GLOBCORINE 2009

Description and Validation Report

Milestone	Final meeting
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Distribution	ESA : Olivier Arino, Vasileios Kalogirou

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Acronyms

CLC	: Corine Land Cover
EEA	: European Environmental Agency
ENVISAT	: European Space Agency Environmental Satellite
ESA	: European Space Agency
FRS	: Full Resolution Full Swath
LC	: Land Cover
LCCS	: Land Cover Classification System
MC	: Mean Compositing
MERIS	: Medium Resolution Imaging Spectrometer Instrument (http://envisat.esa.int)
ROI	: Region Of Interest
SRTM	: Shuttle Radar Topography Mission
SWBD	: SRTM Water Body Dataset
UN	: United Nations

Applicable documents and references

Applicable documents

[AP-1] GLOBCORINE 2005, Description and validation report, November 2009 (http://ionia1.esrin.esa.int/globcorine)

[AP-2] GLOBCORINE, Technical Specification, 2.2.

[AP-3] GLOBCOVER, GlobCover Validation Report I2.1, December 2008 (http://ionia1.esrin.esa.int/globcorine)

[AP-4] SRTM Water Body Data Product Specific Guidance, v 2.0, March 12 2003 (http://edc.usgs.gov/products/elevation/swbd.html)

Reference

[RD-1] European Environment Agency. 2006. Land accounts for Europe 1990-2000, EEA Report No 11/2006 prepared by Haines-Young, R. and Weber, J.-L. (http://reports.eea.europa.eu/eea_report_2006_11/en)

[RD-2] Vancutsem, C., Bicheron, P., Cayrol, P. and Defourny, P. 2007. Performance assessment of three compositing strategies to process global ENVISAT MERIS time series, *Canadian Journal of Remote Sensing*, 33, 492-502.

[RD-3] Strahler, A.H., Boschetti, L., Foody, G.M., Friedl, M.A., Hansen, M.A., Mayaux, P., Morisette, J.T., Stehman, S.V. and Woodcock, C.E. 2006. Global Land Cover Validation: recommendations for evaluation and accuracy assessment of global land cover maps, Office for Official Publications of the European Communities, Luxembourg.

1. General introduction

The GlobCorine project, which was initiated by the European Space Agency (ESA), focuses on the production of a land cover map dedicated to the pan-European continent and driven by the European Environmental Agency (EEA) recommendations and needs. The GlobCorine project aims to address this issue by making the full use of the potential of the ENVISAT's Medium Resolution Imaging Spectrometer Instrument (MERIS) Full Resolution Full Swath (FRS) time series and by further developing the GlobCover classification approach. With regard to this latter concern, the GlobCover classification module has to be adjusted in order to produce a land cover map as compatible as possible with the Corine Land Cover (CLC) aggregated typology which is more land use oriented than the GlobCover legend.

A first GlobCorine land cover map (hereafter referred to as "GlobCorine 2005 map") was produced based on MERIS FRS time series from December 2004 until June 2006. It was made available on the 6th May 2010 through the following website: http://ionia1.esrin.esa.int/globcorine .

In 2010, a "GlobCorine 2009 map" has been generated using MERIS FRS time series from 2009, with the aim of demonstrating the capacity of the developed automated classification system to produce continental land cover maps on a yearly basis.

This document describes the GlobCorine 2009 product, as it is released to the users. It is structured as follows:

- A presentation of the GlobCorine 2009 land cover product is provided in section 2.
- A quantitative validation of the GlobCorine 2009 land cover product is proposed in section 3.
- The GlobCorine 2009 land cover product is discussed and general recommendations are reported in section 4.

2. Description of the land cover product

2.1. Data coverage

The GlobCorine 2009 land cover map has been generated using MERIS FRS time series over the period spanning the entire year 2009 (1st January to 31st December). The MERIS FRS time series were pre-processed at level 1C (i.e. calibrated top of atmosphere gridded surface reflectances) and organized on a 5° by 5° tiling without any overlap. The product covers the European continent extended to the Mediterranean basin, as shown in Figure 1.

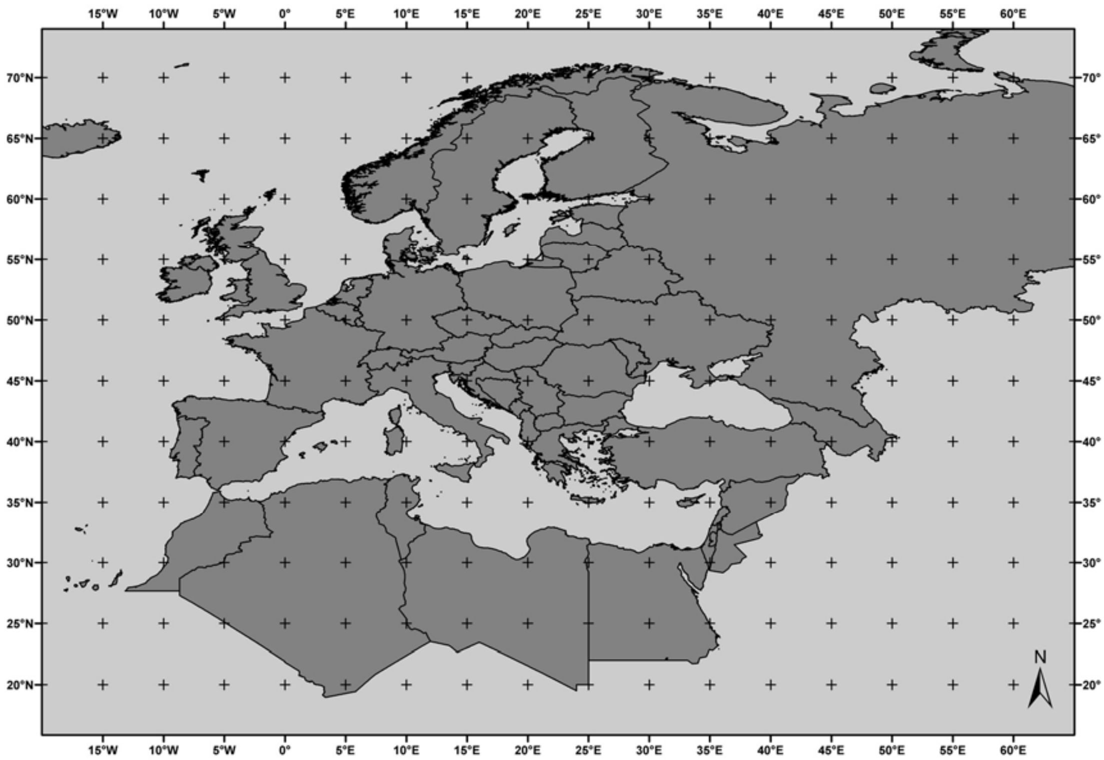

Figure 1: Pan-European extent of the GlobCorine 2009 land cover map

The very first challenge of the GlobCorine project was the continental acquisition of a MERIS time series while the instrument was not initially designed to do so. As expected, the number of valid observations after the pre-processing steps, in particular that of cloud and snow screening, is rather variable (Figure 2). In particular, the Northern region (North of England and Ireland, Norway, Sweden, Finland and North of Russia) suffers from a poor data coverage (less than 16 decades out of 36).

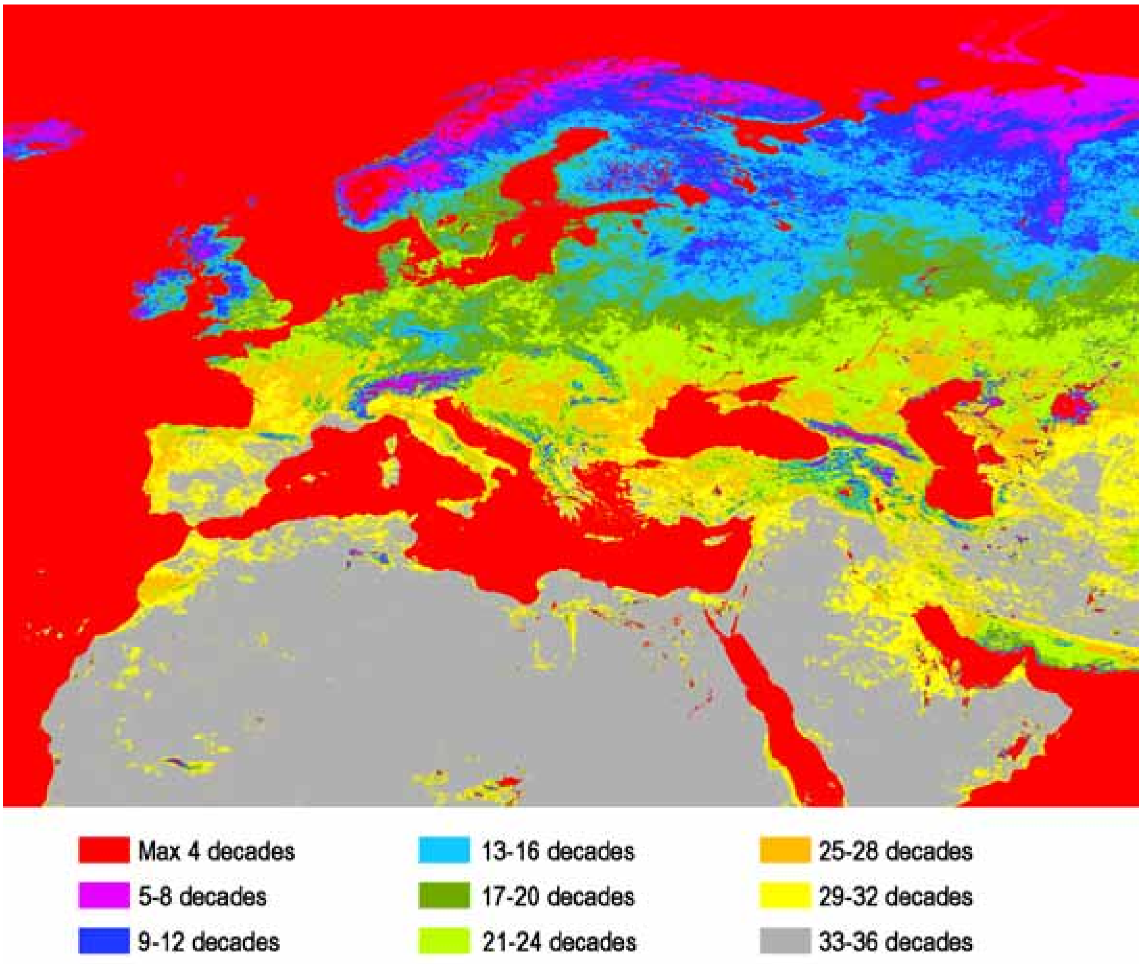

Figure 2. Number of decades (10-day periods) where there are observations after 12 months (1st January to 31st December 2009) of MERIS FRS acquisitions.

2.2. Description of the algorithm

The GlobCorine 2009 land cover map has been generated based on the classification chain developed in the GlobCorine 2005 project [AP-1].

The GlobCorine 2005 classification chain consists in transforming the MERIS multispectral mosaics into a meaningful pan-European land cover map. As explicitly requested by ESA and EEA, the challenge is twofold: (i) producing, in an automatic, repeatable and global way, a pan-European land cover map at 300-m spatial resolution and (ii) defining and documenting a legend as compatible as possible with the CLC aggregated typology and the UN Land Cover Classification System (LCCS). The classification module has been designed by UCL-Geomatics to combine both the spectral and temporal range of the MERIS FRS time series and to be globally consistent while regionally-tuned.

Table 1 presents a summary of the methodology used to produce the GlobCorine land cover map. The classification algorithm was exhaustively described in the GlobCorine 2005 TS document [AP-2].

Processing step	**Algorithmic description**
Pre-processing level Step 1: seasonal syntheses production	The pre-processed daily images are composited into MERIS FRS seasonal syntheses, through a Mean Compositing (MC) algorithm [RD-2]. The status of each pixel is validated and daily surface reflectance values are averaged for a specified period, ranging from two months to one year. The compositing period is determined according to the seasonality and the availability of daily images. This step results in MERIS FRS seasonal syntheses, organised by 5° x 5° tiles.
Pre-processing level Step 2: pan-European mosaics production	MERIS FRS seasonal syntheses are merged to produce MERIS FRS seasonal mosaics.
Classification level Step 0: stratification	The pan-European continent is stratified in 5 equal-reasoning areas from an ecological and a remote sensing point of view, with a twofold objective: (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 (water bodies as oceans and rivers, mountains areas, etc.) and on sharp interfaces clearly depicted from a remote sensing point of view (e.g. forest-grassland interfaces). Each delineated equal-reasoning area is then classified independently.
Classification level Step 1a: spectral supervised classification	The supervised classification aims to identify land cover classes that are not well represented in the strata (urban areas and wetlands). Region of Interest (ROI) are defined for each land cover class. First, an unsupervised spectral classification is performed in each ROI in order to delineate several clusters representative of the corresponding land cover classes. Second, mask areas are defined (i.e. areas which include the previous ROI and where the supervised classification will be performed)

	and the supervised spectral classification is achieved to identify the land cover classes.
Classification level Step 1b: spectral unsupervised classification	An unsupervised spectral classification is performed on the pixels that were not classified by the step 1a, with the aim of creating clusters of spectrally similar pixels.
Classification level Step 1c: merge of the spectral classifications	The step 1c merges the two spectral classifications obtained from the steps 1a and 1b.
Classification level Step 2: first reference-based labeling	The step 2 transforms the spectral classes identified in the step 1 into land cover classes. The labeling procedure is automated. The GlobCorine land cover labels are decided according to the correspondence between the spectral classes obtained from the step 1 and the classes described with the reference land cover map. Several decision rules have been defined to derive unique label for each spectral class. A code that expresses the ambiguity of the labeling is associated with each class.
Classification level Step 3a: temporal characterization	The step 3 focuses on pixels classified as crop or mosaic classes after the step 2. The step 3a applies an unsupervised classification on MERIS 10-day NDVI profiles to create clusters of pixels similar in the temporal space.
Classification level Step 3b: temporal classification	The mosaic classes obtained in step 2 are then sub-divided using the step 3a temporal information. That disaggregation aims to create new smaller and more homogeneous spectro-temporal classes.
Classification level Step 4: second reference-based labeling	A second labeling procedure is performed in order to transform the temporal classes into land cover classes. The step 4 is based on the same procedure than step 2 but on different labeling rules.
Classification level Step 5: merge of classifications	The step 5 merges the land cover classes derived from the spectral classification (step 1 and 2) and those derived from the spectro-temporal classification (step 3 and 4) in order to produce the GlobCorine land cover map.

Post-classification edition Step 6a: gap filling	In step 6a, gaps in the GlobCorine land cover map are filled with the reference land cover.
Post-classification edition Step 6b: water bodies	To deal with imprecision in the land/water mask used in the pre-processing [AP-3], the step 6b makes uses of an external dataset in order to improve the "water bodies" delineation in the GlobCover classification. This dataset is the Shuttle Radar Topography Mission (SRTM) Water Body Dataset (SWBD) [AP-4].

Table 1. Summary of the GlobCorine classification methodology

As just mentioned, the GlobCorine 2009 land cover map has been generated using exactly the same methodology than the one developed for producing the GlobCorine 2005 land cover map [AP-1]. The only differences are in the input data:

- 12 months of MERIS FRS time series from 2009 are used instead of the 19 months from December 2004 to June 2006
- The GlobCorine 2005 land cover map is used as reference dataset instead of the previous land cover database made of CLC 2000 and 2006, GlobCover 2005 and Africover maps.

2.3. Description of the legend

The legend associated with the GlobCorine 2009 land cover map is identical to the GlobCorine 2005 one [AP-1]. This legend was defined to be as compatible as possible with the CLC aggregated typology [RD-1] and with the LCCS system.

The GlobCorine land cover products have been designed to be consistent continental land cover maps. Therefore, their legend is determined by the level of information that is available and that makes sense at the scale of the pan-European continent. The GlobCorine legend counts 14 classes and meets this requirement (Table 2).

NB_LAB	LAB	Color
10	Urban and associated areas	
20	Rainfed cropland	
30	Irrigated cropland	
40	Forest	
50	Heathland and sclerophyllous vegetation	
60	Grassland	
70	Sparsely vegetated area	
80	Vegetated low-lying areas on regularly flooded soil	
90	Bare areas	
100	Complex cropland	

110	Mosaic cropland / natural vegetation	
120	Mosaic of natural (herbaceous, shrub, tree) vegetation	
200	Water bodies	
210	Permanent snow and ice	

Table 2. 14 classes of the GlobCorine legend

A 15th class (coded as "230") has been added to the final legend to account for no data pixel-values or for areas that are not covered by the project.

The LCCS definition of each GlobCorine class and their correspondence with the CLC aggregated typology are provided in Appendices A and B.

2.4. Review

The GlobCorine land cover product is the third 300-m land cover map – after the GlobCover and GlobCorine 2005 land cover maps – produced for the pan-European continent. This is the first one for the year 2009. The map projection is a Plate-Carrée (WGS84 geoid).

The GlobCorine 2009 classification counts 14 land cover classes that are well documented and comparable all over the pan-European continent. Figure 3 presents the pan-European GlobCorine 2009 land cover map.

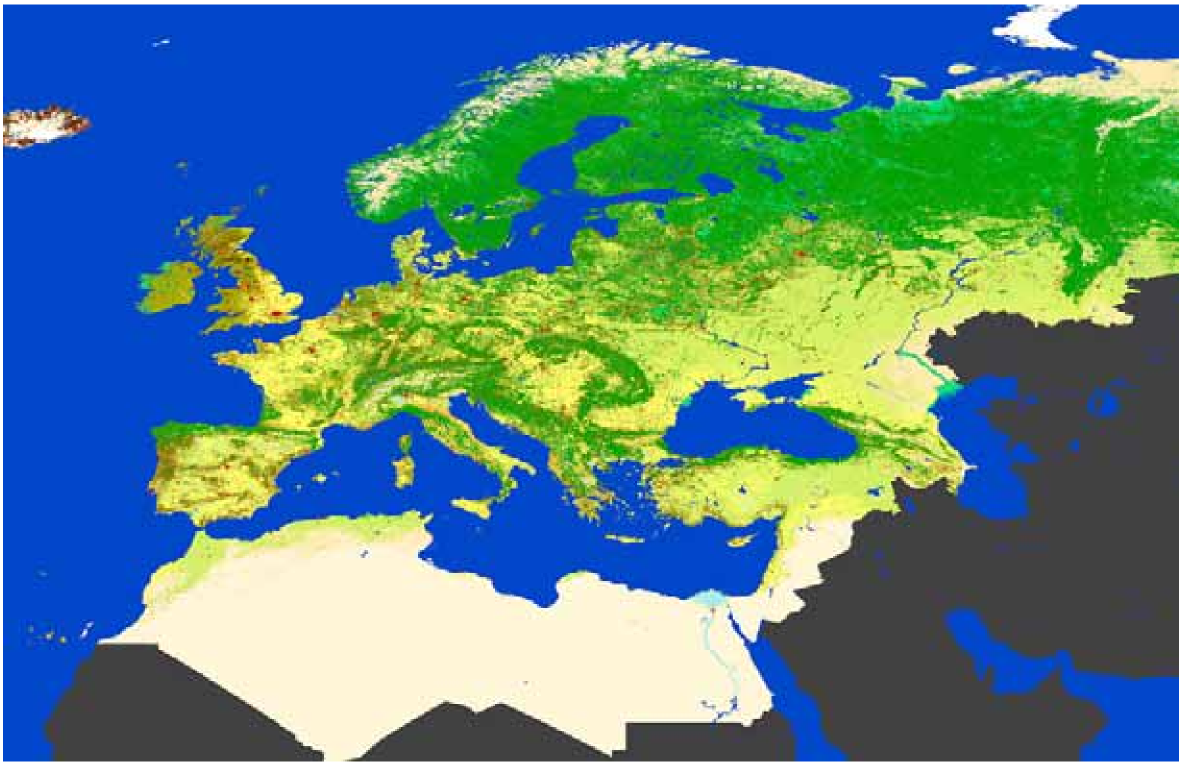

Figure 3. The GlobCorine 2009 product as the first 300-m pan-European land cover map for the year 2009

2.4.1. General observations

Figure 4 presents the area covered by the 14 global classes, computed after a projection of the land cover map into an equal area projection and expressed in percentage. Some classes are little represented as expected: class 10 “Urban and associated areas”, class 30 “Irrigated cropland”, class 50 “Heathland and sclerophyllous vegetation”, class 60 “Grassland”, class 80 “Vegetated low-lying areas on regularly flooded soil” and class 100 “Complex cropland”. The land cover classes distribution is highly similar to the one associated with the GlobCorine 2005 land cover map [AP-1], as illustrated in Figure 5.

