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EFFICIENCY OF A SIMPLE SPLIT-WINDOW FOR LAND SURFACE TEMPERATURE ESTIMATION USING MODIS PRODUCTS

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Abstract

The determination of land surface temperature (Ts) through satellite images has been object of several studies. The product MOD11A1, broadly used by the scientific community, supplies good results for Ts with a spatial resolution of 1 x 1 km. Ts supplied by MOD11A1 is obtained from radiance image using a *split-window* technique that depends on emissivity, brightness temperature (Tb), precipitable water and zenith angle, and other empiric parameters. In this work, we present an efficiency form of a *split-window*, in which Ts is determined by a direct relationship with Tb, established by the atmosphere transmittance, attributed to the water vapor. That transmittance is computed by simple equations obtained through the parameterizations and atmospheric profiles from the product MOD07. The method is compared with the one proposed by Becker and Li (1990) and products MOD11A1. A radiance image MOD021km on 12th July 2005 in Paraíba State, semi-arid area of Northeast Brazil, was used. The results show that Ts modeled from the presented method is 0.5 K smaller than the average supplied by the product MOD11A1, while that difference with Becker and Li (1990) is 1.7 K larger. Other images together with surface measurements during the satellite overpass it is necessary for final conclusions.

1. INTRODUCTION

Land surface temperature (Ts) is an important variable in the changes of energy between the surface and atmosphere, climatic variability and climate change (Valor and Caselles, 1996). Information's of the remote sensing are important to estimate land surface temperatures at regional or global scale. In this sense, the development and validation methods for Ts determination have been formulated through information registered with orbital sensors.

The radiance recorded in a satellite sensor, emerges from the surface and when crossing the atmosphere it suffers modifications in different spectral bands. Radiance data and the inversion of Planck function provide the brightness temperature (Tb) and the elimination of atmospheric effects leads to Ts. Consequently, a good algorithm to determine land surface temperature depends, among other factors, of an exact evaluation of the atmospheric effect (Wan, 1999). The radiance that reaches the top of the atmosphere in 8 to 13 μm band, is composed by the thermal emittance of the land surface, B(Ts), plus the thermal radiance produced by the atmosphere, B(Ta).

In the *split-window* (Eyre,1986; Kidder and Vonder Haar, 1995), the information of two channels allow to eliminate the influence of the thermal emission of the atmosphere, restricting the atmospheric correction just the transmittance due to the water vapor. To estimate the atmosphere transmittance with good precision it is necessary the use a radiative transfer code and data from the of atmosphere profile, which present operational difficulty to be used. In this work, that problem is solved with the use of the Robert et al. (1976) parameterization applied to atmospheric MOD07 product.

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2. MATERIAL AND METHODS

2.1. Materials

Three MODIS/Terra images for 12th July 2005 were used: a) MOD07, to obtain data regarding the atmosphere temperature profile, amount of precipitable water and sensor view angle; b) MOD021km, to obtain the brightness temperature in the bands 31 and 32; c) MOD11 product, that supplies corrected Ts values. Those images were processed with Erdas 8.7 software and the study area comprises Paraíba State, semi-arid area in Northeast of Brazil (Figure 1).

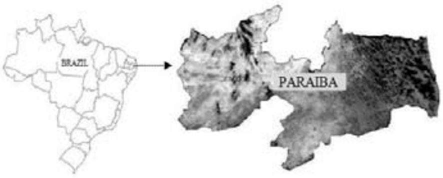

Figure 1. Paraíba State, Brazil.

2.2. Methods

The brightness temperature, Tb (K), of a body in the wavelength λ (μm) corresponding to the radiance, $L(\lambda)$ (mW m^{-2} sr^{-1} μm^{-1}), registered by a satellite sensor, can be estimated from the Planck function inversion:

$$Tb = \frac{k_2}{\ln(\frac{k_1}{L(\lambda)}+1)} , \quad (1)$$

where $k_1 = \frac{C_1}{\lambda^5}$, $k_2 = \frac{C_2}{\lambda}$, C_1 = 1.19104356 x10^{-16} (W m^2) and C_2 = 1.4387685x10^4 (μm K) are constants, λ is the mean length wave obtained according to the spectral answer of the sensor in each band, and the radiance $L(\lambda)$ is obtained by:

$$L(\lambda) = (DN - b_i)a_i , \quad (2)$$

where *DN* is the digital number regarding radiance of each pixel, a_i is a scale factor and b_i (Wm^{-2} μm^{-1} sr^{-1}) the radiance offset, found in the MOD02 image header.

