Harmonisation, mosaicing and production of the Global Land Cover 2000 database (Beta Version)

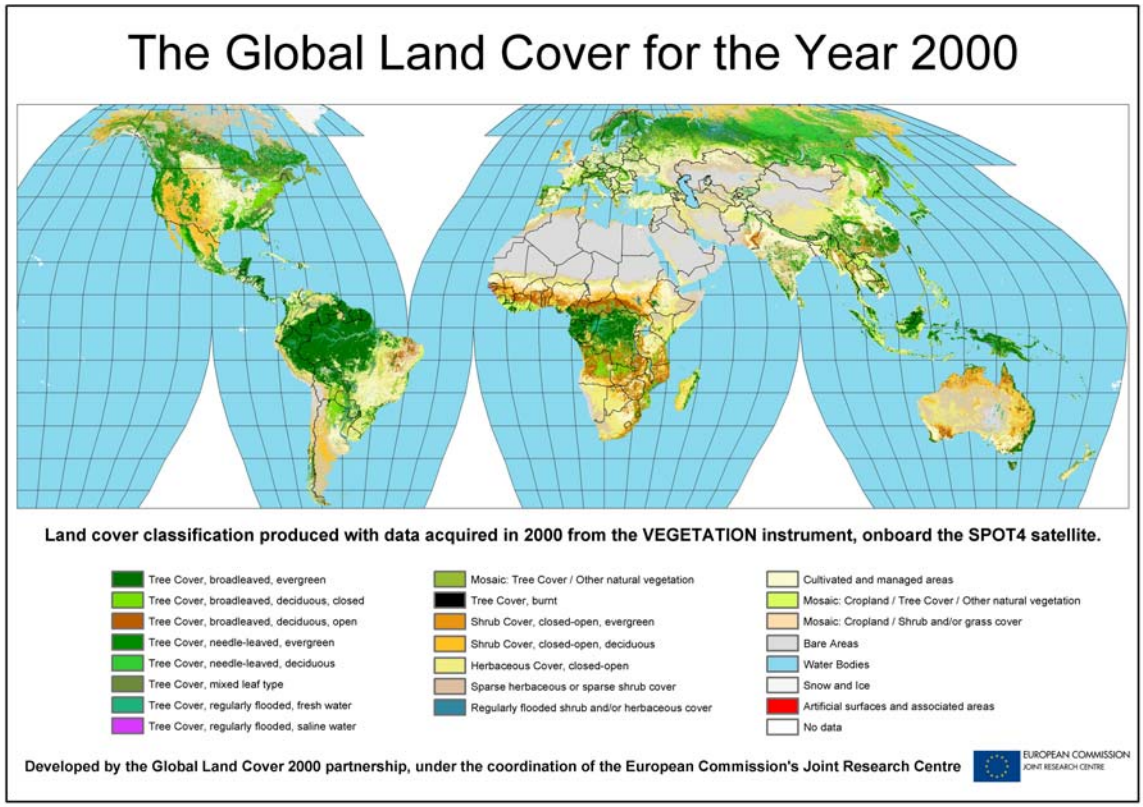

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Table of Content

1. Introduction - The GLC 2000 project

The co-ordination of the Global Land Cover 2000 project has been carried out under the Fifth Framework Programme 1999-2002 for Research of the European Commission. It is part of the project of the European Commission called Global Environment Information System (GEIS).

The GLC2000 project was carried out to provide information to the International Conventions on Climate Change, the Convention to Combat Desertification, the Ramsar Convention and the Kyoto Protocol. Furthermore the GLC2000 land cover database has been chosen as a core dataset for the Millennium Ecosystems Assessment. This means in particular that the GLC2000 dataset is a main input dataset to define the boundaries of the different ecosystems such as forest, grassland, and cultivated systems.

Since land cover information provides the boundary conditions for a number of climate and land surface process models, accurate information on land cover is essential. However, accurate land cover information is also needed to measure the impact and effectiveness of management actions associated with sustainable development policies. Addressing issues such as sustainable management and use of forests and other land resources, forest conservation and restoration, extension of surfaces dedicated to agriculture, desertification or watershed degradation will all substantially benefit from the availability of accurate baseline land cover information (United Nations, 2002).

In contrast to former global mapping initiatives the GLC2000 project is a bottom up approach to global mapping. In this project more than 30 research teams have been involved, contributing to 19 regional windows. There were two conditions to be fulfilled by the regional experts to guarantee a certain degree of consistency. The data had to be based on SPOT-4 VEGETATION VEGA2000 dataset, which was made freely available by CNES (Centre National d'Études Spatiales). Secondly, the partners agreed to use the Land Cover Classification System which was provided by FAO (Di Gregorio and Jansen, 2000). The fact that the mapping was carried out by regional experts has a number of benefits. Firstly, since each regional expert has a high level of understanding of their particular region, a certain level of quality can be guaranteed. Secondly, each partner has the freedom to apply their own methods of mapping and define their own regional legend. This allows the partners to apply the classification techniques they find most appropriate for land cover mapping in their respective region. Thirdly, the regional mapping approach ensures that access could be gained to reference material. For more information on the partners and the production of the regional products go to the web site (http://www.gvm.jrc.it/glc2000) and consult our metadata database (http://www.gvm.jrc.it/glc2000/Products/fullproduct.asp) under the topic'description'. Figure 1 shows the 19 different windows which were mapped under the GLC2000 partnership co-ordinated by the JRC and Table 1 provides a list of the different regions.

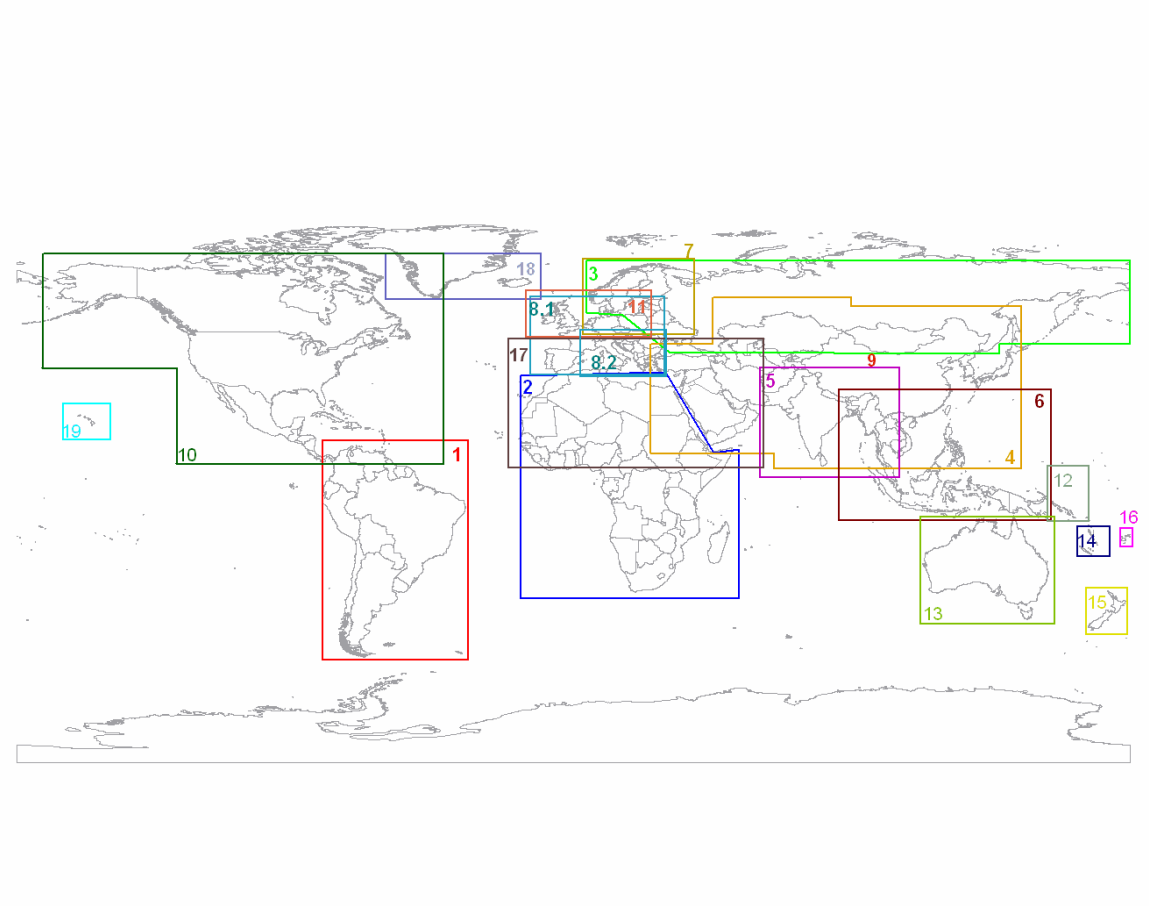


Figure 1: The 19 different windows

Table 1: Regional windows

Number	Region
1.	South America
2.	Africa
3.	Northern Eurasia
4.	Asia
5.	South Central Asia
6.	South East Asia
7.	North East Europe
8.1	Europe
8.2	Southern Europe
9.	China
10.	North America
11.	North West Europe
12.	Solomon Islands
13.	Australia
14.	New Caledonia and Vanuatu
15.	New Zealand
16.	Fijian Islands
17.	North Africa
18.	Greenland and Iceland
19.	Hawaiian Islands

2. Production and harmonisation of the Global Land Cover 2000

In order to produce a harmonised high quality Global Land Cover product a number of steps were required which involved a close collaboration with the GLC2000 partners. Figure 2 shows interactions between the JRC and the GLC2000 partners and illustrates the different processes required to harmonise and mosaic the Global Land Cover 2000 product.

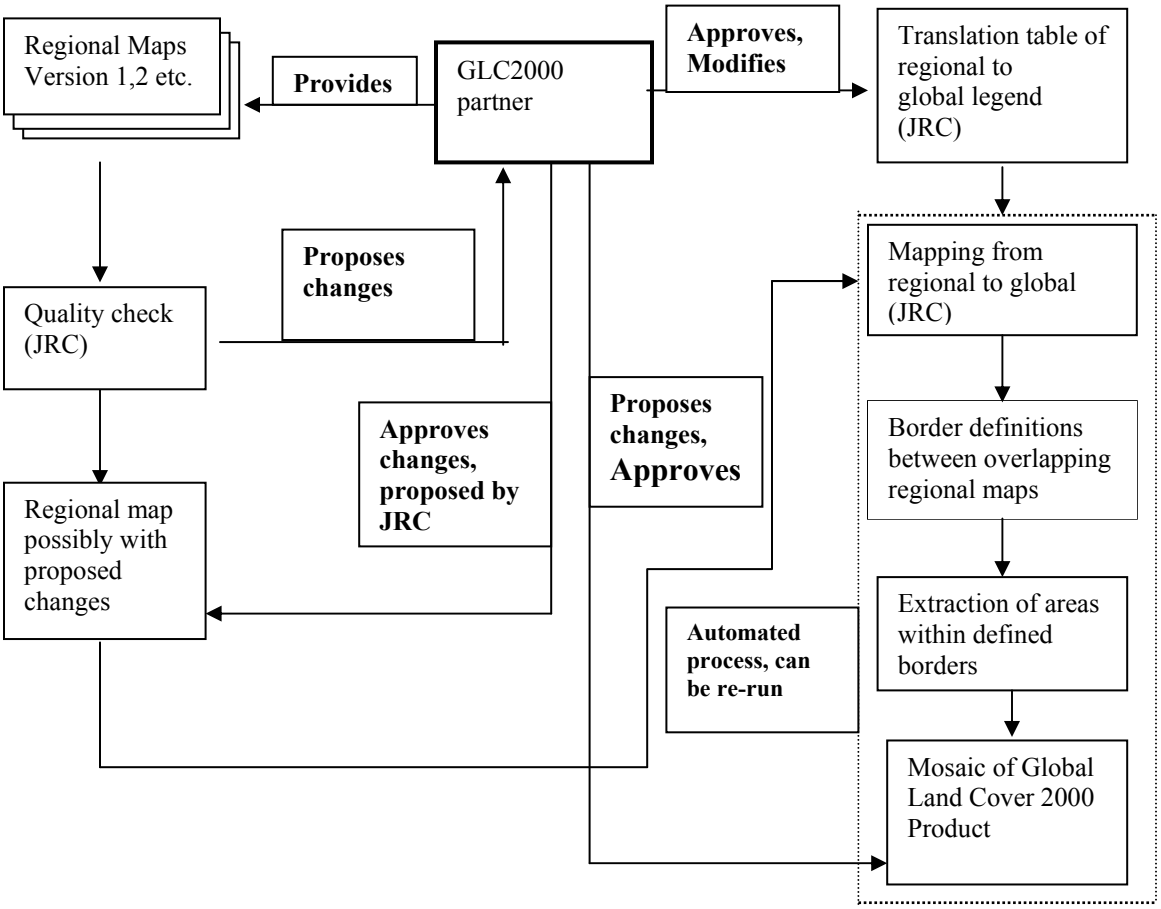


Figure 2: The different steps of harmonisation of the Global Land Cover 2000 product.