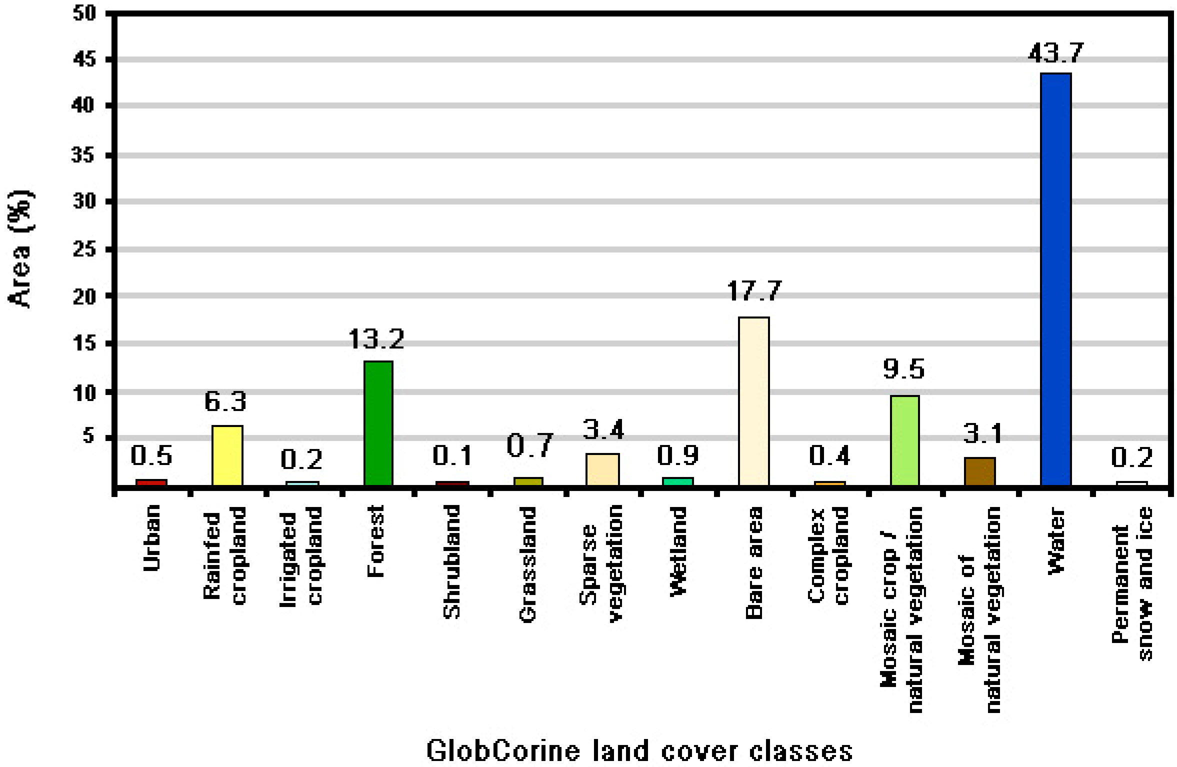

Figure 4. Area (%) covered by the 14 GlobCorine classes in the 2009 product

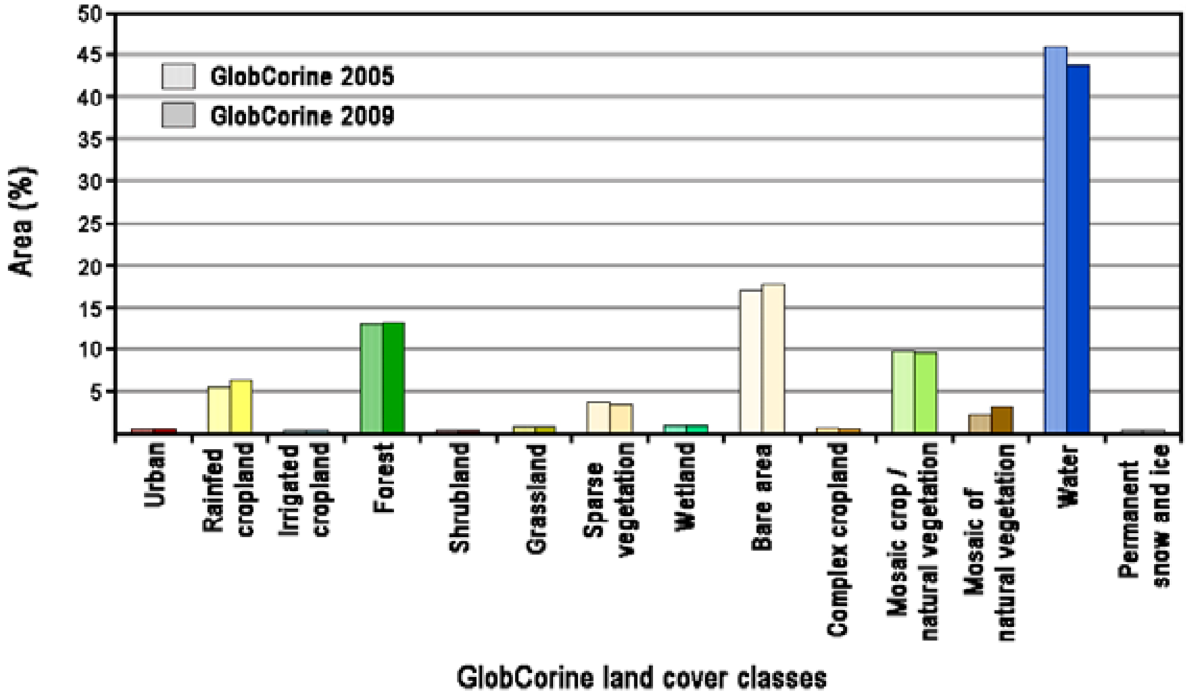

Figure 5. Comparison of classes proportions between GlobCorine 2005 and 2009 products

However, even if the proportions of the land cover classes are similar between the 2005 and 2009 maps, the two products show significant differences in the land cover classes' spatial distribution. First, the classification of the MERIS time series from 2009 results in a more compact and homogeneous spatial pattern. According to the regions, this can have negative or positive impacts in the GlobCorine 2009 land cover map (Figure 6 a and b, respectively).

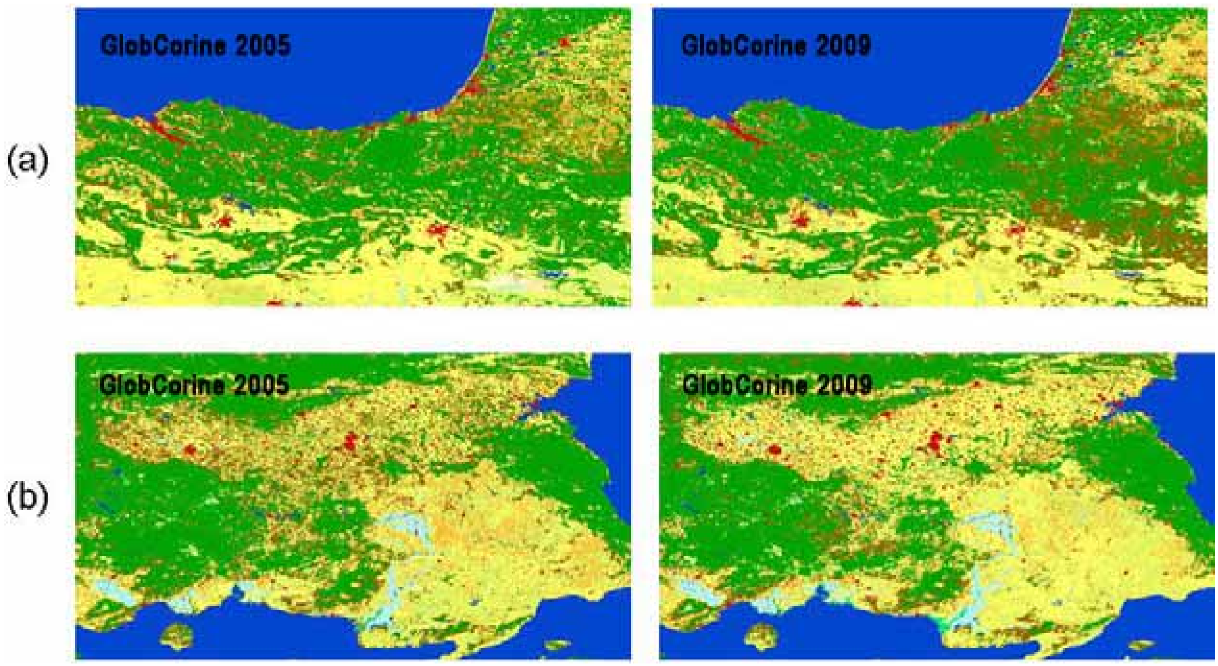

Figure 6. Compact aspect of various land cover classes in GlobCorine land cover map 2009, in comparison with the GlobCorine 2005 product

In addition, an increase of the "mosaic" class proportions can be observed in the GlobCorine 2009 product as shown in Figure 7.

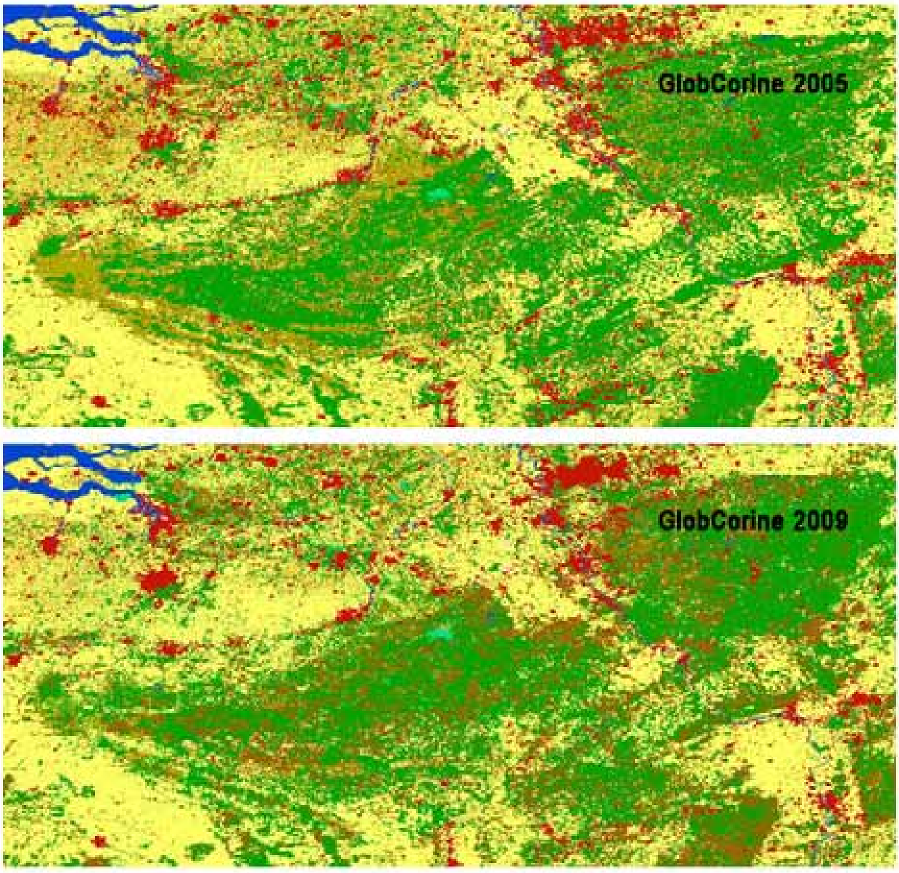

Figure 7. Snapshots over Belgium, Luxembourg, France and Germany. Significant increase of the mosaic class of natural vegetation (class 120 colored in brown) in the GlobCorine 2009 map (bottom), when compared to the GlobCorine 2005 product (top)

As already noted for the GlobCorine 2005 product [AP-1], the quality of the GlobCorine product is highly dependent on the input time series and on the reference land cover database used for the labeling process.

In the GlobCorine 2009 project, the number of valid observations available for the classification has significantly decreased compared with the GlobCorine 2005 product (Figure 8).

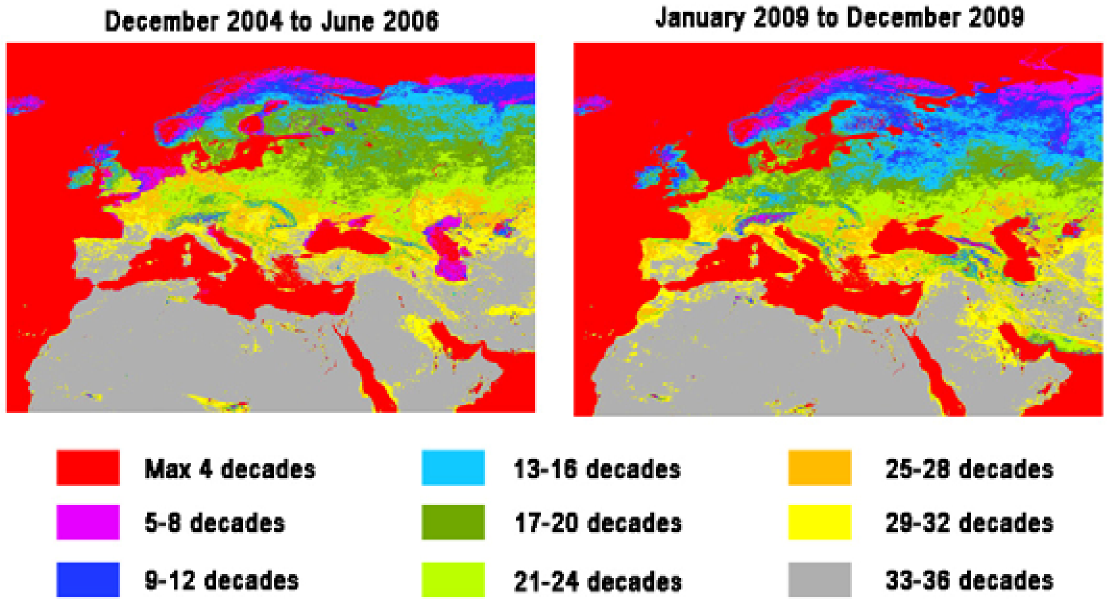

Figure 8. Comparison between the number of valid observations available to produce the GlobCorine 2005 (left) and 2009 (right) product

This decrease had consequences on the consistency of the time series and on the GlobCorine classification algorithm. In particular, the compositing step (pre-processing step 1 in Table 1) had to be adjusted. The compositing period definition has to be achieved in order to optimize the discrimination between the different land cover types according to their phenology. However, it is also constrained by the availability of daily images. In 2009, there were less valid observations than in 2005 and as a result, the compositing period had to be slightly increased for some seasons and regions (e.g. the “spring” composite over the Northern region had to be based on 3 months in 2009 instead of 2 in 2005).

This increase in the compositing period allows ensuring higher spatial consistency in the composites but in turn, the resulting composites offer less discrimination possibilities between land cover types. For instance, bare areas seem to be more difficult to discriminate from forest in the Scandinavian region in 2009 than in 2005 (Figure 9).

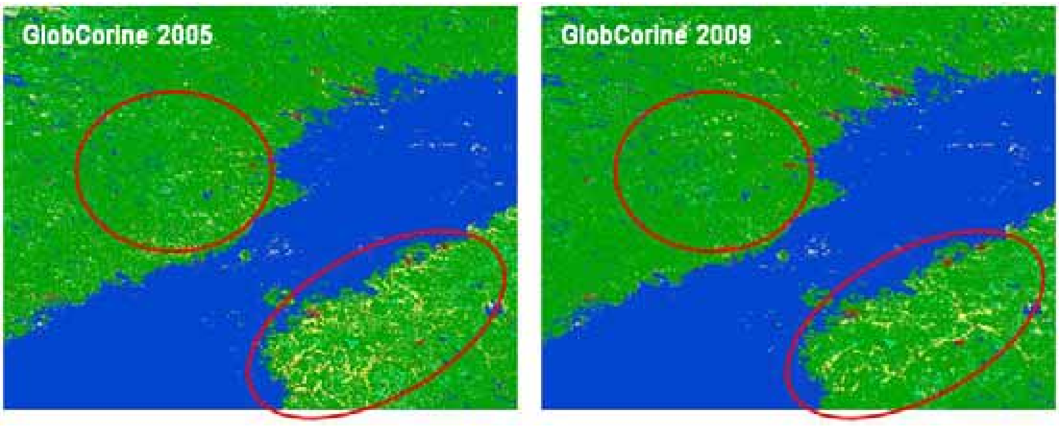

Figure 9. Snapshot of Sweden illustrating the difference in bare areas classification in the GlobCorine 2005 (left) and 2009 (right) land cover maps

The decrease in the number of valid observations between 2005 and 2009 could be explained by the decrease of the acquisition period (12 months instead of 19) but also, possibly, by a more important cloud cover in 2009 than in 2005.

The snow cover also impacts the input dataset and so, the resulting GlobCorine map. As shown in Figure 10, the permanent snow cover (identified through an annual composite) was larger in 2005 than in 2009. In consequence, the snow class is rather different in the 2005 and 2009 land cover map.

Similarly, fires have also affected the vegetation in a different way in 2009 than in 2005, thus possibly resulting in different classifications.

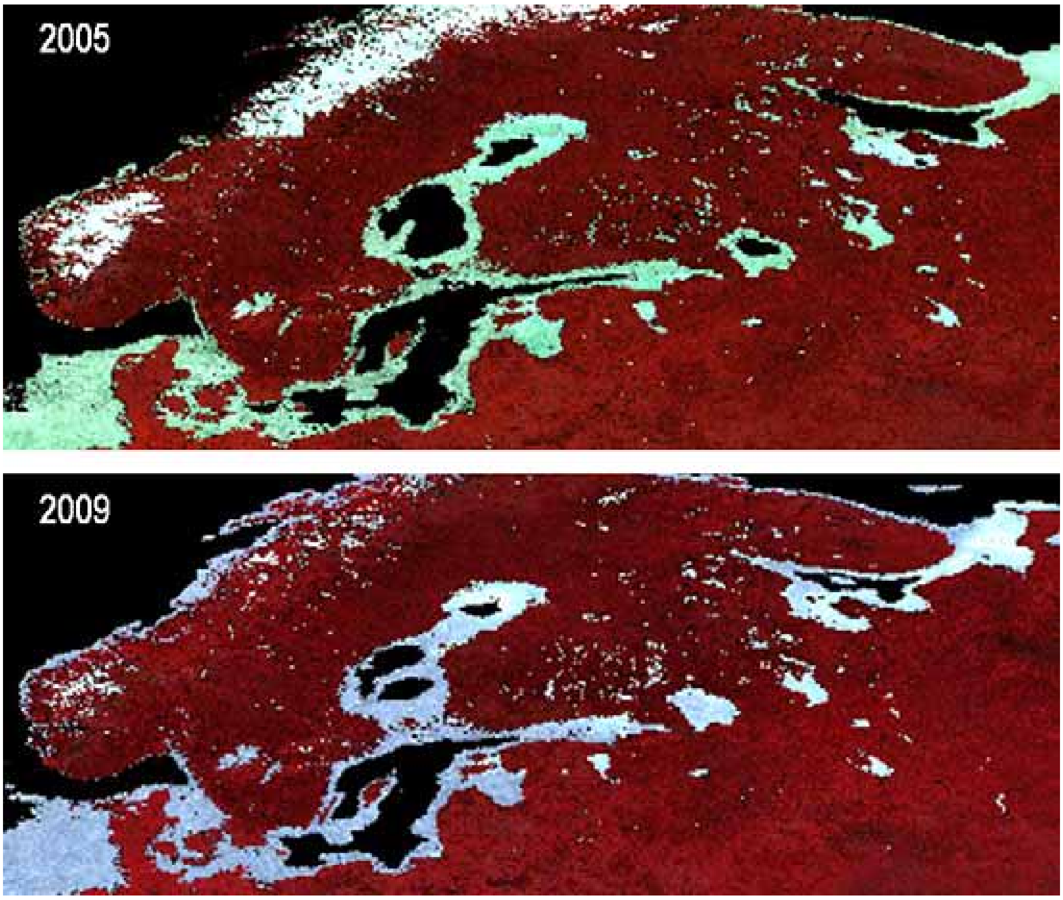

Figure 10. Difference in snow cover over the Scandinavian countries between 2005 and 2009

As for the dependence of the product quality on the reference land cover database used for the labeling process, the use of GlobCorine 2005 land cover map as reference also needs to be discussed. In order to generate the GlobCorine 2005 land cover map, the reference database had been compiled from the CLC (2000 and 2006), the GlobCover 2005 and the Africover maps. These datasets were selected as the most accurate ones for the region of interest, with the highest spatial resolution and with a GlobCorine-compatible legend.