In the atmospheric window (10 to 13 μm) the water vapor is the main responsible for the radiation absorption, so in this work the atmospheric correction is restricted just to that component and the parameterizations of Robert et al. (1976) will be used for such purpose. In these parameterizations the coefficient of absorption for water vapor (β_w) is estimate according to (Liou,1992):

$$\beta_w = C(v,T)[e + 0.002(p-e)] . \quad (3)$$

$$C(v,T) = C(v,296)\exp\left[6.08\left(\frac{296}{T}-1\right)\right] . \quad (4)$$

$$C(v,296) = 4.18 + 5578\exp(-0.00787v) , \quad (5)$$

where *v* is the wave number (cm^{-1}), p (atm) and *e* (atm) are the total and the partial pressure of the water vapor, respectively; *C* is measured in cm^2 g^{-1} atm^{-1} and, consequently, the unit of β_w is cm^2 g^{-1}.

The transmittance due to water vapor (Γ_W) is given by:

$$\Gamma_W = \exp(-\beta_w . \rho_w . z/\mu_0), \quad (6)$$

where ρ_w(g cm^{-3}), z(cm) and μ_0 are the water vapor density, geometric thickness of the atmospheric layer and the cosine of zenith angle, respectively.

Applying data of atmospheric profile extracted from MOD07 image in the parameterizations of Robert et al. (1976), for 8 atmospheric profiles, with precipitable water in the atmosphere varying between 2 and 4 g cm^{-2}, in the illustrated area of Figure 1, the atmospheric transmittance (Γw), for all of observed profiles, in the bands 31 and 32 of MODIS, can be estimated according to the expressions:

$$\Gamma w_{31} = 0.01w^2 - 0.2w + 1.17. \quad (7)$$

$$\Gamma w_{32} = 0.016w^2 - 0.3w + 1.3 , \quad (8)$$

where $w = W/\mu_v$, and *W* (g cm^{-2}) it is the amount of precipitable water in the atmospheric column, obtained in each pixel through the MOD07 product, and μ_v is the sensor view angle.

In the *split-window* method Ts is estimate by:

$$Ts = Tb_{31} + \frac{1-\Gamma w_{31}}{\Gamma w_{31} - \Gamma w_{32}}(Tb_{31} - Tb_{32}) , \quad (9)$$

where Tb_i e Γw_i are brightness temperature and atmospheric transmittance in band i, respectively.

In Becker and Li (1990) Ts is obtained according to the expressions:

$$Ts = A_0 + \frac{A_1(Tb_{31}+Tb_{32}) +_2 A_2(Tb_{31} - Tb_{32})}{2} . \quad (10a)$$

$$A_0 = 1.274;$$

$$A_1 = 1 + \frac{0.15616\ (1-\varepsilon)}{\varepsilon} - \frac{0.482\Delta\varepsilon}{\varepsilon^2} . \quad (10b)$$

$$A_2 = 6.26 + \frac{3.98(1-\varepsilon)}{\varepsilon} + \frac{38.33\Delta\varepsilon}{\varepsilon^2} . \quad (10c)$$

$$\varepsilon = \frac{\varepsilon_{31}+\varepsilon_{32}}{2};\ \Delta\varepsilon = \varepsilon_{31} - \varepsilon_{32}, \qquad (10d)$$

where ε_i is the emissivity of band i.

