Analysis of the NDVI temporal dynamics in semi-arid ecosystems: Brazilian Caatinga and African Western Sahel

Humberto Alves Barbosa [1]
T.V. Lakshimi Kumar[2]
Ivon Wilson da Silva Junior[3]

[1,3] Universidade de Federal – UFAL/ICAT
Campus A. C. Simões, BR 104 Norte Km 97 – 57072-970 – Maceió – AL, Brasil
{barbosa33@gmail.com, ivon.ws}@gmail.com

[2] SRM University City
600 026 – Jawaharli Nehru Salai (100 feet Road) – Vadapalani Chennai – Tamil Nadu – India
lkumarap@gmail.com

Abstract. The results indicated that the effect caused by the El Niño event in the various types of vegetation in the semi-arid region of Northeast Brazil during the last two decades of the last century, presented a differing seasonal and interannual patterns from the vegetation types in the African Sahel. The seasonal amplitude of Normalized Difference Vegetation Index - NDVI variation in the African Sahel was not altered by the climatic effect of El Niño, however, in the semi-arid region of Northeast Brazil, the vegetation types were affected during the El Niño events. Furthermore, it was observed that the NDVI varies according to the local climatic conditions, presenting a temporal gap between the precipitation occurrence and water absorption available from the vegetation. This information is important to show contour conditions for climatic models and also for the weather numerical forecasting.

Key words: Vegetation, drought, satellite.

1. Introduction

The temporal analysis of the vegetation dynamics (i.e., the response of vegetation to climatic conditions) in the semi-arid tropical region is important to improve the climate modeling studies in simulating Sea Surface Temperature (SST)-dependent vegetation variability at climatic extremes (Cramer and Fischer, 1996). The climate, in a first approach, is highly dependent on the vegetation coverage conditions. It's known that in wet (drought) conditions the vegetation coverage tends to increase (decrease). In areas such as Northeastern Brazil and the West African Sahel, where drought conditions have been most severe, there is increasing evidence that theses two factors may be related and that land surface conditions may help to reinforce and sustain the meteorological drought (Hulme 2001).

In earlier studies (Barbosa 1998; Nicholson and Farar, 1994) mostly held in the atmospheric dynamics context have incorporated long time series of Normalized Difference Vegetation Index (NDVI) data taken by the National Oceanic and Atmospheric Administration (NOAA) Advanced Very High Resolution Radiometer (AVHRR) to monitor the dynamics of the temporal structures of vegetation responses to climatic fluctuations across the Northeastern Brazil and the West African Sahel's landscapes. These investigations have found clear and positive linear relationships between NDVI and rainfall thanks to different analyses across the semi-arid tropical ecosystems where rainfall is below an absolute amount of rainfall of 50-100 mm/month. In this study we have the objective to investigate the NDVI responses to rainfall oscillations at seasonal scale over the last two decades of the 20^{th} century.

2. Data and Methods

Temporal analyses performed in this research were based on the monthly NDVI imagery from the Goddard Distributed Active Archive Center (GDAAC) for the 1982 to 2000 period. The NDVI images were originally in the Goode's Interrupted Homolosine projection, and they were geo-referenced to a geographical coordinate system (latitude and longitude). The 20-year series of monthly NDVI data for Brazilian semi-arid and West African Sahel regions were extracted from NDVI images with a resolution spatial of 7.6 km.

Aiming to characterize the seasonal variability of land cover types in Caatinga and Savanna Biomes to the understanding of their responses to the seasonal rainfall variability, we verified how available GDAAC NDVI are able to capture the climatic variability, and how it could be used in ecological studies, at the local level. Based on the vegetation map published by the Brazilian Institute for Geography and Statistics (IBGE, 1993) and by author's local knowledge, as a basis, four homogeneous vegetation sites covering semi-arid Caatinga in Northeastern Brazil were selected from vegetation classes, and located by ground meteorological stations (sites): site#1-caatinga arbórea aberta (open arboreous shrubbery) ($4^0$31'S; $40^0$12'W), site#2-caatinga arbustiva densa (dense shrubbery) ($4^0$37'S; $42^0$7'W), site #3-caatinga arbórea densa (dense arboreous shrubbery) ($8^0$37'S; $42^0$7'W), and site #4-caatinga arbustiva aberta (open shrubbery) ($9^0$25'S; $41^0$7'W). For the semi-arid Sahelian region, four vegetation classes were conducted over the UNESCO map produced by White (1983). Representatives from the following land cover types dominated in this classification: site#1-woodland ($10^0$55'N; $14^0$19'W), site#2-woodland ($110^0$26'S; $7^0$25'W), site#3-woodland ($11^0$04'N; $7^0$42'E), and site#4-wooded grassland ($11^0$04'N; $39^0$47'E) (Fig.1).

