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Texture Analysis of Tropical Rain Forest Infrared Satellite Images

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Abstract

This paper describes a new application of the Fourier transform for texture analysis of low reflectance, rain forest satellite images. After correction of edge effects, angular power spectra have been analyzed on windows of 64 by 64 pixels in size. Results of spectra analysis are compared to visually extracted linear features of near infrared SPOT images from South Cameroon forested areas. This method allows for the detection of low-contrast, periodic luminance variations and the extraction of lineament direction with an accuracy of 10°. An algorithm of processing of the whole image aimed at regional studies of texture networks is proposed. Applications to structural geology, forest-type discrimination, and soil studies in the tropics are briefly evaluated.

Introduction

Infrared spectral bands are often used in texture analysis and pattern recognition of forested areas. Remote sensing and photo-interpretation techniques are based on the low near infrared (NIR) absorption of the vegetation and on the sensitivity of this spectral band to moisture. Both methods are commonly coupled for identification, extraction, and analysis of regional or local lineament networks (Yésou *et al.*, 1993; Almeida-Filho and Castelo Branco, 1992; Lowman *et al.*, 1992; Moore and Waltz, 1983).

However, owing to atmospheric noise effects, satellite images from areas of tropical, dense forest cover are seldom reported. Rain forest images obtained from optical sensors are often characterized by a poor spectral quality, including low reflectance values and a narrow grey level variations scale. On oblique imagery, these effects increase in proportion to the viewing angle value (Barnsley, 1984). In addition, bidirectional reflectance studies have established that visible and NIR radiance of vegetated areas are significantly dependent on sun elevation angle and on recording geometry conditions (Lee and Kaufman 1986; Jackson *et al.*, 1990; Pinter *et al.*, 1987).

Thus, optical rain forest satellite images are best described by their textural rather than by their spectral properties. Recent studies of the SPOT NIR channel (XS3) from high-angle, oblique images from South Cameroon rain forest suggest that some of the NIR radiance variations of the canopies record moisture variations of the soil surface. Moreover, these radiance variations are periodically distributed along a welldefined, hectometric textural pattern that can be detected within most of the forest types (Riou and Seyler, 1995). Within the NIR spectral range, texture analysis of rain forest satellite images may be a useful approach aimed at water resources investigation and at geological or soil-features recognition and mapping.

Existing texture operators applied to large-image processing are usually divided into statistical and structural methods (Wang and He, 1990).

For the statistical methods, texture is considered to reflect the spatial distribution of grey levels in an image, and textural information can be extracted by co-occurrence-matrix (Haralick, 1979) or texture-spectrum operators (He *et al.*, 1987; Wang and He, 1990; He and Wang, 1991).

For the structural methods, texture is the repetition of a basic primitive pattern with a rule of placement that can be analyzed by Fourier analysis (Haralick, 1979; He *et al.*, 1987; Matsuyama *et al.*, 1980; D'Astous and Jernigan, 1984).

Existing texture operators, however, are not suitable for the extraction of fine-scale textural data from low-reflectance, low-contrast images. Methods involving digital filtering prior to texture analysis (Wang *et al.*, 1981; Drury, 1986; Blusson *et al.*, 1985) induce a degradation of image resolution and alteration of textural patterns. Methods based on Fourier analysis, although of great potential interest, are limited by the small size of the analyzing window necessary to match direction changes at the hectometric scale.

This paper presents a new method of texture enhancement and extraction, using Fourier analysis, adapted to low-reflectance, low-contrast images. Application to processing of large images focused on multiscale lineament network analysis is proposed. New developments for geological, vegetation, and soil studies in the tropics are evaluated and discussed.

Methodology

In image coding applications, the Fourier transform has been used for texture characterization and classification. Position of the main peaks on frequency spectra, together with shape of the distribution of frequency components, has been proved to be related to the structural morphology of the image (Matsuyama *et al.*, 1980; D'Astous and Jernigan, 1984).

Two-dimensional edge detection and network analysis can also be deduced from power spectra shapes, providing that these discontinuities are periodically distributed within the image. Identification of frequency peaks on angular power spectra can successfully be related to the textural characteristics of the images (Coggins and Jain, 1985; Kon-omopoulos and Unser, 1984).

