Spatial patterns of the canopy stress during 2005 drought in Amazonia

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Abstract - **In the last decades, the detection of drought occurrences and assessment of its severity using satellite data are becoming popular in disaster, desertification, crop production, phenology, land cover change and climate change studies. To detect the drought effects on different vegetation types, many methodologies have been developed, mostly relying on the use of vegetation indices. This communication reports the first attempt to assess the capability of MODIS NDVI, Enhanced Vegetation Index (EVI) and Normalized Difference Water Index (NDWI) from 2000 to 2006 time-series to detect the 2005 drought in Amazonia. To reach this objective, monthly composites of the MOD13A2 product were generated from period. Then, monthly anomalies were calculated, considering anomalous values when lower than -1 standard deviation (sd) or higher than 1 sd. Rainfall data provided by the Tropical Rainfall Measuring Mission (TRMM) was also acquired for the same time-series with the objective of supporting the understanding of vegetation response with the precipitation. Water deficit data calculated based on the TRMM data were also used to guide the sampling scheme. A land cover map for South America updated with natural land cover changes detected by the Near Real Time Deforestation Detection Project (DETER) was used as a mask to avoid false anomalies in the Brazilian Amazon. In general, NDWI and EVI showed to be sensitive and consistent for the temporal series used. NDVI presented a high variability and though a difficult interpretation. Critical months in the NDWI and EVI series coincided with the months with higher water stress calculated based on the TRMM data. EVI also showed to detect changes in the canopy structure. These preliminary results suggest that this is a strong methodology to be used in the spatial analysis of the extent of the drought effects in the vegetation. Literfall data will be incorporate in this research for validation purposes.**

Keywords - Amazon; vegetation indices; drought; MODIS.

I. INTRODUCTION

The response of tropical forest ecosystems to natural or anthropogenic environmental changes is a central topic in ecology [1,2].

Changing climate affects plant growth through shifts in seasonal cycles, for example due to shifts in precipitation patterns or longer growing seasons [3]. In addition, changes in plant growth may lead to biogeographical changes in vegetation distribution and composition [2].

The estimation of quantitative variables such as leaf biochemical and canopy biophysical parameters is a key element in vegetation monitoring, and a major goal in long-term research of the terrestrial ecology.

Between 1975 and 2005 the atmospheric concentration of CO_2 increased 14%, from 330 to 377 ppm [4]. Tropical forests could be expected to have responded to these changes directly and in a short-term period. Temperature, rainfall, atmospheric CO_2, and radiation affect photosynthesis and respiration, resulting in changes in the net carbon balance, carbon allocation, and productivity.

Models simulations suggest that climate and CO_2 affects the Amazonian ecosystems. From the Glacial to the Holocene period, it is suggested that climate change drives replacement of drought-adapted vegetation by rain forest, while CO_2 is associated with changes in ecosystem carbon storage. Recent changes in temperature are expected to decrease the productivity in tropical ecosystems [5]. Both cases, the increase in the temperature and CO_2, and its implications are important for the actual understanding of the tropical forest dynamics.

In 2005 the Amazon region experienced a drought and there are suggestions that climate change could drive increased drought frequency in Amazonia, resulting on impacts on ecosystems and human populations [6]. Low water availability for plant uptake may have direct impacts on vegetation phenology, physiology, structure and composition of Amazonian forests. During drought years, there may also be an increase in tree mortality, implying in a higher amount of carbon being released to the atmosphere. This event brings an opportunity to better understand vegetation response to a drought occurrence in a temporal and spatial scale for a better knowledge of ecosystem functioning in a possible scenario for the future of the region, pointing out more susceptible areas.

II. STUDY SITE

The Amazon forest contains the large extent of tropical forest on Earth, and accounts for a large proportion of the plant's animal and plant species (Figure 1). The diversity of this region is related not only with the differences in structure and composition of the evergreen forest, but also with the patches of other biomes, such as the Cerrado. The Amazon forest is also recognized as a potential sink for atmospheric CO_2, and uncertainties on the biomass stocks, land cover changes and productivity remain. The occupation and development of Amazon since 1950s has impacted the vegetation cover and the atmospheric composition. The population over this region has grown rapidly and the development of this area occurred based on the deforestation for croplands, pasture lands, logging, mining, urban expansion and settlement projects.

Figure 1. Limits of the study area.

