Chapter 2
Global Land Cover Mapping: Current Status and Future Trends

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2.1 Introduction

The observation of global-scale land cover (LC) is of importance to international initiatives such as the United Nations Framework Convention on Climate Change (UNFCCC) and Kyoto protocol, governments, and scientific communities in their understanding and monitoring of the changes affecting the environment, and the coordination of actions to mitigate and adapt to global change. As such, reliable and consistent global LC (GLC) datasets are being sought. For instance, GLC datasets are used as an input for many Global Circulation Models, Earth Systems Models and Integrated Assessment Models used for global and regional climate simulations, dynamic vegetation modelling, carbon (stock) modelling, ecosystem modelling, land surface modelling, and impact assessments (Hibbard et al. 2010; Herold et al. 2011).

The selection of GLC datasets and their quality have a significant influence on the outcomes of these models (Hibbard et al. 2010; Nakaegawa 2011). However, the existing GLC datasets are often selected without considering their quality and suitability for a specific application (Verburg et al. 2011). This is due, notably, to the lack of interoperability and inter-comparability between the datasets (Jung et al. 2006; Herold et al. 2008). Uncertainties of LC datasets also result in considerable differences in modelling outcomes (Hibbard et al. 2010; Nakaegawa 2011; Verburg et al. 2011). For instance, Benitez et al. (2004) have noted that the choice of GLC dataset influenced the model results by as much as 45 %. Moreover, lower

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quality LC datasets (e.g., <80 % overall accuracy) have strong effects on atmospheric simulations (Ge et al. 2007; Sertel et al. 2010). The need for GLC datasets with better quality and increased interoperability and inter-comparability has also been highlighted by GLC dataset user surveys for GlobCover maps and the LC Climate Change Initiative (LC-CCI) (Herold et al. 2011; Verburg et al. 2011).

In response to this need, international bodies such as Group on Earth Observation (GEO) and Global Climate Observation System (GCOS) were initiated to coordinate global cooperation to advocate and foster the establishment of an operational and continuous global-scale LC observing system (GCOS 2012; GEO 2012). Earth observation (EO) communities in Europe have been involved in the developments in GLC observation. For example, the European Commission Joint Research Centre, the Université Catholique de Louvain (UCL), Wageningen University and other partners are actively working on the production of GLC maps such as GLC 2000 (Bartholomé and Belward 2005), GlobCover (Arino et al. 2007), and LC-CCI (Defourny et al. 2011a, b, see Sect. 2.4 in this book) and on the integration, harmonization and validation of GLC datasets via their participation to other international initiatives such as the Global Observation of Forest Cover and Land Dynamics (GOFC-GOLD) initiative, and GEO (GEO 2012).

This chapter reviews the current status in GLC mapping and foresees upcoming developments within the field. The existing GLC maps and their characteristics are briefly summarized in Sect. 2.2.1. Section 2.2.2 highlights current issues that need to be overcome in GLC mapping initiatives. Sections 2.3 and 2.4 discuss upcoming solutions and recommendations, respectively.

2.2 Status and Improvements for Land Cover Maps

2.2.1 Existing Land Cover Maps

Advancements in remote sensing technologies during the last two decades have enabled the production of several GLC datasets supporting their extensive use in scientific research on modelling notably. The first attempts to map GLC using remote sensing produced 8 km and 1° of latitude coarse spatial resolution maps for years 1984 and 1987 respectively (DeFries and Townshend 1994; DeFries et al. 1998). Following these efforts, International Geosphere-Biosphere Programme Data and Information System's GLC map (IGBP – DISCover) and University of Maryland (UMD) datasets, the first 1 km resolution GLC datasets, were produced for the 1992–1993 period (Hansen et al. 2000; Loveland et al. 2000). Moderate-resolution Imaging Spectroradiometer (MODIS), GLC2000, and GLC by National Mapping Organizations (GLCNMO) products were also developed afterwards with data acquired around 2000, with the same spatial resolution (1 km) (Friedl et al. 2002; Bartholomé and Belward 2005; Tateishi et al. 2011). Moreover, 300 m and 500 m spatial resolution GlobCover and MODIS GLC maps were produced with the recent development of higher resolution time series satellite data for different periods (Table 2.1) (Arino et al. 2007; Friedl et al. 2010).