However, one major drawback of this method arises from frequencies related to edge transitions. Variations in average radiometry between left-right or top-bottom limits of the image induce infinite or large-magnitude, low-frequency components that do not belong to the image frequency domain (Pratt, 1978).

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Conventional Angular Power Spectrum

On a 0 to 180° frequency versus amplitude plot obtained by the Fourier transform of a NIR SPOT subscene of homogeneous rain forest (Figures 1A to 1E), prominent peaks located along the coordinate axes of the transform plane at $\pi/4$, $\pi/2$, and $3\pi/2$ result from edge transitions. The importance and the amplitude of these frequencies are inversely proportional to the size of the analyzing window (Figures 1A to 1C). The ratio of the main $\pi/2$ peak on the average image frequency value critically increases from 1 to 2 for a 512- by 512-pixel window (Figure 1A) to more than 5 for a 128- by 128-pixel window (Figure 1C). A comparison between two angular power spectra obtained on a 64- by 64-pixel window before and after a clockwise 20° rotation (Figures 1D and 1E) shows evidence of the presence of a major frequency peak of the image (arrow subscript) hidden by a $\pi/4$ edge transition peak. Thus, the edge transition effects strongly restrain the use of Fourier analysis for lineament networks analysis.

Correction of these effects can be achieved by using low-pass filters or by smoothing edges transitions with the aid of a parabolic transfer fonction (Coster and Chermant, 1989). However, this type of image pre-processing induces a significant loss of information which precludes any directional analysis of angular power spectra on low-contrast images. Loss of angular information linked with the use of low-pass or pass-band filter varies between 4 and 35 percent, according to the size of the image and the characteristics of the filter.

Synthetic Angular Power (SAP) Spectrum

A new adaptation of Fourier transform designed to minimize loss of angular information has been tested on different image sizes from 512 by 512 to 32 by 32 pixels. The basic concept is to reconstruct a synthetic angular power spectrum by the addition of two individual spectra corresponding, respectively, to the original sub-scene (Figure 1D) and to the same sub-scene after rotation (Figure 1E). The rotation angle is chosen between 0 and $\pi/8$, in order to encompass the range of domain error resulting from the use of common low-pass and pass-band filters. Processing consists in (1) elimination of edge transitions frequency peaks on both spectra and (2) concatenation of the valid sectors of two spectra to give a synthetic angular power spectrum (Figure 1F). This Synthetic Angular Power (SAP) spectrum provides a precise representation of angular distribution of the image frequencies that can be extracted by standard spectrum analysis. Preprocessing the images with a pass-band filter, adjusted to select frequencies corresponding to a given period (80 to 100 m in the chosen example), allows comparisons between SAP spectrum with visual interpretation of lineament orientation.

Image Processing

A quantitative evaluation of the ability of this technique to extract lineament directions was performed on a whole SPOT image, using a moving window of 64 by 64 pixels and a step of 32 pixels in rows and columns. Results of spectra analysis are graphically expressed in the form of a grid composed of segments whose orientation fit the position of the main frequency peak on the 0 to 90° SAP spectrum with an accuracy of 10° (Plate 1).

In order to eliminate spectra that do not display any significant frequency peak, an amplitude test based on the ratio value of the main peak over the image average frequencies has been applied. On these low-contrast images, a ratio factor of 5 to 7 validates more than 95 percent of the spectra.

Evaluation and Application

Radial and SAP spectra were calculated on a set of 64- by 64-pixel subscenes extracted from a set of SPOT images from the South Cameroon forested plateaus. Details concerning dates of acquisition, recording parameters, and vegetation cover can be found in Riou and Seyler (1995). Several types of comparisons between forested and cultivated areas or between different types of rain forests have been made. Effects of viewing/irradiation geometry and multidate (wet or dry season) image acquisition are also discussed.

