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WHAT IS DRIVING THE PHENOLOGY ACROSS THE AMAZON? A BENCHMARK FOR LAND-SURFACE MODELS

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ABSTRACT

We present a study which has used a Fourier-based time-series analysis method applied to 8 years of EO-derived observations of phenology (vegetation indices) and their potential drivers (downward shortwave radiation and precipitation). We use these data sets to test the correlation (coherency) of the phenology to the driving variables and to determine the relative timing of their seasonal cycles. This has led to a better understanding of the linkages between phenology and their driving factors. Typically Amazonian canopy vegetation has varying timing in phenology on small (sub-pixel) scales. However, at the spatial resolution of 1 km2 spectral analysis shows that the sub-pixel phenology is well synchronised for a large proportion of the Terra Firme forest. Across the whole of northern South America about 60% of the land shows a significant seasonal cycle in grassland- and forest-biomes. Within this area having seasonal cycles, 43% has phenology in-phase with radiation of which 75% is Terra Firme-type forest and 25% is mainly grassland. 37% of the area with seasonal cycles is in-phase with precipitation, of which 40% is grassland and the remainder is forest. These results are in agreement with recent research that suggests much of the Amazon over humid tropical forests may be radiation-driven. However, we also support the hypothesis that in places both radiation and precipitation are influential, but may not be completely in-phase with the phenology. We identify core areas where the phenology-radiation and phenology-precipitation relationships are most apparent. The information regarding spatial controls of phenology provides a benchmark for land-surface modellers.

1. INTRODUCTION

The Amazon region covers a significant area of the global land-mass and predictions indicate land-cover or climatic change in this area could have regional and global impacts on the Earth system (Houghton et al. 2001; Silva Dias et al. 2002; Werth & Avissar 2002; Asner et al. 2004; Salazar et al. 2007). Computer models also predict, with some uncertainty, that climate change may involve feedbacks that alter atmospheric CO2 concentrations such as dieback in North East Amazonia contributing to increased CO2 emissions from soil carbon stocks (Cox et al. 2000, 2004). A key factor in modelling the biosphere – atmosphere interface is being able to simulate vegetation activity, i.e. cycles of dormancy, active growth and reproduction, referred to as the phenology cycle. The correct representation of tropical phenology in vegetation models remains a research challenge particularly as most algorithms have been developed with an understanding of temperate climates e.g. the land surface model of the Joint UK Land Environment Simulator (JULES, Best, 2005). To improve Dynamic Global Vegetation Models (DGVMs) a better understanding of spatial and seasonal variation in phenology is needed. We begin to address this challenge by exploring where, which and to what extent climate factors, radiation and precipitation, drive phenology in the Amazonian tropics.

2. STUDY AREA

The study region is focused on the South America tropics, north west corner: 10.0° N, 81.0° W and south east corner: 20.0° S, 40.0° W. Models have predicted a severe dieback in this area by 2050 so it is logical that we assist any validation / model parameterization in such a critical area.

3. EARTH OBSERVATION DATA

For the phenology we downloaded 1 km monthly EVI MODIS composites (MOD13A3 collection 5) for the period between the dates April 2000 to Dec 2007. For monthly precipitation (Ppt) data we used the TRMM data and other sources rainfall data set at 0.25° by 0.25° resolution acquired from the Goddard Distributed Active Archive Center for the corresponding time period to the vegetation indices. For the net radiation (Rn) budget we used monthly 0.4° x 0.4°downward (incoming) shortwave radiation modelled estimates from the Centro de Previsão de Tempo de Estudos Climaticos (CPTEC) GL-1.2 physical model (Ceballos et al. 2004).

4. METHODS

The processing involved three main steps. First, a standard linear detrending was carried out on all time series. Second, using the Fourier Transform, we determined for each pixel the presence or absence of annual cyclical behaviour in the phenology, radiation and precipitation time series and the strength of the seasonality by identifying if the peak is significant or not. Third, where annual cycles occurred, cross-spectral analysis was used to compare pairs of time series to give a measure of coherency and phase differences. The phenology time series was then resampled to 0.25º for precipitation and 0.4º for radiation using the mean aggregate amplitude of the original 1km pixels to avoid a bias towards the presence of larger phenology amplitudes. Fourth the phase value and phase error were used to categorise the phase relationships between radiation and phenology and between precipitation and phenology. These relationships were then mapped.

5. RESULTS

A large proportion of the Amazon and surrounding area shows significant annual cycles in radiation, precipitation and phenology (Fig. 1 a,b,c). These results are reasonable since annual cycles, or seasonality, have been observed at research sites across the Amazon through a combination of precipitation, radiation and leaf-litter fall measurements, in tropical rainforest, (Malhi et al. 1998; Huete et al. 2006), transitional tropical forest (Vourlitis et al. 2001, 2004) and savanna (Miranda et al. 1997). Fig. 1a shows the distribution of the strength of the phenology cycle across our study area represented by the relative power for the annual cycle of the EVI. Of the area analysed, 59% (6.2 x 106 km2) reach at least the 90 % confidence level in power, a further 2% reach the 95% confidence level in power whilst the remaining 39% show no significant or detectable annual cycle. With respect to radiation, 86 % of the land area has annual cycles above the 90 % confidence level (Fig. 1b). Less than 1% of the area has no peak at all and this is found scattered across the Andean mountains. For precipitation, the annual cycles above the 90 % confidence level cover 95 % of the land area (Fig. 1c).

The results of overlapping the phase categories of phenology-radiation and phenology -precipitation are shown in Fig. 2(a) and (b) for ±1.0 month tolerance. Figure 2(a) shows where at least one of the drivers is 'in phase' with phenology.