The regional land cover map provided by the GLC2000 partner undergoes a first quality check from the JRC. In particular, it is investigated how the overlapping classifications in the same eco-regions match. In case of inconsistencies, the GLC2000 partner is asked to check and possibly change either the regional classification or change the translation table which maps from the regional to the global legend. This translation is defined in collaboration with the GLC2000 partners based on the Land Cover Classification System of FAO. The processing chain which creates the global land cover 2000 product firstly extracts the relevant areas from the regional product, based on defined borders; secondly it translates from the regional to the global legend; and then thirdly, it mosaics together each extracted area. Since improved versions of the regional product and the translation

tables have become available, this process was automated with VBA in Excel and Arc Macro Language in ArcGIS 8.

In areas where windows overlapped, the window deemed to be mapped to the highest quality had to be chosen. The selection of the windows and the definition of the borders (see Figure 3) was based on expert opinion and the consultation of ancillary data such as TM Quicklooks and regional and national maps. In overlapping areas agreement scoring was used as further quality indicator (see section 5).

Figure 4: Definition of borders between windows (zoom in Square of Figure 3)

The mosaicing was based on a number of criteria

1. Regional experts defined the areas where they were more confident about the accuracy of their product so that the area with higher confidence would be used.
2. The window with the highest agreement score was maximised when no regional knowledge was available (based on agreement scoring see section 5)
3. Borders between the windows were drawn based on two criteria - along natural boundaries like water, river, lakes - along the same land cover types of the overlapping windows (see Figure 4)
4. In cases where land cover types differed, the line was chosen in a way so that the border effects between the two different windows were minimised.

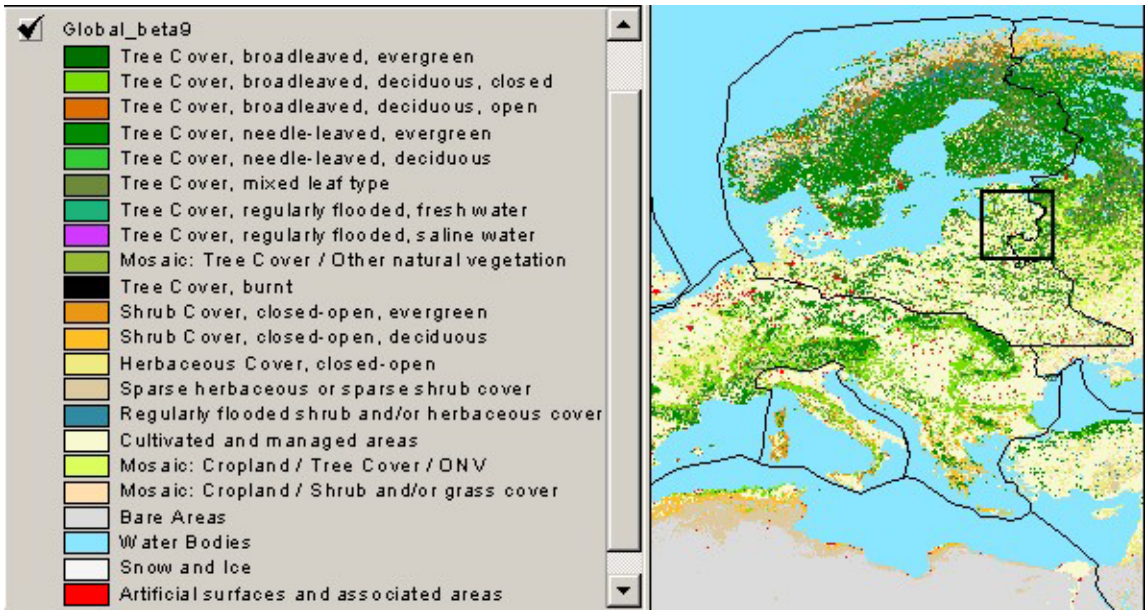
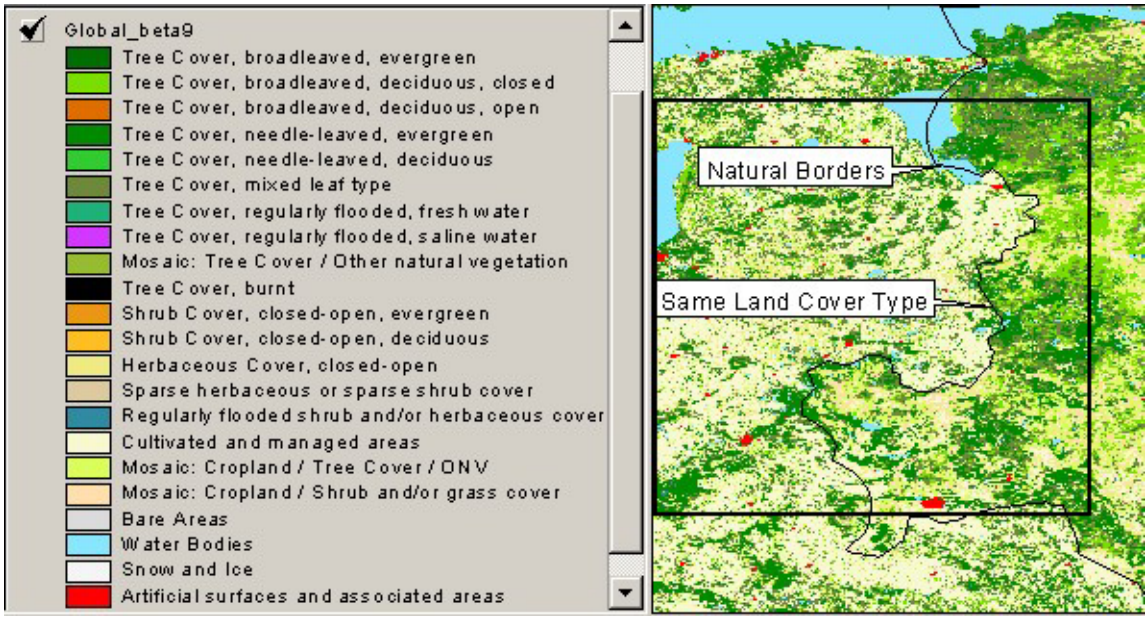


Figure 3: Definition of borders between the windows



Fugure 4: Zoom in black box of Figure 3 showing the mosaicing along natural borders and identical land cover types

Figure 5 shows the global mosaic and Table 2 shows which part of the window (see Figure 1) was extracted for the Global Land Cover 2000 product. The capital letters (A-S) refer to the extracted area.

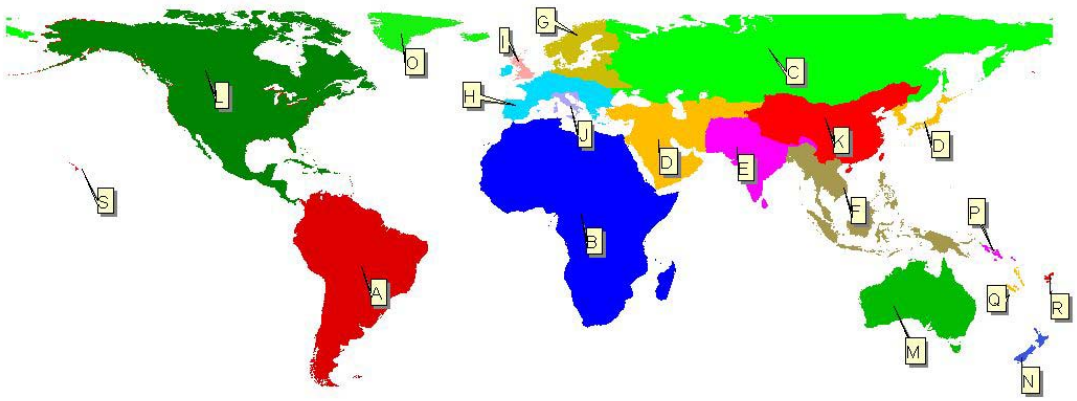


Figure 5: Global mosaic

Table 2: The Mosaics used from the different windows

Capital letter	Area description	Window number in Figure 1	Area description of window
A	**South America**	**1**	**South America**
B	**Africa**	**2**	**Africa**
C	**Northern Eurasia**	**3**	**Northern Eurasia**
D	**Middle East, Japan, Korea (S/E)**	**4**	**Asia**
E	**South Asia**	**5**	**South Asia**
F	**South East Asia**	**6**	**South East Asia**
G	**North East Europe**	**7**	**Europe – North East Europe**
H	**Ireland, Central-Southern Europe**	**8**	**Europe**
I	**UK**	**11**	**North West Europe**
J	**Italy**	**8**	**Southern Europe**
K	**China**	**9**	**China**
L	**North America**	**10**	**North America**
M	**Australia**	**11**	**Australia**
N	**New Zealand**	**12**	**New Zealand**
O	**Greenland Iceland**	**18**	**Greenland Iceland**
P	**Solomon Islands**	**12**	**Solomon Islands**
Q	**New Caledonia and Vanuatu**	**14**	**New Caledonia and Vanuatu**
R	**Fijian Islands**	**16**	**Fijian Islands**
S	**Hawaiian Islands**	**19**	**Hawaiian Islands**

3. Mapping from the regional to the global product

The regional legends are compatible with the Land Cover Classification System of the FAO (Di Gregorio and Jansen, 2000). The LCCS is a comprehensive, standardised *a priori* classification system. LCCS describes land cover according to a hierarchical series of classifiers and attributes. These separate vegetated or non-vegetated surfaces; terrestrial or aquatic/flooded; cultivated and managed; natural and semi-natural; life-form; cover; height; spatial distribution; leaf type and phenology. Coding each class with LCCS allows a map legend to be progressively more detailed for regional, and in some cases, national level users. Due to its hierarchical structure it is possible to translate the regional classification into a more general one - the global legend.

