Development of an operational system for monitoring forest cover at national scale in 1990, 2000 and 2010

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Abstract: Tropical deforestation is today considered as a major environmental issue. And it is accepted that deforestation and forest degradation are estimated to contribute to about 7 to 15 % of the total greenhouse gas emissions. A post-Kyoto protocol mechanism was developed, termed the Reduction of Emissions from Deforestation and forest Degradation (REDD+). The development of deforestation monitoring systems and determination of historical trends for forest cover change are key point in the establishment of national or sub-national carbon policy. This paper aim to show how through three different projects, and four different countries, a single standardized methodology has been developed and applied to monitor forest cover in 1990, 2000 and 2010. Each of those projects (project GSE FM REDD in Gabon funded by the European Spatial Agency, REDDAF in CAR and Cameroon funded by the European Commission and SLCS in Bolivia funded by the CNES) aim to make an inventory of forest areas at national or sub-national scale in order to take stock of the forest cover changes over the past 20 years. The proposed services will form the basis of a wall-to-wall regional-wide forest cover monitoring in this four countries. Therefore, a new and cost efficiency methodology was set up in order to automatically map forest cover using only optical data.

Keywords: Remote Sensing, Image Processing, Forest monitoring.

1. Introduction

Tropical deforestation is today considered as a major environmental issue Justice et al. (2001), Zhang et al. (2005), Hansen et al. (2008). Deforestation and forest degradation are estimated to contribute to about 7 to 15 % of the total greenhouse gas emissions Achard et al. (2007), GOFC-COLD (2011). A post-Kyoto protocol mechanism was developed, termed the Reduction of Emissions from Deforestation and forest Degradation (REDD) and initiated at the UNFCCC Conference of Parties (COP) 11 in Montreal in 2005. One of the fundamental requirements in the UNFCCC process is the establishment of robust and transparent national forest monitoring systems. Moreover determination of historical trends for forest cover change is also a fundamental input in the establishment of national or sub-national policy in relation to REDD.

Land cover maps fulfill several functions in monitoring forest cover change. Firstly, they serve as a reference baseline against which future change can be assessed. Secondly, they help establish forest areas that need to be monitored for change. When using a land cover map to assess future change, consistent methodology and spatial resolution are critical for the interpretation of results Achard et al., (2007). Different methods are appropriate and reliable for forest cover mapping or monitoring at regional or national scales using remote sensing data. An approach using spatially explicit land conversion information derived from sampling Bodart et al., (2009) or wall-to-wall mapping techniques is considered the most appriate (GOFC-COLD, 2011).

Herein, a standardized method for monitoring forest cover and forest cover change from optical Earth observation data was developed and applied over significant areas in four separate countries listed in table 1.

Table1. Forest cover mapping project undertaken by sirs

country	Project	Funded by	user	area
Bolivia (Pando)	SLCS Carbone	CNES	COINACAPA	63 000 KM²
Gabon (1/3 country in 2010)	GSEFM REDD	ESA	AGEOS	267 000 KM²
Central African Republic (Sangha Mbaéré, Lobaye and Ombella-M'Poko)	REDDAF	EU Commission	MEE RCA	87 000 KM²
Cameroon (Central Province)	REDDAF	EU Commission	MEE CAMEROON	90 000 KM²

The estimation of deforestation is a function of the forest definition, in the absence of national forest definition; the service will comply with FAO forest definition IPCC (2006), which provides a range of values from which countries can select their forest definition. Forest should be an area of minimum 1 ha, with a minimum tree crown cover (or equivalent stocking level) of 30% and a minimum tree height at maturity of 5m. The proposed services will form the basis of a wall-to-wall regional-wide forest cover monitoring. Therefore, a new and cost efficiency methodology was set up in order to automatically map forest cover using only optical data. Technical specifications of forest area maps and forest cover change maps for 1990, 2000 and 2010 are listed in table 2.