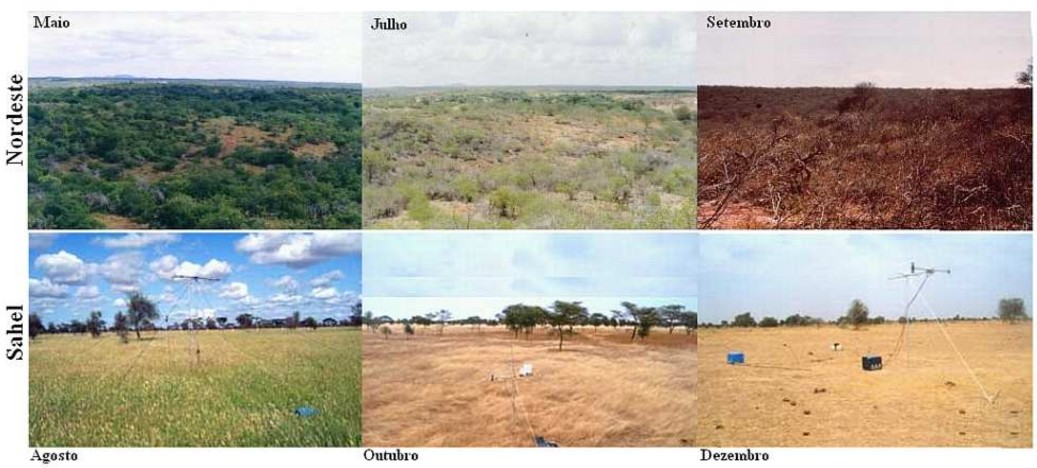

Figure 1. The vegetation dynamic of the Brazilian Caatinga and the African Savanna is directly connected to the climatic conditions (photos). Site#1: (Nordeste Lat=-4°53'S; Long= 40°20' W) e (Sahel Lat=11°76'N, Long=34°35'E).

The 20-year integrated series of monthly NDVI data were extracted by averaging the NDVI values for a window of 3 by 3 pixel arrays at selected locations within each land cover type in order to characterize the seasonal variability in land cover type for each series. The database consisted of land cover classes from the IBGE (1993) and White (1983) vegetation maps (1:5,000,000) that were used to guide site locations by using the geo-referenced meteorological stations on the ground in conjunction with NDVI data.

3. Results

Seasonal variations in the NDVI of Cattinga and Savanna vegetation types are illustrated in Figure 2. For each location, the average monthly values of NDVI were extracted from September 1981 to September 2001 (20-years) at a 519.84 km^2 (averaged area of nine pixels) for each site. The average monthly values of rainfall for the specific location within each land cover type are representative over the 30-year climatology period of 1961 to 1990. Both NDVI and rainfall series for the four caatinga types show a clear unimodal seasonal cycle. While the differences in magnitude of the NDVI are different over each site, the NDVI series show that phenological behavior varies slightly from north (site#1) to south (site#4). The annual total rainfall gradually varies from site#4 (549.10 mm) to site#3 (657.2 mm), to site#1 (839.13 mm) to site#2 (1046.12 mm). At these four sites, the beginning of the vegetation season is mostly driven by rainfall, while mean maximum temperature is quite constant during year and around 31^0C. Moreover, the NDVI related to dry and rain seasons are very pronounced, with a minimum of 0.21 ± 0.02 over site#4 in August to October and maximum of 0.68 ± 0.02 over site#2 in April to June. On average, NDVI and rainfall have a similar pattern (both increase and both decrease together) with a lagged response due to the differences between the onset of the rainy season occuring in October or November, and the vegetation growth in November or December. Contemporaneously, from May to October there is a downward trend in NDVI values for all four Caatinga types, with the lagged response of the vegetation to rainfall being two months. While the upward trend in NDVI values is certainly due in part to stored soil moisture during the rainy season, the downward trend is likely to be more closely related to the different soil types and their physical properties.