3. RESULTS AND DISCUSSION

In Fig. 2, the results of the mean Ts values are presented for 290 columns of 13 pixels, regarding a horizontal cut, east-west direction of Fig. 1. Ts-split represents the values obtained by the method proposed in this work, while Ts-becker, Ts-modis, Tb-31 and Tb-32 are respectively Ts obtained according to Becker and Li (1990), Ts supplied by the MOD11A1 product, and brightness temperatures in the bands 31 and 32. Pixels possibly polluted for clouds were excluded, mainly in the columns from 86 to 90 (vertical dotted line). Among Tb, Ts-split and the Ts-becker, a correlation of 0.99 was observed; the correlation coefficient between Tb and Ts-modis is equal 0.92. The mean difference between Ts-split and Ts-modis is - 0.5 K, while between the Ts-becker and Ts-modis it is equal to +1.6 K. The amount of precipitable water in atmosphere varied between 2.6 and 4.3 g cm^{-2} and the sensor view angle between 0.3° and 26°.

The mean Ts values for column, in areas of 16 for 16 pixels (16 lines for 16 columns) located in areas of Paraíba State are represented in Fig. 3. The results show the same performance of the method presented in this work when compared to the values supplied by MOD11A1 product. In relation to Ts-modis, white the Ts-split presents a difference varying between -0.3 and -0.6 K, the Ts-becker it varies between +1.3 and +1.7 K. Is observed that the correlation between Ts-split and Tb is practically the same of the previous application, what doesn't happen in relation to Ts-modis.

The presented method has the advantage of using just the atmospheric transmittance to establish the relationship between Tb and Ts. The efficiency of the method is due to the fact of determining, with good precision, the atmospheric transmittance pixel by pixel, in the which is takes into account the zenith angle and precipitable water in the atmosphere. On the other hand, the Becker and Li (1990) method, and the *split-window* used in MODIS products as well, have as main variable the surface emissivity, and, in agreement with Dash et al. (2002), Ts is very sensitive to the emissivity. According to the results the correlation between Ts-split/Tb is much better than between Ts-modis/Tb. That observation can elapse of the introduction of empiric factors introduced in the generalized *split-window* used to supply Ts-modis.

In the Table 1 shown mean Ts (estimate for the method proposed in this work, estimate for the Becker and Li (1990) method and supplied by the product MOD11A1) and the standard deviation regarding the areas of the Fig. 3. In agreement with the same, the standard deviation is practically the same. The difference between Ts-split and Ts-modis is smaller than 0.6 K, already the difference among the Ts-becker and Ts-modis is superior to 1.6 K.

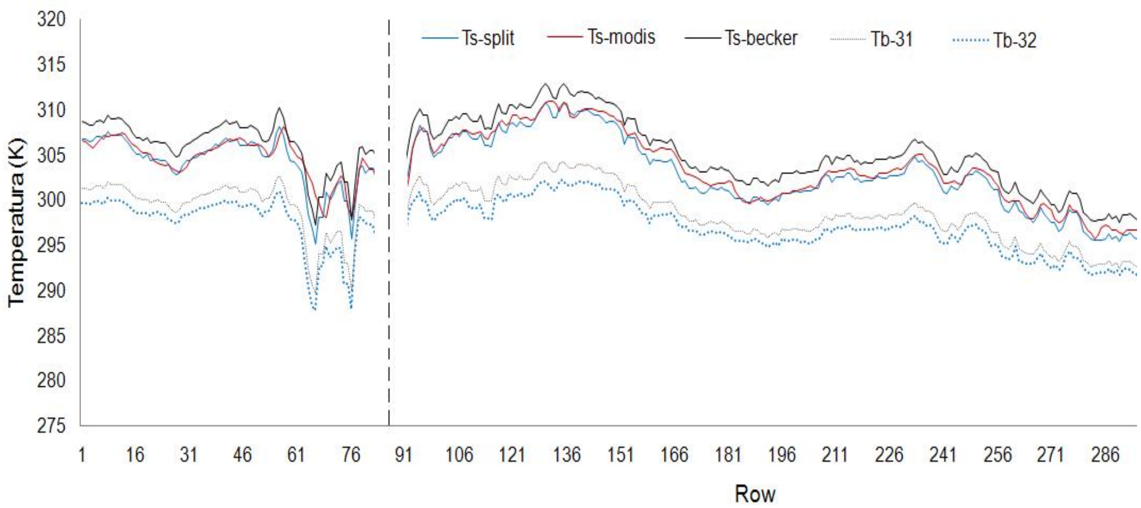

Figure 2. Mean values of temperatures regarding 290 columns of 13 pixels each.