In order to generate the GlobCorine 2009 land cover map, the reference was the GlobCorine 2005 land cover map. However, it appears that the use of the CLC2006 map as reference would have permitted to increase the accuracy of the GlobCorine 2009 product. Indeed, the GlobCorine 2005 land cover map is less detailed than the CLC maps both from the thematic and spatial point of view.

As for the thematic content of the map, there are significant differences in the representativeness of “pure” and “mosaic” classes between the reference dataset used to produce GlobCorine 2005 (mainly based on CLC maps) and the GlobCorine 2005 land cover (used as reference in GlobCorine 2009). This is clearly illustrated in Figure 11. As for the natural vegetation, classes of shrubland (“Heathland and sclerophyllous vegetation” - class 50) and of grassland (class 60) are present in a lesser quantity in the 2009 reference (-62% and -59%, respectively). With regard to the cultivated areas, the rainfed cropland and the complex cropland classes have also decreased (-14% and -36%, respectively). Conversely, the proportions of forest (class 40) and of the mosaic class between cropland and natural vegetation (class 110) have increased (+5% and +33%, respectively).

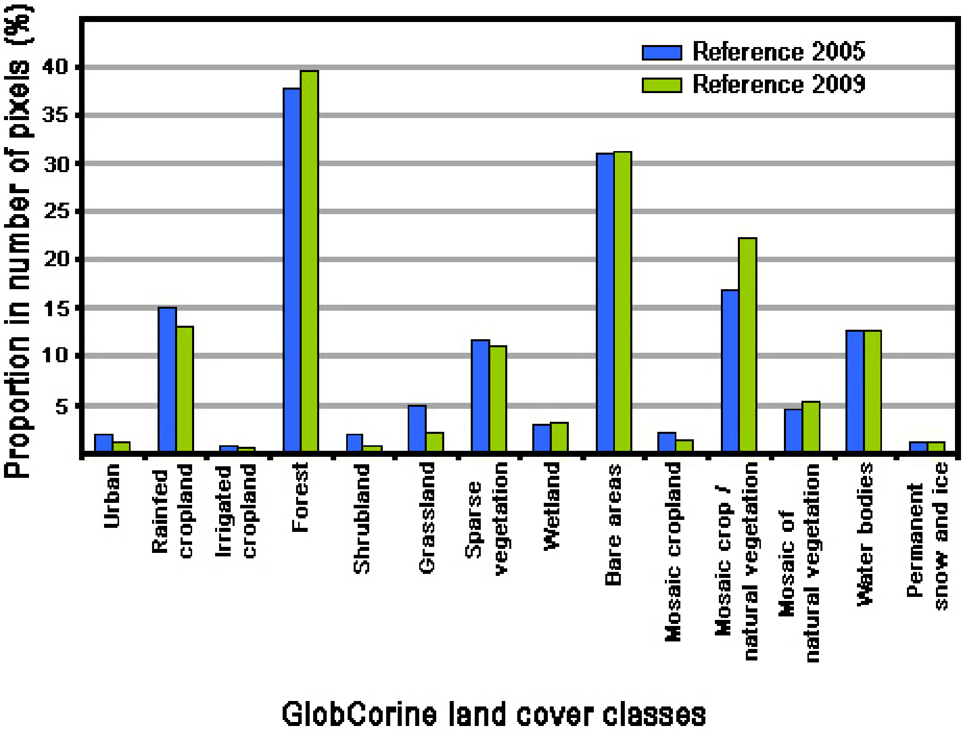

Figure 11. Mosaic classes proportions in the GlobCorine 2005 land cover map and in the 2005 reference dataset

This simplification of the reference dataset impacted the accuracy of the labeling procedure: it proved to be more challenging to label clusters resulting from the unsupervised classification in classes under-represented in the reference dataset. This could be the case for the situation illustrated in Figure 7: the lesser representation of shrubland (“Heathland and sclerophyllous vegetation” - class 50) and of grassland (class 60) in the reference could favour the labeling in the class “Mosaic of natural vegetation” (class 120).

2.4.2. Detailed review

In comparison with the GlobCorine 2005 project, the auxiliary data associated with the supervised classification (classification step 1a in Table 1) have been slightly modified, with the aim of improving the classification performances. In particular, the regions of interest were refined using unsupervised classifications and high spatial resolution imagery from Google Earth.

As a result, the urban areas classification has been improved comparing to the GlobCorine 2005 product. The systematic problem observed in 2005 with the classification of city centers with highest population density values as bare rock, cropland mosaics or even wetlands has been solved. This is mainly visible for large cities (Figure 12). In addition, the urban patterns in 2009 look generally more realistic than in 2005 in the Mediterranean region (Figure 13). Yet, the mapped urban areas in 2009 are sometimes too compact (Figure 14), which may shrink borders towards centres.

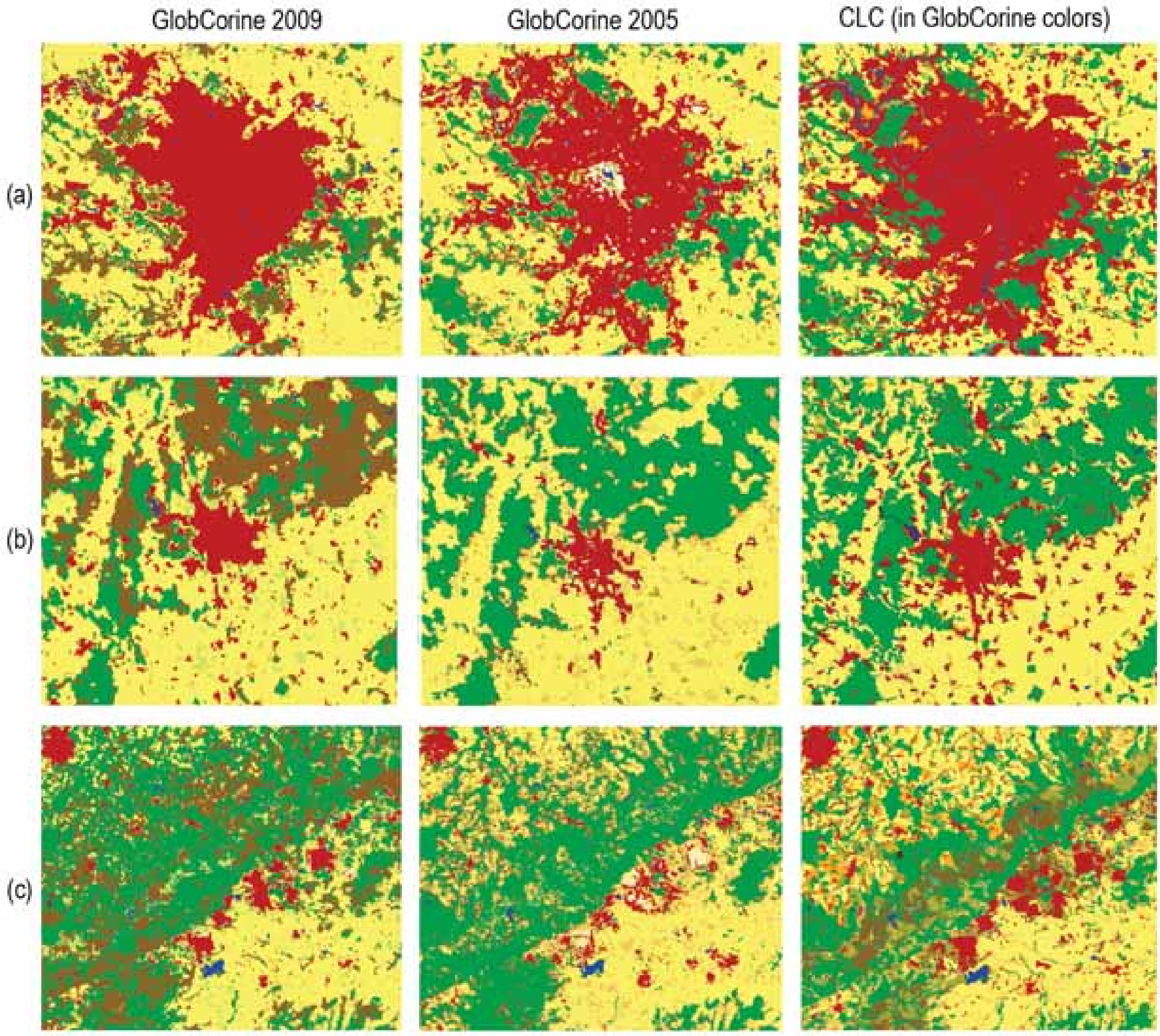

Figure 12. Improvement of the urban areas detection in GlobCorine 2009 (left), when compared with the GlobCorine 2005 product (center) and the CLC2006 map (right). Urban areas are mapped in red. The case of large cities (Paris, France - (a)), of medium cities (Brno, Czech Republic - (b)) and of small cities (mining areas in West of Bohemia, Czech Republic - (c)) are represented.

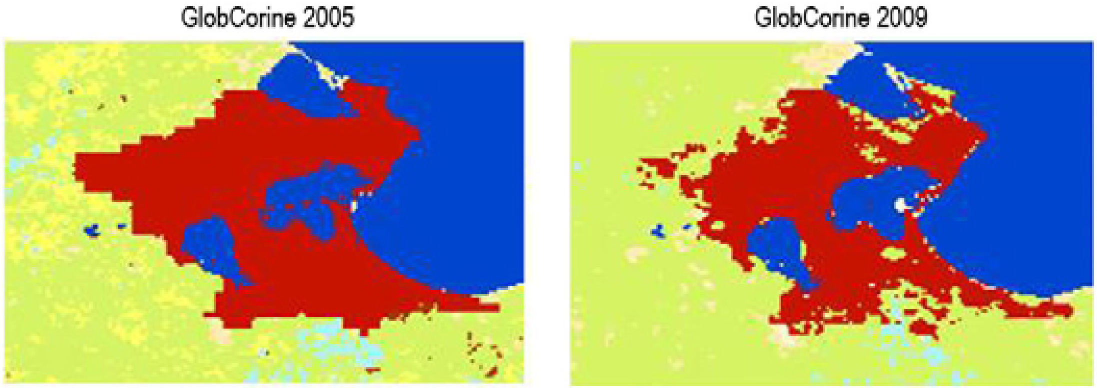

Figure 13. More realistic pattern of urban areas observed in the 2009 classification, illustrated with the city of Tunis (Tunisia)

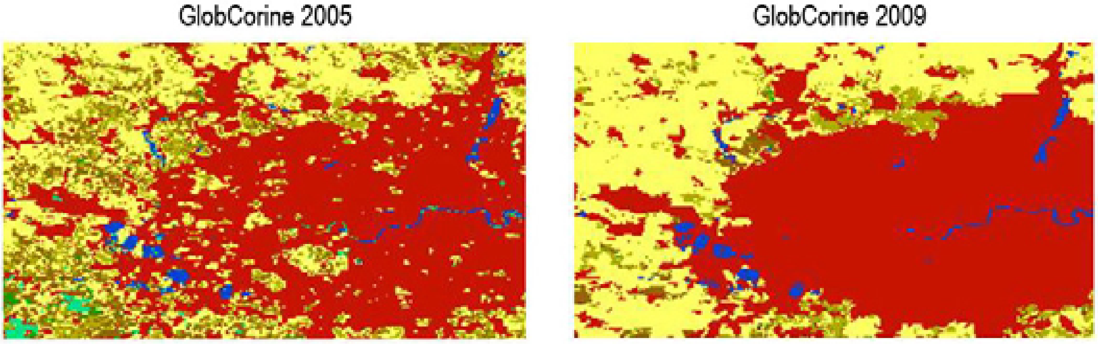

Figure 14. Compactness of urban areas observed in the 2009 classification, illustrated with the city of London (United Kingdom)

As for the wetland classes, a better agreement is observed with the CLC map than in the previous 2005 classification, mainly in the shape that is more compact (Figure 15).

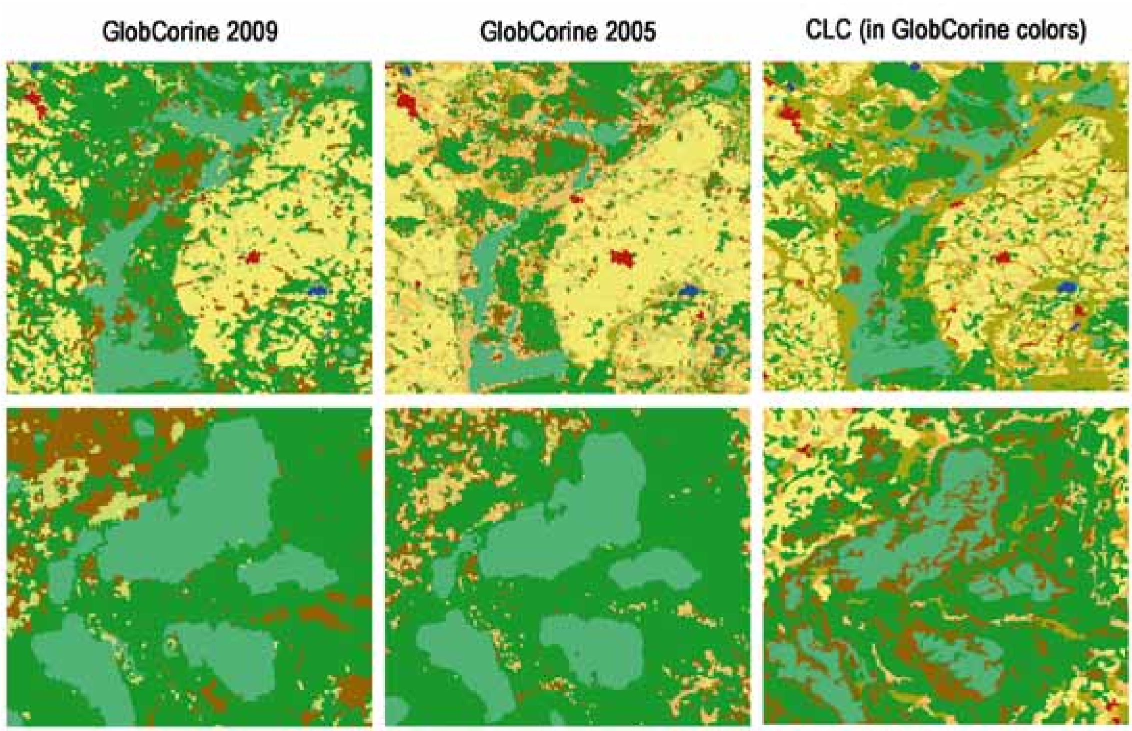

Figure 15. General improvement of the wetland class discrimination in the GlobCorine 2009 product (left) in comparison with the GlobCorine 2005 map (center) when taking the CLC2006 map as reference (right). Illustrations with the Biebrza River Marshes in Biebrzanski National Park, northeastern Poland (up) and the large bogs in Soomaa National Park, south-western Estonia (down)

With regard to the other land cover classes (i.e. those that are detected through the unsupervised algorithm), their classification is rather similar to the previous version except that they are affected by large spread of “Mosaic of natural (herbaceous, shrub, tree) vegetation” class. This is particularly the case for the classes of “Complex cropland”, “Grassland” and “Forest” (Figure 16).

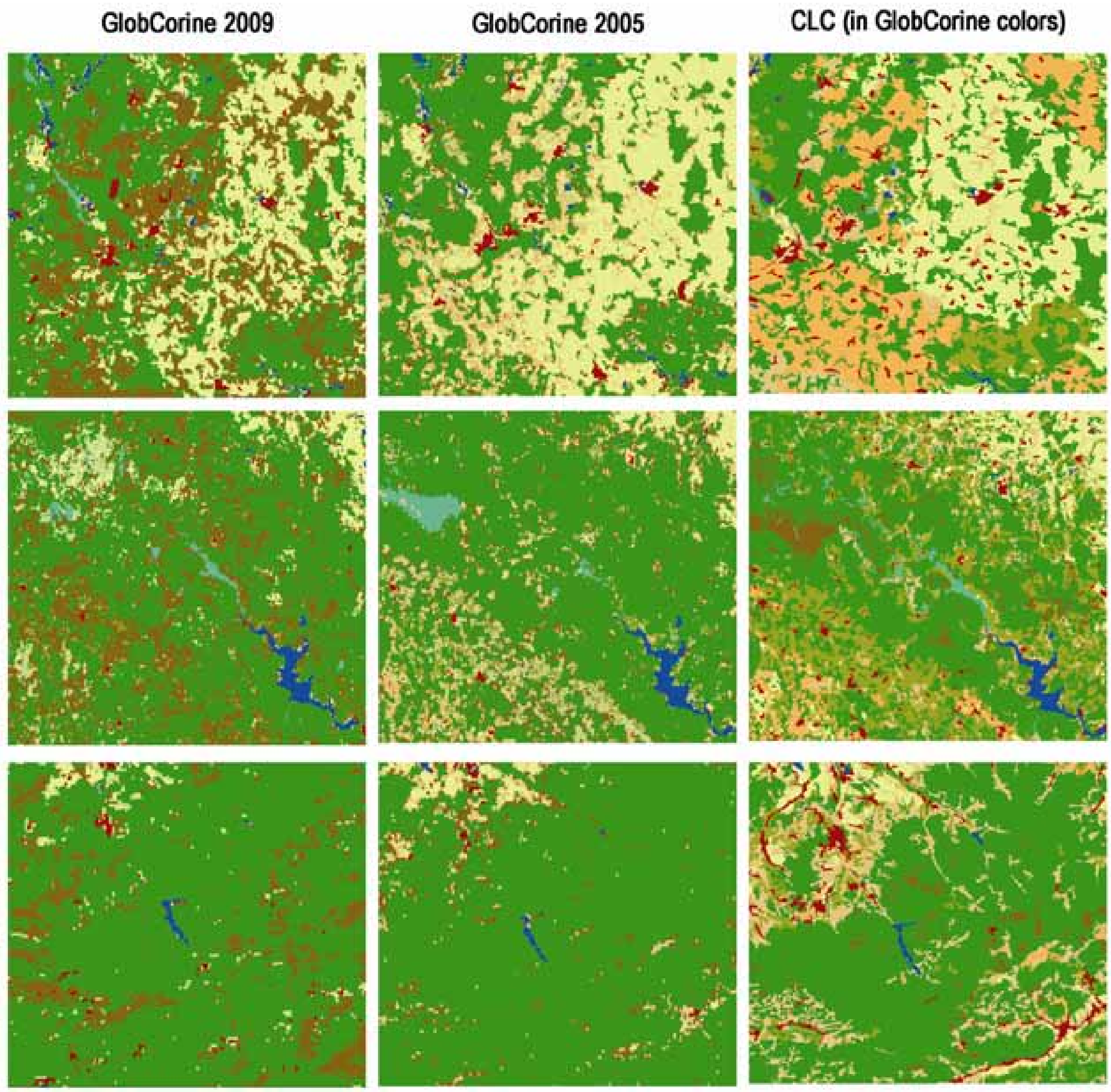

Figure 16. Contamination of the GlobCorine 2009 map by the class of "Mosaic of natural (herbaceous, shrub, tree) vegetation", illustrated with examples in Czech Republic for the "Complex cropland" class (top), the "Grassland" class (center) and the "Forest" class (bottom)

Finally, the identification of water bodies is similar in GlobCorine 2009 than in the 2005 product. Due to erroneous "water flags" in the pre-processing of the MERIS FRS time series, classification errors significantly affect the water bodies. Like in GlobCorine 2005, this issue has been addressed by correcting the GlobCorine classification using the SRTM product. As a result, the water classification remains rather stable between the 2005 and 2009 land cover maps (Figure 17). However, the use of the SRTM product does not allow correcting all the errors, especially those occurring in the mountain areas where "bare areas" are often erroneously classified as "water" (Figure 18).