The following sections describe briefly the regional product and the classification technique used. Furthermore, it is shown how the regional legend has been translated into the global. Moreover, differences between regional and global products are outlined. Due to the fact that some partners had re-projected the spatial data, the original geo-referencing was not always maintained. Either the partners were contacted to adjust geo-

referencing and cell size to the original data or the data was adjusted at the JRC. Other changes made at the JRC were corrections of urban classifications using DMSP data (stable night time lights) and adjustments of vegetation types using a digital elevation model. Further changes were made when the boundary between the datasets was strongly visible. Table 3 shows the global legend with its vegetation classes.

Table 3: global legend with its vegetation classes

Nr.	Global Land Cover Class
1	Tree Cover, broadleaved, evergreen
2	Tree Cover, broadleaved, deciduous, closed
3	Tree Cover, broadleaved, deciduous, open
4	Tree Cover, needle-leaved, evergreen
5	Tree Cover, needle-leaved, deciduous
6	Tree Cover, mixed leaf type
7	Tree Cover, regularly flooded, fresh
8	Tree Cover, regularly flooded, saline, (daily variation)
9	Mosaic: Tree cover / Other natural vegetation
10	Tree Cover, burnt
11	Shrub Cover, closed-open, evergreen (with or without sparse tree layer)
12	Shrub Cover, closed-open, deciduous (with or without sparse tree layer)
13	Herbaceous Cover, closed-open
14	Sparse Herbaceous or sparse shrub cover
15	Regularly flooded shrub and/or herbaceous cover
16	Cultivated and managed areas
17	Mosaic: Cropland / Tree Cover / Other Natural Vegetation
18	Mosaic: Cropland / Shrub and/or Herbaceous cover
19	Bare Areas
20	Water Bodies (natural & artificial)
21	Snow and Ice (natural & artificial)
22	Artificial surfaces and associated areas
23	No data

3.1 South America

The South American window was mapped at the JRC by Hugh Eva with contributions from a number of regional experts (Eva *et* al, 2002). The classification was based on multi-resolution satellite data where each source of data used contributes to mapping a specific ecosystem or land cover type. Analysis of high resolution satellite imagery over the tropical portion of the map provided a preliminary accuracy assessment. This was found to be high for aggregated classes of forest, grasslands, mosaics of agriculture and intensive agriculture (Eva *et al.* 2003).

At the regional level shrublands were not differentiated into evergreen and deciduous classes. However, for the global legend deciduous shrubland was delineated on a map using NDVI profiles (see Figure 6). Table 4 shows the modifications which were made for South America for the global product.

Table 4: Modifications in Global Product for South America

Legend transformation (see Table 5)
clipping of areas (see Figure 5)
splitting of the regional class shrubland into deciduous and evergreen (see Figure 6)

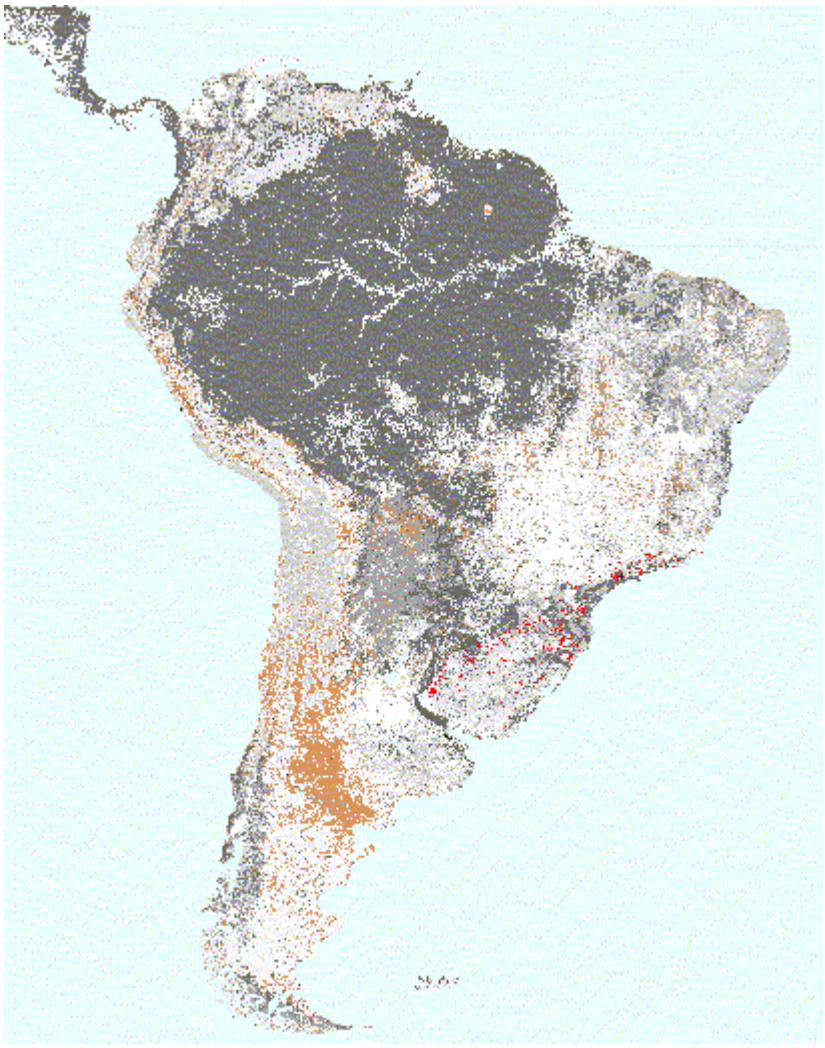


Figure 6: Differentiation between deciduous (in brown) and evergreen (in red) shrub

Table 5: Legend translation table (South America)

Global Land Cover Class	**South America regional**
Tree Cover, broadleaved, evergreen (LCCS >15% tree cover, tree height >3m)	Closed evergreen tropical forest Open evergreen tropical forest Bamboo dominated forest Closed semi-humid forest Open semi-humid forest Temperate closed evergreen broadleaf forest Closed semi deciduous forest Open semi deciduous forest Semi deciduous transition forest Montane forests 500-1000 – dense evergreen Montane forests 500-1000 – open evergreen Montane forests 500-1000 – bamboo Montane forests 500-1000 - closed semi humid Montane forests 500-1000 - open semi humid Montane forests 500-1000m - closed semi –deciduous Montane forests 500-1000m - open semi- deciduous Montane forests 500-1000m - transition forest Montane forests 500-1000m -temperate closed broadleaf Montane forests >1000m - dense evergreen Montane forests >1000m - open evergreen Montane forests >1000m - bamboo dominated Montane forests > 1000m - closed semi humid Montane forests > 1000m - open semi humid Montane forests >1000m – closed semi –deciduous Montane forests >1000m - open semi- deciduous Montane forests >1000m - transition forest Montane forests >1000m -temperate closed broadleaf
Tree Cover, broadleaved, deciduous, closed	Closed deciduous forest Temperate closed deciduous broadleaf forests Forest plantations (Llanos of Venezuela) Montane forests 500-1000m - closed deciduous Montane forests 500-1000m - closed temperate deciduous Montane forests >1000m - closed deciduous Montane forests >1000m - closed temperate deciduous
Tree Cover, broadleaved, deciduous, open	Open deciduous forest Temperate open deciduous broadleaf forests Montane forests 500-1000m - open deciduous Montane forests 500-1000m - open temperate deciduous Montane forests >1000m - open deciduous Montane forests >1000m - open temperate deciduous
Tree Cover, mixed leaf type	Temperate mixed evergreen broadleaf forests Montane forests 500-1000m - temperate mixed Montane forests >1000m - temperate mixed
Tree Cover, regularly flooded, fresh	Fresh water flooded forests Permanent swamp forests Montane forests 500-1000m - flooded forest Montane forests 500-1000m - flooded forest Montane forests 500-1000m - flooded forest Montane forests > 1000m flooded forest Montane forests > 1000m flooded forest Montane forests > 1000m flooded forest
Tree Cover, regularly flooded, saline, (daily variation)	Mangroves
Mosaic: Tree cover / Other natural vegetation	
Shrub Cover, closed-open, evergreen (with or without sparse tree layer)	Closed shrublands
Herbaceous Cover, closed-open	Grass savannah
	Shrub savannah Moorlands / heathlands

	Closed montane grasslands Closed steppe grasslands Open montane grasslands
Sparse Herbaceous or sparse shrub cover	Open shrublands Open steppe grasslands Sparse desertic steppe shrub /grasslands
Regularly flooded shrub and/or herbaceous cover	Periodically flooded savannah Periodically flooded shrublands
Cultivated and managed areas	Agriculture – intensive
Mosaic: Cropland / Tree Cover / Other Natural Vegetation	Mosaic agriculture / degraded forests
Mosaic: Cropland / Other natural vegetation	Mosaic agriculture / degraded vegetation
Bare Areas	Barren / bare soil Desert Salt pans
Water Bodies (natural & artificial)	Water bodies
Snow and Ice (natural & artificial)	Permenent snow /ice
Artificial surfaces and associated areas	Urban

3.2 Africa

The African window was mapped at the JRC by Philippe Mayaux with contributions from a number of regional experts (Mayaux *et* al. 2003). The African map has also been created with a multi-sensor approach, combining SPOT VGT, radar and DMSP data. Methods combining the spatial detail of S1 products (Cabral *et al.,* 2003; Van Cutsem *et al.,* 2003) and the temporal profile of the NDVI (Bartholomé *et al.,* 2002) have been specifically developed. Synthetic images and NDVI profiles are classified using unsupervised clustering. Class labels are subsequently assigned using ancillary information from about 50 national or local maps and the local knowledge of the regional experts. The clusters to the South and the North of the Equator are merged according to the duration and the intensity of the growing season - the inversion of the growing season is ignored.

The map is then subject to systematic quality assessment. The map is divided into 2 by 2 degrees cells and Landsat or SPOT quick-looks, local vegetation maps and experts then check the veracity of the map for each cell. Where inaccuracies were detected, the dataset was reprocessed.

The map shows spatial details never achieved before for a continental map, such as the irrigated agriculture in Libya, the swamp forests or the linear ribbons of rural complex following the former colonial road network in the Congo Basin. Other features present in previous land-cover maps, such as the forest reserves in Ghana or the large agricultural landscapes in Zimbabwe are delineated with better spatial accuracy than previously available. On the other hand, the detection of agriculture is quite problematic due to farming systems and the spatial pattern of croplands. The fields are small and mixed with savannas and fallows, which preclude a reliable mapping at 1 km spatial resolution. On the other hand, the low intensification level of agricultural techniques induces spectral or temporal properties of agriculture close to the surrounding natural vegetation. Modifications made for Africa in the global product are listed in Table 6.