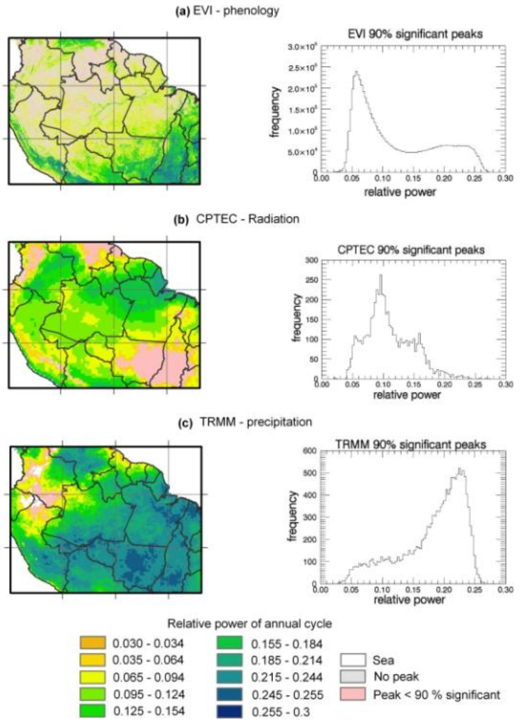

Figure 1 (a-c): Spatial distribution and frequency distribution of relative power of the annual cycle for: (a) EVI-phenology; (b) CPTEC-surface radiation; and (c) TRMM-precipitation. Pixels that fell below the 90% significance threshold for background noise but still have annual peaks are in pink, areas in grey have no annual cycle.

Phenology 'in phase' with radiation (classes 4 and 5) mainly covers the Amazon basin and corresponds to the 'Terra Firme forest'. In class 4, precipitation 'lags' or is 'in anti-phase' with phenology, indicating that in these regions radiation is driving phenology. In class 5 precipitation 'leads', this could indicate that phenology has a delayed response to precipitation followed by a direct response to radiation. Precipitation is 'in phase' with phenology (classes 1 and 2) to the south and central north of the study region; this is mainly in savanna locations. Here radiation mostly 'lags', 'leads' or is 'in anti-phase' with phenology suggesting that in these areas precipitation is driving phenology. However part of category 2 where phenology is 'in phase' with precipitation, occurs in the 'Terra Firme' forest to the south west of the Amazon basin. This roughly corresponds with seasonal forests and shows that not all the Terra Firme forest is radiation driven. Radiation and precipitation are only statistically 'in phase' together (class 3) in small patches to the north, the west and south west of the study area showing that in most of the Amazon region both drivers are rarely coincidental.

There are areas where neither climate driver is 'in phase' with the phenology, Figure 2b. In these locations there may be a delayed response to the climate drivers. Phenology may have a delayed response to precipitation to the west and south west (classes 6 and 7) or a delayed response to radiation in the central areas (classes 6 and 8). Some of these areas correspond to areas of anthropogenic disturbance where other drivers may be dominating phenology cycles.

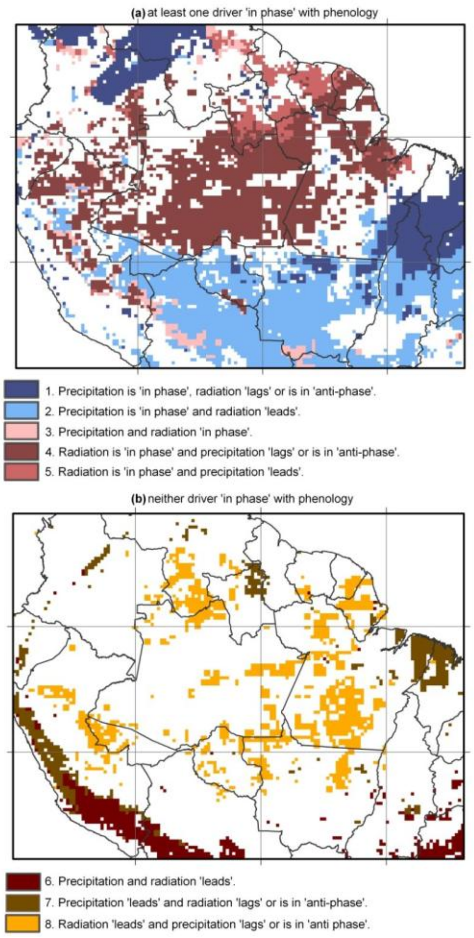

Figure 2 (a,b) Major areas of the combined radiation and precipitation phase relationships with phenology, (a) Areas where phenology is 'in phase' with at least one driver, classes 1-5 and, (b) areas where phenology is not 'in phase' with either driver classes 6-8.

6. DISCUSSION

The maps presented here are being taken forward as a basis to enhance vegetation models with increasingly sophisticated depictions of ecosystem processes. Firstly at the pixel level, synchronicity of phenology may help determine locations that would respond in the same way to climate change (e.g. the Amazon dieback, Cox et al. 2004). The amount of deciduousness and behaviour in the upper canopy may assist in estimating cohorts of plants and different age classes within the same biome (e.g. the Ecosystem Demography model, Moorcroft 2001). Secondly the driver zones can be used to help land surface models such as JULES (Best 2005) in tropical regions to force the timing of phenology events to driving forces (Bradley et al. 2009) and investigate what may happen in wet or dry years (e.g. greening up, Saleska et al. 2007 Samanta et al. 2010).

The cross spectral analysis can shed light on the coincidence of seasonal cycles using a relatively short time series. We have confidence in these results as they generally agree with existing research that links vegetation activity with radiation and precipitation. We have summarised where and when radiation and precipitation interact with phenology cycles providing a benchmark for modellers to improve their representation of phenology. On condition that these data sets are available this method can be transferred to other regions, or with sufficient computing power, globally

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