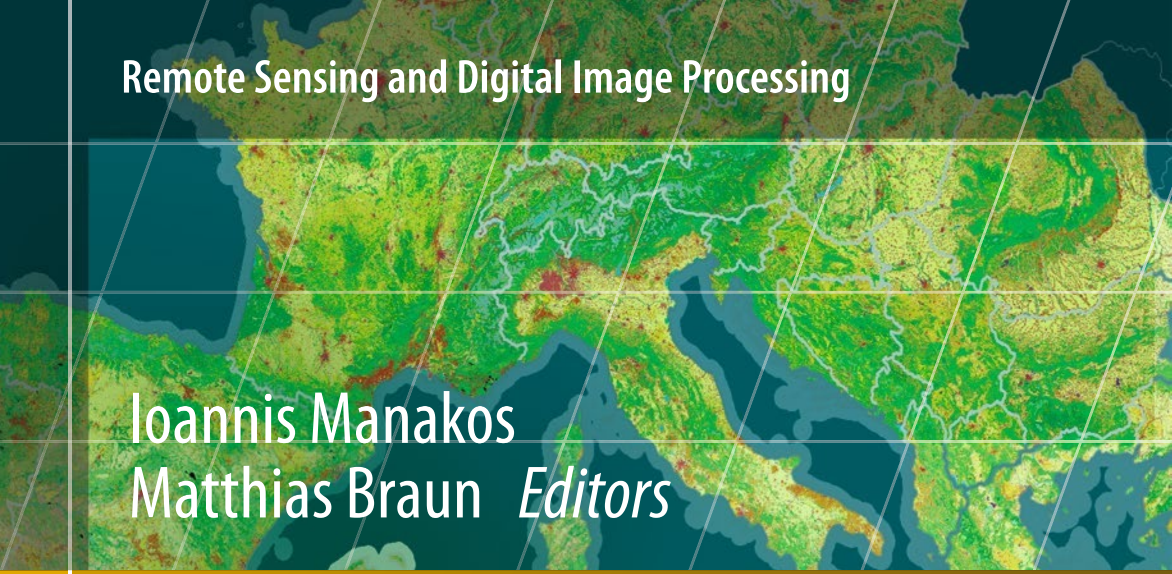

Remote Sensing and Digital Image Processing

Ioannis Manakos
Matthias Braun *Editors*

Land Use and Land Cover Mapping in Europe

Practices & Trends

EARSeL

Springer

Land Use and Land Cover Mapping in Europe

Remote Sensing and Digital Image Processing

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Preface

Land use and land cover (LULC) is a core information layer for a variety of scientific activities and administrative tasks (e.g. hydrological modeling, climate models, land use planning). In the last two decades, land use cover change (LUCC) became an additional irreplaceable observation feature not only within Europe but on a global context. LULC mapping products constitute mandatory baseline datasets, which are required over large areas in different levels of detail and shall be provided in a homogeneous and reliable way. To this end, space- and air-borne remote sensing techniques coupled with field information are gaining ground against large-scale statistical surveys based on in situ observations.

Europe has a long heritage on land use cover mapping activities. CORINE land cover currently experiences its fourth update, as part of the GIO land (GMES/Copernicus Initial Operations Land) project, with an intended update every 5 years. Under the umbrella of the Copernicus Program of the European Space Agency and the European Commission, a Fast-Track-Service on Land with regular European-wide coverage and updates is anticipated. It forms the base for subsequent so-called nationally funded downstream services.

The aim of the proposed book is to synthesize recent and current activities on land cover mapping in Europe and from Europe. It shall provide an overview on activities and projects covering large-scale mapping from an operational point of view (state-of-the-practice) and state-of-the-art analysis techniques from the scientific point of view. It is complemented by additional review papers and best-practice examples covering various specific aspects of LULC as e.g. degradation, deforestation or nature conservation, but also gives perspectives of data use and integration such as the integration into LULC modeling.

The editors are aware that due to the multitude of LULC and LUCC studies on local, national and European level – performed and initiated from science, industry, and public administration – this book can only cover a subset of contemporary observations and activities, as an indication of the pulse of science, applications, and perspectives in its era. An equivalent multifold thematic compilation on Remote Sensing advancements in LULC and LUCC mapping is not yet available for Europe. The editors wish to raise awareness, discussion points, and set challenges, indicating the pace of progress along with dead-ends and bottlenecks. Please, enjoy reading.

