Analysis of Vegetation Seasonal Evolution and Mapping of Forest Cover in West Africa with the Use of NOAA AVHRR HRPT Data

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ABSTRACT: The Advanced Very High Resolution Radiometer (AVHRR) 1.1-km resolution data have been used for two purposes over the forest-savanna contact in Western Africa. First, the seasonal rhythms of the principal plant communities have been assessed using 34 NOAA images from October 1986 to September 1987. The feasibility of using the Normalized Difference Vegetation Index (NDVI) and Surface Temperature (ST) was also tested. The second part of the study consisted in selecting a single good quality image of the dry season for mapping the main vegetation types. For this, reflectances derived from channel 2 were used to separate dense forest areas from surrounding areas of mixed agriculture and degraded forests in southern Ivory Coast. These results show the potential usefulness and limitations of 1-km resolution NOAA data for monitoring vegetation phenological cycles and for assessing deforestation processes on a regional scale.

INTRODUCTION

ONE OF THE MAJOR SCIENTIFIC ISSUES TODAY is the accelerating conversion of tropical forest to agriculture. Despite the considerable amount of technology available today to assess the rate of tropical deforestation and to understand the real impacts on atmospheric and climatic modifications (Prance *et. al.*, 1986), figures are extremely variable and much debated. A good example of accelerated depletion of tropical forests can be seen in Côte d'Ivoire (Ivory Coast) where the annual rate of deforestation has been about 300,000 ha since 1956. The present spatial extent of this biome in this country is 4,500,000 ha (FAO,1988).

Satellite data have been used for many years to illustrate a variety of changes occurring in the vegetation cover of the Earth's surface (Blasco and Achard, 1989). The Institute for the International Map of the Vegetation (Toulouse-France) has recently produced small scale maps (1:5,000,000) of South America, Africa, and Tropical Asia. These reference vegetation maps, which are now digitized (FAO, 1987), clearly delineate the remaining natural forests and outstanding ecological subdivisions in the tropical world. The satellite data most commonly used for the preparation of these maps are those provided by the Landsat Multispectral Scanner (600 scenes for South America alone). The resulting maps are very detailed, but it can take up to 10 years to get full satellite coverage of each continent and the adopted methodology is not applicable for monitoring purposes.

Observations of a more global nature using the 1.1-, 4-, or 15-km resolution data of the Advanced Very High Resolution Radiometer (AVHRR) are expected to be better suited for vegetation monitoring (Townshend and Justice, 1986). Moreover, they can also be used as a tool for vegetation classification (Norwine and Greegor, 1983; Tucker *et. al.*, 1985).

The first objective of the present study is to identify the seasonal rhythms of the various vegetation types which constitute the forest-savanna contact in West Africa. Seasonal rhythms can be considered as the global expression of phenology. Phenology is the study of the timing of recurring natural phenomena such as leaf shedding, flowering of plants, etc.. Each vegetation unit has its own phenological behavior which can be detected by satellite sensors. Temporal variations of vegetation indices calculated from satellite data are primarily determined by phenological cycles. The main original vegetation types on both sides of the contact are semi-deciduous dense forests in the south and various mixed vegetation types including a variety of savannas with scattered trees and shrubs in the north. Global classification, which is the second major objective, is based on a detailed analysis of NOAA AVHRR data and can be extended to tropical forest mapping in the study area.

DATA ACQUISITION AND PREPROCESSING

GROUND DATA

The studied zone is shown on Figure 1. It covers two countries, i.e., Côte d'Ivoire (Ivory Coast) and Burkina Faso. A large amount of ground data was collected by our institution and we have gathered a good knowledge of ecological and phytogeographical conditions prevailing in these countries. The selected sites are two forest reserves in the central Ivory Coast, i.e., Marahoué's National Park and Haut-Sassandra Reserved Forest (site 1 and 2) and one site in southwestern Burkina Faso (site 3). Sites 1 and 2 are located in the "Guinean phytogeographic zone" where dense forest is the dominant vegetation type. Site 3 is located in the "Sudanian phytogeographic zone" and includes mainly various tree and shrub savannas.

For each selected site, the main vegetation types have been

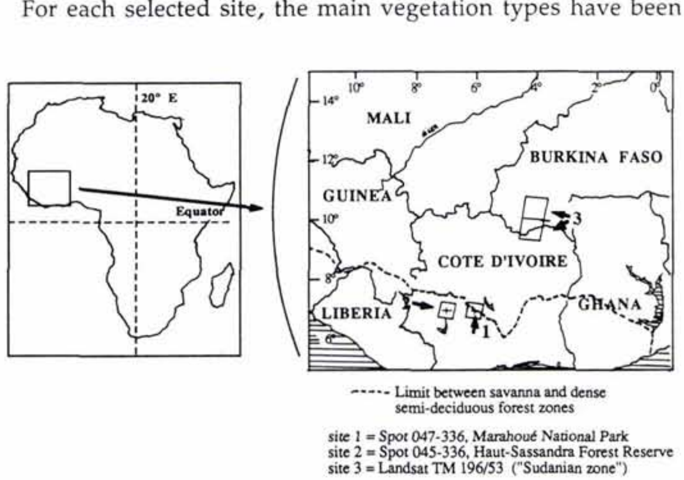

FIG. 1. Location of the study zone.

