

 Université catholique de Louvain		GLOBCOVER 2009		
		Product description and validation report		
		Page	Date	
		1	18/02/2011	

GLOBCOVER 2009

Products Description and Validation Report






Authors	UCLouvain Team : Sophie Bontemps, Pierre Defourny, Eric Van Bogaert, ESA Team : Olivier Arino, Vasileios Kalogirou, Jose Ramos Perez
Distribution	UCLouvain & ESA Team

Acronyms

BRDF	: Bidirectional Reflectance Distribution Function
CDD	: Charged Couple Device
CNES	: Centre National d'Etudes Spatiales (French space agency)
DEM	: Digital Elevation Model
ECMWF	: European Climate Meteorological Weather Forecast
FAO	: Food Agricultural Organisation
DUE	: Data User Element
EEA	: European Environmental Agency
ENVISAT	: ESA Environmental Satellite
ESA	: European Space Agency
ESRIN	: European Space Research Institute
FR	: Fine Resolution
FRS	: Fine Resolution Full Swath
GOFC-GOLD	: Global Observation of Forest and Land Cover Dynamics
GLC	: Global Land Cover
GLOBCOVER	: ESA DUE (http://dup.esrin.esa.it/invitations.asp)
HDF	: Hierarchical Data Format-EOS2
IGBP	: International Geosphere-Biosphere Programme
IR	: Infra-Red
JRC	: Joint Research Center
LCCS	: Land Cover Classification System
MERIS	: Medium Resolution Imaging Spectrometer Instrument (http://envisat.esa.int)
NDVI	: Normalized Difference Vegetation Index
NDWI	: Normalized Difference Water Index
NIR	: Near Infra-Red
RGB	: Red-Green-Blue
RMS	: Root Mean Square
RR	: Reduced Resolution
SPOT-VGT	: CNES Earth's observation sensor onboard SPOT-4
SRTM	: Shuttle Radar Topography Mission
SWBD	: SRTM Water Body Data
SWIR	: Short-Wave Infra-Red
TOA	: Top Of Atmosphere
UCL	: Université catholique de Louvain
UN	: United Nations
UNEP	: United Nations Environment Programme
WGS	: World Geodetic System

References

- Arino, O., Ramos, J., Kalogirou, V., Defourny, P. and Achard, F., “GlobCover 2009”, *Proceedings of the living planet Symposium*, SP-686, June 2010.
- Arino, O., Bicheron, P., Achard, F., Latham, J., Witt, R. and Weber, J-L., “GlobCover the most detailed portrait of Earth”, *ESA Bulletin*, 136, pp 25-31, November 2008.
- Arino, O., Ranera, F., Bicheron, P., Leroy, M., Brockmann, C., Defourny, P., Vancutsem, C., Schouten, L., Achard, F., Eva, H., Stiebig, H-J., Weber, J-L., Mainer, A., Latham, J., Di Gregorio, A., Witt, R., Van Woerden, J., Schmullius, C., Herold, M., Plummer, S., Bourg, L., Gonzalez-Alonso, F., Houghton, N. and Goryl, F., “GlobCover”, *Proceedings of the 2d MERIS-AATSR Workshop*, SP-666, September 2008.
- Arino, O., Gross, D., Ranera, F., Leroy, M., Bicheron, P., Brockmann, C., Defourny, P., Vancutsem, C., Schouten, L., Achard, F., Bourg, L., Latham, J., Di Gregorio, A., Witt, R., Herold, M., Sambale, J., Plummer, S. and Weber, J-L., “GlobCover: ESA service for Global Land Cover from MERIS”, *Proceedings of the International GeoScience and Remote Sensing Symposium (IGARSS)*, Barcelona, Spain, 2007.
- Arino, O., Bicheron, P., Ranera, F., Gross, D., Leroy, M., Nino, F., Brockmann, C., Vancutsem, C., Defourny, P., Bourg, L., Achard, F., Durieux, L., Weber, J-L., Witt, R., Latham, J., Di Gregorio, A., Plummer, S., Schmullius, C., Herold, M., Laur, H., Goryl, P. and Houghton, N., “ESA GlobCover DUE project”, *Proceedings of the ENVISAT Symposium*, SP-636, 2007.
- Arino, O., Trebossen, H., Achard, F., Leroy, M., Brockmann, C., Defourny, P., Witt, R., Latham, J., Schmullius, C., Plummer, S., Laur, H., Goryl, P. and Houghton, N., “The GlobCover Initiative”, *Proceedings of the MERIS-AATSR workshop*, Frascati, Italy, September 2005.
- Bicheron, P., Amberg, V., Bourg, L., Petit, D., Huc, M., Miras, B., Brockmann, C., Hagolle, O., Delwart, S., Ranera, F., Leroy, M. and Arino, O., “Geolocation assessment of MERIS GlobCover orthorectified products”, Submitted and accepted in *IEEE Transactions on Geoscience and Remote Sensing*, 2011.
- Bicheron P., Defourny P., Brockmann C., Schouten L., Vancutsem C., Huc M., Bontemps S., Leroy M., Achard F., Herold M., Ranera F. and Arino O., “GlobCover 2005 – Products description and validation report”, Version 2.1, 2008 (a). Available on the ESA IONIA website (<http://ionia1.esrin.esa.int/>).
- Bicheron, P., Amberg, V., Bourg, L., Miras, B., Brockmann, C., Delwart, S., Goryl, P., Ranera, F., Hagolle, O. and Arino, O., “Geo-location assessment of MERIS GlobCover ortho-rectified products”, *Proceedings of the 2nd MERIS-AATSR Workshop*, SP-666, September 2008 (b).
- Bontemps S., Van Bogaert E., Defourny P., Kalogirou V. and Arino O., “GlobCover 2009 – Products Description Manual”, version 1.0, December 2010. Available on the ESA IONIA website (<http://ionia1.esrin.esa.int/>).
- Bontemps, S., Defourny, P., Van Bogaert, E., Weber, J-L. and Arino, O., “GlobCorine - a Joint EEA-ESA Project for Operational Land Cover and Land Use Mapping at Pan-European Scale”, *Proceedings of the living planet Symposium*, SP-686, June 2010.
- Bontemps, S., Defourny, P., Van Bogaert, E., Weber, J-L. and Arino, O., “GlobCorine – A joint EEA-ESA Project for Operational Change Detection at Pan-European Scale”, *Proceedings of the 33rd International Symposium on Remote Sensing of Environment (ISRSE)*, Stresa, Italy, May 2009.

 Université catholique de Louvain		GLOBCOVER 2009		
		Product description and validation report		
		Page	Date	
		4	18/02/2011	

Bourg, L. and Etanchaud, P., “The AMORGOS MERIS CFI (Accurate MERIS Ortho Rectified Geo-location Operational Software)”, Software User Manual and Interface Control Document, PO-ID-ACR-GS-003, February 2007.

Coppin, P., Jonckheere, I., Nackaerts, K. and Muys, B., “Digital change detection methods in ecosystem monitoring: a review”, *International Journal of Remote Sensing*, 25, 9, 1565-1596, 2004.

Defourny, P., Bontemps, S., Obsomer, V., Schouten, L., Bartalev, S., Herold, M., Bicheron, P., Van Bogaert, E., Leroy, M. and Arino, O., “Accuracy Assessment of Global Land Cover Maps: lessons learnt from the GlobCover and GlobCorine Experiences”, *Proceedings of the living planet Symposium*, SP-686, June 2010.

Defourny, P., Bicheron, P., Brockmann, C., Bontemps, S., Van Bogaert, E., Vancutsem, C., Huc, M., Leroy, M., Ranera, F., Achard, F., Di Gregorio, A., Herold, M. and Arino O., “The first 300-m Global Land Cover Map for 2005 using ENVISAT MERIS time series: a Product of the GlobCover System”, *Proceedings of the 33rd International Symposium on Remote Sensing of Environment (ISRSE)*, Stresa, Italy, May 2009.

Defourny, P., Schouten, L., Bartalev, S., Bontemps, S., Caccetta, P., de Witt, A., di Bella, C., Gerard, B., Giri, C., Gond, V., Hazeu, G., Heinimann, A., Herold, M., Jaffrain, G., Latifovic, R., Ling, H., Mayaux, P., Muncher, S., Nonguierma, A., Stibig, H-J., Van Bogaert, E., Vancutsem, C., Bicheron, P., Leroy, M. and Arino, O., “Accuracy Assessment of a 300-m Global Land Cover Map: the GlobCover Experience”, *Proceedings of the 33rd International Symposium on Remote Sensing of Environment (ISRSE)*, Stresa, Italy, May 2009.

Fischer, J. and Grassl, J., “Detection of cloud top height from backscattered radiances within the Oxygen A band-Part I: theoretical study”, *Journal of Applied Meteorology*, 30, 1991.

Gangkofner, U., Weichselbaum, J., Hoffmann, C., Arino, O., Kleeschulte, S. and Weber, J-L., “Browsing the scales – The Carto-Change project”, *Proceedings of the ENVISAT Symposium*, SP-636, Montreux, Switzerland, 2007.

Leroy, M., Bicheron, P., Brockmann, C., Krämer, U., Miras, B., Huc, M., Ninô, F., Defourny, P., Vancutsem, C., Petit, D., Amberg, V., Berthelt, B., Arino, O. and Ranera, F., “GlobCover: a 300-m global land cover product for 2005 using ENVISAT MERIS time series”, *Proceedings of the 2nd International Symposium Recent Advances in Quantitative Remote Sensing*, Torrent (Valencia), Spain, September 2006.

Leroy, M., Bicheron, P., Niño, F., Miras, B., Huc, M., Brockmann, C., Krämer, U., Defourny, P., Vancutsem, C., Arino, O. and Ranera, F., “GlobCover: a 300-m global land cover product for 2005 using ENVISAT MERIS time series”, *Proceedings of the 4th Global Vegetation Workshop (CEOS Working group on Calibration and Validation, Land Product Validation Subgroup)*, Missoula, Montana, August 2006.

Pelligrini A., Mellano, L. and Muller, P., “ENVISAT-1 products specifications, MERIS products specification”, Version 4.4, 2004. Available at:
http://earth.esa.int/pub/ESA_DOC/ENVISAT/Vol11_Meris_5b.pdf.

Rast, M., Bézy, J-L. and Delwart, S., “The ESA Medium Resolution Imaging Spectrometer (MERIS) – A review of the instrument and its mission”, *International Journal of Remote Sensing*, 20, 1681-1702, 1999.

Vancutsem, C., Peckel, J-F., Bogaert, P. and Defourny, P., “Mean Compositing: an alternative strategy for producing temporal syntheses. Concepts and performance assessment for SPOT VEGETATION times series”, *International Journal of Remote Sensing*, 28, 5123-5141, 2007.

Table of contents

1. INTRODUCTION.....	6
2. PRINCIPLES OF GLOBCOVER PROCESSING CHAIN	7
2.1. Surface Reflectance mosaics generation	7
2.2. Land cover product generation	9
3. DESCRIPTION OF SURFACE REFLECTANCE MOSAICS	12
3.1. The MERIS instrument.....	12
3.2. Data coverage	13
3.3. Products description	15
3.4. Identified issues	16
4. DESCRIPTION OF LAND COVER PRODUCTS	19
4.1. Legend description.....	19
4.2. Product description	20
4.3. Quantitative validation	21
4.4. Qualitative assessment	39
4.5. Identified issues.....	44
4.6. Comparison with the GlobCover 2005 map	44
5. RECOMMENDATIONS - DISCUSSION - CONCLUSION	47
6. DATA POLICY	49
APPENDIX I – SURFACE REFLECTANCE MOSAICS: DATA FORMAT AND CONTENT	50
APPENDIX II – LCCS & THE GLOBCOVER LEGEND	52

1. Introduction

In 2008, the ESA-GlobCover 2005 project delivered to the international community the very first 300-m global land cover map for 2005 as well as bimonthly and annual MERIS (Medium Resolution Imaging Spectrometer Instrument) Fine Resolution (FR) surface reflectance mosaics. The ESA-GlobCover 2005 project, carried out by an international consortium, started in April 2005 and relied on very rich feedback and comments from a large partnership including end-users belonging to international institutions (JRC, FAO, EEA, UNEP, GOC-GOLD and IGBP) in addition to ESA internal assessment. The ESA-GlobCover 2005 deliverables clearly demonstrated the possibility to develop an automated service, from the level 1B imagery to the final land cover map, including all the pre-processing steps and the classification process.

In 2010, the GlobCover chain was run by ESA and the Université catholique de Louvain (UCL) in order to produce bimonthly and annual MERIS FR mosaics for the year 2009 and to derive a new global land cover map from this time series of MERIS FR 2009 mosaics. The objective was to deliver the set of GlobCover 2009 products during the year 2010, thus demonstrating the operational service provided by the developed GlobCover chain. The objective of this report is to describe the GlobCover 2009 deliverables as they are released to the users and their respective validation.

The GlobCover 2009 products are the following:

- ***Bimonthly GlobCover 2009 MERIS FR surface reflectance mosaics (6 products a year):***
The bimonthly MERIS FR mosaics are computed every 2 months and provide the average surface reflectance values in 4 MERIS bands (see Appendix I), calculated from all valid observations of this 2 months period. They cover the following periods: January-February 2009, March-April 2009, May-June 2009, July-August 2009, September-October 2009 and November-December 2009;
- ***Annual GlobCover 2009 MERIS FR surface reflectance mosaic (1 product a year):***
The annual MERIS FR mosaic is computed by averaging the surface reflectance values over the whole year. It covers the period between the 1st of January 2009 and the 31st of December 2009;
- ***GlobCover 2009 land cover map (1 product a year):***
The land cover map is derived by an automatic and regionally-tuned classification of a time series of global MERIS FR mosaics for the year 2009. The global land cover map counts 22 land cover classes defined with the United Nations (UN) Land Cover Classification System (LCCS).

This document is structured as follows:

- The principles of the GlobCover processing chain are presented in section 2;
 - The GlobCover 2009 surface reflectance mosaics are described in section 3;
 - A presentation of the GlobCover 2009 land cover map is provided in section 4, as well as qualitative and quantitative validations;
 - Products discussions and general recommendations are reported in section 5.
-

2. Principles of GlobCover processing chain

The challenge of the GlobCover processing chain is to automatically deliver a land cover map from MERIS Fine Resolution Full Swath (FRS) level 1B data. A processing chain has been developed considering two major modules (Figure 1):

- a **pre-processing module** leading to global mosaics of land surface reflectance at 300 m resolution which is described in more detail in section 2.1;
- a **classification module** leading to the final land cover map at 300 m resolution which is described in more detail in section 2.2.

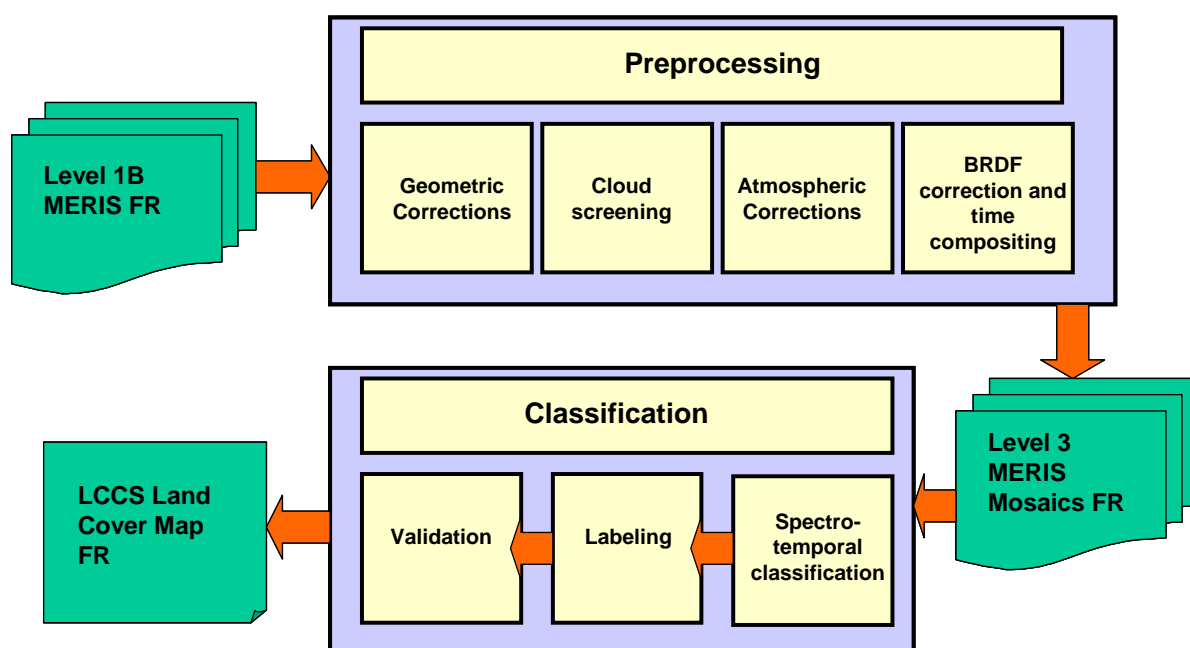


Figure 1. Algorithmic principles of the GlobCover chain

2.1. Surface Reflectance mosaics generation

Overall around 20 Terabytes of MERIS FRS level 1B data have been processed to produce the land surface reflectance mosaics for the year 2009. The surface reflectance mosaics are obtained from the MERIS FRS level 1B images with a series of pre-processing steps, including the following modules:

- geometrics correction of the input data to achieve at least a 150 m geo-location accuracy;
- atmospheric correction, including aerosol correction;
- cloud screening and shadow detection;
- land/water reclassification and a correction of the smile effect;
- Plate-carrée projection;
- Bidirectional Reflectance Distribution Function (BRDF) effect reduction and temporal compositing.

Geometric corrections

The geometric corrections are done using the AMORGOS tool (Bourg et al., 2007) provided by ESA and developed by ACRI. AMORGOS gives the geographical location (latitude and longitude) and the altitude for every pixel in the unprojected grid image. Software inputs are the MERIS FRS data, altitude files and operational or precise orbit files. Digital Elevation Model (DEM) used for orthorectification is based on the ACE DEM and is called Getasse 30.

The ortho-rectified images in output of AMORGOS and of the projection tools have demonstrated a relative geo-location accuracy of 52 m Root Mean Square (RMS) and an absolute accuracy of 77 m RMS (Figure 2). These performances are seen as satisfactory and permit to use the MERIS images at their full resolution of 300 m (Bicheron et al., 2008a; Bicheron et al., 2011).

