modelling frameworks and model coupling should be considered. The FAO Land Use working group and the GLCN programme are leading the way in the U.N agencies community to evolve, with the scientific community, an agreed approach. Key scientific communities involved in such efforts are related to IGBP-LUCC and the recently launched Global Land Project (GLP). Ultimately, this development should lead to a standardized framework for mapping, monitoring and modelling in support of planning and management of terrestrial resources.

The common characterization of ecosystems worldwide should also build upon existing resources for land cover characterization. An ecosystem reference classification system should be fostered, but has to be linked to land cover as common land surface feature to allow compatibility. Moreover, GEOSS in its annual workplan, for 2006, identifies the development of a harmonized classification of ecosystems as a major priority, it is envisaged that strategies similar to the parametric approach of LCCS may be adopted.

5. Implementation framework for land cover observations

Based on the suite of evolving land cover standards different actors have started their exploration and implementation in an international and national context.

5.1 International implementation

FAO-UNEP have evolved the first and second generation of the standard which have formed the basis of the global regional and national level approaches for land cover harmonization. The implementation strategy for the international level is being developed in conjunction with actors involved in land cover mapping. In the period 2000–2002 the Joint Research Centre of the European Union, the FAO, and UNEP together with regional partners developed the second iteration of a global land cover product, the classes of which were defined by regional groups to be compatible with the standards of LCCS. Global validation of the product has set the basis of future global land cover product generation. Key agencies in fostering the evolving standards for future products include the JRC, EU; are the UN Global Land Cover Network (GLCN) and the Global Observation of Forest Cover and Land Dynamics (GOFC-GOLD) a technical panel of the Global Terrestrial Observing System of the United Nations (GTOS); UNEP and the European Space Agency. The new generation of global products will be developed from MERIS data and provide a resolution approximating 300–400 metres. The main targets of international implementation activities are land cover data producers (e.g. space agencies and land cover mapping facilities), the scientific community (e.g. IGBP-LUCC and GLP), and data users (e.g. UN organizations).

5.1.1 Existing resources and capacity building. A series of workshops, convened by FAO/UNEP; and others organized by GTOS-GOFC/GOLD have helped to develop consensus that LCCS provides the common language and legend translation device (Herold and Schullius 2004). Capacity building is ongoing to raise awareness about existing resources for land cover harmonization and standardized development of land cover products.

5.1.2 Harmonization experiences for existing datasets. Exercises are needed and to some extent underway to evaluate evolving standards and provide better understanding on how to harmonize the variety of existing land cover datasets and their legends. The first step is to develop legend translation protocols for the different existing legends into LCCS (see www.glcnlccs.org and Herold and Schullius 2004). Translations, comparative analysis and evaluation of the translated land cover products should be based on local and regional expertise and reference data. Despite successful examples for legend translation, this step only resolves some inconsistencies between semantics of land cover datasets. The process of legend translation highlights differences between legends and shows which classes can be harmonized (and thus directly compared) and where legends show inconsistencies. Also, other issues still remain, e.g. from cartographic standards, or from unresolved differences in classifier definitions. Limitations are expected for ‘*a posteriori*’ harmonization or retro-fitted inter-comparison of existing legends even after a successful translation. Hence, harmonization exercises for current land cover datasets should mainly focus on outlining these inconsistencies and try to improve understanding of how and why these datasets are not directly comparable. This information is helpful for future projects and the gain experiences about evolving standards. Future efforts should pay particular attention to these results for upcoming land cover mapping efforts.

5.1.3 Guidelines for future mapping projects. Efforts will be most effective when applied in the development phase of projects producing land cover datasets. In fact,

the whole implementation of standards can only be successful if there is an influence on operational land cover data collection. Mapping projects are encouraged to profit from resources and harmonization experiences, especially in terms of identified problems and inconsistencies in existing legends. One key issue is to find consensus on a basic set of internationally agreed classifiers for land cover that are developed from LCCS. Commonly used classifiers are:

- (a) vegetation life form (trees, shrubs, herbaceous vegetation, lichen and mosses, non-vegetated);
- (b) leaf type (needle-leaf, broad-leaf) and leaf longevity (deciduous, evergreen);
- (c) non-vegetated covers (bare soil/rock, built up, snow, ice, water);
- (d) density of each land category in percent cover.

Basically, this provides a framework for a common ground in land cover mapping without predefining one specific legend, hence a list of names. The approach purely focuses on land cover descriptions as key feature. These suggestions are congruent with continuous field approaches to land cover that map similar land characteristics (e.g. life form, leaf type etc.). Additional information could be applied in combination with these classifiers or should be treated as an additional layer of information, e.g. land use information: managed/cultivated versus (semi)natural land, or terrestrial versus regularly flooded areas. A proper consideration of mixed units between different categories is essential and provided by LCCS. This implies a solid definition of density thresholds (e.g. 15/40/65 %) for each category.

In that context, mapping initiatives are urged to consider the following options.