Table 6: Modifications in Global Product for Africa

Legend transformation (see Table 7)
clipping of areas (see Figure 5)

Table 7: Legend translation table for Africa

Global Land Cover Class	**Africa**
Tree Cover, broadleaved, evergreen (LCCS >15% tree cover, tree height >3m)	Closed evergreen lowland forest Submontane forest (900 -1500 m) Montane evergreen forest (> 1500 m) Degraded evergreen forest
Tree Cover, broadleaved, deciduous, closed	Closed decidous forest (Miombo)
Tree Cover, broadleaved, deciduous, open	Deciduous woodland
Tree Cover, regularly flooded, fresh	Swamp forest
Tree Cover, regularly flooded, saline, (daily variation)	Mangrove
Mosaic: Tree cover / Other natural vegetation	Mosaic Forest / Savanna
Shrub Cover, closed-open, deciduous (with or without sparse tree layer)	Deciduous shrubland with sparse trees Open deciduous shrubland
Herbaceous Cover, closed-open	Closed grassland Open grassland with sparse shrubs
Sparse Herbaceous or sparse shrub cover	Sparse grassland
Regularly flooded shrub and/or herbaceous cover	Swamp bushland and grassland
Cultivated and managed areas	Croplands (>50%) Irrigated croplands Tree crops
Mosaic: Cropland / Tree Cover / Other Natural Vegetation	Mosaic Forest / Croplands
Mosaic: Cropland / Shrubland and/or Herbaceous cover	Croplands with open woody vegetation
Bare Areas	Sandy desert and dunes Stony desert Bare rock Salt hardpans
Water Bodies (natural & artificial)	Waterbodies
Artificial surfaces and associated areas	Cities

3.3 Northern Eurasia

The land cover mapping of the Northern Eurasia's window was performed by Sergey Bartalev at the JRC with contribution of partners from the Centre for Forest Ecology and Productivity of Russian Academy of Sciences. Pre-processing involved the elimination of pixels contaminated by clouds/snow and anomalous pixels values caused by sensor defects and the production of a number of advanced data products, such as seasonal mosaics of spectral channels, a Wave Likeness Index, an Anisotropy Index, a Wetness Index and snow cover duration product. Seasonal mosaics were clustered to derive temporal cluster maps, which were labelled. By using the different indices and the snow cover map, ambiguous labels were removed and to each cluster a thematic class was assigned (Bartalev *et* al. 2003). A first validation step compares the percentage forest cover from the map for each administrative region of the Russian Federation with the official forest cover statistics giving an R^2 of 0.93. Whilst not statistically valid for all classes this gives us confidence in the map's quality. Full qualitative validation based on a regular grid with 2^0 by 2^0 cells was performed with the collaboration of Russian experts

and demonstrated satisfactory quality of the map. Results of the map's qualitative validation were presented at XI International IBFRA Conference (Bartalev *et* al., 2002).

Table 8: Modifications in Global Product for Northern Eurasia

Legend transformation (see Table 9)
Clipping of areas (see Figure 5)

Table 9: Legend translation table for Northern Eurasia

Global Land Cover Class	**Northern Eurasia**
Tree Cover, broadleaved, deciduous, closed	Deciduous Broadleaf Forest
Tree Cover, needle-leaved, evergreen	Evergreen Needle-leaf Forest
Tree Cover, needle-leaved, deciduous	Deciduous Needle-leaf Forest
Tree Cover, mixed leaf type	Needle-leaf/Broadleaf Forest Mixed Forest Broadleaf/Needle-leaf Forest
Mosaic: Tree cover / Other natural vegetation	Forest - Natural Vegetation complexes
Tree Cover, burnt	Recent burns Burns of year 2000
Shrub Cover, closed-open, evergreen (with or without sparse tree layer)	Needle-leaf evergreen shrubs
Shrub Cover, closed-open, deciduous (with or without sparse tree layer)	Broadleaf deciduous shrubs Shrub tundra
Herbaceous Cover, closed-open	Humid grasslands Sedge tundra
Sparse Herbaceous or sparse shrub cover	Steppe Barren tundra Prostrate shrub tundra
Regularly flooded shrub and/or herbaceous cover	Bogs and marches Palsa bogs Riparian vegetation
Cultivated and managed areas	Croplands
Mosaic: Cropland / Tree Cover / Other natural vegetation	Forest - Cropland complexes
Mosaic: Cropland / Shrub and/or Herbaceous cover	Cropland - Grassland complexes
Bare Areas	Bare soil and rock Salt-march
Water Bodies (natural & artificial)	Water bodies
Snow and Ice (natural & artificial)	Permanent snow/ice
Artificial surfaces and associated areas	Urban

3.4 Asia

The central Asia window has been mapped by the Center for Environmental Remote Sensing (CERES), Chiba University, Japan. Ryutaro Tateishi has been in charge of this window. Maximum NDVI has been used to remove contaminated pixels. Monthly NDVI composites were used as an input for a supervised classification using 338 sites of ground data.

The legend for Central Asia is developed by Sato and Tateishi (2002). The ground data (or training data) are collected from field surveys, interpretation of Landsat image, phenological information from SPOT/VEGETATION and AVHRR, existing land use or vegetation maps, and experts' knowledge. These ground data are available from the web site of CEReS, Chiba University (2003).

Feedback from regional experts indicates that the data of the Asian window must be improved. Since a high number of urban areas did not correspond to stable lights derived from DMSP night time luminosity data, the probability of misclassification is high. It has been shown previously that a very high correlation between urban areas and stable night

time lights exists (Imhoff *et al*, 1997). Therefore urban areas lying outside a relatively low night time luminosity threshold were removed. Table 10 shows the modifications made for Asia in the global product (Beta Version).

Table 10: Modifications in Global Product for Asia

Legend transformation (see Table 11)
Clipping of areas (see Figure 5)
Corrections of Urban Areas using DMSP data

Table 11: Legend translation table for Asia

Global Land Cover Class	**Asia**
Tree Cover, broadleaved, evergreen (LCCS >15% tree cover, tree height >3m)	Broadleaf Evergreen Forest
Tree Cover, broadleaved, deciduous, closed	Broadleaf Deciduous Forest
Tree Cover, broadleaved, deciduous, open	Broadleaf Deciduous Woodland
Tree Cover, needle-leaved, evergreen	Needleleaf Evergreen Forest
Tree Cover, needle-leaved, deciduous	Needleleaf Deciduous Forest Needleleaf Deciduous Woodland
Tree Cover, mixed leaf type	Mixed Forest
Tree Cover, burnt	Forest fire
Herbaceous Cover, closed-open	Herbaceous, single layer Herbaceous with Sparse Tree/Shrub
Sparse Herbaceous or sparse shrub cover	Shrub Sparse Herbaceous / Shrub Lichens / Mosses
Regularly flooded shrub and/or herbaceous cover	Wetland
Cultivated and managed areas	Cropland Coconuts Rice, paddy Wheat
Mosaic: Cropland / Shrub and/or herbaceous cover	Cropland / Natural Vegetation Mosaic
Bare Areas	Bare Consolidated Bare rock Gravels, stones and boulders Hardpan Unconsolidated Bare soil / Other unconsolidated Loose and shifting sands
Water Bodies (natural & artificial)	Water
	Water (60-70%) and many small islands
Snow and Ice (natural & artificial)	Snow / Ice
Artificial surfaces and associated areas	Urban

3.5 South Asia

The South Asian window was produced at the Indian Institute of Remote Sensing by S. Agrawal, Y. Shukla, P.K. Joshi and P.S. Roy.

The discrimination of the land cover classes was based on the phonological variation of the vegetation types (Roy & Joshi, 2000). The Normalised Difference Vegetation Index (NDVI) has been observed to be sensitive to the phenology of vegetation, including ecosystem scale cycles of plant greenup and senescence (Justice *et* al. 1985, Davenport *et* al.1993). It is also sensitive to the crop cycle and the cropping pattern of agricultural land use. The changes in the NDVI observed over time reflect vegetation type, phonology and local environmental conditions which help in discriminating the various land cover classes.

Five-day composites were generated to remove stripes of missing data. Monthly maximum value NDVI composites were produced for the nine months ranging from November 1999 to December 2000. The entire data was divided into 11 ecological zones in order to overcome the large amount of spectral variability in the various land cover classes in the region. This data was also stratified into forest and non-forest classes based on the NDVI values. Further ISODATA clustering was carried out on the maximum NDVI composite layer of the above nine-month data to obtain the land use / land cover map. The clusters were assigned various classes based on ground truth and reference information available for the region. For the areas where accurate and up-to-date ground truth information was not available the temporal profile of NDVI was studied and the classes were assigned accordingly. Finally, a mosaic of all the land use / land cover classes obtained in the different eco-regions was generated. Stable night-time lights (derived from DMSP data) were used to discriminate urban areas. Table 12 shows the modifications made for Eurasia in the global product.

Table 12: Modifications in Global Product for South Asia

Legend transformation (see Table 13)
Clipping of areas (see Figure 5)

Table 13: Legend transformation table for South Asia

Global Land Cover Class	**South Central Asia**
Tree Cover, broadleaved, evergreen (LCCS >15% tree cover, tree height >3m)	Tropical Evergreen Subtropical Evergreen Tropical Montane Tropical Semi-evergreen Temparate broadleaved
Tree Cover, broadleaved, deciduous, closed	Tropical Moist Deciduous Tropical Dry Deciduous
Tree Cover, broadleaved, deciduous, open	Dry Woodland
Tree Cover, needle-leaved, evergreen	Temperate Conifer Subtropical Conifer Junipers
Tree Cover, regularly flooded, fresh	
Tree Cover, regularly flooded, saline, (daily variation)	Mangroves
Shrub Cover, closed-open, evergreen	Shrubs Bush
Shrub Cover, closed-open, evergreen (with or without sparse tree layer)	Shrub Bush Savannah Spare Woods
Shrub Cover, closed-open, deciduous (with or without sparse tree layer)	Thorn Forest/Scrub (northern) Thorn Forest/ Scrub (Southern) Thorn scrub/Desert (hot)
Herbaceous Cover, closed-open	Plain Grasslands Slope Grasslands Alpine Meadow Alpine Grasslands Desert Grassland
Sparse Herbaceous or sparse shrub cover	Sparse vegetation (cold) Sparse vegetation (hot) Gobi
Regularly flooded shrub and/or herbaceous cover	Mud Flats Swamp Salt Pants
Cultivated and managed areas	Coastal vegetation Irrigated Intensive Agriculture Irrigated Agriculture Slope Agriculture Rainfed Agriculture
Mosaic: Cropland / Tree Cover / Other natural vegetation	Degraded Forest Abandoned Jhum Current Jhum

Bare Areas	Desert (cold) Barren Bare Rock
Water Bodies (natural & artificial)	Coral reef Water Bodies
Snow and Ice (natural & artificial)	Snow
Artificial surfaces and associated areas	Settlement

3.6 South East Asia

Mapping of the Southeast Asian sub-region has been carried out by the JRC, the person in charge has been Hans-Jürgen Stibig. Due to very different climatic conditions in the continental and insular parts of this sub-region, image processing and mapping had to be done in two separate processes. In order to cope with the high cloud cover, a particular problem of the insular part of Southeast Asia, S10 data from 1998 to 2000 has been used to create the image mosaics. The land cover classification was carried out by using an unsupervised digital clustering method. Mapping and labelling of the classes has been supported by Landsat TM image interpretation and field records. For insular Southeast Asia, support has been received from the Agricultural University (IPB) at Bogor, Indonesia. It should be noted that for continental Southeast Asia test classifications were also performed with S1 data by JRC and CIESIN (Columbia University, USA). Results however were found inferior to those obtained from the S10 data.

For the continental part of Southeast Asia an image mosaic was created of S10 data for the two dry seasons of 1998/1999 and 1999/2000, including the period from the end of December to the end of March. An image mosaic of acceptable quality for insular Southeast Asia could only be created by including all S10 data from March to November in the years 1998 and 1999, and from January to March of 2000. Mapping of the complex land cover pattern of continental Southeast Asia required to a certain extent a re-assignment of the original digital classes for broadly defined bioclimatic geographical strata. Mapping of insular Southeast Asia could be done by a straight forward process of cluster assignment, except that for the assigning of mangrove and swamp forests a reference layer from WCMC had to be used (Iremonger, 1997). Table 14 shows the modifications made for South East Asia in the global product.