Table 2.1 Description of previous Global Land Cover (GLC) maps

Spatial resolution/ pixel size	IGBP-DISCover			MODIS 5	GLC 2000		Glob Cover	Glob Cover v2
	1 km	UMD	MODIS	500 m	1 km	GLCNMO	300 m	
Input data	AVHRR: Monthly NDVI from 10 day composites	AVHRR: Monthly NDVI and 5 bands from 10 day composites	MODIS: 16 day composites of 7 bands and EVI	MODIS: Monthly EVI, LST and 7 bands from 8 day composites	SPOT-Vegetation: Monthly to 3 monthly NDVI composites	MODIS: 16 day composites of NDVI and 7 bands	MERIS: Bi-monthly from 10 day composites	
Time of data collection	1992–1993		2001	2001–2008	Nov 1999- Dec 2000	2003	2005–2006	2009
Classification method	Unsupervised clustering	Supervised classification tree	Supervised decision tree	Supervised decision tree boosting	Optimal classification methods	Supervised classification	(Un)supervised spatio-temporal clustering	
Classification scheme	IGBP 17 class	Simplified IGBP 14 class	IGBP, UMD and other	5 different LC classification system including IGBP, UMD	LCCS 22 class	Modified LCCS 20 class	LCCS 22 class	
Validation data	Independent validation datasets from HR satellite data	Evaluated using other dataset	Cross validated using HR satellite data		Independent validation datasets from HR satellite data	Independent validation datasets from HR satellite data and other datasets	Independent validation datasets from VHR satellite data and other datasets	
Absolute positional accuracy (RMSE)	~1 km		1–1.5 km	50–100 m	300 m ~1/3 pixel	141–277 m	77 m	

(continued)

Table 2.1 (continued)

Spatial resolution/	IGBP-DISCover			MODIS 5	GLC 2000		Glob Cover	Glob Cover
pixel size	1 km	UMD	MODIS	500 m	1 km	GLCNMO	300 m	v2
Area weighted thematic overall accuracy (%)	67		71.60 ± 2.5	74.8 ± 1.3	68.6 ± 5	81.20	73.10	67.50
Reference	Scepan et al. (1999), and Loveland et al. (2000)	Hansen et al. (2000)	Friedl et al. (2002, 2010)		Bartholomé and Belward (2005) and Mayaux et al. (2006)	Tateishi et al. (2011)	Bontemps et al. (2011), and Defourny et al. (2011b)	

Table 2.2 User distribution for the GLOBCOVER map by thematic field and organization type

	Carto graphy (%)	Climate/ meteorology/ hydrology (%)	Information technology/ GIS (%)	Natural resources (Agriculture, forestry, biodiversity) (%)	Remote sensing (%)	Total (%)
Commercial sector	2.69	2.42	9.41	3.48	2.96	20.97
Government organization	1.88	1.88	2.96	3.50	3.76	13.98
Non-government organization	2.69	2.96	4.30	6.45	0.81	17.20
University/ Research	3.23	8.87	10.22	13.98	11.56	47.85
	10.48	16.13	26.88	27.42	19.09	100.00

Source: GLOBCOVER user survey, N = 372, Herold et al. (2011)

Mid to coarse spatial resolution sensors such as AVHRR, SPOT-VEG, MODIS and MERIS are the main source for the existing GLC datasets. As shown by Chander et al. (2010) calibration of top of atmosphere reflectance EO data has improved over the recent years. GLC mapping initiatives benefit from these advances notably for LC change analysis. Different categories of classification algorithms (unsupervised/supervised, parametric/non-parametric) were applied to characterize GLC using IGBP and LCCS classification schemes (Loveland et al. 2000; Di Gregorio and Jansen 2005). GLC maps have been validated using varying approaches that comprised different reference datasets, sample selection scheme, sample unit size, minimum mapping unit, and reference data classification procedure *etc*. (Scepan et al. 1999; Hansen and Reed 2000; Mayaux et al. 2006; Friedl et al. 2010; Bontemps et al. 2011; Tateishi et al. 2011).

2.2.2 *What Needs to Be Improved*

User requirements surveys for GlobCover and the upcoming LC-CCI GLC datasets were conducted to address the needs of general and key users (e.g. the climate modelling community) (Herold et al. 2011). As highlighted in Table 2.2, the users of existing GLC maps are diverse, coming from different thematic fields and different organization types. While almost half of the users are coming from a university/research background, there is also significant use in governmental, non-governmental and commercial sectors across several disciplines.

The user survey for observing LC as Essential Climate Variable (ECV) has highlighted that LC remains a key dataset that serves as a base for many land surface parameters and associated temporal variability (Bontemps et al. 2011). The users stressed some requirements in terms of accuracy, stability, spatial resolution, and thematic content that are not met by the GLC datasets currently available (Bontemps et al. 2012; Herold et al. 2011). In addition, further investigation and advancements on consistency issues across GLC datasets and validation efforts for GLC monitoring are also emphasized by the mapping communities (Herold et al. 2008; Olofsson et al. 2012).

