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STUDY OF THE PHENOMENA OF URBAN HEAT ISLAND IN NORTHEAST OF BRAZIL IN THE STATES OF CEARÁ AND RIO GRANDE DO NORTE

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ABSTRACT

This work has the purpose of analyzing the formation of the Urban Heat Island (UHI) in the Northeast of Brazil (NEB) in some cities of the state of Ceará and Rio Grande do Norte. The UHI is a climatic phenomenon that occurs from the elevation of the temperature of an urban region compared to the rural region. Heat conduction is higher in the urban environment because of the physical properties of building materials, which consequently contribute to the increase in temperature contrast in relation to areas with more vegetation. The data used refer to the period from January 2000 to March 2016. These data are part of the Land Surface Temperature (LST) captured by the MODIS (Moderate Resolution Imaging Spectroradiometer) sensor, product MOD11 (Land Surface Temperature and Emissivity). Through these data, mean temperatures were obtained in the urban and rural regions, with the purpose of comparing them for the identification of UHI. In the city of Fortaleza, the maximum variation of diurnal temperature analyzed was in the first quarter of 2014, reaching 4ºC. In the first semester of each year the variation remained constant in average 2,5ºC. In the night period, the maximum variation occurred in the third quarter of 2011, where the variation reached 2.5ºC. The daytime UHI in the city of Sobral shows seasonality in the urban heating patterns during the day. The variation of the maximum diurnal temperature analyzed occurred in the years of 2004 and 2012, surpassing the 3.0ºC. In the city of Mossoró, the UHI presents a seasonal heating pattern, with the maximum variation of diurnal temperature analyzed being 3.5ºC.

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INTRODUCTION

The Urban Heat Island (UHI) is a climatic phenomenon that occurs from the elevation of the temperature of an urban area compared to the rural area.

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It occurs due to the removal of the vegetation cover of the city and the construction of large urban clusters, forming real "labyrinths" reflectors, that reflect the light and the solar radiation, as well as they prevent the air circulation, which provides the increase in the temperature. NASA (National Aeronautics and Space Administration) undertook a program of research, observation and long-term analysis of the planet with the launch in December 1999 of the TERRA satellite, formally known as EOS (Earth Observing System).

The MODIS (Moderate Resolution Imaging Spectroradiometer) sensor is one of the five satellite instruments responsible for producing images of the earth and the atmosphere (JUSTICE *et al.,* 2002). The Normalized Difference Vegetation Index (NDVI) is used to identify the presence of green vegetation in a region and is calculated from the reflectance values of the red to infrared spectral bands. In the rural and forest areas, the vegetation cover allows the process of evaporation and evapotranspiration, which reduces temperatures, which is not the case in large cities, which are waterproofed by buildings and without vegetation cover, which consequently causes an increase in the temperature of the region. In a study by Weng and collaborators (2004) in the city of Indianapolis, USA, analyzed the amount of vegetation and the UHI formation with Landsat ETM + sensor images (thermal infrared data of 60 m). UHI detection generally uses NDVI as an indicator of abundance of vegetation to estimate the temperature of the earth's surface. Land Surface Temperature (LST) provides information on the temporal and spatial variations of the steady state of the surface. LST is also used to estimate evapotranspiration, vegetation monitoring and urban climate. The UHI formation is related to the increase in LST and the increase in the air temperature of an urban region in relation to neighboring areas with more vegetation (GIANNAROS *et al.,* 2013).

In some regions of the city, it is common to find the temperature of the air in urban environments through meteorological stations, since these stations are usually isolated in parks and airports, not taking into account all the heterogeneity of the city. Observing this difficulty, LST is a good option for spatial evaluation of temperatures in large urban areas, since temperature is estimated through satellite images (Barros; Lombardo, 2016). The LST used is estimated from the radiance data collected by the MODIS sensor during its daytime and nighttime passage, around 10:30 am and 9:00 pm local time, respectively, with a spatial resolution of 1 km and a temporal resolution of 8 days (LI *et al.,* 2013). In a study carried out in the city of Shanghai, China, 11 meteorological stations and data from the LST of the MODIS sensor were used to investigate the formation of UHI in the year 2005. The research indicates that the air temperature and LST were spatially identical to those observed in central Shanghai, with only a slight difference in scope and scope. Thus, the heat island intensity, expressed by air temperature and LST, became basically similar (LIU *et al.,* 2013). The intensification of the UHI causes some impacts on society, such as health problems and increased consumption of electric energy. The higher the UHI, the greater the thermal discomfort and the illnesses. Knowing this, this work focuses mainly on the technical aspects of UHI, such as its intensity.

MATERIALS AND METHODS

The strategy used is to construct rectangular boxes with identical areas on the urban part of the city and the rural part with the purpose of comparing the LST of the urban box with the average LST of the rural boxes. We consider urban areas with more than 60% of construction and rural areas with less than 20% of construction. In order to minimize the effects of altitude differences between boxes on temperature, rural boxes with altitudes above 100 meters from the urban box are excluded. In order to identify the urban and rural area, the globeland30 data was used with the resolution of 30 meters, the resolution of the LST data of the MODIS sensor being 500m.

