A near-real time forest-cover map of Madagascar derived from SPOT 4-VEGETATION data

Mayaux Philippe, Gond Valéry and Bartholomé Etienne.
Global Vegetation Monitoring Unit
Space Applications Institute
TP 440 - Joint Research Centre
21020 Ispra (VA) - Italy

Abstract

Using SPOT-4 VEGETATION data for near-real time mapping is new. In this letter, a robust technique for cloud decontamination of the ten-day composites is presented. A forest-cover map of Madagascar is derived from monthly images from October 1998 to September 1999 with a user's accuracy of 87.8%.

Introduction

Madagascar is considered to be one of the conservation priorities on Earth, due to its rich and diverse flora and fauna and of its high rate of forest conversion. About 8,000 endemic species of flowering plants are present in Madagascar and are concentrated in the humid eastern forests. The island can be divided into two major floristic zones corresponding to different topographic and climatic regions: a moist Eastern region and a drier Western region (White, 1983). The dense humid forests extend from the eastern coast to the central mountains, under a wet climate (mean annual rainfall over 2000 mm). Below 800 m, most of the lowland rain forests have been converted to a mosaic of cultivation and secondary formations by an important human population practising shifting cultivation (Green and Sussman, 1990). Dense dry forest represents the main type of primary vegetation in the Western region.

The annual rate of deforestation of these ecosystems is estimated between 2 and 3 % (Green and Sussman, 1990). It shows the situation's urgency and the crucial need for reliable information on the forest state and evolution. Some studies have mapped the Madagascar forests using Landsat Thematic Mapper (TM) data (Green and Sussman, 1990; Faramala, 1981) or NOAA's Advanced Very High-Resolution Radiometer (AVHRR) data (Nelson and Horning, 1993). For continuous monitoring of Madagascar forests, Landsat TM data suffer from limitations due to cloud-cover, while AVHRR data are known for their poor geometric accuracy and the absence of radiometric calibration (Meyer, 1996; Cihlar *et al*., 1998). Recently, new sensors with enhanced spatial and spectral characteristics have become available, such as SPOT-VEGETATION and the ERS Along Track Scanning Radiometer (ATSR). These data are delivered in near-real time after standardised pre-processing.

The objective of this letter is to demonstrate the possibility of updating forest-cover maps in ecosystems affected by rapid changes using VEGETATION data in a limited time.

Background

The VEGETATION Sensor

The VEGETATION instrument was launched on-board SPOT-4 in March 1998. The principal characteristics of the sensor (Table 1) are optimised for global scale vegetation monitoring. Although the VEGETATION and AVHRR sensors have similarities, they differ in a few fundamental characteristics. First, the acquisition is based on a push-broom system, which drastically limits the off-nadir pixel-size augmentation. Second, there is a short wave infrared channel (SWIR), which is sensitive to the vegetation water content (Allen *et al*., 1970). Finally, the ground segment is organised to acquire, process and archive all daily data over land surfaces at full resolution. Global products are mosaicked, radiometrically calibrated, corrected for atmospheric effects and delivered to the end-user few days after acquisition (VEGETATION Web site, 1999).

Procedure

Data processing

The VEGETATION data used in this study are the standard ten-day images including the ground reflectance of all spectral channels, and composited following the highest daily Normalised Difference Vegetation Index (NDVI) of the period. The 36 composites used in this study cover the period October 1998-September 1999, with three missing periods: first of November, first and second of January.

These composite images were still too contaminated by clouds and haze to allow for direct classification. Monthly images were produced in order to reduce the remaining clouds. Two different criteria of second-stage compositing were tested: the maximum NDVI and the minimum SWIR.