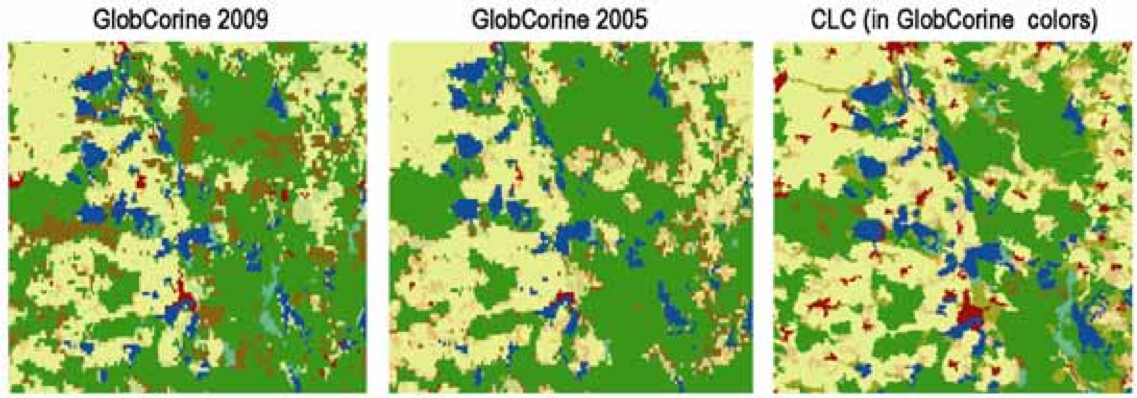

Figure 17. Snapshot from South Bohemia (Czech Republic) showing the stable water classification in the GlobCorine 2009 (left) and 2005 (center) products and its general agreement with the CLC2006 map (right)

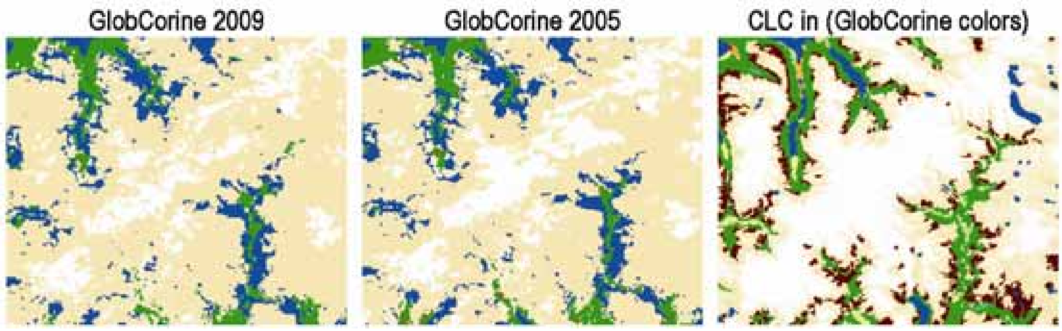

Figure 18. Snapshot from Norway mountain areas: small inland water features are erroneously mapped on on high altitudes

3. Land cover validation

3.1. Land cover validation based on the GlobCover validation dataset

The quantitative validation of the GlobCorine land cover product aims to assess the accuracy of the 14 classes of the land cover map from an independent reference dataset. The validation results allow a potential user determining the map's "fitness for use" for his or her application. The validation process is designed to be scientifically sound, internationally acceptable and feasible from a cost and a time point of view. This is based on the document of the CEOS Land Product Validation subgroup: *"Global Land Cover Validation: Recommendations for Evaluation and Accuracy Assessment and of Global Land Cover Maps"* [RD-3].

The validation process of the GlobCorine 2009 land cover map made use of the validation dataset already used in the GlobCorine 2005 project and that was constituted in the GlobCover 2005 project [AP-3]. The hypothesis that no change had occurred between 2005 and 2009 was done.

First, the validation samples related to the GlobCorine area (Europe, Northern Africa and European Russia) were extracted. Second, the set of classifiers and attributes that was collected in order to characterize the land cover of a particular site were transformed to the legend of the GlobCorine product to make them comparable. Finally, the GlobCorine product's accuracy was assessed.

3.1.1. GlobCorine validation dataset

Over the 4258 points contained in the GlobCover validation dataset, 788 points overlaid the GlobCorine area. The distribution of these 788 points is shown in Figure 19. The validation dataset was further reduced to 430 points by removing all the points where the experts were not explicitly certain that the information they provided was correct.

Figure 19. Distribution of the 788 points in the GlobCorine validation dataset.

3.1.2. GlobCover validation dataset interpretation

For observational units where the experts only report one land cover type, the GlobCover validation dataset interpretation is a relative straightforward process. The set of selected classifier values is transformed into a single GlobCorine class, according to the GlobCorine-LCCS correspondence given in Appendix A.

In case the experts described two or three land cover types to describe the area covered by an observational unit, the translation process becomes less obvious. Indeed, the fact that several land cover types have been identified for one observational unit gives cause to consider mosaic classes as well. The GlobCorine legend includes 3 mosaic classes (coded as 100, 110 and 120), which correspond to the combinations of land cover types indicated by the experts.

For illustration purpose, Table 3 reports the values of LCCS classifiers selected by the expert to describe a given observational unit. In Europe, the experts assigned maximum two land cover types to the observational units. These two sets of classifiers can then be translated into two different “pure” GlobCorine classes and into one “mosaic” GlobCorine class, as shown in the Table 4. These different possible translations of the classifiers set provided by the expert must be taken into account to analyze the confusion matrix comparing the GlobCorine product with the validation dataset.

Furthermore, it is worth mentioning that many combinations of land cover types cannot be transformed into a GlobCorine mosaic class. Indeed, a legend that would cover for all these potential combinations is not desirable because the mosaic classes are often considered less informative and therefore less useful from an end-user point of view.

Land cover 1 (LC1)	**Land cover 2 (LC2)**
Natural & Semi-natural terrestrial vegetation	Cultivated & managed lands
Shrubs	Herbaceous
Open (70-60 - 20-10%)	Rainfed
5-0.3 m	
Broadleaved	

Table 3. Two sets of LCCS classifiers that describe the land cover for an observational unit out of the validation dataset

Pure GlobCorine class describing LC 1	**Pure GlobCorine class describing LC 2**	**GlobCorine mosaic class describing the combination of LC1 and LC2**
Heathland and sclerophyllous vegetation	Rainfed herbaceous cropland	Mosaic cropland / natural vegetation

Table 4. GlobCorine classes to which the land cover types from Table 3 have been assigned

3.1.3. Validation results

Over the 430 "certain" points, 403 could be translated into a GlobCorine class. The reference dataset of these 403 "certain and valid" points was then matched to the GlobCorine 2009 map codes extracted for all the validation points in order to build a confusion matrix (Table 5). Next to the overall accuracy, the user's and producer's accuracies have also been computed. It is important to mention that the dominance between land cover types identified by the expert for a given sample has not been taken in account in the validation process.

The accuracy level is found to be **78%**. This accuracy figure was 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 conversely, classes that cover large surfaces may have been underrepresented in the set.

As proposed by the CEOS recommendations, the overall accuracy value has to be weighted by the area proportions of the various land cover classes, resulting in an accuracy of **81.28%**. The weighting factor corresponding to the area proportion of the given class has been derived from the GlobCorine 2009 product that has been projected in an equal area projection.

		Reference															
		10	**20**	**30**	**40**	**50**	**60**	**70**	**80**	**90**	**100**	**110**	**120**	**200**	**210**		
GlobCorine	**10**	4			1											5	80%
	20	2	48	4	5	1	2			1	6	4				73	79.5%
	30		2	8												10	80%
	40		8		50	3	3			1		11	6			82	81.7%
	50															0	NA
	60		4				2					1	2			9	55.6%
	70	1	1	1			3	1		1	1				2	11	9.1%
	80												1	1		2	0%
	90					1				65				1		67	97%
	100		6													6	100%
	110	3	26	19	2		5			3	5	10	2			75	89.3%
	120	1	11	1	13	1					1	10	1			39	38.5%
	200		1				1					1		6		9	66.7%
	210															0	NA
		11	107	33	71	6	16	1	0	71	13	37	12	8	2	**78%**	
		36.4%	74.8%	81.8%	91.5%	16.7%	43.8%	100%	NA	91.5%	84.6%	70.3%	75%	75%	0%		

Table 5. Adjusted contingency matrix that considers the product and the validation dataset. Green cells are cells that show direct agreement between classification and validation. Yellow cells show cells that have been considered to show agreement, accounting for the definition of mosaic classes. The value in red shows the overall accuracy

These final accuracy results document the quality of the GlobCorine 2009 product. Although these figures are slightly lower than for the GlobCorine 2005 product, they remain quite acceptable for a pan-continental demonstration product. Yet, it has to be pointed out that the overall accuracy figure has to be used cautiously, i.e. it needs to be moderated by the users and producers accuracies and by the sampling validation strategy. Some critical points are discussed hereafter.

First, Table 5 indicates that the number of validation points largely varies between classes. This is due to the fact that the stratified sampling that generated the validation dataset was achieved on a global scale, based on the GlobCover product. The stratification, which ensures that each class is representatively sampled, is thus not necessarily valid at the GlobCorine pan-European scale. This validation exercise has to deal with this slight bias, which mainly affects the classes of “Heathland and sclerophyllous vegetation” (class 50), of “Sparsely vegetated areas” (class 70), of “Vegetated low-lying areas on regularly flooded soil” (class 80), of “Water bodies” (class 200) and of “Permanent snow and ice” (class 210). This bias impacts the overall accuracy value weighted by the class area, which is artificially slightly increased. Accordingly, it is strongly recommended to also account for user’s and producer’s accuracies to have a clear idea of the GlobCorine map accuracy.

Second, Table 5 reveals that the classes that perform best have been validated with the largest numbers of points, providing a reliable accuracy estimate for these classes.

Finally, Table 5 reveals a clear contribution of the mosaic classes in the high global accuracy figure. Indeed, their agreement with several (both pure and mosaic) classes increases the global accuracy. However, these classes are not easily interpretable and they should thus be avoided as much as possible. The GlobCorine 2009 land cover map shows a higher proportion of such mosaic classes, due to both the lower quality of the input MERIS 2009 dataset and the use of the GlobCorine 2005 land cover map as reference.

In the GlobCorine classification chain, the mosaic classes can occur by two different ways. First, they can be created because “pure” land cover types cannot be automatically discriminated in an appropriate way. They are then grouped into a mosaic class. Second, they can be inherited from the reference dataset that is used in the labeling step and have therefore nothing to do with the performance of the classification algorithm or the quality of the input MERIS time series. For the GlobCorine 2005 product, this explanation was only valid over the European Russia [AP-1] for which the reference dataset was the GlobCover 2005 map. For the GlobCorine 2009 product, mosaic classes are present in the reference dataset over the whole study area since it is the GlobCorine 2005 map.

3.2. Land cover validation based on the CLC dataset

A quantitative evaluation of the GlobCorine product has also been achieved on the pan-European level by the ETCLUSI (GISAT). Firstly, the assessment focused on a quantitative validation of the new 2009 product *versus* existing remapped Corine Land Cover european product.

This assessment was performed using the CLC2006 data available on November 2009 as reference dataset. It has to be stated that large countries like Finland, Germany, Greece, Italy, Norway, Spain, Sweden and United Kingdom were missing in this reference dataset. This evaluation has been done with the same approach than in 2005 [AP-1] to keep consistency in the methodology.

The CLC2006 dataset has been re-mapped into the GlobCorine legend (Table 2) and GlobCorine reference grid. No sampling was defined: all pixels with valid GlobCorine product were considered.

Table 6 shows the agreement table between the GlobCorine product and the re-mapped CLC2006 dataset and Table 7 presents the corresponding accuracy statistics.

Table 6 shows that, like for the 2005 product, the overall accuracy of the GlobCorine 2009 land cover map is affected by mosaic classes present in the legend (classes 100, 110 and 120).

		Reference													
		10	**20**	**30**	**40**	**50**	**60**	**70**	**80**	**90**	**100**	**110**	**120**	**200**	**210**
GlobCorine	**10**	77.2	7.2	0.1	4.8	0.7	2.1	0.1	0.3	0.1	3.2	2.1	1	1.3	0
	20	4.7	64.9	0.1	5.1	0.7	9.3	0.4	0.2	0.1	8.6	4.2	1.3	0.4	0
	30	1.3	11.8	68.1	6.5	0.6	1.3	0.4	0.1	0.1	6	2.2	1.1	0.4	0
	40	1.4	6.6	0	62.8	0.6	10.6	0.1	0.1	0	5	6.3	6.2	0.2	0
	50	3	4.3	0.3	7.9	19.1	18.8	2.1	7.9	2.6	2	9.8	20.2	2	0
	60	1.6	7.2	0	9.4	0.5	64.2	0.1	1.1	0.1	6.2	5.8	3.5	0.3	0
	70	20.8	14.2	0.1	2.9	2.9	12.7	18.8	1.9	15.9	2.2	0.6	2.9	4	0.1
	80	1	3.9	0.1	5.7	0.9	6.2	0.3	68	0.5	0.9	2.1	6.6	3.9	0
	90	1.4	0.2	0	0.6	1.1	2.9	15.1	0.3	66.6	0	0	0.2	2.5	9.1
	100	5.2	38.6	0.8	8.2	1.9	12.9	0.5	0.1	0.1	21.8	6.5	2.9	0.4	0
	110	4.6	27.3	0.3	18.5	3.2	17.4	2	0.2	0.8	10.5	8.8	5.4	0.8	0
	120	2.2	12.4	0.1	43.5	2.3	13.7	0.5	0.4	0.2	8.6	8.2	7.5	0.3	0
	200	2.1	1.6	0	2.9	0.5	2.4	0.2	8.4	1.4	0.7	1.2	0.6	77.6	0.4
	210	0	0	0	0	0	0.4	1.6	0	43	0	0	0	0	55.1

Table 6. Matrix showing the agreement between the GlobCorine 2009 product and the re-mapped CLC2006 dataset. Green cells are cells that show direct agreement between GlobCorine and CLC2006

Average accuracy	48.6%
Overall accuracy	48.6%
Kappa coefficient	0.475

Table 7. Accuracy statistics showing the agreement between the GlobCorine 2009 product and the re-mapped CLC2006 dataset

3.3. Consistency between GlobCorine 2005 and 2009 products

The section 2.4 of this report showed that, even if the land cover classes are present in similar proportions in the 2005 and 2009 products (Figure 5), there are differences in their spatial distribution. Table 8 shows the agreement table between the GlobCorine 2005 and 2009 products.

It has to be pointed out that these figures have been obtained through a per-pixel analysis. Interestingly, when looking at the overall spatial pattern of each land cover class in 2005 and 2009, they look globally consistent. This is illustrated for the “Forest class” in Figure 20 while the figures for all the other classes are presented in the Appendix C. This could be explained by the fact that most pixels which have changed of classes between 2005 and 2009 are pixels located on the edges of the classes. As a result, the general structure of the landscape remains more or less similar between 2005 and 2009.

		Reference													
		10	20	30	40	50	60	70	80	90	100	110	120	200	210
GlobCorine	10	57	17.9	0	4.7	0.1	0.2	1.6	0.2	0.3	2.1	13.3	1.7	1	0
	20	1.4	74.4	0.1	2.4	0.2	1.5	0.2	0.2	0	3.9	13	2.6	0.2	0
	30	0.7	9.8	53.7	2.1	0.7	0	0.1	0	0	7.5	21.3	3.8	0.3	0
	40	0.2	5.3	0	72	0	1.8	0	0.1	0	1.3	7.9	11.3	0.1	0
	50	0.8	7.6	0.1	4.6	44.7	15.2	0.7	2.4	0.5	0.6	6	13.8	3.1	0
	60	0.2	5	0	3.4	0.3	77.8	0	0.3	0	1.3	3.7	7.8	0.3	0
	70	5.9	21.2	0	2.3	0.4	0.8	31.6	1	15	0.6	16.2	0.9	3.6	0.5
	80	0.5	7.9	0	8.9	2	9	0.8	49.9	0.2	1.2	8.9	5.1	5.6	0
	90	0.5	2.8	0	0.3	0.4	0.5	20.6	0.6	53.3	0	6.2	0.3	3.1	11.2
	100	0.8	22.3	0.2	4	0.4	1.9	0	0	0	49.2	16.2	4.8	0.2	0
	110	2.1	13	0.1	17.6	0.8	2.4	1	0.2	0.3	2.5	44.5	15	0.6	0
	120	0.5	10.9	0	44	0.5	2	0	0.2	0	2.9	16.6	22	0.2	0
	200	1.3	3.2	0	5.2	0.3	0.9	0.5	0.9	0.6	0.4	4.7	1.4	80.2	0.3
	210	0	0	0	0	0	0.3	1	0	14	0	0.9	0	0	83.8

Table 8. Matrix showing the agreement between the GlobCorine 2005 and 2009 products. Green cells are cells that show direct agreement between the two maps and yellow cells show cells that have been considered to show agreement, accounting for the definition of mosaic classes.

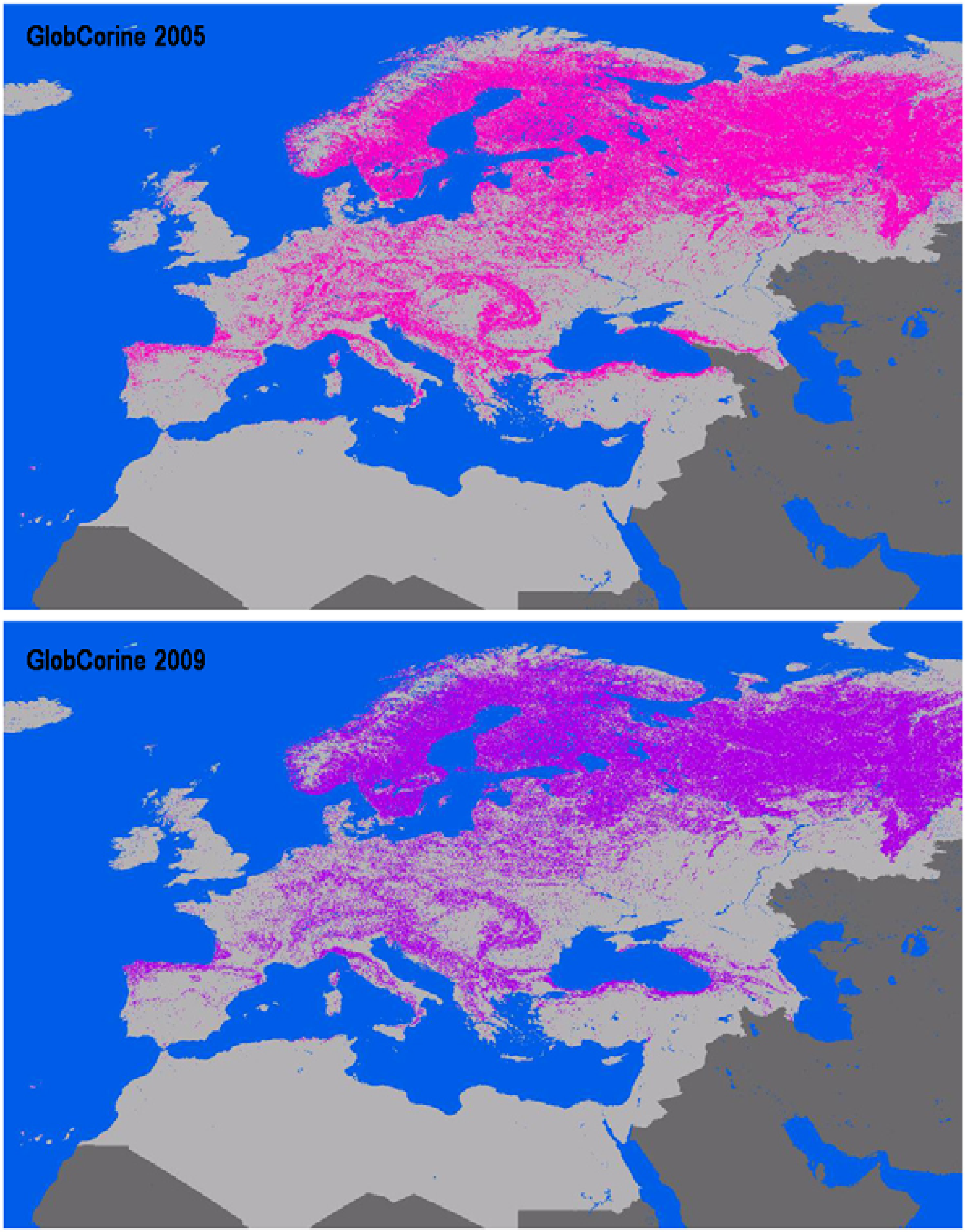

Figure 20. Spatial distribution of the “Forest” class in the GlobCorine 2005 and 2009 maps

With regard to pixels which are not identically classified in 2005 and 2009, their "trajectories" have been analyzed. In this context, the expression "trajectory" does not refer to any land cover change having occurred between 2005 and 2009 but rather to classification instabilities between the two GlobCorine maps.