Table 2.1 shows the existing GLC maps have around 70 % (varying from 67 to 81 %) overall area-weighted correspondence with reference datasets. However, GLC map-like users have stressed that such datasets should have a maximum error of 5–15 % as a target, or at least higher than current quality, to be further used in modelling applications (Herold et al. 2011). Thus, there is a clear need to improve the current quality of GLC maps. Moreover, the relative importance of different class accuracies varies significantly depending on the users. Commonly, evergreen broadleaf trees, snow/ice, barren land classes show high accuracy (Giri et al. 2005; McCallum et al. 2006). On the other hand, general inability of GLC mapping approaches to clearly discriminate mixed trees, shrubs, and herbaceous vegetation due to low spectral separability has been noted. More attention is needed to improve the accuracy of these classes and the overall quality of the maps (Herold et al. 2008; Fritz et al. 2011).

Consistency and comparability of different GLC maps needs to be further analysed for a better understanding of their suitability and limitations for specific applications. Currently, the use of differing methodological approaches (e.g., classification scheme, data sources and algorithms) for GLC map production raises consistency issues and makes comparisons difficult. Consistency and comparability studies are commonly implemented using per pixel spatial (dis)agreement analysis (Hansen and Reed 2000; Göhmann et al. 2009; Fritz et al. 2011). These analyses show good overall agreement on spatial pattern, but limited agreement for some classes in specific areas (Giri et al. 2005; Herold et al. 2008). Disagreement is mostly observed in transition zones where a mixture of main vegetation components like shrub, tree grass (Hansen and Reed 2000; Herold et al. 2008). Unfortunately, LC change primarily occurs in transition zones, which makes it difficult to observe from differences between GLC datasets (Herold et al. 2008). Temporal instability of multi-year GLC products is also regarded as a major challenge in GLC change observations (Herold et al 2012; Bontemps et al 2012). This situation calls for strengthened international cooperation between GLC mapping communities to agree on a common set of harmonized GLC mapping procedures.

As indicated, landscape heterogeneity is one main driver of inconsistencies between the LC datasets, and it is identified as a major challenge for GLC mapping (McCallum et al. 2006; Herold et al. 2008; Wu et al. 2008). In addition, the use of coarse spatial resolution datasets ($\geq$300 m) induces the presence of several LC types in one pixel especially in transition zones. Current spatial resolution of GLC maps can be sufficient for some users such as climate modelling community. However, Landsat-type fine resolution datasets are also required for some model parameters and for description of change (Herold et al. 2011). Thus, the use of fine resolution satellite dataset will not only increase the usability of GLC datasets, but also help to ensure higher quality of LC characterization in heterogeneous and transition zones. Nevertheless, data availability of such fine resolution satellite data with high temporal frequency, particularly in consistent cloud covered areas is the biggest constrain for this.

Several statistically rigorous assessments of GLC maps were done using independent validation datasets (Scepan et al. 1999; Herold et al. 2008; Bontemps et al. 2011). As GLC maps are used for a large number of applications, user-oriented accuracy reporting can help understanding the uncertainty and limitations of LC datasets for specific applications (DeFries and Los 1999). Such accuracy reporting from GLC map user perspectives are limited (DeFries and Los 1999; Mayaux et al. 2006). More work is needed to improve flexibility of user oriented accuracy assessment methods as current overall accuracy and class-specific methods cannot provide comprehensive information addressing varying specific end-user needs. Validation datasets used for the GLC map quality assessment also calls for an international cooperation and requires significant effort to reach high-quality reference datasets. Thus, a comprehensive approach making best use of existing resources to develop an operational integrated and flexible reference dataset is sought (Herold et al. 2011). However, varying methodical approaches (e.g. sampling design, sample unit, legends, and classification approaches) applied for current reference datasets makes it a challenge (Olofsson et al. 2012).

An operational GLC observing system must provide LC change estimates for a comprehensive delivery of societal benefits. Coarse-resolution LC change observation provides useful information on long-term trends, inter-annual versus intra-annual dynamics, and the indication of large and cumulative land change, and hot spots; however, the reliability of this information is often questioned particularly in transitional and heterogeneous areas. On the other hand, fine-scale (i.e. Landsat-type) satellite data are currently the most suitable data sources for observing a large array of LC/land use change processes with confidence, but only a few examples have demonstrated operational feasibility (Kennedy et al. 2010; Goodwin et al. 2013). Thus, a combined approach using coarse and fine scale satellite observations, and in-situ observations seems the most suitable avenue for global and regional scale LC change studies (Bontemps et al. 2012). The need for such operational approaches is currently emphasized in starting or strengthening national forest monitoring activities in many developing countries to build capacity for a global participation in the Post-2012 Agreement on Climate Change (GLCA 2009). Progress in monitoring forest loss using the combination of coarse and fine scale satellite images at global level can be observed now (Hansen et al. 2010). Successful implementation and technical credibility of a GLC change assessment require agreement, dedication, collaboration and coordination among countries and this, from the supply of consistent observation data to the delivery of harmonized LC products.