Viewing/Irradiation Geometry

Satellite images of forests in the tropics are highly view-angle dependent as a result of a combination of atmospheric effects and the non-Lambertian behavior of vegetation (Jackson *et al.*, 1990). Although shadowing effects are less marked for the NIR than for the red spectral band, extreme pointing angles of HRV SPOT sensors may affect the visual perception of image texture. In order to evaluate the effects of viewing versus irradiation geometry on image frequencies, Figure 2 compares two SAP spectra performed on a 64- by 64-pixel subscene that has been extracted from two high-angle oblique images (with, respectively, 28°W and 18.6°E off-nadir angle). The two scenes picture a zone of dense, primary, semi-deciduous rain forest belonging to the Congo-Guinean district (Letouzey, 1985). Both images were recorded by the end of the 1991-1992 rainy season, in conditions of very clear atmospheric visibility. It is noteworthy that both spectra display a very similar frequency distribution with only small differences in relative amplitude of the first-order 5° and 25° frequency peaks. These peaks are clearly indicative of the presence of N0° to N30° linear features within the analyzing windows that are weakly detectable on the raw XS3 image. Second-order frequency peaks are more apparent on the west-viewing, high-angle-recorded scene that provide the best discriminating performance for texture studies. Thus, SAP frequency spectra provide an additional and complementary tool to visual interpretation of texture, independently of the recording conditions of the images.

Application to Lineament Analysis

Orbital remote-sensing techniques are commonly used for mapping regional lineament patterns and studying crustal structures of crystalline shields.

Attempting to evaluate the performance and the accuracy of the SAP spectrum in lineament analysis and discrimination, a SPOT subscene illustrating two representative lithological units of the Central African Archaean crystalline basement was selected. Figure 3 shows the regional geological background and scene location, based on the data of several investigators (Bessoles and Trompette, 1980; Maurizot, 1985; Nédelec *et al.*, 1986). Raw XS3 data (Figure 4A) are presented together with a sketch map depicting lithological boundaries and visually extracted lineament networks (Figure 4B). Rock units include (1) Archaean charnockitic gneisses and quartzites characterized by a dominant northeast-southwest migmatitic foliation and (2) late-Archaean, dome-shaped, leucogranitic apophyses. A regional network of N0°E to N10°E strike-slip faults, mainly resulting from the reactivation of the Archaean basement faults during the Pan-African orogeny, is a dominant feature of this area (Nkonguin-Nsifa and Riou, 1990). Recent movements along these structures, that extend far beyond the limit between the Congo Craton and the Pan-African metamorphic belt, have been detected on SPOT imagery and are currently under investigation.

Each rock unit is represented by 64 by 64 pixels. Migmatites (Figure 4Bb) displays a regular, hectometric, linear distribution of low-reflectance zones orientated N50°E, locally interrupted by ill-defined, irregular N140°E to N150°E alignments. Granite texture, although visually less regular than that of migmatites, can be characterized by a rhombo-

