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SPACE TIME VARIABILITY OF SURFACE TEMPERATURE IN THE SEMI-ARID PERNAMBUCO BASED IMAGE TM / LANDSAT

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ABSTRACT

In this study we used remote sensing techniques to estimate and evaluate the spatial and temporal variability of surface temperature (Ts) in the semiarid pernambucano. Four images of the sensor Thematic Mapper (TM), Landsat 5, dated 12/12/1991, 09/12/1996, 13/12/2003 and 27/11/2009, constituted the experimental unit, which were estimated using the algorithm Surface Energy Balance Algorithms for Land (SEBAL). The main results indicated that the maximum surface temperature varied between 32.5 and 46.1 º C, found in areas with exposed soil or areas used for crops irrigated by the river São Francisco. In general, it can be seen that where there is natural vegetation Ts was always lower in relation to the modified areas, which are present systematically higher temperatures studied on all days. It is concluded that remote sensing techniques proved efficient to quantify the spatio-temporal variability of surface temperature for semiarid conditions pernambucano.

Key words: Remote sensing, SEBAL, Seasonal caatinga vegetation.

Introduction

The Brazilian semiarid region is one of the largest and most populous in the world. According to Cyril et al. (2007) it extends over an area covering most of all the states in the Northeast (86.46 %), the northern region of Minas Gerais (11.01%) and the north of the Espírito

Santo (2,51 %), occupying a total area of 974 752 km^2. Most of the Northeast Region of Brazil comprises the semi-arid northeast, where the annual average temperature ranges from 24 to 28 º C, there is a spatial and temporal irregularity in the amount and distribution of rainfall and high evaporation rate (Strang, 1972) precipitation. This region is often subjected to the effects of droughts, being more pronounced in areas called "Drought Polygon", with average annual rainfall is less than 500 mm, reaching extreme values below 400 mm in the semiarid part of Paraíba and Pernambuco, as well as near Petrolina in San Francisco (Strang, 1972) valley.

The Lower Basin of the São Francisco is the main center producer and exporter of table grapes in Brazil, especially the municipalities of Santa Maria da Boa Vista and Petrolina, in Pernambuco State, with 54 % of the cultivated area, followed by municipalities Juazeiro, Casa Nova, Sento Sé and Curaçá, Bahia State, where the vine is of great socioeconomic importance for the large number of jobs generated. The area planted to this crop has expanded significantly in recent years, this region (Silva & Correia, 2000).

The vegetation is predominated by several morphological patterns depending on the geographical location and climatic conditions. The most semiarid portion focuses on the shrub, dense or open savanna that loses its leaves during the dry season and green leaf soon after the return of the rains (IBGE, 2004). The undergrowth as the predominant type of coverage provides a high rate of runoff, accelerating the evaporation process. With the combination of soil characteristics of the region that has in some areas of the predominance of semiarid clay soil there is not much infiltration and as a result has hardly recharging of aquifers. Another natural factor is the proximity of the equator, because the low-latitude region affects the high temperatures and the high number of photoperiod, due to higher perpendicular sunlight on the surface of the soil, with a high evaporation rate (Amaral, 2003).

In northern Northeast, water availability is less than half of what the United Nations (UN) establishes the minimum for the sustainability of human life. According to the UN, life is minimally sustainable when water availability is 1,500 m³ per capita / year. This significant portion of the national territory for centuries lacks efficient public policies that address the issue of periodic droughts permanently, with the effective participation of those who experience its reality; to thus make a decent life for rural families since long ago the Northern Northeast suffers from water scarcity, and the inhabitants of that region that store water in small reservoirs shall be subject to constant evaporation (CHESF, 2005).

Contemporary studies with physical-environmental approach and the use of geotechnology have relevance in the scope of the geosciences, because from them it is possible to understand the general conditions of the landscape, contributing to the development of prognostic and geoenvironmental interpretations (Lang et al. 2009).

Currently, with access to the products obtained from satellite sensors such as multi-temporal images and interferometry data, it is possible to develop various products, including maps of slope, contour lines, shaded terrain models, highlighting the architecture of relief (structures, modeled, drainage network, drainage hierarchy, among others) in various scales (local, regional and continental) providing various types of analyzes in the context of geo-environmental studies (Valeriano, 2008; Ross, 2006 and Florenzano, 2008).

