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Vegetation Index and Air Temperature Behavior in Tefé-Amazonas, Brazil

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A B S T R A C T
The objective of this work is to analyze the modification of land use in the air temperature behavior in the municipality of Tefé-AM. For this, the data of minimum and maximum air temperature of the INMET meteorological station in Tefé of the period 1993-2012 were collected. The data were treated with statistical descriptive techniques such as: mean, maximum, median, coefficient of variation, amplitude, quantiles and standard deviation. In addition, data processing for the elaboration of vegetation index of the normalized difference (NDVI) was carried out to evaluate the transformations of land use in Tefé. The results showed the substitution of the forest area with the expansion of the urban mesh, in the surface-atmosphere radiation balance has been altered, demonstrating the temporal increase of the minimum and maximum temperatures due to the process of appropriation of nature on a local scale. It is concluded that it is necessary that the territorial planning take into account the physical-natural conditions of the Amazonian landscape.
Keywords: air temperature, NDVI, land use, Tefé.

Índice de Vegetação e Comportamento da Temperatura do Ar em Tefé-Amazonas, Brasil

R E S U M O
O objetivo deste trabalho foi analisar a modificação do uso da terra no comportamento da temperatura do ar no município de Tefé-AM. Para isso, foram coletados os dados de temperatura mínima e máxima do ar da estação meteorológica do INMET em Tefé do período de 1993-2012. Os dados foram tratados com técnicas estatísticas descritivas como: média, máxima, mediana, coeficiente de variação, amplitude, quantis e desvio padrão. Além disso, foi realizado o processamento de dados para elaboração de índice de vegetação da diferença normatizada (NDVI) para avaliar as transformações do uso da Terra em Tefé. Os resultados mostraram a substituição da área de floresta com a expansão da malha urbana, em o balanço de radiação superfície-atmosfera tem sido alterado, demonstrando o aumento temporal das temperaturas mínimas e máximas devido o processo de apropriação da natureza em escala local. Conclui-se que é necessário que o ordenamento territorial leve em consideração as condições físico-naturais da paisagem amazônica.
Palavras-chave: temperatura do ar, NDVI, uso da terra, Tefé.

Introduction

Air temperature increases observed worldwide indicate serious socio-environmental problems to be faced. Studies performed in the Brazilian Amazon have shown that changes in land use caused by deforestation and replacement of forest areas with pasture and monocultures are leading to an increase in the surrounding temperature and, at a regional scale, to a decrease in rainfall and prolonged drought periods (Bagley *et al.*, 2014; Buarque *et al.*, 2010; Nobre, 2001).

Many doubts persist mainly on the reliability of climate models used in studies of climatic variability in the Brazilian Amazon since the data series analyzed are not long enough and there is a shortage of observational climatic data and scientific research in parts of this region.

Rainfall is high in the region, with pluviometric totals above 3500 mm per year in some localities. According to Marengo and Nobre (2009), about 50% of the water vapor added to rainfall formation returns to the atmosphere by evapotranspiration, demonstrating the importance of forest conservation and public policies for land use planning, integrating the dynamic factors of the landscape.

According to Marengo and Nobre (2009),

despite the important feedback of precipitation and temperature due to the high evapotranspiration in the Amazon, assessing the hydrological cycle is difficult due to a lack of surface stations and frequency of space-time measurements.

We should also consider that different types of vegetation in a multiple biodiversity are responsible for evapotranspiration in a higher or lower quantity. Thus, the assessment of land use and biota is important for climate analysis in the region.

The Amazon region has a little thermal amplitude. Due to its location near the equator, it receives a high amount of solar energy during the entire year, which is reflected in high temperatures regardless of the season, except for cold spell days.

A temporal-spatial analysis of temperature by means of data series allows the diagnosis of the society's role reflected in changes in landscape characteristics, influencing climate to a regional and local extent. Climate elements, including air temperature, are intrinsically related to the balance of energy in the Earth-atmosphere system, derived from the input and output of ultraviolet and infrared radiations.

However, air temperature is also spatially influenced by geographical factors of climate such as latitude, altitude, relief, continentality, maritimity, vegetation, and anthropic activities. In studies on the behavior of a microclimate, a previous knowledge about some of the elements and climatic factors of the place under analysis is necessary.

Land-use changes from natural to agricultural systems in the Amazon may result in a number of socio-environmental problems, such as loss of biodiversity, climate change at meso- and microscale, among others related to the processes of appropriation of nature.

These aspects might be closely related to the changes of the Amazon landscape, altering the radiation balance and convective process associated with rainfall formation.

Thus, the main environmental problems related to land use are observed in areas of incompatibility between use and physical-natural characteristics, which correspond to areas of deforestation and burnings. These areas are normally used inadequately for the development of activities such as livestock, agriculture, and logging, where their physical-natural limitations are not respected.