III. DATA

A. MODIS data

We used the MOD13A2 product as a basis for this study. This product is a sample of the MODIS/Terra Vegetation Indices 16-Day composite, level 3, 1 km spatial resolution, with nadir BRDF-adjusted reflectance. This product contains the NDVI, EVI and the spectral bands: red reflectance (MODIS band 1, 620-670 nm), near infra-red (NIR) reflectance (MODIS band 2, 841-876 nm), blue reflectance (MODIS band 3, 459-479 nm), and mid-infrared (MIR) reflectance (MODIS Band 7, 2105-2155 nm), and also include quality assurance (QA) flags with statistical data that indicate the quality of the VI product and input data. Here, we explored the NDVI, EVI and the normalized difference water index (NDWI) (1). The original normalized difference water index [8] is based on the upon water absorption at 1240 nm. Here, we explored the water absorption in the short-wave infrared SWIR, as it has been used by the community for vegetation monitoring [11], and others.

$$NDWI = (NIR - SWIR) / (NIR + SWIR) \quad (1)$$

B. Precipitation data

Precipitation data was acquired by the Tropical Rainfall Measuring Mission (TRMM) data, product 3B43, from 1998 to 2006, with a spatial resolution of 0.25 degrees. This product encompasses daily measurements (mm h^{-1}) and total cumulative monthly precipitation was estimated in mm $month^{-1}$.

C. Land cover map

The TREES Vegetation Map of Tropical South America [9] was used, actualized by deforested areas in the Brazilian Amazon by the PRODES data project [10] until 2005 and INPE/DETER project [11] for the 2006 new clearings. The final map resulted in the vegetation classes of the TREE map, with a mask for land cover changes from 1998 to 2006 (Figure 2a). In addition, a buffer zone of 2 km for the converted forest was applied to diminish geo-referencing problems.

IV. METHODOLOGY

First, monthly data were generated for the vegetation indices products using a pixel based algorithm that selects the maximum NDVI, with the objective of reducing cloud cover and water vapor effects on the dataset. Then, this dataset was resampled for 0.25 degrees, using an algorithm to select the highest NDVI value in the grid with the objective to diminish the noise in the data, as the Amazon region has a high percentage of cloud coverage during the whole year.

To identify the areas, intensity and duration of the canopy change / stress due to the drought across Amazonia, we calculated vegetation indices anomalies for 2005 and 2006 ($NDVI_{anomaly}$, $EVI_{anomaly}$, $NDWI_{anomaly}$) as the departure from the 2000–2006 mean ($VI_{2000-2006}$), normalized by the standard deviation (σ) in a pixel-by-pixel basis (i,j), where y= year (2):

$$VI_{anomaly,}(i,j) = \frac{VI_{y,}(i,j) - VI_{2000\text{-}2006}(i,j)}{\sigma_{2000\text{-}2006,}(i,j)} \quad (2)$$

The TRMM data was used to complement the understanding and to explore the relationship rainfall and vegetation indices in terms of the spatial variation not only the areas with anomalous precipitation values, but also areas with water deficit, based on the publication of [7]. The precipitation anomaly was calculated based on the same equation used to estimate the vegetation indices anomaly (Equation 2); however, we departure from the 1998-2006 mean, and then normalized by the standard deviation. The maximum water deficit (MWD) calculated corresponds to the maximum value of the accumulated water deficit (WD) reached for each pixel within the year. For this, we first calculated the monthly cumulative water deficits based on the approximation that a moist tropical canopy transpires ~100 mm $month^{-1}$, though when rainfall <100 mm $month^{-1}$ the forest enters into water deficit (Figure 2b). This value is derived from the mean ($\pm$ σ) evapotranspiration value of 103.4 ± 9.1 mm $month^{-1}$ obtained by ground measurements and models in different locations and seasons in Amazonia [12]. The MWD is a useful indicator of "meteorologically-induced" water stress without taking into account local soil conditions and plant adaptations, which are poorly understood in Amazonia.

Finally, the land cover map was used to mask areas where anthropogenic actions occurred, avoiding the detection of "false" anomalies in the vegetation indices. Based on the combination of the water stress map and land cover map, 3 regions were selected: Acre state (Brazil), Western Peru and northern Bolivia (Figure 2a). 5 samples of 10x10km were acquired in each region. The monthly mean values of vegetation indices and precipitation were acquired and the anomalies were calculated. Values between -1 and 1 sd were not plotted in the Figure 3, as it indicates no change.