The surface temperature (Ts) is a key element in the physical processes of the Earth's surface at regional and global scales, combining the results of all surface - atmosphere interactions and energy fluxes between the atmosphere and soil (Wan, 2008). Then, recent research in remote sensing Ts identified as one of the basic parameters for the control of physical, chemical and biological processes at the interface between land and the atmosphere, say Zhang et al. (2009). The research on Ts show that this partition of heat flows and radiation response of the surface is a function of surface variables, (Owen et al., 1998).

When there is a lot of vegetation Ts in this area will be closer to the temperature of the leaves, having a great relationship with this canopy. Therefore, according to Weng & Lu (2008), the relationship between surface temperature and vegetation density is a growing study in remote sensing.

Many studies have been conducted to estimate the Ts. The results highlight Fu et al. (2011) Vancutsen et al. (2010), who obtained the Ts to estimate the temperature of the air by MODIS. Using MODIS sensor Wan (2008), Wang & Liang (2009) and Tang et al. (2010) estimated the surface temperature. Already, Weng & Lu (2008), Amiri et al. (2009) and Zhang et al. (2009) obtained a surface temperature through sensor TM while Pine et al. (2006) and Katsiabani et al. (2009) obtained with the AVHRR. In the present work we used remote sensing techniques to estimate and assess the spatial and temporal variability of surface temperature in Pernambuco semiarid.

Materials and Methods

The study area shares parts of the territory of the municipalities of Petrolina -PE, Lagoa Grande- PE and Juazeiro - BA. The clipping has 1700.0 km2 resulting in a rectangle with the following coordinates: upper-left corner of -8.73° and -40.41°; and bottom right corner of -9.08° and -40.01° Figure 1. The climate of the region is semi-arid, with average annual temperatures of 27º C, rated by Bswh (Köppen, 1928). Depending on the characteristics of climate and temperature associated with the intertropical geographical location, potential evapotranspiration is very high, being of the order of 3,000 mm annually. Also, they are high insolation and low relative humidity. The dry period is prevalent, with about 6-8 months. The average annual rainfall is around 400-650 mm, which occurs irregularly and concentrated way in 2-3 months of the year, heavy rainfall (120-130 mm) may occur within 24 hours. The savanna vegetation, predominant in almost any area of the Lower Basin of the São Francisco Valley, consists of dense formations xenophiles usually thorny, woody, deciduous, with the presence of succulent plants, both woody shrub as standard, sparse and with seasonal herbaceous (Andrade Lima, 1992).