Moreover, territorial expansion of urban areas towards the Amazon region in a disorderly and unequal way interferes with the land use and occupation and hence its microclimate.

In this context, the aim of this study was to analyze the effect of land use changes on the air temperature behavior in Tefé, AM, Brazil.

Methodological procedures

Series of monthly and daily air temperature data in the region of Tefé were collected from the Meteorological Station of the Brazilian National Institute of Meteorology (INMET).

The INMET conventional meteorological station, which measures the maximum and minimum air temperature, started its operation on January 4, 1929. However, the historical data available in the Historical Database platform (BPMEP) begins from the 60/70's.

Daily, monthly, and annual data presented many gaps, being considered for the analysis of this study a 20-year series from 1993 to 2012, which is the most representative period and of better quality. Fault fills were performed in months with missing data.

Monthly data with gaps were treated by means of to fill in the missing data, using the data of the nearest meteorological station located in Coari, which also has a low altitude.

These data were statistically treated by statistical descriptive techniques such as mean, median, coefficient of variation, standard deviation, maximum and minimum values, amplitude, and quantiles.

The normalized difference vegetation index (NDVI) was also obtained by processing the data. This index consists of a parameter to establish reflectance levels of a healthy vegetation, allowing the analysis of areas of dense and dispersed vegetation, as well as over-time changes in the forest such as replacement with pasture areas, deforestation, agriculture, and urban expansion.

We selected Landsat 5 TM satellite images from 1991 to 2011, which encompass the vicinities of the urban area of Tefé.

In this sense, bands 4 and 5, which comprise the visible red (R) and near-infrared (NIR) channels of Landsat 5 TM images, were used to determine the vegetation indices, which were then processed by the SPRING software, using the following arithmetic operation:

$$\mathbf{C = Gain*((A+B)/(A-B)+Offset}$$

Wherein: C is the NDVI, A is the near-infrared (NIR) channel, and B is the visible red (R) channel, as in Figure 1.

After applying the arithmetic operation, an image is generated by the SPRING application in the Geographic Information System environment. This image contains the vegetation index, whose variation of digital levels of pixels is from −1.0 to 1.0. Values near −1.0 represent areas with a low vegetation index such as bare soil, deforestation, grassy vegetation, alluvial deposits, urban area, and water bodies, while indices close to 1.0 represent areas with arboreal vegetation such as forest areas.

The NDVI of the processed images allowed a landscape analysis where positive values (> 0) stand for areas of green dense vegetation with arboreal size, whereas the null values (or close to zero) are surfaces with no vegetation and, finally, areas with negative values represent water bodies and clouds.

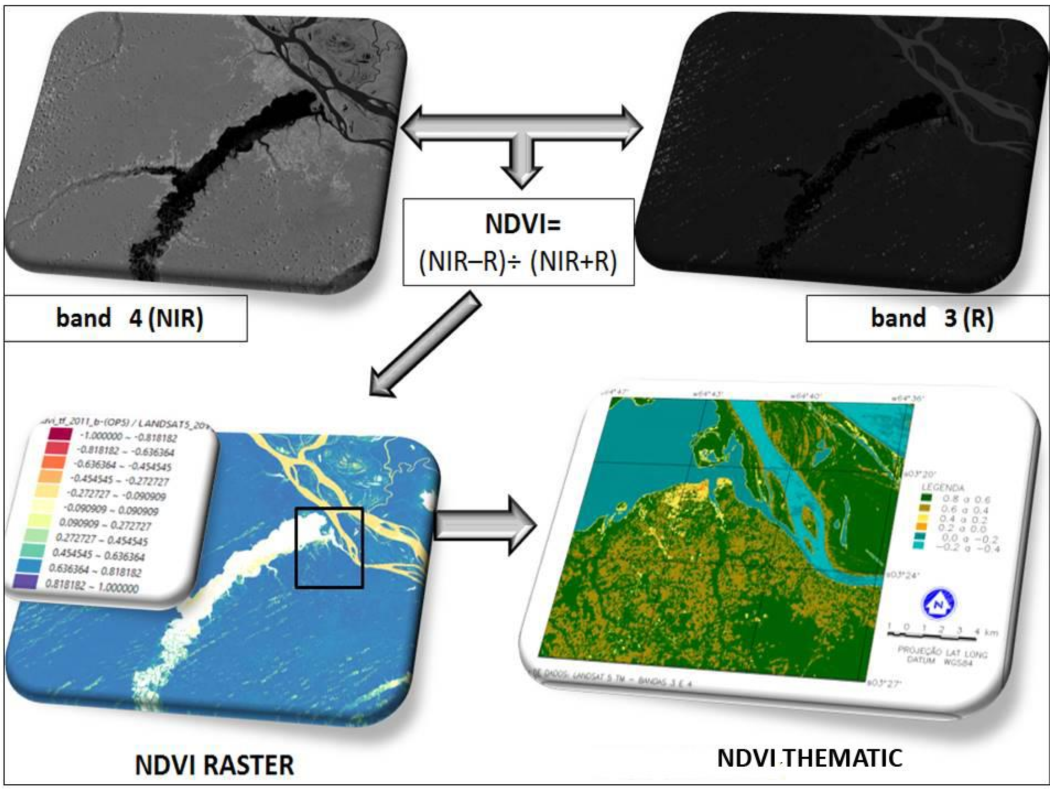


Figure 1: Organization chart to elaborate the NDVI.

