Mangroves dynamics from FOTO of IKONOS images and Lidar data

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Abstract: Monitoring structural organization and biomass of mangroves from remote sensing observations constitutes a great challenge. For this, texture analysis of very high spatial resolution (VHR) data can significantly contribute to understand the link between image aspect and forest structure. In this paper, we synthesize the main results obtained on the characterization of canopy grain using Fourier-based textural ordination (FOTO) of metric Ikonos images acquired over high biomass mangroves in French Guiana. We also present new results obtained from FOTO of lidar-derived canopy height images with the aim of evaluating the FOTO method for capturing 3D forest structural attributes.

Introduction

Conservation and protection of many imperiled tropical coasts urgently require mapping and monitoring structural characteristics of mangroves. The context of pristine coasts which are not subjected to human activities is rather different. They still have their own resilience strategy that any ecosystem develops to face environmental pressures. In the case of the coasts under the influence of the Amazon sediment dispersal system, vitality of mangrove ecosystem seems to be reinforced by drastic geomorphological changes imposed by drifting of giant mud banks. The analysis of mangrove structuration could yield to a better understanding of how the ecosystem is answering to littoral changes through time. However, in this region, accessing thousands of hectares of such unexplored mangroves requires important logistic means and efforts. These are many reasons advocating for the development of a spatial and reproductive approach aiming at mapping and monitoring mangrove dynamics over various and large areas. Within this objective, a new method based on the canopy grain analysis is becoming of great interest.

Data

The experimental sites are located in French Guiana, South America and are named Sinnamary (SI, 5°26' N, 53°02W) and Kaw (KA, 4°45'N, 52°5'W). SI and KA mangrove sites both display flat topography and are not subjected to logging. Due to the coastal dynamics of the region, mangrove growth stages are patchily distributed over the coastal landscape with clusters of young trees sometimes occurring in close vicinity to patches mature trees of 40-m height mature trees (Fromard et al. 2004). Field experiments were conducted in order to measure the main structural parameters in a wide range of forest situations or growth stages. The KA and SI regions were imaged by IKONOS in 2001 and 2003, respectively. In addition, Lidar data were acquired over a part of the SI Ikonos scene so that the laser dataset did not include all forest plots available on this site. To be compared with panchromatic Ikonos images, canopy height images were derived from clouds of laser echoes using one meter cells. For each of these cells, a statistical analysis of the distribution of laser points elevations above ground elevation was performed using quintile values. Each cell of the canopy height image has thus 6 values which are 1) minimum, 2) Q1 corresponding to 20% of the total number of laser echoes above the cell, 3) Q2 (40%), 4) Q3 (60%), 5) Q4 (80%) and 6) maximum values. Contrasted textural aspects of the mangrove canopy are apparent on both panchromatic Ikonos images and lidar-derived canopy height models (Fig. 1).

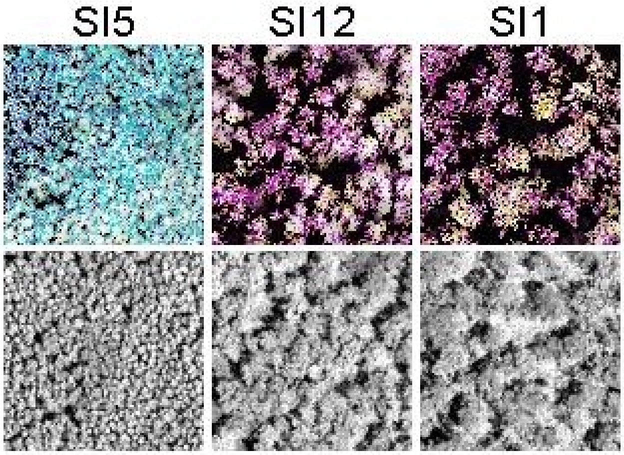

Figure 1: Particular examples of one hectare square windows for mangroves, Sinnamary site. Top images are lidar-derived canopy height images and bottom images are corresponding subsets of the panchromatic Ikonos image.

The FOTO method

FOTO stands for Fourier-based textural ordination and was first applied to the processing of aerial photographs (Couteron, 2002; Couteron et al., 2005). A given run of the method starts with the specification of a window size and the windowing of the images. The Fourier azimuthally-averaged r-spectrum (i.e. the radial power spectrum) is computed for each window. R-spectra are the result of the partition of an image variance into spatial frequency bins. In other words, for frequency, the amplitude of the r-spectrum at a given frequency informs us on the relative contribution of heterogeneities at the corresponding scale in the image. The variability between spectra is analyzed by principal components analysis (PCA). Window scores on the most prominent axes are then used as texture indices. A unique windows size of 100 m was used throughout the present study. For additional details, please refer to Proisy et al., (2007) and http://amapmed.free.fr/FOTO/.