Figure 1 shows the separation of the urban and rural zones into boxes. The data used refer to the period from January 2000 to March 2016, the product used is MOD11 (Land Surface Temperature and Emissivity). Through these data were obtained mean temperatures in the urban and rural regions, with the purpose of comparing them for the identification of UHI. The objective of this research is to estimate the amplitude of the UHI phenomenon, day and night, in the states of Ceará and Rio Grande do Norte, Brazil, using remote sensing using MODIS sensor data on the Terra satellite. To perform this research was used the program Ferret.

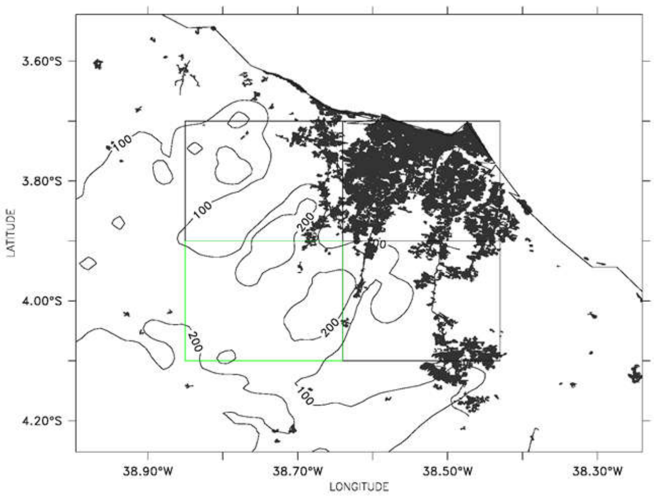

Figure 1. Separation of study regions through boxes in the city of Fortaleza

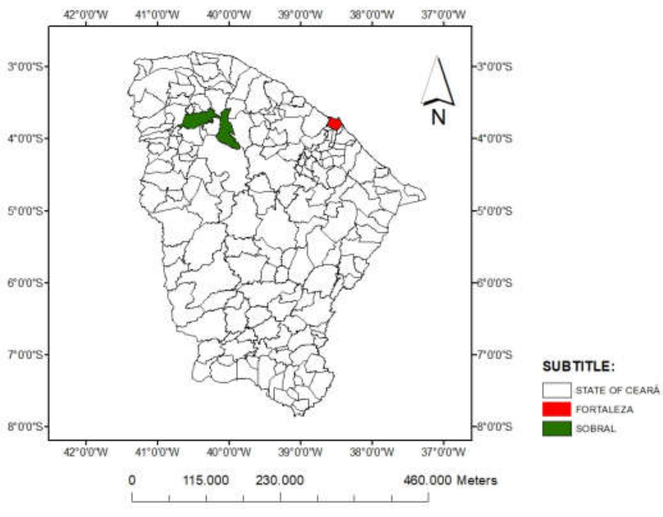

Figure 2. Map of the state of Ceará with the cities studied

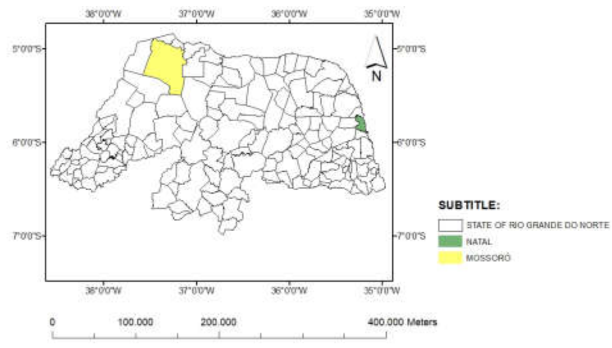

Figure 3. Map of the state of Rio Grande do Norte with the cities studied

Study area

The study area is located in the Northeast of Brazil (NEB) and is located in two states: Ceará and Rio Grande do Norte, as shown in Figures 2 and 3. The state of Ceará has a total area of 148,920,472 km². The population of the state estimated for the year 2017 was 9,020,460 inhabitants, data from the IBGE (2017), the population of the capital Fortaleza estimated at 2,627,482 inhabitants and its area of 313,140 km². The city of Sobral has the estimated population of 205,529 inhabitants, being its area of 2,130 km². The state of Rio Grande do Norte has a total area of 52,811,126 km², with a total population of 3,507,003 inhabitants, data from the IBGE (2017), with the population of Natal capital estimated at 885,180 inhabitants and its area of 167, 3 km². The city of Mossoró has the estimated population of 295,619 inhabitants, and its area is 2,110 km². This work aims to analyze the formation of UHI in the main cities of the state of Ceará and Rio Grande do Norte.

