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Remotely-Sensed Carbon and Water Variations in Natural and Converted Ecosystems with Time Series MODIS Data

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Abstract. We investigated the spatial and temporal variations in vegetation biologic activity across an eco-climatic transect traversing Amazon forest, transition, cerrado, and associated land conversion areas with MODIS time series data. We utilized 4 years of vegetation index and land surface water index data to depict carbon and water variations over our study areas. The coupled water and carbon indices were investigated with hyperspectral Hyperion data and scaled up to MODIS data for spatial and seasonal extension. Land surface moisture and carbon patterns behaved in an opposite manner between natural and converted areas and exhibited significant seasonal variations. Whereas the enhanced vegetation index (EVI) was positively correlated with the land surface water index (LSWI) in converted pastures and cerrado ecosystems, there was an inverse relationship between these two indices over primary forest areas. Our results show that these MODIS datasets can track vegetation activity in the Amazon region, including biologic responses to shifts in vegetation type and disturbance. Remotely-sensed land surface water indices combined with the carbon products yield important information useful in the prediction of vegetation health response to climate change and human land cover modifications.

Key words: remote sensing, enhanced vegetation index, land surface water index, MODIS, time series data.

1. Introduction

The assessment and monitoring of spatial and temporal patterns of vegetation activity are important in ecosystem variability studies and in understanding linkages between ecosystem structure and function and climate variability including changes in ecosystem processes associated with land conversions. There have been limited investigations on the operational utilization of remote sensing data to effectively monitor the Amazon basin and associated biomes and transition zones. Part of this problem concerns the extreme case of cloud contamination, low spatial resolution, and the difficulty in spectral differentiation of the various land cover classes and their converted areas. The Landsat TM and ETM+ imagery offer much better quality data sets but at infrequent intervals to capture the seasonal dynamics of forest and transition biomes.

The recently launched Terra MODIS instrument with newly developed terrestrial products, at 250m, 500m, and 1km resolutions, may contribute significantly to further investigations and monitoring of the Earth's vegetation. In comparison to the AVHRR sensor, the MODIS sensor offers improved cloud screening, finer spatial resolution, and atmosphere correction with no water vapor influence (Running 1994). This may better depict the regional seasonal behavior of the various Amazon land cover types for improved carbon metabolism studies and improved discrimination of the components of interannual variability, and improved land cover differentiation.

The MODIS vegetation indices (VI) include an improved Enhanced Vegetation Index (EVI) designed for extended sensitivity into high biomass and chlorophyll-saturated conditions (Huete, Didan et al. 2002). MODIS also provides a set of shortwave-infrared bands which allow the land surface water index (LSWI) to be computed as a moisture index. The spectral vegetation and water indices are particularly useful in seasonality studies in that they represent *integrative 'greenness'* and '*moisture*' measures of many vegetation properties and are sensitive to their combined response through the growing season.

Natural ecosystems in tropical regions of Brazil have been under increasing land use change pressure. Land conversion activities change vegetation composition and physiognomy and alter ecosystem metabolism, phenology, and response to rainfall seasonality (Shimabukuro, Holben et al. 1994; Asner, Bustamante et al. 2003; Novo 2004). Forests tend to have plant activity less sensitive to rainfall response as their biologic available water is supplemented by facultative use of deeper soil moisture layers. In grassland, pastures, agriculture ecosystems, photosynthesis and evapotranspiration are more directly driven by precipitation inputs. In secondary forests and more woody plant cover types, such as savannas (cerrado), ecosystem photosynthesis are moderately responsive to precipitation. The response for each land transformation type to rainfall will have different functional implications. The forest would be associated with higher photosynthesis and higher evapotranspiration in the dry season relative to the converted land cover, such as pasture that would have lower photosynthesis and lower ET in the dry season.

The objective of this study is to analyze the MODIS carbon and water indices over natural and altered converted ecosystems and through dry and wet seasons and interannual variations. We hypothesized that in combination, these 2 indices will provide a more accurate depiction of the complex patterns of carbon and moisture variations in altered and natural ecosystems.

2. Methods and Study Sites

MODIS data was extracted along various eco-climatic transects, which included primary forest formations, cerrado-Amazon forest transition, as well as their land use converted areas. We extracted windows along the transect at Tapajos, Manaus, Caxiuana sites with the 250m and 0.05^{o} (CMG) MODIS composites, and plotted their seasonal profiles using the QA filter criteria to delete pixels that were labeled cloud contaminated and selected pixels of the medium and highest quality labeling. Four years of data were analyzed, 2000 - 2003 growing seasons. In addition, we analyzed the Fazenda Fatura, Cangacu, and Santana do Araguaia transitional area with Hyperion and MODIS data in order to analyze in more detail and calibrate the moisture and carbon indices.