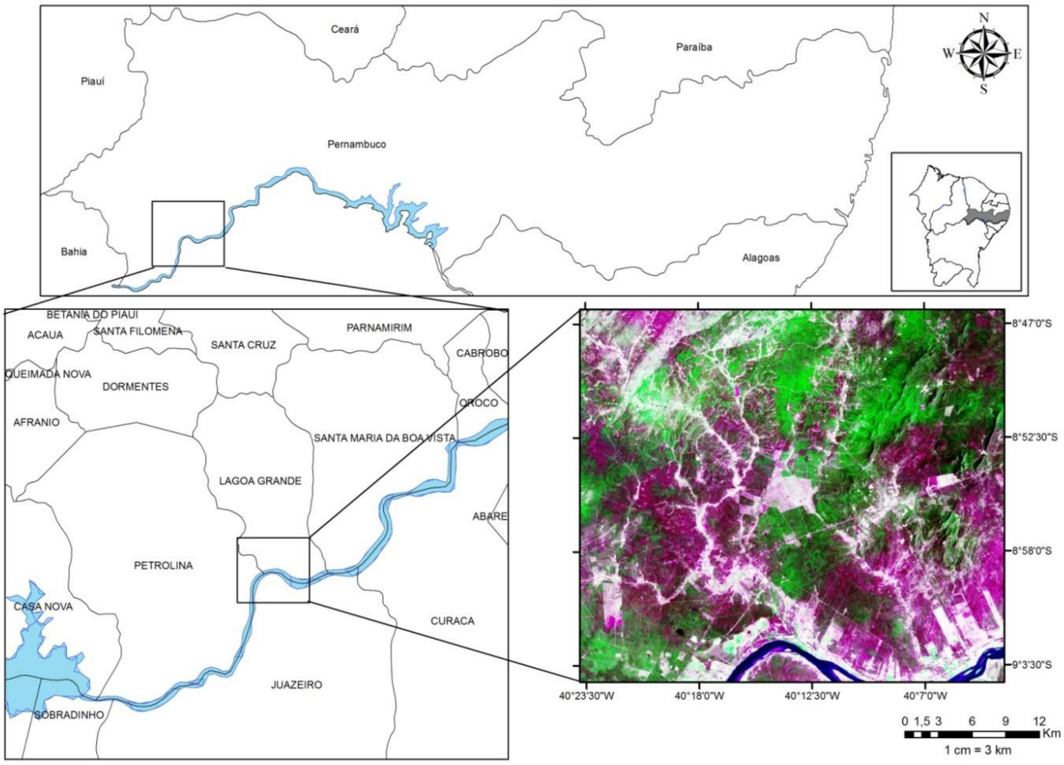

Figure 1. Localization of the study area.

Remote sensing data

The TM images - Landsat 5 selected for this study were obtained from the National Institute for Space Research (INPE) site, referring to the orbit and the 217 point 66 days: December 12, 1991, December 9, 1996, December 13, 2003 and November 27, 2009 (Figure 2).

For image processing we used the ERDAS Imagine 9.2 software, using the re-sampling tasks, stacking, clippings and georeferencing of images and mathematical operations in the calculation of surface parameters. Table 1 contains the date, day of the year of order (DOA) and time of the satellite passage (GMT - Greenwich Mean Time), and the correction of the eccentricity of Earth's orbit (dr) and cosine of the solar zenith angle (cos Z), Representative of the time the satellite passed over the study area.

Table 1. Date, day order of year (DOY), Greenwich Mean Time (GMT), Sun Elevation Angle (E) and Solar Zenith Angle (Z).

Date	DOY	Hours		Angle	
		(GMT)	Local	E (°)	Z (°)
12/12/1991	346	12:12:28	09:12:28	53.55	36.45
12/09/1996	343	12:09:19	09:09:19	53.39	36.61
12/13/2003	347	12:26:31	09:26:31	56.55	33.45
11/27/2009	331	12:38:27	09:38:27	61.22	28.78

Radiometric calibration

After making the cut image, proceeded to the radiometric calibration of the seven spectral bands of TM, which is to convert the digital number (DN) of each pixel and band spectral radiance ($L_{\lambda i}$, em W m^{-2} sr^{-1} μm^{-1}), is determined by Equation (1), proposed by Chander & Markham (2003)

$$L_{\lambda i} = a_i + \frac{b_i - a_i}{255} ND$$

where:

$L_{\lambda i}$ is spectral radiance;

a and b are minimum and maximum radiance, Table 2;

DN is digital number and i is bands (1, 2, 3, ... e 7) to TM – Landsat 5.

