TEMPLATE PHENOLOGY FOR VEGETATION MODELS.

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ABSTRACT

To assist the representation of phenology in vegetation models we created several templates of phenology-driver relations by characterizing the annual phase differences between phenology and two phenology drivers. We did this using the results of a cross spectral analysis of MODIS EVI with radiation (CPTEC) and with precipitation (TRMM). Four phase ranges were identified for phenology-radiation and three phase ranges for phenology-precipitation. These ranges were classified and mapped together into 12 zones of our study area where particular phase relationships coincided. Around ~25% area was in phase with radiation, with varying phase ranges of precipitation, and ~ 16 % was in phase with precipitation with varying phase ranges of radiation. For each zone we conceptualized the phenology-driver relationships with phase lagged curves. The phase timing of these plots matched well with average time series plots from the same zones, but more work is needed on the representation of amplitude.

Index Terms— Satellite applications, Vegetation mapping, Fourier transform, spectral analysis, modeling.

1. INTRODUCTION

The timing of phenology events have been recorded by various remote sensors and projects e.g. MODIS[1], and are available to the modeling community. Events, such as green up and senescence are frequently put to use by vegetation modelers to simulate vegetation productivity. Simulating vegetation productivity is important since, the turnover of carbon in the atmosphere is said to have a major influence on climate and climatic variation. However, in the case of JULES[2] and many other vegetation models, the rates of change in vegetation greenness in the periods between these phenology events are often poorly simulated. Realistic simulations of these intermediate periods, contribute to modeled calculations of Net Primary Productivity. Getting these estimates close to reality is critical since variations in productivity across large areas, such as the Amazon (our study area) would have a significant effect on the modeling of global atmospheric CO_2 (annually the Amazon produces up to twice the amount of human emissions [3]). One of the problems modelers have is being able to estimate exactly what drives the timing of phenology events and what drives the intermediate intensity of greenness in the rest of the phenology cycle. A further problem with modeling large areas is the inevitable spatial variation in productivity and understanding what drives the spatial patterns. At present ground based and remote sensing studies have conflicting ideas on productivity variation, an example of which is the effect of drought on the Amazon. Some research suggests drought can reduce tropical productivity in certain areas [4] whilst others suggest the increased radiation during a drought period may boost tropical productivity in certain areas as vegetation makes use of soil moisture [5]. What many modelers require then is two bases of reference and these are a link of the phenology metrics to the drivers of the phenology and a spatial understanding of these interactions. Previous research by this group has used remote sensing data to examine the relationships between phenology and potential drivers, e.g. precipitation and radiation [6] using the Enhanced Vegetation Index (EVI), data from the Tropical Rainforest Monitoring Mission (TRMM) [7], and radiation from the CPTEC (NOAA) net radiation data set [8]. We now show how we move towards the characterization of the relationships between phenology with radiation and phenology with precipitation, to (i) identify and characterize the relationships in timing between the phenology and each driver and (ii) identify and characterize the spatial patterns in timing of phenology with both of the drivers. We then show how these products are being developed for the JULES[2] vegetation model.

2. STUDY AREA

We covered the Amazon region, 10.0° N, 81.0° W (north west corner) and 20.0° S, 40.0° W (south east corner), figure 1, because this research was supporting goals of the QUEST QUERCC project [9] in which modelers were concerned with a predicted drying of the Amazon [10].

4. METHOD

The temporal change in a time series of EVI or vegetation greenness was used as an analogy to the phenology cycle. A cross spectral analysis was made by pairing monthly averaged EVI (1 km by 1 km 16 day MODIS composites from the NASA LPDAAC archive April 2000 to Dec 2007) with (i) CPTEC (NOAA) net