Table 14: Modifications in Global Product for South East Asia

Legend transformation (see Table 15)
Clipping of areas (see Figure 5)

Table 15: Legend transformation table South East Asia

Global Land Cover Class	South East Asia
Tree Cover, broadleaved, evergreen (LCCS >15% tree cover, tree height >3m)	Tree cover, broadleaved, evergreen
Tree Cover, broadleaved, deciduous, open	Tree cover, broadleaved, deciduous, mainly open (incl. Dry Dipterocarp forests)
Tree Cover, regularly flooded, fresh	Tree cover, regularly flooded: Swamp forest)
Tree Cover, regularly flooded, saline, (daily variation)	Tree cover, regularly flooded: Mangrove forest
Mosaic: Tree Cover / Other natural vegetation	Mosaic: Tree cover / Other natural vegetation and cropland
Shrub Cover, closed-open, deciduous (with or without sparse tree layer)	Deciduous shrub cover / Mosaics of deciduous shrub cover and cropping (shrub component dominant)
Herbaceous Cover, closed-open	Herbaceous cover, incl. alpine grasslands
Sparse Herbaceous or sparse shrub cover	Sparse herbaceous cover, alpine, > 3000m Sparse herbaceous or sparse shrub cover (dry or burnt)
Cultivated and managed areas	Cultivated and managed land, non irrigated Cultivated and managed land, irrigated or flooded (e.g. rice, shrimp farms)
Mosaic: Cropland / Tree Cover / Other Natural Vegetation	Mosaics of shrub cover (dominant), mainly evergreen, and other vegetation or cropping Mosaic cropland, regrowth and other natural vegetation (shrubs, trees)
Bare Areas	Bare areas (Rock: Lime stone)
Water Bodies (natural & artificial)	Water bodies
Snow and Ice (natural & artificial)	Snow and ice
Artificial surfaces and associated areas	Artificial surfaces

3.7 North East Europe

The North East Europe window was produced by the Metria Miljöanalys / Lantmäteriet (Stockholm). In charge of the map was Michael Ledwith. Input data used were SPOT VGT 10-day composites from 01-04-2000 to 21-10-2000 and several SPOT VGT S-1 composite data for June and September. Pre-processing involed the removal of inappropriate Short Wave Infrared (SWIR) data, water rings around coasts, the removal of pixels with a Viewing Zenith Angle (VZA) greater than 50 degrees, and the removal of clouds, snow and urban areas (based on anciallary data). An unsupervised classification was undertaken on the data, creating 40 classes, by majority clustering, which then were assigned labels according to relatively accurate reference data.

For the actual classification, an algorithm, based on matching input satellite data clustered pixels to the corresponding reference data clusters, was used. The process is multi-phased and iterative. During the classification process, a pixel can match the criteria for labeling a pixel within several of the classification steps. That is, a pixel can be assigned to different land cover classes. However, all information produced in the different steps are merged together into a single land cover dataset in a predefined priority order (parallelpiped), thus the pixel is assigned to the land cover class it has the highest likelihood of belonging to. Clusters to which over 90% of the pixels have been "correctly" classified (according to the reference data) are labeled as such and removed from the dataset. The remaining data, which is much more streamlined with respect to spectral variation, is then processed an additional time through the algorithm. Finally any remaining unclassified clusters are addressed manually based on spectral characteristics.

Validation of the resulting dataset was accomplished according to the recommended GLC2000 Project Guidelines. Ten countries where evaluated individually. No noticeable problems were encountered with the classification for the Central European countries of Germany, Poland, Russia (Kaliningrad) and Lithuania. In Latvia and Estonia, there appears to be a misclassification of wetlands, which is sometimes labelled as cropland / tree cover mosaic. In all of the Scandinavian countries, the class herbaceous, closed-open (pastures) as well as wetlands are generally under represented. Overall however, following validation, the north-eastern Europe GLC2000 product has been classified to a good level of accuracy. Table 16 shows the modifications made for North East Europe in the global product.

Table 16: Modifications in Global Product for North East Europe

Legend transformation (see Table 17)
Clipping of areas (see Figure 5)

Table 17: Legend translation table for North East Europe

Global Land Cover Class	**North East Europe**
Tree Cover, broadleaved, deciduous, closed	Tree cover, broadleaved, deciduous, closed
Tree Cover, broadleaved, deciduous, open	Tree cover, broadleaved, deciduous, open
Tree Cover, needle-leaved, evergreen	Tree cover, needleleaved, evergreen, closed Tree cover, needleleaved, evergreen, open
Tree Cover, mixed leaf type	Tree cover, mixed phrenology, closed
	Tree cover, mixed phrenology, open
Herbaceous Cover, closed-open	Herbaceous, closed - pastures, natural grassland
	Herbaceous, open with shrubs
Sparse Herbaceous or sparse shrub cover	Sparse herbaceous or sparse shrubs Lichens and mosses
Regularly flooded shrub and/or herbaceous cover	Regularly flooded shrub and/or herbaceous
Cultivated and managed areas	Cultivated and managed terrestrial areas
Mosaic: Cropland / Tree Cover / Other Natural Vegetation	Mosaic: crop/ tree cover
Bare Areas	Bare areas
Water Bodies (natural & artificial)	Water
Snow and Ice (natural & artificial)	Snow and ice
Artificial surfaces and associated areas	Artificial surfaces and associated areas

3.8 Europe

The Central European window was mapped by the by the Department of Environmental Sciences and Land Use Planning, at UCL, Belgium. The person in charge of this window was Jean Francois Pekel.

Firstly, annual and seasonal composites were created using the mean compositing method (Vancutsem *et* al., in revision, 2003). The resulting composites were then corrected to remove coastal values, and to discriminate permanent snow from temporary snow cover. An unsupervised classification, based on the simultaneous use of spectral and temporal patterns, was applied to the composites. In order to maintain a good spatial consistency, the classification process was applied to areas delimited by natural borders.

The methodology was based on a hierarchical approach. Each land cover type was identified by using the most appropriate combination of seasonal composites for each class. When a land cover type was properly discriminated, it was masked from images used further along the processing chain, in order to reduce uncertainty and improve the identification of other land cover types. Fifteen land cover classes have been determined and labelled using a combination of reference information from the CORINE landcover database, the interpretation of high resolution satellite imagery (Landsat TM) and the knowledge of the local experts. Modifications made for Europe in the global product are listed in Table 19. Table 18 shows the modifications made for Europe in the global product.

Table 18: Modifications in Global Product for Europe

Legend transformation (see Table 19)
Clipping of areas (see Figure 5)

Table 19: Legend translation table (Europe)

Global Land Cover Class	**Europe central**
Tree Cover, broadleaved, deciduous, closed	Closed deciduous broadleaved forest
Tree Cover, needle-leaved, evergreen	Closed evergreen needleaved forest
Tree Cover, mixed leaf type	Mixed needleaved and broadleved forest
	Mixed closed forest and shrubland
Shrub Cover, closed-open, deciduous (with or without sparse tree layer)	Closed shrubland
	Open shrubland
Herbaceous Cover, closed-open	Grassland
Sparse Herbaceous or sparse shrub cover	Bare soil and sparsely vegetated area
Regularly flooded shrub and/or herbaceous cover	Wetland
Cultivated and managed areas	Cultivated and managed areas, herbaceous crops, non-irrigated
	Cultivated and managed areas, herbaceous crops, irrigated
	Extraction site
Mosaic: Cropland / Tree Cover / Other natural vegetation	Mixed grassland and cultivated and managed areas, herbaceous crops, non-irrigated
Snow and Ice (natural & artificial)	Snow and Ice
Artificial surfaces and associated areas	Urban

3.9 North West Europe

The north western European window was produced by ALTERRA by Erik de Badts in consultation with Sander Mücher. The initial image enhancement was done with IDL-ENVI and the HANTS algorithm to obtain a cloud-free time series dataset. The HANTS algorithm (Roerink *et* al. 2000) considers only the most significant frequencies expected to be present in the time profiles, and applies a least squares curve fitting procedure based on harmonic components (sines and cosines). For each frequency the amplitude and phase of the cosine function is determined during an iterative procedure. Input data points that have a large positive or negative deviation from recalculation of the coefficients and the bases of the remaining points, the procedure is repeated until the maximum error is acceptable or the number of remaining points has become sufficiently small. The classification itself was based on thresholding with CART (Salford Systems). For each sub region specific thresholds were defined for each class. This classification of NDVI time series had proved to be successful for classifying large areas. For water, urban areas and wetlands a mask was derived from the PELCOM land cover database (Mücher *et* al. 2001), this also made it possible to more precisely compare the GLC2000 classification and the PELCOM land cover database. For validation, the CORINE land cover database was used as the reference database. The total accuracy for the regional window of GLC 2000 was 50.0% and for PELCOM 48.5%. These values are quite low but are also due to geometric distortions in the reference database. In the PELCOM report (Mücher *et al.* ,2001) an overall accuracy of 69.2% was reached. The difference was that for the PELCOM project, CORINE was resampled to 1km pixels using a majority filter. The GLC2000 product does have a better geometry that PELCOM due to the push-broom sensor of SPOT-Vegetation.

It was found that the patterns for heather and moorland in Britain were classified more accurately within the European window processed by UCL, Belgium. By overlaying the heather and moorland class from ULC over the North-Western product produced by ALTERRA, an overall better accuracy could be achieved. However, the natural grassland class from the original North Western window was maintained. Table 20 lists the modifications made for North West Europe in the global Product.

Table 20: Modifications in Global Product for North West Europe

Legend transformation (see Table 21)
Clipping of areas (see Figure 5)
Combining the European and North-West European Map

Table 21: Legend translation table for North West Europe

Global Land Cover Class	**North West Europe**
Tree Cover, broadleaved, deciduous, closed	Deciduous forest
Tree Cover, needle-leaved, evergreen	Needle leaved forest
Tree Cover, mixed leaf type	Mixed Forest
Shrub Cover, closed-open, evergreen (with or without sparse tree layer)	Shrubland
Herbaceous Cover, closed-open	Pasture Natural Grassland
Regularly flooded shrub and/or herbaceous cover	Wetlands
Cultivated and managed areas	Arable Land
Water Bodies (natural & artificial)	Water bodies and Sea
Artificial surfaces and associated areas	Urban Areas

3.10 Southern Europe

Southern Europe was mapped at the JRC by Susanne Kolmert. Input data from S10 composites between January and October 2000 were used. Pre-processing involved cloud elimination by using a threshold value in the blue and short-wave infrared (SWIR) bands, a pixel was defined as being clear (not cloudy) if the blue band was less than 230 or the short wave infra-red band was less than 50. All cloudy regions/pixels were increased in size by one pixel in all directions to avoid problems with half cloudy, half clear pixels. In order to eliminate the unwanted vertical stripes in the SWIR band, a saturation mask was created of all values above 1000 in the SWIR band. By creating a mask using a threshold value from the NDVI composites the ring effects along the coastline were eliminated.

Two-month mean composites were created, of the corrected S10 data, for the red, NIR and SWIR bands. The mean composites were used as input data for an unsupervised classification with, initially, 110 clusters. The composites used depended on the region that was classified, and its vegetation period. The clusters were labelled according to CORINE data as main reference data set. PELCOM and Landsat TM Quicklooks were used as complementary ancillary data. Modifications made for Southern Europe in the global product are listed in Table 22.