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Erlangen, Germany Matthias Braun

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The editors are also grateful to both the European Association of Remote Sensing Laboratories (EARSeL) and Springer Verlag for the opportunity to act as a platform for dissemination and discussion of such spearhead topics. Ideas for the structure of this book were gathered by the Workshops of the EARSeL Special Interest Group "Land Use & Land Cover", to whose members and contributors the editors feel in debt.

Their special thanks go to the Book Series Editor of EARSeL, André Marçal, and to the former Chairman of EARSeL, Rainer Reuter, for their continuous support and promotion of our initiative during the preparation of this book.

The Editors received support in their authors' coordination and editing role by Dimitrios Biliouris and Zisis Petrou, without whose active engagement this book could not have been realized. We share therefore with you our high appreciation for their involvement.

As none of these could have become reality without the consensus of their employing Institutes, the editors would like to express their gratitude to their host Institutes, the Centre for Research and Technology Hellas, and the University of Erlangen-Nürnberg, for their support.

Sincerely,
Ioannis Manakos & Matthias Braun

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Part I
Framework Conditions

Chapter 1
Remote Sensing in Support of the Geo-information in Europe

Ioannis Manakos and Samantha Lavender

1.1 How Policy Feeds into the Development of Information Services

The primary goal of European States' policies is the preservation and, wherever possible, improvement of the citizens' quality of life. However, challenges remain in relation to the conservation of natural resources, reduction of risks and threats, sustainability of urban and rural development and resource security including food and water. The human/natural environment interaction needs to be managed in 4 dimensions (4D), 3D spatial and temporal, which requires an underpinning Information Service including a system to assimilate data and model scenarios. The Millennium Ecosystem Assessment (Hassan et al. 2005) has paved the way by assessing the consequences of ecosystem change for human well-being (security, resources needed for a good life, health, and good social relations leading to freedom of choice and action) leading to the definition of ecosystem services (supporting, provisioning, regulating, and cultural ones). Direct drivers include: changes in local Land Use & Land Cover (LULC); species introduction or removal; technological adaptation and use; consumption of resources; climate change; various natural, physical, and biological drivers besides climate change. Indirect drivers would include: demographics; economics; socio-political; Science & Technology; cultural & religious. The Condition and Trends Working Group found that over the past 50 years, humans have changed ecosystems more rapidly and extensively than in any comparable period of time in human history; largely to meet rapidly growing demands for food, fresh water, timber, fibre and fuel.

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Strategic areas of intervention are recognized by the European Environmental Agency (EEA) (Dufourmont 2011), with topics being categorised as:

- **Environmental:** such as air quality, air pollutant emissions, biodiversity, greenhouse gas emissions and freshwater availability and condition.
- **Cross-Cutting:** such as climate change impacts, vulnerability and adaptation of ecosystems, environment and health, maritime issues, sustainable consumption including production of waste, land use, agriculture, forestry, energy and transport.
- **Integrated Environmental Assessment:** such as integrated environmental assessment, regional and global assessment, decision support systems, economics and strategic design.
- **Information Services and Communication:** such as shared environmental information systems and communications.

European Union (EU) policies are driven by the aforementioned considerations; being supported and iteratively improved through the results of directed research undertaken according to EU's funding frameworks. Ultimately, the aim is to operationalize the research results, through information services, in addition to dissemination and awareness raising campaigns. Feedback from beneficiaries and end users across the Member States is sought, which feeds back into policy and there-by closes the innovation circle new funding calls are opened.

Supporters of the development and implementation of Europe's policy in terms of geospatial data acquisition, processing and distribution include the EEA, European Space Agency (ESA), Copernicus Programme (formerly called GMES, an acronym for Global Monitoring for Environment and Security), and networks of excellence including commercial and scientific associations acting at both National and European levels. European networks include the European Association of Remote Sensing Companies (EARSC), European Association of Remote Sensing Laboratories (EARSeL), European environment and information network (EIONET) and EURISY. These networks have complimentary and overlapping missions with activities related to:

(a) Space infrastructure development which supports core services that address strategic areas of intervention.
(b) Methodological advancement that includes the ability to standardized information and provides it in near real time (NRT).
(c) Definition and expansion of the downstream services to create value added (VA) products for the end users, including sophisticated products with a simple user interface for everyday life.
(d) Dissemination and promotion of data, information and techniques.
(e) Training and capacity building.