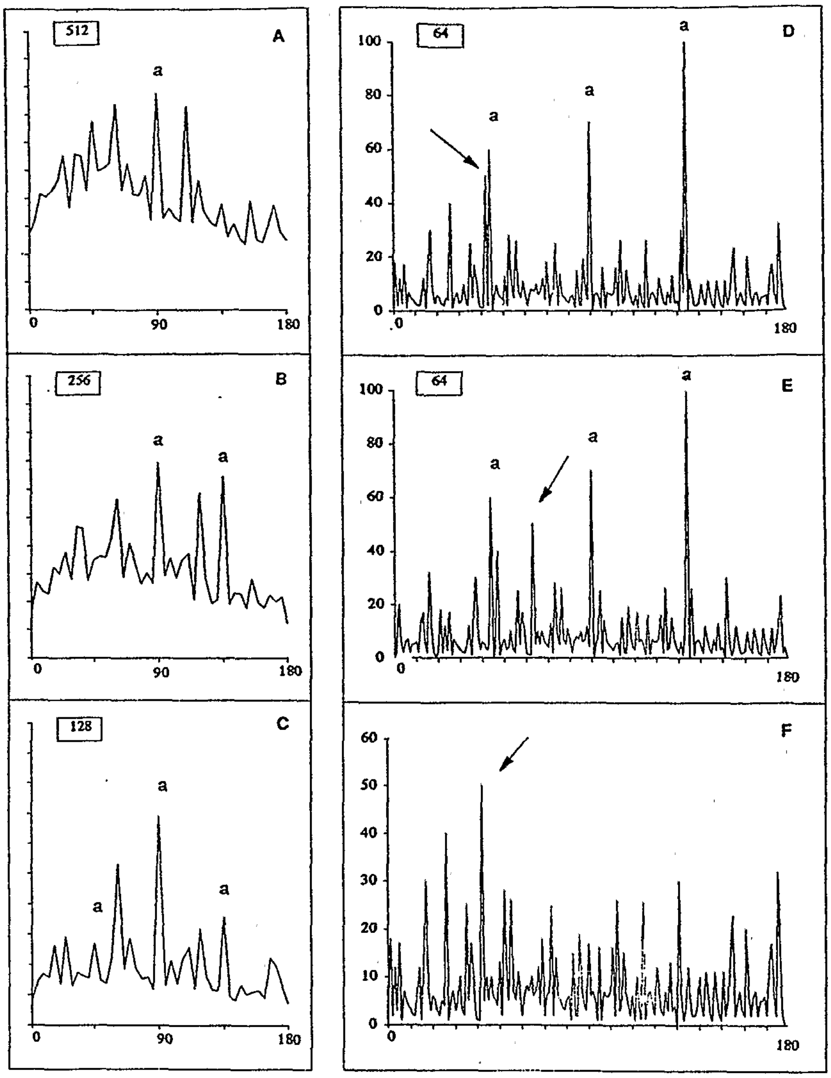

Figure 1. Edge effects on image frequency distribution and Synthetic Angular Power (SAP) spectrum (XS3 subscenes of rain forest from SPOT scene K,J: 86-344 of 07-01-1992, © CNES, 1992). (A to D) Standard angular power spectra obtained by Fourier tranform on subscenes of 512, 256, 128, and 64 pixels in size, respectively. Subscript "a" indicates frequency peaks related to edge transitions. (E) Standard angular power spectrum identical to D after a clockwise rotation of 20 °. *Arrow indicates the position of the main frequency* peak of the image. (F) SAP spectrum identical to D after elimination of edge frequency peaks.

hedral network delineated by N80°E to N100°E and N140°E low reflectance zones.

SAP spectra show a unimodal frequency distribution with a dominant peak at 50° for migmatites (Figure 4D) and a bimodal distribution with a dominant 130° peak and three second-order peaks between 70° and 95° for granite (Figure 4C). Angular values are referenced from the border of the image and, thus, are shifted from 10° relative to the north direction (SPOT images have been processed at the 1B level). After correction, angular values extracted from SAP spectra analysis match those of the lineament orientations derived from the visual interpretation of the images. Moreover, the presence of a significative frequency peak at 170 to 180° on both spectra can possibly be related to the proximity of a meridian strike-slip fault, close to the western limit of the analyzing windows. Although not visible on the image, the high-frequency components recorded by the SAP spectra could be induced by shearing discontinuities that are more or less parallel to the direction of the strike on both sides of the fault axis. This interpretation is strongly supported by field observation of multi-scale (centimetric to decametric) left-lateral ductile zones with deformation pattern consistent with strike-slip tectonics.

These results demonstrate the good discriminating performance of the method in lineament analysis and its potential interest in structural geology of forested areas.

Application to Forest Change Detection

Traditional agricultural and pastoral activities have induced major changes within forested areas in the tropics. These ef-