Table 22: Modifications in Global Product for Southern Europe

Legend transformation (see Table 23)
Clipping of areas (see Figure 5)

Table 23: Legend translation table for Southern Europe

Global Land Cover Class	Southern Europe
Tree Cover, broadleaved, deciduous, closed	Tree cover -Mixed leaf type (mostly broadleaved 60 - 80%) Tree cover -Closed deciduous, broad leaved forest
Tree Cover, needle-leaved, evergreen	Tree cover -Closed evergreen needle leaved Tree cover -Mixed leaf type (mostly needle leaved 60-80%)
Tree Cover, mixed leaf type	Tree cover -Mixed leaf type (50/50%)
Mosaic: Tree cover / Other natural vegetation	Mosaic Tree cover /Natural vegetation
Shrub Cover, closed-open, evergreen (with or without sparse tree layer)	Shrub Cover Closed evergreen needle leaved Shrub Cover -Open evergreen
Shrub Cover, closed-open, deciduous (with or without sparse tree layer)	Shrub cover -Dense to open deciduous broad-leaved shrub cover Mosaic Tree Cover Open deciduous forest/Shrub cover
Herbaceous Cover, closed-open	Grassland –Herbaceous, closed –open
Regularly flooded shrub and/or herbaceous cover	Wetland
Cultivated and managed areas	Cropland (rainfed cultivation) Cropland (Irrigated) Cropland- Wooded cropland (olive trees, fruit trees etc.)
Mosaic: Cropland / Shrub and/or herbaceous cover	Mosaic Natural vegetation/cropland
Bare Areas	Bare Areas (soil/rock)
Water Bodies (natural & artificial)	Water Bodies (natural &artificial)
Snow and Ice (natural & artificial)	Snow
Artificial surfaces and associated areas	Urban areas

3.11 China

The China window was mapped by the Institute of Remote Sensing Applications, Chinese Academy of Sciences. The China window has been developed using 10 day composites of SPOT-VGT NDVI data set over a period of 01 January 2000 to 31 December 2000. The area with poor vegetation in northwest China was mapped using the multispectral data for the last ten days in August 2000. The whole of China was divided into nine strata according to temperature (above ten degrees centigrade) and precipitation, because land cover mapping for such a large area encounters the problem of large variations in the study area landscape with respect to the climate, terrain and soil. In order to remove cloud contamination and interpolate the missing data masked by cloud, the Harmonic Analysis of Time Series (HANTS) was applied to pre-process the 36 layers of VGT S10 NDVI dataset, and the ancillary metric derived from temperature, precipitation and DEM has been developed with the Analytic Hierarchy Process (AHP) method to improve the discrimination ability of VGT metrics. Classification was undertaken by using an unsupervised clustering method, and labelling of the classes was supported by a 1:1,000,000 land use map in China along with expert opinion. The legend was exported from the LCCS software, which was developed by the UN Food and Agriculture Organization (FAO). The accuracy assessment, approximately 60%, was complemented by comparing the GLC2000 product with data from the Chinese Statistics Bureau.

For China, several changes in the global product were made. The US Geological Survey's 30 arc-second digital elevation model was used to define a 2000 meter threshold (USGS, 1996). Below this threshold a high percentage of shifting cultivation is found within the grassland class. Therefore, grassland below this 2000 m threshold was re-

classified to a mosaic of cropland and shrub/herbaceous cover. Above the 2000m threshold bush was re-classified to alpine meadow since above that threshold bush is much less likely to be found. Another modification was undertaken, which used the 1500 meter threshold to differentiate between broadleaved/needleleaved evergreen forest and mosaic of cropland/tree cover/other natural vegetation. This modification was undertaken in the tropical part of the Yunnan province since in that part the broadleaved/needleleaved forest is heavily fragmented due to shifting cultivation under 1500 meters. All the modifications which were made for China in the global product are listed in Table 24.

Table 24: Modifications in Global Product for China

Legend transformation (see Table 25) *Clipping of areas (see Figure 5)* *Change from grassland to Mosaic (cropland/shrub or herbaceous cover) below 2000m* *Change from bush to alpine meadow above 2000m* *Change from broadleaved/needleleaved evergreen forest to Mosaic/ Cropland/Tree cover/Other Natural Vegetation below 1500m in the tropical part of the Yunnan Province*

Table 25: Legend translation table for China

Global Land Cover Class	**China**
Tree Cover, broadleaved, evergreen (LCCS >15% tree cover, tree height >3m)	broadleaved evergreen forest
Tree Cover, broadleaved, deciduous, closed	broadleaved deciduous forest
Tree Cover, needle-leaved, evergreen	needleleaved evergreen forest
Tree Cover, needle-leaved, deciduous	needleleaved deciduous forest
Mosaic: Tree cover/Other natural vegetation	sparse woods
Shrub Cover, closed-open, evergreen (with or without sparse tree layer)	Bush
Herbaceous Cover, closed-open	alpine and sub alpine meadow slope grassland plain grassland alpine and sub-alpine plain grassland meadow
Sparse Herbaceous or sparse shrub cover	desert grassland
Regularly flooded shrub and/or herbaceous cover	Seaside wet lands swamp
Cultivated and managed areas	Farmland
Bare Areas	bare rocks Gravels Dersert
Water Bodies (natural & artificial)	River Lake
Snow and Ice (natural & artificial)	glacier
Artificial surfaces and associated areas	city
Mosaic/ Cropland/Tree cover/Other Natural Vegetation (created)	broadleaved evergreen forest needleleaved evergreen forest (below 1500 m) in Yunnan
Mosaic (cropland/shrub or herbaceous cover)	Grassland (below 2000m)

3.12 North America

The Land Cover Map of North and Central America for the year 2000 (GLC2000-NCA), was prepared by NRCan/CCRS and USGS/EROS Data Centre as a regional component of the Global Land Cover 2000 project. The mapping procedure for transforming satellite observations acquired by the SPOT4/VGTETATION (VGT) sensor into land cover information includes: 1) conversion of daily data into ten-day composites; 2) post-seasonal correction and refinement of apparent surface reflectance in ten day composite images; and 3) extraction of land cover information from the composite images. The GLC2000–NCA land cover map is provided as a regional product with 28 land cover classes based on Federal Geographic Data Committee/Vegetation Classification Standard (FGDC NVCS) classification system, and as part of a global product with 22 land cover classes based on the Land Cover Classification System (LCCS) of the Food and Agriculture Organisation. The map was compared on both area and per-pixel bases over North and Central America to the International Geosphere-Biosphere Programme global land cover classification (IGBP), the University of Maryland global land cover classification (UMd) and the MODIS Global land cover classification produced by Boston University (BU). There was good agreement (79%) on the spatial distribution and area extent of forest between GLC2000–NCA and the other maps, however, GLC2000–NCA provides additional information on the spatial distribution of forest types. The GLC2000–NCA map was produced in co-operation with regional partners, and therefore should meet, to a greater extent, their specific needs at the sub-regional level. Modifications made for North America in the global product are listed in Table 26.

Table 26: Modifications in Global Product for North America

Legend transformation (see Table 27)
Clipping of areas (see Figure 5)

Table 27: Legend translation table for North America

Global Land Cover Class	**North America**
Tree Cover, broadleaved, evergreen	Tropical or Sub-tropical Broadleaved Evergreen Forest - Closed Canopy
Tree Cover, broadleaved, deciduous, closed	Tropical or Sub-tropical Broadleaved Deciduous Forest - Closed Canopy Temperate or Sub-polar Broadleaved Deciduous Forest - Closed Canopy
Tree Cover, needle-leaved, evergreen	Temperate or Sub-polar Needleleaved Evergreen Forest - Closed Canopy Temperate or Sub-polar Needleleaved Evergreen Forest - Open Canopy Subpolar Needleleaved Evergreen Forest Open Canopy - lichen understory
Tree Cover, mixed leaf type	Temperate or Sub-polar Needleleaved Mixed Forest - Closed Canopy Temperate or Sub-polar Mixed Broadleaved or Needleleaved Forest - Closed Canopy Temperate or Sub-polar Mixed Broaddleleaved or Needleleaved Forest - Open Canopy
Mosaic: Tree cover / Other natural vegetation	Temperate or Subpolar Grassland with a Sparse Tree Layer
Tree Cover, burnt	Burnt area (resent burnt area)
Shrub Cover, closed-open, evergreen (with or	Temperate or Subpolar Needleleaved Evergreen Shrubland - Open

without sparse tree layer)	Canopy
Shrub Cover, closed-open, deciduous (with or without sparse tree layer)	Temperate or Subpolar Broadleaved Deciduous Shrubland - Open Canopy Temperate or Sub-polar Mixed Broadleaved and Needleleaved Dwarf-Shrubland - Open Canopy
Herbaceous Cover, closed-open	Temperate or Subpolar Grassland Temperate or Subpolar Grassland with a Sparse Shrub Layer
Sparse Herbaceous or sparse shrub cover	Polar Grassland with a Sparse Shrub Layer Polar Grassland with a Dwarf-Sparse Shrub Layer Unconsolidated Material Sparse Vegetation (old burnt or other disturbance) Consolidated Rock Sparse Vegetation
Regularly flooded shrub and/or herbaceous cover	Wetlands Herbaceous Wetlands
Cultivated and managed areas	Cropland
Mosaic: Cropland / Other natural vegetation	Cropland and Shrubland/woodland
Water Bodies (natural & artificial)	Water bodies
Snow and Ice (natural & artificial)	Snow and Ice
Artificial surfaces and associated areas	Urban and Built-up

3.13 Australia

The Australian window was mapped at the JRC by Philippe Mayaux. Four seasonal composite images were created using the *average* algorithm (Van Cutsen *et* al., in revision). Each synthesis represents a 3-month average of all the cloud-free images during this period. The Red, NIR and SWIR channels of the 4 composites were then clustered in 100 statistical classes. The labelling was supported by the Vegetation Map of Australia in an objective manner. The composition of each cluster is computed in a GIS and the cluster is assigned to the main land-cover class within the cluster. In the case of mixed clusters, a detailed analysis allowed an accurate allocation of the cluster to a class, following a spatial revision of the cluster. Feedback from an Australian regional expert helped to improve the classification.

The classification comprises 13 land-cover classes, most of them in the natural vegetation domain, with one class for croplands and one for cities. The pastures could not be identified as such and were regrouped with grasslands. Modifications made for Australia in the global product are listed in Table 28.