Landscape and air temperature changes in Tefé, Amazonas state, Brazil

Most of the deforestation concerns in the Brazilian Amazon are focused on the agricultural frontier known as the "Arc of Deforestation", among the states of Rondônia, Mato Grosso, Pará, and southern Amazonas. However, deforestation process is less intense in the interior of the Amazon when considering only the deforested area. This process is equally harmful to local populations and biodiversity, both from an environmental and social point of view.

The replacement of green/forest areas is associated with changes in local microclimate, leading to alterations in quality of life of the population living in the surrounding cities.

Tefé is located in the Middle Solimões region, in the Amazonas state (Figure 2), about 520 km far from the capital Manaus in a straight line. This city presents an equatorial climate with high temperatures and wide rainfall volumes (ALEIXO and SILVA NETO, 2015a; CORDEIRO and FREITAS, 2016). The highest total monthly rainfall is concentrated between January and May, a period known as the flood season in the Central Amazon, and the lowest total monthly rainfall occurs from June to December, characterizing the dry season (ebbing) (ALEIXO and SILVA NETO, 2015b).

The analysis in a local perspective reveals significant changes in the landscape near the urban area and in road margins passing through Tefé.

A temporal analysis using images from different periods, within about two decades, allowed observing that, by means of NDVI, the analyzed cities of the Middle Solimões region presented a representative loss of areas of dense and healthy vegetation. In this sense, in the vicinities of urban areas of the analyzed cities, forested areas have been replaced with areas of deforestation, burning for agricultural purposes, logging, and livestock (Figures 3 and 4).

The main change in NDVI was an increase, in 2011, of areas with values between 0.6 and 0.4. In 1991, on the other hand, these areas had values between 0.8 and 0.6. These areas of healthy vegetation in 1991 were replaced with areas of secondary vegetation, deforestation, urban sprawl, and agriculture.

The replacement of forest areas in the last 20 years is associated with a harmful process of deforestation, where the burning process is carried out as it is a method that requires little financial or technical resources but generates unrecoverable impacts on biodiversity and natural attributes of these areas.

