PFG 2015 / 5, 0395–0410
Stuttgart, October 2015 **Report**

High Resolution Land Cover/Land Use Mapping of Large Areas – Current Status and Upcoming Trends

Klaus-Ulrich Komp, Münster

Keywords: land use, land cover, monitoring, advanced methodologies, validation

Summary: Land use, land cover, and their dynamics are of high relevance for geographic research and increasingly interesting for many administrative, economic and environmental institutions. During the past four decades remote sensing from satellite images has been an emerging technology which allowed for the observation of the Earth's surface even in remote parts of the world. Starting in the field of global meteorological and climatic dynamics, observations expanded to vegetation monitoring, which in turn can specifically support research and development in the field of food production. This report from science and technology highlights the methodological challenge for extracting land use classes from land cover types, the technological progress since the 1970s and recent applications on European and global levels.

The report introduces two different publicly available regional and global land cover maps as well as land cover monitoring datasets. It reports on their significance of class definition, spatial resolution and thematic focus. Recent high resolution global datasets are evaluated according to their methodological progress and their potential for further applications. Finally, the upcoming trends in high resolution global mapping and monitoring are presented.

The focus is not only on scientific progress but also on changing information demand, as needs from different fields of application will help to generate the necessary funds for the improvement of methods. The overall benefit will be a better knowledge of the actual dynamic of the world regarding food resources and environment.

Zusammenfassung: *Hochauflösende großräumige Kartierung von Bodenbedeckung und Bodennutzung – Aktueller Status und sich abzeichnende Trends.* Bodenbedeckung und Landnutzung und ihre Veränderung sind nicht nur für die geographische Forschung von großem Interesse sondern auch für den wachsenden Informationsbedarf vieler administrativer, wirtschaftlicher und umweltrelevanter Institutionen. Seit vier Jahrzehnten hat sich die Fernerkundung mit Satellitenbildern als Technologie etabliert, um auch die entferntesten Regionen der Welt zu beobachten. Beginnend mit der Beobachtung globaler meteorologischer und klimatischer Veränderungen entwickelte sich die Vegetationsbeobachtung mit ihren präzisen Beiträgen zur Nahrungsmittelproduktion als Forschungs- und Entwicklungsfeld. Der Beitrag beleuchtet die methodische Herausforderung, unterschiedliche Landnutzungen aus Klassen der Bodenbedeckung abzuleiten, sowie die technologischen Fortschritte seit den 1970er Jahren und die aktuellen Anwendungen auf europäischer und globaler Ebene.

Der Beitrag stellt verschiedene regionale und globale öffentlich zugängliche Datensätze der Bodenbedeckungskartierung und Landnutzungsveränderungsentwicklung vor. Er untersucht die Signifikanz der Klasseneinteilung, der räumlichen Auflösung und der thematischen Ausrichtung soweit zutreffend. Aktuelle Ergebnisse hochauflösender regionaler und globaler Datensätze werden hinsichtlich ihres methodischen Fortschritts und ihres Potenzials für zukünftige Anwendungen evaluiert. Schließlich werden die sich abzeichnenden Trends regionaler und globaler Kartierung und Veränderungsbeobachtung vorgestellt. Der Fokus liegt dabei nicht nur auf dem wissenschaftlichen Fortschritt, sondern auch auf dem sich wandelnden Informationsbedarf, weil die Anforderungen verschiedener Anwendungsfelder dazu beitragen werden, die notwendigen Mittel für den methodischen Fortschritt zu generieren. Der Gesamtnutzen wird sich durch eine bessere Kenntniss der Weltdynamik hinsichtlich Resourcen und Umwelt darstellen.

DOI: 10.1127/pfg/2015/0276 1432-8364/15/0276 $ 4.00

1 Introduction

Beginning with the start of the first Earth Resource Satellite missions in the early 1970s there have been many attempts to obtain global overviews on land use and land cover, vegetation, settlements and natural resources. While the first satellite capacities could not easily provide a real global data coverage in short time periods among others due to revisit limitations, several modern satellite systems today offer such opportunities like more frequent observations at high geometric resolutions. The readily available image data now allows for more precise evaluation of limits and potentials of thematic land mapping and the respective maps showing the land use, the land cover, or the vegetation status and development.

There is a very strong demand for determining and monitoring the land use on all scales. Remote sensing has been perceived as a solution to overcome the unbalanced updating of cartographic maps (Konecny 2013). Not only for scientific but especially for environmental and economic reasons information on land use and land use development are required. For instance, the actual land use and the potential for land use development together with crucial questions of land ownership are amongst the prime determining factors in socio-economic and investment decisions.

However, satellite images predominantly offer information on land cover and can hardly supply such specific information demand. In the early global and continental remote sensing products of low and medium resolution, this challenge was not obvious. Some investigations show that this gap between potentials and demands was already recognized early (Anderson et al. 1976), but the new potential of remote mapping was frequently overestimated. With improved data resolutions and a more detailed differentiation of land use classes, the problem of ambiguities between land cover and land use has become more apparent. For instance, the land cover "grassland" may result from different land use types, such as a meadow within the land use "agriculture", a lawn within the land use "public recreation", a soccer turf within the land use "sport field" or even a grass field within the land use "airport". These problems have been tackled either by local validation or by attempts of automatic semantic and geometric interoperability. In those approaches, the difficulty of applying regional mapping solutions to large area applications became evident. In addition, the variety of ecological, hydrological and sub surface conditions demand regional adaptions of classification methods for mapping extensive areas.

In this paper, the forthcoming trends will be examined not only on the basis of their scientific and technical aspects, but also with respect to their societal, administrative and economic aspects.

2 Large Area Land Cover

To understand the different approaches, it is worth looking at large scale land cover mapping projects. There, study areas cover entire countries or continents and remote sensing has to be performed without or with only reduced access to ground truth information for training and validation. From 1974 until 1977, the United States Department of Agriculture (USDA), NASA and NOAA conducted the first phase of the Large Area Crop Inventory Experiment (LACIE). The experiment was designed to develop a monitoring method targeted on wheat production in important agricultural regions throughout the world (U.S., Canada, USSR, and Brazil). The technological basis was the image data received since 1972 by the Earth Resource Technology Satellite (ERTS), later renamed Landsat-1. The project achieved proving the usefulness of multispectral image data to extract timely crop information with a strong focus on wheat (Erb & Moore 1979). This initial concentration on a single-class classification of multispectral data as well as the political support and significance contributed to its success: As a result it became possible for the United States to predict the wheat harvest for extensive wheat production regions in the Soviet Union several weeks prior to harvest within a relatively small margin of error. Yield predictions rely not merely on the determination of crop extend and acreage, but also on crop conditions, which are highly influenced by the spatio-temporal variability of temperature and precipitation. This explains why the researchers of the LACIE project used additional meteorological data to refine their results (NASA 1978).