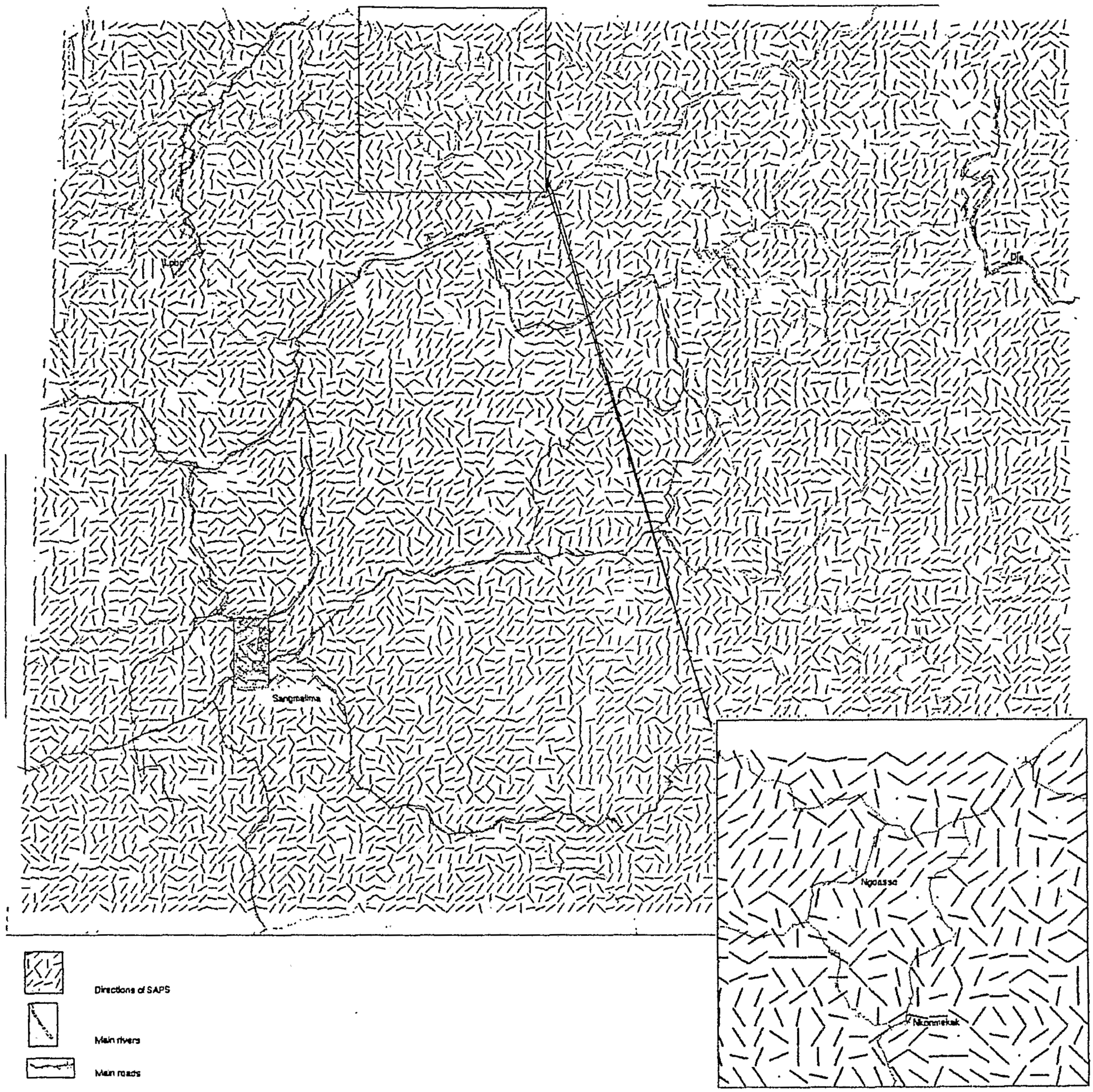

Plate 1. Grid showing the result of a spectra analysis on a whole (3000 by 3974 pixels) SPOT scene (id to Figure 1). Analyzing window of 64 by 64 pixels, step in row and column of 32 pixels, preprocessing with a 3 to 8 pass-band filter (corresponding periods of 80 to 230m). Graphical representation is sketched with an accuracy of 10°.

fects are dramatically increased by industrial wood exploitation, mainly because it provides new access to preserved primary forested areas. Remote sensing is commonly used for forest survey, including forest damage assessment or major changes and evolutions.