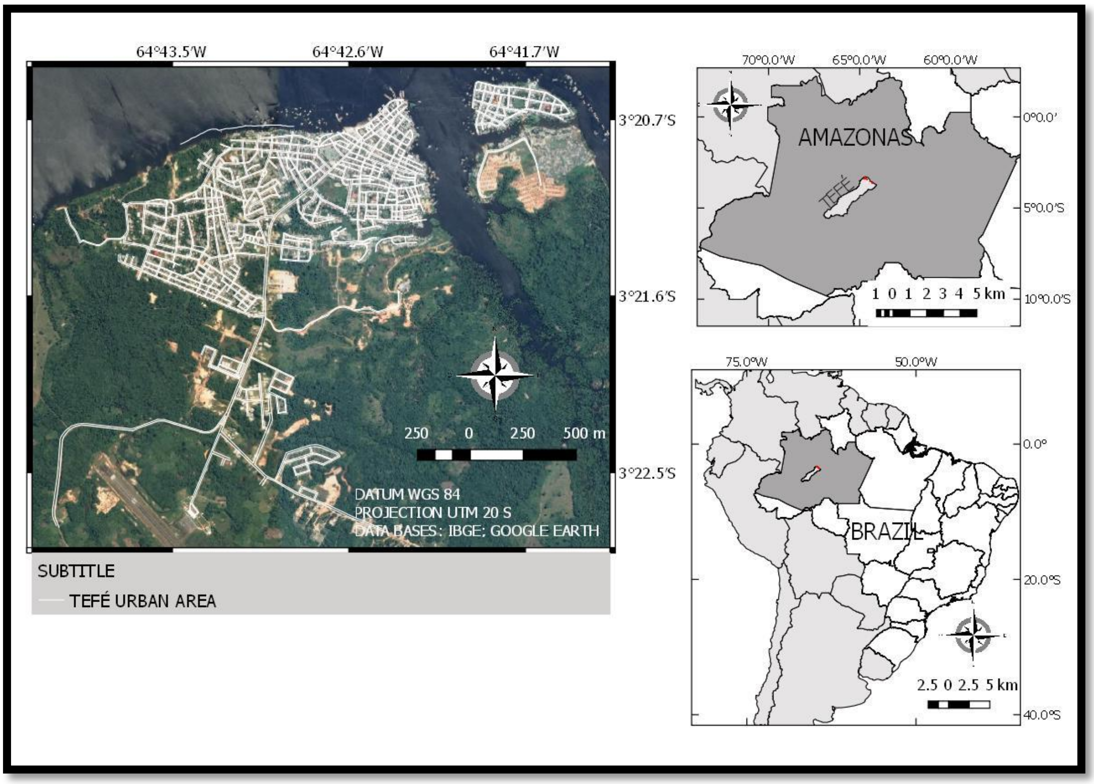


Figure 2. Location of the municipality of Tefé-AM. Produced by: Authors (2016)

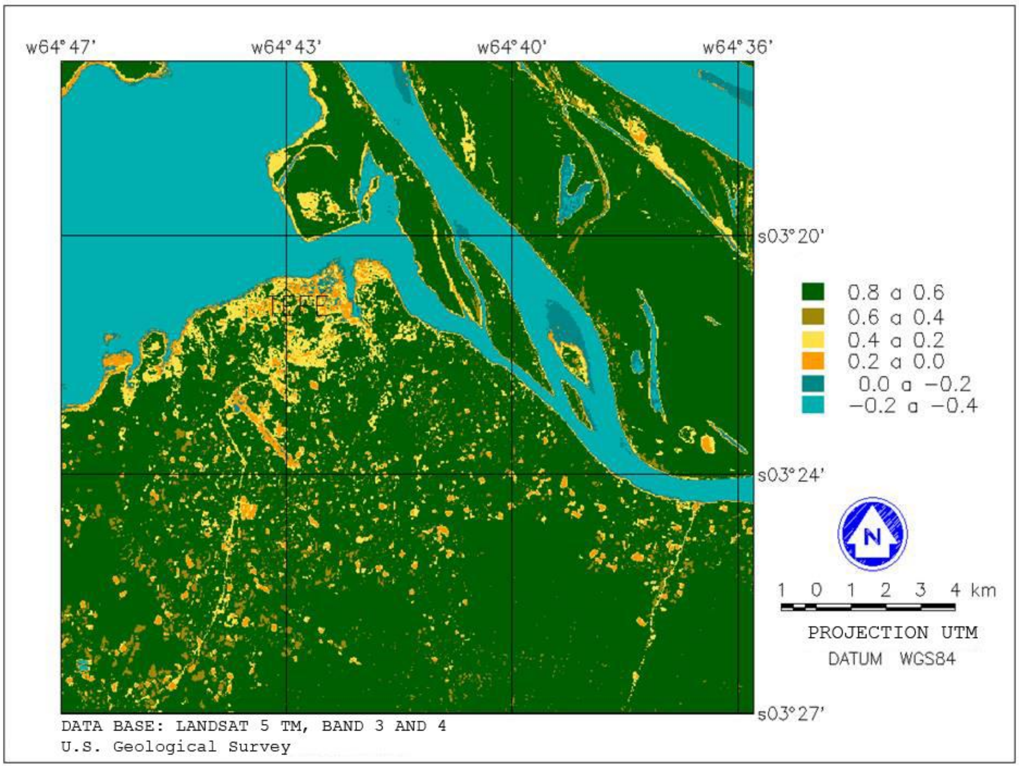


Figure 3. Vegetation Index the Normative Difference (NDVI) of the adjacencies of the urban area of Tefé in the year 1991.
Produced by: Authors (2016)