2.3 Moving Forward

The development of new sensors is aimed to ensure continuity and increased frequency for consistent and continuous LC observations. Furthermore the necessity to provide supplementary and new sources of information has been urged since the failure of the Landsat-5 platform (Fall 2011) and the failure of ENVISAT MERIS mission (April 2012). The concomitant development of improved data processing methods, as well as the establishment of standardized or harmonized data processing procedures, demonstrates an accelerating trend towards the production of sound, and consistent global products. We present the main national and multi-national initiatives currently being led to overcome the aforementioned issues and meet the needs expressed by the users of LC information. We present also the emerging trends in terms of services, tools, applications, and the new users associated to GLC products.

2.3.1 Satellite Missions Allow Moving to Inclusion of Multiple Sensors, Finer Scale and Longer Time-Series Products

Looking forward from the progress of the last four decades in satellite observation the European Global Monitoring for Environment and Security (GMES) (now Copernicus) programme is aimed at providing information on Earth and its climate to better understand the role of human activities on the changes being observed at the global scale. The GMES programme provides a range of services among which satellite, airborne, and *in-situ* data for EO (Aschbacher and Milagro-Pérez 2012). As part of this programme, the launch of a series of EO *Sentinel* satellites is scheduled for the coming years. The first series will include a Synthetic Aperture RADAR (SAR) sensor (Sentinel-1), a high resolution optical sensor (Sentinel-2) (Drusch et al. 2012), and a moderate spatial resolution (300 m) optical sensor, and microwave sensors (Sentinel-3). Each of these satellite missions will encompass a pair of satellites to improve revisit time period, geographical coverage and rapid data dissemination (Berger et al. 2012). The launch of the first Sentinel-2 satellite is currently scheduled for mid-2014. In addition to Copernicus programme, the Pléiades constellation is another satellite constellation that is designed by France and Italy under the Optical & Radar Federated EO (ORFEO) programme (Lamard et al. 2008; CNES 2012). The satellites are designed to provide multi-spectral optical images with a two meter spatial resolution. Commercial distribution of images from Pléiades-1A is effective while images from the second satellite (1B was launched in December 2012) will start during 2013. Furthermore, a constellation of two new high-resolution (8 m for multi-spectral bands), optical imaging satellites from the Système pour l'Observation de la Terre (SPOT) series is also expected. First satellite (SPOT-6) was launched in September 2012 and launch of SPOT-7 is scheduled for 2014 (Astrium 2012). In the United States of America (USA), the National Aeronautics and Space Administration (NASA) and the United States Geological Survey (USGS) lead the Landsat Data Continuity Mission (LDCM). As part of this initiative the Landsat-8 satellite was launched in February 2013. The new satellite provides images of similar characteristics compared to its latest predecessor. First data is now available for download.

Existing EO systems combined with the scheduled arrival of new space-born sensors, especially embedded in platform constellation will facilitate the mitigation of atmospheric constraints inherent to the acquisition of optical images in tropical and boreal areas. For instance a 5-day revisit time period is expected for a given location when Landsat-8 and Sentinel-2 constellation satellites will be operational and combined. Positive outcomes are also expected regarding global-scale change detection monitoring with the generation of more complete time-series data. Building upon the existing archives of Landsat, MODIS, MERIS, AVHRR, and ERS/ASAR data are instrumental for long-term consistency and continuity of tracking land surface dynamics.

2.3.2 Novel Global Land Cover Products Are Being Developed

A clear trend towards the use of satellite data of higher spatial resolution for GLC analysis can be observed (Table 2.1). This dynamic is further reinforced by the GLC mapping projects from scientists in China and the USA. A GLC mapping project from Tsinghua University (Beijing) based on Landsat, Hun Jin (HJ), and Beijing (BJ) satellite data aims to provide GLC map products with an emphasis on water bodies, wetlands, and human settlements (Liao 2013; Chen 2012). Map products should be finalised and made available by the end of 2013. A Landsat-based GLC map product has been released (early 2013) by another team from Tsinghua University (Gong et al. 2013). The product depicts Earth's LC circa year 2010. While the first Chinese project relies on an automatic classification procedure and significant manual checking and editing, the second project is based on automatic classification procedures solely. In the USA, the NASA and USGS support a 30-m spatial resolution GLC mapping project based on Landsat data ($n \simeq 10{,}000$) acquired around 2010 (Stone 2010; Lee-Ashley and Moody 2010). These two GLC maps are expected to be released within the next 2 years and will meet the recommended requirements for GLC products expressed in terms of spatial resolution (Herold et al. 2009). For instance, Landsat-type data has been proven to be efficient at providing sufficient information for LC and LC change mapping at national scale with Minimum Mapping Units (MMU) comprised between 1 and 5 ha (Herold et al. 2009). Global characterization of tree cover using Landsat data is also recently released (Sexton et al. 2013; Townshend et al. 2012).