Table 2.Forest Cover Maps 1990, 2000, 2010 and Forest Cover Change Maps 1990-2000 and 2000-2010 product specifications

Forest cover map		*forest cover change map*	
Criteria	**Specification**	**Criteria**	**Specification**
Geometric accuracy	Around 30 meters	Geometric accuracy	Around 30 meters
Reference system	WGS 1984 UTM	Reference system	WGS 1984 UTM
Image quality	30 metres	Image quality	30 metres
Image acquisition	+/- 3 years	Image acquisition	+/- 3 years
Minimum mapping unit	1 ha	Minimum mapping unit	1 ha
Map classes	Forest / Non Forest	Map classes	IPCC
Thematic accuracy	85% +/- 5%	Thematic accuracy	85% +/- 5%

In Gabon, the ESA GSE FM REDD extension project aims at developing a pre-operational system for monitoring forest cover within the REDD framework. The activities in Gabon are coordinated by SIRS and the overall project by GAF AG. The Gabonese Agency for Space Studies and Observations (AGEOS) was set up in 2010 with the aim to establish a national infrastructure for environmental monitoring and preventing the impacts of climate change. One of the objectives of the AGEOS is to develop its capacity to monitor forest cover at national level. The Gabonese authorities see the GSE FM REDD project as a precursor to the establishment of such national forest monitoring system.

In Bolivia, the main aim of the SLCS project funded by the CNES and coordinated by SIRS is to develop a monitoring system to facilitate access to payment for environmental services by local fair-trade organizations involved in agroforestry and deforestation avoidance projects. The case study in the Pando district in Bolivia has been developed in partnership with an organization of producers of Brazil nuts (COINACAPA). These nuts are not cultivated but harvested in the Amazon rainforest. This case study aims to show that it is an activity that contributes to preserving forest resources in the area in which they operate.

Finally, the FP7 REDDAF project coordinated by GAF AG, seeks to develop and implement improved methodologies for assessing activity data and emission factors which are key input data for carbon accounting in the REDD process. The improved methodologies support the development of operational service chains for forest monitoring. Two demonstration areas were selected to develop and implement these methodologies, one in Central African Republic (Sangha Mbaéré, Lobaye and Ombella-M'Poko) and a second in Cameroon (Central Province). Both service providers SIRS and GAF AG were involved in the production of the map products to further demonstrate the interoperability of the mapping service developed.

2. Methodology

The Forest Cover Map (Forest/Non-Forest map) generation is based on Optical imagery and the overall production process follows a stepwise approach.

2.1 Data source

The production of the forest cover and forest cover change maps were exclusively based high resolution Optical data. For the four study area, in 1990 and 2000, Landsat data appears to be the most suitable data for historical mapping: datasets are freely available (USGS), the satellite has a repetitivity of 16 days and the spatial resolution meets the services 'criteria (cf. table 1) Thus, Landsat TM 4 and TM 5 were used for 1990 and Landsat 7 ETM+ for 2000. For 2010, in Gabon, a combination of Landsat 7 ETM+ SLC off and ASTER data were used, in Pando (Bolivia) only Landsat 7 ETM+ SLC off were used. In CAR and Cameroon, a mix of RapidEye and Deimos data were used. Due to the heavy cloud cover conditions generally experienced over tropical area, several images were required to cover a scene entirely. It was almost always possible to acquire the imagery within the required time interval (i.e. +/- 3years from the reference year).

2.2 Pre-Processing

All data acquired were already georeferenced by the provider to an UTM projection. The image-to-image registration was performed using Landsat GLS-1990/2000/2005 as reference dataset Gutman *et al*. (2008). All input dataset was initially checked visually and a minimum set of 10 evenly distributed check points were selected to assess the quality of the registration. In cases when the computed RMS exceeded 30m, the image was rectified using a first order polynomial model. All were resampled to an output pixel size of 30m to create a consistent dataset for change detection. Finally a topographic normalization was applied for each image.

A cloud detection algorithm was developed based on the combination of an unsupervised classification approach combined with a visual comparison of the results with the input image to determine the threshold between cloudy and non-cloudy pixels. A cloud mask was produced for each input image to derive cloud cover statistics and to determine the effective coverage. Gap stripe on Landsat 7 ETM+ SLC off were processed as cloud area and thus were masked and considered as no data area.