Table 28: Modifications in Global Product for Australia

Legend transformation (see Table 29)
Clipping of areas (see Figure 5)

Table 29: Legend translation table for Australia

Global Land Cover Class	**Australia**
Tree Cover, broadleaved, evergreen (LCCS >15% tree cover, tree height >3m)	Closed multi-layered forest
	Closed forest (Eucalyptus)
	Open forest (Eucalyptus)
Tree Cover, broadleaved, deciduous, open	Open woodlands
Tree Cover, regularly flooded, fresh	Swamp Forest
Tree Cover, regularly flooded, saline, (daily variation)	Mangroves
Shrub Cover, closed-open, deciduous (with or without sparse tree layer)	Closed shrublands
Herbaceous Cover, closed-open	Open Shrublands
Sparse Herbaceous or sparse shrub cover	Grasslands with sparse shrubs (A
Cultivated and managed areas	Croplands
Bare Areas	Bare soil
Water Bodies (natural & artificial)	Water
Artificial surfaces and associated areas	Cities

3.14 New Zealand

The window of New Zealand was mapped at the JRC by Hans-Jürgen Stibig. Monthly image mosaics were created by Philippe Mayaux, applying the *average* algorithm (Van Cutsem *et* al. in press). The monthly mosaics were visually screened, the mosaic of the month of December, being of best quality, was selected for land cover mapping. An unsupervised digital clustering was performed. The spectral clusters were then labeled and regrouped to eleven land cover classes, using the Waikato Region Landcover Database (LCDB) from the year 1997 as a reference. The assignment of forest cover to pine plantations could only be achieved by using this reference map as a stratification layer. For three manually defined small polygons, corrections were applied by reassigning some pixels to shrubland, originally labelled (i) as ‘bare’ in the far northern and far southern tips of the country, or (II) as grassland on the northern island. Modifications made for New Zealand in the globa**l** product are listed in Table 30.

Table 30: Modifications in Global Product for North America

Legend transformation (see Table 31)
Clipping of areas (see Figure 5)

Table 31: Legend translation table for New Zealand

Global Land Cover Class	**New Zealand**
Tree Cover, needle-leaved, evergreen	Forest needleleaved, evergreen (Coniferous Plant. : Pinus, Chamaecypar
Tree Cover, mixed leaf type	Forest, mixed leaftype, mainly evergreen (Aghatis, Pdodcarpus, Nothofa
Shrub Cover, closed-open, deciduous (with or without sparse tree layer)	Shrub cover (incl. scrub & horticulture)
Herbaceous Cover, closed-open	Herbaceous cover, broadleaved, deciduous, (Tussock)
Cultivated and managed areas	Cultivated and managed
Mosaic: Cropland / Other natural vegetation	Cultivated and managed (Cropland, mixed with tussock()
Bare Areas	Bare areas, unconsolidated (bare soils)
	Bare, areas, consolodated (Rocks+Ice, Snow)
Water Bodies (natural & artificial)	Inland Water Bodies
	Sea
Artificial surfaces and associated areas	Artificial Surface: Built UP, Urban (Cities)

3.15 Greenland and Iceland

The map of Southern Greenland and Iceland was developed at the JRC by Sergey Bartalev in collaboration with the Russian Academy of Sciences' Space Research Institute. The map legend was adopted from a recently developed Circumpolar Arctic Vegetation Map (Walker *et* al. 2002). The mapping method includes detection of pixels contaminated by clouds/snow and defective sensor detectors; a synthesis of spectral channels' mosaics; and hybrid supervised and unsupervised land cover classification with use of these mosaics. Modifications made for Greenland and Iceland in the globa**l** product are listed in Table 32.

Table 32: Modifications in Global Product for Greenland and Iceland

Legend transformation (see Table 33)
Clipping of areas (see Figure 5)

Table 33: Legend translation table for Greenland and Iceland)

Global Land Cover Class	**Iceland Greenland**
Shrub Cover, closed-open, deciduous (with or without sparse tree layer)	Low-Shrub tundra Prostrate shrub tundra
Herbaceous Cover, closed-open	Sedge tundra
Sparse Herbaceous or sparse shrub cover	Barren tundra
	Dwarf-shrub tundra
Regularly flooded shrub and/or herbaceous cover	Wetlands
Bare Areas	Bare soil and rock
Water Bodies (natural & artificial)	Water bodies
Snow and Ice (natural & artificial)	Permanent snow/ice
Artificial surfaces and associated areas	Urban

3.16 Solomon Island

This window was mapped by Andrew Hartley at the JRC. Due to the wet climate of the Solomon Islands, it was not possible to create a seasonal mosaic suitable for vegetation mapping using S10 data, within the period of the study. Instead, relatively cloud-free S1 data was selected, and after cloud was removed from the images, an unsupervised ISODATA classification was used to create 25 clusters per image. Clusters were assigned to classes by referring to freely available Landsat TM imagery, and to ancillary information describing the vegetation of the islands.

Table 34: Legend translation table for the Solomon Islands

Global Land Cover Class	Solomon Islands
Tree Cover, broadleaved, evergreen	Broadleaved evergreen forest Degraded evergreen forest
Mosaic: Tree cover / Other natural vegetation	shrubland / degraded forest mosaic
Tree Cover, broadleaved, deciduous, open	Seasonally dry forest, and grassland
Shrub Cover, closed-open, evergreen (with or without sparse tree layer)	Open shrubland
Herbaceous Cover, closed-open	Herbaceous cover
Cultivated and managed areas	Arable agriculture Oil palm plantation
Bare areas	Fluvial sediment
Mosaic: Cropland / Shrub or herbacious cover	Mosaic Cropland / Shrub / herbaceous

3.17 New Caledonia and Vanuatu

This window was mapped by Steffen Fritz at the JRC. A composite of 5 S10 and 7 relatively cloud free S1 images was created. First, cloud cover was removed in all the S-1 and S-10 images and then the average method as described in Van Cutsem (2003, *in Revision*), was applied. Vanuatu and New Caledonia were classified separately was by applying and ISODATA classification separating 20 Clusters. Clusters were labeled by using ancillary data. The Atlas de la Nouvelle Caledonie, ORSTOM, Paris was used as the primary ancillary dataset.

Table 34: Legend translation table for New Caledonia and Vanuatu

Global Land Cover Class	New Caledonia and Vanuatu
Tree Cover, broadleaved, evergreen	Evergreen Broadleaved Forest
Tree Cover, regularly flooded, saline	Mangroves
Evergreen Shrubland	Maquis
Mosaic: Cropland / Tree Cover / Other natural vegetation	Fragmented Forest/ Cropland
Water Bodies (natural & artificial)	Water bodies

3.18 Fijian Islands

This window was mapped by Andrew Hartley and Steffen Fritz at the JRC. Due to very difficult climatic conditions, it was not possibly to create an accurate seasonal mosaic of the Fiji islands. Therefore, three relatively cloud free S1 images were chosen, and on each image an unsupervised ISODATA classification was performed, creating 25 clusters per image. Clusters were assigned to classes using Landsat TM Quicklooks, and ancillary landcover data from the Management Services Devision (located at Colo-i-Suva) of the Fiji Forestry Department. The classifications of the three images were then mosaiced together, by using the classification of the clearest image first, followed by the remaining 2 images to fill in the areas of no data in the first image. The map was directly classified according to the global legend.

3.19 Hawaiian Islands

This window was mapped by Andrew Hartley at the JRC. A colour composite was created of SPOT Vegetation S1 cloud-free data, by applying the averaging algorithm (Van Cutsem *et* al., *in Revision*) to the selected images. Due to the high contrast in spectral response observed between different islands in the archipelago, it was decided to divide the classification into 3 separate parts. Each part was classified separately, using an unsupervised ISODATA classification, creating 25 clusters which were then assigned to classes using Landsat TM imagery, and ground truth data obtained from the Hawaiian land cover analysis project (NOAA, 2002). The map was directly classified according to the global legend.

3.20 Northern Africa and South-Western Asia

This window contains information on the duration of vegetation growth, maximum vegetation cover and seasonality. It is not a land cover product and is in that respect different from the other windows.

The window was identified specifically according to the needs of the team at FAO that monitors the development of desert locust population and associated risks for agriculture. The area stretches from 4°N to 46°N and from 19°W to 80°E. It is centred on the largest desert areas of the globe and includes very diverse vegetation types, as it may be expected from the area extension.

Data classification was entirely based on the analysis of transformed NDVI temporal signal.

The input data is the classical 10-day Maximum Value Composite NDVI for the year 2000. Six months of data in 1999 and 6 months in 2001 were also included to facilitate analysis. In a first step the bare-soil NDVI value was identified on a per-pixel basis for all pixels where vegetation can be assumed to become completely unnoticeable for some time during the year. NDVI values were then transformed into apparent green cover percentage using a linear transformation rule, and taking the per-pixel bare soil value on

one hand, and the overall window maximum value for 0% cover and 100% cover respectively. Finally the temporal profile was cleaned from cloud and atmospheric effects by iteratively applying a 5^{th} degree polynomial on temporal blocks of 21 consecutive observations. At each step of the iteration measured values that were lower than values computed with the polynomial were replaced by these computed values. The result of the process was a clean and smoothed temporal green cover curve passing through all measured points that were unaffected by atmospheric effects, while the other points were replaced with polynomial values.

The classification process aimed at identifying categories of vegetation growth duration, vegetation maximum cover, and seasonality (i.e. Summer, winter or double growth cycle). This was achieved by simply applying a number of pre-defined thresholds. Only classes with more than 3% apparent green cover were retained: this was considered to be the minimum value for safe identification of vegetation occurrence. Moreover, to be confirmed as "vegetated" a pixel had to be detected as vegetated for at least two successive 10-day periods. It should be noted that with this process it was possible to identify the occurrence of ephemeral vegetation in conjunction with sporadic rainfall, a vegetation type that is usually omitted in land cover maps.

Identification of land cover classes has to be done by ecological sub-regions, as the land-cover meaning of a given category may differ substantially, for instance between temperate Europe, tropical Africa, or the Himalayan piedmont in India. This work has been completed for the African continent so far, and has been integrated in the African window.

4. Map finalisation

An area in the Gobi desert had not been mapped by the GLC2000 project. This area was however, 100% bare soil as observed on TM Quicklooks and therefore the class bare area was assigned. Since some of the northern areas were not mapped (north of 72 degrees in some areas in Northern Eurasia) a nodata value was assigned. The country borders were extracted from Global Insight (reference missing). Further remaining islands like the Faroe Island (UK) were mapped. Due to the fact that the Russian window and the North Eastern European window had some differences in the classification of agricultural landscapes, a small area of the Ukraine, by the Black Sea, was re-mapped using training data obtained from the European classification. This was then used to classify the summer seasonal mosaic created for Eurasian classification. This was mainly an aesthetic correction since the border of the maps shows up quite strongly.

5. Agreement scoring

In order to be able to compare the different windows and to see how well the different classifications correspond, a specific method was developed which is termed here 'agreement scoring'. It has to be pointed out that agreement scoring does not tell you where the pixels correspond and cannot be considered as an accuracy assessment. In particular the overlapping areas are not always an indication of the quality of the

classification, since by being on the edge of a window, they may fall outside the area of knowledge of the regional expert. For this reason, the regional experts were fully consulted, when choosing the cut lines in cases of regional overlaps, when creating the global mosaic.

Nevertheless agreement scoring can give an indication of the quality of a map. For example if two overlapping maps have a high agreement on the different vegetation classifications, the quality of both maps is most likely quite high. In contrast if there is a low agreement of two maps in the overlapping areas, at least one of the two might have a poor quality.

Major overlaps occur in the European and Asian windows. The following matrix was applied to overlapping pixels. The partial agreement was defined since in some cases classifications have a class which is from its spectral response and in terms of ecological condition quite similar. This matrix is kept very simple and has only 3 classes which are no agreement, partial agreement and full agreement. It could be refined by using a fuzzy approach and by using more refined terms such as very little, medium, strong agreement. However the applied technique was considered to be sufficient in order to determine the agreement of land cover classes within the different overlapping windows. The following symbols have been used in the table. Full agreement (+); the land cover classification is identical. No agreement (X), the land cover class is very different. Partial agreement (-); the assigned land cover class has similar land cover characteristics.

Table 34: agreement scoring within overlapping areas: full (+), partial (-) and no agreement (X) between land cover types.