The European Space Agency (ESA) has initiated the Climate Change Initiative (CCI), a programme for the monitoring of Essential Climate Variables (ECV) (Sect. 2.4). Besides providing satellite data, data processing algorithms and methods, the ESA CCI will also produce a suite of spatially explicit ECVs. LC is one of the 14 terrestrial ECVs. ECV monitoring is to be conducted in 3 phases. After consulting the scientific community and dressing the detailed list of requirements and specifications in phase 1, the systems were developed and first maps were produced during Fall 2012 (phase 2). Phase 3 will consist in assessing the trends of the generated products, optimizing model calibration and validation, and quality assessment procedures, in close collaboration with the climate research community (Food and Agriculture Organization 2007). Maps for three epochs (2000, 2005, and 2010) will be released during fall 2013. Thus, the trend towards deriving more accurate GLC products targeted at the need for specific user community is obvious and a logical development given that there is a large variety of users whose needs cannot be all met by the current products.

To achieve the goal of producing sound and consistent GLC products, the data acquisition, the processing chain, and the implementation of the mapping procedures to make the products available to the user community need to comply with a series of standardized or harmonized practices that facilitate global-scale coordination between the stakeholders. The establishment and acceptance of such guidelines is an on-going process involving a range of institutions and persons coming from universities, public research centres non-governmental organizations (NGOs), private sector, and governments. These efforts need to include the option to ingest data on land change in near-real time (Verbesselt et al. 2012).

2.3.3 International Coordination and Harmonization Remain Vital

On-going international initiatives offer opportunities to improve relevance, acceptance, and approaches to operationalize and coordinate global and regional LC mapping surveys. Efforts are currently made via four major thematic areas: (a) standards for LC characterization, (b) standards methods for LC accuracy assessment, (c) GLC observations and applications and (d) LC change monitoring (Herold et al. 2012). Several initiatives that take lead on such efforts are summarized below.

The Group on Earth Observation (GEO) is one of the most prominent scientific and technical processes specifically concerned with EO sponsored by a partnership of 88 governments and 64 international organizations (as of March 2012). The GEO has recently recognized the importance of LC information to contribute to the nine GEO societal benefits (see Sect. 2.3.7 in this chapter: citation *to be fused later with:*) (GEOSS 2005). A specific GEO Task for GLC and LC change is aimed at providing recommendations for the production of consistent GLC datasets and services. The current trend is to move forward the development of products of higher spatial resolution (<50 m) and to emphasize the use of time-series products to characterize LC change and its dynamics. Such LC products are meant to be available to the user community through the Global Earth Observation System of Systems (GEOSS) infrastructure. Following the GEO 2009–2011 Work Plan (GEO 2010), the 2012–2015 Work Plan is being developed by a range of international bodies among which the GOFC-GOLD initiative (GEO 2011).

The GOFC-GOLD initiative is a panel of the Global Terrestrial Observing System (GTOS) sponsored by the Food and Agriculture Organization (FAO), the United Nations Educational, Scientific and Cultural Organization (UNESCO), the World Meteorological Service (WMO), the International Council for Science (ICSU), and the United Nations Environment Programme (UNEP). Specifically, the GOFC-GOLD LC Project Office is a major international body funded by ESA that contributes to the advancements in the four aforementioned thematic areas (gofcgold.wur.nl). The GOFC-GOLD LC Office is currently engaged in (1) ensuring continuity and consistency of observations, (2) promoting harmonization, interoperability and synergy of LC products, (3) developing validation standards and supporting their implementation, (4) improving adequacy and advocacy of land information products, and (5) supporting capacity development. The GOFC-GOLD LC Implementation Team (IT) has contributed to large series of international LC programmes, such as working on the development of standard reports for the LC and Biomass ECVs, the validation framework and implementation of GlobCover products and doing comparative validation studies between GLC products (Herold et al. 2008; Bontemps et al. 2011). The GOFC-GOLD LC-IT has taken lead roles in the implementation of several GLC-related GEO tasks (GEO 2011). The GOFC-GOLD LC Office and REDD + Working Group have played also a leading role in the development and update of the Reducing Emissions from Deforestation and forest Degradation (REDD+) Sourcebook (version 18 released in Fall 2012) in which LC information remains crucial (gofcgold.wur.nl/redd). The Sourcebook provides methods and procedures for monitoring and reporting anthropogenic greenhouse gas emissions and removals associated with deforestation, gains and losses of carbon stocks in remaining forests, and reforestation. Future updates of the Sourcebook are expected regarding good practices on LC map accuracy assessment. The subsequent presentation of international harmonization and standardization initiatives for GLC mapping further highlights the active role of the GOFC-GOLD LC Office in this field.

