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Medición y monitoreo de la fenología en ecosistemas forestales tropicales con el sensor MODIS.

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RESUMEN

El estudio de los eventos periódicos naturales, o fenología, son importante y pueden indicar las cambias ambientales y cambia de clima. En este trabajo analizamos los datos temporales del sensor MODIS para investigar la fenología de los bosques maduros tropicales y los bosques convertidos y sucesionales. Validamos nuestros resultados de MODIS aparte de torres de medidas de flujos de carbono y agua para tener mas confianza en los datos MODIS.

Palabras claves: MODIS, fenología, bosques tropicales

ABSTRACT

The study of natural periodic events, or phenology, are important and can indicate environmental changes and climate change. In this study, we analyzed MODIS time series data to assess phenology patterns of mature tropical forests, converted forests, and successional forests. We validated our results with tower flux measures of carbon and water in order to confirm and establish confidence in the MODIS measures.

Keywords: MODIS, phenology, tropical forests

Introduction

Tropical forests comprise a major and critical component of the global Earth system through their role in climate and hydrologic and biogeochemical cycling, and as a principal reservoir of the planet's biological diversity. Tropical forest ecosystems also have social, cultural and economic significance as sources of important renewable and non-renewable resources. Despite their importance, the mechanisms, interactions, and impact of environmental and human factors on tropical forest functioning remain poorly understood. Knowledge of tropical forest temporal dynamics and spatial heterogeneities at multiple scales is necessary to understand how these ecosystems may respond to or adapt to global change and human interactions.

At the landscape level, many climate and productivity models characterize tropical evergreen rainforests as lacking seasonal variation in biophysical plant properties such as leaf area index (LAI) and fraction of absorbed photosynthetically active radiation (fAPAR). Much of what is known about tropical forest dynamics and climate- vegetation interactions comes from coarse resolution, multi-temporal satellite measurements, such as the NOAA-Advanced Very High Resolution Radiometer (AVHRR) time series data, which have characterized the phenology. MODIS EVI has been shown to be highly correlated with gross primary productivity (GPP)

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of tropical evergreen forests as seasonally constant.

On the other hand, plot-level and local eddy tower flux measurements have shown distinct seasonal changes in neotropical evergreen forests in the Amazon, including flushing and exchange of new leaves, and canopy photosynthesis that follow the availability of sunlight (Saleska et al. 2003). Seasonal peaks in evapotranspiration (ET) have been measured in the late dry season in tropical evergreen forests in northern Thailand and in the Amazon (Tanaka et al., 2003). These forests showed little evidence of moisture stress with tree roots maintaining access to deep soil moisture layers, even during the dry season.

Phenologic variations, a characteristic property of ecosystem functioning and predictor of ecosystem processes, are important to resolve, as they depict a canopies' integrated response to environmental change and influence local biogeochemical processes, including nutrient dynamics, photosynthesis, water cycling, soil moisture depletion, and canopy physiology.

Several constraints inherent in coarse resolution satellite data may contribute to the difficulties in detecting temporal and spatial variability in tropical forest phenology, including poor spatial resolution (>4 km), cloud contamination, sensitivity to seasonally variable atmosphere conditions, limited spectral content, and low optical depth of penetration through densely vegetated canopies, (Kobayashi and Dye, 2005).

Saturation of the NDVI in tropical forests has been noted in both fine and coarse resolution satellite data, resulting in not only weak seasonal variability and phenology characteristics (leaf age), but also hampered discrimination of primary and successional regenerating forests (Xiao et al., 2006).

Some recent and advanced moderate resolution satellite sensors, including SPOT VEGETATION (VGT) and the Moderate Resolution Imaging Spectroradiometer (MODIS) with better sensor capabilities have revealed distinct local- and region-wide phenology patterns in tropical forests using the enhanced vegetation index (EVI, an index of canopy photosynthetic capacity) (Xiao et al., 2006).

Carbon and water science

Recent applications of highly calibrated MODIS VI's have demonstrated their utility in studies of metabolism and ecosystem functioning which affect net ecosystem exchange of carbon and water between the land and the atmosphere across a wide series of Ameriflux tower sites in North America (Sims et al., 2006). These studies suggest that EVI can be used to estimate GPP with relatively high accuracy for most sites without direct consideration of light-use efficiency (LUE), thus simplifying carbon balance models over most vegetation types. Most carbon exchange models use a relationship in which LUE is derived and scaled down with meteorological information available, normally, at very coarse resolution.

Huete et al. (2006) found Amazon rainforests to green-up by 25% in the dry season in response to the availability of sunlight, a finding confirmed by close couplings to tower-calibrated GPP measurements. Strong linear and consistent relationships between seasonal EVI and tower-calibrated GPP measurements of carbon fluxes were found in both intact rainforest and forest conversion to pasture/ agriculture sites in the Amazon.

These studies yield consistent depictions of tropical forest seasonality but contradict many ecosystem model predictions that water limitation should cause dry season declines in forest canopy photosynthesis and ET.

