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Quantifying the effect of waterways and green areas on the surface temperature

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ABSTRACT. The cooling effects of urban parks and green areas, which form the "Park Cool Island" (PCI) can help decrease the surface temperature and mitigate the effects of urban heat islands (UHI). Therefore, the objective of this research was to know the temporal variability of PCI intensity, as well as analyze the factors that determines it and propose an equation to predict the PCI intensity in Iporá, Goiás State, Brazil. To this purpose, the PCI intensity values were obtained using the Landsat-8 satellite (band 10), and then correlated with the NDVI and the LAI, in which proposes equations through multiple linear regression to estimate the PCI intensity. The results indicated that: 1) the greater the distance of the natural area, greater the surface temperature; 2) there is a great seasonality in PCI, in which the intensity of PCI is much higher in the spring (or close to it); 3) the relationship between NDVI and LAI variables, showed good coefficients of determination; 4) the equations for the buffer of 200 and 500 m, had low RMSE with high coefficients of determination (r^2 = 0.924 and r^2 = 0.957 respectively).

Keywords: urban heat island (UHI), *Park Cool Island* (PCI), surface temperature.

Quantificando o efeito dos cursos d'água e área verde na temperatura de superfície

RESUMO. Os efeitos de resfriamento de parques urbanos ou áreas verdes, que formam o "*Park Cool Island*" (PCI) podem ajudar a diminuir a temperatura da superfície e atenuar os efeitos das ilhas de calor urbanas (ICU). Diante disso, o objetivo desta pesquisa foi de conhecer a variabilidade temporal da intensidade da PCI, assim como analisar os fatores que a determina, propondo uma equação para predizer a intensidade da PCI em Iporá, Estado de Goiás, Brasil. Para tanto os valores da intensidade da PCI foram obtidos a partir do satélite Landsat-8 (banda 10) e em seguida correlacionados com o NDVI e o IAF, nas quais foram propostas equações, por meio de regressão linear múltipla, para estimar a intensidade da PCI. Os resultados indicaram que: 1) quanto maior a distância da área natural maior a temperatura de superfície; 2) existe grande sazonalidade na PCI, na qual a primavera (ou próximo dela) a intensidade da PCI é muito superior; 3) a relação entre as variáveis NDVI e IAF mostraram bons coeficientes de determinação; 4) as equações obtidas para o buffer de 200 e 500 m apresentaram baixo RMSE com elevados coeficientes de determinação (r^2 = 0,924 e r^2 = 0,957 respectivamente).

Palavras-chave: ilha de calor urbana (ICU), *Park Cool Island* (PCI), temperatura de superfície.

Introduction

Urbanization is one of the most obvious results of human activity on the climate. Weather variables such as: air temperature, wind, humidity, heat stress, air pollution and many others are influenced (Alcoforado, Lopes, Alves, & Canário, 2014; Alves & Biudes, 2012). According to Parlow, Vogt, and Feigenwinter (2014) there are basic differences between the urban area and non-urban, therefore, the urban area:

(1) Has a roughness in the high aerodynamic surface that influences the vertical turbulence and wind fields.

(2) Has a radiation and a completely different energy balance, due to the physical and thermal properties of building materials.

(3) It is highly three-dimensional and, therefore, a very complex surface to all exchange processes within the urban boundary layer.

(4) It is a significant source of pollutants and heat.

The most prominent feature of urban climate is the effect of the urban heat island. The urban heat island (UHI) is a phenomenon in which the air temperature in densely populated cities is higher than rural areas, this is, currently, the main character of the urban climate (Lopes, Alves, Alcoforado, & Machete, 2013; Lu, Li, Yang, Zhang, & Jin, 2012; Parlow et al., 2014).

The UHI not only causes high temperatures in the summer and increase in energy consumption for cooling, but also leads to serious problems in the thermal comfort of people and even health (Abreu-Harbich, Labaki, & Matzarakis, 2013; Ali-toudert, Djenane, Bensalem, & Mayer, 2005; Gabriel & Endlicher, 2011; Tan et al., 2010). Thus, mitigating the UHI is essential.