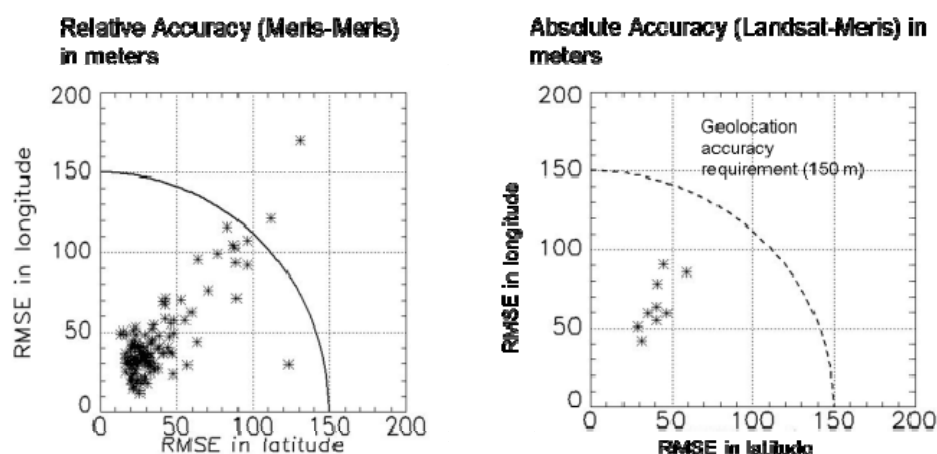


Figure 2. MERIS ortho-rectified images geo-location accuracy (Bicheron et al., 2008a)

Atmospheric correction

The atmospheric correction permits to transform Top of Atmosphere (TOA) radiances into surface reflectances. The effects of Rayleigh and aerosol scattering and gaseous absorption are taken into account. A neural network based on the so-called MOMO method (Fischer and Grassl, 1991) is applied with several inputs. Major input is the aerosol content which is taken from LARS_RR_L3 monthly products for 2009. Ozone is derived from European Climate Meteorological Weather Forecast (ECMWF) data present in the MERIS auxiliary data, O₂ and H₂O are derived from particular spectral bands plus polynomial coefficients from LUT delivered by ESA (Pelligrini et al., 2004).

Cloud screening

Two methods are combined to screen clouds, the first one using the MOMO method already quoted, and the second one using thresholds of reflectance on the bands at 443, 753, 760 and 865 nm. From the first method, two output states (clear and cloud) are possible and with the second one, four states can be detected (clear, thin cloud, dense cloud and snow). The final cloud mask merges both results excluding snow and clear states. The “Cloud Top Height” is also estimated for a better determination of cloud shadows and the snow reflectance is kept at its TOA level.

As a cloudy pixel is detected, all the pixels over a 7 x 7 square are fixed to “suspect”. This process does not take place over pixels covered with snow.

Land/Water and Water/Land reclassification

The original MERIS level 1B Land/Ocean mask that covers sea, oceans, and the largest in-land lakes is applied and the reflectances are computed only for the unmasked water bodies. Yet, this mask presents some geo-location inaccuracies and is therefore not absolutely correct. In order to take into

account these inaccuracies, a Land/Water and Water/Land reclassification is applied to finally generate status “Land”, “Water” or “Flooded” (corresponding to pixels declared wrongly as “Land” before the reclassification).

Plate-Carrée projection

The surface reflectance mosaic products are projected in a Plate-Carrée projection (WGS84 ellipsoid). The geographic location information is given in Table 1.

Field	Description
Projection	Plate-Carrée with a Geographic Lat/Lon representation (GCTP_GEO)
Reference ellipsoid	WGS 84 (R= Spherical Radius= Equatorial Radius=Re= 6378,14km)
Pixel resolution	1/360°
Tile Upper Left pixel location	<p>Tiles $H\{h\}V\{v\}$ with $H\{h\}: h \in [0 ; 71]$ and $V\{v\} v \in [0; 35]$</p> <p>Upper Left pixel longitude: $-180^\circ + h \times 5^\circ \text{ E}$</p> <p>Upper Left pixel latitude : $90^\circ - v \times 5^\circ \text{ N}$</p>
Tile size	<p>Angular size: $5^\circ \times 5^\circ$</p> <p>Size in pixels: 1800 x 1800</p>
Tile Upper Left corner of Upper Left pixel	<p>Upper Left corner of Upper Left pixel longitude:</p> <p>$-180^\circ + h \times 5^\circ - 0.5 \times \text{Res}_{\text{deg}} \text{ E}$</p> <p>Upper Left pixel of Upper Left pixel latitude :</p> <p>$90^\circ - v \times 5^\circ \text{ N} + 0.5 \times \text{Res}_{\text{deg}}^\circ \text{ N}$</p>

Table 1. Geographic location information of the GlobCover 2009 products

BRDF effect reduction and temporal compositing

Two methods are combined to reduce the directional effects due to variations of sun and view geometry in the successive measurements of surface reflectances. The Mean Compositing method (Vancutsem et al., 2007) is first processed over a compositing period of reference. This period is of 2 weeks for the internal biweekly composites, of 2 months for the bimonthly composites and of 12 months for the annual composite. An iterative procedure is then applied for detecting “valid” surface reflectance values. Finally, a mean is applied over the “valid” surface spectral reflectances at several temporal frequencies according to the products type.

2.2. Land cover product generation

The classification process transforms the cloud-free reflectance mosaics into a land cover map. It is organized in four main steps (Figure 3). Before the classification process, the world is stratified in equal-reasoning areas. The classification process has been designed to run independently for each delineated equal-reasoning area. More details on the stratification and classification can be found below. The land cover product editions that were realized after the classification are also listed.

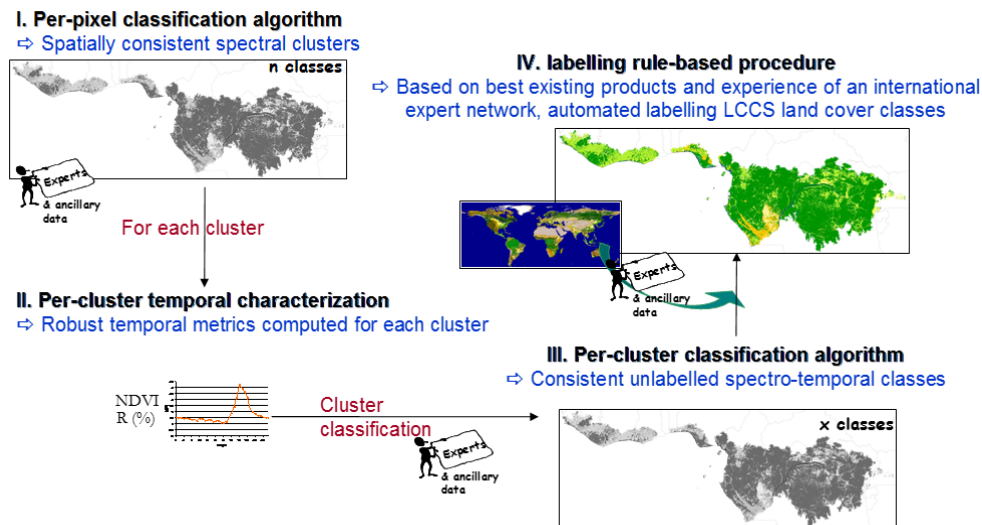


Figure 3. Scheme showing the principle of the classification algorithm starting with biweekly mosaics

Stratification

The stratification splits the world in equal-reasoning areas from an ecological and a remote sensing point of view. The objectives are twofold: (1) reducing the land surface reflectance variability in the dataset in order to improve the classification efficiency and (2) allowing a regional tuning of the classification parameters to take into account the regional characteristics (vegetation seasonality, cloud coverage, etc).

The stratification mainly relies on natural discontinuities (oceans, seas, mountains area, etc) and on sharp interfaces clearly depicted from a remote sensing point of view (e.g. forest-savannah interfaces). Figure 4 provides an overview of these areas.

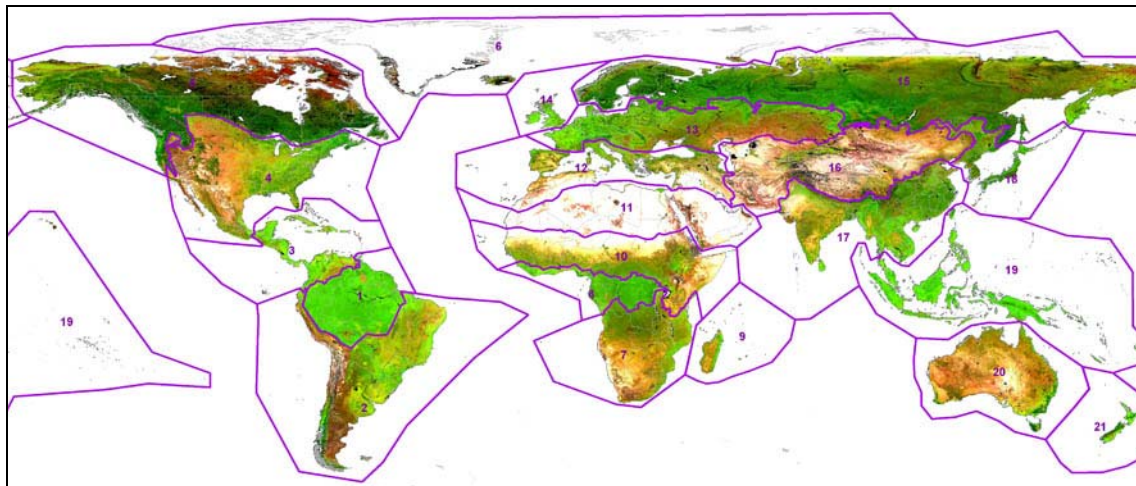


Figure 4. Overview of the stratification coarse limits. The 22 areas are overlaid to the annual composite of SPOT-VGT (SWIR, NIR, Red - year 2000)

Step I. Per-pixel classification algorithm

The spectral classification consists of a supervised and an unsupervised classification. The supervised classification aims at identifying land cover classes that are not well represented, i.e. urban and wetland areas. The pixels classified through this process are masked and an unsupervised classification is then applied on the remaining pixels to create clusters of spectrally similar pixels.

Step II. Per-cluster temporal characterization

The second step is the temporal characterization of the spectral clusters produced by the unsupervised classification in the equal-reasoning areas which present a high seasonality. In these strata, two phenological metrics (minimum and maximum of vegetation) are derived from the MERIS time series and spatially averaged for each cluster.

Step III. Per-cluster classification algorithm

From the temporal information that characterizes each cluster, this third step groups the clusters into a manageable number of spectro-temporal classes according to their similarity in the temporal space.

Step IV. Labelling-rule based procedure

The labelling procedure merges and transforms the spectro-temporal classes into land cover classes defined with the UN LCCS. The labelling procedure is automated and based on a global reference land cover database which is, in the GlobCover 2009 project, the GlobCover 2005 (V2.2) land cover map.

The GlobCover land cover label is decided according to the correspondence between both set of classes, i.e. the spectro-temporal classes and the reference land cover classes. Several decision rules have been defined with the help of international land cover experts to derive unique label for each spectro-temporal class.

Post-classification edition

o Gap filling

As shown in the GlobCover 2009 Product Description Manual (Bontemps et al., 2010), the data coverage of MERIS 2009 acquisitions is uneven due to programmatic constraints, resulting in gaps in the data (see Figure 7 in section 3.2) and therefore in the land cover product (about 5% of the total surface). These gaps are filled out using the reference land cover database (which is the GlobCover 2005 land cover map).

o Flooded forest

The lack of Short-Wave Infrared (SWIR) band in the MERIS sensor has hampered some discrimination. Typically, the classes “Closed broadleaved forest regularly flooded with fresh water” and “Closed broadleaved semi-deciduous and/or evergreen forest regularly flooded with saline water” appeared to be largely under-estimated in the GlobCover classification. They are therefore directly imported from the reference land cover database.

o Water bodies

As already mentioned, a Land/Water mask is applied for the production of the land surface reflectance products (section 2.1). Yet, this mask is not absolutely correct: it is not exhaustive – especially regarding inland water bodies – and it presents some geo-location inaccuracies. In order to face this problem, it has been decided to use an external dataset, the Shuttle Radar Topography Mission (SRTM) Water Body Data (SWBD), to improve the “water bodies” delineation in the GlobCover classification.

3. Description of surface reflectance mosaics

The GlobCover 2009 MERIS FR surface reflectance mosaics include:

- GlobCover bimonthly MERIS FR 2009 surface reflectance mosaics (6 products a year):***
 The bimonthly MERIS FR 2009 mosaics are computed every 2 months and provide the average surface reflectance values for 4 MERIS bands, calculated from all valid observations of this 2 months period. The average NDVI, as well as the Number of Valid Observations (NMOD) per pixel is also included (see Appendix I). The product covers the following periods: January-February 2009, March-April 2009, May-June 2009, July-August 2009, September-October 2009 and November-December 2009;
- GlobCover annual MERIS FR 2009 surface reflectance mosaic (1 product a year):***
 The annual MERIS FR mosaic is computed by averaging the surface reflectance values of the whole 2009. Details are provided in the Appendix I. The product covers the period between the 1st of January 2009 and the 31st of December 2009.

3.1. The MERIS instrument

On-board ENVISAT launched in 2002, MERIS is a wide field-of-view pushbroom imaging spectrometer measuring the solar radiation reflected by the Earth in 15 spectral bands from about 412.5 nm to 900 nm (Rast et al., 1999). Each of these 15 bands is programmable in position and in width. MERIS is designed to acquire data over the Earth whenever illumination conditions are suitable. The instrument's 68.5° field of view around nadir covers a swath width of 1150 km at a nominal altitude of 800 km enabling a global coverage of the Earth in 3 days. This wide field of view is shared between five identical optical modules (Figure 5) arranged in a fan shape configuration. Linear Charged Couple Device (CCD) arrays provide spatial sampling in the across-track direction, while the satellite's motion provides scanning in the along-track direction. A spatially bi-dimensional image is obtained by the gathering and the processing of subsequent images as ENVISAT moves along.

MERIS is able to deliver Fine and Reduced spatial Resolution products (FR and RR mode). These two spatial resolutions are at sub-satellite point 290 m (along track) x 260 m (across track) for the full spatial resolution and 1.2 km x 1.04 km for the reduced resolution. The spatial resolution varies only slightly from the sub-satellite point to the image edge in spite of its large field of view. RR mode is activated on a global basis whereas the FR mode is acquired regionally following programming schedule and on-board registration.

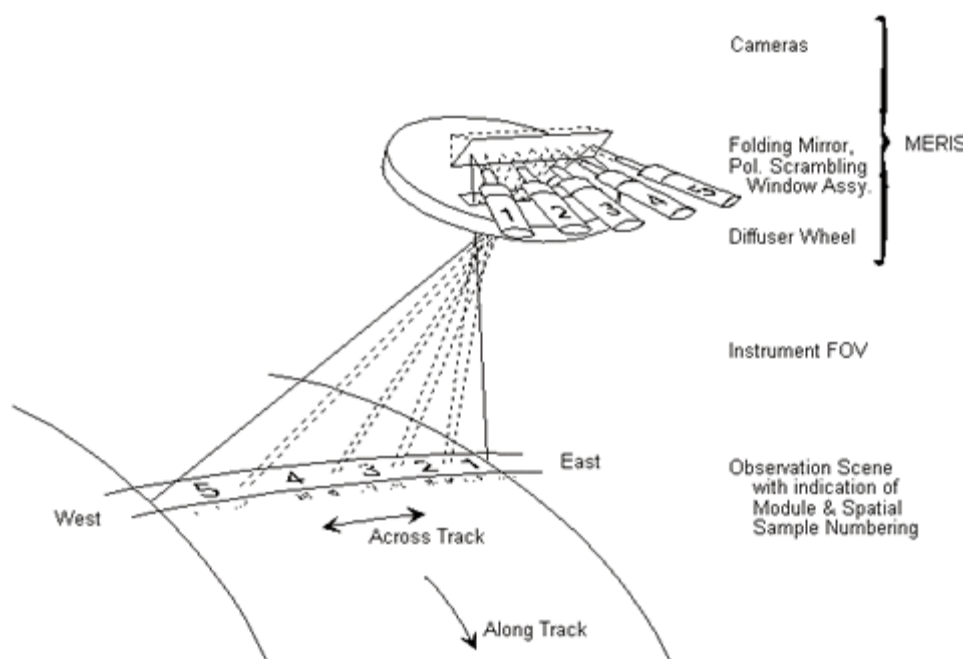


Figure 5. MERIS sensor: FOV, camera tracks, pixel enumeration and swath dimension (source ESA)

The GlobCover 2009 project has benefited from 12 months of global FRS products available from January 2009 until December 2009 processed at level 1B, i.e. calibrated top of atmosphere gridded radiances.

3.2. Data coverage

Each MERIS FR mosaic is available in the Hierarchical Data Format-EOS2 (HDF) and is organised on a 5° by 5° tiling without any overlap. The geographic representation of the GlobCover tiling schema in the Plate-Carrée projection is provided on Figure 6.

Each tile of the MERIS FR mosaics has an approximate size of about 41 Mbytes. The entire Earth is covered by 2592 tiles (72 horizontal tiles x 36 vertical tiles), however only tiles including land cover are processed, which reduces the number of available tiles accordingly.

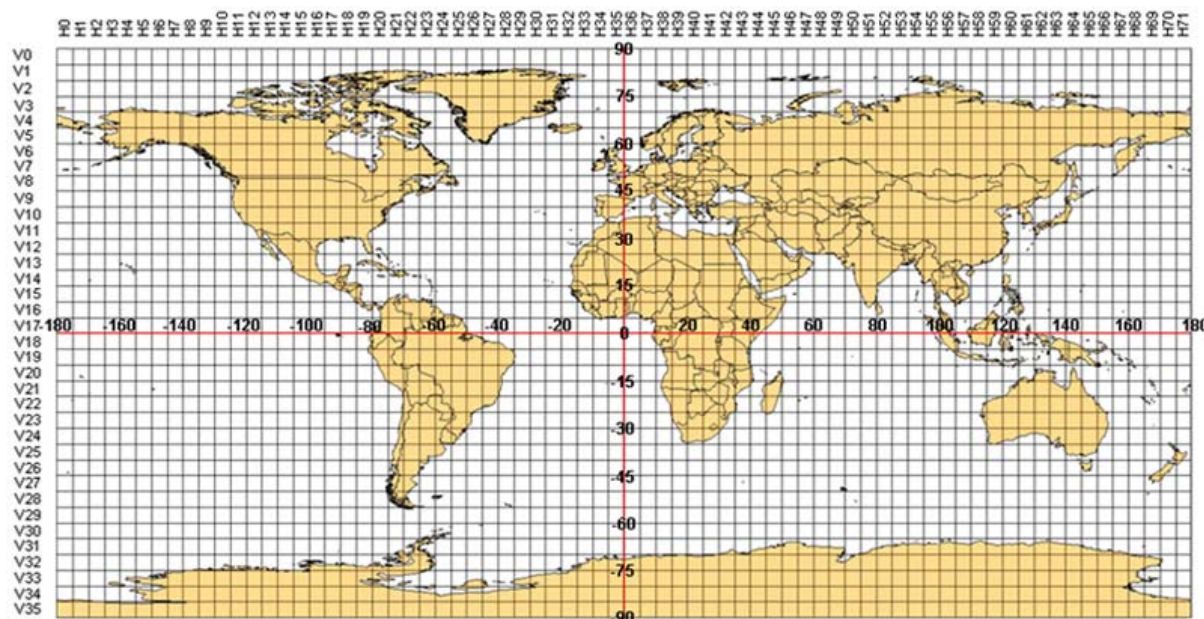


Figure 6. Scheme of the GlobCover tiles location

The global acquisition of a MERIS time series constitutes an important issue since the instrument was not initially designed to do so. As shown in Figure 7, the data coverage in 2009 is uneven due to programmatic constraints. In areas such as Central and South America, Western Canada, East Siberia, and Northern regions, the data coverage is significantly lower than elsewhere.

As expected, the number of valid observations (expressed as the parameter “NMOD” in Appendix I) after the pre-processing steps – in particular that of cloud screening – is also rather variable.