The UNFCCC and the International Panel on Climate Change (IPCC) among other United Nations (UN) bodies support initiatives to implement systematic observations of ECVs (IPCC 2006). There are currently 50 ECVs comprising LC as one of them (GCOS 2010). Under the supervision of the GTOS, the report on the LC ECV dresses the list of current data, products and capabilities for operational GLC mapping (Sect. 2.4). A series of recommendations are also provided among which to strengthen continuity and availability of data at different observation scales, the production of a flexible and continuous reference data in support of the calibration and validation of the models, the need for further international development and adoption of LC and LC change mapping standards, and a better coordination of the efforts between the stakeholders.

The outcomes of the GlobCover user survey show a good match between user requirements and the broader requirements from relevant international panels, e.g., those presented in the report on the LC ECV (Herold et al. 2009). The user groups express a need for stable LC data, increased capacity for time-series analyses, consistency among the model parameters, capacity to discriminate anthropogenic vegetation from natural vegetation, and establish the history of disturbance. LC products should also allow flexible use to serve at different scales and purposes. A general need for transparent information on the processing steps and the quality of LC products is expressed as well. Specifically, the availability of a multi-date accuracy assessment system and the use of the LC Classification System (LCCS, Di Gregorio and Jansen 2005) is advocated. The LCCS has been developed by FAO and UNEP as a comprehensive and standardized classification system designed for mapping purposes. The system is independent from the mapping scale and allows a dynamic creation of classes without obliging the user to relate to a pre-defined list of names by a dynamic combination of LC diagnostic attributes called *classifiers*. The last version of the LCCS, i.e., the LC Metadata Language (LCML – LCCS v.3), is proposed as a standard by the International Organization for Standardization (ISO) under the reference ISO 19144–1. Complementary specifications are under development under the reference WI 19144–2. Some GLC map products already use the LCCS (see Table 2.1). The outcomes of the GlobCover user requirements analysis were used as input for the product specification of the ESA LC-CCI in addition to LC-CCI user survey (Herold et al. 2011).

2.3.4 GLC Validation Is Becoming Operational

The Land Product Validation sub-group of the Working Group (WG) on Calibration and Validation (Cal/Val) from the Committee on Earth Observation Satellites (CEOS) aims to address the challenges associated with the validation of GLC products (NASA 2012). Accordingly, the CEOS Cal/Val WG compiled a document on recommended practices for validation of regional and GLC maps (Strahler et al. 2006). Moreover, CEOS Cal/Val WG in collaboration with GOFC-GOLD LC-IT initiated an operational GLC validation effort. This effort aims to develop a "living" dataset of validation sites to be used for statistically rigorous validation of GLC maps. Such dataset should have probability sampling scheme independent of any specific LC map and support statistically rigorous accuracy estimation. Currently, a research group at Boston University is developing an independent LCCS-compliant validation dataset consisting of 500 globally distributed sites for GLC products (Fig. 2.1) (Olofsson et al. 2012). A suite of multi-spectral very high spatial resolution ($<$1 m) satellite images is being acquired, segmented, classified, and visually checked. The production of validation data at such spatial resolution follows the trend observed for GLC products now being generated at higher spatial

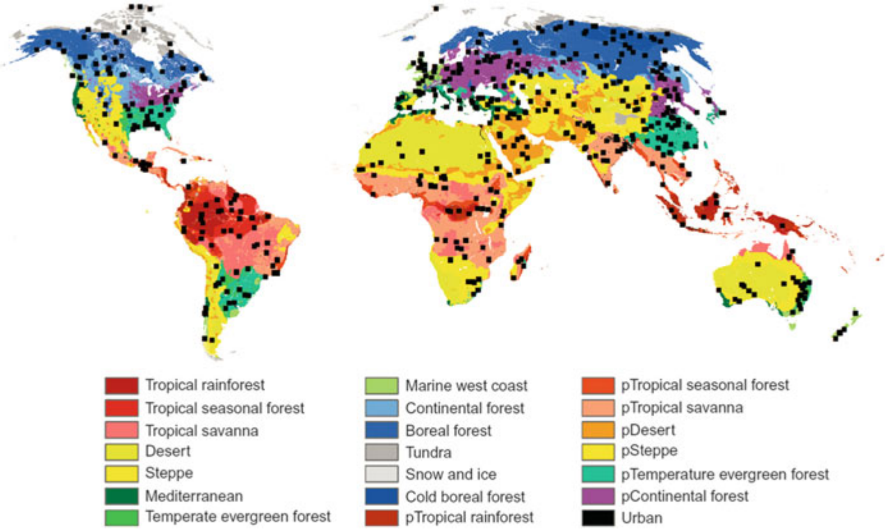

Fig. 2.1 Spatial distribution of validation sites from the Boston University database (Source: Olofsson et al. 2012). Land cover classes are derived from the Köppen climate classes (Peel et al. 2007)