It is well known that urban green areas can reduce temperatures in cities through shading and evaporative cooling (Bernatzky, 1982; Oliveira, Andrade, & Vaz, 2011). Urban parks have been considered an important part of urban vegetation, which are cooled more than their surrounding areas and may form the effect of 'island of freshness' of the Park ('*Park Cool Island*', or PCI) (Cao, Onishi, Chen, & Imura, 2010; Jauregui, 1990).

Therefore, the aim of this study was to know the temporal variability of PCI intensity of the waterway (Tamanduá Creek) and surrounding green area, and analyze the factors that determines it, proposing an equation to predict the intensity of PCI in Iporá, which will serve urban planners to mitigate heat islands, either by creating green areas, or for its optimization.

Material and methods

This study took place in the city of Iporá, Goiás State, Brazil. The study site is located in the southwestern state of Goiás. The municipality of Iporá has a land area of 1,026.384 km^2 with a population of 31,274 inhabitants Instituto Brasileiro de Geografia e Estatística (IBGE, 2014). The climate can be divided into two typical seasons, a hot and dry and another hot and rainy. The location of the city Iporá can be observed in Figure 1.

PCI calculation

Usually the intensity of PCI is measured based on observations of the air temperature along transects or stations within green areas and the surrounding urban area (Cao et al., 2010). Following the definition of the urban heat island intensity, as the temperature difference between the warmer area of the city and its suburb (Oke, 1973), in this research, as well as in the work of Cao et al., (2010), Chow, Pope, Martin, and Brazel (2011) and Ren et al., (2013), the intensity of PCI was defined as in the Equation 1.

$$T_{PCI} = T_C - T_V \quad (1)$$

where T_C is the average of the surface temperature surrounding the green area with *buffer* of 200 and 500 m, and T_V is the average surface temperature in the green area.

Surface temperature calculation

Using the thermal band (band 10) of the Landsat - 8 to calculate the surface temperature, with spatial resolution of 100 m, but processed to 30 m, with wavelength of 10.6 to 11.19 μm. Using images of the year 2015. However, due to imaging problems or cloud covering, common in the rainy season in the Cerrado region, as noted by Santos, Ferreira Júnior, and Ferreira (2011), only the following dates were selected: 5/30/2015, 6/15/2015, 7/1/2015, 7/17/2015, 8/2/2015, 8/18/2015, 9/3/2015, 9/19/2015 and 10/5/2015.