Within the southern Cameroonian forested plateau, major changes in the forest are strongly dependent on road access and distribution of villages and individual huts along main tracks. Man-influenced zones extend to an average width of 2.5 km on each side of the road, and can be clearly delineated from residual primary forest or from dense forest regrowth by a higher NIR reflectance and a more variable textural pattern. From the road to the dense forest, texture zonation includes (1) fine-textured, homogeneous zones located in the vicinity of the villages and related to orchards and gardens; (2) irregular, roughed-textured, larger zones corresponding to small to medium-sized food crops (such as corn, ground-nuts, manioc) interfingered with cocoa plantations; and (3) ill-defined, irregular narrow zones at the forest skirts characterized by a higher content of large clear-cuts and burned areas that are clearly identified by their high spectral reflectance. These high NIR reflectance values have been re-

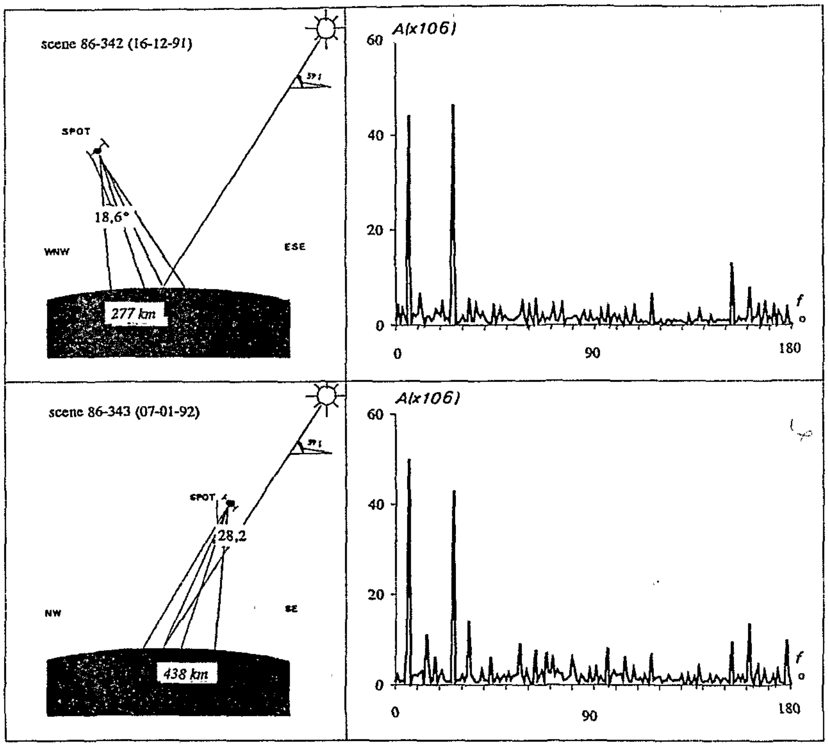

Figure 2. Effects of recording geometry on SAP spectra shape. South Cameroon semi-decideous rain forest. The two subscenes (64 by 64 pixels in size) have been extracted within the overlapping zone of two XS3 SPOT images (© CNES, 1991 & 1992).

ated to grass regeneration during the rainy season or to vigorous regrowth of pioneering tree species like *Musanga cecropioides* (Riou and Seyler, 1995), or both.

Frequency distribution can be used in accordance with the spectral properties of the images to detect forest changes. On SPOT XS3 images, dense, forested areas are characterized by an even distribution of frequencies, with an average value that is proportional to the average image brightness. In contrast, agricultural or deforested zones display a more contracted distribution pattern with a higher proportion of low-