RESULTS

Figure 4 shows UHI diurnal in the city of Fortaleza, highlighting the seasonality in the patterns of urban heating during the day. The semester without rain UHI intensification tends to decrease, or even reverse in the drier years. It is observed that in rainier years, such as 2004 and 2009, the seasonality in daytime UHI tends to decrease. In the drier years this seasonality is accentuated and there is a decrease in daytime UHI in the second half of 2012, coinciding with the prolonged period of the drought. The reduction in daytime UHI in the second semester can be explained by: 1) the intensification of large-scale winds in this period, which reduces the Daytime Temperature (GT); 2) reduction of vegetation fraction in this period, which increases the Surface Temperature (ST) in rural areas. Both effects are inversely correlated with UHI in the second half of rainy years (eg, 2009) can be explained by the greater vegetation cover in the rural or suburban area in these years. Figure 5 shows night UHI in the city of Fortaleza, highlighting the seasonality of urban heating patterns during the night. The nocturnal UHI in the city is less intense than the daytime UHI and the presence of the UHI. The UHI at night is less intense than the daytime in Fortaleza. However, the effect of seasonality of the intensity of the winds on the nocturnal GT is lower. Soil moisture and surface heterogeneities (built and vegetated areas) are more effective in determining the nocturnal UHI in Fortaleza. The formation of UHI diurnal and nocturnal in the city of Fortaleza is shown in Figure 6. These values of thermal amplitude represent the diurnal and nocturnal course of the surface temperature. It is observed that the variation of the temperature in the diurnal period is greater than the nocturnal period. The maximum variation of diurnal temperature analyzed in the period of 16 years was in the first quarter of 2014 that reached 4ºC. In the first semester of each year the variation remained constant in average 2,5ºC. In the night period, the maximum variation occurred in the third quarter of 2011, where the variation reached 2.5ºC. The daytime UHI in the city of Sobral shows seasonality in the urban heating patterns during the day. In the non-rainy months the UHI tends to decline, and some cases to reverse, for example, at the end of the years 2004, 2012, 2013 and 2014 and the beginning of the years of 2006 and 2009. The decrease of the daytime UHI in the second half is explained by the reduction of vegetation fraction in this period, which increases TS in rural areas. The variation of the maximum diurnal temperature analyzed occurred in the years of 2004 and 2012, surpassing the 3,0ºC.

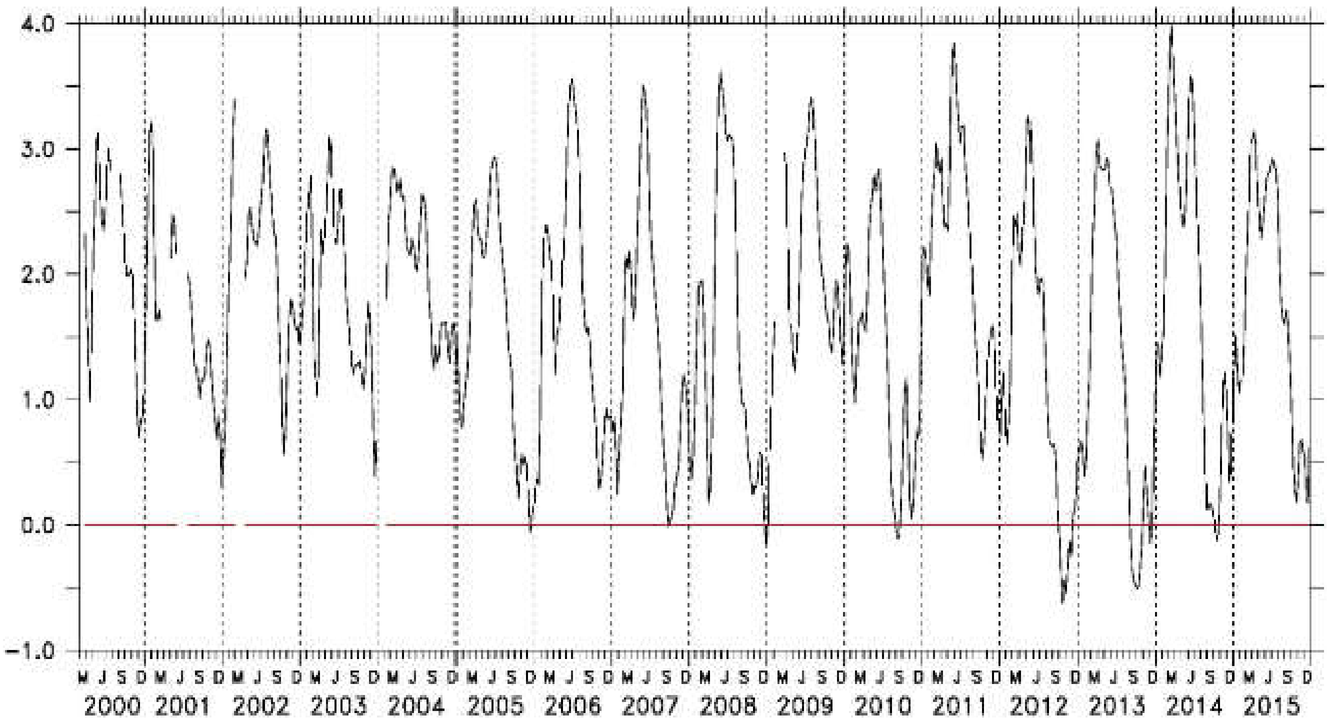

Figure 4. Temperature difference in the city of Fortaleza between urban and rural area during the daytime period