2.3 Thematic Processing

Depending on statistical results of data covers calculations for each reference years (1990, 2000 and 2010), the reference year getting the best coverage of data is chosen as time 0 (*t0*). *t0* was selected as it provided the most complete and homogeneous image coverage will be used as the basis of classification forest / non-forest. For forest cover map and forest cover change map in Gabon and Bolivia, *t0* correspond to the reference year 2000, in CAR and Cameroon, *t0* correspond to reference year 2010.

In a first step, the segmentation and classification of EO dataset from *t0* was carried out, followed by manual/visual enhancements of the classified Forest Cover Map. The derived classified map product from *t0* and the Landsat data from *t1* are used to derive the Forest Cover Map for *t1* and the Forest Cover Change Map *t0/t1* (classified into IPCC compliant

Land Use classes). The *t0* or *t1* Forest Cover Map and the current EO data set from *t2* are then the basis to derive the Forest Cover Map from *t2* and the respective mapped Forest Cover Changes. A more detailed description of the single processing step is outlined in the following paragraphs.

2.3.1 Semi-Automatic Classification of Forest Cover and Segmentation Process

The classification of the area of interest into Forest & Non-Forest was performed for each cloud and cloud shadow masked image, by using the ERDAS Imagine software. Optical data from *t0* were used as input. An unsupervised classification of the area of interest was conducted with a large number of spectral classes to ensure a good representation of the thematic classes' variability. An interactive comparison of the classified image was performed to label each spectral class according to the Forest/ Non Forest thematic classes. A post-processing classification routine was applied to vectorise the results and eliminate polygons smaller than 1 ha.

2.3.2 Manual Post-Processing

Subsequent to the automated classification, an intensive interactive post-processing was applied. Areas incorrectly classified were relabelled. The manual post-processing was performed using in house developed tools built on the ESRI software suite, especially designed for this type of activity. Additional information sources (e.g. topographic maps) can be used to support this interpretation. In case of discrepancies between the ancillary data sources and the satellite images, the most up-to-date information from the satellite imagery was used.

2.3.3 Detection of Forest Cover Changes

The *t0* Forest Cover Map was used as a Mask with the *t1* imagery to identify areas of change. The geometry of the *t0* map was kept when no change was detected to avoid the creation of artefacts. This process was repeated for *t2*. The detected change areas identified as part of the *t1* and *t2* Forest Cover Map production process were classified into cropland, grassland, wetland, settlement or other land use which are IPCC compliant.

2.4 Accuracy assessment of classification results

As shown in Table 1, the thematic accuracy should reach 90%. Many methodologies to assess the accuracy of a map have been developed Stehman, (2009), Czaplewski et al, (2004), Czaplewski (2003), Congalton, (2001), (1999), (1991). The main objectives of the implementation of the thematic map accuracy assessment procedure are to provide objective unbiased information on the map accuracy, and a cost-efficient and well accepted procedure. The easiest way to ensure that a sample is unbiased is to select each element randomly Stehman and Czaplewski, (1998**).** Despite the fact that, random selection is completely unbiased, it can leave some areas uncovered resulting in a non-fully representative sample. Therefore, a good alternative is a combination of systematic and random approach resulting in a randomly unaligned systematic sample scheme shown in figure 1 Czaplewski et al, (2004), Stehman and Czaplewski, (1998). It consist in a systematic grid of 20 by 20 km cell within a single sample of 2 by 2 km is randomly selected. Each segment was photo-interpreted by a qualified photo-interpreter independent from the production team. Then 50 points are randomly selected in each sanple. A confusion or error matrix is usually produced Congalton, (1991) based on a comparison of single points on the maps. The overall classification accuracy can be calculated together with user's and producer's accuracies which represent respectively errors of omission and commission. This approach is particularly suited for the Forest Cover and Cover Change Map products.