Results

Capability of very high resolution IKONOS images

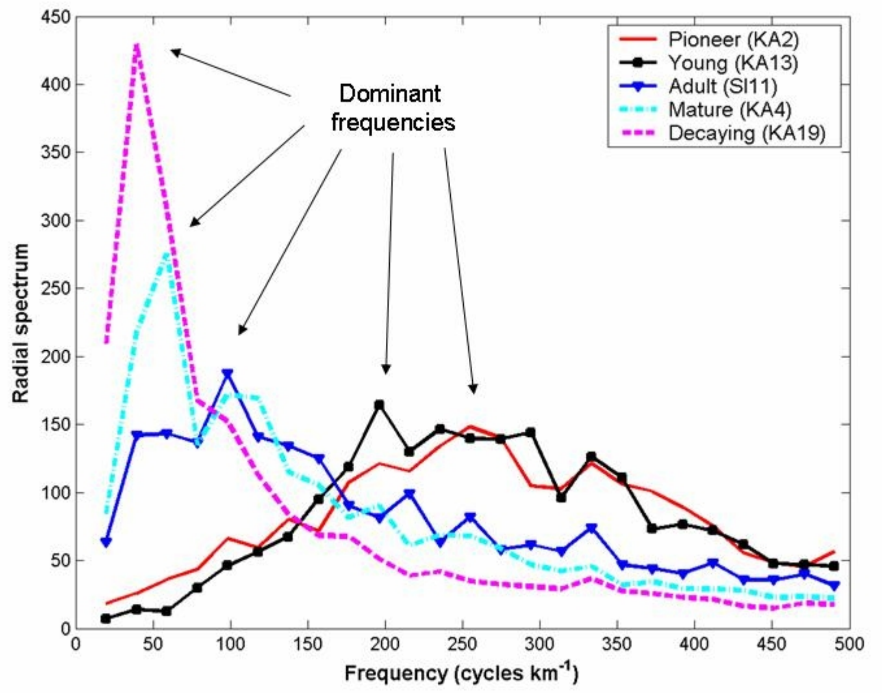

Figure 2 : Averaged r-spectra for successive mangrove development stages as obtained from FOTO of panchromatic

Textural indices derived from the three main axes of the principal component analysis of Fourier r-spectra demonstrated their ability to capture the whole gradient of canopy grain observed from the youngest to the decaying stages of mangrove development (Fig. 2). It is notable here that consistent results were drawn from two distinct images without prior radiometric correction, such as reflectance calibration, or histogram range concordance. Following coding into RGB composite images, FOTO maps usefully revealed at a glance the spatial distribution of mangrove types within a study site and showed contrast in terms of past and ongoing mangrove dynamics (Fig. 3). Using the three textural indices as independent variables allowed us to reach accurate and unbiased predictions of both total aboveground and trunk biomass, as well as reasonable predictions for branch biomass (Proisy et al., 2007). FOTO maps thus appear able to provide information about the spatial distribution of biomass and mangrove types over thousands of unexplored hectares. However, allometric relationships predicting mangrove tree biomass from field measures (i.e. trees diameters) have to be improved and refined thanks to additional in-situ measurements encompassing a wider range of different dendrometric structures. Besides contrasting stages of development with distinct canopy textures, e.g. young and decaying stands, may sometimes display similar biomass values (Proisy et al., 2002), which may also bias the FOTO estimation. Nevertheless, we believe that FOTO RGB texture maps can be very useful in the orientation of necessary field verification and will greatly contribute to research programs conducted on Amazonian mangrove forests.

Both the present work and previous studies (Couteron et al., 2005; 2006) confirm the premise that swapping the spatial domain for the frequency domain is an efficient way to characterize vegetation and landscape spatial patterns using quantitative and objective coarseness/fineness gradients.

FOTO of Lidar-generated height images (LGH)

In addition, the analysis was conducted on all plots available in the Lidar coverage. As an example, Fig. 4 shows averaged-r specta for two contasted mangrove growth stages. On the whole, VHR and LGH maximum images presented a similar dominant frequency, i.e., around 120 and 40 cycles per kilometers for young and decaying stages, respectively. R-spectra of the young forest (SI5) had similar behaviors whatever the observed quintile whereas r-spectra of the decaying forest (SI1) showed differences at low frequencies and high frequencies. The forest area SI5 had no substratum vegetation and crown biomass was above 10 m above ground with a canopy height of about 22 m. The SI5 canopy was closed (2000 trees/ha), and Lidar echoes mainly came from the upper part of the canopy explaining why differences between LGH channels were not significant. For SI1 with a median height of 40 m, understorey vegetation was composed of 3-4m tall Acrostichum ferns and first branches of canopy trees were observed at around 15 m above ground. Contrary to SI5, SI1 had an open canopy with a low density of adult trees (72 trees/ha) so that the r-spectra revealed Lidar signal from both understorey and crown of adult trees. The dominance of the corresponding low frequency decreased with quintile values varying from maximum to minimum values. However, beyond 350 cycles per kilometer for SI5 and 200 cycles per kilometer for SI1, Lidar r-spectra were above Ikonos r-spectra. At these high frequencies, Lidar r-spectra showed highest values for lowest quintiles. Such differences may be attributed to infrared laser beam capability to penetrate forest canopy. This may