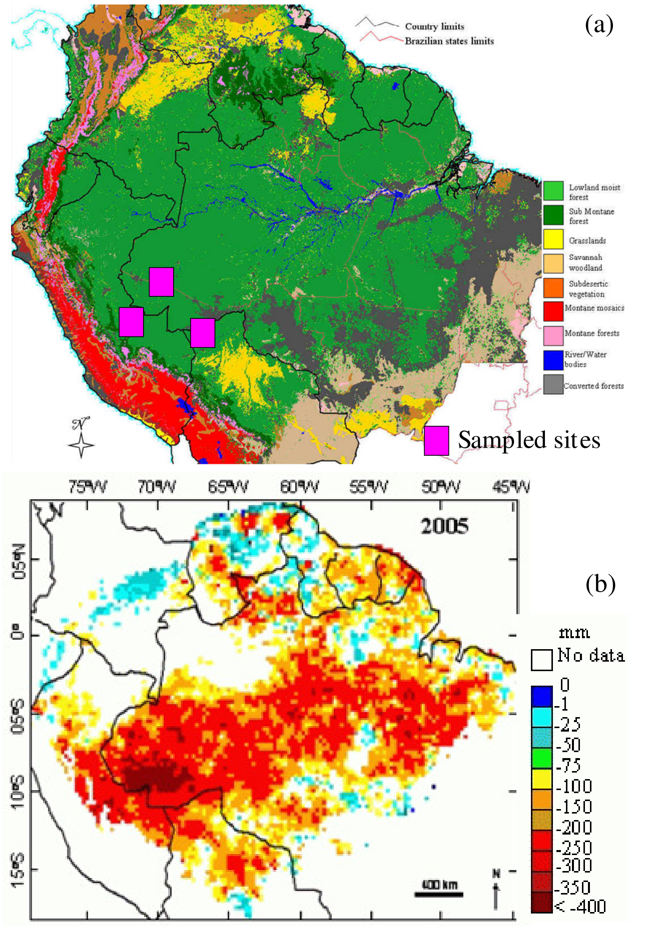

Figure 2. a) Final land cover map with the sampled regions; b)Maximum cumulative water deficit (MWD) anomaly for 2005 estimated by TRMM {MWD = cumulative months with precipitation < 100mm}.

V. Results

The results for the 3 regions studied are presented in Figure 3. In general, the NDWI (first line) and EVI (second line) presented the most consistent results than NDVI (third line), that presented a higher variation.

The NDWI for the Acre and Peruvian region presented in 2005 a persistent positive anomaly (higher than 1 standard deviation). In Acre (Figure 3a), from April to June, was observed the higher anomaly, coincident with the most anomalous months in terms of water deficit. Then, constant anomaly was observed until August. It is also interesting to note that in 2006, a NDWI anomaly in April to June occurred again. This signal may be a lag of the vegetation response to the drought event. In the Peruvian sampled region (Figure 3b), April to August presented the anomalous months, and strong signals in 2006 were also observed. The Bolivian region (Figure 3c) didn't present a strong anomaly in NDWI values, and it may be associated with the sampled site, that was not located in the epicenter of the region where the string water deficit occurred. Also, the forest composition and structure in this area (Bosque Chiquitano) is different from the Peruvian and Brazilian sites.

In the EVI analysis, Acre region presented a negative anomaly in August and September, and also in 2006, showing variability (Figure 3d). On the other hand, in the Peruvian site, it was observed a positive anomaly in April and May 2005, that can be associated with changes in the canopy structure. In 2006, this region presented a high negative EVI anomaly in the same months (Figure 3e). In the Bolivian site, we observed a strong positive EVI anomaly in August to October 2004, in the months with negative precipitation anomaly (Figure 3f). In relation to the NDVI analysis, we observed a high variation during the entire multitemporal series. In the Peruvian site, the NDVI was possibly sensitive to the drought event in 2005, but due to the variation in the others years, it suggest that this index is the less adequate to be used.

Next steps in this research will include a more detailed vegetation map of the region, and soil map to assist the understanding of different forest physiognomies phenology and response to the drought in 2005. A spatial analysis will be conducted and literfall data will be used for validation purposes.

VI. Conclusions

Despite the high variability of the vegetation indices response in the temporal series studied, the NDWI and EVI showed able to detect changes in the canopy pattern seasonality during the 2005 drought event. The results suggest that the methodology is adequate, and is potential to generate a spatial analysis for the entire region. An analysis including a temporal series of literfall collected in 4 sites in the Amazon will support the next analysis. The final results will be a major contribution for identifying more sensitive forested areas to climate change.