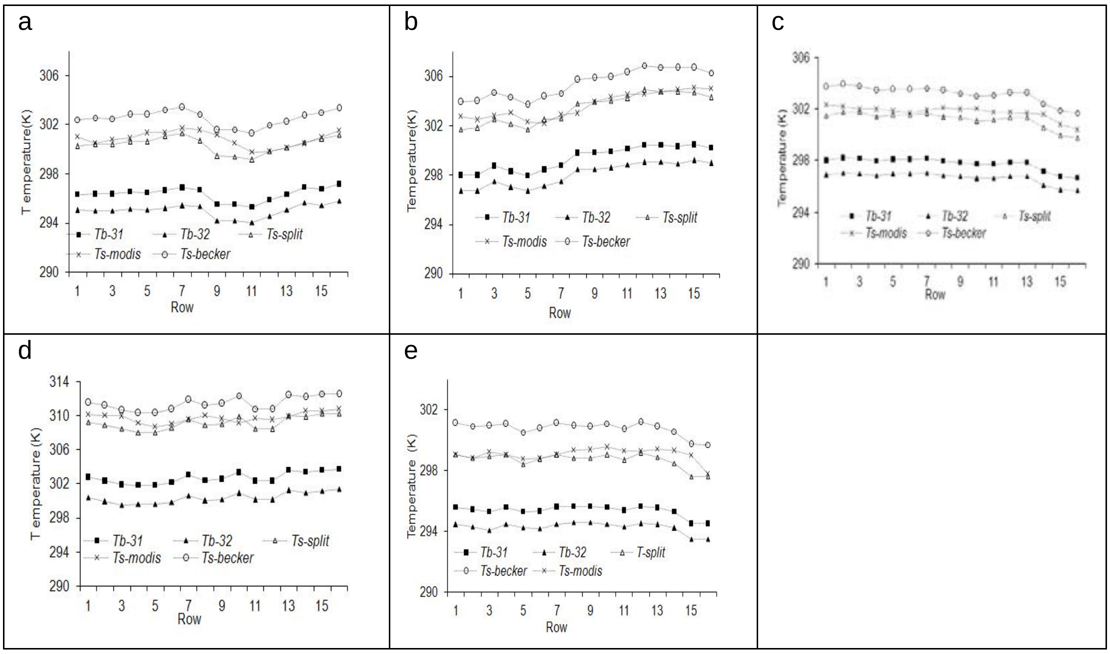

Figure 3. Mean temperature for column in areas of 16 x 16 pixels: a), area with center in (36°31'09"W, 7º15'02"S); b) area with center in (36°48'14"W, 7°39'44"S); c) area with center in (37º44'44"W, 7°26'54"S); d) area with center in (37º18'24"W, 6°08'58"S); e) area with center in (36°01'05"W, 7°29'43"S).

Table 1 - Statistical parameters, mean temperature and standard deviation for each illustrated area in the Figure 3.

Figures	Ts-split (K)/ standard deviation	Ts-modis (K)/ standard deviation	Ts-becker (K)/ standard deviation
Figure 3a	300.4 (1.4)	300.9 (1.4)	302.5 (1.4)
Figure 3b	303.4 (1.5)	303.7 (1.4)	305.4 (1.5)
Figure 3c	301.2 (1.6)	301.8 (1.5)	303.2 (1.6)
Figure 3d	309.1 (1.6)	309.8 (1.4)	311.4 (1.6)
Figure 3e	298.7 (0.9)	299.1 (0.8)	300.8 (0.9)

4. CONCLUSIONS

The *split-window* described by Eq. (9), it is a simple method, and his efficiency depends on the atmospheric transmittance due to water vapor. That transmittance can be estimated just applying the Robert et al. (1976) parameterizations or a radiative transfer code like MODTRAN. To define a transmittance function, with the objective of determining Ts, it is only necessary to know the atmospheric profile. For different areas it is possible to find different formulas for the atmospheric transmittance. For the studied images over Paraíba State, estimated Ts for the *split-window* is compatible with that one supplied by MOD11A1 product. The presented results show that the *split-window* proposed is efficient. However, to have a more solid conclusion it is necessary apply the method covering other MODIS images and take a set of land surface temperature measurements for validating the results.

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