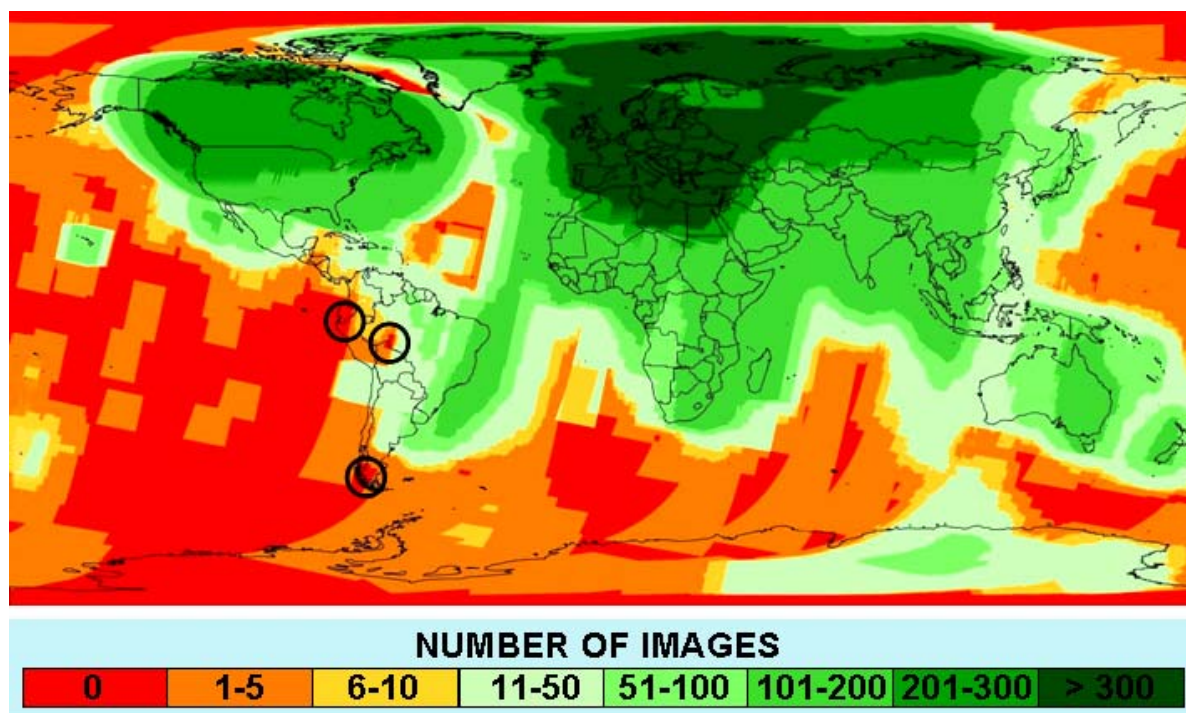


Figure 7. Density of MERIS FRS acquisitions from 1st January to 31st December 2009

3.3. Products description

A complete description of format and content of the GlobCover surface reflectance mosaics is given in the Product Description Manual (Bontemps et al., 2010) and is briefly recalled in Appendix I.

The surface reflectance mosaics have both a global and a regional character. It is not possible to illustrate at the same time the fine resolution of the product and its global feature. Figure 8 illustrates the global aspect and Figure 9 the regional aspect.

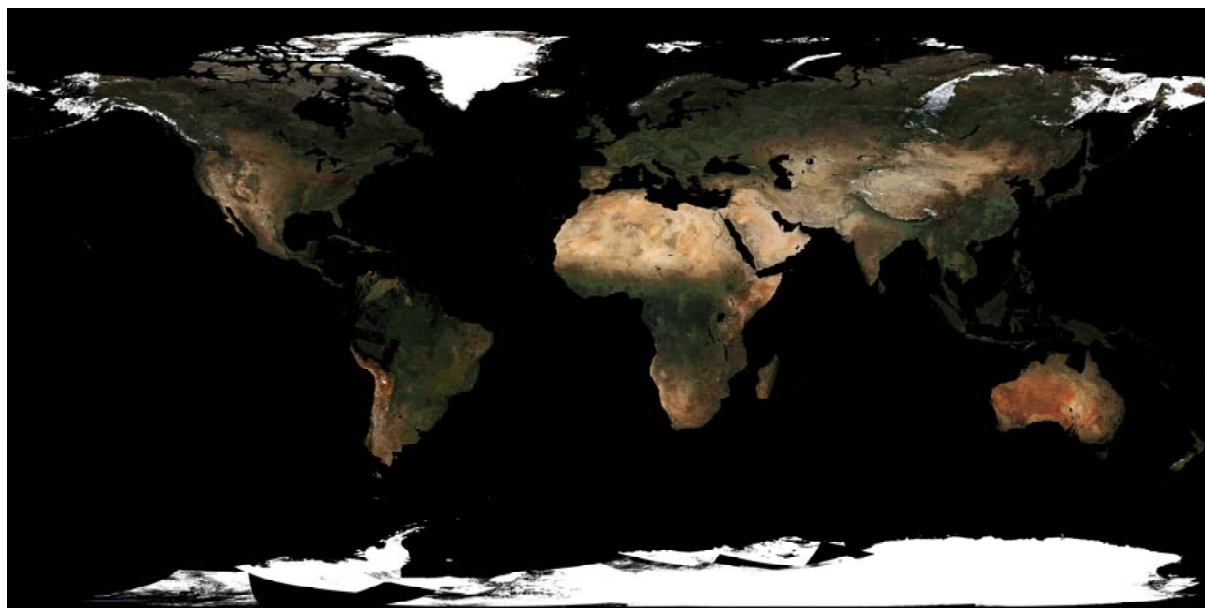


Figure 8. Annual GlobCover 2009 MERIS FR surface reflectance mosaic

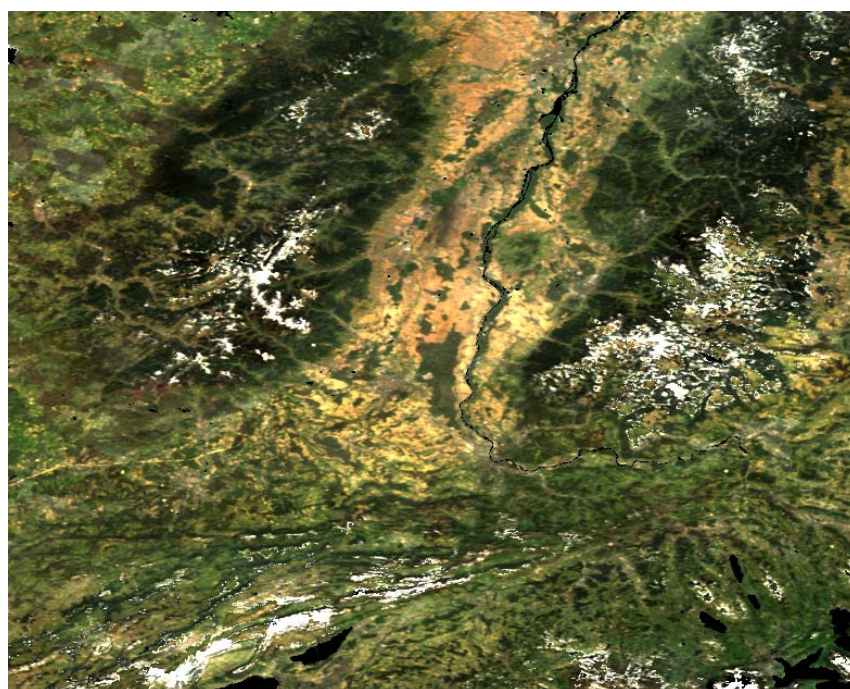


Figure 9. Seasonal composite March-April over Central Europe (France-Germany-Switzerland border)

3.4. Identified issues

The issues identified in the GlobCover surface mosaic products are:

(i) Cloud detection

Cloud detection is generally satisfactory. Initially, in some regions (e.g. South Mexico), clouds were flagged correctly but appeared in the mosaic associated with very high reflectance values. The issue was corrected with a post-processing script by re-setting the reflectance of all pixels flagged as “cloud” to zero (the same applies for sea/water).

However, clouds that have dimensions close to that of a pixel (or usually slightly larger) sometimes are not masked and appear on the composites. This issue particularly concerns **scattered cumulus clouds** (which are a particular type of clouds, hard to be detected) and affects Brazilian tropical forest or similar environments. As a result, unmasked clouds can remain in the product, as shown in Figure 10.

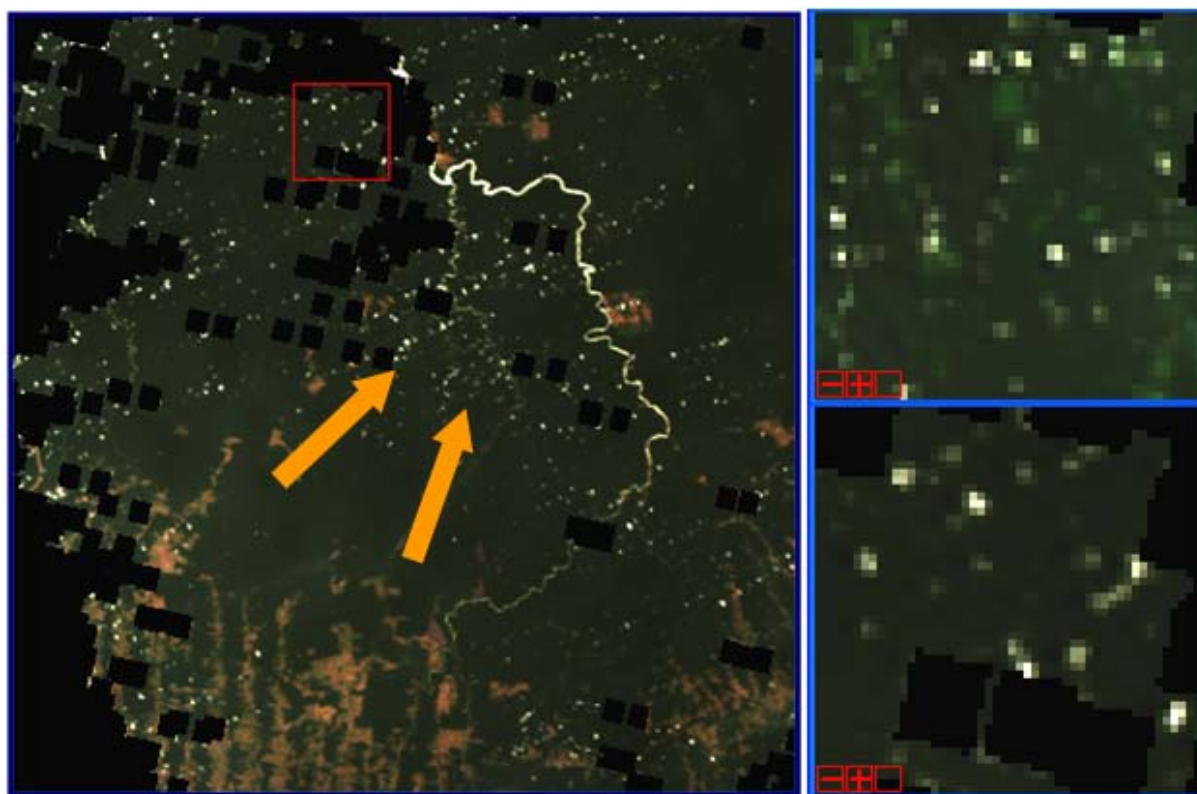


Figure 10. Cumulus clouds (white dots) observed on bimonthly composite over Brazilian tropical forest. Some clouds are masked, some not.

(ii) Snow masking

An undesirable effect (we refer to that as “**snow swath**”) might exist in high-latitude areas where snow is present for most part of the year. Above these areas, the number of valid observations is generally low and in addition, these observations are often only acquired during snow-cover conditions. As a result, these areas appear as permanent snow (pixels having high reflectance values) in the annual composite. The **snow swath** issue affects pixels that surround these areas of permanent snow. Indeed, such pixels are observed during both snow and no-snow seasons. This creates step-like transitions from no-snow to snow-covered areas, which are visible in the annual composite. An example is provided in Figure 11, with the area of Koryakskiy: only some areas have snow-free observations

during the 4th and 5th bimonthly period, thus resulting in strong “snow-swath” artifacts on the annual composite.

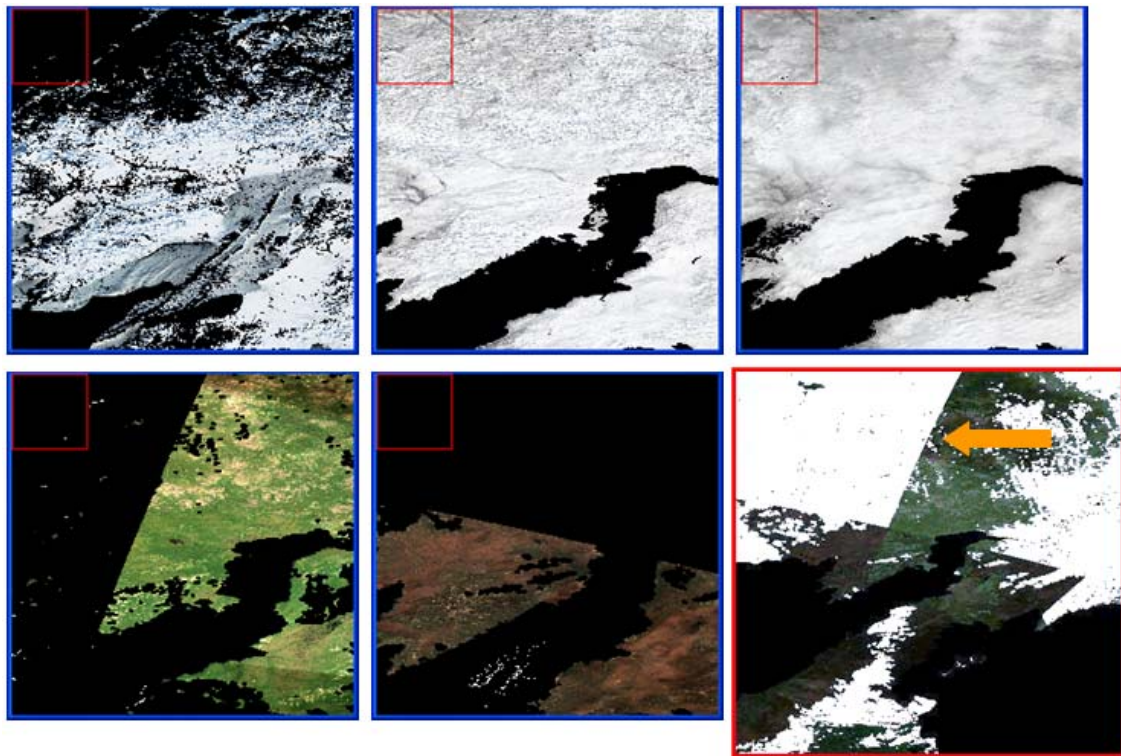


Figure 11. Series of bimonthly composites over the year 2009 in blue outline (for the 6th composite, there was no observation) and the annual composite in red outline (tile H68V5) where the snow-swath effect is observed

(iii) Water masking

Two issues have to be considered: a) some inland water bodies are not masked and, b) coastlines sometimes appear with a “sea-water buffer” meaning that many water MERIS pixels remain in the product. Yet, this is not a major problem; the opposite situation (where land is clipped) is a more serious error. Examples of the aforementioned issues are provided in Figure 12.

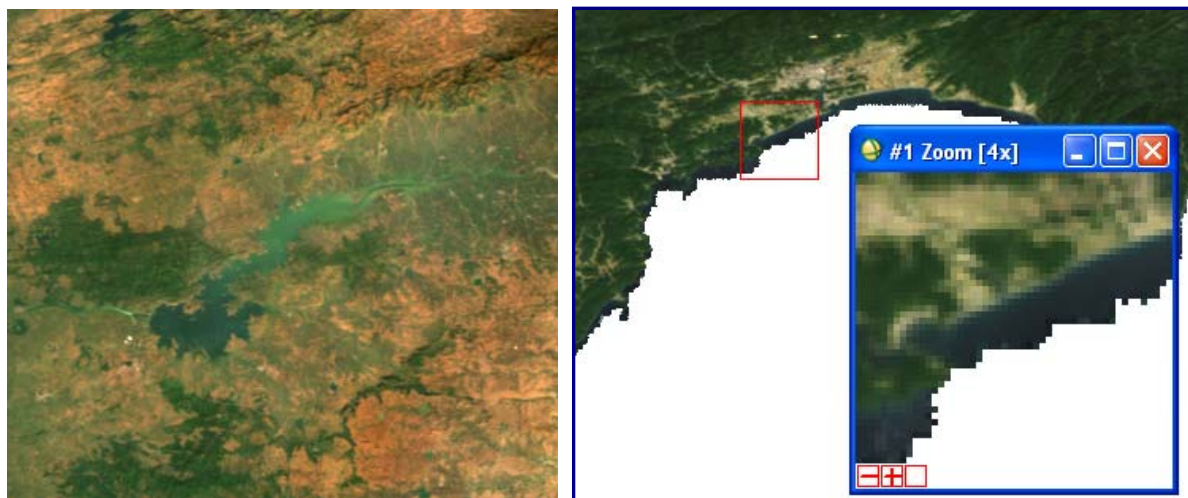


Figure 12. Unmasked inland water during the pre-processing steps is shown on the left (tile H50V13). On the right, the issue of “sea-water buffer” along the coastlines is illustrated in Japan (tile H63V10)

(iv) Haze removal

In areas where haze is often present, patchy step changes might appear in the mosaics. Sometimes those patches are not visible with a normal stretching. The processing chain was adapted during the very first stages of GlobCover to account for these effects that were already observed in the first versions. However, those effects still exist and are more particularly visible in highly vegetated surfaces (tropics).

(v) Bright surface

Some very bright surfaces (strong reflectors or desert areas) might be masked-out of the product as clouds. Example is provided in Figure 13. The problem is known and appeared also in the previous version. It is of minor importance since it affects only some particular areas.



Figure 13. A spot in South Spain with strong reflectors (greenhouses), which is masked-out as cloud in the final annual composite (H35V10)

4. Description of land cover products




















The classification module of the GlobCover processing chain consists in transforming the MERIS FR multispectral mosaics produced by the pre-processing modules into a meaningful global land cover map. The global land cover map has been produced in an automatic and global way and is associated with a legend defined and documented using the UN LCCS.

The GlobCover 2009 land cover map is delivered as one global land cover map covering the entire Earth. Its legend, which counts 22 land cover classes, has been designed to be consistent at the global scale and therefore, it is determined by the level of information that is available and that makes sense at this scale.

4.1. Legend description

In LCCS, the land cover classes are defined by a set of classifiers. LCCS has been designed as a hierarchical classification, which allows adjusting the thematic detail of the legend to the amount of information available to describe each land cover class, whilst following a standardised classification approach.

The GlobCover 2009 legend is identical to the GlobCover 2005 legend, thus being compatible with the GLC2000 global land cover classification. Table 2 contains the 22 classes of the GlobCover 2009 global land cover map. The explicit LCCS definition of each GlobCover class is provided in Appendix II.