Objectives

In this study, we investigate environmental (light, moisture) controls and anthropogenic forcings on tropical forest functioning and phenology. We also examine phenologic gradients within tropical forest land cover types of varying successional 'age' classes and along transitional ecotones. Lastly, we explore the measure of VI 'greenness' in order to better characterize seasonal tropical forest canopy dynamics, and its input to production efficiency models.

Study Site and Methods

We analyzed satellite phenology patterns at several local tower sites in Amazon and southeast Asia tropical regions with 5 years (2001-2005) of MODIS EVI satellite measures of 'greenness' (Fig. 1).

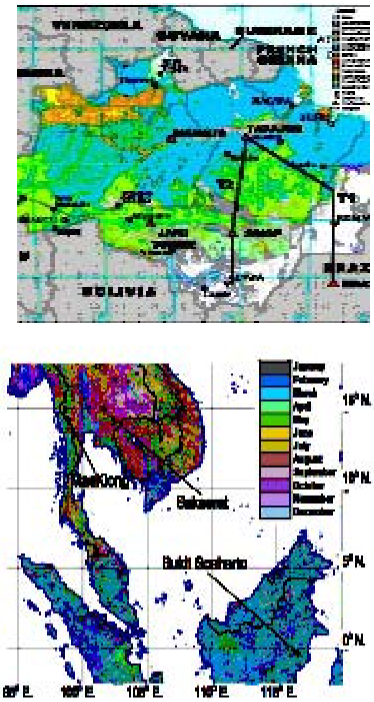

Fig. 1. Study areas in (a) Brazil with Tapajos and Jaru tower sites and ecotone region and (b) southeast Asia study area with 3 tower sites.

We used MOD13A2 at 1 km spatial resolution and 16-day compositing for both local scale tower site analysis (3x3 pixel window), and for region-wide analyses. Strict quality assurance (QA) criteria were applied to the product to remove much of the residual cloud and aerosol contamination. The 16-day composites were aggregated to monthly time steps and the average of the good QA pixels remaining within a 3x3 pixel window were averaged to represent satellite EVI values for comparisons with tower flux measurements. A 4-year average, gap filled seasonal profile was also computed for climate and regional phenology analyses.

The EVI is an optimized combination of blue, red and NIR bands, designed to extract canopy greenness, independent of the underlying soil background and atmospheric aerosol variations,

$$EVI = 2.5\,[r_{NIR}-r_{red}] / [1+r_{NIR}+6\,r_{red}-7.5r_{blue}] \quad [1]$$

where the coefficient '1' accounts for canopy background scattering; and the blue and red band coefficients, 6 and 7.5, minimize residual aerosol variations (Huete et al., 2002).

Tower flux measures of gross primary productivity were generated at monthly temporal periods over a variety of LBA and AsiaFlux network tower sites in the Amazon and southeast Asia. Gross primary productivity (GPP) shows the amount of canopy photosynthesis and was derived by subtraction of night-time ecosystem respiration from net ecosystem exchange of carbon fluxes. Incident photosynthetically active radiation (PAR) as well as fraction of canopy absorbed PAR, or fAPAR, were also computed at monthly time scales. The use of towers in different vegetation types can serve to calibrate spatially extensive satellite data to improve predictions and modeling of regional carbon fluxes.

Results

A gradient of phenology variations across the Brazilian rainforest – ecotone - savanna region (cerrado) are depicted in Fig. 2. All phenology profiles were adjusted to the «local» start of the dry season, defined as 2 consecutive months of rainfall below 60 mm. The uppermost profiles are located in the rainforest region and show increasing 'greenness' throughout the dry season, in response to the increased availability of light, while the lower profiles are in the cerrado and show decreasing greenness through the dry season, as the savanna herbaceous layer dries out from moisture deficits. The transitional vegetation profiles show both light and moisture limitations decreasing greenness over the first part of ther dry season followed by increasing vegetation activity in the second half of the dry season and prior to the onset of the wet season (Fig. 2).

An example of how well seasonal EVI tracks tower-calibrated seasonal and interannual GPP measurements of carbon fluxes at the MaeKlong Experimental Watershed Station in Thailand is shown in Fig.

3a. There is a much stronger synchrony between satellite EVI and tower measures of photosynthesis, compared with EVI and the tower-derived measures of fAPAR (Fig. 3b). The multi-year relationship of tower GPP with satellite EVI was R^2 of 0.620, while that of tower fAPAR with EVI was R^2 of 0.347 (Fig. 4).

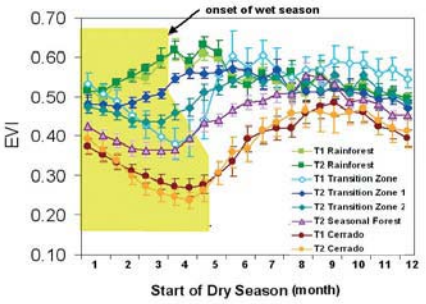

Fig. 2. Phenology profiles along the Brazil rainforest – ecotone- cerrado region adjusted to the local start of the dry season.

