A NEW LAND COVER MAP OF THE DEMOCRATIC REPUBLIC OF CONGO

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ABSTRACT

The land cover mapping of the Democratic Republic of Congo has always been considered as an outstanding challenge because of its important cloud cover, its limited accessibility, its equatorial localization, and its extended territory. Up to recently, no cartographic document presented the state of the land cover of this country in an exhaustive way. Very recently, in the framework of the AFRICOVER program, a land cover map of the DRC has been produced based on visual interpretation of Landsat images acquired at different years and different seasons, by several experts. While providing a great deal of details, the production of such a map encounters some difficulties because of the heterogeneity of the acquisition dates, images and interpretation from one scene to another. The objective of this study is to demonstrate an alternative mapping strategy based on high temporal resolution data to produce a spatially consistent and easily updated land cover map covering all the Congo territory. Seasonal and annual satellite image composites have been generated from SPOT VEGETATION temporal series acquired during the year 2000. The compositing procedure used, i.e. the mean compositing strategy, provides cloud-free and spatially consistent colour composites as never realized before. Based on the temporal and spectral information of satellite data, regional unsupervised digital classifications have been completed. Thanks to the collaboration of several experts having an extensive field knowledge of this region and thanks to the support of several reference maps, documents and high spatial resolution images, the classes have been interpreted, described and clustered in 16 final classes. The land cover map has been produced at the 1: 2,500,000 scale. Finally, forest cover areas have been estimated and compared to other sources.

1 INTRODUCTION

The land cover mapping of the Democratic Republic of Congo (DRC) has always been considered as an outstanding challenge because of its important cloud cover, its limited accessibility, its equatorial localisation (inversion of seasonality between north and south), and its extended territory. Up to recently, no cartographic document presented the state of the land cover of this country in an exhaustive way. Indeed, existing maps present either a detailed information on limited regions like the INEAC (Institut National pour l'Etude Agronomique du Congo) vegetation maps [2,4,6,9], or a nationwide but outdated information, e.g. the Devred [3] and the White vegetation maps [11], or a very specific information like the TREES (Tropical Ecosystem Environment Observation by Satellite) map [8], or a recent but coarse information like the GLC2000 map [7].

Very recently (October 2003), in the framework of the AFRICOVER programme, a land cover map of the DRC has been produced based on the visual interpretation of Landsat images acquired at different years and different seasons, by several experts. While providing a great deal of details, the production of such a map encounters some difficulties because of the heterogeneity of the acquisition dates, of the images and the interpretation from one scene to another.

The objective of this study is to propose and demonstrate an alternative mapping strategy based on high temporal resolution data to produce a spatially consistent and easily updated land cover map covering all the Congo territory. However, to achieve this objective, the main challenge is the production of cloud-free and spatially consistent images over large areas. Recently, a new compositing strategy, i.e. the mean compositing (MC) proved to improve considerably the quality of the temporal syntheses for a large number of samples in different parts of the world [10]. The methodology has been also successfully applied to the entire European continent and to the African Great Lakes Area to produce land cover maps in the framework of the Global Land Cover 2000 program [7] and recognised as a valuable alternative to the existing methods.

This research will both exploit this original approach and collect the knowledge of several botanists, having an extensive field experience in order to produce a new land cover map of the DRC at the 1/2,500,000 scale.

2 DATA

The dataset used to produce the land cover map consists of 366 daily SPOT VEGETATION images of the year 2000 in 4 wavelengths: the blue (0.43-0.47 ?m), the red (0.61-0.68 ?m), the near infrared (NIR) (0.78-0.89 ?m) and the middle infrared (MIR) (1.58-1.75 ?m).

The 2 major reasons for using the SPOT VEGETATION products are: (i) the daily multispectral reflectance measurements are radiometrically calibrated and atmospherically corrected; (ii) the global dataset presents a high multitemporal co-registration accuracy.

Moreover, other types of data were used as a support for the interpretation and the clustering of the land cover classes: Landsat images acquired at different dates, from 2000 to 2003, and reference vegetation maps such as the Devred [3] and the INEAC vegetation maps [2,4,6,9].