Value	GlobCover global legend	
11	Post-flooding or irrigated croplands	
14	Rainfed croplands	
20	Mosaic Cropland (50-70%) / Vegetation (grassland, shrubland, forest) (20-50%)	
30	Mosaic Vegetation (grassland, shrubland, forest) (50-70%) / Cropland (20-50%)	
40	Closed to open (>15%) broadleaved evergreen and/or semi-deciduous forest (>5m)	
50	Closed (>40%) broadleaved deciduous forest (>5m)	
60	Open (15-40%) broadleaved deciduous forest (>5m)	
70	Closed (>40%) needleleaved evergreen forest (>5m)	
90	Open (15-40%) needleleaved deciduous or evergreen forest (>5m)	
100	Closed to open (>15%) mixed broadleaved and needleleaved forest (>5m)	
110	Mosaic Forest/Shrubland (50-70%) / Grassland (20-50%)	
120	Mosaic Grassland (50-70%) / Forest/Shrubland (20-50%)	
130	Closed to open (>15%) shrubland (<5m)	
140	Closed to open (>15%) grassland	
150	Sparse (>15%) vegetation (woody vegetation, shrubs, grassland)	
160	Closed (>40%) broadleaved forest regularly flooded - Fresh water	
170	Closed (>40%) broadleaved semi-deciduous and/or evergreen forest regularly flooded - Saline water	
180	Closed to open (>15%) vegetation (grassland, shrubland, woody vegetation) on regularly flooded or waterlogged soil - Fresh, brackish or saline water	
190	Artificial surfaces and associated areas (urban areas >50%)	

200	Bare areas	
210	Water bodies	
220	Permanent snow and ice	

Table 2. 22 classes of the GlobCover legend

A 23rd class (coded as “230”) has been added to the final legend to account for no data pixel values.

4.2. Product description

The GlobCover 2009 land cover product is the second 300-m global land cover map produced from an automated classification of MERIS FR time series. This is the first one for the year 2009. The map projection is a Plate-Carrée (WGS84 ellipsoid) just like the surface reflectance products (section 2.1).

The GlobCover classification has a global character. As explained in section 4.1, the global land cover product has the property to be consistent: it is described by a legend counting 22 land cover types that are well documented and comparable all over the world. Figure 14 presents the global GlobCover 2009 land cover map.

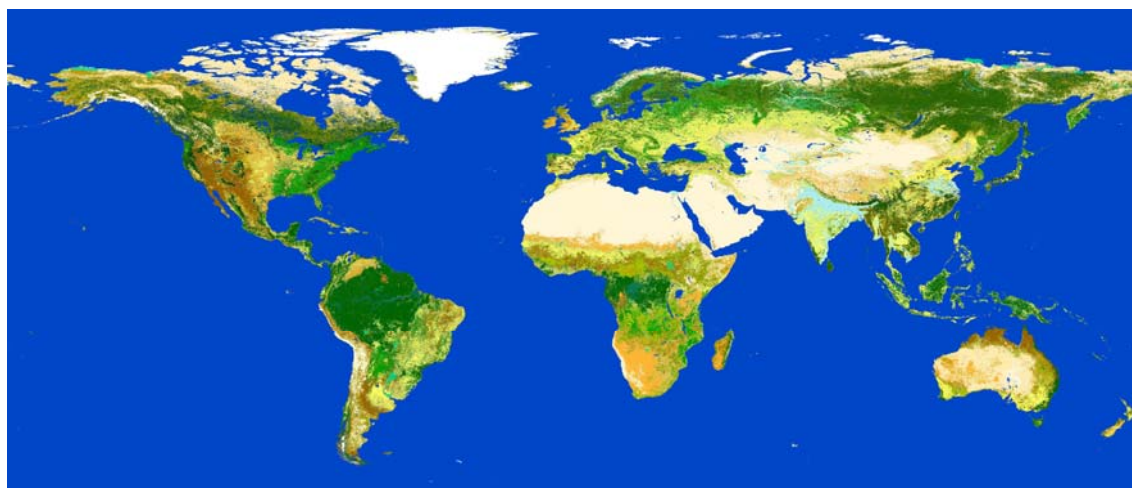


Figure 14. The GlobCover 2009 global land cover map as the first 300-m global land cover map for the year 2009

Figure 15 presents the area covered by the 22 global classes, computed after a projection of the land cover map into a Lambert conical equal area projection and expressed in percentage. Some classes are little represented as expected: classes 160 “Closed (>40%) broadleaved forest regularly flooded - Fresh water”, 170 “Closed (>40%) broadleaved semi-deciduous and/or evergreen forest regularly flooded - Saline water”, 180 “Closed to open (>15%) vegetation (grassland, shrubland, woody vegetation) on regularly flooded or waterlogged soil - Fresh, brackish or saline water” and 190 “Artificial surfaces and associated areas (urban areas >50%)”.

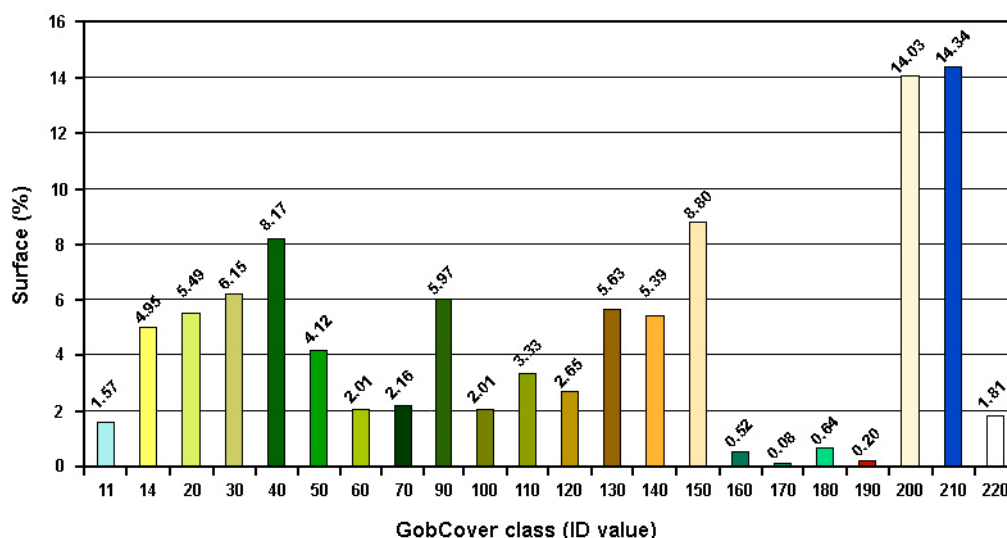


Figure 15. Area (%) covered by the 22 land cover classes

4.3. Quantitative validation

The GlobCover 2009 land cover map has been quantitatively assessed based on the same methodology than those developed within the GlobCover 2005 project. Readers are referred to the GlobCover 2005 project report (Bicheron et al., 2008a) for a complete description of the validation strategy. This report only presents the updates and improvements specific to this GlobCover 2009 project.

4.3.1. Update and improvement of the validation database

A specific effort was made in this project to update the validation database that was acquired during the GlobCover 2005 project in order to have description of the land surface in 2009. Experts involved in 2005 were asked to contribute again to this project and a new improved and online validation tool was developed to avoid them travelling abroad. The validation points sampling scheme was also adapted to enhance the spatial representation over the land mass.

4.3.1.1. Experts network

The experts network was a key element of the validation process. Most of the experts who participated in the GlobCover 2005 validation exercise have truly committed themselves to update the validation dataset. In inviting the experts, the same five criteria than in 2005 were considered:

- undisputed expertise on land cover over relative large areas;
- familiarity with interpreting remote sensing imagery;
- commitment;
- complementarity to the other experts;
- experts must already be in the network of a member of the team.

Expertise

It is clear that we seek people with some reputation. Their ability to assess the land cover should be undisputed and if they assign a certain land cover type to a sample point, we must be confident that it is trustworthy. Errors can never be completely avoided, but the experts must more or less guarantee

the highest possible quality validation set that we can obtain within the context of this project. On top of this, they need to have this expertise over a substantial area. It does not suffice to have thorough knowledge of land covers that may exist on the island of Java, or on the North Island of New Zealand. This would have meant that we ended up with a team of almost a hundred experts. We agreed that the network should be composed of around 15 experts.

Even though not every expert that participated in the workshops may have an undisputed reputation, we do believe that we either had experts who do have such a reputation or we had experts that were recommended by well known specialists on whose judgements we can rely.

Familiarity

Some experts on land cover may have built their knowledge on the basis of extensive field surveys, but lack the experience of using remote sensing imagery. This could play a role in deciding which expert will be selected in the end. Ultimately the knowledge of the expert on the vegetation / land cover is the main criterion. Yet, we do realise that time can be a factor. If the experts need a substantial part of the available time to make themselves familiar with the data, the effectiveness of their contribution is affected. Therefore, we prefer to choose experts who already know what kind of information they can expect to find in satellite images and who know how satellite data can be used.

Commitment

The experts need to commit themselves to the GlobCover product in two different ways. The first one is obvious in the sense that their agreement to participate is not without obligations. If they agree to join the experts' network, then they will have to allocate some time for the validation at some stage of the project. It should be clear to everyone involved that this is a direct consequence of the agreement. The second commitment is less obvious but perhaps equally important. They will have to comply with the methods that the GlobCover team has designed for the calibration/validation no matter what traditions and/or ideas they normally work with. In order to have a consistent dataset, this has to be a well-understood and accepted principle.

Complementarity

The ultimate goal has been to build a team of experts that brings in complementary knowledge. For example, there is no point in accepting a 4th or 5th expert for South America, if we still lack experts for Africa or Asia. Some overlap in expertise can be beneficiary to the project (as this gives us the opportunity to check the consistency in their judgement), but looking at the entire network the expertise of the network members should be complementary.

Part of existing network

The experts we have invited were known, either directly or indirectly, individuals to one or more members who make up the GlobCover team. We have not searched for experts on the Internet, as we wanted to have some reassurance that the experts were indeed of the quality we sought for.

Table 3 summarizes the experts who were involved in the GlobCover 2009 validation exercise.

Region	Experts	Institution
Africa	Bruno Gérard	International Crops Research Institute for the Semi-Arid Tropics
	Philippe Mayaux	Global Environment Monitoring unit – Joint Research Centre
	Jean-Paul Kibambé	Université catholique de Louvain
Europe	Gabriel Jaffrain	European Topic Center on Land Use and Spatial Information (Technical Team)
Russia	Sergey Bartalev	Space Research Institute, Russian Academy of

		Science
Asia	Huang Lin	Institute of Geographical Sciences and Natural Resources Research, Chinese Academy of Sciences
	Hans-Jürgen Stibig	Global Environment Monitoring unit – Joint Research Centre
	Andreas Heinimann	National Centre of Competence in Research North-South, Centre for Development and Environment
North and Central America	Rasim Latifovic	Canada Centre for Remote Sensing – Ottawa – Canada
	Chandra Giri	United States Geological Survey – EROS Data Center
South America	Carlos di Bella	Instituto Nacional de Tecnología Agropecuaria – Argentina
	Valéry Gond	CIRAD-Guyane – Université Laval
	Yosio Shimabukuo	Instituto Nacional de Pesquisas Espaciais (Brazilian Space Agency)
Australia	Peter Cacetta	Commonwealth Scientific and Industrial Research Organisation – Australia

Table 3. Experts involved in the GlobCover 2009 validation exercise

With regard to the 2005 validation exercise, South America was better assessed with the addition of 2 experts (V. Gond and Y. Shimabukuro) while in Europe, only one expert was involved. Expertise was still lacked in Middle East and in the Indian subcontinent, resulting in an absence of validation over this area (see Figure 18 in section 4.3.4.1).

4.3.1.2. Sampling strategy

The 2009 sample of validation points was based on the 2005 sampling and adjusted in order to reach 3 criteria:

- Ensure a better representation of each continent and of each land cover class, based on the GlobCover V.2.2¹ land cover map;
- Ensure minimum 30 point per class, based on the GlobCover V.2.2 land cover map;
- Propose around 250 points to each expert.

According to these criteria, the final sampling (Figure 16) counts 4164 points, of which 2036 belong to the 2005 sampling and 2128 are new.

¹ The GlobCover V2.2 version is the one using MERIS data from Dec.2004-Jun.2006. We also refer to that map version as the **GlobCover 2005** map.

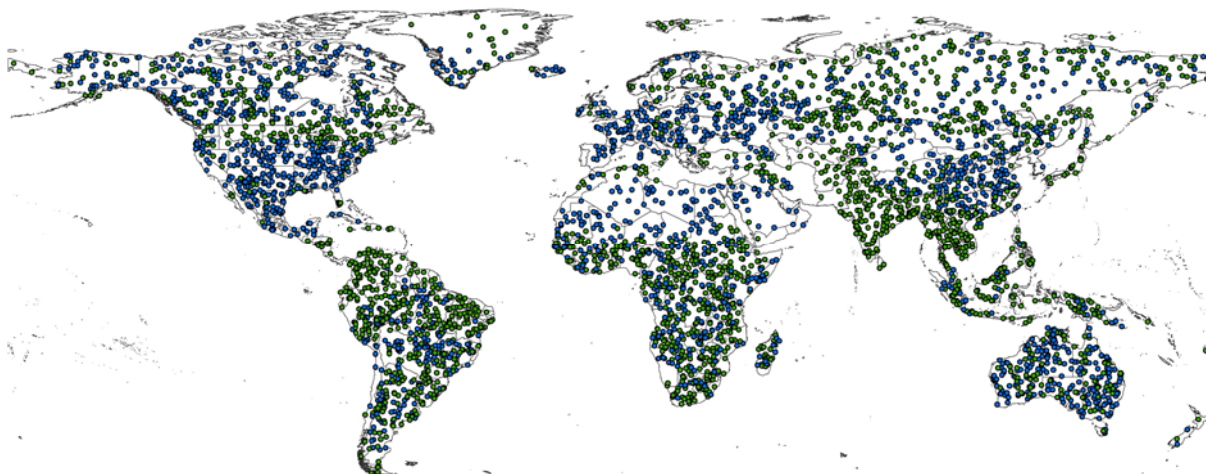


Figure 16. Distribution of the points sample used for the validation of the GlobCover 2009 land cover map. Blue points are the ones derived from the 2005 database and green points are the new ones.

4.3.1.3. Validation tool

The validation tool developed in the framework of the GlobCover 2005 project was improved in order to (i) make it available on-line and (ii) allow the updating of information.

The first main improvement achieved in 2009 was to provide online interface available to the expert on reception of the *URL* with associated password (Figure 17). The system is based on *php* technologies coupled with Google map facilities. The second one was to allow a live link with Google Earth. Indeed, the validation screen integrates four types of information (Figure 17):

- Information about LCCS code which need to be fulfilled by the expert (part 1);
- New background information to perform GlobCover 2009 validation (part 2);
- Live link to Google Earth (part 3);
- Other information to finalize the validation exercise of each point (part 4).

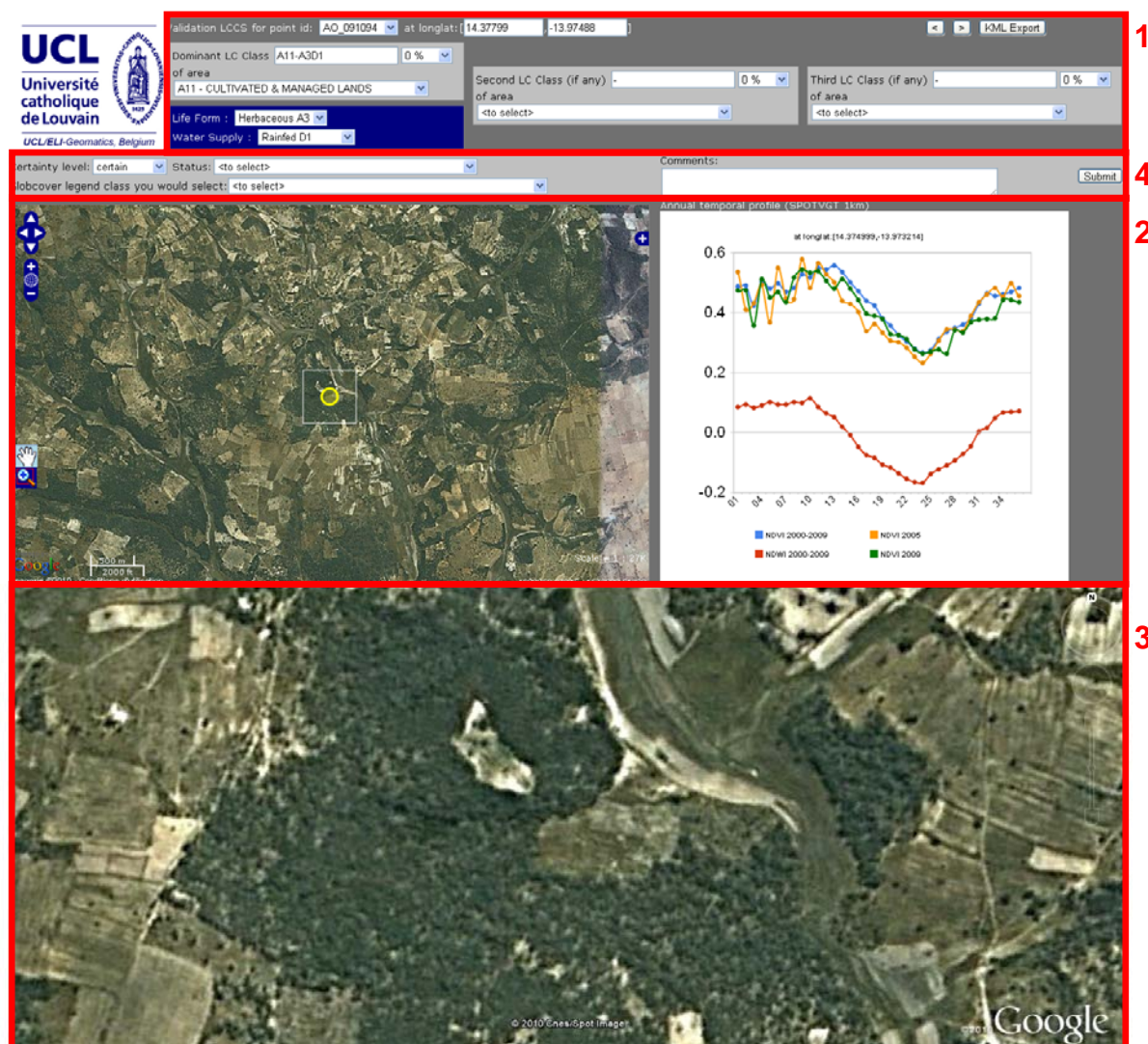


Figure 17. Sub-spaces integrated in the main page of the online validation tool

The validation tool offered several sources of information to the experts in order to help them making their interpretation. Table 4 summarizes the set of data available for the GlobCover 2009 validation exercise.