PHOTOGRAMMETRIC ENGINEERING AND REMOTE SENSING,
Vol. 56, No. 10, October 1990, pp. 1359–1365.

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identified according to their physiognomic properties. Ground data were collected in May 1986 and February 1988. Based on UNESCO's classification (1973), Table 1 gives a short description of the various natural vegetation types existing in the areas. The "Guinean" and "Sudanian" zones have contrasting floristic, physiognomic, and seasonal features. For each site, three or four homogeneous training areas were selected during our field trips. They are representative of each vegetation unit and contain approximately 200 SPOT or TM pixels. It is worth mentioning, however, that the term "homogeneous" is easier to define for pure units, such as a crop or a dense forest cover, than for a natural vegetation cover including grasses (savanna) with scattered trees. One of our field activities has been to measure, in each vegetation unit and on a horizontal projection, the surface covered by trees, by shrubs, and by grasses (see mean values on Table 1), i.e.,

$(P_{tree} + P_{shrub}) + P_{grass} + P_{crops} = 100\%$

where P_{layer} = cover percentage of the considered layer.

The phenological cycles of each strata (trees, grasses, and crops) were also recorded during field work (Figure 2).

SATELLITE DATA

Three SPOT and Landsat TM high resolution images were used to map the tree cover of test sites:

- SPOT 047-336 on 25 Nov 1986. Scene center: N 07°01'-W 06°02'
- SPOT 045-336 on 26 Dec 1986. Scene center: N 07°01'-W 07° 01'
- Landsat TM 196-53 on 01 Mar 1987. Scene center: N 10°07'-W 03°44'; only the two western quadrant scenes are used.

Digital numbers were used for the classification process.

To plot statistics as scatter diagrams (red, near-infrared), reflectances at the top of the atmosphere were used. For this, raw data were converted to reflectances using the calibration constants for the radiance conversion. Solar incidence angle was also taken into account for the radiance correction, i.e.,

$R_i = (\alpha_i \cdot DN_i + \beta_i) \cdot \pi / (\cos\theta \cdot ESUN_i)$

where R_i is the Reflectance, α_i and β_i are calibration constants (slope and intercept), DN_i is the digital number, $ESUN_i$ is the solar incidence energy in the channel i, and θ is the solar incidence angle.

Though the NOAA AVHRR sensor was designed for meteorological applications, the first two bands (0.58 to 0.68 μm and 0.725 to 1.10 μm) are sensitive both in the red and near infrared parts of the spectrum and can be used for a large number of terrestrial applications. Bands 1 and 2 are sensitive respectively to absorption by chlorophyll and other plant pigments (and hence to photosynthetic activity), and to the mesophyll structure of leaves. Similar spectral bands are also present in the SPOT HRV (XS2: 0.61 to 0.68 μm and XS3: 0.79 to 0.89 μm) and Landsat TM (TM3: 0.63 to 0.69 μm and TM4: 0.76 to 0.90 μm) sensors.

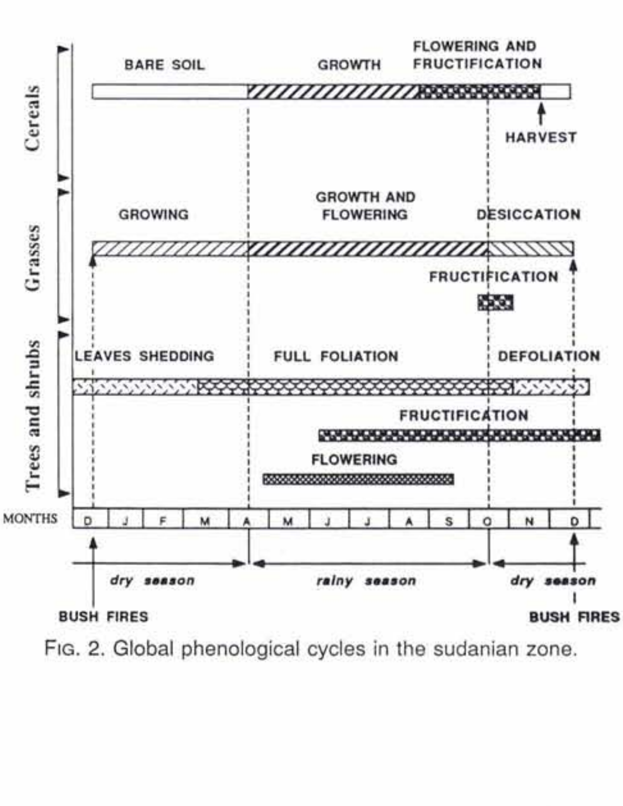


FIG. 2. Global phenological cycles in the sudanian zone.

TABLE 1. A SIMPLIFIED ANALYSIS OF VEGETATION UNITS FOUND IN THE STUDY ZONE (WEST AFRICA).