2.1 *Pan-European Approach of CORINE*

In 1985, the European Commission initiated the project "Coordination of Information on Environment" (CORINE), a very ambitious programme to monitor a great number of environmental features and their spatial distribution and development. In the end, the only feature which was successfully realised was land cover, because the methods by remote sensing from orbital platforms available at this time could not resolve high levels of detail required for more specific land use mapping. Most of the other important environmental features could not be implemented due to unresolved scientific and administrative discussions about definitions and observation techniques on a European scale. When the first CORINE Land Cover (CLC) started, it was based on the reference year 1990 and on Landsat 5 data. Initially the inventory was designed with a minimum mapping unit (MMU) of 25 ha and 44 land cover classes. For the subsequent updates, the Landsat 7 and SPOT data were included, and the MMU of changes was reduced to 5 ha (Figs. 1 and 2).

After the European Environment Agency (EEA) became operational in 1994 in Copenhagen, tasks within the Directorate General Environment were assigned step by step to the EEA, including the CLC 2000 update. Later on the CLC time series were embedded in the structural context of the programme "Global Monitoring for Environment and Security" (GMES). From 2012 onwards, after GMES had been renamed to Copernicus, the CLC time series became part of this programme, too. Where member states are using national digital landscape models updated with satellite image data such as the DLM-DE (Basic Digital Landscape Model for Germany, see section 4.2), the CLC updates will no longer be performed separately, but will be derived from these landscape models.

Working experiences through more than two decades of CLC mapping have shown the specific challenges of large area cover approaches. There are several land cover classes which do not occur in certain regions or which will have different ecological relevance e.g. according to site-specific edaphic conditions. Comparing the different European member-states discloses a certain variability of ecological zones and agro-climatic conditions. For accurate mapping within these zones different seasonal windows for acquiring satellite image data are useful. As the national land cover classes have developed independently in most cases, the CLC approach has to be recognised as a successful attempt to harmonise the European land cover map on an unbiased basis of Earth observation methodology.

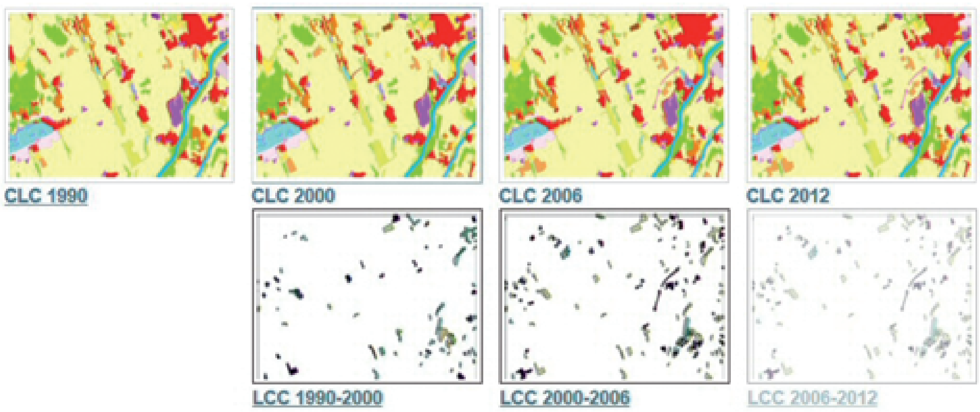

Fig. 1: Monitoring stages of CORINE Land Cover (Copernicus 2014).

Fig. 2: CORINE Land Cover 2006 main classes (Copernicus 2014).

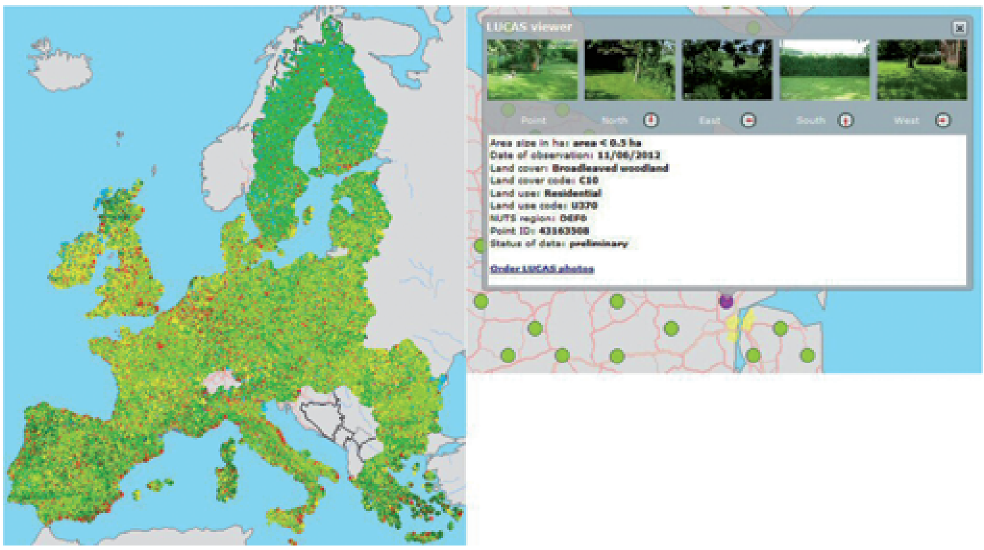

Fig. 3: LUCAS 2012 survey results: Overview of land cover sample points main classes (left); Example LUCAS terrain sample survey and photos (right) (Copernicus 2014).

2.2 *LUCAS – the European Sample Monitoring Approach*

In 2001 surveys throughout the European member states were started which have been conducted approximately every three years. The latest update (2015) consists of another 270,000 points observed in a sample survey of land cover classes, actual land use, soil conditions, and ecological features including a photo documentation of about 1.5 million terrain witness photos. Based on a stratified sampling in a 2 km by 2 km grid, the database of EUROSTAT (2015) offers a unique pool of land use/land cover samplings on the ground. Fig. 3 shows an overview of the 2012 survey results depicting the main land cover classes.

The right part of Fig. 3 shows an example of the terrain photos. The first image in the series shows the sample point itself and the other four depict the neighbourhood of the sample point in cardinal directions. Over the last 15 years, the LUCAS database has been a unique source of information on the spatial development of land cover change throughout Europe, a big dataset showing the relation between land cover and land use, as well as an on-site view collection which could provide a valuable calibration source for further refinement of remote sensing classifications.

3 Global Approaches

The early approaches for a global coverage were often limited by capacity constraints of the few existing satellites and by frequent cloud cover in many parts of the world. Therefore, the first global satellite maps often needed more than five years to achieve a complete coverage. More recently several satellite constellations are providing image data with a ground sampling distance (GSD) between 30 m and 5 m at short repeat cycles. Methodologically, the global view has highlighted additional problems arising from the different climatic zones and the different seasonal characteristics between the tropic zone, the Northern and the Southern hemispheres. Hence the global approaches of Earth observation had to incorporate various ecological patterns and a regional adapted scheme of object catalogues. As a general rule it can be stated that the need for regional adaption is growing with the reduction of the MMU.