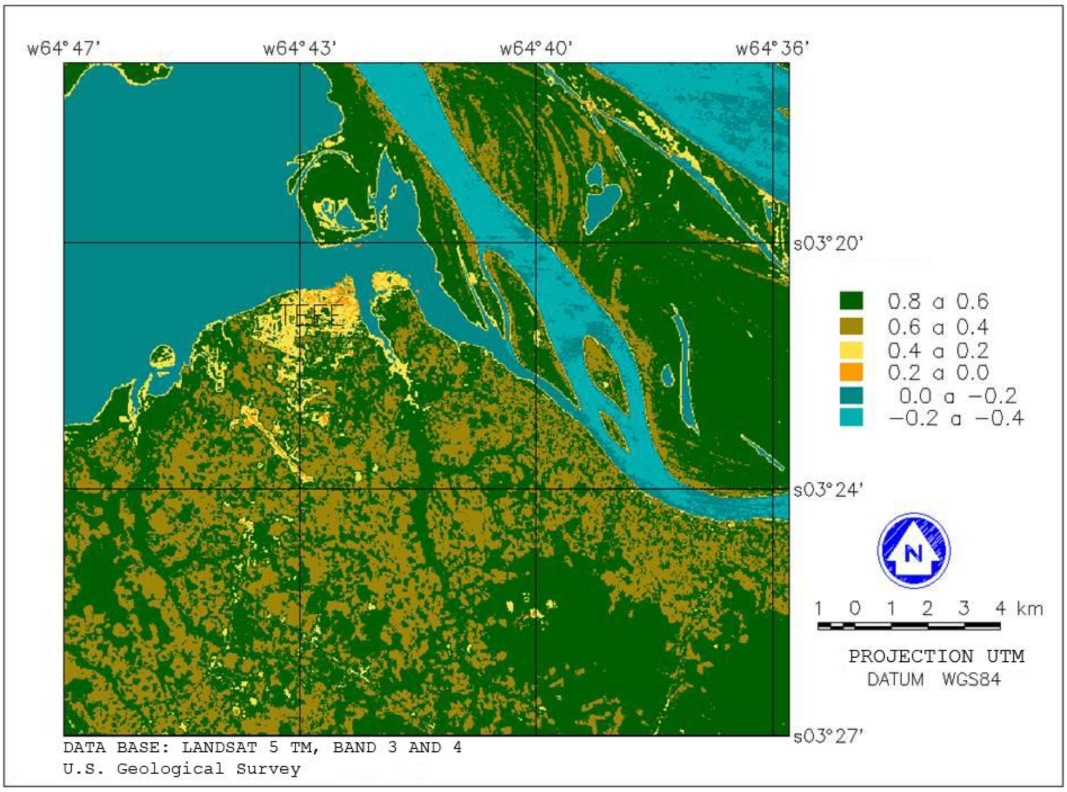
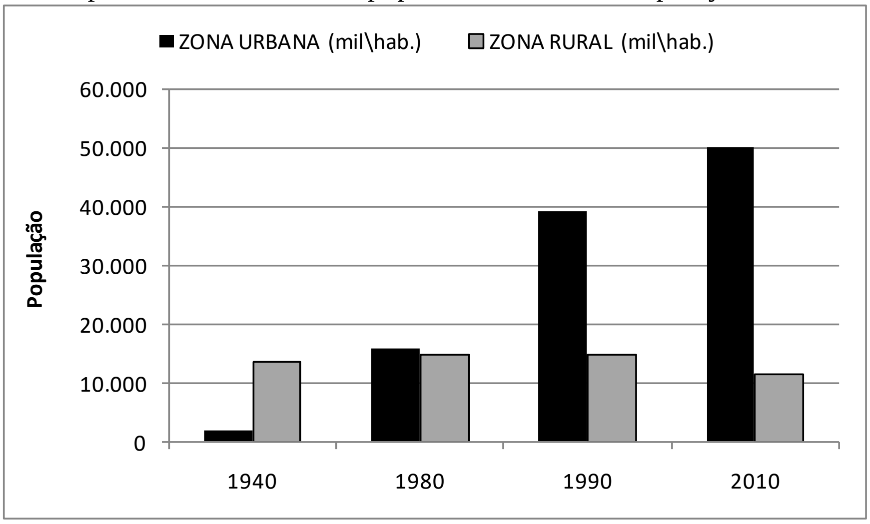


Figure 4. Vegetation Index the Normative Difference (NDVI) of the adjacencies of the urban area of Tefé in the year 2011.
Produced by: Authors (2016)

In addition, the expansion of urban areas resulting from the increased population that has come to live in the city over the years contributes to this landscape change. According to IBGE

(2010), urban population surpassed that living in the rural areas of Tefé from 1980 (Graphic 1).

Graphic 1. Urban and rural population of the municipality



Source: Pessoa (2004), IBGE(2010)

These land use changes may have direct effects on the microclimate of Tefé, such as an increase in temperature associated with changes in soil use and hence an arboreal vegetation reduction.

Thus, regional urban sprawl has also demonstrated wide changes in physical-natural attributes, such as vegetation, watercourses, and soil, and even in the local climate.

Table 1 shows that the average minimum temperature over the 20-year period was 22.7 °C whereas the average maximum temperature was 32.8 °C. These variables presented a standard deviation and coefficient of variation of 0.84 and 0.03 for the average minimum temperature and 0.91 and 0.04 for the average maximum temperature, respectively. Although the coefficients of variation are low, an increase in the average values of both variables was observed over the two decades. The average minimum temperature increased from 22.3 °C in the period of 1993–2002 to 23.1 °C in the period of 2003–2012.