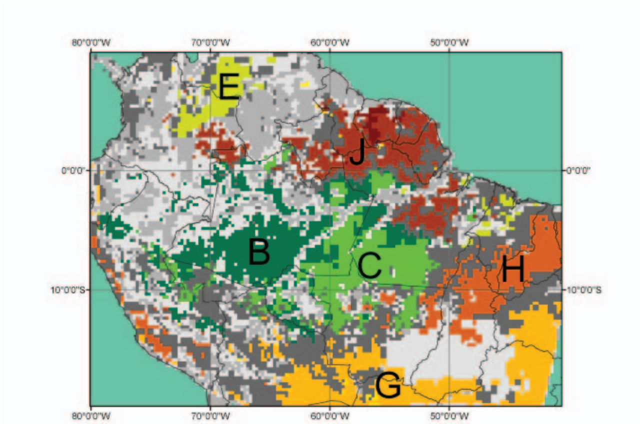

Figure 1. Study area and phenology-driver phase difference zone map. South American countries and Brazilian states are black lines. Colors represent phase zones, letter labels correspond to zones in table 1 greater than 1% total area. Dark grey, areas outside phase difference ranges; light grey, areas below a 95% coherence threshold, see [11].

radiation data set of average monthly total radiation at 0.4° by 0.4°, acquired from the INPE (National Institute for Space Research, Brazil) and, (ii) TRMM data and other sources rainfall data set at 0.25° by 0.25° resolution acquired from the Goddard Distributed Active Archive Center, for precipitation, for the corresponding time period. For the cross spectral methodology we produced coherency and phase details for each of the paired data sets, re-sampled to the minimum resolution of 0.25° by 0.25°, for details see [6, 11]. The frequency distribution of these phase difference values were then plot to see if there were any characteristic phase differences, i.e. where there were distinct peaks in the distribution. If any peaks were present, a manual threshold was applied at the break of each curve, the peak phase difference and range was recorded and the data between was allocated to a class. These classes were then mapped for both phenology-radiation and phenology-precipitation to illustrate if there was any spatial consistency in phenology-driver relations. The two classified maps of phenology-radiation and phenology-precipitation were then merged to produce a phenology-driver phase difference zone map to identify where phase difference characteristics were the same. The phase difference combinations for both drivers in each zone was then noted from the frequency distribution and assigned to a class. For each zone, we created a template to represent the phase difference between the phenology, radiation and precipitation. This was created by wrapping three modified 12 month cycle sine curves over a period of 18 months to allow for the maximum 6 month phase difference between two time series. We used the characteristic phase differences from the frequency distributions to determine the phase differences. For each phase difference zone we calculated average time series curves from the original data sets to find out if the template bore any relation to reality.

5. RESULTS

After removing non-coherent data with a 95% confidence interval [6] the plots of the phase difference values of phenology-radiation had characteristic peak phase differences of -4.2, +0.8, +1.8 and + 5.2 months and for phenology-precipitation the peak phase differences were -3.9, +1.0 and +5.0 months (figure 2). This gave

(a)

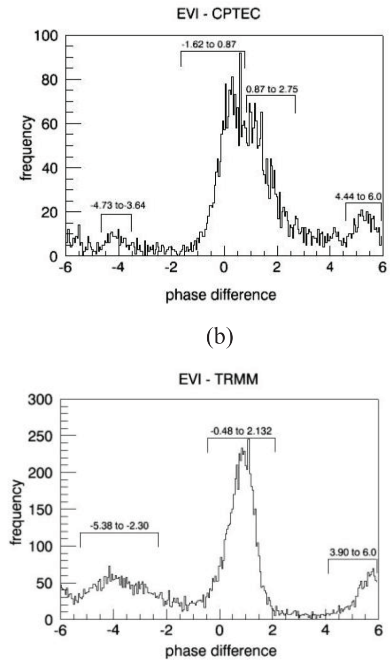

Figure 2 a and b. Characteristic phase peaks –left to right for (a) phenology-radiation, -4.2, +0.8, +1.8 and + 5.2 months; and (b) phenology-precipitation, -3.9, +1.0 and +5.0 months. Annotations on the plots refer to the phase ranges.

a possible 12 (4 x 3) classes of phenology-driver phase difference relationships to map. Table 1 shows the combinations and the percentage of the study area that each combination represented. The map illustrates that some classes were well represented and formed widespread areas whilst other classes were not well represented at all and often fragmented covering areas of less than 1 % (figure 1). Almost 25 % of the area is virtually in phase with radiation, with varying precipitation phase differences, whilst almost 16 % is in phase with precipitation with varying radiation phase differences. For almost 9 % of the area both variables are in phase. From these phase difference combinations it was possible to construct the phenology driver templates. Four of these combinations are illustrated on the LHS of figure 3 (a-d). Correspondingly a comparison of the monthly averaged time series data was calculated for these zones and compared to the template phenology, RHS figure 3 (a-d). Zone B, figure 3(a), demonstrates radiation in phase with a precipitation lag, mainly in rainforest of central Amazonia. Zone G, figure 3(b) demonstrates both drivers in phase, mainly in savanna regions in the south of the study area. Zone J, figure 3(c), demonstrates precipitation leading, with radiation in phase, in tropical forest to the north east and Zone E, figure 3 (d) demonstrates precipitation in phase with a radiation lag, in a region of savanna to the north.