	Mean tree cover percentage
Guinean zone	
–Dense forest: Evergreen forest in ombrophilous areas (rain-forest) : dense, tall (40m), multistrata Semi deciduous forest in mesophilous areas : multistrata, upper canopy partly deciduous during dry season, lower tree layer evergreen ; characteristic tree species : *Celtis spp.* and *Triplochliton scleroxylon, Aubrevillia kertingii* and *Khaya grandifolia*.	Tree 100 %
–Forest - crops mosaic with forest cover percentage > 50%.	Shrub 25 % Tree 75 %
–Forest - crops mosaic with forest cover percentage < 50%.	Shrub 75 % Tree 25 %
–Tropical crops such as coffee, cocoa and banana plantations or recent agricultural clearings.	Shrub 100 %
–Included savanna : tall grass with scattered palms (*Borassus aethopium*).	Shrub and tree < 3 %
–Bare soils ("Inselberg").	0 %
–Water or swamp savanna.	0 %
Sudanian zone:	
–Dry forest : one tree layer, dense, deciduous ; Main tree species: *Ceiba pentandra, Anogeissus leiocarpus, Cola cordifolia, Chlorophora excelsa*.	Tree 100 %
–Woodland : open stands of dry deciduous trees, trees coverage of at least 40 %, dense herbaceous layer; Main tree species: *Isoberlinia doka, Uapaca togoensis, Daniella oliveri, Terminalia glaucescens*, etc.	Tree 70 %
–Savanna woodland : tree height lower than 20 m	Shrub 30 % Tree 30 %
–Tree savanna : tall grass with scattered dry deciduous trees, tree coverage less than 15 %, sometimes with a shrub layer.	Shrub 20 % Tree 10 %
–Grass savanna : dense herbaceous vegetation taller than 1 m	Shrub and tree < 3 %
–Raid-fed crops such as millet and sorghum.	0 %

A set of multitemporal NOAA-9 AVHRR SHARP (SHARP: Standard HRPT Archive Request Product; HRPT: High Resolution Picture Transmission) images has been used. The data were collected at the Mas Palomas receiving station in the Canary Islands (Spain). The data set used in this study consists of 34 images individually spaced in time with approximate ten-day intervals (from October 1986 to September 1987).

The two satellite data sets (SPOT HRV and Landsat TM on one hand and NOAA AVHRR on the other hand) are complementary because the main characteristics of these two types of satellite data are

- the high spatial resolution (20 m and 30 m) and the temporal low frequency (every 26 days or 16 days) for SPOT and Landsat TM data, and
- the high acquisition frequency (daily) but low resolution (0.8 km by 1.1 km at nadir) for the AVHRR data.

AVHRR scenes have been selected after visual analysis of daily METEOSAT data in order to select the dates least affected by the cloud cover, atmospheric moisture, etc. Images with minimum cloud cover were selected, taking also into account the satellite sub-track position with respect to the scene center so as to have images as close as possible to nadir conditions. Pixels at nadir have nominal resolution and are less subject to directional effects.

The selected AVHRR scenes have been preprocessed for geometric corrections using ground control points and radiometric calibration. The resulting image is a subset of 1200 rows and 1000 lines in (longitude, latitude) projection with a 0.01° resolution. The root-mean-square registration error is 1.3 pixels along the rows and 0.8 pixels along the lines for each image.

The radiance calibration is performed using standard calibration coefficients. Solar elevation is accounted for. Channel 3 (3.55 to 3.95 μm) radiance values are corrected for thermal emission using the surface temperature estimated from channels 4 and 5. No atmospheric corrections were performed and reflectances in the shortwave channels are thus reflectances at the top of the atmosphere.

The Normalized Difference Vegetation Index (NDVI) and Surface Temperature (ST) were computed.

$$\text{NDVI} = (\text{near infrared} - \text{red}) / (\text{near infrared} + \text{red}) = (R_2 - R_1) / (R_2 + R_1).$$

ST is estimated by a "split window" method using the emission temperatures of both bands 4 and 5 (Deschamps and Phulpin, 1980) and adding 4 °K for land surface temperature retrieval (Kerr and Lagouarde, 1989). A brightness index was also calculated from channels 1 and 2: i.e.,

$$\text{BI} = (R_2 \,.\, R_2 + R_1 \,.\, R_1)^{1/2}.$$

METHODOLOGY

The first phase consisted in mapping the vegetation of the three test sites using high resolution images and ground data. It allowed us to have "reference" pixels at our disposal for the AVHRR data analysis.

The temporal evolution curves of the pixels identified during the first phase were plotted for 1-km² pixels using the set of multitemporal AVHRR images. The evolution of the Normalized Difference Vegetation Index (NDVI) and of the Surface Temperature (ST) were then analyzed in order to monitor the phenology of each main vegetation unit.

Ultimately, these phenological curves gave the basic information for the selection of the most appropriate data for the identification of main vegetation units and their mapping in this part of the world.