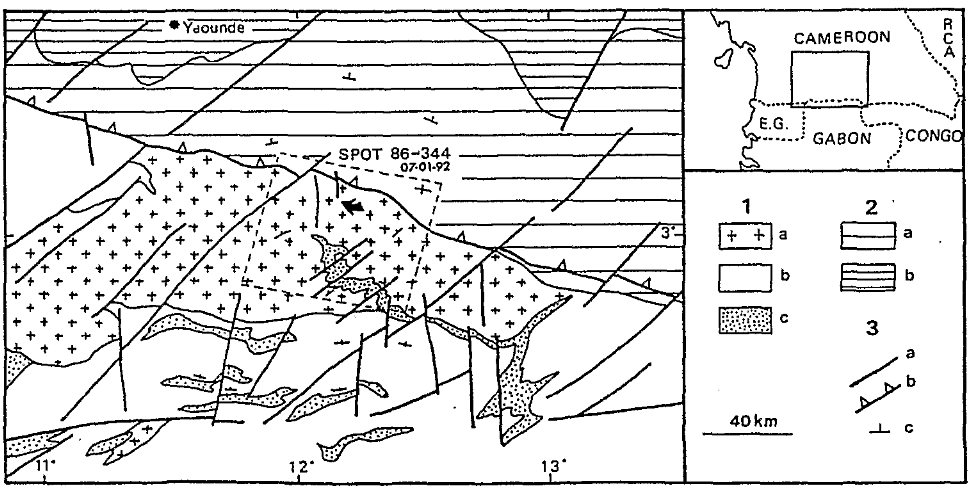

Figure 3. Geological setting of the South Cameroon forested plateaus. The arrow indicates the location of Figure 4A subscene within the SPOT image (SPOT scene id. to Figure 1). Symbols: 1-Congo craton (a: migmatites and granites, b: banded gneisses, c: quartzites), 2 - Pan-African metamorphic belt (a: micaschists, b: gneisses and migmatites), 3 - Structural trends (a: faults, b: foliation with dip indication). Data after Maurizot (1985).

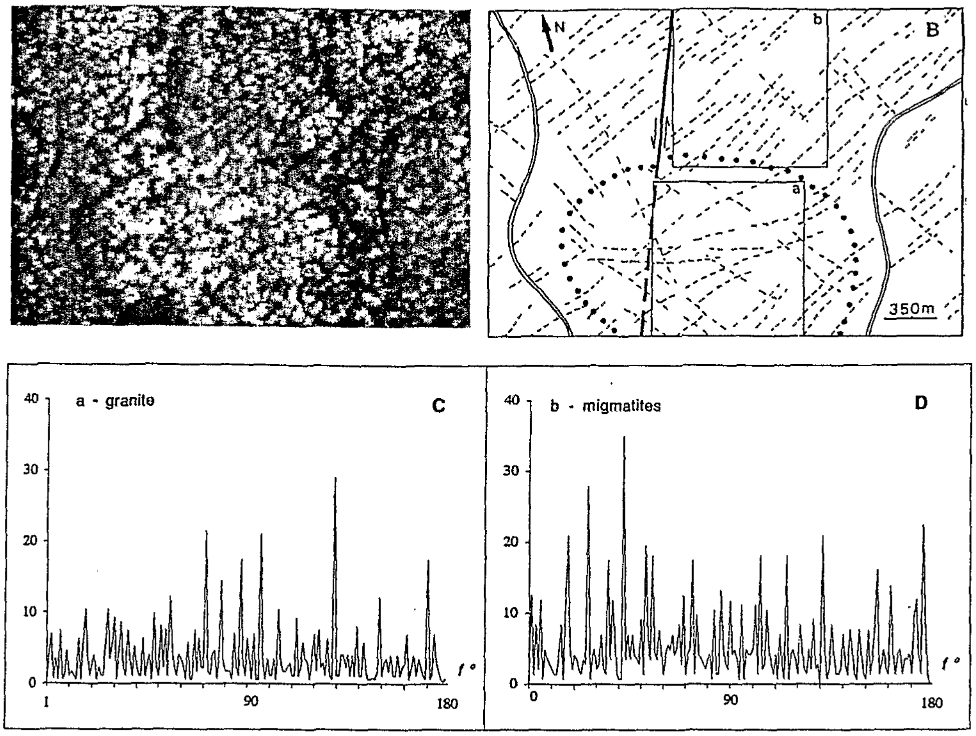

Figure 4. (A) XS3 SPOT subscene (200 by 140 pixels) within a secondary rain forest area. (B) Lineament sketch-map compiled from A with granite/migmatites outlines and location of two 64- by 64-pixel analyzing windows. Heavy line corresponds to a senestral strike-slip fault and double line indicates motorable tracks. (C and D) SAP spectra corresponding to granite and migmatites, respectively, after extraction of hectometric periodic elements by a 3 to 8 pass-band filter.

frequency components. On both type of spectra, the presence of outstanding peaks other than the average-frequency-curve envelope is an indication of the existence of linear, textural pattern within the images.