5. DISCUSSION

This research has worked towards channeling the results of a cross spectral analysis of remotely sensed data into a modeling application. We reached our aims by characterizing the cross spectral analysis into simple phase relationships and mapped the

	phase ranges (months)			
EVI v TRMM	**EVI v CPTEC**			
	-4.730 to - 3.640	**-1.062 to 0.865**	**0.866 to 2.749**	**4.40 to 6.000**
-5.500 to -2.300	Zone A 0%	Zone B 9.1%	Zone C 7.1 %	Zone D <1 %
0.048 to 2.130	Zone E 1.3%	Zone F <1 %	Zone G 8.8 %	Zone H 5.32 %
3.900 to 6.000	Zone I <1 %	Zone J 5.7%	Zone K <1 %	Zone L 0 %

Table 1. Final phase difference classes for each area showing the phase difference zone combinations and percentage of the study area (total area ~11.68 x 10^6 km^2). Phase ranges refer to annotations on figure 2 (a) and (b).

spatial patterns. The analysis has shown that at our scale of mapping, 0.25° by 0.25°, that there are characteristic phase peaks (and ranges) for each driver in the study area. When these ranges were mapped together we demonstrated that large contiguous areas of the phase difference combinations do exist. For example the results have shown that around a quarter of the phenology in the Amazon is virtually in phase with radiation whilst precipitation is not and this relationship along with all the other phase difference zones provided several templates for phenology. The comparison with real time series data gives us some confidence in the reality of the template phenology. With respect to timing the templates reflect the phase differences between the averaged annual time series cycles well. With respect to amplitude the curves do not compare well. This is not surprising since the amplitude of the phenology template is unitless and all curves have the same magnitiude – which as the average time series (figure 3 (a-d)) illustrates is far from the case. In the present form then the templates can only stand as a conceptual approach to phenology driver relationships. However this has an advantage as there is scope for some flexibility in the modeling process, since a modeler can now substitute real or hypothetical values into the templates and incorporate these values into the model calculations. The value of these templates is that we now have a simplified view, minus all the noise and outliers of how phenology is related to these two drivers – information that JULES can now exploit. For example we can now pay attention to the timing of particular features i.e. relative timing of the phenology and driver peak, and the ascending and descending limbs of the peak. Peaks that are in phase are more likely to be driving the phenology (figure 3 (b)), whereas peaks that are out of phase (figure 3 (a) precipitation and figure 3 (d) radiation) may be having an indirect effect or have no effect at all. In the first instance the driver will have a more direct role in model calculations, in the second instance a modeler can identify and place more emphasis on other driving factors. These other factors may be, for example, soil moisture conditions where periods of recharge or deficit can be identified. Once the main driving factor has been identified in each zone a modeler can now incorporate these processes with more certainty in the spatial domain, for example 25 % of the study area could be simulated as radiation driven. There are improvements that can be made to this method. Presently the manual threshold of the phase ranges around a peak (figure 2) leaves large areas that are not classified (figure 1). Furthermore the classification is dependent on the data set itself since a subset or larger area may not yield the same frequency distribution as figure 2. Current research is also experimenting with an automated method that will overcome these problems. Once automation is in place we can transfer this concept to another continent or perhaps scale up to the globe. Either way both will greatly benefit regional as well as global vegetation modeling.

6. CONCLUSION

This method of classifying ranges of phase differences between two time series has successfully characterized and spatially mapped the relationships of phenology with two drivers, radiation and precipitation. The timing of our simulated phase difference plots compare well with average time series, however we now need to work on quantifying these curves with realistic values. Spatial continuity of the phenology-driver relations mean that modelers can use these templates to improve their phenology simulations in the spatial domain. In terms of expanding the analysis to the continental and global scale an automated classification would be advantageous. These improvements are now a current focus of our research.