Dataset	Description
Google Earth	Virtual globe, map and geographical information program. It maps the Earth by the superimposition of images obtained from high (or very high) spatial resolution satellite imagery, aerial photography and GIS 3D globe. This was the main source of information used by the experts.
Virtual Earth	Geospatial mapping platform produced by Microsoft. The imagery includes samples taken by satellite sensors, aerial cameras, Streetside imagery, 3D city models and terrain. It was provided as an alternative to Google Earth.
Yahoo Satellite	Free online mapping portal provided by Yahoo, which was provided as an alternative to Google Earth.
Open Street Map	Collaborative project aiming at creating a free editable map of the world. The maps are created using data from portable GPS devices, aerial photography, other free sources or simply from local knowledge. It was provided as a source

	of information complementary to Google Earth.
SPOT-VGT annual composite over 10 years	SPOT-VGT daily images, acquired during the 10-year period between 2000 and 2009 were composited, using the Mean Compositing algorithm (Vancutsem et al., 2007) in order to generate an averaged annual composite. The composite was displayed using the SWIR, NIR (Near Infra-Red) and Red channels.
MERIS annual composite (RGB display) for the year 2009	MERIS annual composite over the year 2009 (1 st January to 31 st December). The composite was displayed using the MERIS channels 3, 5 and 7.
MERIS annual composite (IR display) for the year 2009	MERIS annual composite over the year 2009 (1 st January to 31 st December). The composite was displayed using the MERIS channels 5, 7 and 14.
MERIS annual composite (RGB display) for the year 2005	MERIS annual composite over the 19-month period between 1st December 2004 and June 2006. The composite was displayed using the MERIS channels 3, 5 and 7.
MERIS annual composite (IR display) for the year 2005	MERIS annual composite over the 19-month period between 1st December 2004 and June 2006. The composite was displayed using the MERIS channels 5, 7 and 14.
4 time profiles based on SPOT-VGT	Annual time profiles, based on a 10-day period, related to: NDVI values over the year 2009 (over 36 decades) NDVI values over the year 2005 (over 36 decades) NDVI value averaged over the 10-year period between 2000 and 2009 (over 36 decades) NDWI value averaged over the 10-year period between 2000 and 2009 (over 36 decades)

Table 4. Description of the dataset available for the GlobCover 2009 validation exercise

In addition to the interface, the information content asked to the experts was also enhanced with regard to the 2005 validation exercise. First, experts were asked to quantify the dominant character of each land cover class he describes. Indeed, the expert had the option to use up to 3 classes to describe the point. In this case, he had to start with the dominant land cover type and then enter the second and third classes according to their dominant character. This possibility was already offered to the expert in 2005 but this time, he also had to provide an estimation of the surface percentage allocated to each class he described.

Second, additional information – related to the “status” of the point – was asked to the expert in order to allow updating the database. In this 2009 validation exercise, two kinds of points were proposed to the experts: points that were already validated (by the same or another expert) in the 2005 exercise and new points sampled for 2009. Proposing points from 2005 had a twofold objective: reinforcing the reliability of the 2005 exercise and detecting possible changes occurred between 2005 and 2009. For new 2009 points, the expert had to make its interpretation starting from scratch. For points already proposed in the GlobCover 2005 exercise, the 2005 interpretation was proposed by default and the experts had to update the information. Four possibilities were foreseen:

- The 2005 diagnostic was correct and was still valid in 2009. The expert did not change anything in the LCCS description and described the point as “Unchanged LC and non improved 2005 interpretation”;

- The 2005 diagnostic was correct but the land cover changed in 2009. The expert updated the description based on LCCS classifiers and described the point as “Changed LC and non improved 2005 interpretation”;
- The 2005 diagnostic was not the best one and no change occurred between 2005 and 2009. The expert improved the interpretation by modifying the description based on LCCS classifiers. In this case, the point had to be described as “Unchanged LC and improved 2005 interpretation”;
- The 2005 diagnostic was not the best one and a land cover change occurred between 2005 and 2009. The expert updated the interpretation based on LCCS classifiers in order to describe the 2009 land cover. The point had to be described as “Changed LC and improved 2005 interpretation”.

Changes in land cover between 2005 and 2009 could be detected by analyzing the 2005 and 2009 time profiles based on SPOT-VGT dataset (see Table 4) and by using the time scale proposed in the Google Earth interface. This time scale allows visualizing images of different dates (according to their availability in Google Earth).

4.3.2. Retrieving GlobCover values

The map codes of the GlobCover product have been retrieved using ArcGis software (version 10), according to the criteria used in 2005 (Bicheron et al., 2008a):

- over a window of 3x3 pixels size;
- using a majority rule (and in case no class met the majority threshold, the centre value was retrieved).

4.3.3. Validation data translation and comparison with the GlobCover product

The set of classifiers and attributes that were selected by the experts in order to characterize the land cover of a particular site was transformed to the legend of the GlobCover product, using the same rules than in 2005 (Bicheron et al., 2008a). These rules aimed at compressing the information provided by the experts to the 22 classes that make up the GlobCover product. As not all the information provided by the experts could be interpreted unambiguously, we assigned some points to more than 1 class. The comparison of these land cover classes will be performed in this paragraph. It is comprised of four steps:

- compare the GlobCover product with Land Cover 1 (the land cover type that is the most dominant one in the observational unit according to the regional expert) from the validation dataset;
- when the GlobCover product does not correspond with Land Cover 1, compare the product with Land Cover 2;
- when the GlobCover product does not correspond with Land Cover 1 and Land Cover 2, compare the product with Mosaic Class 1;
- when the GlobCover product does not correspond with Land Cover 1, Land Cover 2 and Mosaic Class 1, then compare the product with Mosaic Class 2.

4.3.4. Results and findings

4.3.4.1. Validation database

3134 out of the 4164 points of the validation sampling are described by an interpretation provided by experts. Over these 3134 points, 733 points are associated with a description derived from the 2005 validation exercise and 2401 points have been interpreted in 2009 (Figure 18).

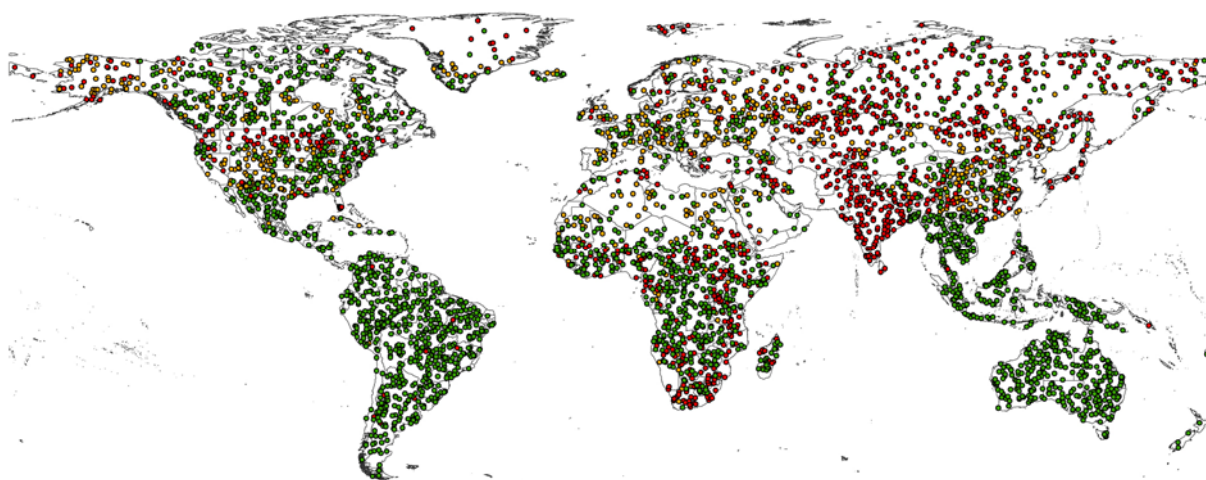


Figure 18. Validation effort achieved in the GlobCover 2009 project. Red points are points which are not described by LCCS classifiers (i.e. unusable points). Orange points were inherited from the 2005 validation exercise but were not updated in 2009. Green points represent points that were interpreted in 2009.

Points that have been interpreted in 2009 (green ones in Figure 18) can be either points already validated in 2005 and updated in 2009 (1298 points) or new points sampled and interpreted in 2009 (1103 points), as shown in Figure 19.

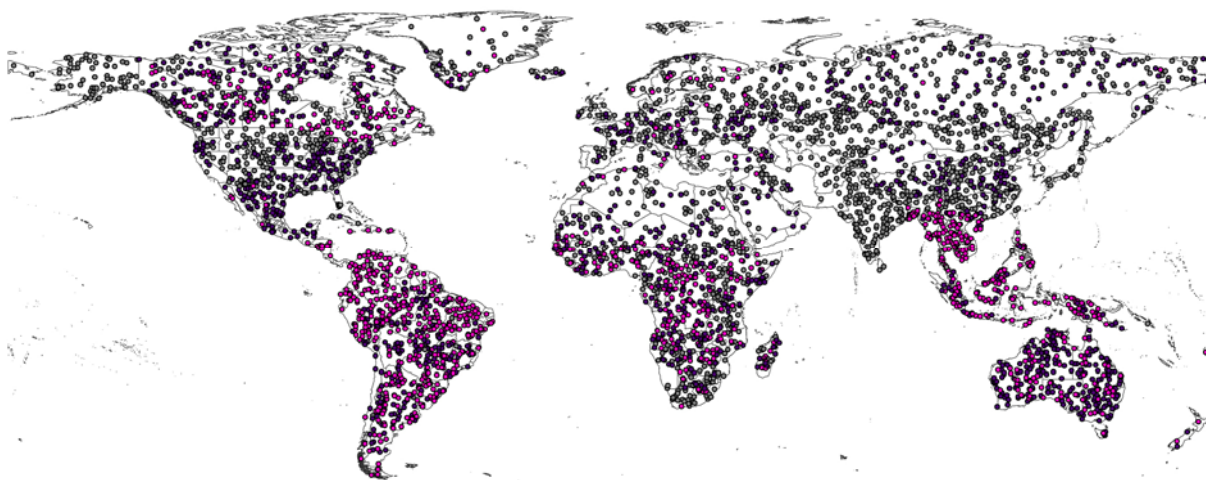


Figure 19. Distribution of points already proposed in 2005 and re-validated in 2009 (in mauve) and of new points sampled and interpreted in 2009 (rose).

Over the 3134 points for which a LCCS description is available (green and orange points in Figure 18), 1924 were described with a single land cover while 1210 points were associated with 2 or 3 land cover types. The first ones are hereafter referred to as “homogeneous” while the second ones are called “heterogeneous”.

In addition, for each point, the experts were asked to provide information about their confidence in their interpretation. Three levels were proposed: 2184 points were “certain”, 631 points were “reasonable” and 74 points were “doubtful”. This information was not provided for 245 points.

For points already proposed in 2005 and re-validated in 2009 (mauve ones in Figure 19), the experts were asked to describe a “status” and four possibilities were proposed (4.3.1.3). Over the 1298 points:

- 819 points were interpreted as unchanged and the 2005 interpretation was not improved;
- 340 points were described as changed, the 2005 interpretation being considered as correct;
- 12 points were considered as unchanged but the 2005 interpretation was improved;
- 22 points interpreted as changed while the 2005 interpretation was not the best one.

The status was not provided for 105 points. Figure 20 illustrates this distribution.

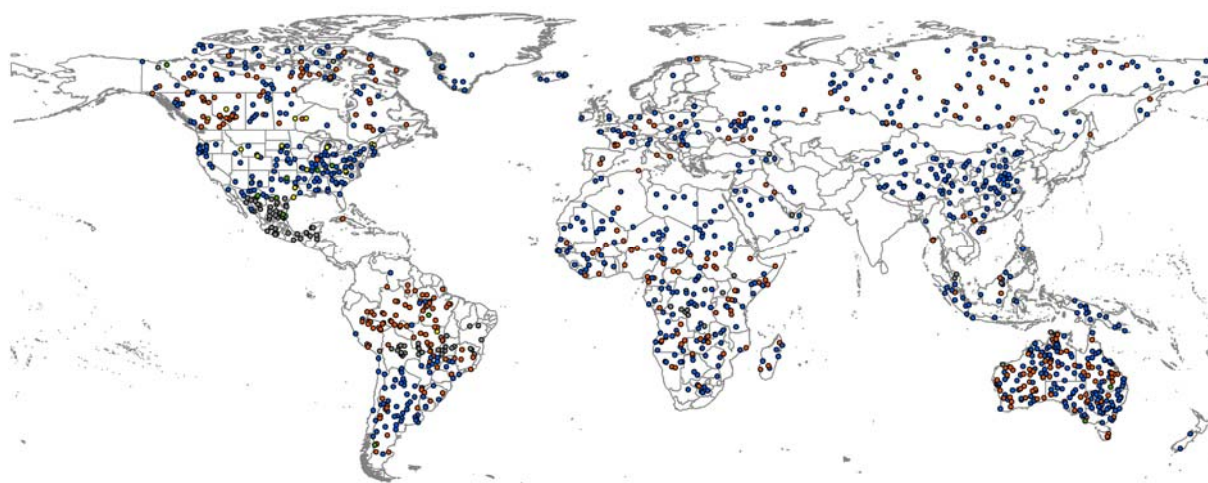


Figure 20. Status of points already proposed in 2005 and re-validated in 2009. Blue points are those described as “unchanged and non improved 2005 interpretation”. Blue points are the “unchanged land cover and not improved interpretation”; orange points are the “changed land cover and not improved interpretation”; green points are the “unchanged land cover and improved interpretation”; yellow points are the “changed land cover and improved 2005 interpretation”. In grey, no status was provided.

4.3.4.2. Contingency matrix

The contingency matrix is composed by comparing the GlobCover 2009 product with the validation dataset that is interpreted to GlobCover classes (Table 2). In some cases, the information provided by the experts was limited and not specific enough to convert the classifiers into GlobCover classes. Especially in the case of the Natural and Semi-natural terrestrial vegetation, it is essential to have a minimum number of classifiers. But, if the expert could not specify more than just “Trees”, “Woody vegetation” or “Shrubs”, the practical use of the point was almost absent. As a result, the classifiers could not be interpreted to any land cover class at all. This was the case for 192 points, affecting one or more land cover types.

Each column of the matrix represents the instances of the land cover classes according to the validation dataset while each row represents the instances in the classified land cover classes. The overall accuracy value (which is calculated by dividing the number of correctly classified samples by the total number of samples) indicates the proportion of rightly classified samples. The user’s and producer’s accuracy are also provided. These figures complement the overall accuracy figure by informing about the classification performance for each class. Finally, the sum of the samples is also

indicated for each row and column, in order to allow putting some figures in perspective. Indeed, if the sum of a row or column is less than 10, the concerned accuracy is based on too few samples to be of any use. The chance factor to have few samples by class is relatively big when class frequencies are low.

In the GlobCover 2009 validation exercise (like in the GlobCover 2005 project), the overall accuracy is not only calculated based on the diagonal cells of the matrix but also accounts for other cells which mark agreement between the product and the validation dataset. This can be fully justified by the existence of several sources of confusion in the GlobCover legend (Bicheron et al., 2008a).

A first source of confusion is the way the forests have been interpreted by the experts. The experts often did not provide the information (typically the leaf type and the leaf phenology) that allowed us to assign the points to a specific forest type. As a result, the only possibility was to assign the forest point to the class 100 of “Mixed Forest”. For this reason, it was decided to consider the validation points assigned to the class of “Mixed Forest” as being in possible agreement with all the forest classes from the GlobCover product (classes 40 to 100).

A second source of confusion lies in the mixed mapping units of the GlobCover product (classes 20, 30, 110 and 120) which include a wide range of land cover types. In the assessment of these units with the validation dataset, two scenarios should be considered:

- Agreement between the product and the validation dataset is considered only when both products show the same mixed mapping unit. This is the strict scenario;
- Agreement between the product and the validation dataset is accepted when the validation dataset gives a class that falls within the range of land cover types included in the mosaic class and complies with the dominance criteria given in the class definition. This scenario is more flexible, yet it is well defendable.

A last source of confusion lies in the division of the Cultivated and Managed land into “Irrigated or post-flooding” and “Rainfed” agriculture, which may not work out well in all situations, depending on the date of the high spatial resolution images which are available for the validation.

Considering these sources of confusions, new possibilities of agreement between the product and the validation dataset (which are different from the diagonal cells) can be foreseen. They are summarized in Table 5.

Product class	In agreement with	Validation class
11 - Post-flooding or irrigated croplands	↔	14 - Rainfed croplands
14 - Rainfed croplands	↔	11 - Post-flooding or irrigated croplands
20 - Mosaic Cropland (50-70%) / Vegetation (grassland, shrubland, forest) (20-50%)	↔	11 - Post-flooding or irrigated croplands 14 - Rainfed croplands 20 - Mosaic Cropland (50-70%) / Vegetation (grassland, shrubland, forest) (20-50%)
30 - Mosaic Vegetation (grassland, shrubland, forest) (50-70%) / Cropland (20-50%)	↔	30 - Mosaic Vegetation (grassland, shrubland, forest) (50-70%) / Cropland (20-50%) 40 - Closed to open (>15%) broadleaved evergreen and/or semi-deciduous forest (>5m) 50 - Closed (>40%) broadleaved deciduous forest (>5m)

		60 - Open (15-40%) broadleaved deciduous forest (>5m) 70 - Closed (>40%) needleleaved evergreen forest (>5m) 80 - Closed (>40%) needle-leaved deciduous forest (>5m) 90 - Open (15-40%) needleleaved deciduous or evergreen forest (>5m) 100 - Closed to open (>15%) mixed broadleaved and needleleaved forest (>5m) 130 - Closed to open (>15%) shrubland (<5m) 140 - Closed to open (>15%) grassland
110 - Mosaic Forest/Shrubland (50-70%) / Grassland (20-50%)	↔	40 - Closed to open (>15%) broadleaved evergreen and/or semi-deciduous forest (>5m) 50 - Closed (>40%) broadleaved deciduous forest (>5m) 60 - Open (15-40%) broadleaved deciduous forest (>5m) 70 - Closed (>40%) needleleaved evergreen forest (>5m) 80 - Closed (>40%) needle-leaved deciduous forest (>5m) 90 - Open (15-40%) needleleaved deciduous or evergreen forest (>5m) 100 - Closed to open (>15%) mixed broadleaved and needleleaved forest (>5m) 130 - Closed to open (>15%) shrubland (<5m)
120 - Mosaic Grassland (50-70%) / Forest/Shrubland (20-50%)	↔	140 - Closed to open (>15%) grassland
40 - Closed to open (>15%) broadleaved evergreen and/or semi-deciduous forest (>5m) 50 - Closed (>40%) broadleaved deciduous forest (>5m) 60 - Open (15-40%) broadleaved deciduous forest (>5m) 70 - Closed (>40%) needleleaved evergreen forest (>5m) 80 - Closed (>40%) needle-leaved deciduous forest (>5m) 90 - Open (15-40%) needleleaved deciduous or evergreen forest (>5m) 100 - Closed to open (>15%) mixed	↔	100 - Closed to open (>15%) mixed broadleaved and needleleaved forest (>5m)

broadleaved and needleleaved forest (>5m)		
---	--	--

Table 5. Cells of the contingency matrix that are not diagonal cells but that show agreement between the two datasets, and that are thus taken into account in the overall accuracy calculation

In the matrix representation, diagonal cells are coloured in green while cells which mark a clear agreement between the two datasets (or differently said, which represent samples that do not disagree with the classified result) are coloured in yellow. The overall accuracy calculation is based on both types of cells.

Table 6 presents the contingency matrix calculated by comparing the GlobCover 2009 land cover map with the validation dataset. This assessment has been done using the “certain” and “heterogeneous” points of the validation dataset.