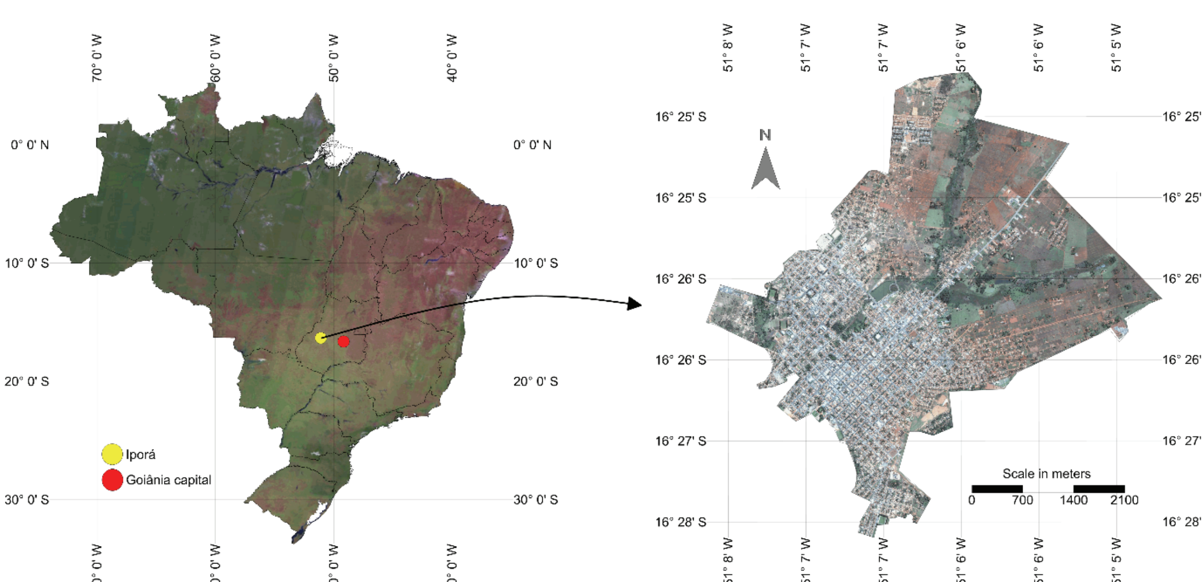

Figure 1. Location of the city Iporá, Brazil.

The calculations used to obtain the surface temperature are in the method DOS1 (*Dark Object Subtraction*) that consists of an atmospheric scattering correction method in estimating the atmospheric interference directly from the digital numbers (DN) of the satellite image, ignoring atmospheric absorption. For the application of this technique, there is no need to obtain data about the atmospheric conditions on the date for the images collected.

Shape calculation

The shape and size of green areas can affect the PCI. Studies by Cao et al., (2010), Chang, Li, and Chang (2007), Ren et al., (2013), Spronken-Smith and Oke (1998) and Zhang, Zhong, Feng and Wang (2009) discovered that there is a positive and significant correlation between the intensity of the PCI and the size of the urban park. The *Landscape shape index* (LSI) is a way to compute the relationship between the perimeter and the area, this measurement was used by Cao et al., (2010), McGarial and Marks (1995) and Patton (1975), the more concentrated and compact the areas are, lower the LSI value, which can be obtained by the Equation 2.

$$LSI = \frac{P_t}{2\sqrt{\pi \times A}} \quad (2)$$

where

P_t is the total perimeter around the green area and A is its area. Here, we calculated the LSI value through the buffer of 30 m from the waterway surrounding the green area (Figure 2).

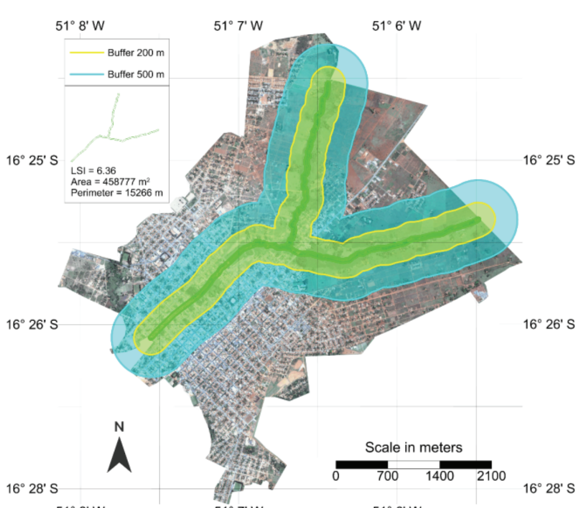

Figure 2. *Buffers* used for the PCI calculation.

Ideally LSI should be equal or close to 1 (Cao et al., 2010). In the Figure 2 are the buffer of 30 m (regarding the waterway and the green area) and the buffers of 200 and 500 m. The definition of the buffer of 200 m was based on the observations of Alves and Biudes (2013) and 500 m in Oke (2006).

Results and discussion

The surface temperature in the green area and the *buffers* of 200 and 500 m, are in the Figure 3. There is high seasonality in the surface temperature values, with a significant increase throughout 2015. The images for the fall showed the lowest values, in the day 5/30/2015 the surface temperatures were between 22 and 28°C and in the day 6/15/2015 varied from 23 to 29°C, that is, low surface temperatures with little temperature variation. From the beginning of the winter, the temperatures increased significantly, with its apex in the picture of the day 9/19/2015 with a minimum value of 31.4°C and maximum of 47.5°C. In all the images (Figure 3) there is the effect of the green area surrounding the waterway (Tamanduá Creek), on these images is already possible to verify the existence of the PCI.