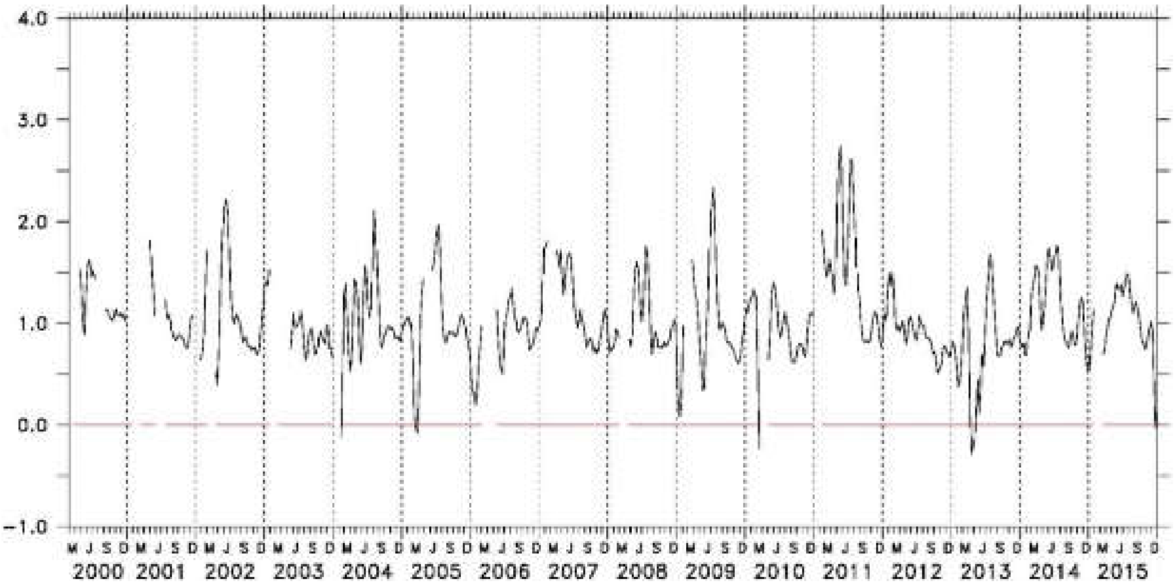

Figure 5 - Temperature difference in the city of Fortaleza between urban and surrounding area at night time

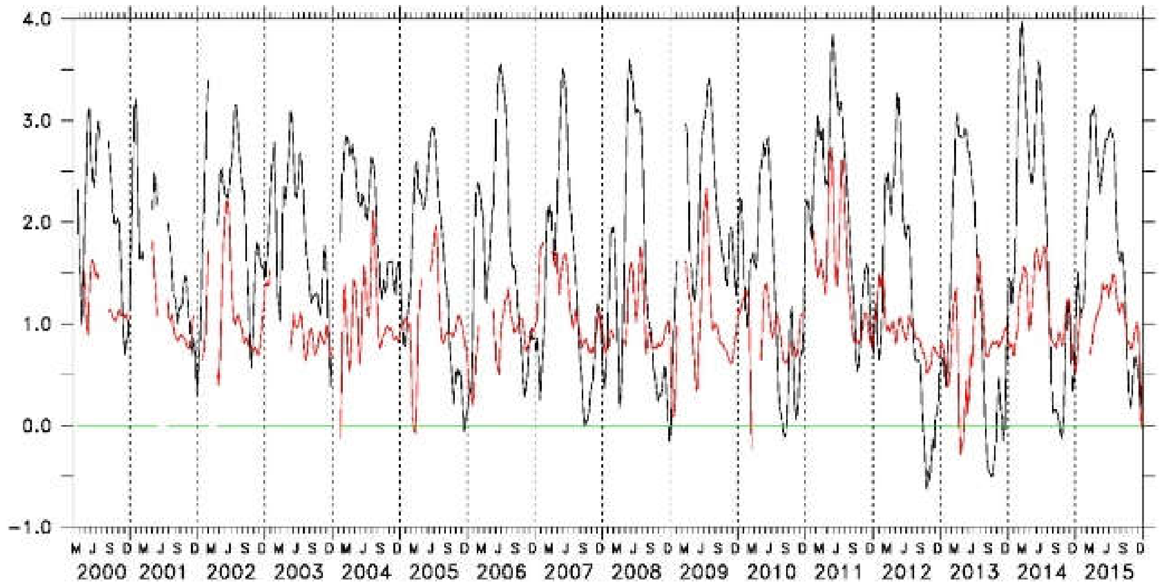

Figure 6. Temperature difference in the city of Fortaleza between urban area and surrounding area in the diurnal (black) and nocturnal (red)

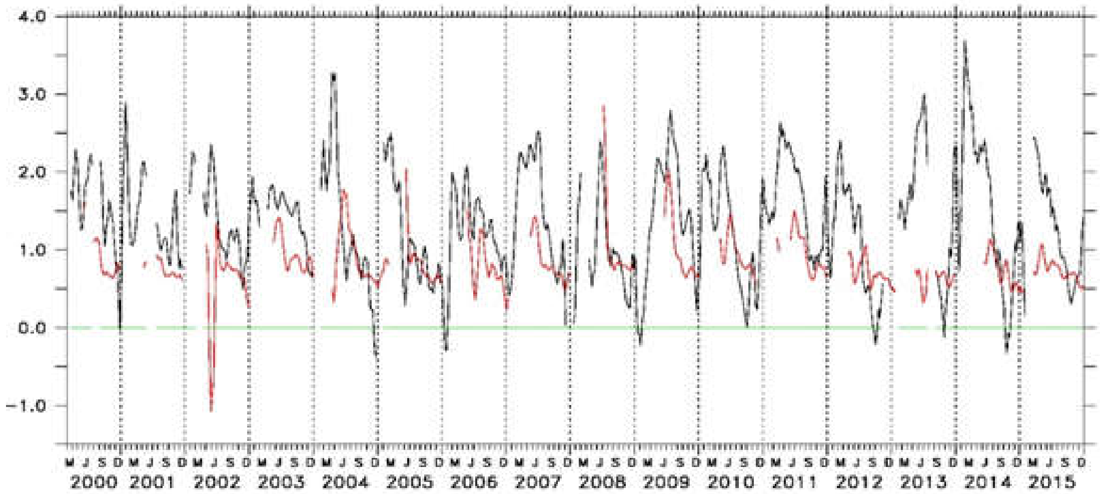

Figure 7. Temperature difference in the city of Sobral between urban area and surrounding area in the diurnal (black) and nocturnal (red)

