Evaluating MODIS LAI Uncertainty over the Amazon Region Using Evapotranspiration Estimated from the Penmann-Monteith Method

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Resumo

Este estudo apresenta uma análise de sensibilidade usando um método compreensive chamado SOBOL para avaliar os efeitos sazonais e espaciais dos erros na inferência de dados de Indice de Área Foliar (LAI) usando o sensor MODIS. Para isso é utilizada a evapotranspiração modelada pelo método de Penmann-Monteith para análise de incerteza no LAI. Essa equação é usada para 8 sítios do LBA situados em diferentes ecossystemas sobre a floresta Amazônica. Alguns dos resultados incluem: (1) a interação entre parâmetros no P-M é desprezível, o que confirma essa equação como um método robusto (2) a incerteza resultante da inferência do LAI pelo sensor MODIS para areas com 7 x 7 Km e com controle de qualidade de contaminação por nuvens se mostra aceitável para aplicações de estimativas de evapotranspiração. Os resultados desse estudo mostram a grande utilidade do P-M combinado com estimativas de LAI pelos sensor MODIS para aplicações de evapotranspiração.

1. Introduction

Vegetation phenology (i.e. the expression and timings in the periodic cycles of plant development) represents an important factor in seasonal and inter-annual climatic variability. A number of studies have demonstrated the importance of vegetation phenology in the timing and magnitude of biosphere events i.e. onset of wet or dry season, regulated by climatic states such as precipitation and temperature (Jarvis, 1976; Scheifinger et al., 2002; vanVliet et al., 2003; Larcher, 2003; Betancourt et al., 2005; Menzel et al., 2006).
In this study, we address the use of the Penman-Monteith method proposed by the Food and Agriculture Organization (Allen et al., 1998) and considered largely by the scientific community as a reliable mean to estimate reference evapotranspiration: in doing so, we also do test this widely-assumed reliability of this equation, especially under uncertainty.
To put ET uncertainty in context from studies that do not consider considering MODIS LAI errors in ET calculations, there exist modeling studies as well as field measurements.

2. Material and Methods

The LBA sites BAN, K34, RJA, K67 and K83 present the same constancy in monthly LAI. All of them are forest sites (Table 1) and the monthly LAI is practically constant in the time. Differently, K77, FNS and PDG have their specific seasonalities. The K77's LAI increases from March to August, PDG's LAI from February to September and FNS's LAI decrease from April to September.

3. MODIS LAI data product

The MODIS LAI values were obtained from remote sensing, using data from MOD15A2, one of the 44 products provided by the MODIS sensor. This sensor is on board the Terra and Aqua platforms, which are part of the Earth Observing System (EOS), led by NASA (National Aeronautics and Space Administration) for the study of global changes. Data from MOD15A2 are at a composition of 8 days, with a resolution of 1 km. Protocol LBA-MIP (2008) performed a filtering of the data and calculated LAI monthly averages of each period for the different LBA sites (Figure 1).

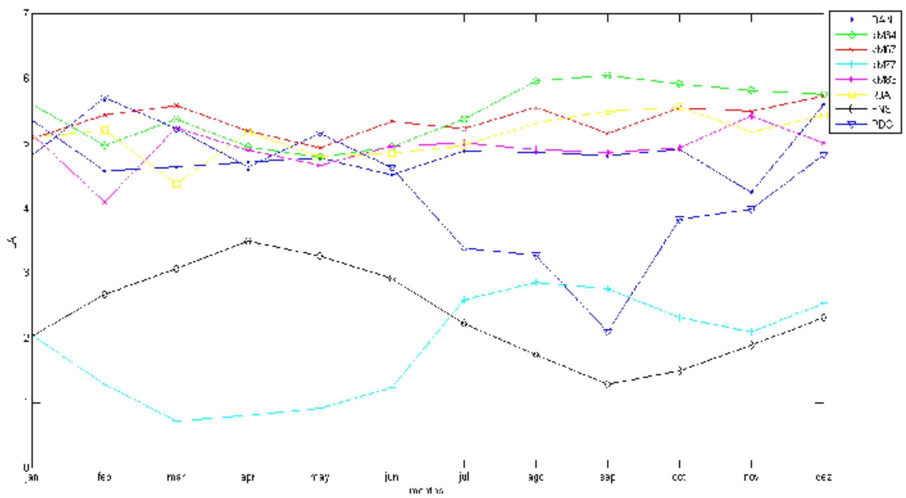


Figure 1 – Monthly variations of LAI at the different LBA-MIP sites.