The MODIS VI products ingest the level 2G (gridded) daily surface reflectances (MOD09 series), which are corrected for molecular scattering, ozone absorption, and aerosols. Two VI's, the normalized difference vegetation index (NDVI) and the enhanced vegetation index (EVI), are produced:

$$NDVI = \frac{\rho_{NIR} - \rho_{Red}}{\rho_{NIR} + \rho_{Red}} \qquad (1)$$

$$EVI = G \times \frac{\rho_{NIR} - \rho_{Red}}{L + \rho_{NIR} + C_1 \times \rho_{Red} - C_2 \times \rho_{Blue}} \qquad (2)$$

where ρ_{NIR}, ρ_{Red}, and ρ_{Blue} are the surface reflectances in their respective sensor bands; L is a canopy background adjustment that addresses non-linear, differential NIR and red radiant transfer through a canopy, and C_1 , C_2 are the coefficients of the aerosol term, which uses the blue band to correct for aerosols in the red band (Huete, Didan et al. 2002).

The LSWI using 2100 nm in lieu of the red band has been broadly used as an independent vegetation measure related to canopy moisture condition instead of chlorophyll amount,

$$LSWI = [\rho_{860nm} - \rho_{2130\ nm}] \ / \ [\rho_{860nm} + \rho_{2130nm}]$$

(Fensholt and Sandholt 2003) applied their formulation of LSWI with MODIS band 6 (1640 nm), and found this index to be a strong indicator of canopy water content and soil moisture during the growing period in the Sahel.

Table 1. Some of the study sites used for intensive analyses with MODIS and Hyperion data.

Site Name	Lat/ Long (center)	Acquisition date	Description Land Cover
Cangacu	-9.9775, -50.0071	08/22/2002	Forest tower site
Tapajos National Forest	-2.9370, -54.9649	9/19/2002	Forest tower site
Santarem Pasture	-3.2534, -54.9460	08/14/2003	Converted tower site
Manaus	-2.5892, -60.1604	08/30/2002	Forest tower site
Cauaxi	-3.6714, -48.3890	10/25/2002	Forest field site
Fazenda Fatura	-9.7055, -50.3993	06/13/2003	Converted field site

3. Results

In Figure 1 we show the MODIS EVI values along the east to west ecoclimatic transect as it traverses through seasonally-dry topical forests on the east side onto the more perhumid primary forests at the western end of the transect. The area between Santarem and Caxiuana shows the greatest seasonal variations in EVI while the area west of Manaus shows smaller variations. The Santarem area also shows the highest EVI values indicating greater productivity and green biomass accumulation than in the more humid western portion of the transect. Various studies have shown the Amazon region as light-limited and the dry season in the eastern side may be conducive to greater growth and production. Figure 2 shows a different pattern of behaviour with the land surface water index (LSWI). The western side of the transect shows the highest water index values while the Santarem area is within the lowest range of LSWI values. Caxiuana also shows very high LSWI values, particularly in August. In contrast, the month of August resulted in medium to low EVI values while the November profiles were the highest (Fig. 1). The dry and wet seasonal patterns between the EVI and LSWI thus differ significantly.