SPOT and TM Image Classification

Ground data were used as training sets to perform a supervised classification on well identified and well known forest sites, using the visible and near-infrared channels : XS1, XS2, and XS3 for SPOT and TM2, TM3, and TM4 for Landsat. The list of vegetation units is given in Table 1.

The statistics (mean and covariance matrix) of training sets were extracted from these three bands at 30-m resolution for four 512- by 512-pixel windows of the TM quadrant scenes. A maximum-likelihood classifier assuming Gaussian distribution was applied to these extracts. The entire quadrant scenes and the classified windows were then spatially degraded by aggregating 6- by 6-pixel blocks. The mean value of the radiances and the mean of the tree cover percentage of 6- by 6-pixel blocks were assigned to the aggregated pixel. Whenever the heterogeneity (defined as the block variance of tree cover percentage) of the pixels exceeded a threshold of 20 percent (optimal value in order to keep the same vegetation description), the block element was considered as unclassified.

New statistics were extracted from Landsat TM quadrant scenes at 180-m resolution using degraded classified windows as training areas. They allowed the application of a supervised classification to these degraded resolution scenes. The resulting thematic classified images had a resolution of 180 m. Such a figure is compatible with the 250-m resolution recommended by Townshend and Justice (1988) for the sensors to come on board the next satellite generation.

As far as SPOT scenes are concerned, the method has been simplified. It was possible to define 40-m resolution training areas for the three basic classes in the "Guinean phytogeographic zone" : dense forest, crops, and grass savanna. Classified images were then degraded to 120-m resolution.

These results were further degraded to give 1-km resolution images on the same projection as for the NOAA images. The mean value of all composing pixel group was attributed to each 1-km grid element (defined from 120-m and 180-m resolution classifications) when the heterogeneity of tree cover percentage was lower than the previous threshold of 20 percent. Significant vegetation classes were selected for the next step and class areas were eroded (one pixel wide along their outline) because of the geometrical accuracy of the NOAA imagery. Each pixel is a grid element of 0.01° longitude by 0.01° latitude corresponding approximately to 1.1 km by 1.1 km = 121 ha.

NOAA AVHRR Image Processing

Although it is not possible currently to infer directly a specific vegetation cover from a given vegetation index, it can be reasonably assumed that the temporal evolution of the NDVI throughout the year is a useful variable for characterizing vegetation types (Tucker, 1979; Townshend and Justice, 1986). The use of Surface Temperature is still not common for this purpose.

NDVI and ST evolution curves have been drawn for the main vegetation units identified on classified images degraded to 1-km resolution. The plotting software includes a cloud filtering algorithm : pixel values for which the brightness index exceeded the threshold of 20 percent reflectance were considered cloud covered. For each site, only the most densely wooded classes, crops, and savanna classes were considered. The mean values of the NDVI and ST were computed from all pixel values of eroded classes (Figures 3 and 4).

RESULTS AND DISCUSSION

High Resolution Images Classification

Accuracy assessment of the classification was given by the mean percentage of correctly classified pixels in each training area. Mean percentages of well classified pixels for training areas were 81.5 percent in the "Sudanian" test site with TM pixels at 30-m resolution and more than 95 percent in the "Guinean" test site of the Marahoué National Park with SPOT pixels degraded at 40-m resolution. The accuracy of the classification is sufficient for our purposes (Achard *et. al.*, 1988).

In the "Sudanian" test site, classes such as dry deciduous forests and woodlands are poorly represented. They cover 4,600 ha out of the 2 × 810,000-ha total area of the two TM quadrant scenes. These data suggest that these two vegetation units cannot be distinguished with a 1-km² resolution. However, savanna woodlands, which are less densely wooded (30 percent of trees plus 30 percent of shrubs) can be recognized. The areas estimated for each vegetation type are as follows:

- 74,000 ha (611 pixels) of rain-fed crops,
- 65,600 ha (542 pixels) of grass savanna, and
- 21,900 ha (181 pixels) of savanna woodland.

In the "Guinean" test sites the distribution of the vegetation units in two SPOT scenes (2 × 360,000 ha) is the following:

- 84,600 ha (699 pixels) of crops (coffee, cocoa plantations, etc.),
- 54,800 ha (453 pixels) of dense forests, and
- 3,000 ha (23 pixels) of grass savanna.