Figure 21 illustrates this instability for "forest" pixels. The "blue" histogram is related to pixels which were classified as "forest" in 2005 but not in 2009 and the "green" histogram is associated with pixels which are classified as "forest" in 2009 but not in 2005. Histograms show how the "unstable" forest pixels are classified in the GlobCorine product where they are not "forest". For instance, pixels which were classified as "forest" in 2005 and not in 2009 are mostly classified as "Mosaic cropland / natural vegetation" (28%) and "Mosaic of natural vegetation" (43%) in 2009.

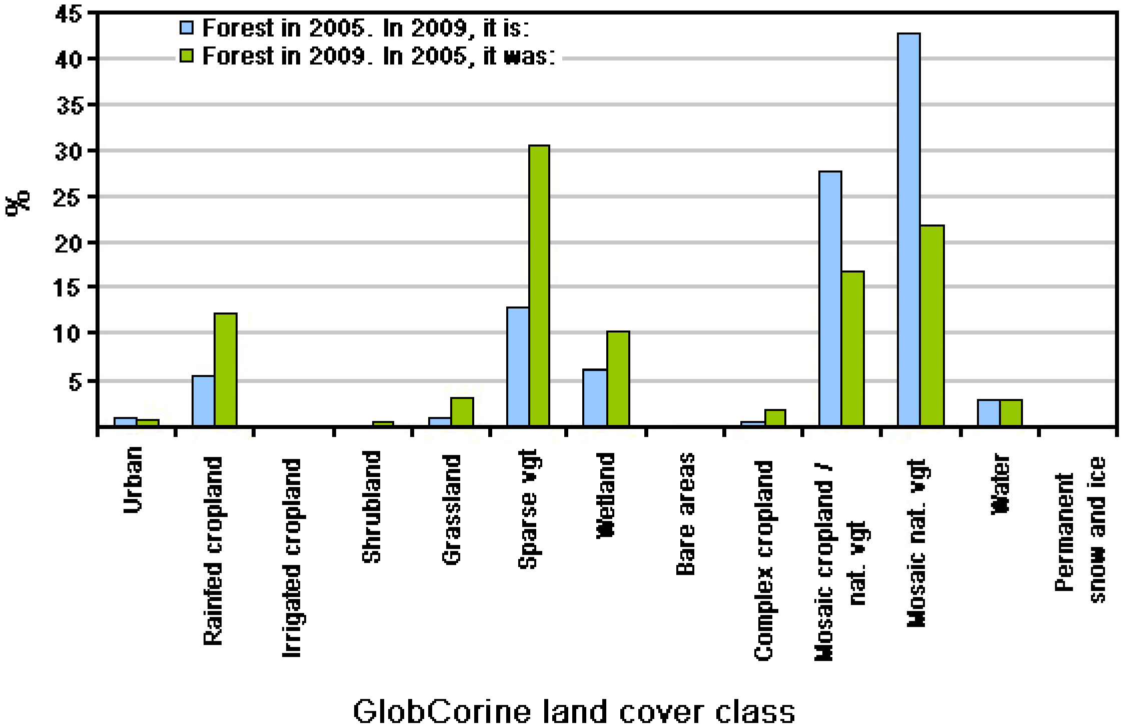

Figure 21. Classification instabilities for the "forest" class between the 2005 and 2009 GlobCorine maps

Similar figures related to the whole set of GlobCorine land cover classes are presented in the Appendix D. This analysis seems to indicate that most often, classification instabilities occur between "pure" and "mosaic" classes.

4. Recommendations – discussion – conclusion

This document reports on the accuracy of the 300-m pan-European land cover product delivered for the year 2009 (1st January to 31st December) in the course of this GlobCorine 2009 project.

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

- An automated classification approach based on ENVISAT's MERIS FRS time series;
- A 14-classes legend which have proved to be coherent at the continental scale and with transparent links both with LCCS and CLC.

Two comprehensive validation exercises have been completed providing quantitative figures of the product accuracy. According to the exercise based on the GlobCover validation dataset, the **overall accuracy reaches 78%** (**81.3%** when the overall accuracy value is **weighted** by the class area) using 403 points globally distributed and including homogeneous and heterogeneous landscapes. This accuracy is higher than that of GlobCover but slightly lower than that of the GlobCorine 2005 product. A second validation exercise, based on a direct comparison with the CLC2006 map, indicates an overall agreement of 48.6%.

The two validation exercises emphasize the impact of the mosaic classes on the overall accuracy. They also inform that the GlobCorine 2009 map quality varies according to the thematic class and to the region of interest. Looking at the contingency matrices (Table 5 and Table 6) gives indication about the accuracy of each class. Land cover classes such as the "Rainfed cropland", "Irrigated cropland", "Forest" and the "Bare areas" were found to be quite accurately mapped. On the other hand, classes such as "Heathland and sclerophyllous vegetation", "Grassland", "Sparsely vegetated areas", "Complex cropland" and "Permanent snow and ice" can be affected by errors. In particular, they can be affected by contamination errors with spreads of the class "Mosaic of natural (herbaceous, shrub, tree) vegetation". As for the "Urban areas" and "Wetland" classes, a clear improvement was noted comparing to GlobCorine 2005. The number of points used for the validation exercise based on the GlobCover dataset has also to be taken into consideration, since this dataset does not ensure that each class is representatively sampled. Typically, the classes of "Heathland and sclerophyllous vegetation", of "Sparsely vegetated areas", of "Vegetated low-lying areas on regularly flooded soil" and of "Permanent snow and ice" are under-sampled.

The limitation of the GlobCorine product can mainly be explained by several strategic choices. First, only MERIS data are used, thus always missing the critical SWIR band for the forest discrimination. Second, the automation of the interpretation chain requires relying for the class labeling on already existing land cover products.

Finally, the consistency between the GlobCorine 2005 and 2009 products is evaluated through visual and quantitative comparisons between the two maps. It reveals that despite similar proportions of the land cover classes shared by the two products, the GlobCorine 2009 land cover map seems to show differently some aspects of the European landscapes. To some extent, the GlobCorine 2009 map is indeed less detailed than the GlobCorine 2005 map both from the thematic and spatial point of view. This is notably due to the quality of the input time series (decrease in the amount of available MERIS FRS acquisitions), to some inter-annual variability effects (such as permanent snow cover or fires) and to the use of the GlobCorine 2005 map as reference dataset for the labeling procedure.

The GlobCorine 2009 project has clearly demonstrated the operational service provided by the developed automated classification chain since a product related to the year 2009 has been delivered in the course of the following year. However, as already mentioned, due to a lesser quality of the input data and to the use of a new reference map used for the labeling procedure, the GlobCorine 2009 land cover map is associated with a lower overall accuracy than the GlobCorine 2005 product.

As already demonstrated by the Corine experience in change mapping, reliable change detection can never be achieved by comparing two independent successive land cover maps. Therefore, **the GlobCorine 2009 land cover map cannot be used for any change detection application**. In particular, **the direct comparison with the previous GlobCorine 2005 product should be avoided** since it cannot guarantee accurate land cover change quantification. The GlobCorine maps are provided as they are, with a quantified error and their accuracy surely prevents any consistent comparison with older maps to depict the change area. Indeed, the change rate will always be much lower than the classification errors, thus hampering any relevant use for change mapping.

Appendix A. Correspondence between the GlobCorine legend and the LCCS

VALUE	LABEL	LCCS MAIN TYPE	LCCS CODES
10	Urban and associated areas	B15	XX
20	Rainfed cropland	A11	A1D1// A2D1// A3D1
30	Irrigated cropland	A11	A1D3//A2D3//A3D2//A3D3
40	Forest	A12	A3A11XXXXXXXX//A3A13XXXXXXXX//A3A20XXXXXXXX//A3A21XXXXXXXX
50	Heathland and sclerophyllous vegetation	A12	A1A11XXXXXXXX//A1A13XXXXXXXX//A1A20XXXXXXXX//A1A21XXXXXXXX//A4A11XXXXXXXX//A4A13XXXXXXXX//A4A20XXXXXXXX//A4A21XXXXXXXX
60	Grassland	A12	A2A11XXXXXXXX//A2A13XXXXXXXX//A2A20XXXXXXXX//A2A21XXXXXXXX
70	Sparsely vegetated area	A12	A1A14XXXXXXXX//A2A14XXXXXXXX//A3A14XXXXXXXX//A4A14XXXXXXXX//A7A14XXXXXXXX
80	Vegetated low-lying areas on regularly flooded soil	A24	A1A21XXXXXX//A2A21XXXXXX//A1A20XXXXXX//A2A20XXXXXX
90	Bare areas	B16	XX
100	Complex cropland	A11/A11	A1D1//A1D3//A2D1//A2D3//A3D1//A3D2//A3D3/A1D1//A1D3//A2D1//A2D3//A3D1//A3D2//A3D3

110	Mosaic cropland / natural vegetation	A11/A12	A1D1//A1D3//A2D1//A2D3//A3D1//A3D2//A3D3/A2A11XXXXXXXX//A2A13XXXXXXXX//A2A20XXXXXXXX//A2A21XXXXXXXX//A1A11B3XXXXXX//A1A13B3XXXXXX//A1A20B3XXXXXX//A1A21B3XXXXXX//A4A11B3XXXXXX//A4A13B3XXXXXX//A4A20B3XXXXXX//A4A21B3XXXXXX//A3A11B2XXXXXX//A3A13B2XXXXXX//A3A20B2XXXXXX//A3A21B2XXXXXX
120	Mosaic of natural (herbaceous, shrub, tree) vegetation	A12/A12	A2A11XXXXXXXX//A2A13XXXXXXXX//A2A20XXXXXXXX//A2A21XXXXXXXX/A1A11B3XXXXXX//A1A13B3XXXXXX//A1A20B3XXXXXX//A1A21B3XXXXXX//A4A11B3XXXXXX//A4A13B3XXXXXX//A4A20B3XXXXXX//A4A21B3XXXXXX//A3A11B2XXXXXX//A3A13B2XXXXXX//A3A20B2XXXXXX//A3A21B2XXXXXX/A2A11XXXXXXXX//A2A13XXXXXXXX//A2A20XXXXXXXX//A2A21XXXXXXXX/A1A11B3XXXXXX//A1A13B3XXXXXX//A1A20B3XXXXXX//A1A21B3XXXXXX//A4A11B3XXXXXX//A4A13B3XXXXXX//A4A20B3XXXXXX//A4A21B3XXXXXX//A3A11B2XXXXXX//A3A13B2XXXXXX//A3A20B2XXXXXX//A3A21B2XXXXXX
200	Water bodies	B27/B28	A1
210	Permanent snow and ice	B27/B28	A2//A3

Appendix B. Correspondence between the GlobCorine and CLC nomenclatures

VALUE	LABEL	CLC CODES (LEVEL 3)	CLC LABELS (LEVEL 3)
10	Urban and associated areas	111	Continuous urban fabric
		112	Discontinuous urban fabric
		121	Industrial or commercial units
		122	Road and rail networks and associated land
		123	Port areas
		124	Airports
		131	Mineral extraction sites
		132	Dump sites
		133	Construction sites
		141	Green urban areas
		142	Sport and leisure facilities
20	Rainfed cropland	211	Non-irrigated arable land
		221	Vineyards
		222	Fruit trees and berry plantations
		223	Olive groves
30	Irrigated cropland	212	Permanently irrigated land
		213	Rice fields

40	Forest	311	Broad-leaved forest
		312	Coniferous forest
		313	Mixed forest
50	Heathland and sclerophyllous vegetation	322	Moors and heathland
		323	Sclerophyllous vegetation
60	Grassland	231	Pastures
		321	Natural grasslands
70	Sparsely vegetated area	333	Sparsely vegetated areas
80	Vegetated low-lying areas on regularly flooded soil	411	Inland marshes
		412	Peat bogs
		421	Salt marshes
		423	Intertidal flats
90	Bare areas	332	Bare rocks
		331	Beaches, dunes, sands
100	Complex cropland	241	Annual crops associated with permanent crops
		242	Complex cultivation patterns
110	Mosaic cropland / natural vegetation	243	Land principally occupied by agriculture, with significant areas of nat. veg.
		244	Agro-forestry areas

120	Mosaic of natural (herbaceous, shrub, tree) vegetation	324	Transitional woodland-shrub
200	Water bodies	511	Water courses
		512	Water bodies
		521	Coastal lagoons
		522	Estuaries
		523	Sea and ocean
210	Permanent snow and ice	335	Glaciers and perpetual snow

Appendix C. Visual comparison of the spatial distribution of each class in GlobCorine 2005 and 2009

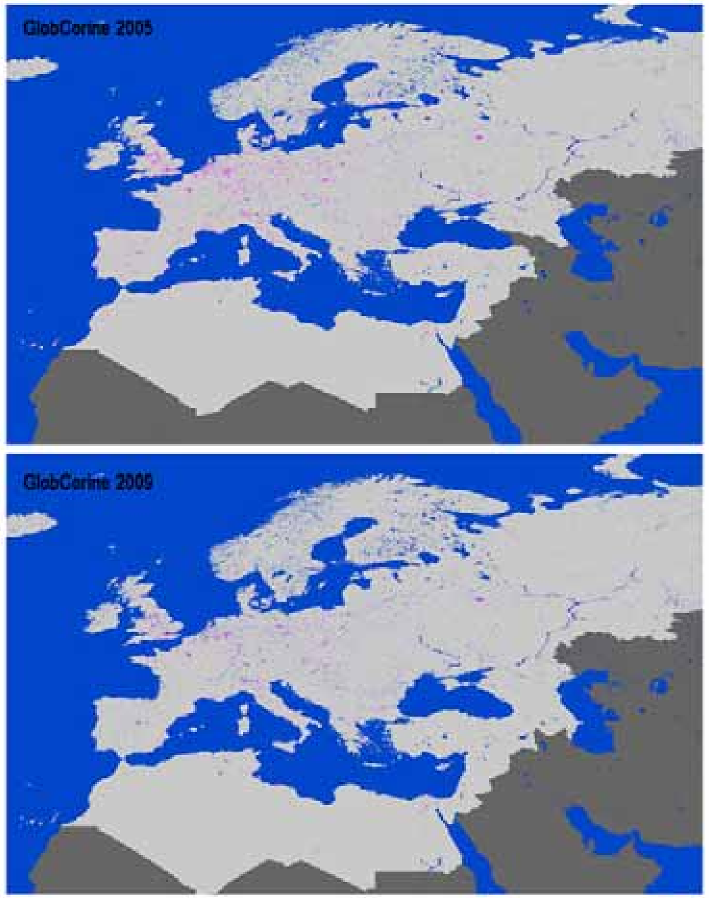

Figure 22. Spatial distribution of the "Urban" class in the GlobCorine 2005 and 2009 maps

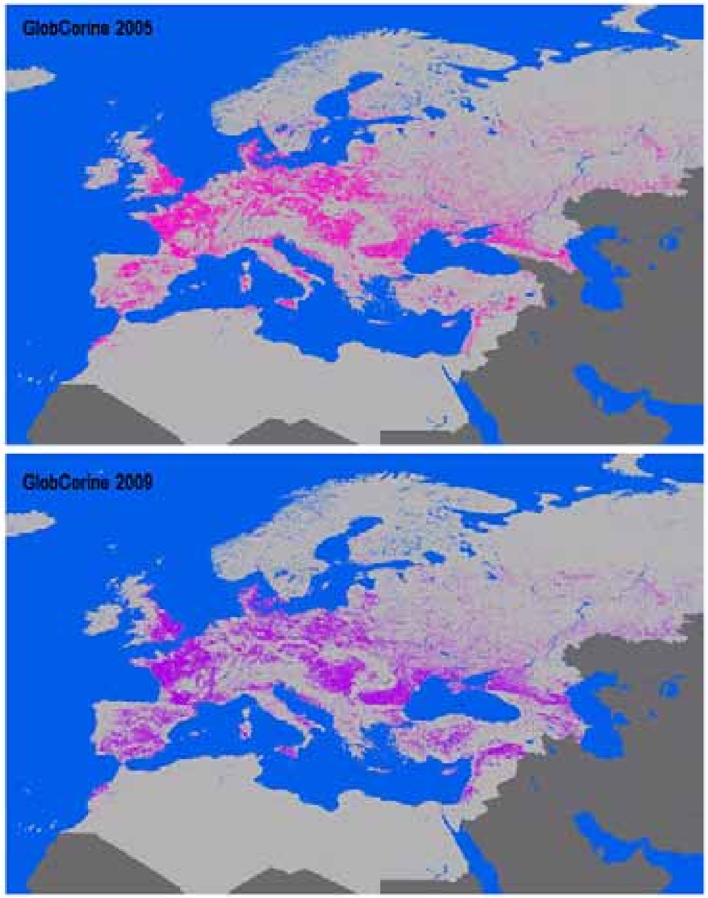

Figure 23. Spatial distribution of the "Rainfed cropland" class in the GlobCorine 2005 and 2009 maps

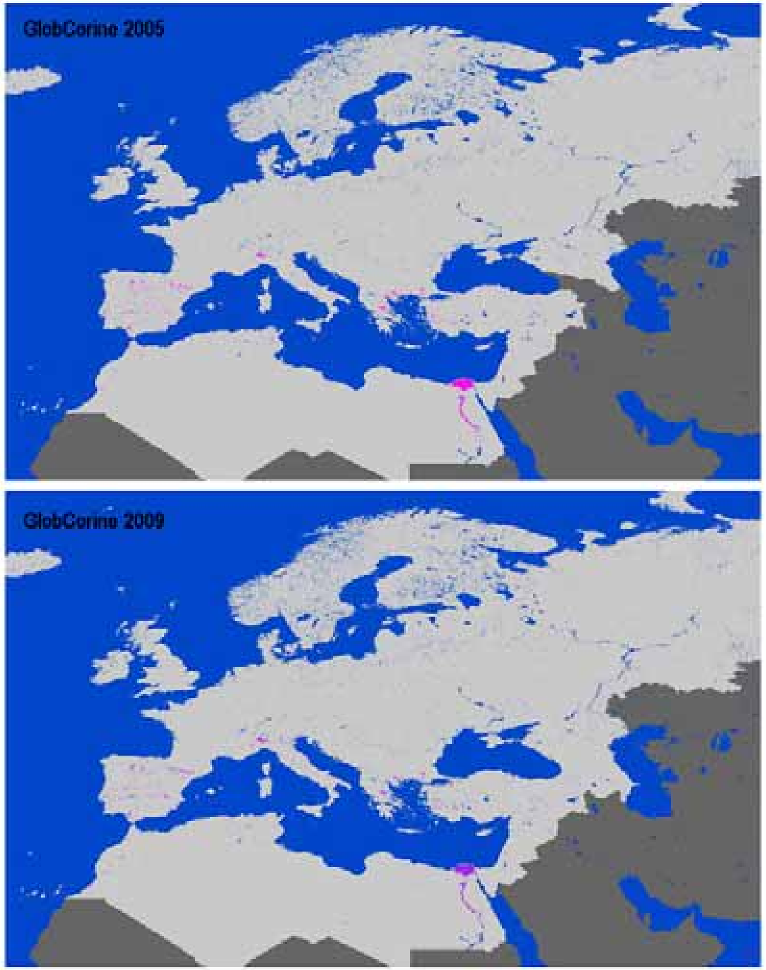

Figure 24. Spatial distribution of the "Irrigated cropland" class in the GlobCorine 2005 and 2009 maps