3.1 *Copernicus Global*

In 1988, the European Commission initiated a joint programme with the European Space Agency (ESA) called "Global Monitoring of Environment and Security", better known under its acronym GMES. Under this umbrella a great number of initiatives, projects, and service elements were developed. Three examples of this programme's output are A) the service element of "Global Monitoring for Food Security" (GMFS) with regional components directed towards Africa (Brockmann et al. 2011, Komp & Haub 2012, Haub et al. 2013), B) the Fast Track Service "Land" under the Framework Programme FP7 of the European Commission within the GMES initiative, and C) a bundle of Geoland 2 projects, like the African Area Frame Sampling in the course of the SATChMo projects. Parallel to those R&D projects, the European Commission initiated direct global monitoring themes, predominantly focussing on biophysical parameters like climate and vegetation. Copernicus, previously known as GMES, is the European Programme for the establishment of a European capacity for Earth observation. The different projects, results and reports are now accessible through the Copernicus Land Monitoring Services of the European Commission (Copernicus 2014).

One attempt at global monitoring within this framework was the Global Land Cover Project initiated by the Joint Research Centre (JRC) of the European Commission. This venture started under the umbrella of a project entitled as Global Environment Information System (GEIS). The task was to "provide information on changes in the world's vegetation cover for EU policy in the area of environment, development and external affairs" (Bartholomé et al. 2002). The Vegetation instrument on board of the SPOT 4 satellite offered a quick but coarse coverage. A cooperation of about 30 research groups developed a common legend for the GLC 2000 product, using the "Land Cover Classification System"

(LCCS) terminology concerted between JRC and United Nations Food and Agriculture Organisation (FAO) (Fig. 4).

Simultaneously, similar attempts were conducted by the FAO. The current product is called "Global Land Cover – SHARE" (GLC-SHARE) and was launched as a beta release in March 2014. The database utilises the ISO standard LCCS to harmonize various land cover databases of land cover products from all over the world (Fig. 5). The improved LCCS has been used as basis for the "Land Cover Meta Language" (LCML), which is able to specify any land cover type around the world according to detailedness and scale. By using LCML, the researchers were able to create 11 global land cover classes in accordance with to the System of Environmental Economic Accounting (SEEA).

The database is geometrically compiled within a pixel resolution of 30 arc-seconds, corresponding to ~1 km × ~1 km. The area south of latitude 60° S was not included in the data base. While Northern America, Eu-

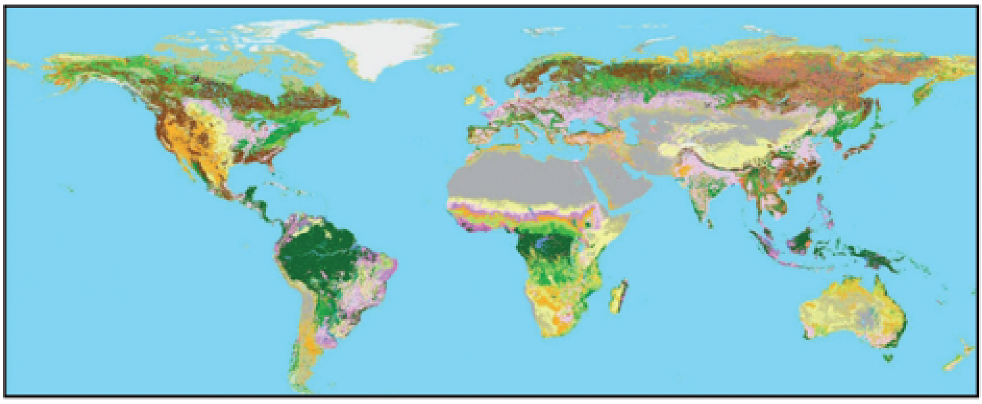

Fig. 4: Global Land Cover2000 Product (Bartholomé et al. 2002).

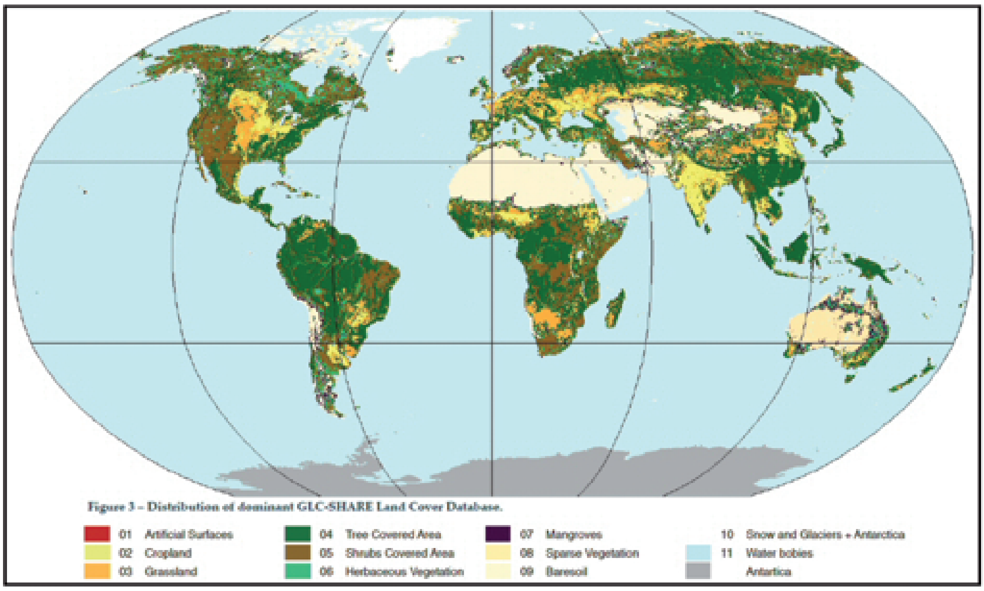

Fig. 5: GLC SHARE Land Cover Data Base Map (Latham et al. 2014).

Tab. 1: CLC-SHARE 2014 Quality Assessment (own compilation from Latham et al. 2014).