Land-cover classification

A forest-cover classification was derived from the 12 monthly composite images. The blue channel, strongly influenced by the atmospheric conditions, was not used in the classification procedure. In a first step, the 36-band image was classified into 40 clusters using the "Isodata" unsupervised method. This classification statistically separates the entire population of pixels into homogenous clusters in terms of spectral and temporal characteristics. Then, the interpreter labels the clusters. The class labelling was based on available field knowledge, ancillary information such as the Faramala map (Faramala, 1981), and a visual analysis of spatial distribution patterns. Five classes were mapped: dense humid forest (lowland and montane), dense dry forest, mangrove, secondary complex and savannah (woody savannah, grasslands and bare soil). The accuracy of the resulting map was assessed by comparison with Landsat classifications interpreted by local experts (Foiben-Taosarintanin'I-Madagasikara, 1999) over three sites (Path-Row 158-070, 158-072 and 158-074). The Landsat TM classifications were co-registered to the VEGETATION classification and then degraded to 1 km spatial resolution in order to compare the two datasets at the same spatial resolution, without adding any spatial aggregation error (Mayaux and Lambin, 1997).

Results and discussion

Compositing and seasonal profile

The algorithm based on the minimum SWIR was selected because it produced more spatially homogenous monthly composites. The ten-day composites look very noisy due to the remaining clouds (Fig 1a), while the monthly profiles are interpreted in terms of vegetation phenology (Fig 1b).

1. The '*dense humid forest'* and the '*secondary complex*' types located on the eastern slope of Madagascar grow under wet conditions, with more than 2,000 mm from November to August (FAO, 1984). The reflectance is low in Red, high in NIR and low in SWIR, corresponding to a high amount of moist vegetation. It is interesting to note the stability of the '*dense humid forest'* and the high NIR reflectance of the '*secondary complex*' related to the structural properties of the canopy. The '*mangroves*' show a similar behaviour to the '*dense humid forest*' class.
2. The '*dense dry forest*', the '*savannah*' and the '*woodlands*' are mainly located on the western and central regions, where the rainy season is shorter, from November to April. The general

trend of the curves is decreasing in the red reflectance during the wet season (except for the '*woodlands*' class which reaches its lowest level at the end of the rainy season). In the NIR reflectance, all curves increase with the vegetation development. The SWIR reflectance decreases during the rainy season with the water presence.

Figure 2a shows the remarkable quality of the monthly composite images. The geometric accuracy of the sensor preserves the spatially fine features, which was not the case in AVHRR composites.

Forest-cover map of Madagascar

The forest-cover map (Fig.2b) illustrates the spatial distribution of the vegetation types analysed in the previous section: (i) the eastern moist region with dense humid forest mostly converted into a secondary complex in the lowland part and limited to the mountains, and (ii) the western drier region, nearly entirely covered by grassland, savannah and agriculture, with some patches of dense dry forest.

Table 2 compares the forest areas directly derived from our map with the Faramala map (Faramala, 1981). Our estimates are consistent with Faramala when taking into account the deforestation rate observed by Green and Sussman (1990).

The accuracy assessment (Table 3) shows the high correspondence of the VEGETATION-derived map with Landsat TM classifications validated on the field. The user's accuracy for the '*dense humid forest'*, which is our main class of interest is 87.8%, with a producer's accuracy of 85.6%. Note that a part of the misclassifications can be due to the difficulty to achieve a perfect coregistration between data sets at very different spatial resolutions.

Conclusions

This work, focused on Madagascar, illustrates the capacity of SPOT-4 VEGETATION data to update the forest-cover maps in a fast manner. The last 10-day synthesis was delivered to our laboratory within less than one week after the image acquistion and the forest-cover map was produced two weeks after. Compared to previous similar exercices with AVHRR (Nelson and Horning, 1993; Mayaux *et al*., 1999), VEGETATION data offered among others three main comparative advantages: (i) the fast access to ready-to-analyse preprocessed data, (ii) the high geometric accuracy which allows for perfect image superimposition, and (iii) the systematic data acquisition which permits data recompositing to reduce or eliminate residual atmospheric effects. Beyond these first results, other applications can profit from the global scale of the instrument quality in terms of geometric accuracy and radiometric calibration: vegetation monitoring, burned surfaces assessment, land-cover mapping, flooding extension.