3 METHOD

The land cover mapping methodology consists of 4 steps: (i) the data processing or the compositing process, (ii) the stratification, (iii) the classification of the composites, and (iv) the map edition. The 3 first steps are illustrated at the Fig.1.

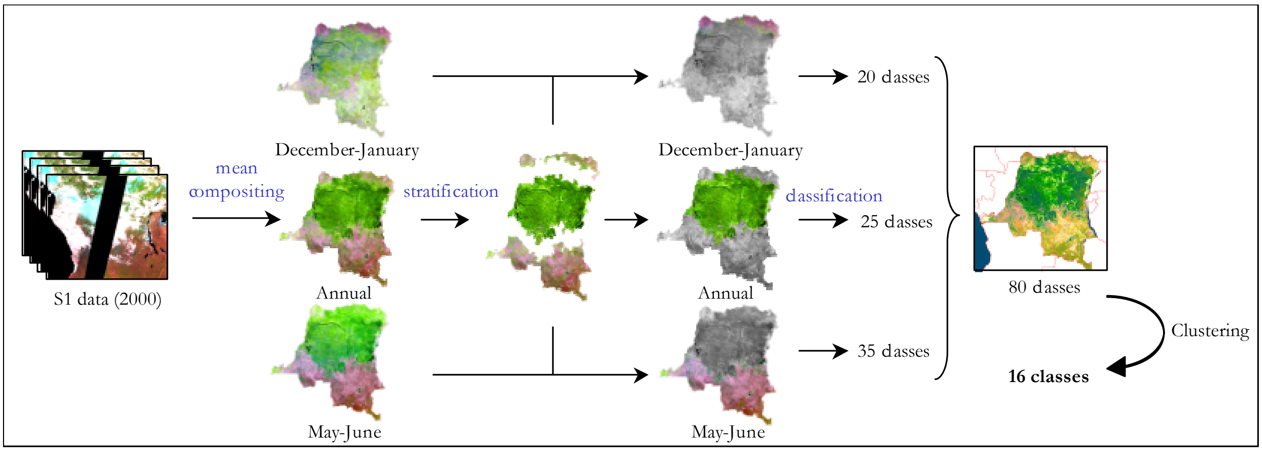


Fig. 1. The 3 first steps of the land cover mapping methodology

3.1 Data processing

Seasonal and annual satellite image composites have been generated from the temporal SPOT VEGETATION series acquired during the year 2000. The compositing procedure used is the MC strategy [10]. The main advantage of this strategy is to make use of all the available and useable information to feed the interpretation step with the most representative signal for each pixel for a given period of compositing. In addition it is very flexible in terms of period of compositing, which may be adapted according to the cloud coverage frequency and the target seasonality.

The MC strategy requires an efficient quality control of the reflectance values as a preliminary step. This includes the cloud screening and the removal of all the sensor anomalies and artefacts values. After this quality control procedure, the valid reflectance values are averaged for each pixel and in each wavelength during the chosen compositing periods.

Three composites have been produced: (i) a seasonal composite of December-January corresponding to the dry season of the north of the country (over the equator), (ii) an annual composite and (iii) a seasonal composite of May-June corresponding to the dry season of the south (below the equator).

Moreover, a time series of 15-day composites has been produced to characterize the seasonality of all vegetation types.

Fore each composite, three wavelengths (over 4) have been used in the further processes, i.e. the red, the NIR and the MIR, the blue band being too sensitive to the atmospheric variations.

3.2 Stratification

The objective of this step is to address the seasonality inversion issue. In order to preserve the spatial consistency of the composites and the natural limits, the stratification was based an NDVI threshold. The country has been divided in 3 regions : the north, the centre and the south. They correspond respectively to the savannah areas in the north, the dense forest area in the centre, and the savannah and woodland areas in the south. In this way, it was possible to use different composites for the north and for the south and so optimise the period of compositing according to the specific seasonality of each region.

3.3 Classification

Based on the temporal and spectral informations of the time series, 3 unsupervised digital classifications were completed for each region. (i) 20 classes were derived from the seasonal composite of December-January in the north. (ii) 25 classes were derived from the annual composite in the centre region, and (iii) 35 classes were derived from the seasonal composite of May in the south.