resolution (30 m). The GOFC-GOLD LC-IT is also working on the development of an online information system to make these validation sites available to the community along with a set of recommendations to guide the user to the most appropriate dataset and usage (good practices). A beta version of the web portal has been released (gofcgold.wur.nl/sites/gofcgold_refdataportal.php) and the platform is expected to be operational in late 2013, hosting a dozen of reference datasets.

The ESA-CCI follows the reporting standards that are being developed under the lead of the GTOS, the Global Climate Observing System (GCOS), and its panels. The overall objective of the ESA initiative is to revisit the algorithms required to generate the GLC maps, design and implement a system that can provide GLC products derived from various EO sensors to the climate change community. In the frame of the ESALC-CCI an independent product validation and comparison will be performed to provide a robust assessment of LC product accuracy and precision. Strengthened user confidence in these LC products, acceptance, and legitimacy of the products are also expected within the international user and producer community. As such, a review of the GlobCover product validation sites (Bontemps et al. 2011; Defourny et al. 2011b) is undergoing under the lead of the Université Catholique de Louvain. The UCL is assisted by the GOFC-GOLD LC-IT for this task and the dataset will be made available on the aforementioned reference data portal.

2.3.5 New Services and Tools

The outcomes of the Sentinel-2 Preparatory Symposium (s2symposium.org/) stressed specific demands in terms of services and tools from different LC user communities. A series of recommendations and requests were addressed to ESA showing what current and future needs of the GLC mapping community as a whole are: open and free access to data, higher revisiting capacity, availability of procedures to process large data loads (corrections, cloud masking, mosaicking, classification, time-series analysis). Interoperability between data sources from different sensors (inter-sensor calibration, archive linkage) has been stressed as well, to enhance temporal revisit. In addition capacity development, in Non-Annex 1 countries in particular, still needs to be further strengthened. Note the GEO Global Forest Observation Initiative (GFOI) and the GOFC-GOLD Regional Networks among other initiatives, play an active role to reduce capacity gaps through different training programs. While stakeholders recognized the feasibility of GLC mapping with existing data and tools, on-going research notably focuses on techniques allowing the integration of different and complementary sources of information such as optical, Radar and Lidar data (Lucas et al. 2006; Bork and Su 2007; Lu et al. 2011; Li et al. 2012) and time-series analysis for change detection (Gutman and Masek 2012; Verbesselt et al. 2012).

2.3.6 The First Global Assessments of Land Cover Change

Characterization of change and dynamics of LC is a developing research area in the EO community especially since the advent of new processing techniques and a facilitated access of EO data (Sect. 2.3.5). Intra-annual LC dynamics can be characterized through the observations of vegetation phenology, seasonal snow coverage, flooding, fire occurrence, *etc.*, (Defourny et al. 2012; Bontemps et al. 2012). Many EO initiatives such as ESA-CCI, NASA-MODIS Land Program are actively working on the monitoring of such variables. Daily to yearly products characterizing the GLC condition are being produced using time-series analysis with MODIS, MERIS, SPOT and AVHRR data. Similarly, large-area LC change and longer-term trends in vegetation and fire characteristics can also be estimated using time-series analysis (Huang et al. 2002; Verbesselt et al. 2012). As an example, the University of Maryland produces an annual Vegetative Cover Conversion product, which consists in a global-scale LC change detection system at a 250 m spatial resolution (Carroll et al. 2006) that have now been used as input to the estimation of deforestation carbon emission patterns globally (Harris et al. 2012).

However, LC change mostly occurs at a smaller scale than this coarse resolution data can observe. It is now increasingly possible to overcome such a limitation as finer spatial resolution earth observation data (e.g. Landsat imagery) becomes more openly available at global scales. First serious attempts are being made using now freely available Landsat data provided by the Global Land Survey collection from the USGS and NASA (Gutman et al. 2012). The USA and China are currently using this Landsat archive to produce GLC maps (see Sect. 2.3.2). It is envisioned that the LC information of the American products will be updated every year or every 5 years, depending on the product (Stone 2010; Lee-Ashley and Moody 2010). Focused on forest cover and land use change, a sample-based global remote sensing survey is being conducted as part of the Global Forest Resources Assessments (FRA) led by the FAO (Gerrand et al. 2009) in cooperation with EU Joint Research Centre's TREES III project (ies.jrc.ec.europa.eu/index.php?page=70). Forest area and change rates have been calculated for years 1990, 2000, and 2005 using samples (≃13,500) from classified Landsat scenes validated by national experts. The same assessment exercise is planned for year 2010. The first results have been presented with more comprehensive analysis (Anonymous 2011).