References

- Allen, W.A., Gausman, H.W., Richardson, A.J. and C.L. Wiegand, (1970) Mean Effective Optical Constants of Thirteen Kinds of Plants Leaves. *Appl. Opt*. Vol **9**: 2573-2577.
- Cihlar, J., Chen, J.M., Li, Z., Huang, F., Latifovic, R., and Dixon, R. (1998) Can interannual land surface signal be discerned in composite AVHRR data? *Journal of Geophysical Research,* **23**:23,163-23,172.
- FAO (1984), Agroclimatological data for Africa, Vol.2 Countries south of the equator, Roma.
- Faramala, M.H., (1981) Etude de la végétation de Madagascar à l'aide de données spatiales. PhD Thesis, Université Paul Sabatier, Toulouse, France.
- Foiben-Taosarintanin'I-Madagasikara (1999) Evolution de la couverture forestière à Madagascar. *Final report to the Joint Resarch Center, contract number 279518 V*, Ispra, Italy.

- Green, G.M., and Sussman, R.W. (1990) Deforestation History of the Eastern Rain Forests of Madagascar from Satellite Images, *Science*, **248**:212-215.
- Mayaux, P., and Lambin, E.F. (1997) Tropical forest area measured from global land-cover classifications : inverse calibration models based on spatial textures. *Remote Sensing of Environment*, **59**: 29-43.
- Mayaux, P., Richards, T., and Janodet, E. (1999) A vegetation map of Central Africa derived from satellite imagery. *Journal of Biogeography,* 26:353-366.
- Meyer, D.J. (1996) Estimating the effective spatial resolution of an AVHRR time series. *International Journal of Remote Sensing*, **17**:2971-2980.
- Nelson, R,. and Horning, N. (1993) AVHRR-LAC estimates of forest cover area in Madagascar, 1990. *International Journal of Remote Sensing*, **14**:1463-1475.
- Rahman, H. and Dedieu, G., (1994) SMAC: a simplified method for atmospheric correction of satellite measurements in the solar spectrum, *International Journal of Remote Sensing*, **15**:123-143.
- VEGETATION Web site, (1999) http://sirius-ci.cst.cnes.fr:8080/hmpg.html
- White, F. (1983) *The vegetation of Africa*, Paris, UNESCO, 356 pp.

Table 1: SPOT 4 - VEGETATION instrument and products characteristics

Field of view	101º
Ground swath	2250 km
Altitude	830 km
Inclination orbit	98.72º
Instantaneous Field Of View	1.15 km at nadir 1.3 km at 50º off-nadir
Absolute positioning pixel	~ 0.5 km
Multitemporal superimposition	~ 0.5 km
Blue channel	0.43 – 0.47 µm
Red channel	0.61 – 0.68 µm
Near Infrared channel	0.78 – 0.89 µm
Short Wave Infrared channel	1.58 – 1.75 µm
Atmospheric correction	SMAC (Rahman & Dedieu, 1994)
Absolute calibration	< 5 %
Projection	Geographic (Lat/Long)
Ellipsoid	WGS 84
Pixel size	1/112 degree

Table 2: Land-cover areas of Madagascar derived from various maps (10^3 ha). Surfaces are derived from Lambert-Azimuthal Equal Area maps.