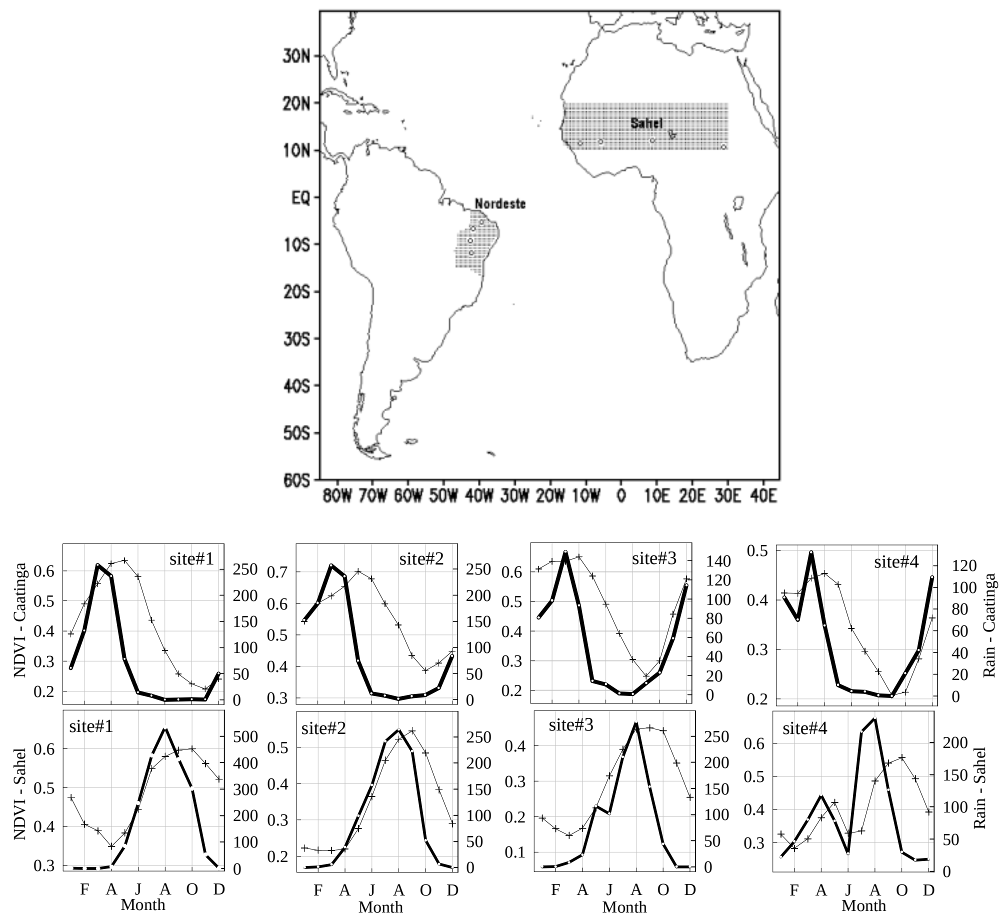

Figure 2. Time series of monthly composites of NDVI (thin solid line) and rainfall (thick solid line). The monthly composites of NDVI relative to the 20-year Pathfinder data period from 1981 to 2001. The mean monthly rainfall values relative to the 30-year climatological period of 1961-1990.

For the West African Sahel, the seasonal pattern of NDVI for all four vegetation types closely responds to the seasonal cycle of rainfall as illustrated in Figure 2, with a peak in rainfall followed by a peak in NDVI. The majority of NDVI and rainfall series in these figures are dominated by an indistinct unimodal pattern, except for site#4 that shows two peaks. These two NDVI peaks capture the effects of two seasonal monsoons that are related to the north-south movement of the ITCZ. The first peak occurs in early May, when the ITCZ is at its southernmost extent. The second peak occurs when the ITCZ is at its northernmost extent in early October, and is also higher than the first peak. These seasonal variations in rainfall time series represent both meteorological and geographical factors resulting a bimodal greenness pattern in the NDVI time series. The unimodal cycle of the other three selected sites show a similar phonological behavior (peaking in October), but they exhibit differences in amplitude of the NDVI time series among them.