GLC-SHARE Land Cover Types	Label	Global fraction	User's accuracy	Producer's accuracy
Artificial Surfaces	01	0,6 %	70,0 %	100,0 %
Cropland	02	12,6 %	94,9 %	88,8 %
Grassland	03	13,0 %	75,4 %	65,6 %
Tree covered Areas	04	27,7 %	94,9 %	91,8 %
Shrub covered Areas	05	9,5 %	50,0 %	67,9 %
Herbaceus vegetation	06	1,3 %	56,0 %	53,8 %
Mangroves	07	0,1 %	80,0 %	100,0 %
Sparse vegetation	08	7,7 %	50,0 %	44,3 %
Baresoil	09	15,2 %	57,3 %	89,6 %
Snow and glaciers	10	9,7 %	96,3 %	72,2 %
Water bodies	11	2,6 %	100,0 %	66,7%
Total		100,0 %		

rope, the Eastern half of Africa, Russia, China, some Southern Asian states, and Australia were covered by high resolution datasets, Southern America, the Western half of Africa, the Arabian Peninsula, India, and the Indonesian Archipelago were only covered by global datasets of coarse resolution.

Nearly 1,000 sampling sites were included using a stratified random design in order to perform a validation of CLC-SHARE 2014. The result of the accuracy assessment is shown in Tab. 1. The overall accuracy has been calculated to be 80.2 %. FAO is expecting that the reliability will increase with updates which may use improved databases.

3.2 *GLC Global Land 30*

Between 2010 and 2013, the Chinese National Geomatics Center (NASG) prepared two global land cover maps with a resolution of 30 m for the reference years 2000 and 2010 from freely available Landsat scenes. The initiative was launched as a national 30 m GLC mapping project. It was listed as a GEO subtask SB-02 C1 (Chen 2013).

To obtain a dataset for the reference year 2000, the National Geomatics Centre of China in Beijing processed 10,270 Landsat TM scenes. For the update 2010, they included 2,640 scenes from the Chinese HJ-1 satellite together with 9,907 Landsat TM datasets. For four years, around 500 scientists worked on the geo-coding and thematic processing of this data and developed a variety of sampling techniques, classification and change detection procedures, e.g. the spectral gradient difference (SGD) based approach for land cover change detection (Chen et al. 2013). The GLC30 product comprises 10 land cover classes (Fig. 6).

For the scientific user community it is very important that the complete data base for both reference years including sample areas and reference data like CORINE are available as a web service (GLC30 2015). About 139 map sheets have been independently validated in sample areas by five international research groups, confirming a disagreement generally lower than 5%.

3.3 *Need for Validation*

All of the aforementioned land cover products face the same fundamental problem: The lower the number of ground samples, the more the automated classification approaches have to extrapolate land cover characteristics into

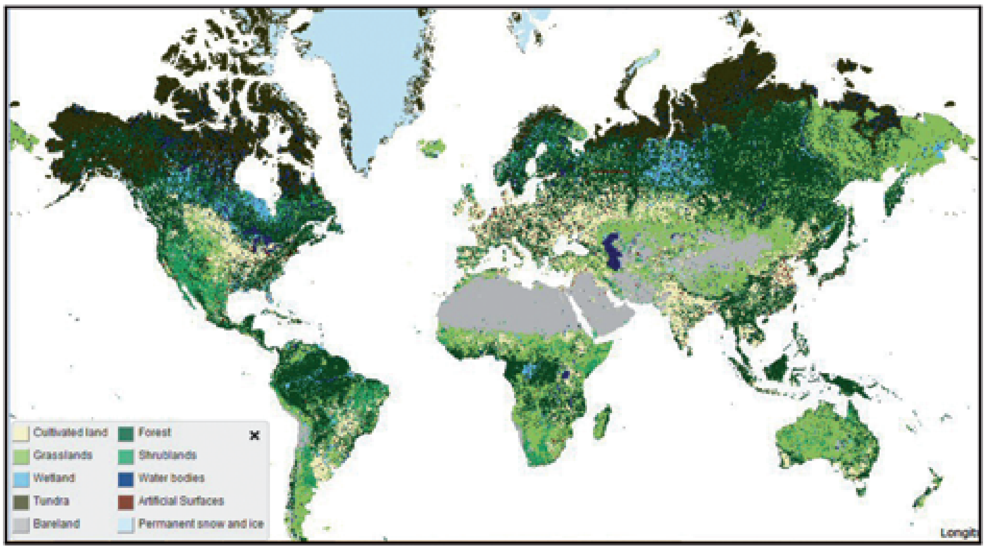

Fig. 6: GLC Global Land 30 result for 2010 (GLC30 2015).

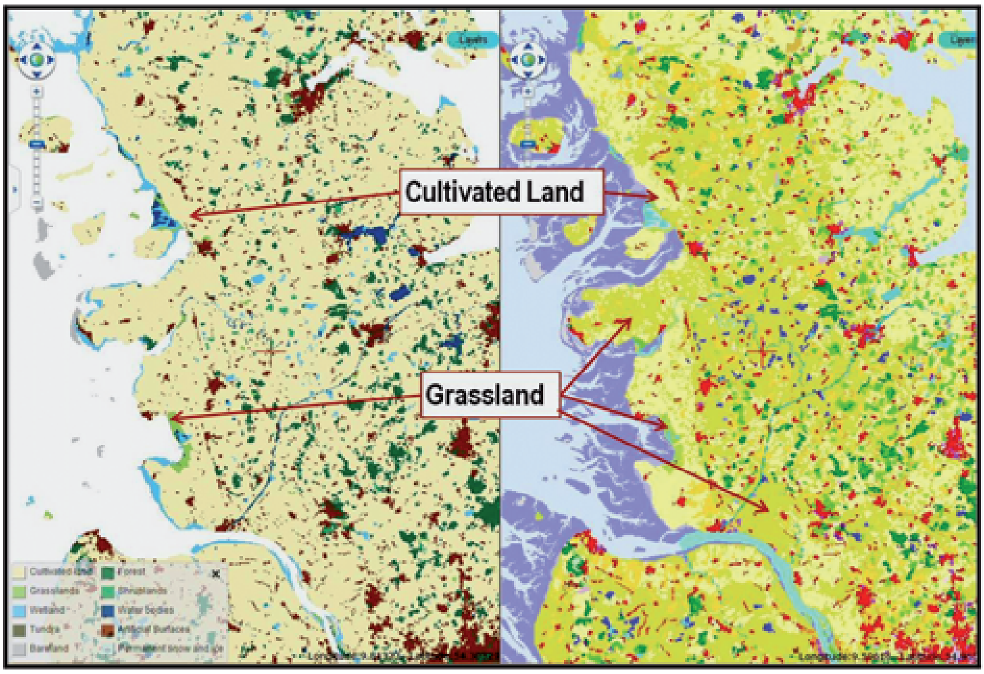

Fig. 7: Validation of GLC Global Land 30 (2010) against CORINE (CLC) at the example of North-West Schleswig-Holstein in Northern Germany (GLC30 2015).

unsampled regions, which in turn increases the risk of misclassification. However, world coverage will hardly be completed without a certain margin of uncertainty inherent to time saving automation.

