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Estimation of long term low resolution surface urban heat island intensities for tropical cities using MODIS remote sensing data

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ABSTRACT

The present contribution estimates long term (2001–2014) low resolution (0.05°), surface urban heat island (SUHI) intensities for two tropical urban areas: the Metropolitan Area of São Paulo (MASP) and the Metropolitan Area of Rio de Janeiro (MARJ) located in Brazil's south-east region. For this purpose, it were used two methods: the first one is the Streutker's method, which quantifies SUHI intensities using a Gaussian surface to fit the difference between urban and rural patterns of land surface temperatures (LST). The second new proposed method, estimates SUHI intensities by the difference between the quantile 0.95 of LST for urban area and the median of LST for rural area, separated with yearly Land Cover Type MODIS product at 0.05° resolution. Both methods use remote sensing data obtained from MODIS sensor on board of TERRA and AQUA satellites. An advantage of the quantiles method is that can be used as alternative procedure when the city's shape it is not ellipsoidal or when the spatial resolution is so high that it does not allow a Gaussian surface fit. A drawback is that it would not be possible to calculate a footprint area of the SUHI because the method doesn't fit the LST data to any surface. For the MASP, the results of both methods show an acceptable level of agreement for both daytime and night-time periods. For the MARJ, the SUHI intensities obtained with Streutker's method are lower than the values obtained with the quantiles method by about 2 °C, specially in summer and night-time periods. In general, the quantiles method may be useful as a complementary analysis of the Streutker's method for cities with more than one

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center of maximum surface temperature or with non ellipsoidal shapes. Moreover, by using vegetation indices (NDVI and EVI) data from MODIS, it was shown that the presence of larger amount of vegetation cover within the urban area of the MARJ compared with the MASP, can partially explain the higher SUHI intensities of the MASP in relation with the MARJ.

1. Introduction

The global urban population has increased by a factor of five, from 0.7 billion in 1950 to 3.9 billion in 2014. It is expected to increase by another 60% by 2050, when 6.3 billion people are projected to live in urban areas (Buhaug and Urdal, 2013). In contrast, the global rural population is ceasing to grow and it is projected to reach a peak of just under 3.4 billion shortly after 2020 and then to decline thereafter to 3.2 billion in 2050 (United Nations, 2014). The urbanization process in Brazil became above the global average and surpassed developed countries during the 1980s given its industrial development. It increased from 36.2% in the 1950s to 86.5% in the 2010s (IBGE, 2011) and has a projection to increase to 91.1% in 2030 (United Nations, 2011). The Metropolitan Area of São Paulo (MASP) and the Metropolitan Area of Rio de Janeiro (MARJ) reflect the intense urbanization process between 1950 and 2010. The population of the MARJ increased four times, from 3 million to 12 million inhabitants while the MASP increased ten times from 2 million to 20 million in the past 60 years.

These two major mega-cities are dramatic examples of the environmental problems associated with land use change, as it is highlighted for the MASP in the study of Ferreira et al. (2013). Actually, the MASP has an area of 8051 km^2 and the MARJ an area of 5384 km^2. Both large urban areas (MASP and MARJ) are located in the south-east region from Brazil which exhibit transitional climatic conditions in zonal and regional levels: For the MARJ, because it is crossed by the tropic of Capricorn, therefore with lands in the tropics and subtropics, and for the MASP, because it is located in a band of conflict between tropical and extra-tropical systems, with their circulation mechanisms under the control of the dynamics of polar fronts. However, because the different arrangement of geographical and topographic factors there are several climatic and energetic differences between both urban areas.

The development of urban areas produce large modification of land surface and local climates can be modified by these changes (Changnon, 1978; Lemonsu et al., 2010; Mishra et al., 2015). The introduction of new surface materials (such as concrete, asphalt, tiles) coupled with the emission of heat, moisture and pollutants that produce atmospheric turbidity (Flores et al., 2016) alter the exchange of energy and moisture between surface and atmosphere, sometimes changing dramatically radiative, thermal, moisture, roughness and emission properties of the surface-atmosphere system (Hung et al., 2006). These changes generated by urban surfaces cause the local air and surface temperatures to rise several degrees higher than the simultaneous temperatures of the surrounding rural areas.

In general, urban microclimates are warmer than their surrounding for any specific time of the day in mid-latitude cities. This phenomenon is known as urban heat island (UHI) (Oke, 1987; Dimoudia et al., 2013; Parece et al., 2015). The shape and size of the UHI varies with time, weather and urban surface patterns (Oke, 1987). Two types of UHI can be distinguished: the urban canopy layer (UCL) heat island and the urban boundary layer (UBL) heat island. In general, the UCL lies below the mean roof level and consist of several microclimates generated by the heterogeneous nature of the individual elements of the urban canopy (rows,houses,trees,etc). In contrast, the UBL presents characteristics modified by the integration of the UCL effects into a regional or mesoscale climate (Roth et al., 1989).

The UHI intensities for tropical and subtropical urban areas are less intense than at higher latitudes. They are more evident during the day in summer, driven by solar radiation heating over urban canopies (Arnfield, 2003; Roth, 2007) and their seasonal variability can be modulated by urban-rural differences in soil moisture content (Pearlmutter et al., 2005; Heisler and Brazel, 2010). In contrast, in middle latitudes the UHIs are more evident in winter during early night. For Brazilian metropolitan cities, the study of Ferreira et al. (2012) showed maximum UHI in the MASP between 1700 UTC and 1900 UTC varying between 2.6 °C in July and 5.5 °C in September. They also indicated higher correlation between UHI intensity and the net solar radiation.