1.2 Current Status and Challenges

Internationally, initiatives are increasingly being taken by agencies acting at a national, regional, and continental or global level in an effort to establish a benchmark for assessing LULC changes. However, it's important to quantify the reliability of the information received, and to enhance the potential of space applications by improving hardware and software technology in support of new scientific discoveries and ultimately end user requirements; the aim being the provision of the most relevant information in a form that is of use to decision and policy makers.

During the last decade, the EEA and ESA through Copernicus and wider activities have provided many hundreds of millions of Euros of funding to support the development of science leading to operational applications. This has included the geoland, geoland2, and BOSS4GMES series of projects that provided a prototype land core service (http://land.copernicus.eu/) that lead into the GMES Initial Operation (GIO) contract for Europe (EEA 2011). The prototype marine core service is currently the MyOcean2 7th Framework Programme (FP7) project, which provides a wide range of temporal datasets including: monitoring (encompassing NRT), multi-year, time invariant and forecast. The parameters are both physical (e.g. salinity, sea level, temperature and sea ice thickness) and biological (e.g. optical characteristics and phytoplankton biomass) in nature. MACC-II – Monitoring Atmospheric Composition and Climate – is FP7 project currently delivering regional and global pre-operational atmosphere services with recent (historical) data, present conditions and forecasts including air quality, climate forcing, stratospheric ozone, UV radiation and solar-energy resources. In February 2013 the EU Council agreed to mobilize around €3.8Bn for Copernicus through the Multiannual Financial Framework agreement (2014–2020), which the European Parliament approved in July 2013, with the ocean and atmospheric services due to become operational in 2014.

Products from the Copernicus services and projects rely on the provision of satellite imagery from contributing missions, with the first mission called Sentinel-1 (a polar-orbiting satellite carrying a C-band Synthetic Aperture Radar, SAR) due for launch in 2014; agricultural applications are expected to benefit greatly from Sentinel-1's all-weather images. In July 2013 it was agreed that data and information produced in the framework of the Copernicus programme should be made available to the users on a full, open and free-of-charge basis, in order to promote their use and sharing, and to strengthen Earth Observation (EO) markets in Europe; on the assumption that any harm to private-sector satellite operators will be outweighed by the expected growth in value-added services derived from the data. A challenge for users will be 'big data' as it's expected that the Sentinel missions will provide at least tenfold increases in data volume compared to Envisat comparable instruments e.g. the average Sentinel-1 scenario will produce over 500 Gb per day of NRT data.

Asian and American Organizations, acting together under common initiatives such as the Group on Earth Observation (GEO) and the International Society of Digital Earth (ISDE) or UNESCO Natural and Cultural Heritage Programmes, have been seeking partnerships and solutions in an effort to generate LULC products with the highest possible precision (i.e. GEO 2011). Questions arising in LULC Special Interest Groups (SIGs), such as those of EARSeL and the International Society of Photogrammetry and Remote Sensing (ISPRS), are always focused around the same keywords: methodology improvement; efficient homogenization of the production; precision of information retrieved; regional model adaptation and adjustment whilst having standardized data assessment procedures. In addition, the International User Community is setting (with scientific support) its input requirements so that a series of satellites can be launched (Copernicus Sentinel missions plus recently launched European PROBA-V and Chinese ZY-3 among others) to guarantee a continuation of data provision.

Within the aforementioned framework, one may notice from the literature and ones' own experience that systematically acquired ground truth data is missing, whilst EO datasets still suffer from mistrust in terms of both reliability and applicability. The EEA supports the in-situ activity within Copernicus, but focused on infrastructure metadata generation rather than directly supporting the data collection itself that remains the responsibility of National agencies. There are also important debates in the scientific community about the quantification of accuracy assessment rules and (for land products in particular) the influencing factors of topography, projection systems, and rule set definition for LULC and change detection mapping. The final outcome of all these discussions is that enough data and methodologies exist, but more coordination and homogenization is needed for the ultimate goal of end user acceptance to be reached. The INSPIRE Directive (INSPIRE 2007) supports this endeavour and Europe's networks are closely following.