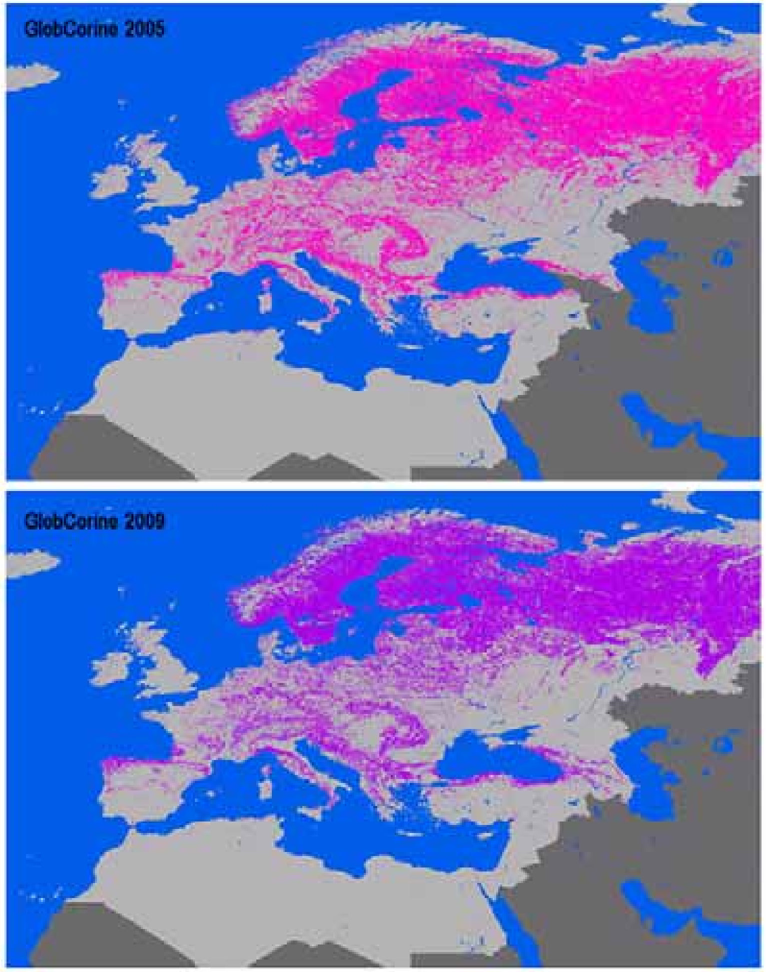

Figure 25. Spatial distribution of the "Forest" class in the GlobCorine 2005 and 2009 maps

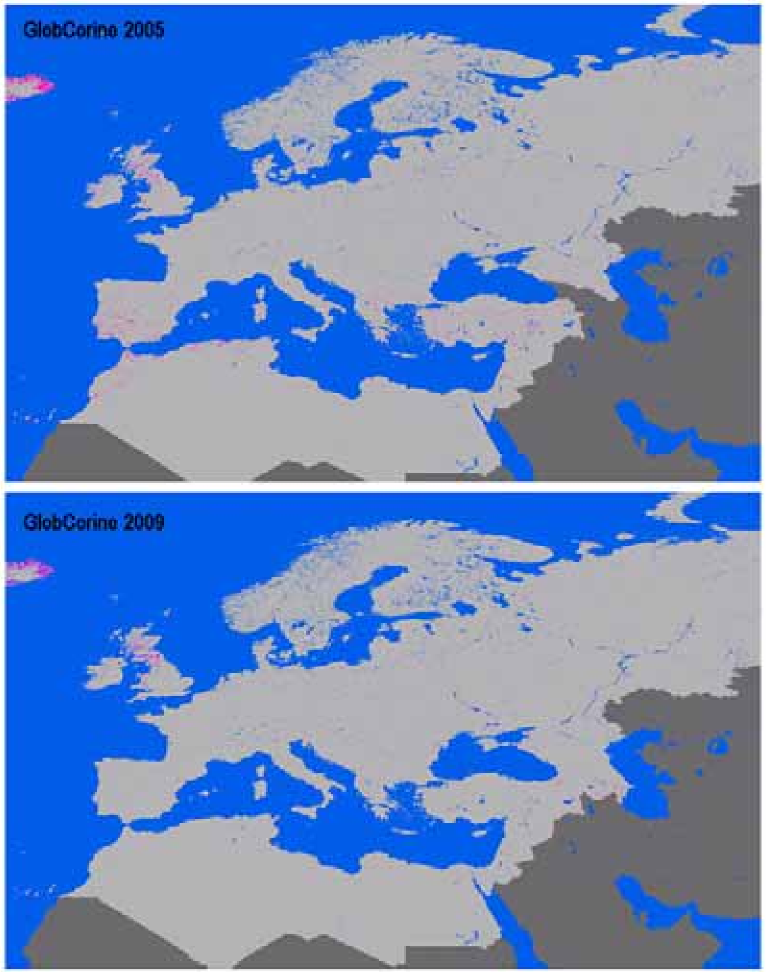

Figure 26. Spatial distribution of the "Shrubland" class in the GlobCorine 2005 and 2009 maps

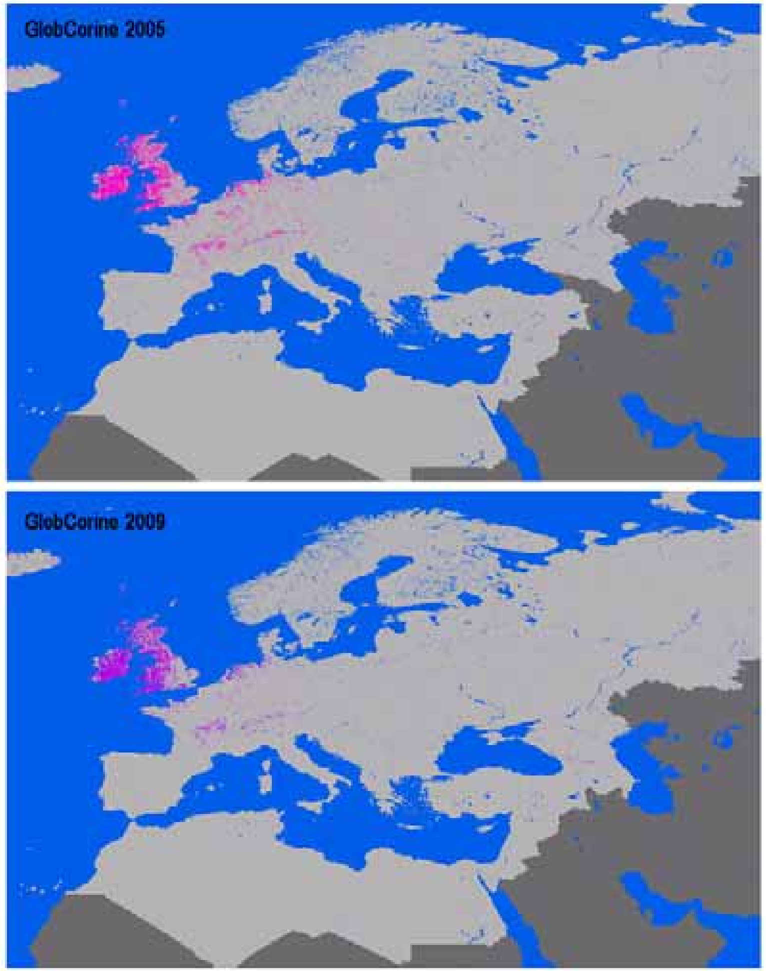

Figure 27. Spatial distribution of the "Grassland" class in the GlobCorine 2005 and 2009 maps

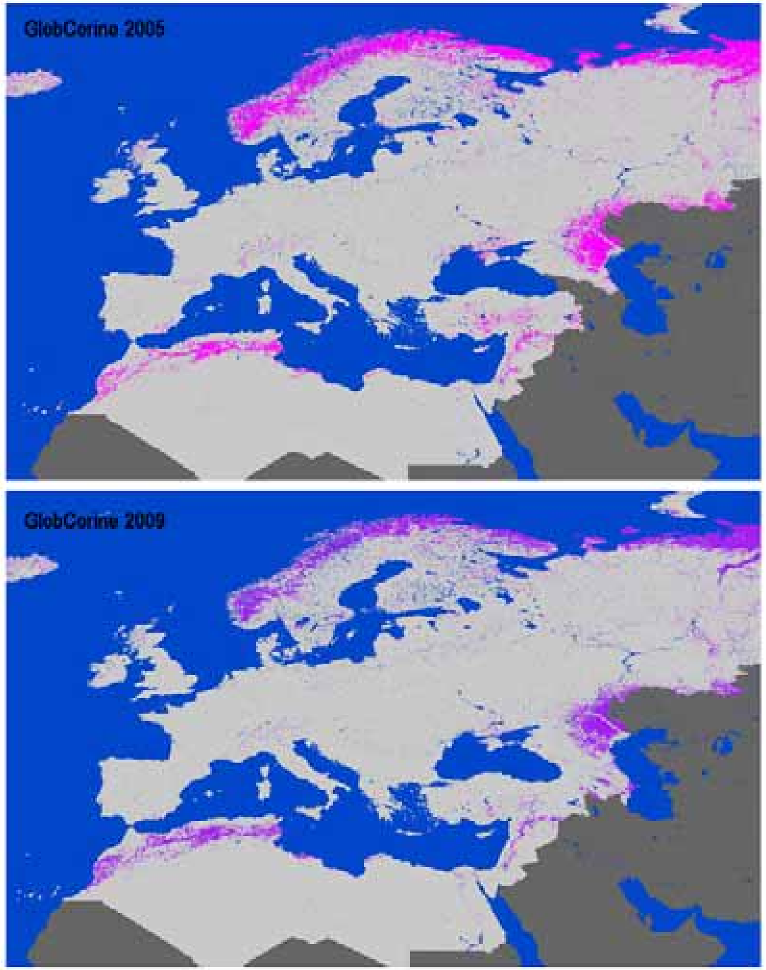

Figure 28. Spatial distribution of the "Sparse vegetation" class in the GlobCorine 2005 and 2009 maps

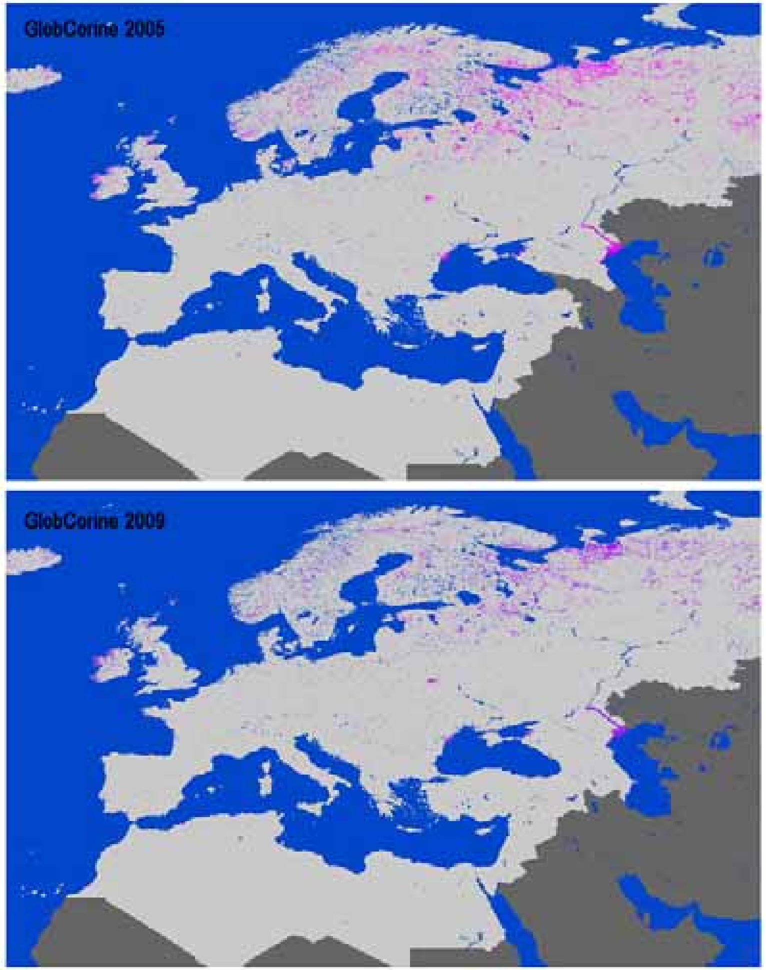

Figure 29. Spatial distribution of the "Wetland" class in the GlobCorine 2005 and 2009 maps

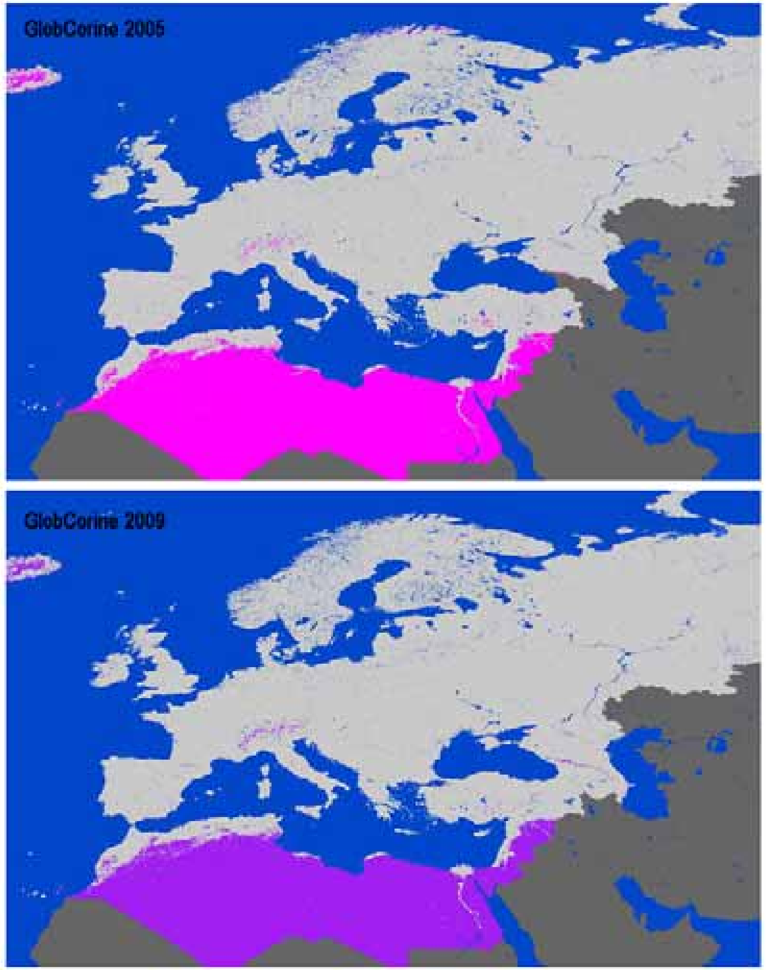

Figure 30. Spatial distribution of the "Bare areas" class in the GlobCorine 2005 and 2009 maps

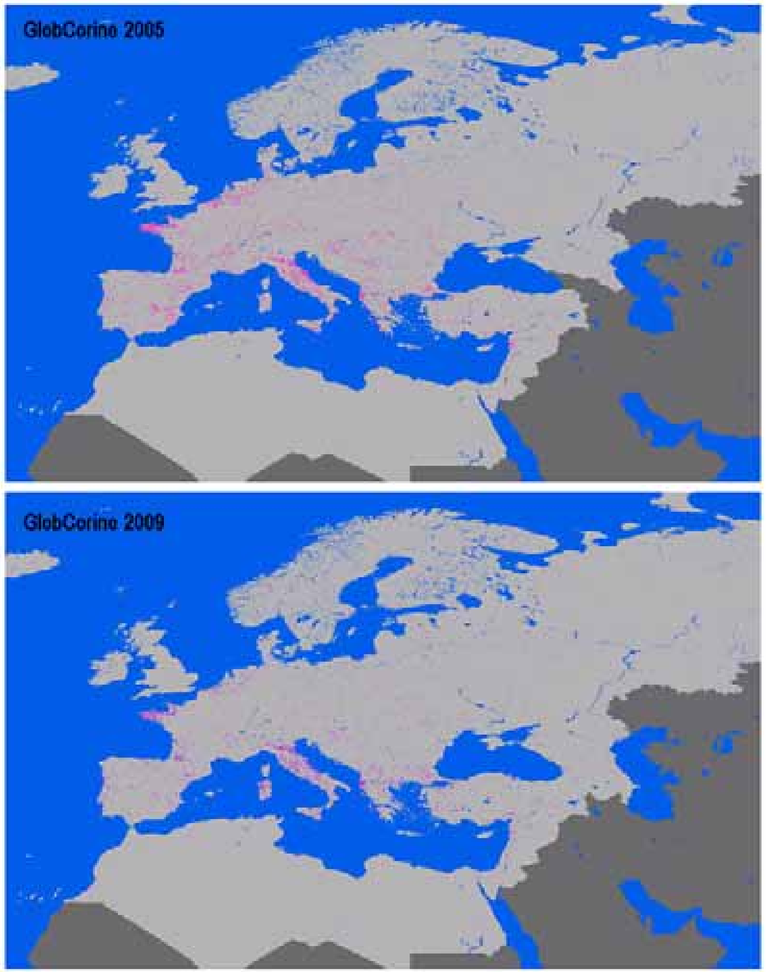

Figure 31. Spatial distribution of the "Complex cropland" class in the GlobCorine 2005 and 2009 maps

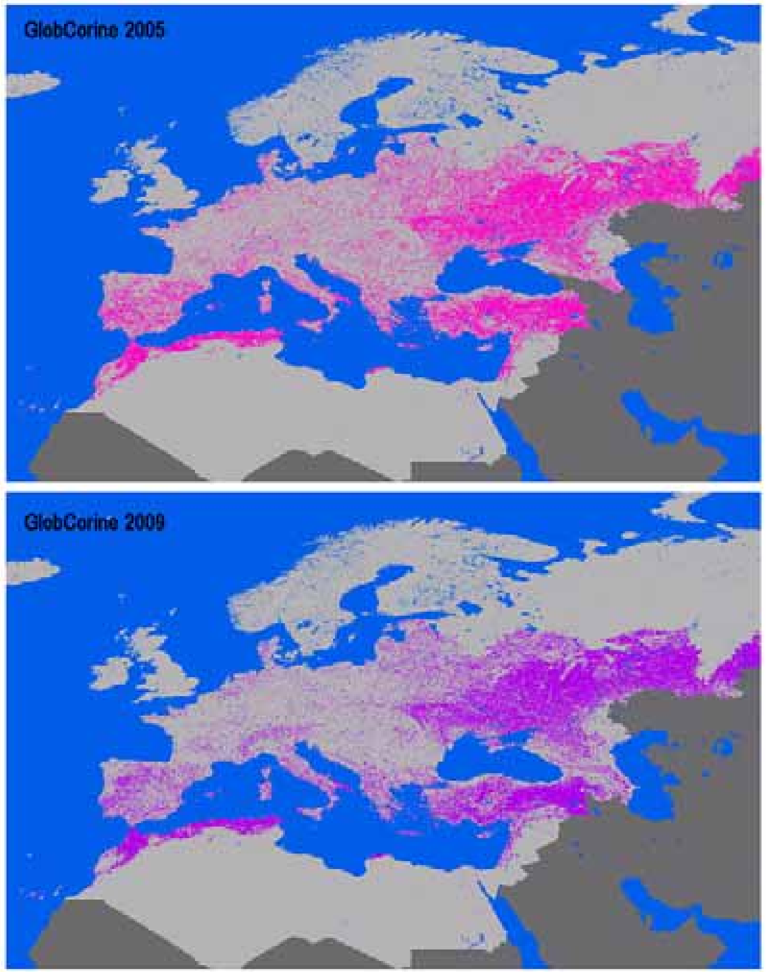

Figure 32. Spatial distribution of the "Mosaic cropland / natural vegetation" class in the GlobCorine 2005 and 2009 maps