Thanks to the collaboration of several botanists having an extensive field knowledge of these regions and thanks to the support of several reference maps, documents, high spatial resolution images, and the NDVI temporal profiles, the classes have been interpreted, described and clustered in 16 final classes.

3.4 Map edition and characterization of the land cover classes

All the 16 classes have been described in an explanatory note. Moreover, the temporal profile of each vegetation class has been extracted to describe its seasonality.

The land cover map has been produced at the 1: 2 500 000 scale.

Cartographic vector information has been added to the classification. Roads and international boundaries were derived from the Global Insight dataset (Europa technologies, 2000). The rivers were derived from the Shuttle Radar Topography Mission (SRTM) data. The places are coming from the repertory of the collect places of Zaire, Rwanda and Burundi [1].

4 RESULTS

4.1 Compositing

The annual composite (Fig.2) is remarkable for his spatial consistency in the 3 spectral bands, i.e. the red, the NIR and the MIR wavelengths, over the entire central Africa region and for the absence of clouds and hazes. The major features of the dense moist forest biome are the presence of swamp forest along the rivers (Fig.2a) and the ribbons of secondary forest formations along the road network (Fig.2a,2d). It is also possible to distinguish the rural complex areas surrounded by the secondary forest (Fig.2c). In the north of the Congo basin, the transition between the forest and the savannah is quite abrupt (Fig2b,2d) whereas in the south, the gallery forests interpenetrates into the savannah areas (Fig2e). Vast savannah areas also appear in the forest domain, either as large patches surrounding the forests or as small islands of grasslands enclosed within the forest (Fig.2e,2f).

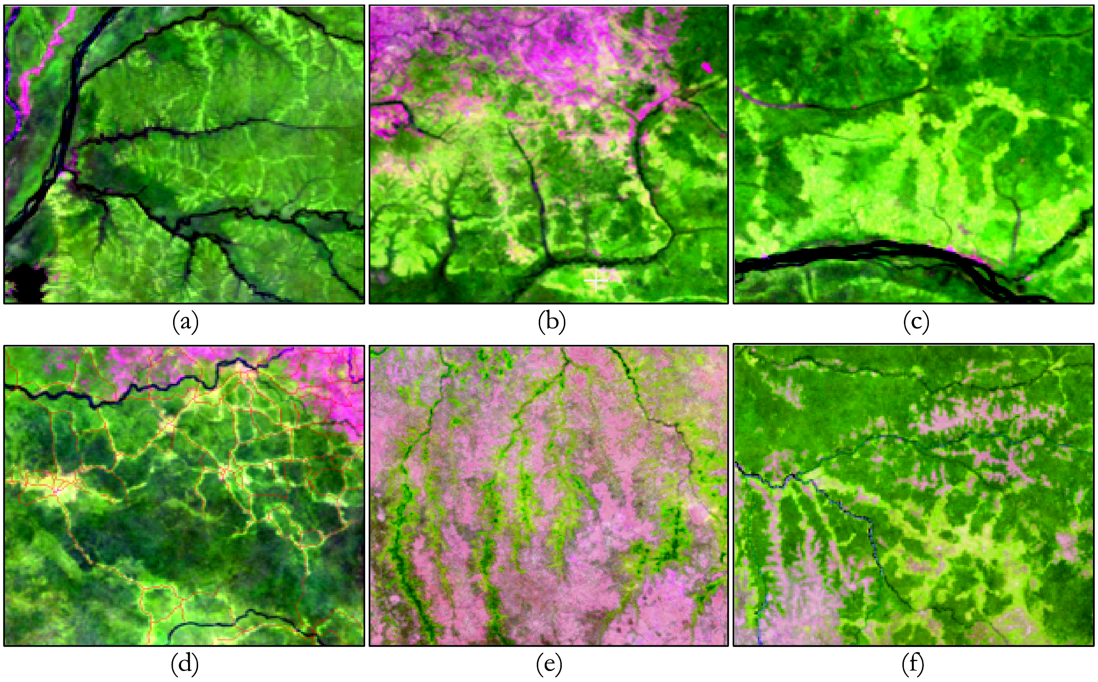


Fig.2. Samples of the annual mean composite (MIR-NIR-Red) for the Democratic Republic of Congo (2000)

The 2-months composites are particularly interesting for the north and the south parts of the country. The contrast between land cover types is more pronounced compared with the annual temporal synthesis. In particular, the May-June composite allows a very good identification of the Miombo woodland (Fig.3).