The sets of surface temperature data of each *buffer*, represented by the *boxplots* (Figure 4), denote the pattern observed in Figure 3. The farther from the core of the green area, the greater the ST. In all thermal images, the buffer of 30 m (green area/waterway) had the lowest values of ST.

As shown in Figure 4, the highest temperature ranges were observed on the *buffer* of 500 m, either by owning more data (larger area), or entering in urban areas and therefore have more influence of the characteristics of urban land use. The highest and lowest amplitude of ST occurred in the days 9/19/2015 (16°C), 5/30/2015 and 6/15/2015 (both with amplitude of 6°C).

The intensity of the PCI (Figure 5) varies according to the variation of the surface temperature (Figure 3 and 4), with lower values in the fall, gradually increasing to its maximum value of 2.8 and 4.5°C in 9/19/2015, respectively in the *buffers* of 200 and 500 m. In the *buffer* of 500 m, in all observations (nine thermal images), recorded the highest intensities of PCI compared with the *buffer* of 200 m.

The seasonality of the PCI has been observed in other studies: Ren et al., (2013) observed the variation of PCI in the summer and autumn in the parks of the city of Changchun in China and found that in the summer, the intensity of the PCI was far superior to the autumn.

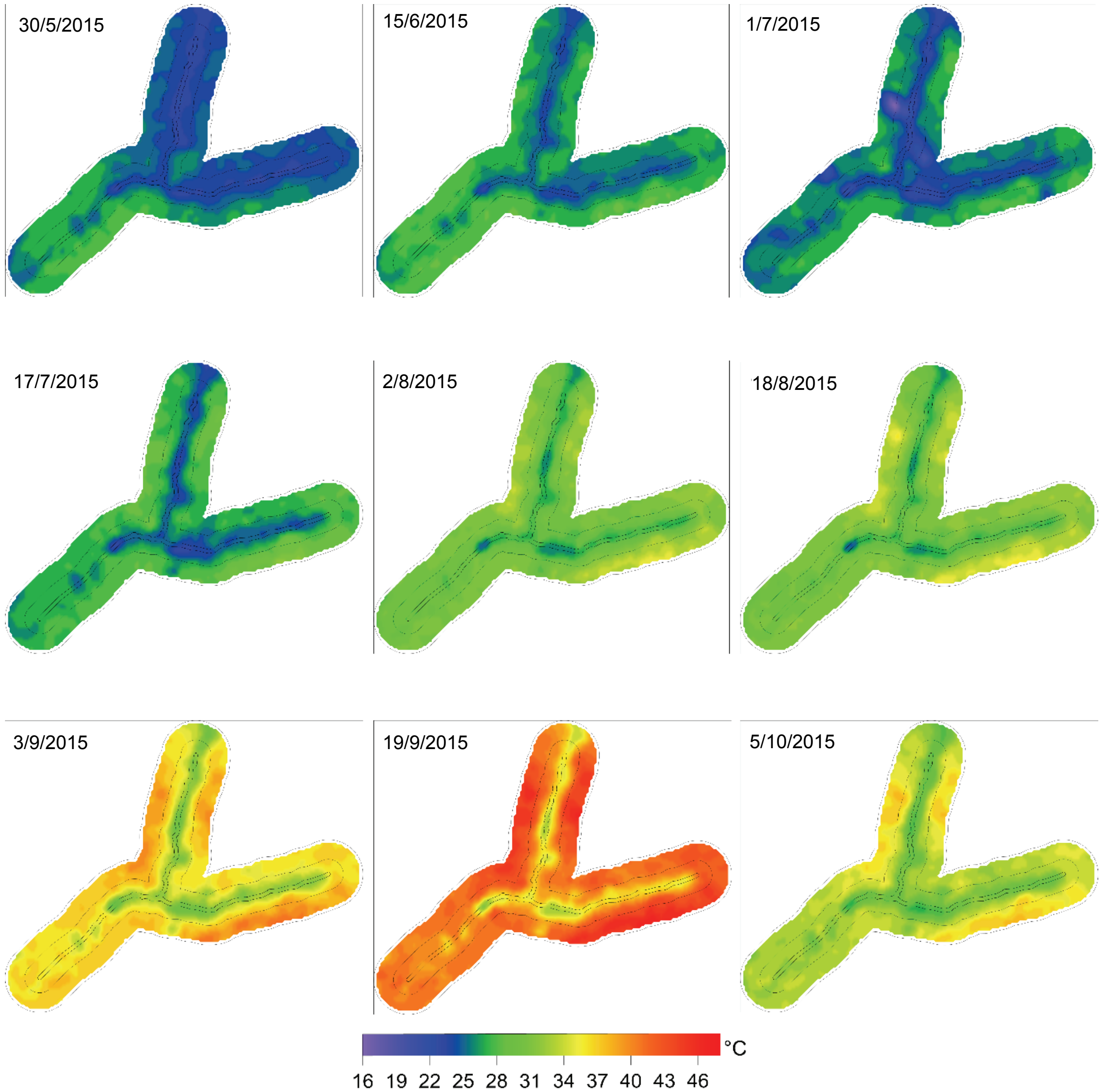

Figure 3. Surface temperature in Iporá. The black lines correspond to the boundaries of the *buffers*.

By analyzing parks of Nagoya in Japan, Cao et al., (2010) observed that the intensity of the PCI was higher in the summer followed by the spring. These results obviously refers to places with completely different climates to the climate in the city of Iporá. In this study, it was not possible to obtain thermal images for the summer, as this characterizes as the rainiest period of the region. However, it observed that in the spring or close to it, the intensity of the PCI was far superior to PCI of other dates.

Some studies have used satellite images to estimate the surface temperature and the cover of vegetation in many urban locations. Many studies that follow this approach, found a negative correlation between vegetation indices such as NDVI, LAI and temperature (Andrade & Vieira, 2007; Bowler, Buyung-Ali, Knight, & Pullin, 2010; Chang et al., 2007; Jin & Zhang, 2002; Liu & Zhang, 2011).

The relationship between PCI and NDVI was observed by Feyisa, Dons and Meilby (2014), the authors found that intensive coverage of trees (in this case, NDVI data) led to a cooling, significantly greater at all times of the day. This was a clear indication that the density of vegetation, in parks, play a vital role in increasing the cooling effect on the air temperature during the day.