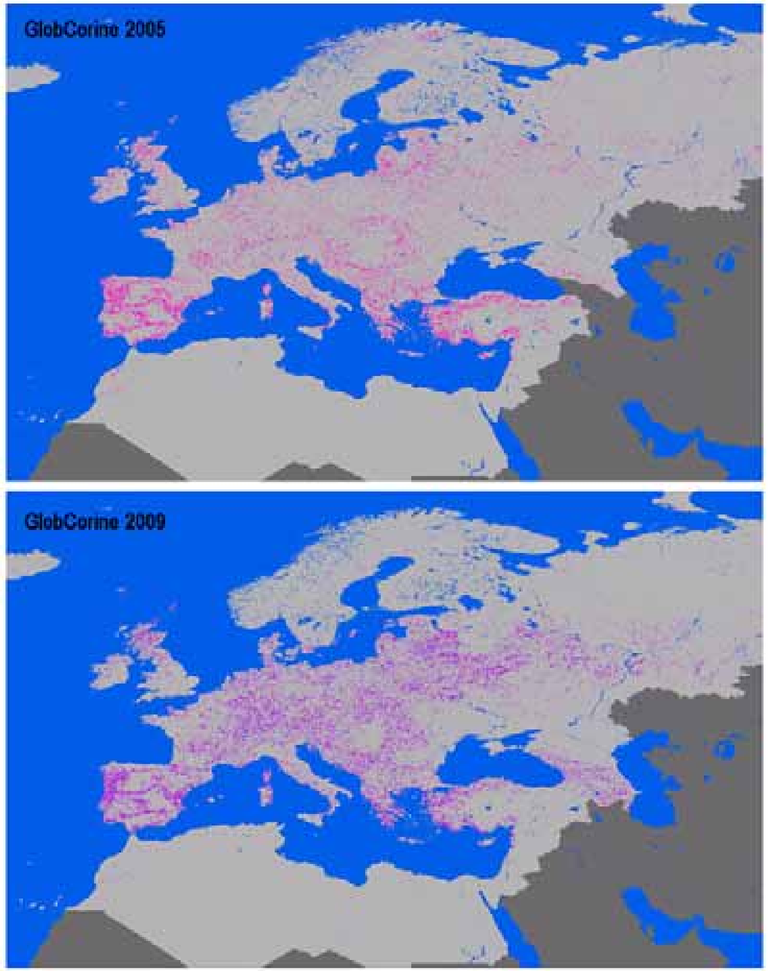

Figure 33. Spatial distribution of the "Mosaic of natural vegetation" class in the GlobCorine 2005 and 2009 maps

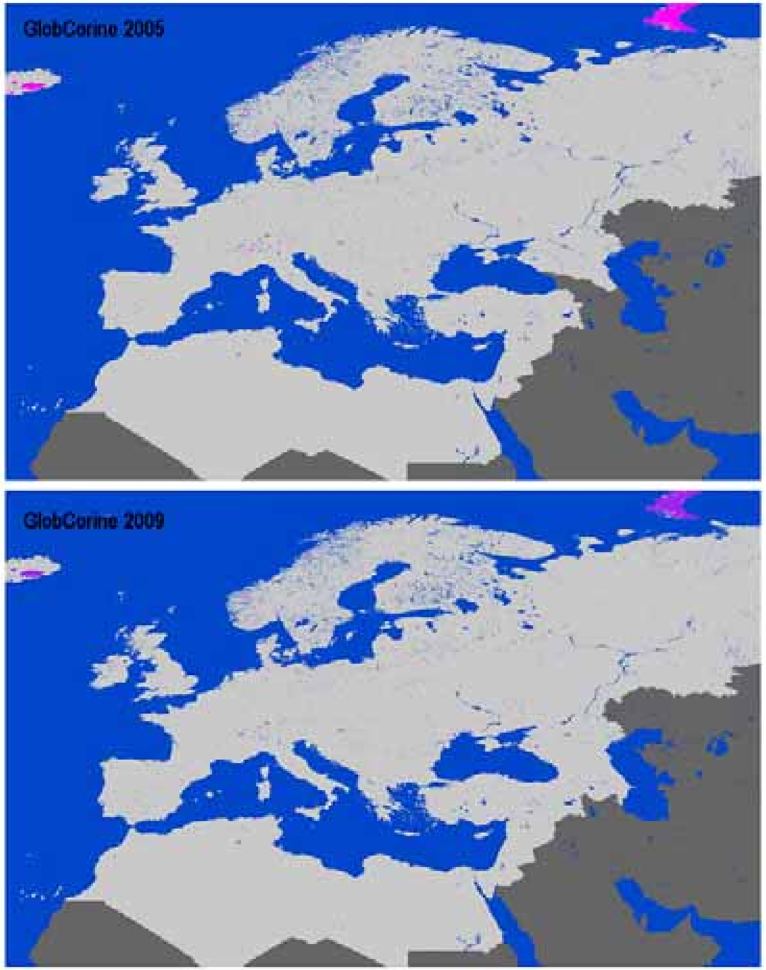

Figure 34. Spatial distribution of the "Snow" class in the GlobCorine 2005 and 2009 maps

Appendix D. Classification instabilities between 2005 and 2009 for each land cover class

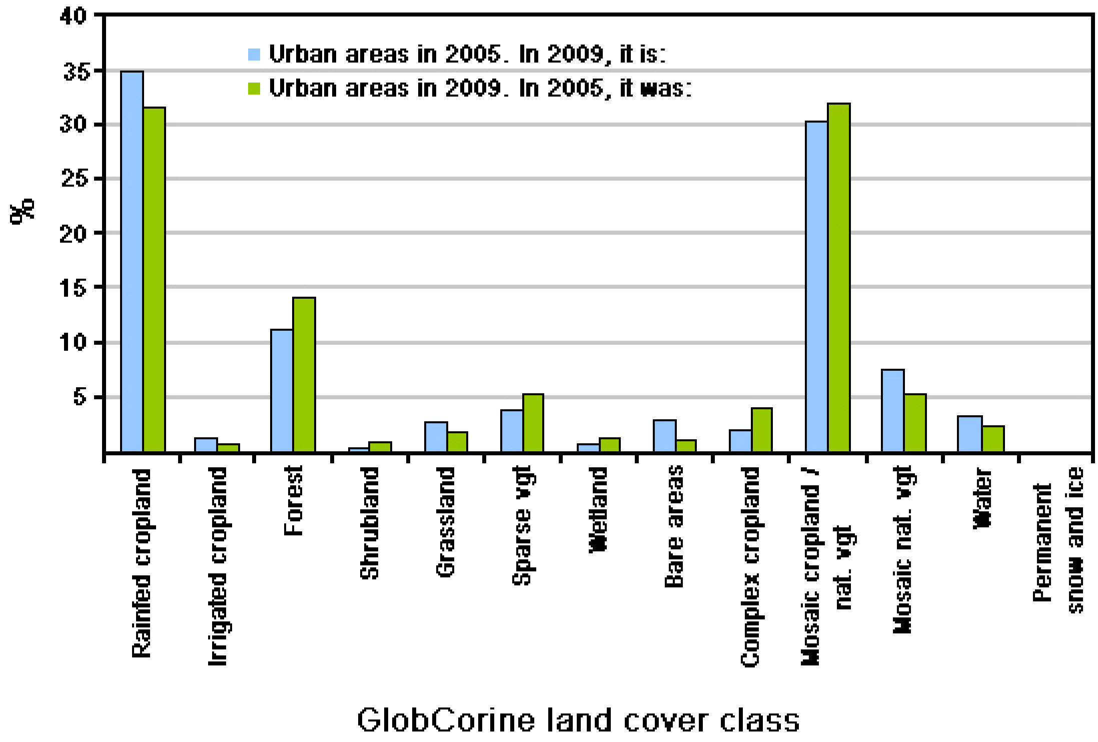

Figure 35. Classification instabilities for the "Urban" class between the 2005 and 2009 maps

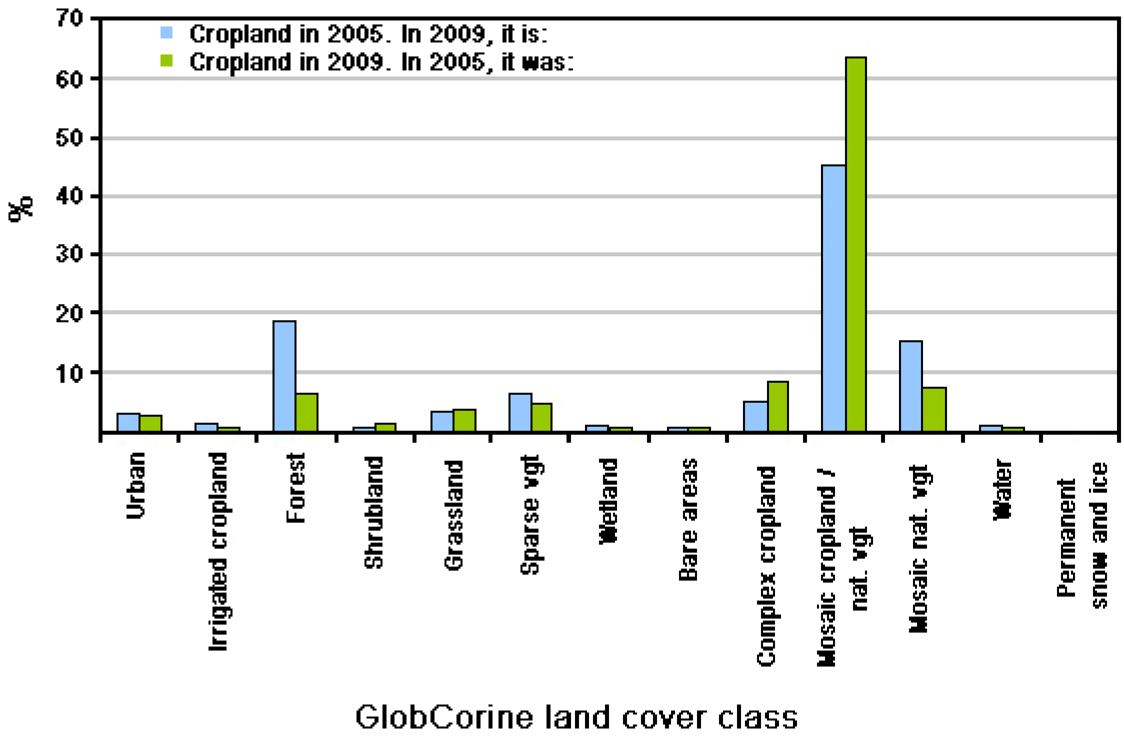

Figure36. Classification instabilities for the "Rainfed cropland" class between the 2005 and 2009 maps

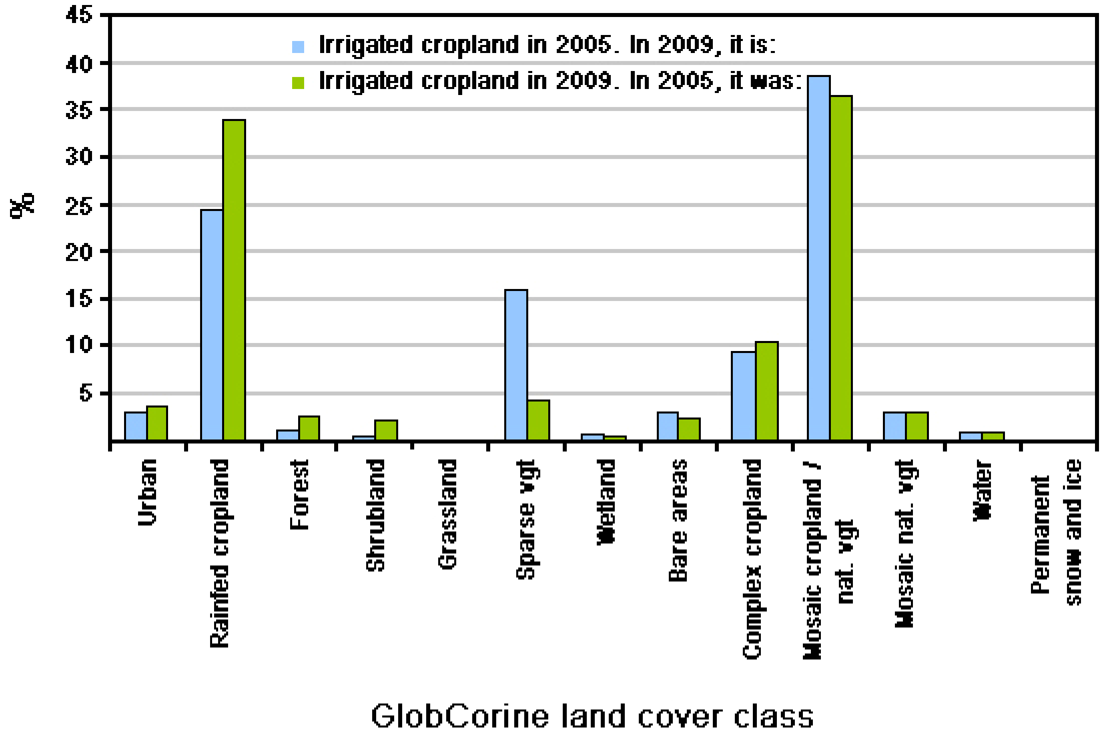

Figure 37. Classification instabilities for the "Irrigated cropland" class between the 2005 and 2009 GlobCorine maps

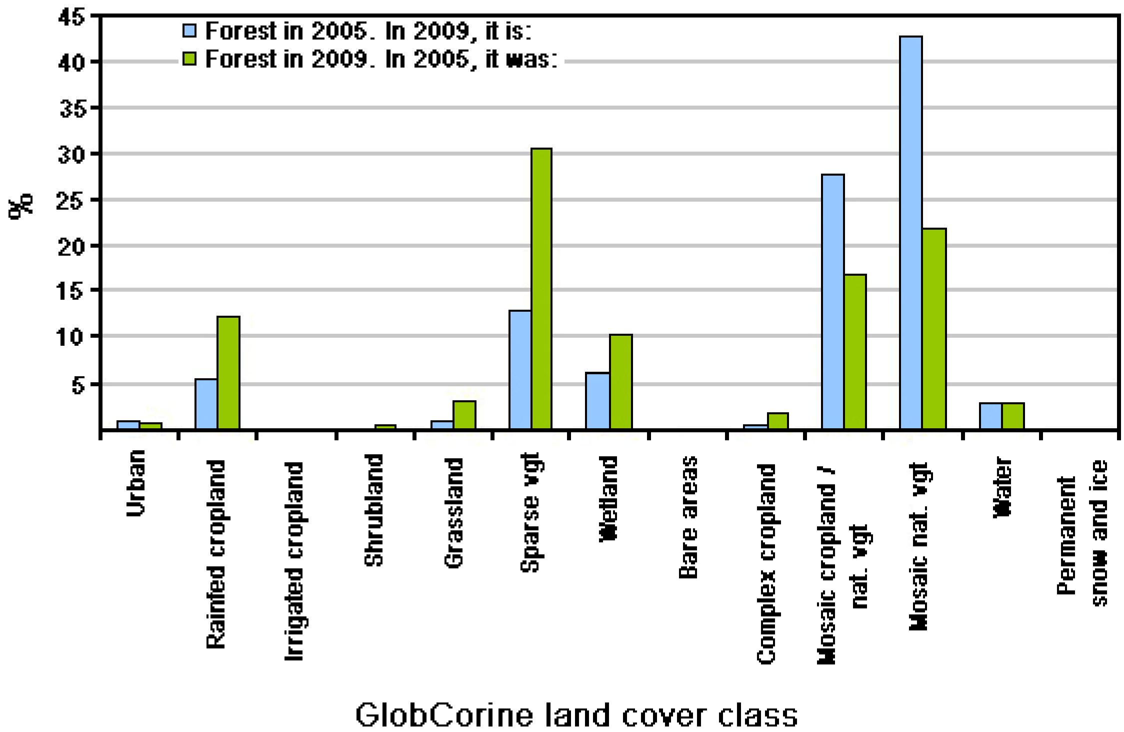

Figure 38. Classification instabilities for the "Forest" class between the 2005 and 2009 GlobCorine maps

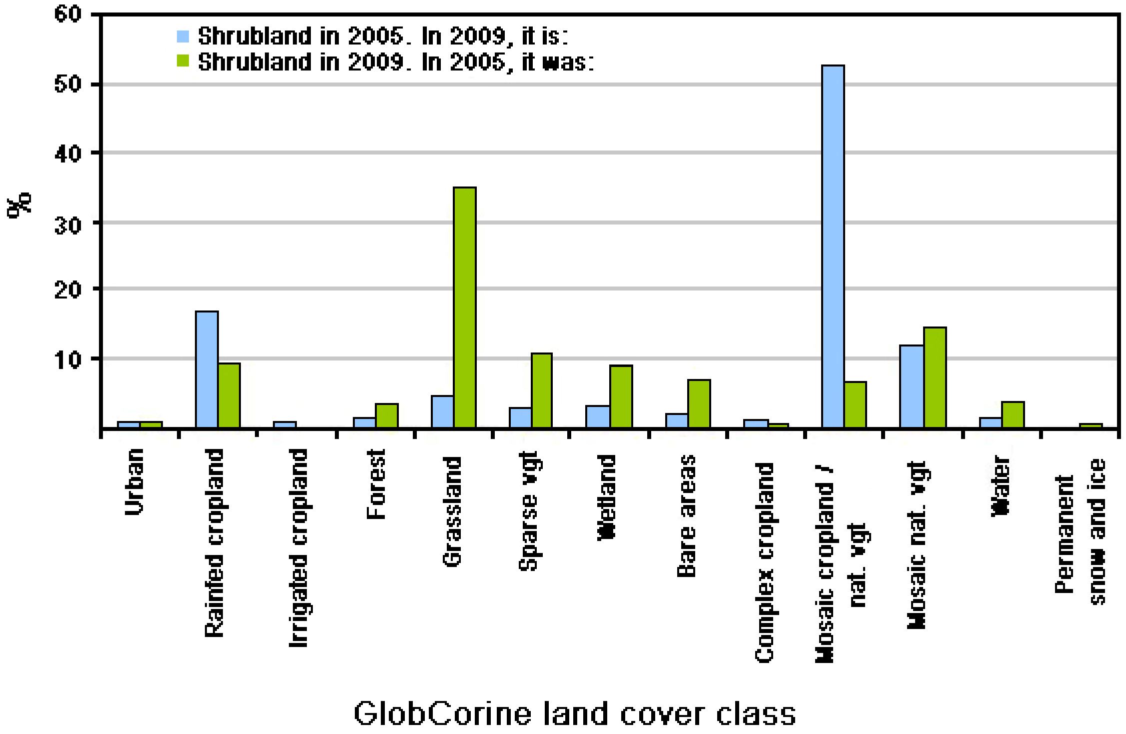

Figure 39. Classification instabilities for the "Shrubland" class between the 2005 and 2009 GlobCorine maps

