DIRECT AND DIFFUSE RADIATION AS PHENOLOGICAL TRIGGERS IN SOUTHERN BRAZIL

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INTRODUCTION

The transmission of light through forest canopy and the amount of light that reaches the forest ground is associated to several interactions, which may reflect in structural or functional directions of such areas (Pearcy, 2007). Photosynthetically active radiation (PAR) has two primary ways of incoming, diffuse and direct beam solar components, which differ in the way they transfer energy through plant canopies and affect photosynthesis (Jacovides *et al.*, 007). To both components, the amount of energy (Kwatts.hour $^{-1}$.m^{2}) reaching a horizontal surface is associated to the solar azimuth (degrees) and solar elevation (degrees), that varies across the solar year and from the Equator (tropical region) toward the north and south poles.

During the solar year, sun changes sunrise and sunset due to earth inclination associated to translation and also, in a determined period of the day (e.g. noon) sun changes its inclination related to a horizontal surface, which generates differences in photon incidence. Indeed, horizontal surfaces are less frequent than other topographic surfaces, generating several differences in site exposition, direction of summer and winter equinoxes as well as duration and consequently amount of received energy.

Tropical and subtropical forests present several phenological patterns related to climate seasonality. Increasing seasonality frequently generates restricted phenological responses within a site (Morellato *et al.*, 995) and, to several areas from tropical areas, precipitation seasonality present a key role in timing and duration of leaf - fall, flushing and reproductive phenophases. By other hand, in subtropical forests, as showed in southern Brazil, precipitation is not a limiting factor and in such cases, photoperiod and associated temperature were showed to predict vegetative and reproductive events better than precipitation (Athayde *et al.*, 009; Marchioretto *et al.*, 007, Marques *et al.*, 004). As a constant factor not related to climate, photoperiod (the total sunlight in a day) definitively may trigger phenological events because it is related to the energy received along the year. The influence of day length on tree phenology was suggested by Morellato *et al.*, (2000), Richards (1996) and Wright & van Schaik (1994). However, photoperiod cannot directly predict the amount of energy a site receives due to differences in surface exposition and other topographic differences as well as the solar azimuth and elevation, which changes during the year at the same geographical position. In those cases, relative values of direct and diffuse radiation enable comparisons among sites with different topographical features. On this hand, a detailed structural approach, relating to taxonomic and functional diversity would generate more powerful analysis on primary productivity, water balance, carbon absorption, among others (Sánches - Azofeifa *et al.*, 008, Clark *et al.*, 008).
On this way, we hypothesized that solar radiation is more powerful in determining some phenological patterns than daylenght. In addition, air temperature should trigger phenological events with a distinct way because it's also related to climatic oscillations.

OBJECTIVES

In this contribution we focused our attentions to the following questions: do solar radiation and daylenght show positive correlation with phenological patterns of leaf fall, flower and fruit production and leaf flushing in a subtropical forest, which present a typical annual oscillation in both variables, as well as temperature? Does annual rainfall show some relations with phenological patterns and with other abiotic variables?

MATERIAL AND METHODS

Study site, plant species and abiotic variables
In order to test our hypothesis we monitored phenological patterns for flowering, fruiting, production of new leaves and

new branches, presence of mature leaves and leaf fall from 13 tree species located at Alto Uruguai region, northern Rio Grande do Sul state. This region shows a typical transition from subtropical temperate "Cfb" to subtropical warm "Cfa" climates. Data analysis from Erechim (750 m.s.l.) presented annual temperature mean of 17.6 ºC and the annual rainfall near 1,910 mm, with rainfall well distributed throughout the year. The Alto Uruguai region originally encompassed transitional vegetation from Seasonal Semideciduous Forest and Mixed Rain Forest, reflecting climatic fluctuations since the Late Glacial Maximum. Nowadays, isolated remnants are distributed in the entire area with well distributed species as Araucaria angustifolia (Bert.) O. Kuntze, Apuleia leiocarpa (Vogel) J.F. Macbr, Parapiptadenia rigida (Benth.) Brenan, Piptocarpha angustifolia Dusén ex Malme and Pilocarpus pennatifolius Lem., showing that both seasonal tree species from central and eastern Brazil as well as temperate species occur in the area.