Table 1. Minimum and maximum air temperature in Tefé (1993-2012)

Período de 1993-2012					
Variáveis	**Média do período**	**Desvio padrão**	**C.V**	**Média 1993-2012**	**Média 2003-2012**
T. Mínima	22,7	0,84	0,04	22,3	23,1
T. Máxima	32,8	0,91	0,03	32,6	33

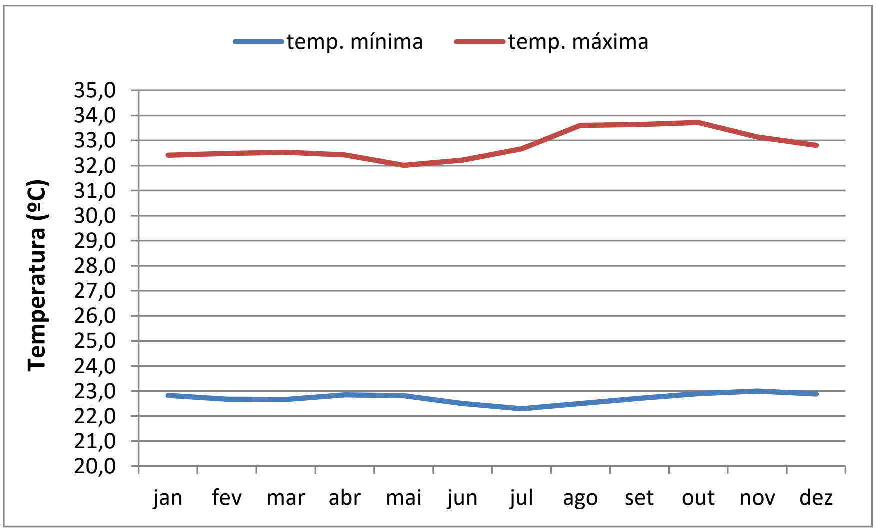
Produced by: Authors (2016)

From 1993 to 2012, the average minimum temperature was 22.8 °C in the summer, 22.8 °C in the autumn, 22.4 °C in the winter, and 22.9 °C in the spring (Graph 2).

The average maximum temperature was 32.6 °C in the summer, 32.3 °C in the autumn, 32.8 °C in the winter, and 33.5 °C in the spring.

Thus, the period during spring presented the highest values of temperature whereas the autumn presented the lowest values although the thermal amplitude between both periods is small, with a value of 1.2 °C. However, the minimum temperature is relatively constant over the seasons.

Graphic 2. Minimum and maximum air temperature in Tefé (1993-2012)



Source: INMET.
Produced by: Authors (2016)

The analysis of the average monthly temperature showed that over the years there was a tendency of increasing the number of warm and very warm months, especially from October to April. From 1993 to 2002, we observed 12 months with values tending to moderately warm and 2 months with values tending to warm.

However, in the period from 2003 to 2013, we observed 40 months with the highest minimum temperature (moderately warm) and 11 months with a temperature tending to warm (Table 2).

This increased average minimum temperature over the months, especially in the rainiest months, is in accordance with Aleixo and Silva Neto (2014), who observed an increase from 22.3 to 23.1 °C from the period of 1993–2003 to 2003–2012, respectively.

Table 2. Average monthly minimum temperature in Tefé-AM from 1993-2012.

ano	jan	fev	mar	abr	mai	jun	jul	ago	set	out	nov	dez
1993												
1994												
1995												
1996												
1997												
1998												
1999												
2000												
2001												
2002												
2003												
2004												
2005												
2006												
2007												
2008												
2009												
2010												
2011												
2012												

Source: INMET.
Produced by: Authors (2016)

The average monthly maximum temperature also showed a tendency to increase the values considered as moderately warm and warm, mainly from August to November. Thus, the less rainy months presented a tendency to increase the maximum temperatures, with a predominance of warm months from 2009 (Table 3).

From 1993 to 2002, 21 months presented a tendency of being moderately warm and 1 month warm, while from 2003 to 2012, 34 months tended to be moderately warm and 7 months warm.

According to Aleixo and Silva Neto

(2014, p. 8), "the increased temperature in the city may be related to land use changes and occupation around the meteorological station, which has in the surroundings a greater soil waterproofing, with the constructions of villages of military dwellings, altering the surface-atmosphere energy balance."

In addition, the months in which minimum and maximum temperatures increased over the years are different. Minimum temperatures increased in the rainy months (flooding) and maximum temperatures in the less rainy months (ebbing).

Table 3. Maximum monthly average temperature in Tefé-AM from 1993-2012

ano	jan	fev	mar	abr	mai	jun	jul	ago	set	out	nov	dez
1993												
1994												
1995												
1996												
1997												
1998												
1999												
2000												
2001												
2002												
2003												
2004												
2005												
2006												
2007												
2008												
2009												
2010												
2011												
2012												

Source: INMET.
Produced by: Authors (2015)

Analysis of the average minimum temperature in Tefé, Amazonas state, Brazil

The statistical analysis of the minimum temperature data showed, in general, a small variation, i.e. the data were less dispersed from the mean of the series and had values of coefficient of variation (CV) between 0.01 (1995, 1998, 2009) and 0.06 (2012) (Table 4).