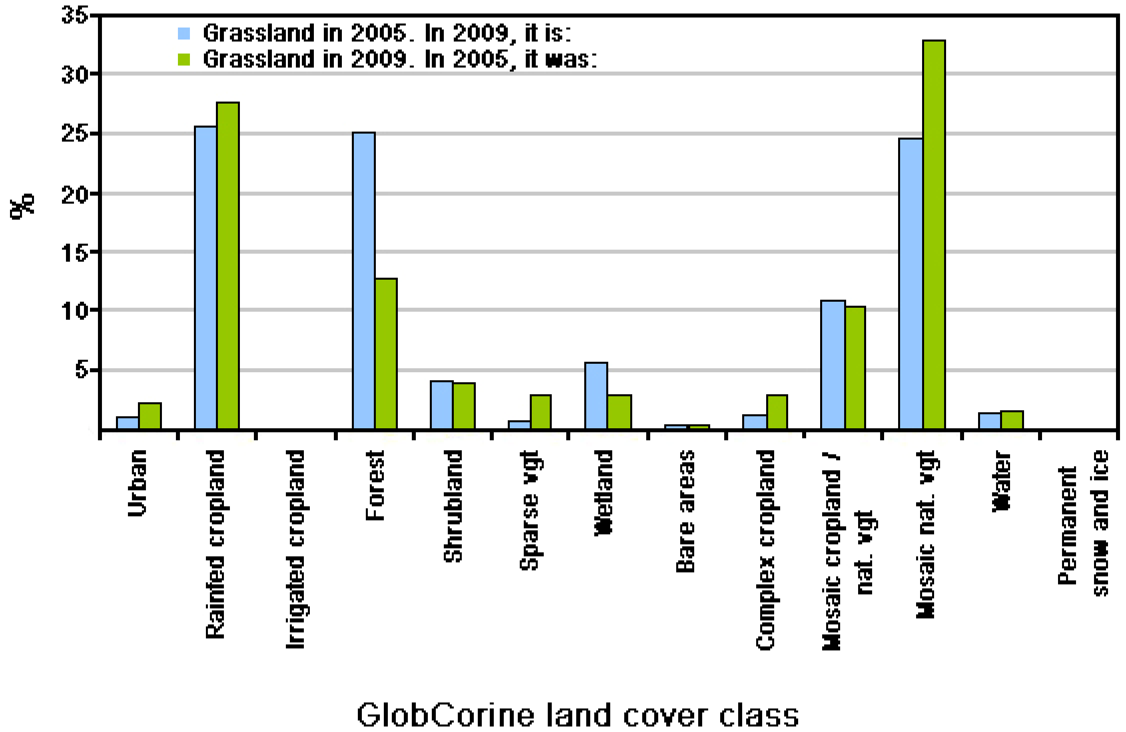

Figure 40. Classification instabilities for the "Grassland" class between the 2005 and 2009 GlobCorine maps

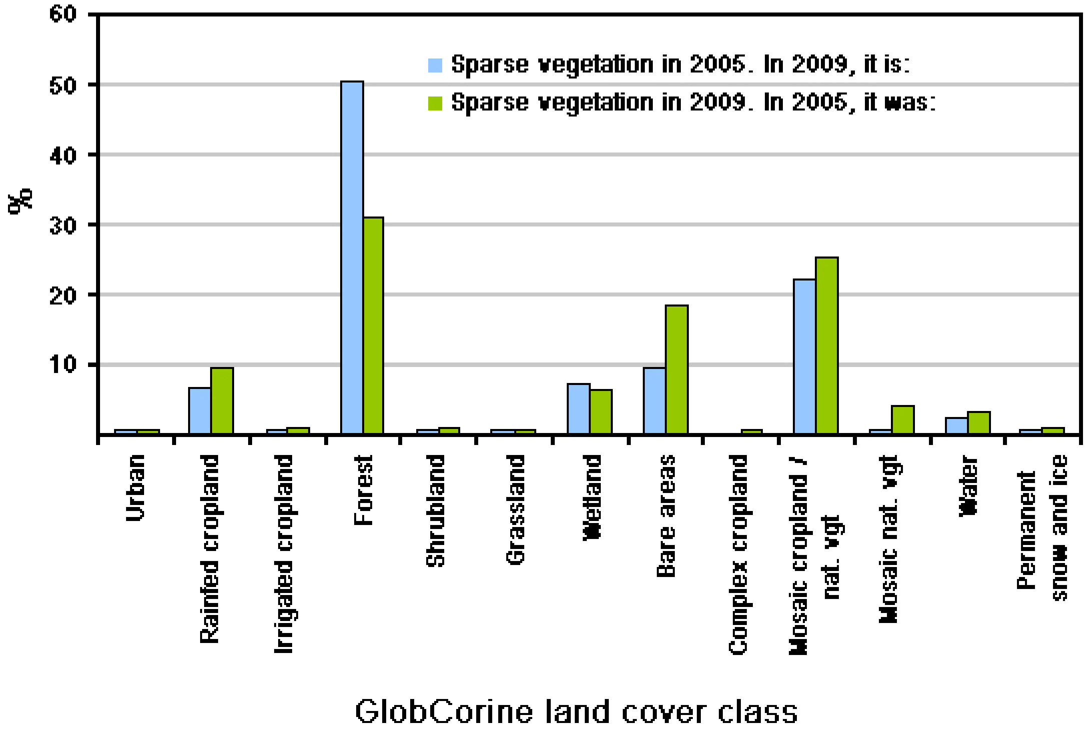

Figure 41. Classification instabilities for the "Sparse vegetation" class between the 2005 and 2009 GlobCorine maps

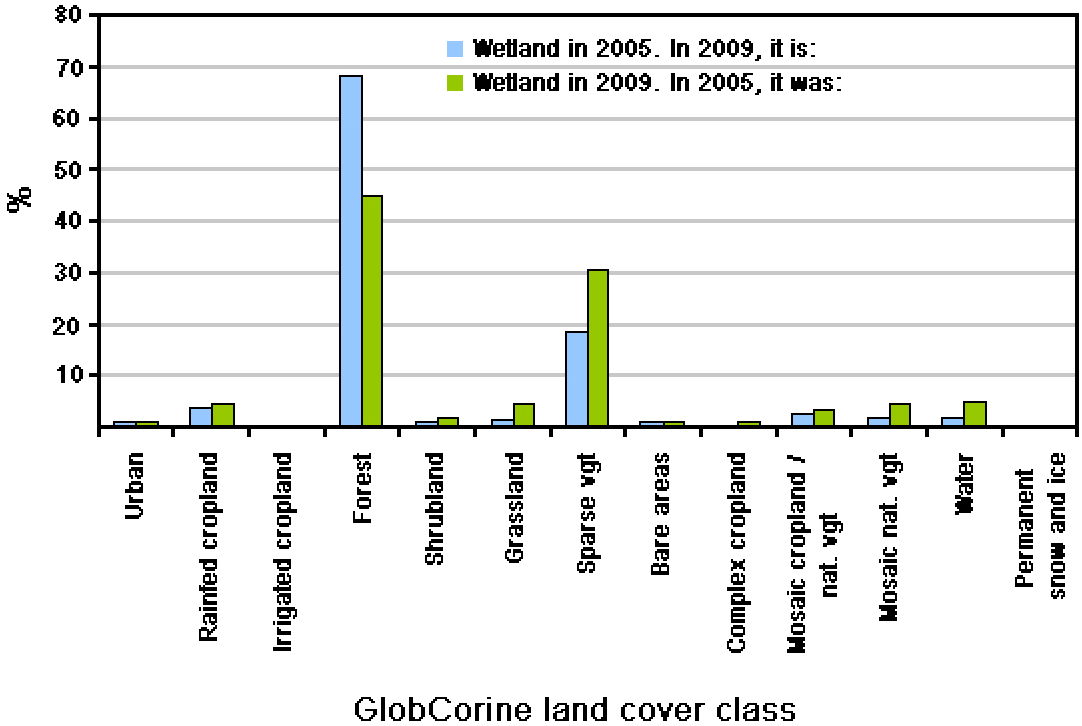

Figure 42. Classification instabilities for the "Wetland" class between the 2005 and 2009 GlobCorine maps

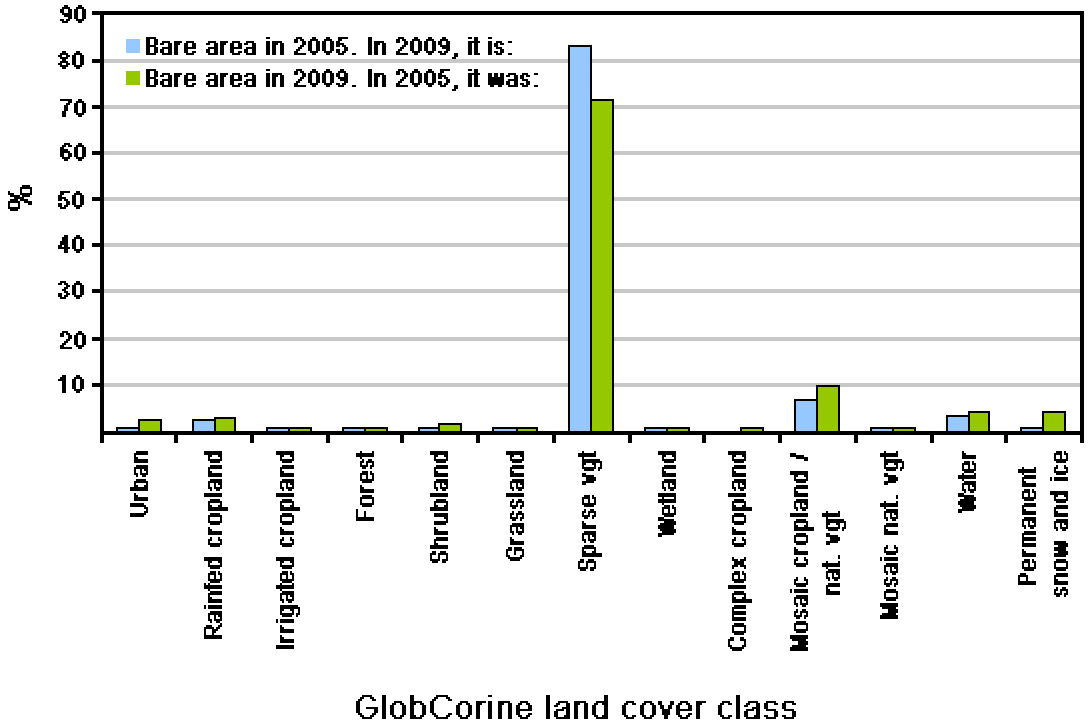

Figure 43. Classification instabilities for the "Bare areas" class between the 2005 and 2009 GlobCorine maps

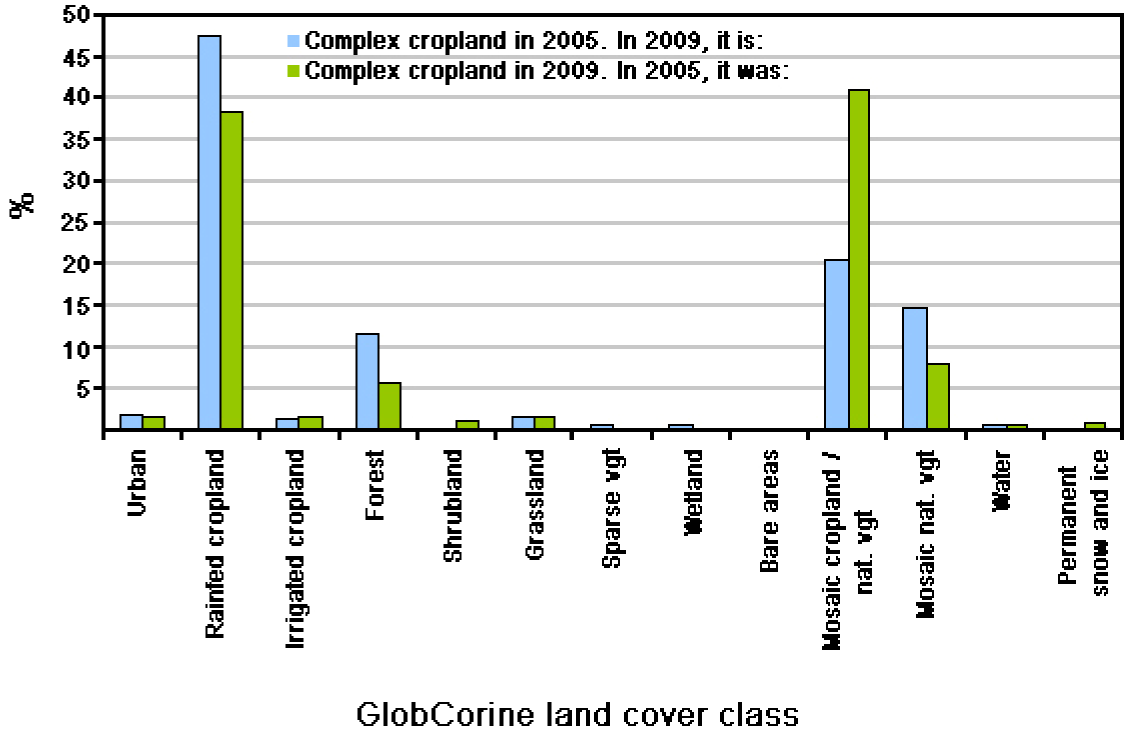

Figure 44. Classification instabilities for the "Complex cropland" class between the 2005 and 2009 GlobCorine maps

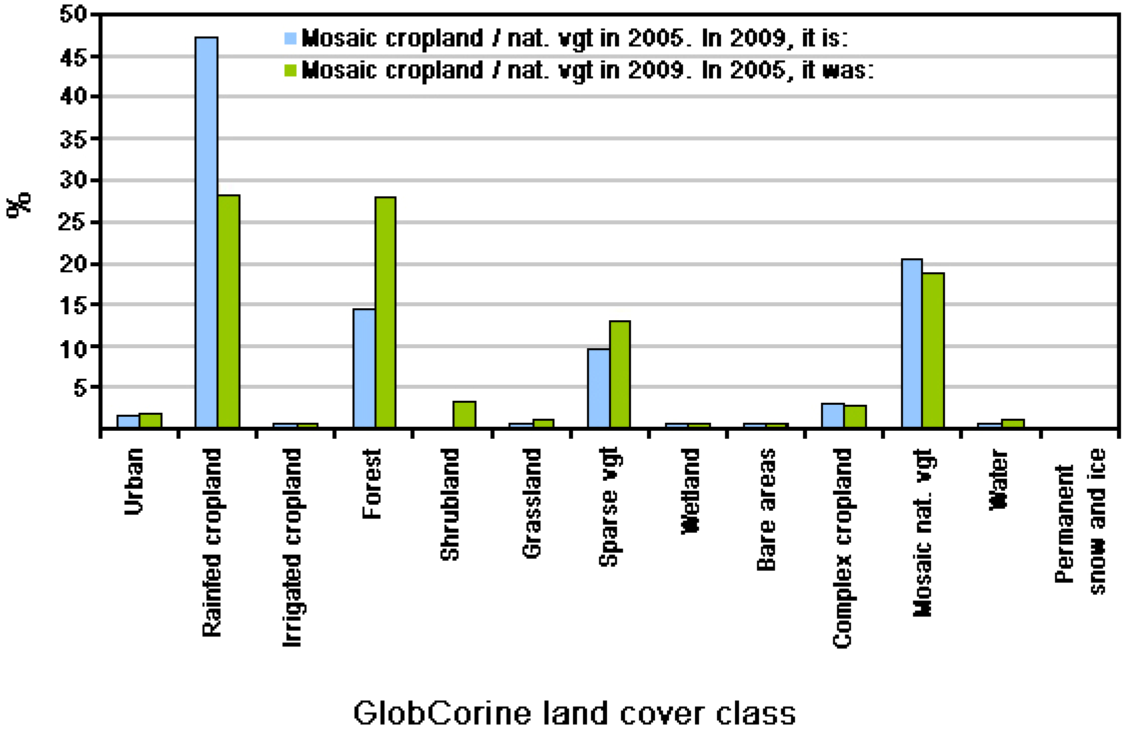

Figure 45. Classification instabilities for the "Mosaic cropland / natural vegetation" class between the 2005 and 2009 GlobCorine maps

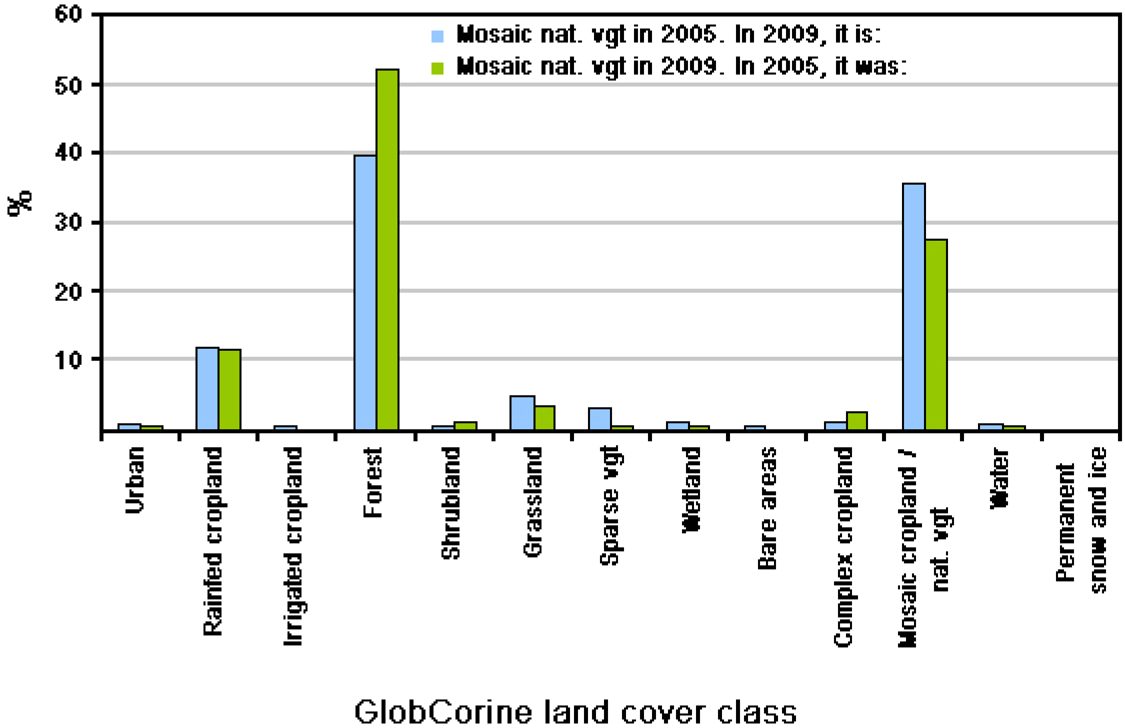

Figure 46. Classification instabilities for the "Mosaic of natural vegetation" class between the 2005 and 2009 GlobCorine maps

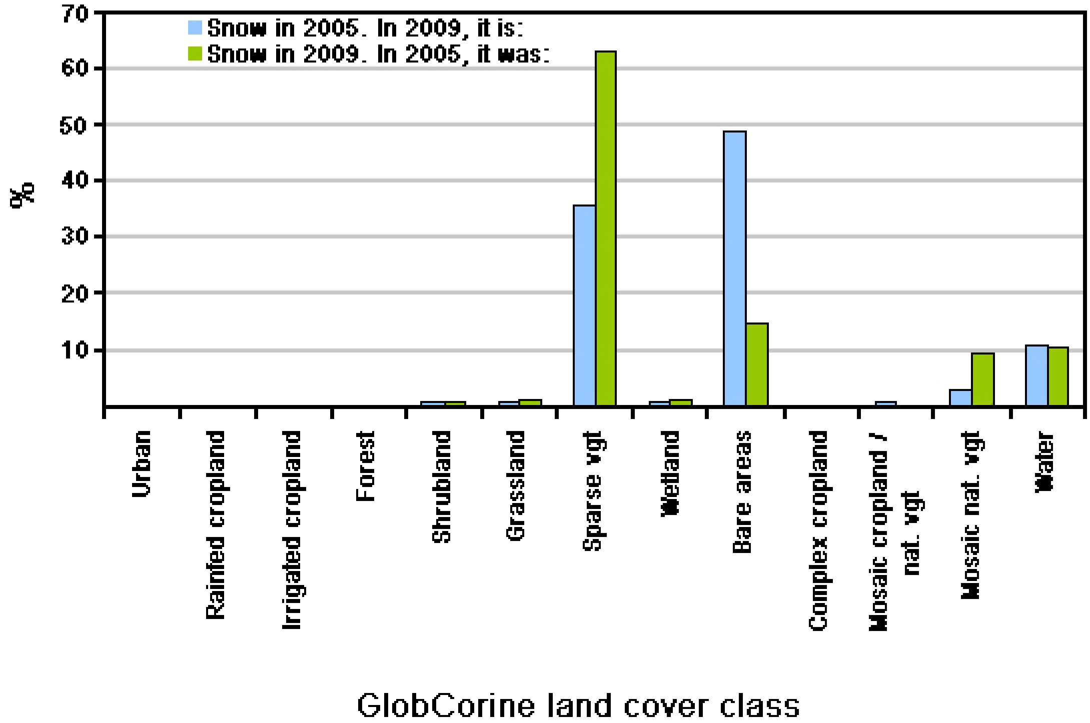

Figure 47. Classification instabilities for the "Snow" class between the 2005 and 2009 GlobCorine maps