Therefore, remote sensing of land surfaces faces the following challenges driven by recent research and technological developments (Manakos 2013):

(a) **Image Classification**: very high resolution (VHR) and hyperspectral sensors require the development of a new generation of classification techniques. Two different operational scenarios are suggested: (i) definition of training sets by interactive labelling of unlabelled samples carried out by photointerpretation, and (ii) definition of training set by using active learning techniques to drive in-situ data collection campaigns. Therefore, new strategies that integrate semi-supervised learning with active learning need to be investigated (Bruzzone and Marconcini 2009), as well as techniques that leverage on previous existing knowledge and datasets.

(b) **Change Detection (CD) Analysis:** from the simple post classification comparisons undertaken in the 1970s up to the complex algebra transformations and classifications of the 2000s (e.g. Texture-based Algebra, Robust Change Vector Analysis (CVA), Transformation Kernel Principal Component Analysis (PCA), Fast Fourier Transform, Object-based Post-Classification Comparison (PCC), Multisource PCC Support Vector Machines (SVMs)) challenges remain, such as the: pre-processing issues (geometry & radiometry); influence of the CD algorithm; segmentation approach and threshold selection; accuracy of the change mask; influence of number and type of sensors; influence of surface features (also in 3D). Further investigation is needed if optimal approaches are going to be defined for operational users.

(c) **Data Fusion from optical, radar, and thermal infrared sensors, operating at different spatial and temporal scales, and from multifaceted products:** information retrieval potential relies on the synergy and complementarity of combining remotely sensed data from multiple sources; especially when the radiation interacts with the surface in very different ways. However, the fusion of such data remains a challenge; since the launch of Envisat the community has discussed the synergistic usage of the sensors on-board, but the number of scientific publications addressing this remains low as considerable effort has been required to understand and improve the data coming from individual sensors. In addition, the increased availability of processed image analysis products as continuous data sets for various land use/land cover bio-geophysical parameters (e.g. biomass, vegetation composition, tree heights, percentage of tree/shrub cover) rather than fixed classes requires the further development of legends and classification schemes that allow for their interpretation and fusion in the data-, and knowledge-base for an area. Overall, the primary objective remains the same i.e. a performance improvement in capturing spatio-temporal variation of surface elements.

(d) **Accuracy Assessment:** Ground data quality is of major importance when estimating the accuracy of LULC extent and change detection. Quality impacts vary with the nature of errors and often with prevalence. Challenges may be identified in terms of the: genuine difficulty in discriminating classes (definition) i.e. biological variability; technical problems such as misregistration and pre-processing; use of inappropriate reference targets i.e. leading to spatial autocorrelation; use of misleading measures of accuracy; use of a biased approach to accuracy assessment. In addition, one has to recognize that sources of error and uncertainty originate from error in the ground data (Foody 2010), which is often not assessed. Recently there is an effort to find ways to utilize the plethora of available increasing amount of in-situ images from citizen sensors acquired for arbitrary reasons to increase the training capacity of the classifier, and accuracy of the derived products (e.g. 'Mapping and the Citizen Sensor' COST Action TD1202).

In addition, the challenges facing Copernicus and other multi-faceted programmes such as Galileo is conveying their importance (and ultimately value for money) to the citizens so that continued underpinning financial support is available; in July 2013 Copernicus received the European Parliament's approval for its inclusion in the Multiannual Financial Framework (MFF) budget for 2014–2020 with provision of €3 786 million (at 2011 economic conditions). This approval follows several months of difficult negotiations, and so is a significant political milestone. The Committee of the Regions (CoR) is the voice of Europe's local and region authorities that is ready to assume the role of intermediary and coordinator between themselves and the relevant bodies involved in Copernicus (Stahl 2012).