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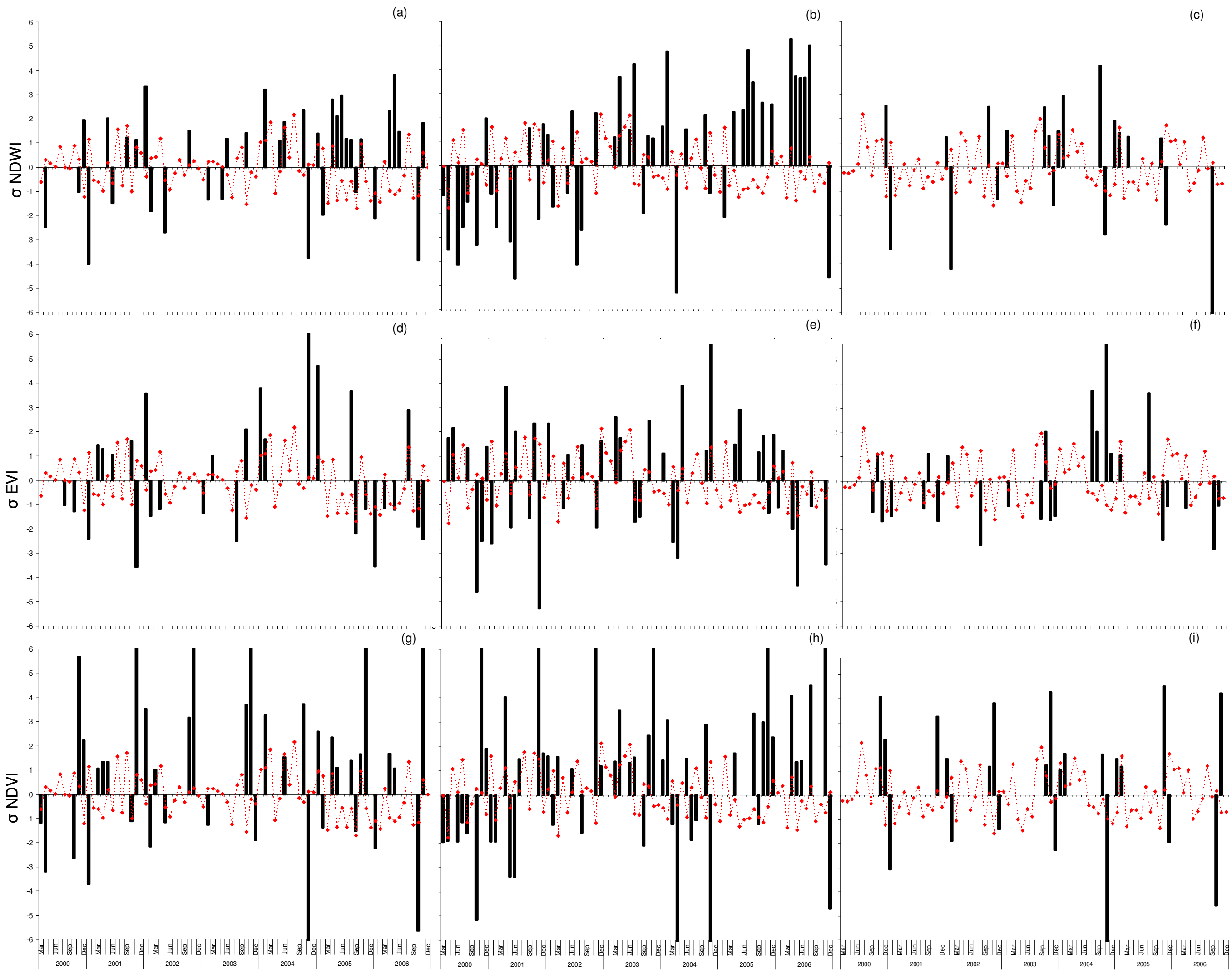

Figure 3. Vegetation indices anomalies are presented in black bars and precipitation anomalies are presented in red lines. NDWI anomalies for Acre (a), Peru (b) and Bolivia (c); EVI anomalies for Acre (d), Peru (e) and Bolivia (f); NDVI anomalies for Acre (g), Peru (h) and Bolivia (i).

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