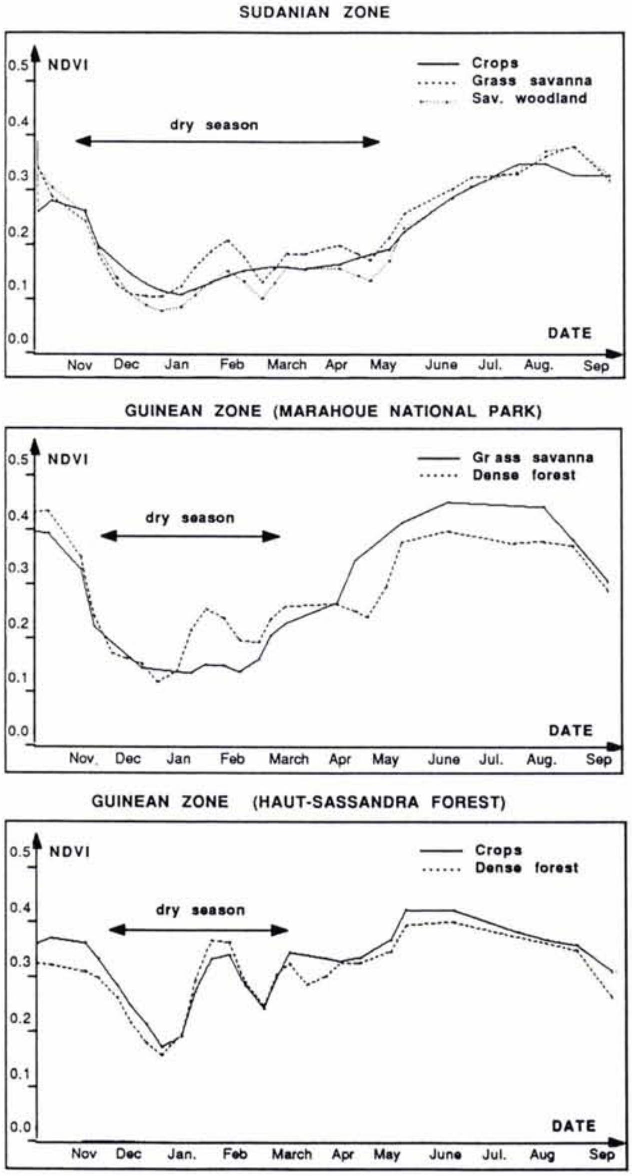


FIG. 3. Evolution of Normalized Difference Vegetation Index (NDVI) (mean value of all pixels in each class).

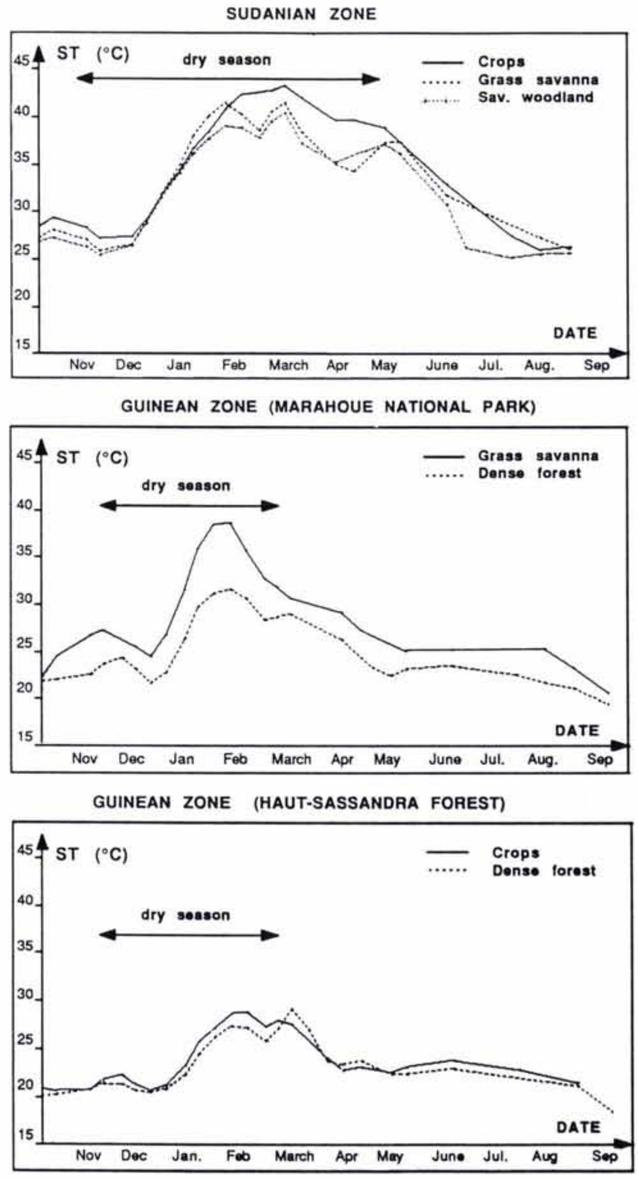


FIG. 4. Evolution of Surface Temperature (ST) (mean value of all pixels in each class).