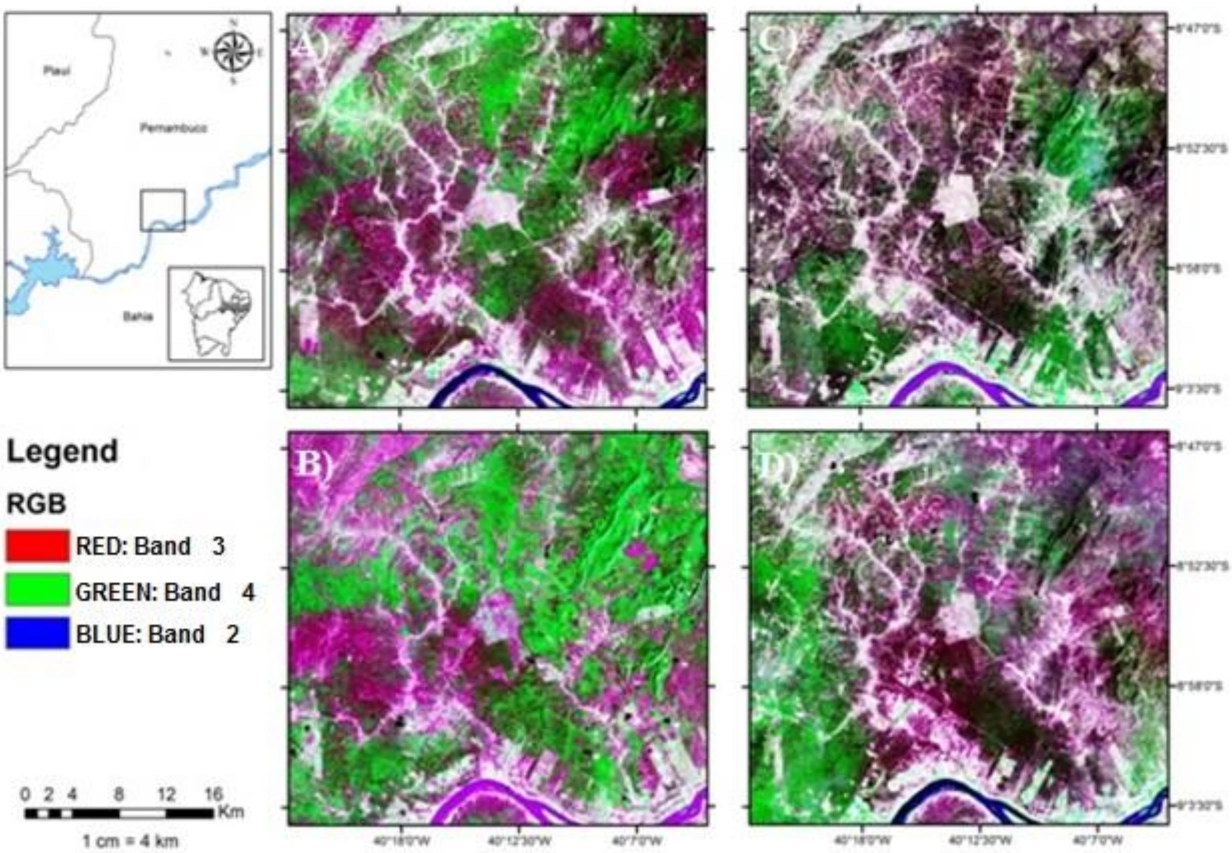

Figure 2. RGB342 composition of the TM - Landsat 5 in 12/12/1991 (A), 12/09/1996 (B), 12/13/2003 (C) and 11/27/2009 (D).

Table 2. Calibration coefficients and solar irradiance in atmosphere top, TM – Landsat 5.

Band	a ($Wm^{-2}sr^{-1}\mu m^{-1}$)	b ($Wm^{-2}sr^{-1}\mu m^{-1}$)	$K_{\lambda i}$($Wm^{-2}\mu m^{-1}$)
1	-1,52	193,0	1957
2	-2,84	365,0	1826
3	-1,17	264,0	1554
4	-1,51	221,0	1036
5	-0,37	30,2	215,0
6	1,2378	15,303	-
7	-0,15	16,5	80,67

Monochromatic Reflectance

The monochromatic reflectance ($\rho_{\lambda i}$) in top of atmosphere to bands 1 a 5 and 7 is calculated by ratio between the flow of reflected solar radiation and the incident solar radiation was determined by the equation (2) by (Chander & Markham, 2003):

$$\rho_{\lambda i} = \frac{\pi . L_{\lambda i}}{K_{\lambda i} . \cos Z . dr} \qquad (2)$$

where:

$K_{\lambda i}$ is monochromatic irradiance in each band (W m^{-2} μm^{-1}). The value you see in Table;

Z is Zenite Solar angle (degrees);

dr is the inverse of the square of the relative distance Earth-Sun obtained by Equation (3):

$$dr = 1 + 0{,}033 \cos\left(\frac{DOA2\pi}{365}\right) \qquad (3)$$

where:

DOY is ordem day year.

Vegetation index

The Normalized Difference Vegetation Index (NDVI) is an indicator of the quantity and condition of the vegetation of the earth surface and the values range from -1 to +1. The NDVI is obtained by dividing the difference in reflectivity of near infrared (ρ_4) and red (ρ_3) and e the sum of these obtained according to the description of Equation (4) by Allen et al. (2007):

$$NDVI = \frac{\rho_4 - \rho_3}{\rho_4 + \rho_3}$$

The Soil Ajusted Vegetation Index (SAVI) was obtained by Huete (1991) using equation (5)

$$SAVI = \frac{(1 + L)(\rho_4 - \rho_3)}{(L + \rho_4 + \rho_3)}$$

Where: L is constant, the value used in this study was 0.1 (Allen et al., 2007).

The Leaf Area Index (LAI) is defined as the ratio of leaf area of all vegetation per unit area of vegetation. The LAI is an indicator of biomass of each pixel of the image, which has been computed by Equation (6) (Allen et al, 2007.)

$$LAI = -\frac{ln\left(\frac{0,69 - SAVI}{0,59}\right)}{0,91} \qquad \textbf{(6)}$$

According to the above expression the maximum value reached by the LAI is equal to 6.0, occurring when the SAVI worth 0.69.