		REFERENCE: VALIDATION DATASET																								SUM	User (%)	Acc.
		11	14	20	30	40	50	60	70	80	90	100	110	120	130	140	150	160	170	180	190	200	210	220				
PRODUCT: GLOBCOVER 2009 LAND COVER MAP	11	19	4	0	0	0	0	0	0	0	0	0	0	0	1	2	0	0	0	0	0	0	0	0	26	88		
	14	29	141	0	0	7	1	0	0	0	0	0	0	0	9	11	2	0	1	1	5	4	0	0	211	81		
	20	10	75	20	0	11	3	2	1	0	0	3	0	0	12	14	3	0	0	0	7	2	0	0	163	64		
	30	6	58	0	12	12	1	1	0	0	0	1	0	0	17	21	3	1	0	1	2	5	0	1	142	46		
	40	2	16	0	0	249	3	1	0	0	0	1	0	0	8	1	0	1	0	0	0	1	0	0	283	88		
	50	0	17	0	0	20	53	2	6	2	2	12	0	0	15	3	0	0	0	1	0	1	1	0	135	48		
	60	0	11	0	0	10	2	7	0	0	0	1	0	0	14	3	1	0	0	2	0	0	0	0	51	16		
	70	0	3	0	0	2	2	2	28	0	6	4	0	0	9	5	0	0	0	1	3	1	3	1	70	46		
	80	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	N/A		
	90	1	0	0	0	1	3	2	17	15	24	4	0	0	7	11	2	0	0	3	0	2	5	1	98	29		
	100	0	1	0	0	1	9	0	8	1	1	13	0	0	6	8	0	0	0	2	0	2	0	0	52	25		
	110	0	14	0	0	1	2	0	0	1	1	2	5	0	18	20	4	0	1	1	3	8	0	0	81	37		
	120	1	8	0	0	0	2	0	1	0	6	2	0	3	17	16	5	0	0	2	0	5	0	0	68	28		
	130	1	24	0	0	12	7	2	3	0	1	0	0	0	66	19	2	0	0	1	5	2	1	3	149	44		
	140	1	24	0	0	0	0	3	1	0	1	4	0	0	20	38	12	0	0	2	6	11	1	0	124	31		
	150	0	4	0	0	0	1	0	3	1	6	2	0	0	5	30	57	0	0	2	4	29	13	7	164	35		
	160	0	0	0	0	16	0	0	0	0	0	0	0	0	1	0	0	3	0	0	0	0	1	0	21	14		
	170	1	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	1	6	2	0	0	0	0	11	55		
	180	1	0	0	0	1	0	0	0	0	0	0	0	0	1	5	0	0	0	7	0	0	3	0	18	39		
	190	1	1	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	9	1	0	0	13	69		
	200	3	1	0	0	0	0	0	0	0	0	1	0	0	3	5	6	0	0	0	1	169	1	1	191	88		
	210	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	0	2	77	0	83	93		
220	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	1	4	30	36	83			
	SUM	78	402	20	12	344	89	22	68	20	48	51	5	3	229	213	97	6	8	30	45	246	110	44	2190			
	Prod. Acc (%)	74	55	100	100	76	63	36	41	5	52	75	100	100	44	35	59	50	75	23	20	69	70	68		58.0%		

Table 6. Adjusted contingency matrix that considers the GlobCover 2009 product and the “certain” and “heterogeneous” points of the validation dataset. Green cells mark diagonal cells while yellow cells represents other samples that also mark a clear agreement

Table 6 shows an overall accuracy of 58.0% based on both green and yellow cells. Considering only green cells (i.e. cells in full agreement), the overall accuracy figure is of 47.3%. In the GlobCover 2005 project, the corresponding figures were 59.9% and 48.5% respectively (Bicheron et al., 2008a).

It is worth mentioning that, in 2009, the translation of the validation database into GlobCover classes was more precise since it has taken into consideration the dominance criteria. In 2005, this dominance criterion was not specified by the experts. As a result, a point described by more than one land cover type could often be translated in 2 mosaic classes. An example of this situation is provided below, with Table 7 and Table 8 illustrating the translations.

Example: for a specific sample point, the expert described three land cover types with respective sets of classifiers (Table 7):

Land Cover 1	Land Cover 2	Land Cover 3
Natural & Semi-natural terrestrial vegetation	Cultivated & managed lands	Natural & Semi-natural terrestrial vegetation
Shrubs	Herbaceous	Trees
Open (70-60 - 20-10%)	Rainfed	Open to very open (40-20 - 10%)
5-0.3 m		>30-3 m (for Trees)
Broadleaved		Broadleaved evergreen

Table 7. Three sets of classifiers describing the land cover for a sample point

These three sets of classifiers could be directly assigned to three different GlobCover classes (Table 8):




GlobCover describing LC 1	GlobCover describing LC 2	GlobCover describing LC 3
Closed to open (>15%) (broadleaved or needle-leaved, evergreen or deciduous) shrubland (<5m)	Rainfed (cultivated and managed lands)	Closed to open (>15%) broadleaved evergreen or semi-deciduous forest (> 5m)

Table 8. GlobCover classes to which the land cover types from Table 7 could be assigned

The fact that more than one land cover type was identified for the sample point gave cause to consider mixed mapping units as well. In the GlobCover 2005 project, the dominance between the 3 described land cover types was not specified by the experts. As a result, two possible GlobCover classes were also associated with the validation point:

- Class 30: Mosaic vegetation (grassland/shrubland/forest) (50-70%) / cropland (20-50%);
- Class 20: Mosaic cropland (50-70%) / vegetation (grassland/shrubland/forest) (20-50%).

However, in the GlobCover 2009 project, information about dominance was asked to the experts. This information was taken into consideration when translating the validation database into GlobCover classes. In the example given below, assuming that the LC1 and LC2 respectively cover 80% and 20% of the validation point, only one mosaic class can be assigned to the point, which is the class 30 (Mosaic vegetation (grassland/shrubland/forest) (50-70%) / cropland (20-50%)). More generally, the integration of this dominance criterion thus reduced the possibility of agreement between the GlobCover product and the validation dataset.

 UCL Université catholique de Louvain		GLOBCOVER 2009		
		Product description and validation report		
		Page	Date	
		35	18/02/2011	

In addition, the integration of the dominance criterion in the validation dataset also reduces the number of “yellow cells” in the contingency matrix. Indeed, without considering the dominance criterion, the number of “pure” classes in agreement with the mosaic classes (20, 30, 110 and 120) increases:

- Class 20 also agrees with classes 40, 50, 60, 70, 80, 90, 100, 110 and 120;
- Class 30 also agrees with classes 11 and 14;
- Class 110 also agrees with classes 140;
- Class 120 also agrees with classes 30, 40, 50, 60, 70, 80, 90 and 100.

Without considering this dominance criterion (neither for the interpretation of the validation points nor in the contingency matrix), the overall accuracy of the GlobCover 2009 land cover map increases up to 65.2%.

In the GlobCover 2005 project, the final overall accuracy figure was derived from the contingency matrix obtained by comparing the land cover map with the “certain” and “homogeneous” of the validation dataset without considering the dominance criterion. For the sake of comparison, the corresponding contingency matrix has been calculated for the GlobCover 2009 land cover map. It is presented in Table 9.

Table 9 shows an overall accuracy of 70.7% based on both green and yellow cells for the homogeneous points. Considering only green cells (i.e. cells in full agreement), the overall accuracy figure is of 51%. In the GlobCover 2005 project, the corresponding figures were 67.6% and 54.9% respectively (Bicheron et al., 2008a). These figures reveal the greater importance of the indirect agreement (mostly related to the mosaic classes) in the 2009 overall accuracy figure than in 2005.

Bare areas, closed to open broadleaved evergreen forest and snow and ice are classes that perform the best. This is surely not surprisingly, as these classes are homogeneous, unambiguous and recognisable. We have to add though that Snow and Ice do seem to be hampering the view on the underlying land cover from time to time.

Confusions between croplands (classes 11 and 14 and to some extent, class 20) and the grassland (class 140) indicate that the identification and subsequent classification of pastures and meadows proves to be a difficult issue. In the image processing line, the pastures have been regarded as semi-natural vegetation, but some of the experts have interpreted the pastures as meadows.

Confusions between evergreen and deciduous forests (classes 40 and 50) and broadleaved and needleleaved forests (contamination errors of class 90) are also observed, indicating that the temporal information was not optimally used either by the experts when they had to describe the leaf phenology or by the classification algorithms (when the compositing periods had to be defined). This latter possibility would indicate that, even if the processing chain proved to be able to be run in a repetitive way, a specific attention should be paid to the algorithm parameters in order to possibly adjust them. The lack of SWIR channel of the MERIS sensor could also partly explain errors in forest identification.

Like in the GlobCover 2005 project, the experts identify more urban areas than the GlobCover product portrays. This could be due to the heterogeneous character of built up areas.

Classification patterns of wetlands, grasslands and shrublands show clear discrepancies with interpretations of experts. This may be due to the absence of a SWIR channel that may affect the ability to identify these land cover types on the MERIS data.

		REFERENCE: VALIDATION DATASET																								SUM	User Acc. (%)
		11	14	20	30	40	50	60	70	80	90	100	110	120	130	140	150	160	170	180	190	200	210	220			
PRODUCT: GLOBCOVER 2009 LAND COVER MAP	11	8	1	0	0	0	0	0	0	0	0	0	0	0	2	0	0	0	0	0	0	0	0	0	11	82	
	14	16	102	0	0	6	1	0	0	0	0	0	0	5	5	2	0	1	0	4	0	0	0	142	83		
	20	7	60	0	0	11	1	2	1	0	0	2	0	0	10	10	0	0	0	3	0	0	0	107	97		
	30	4	46	0	0	9	1	1	0	0	0	1	0	0	15	18	1	0	1	0	2	0	0	99	96		
	40	1	8	0	0	213	2	1	0	0	0	1	0	0	2	0	0	1	0	0	0	0	0	229	93		
	50	0	2	0	0	20	30	1	5	1	1	5	0	0	9	0	0	0	0	1	0	0	0	0	75	47	
	60	0	4	0	0	5	1	5	0	0	0	1	0	0	10	2	1	0	0	2	0	0	0	0	31	19	
	70	0	2	0	0	1	2	2	19	0	2	2	0	0	4	4	0	0	0	1	2	1	1	1	44	48	
	80	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	N/A	
	90	1	0	0	0	1	0	0	6	7	8	2	0	0	4	3	1	0	0	1	0	0	1	0	35	29	
	100	0	0	0	0	1	4	0	2	1	0	8	0	0	1	4	0	0	0	1	0	0	0	0	22	36	
	110	0	12	0	0	1	0	0	0	1	0	1	0	0	15	12	2	0	1	0	1	3	0	0	49	61	
	120	0	4	0	0	0	1	0	1	0	4	0	0	0	8	6	2	0	0	2	0	2	0	0	30	67	
	130	0	15	0	0	9	4	2	3	0	0	0	0	0	52	8	2	0	0	0	5	1	0	2	103	50	
	140	1	18	0	0	0	0	3	1	0	0	2	0	0	17	14	10	0	0	2	5	2	1	0	76	18	
	150	0	4	0	0	0	0	0	0	0	0	1	0	0	4	6	11	0	0	0	3	17	8	5	59	19	
	160	0	0	0	0	10	0	0	0	0	0	0	0	0	0	0	0	3	0	0	0	0	0	0	13	23	
	170	1	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	1	5	2	0	0	0	0	10	50	
	180	1	0	0	0	1	0	0	0	0	0	0	0	0	0	2	0	0	0	1	0	0	0	0	5	20	
	190	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	7	0	0	0	7	100	
200	1	1	0	0	0	0	0	0	0	0	1	0	0	3	4	6	0	0	0	0	0	137	0	1	154	89	
210	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	0	2	69	0	75	92		
220	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	1	4	26	32	81		
	SUM	43	279	0	0	289	47	17	38	10	15	27	0	0	159	101	38	5	7	16	30	168	84	35	1408		
	Prod. Acc (%)	72	58	N/A	N/A	77	66	35	50	10	53	78	N/A	N/A	52	38	29	60	71	6	23	82	82	74		70.7 %	

Figure 21 summarises the criteria that have been followed in the two scenarios applied in the accuracy assessment and gives the corresponding overall accuracy values.

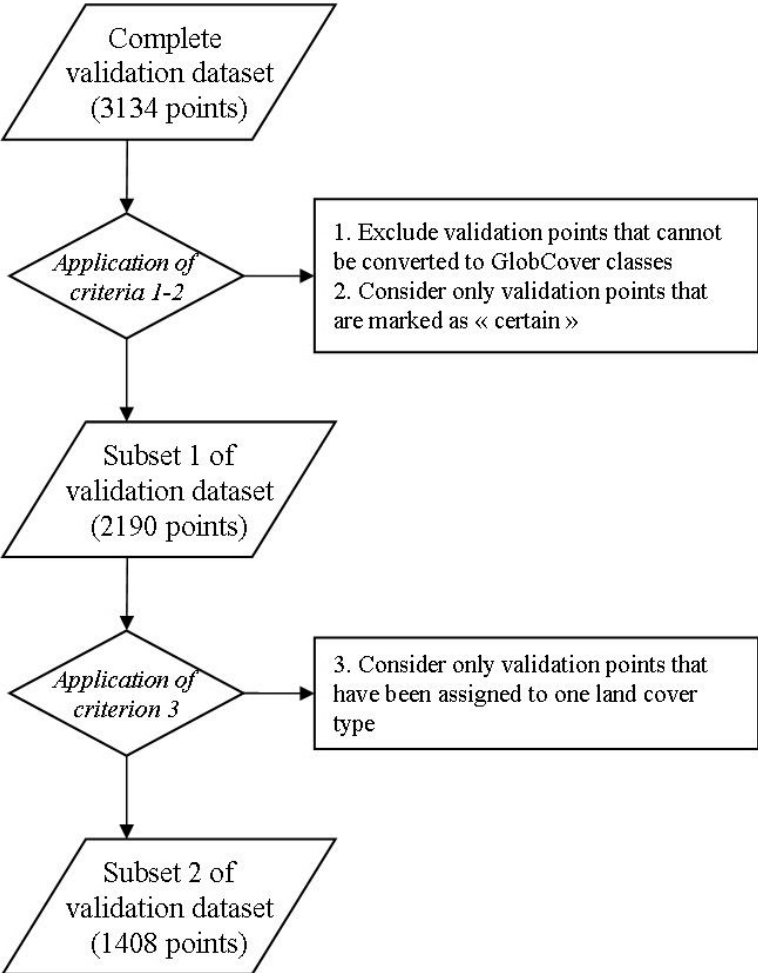
Process to eliminate uncertainty and heterogeneity from the validation dataset	Overall accuracy			
	With dominance		Without dominance	
	Full agreement	Not in disagreement mnt	In full agreement	Not in disagreement mnt
 <pre> graph TD A[/Complete validation dataset (3134 points)/] --> B{Application of criteria 1-2} B --> C[/Subset 1 of validation dataset (2190 points)/] B --> D[1. Exclude validation points that cannot be converted to GlobCover classes 2. Consider only validation points that are marked as « certain »] C --> E{Application of criterion 3} E --> F[/Subset 2 of validation dataset (1408 points)/] E --> G[3. Consider only validation points that have been assigned to one land cover type] </pre>	47.3%	58%	48%	65.2%
	51%	62.6%	51%	70.7%

Figure 21. Scheme that summarises the steps of the conducted quantitative accuracy assessment; the criteria that have been implied to generate a homogeneous reference dataset and the overall accuracies that have been computed for the concerned validation dataset. The first overall accuracy, labelled as “in full agreement” considers the diagonal cells of the matrix, the second one, labelled as “not in disagreement”, also considers the points that are not in clear disagreement with the product.

The second step after having established the overall accuracy figures is to test if they meets the quality requirements previously defined (Bicheron et al., 2008a): to be 95% sure that the accuracy would be 70%. For a binomial distribution, the confidence interval can be obtained from the following expression:

$$\bar{p} \pm z_{\alpha} \sqrt{\frac{\bar{p}(1 - \bar{p})}{n} + \frac{1}{(2n)}}$$

with z_{α} : the z-value for confidence level α

n : the sample size

\bar{p} : the accuracy estimate

For the sake of comparison with GlobCover 2005, the overall accuracy figure obtained using the set of 1408 “certain” and “homogeneous” points without considering the dominance criterion is used. Using equation 1 and different confidence levels, Table 10 shows the corresponding confidence intervals.

Confidence level	z-value	Confidence interval for the set of 1408 homogeneous points	Confidence interval for the set of 2190 heterogeneous points
90%	± 1.647	0.7 ± 0.020 (i.e. from 68.0% to 72.0%)	0.7 ± 0.016 (i.e. from 68.4% to 71.6%)
95%	± 1.960	0.7 ± 0.024 (i.e. from 67.6% to 72.4%)	0.7 ± 0.019 (i.e. from 68.1% to 71.9%)
99%	± 2.586	0.7 ± 0.032 (i.e. from 66.8% to 73.2%)	0.7 ± 0.026 (i.e. from 67.4% to 72.6%)
99.9%	± 3.290	0.7 ± 0.041 (i.e. from 65.9% to 74.1%)	0.7 ± 0.032 (i.e. from 66.8% to 73.2%)

Table 10. Confidence intervals around an accuracy of 70% obtained for different confidence levels

Table 9 reveals that the initial hypothesis has to be rejected when the dominance criterion is taken into consideration. When this is not the case, the overall accuracy figure obtained with the set of 1408 homogeneous point satisfies the hypothesis. This was also the case in the GlobCover 2005 project.

4.3.4.3. Accuracy corrected for surface area

The previous accuracy statements were derived with equal weighting for each of the stratified randomly sampled reference points. Classes that cover only small surfaces are overrepresented in the sample set and classes that cover large surfaces may have been underrepresented in the set. To account for the stratification, the overall accuracy values were weighted by the area proportions of various land cover classes. The surfaces of the various land cover classes were determined based on the GlobCover 2009 product itself, projected in an equal area projection (Figure 15).

User’s accuracy values were taken from the contingency matrices and used to compute how many pixels per class have been classified in agreement with the assessment of the experts. The overall accuracy weighted for the surface is calculated using the following equation:

$$Global_accuracy = \frac{\sum_{i=1}^{i=n} s_i * ua_i}{\sum_{i=1}^{i=n} s_i}$$

With s_i : the surface of land cover type i

ua_i : the user’s accuracy of land cover type i

n : the total number of land cover classes of the product.

Table 11 presents the overall accuracy figures weighted by surface, for the overall accuracy figures obtained with the subsets 1 (“heterogeneous” and “certain” points) and 2 (“homogeneous” and “certain” points) of the validation dataset (see Figure 21) and when accounting for the dominance criterion or not.

	Accounting for dominance	Without accounting for dominance
Subset 1 (2190 points)	61.34%	67.5%
Subset 2 (1408 points)	59.9%	66.95%

Table 11. Accuracy of the GlobCover 2009 land cover map based on surface area figures per class and the user's accuracy.

It has to be noted that, when it is weighted by surface, the overall accuracy figure obtained using the subset 1 without accounting for dominance satisfies the hypothesis of 70% accuracy with 99% confidence.

4.4. Qualitative assessment

As already noted in the GlobCover 2005 validation report (Bicheron et al., 2008a), the quality of the GlobCover product is highly dependent on the number of valid observations available as input and on the reference land cover database used for the labelling process.