Data Analysis

Phenological patterns were monitored twice per month from ten individuals of each species from set - 2007 to oct - 2008. From the Meteorological state service-FEPAGRO, we obtained climatic data of daily temperature (maximum, minimum an average) and daily rainfall, which were transformed in order to compare with biological information. Daylenght was recorded by using SkyMap 9.9, which enables one to obtain a particular daylenght for a horizontal surface (Marriott, 2002).

We calculated daily and instantaneous diffuse and direct solar radiation received by a horizontal surface, as well as the solar position (azimuth angle from the geographical north and elevation angle from the horizon). This analysis was conducted with the Solar Position and Radiation Calculator from NOAA, modified by Pelletier (2008). According to this model, the azimuth and elevation angles of the Sun relative to a determined point on the Earth's horizontal surface can be obtained by calculations over geographical position, elevation (relative to the mean sea level of the site) and atmospheric factors (optical effect of gases and particles on the absorption, transmition and difracton). Based on the Cosine Law, the resulted angles now can be used to measure how much radiation such point will receive (watts per time period) without considering weather conditions as rainfall or cloudy days.

In order to modeling direct and diffuse radiation on slope surfaces, we started by obtaining a digital elevation model (DEM) from Alto Uruguai region, generated by TIN (Triangulated Irregular Network) interpolation of hypsometrical data with IDRISI Kilimanjaro GIS (Eastman, 2004). The effect of relief over direct radiation was performed by the Analytical Hill Shading module provided by Idrisi GIS. We analyzed distinct situations into the nictemeral and seasonal cycles and topographical conditions.

To seek for relations among phenological patterns and abiotic variables we applied regression analyses to all biological events as dependent variables and considering abiotic conditions as predictors. To modeling multiple relations we applied multiple regression analyses in such way to identify most relevant predictors in explain biological phenomena. Because biotic events frequently show a time shift between trigger and effect, we also verified relations with subsequent longer periods, from one month to 2.5 months in late.

RESULTS AND DISCUSSION

Alto Uruguai region receives an average of 1.511 Kwatts.day $^{-1}$ of direct radiation and 355 Kwatts.day $^{-1}$ of diffuse radiation. The highest radiation occurs at the second half of December, as well as the longest daylenght. The lowest radiation and daylenght occur in the second half of June. The energy received in the lowest period is 57% from the energy received in December, which generates a periodical (annual) and sharp variation in energy and daylenght. Regression analysis showed that daylenght and radiation have 99.4% of relation in a horizontal surface, which means they present a positive correlation. Both temperature and rainfall showed no relations with daylenght and radiation to the studied time, reflecting, by other hand, the need of long time data series to infer further considerations.

Vegetative and reproductive phenological patterns showed strong relations with abiotic variables. Production of new leaves and branches and presence of developed leaves showed a peak after lower daylenght and solar radiation ($P < 0.001$) with peak two months after lowest daylenght and radiation averages. Leaf fall also presented a peak related to daylenght and radiation, as well as all reproductive phenophases (floral buds, flowering and fruiting). The peak of bud production started after lowest radiation and daylenght and increased until starting flowering. Flowering presented a peak during October, when plants already presented a rising of new leaves. Fruit production followed flowering with peak of fruits in November.

As suggested for Athayde *et al.*, (2009) rainfall does not presented any relations with biological changes in phenology, which is quite different from areas with seasonal rainfall. Marques *et al.*, (2004) found the same pattern, with daylenght and temperature as predictors for both reproductive and vegetative phenologies and no relations with precipitation, which is unpredictable and generates no regular dry periods (Athayde *et al.*, 009).

As predicted by our hypothesis, solar radiation showed to be a reasonable predictor for different phenologies, but, daylenght is quite important as well. Both variables presented high correlation probably because they were measured on horizontal surfaces. Different papers showed the need for better predictors of plant changes over time (Morisette *et al.*, 009) and in this case, the quantity of received would be better than daylenght when topographical features should be considered. Typical examples of such features are phenological works developed attached with structural of functional data (plant functional types), when considering those topographical conditions. Because daylenght cannot predict light quality, radiation should be preferred in those situations.

CONCLUSION

As expect by our predictions, diffuse and direct radiation provide powerful information on predicting phenological changes in southern Brazil. These data are closely related to daylenght, however, as radiation can be measured with more accuracy than daylenght in particular exceptions, as those areas where horizontal surface are rare, radiation may provide better descriptors and qualify an important resource to plants: the quantity of received energy in a specific area and during a specific time length.

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