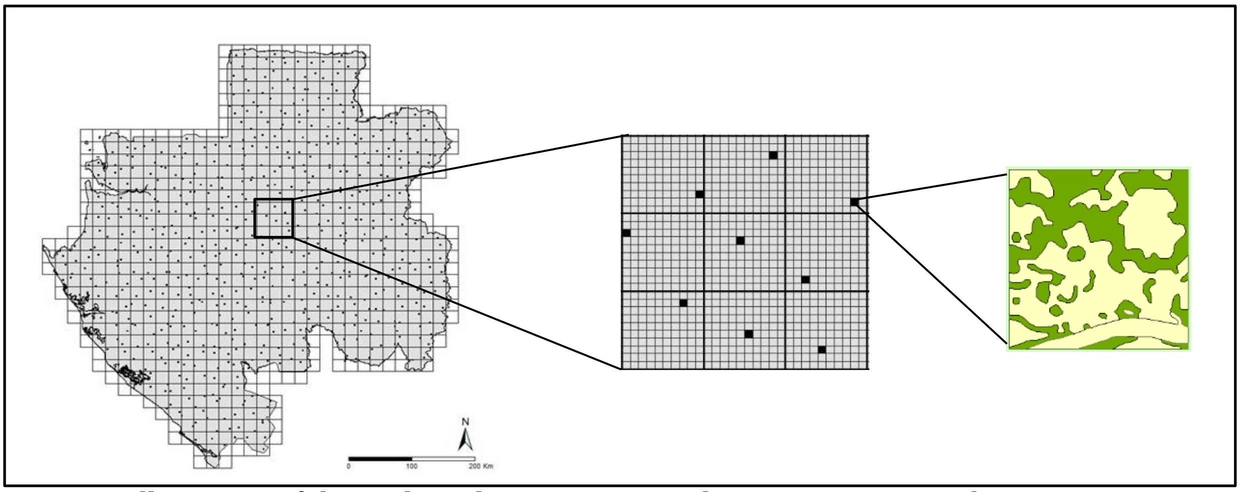

Figure 1. Illustration of the unaligned systematic sampling strategy over Gabon.

3. Results

Table 2 show initial results of forest cover by project and the table 3 the associated overall accuracy by reference year. In Cameroon results must be confirmed by the improvements of the dry-forest classification, it will be done during the phase 2 of REDDAF. Table 3 resume the deforestation rate by project and confirm the generally low level of deforestation in these four regions and in Gabon and Cameroon in particular.

Table 2. Forest covers for 1990, 2000 and 2010

	GABON	CAMEROON	CAR	BOLIVIE
1990	89.88%	73.14%	66.56%	96.40%
2000	89.64%	72.92%	65.56%	95.80%
2010	86.13%*	74,14%	64.03%	94.40%

* Deforestation rate for Gabon for a third of the country (102 000km²)

Table 3. Overall accuracy for 1990, 2000 and 2010

	GABON	CAMEROON	CAR	BOLIVIE
Overall accuracy 1990	98.8%	95.05%	90.1%	98.2%
Overall accuracy 2000	97.9%	95.18%	89.9%	97.7%
Overall accuracy 2010	97.4%	96.47%	91.6%	97.3%

Table 4. Deforestation rate by country for 1990/2000, 2000/2010 and 1990/2010

	GABON	CAMEROON	CAR	BOLIVIE
1990/2000	0.26%[1] 0.20%[2]	0.22%	1.5%	0.6%
2000/2010	0.04%[2]	-0.52%[3]	0.8%	1.5%
1990/2010	0.24%[2]	-0.30%[3]	2.3%	2.1%

[1]Deforestation rate for Gabon between 1990 and 2000 are for the whole country (267 000km²)
[2]Deforestation rate for Gabon for a third of the country (102 000km²)
[3]The change results between 2000 and 2010 seem to overestimate the increase in forest areas due to misclassification of Dry Forest areas in the Centre Province of Cameroon. In phase 2 of REDDAF, the Dry Forest thematic will be more investigated to improve the overall results of the Deforestation mapping.

4. Conclusions

It was shown that it was possible to make wall to wall forest cover map at three time period at national or sub national scale using only optical data in tropical area known for heavy cloud cover, especially in Gabon. The maps produced are fully compliant with the product specifications agreed at the beginning of the project with all the users. The results shown indicate that the methodology developed is applicable in a range of different environments. The examples of CAR and Cameroon illustrate that a homogenous forest cover map can be produced by two separate service providers. In addition, as it is based on relatively simple and robust methods, it can potentially be implemented by countries wanting to develop their own forest monitoring system in the framework of REDD. And at international level to produce standardized reference forest cover map.