In the GlobCover 2009 project, the reference database was the GlobCover 2005 land cover map (V2.2 as released on the ESA IONIA website). Since the quality of the GlobCover 2005 land cover map varied according to regions (Bicheron et al., 2008a), these variations are also visible in the GlobCover 2009 land cover map. Therefore, Europe presents higher thematic details than the North-African region (Figure 22).

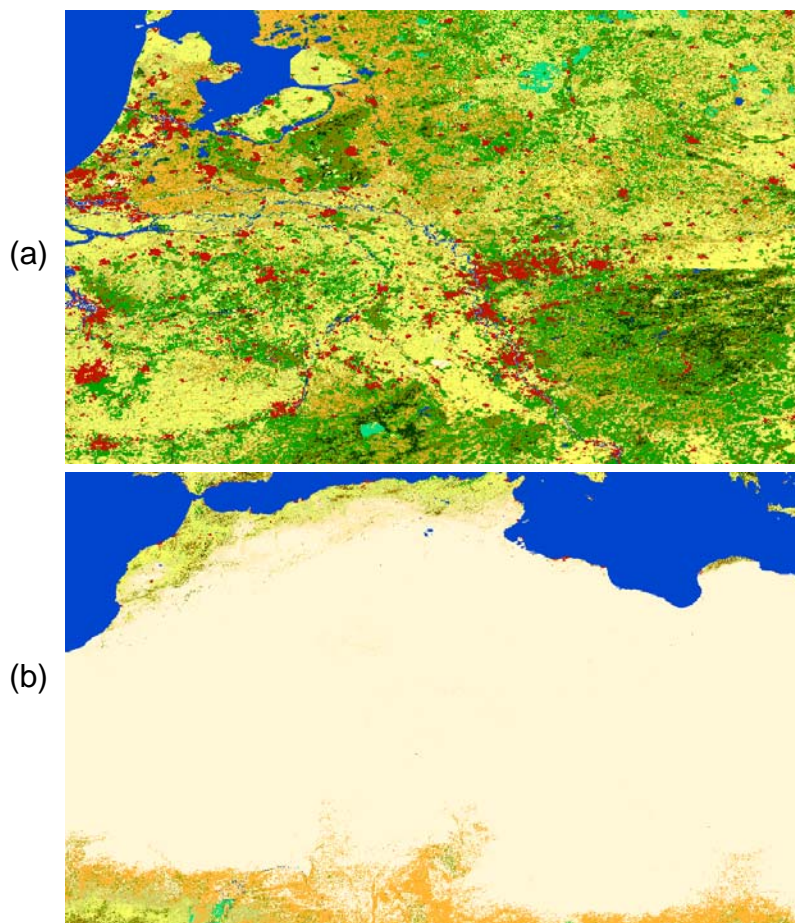


Figure 22. GlobCover 2009 product over Belgium, the Netherlands and Germany (a), compared with the North African region (b). The high level of spatial patterns and details over Europe which was inherited from the CLC map in the GlobCover 2005 product is still present in the GlobCover 2009 land cover map.

On the other hand, the number of valid observations is a restrictive factor. The spatial coverage of the MERIS data clearly determines the quality of the temporal mosaics and therefore, of the land cover map. For instance, over some parts of Canada, the number of MERIS valid observations available for the GlobCover 2009 project was reduced in comparison with the 2005 project. Figure 23 illustrates that the land cover variability that was observed in 2005 is now lost, thus highlighting the importance and impact of valid observations in the product.

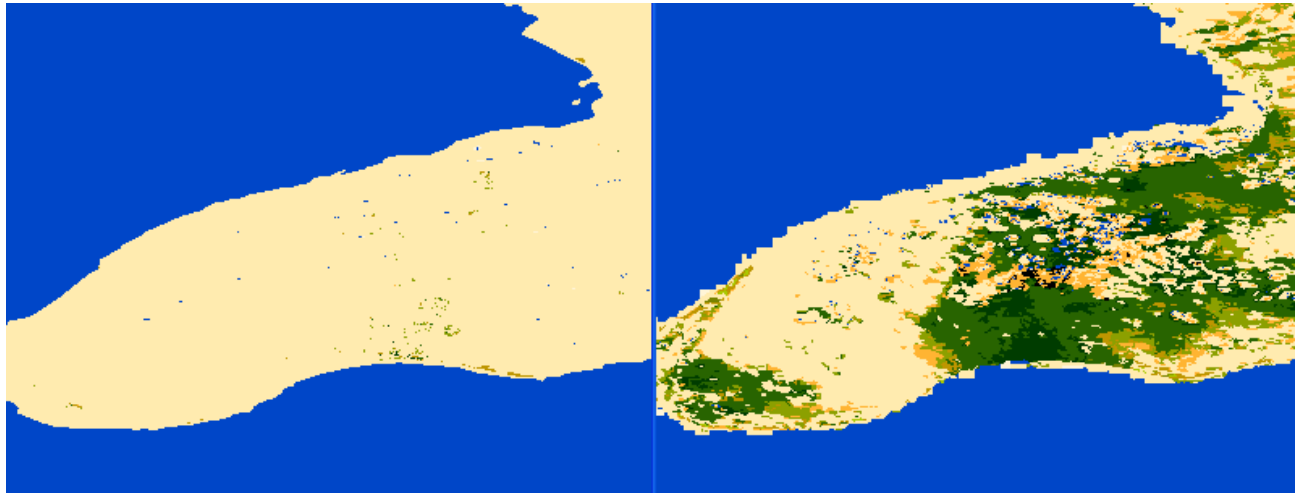


Figure 23. GlobCover 2009 (left) with reduced land cover classes variability (in this case), when compared to the previous 2005 map (right).

Another interesting observation is related to the classification of deforestation patterns. Intensive cloud cover and thick aerosol effects can impact the classification process in tropical areas. Figure 24 presents an example from Brazil, where unreal deforestation patterns were visible in the previous 2005 product. In the GlobCover 2009 land cover map, those effects are reduced and more forest is present on the map. As it can be seen from the Google Earth imagery, the central area was always forest and deforestation never reached it. So, in this case, the new map looks closer to reality, although some unreal effects remain present.

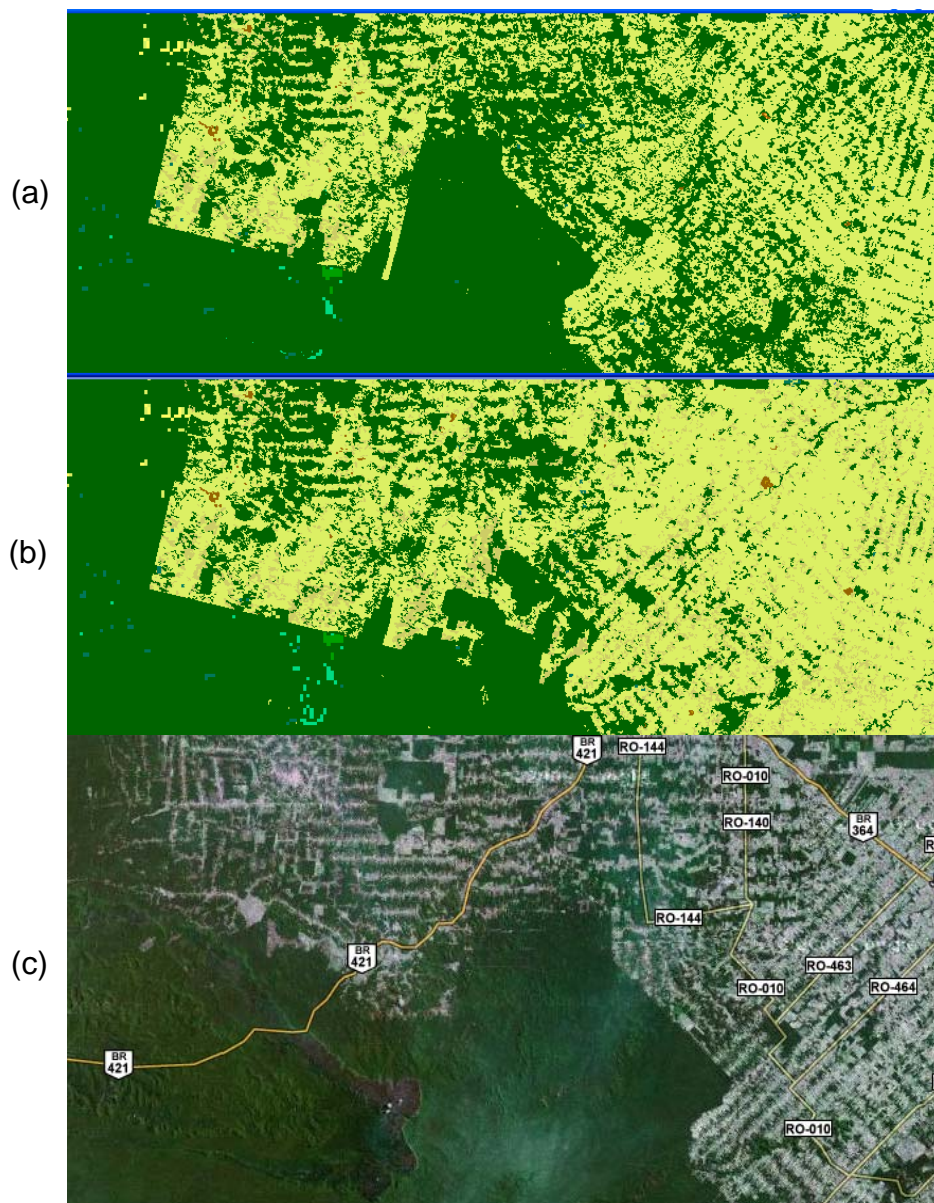


Figure 24. GlobCover 2009 (top), GlobCover 2005 (middle) and GoogleEarth (bottom). In the center of the area, an unreal deforestation pattern which exists in the GlobCover 2005 product can be seen. It is not present in the 2009 land cover map.

As for the classification of urban areas, some rather “blocky” patterns appear in the product in some areas, as shown in Figure 25. However, in general and apart from some specific problematic cases, the urban classification shows some reasonable consistency with the previous version.

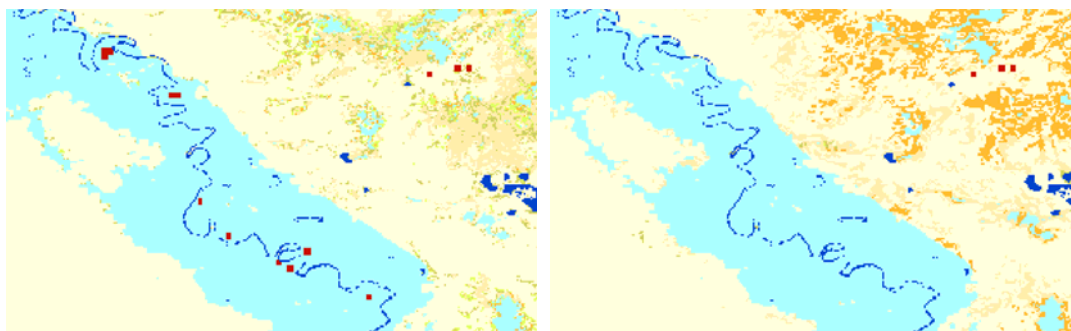


Figure 25. Example of 'blocky' urban spots on the GlobCover 2009 (left), which were not present in the 2005 product (right).

Similarly with the GlobCover 2005 land cover map, the SWBD was used to improve the water bodies' delineation in the GlobCover classification. As a result, the water bodies are delineated with a greater spatial accuracy than the MERIS pixel size and the water classification consistency between the GlobCover 2005 and 2009 land cover maps is high (Figure 26).

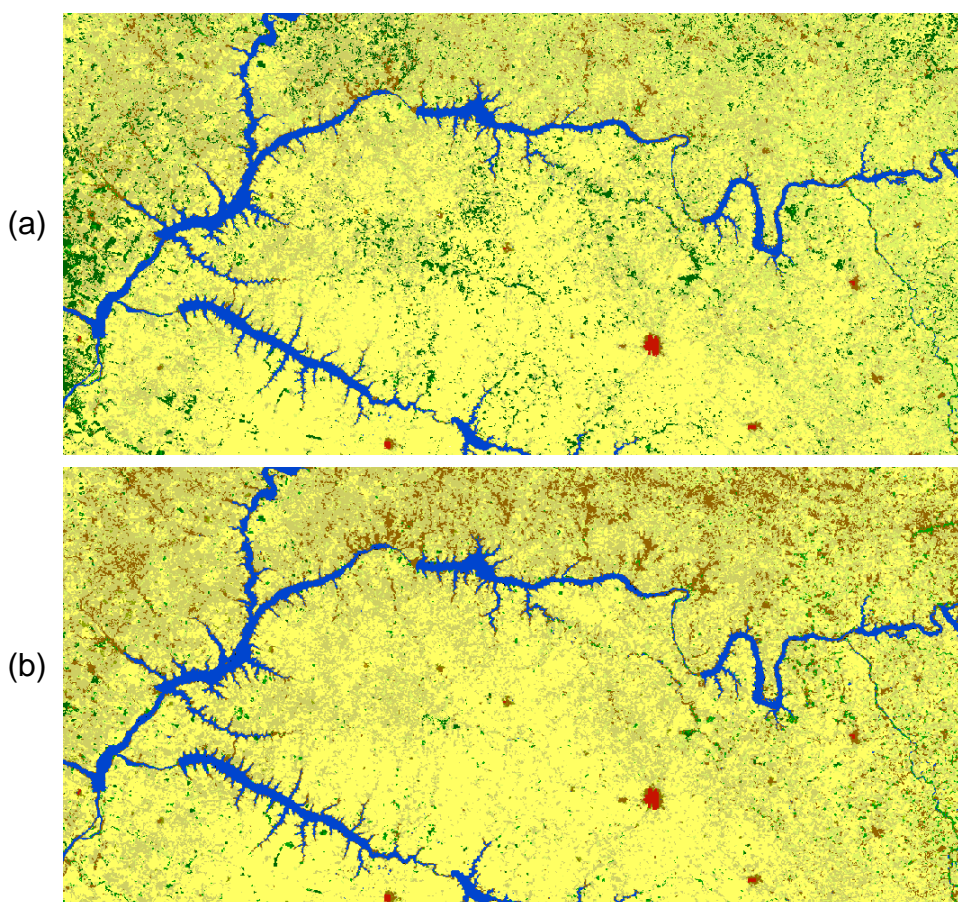





Figure 26. Delineation of the Parana river and of its tributaries in Brazil in the GlobCover 2009 (top) and 2005 (bottom) land cover map

		GLOBCOVER 2009		
		Product description and validation report		
		Page	Date	
		44	18/02/2011	

4.5. Identified issues

The issues identified in the GlobCover 2009 land cover product are similar to those observed in the GlobCover 2005 product. They mainly concern:

(i) the relevance of the GlobCover legend

Amongst the global classes, the “closed needle-leaved deciduous forest” (previously coded as the class 80) does not appear in the final product. In addition, some land cover classes (such as the different forest classes or the “artificial surfaces and associated areas”) are not mapped with the same consistency at the global scale.

(ii) inconsistencies due the lack of data

There are some regions of the world (e.g. some areas in Amazonia and in the Northern regions) where data coverage is limited (Figure 7). The limited number of available data has consequences on the quality of the land surface reflectance mosaics and therefore, it can have several effects on the land cover product.

In areas of very low data coverage (about 5% of the world continental areas), the pixel values were derived from the reference land cover map leading to possible discontinuity in the classification. In this GlobCover 2009 project, the reference land cover map consisted of the GlobCover 2005 land cover map (V2.2).

A flag indicating whether the reference dataset has been used instead of the output of the GlobCover classification scheme has been documented in the CLA_QL file and it is strongly recommended that users consult this information.

(iii) forest estimation

The lack of SWIR channel in the MERIS sensor contributes to misclassifications in tropical forests. The case of the flooded forests (classes 160 and 170) is particularly problematic; their identification is thereby mainly resulting from the reference dataset. In addition, the identification of leaf type and phenology also proved to be an issue.

(iv) lakes and rivers

It has to be kept in mind that the identification of water bodies is largely based on the SWBD (see section 2.2). It should furthermore be noted that the SWBD is based on year 2000 data and is limited on -60° and +60° of latitude.

(v) classes with a limited spatial extent

Sometimes, a lower accuracy for land cover classes with small spatial extent, e.g. “urban areas” or “flooded lands” has been noted.

(vi) thematic errors

It’s noteworthy that, from the end-users point of view, the GlobCover land cover map contains a significant amount of mosaic classes, which may limit the thematic sharpness of the GlobCover product and its relevancy to derive very specific products.

4.6. Comparison with the GlobCover 2005 map

The land cover classes distribution is highly similar to the one associated with the GlobCover 2005 land cover map (Bicheron et al., 2008a), as illustrated in Figure 27.

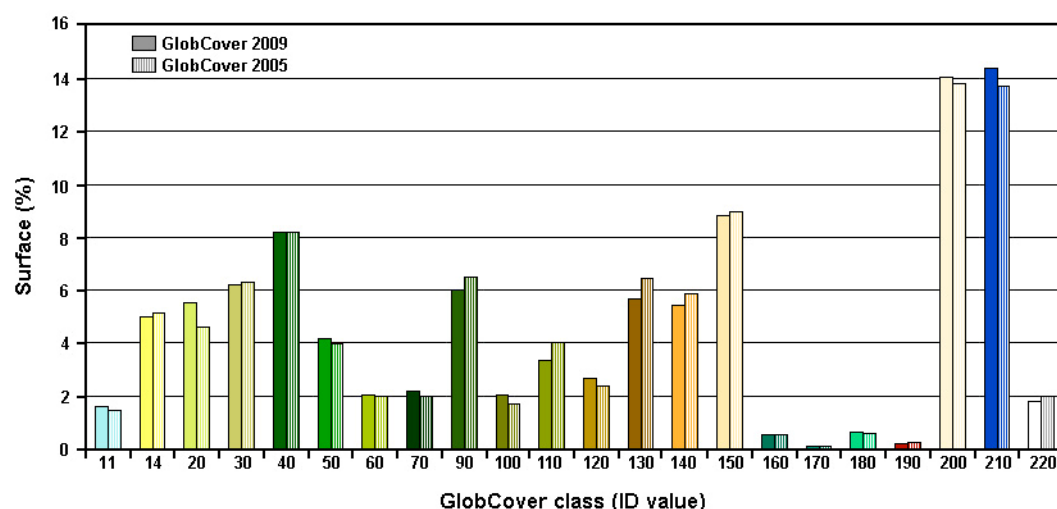


Figure 27. Comparison of classes proportions between GlobCover 2005 and 2009 land cover products

However, even if the distributions look similar between the two land cover maps, significant differences are observed in the classes spatial distributions, as illustrated in Figure 28.