4. The P-M equation

The Penman-Monteith method combines the aerodynamic and thermodynamic aspects, and the resistances to the flow of sensible heat and water vapor (surface resistance, rs, and aerodynamic resistance, ra). The Penman-Monteith evapotranspiration (mm) is calculated as follows:

$$E_{PM} = \frac{\Delta \cdot (R_n - G) + \rho_a \cdot c_p \cdot \dfrac{(e_s - e_a)}{r_a}}{\Delta + \gamma \cdot \left(1 + \dfrac{r_s}{r_a}\right)}$$

where R_n is the net radiation [$J/m^2 dia$]; Δ is the slope of the saturation vapor pressure curve at air temperature [$Pa/°C$]; G is the soil flux [$J/m^2 dia$]; ρ_a is the air density [kg/m^3]; c_p is the specific heat [$J/kg°C$]; γ is the psychometric constant [$Pa/°C$]; r_a and r_s are the aerodynamic and surface resistance, respectively, in units [s/m]. The e_a is the actual vapor pressure [Pa] given by:

$$e_a = \frac{q \cdot P}{[0.622(1-q)+q]}$$

where q is the specific humidity and P is the atmospheric pressure. Also, e_s is the saturation vapor pressure [Pa] estimated only from air temperature T [°C]:

$$e_s = 611 \cdot \exp\left[\frac{17{,}27 \cdot T}{237{,}3 + T}\right]$$

The slope of the saturation vapor pressure curve at air temperature is calculated as follows:

$$\Delta = \frac{de_s}{dT} = \frac{4.098 \cdot e_s}{(237{,}3 + T)^2}$$

According to Allen et al. (1998), the equation that describes the aerodynamic resistance (ra) is:

$$r_a = \frac{\ln\left[\frac{z_m - z_0}{z_{0m}}\right] \cdot \ln\left[\frac{z_h - z_0}{z_{0h}}\right]}{k^2 \cdot u}$$

where zm and zh are the wind and humidity measurement height[m] respectively, z_0 is the zero plane displacement [m], z0m and z0h surface roughness length for moment and energy transport [m], respectively; k is the von Karman constant, and u [ms-1] is the wind velocity measured at zm.

5. The SOBOL method

5.1 Sensitivity analysis of the P-M evapotranspiration estimates

In this study, 'sensitivity' and 'influence' mean the same. The influences of the following parameters are calculated using the PM method: z0, z0m, z0h, LAI01, LAI02, LAI03, LAI04, LAI05, LAI06, LAI07, LAI08, LAI09, LAI10, LAI11, LAI12. The last twelve parameters represent LAI values for each month of the year. In the sensitivity analysis, the parameter datasets were generated in a quasi-random normally distributed arrangement, using the Sobol's sequence. A perturbation was added to the mean values as follows:

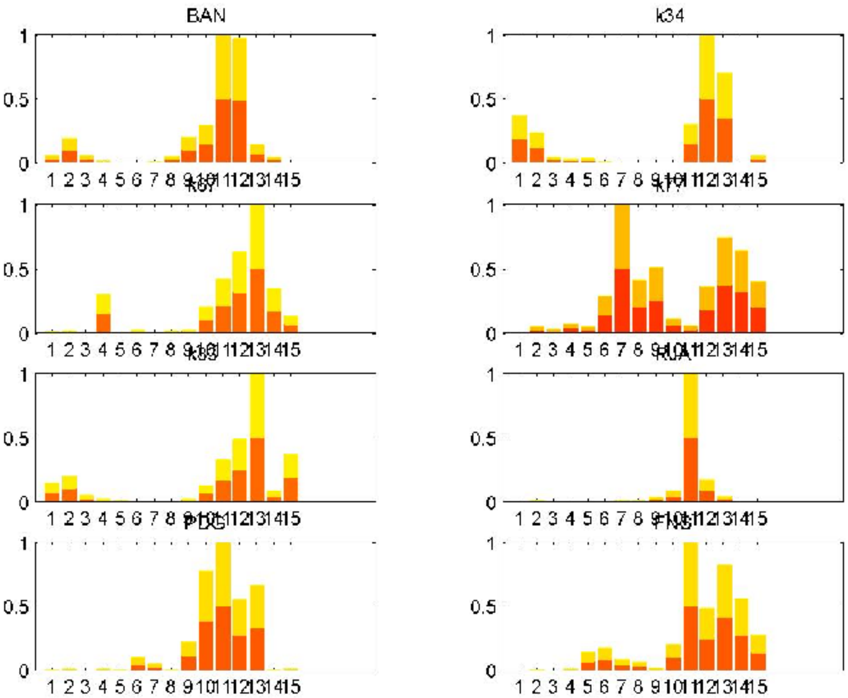
$$x = x_{\min} + y\,dx$$

Where x is a parameter, $dx = x_{\max} - x_{\min}$, $x_{\max}$ and $x_{\min}$ are the maximum and the minimum theoretical or experimental parameter value and y is the Sobol output variable. The resulting sample size for a first and total order analysis of the set of 15 parameters is 65000. However, given the relative simplicity of the P-M equation there was little computational burden.