On SAP spectra, dense forested areas (Figure 2) are nearly always characterized by a unimodal frequency distribution indicative of a dominant linear textural pattern that fits very well with low reflectance alignments that are visible on the images (Riou and Seyler, 1995, Figure 4). On the other hand, agricultural zones display a typical bimodal frequency distribution (Figures 5A and 5B) reflecting a lattice-like textural organization.

Application to Soil Studies

That previous study (Riou and Seyler, 1995) has shown that part of the solar energy transmitted through dense forest canopies can be reflected by the soil surface towards the sensor. The study has also demonstrated that NIR differential absorption by the first layers of the ferrallitic soils, owing to soil moisture variability, accounts for the radiance variations and for the periodic, linear pattern detected on dense homogeneous rain forest cover. The new observations reported here suggest that ferrallitic soil surface water content may depend on the distribution of structural discontinuities of the underlying rocks. A comparison made between SAP spectra performed on agriculturally degraded forest zones during wet and dry seasons shows that the bimodal distribution characterizing the lattice-like organization of the soil moisture variability is strongly reduced at the end of the dry season (Figure 5). This could be related to seasonal fluctuations of the soil water content. Therefore, the relevancy of this method to soil functioning implies a better knowledge of seasonal water storage capabilities of tropical ferrallitic soils.

Conclusion and Discussion

Texture analysis provides a tool that is complementary to multispectral studies of satellite images, and in the tropics, it is commonly the only alternative approach, owing to the poor quality of the channels recorded in the visible part of the spectrum.

A new application of the structural method of texture analysis based on the Fourier transform is aimed at characterization of fine-scale textural patterns of dense rain forests.

These features are analyzed on low-contrast, low-luminance NIR small SPOT subscenes. After correcting for edge effects, the lineament orientations have been monitored with an accuracy of 10° at a kilometric scale (that is, on a 64- by 64-pixel analyzing window for a multispectral SPOT image of 20 m ground resolution).

The application of this method to the study of the periodic radiance changes of different rain forest types clearly indicates the presence of a mosaic-like textural organization of the canopy reflectance, which is independent of the recording conditions of the images.

In this study, three applications have been outlined. The first application consists of a discrimination between the orientation of lineament networks of two Precambrian rock-units from the central Africa cratonic shield. In this example, the good agreement that exists between the frequency signatures of the fracture/foliation networks and the visual interpretation of the images allows for new developments in structural geology of forest-covered cratonic zones. The second applica-

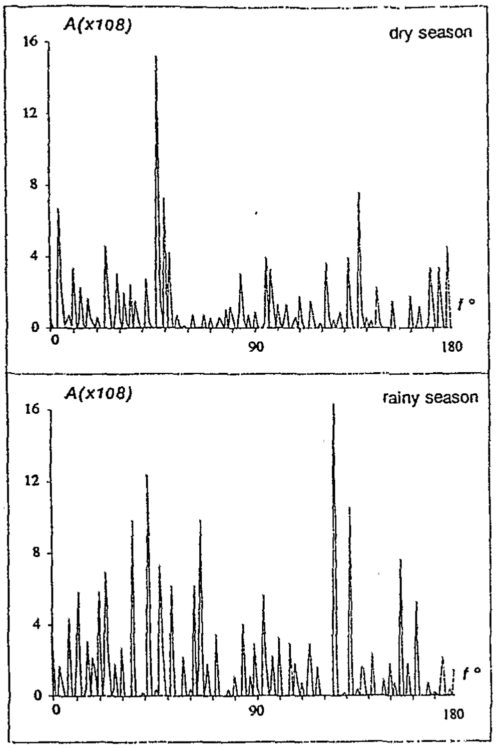

Figure 5. SAP spectra on NIR images (64 by 64 pixels) from secondary forest type (agricultural and young forest regrowth with *Musanga cecropioides*). (A) End of the dry season (SPOT scene, 86-344 on 22-02-1990, © CNES, 1990). (B) End of the rainy season (SPOT scene, 86-344 on 07-01-1992, © CNES, 1992).

tion shows that the frequency distribution pattern can be used to detect forest changes. The third application aims at the description of water storage capabilities of tropical soils.

Further evaluations of this method in spatial investigation and thematic mapping of tropical zones are in progress.

Acknowledgments

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