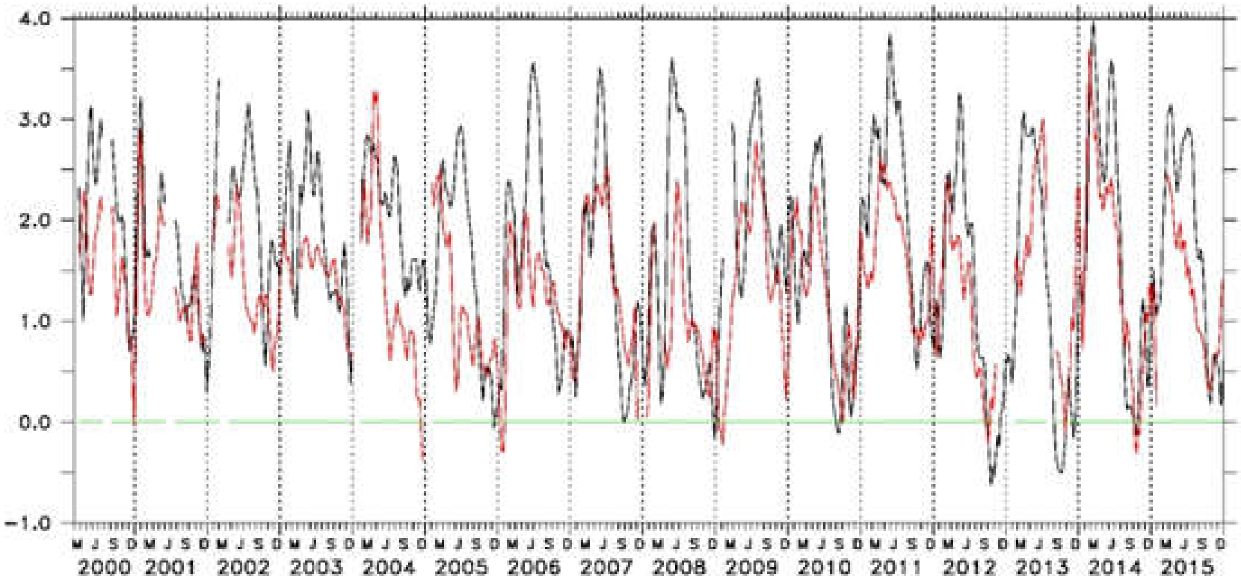

Figure 8. Diurnal temperature difference between urban and rural regions in the city of Fortaleza (in black) and the city of Sobral (in red)

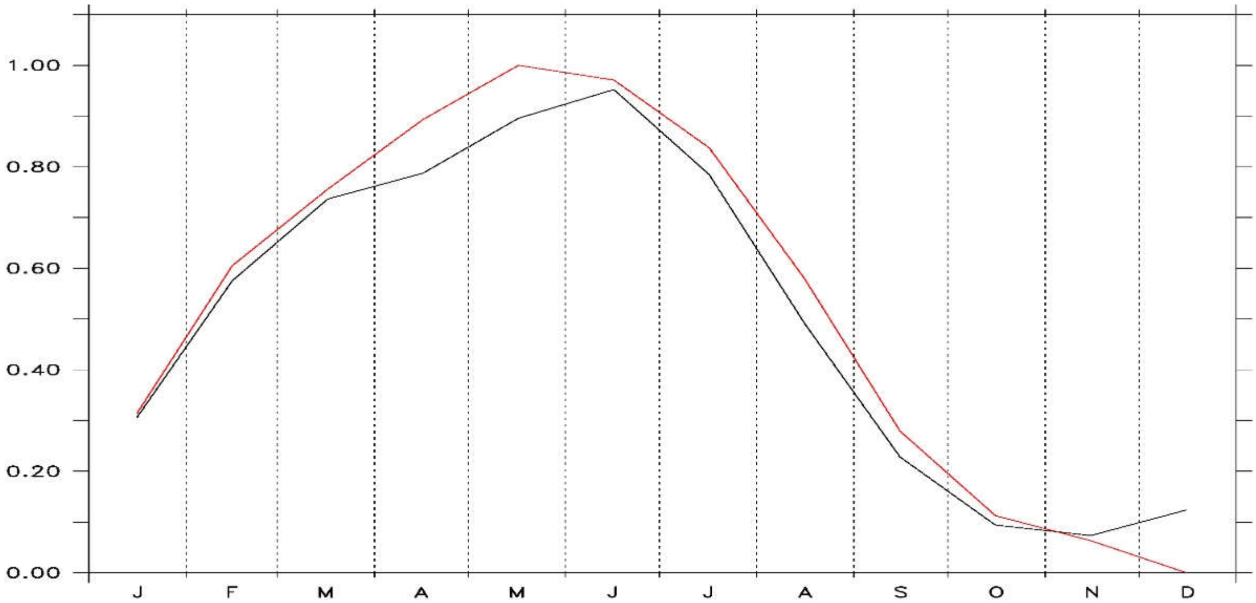

Figure 9. Evolution of vegetation and temperature difference between urban and rural regions in the city of Fortaleza. Difference in temperature (in black) and amount of vegetation (in red)