Emissivities

The pixels do not emit electromagnetic radiation like a black body, so to calculate the surface temperature needs to calculate the emissivity of each pixel (ε_NB) in the spectral domain of the TM thermal band - Landsat 5 (10.4 to 12.5 mM). For that we made use of Equation (7) parameterized by Allen et al. (2007)

$$\varepsilon_{NB} = 0,97 + 0,0033 \times LAI \qquad \textbf{(7)}$$

To calculate the longwave radiation emitted by each pixel, which is the surface emissivity (ε_0), one must consider the emissivity of broadband, which includes the range of 4 to 100 micron, we used the equation (8) proposed by Allen et al. (2007)

$$\varepsilon_0 = 0,95 + 0,01 \times \text{LAI} \qquad \textbf{(8)}$$

In Equations 7 and 8, emissivities ε_{NB} and ε_0 were valided for NDVI > 0 and LAI $\leq$ 3. For pixels with LAI ≥ 3, ε_{NB} = ε_0 = 0,98 and to water (NDVI < 0) use ε_{NB} = 0,99 and ε_0 = 0,985 (Allen et al., 2007).

Surface temperature

Having obtained the letters of the spectral radiance of the band 6 (Lλ6) and the thermal emissivity of the band (εNB) was determined surface temperature (TS) in degrees Kelvin, using Equation (9) proposed by Markham & Barker (1987)

$$T_S = \frac{K_2}{ln\left(\frac{\varepsilon_{NB}K_1}{L_{\lambda,6}} + 1\right)}$$

where:

K_1 e=and K_2 = constants specific radiation for TM - Landsat 5, with values of 607.76 W m-2 sr-1 mM-1 and K 1260.56.

Results and discussion

Table 3 shows the minimum, maximum, mean, median, mode and standard deviation of the surface temperature (Ts) are presented. The oscillations of the three temperature ranges, respectively, 19,9 to 25,8 ºC; 32,5 to 46,1 ºC and 24,0 to 31,9 ºC.

Table 3. Surface air temperatures (º C): minimum, maximum, mean, median, mode and standard deviation (D Pad.), Obtained in the statistical analysis of the TM sensor, for the semi-arid Pernambuco.

Date	Mín	Max	Median	Mediane	Mode	SD
12/12/1991	22,2	46,1	31,9	31,5	30,2	2,2
09/12/1996	19,9	32,5	24,0	23,9	23,0	1,5

13/12/2003	22,7	39,0	30,0	30,2	29,8	3,2
27/11/2009	25,8	45,4	31,9	31,9	31,9	4,3

Regarding the results for minimum temperature, the values were very close to 20.7 and 23.7 ° C obtained on the surface of the water in Lake Sobradinho by Silva et al. (2005), while Giongo (2008) found in the Lake district of Santa Rita do Passa Quatro, averages between 18.3 and 25.1 ° C and Gomes et al. (2009), 17.8 and 25.3 º C for the Pond Cut-SP. Silva et al. (2011) found values of Ts Weir of São Gonçalo, PB between 13.9 and 18.8 ° C. The maximum values of the surface temperature varied between 32.5 and 46.1; found in exposed areas or areas used for irrigated crops on the banks of the São Francisco River soil. However it is important to relate the values obtained to the time of satellite overpass and the conditions of soil cover on the day of registration of the image. The surface temperature maps of the study area are shown in Figure 3.