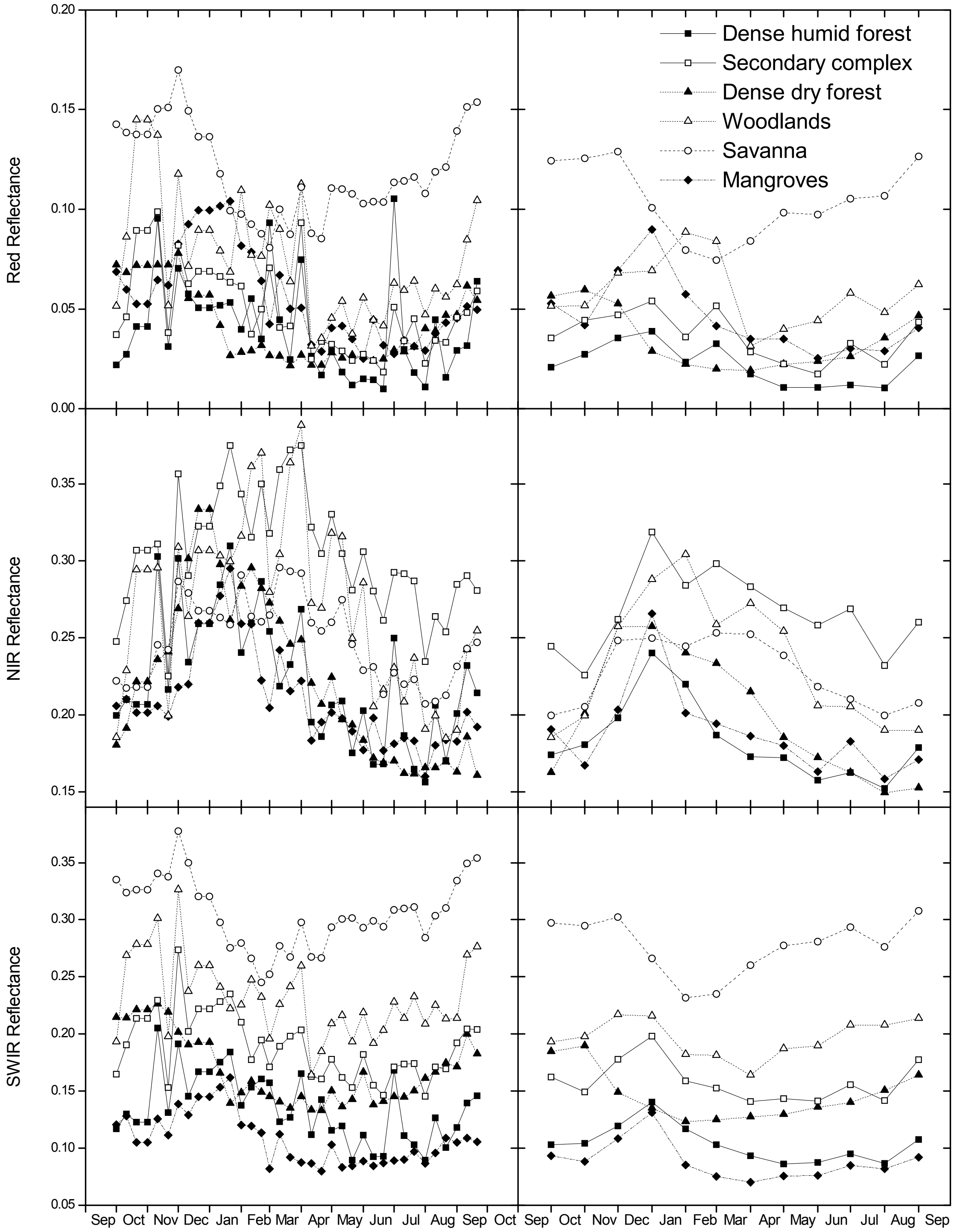
Land-cover classes	Faramala (1981)	TREES (1999)
Dense humid forest	68217	55328
Dense dry forest	34416	41183
Mangrove	3399	4530
Secondary complex	48812	71991
Other	440479	419591

Table 3: Confusion matrix between the SPOT VEGETATION and the Landsat TM classifications.

		Landsat TM					
		Forest	Wooded savanna	Grasslands	Crop mosaics	Water	Total
SPOT VEGETATION	Dense humid forest	32.09%	1.89%	1.00%	1.36%	0.23%	36.57%
	Secondary complex	4.99%	16.05%	4.74%	12.88%	0.14%	38.80%
	Savanna	0.41%	3.02%	16.75%	1.53%	0.07%	21.77%
	Water	-	-	-	0.01%	2.29%	2.30%
	Total	37.49%	20.96%	22.50%	15.77%	2.73%	100.00%

Figure Captions

Figure 1: Seasonal profile of several Madagascar ecosystems in the Red, Near InfraRed (NIR) and Short Wave Infrared (SWIR) reflectances calculated (a) by ten-day period, (b) by month. Each point corresponds to 12 samples of a given land-cover class.



<u>Figure 2</u>: SPOT-4 VEGETATION products over Madagascar : (a) colour composite of the monthly synthesis of June 1999 (Red=SWIR, Green=NIR, Blue=Red), (b) forest-cover map derived from the monthly composites from October 1998 to September 1999.