Fig. 7 shows the comparative view of an extract from the GLC30 and the corresponding CLC 2006 of a small part of Northern Germany between the city of Hamburg in the lower right corner and the German-Danish border of about 16,500 km^2, separating the North Sea (West) from the Baltic Sea (East). Artificial surface, water bodies, and forest show a very good compliance. However, the GLC30 maps differ from the CLC map in a strip of 40 km width and 120 km length parallel to the Western coast, where the CLC maps shows predominantly grassland (CLC code 231). At least in this area, this will result to an underestimation of grassland cover to the benefit of the cultivated land ratio. Some other differences in the tidal flats along the North Sea coast are not of great importance as in the global view, these tidal amphibious lands are in the range of Mangrove coasts extensions, which also are not subject of GLC30. This example may underline the potentials for further improvements of the reference database as part of the next update of GLC30, which has already been announced in Chen (2013).

In order to cross-check the assumption of the CLC map being a valid data base, the results from the Copernicus project, funded under the FP7 scheme, were consulted. There are results available from a temporal analysis of a representative part of Schleswig-Holstein, which are shown in Fig. 8 in the development from 1990 to 2001 to 2013. The source for the

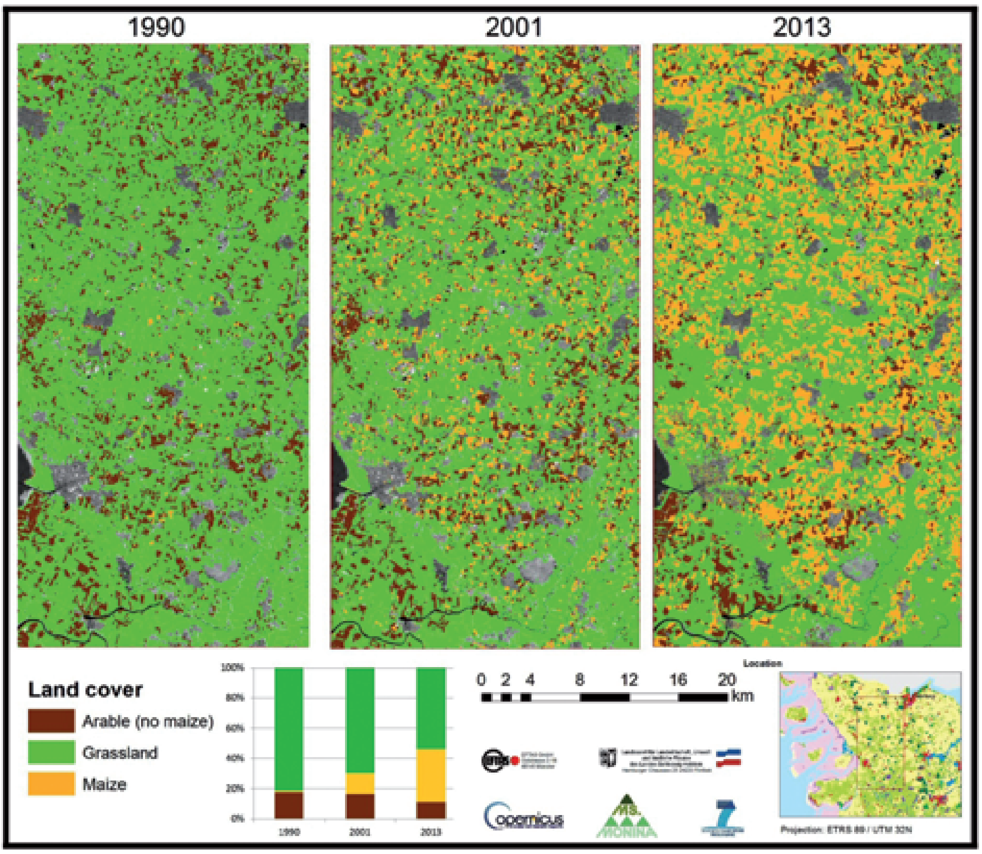

Fig. 8: Dynamics of agricultural changes in the validation area for Schleswig-Holstein in Northern Germany through conversion of grassland into bio-fuel production area with maize (adapted from Buck et al. 2013, Buck et al. 2015, and MS.MONINA 2013).

map of 2013 was satellite data from Landsat 8, acquired on 2013-05-02, 2013-06-03 and 2013-07-21. The base classification from 1990 and 2001 were used from the state BNTK data base (Survey of Biotope and Land Use Types), which has also used SPOT5 data. Using recent satellite image data from 2013, agricultural changes were classified. A conversion of grassland to arable land (cultivated cropland) could be identified and compared to existing previous classifications (Buck et al. 2013, Buck et al. 2015). Due to its edaphic conditions grassland habitats dominate the region. In 1990, there had still been a predominant exploitation of grassland. The statistical distribution diagram below the three maps shows about 81% of grassland for 1990 and only few maize cropping. Around 2001, a considerable conversion of grassland began for the biomass production through planting maize. In 2013, the proportion of grassland was found reduced (55%) at the expense of maize area (35%). This shows that different from the GLC30 in 2010 with mainly cropland in this area, there was still about 55% of grassland left even in 2013 (Figs. 7 and 8). The latter is being monitored by the regional Ministry of Agriculture as these biofuel production areas are in the vicinity of Natura 2000 sites.

4 Monitoring Land Cover / Land Use Changes

4.1 *Methodological Challenge to bridge the Gap between Land Cover and Land Use*

Spatial patterns on the surface of the Earth are of special socio-economic interest in terms of their actual use or the potential to change the actual use by different actors. The value of usable parts of the Earth's surface is determined by natural properties of the land or by access to the land and increases with competing human interests. Land offers potential for food production, cattle husbandry, settlement, economic production, circulation, recreation and extraction of Earth resources. Therefore, the knowledge of the land use is an important parameter in decisions concerning most human activities, especially with regard to a growing world population on a limited Earth surface. This also applies to militant annexation of foreign land as well as the present globalisation of trade and exchange. Many stakeholders, regional planners and investors require to know about the land use more or less worldwide.

The principal gap between required land use and observed land cover manifests in different parameters and their values. Generally spoken, the size of the gap grows with reduced pixel size and with increasing number of land use classes. In the initial ERTS-1 pixel size of 80 m × 80 m most natural or urban surfaces appeared rather interpolated and therefore appropriate to pixel based classification techniques of that time. Today's high-resolution satellite data, ranging from 10 m to 5 m is more difficult to classify due to many small differentiations, height differences, shadows and variations in illumination. In high resolution images there are less areas of homogeneous appearance than in image data of medium resolution. The problem naturally increases when using very high resolution image data (<5 m).