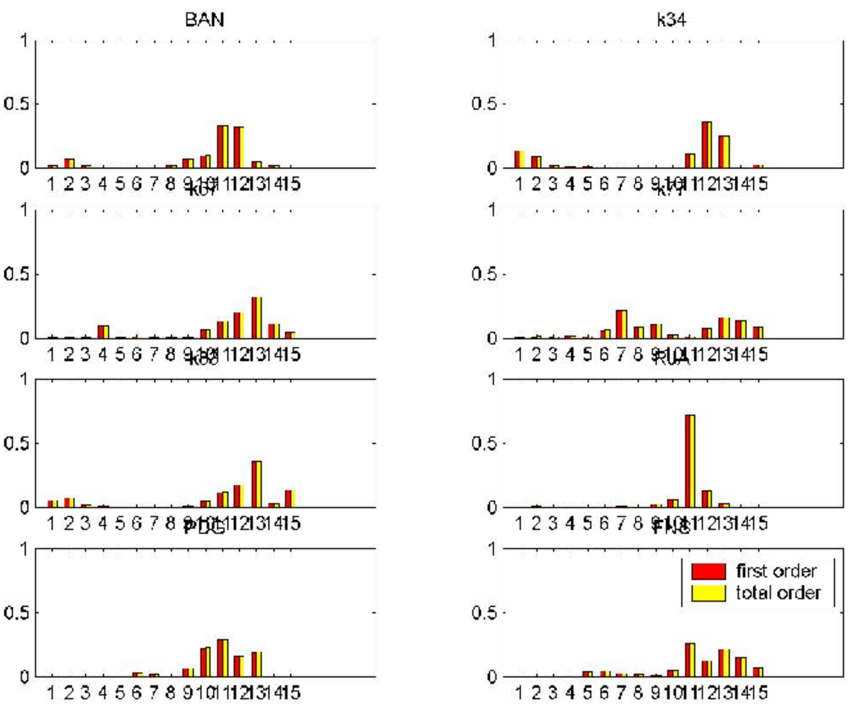
The results of sensitivity analyses computed show that the different parameters given similar contribution in the method sensitivity for different sites (Figure 2a). The difference between first and total order is on 10-4 (Figure 2c).

z0 and z0m are sensitivity only in tree sites: BAN, KM34 and KM83.

The parameters that represent the monthly LAI monthly have higher indices of sensitivity in the second half of the year (represented by LAI07 to LAI12). Indices of sensitivity above 10% appear only in August (LAI08), September (LAI09) and October (LAI10) for almost all sites. The November index (LAI11) shows sensitivity above 10% for three sites: KM67, KM77 and FNS



(a)



(b)

Figure 2 – (a) First and (b) total order sensitivity indices of parameters in the PM equation.

6. Results

Table 2 Shows mean and variance of ET for the entire period. Table 3 groups the Table 2 entries to the following same vegetation sites: TR for Tropical rainforest,: k34, k67, RJA, K83; SA=Savanna: BAN, PDG; PA=Pasture: K77, FNS

Table 1. Mean and variance ET and mean and variance PM for each site for all period

	BAN	K34	K67	K77	K83	RJA	FNS	PDG
meanET	3.5679	2.9803	3.0711	2.6821	3.6992	2.9015	2.1510	2.7471
stdET	0.6674	1.0279	0.7189	0.8801	0.6565	0.8159	0.6449	0.7000
meanPM	5.6254	3.0804	3.6299	2.7235	4.2297	3.4205	3.4299	3.1897
stdPM	1.0102	1.0895	0.7105	0.6169	0.7824	0.9447	0.7663	0.9496

Table 3. Mean and variance ET and mean and variance in PM for all period for same type of vegetation

	TR	SA	PA	All sites
meanET	3.1630	3.1575	2.4166	2.9750
stdET	0.8048	0.7211	0.7625	0.7733
meanPM	3.5901	4.4075	3.0767	3.6661
stdPM	0.8818	0.9799	0.6916	0.8588

7. Discussion

For all sites the mean of experimental ET was 2.97 mmd-1, and for PM the mean ET was 3.66 mmd-1, that represent a difference of 23% between experimental and PM ET. Estimates based on global model reanalysis data suggest a value around 4.3 mm/d, which represents 44% difference when compared with the experimental ET.

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