The average minimum temperature presented the lowest value (22 °C) in 2000 and the highest value (23.8 °C) in 2010.

The standard deviation of minimum temperatures showed that February, March, June, July, August, and September had negative deviations and April, May, October, November, and December presented deviations above the average. The analysis of annual deviations associated with the average minimum temperature showed that the limit of positive deviation was exceeded only in 2010 whereas the limit value of negative deviation was exceeded in 1994 and 1995.

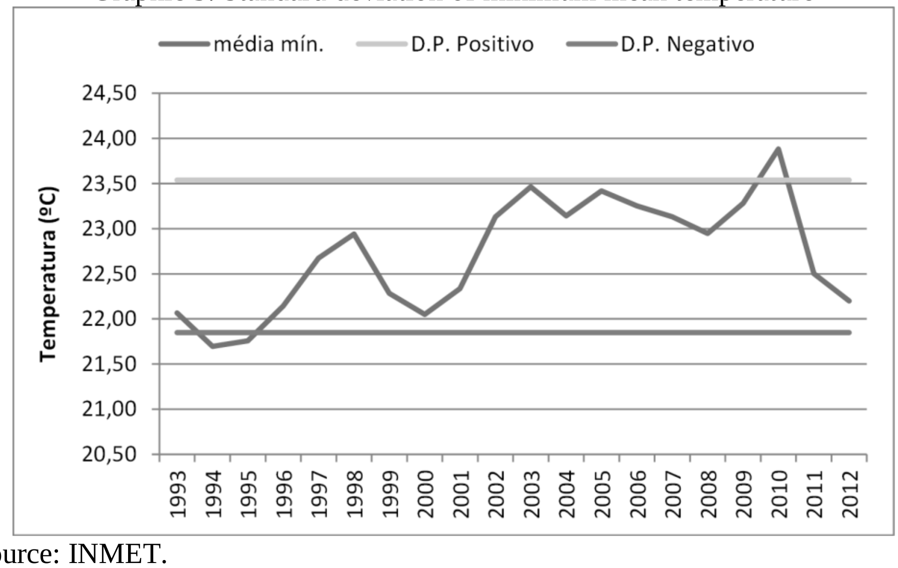
In general, the average minimum temperature presented annual values with significant increments from 2000 when compared to the previous decadal period, except for 2011 and 2012 (Graph 3).

Table 4. Annual average minimum temperature.

ano	D.P.	média	c.v
1993	0,59	22,07	0,03
1994	0,39	21,70	0,02
1995	0,32	21,76	0,01
1996	0,62	22,14	0,03
1997	0,48	22,67	0,02
1998	1,15	22,94	0,05
1999	0,46	22,28	0,02
2000	0,44	22,05	0,02
2001	0,79	22,34	0,04
2002	0,37	23,13	0,02
2003	0,46	23,46	0,02
2004	0,48	23,14	0,02
2005	0,52	23,42	0,02
2006	0,39	23,25	0,02
2007	0,50	23,13	0,02
2008	0,32	22,95	0,01
2009	0,29	23,28	0,01
2010	0,57	23,88	0,02
2011	0,49	22,50	0,02
2012	1,34	22,20	0,06

Produced by: Authors (2016)

Graphic 3. Standard deviation of minimum mean temperature



Source: INMET.
Produced by: Authors (2016)

Analysis of the average maximum temperature in Tefé, Amazonas state, Brazil

The statistical analysis of the maximum temperature data showed, in general, a small variation, i.e. the data were less dispersed from the mean of the series and had values of coefficient of variation (CV) between 0.00 (1995) and 0.04 (2001) (Table 5).

The average minimum temperature presented the lowest value (31.95 °C) in 1997, while the highest value (33.46 °C) was observed in 2010.

The standard deviation of maximum temperatures showed negative deviations from January to July whereas deviations above the average were observed from August to November.

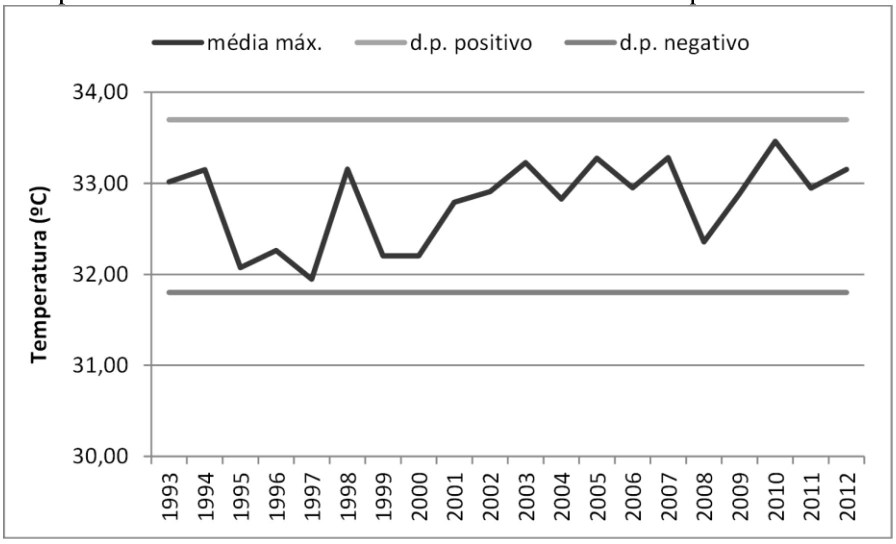
In Graph 4, the analysis of the annual deviations associated with the average maximum temperature showed an oscillation between positive and negative annual deviations. In general, the average maximum temperature presented annual values with significant increments from 2000 when compared to the previous decadal period.