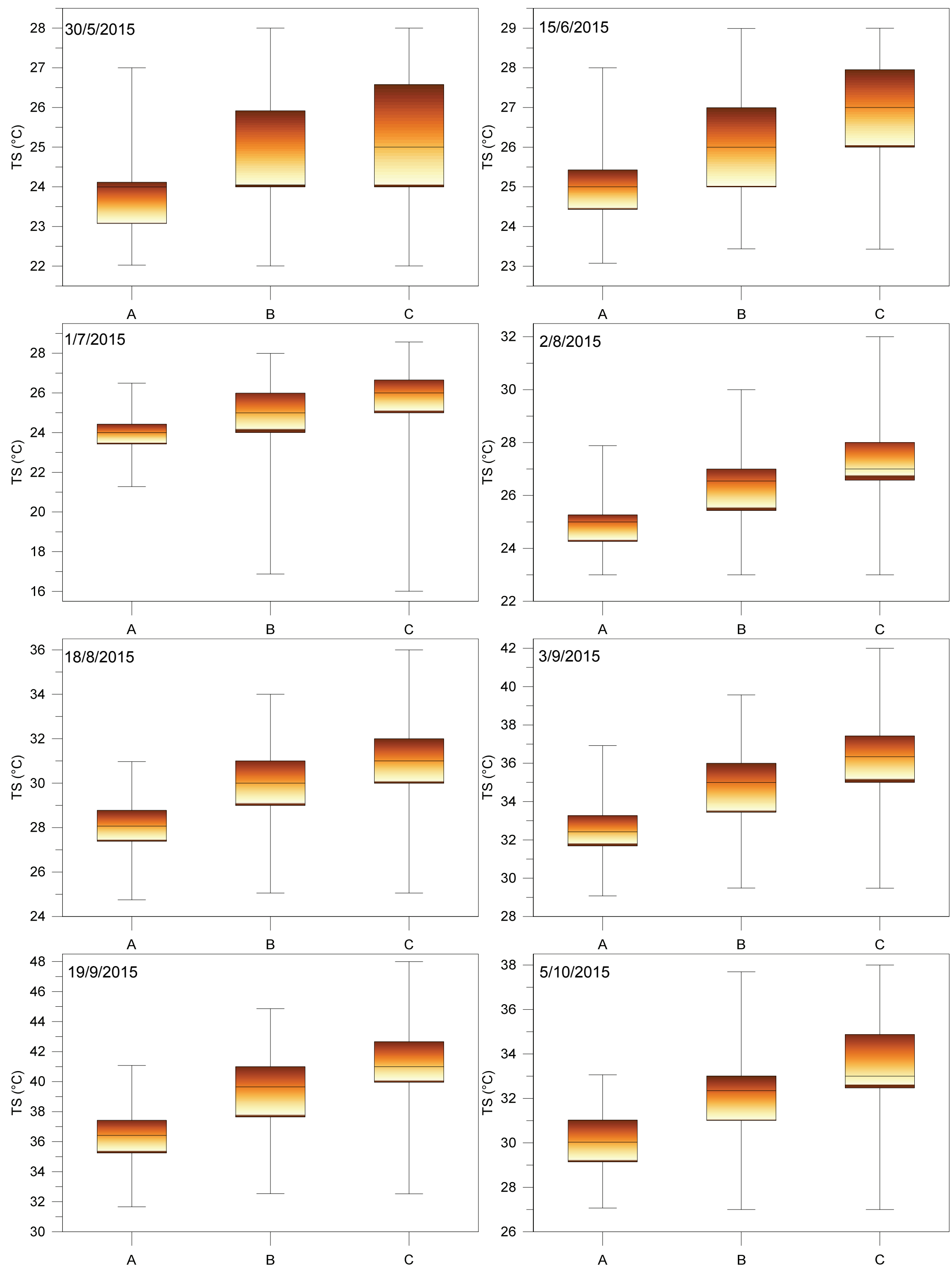

Figure 4. *Boxplots* of the ST in the *buffers* of 30 (A), 200 (B) and 500 m (C).

In order to verify the relationship between the PCI and the vegetation index (NDVI and LAI) carried out a multiple linear regression, as shown in Figure 6 and 7. The relations of intensity of the PCI with the difference of NDVI (200 m) and NDVI (30 m) as well as the difference of NDVI (500 m) and NDVI (30 m) was negative (Figure 6), i.e., the lower the differences in NDVI, the lower the intensity of the PCI. Also, in Figure 6 note that the NDVI is an excellent indicator of the PCI and can explain 91% of its variability for the *buffer* of 200 m and 93% for the *buffer* of 500 m.

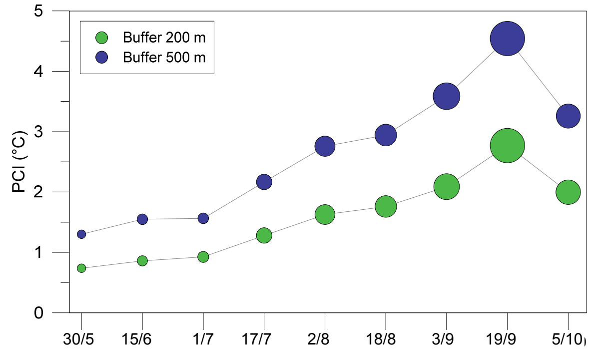

Figure 5. Seasonal values of PCI.