The second reason for a gap between required land use and observed land cover is the number of land use classes. The CORINE Land Cover describes land cover and land use according to a nomenclature of 44 classes organised hierarchically in three levels. The first level comprises four classes, the second level 15 classes, and the third level 44 classes. Especially in the latter case spectral confusion occurs in particular when one land cover type can refer to several land use classes. As a consequence, there have been a series of different approaches tested during the last decades to refine automatic land cover classification by introducing algorithms for calibration, interpretation keys gained from field observation, libraries of spectral characteristics (reference signatures), knowledge based training parcels and object based class similarities.

4.2 *Methodological Advances in DeCOVER*

In the course of a R&D project for space-based services for German land cover, the DLR initiated the development of approaches to overcome the gap between land cover and land use. The project DeCOVER focussed on the existing international and national land cover models like CORINE land cover, ATKIS Basis-DLM (Authorative Topographic-Cartographic Information System – Basic Digital Landscape Model), and DLM-DE with the aim of also supporting the future of the European land service components within Copernicus. Methodologically, different services had to be addressed: The automatic detection and classification of land cover changes, agricultural monitoring, environmental monitoring, and the crucial question of overcoming the partial discrepancies between the different existing national and international land cover models.

This special research field needs to be explained in detail. Satellite based land cover data is supposed to have an area fully covered by a number of land cover classes, without overlaps and without any unclassified gaps between adjacent areas. Contrary to this, the ATKIS Basis DLM provides information on land cover and land use, normally with several layers of information (cadastre, legal requirements, land use, built-up structures, public limitations on real estate use, economic zoning, etc). The project has improved approaches to semantic and geometric interoperability in order to derive object classes from different cadastre objects, comparable based on a common vocabulary as shown in Fig. 9 (Christ & Lessing 2012, DeCOVER 2013). A method was developed that allows semantic translations for many classes. For some classes even a geometric translation between the remote sensing derived land cover and the administrative and legal land use became possible. For now, these are R&D results achieved within the realm of knowledge-based regional context. To further develop this method into a reliable service element, i.e. a method transferable to other areas, additional experience-based case applications are still required. The fast spread satellite based monitoring of large areas at high resolution will be limited by not enough regional knowledge bases of the same standards. Potentially, the 15 years of recurrent LUCAS surveys can help to extend the knowledge base of land use and land cover, at least in Europe.

These recent developments of methodological advances combined with repeatedly updated sample surveys give a very good perspective on improving the possibilities for large area land cover/land use monitoring based on ubiquitously available high-resolution satellite data.

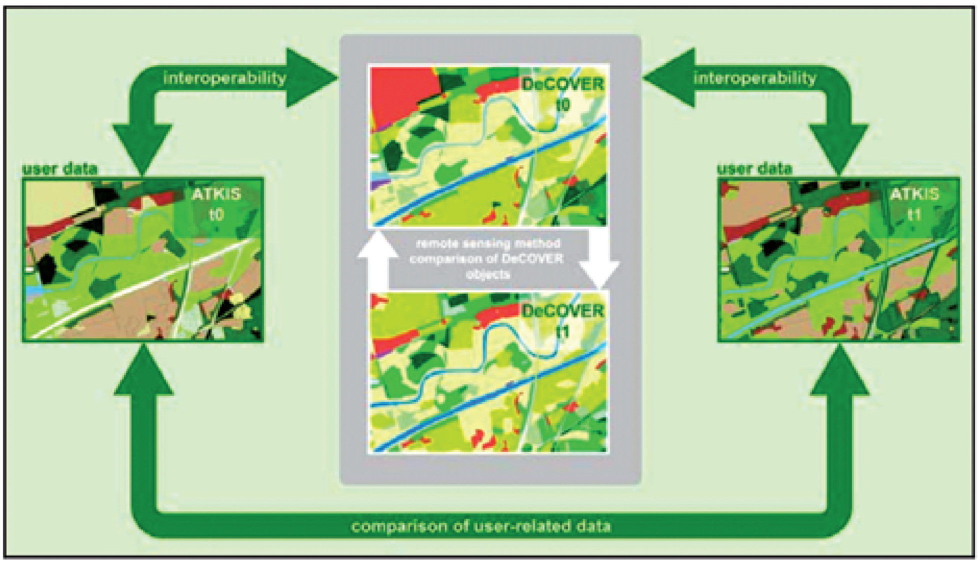

Fig. 9: Knowledge based semantic and geometric interoperability (DeCOVER 2013).

5 Upcoming Trends in Large Area Monitoring

Several trends that can be observed of late will strengthen further advances in high-resolution large scale land cover products. One important issue is the continuation of high-resolution satellite programmes, even as a combination of satellite resources from different providers. It is very promising that there is not only the Landsat continuity. Also the upcoming Sentinel series, the RapidEye constellation, Spot 7, ResourceSat-2 of India and the Chinese HJ-1 have already been enlarging the observation capacity (Tab. 2). Further follow-up satellites are either already under construction or planned.

A second supporting field emerges from various projects and international initiatives: Originated as a project only, the "Global Observation of Forest Cover – Global Observation of Land Dynamics" (GOFC_GOLD) has now become an initiative working actively for several years to promote and improve global Earth observation. The Committee on Earth Observation Satellites (CEOS), the Group of Earth Observation (GEO), the United Nations (often through FAO), and many regional or national governmental institutions are pushing Earth observation into a confluence of methodological and technical progress (Mora et al. 2014).

Fortunately, there is another trend with a growing driving force, though sometimes not in the focus of the scientific communities. This support comes from an emerging group of users of global land cover information. The first global information of coarse resolution has created rising interest for information of better geometric and temporal resolution. The traditional user group has different administrative interests, like disaster mitigation, support to regional planning and zoning, monitoring of water resource regions, desertification, climate, biodiversity, ecosystem conservation and vegetation characteristics and change (Mora et al. 2014). Additionally, there is a special demand among the governmental user group to apply Earth observation for supporting information collection and mapping in developing countries and less-favoured regions (Komp et al. 2010, Völker et al. 2011). The ongoing globalization of all social and economic relations has created a third important support group: the private sector, meaning the society as a whole. Besides the scientific interest of all Earth-related disciplines, there is increasing interest in free access to global land cover information from private persons for travel, foreign investments, social engagement of NGOs

Tab. 2: Specification of existing and upcoming satellites for high resolution EO mapping (selection compiled from information of the different satellite operators).