1. Start discussion on the adoption of evolving mapping standards and explore avenues how existing resources and harmonization experiences might be beneficial for the mapping objectives.
2. Existing legends should be revisited in the context of evolving land cover standards. Common problems of existing legends are mixing of land cover and land use terms, unclear and incompatible class definitions, regionally specific class names, semantics gaps and overlaps, and improper definition of mixed units. Basically, map producers are not asked to completely change their way mapping. It is rather the question on how to embed them in the context of the evolving international standards.
3. Based on user requirements, 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.
4. 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. Some global land cover maps are already developed using the proposed framework, e.g. Global Land Cover 2000 from the European Joint Research Center.
5. There can be possible tradeoffs between the quality of the datasets, its application relevance and the level of standardization that should be considered.

This implementation strategy is endorsed through the international panels (e.g. GTOS - GOF-C-GOLD etc.). There is a motivation for developers of land cover products, especially in the science community, and more particularly in development and planning agencies, to seek comparability and develop their legends, application-driven,

from a standard classification framework. This should be especially true for land cover products that are derived for a variety of purposes and not for a specific user or application.

5.1.4 Validation. Given the importance of validation, a common language and understanding of semantic differences between existing land cover datasets is essential for comparative analyses of accuracy. Thus, the implementation of land cover characterization and validation standards are parallel efforts. For example, *in situ* or reference data for accuracy assessment need to be acquired in a standardized way to be of value and comparable for a variety of land cover datasets and legends on different scales. Hence, the individual validation site interpretations will be generic descriptions of land cover characteristics and independent of any land cover legend in LCCS language. LCCS will assign the right land cover class based on the different implemented legend translations. This makes the validation process transparent, consistent, and applicable to any land cover map compatible with LCCS. The resulting comparative validation will move forward the degree of harmonization and interoperability of land cover datasets. An understanding of joint dataset uncertainties is essential for synergetic use and the combination and aggregation of different land cover information. Such information is important to users and any application and will improve the knowledge available for future mapping efforts. The development of an international land cover harmonization/validation initiative is underway (Herold *et al.* 2006). Moreover, the GLCN programme has now introduced the Mapping Accuracy Program (MAP) which is a statistical program to allow the automatic calculation of the thematic mapping accuracy using different methods and different expected level of statistical confidence. The accuracy assessment methods used are both qualitative and quantitative. In this latter case, the assessment can be done by single point, by multiple points or by polygon area.

5.2 National implementation

In general, the implementation steps on the international and national level are complimentary and follow the same framework. International bodies and agencies are very effective in developing consensus on standards and provide the implementation resources. Basically, the international community can help individual nations in data acquisition given general requirements so the information can be used in an international context. The authority and integrity of individual nations provides the right framework for implementing standards on regional and local scales, guided by international bodies, and to provide the required resources.

The United Nations Global Land Cover Network (GLCN) has been driving the national implementation of the evolving land cover standards. 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. The international community provides directions and resources for awareness raising, capacity buildings, mapping support, and acts as moderator between the different national agencies. Despite its national focus, the overall objective of the GLCN is to increase the availability of reliable and standardized information on land cover and its changes at the global level. This is ensured by a standardized mapping in many countries with the land cover maps being comparable different countries (figure 1).



Figure 1. Status of the international mapping and legend translation activities using LCCS as part of GLCN activities (as of November 2006).

6. Benefits

The implementation framework urges a new perspective in land cover mapping. We have learnt that traditional mapping approaches are not appropriate in the era of GIS and advanced spatial analysis, and for implementation of operational land observations. Using evolving standards would allow a vertical interoperability of land information among scales; between in-situ, and fine and coarse resolution satellite observations. More specifically, the goal is to combine the high-temporal (daily-monthly-annual) resolution of coarse-scale satellite sensors describing vegetation dynamics, with fine-scale land cover maps (1–5 years updates) describing vegetation physiognomy, and detailed in situ observations that may describe vegetation floristics or are used to verify satellite-based products. Horizontal interoperability would provide comparisons of land information between countries and disciplines. We will not be able to derive sufficient regional or global estimates of land characteristics and changes until we are able to combine and compare these measurements. Common standards would allow continuous updating of maps, comparative validation, and comprehensive land change assessment, e.g. as required for government obligations to report on carbon accounting or as response to environmental treaties.

Standards are beneficial for an optimal use of resources. They help to avoid duplication and heterogeneity in the land observation products, e.g. in their

development, validation, and application. This directly results in financial benefits and, with reduced risks and development costs for research and applications, economic growth in the field of land observation services.

The user community would directly benefit from improved adequacy, flexibility, transparency, and interoperability of the mapping products. There will be increasing understanding, availability, and sharing of land information, that ultimately results in more efficient, effective, and economic use of such data in a national and international context. Currently, the discussions aim at international agreement on the data and data products. However, the goal should be to find international consensus on the answers provided by operational land observations to questions posed by international conventions and treaties and, thus, contribute to unified approach in addressing ecological and humanitarian problems on all geographic scales.

7. Conclusions

There are ongoing efforts for an international consensus oriented initiative to evolve and implement standards for land characterization and validation. The need and benefits of such efforts are obvious and are essential to develop an operational and efficient land observation system. The political framework, the organizations for international cooperation, and the methodological resources to support this initiative are existing or developing. It is now up to the individual members of the community to provide their share in this initiative. Actors involved in land mapping are encouraged to participate, evaluate, and contribute in this important step towards operational mapping of land.

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