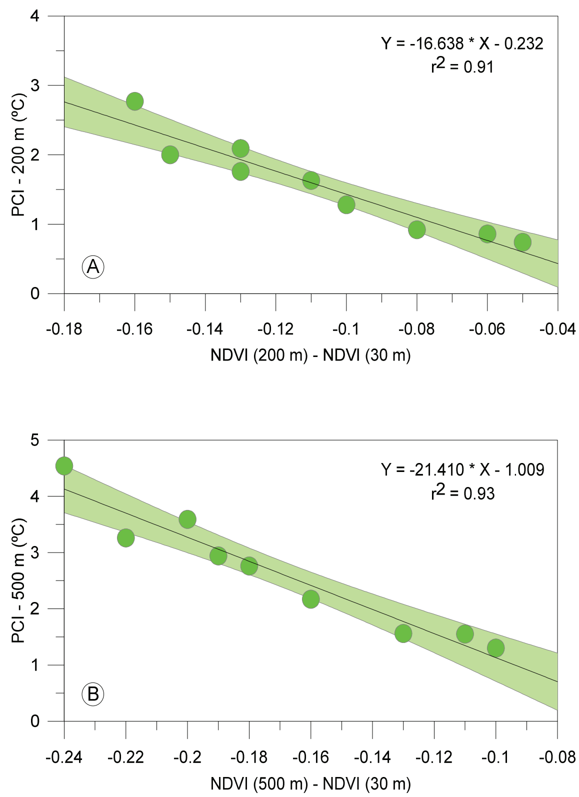

Figure 6. Relationship between the PCI of the *buffers* of 200 and 500 m and the difference of NDVI between the *buffers* of 200 (A) and 500 m (B) with the *buffer* of 30 m.

There are not many studies linking PCI and LAI. However, Ren et al., (2013) observed a coefficient of determination of the PCI by LAI of 0.52 for the summer, and 0.43 for the fall. As well as for the NDVI, the relationship between intensity of the PCI with the LAI was negative (Figure 7). The linear regression resulting from the difference in LAI in the *buffer* of 200 and 500 m with the LAI of 30 m, with the PCI, revealed a power of explanation lower than the NDVI, however, still got r^2 significant (r^2 = 0.68 for the *buffer* of 200 m and r^2 = 0.56 for the *buffer* of 500 m).

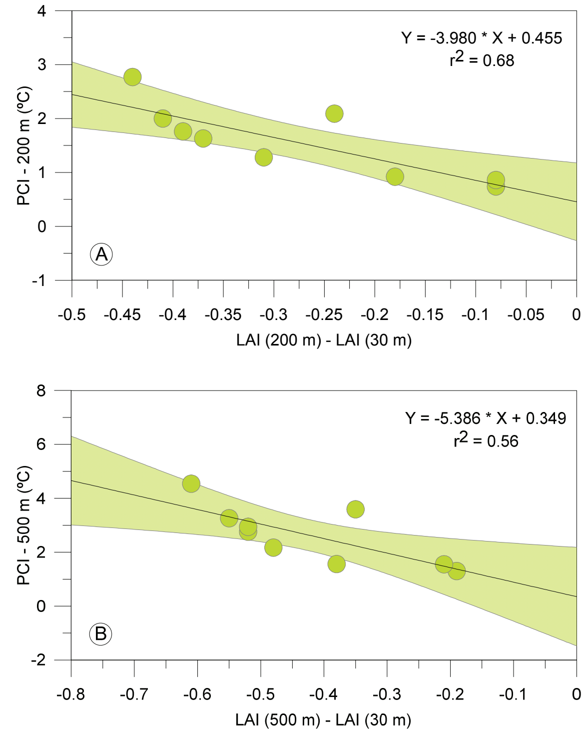

Figure 7. Relationship between the PCI of the *buffers* of 200 and 500 m and the difference of LAI between the *buffers* of 200 (A) and 500 m (B) with the *buffer* of 30 m.