Satellite	GSD	Bands	Repeat Cycle	Operation
RapidEye constellation	5 m	5 MS	1 day (5 satellites)	since 2.2009
HJ-1A/HJ-1B	30 m	4 MS	4 days (2 satellites)	since 1.4.2009
Resource Sat-2	6 m LISS-4 / 30 m LISS-3	3 MS / 4 MS	24 days	since 28.4.2011
Landsat 8	30 m MS / 15 m pan	9 MS / 1 pan / 2 mw	16 days	since 11.2.2013
Sentinel 1A	5 m x 5 m strip map mode	1 C-SAR	12 days	since 3.4.2014
Spot 7	6 m / 1.5 m	4 MS /1 pan	26 days	since 30.6.2014
Sentinel 2A	10 m / 20 m / 60 m	4 MS / 6 MS / 3 mw	10 days	since 22.6.2015
Sentinel 1B	5 m x 5 m strip map mode	1 C-SAR	6 days (2 satellites)	planned for 2016
Sentinel 2B	10 m / 20 m / 60 m	4 MS / 6 MS / 3 mw	5 days (2 satellites)	planned for 2016
EnMAP	30 m	250 hyperspectral	21 days	planned for 2018

and various economic activities. It has to be pointed out, that apparently free Internet access to data for navigation, maps, aerial views and street views does not mean that this data has been created and provided free of charge. Those charges are covered by a global, powerful advertising industry which will refinance these costs through increasing sales and profit, which in turn will result in tax income of the concerned states. Globally these applications of "free" spatial information for the purpose of navigation, travelling, and other social activities not only create a rising demand for actualized spatial data but also contribute via tax income to public research budgets.

Initially, the main profiting sectors are agriculture, forestry, mineral resources extraction, and the energy sector. All of these depend on knowing the spatial patterns in up-to-date, precise terms and often benefit significantly from land cover information. These stakeholders are prepared to finance projects that go beyond the free access of information, and generate information that is more specific. Such growing demand driven by globalisation will provide funding for scientific progress in Earth observation, even in times of declining budget resources.

The developments above will be the basis for the scientific-technical trends in high-resolution global land cover mapping. The ongoing changes are evident in user-oriented alterations of monitoring cycles, monitoring scales and monitoring subjects. In regions like the upper Amazonian forest or the North Siberian tundra, in the absence of governmental programmes, large scale mapping will only occur on demand.

Simultaneously, another trend is the increasing online access to all geographic data. The Chinese GLC30 data base already offers an online validation tool which may in future serve to broaden the sources for local input of knowledge ("crowd sourcing validation"). Furthermore, the number of people travelling for private or work related reasons will increase further and require more specific information on their destination via online access. Undoubtedly, this will produce new forms of displaying tailored land cover mapping with individual focus on specific user needs. This means that areas of economic, touristic or political interest will enjoy more frequent mapping and updates than other regions. Those regions with low or no interest will be left to the possibilities of public cartographic updates.

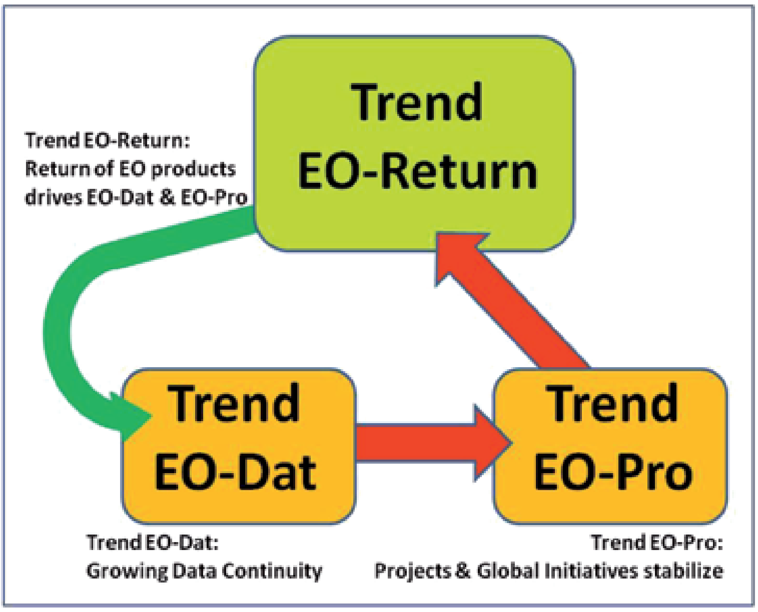

Fig. 10: Upcoming trends in Earth observation and their interaction.

The interaction of different upcoming trends in Earth observation is illustrated in Fig. 10. Based on the described developments, three major trends emerge, effectively shaping the next decade of Earth observation. The first trend may be labelled as "**Trend EO-Dat**". We observe that the data continuity is growing because of a rising number of satellite systems in orbit. As projects and global initiatives are stabilising in growth, they form the driving force which we label as "**Trend EO-Pro**". The GOFC-GOLD Initiative, CEOS, GEO, the United Nations, and the FAO are pushing EO into a confluence of methodological & technical progress. The third major development can be summarized as "**Trend EO-Return**". As pointed out above, we find many global application fields where products of Earth observation already produce an important economic and technical return on investments.

Economic sector studies have predicted solely for the European downstream market induced by the Copernicus EO programme additional 63,000 jobs until 2030, connected to a downstream market potential of 1.8 billion € (Space-Tec Partners 2012). 25 years ago the activities of Earth observation remained still in the shadow between photogrammetric mapping and scientific research depending only on public budget allocations. The example of car navigation systems may stand for the bigger investments done by the industrial sector to produce in a few years image and map coverages. Nobody did expect that Earth observation including the geo-information sector would become subject to merger and acquisition activities of global importance. The US company Planet Labs, founded 2010 in San Francisco, operates 28 small satellites and has acquired BlackBridge's RapidEye and geospatial businesses in mid 2015. The acquisition of SPOT Image by Astrium or the acquisition of HERE by the automotive industry are just two other examples. Once those EO products have reached a certain level of acceptance and distribution, user requirements will generate the need for further updates, better accuracy, and new product developments. However, the return of EO products has begun to drive the growth of the other trends EO-Dat and EO-Pro. The global trend "EO-Return" enjoys support by different user fields:

- Globalised users of global land cover monitoring who are discovering the social and economic return of EO,
- a global society (private sector) demanding free access to global land cover information,
- navigation and travel,
- social engagement of NGOs,
- the resource sector (Agriculture, Forestry, Minerals, Water) etc.

Growing demand will create user-oriented alterations of monitoring cycles, monitoring scales and monitoring subjects: Return from EO utilisation will finance and drive future R&D projects and monitoring demand.

6 Conclusion

Since the first satellite images have been available, global land cover mapping data has been the key source for researchers, governments and private users. At selected examples this report demonstrated the scientific developments and technological progress since the Large Area Crop Inventory Experiment through which the United States predicted wheat yield in the Soviet Union. Furthermore, different land cover datasets were discussed to highlight regional and global developments of land cover and land use mapping. In terms of high resolution and actuality, the Chinese Global Land Cover change detection dataset presently appears to have the highest standard. The GLC30 product shows a high quality of information content and web based functionalities, but also indicates potential for local improvement. The existing challenge of mapping land use within one land cover class remains a field for further research. The approaches of object-based classifications like the R&D results of the DeCOVER project have shown promising results. The semantic and geometric interoperability will need more regional sample definitions in order to allow the application in large scale Earth observation products.