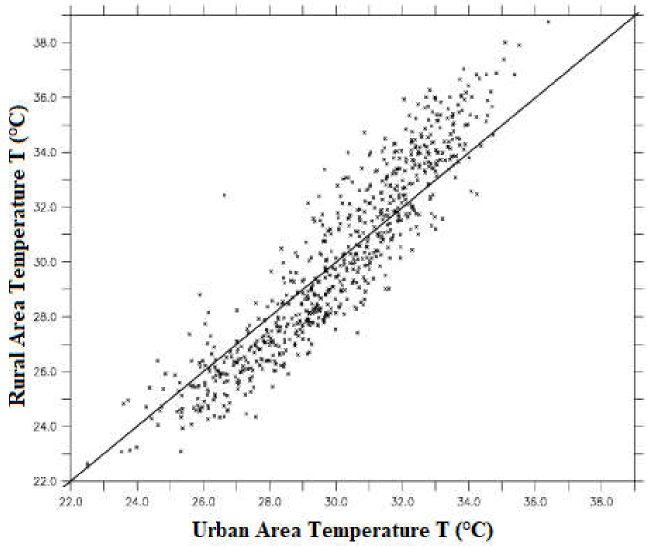

Figure 10. Daytime temperature dispersion in the city of Natal

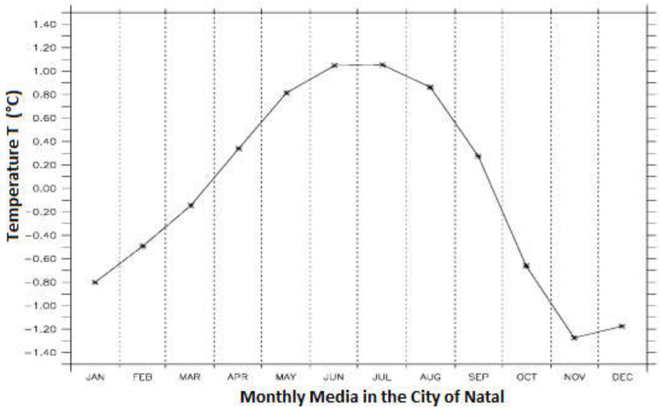

Figure 11. Monthly average of the diurnal temperature difference in the city of Natal between urban and rural area

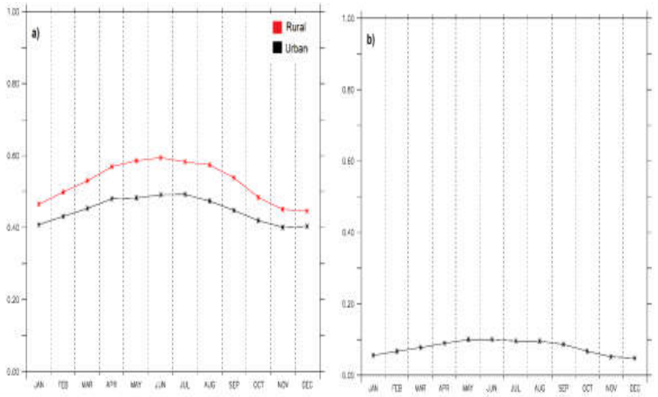

Figure 12. NDVI fraction in the city of Natal during the daytime period (a) Monthly average of NDVI between urban region and rural region (b) Difference of NDVI between regions

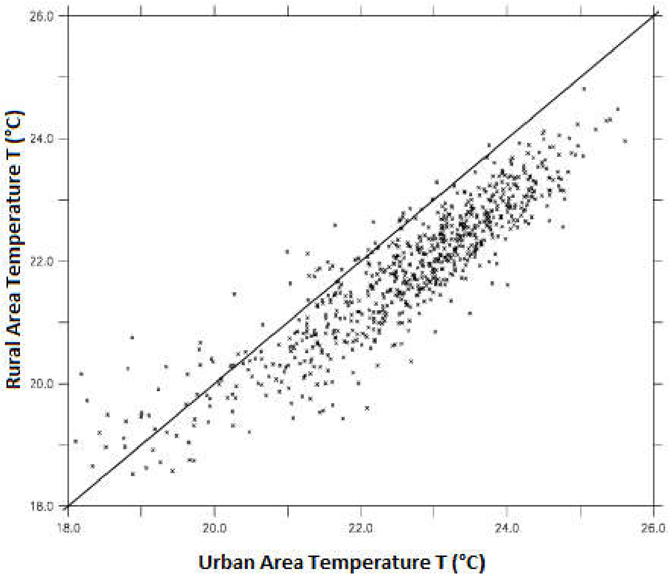

Figure 13. Temperature dispersion at night in the city of Natal

It is observed that the difference in daytime GT between the cities of Fortaleza and Sobral from the strongest winds in the second half of the year tends to equal the diurnal UHI size even in cities with dimensions and microclimates as different as Fortaleza and Sobral. There is a relationship between the amount of vegetation and the temperature in a given place. The plants absorb much of the solar energy that falls on the earth's surface. In this way, more open areas, with little presence of vegetation, tend to absorb more heat, causing the temperature increase in the region. Equation 1 is used to normalize the temperature and amount of vegetation and Figure 9 shows the evolution of the vegetation related to the normalized temperature.