EVOLUTION OF THE VEGETATION INDEX AND OF SURFACE TEMPERATURE

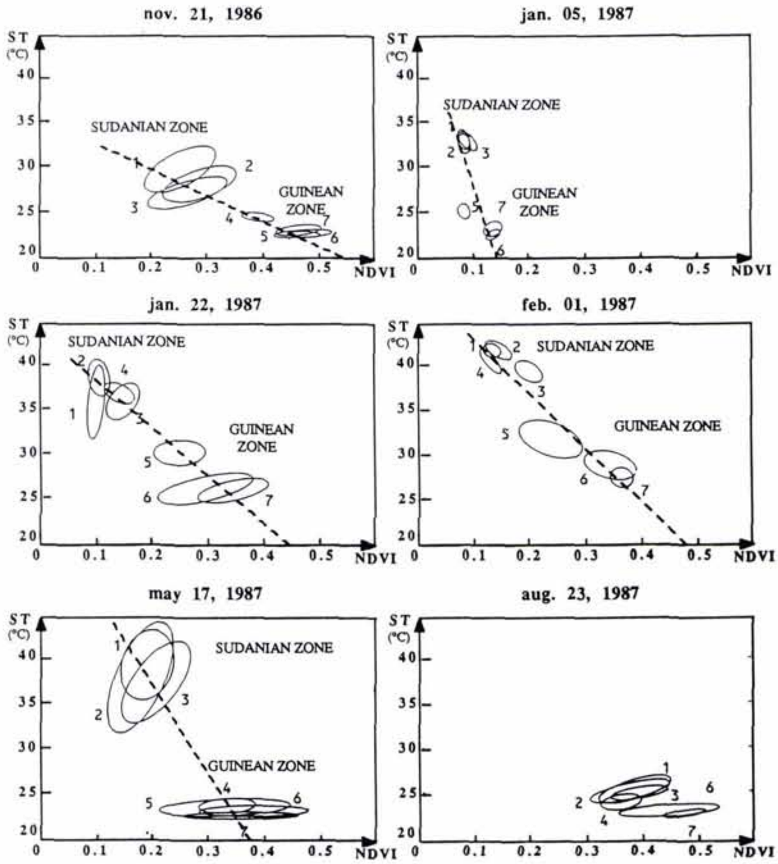
Figures 3 and 4 give an example of current capabilities of AVHRR data for studies related to vegetation cycles in tropical countries. At the end of the dry season, it is possible to discriminate regions bearing natural savannas from wet forests. The Savanna region is characterized by a low vegetation index corresponding to a relatively low photosynthetic activity and high surface temperature, whereas the forest region has a higher vegetation index due to a higher density of trees (greenness), and a lower surface temperature due to the plant cover protection and the cooling effect of evapotranspiration.

Sudanian Zone.

In the "Sudanian zone," the general trend of the three curves is in agreement with vegetation cycles in this region (top of Figures 3 and 4). However, these evolutions are very noisy. The noise is introduced mainly by atmospheric disturbances. Clouds are automatically filtered but the algorithm can filter neither the dry haze (Harmattan) nor the humid haze in cloudy atmospheric conditions.

The distances between the three curves remain almost constant, but are relatively small (range : 0.04). NDVI values of the savanna woodland are higher than those of the two other classes from the middle of dry season onwards. This fact is due to the phenological phase difference between tree and grass canopies. In the "Sudanian" region, trees and shrubs found in savannas and woodlands are putting on their leaves in the middle of the dry season, whereas the development of grasses starts at the beginning of the rainy season.

A comparison of NDVI and ST curves shows a two-month delay on the ST curve as compared to the decrease of the NDVI. It is noteworthy that the surface temperature increases from the end of December whereas the NDVI decreases from October. ST reaches its maximum in March at the beginning of the growing period of savanna grasses. Cereals have the highest temperature values at the end of the dry season, because their soils are often almost barren during most of the dry season.



1. Crops
2. Grass savanna
3. Savanna woodland
4. Grass savanna of Marahoué
5. Dense forest of Marahoué
6. Crops of Haut-Sassandra
7. Dense forest of Haut-Sassandra

FIG. 5. Evolution of variance ellipses in (NDVI, ST) coordinates.

Guinean Zone

In the "Guinean zone", the spectral curves are also very noisy (Figures 3 and 4, middle and bottom). The NDVI curves clearly show that the dense semi-deciduous forest has a higher photosynthetic activity than the savanna during the dry season (December to March) and conversely during the humid season (April to September). A very low vegetation activity is observed between December and January, due to leaf shedding of deciduous trees. In the case of the Haut-Sassandra forest, the NDVI is slightly higher than that of crops (coffee and cocoa) during the dry season, and conversely during the rainy season, but the differences are not significant. This can be explained by the fact that industrial plantations are mainly growing under degraded forests and have almost the same phenological behavior as the dense forest. It is noteworthy that this class (industrial crops) gives the same spectral response on NOAA images as dense forest.

The Marahoué and Haut-Sassandra forests belong to the same dense semi-deciduous forest class. However, the Marahoué forest has a lower response in the NDVI values than the Haut-Sassandra forest. No obvious nor convincing explanation could be found to justify this important difference. As a consequence, it appears that it will be very difficult to separate dense forest and crop classes in the entire subset, using only NDVI or ST data.

Maximum surface temperature is reached at the end of the dry season (Figure 3). Here again, there is no difference between crops and forest classes, but a significant difference exists with the savanna class at the end of the dry season (40° C for the savanna against 31° C for the forest in February). The ST of the forest remains quite constant during the course of the year (mean 23° C for Haut-Sassandra and 24°C for Marahoué).

Scatter Diagrams in NDVI and ST Coordinates

In order to complete the analysis of NDVI at 1-km resolution, variance ellipses (1 σ) have been plotted for the seven main vegetation classes at six dates, on diagrams in which the NDVI is along the X-axis and ST is along the Y-axis (Figure 5).