6. ACKNOWLEDGEMENTS

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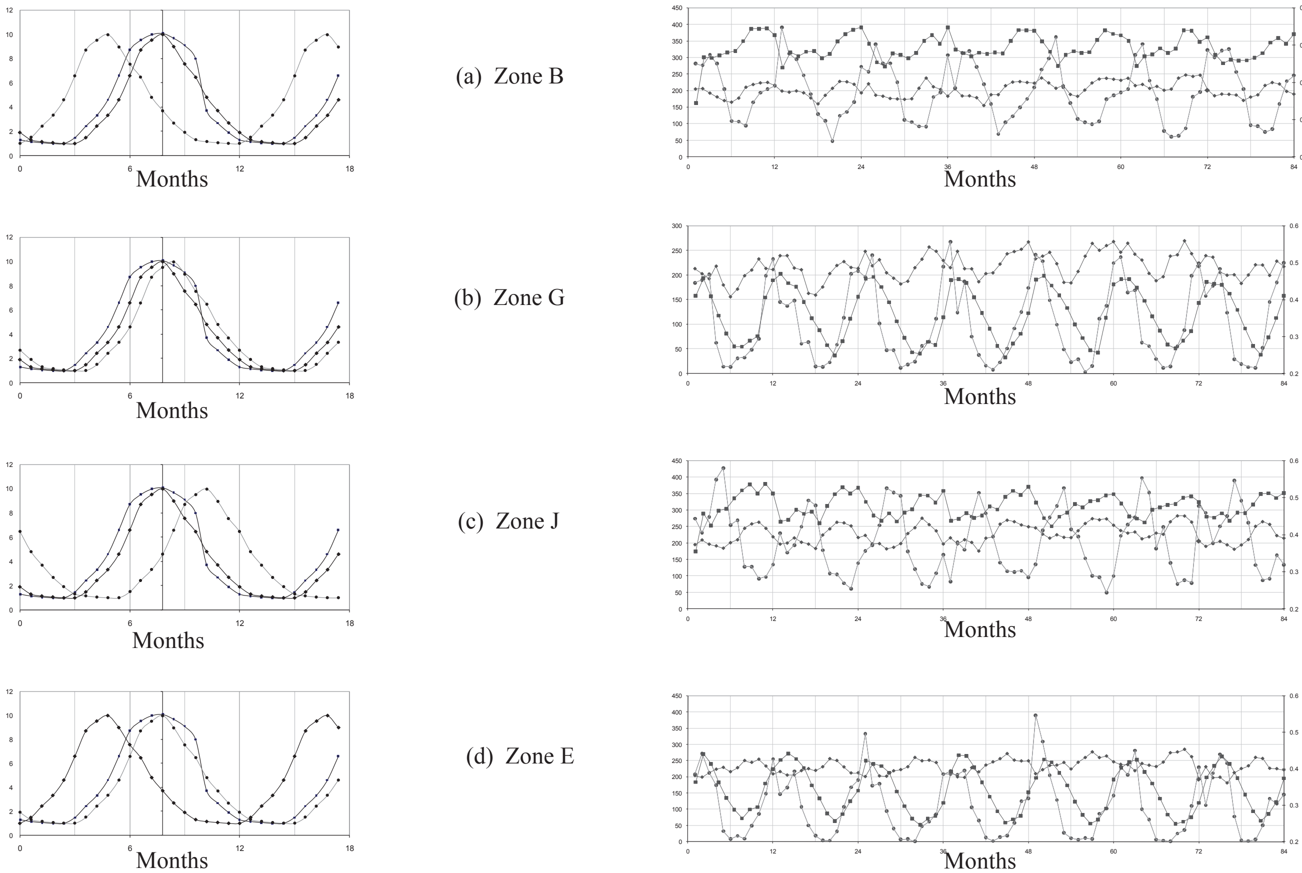

Figure 3(a-d) Left: characteristic phase peaks for phenology-precipitation and phenology-radiation zones, time series symbols and lines correspond to the time series on the right (see below), y axis amplitude has no units.
Right: average time series for the same zones. Y axis for the right hand side: Phenology (EVI) squares on dark line. Y axis on the left hand side: Radiation (CPTEC W/ m^2) diamonds on dark line; Precipitation (TRMM mm/hr) circles on light line.

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