The figures for the Caatinga and Savanna Biomes discussed above underline the relationships between surface greenness and rainfall (varying from r^2=+0.1 to r^2=+0.6, n=360 (rain), n=240 (NDVI), $P<0.05$) and lend support to the time lag between the rainfall and NDVI. The time response of the rate green up due to the rainy season (rainfall) in NDVI profile is longer for semi-arid Sertão caatinga types than Sahelian vegetation types. This is likely because the semi-arid Brazilian is dominated by deeper-rooted arboreal formations. The lagged response of vegetative activity of these deeper-rooted caatinga types to absorb the stored soil moisture is longer than the Sahelian vegetation types, which are dominated by wooded and bushed grassland (herbaceous). In contrast, the time duration of the rate of senescence in the NDVI profile, which is due to the dry season (rainfall deficit), is shorter for Sahelian vegetation type than caatinga types. This might indicate that the caatinga types, which are very drought resistant, have an additional water supply besides rainfall. It is important to note that while the same twenty-year NDVI and thirty-year rainfall periods were used for both the Sertão and Sahel regions, there is a ten-year time shift between the referenced period of the NDVI and rainfall, however, this shift was taken into consideration in our analysis.

A “see-saw” pattern can be also observed from figure 3: while the values of NDVI over the Nordeste present the peak in May, which is associated with peak of humid month, most of values of NDVI over the Sahel present the peak in August, which is associated with peak of humid month. The comparison of the Nordeste curves with the Sahel curves suggest that during the last two decades of twentieth century their Nordeste amplitudes are about half order of magnitude larger than those of Sahel. Considering the whole 1982-2001 period, the Nordeste NDVI increase during the 1980s must be primarily driven by the increase in precipitation during this period. In contrast, the most 1980s and 1990s the NDVI Sahel must be dominated by precipitation decrease. Due to its intrinsically different dynamics, Nordeste and Sahel atmospheric circulations are often regarded separately. For example, in Northeastern Brazil, the inter-annual variability of the atmospheric circulation is predominantly influenced by Sea Surface Temperature (SST) in both the Atlantic and Pacific Oceans, and has exhibited negative anomalies in rainfall during the warm phase of El Niño-Southern Oscillation (ENSO), and positive anomalies during the cold phase (La Niña). The West African Sahel, on the other hand, is mainly influenced by SST in the Indian Ocean with a portion, known as the rainbelt being affected by SST in the Atlantic Ocean. Although warm events in the eastern equatorial Pacific and Indian Oceans are known to induce climatic extremes over much of Africa; the tropical Atlantic Ocean often exhibits an opposing response to ENSO which may further enhance these impacts.

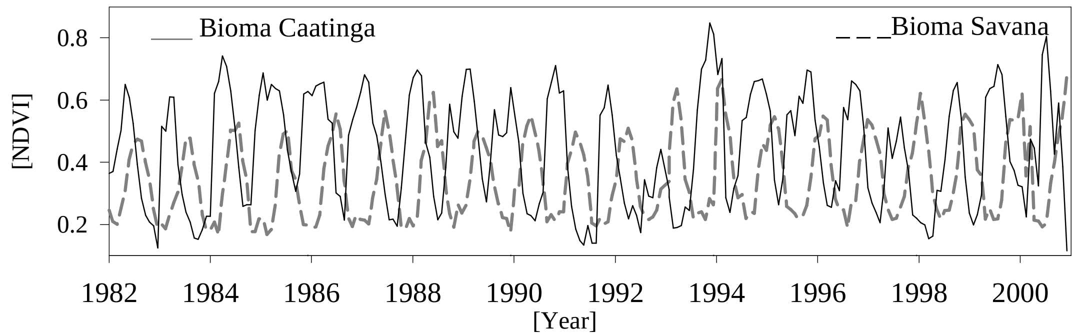

Figure 3. Time series plot of monthly composites of NDVI over the NEB (solid line) and the Sahel (dashed line) period January 1982 through September 2001.

4. Conclusions

The Caatinga and Savanna vegetation covers are likely the most sensitive to changes in climate. They support the conclusion that monitoring the dynamics of their vegetation, in the sense of a regional indicator for climatic and/or anthropogenic changes, might constitute a key element in desertification research.

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