It appears that, on each diagram, ellipses are distributed approximately along a straight line with a negative slope : NDVI and ST are correlated at a given date. But the slope of the lines changes in time. The slopes reach a maximum at the beginning of the dry season (image taken on 5 January 1987) when NDVI is very low for all classes (between 0.08 and 0.15) and when the temperature difference between classes in the "Sudanian zone" and classes in the "Guinean zone" is important (min. 22°C to max. 34°C). In the middle of the rainy season, ellipses are close to the highest NDVI values (0.35 to 0.5) and lowest ST values (22°C to 25°C). The best period to separate classes is the middle of the dry season (images on 22 January and 01 February).

Figure 5 shows the correlation between NDVI and ST at one given date. The evolution of the correlation line slope with time is due to the time offset (phase) between the NDVI cycle and the ST cycle, which is observable on the evolution curves. The increasing temperature is associated with the progressive warming of the tropical atmosphere, but is delayed compared

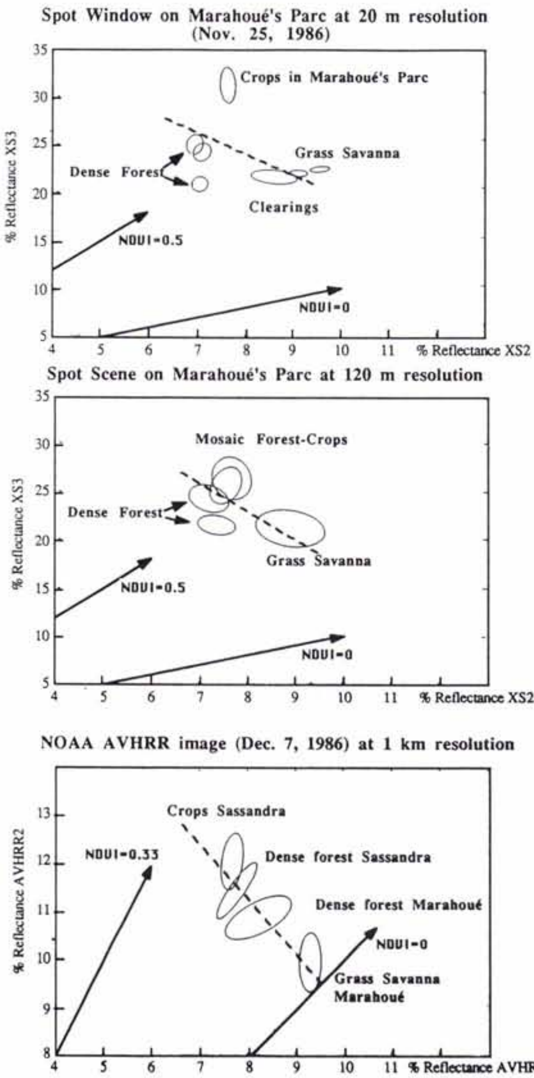


FIG. 6. Reflectances of vegetation classes for the guinean zone.

to the decrease in the vegetation index due to the progressive drying out of seasonal vegetation. This delay of about two months can be explained by the presence of dried herbaceous plants covering the soil during a few weeks. As soon as this phytomass is burnt, soils remain barren and the surface temperature increases rapidly.

STATISTICS IN RED AND NEAR-INFRARED CHANNELS

Explaining the close difference between NDVI measurements is made better by means of comparison between calibrated reflectances of the SPOT HRV and NOAA AVHRR sensors. The calibration in reflectances is described by Price (1987). Figure 6 shows the statistics of reflectances for selected vegetation types in the "Guinean zone" (SPOT scene of Marahoué Park). The ellipses are centered on the mean value of training site pixels and represent 65 percent of the pixel population (1 σ). The reflectances in near-infrared channels are lower for AVHRR band 2 than for HRV band XS3. This is due to the observation geometry and atmospheric effects which have a great importance on the NOAA AVHRR channel 2 measurements because channel 2 includes a vapor absorption band (Dedieu, 1989).

The spatial distribution along one line (the "greenness" line, Figure 6, at 1-km resolution) perpendicular to the soils line

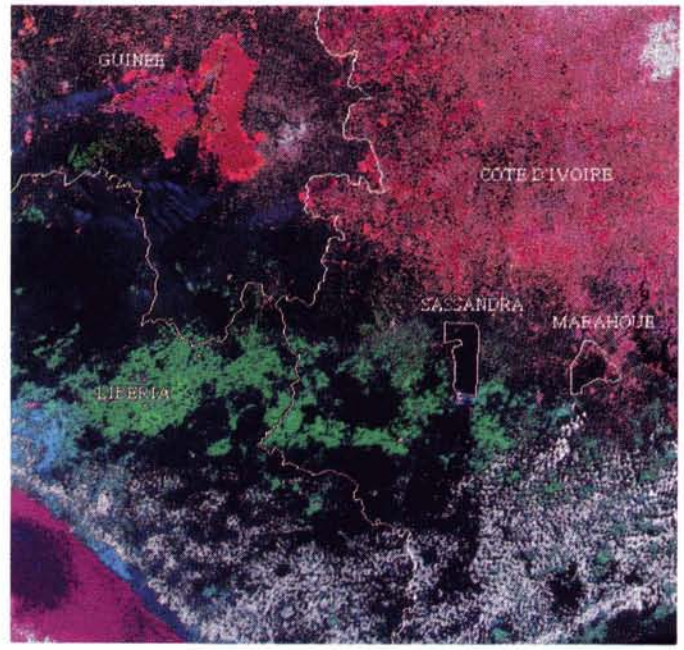


PLATE 1. Color composite of the southwestern part of AVHRR image (13 January 1987).