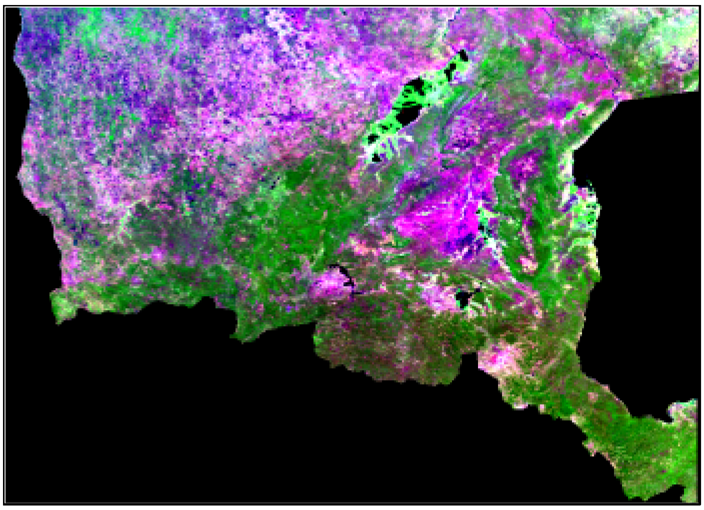
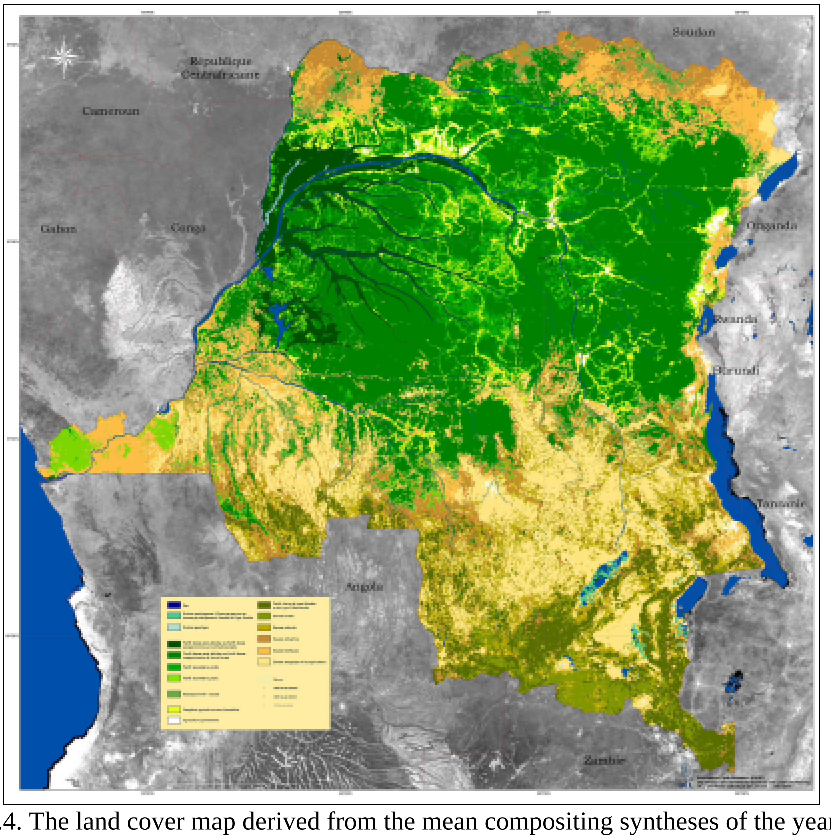


Fig.3. Seasonal mean composite (MIR-NIR-Red) in the Katanga area (May-June, 2000)