Table 5. Maximum average annual temperature

ano	média	D.P.	C.V.
1993	33,02	0,91	0,03
1994	33,15	0,50	0,02
1995	32,07	0,08	0,00
1996	32,26	0,38	0,01
1997	31,95	0,99	0,03
1998	33,16	0,92	0,03
1999	32,20	0,87	0,03
2000	32,20	0,78	0,02
2001	32,79	1,32	0,04
2002	32,91	0,81	0,02
2003	33,23	0,76	0,02
2004	32,83	0,94	0,03
2005	33,28	0,65	0,02
2006	32,95	0,94	0,03
2007	33,28	0,89	0,03
2008	32,36	0,74	0,02
2009	32,89	1,10	0,03
2010	33,46	1,01	0,03
2011	32,95	0,88	0,03
2012	33,15	1,09	0,03

Produced by: Authors (2016)

Graphic 4**.** Standard deviation of the mean maximum temperature



Source: INMET.
Produced by: Authors (2016)

Table 6 shows the missing daily values for both variables. The minimum temperature data presented few values with problems over the 20-year period, with a total of 287 days. However, the maximum temperature had missing values in 963 days.

In the period from 1993 to 2002, we observed 143 missing daily data of minimum temperature and 570 of maximum temperature, while in the period from 2003 to 2012, 144 daily data of minimum temperature and 393 of maximum temperature were missing.

In spite of these problems in the data, maximum and minimum temperature values were analyzed by quantiles.

Table 6. Minimum and maximum daily temperature

Anos	T. Mínima	T. Máxima
1993		
1994		
1995		360
1996		202
1997	91	
1998	48	8
1999		
2000	3	
2001		
2002	1	
2003		
2004	33	31
2005	13	11
2006	1	
2007	2	
2008		132
2009	65	194
2010		
2011	23	25
2012	7	

Produced by: Authors (2016).

In the decade of 1993–2002, 73 days presented maximum temperature values equal to or above than 36 °C, increasing to 89 in the following decade.

Values from 34 to 35 °C increased from 65 in the decade of 1993–2002 to 156 in the following decade. In addition, values from 35 to 36 °C increased from 336 in the decade of 1993–2002 to 480 in the following decade (Table 7).

Daily values of minimum temperature also increased and values equal to or lower than 19 °C decreased, which is an indication of episodes associated with cold spell days in Tefé.

In the decade of 1993–2002, values equal to or lower than 19 °C occurred in 32 days and, in the following decade, only in 5 days.

Values from 19 to 20 °C were observed in 31 days in the decade of 1993–2002 and in 38 days in the following decade. Moreover, daily values from 20 to 21 °C occurred in 316 days in the decade of 1993–2002 and in 143 days in the following decade, indicating a weakening and absence of cold spell events in the area in the last analyzed decade and an increase of values of minimum daily air temperature.

Table 7. Daily temperature.

TEMPERATURA MÁXIMA	34°C< Yi ≤ 35°C	35°C< Yi ≤ 36°C	Yi ≥ 36°C
1993-2002	65	336	73
2003-2012	156	480	89
TEMPERATURA MÍNIMA	Yi ≤ 19°C	19°C< Yi ≤ 20°C	20°C< Yi ≤ 21°C
1993-2002	32	31	316
2003-2012	5	38	143

Produced by: Authors (2016)

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Final considerations

Land use change in Tefé showed that the balance of surface-atmosphere radiation has been altered by the process of appropriation of nature at a local scale.

The increase in the number of days with increased maximum and minimum temperatures were also observed in monthly and annual averages, demonstrating the importance of a territorial planning that takes into account the physical-natural conditions of the Amazonian landscape and incorporates the climatic dimension as support for planning and managing actions from a socio-environmental perspective.

This study also provides subsidies regarding climate changes at a meso- and macroscale over the years. However, the scarcity of observational data did not allow the analysis of a broader temporal and spatial data series.

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