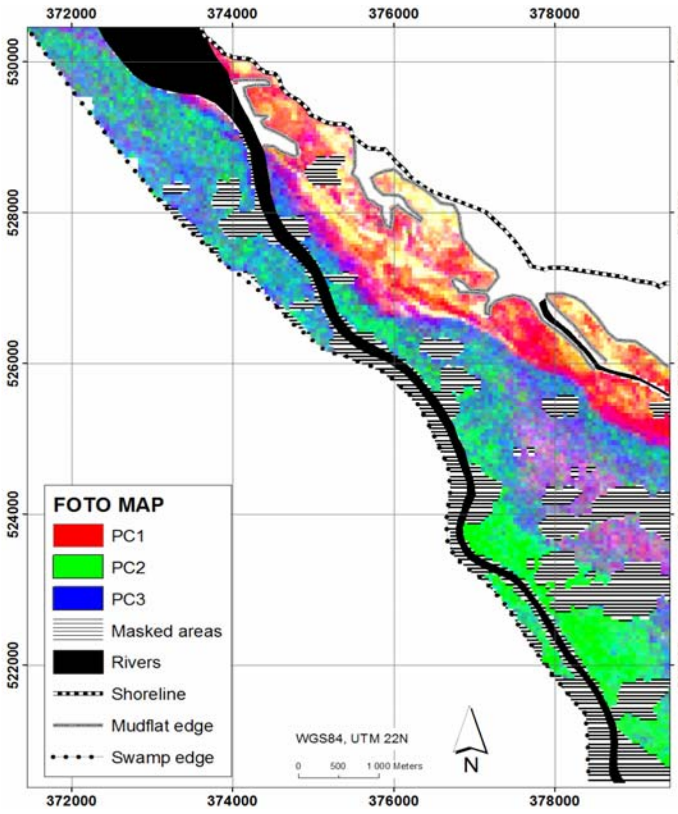

Figure 3: Panchromatic-derived FOTO maps of canopy texture obtained by RGB coding on window scores on the three main PCA axes (red=PC1, green=PC2, blue=PC3).

suggest that internal canopy structuration is not observable from VHR images whereas it is in part from LGH images. Effect of spatial resolution and viewing angles remains also to be better understood.

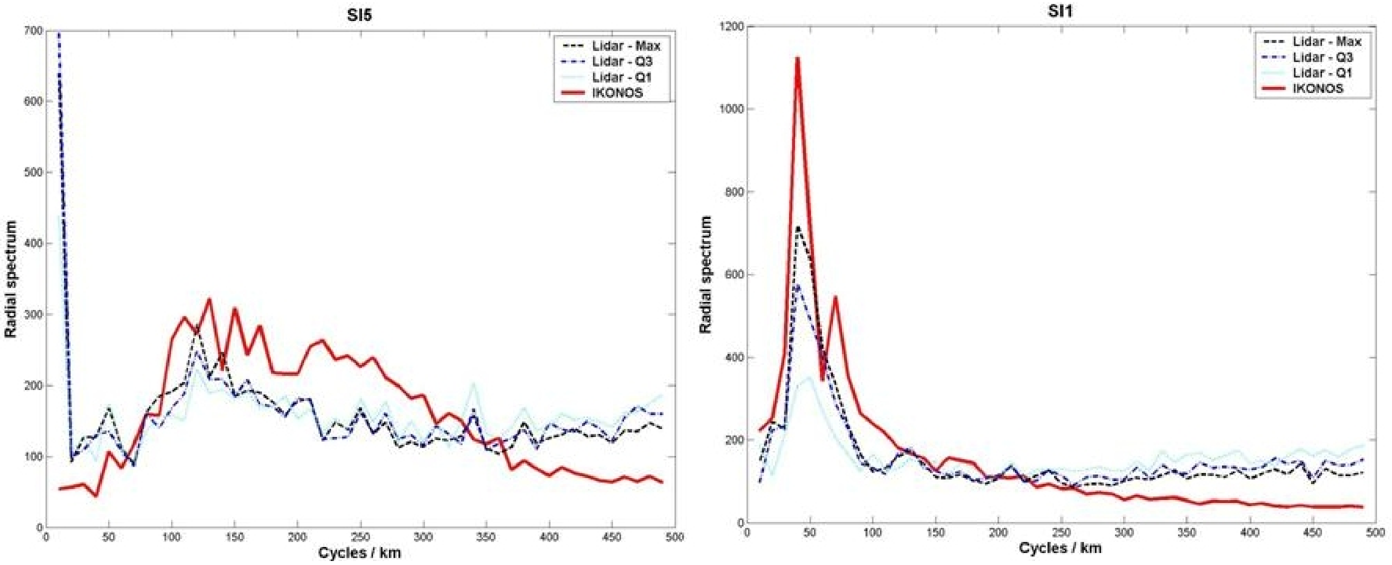

Figure 4: Comparison of averaged-r spectra for two mangrove growth stages (left: young; right: decaying) as obtained from FOTO of a panchromatic Ikonos image and from Q1, Q3, and max channels of the LGH image

Conclusion

The high-biomass equatorial mangrove regions present very favorable conditions for testing a new powerful method of mapping structural characteristics of mangroves. New insight toward the standardization of the FOTO method is achieved thanks to the application of this method to lidar-generated canopy height images.

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