4.2 Land cover map

The land cover map product of the DRC is presented at the Fig.4. Some classes are distributed locally such as the aquatic grasslands found at the periphery of the swamp forests between the Oubangui and the Congo rivers, the swamp grasslands that only appear in the Upemba region and in the south of the lake Moero in Katanga, and the edaphic forests that are mainly present along the rivers of the Congo basin. The most represented class is the dense moist forest (semi-deciduous and evergreen), which covers the majority of the Congo basin and 32.2% of the country area. The old secondary forest class appears between the dense moist forest and the young secondary forest. This formation represents the reconstitution step just before the adult forests in the evolutionary series [5]. As clearly observed on the annual composite, the young secondary forest is mainly developed along the road network and around the villages. It covers 5.6% of the country area. The villages and the agriculture areas in the forest are represented by the rural complex class. The forest-savannah mosaic class appears at the periphery of the dense moist forest and near the boundary with the Sudan, in the west of the Garamba Park. In the south, it is also located along the gallery forests of the Bandundu. The dense woodland is located in the Katanga area where it covers 26% of the province and it is also distributed in the Kwango area. All the savannah formations are represented from the open woodland to the steppic savannah. The open woodland class marks the transition between the dense woodland and the tree savannah. The grasslands are distributed both in the forest domain and at the periphery of the forest. It also dominates the landscapes of the “Bas-Congo” province. Finally, the steppic savannah covers 13.6% of the country. This class mainly appears in the south of the country, especially in the Kwango area and on the top-plateaus of the Katanga.



Land cover classes
1 Edaphic forests
2 Dense moist forest (semi-deciduous and evergreen)
3 Old secondary forest
4 Young secondary forest
5 Forest-savanna mosaic
6 Rural complex (forest area)
7 Agriculture
8 Woodland
9 Savanna woodland
10 Tree savanna
11 Shrubland
12 Grassland
13 Steppic savanna
14 Waterbodies
15 Swamp grassland
16 Aquatic grassland

Fig.4. The land cover map derived from the mean compositing syntheses of the year 2000 and the 16 land cover classes

4.3 Estimation of forest area

The estimated forest area in the DRC corresponds to 44% of the country area. This percentage includes 3 classes: the dense moist forest, the edaphic forest and the old secondary forest. The comparison with other sources of forest area estimation shows that this new land cover product presents the lowest estimation. Nevertheless, it is impossible to conclude about deforestation. Indeed, the land cover areas depend on the type of data used, on the data processing method and on the legend. Therefore, it is very difficult to compare different products. This emphasizes the need of using the same legend, the same data and the same methodology in order to monitor land cover changes.

Table 1. Comparison of forest cover areas estimations from different sources

Source	Land cover classes	km²	%
TREES 1998	Evergreen and Semi-deciduous Forest	1 141 470	49
FAO-FORIS	Closed Broadleaved Forest	1 035 330	44
IUCN	Closed Forest	1 190 740	51
Africover 2003	Evergreen and semi-deciduous forest and edaphic forest	1 112 965	47
UCL 2004	Dense moist forest, edaphic forest and old secondary forest	1 023 357	44

5 CONCLUSIONS

A new land cover map of the DRC has been produced based on high temporal resolution data. This product provides a synoptic and consistent view of this huge territory. Moreover, with the 16 classes produced additionally to the toponymy information, the map presents a high contents of information.

This study shows that the mean compositing strategy provides a great spatial consistency to the composites and consequently to the classification product. For the first time, it is possible to produce complete cloud-free and consistent composites from optical sensor data in all wavelengths over this country. The high contrast between the different land cover types provides a detailed and robust classification. An other benefit of the strategy is the adaptability of the compositing period to the regional conditions.

The close collaboration of the botanic experts has been critical in the interpretation process as well as in the continuous validation of the product. This emphasises the interest of an extensive field knowledge of the vegetation for a better understanding and a true interpretation of the satellite images.

Finally, this work opens new prospects about the monitoring and the land cover changes detection over large territories. Indeed, both the syntheses and the classification products could be easily updated in order to monitor the natural resources, which constitute large policy, economic and ecological stakes.

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