From the relations found between the PCI, the NDVI and the LAI was given two equations (Equation 3 and Equation 4), by means of multiple linear regression, in which obtained high coefficient of determination, r^2 = 0.924 and r^2 = 0.957 for the PCI of 200 and 500 m, respectively (Figure 8), with *p-value* < 0.001 for both equations. The data used for regression refers to all images used in this study (nine images). Using these equations to predict the intensity of PCI.

$$PCI_{200\,m} = -0.335 + \left(1.357 \times (LAI_{200\,m} - LAI_{30\,m})\right) - \left(21.093 \times (NDVI_{200\,m} - NDVI_{30\,m})\right) \quad (3)$$

$$PCI_{500\,m} = -1.075 + \left(2.367 \times (LAI_{500\,m} - LAI_{30\,m})\right) - \left(27.688 \times (NDVI_{500\,m} - NDVI_{30\,m})\right) \quad (4)$$

The relations of estimated and observed PCI, can be ascertained in Figure 8. Note that the observed and estimated values are positively related. The Root mean square error (RMSE) was 0.175 for PCI regression from the buffer of 200 m, and RMSE of 0.211 for the buffer of 500 m. This shows that these models of multiple linear regressions involving the LAI and the NDVI is an appropriate way to predict the intensity of PCI of the green area/waterway in Iporá.

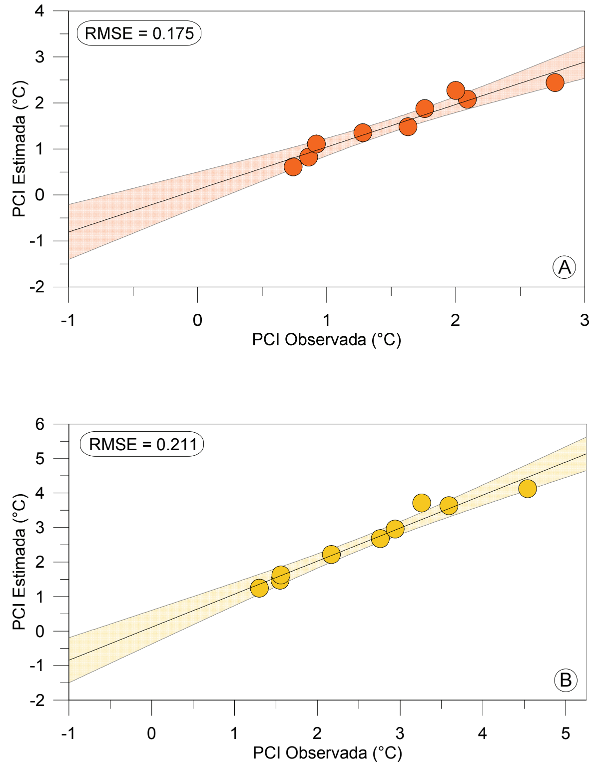

Figure 8. Intensity of the PCI observed and the intensity of the PCI estimated by the multiple linear regression in the *buffers* of 200 (A) and 500 m (B).

Conclusion

The greater the distance of the green area, the greater the surface temperature.

The temporal variation (seasonal) of the intensity of PCI detected in the spring or close to it and the intensity of the PCI was much higher than the PCI of other dates.

The difference of NDVI 200 and 500 m with NDVI of 30 m in relation to PCI showed a negative relationship, with a high coefficient of determination making it an excellent indicator of the intensity of the PCI, the LAI was also able to explain the variability of the PCI.

Was given two equations from the relationships found between the PCI, the NDVI and the LAI, one for the *buffer* of 200 m and another for the *buffer* of 500 m, both showed low RMSE, which indicates high precision in predicting the PCI.

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