	1. Tree Cover, broadleaved, evergreen	2. Tree Cover, broadleaved, deciduous, closed	3. Tree Cover, broadleaved, deciduous, open	4. Tree Cover, needle-leaved, evergreen	5. Tree Cover, needle-leaved, deciduous	6. Tree Cover, mixed leaf type	7. Tree Cover, regularly flooded, fresh water (& brackish)	8. Tree Cover, regularly flooded, saline, (daily variation)	9. Mosaic: Tree cover / Other natural vegetation	10. Tree Cover, burnt	11. Shrub Cover, closed-open, evergreen	12. Shrub Cover, closed-open, deciduous	13. Herbaceous Cover, closed-open	14. Sparse Herbaceous or sparse shrub cover	15. Regularly flooded shrub and/or herbaceous cover	16. Cultivated and managed areas	17. Mosaic: Cropland / Tree Cover / Other natural vegetation	18. Mosaic: Cropland / Shrub and/or herbaceous cover	19. Bare Areas	20. Water Bodies (natural & artificial	21. Snow and Ice (natural & artificial)	22. Artificial surfaces and associated areas
1. Tree Cover, broadleaved, evergreen	+	-	-	-	-	-	-	-	-	X	X	X	X	X	X	X	-	X	X	X	X	X
2. Tree Cover, broadleaved, deciduous, closed	-	+	-	-	-	-	-	-	-	X	X	X	X	X	X	X	-	X	X	X	X	X
3. Tree Cover, broadleaved, deciduous, open	-	-	+	-	-	-	-	-	-	X	X	X	X	X	X	X	-	X	X	X	X	X
4. Tree Cover, needle-leaved, evergreen	-	-	-	+	-	-	-	-	-	X	X	X	X	X	X	X	-	X	X	X	X	X
5. Tree Cover, needle-leaved, deciduous	-	-	-	-	+	-	-	-	-	X	X	X	X	X	X	X	-	X	X	X	X	X
6. Tree Cover, mixed leaf type	-	-	-	-	-	+	-	-	-	X	X	X	X	X	X	X	-	X	X	X	X	X
7. Tree Cover, regularly flooded, fresh water (& brackish)	-	-	-	-	-	-	+	-	-	X	X	X	X	X	X	X	-	X	X	X	X	X
8. Tree Cover, regularly flooded, saline, (daily variation)	-	-	-	-	-	-	-	+	-	X	X	X	X	X	X	X	-	X	X	X	X	X
9. Mosaic: Tree cover / Other natural vegetation	-	-	-	-	-	-	-	-	+	X	X	X	X	X	X	X	-	-	X	X	X	X
10. Tree Cover, burnt	X	X	X	X	X	X	X	X	X	+	X	X	X	-	X	X	X	X	-	X	X	X
11. Shrub Cover, closed-open, evergreen (with or without sparse tree layer)	X	X	X	X	X	X	X	X	X	X	+	-	X	-	-	X	-	-	X	X	X	X
12. Shrub Cover, closed-open, deciduous (with or without sparse tree layer)	X	X	X	X	X	X	X	X	X	X	-	+	X	-	-	X	-	-	X	X	X	X
13. Herbaceous Cover, closed-open	X	X	X	X	X	X	X	X	X	X	X	X	+	-	-	X	-	X	X	X	X	X
14. Sparse Herbaceous or sparse shrub cover	X	X	X	X	X	X	X	X	X	-	-	-	-	+	-	X	X	X	-	X	X	
15. Regularly flooded shrub and/or herbaceous cover	X	X	X	X	X	X	X	X	X	X	-	-	-	-	+	X	-	-	X	X	X	X
16. Cultivated and managed areas	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	+	-	-	X	X	X	X
17. Mosaic: Cropland / Tree Cover / Other natural vegetation	-	-	-	-	-	-	-	-	X	X	-	-	-	X	-	-	+	-	X	X	X	X
18. Mosaic: Cropland / Shrub and/or herbaceous cover	X	X	X	X	X	X	X	X	X	X	-	-	-	X	-	-	-	+	X	X	X	X
19. Bare Areas	X	X	X	X	X	X	X	X	X	-	X	X	X	-	X	X	X	X	+	X	-	X
20. Water Bodies (natural & artificial)	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	+	-	X
21. Snow and Ice (natural & artificial)	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	-	-	+	X
22. Artificial surfaces and associated areas	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	+

Agreement Score (AS) is calculated:

$$AS = \frac{Nf + 0.5 * Np}{Na} * 100$$

where:

AS = Agreement Score
Nf = Number of Pixels with full agreement (marked in Table 34 with +) in overlapping area
Np = Number of Pixels with partial agreement (marked in Table 34 with -) in overlapping area
Na = Number of all Pixels in overlapping area

Table35: Agreement scoring of different regions in overlapping areas.

Country 1	Number of Pixels of Country 1	Country 2	Number of Pixels of Country 2	Full Agreement	Partial Agreement	No Agreement	All pixels	Overlapping Pixels	Percent Overlap	Agreement score (AS)
Northern Eurasia	46,543,129	Asia	50,491,096	3,217,385	9,185,206	7,227,865	97,034,225	19,630,456	20.23	39.79
South Asia	11,177,280	Asia	50,491,096	4,515,326	2,147,862	4,513,722	61,668,376	11,176,910	18.12	50.01
china	12,057,851	Asia	50,491,096	4,767,459	2,874,574	4,415,818	62,548,947	12,057,851	19.28	51.46
South East Asia	6,001,824	Asia	50,491,096	1,112,110	1,333,666	843,270	56,492,920	3,289,046	5.82	54.09
Europe North - East	10,613,160	Eurasia	46,543,129	1,909,832	2,041,276	1,462,311	57,156,289	5,413,419	9.47	54.13
South East Asia	6,001,824	South Asia	11,177,280	834,377	980,645	583,179	17,179,104	2,398,201	13.96	55.24
China	12,057,851	Northern Eurasia	46,543,129	1,306,614	761,745	839,569	58,600,980	2,907,928	4.96	58.03
South Asia	11,177,280	China	12,057,851	1,791,666	651,165	1,094,590	23,235,131	3,537,421	15.22	59.85
Eu all	6,747,729	United Kindom	3,635,836	214,472	67,228	121,509	10,383,565	403,209	3.88	61.53
Eu all	6,747,729	Northern Eurasia	46,543,129	453,095	452,100	197,364	53,290,858	1,102,559	2.07	61.60
Eu all	6,747,729	Italy	2,794,592	1,489,638	378,550	840,846	9,542,321	2,709,034	28.39	61.97
Eu all	6,747,729	Northern Europe	10,613,160	1,629,698	333,758	832,248	17,360,889	2,795,704	16.10	64.26

Table 35 is ranked by agreement score. Low agreement scores are recorded for Northern Eurasia – Asia, South Asia – Asia, China – Asia and South East Asia and Asia. It can be noted that Asia performs overall quite badly since it has a low agreement score with all the other overlapping areas. The comparison between South East Asia – South Asia, China – Northern Eurasia shows a higher agreement score. Comparisons in Europe rank relatively high except the comparison between the North Eastern European and Eurasian window. The reason for the low agreement score results from the fact that a high proportion of agricultural land is found in both windows. In the North-Eastern European

window this area is classified as a 'Cultivated and Managed Area', whereas in the Northern Eurasian window this area is classified as 'Mosaic: Cropland/Shrub Cover or herbaceous cover'.

6. Displaying the global map

The original data was produced in the geographic projection lat/long. The problem however with this projection is that areas in the northern hemisphere close to the pole appear much larger than they are and can give a wrong impression on the actual size. In order to maintain the actual size of areas in the northern hemisphere and to have a good visual appearance land cover data can be displayed in the Interrupted Goode's Homolosine projection (see Figure 7).

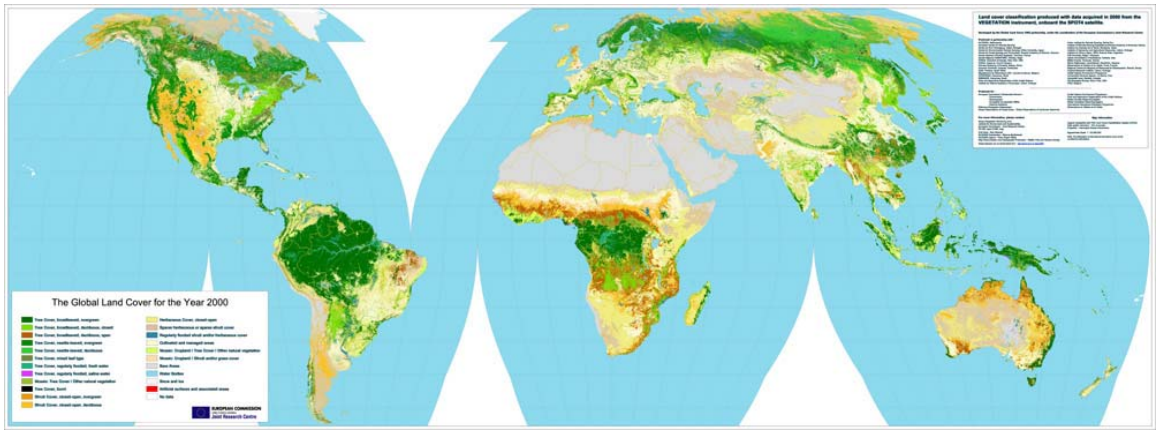


Figure 7: Global land cover in Goode's Homolosine Projection

7. Discussion and Conclusions

19 different regional windows have been mapped by a number of partners and partner organizations under the co-ordination of the JRC. The Global Land Cover 2000 product is a paradigm shift in land cover mapping. Previous models have used a top-down approach. Until recently a single (pre-) classification approach has been applied globally (e.g. recent classifications of IGBP and MODIS). GLC2000 adopts a so called bottom-up approach because the partners have used their regional expertise to produce a regional map which can be directly translated to a global legend. The fact that the mapping is carried out by partners has the benefit that they have a high level of expertise of their particular area. Furthermore, by using sub-windows of the global image archive, spectral bands and the timeframe of the mosaics can be chosen to fit the requirements of a certain region and therefore lead to improved classifications. In order to guarantee consistency all partners used the global Land Cover Classification System (LCCS) provided by FAO. LCCS describes land cover according to a hierarchical series of classifiers and attributes. Coding each class with LCCS allows the map producer to create a regional legend, composed of individual classifiers, which hierarchically map into the more general global

legend. The global scale GLC2000 legend documents 22 land cover types whereas the more detailed regional legends vary between 5 and 44 classes

As it has been demonstrated, a plethora of different methods have been used for each window to account for the difference in environmental conditions. It has also been shown that in the overlapping areas differences in the classification occurs and the quality of the map differs. However by extracting the best dataset from these areas of overlap between regional windows, and through the use of expert opinion and quantitative analysis (agreement scoring) a high quality product can be achieved. It has to be noted that in some parts, the classification of the global product has been improved (Asian and Chinese windows) since additional data such as elevation data and data derived from stable night time light (DMSP) have been consulted.

The product has been visually validated by a number of experts and the overall response has been very positive. However, it has to be noted that in contrast to a global approach, repeatability is more complex. Nevertheless, for the year 2000 a very high quality product has been produced which will eventually become available as a global dataset which also contains the regional subclass and the LCCS code (classifier). It will provide a detailed description of land cover on a global level. This has implications in the field of ecology, natural resource management and nature conservation and will further the understanding of modified ecosystems globally.

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