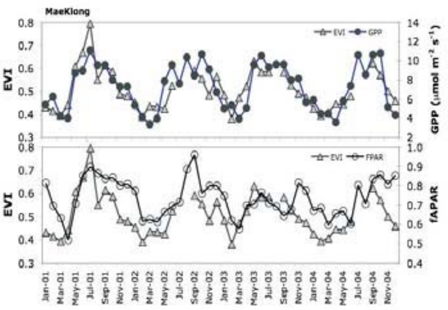

Fig. 3. Interannual and seasonal variations in satellite EVI with (A) tower GPP and (B) tower fAPAR at MaeKlong Watershed Research Station, Thailand.

The MaeKlong site resulted in the best relationship between fAPAR and EVI. At the other sites, there were no correlations found between EVI with fAPAR, as there was very little variation in fAPAR during the season or across years. Poor relationships were found between fAPAR with NDVI due to saturated NDVI profiles regardless of the variation in fAPAR

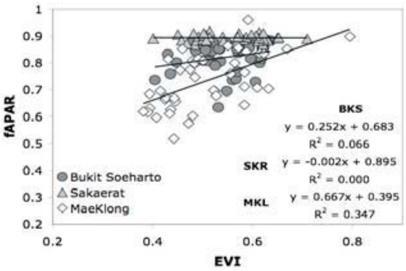

Fig. 4. Relationships of tower measures of fAPAR with satellite EVI at 3 tropical forest sites in southeast Asia.

We included PAR data in our tower GPP and satellite EVI relationship by plotting the ratio of tower GPP to PAR (GPP/PAR ratio) with satellite EVI as in a light efficiency model (Fig. 5). The slope of this line, LUE, incorporates light, water, and nutrient limitations. Although the addition of the PAR term yielded overall good relationships with EVI, this did not improve upon the site specific and cross-site relationships found between the more direct and simpler tower GPP with satellite EVI relationships (Fig. 5). Even in the light limited Bukit Soeharto and Tapajos sites, the addition of the PAR term resulted in a poorer relationship than the direct GPP to EVI relationship.

Conclusions

The lack of a direct correspondence between VIs and fAPAR did not compromise the utility of VIs in predicting photosynthesis. Monteith and Unsworth (1990) noted that VIs can legitimately be used to estimate the rate of processes that depend on absorbed light, such as primary production and transpiration, whereas the relationship of LAI or green fractional cover to absorbed PAR is strongly non-linear and depends on leaf architecture and spectral properties. Furthermore, photosynthesis and transpiration are not evenly distributed through the canopy, but are driven mainly by light absorbed by leaves (LAI) at the top of canopy.

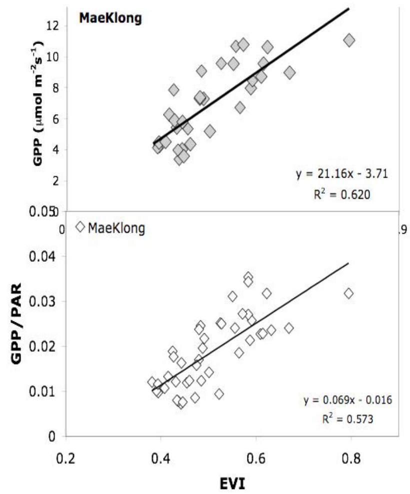

Fig. 5. Seasonal and interannual relationship of (A) tower GPP with MODIS EVI; and (B) tower GPP/ incoming PAR ratio with MODIS EVI at the MaeKlong tower site in Thailand.

EVI may provide a more direct relationship with photosynthesis in high LAI tropical forests by relying on the more sensitive NIR canopy reflectance which is less prone to saturate. This is supported through theoretical analyses concluding that spectral indices that are more functional on the NIR best describe area-averaged canopy photosynthetic capacities and gross primary productivity (Sellers, 1995).

The high direct correlation between VIs and GPP in so many different ecosystems, may seem surprising since, in theory carbon and water exchanges are related not just to foliage density but environmental variables (PAR, air temperature, vapor pressure deficit, etc.), which can vary considerably over short time periods. However, according to the 'resource optimization paradigm', plants tend to adjust their foliage density over time periods of days to weeks, to match the level of photosynthesis that can be supported by the environment .

There remain many challenges on how best to integrate spatially extensive satellite data with local tower measures from multiple sites for regional scaling, modeling, and prediction of vegetation growth in response to climate variability. Further work is also needed on how best to integrate satellite data into ecosystem production efficiency models. Our attempts to improve upon the satellite EVI and tower GPP relationship through the use PAR and fAPAR variables were generally unsuccessful, in part due to the weaker correlation of fAPAR with the satellite greenness measures. There is a need to better separate canopy absorbed PAR into the photosynthetically-active (chlorophyll) and non-active (senesced vegetation, epiphylls, woody material, etc.) components.

Acknowledgements

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