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Monitoring canopy grain of tropical forest using Fourier-based textural ordination (FOTO) of very high resolution images

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***Abstract*: Monitoring structural organization and biomass of tropical forest 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. Within this context, our recent works argued that swapping the spatial domain for the frequency domain permits to consistently characterize vegetation and landscape spatial patterns through coarseness/fineness textural indices. In this paper, we synthesize the main results obtained on the characterization of canopy grain using Fourier-based textural ordination (FOTO) of very high resolution images acquired over terra firme rain forest and high biomass mangroves. In addition, we compare texture indices originating from aerial photographs and Ikonos images. Requirements for developing a standardized measurement of forest canopy grain with broad regional validity are finally discussed.**

Keywords: mangrove, tropical forest, Ikonos, photograph

I. BACKGROUND

The dynamics of tropical forest must be known in order to describe the surface and energy exchange with the atmosphere and quantify carbon pools [1]. This ambitious objective requires the development of methods able to measure structural characteristics of heterogeneous canopies with broad regional validity. Within this context, the use of remote sensing has long been advocated for collecting data over large areas at low cost although predicting relationships between electromagnetic signal and forest parameters over space and time remains a major problem [2]. Calibration of optical images is almost unachievable [3] and neither of optical- and radar-derived intensity measures can properly depict the whole range of structural characteristics and biomass found in tropical forests [2; 4-7].

The use of very high resolution (VHR) data, such as aerial photographs and Ikonos or Quickbird satellite images, has not yet been fully explored despite their potential for predicting small-scale variation in forest canopy. Using metric pixels, tropical forest no longer appears as a continuous 'green' carpet, but rather as contrasted sunlit-shadowed canopy features [8]. However, previous works based on visual interpretation and intensity analysis haven't reached the full potential of VHR images for characterizing forest structure and dynamics. Texture indices, in particular, might allow achieving greater descriptive and predictive power. Recently, [9] and [10] highlighted that canopy grain of undisturbed tropical forests could be consistently mapped from Fourier-based textural ordination (FOTO) of metric images.

The aim of this paper is to assess the potential of the FOTO method for characterizing canopy grain of different types of tropical forests including both undisturbed (terra firme forest and mangroves) and logged over forests (terra firme). Limits and potentials of the method are reviewed in function of sensors parameters and environmental characteristics.

II. SITES, DATA AND METHODS

A. Experimental sites

The experimental sites are located in French Guiana, South America and are named Plomb Mountain (PM, 5°00'N, 52°55'W), Paracou (PA, 5°15' N, 52°56'W), Sinnamary (SI, 5°26' N, 53°02W) and Kaw (KA, 4°45'N, 52°5'W). The experimental PM site is composed of a hilly landscape in the North whereas, in the south, a volcano-sedimentary massif reaches 332 m above sea level. The forest is undisturbed. The PA site has a less marked hilly relief and the forest is managed since 1984. At the opposite, SI and KA mangroves sites both display flat topography and are not subjected to logging. Due to the coastal dynamics of the region [11], 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.

B. Data

Field experiments were conducted in order to measure the main structural parameters in a wide range of forest situations or growth stages [9-10]. A set of black and white IGN aerial photographs at 1:25000 were acquired during 1992 for PM and during 2001 for PA and SI sites. The KA and SI regions were imaged by IKONOS in 2001 and 2003, respectively. To be compared with panchromatic Ikonos images, aerial photographs were digitized with pixel size of 1 meter.

The varied geomorphology of the sites and the patchwork of mangrove growth stages result in contrasted textural aspects of the forest canopy, which are apparent on both digitized aerial photographs and panchromatic Ikonos images (Fig. 1).

C. Methods

FOTO stands for Fourier-based textural ordination and was first applied to the processing of aerial photographs [12]. 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 [9-10; 12]. 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 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. In complement to a synthesis of previously published analyses conducted on PM [9], SI and KA [10] sites, we present new results obtained from the comparison of spectra ordination of IGN (French National Geographic Institute) photographs and panchromatic Ikonos images for both SI and PA sites. A unique windows size of 100 m was used throughout the present study.

III. RESULTS

A. Fourier spectra ordination

For the MP rain forest site, a canopy texture index was defined from ordination of the Fourier spectra computed from aerial photographs [9]. Small, medium and large spatial frequencies, i.e. wavelengths varying between about 5 and 50 m, ordinated themselves along the first PCA axis, which expressed a meaningful gradient of coarseness-fineness (Fig. 1). Five textural classes were defined from K-means clustering of windows scores. Textural classes from UF1 (coarse-grained canopy) to UF4 (fine-grained canopy) were ordinated along PCA axis 1 (PC1) whereas UF5 (not shown) was differentiated along PCA axis 2 (PC2) and corresponded to coarse canopy grain influenced by relief induced illumination discrepancy. UF4 encompassed all windows characterized by a fine grain canopy mostly independently of relief induced effect.
Fourier spectra ordination over mangroves using 1-m panchromatic data yielded different patterns than those observed in rain forest [10]. Absence of relief and presence of juvenile mangrove stands over extensive areas partly explain these differences. Mangrove canopy grain was characterized by a texture gradient ranging from 30m for sparse decaying old-growth stages (UM1-2) to about 3 m for pioneer areas (UM4).