The demand for ongoing large area land cover observation is expressed by different user communities. Upcoming trends comprise more data continuity with higher resolution, harmonisation and standardisation of mapping procedures, but also emerging user demands and new user communities based around web services. In conclusion, these prospects will broaden a user community who perceives the Societal Benefit Areas (SBA) of Earth observation. In turn, this provides a common mandate for all researchers and experts involved to support the advancement of this field, as their engagement in EO and high-resolution land cover monitoring will contribute to a responsible and sustainable development of our planet Earth.

References

Anderson, J.R., Hardy, E.E., Roach, J.T. & Witmer, R.E., 1976: A land use and land cover classification system for use with remote sensor data. – Geological Survey Professional Paper 964, United States Government Printing Office, Washington DC, USA.

Bartholomé, E., Belward, A.S., Achard, F., Bartalev, S., Carmona-Moreno, C., Eva, H., Fritz, S., Grégoire, J.M., Mayaux, P. & Stibig, H.J., 2002: GLC 2000 Global Land Cover mapping for the year 2000. – European Commission, Joint Research Centre, EUR 20524 EN, 66 p., Ispra, Italy.

Brockmann, J., Haub, C. & Komp, K., 2011: Global Monitoring for Food Security Stage 3 (GMFS 3). – PFG – Photogrammetrie, Fernerkundung, Geoinformation **2011** (3): 194–195.

Buck, O., Klink, A., Garcia Millán, V., Pakzad, K. & Müterthies, A., 2013: Image analysis methods to monitor Natura 2000 habitats at regional scales – the MS-MONINA State Service Example in Schleswig-Holstein, Germany. – PFG – Photogrammetrie, Fernerkundung, Geoinformation **2013** (5): 415–426.

Buck, O., Garcia Millán, V., Klink, A. & Pakzad, K., 2015: Using information layers for mapping grassland habitat distribution at local to regional scales. – International Journal of Applied Earth Observation and Geoinformation **2015** (37): 83–89.

Christ, I. & Lessing, R., 2012: Semantische und geometrische Aspekte der Interoperabilität. – DGPF-Tagungsband **21:** 18–25.

Chen, J., Wu, H., Li, S., Liao, A., He, C. & Peng, S., 2013. Temporal logic and operation relations based knowledge representation for land cover change web services. – ISPRS Journal of Photogrammetry and Remote Sensing **83:** 140–150.

Chen, J., 2013: 30-m GLC map. – GEO-X Plenary, Towards International Collaboration on Global Land Cover Products and Services, 14.1.2013, Geneva, Switzerland.

Copernicus, 2014: Copernicus Land Monitoring Services. – www.land.copernicus.eu/pan-european/corine-land-cover (4.3.2015).

DeCOVER, 2013: DeCOVER 2 – Space based services for German land cover. – 12 p., www.decover.info (10.7.2013).

Erb, R.B. & Moore, B.H., 1979: The Large Area Crop Inventory Experiment /LACIE/ – A summary of three years experience. – 5th Canadian Symposium on Remote Sensing, August **1978:** 542–554, A79-36486 15-43,Victoria, BC, Canada.

EUROSTAT, 2015: LUCAS online viewer. – http://ec.europa.eu/eurostat/statistical-atlas/gis/viewer/?myConfig=LUCAS-2012.xml (2.3.2015).

GLC30, 2015: http://globallandcover.com/GLC30Download/index.aspx (14.8.2015).

Haub, C., Kleinewillinghöfer, L., Brockmann, J., Komp, K. & Gilliams, S., 2013: Monitoring Services for Food Security – Successful Transfer of Technology to the Sudanese Government. – PFG – Photogrammetrie, Fernerkundung, Geoinformation **2013** (5): 459–472.

Komp, K., Dienst, H. & Haub, C., 2010: Anwendungspotenziale der Erdfernerkundung für Entwicklungsländer. Erkenntnisse aus dem Technologietransfer – politische und gesellschaftliche Bedingungen für den Einsatz der Fernerkundung in Entwicklungsländern. – Gutachten im Auftrag des TAB (Büro für Technikfolgenabschätzung beim Deutschen Bundestag), Münster, verarbeitet in Fernerkundung: Anwendungspotenziale in Afrika **2012:** 57 p.

Komp, K. & Haub, C., 2012: Global Monitoring for Food Security and Sustainable Land Management – Recent Advances of Remote Sensing Applications to African and Siberian Show Cases. – International Archives of Photogrammetry, Remote Sensing and Spatial Information Sciences XXXIX-B8, **2012:** 265–270, Melbourne, Australia.

Konecny, G., 2013. The International Society for Photogrammetry and Remote Sensing (ISPRS) study on the status of mapping in the world. Global Geospatial Information. – International workshop of the Siberian State Academy of Geodesy and ISPRS: 4–24, Novosibirsk, Russia.

Latham, J., Cumani, R., Rosati, I. & Bloise, M., 2014: Global Land Cover SHARE (GLC-SHARE) database. – Beta-Release Version 1.0., FAO, Rome, Italy.

Mora, B., Tsendbazar, N.-E., Herold, M. & Arino, O., 2014: Global land cover mapping: current status and future trends. Land use and land over mapping in Europe: practices & trends. – Remote Sensing and Digital Image Processing **18:** 11–30, Dordrecht, The Netherlands.

MS.MONINA, 2013: http://geoweb2.sbg.ac.at/ms_monina/doc/MS_MONINA_Del4_4_v10.pdf (15.8.2015).

NASA, 1978: LACIE – Phase I and phase II accuracy assessment final report. – http://www.nass.usda.gov/Education_and_Outreach/Reports,_Presentations_and_Conferences/GIS_Reports/Phase%20I%20and%20II%20Accuracy%20Assessment%20Final%20Report%20%28Pages%201-100%29.pdf (14.8.2015), Houston, TX, USA.

Space-Tec Partners, 2012: Copernicus GIO Lot3 – European Earth Observation and Copernicus Downstream Services Market Study. – Publishable Executive Summary, 17 p., Service Contract 89/PP/ENT/2011 – LOT 3.

Völker, A., Müterthies, A. & Hölzel, N., 2011: Implementation of a monitoring system for land cover changes in the Western Siberian corn-belt – A remote sensing approach from the SASCHA project. – Environment and Natural Resource Management **2011:** 233, Tyumen, Russia.

Address of the Author

Dr. Klaus U. Komp, EFTAS Remote Sensing Transfer of Technology, Oststrasse 2 – 18, D-48145 Muenster, Germany, Fax: +49-251-13307-33, e-mail: klaus.komp@eftas.com

Manuskript eingereicht: Juni 2015
Angenommen: August 2015