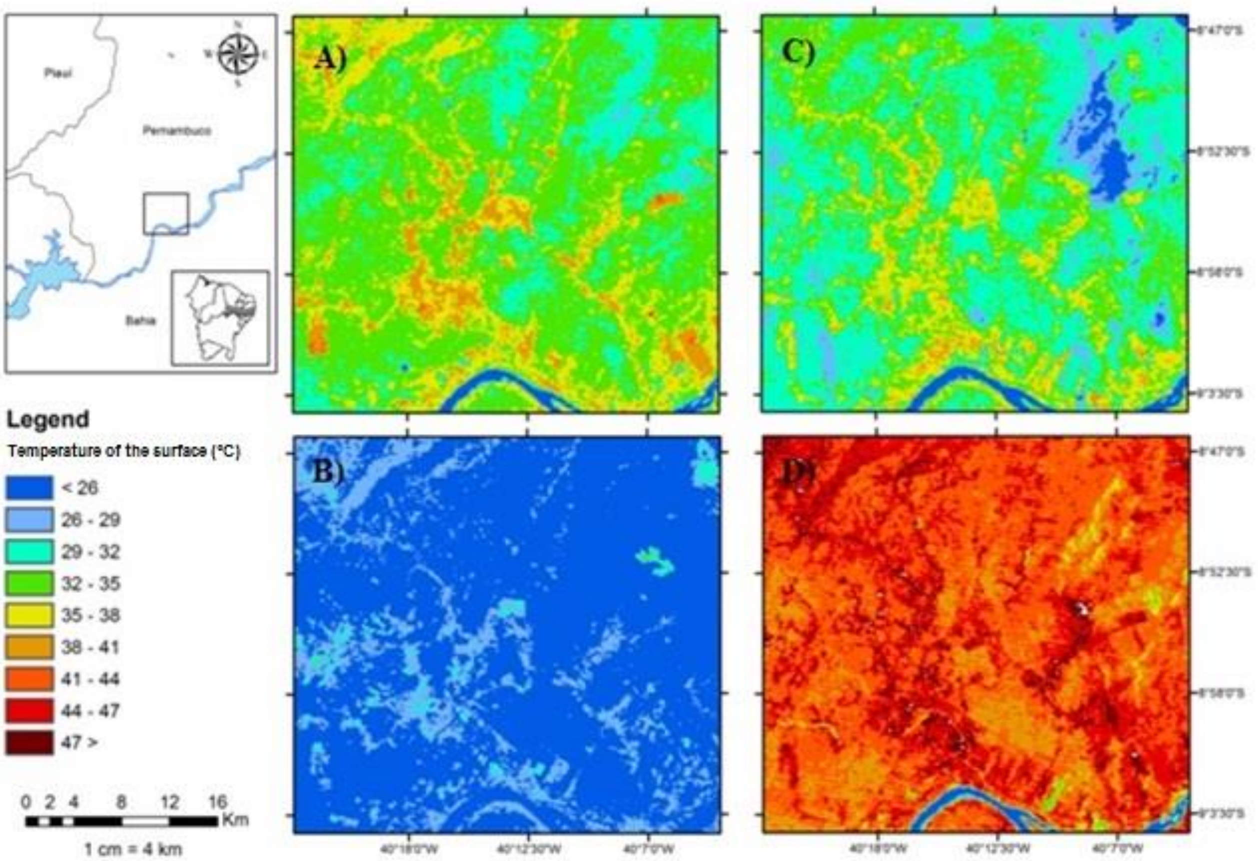

Figure 3. Temperature of the surface obtained by the sensor TM in semiarid pernambucano to day: 12/12/1991 (A) 09/12/1996 (B) 13/12/2003 (C) and 27/11/2009 (D) for the semi-arid Pernambuco.

It is observed that most of the area presented with greater than 32 ° C TS, indicating anthropization except for on 09/12/1996 (Figure 3B) that possessed values lower than 26.0° C. These results are close to those found by Silva et al. (2005), exposed to the city of Petrolina, PE ground, where Ts ranged between 36.9 and 39.8 º C, or Di Pace et al. (2008), in Juazeiro, BA, which varied from 31.5 to 35.9º C. Comparing the tracks

TS images with the albedo of the surface, it is observed that there is agreement among themselves, ie, where the Ts was higher albedo is also lower (disturbed areas) and when Ts is lower albedo was greater (areas of native vegetation) . Although reports of Gomes et al. (2009), state that cannot always explain the increase of Ts result merely decreasing the albedo. However, one should also consider the standards presented by the flows of sensible and latent heat. Thus, it is observed that an increase in Ts over the days studied, corroborate with the albedo and NDVI.

In general, it can be seen that there Ts where natural vegetation was always lower in relation to the modified areas that are presented to systematically higher temperatures studied every day. The letters of Ts presented in Figure 3 show clear evidence that the differences between homogeneous areas, showing the boundaries between them (deforested areas and areas of native vegetation).

Conclusions

The techniques of image processing satellites proved efficient in estimating the surface temperature, it was found that the soil cover acts significantly on lower temperature, the image of 1996 showed the lowest values of Ts, possibly by presenting greater vigor during the image registration.

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