1.3 Future Trends and Conclusions

Based on more than four decades of innovation, developments and achievements in EO technologies, methodologies and applications, Europe is proceeding from the islands of pure research towards multi-modal and multi–source data assessment including processes automation, data harmonization, web downstream service development and tailor made solutions (Manakos 2013). Discussions within the community are focusing on the importance of Quality Assurance e.g. the Quality Assurance framework for Earth Observation (QA4EO, http://qa4eo.org/) that was established and endorsed by the Committee on Earth Observation Satellites (CEOS) as a direct response to a call from GEO and recent discussions co-ordinated by EARSC/ESA (April 2013) on a certification scheme for the EO Industry.

Environmental and agricultural applications include LULC change, disaster response, detailed mapping for monitoring purposes and 3D mapping with expectations directed towards the combination of observations from diverse instruments (Radars, Lidars, radiometers, optical sensors, etc.) in intelligent ways (Freeman 2012). There are high expectations for data acquisition and abundance from the upcoming fleet of Sentinel missions (the first three are expected to follow within 12 months of the MFF budget approval), which together with complimentary mission (including TerraSAR-X, Pleiades, RapidEye, DMCii, the US JPSS missions and Japanese GCOM series) aim to supply the demand from and for most EO applications.

Completed and on-going projects have paved the way towards GMES Initial Operations and Pan-European coverage plus been promoting capacity building and enhancing member states' engagement. With the last call for Space related proposals under FP7 having closed (November 2012), the EU agency expects new projects to establish a basis for the development of innovative products, applications with improved performance and services that combine existing and upcoming sensor data with in-situ sources in a novel manner. In return, results need to feed into end user decision support system and EO methodological/technological developments should take full advantage of the next generation of satellite missions.

Copyright issues are also a "hot" debate topic, addressed within the new EU Framework Programme for Research and Innovation (Horizon 2020). Sawyer and de Vries (2012) suggest that data from the upcoming Sentinel missions should be regarded as Public Sector Information, increasing their value for money. The report notes "GMES may well be Europe's goose capable of laying golden eggs. But how can we ensure a steady sustainable business model: do we take one egg (direct returns from sales of data) or do we allow the egg to hatch, hoping more golden-egg-laying geese will follow?" The free and open data policy for Sentinel data is expected to foster data reuse. From other missions (e.g. change in the U.S. Landsat data policy) there is already evidence that economic benefits are magnified when the data are made available at low or marginal cost so that barriers to entry are minimised; the entire Landsat archive became freely available in December 2008 and since then downloads have been increasing exponentially with one million downloads achieved in August 2009 and 12 million in July 2013.

Within the content of scientific research, one must look at the latest developments and advances of human activities to understand what will be the future requests from the environmental and agricultural remote sensing communities. Today, the land is covered (in general) by artificially sealed and urban areas, arable and permanent crops, forests and wetlands, semi-natural and altered landscapes, open and bare soils, and pastures. In the future we expect to see increasing urban sprawl, bio-fuel crops, food crops, soil degradation, rehabilitation and reforestation activities. The availability of water resources is increasingly worrying to both the scientific community and society, and in addition, climate change impacts shall be identified, confronted and mitigated. Biodiversity, food security, natural resource depletion, deforestation, soil degradation, disaster management, and urban sprawl are among the most important keywords for future EO applications.

Still, whatever the developments will be, the main issues remain as:

– **Engagement of Member States:** Local and Regional governments, e.g. through CoR, need to remain interested and aware of the potential of remote sensing (and Copernicus specifically) for supporting civil security and enhanced quality of life to their citizens. In addition, they need to promote the usage of the new advancements into everyday life once value is proven.
– **Research Direction**, its documentation, and promotion to the wider public of actors and policy implementers. It’s expected that funding will be increased for the Operational Program of the EU and reduced for the research and development sector.
– **Standardization, Harmonization and Usability:** There is an urge and strategy to produce thematic layer products in a standardized and homogenized way, for which quality and credibility remain stable across wider geographical areas so that administrative and projects’ implementation borders do not hinder joined-up utilization.

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

Brice Mora, Nandin-Erdene Tsendbazar, Martin Herold, and Olivier Arino

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/	IGBP-DISCover			MODIS 5	GLC 2000		Glob Cover	Glob Cover
pixel size	1 km	UMD	MODIS	500 m	1 km	GLCNMO	300 m	v2
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).