(NDVI = 0) is noticeable, with the following sequence : grass savanna (Marahoué), dense forests (Marahoué and Haut-Sassandra), and crops class.

During the dry season in the "Guinean zone," it appears from these diagrams that there is a gap between reflectances of the savanna class and reflectances of the forest class and crops class. But the difference between forest and crop classes appears too small along the NDVI axis to be significant (about 0.01). A brightness index of the near-infrared band had to be more closely investigated in order to map deforested areas in this humid environment.

FOREST MAPPING USING A THRESHOLDING ON NEAR-INFRARED CHANNEL

A few works concerning the evaluation of forests areas have been carried out using AVHRR 1.1-km resolution data. According to Malingreau *et al.* (1989), it appears that there is a quite distinct thermal gradient characteristic of a forest savanna transect in Guinea (AVHRR channel 3 analysis). On the other hand, Päivinen and Witt (1988) have tested three methods for forest and non-forest classification in Ghana. A multichannel density slicing method gives preliminary but encouraging results which have yet to be confirmed.

In West Africa we have produced a color composite (Plate 1) in which channel 3 reflectance is displayed in red, channel 2 in green, and channel 1 in blue. It appears that two zones are distinctly differentiated; the boundary between the "dry Sudanian vegetation" and the "moist Guinean vegetation" is characterized by a decrease in AVHRR channel 3 reflectances.

Remnants of dense moist forests (semi-deciduous or evergreen) are scarce and mainly located in protected or less accessible areas. A simple thresholding on channel 2 reflectances at 7.0 percent is sufficient to separate the moist dense forest out of its environment of shrubby crops and plantations. Remaining patches of small forest appear in dark green (near-infrared channel) on this 512 pixels by 480 lines window (see the Marahoué Park and the Haut-Sassandra reserve). This threshold has been selected manually. When applying this method on the eastern adjacent window which contains eastern Côte d'Ivoire and Ghana, the threshold had to be changed to 7.3 percent. It could be due to directional effects (and atmospheric effects) in the parallels direction along 1,000 km wide. As a matter of fact, the satellite track projection passes through the point (5.86°W ; 7.5°N) which is close to the middle of the eastern side visualized window (5.38°W ; 7.6°N).

CONCLUSION

The monitoring of Normalized Difference Vegetation Index and Surface Temperature in the "Sudanian" and "Guinean" zones in West Africa leads to some interesting conclusions regarding the interpretation of NOAA data for vegetation studies.

- Spectral responses are strongly influenced by prevailing atmospheric conditions. In this part of the world, the Harmattan wind during the dry season and the almost permanent cloud cover during the rainy season often degrade image quality. Future studies could easily implement Raleigh effect correction and water vapor correction when their values are known. The effects of other atmospheric particles will be more difficult to correct.
- Discriminating some essential vegetation types is nevertheless made possible, especially at certain periods of time. As expected, savannas have a low NDVI during the dry season, and dry crops in the "Sudanian zone" showed a very high surface temperature just before the beginning of the rainy season (lack of vegetation added to high air temperature).

In wet areas ("Guinean zone"), we have not been able to separate untouched semi-deciduous forests from woody crops (often growing under degraded forests) from NDVI and ST values at 1-km resolution. This clearly means that a "forest non-forest" discriminant at a regional scale is not yet readily available in moist tropical countries.

AVHRR HRPT data allow the discrimination of only a few dominant vegetation classes. It is essential to restrict the global analysis of vegetation cover to a few essential physiognomic classes. And then the existing vegetation mapping methods and vegetation classification systems could be adapted to match low resolution remote sensing data (Blasco, 1988).

It has been shown that statistical overlaps are due not only to resolution degradation, but also to the choice of the NDVI ratio. This is an important factor which has to be taken into account when designing future spatial resolutions and spectral bands for the next generation of Earth observing systems.

ACKNOWLEDGMENTS

This research was funded by the French National Remote Sensing Program (PNTS) through the "Aide CNES 87/1270" and by a program of the Joint Research Center (JRC) of the European Communities Commission at Ispra under contract 3268-87-11 EDISPF.

The authors would like to thank Alain Podaire (LERTS, Toulouse) for his advice, Yann H. Kerr (LERTS) for his contribution to the NOAA processing software, and Jean P. Malingreau (JRC, Ispra) for his constructive comments.

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(Accepted 22 May 1990)