2.3.7 New Users and Applications

The existing and upcoming LC products presented in this chapter can provide useful information for a wider variety of users and for a wider range of applications. The advent of new sources of EO data, improved processing techniques, standards, and services give a glimpse on the added value of such products. For instance, the proposed products and services associated to the nine societal benefits identified by GEO (GEO 2011) show how the scientific community, NGOs, private sector, governments and society as a whole can benefit from LC products. For **Disasters** (fire, earthquakes, flooding), LC information can help short term action planning; for **Health**, LC characteristics can help the identification of favourable conditions for disease vectors; for the **Energy** sector LC information can be useful to characterize the location of energy consumption spots and suitable areas for renewable energies such as wind turbines and solar panels; for **Climate** modellers, LC information can help modelling greenhouse gas emissions cause by LC change and phenology; for **Water** resources, LC information can help optimizing consumption and protect water bodies and wetlands; for **Weather**-related activities, information on LC change can help modelling radiation balance and sensible heat exchange, and provide information on land surface roughness; for **Ecosystems**, LC information can help the characterization of human alterations, monitoring ecosystem conservation, vegetation characteristics and change, as well as driving processes; for **Agriculture**, LC information can help monitoring crop production and cultivation practices and potentially associated land degradation. LC information can help monitoring **Desertification** and plan actions to mitigate and adapt to the phenomenon. Finally **Biodiversity** understanding, monitoring and conservation can benefit from LC information with the characterization of ecosystems, habitats, land fragmentation and connectivity. Thus, the potential use of LC and change data is large and the trend to deriving more targeted products for specific users is already obvious with a current focus on monitoring LC as ECV and for climate-change related, carbon emission assessment, purposes. But it is also expected that many other users will directly benefit from progress made for a specific use application; perhaps not in the full possible scale but to have a starting point to derive more specific products to meet their requirements.

2.4 Conclusion

GLC datasets remain a key input for scientific communities, NGOs, private initiatives, and governments. The need for an operational and continuous GLC observation is emphasized by different user communities. Therefore, the quality and consistency assessments of existing and up-coming GLC datasets should be highlighted for a better understanding of their suitability and limitations for specific applications. Reliable observation of LC is sought by GCOS. For this purpose, GLC dataset producers are working closely with climate modelling user groups (e.g., Climate Modelling User Group (CMUG)) to reflect their requirements. However, long term sustained interactions is not guaranteed. Current approaches on GLC dataset generation, thematic contents and validation still needs to be harmonized. A good documentation of GLC datasets generation and inter-comparison of different LC-ECV products are required for understanding incompatibilities with other datasets. The CEOS Cal/Val working group is actively working on GLC validation and good practice guidelines LC and LCC validations are introduced. New robust validation datasets from Boston University, the LC-CCI, and the Tsinghua GLC validation dataset are coming up while the importance of crowdsourcing validation datasets is also emphasized by the producer community (Fritz et al. 2009).

A number of initiatives from Europe (GMES, SPOT, Pléiades programmes) and the USA (Landsat continuity programme) will secure EO data supply continuity in the years to come. The recent end of life cycle of some satellite platforms (Landsat-5, Envisat, Advanced Land Observing Satellite (ALOS)) act as supplemental incentive to make these programmes operational. A clear trend towards higher spatial resolution map products is observed with the on-going Landsat-scale Chinese and USA GLC mapping projects, and the European GMES projects (Sentinel constellations). In parallel a series of international coordinated efforts to ease data access, to standardize (LCCS) or harmonize (GEO, GOFC-GOLD LC-IT, CEOS Cal/Val WG) mapping procedures, are underway. The GOFC-GOLD initiative as one major international body fosters free access to data and products. This coordination process that involves both GLC information producers and users is now crucial as the emerging new services and tools associated to the availability of new EO data sets broaden the scope of applications and concern a growing number of user communities (GOFC-GOLD 2013).

The Rio+20 – the UN Conference on Sustainable Development – organized in June 2012 in Rio de Janeiro, Brazil, tackled a range of topics embracing the green economy in the context of sustainable development and poverty eradication and the institutional framework for sustainable development. The need for monitoring carbon emission notably due to deforestation and forest degradation was highlighted. As a result this UN initiative represents an important internationally coordinated political incentive to ensure the development of new sensors, the continuity and increased frequency of Earth LC observations, and concomitant development of improved data processing methods as well as the establishment of globally standardized/harmonized data processing procedures.

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