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Reference

Achard F., DeFries R., Eva H., Hansen M., Mayaux P., and Stibig H-J., Pan-tropical monitoring of deforestation. **Environmental Research Letter**, Volume 2, Number 4, 11p, 2007

Bodart C., Beuchle R., Simonett D., Eva H., Raši R., Carboni S., Brink A.,. Stibig H.-J, Achard F., Mayaux P., Global Monitoring of Tropical Forest Cover Changes by Means of a Sample Approach and Object-based Classification of Multi-scene Landsat Imagery: Pre-processing and First Results. **Proceedings of International Symposium on Remote Sensing of Environment (ISRSE) 33**. Stresa, Italy, 17 April 2009

Congalton, R.G. A review of assessing the accuracy of classifications of remotely sensed data. **Remote Sensing of Environment**. 37: 35-46, 1991

Congalton, R.G., Green, K**., Assessing the Accuracy of Remotely Sensed Data: Principles and Practices**, Lweis Publishers, 1999.

Congalton, R.G., Accuracy assessment and validation of remotely sensed and other spatial information, **International Journal of Wildland Fire**, 2001, 10, 321–328, 2001.

Czaplewski, Raymond L. Chapter 5: Accuracy assessment of maps of forest condition: statistical design and methodological considerations, pp. 115-140. **Remote Sensing of Forest Environments: Concepts and Case Studies.** (Michael A. Wulder and Steven E. Franklin, Eds.) Kluwer Academic Publishers, Boston. 515p, 2003.

Czaplewski, R.L., McRoberts, R.E., Tomppo, E. Sample design. In: Andersson, K, Bhandari, N., Czaplewski, R., Hussin, Y., Janz, K., Kleinn, Ch.,Magnussen, S. McRoberts, R. Melin, Y. Persson, R. Reed, D. Sandewall, M., Ståhl, G., Thomson, A., Tomppo, E., Vanclay, J. **Knowledge Reference for National Forest Assessments**. Http://www.fao.org/forestry/NfaKnowledgeRef/en/ , 2004

GOFC-GOLD, 2011, A sourcebook of methods and procedures for monitoring and reporting anthropogenic greenhouse gas emissions and removals caused by deforestation, gains and losses of carbon stocks in forest raining forests, and forestation. **GOFC-GOLD Report** version COP17-1, 203p, 2011

Gutman, G., R. Byrnes, J. Masek, S. Covington, C. Justice and S. Franks, R. Headley, Towards Monitoring Land-cover and Land-use Changes at a Global Scale: The Global Land Survey 2005, **Photogrammetric Engineering & Remote Sensing**, January 2008

Hansen M. C., Roy D. P., Lindquist E., Adusei B., Justice O. C., Alstatt A.. A method for integrating MODIS and Landsat data for systematic monitoring of forest cover change in the Congo Basin. **Remote Sensing of Environment**, 112, 2495-2513, 2008

IPCC 2006, IPCC Guidelines for National Greenhouse Gas Inventories, Volume 4 (Agriculture, Forestry and Other Land Use), National Greenhouse Gas Inventories Program, Eggleston H.S., Buendia L., Miwa K., Ngara T. and Tanabe K. (eds). Published: IGES, Japan, 2006

Justice C., Wilkie D., Zhang Q., Brunner J. , Donoghue C., Central African forests, carbon and climate change. **CLIMATE RESEARCH** Vol. 17: 229–246, 2001

Stehman S. V., Sampling designs for accuracy assessment of land cover, **International Journal of Remote Sensing**, Vol.30, No. 20, 20 October 2009, 5243-5272, 2009

Stehman S. V, Czaplewski, R.L., Design and Analysis for Thematic Map Accuracy Assessment: Fundamental Principles, **Remote sensing of environment**, 64: 331-334, 1998.

Zhang Q., Devers D., Desch A., Justice C., Townshend J., Mapping tropical deforestation in central Africa, **Environmental Monitoring and Assessment** 101: 69–83, 2008.