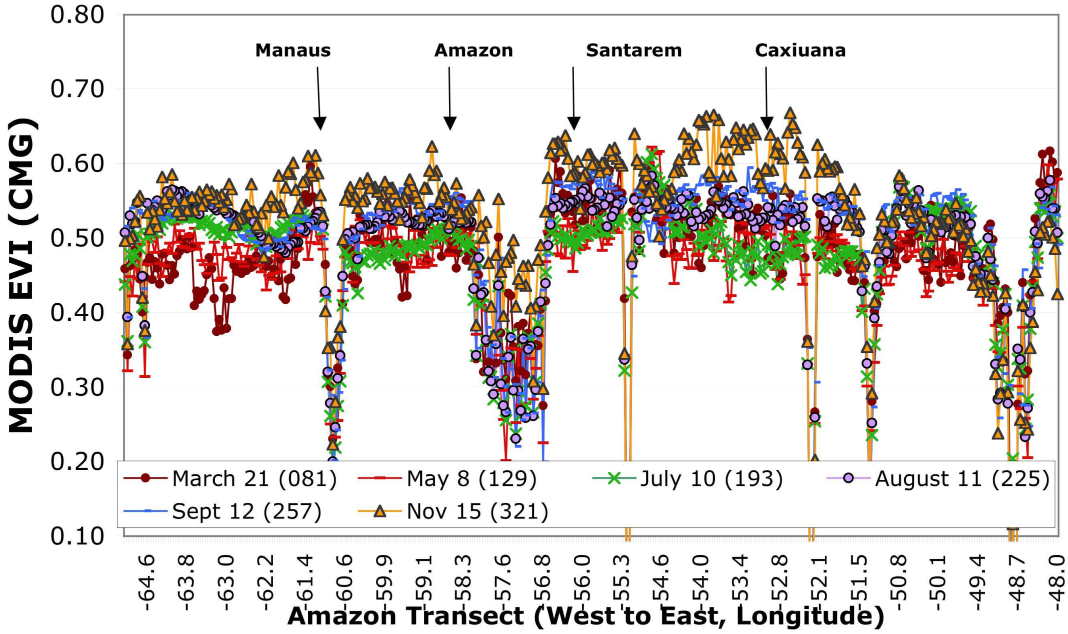

Figure 1. MODIS Enhanced Vegetation Index (EVI) seasonal – spatial profiles along an east to west transect at 2-3 degree south latitude.

In Figure 3 we show an example of EVI and LSWI values plotted against each other for a converted area in Fazenda Vitoria and a primary forest area near Cauaxi. The mostly converted pasture sites show a strong positive relationship between the EVI and LSWI for both dry and wet seasons. In general, as the amount of green biomass increases, both chlorophyll levels and moisture levels of the canopy increase together. However, a different pattern emerges in the primary forfest areas (Fig. 3). In this case, there is an inverse relationship between chlorophyll levels, as measured by the EVI, and the moisture levels, as measured by the LSWI. Thus, in the dry season, there is a sudden flush of new growth in the forests, simultaneous as the land surface is drying out due to the lack of rainfall. The new leaf growth adds to the canopy moisture content, but the soil is drying out and there are also many leaves which are dessicating and falling as litterfall. The net result is a drying process in which EVI values increase with new leaf growth while LSWI values decrease.

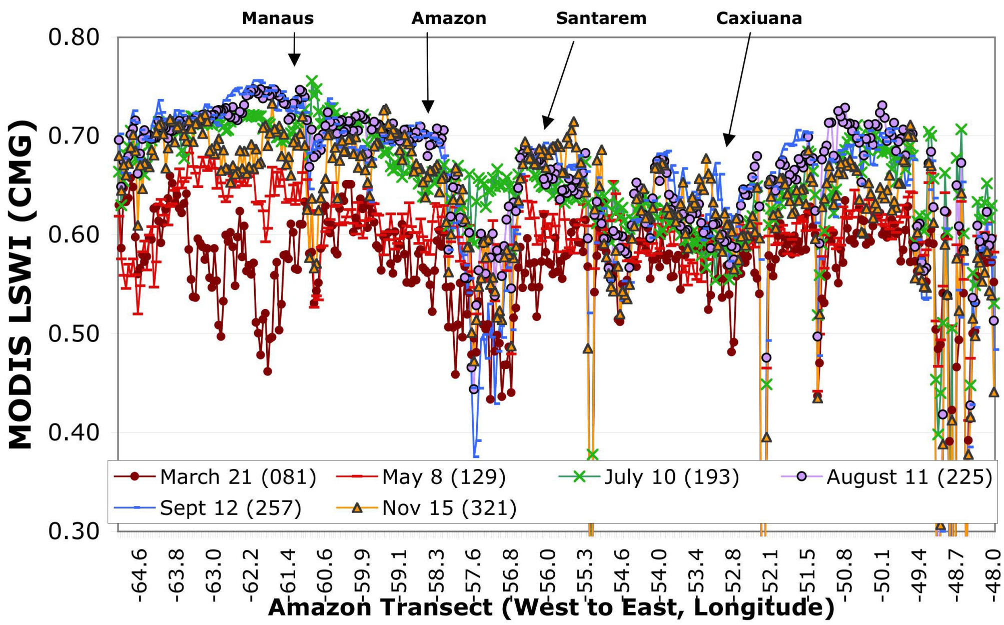

Figure 2. MODIS Land Surface Water Index (LSWI) seasonal – spatial profiles along an east to west transect at 2-3 degree south latitude.

4. Conclusions

An understanding of the spatial and temporal variability of ecosystem responses in the Amazon region, including phenology, would help to answer key questions on variability, forcing and consequences in the carbon cycle, water cycle, and climate change. Improved spatial data on vegetation structure, biomass, and phenology are needed. We found the MODIS data to be of sufficient sensitivity for Amazon spatio-temporal studies of biologic activity and should improve integrative studies of Amazon water and carbon cycles in response to climate variability and anthropogenic forcings. Our results show that these MODIS indices can track vegetation activity in the Amazon region, including biologic responses to shifts in vegetation type and disturbance. Remotely-sensed land surface water indices offer unique information from the vegetation indices and appear to offer new insights into drought studies and ecosystem green-up and drying processes. Combined with the carbon products, they further provide important information useful in the prediction of vegetation health response to climate change and human land cover modifications. Other MODIS products can also capture the seasonal dynamics and provide new opportunities for integrative studies of carbon / water cycles and conversion activities. This work is in progress and awaits the Hyperion results and scaling aspects.