$$V_{norm} = \frac{V(t) - V_{min}}{V_{max} - V_{min}}$$

Where Vnorm is the normalized value of the variable V (t), which in turn is the time series of temperature or NDVI, Vmax is the maximum value of the variable and Vmin is the smallest value of the variable. In the graph of Figure 9, a monthly average of 2000 to 2016 was realized, where it was verified that the temperature difference between the urban and rural regions follows the evolution of the vegetation, this happens because of the difference of vegetation between areas that consequently increases the temperature in the urban region or the rural region. In the period from October to January the vegetation difference is low among the regions, that is, in the rural area there is not so much vegetation, becoming this area similar to the urban area, generating a small variation in temperature. In this time interval the temperature difference falls, due to the absence of vegetal cover that increases energy absorption in this region, being close to the temperature of the big cities. The rainy season in Ceará usually happens from December to March, where vegetation index begins to increase. In the period from April to June there is an increase in the vegetation difference between the regions that consequently increases the temperature variation between the urban and rural areas.

Figure 10 shows the number of events in urban and rural areas. The line represents the average temperature of the two regions. It is noticed that the rural area in some moments has the higher temperature than the urban area. This is due to the constant influence of the sea breeze in the city of Natal, which softens the temperature of the region. Figure 11 shows the temperature difference between the regions, note that the apex of the difference occurs in the months of June and July, reaching a thermal amplitude higher than 1ºC. Figures 10 and 11 show that the city of Natal does not suffer from the intensification of the UHT. This phenomenon is classified as weak, with little influence in the city, due to the presence of the sea breeze and the amount of vegetation in both regions. Directly influence the formation and intensification of UHI. Figure 12 shows the amount of NDVI in the Natal region. Figure 14 shows that there is an UHI formation in the city of Natal at night.

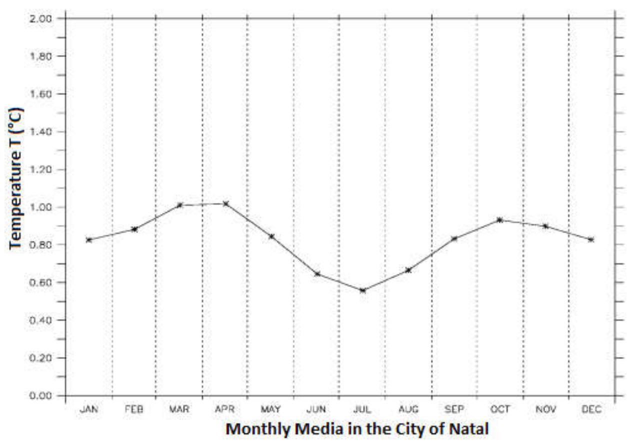

Figure 14. Monthly average of the nocturnal temperature difference in the city of Natal between urban and rural areas

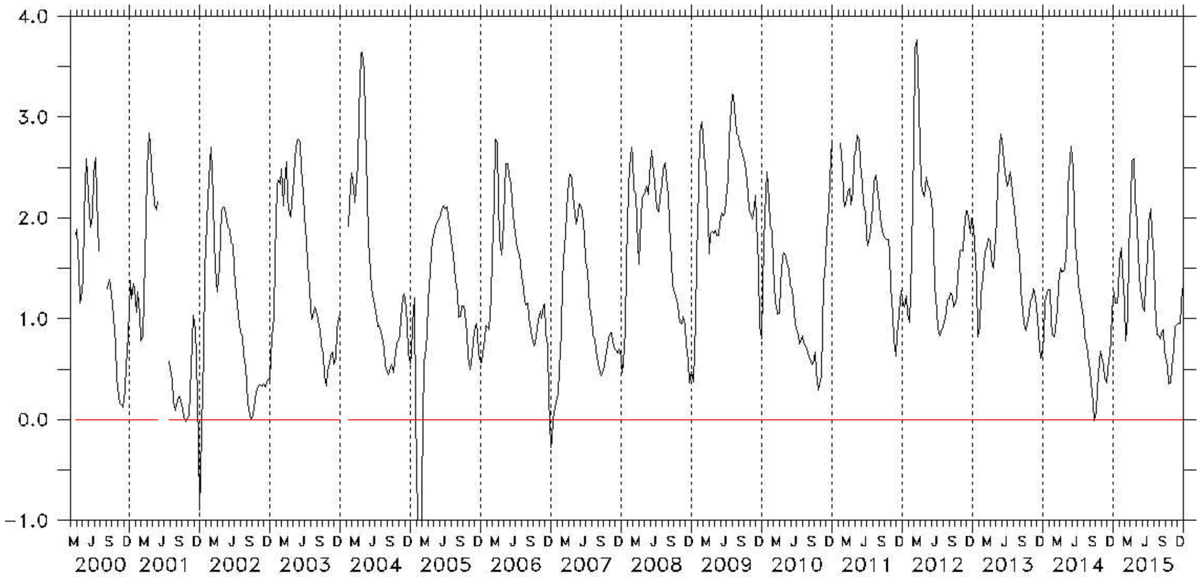

Figure 15. Temperature difference in the city of Mossoró between urban area and surrounding area during the daytime period