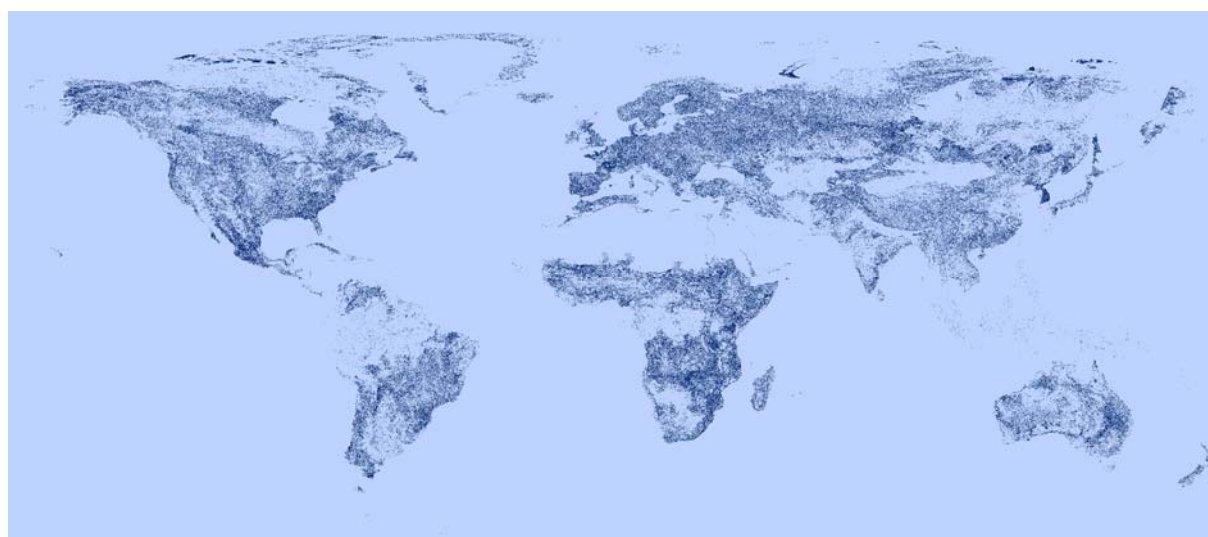


Figure 28. Spatial distribution of pixels which are not identically classified in the GlobCover 2005 and 2009 land cover products

Pixels that are differently classified in the GlobCover 2005 and 2009 land cover maps are too numerous to be representative only for land cover changes. They should rather be interpreted like classification instabilities. It has to be noted that these instabilities do not similarly affect all land cover classes, as shown in Figure 29. Most affected classes are mosaic classes (20, 30, 110 and 120) and forest classes (50, 60, 70 and 100). The class of “Closed to open (>15%) vegetation (grassland, shrubland, woody vegetation) on regularly flooded or waterlogged soil - Fresh, brackish or saline water” (180) also shows significant instability, but this could be related to its implicit mosaic character (since it includes grassland, shrubland and woody vegetation). The “grassland” (140) and “sparse vegetation” (150) classes also show a higher rate of variability, which is coherent with their lower classification accuracy (Table 6).

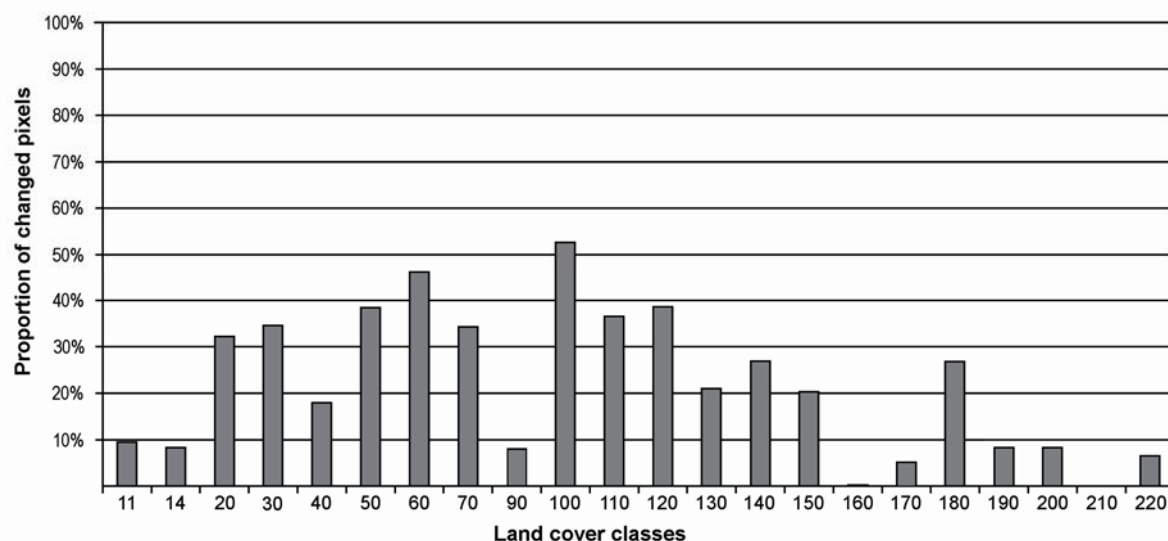


Figure 29. Proportion of pixels, for each class, which are not classified in the same manner between the two GlobCover maps

Finally, Figure 30 presents, on a class-by-class basis, the “classification trajectories” (i.e. the instabilities in classifications) of the pixels which have not been associated with the same classes in 2009 than in 2005. It reveals that most changes occur between classes which are thematically close. For instance, more than 80% of instable “mixed forest” pixels (i.e. pixels that were classified in class 100 in 2009 but not in 2005) were associated in 2005 with another forest class. This can be observed both for cultivated areas and for natural vegetation.

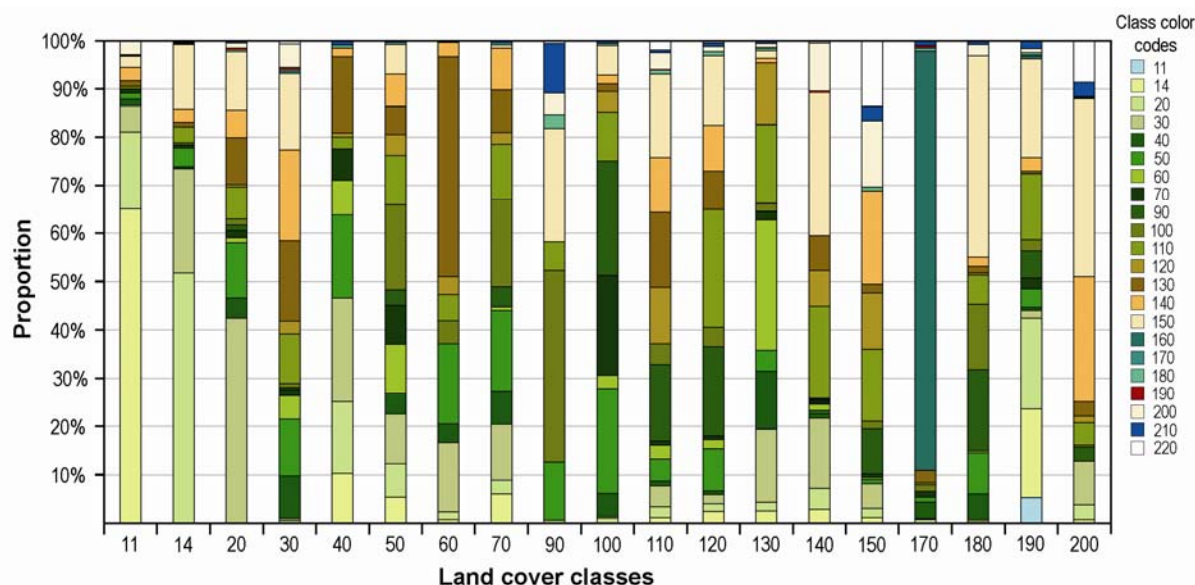





Figure 30. Classification trajectories of the pixels which are not identically classified in the GlobCover 2005 and 2009 land cover products

 UCL Université catholique de Louvain		GLOBCOVER 2009		
		Product description and validation report		
		Page	Date	
		47	18/02/2011	

5. Recommendations - Discussion - Conclusion

This document reports on the quality of the MERIS FR global mosaics and on the accuracy of the first 300-m land cover product delivered for the year 2009 in the course of this GlobCover 2009 project.

This project comes after the GlobCover 2005 project and aims at demonstrating the capacity of the developed automated classification system to produce global land cover maps on a yearly basis. It makes use of the same methodology and legend than the ones defined in the framework of the GlobCover 2005 project:

- An automated pre-processing and classification approach based on ENVISAT's MERIS FRS time series;
- A 22-classes legend which is defined according to LCCS.

The GlobCover 2009 deliverables clearly demonstrate the operational service provided by the automated processing chain set up by the GlobCover consortium.

First deliverables are the land surface reflectance mosaics. The MERIS FR ortho-rectification led to a final geometric accuracy far below the half-pixel requirement. In addition, one also should consider the huge amount of data that has been automatically and rapidly processed. Indeed, a global coverage of MERIS FR acquisition was also operationally set up.




However, the GlobCover dataset for the 12 months covering the year 2009 missed the minimum number of valid observations in some areas. These data gaps required to supplement the GlobCover 2009 land cover map by the GlobCover 2005 product for an area corresponding to **5%** of inland surfaces.

From the classification point of view, the concept of a global Land Cover service operational at global scale requested by ESA has been demonstrated. As a result, this GlobCover 2009 land cover map is a significant step forward since **a product related to the year 2009 has been delivered in the course of the following year.**




An independent validation of the 22-classes land cover product was also carried out to provide a quantitative estimate of its thematic accuracy. Thanks to a set of 14 land cover experts coming from all continents, a reference dataset of more than 3000 points globally distributed was compiled based on the LCCS classifiers, making them reusable. To this end, the validation tool developed in the framework of the GlobCover 2005 project was improved in order to (i) make it available on-line and (ii) allow the updating of information.

The overall accuracy weighted by the class area reaches **67.5%** using 2190 points globally distributed and including homogeneous and heterogeneous landscapes. This accuracy is slightly lower than that of GlobCover 2005 product. This can be due to the fact that, in this case, the dominance between the different land cover types was taken into account when interpreting the mosaic classes. This criterion was not considered in 2005 since it was not included in the validation dataset.

This overall accuracy figure must be balanced by the fact that the GlobCover map quality varies according to the thematic class and to the region of interest. Looking at the number of valid observations available over a region gives a first indication about the input data quality and the expected classification reliability. In particular, land cover classes such as bare areas, rainfed and irrigated croplands, closed broadleaved evergreen forest, water bodies and snow were found quite accurately mapped. On the other hand, classes such as urban areas, sparse vegetation and herbaceous vegetation can be affected by errors.

		GLOBCOVER 2009		
		Product description and validation report		
		Page	Date	
		48	18/02/2011	

The limitation of the GlobCover product can mainly be explained by several strategic choices. Only MERIS data can be used, always missing the critical SWIR band for the flooded patterns. The automation of the interpretation chain requires relying for the class labelling on the already existing but sometimes coarser land cover products. From the end-users point of view, too many mosaic classes were finally mapped limiting the thematic sharpness of the GlobCover product and its relevancy to derive very specific products. Last but not least, it is worth mentioning that **the GlobCover 2009 land cover map cannot be used for any change detection application**. In particular, **the direct comparison with the previous GlobCover 2005 product cannot be done** since it cannot guarantee accurate land cover change quantification. Indeed, the accuracy of any post-classification comparison is known to be totally dependent on the accuracy of the initial classifications (Coppin et al., 2004). The GlobCover maps (both 2005 and 2009) are provided as they are with a quantified error. Their accuracy surely prevents any consistent comparison with older maps to depict the change area since the change rate will always be much lower than the classification errors, thus hampering any relevant use for change mapping.

		GLOBCOVER 2009		
		Product description and validation report		
		Page	Date	
		49	18/02/2011	

6. Data policy

The GlobCover products have been processed by ESA and by the Université catholique de Louvain. They are made available to the public by ESA. You may use the GlobCover land cover map for educational and/or scientific purposes, without any fee on the condition that you credit ESA and the Université catholique de Louvain as the source of the GlobCover products:

Copyright notice: © ESA 2010 and UCLouvain

Should you write any scientific publication on the results of research activities that use GlobCover products as input, you shall acknowledge the ESA GlobCover 2009 Project in the text of the publication and provide ESA with an electronic copy of the publication (due@esa.int).

If you wish to use the GlobCover 2009 products in advertising or in any commercial promotion, you shall acknowledge the ESA GlobCover 2009 Project and you must submit the layout to ESA for approval beforehand (due@esa.int).

Appendix I – Surface reflectance mosaics: data format and content

Nomenclature

The surface reflectances mosaics have the following nomenclature:

GLOBCOVER-L3_MOSAIC_[YEAR]_V2.3_[PERIOD]_H[XX]V[YY].hdf.gz

The [YEAR] indicates the year over which the composite has been computed (2009).

The [PERIOD] indicates the compositing period, either bimonthly (shortened by “BIMONTH_x” where x varies from 1 to 6) or annual (mentioned by “ANNUAL”).

[XX] and [YY] indicate the tile location, [XX] and [YY] referring to the horizontal (from 0 to 71) and the vertical (0 to 35) positions, respectively. See Figure 6 inside the document for the tiling scheme.




Data format and content of surface reflectance mosaics

The surface reflectance products are available for downloading by tiles and by compositing period. The following **bands** are included in the composite products of GlobCover 2009:

	Number of bands	Bands list
Bimonthly	7	MEAN_3, MEAN_5, MEAN_7, MEAN_14, NMOD, SM, NDVI
Annual	16	MEAN_1, MEAN_2, MEAN_3, MEAN_4, MEAN_5, MEAN_6, MEAN_7, MEAN_8, MEAN_9, MEAN_10, MEAN_12, MEAN_13, MEAN_14, NMOD, SM, NDVI

The bimonthly and annual surface reflectance mosaics are available in the **Hierarchical Data Format-EOS2 (HDF)**. Below there is a short description of the bands:

Band name	Description	Precision	Range
SM	Status Map containing 0: LAND: No (cloud, shadow, cloud edge) and land flag 1: FLOODED (L1b_landocean or (not L1b_landocean and alt>-50m)) and not land flag and no (cloud, shadow, cloud edge) 2: SUSPECT (cloud shadow or edge) 3 : CLOUD (cloud flag) 4: WATER (not L1b_landocean and not land flag) 5: SNOW (snow flag) 6: INVALID	None	[0 6]
NMOD	Number of valid observations in the temporal synthesis. ‘Valid’ means that the observation has the same status as that given in the status map.	1	[0 255]
NDVI	Normalized Difference Vegetation Index	4*10e-3	[-.1 0.9] x 250

		GLOBCOVER 2009 Product description and validation report		
		Page	Date	
		51	18/02/2011	




			+25
MEAN_1	Normalized reflectance for band 1	$5 \cdot 10^{-4}$	[0 1.2]
MEAN_2	Normalized reflectance for band 2	$5 \cdot 10^{-4}$	[0 1.2]
...
MEAN_14	Normalized reflectance for band 14	$5 \cdot 10^{-4}$	[0 1.2]

The flags used in the composite are derived from daily reflectance status described below:

<i>Parameter</i>	<i>Description</i>
L1b.land_ocean	MERIS FRS original land flag: 'Land'=1 or 'Water'=0
land_flag	land flag from Land/Water – Water/Land reclassification: 'Flooded'=0 or 'Land'=1
cloud_flag	cloud flag computed in Cloud processing
cloud_shadow	cloud shadow flag from this module
cloud_edge_flag	cloud edge computed in cloud processing
snow_flag	snow flag computed in cloud processing

Appendix II – LCCS & the GlobCover legend

Value	GlobCover legend	LCCS Label	LCCS Entry	
11	Post-flooding or irrigated croplands (or aquatic)	Irrigated tree crops // Irrigated shrub crops // Irrigated herbaceous crops // Post-flooding cultivation of herbaceous crops	Cultivated Terrestrial Areas and Managed Lands	A11
14	Rainfed croplands	Rainfed shrub crops // Rainfed tree crops // Rainfed herbaceous crops		
20	Mosaic cropland (50-70%) / vegetation (20-50%)	Cultivated and managed terrestrial areas / Natural and semi-natural primarily terrestrial vegetation		
30	Mosaic vegetation (50-70%) / cropland (20-50%)	Natural and semi-natural primarily terrestrial vegetation / Cultivated and managed terrestrial areas		
40	Closed to open (>15%) broadleaved evergreen or semi-deciduous forest (> 5m)	Broadleaved evergreen closed to open trees // Semi-deciduous closed to open trees	Woody - Trees	A12 Natural and Semi-natural Terrestrial Vegetation
50	Closed (>40%) broadleaved deciduous forest (>5m)	Broadleaved deciduous closed to open (100-40%) trees		
60	Open (15-40%) broadleaved deciduous forest/woodland (>5m)	Broadleaved deciduous (40-(20-10)%) woodland		
70	Closed (>40%) needleleaved evergreen forest (>5m)	Needleleaved evergreen closed to open (100-40%) trees		
90	Open (15-40%) needleleaved deciduous or evergreen forest (>5m)	Needleleaved evergreen (40-(20-10)%) woodland // Needleleaved deciduous (40-(20-10)%) woodland		
100	Closed to open (>15%) mixed broadleaved and needleleaved forest (>5m)	Broadleaved closed to open trees / Needleleaved closed to open trees		
110	Mosaic forest or shrubland (50-70%) / grassland (20-50%)	Closed to open trees / Closed to open shrubland (thicket) // Herbaceous closed to open vegetation		
120	Mosaic grassland (50-70%) / forest or shrubland (20-50%)	Closed to open shrubland (thicket) // Herbaceous closed to open vegetation / Closed to open trees		
130	Closed to open (>15%) (broadleaved or needleleaved, evergreen or deciduous) shrubland (<5m)	Broadleaved closed to open shrubland (thicket)	Shrub	
140	Closed to open (>15%) herbaceous vegetation (grassland, savannas or lichens/mosses)	Herbaceous closed to very open vegetation // Closed to open lichens/mosses	Herba ceous	
150	Sparse (<15%) vegetation	Sparse trees // Herbaceous sparse vegetation // Sparse shrubs		

 UCL Université catholique de Louvain		GLOBCOVER 2009		
		Product description and validation report		
		Page	Date	
		53	18/02/2011	

160	Closed to open (>15%) broadleaved forest regularly flooded (semi-permanently or temporarily) - Fresh or brackish water	Closed to open (100-40%) broadleaved trees on temporarily flooded land, water quality: fresh water // Closed to open (100-40%) broadleaved trees on permanently flooded land, water quality: fresh water	A24 Natural and Seminal Aquatic Vegetation
170	Closed (>40%) broadleaved forest or shrubland permanently flooded - Saline or brackish water	Closed to open (100-40%) broadleaved trees on permanently flooded land (with daily variations), water quality: saline water // Closed to open (100-40%) broadleaved trees on permanently flooded land (with daily variations), water quality: brackish water // Closed to open (100-40%) semi-deciduous shrubland on permanently flooded land (with daily variations), water quality: saline water // Closed to open (100-40%) semi-deciduous shrubland on permanently flooded land (with daily variations), water quality: brackish water	
180	Closed to open (>15%) grassland or woody vegetation on regularly flooded or waterlogged soil - Fresh, brackish or saline water	Closed to open shrubs // Closed to open herbaceous vegetation	
190	Artificial surfaces and associated areas (Urban areas >50%)	Artificial surfaces and associated areas	B15 Artificial Surfaces
200	Bare areas	Bare areas	B16 Bare Areas
210	Water bodies	Natural water bodies // Artificial water bodies	B28 Inland Waterbodies, snow and ice
220	Permanent snow and ice	Artificial perennial snow // Artificial perennial ice // Perennial snow // Perennial ice	