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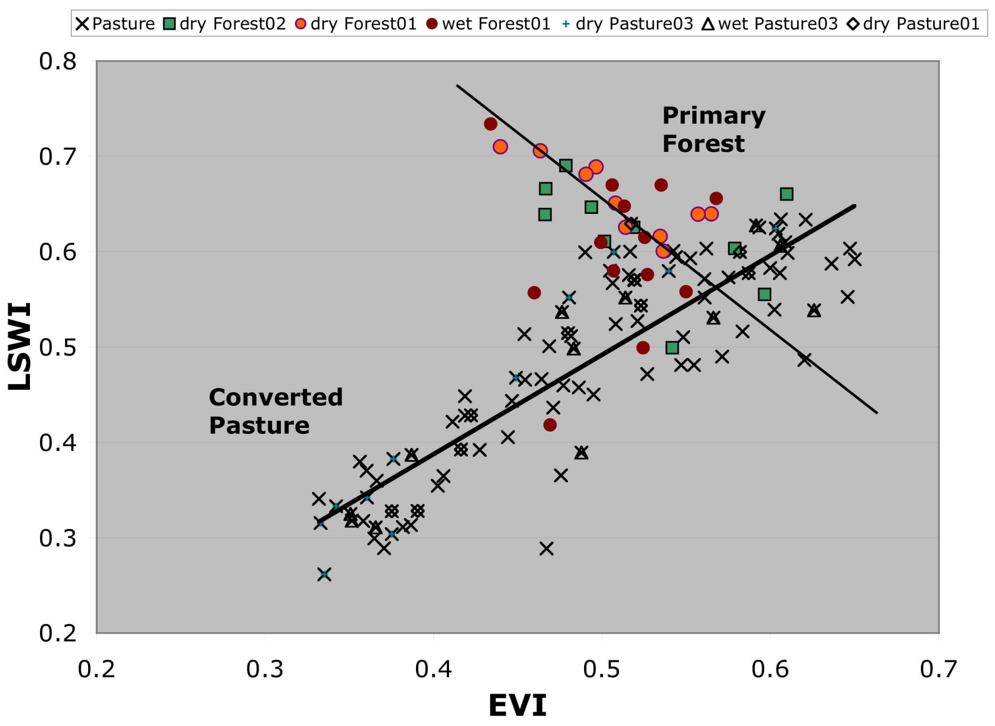

References

Asner, G. P., M. M. C. Bustamante, et al. Scale dependence of biophysical structure in deforested areas bordering the Tapajos National Forest, Central Amazon. **Remote Sensing of Environment 87**(4): 507-520, 2003.

Fensholt, R. and I. Sandholt. Derivation of a shortwave infrared water stress index from MODIS near- and shortwave infrared data in a semiarid environment. **Remote Sensing of Environment 87**(1): 111-121, 2003.

Huete, A., K. Didan, et al. Overview of the radiometric and biophysical performance of the MODIS vegetation indices. **Remote Sensing of Environment 83**(1-2): 195-213, 2002.

Novo, E. M. L., Huete, A., Potter, C., Roberts, D.A., Ferreira, L.G., Hess, L.L., Barbosa, C., Carvalho, C., Sano, E.E., Yoshioka, H., Melack, J.J., Klooster, S., Kumar, V., Myneni, R., Ratana, P., Didan, K., Miura, T., Shimabukuro, Y. Técnicas Avançadas de Sensoriamento Remoto Aplicadas ao Estudo de Mudanças Climáticas e ao Funcionamento dos Ecossistemas Amazônicos. **Acta Amazonica (in press).**

Running, S. W., Justice, C., Salomonson, V.V., Hall, D., Barker, J., Kaufman, Y., Strahler, A., Huete, A., Muller, J.P., Vanderbilt, V., Wan, Z.M., Teillet, P., Carneggie, D. Terrestrial remote sensing science and algorithms planned for EOS/MODIS. **International Journal of Remote Sensing 15**: 3587-3620, 1994.

Shimabukuro, Y. E., B. N. Holben, et al. Fraction images derived from NOAA-AVHRR data for studying the deforestation in the Brazilian Amazon. **International Journal of Remote Sensing 15**(3): 517-520, 1994.