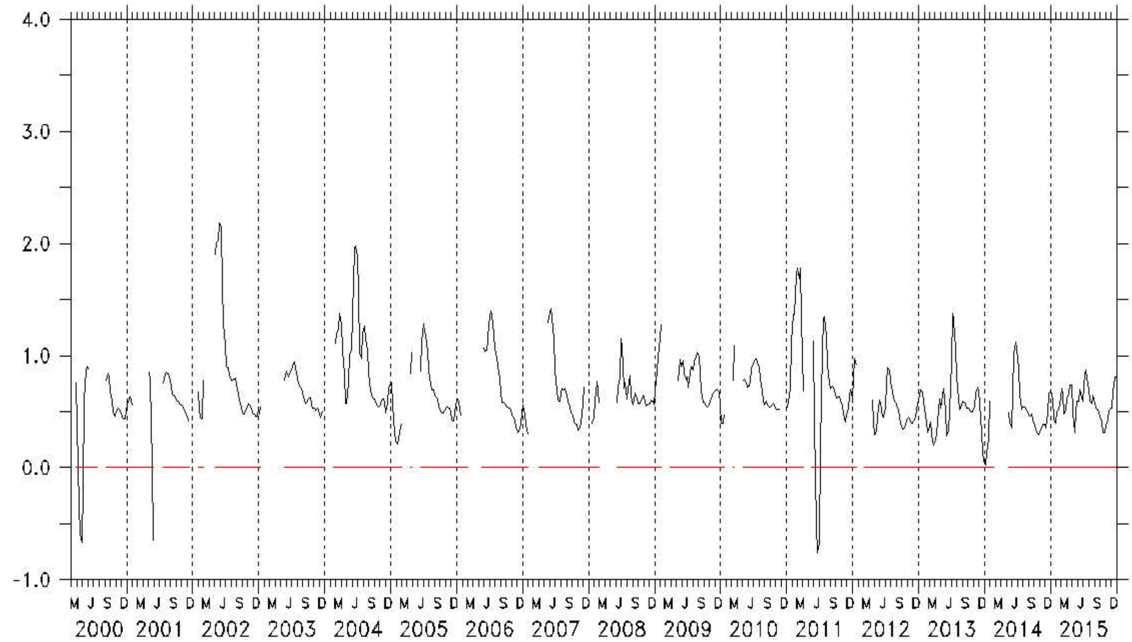

Figure 16. Temperature difference in the city of Mossoró between urban area and surrounding area at night

In this period studied the temperature of the surface of the city is around 1ºC characterizing in a weak UHI. Note that in almost every analyzed period the city temperature is higher than the neighboring areas, showing the continuity and intensification of this phenomenon. The UHI in the city of Mossoró presents a seasonal warming pattern, as shown in Figure 15. The first half is marked by the large temperature difference between the urban and rural regions. In the second semester the difference diminishes due to the absence of rainfall that reduces the amount of vegetation in the rural area. The reduction of vegetation fraction in this period increases the Surface Temperature (ST) in rural areas due to the greater energy absorption on the exposed surface. In rainy years, for example 2009, there is good temperature variation between regions in the second half. This is due to a greater coverage of vegetable in the rural region, which increases the difference in temperature between the two regions. The nocturnal UHI in the city of Mossoró is less intense than the daytime UHI.

The presence of UHI was maintained for a good part of the time, mainly in the years of 2002, 2004 and 2011. These values of thermal amplitude represent the day and night course of the surface temperature in the city of Mossoró. The maximum variation of diurnal temperature analyzed in the 16-year period occurred in the first quarter of 2004 and 2012, reaching 3.5ºC. The daytime UHI presents seasonality in the urban heating patterns during the day. The decrease in daytime UHI in the second semester is explained by the reduction of vegetation fraction in this period, which increases ST in rural areas.

Conclusion

The results obtained in this study show that there is UHI formation in medium and large cities in the state of Ceará and Rio Grande do Norte. The intensification of UHI generates impacts on society, such as thermal discomfort, health problems and increased consumption of electric energy. The city of Fortaleza is considered one of the great metropolis of Brazil and its results demonstrate heating patterns in each zone studied, where the UHI had a seasonal effect during the study period, as shown in Figures 4 and 5. In the first semester of each year the variation remained constant at an average of 2.5ºC. In the night period, the maximum variation occurred in the third quarter of 2011, where the variation reached 2.5ºC. The maximum variation of daytime temperature analyzed in the city of Fortaleza during the 16-year period was in the first quarter of 2014, which reached 4ºC. In medium-sized cities such as Sobral and Mossoró, the UHI presents seasonality in the patterns of urban heating during the day. In Sobral, the variation of the maximum diurnal temperature analyzed occurred in the years of 2004 and 2012, surpassing the 3.0ºC. In the city of Mossoró, the first semester is marked by the great temperature difference between urban and rural regions. The maximum variation of diurnal temperature analyzed reached 3.5ºC in the city of Mossoró. NDVI shows the abundance of vegetation in a region. In cities where the NDVI difference between regions is small, the UHI tends to be weak or even non-existent, as an example of the city of Natal (Figures 10 and 11). According to the result found in this study, the UHI dynamics observed allows us to say that it is seasonal, the UHI phenomenon is more intense in the rainy season, due to the contrast of vegetation between the regions.

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