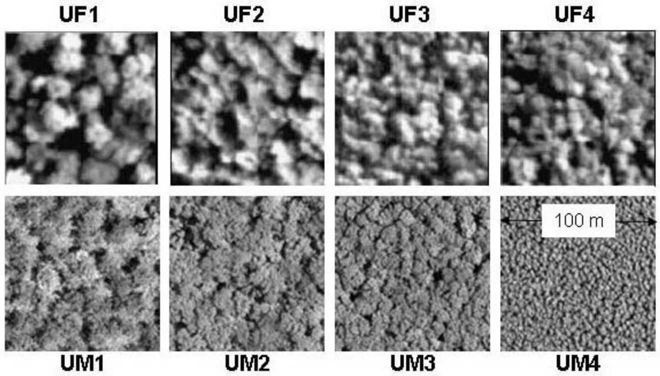

Figure 1: Particular examples of one hectare square windows for undisturbed rain forest (top images) and mangroves (bottom images).

Consequently, two PCA axes were necessary to summarize variations in mangrove canopy grain and a noticeable arch effect was observed. Windows with a coarse canopy grain had the lowest negative scores values against PC1 and the highest scores along PC2 (Fig. 2). Main mangrove growth stages are well discriminated, even the dense pioneer areas composed of trees with small crowns.

B. Forest parameter estimation

The scores of windows corresponding to the location of forest inventory plots were used as independent variables in a linear regression analysis for comparison with forest parameters. Particularly, high correlations were found for tree density (r^2=0.80, n=12) and total above-ground biomass (r^2=0.92, n=26) for rain forest and mangroves, respectively. The robust statistical relationship found between canopy texture and forest parameters points toward a strong, yet poorly understood, coupling between canopy aspect and the three dimensional dynamical processes of vertical growth, intertree competition and self-thinning processes.

C. Multi-sensor analysis

To go further into the analysis, we applied the FOTO method to the aerial photos and 1-m panchromatic Ikonos images on areas for which both coverages were available, i.e., PA and SI sites.
In the case of the PA site, PC1 explained about 29% of the total variance for both source images, whereas PC2 contribution was greater for IGN photograph than for Ikonos image, i.e. 9% versus 5 % (not shown). Windows scores positions displayed similar range of variation along PC1 and a larger variability along PC2 for the IGN image (Fig. 2). In PM site, ordinations scores showed similar patterns [8].
In the case of the SI mangrove forest, PC1 explained about 70% and 63% of the total variance whereas PC2 contributions were about 14% and 19% for IGN and Ikonos images, respectively (Fig. 2). Windows scores were however within the same range of values for both image sources and expressed the same 'horseshoe' pattern [9].

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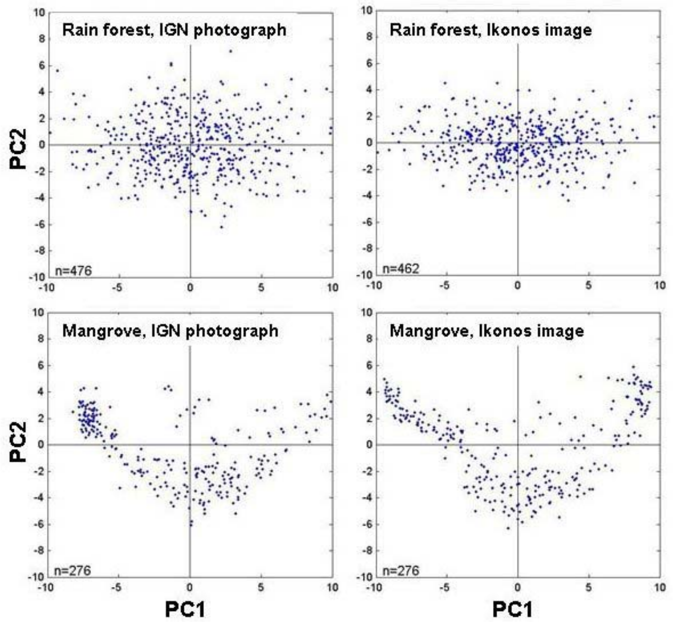

Fig. 2: Windows positions in the plane defined by axes 1 and 2 from FOTO of IGN photographs (left) and Ikonos images (right) for identical forested areas of both rain forest and mangroves (top and bottom, respectively).

IV. Toward the Standardization

A. Relief- and viewing-induced shadowing effects

Relief significantly increases shadowing effects in canopy images and modifies spectral responses of forested areas [8]. Consequently, both local terrain slopes and acquisitions parameters such as solar and viewing angles must be taken into account in the analysis of canopy grain. Such parameters can vary from one scene to the other. Quantitative information on shadowing is needed to account for its influence on the variance of FOTO indices.

Since coastal areas are nearly flat, mangroves provide opportunities for interpreting and gauging the impact on results of the variation of acquisition parameters for both aerial photographs and satellite images.

B. Prospects

New insights should be obtained thanks to a better description of the vertical biomass distribution. Due to the simpler floristic and structural characteristics of the high-biomass equatorial mangroves, the use and the coupling of ecological models [10] to help the interpretation of FOTO maps compose a reachable goal for their study. Further investigations on this topic could benefit from the combined analysis of 3D laser echoes and the application of the FOTO method to Lidar-generated digital maps of canopy height. Other techniques of signal decomposition such as wavelets or local trigonometric bases will be further investigated.

C. Implementations

Requests for the use of the FOTO method for any types of forest would be welcome. We created an easy-to-use interface under Matlab®, which allows the processing of any type of images, the choice of various FOTO configurations and the display of texture indices as RBG maps. Additional details are provided on http://amapmed.free.fr/FOTO.

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