Urban Climate 26 (2018) 231–243

Contents lists available at ScienceDirect

Urban Climate

journal homepage: www.elsevier.com/locate/uclim

Influence of vegetation on the morning land surface temperature in a tropical humid urban area

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A R T I C L E I N F O

Keywords:
Vegetation
NDVI
LST
Tropics
Seasonal variation
Landsat

A B S T R A C T

Urbanization occurring during the last decades has changed the land surface temperature (LST). In this study we analyze the spatial and temporal variation of the Surface Urban Heat Island (SUHI) during the mid-morning warming up period in the tropical humid Metropolitan Area of San Salvador (MASS). LandSat imagery is used to describe the characteristics of SUHI and the influence of the urban expansion between year 2000 and 2015. Warmest and coldest areas of MASS are analyzed in the two climatic seasons (wet & dry). The results show an LST amplitude of 16 °C in the urbanized areas and an increase of around 0.5 °C in the mean SUHI from year 2000 to 2015. Higher SUHI values are observed during the wet season with a mean difference of 1.3 °C with the dry season. However, this seasonal anomaly varies between MASS municipalities and is highly influenced by the amount of vegetation. During the wet season, a higher presence of vegetation slows the mid-morning warming up of rural surfaces, and thus, increases the SUHI during this period of the day. This thermal inertia caused by vegetation can have a relevant impact on the pattern of surface heat accumulation and on the resulting urban climate characteristics.

1. Introduction

During the last century urban areas have been continuously growing. This phenomenon has increased during the last decades especially in developing countries (Roth, 2007). World urban population is expected to increase from actual 7.6 billion to 9.8 billion in 2050 (United Nations, 2017) and thus more people will be exposed to the environmental problems (e.g. air quality, water resources) of intense urbanization.

Extending urban areas changes natural land use characteristics which has an important impact on the regional climate. One of the well-known phenomenon is the Urban Heat Island (UHI) that accounts for the accumulation of heat inside the urbanized areas due to the different thermal behaviour of urban materials with respect to the natural ones, the specific urban geometry, changes in vegetation coverage and the existence of anthropogenic heat emissions (Arnfield, 2003; Oke, 1982). The result is an increase in air temperature and a decrease in water vapor content in the urban canopy layer (Oke, 1987).

This situation can affect thermal comfort and increase the impact of heat waves inside the urban areas, which has adverse impacts on human health (Boumans et al., 2014; Parsons, 2003) and energy demand for indoor cooling (Kolokotroni et al., 2006). In this sense, UHI is nowadays a crucial factor influencing the quality of human life in cities (Wong and Nichol, 2013).

Land Surface Temperature (LST) is of great importance to the study of urban climatology. It conditions air temperature of the lowest layer of the urban atmosphere and is central to the surface energy balance (Voogt and Oke, 2003). Nowadays the satellite-

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https://doi.org/10.1016/j.uclim.2018.09.004
Received 5 August 2017; Received in revised form 26 August 2018; Accepted 10 September 2018

based remote sensing can provide a sufficient spatial resolution of LST (despite a limitation in the temporal resolution) and help the understanding of energy fluxes in urban areas. In this sense, during the last decades satellite imagery has become a valuable tool to study aspects of the UHI phenomenon. However, it is necessary to consider the limitations of the information provided by this technique (Roth and Oke, 1989).

There are various satellite thermal infrared data sources from which LST can be derived at different resolution. MODIS, LandSat and ASTER are some of them. Due to its high spatial coverage and resolution together with its free access, LandSat has been one of the most used for urban LST studies (Fu and Weng, 2016; Liu and Zhang, 2011; Rasul et al., 2015) as well as its relationship with vegetation abundance and land use/land cover (Bokaie et al., 2016; Srivastava et al., 2009; Weng et al., 2004).

However, the remotely sensed surface urban heat island (SUHI), known as the difference between urban and rural LST, is an indirect measurement that needs to consider the intervening atmosphere and the surface radiative properties that influence the emission and reflection of radiation within the spectral wavelengths detected by the sensor (Voogt and Oke, 2003). In this context, it is essential to appreciate the special nature of the satellite-derived LST before making interpretations and comparison with other type of heat island data (Roth and Oke, 1989). Studies of SUHI have been performed worldwide and they are specially increasing in tropical climate areas where there is a growing interest in the causes of UHI phenomenon (Amanollahi et al., 2016; Ayanlade, 2016; Flores R. et al., 2016a; Jusuf et al., 2007; Liu and Zhang, 2011; Priyadarsini et al., 2008).

Characteristics of UHI and SUHI in the tropical region are different to mid-latitude areas (Chow and Roth, 2006; Emmanuel, 2016; Priyadarsini, 2009). In tropical regions, the urban climate pattern can change significantly between the two main climatic seasons (wet & dry). Similar to urban areas in mid-latitudes, the influence of vegetation is strong and turns to be an effective mean to reduce heat storage during daytime (Chow and Roth, 2006).

In this study, we analyze the spatial and temporal variations of SUHI in the tropical humid Metropolitan Area of San Salvador (MASS) during the mid-morning warming up period when the daytime urban boundary layer (UBL) is developed after the night-time period. LST spatial differences are assessed during the two climatic seasons (wet & dry) in regard to the presence of vegetation and its influence in the mid-morning surface energy balance (different to the mid-afternoon or night-time period). Additionally, the impact of the urban expansion and vegetation depletion on LST is evaluated. This work constitutes (based on existing literature) the first SUHI analysis in the region.

2. Study area

The Metropolitan Area of San Salvador (MASS) in El Salvador is settled in a complex terrain and is formed by 14 municipalities. There is a central basin (600–800 m.a.s.l.) where the core of the urban area is located. This includes the municipalities of San Salvador, Soyapango, Mejicanos, Ilopango, Ciudad Delgado. This basin is limited on the east side by Ilopango Lake (438 m.a.s.l.), on the west by the volcano of San Salvador (1967 m.a.s.l.) and on the south by a mountain range reaching 1100 m.a.s.l. together with a hill on the northeast of San Marcos municipality with similar height. The northern part of MASS urban area is limited by lower hills that do not exceed 800 m.a.s.l. (Fig. 1).

MASS gathers approximately 29% of the El Salvador population. The urbanized area covers around 165 km^2 (OPMASS, person. comm.) with altitudes ranging from 400 to 1000 m.a.s.l. (Fig. 1). From 1977 to 2008, the urban sprawl increased 3.24 km^2/year (OPAMSS, 2017). However, during the last decade it has only extended about 1 km^2/year. This situation is due to a reduction in the population of MASS between 2000 and 2015 (MEGES, 2016) as well as a change in the former typology of urban development (low rise) that now focuses on new high-rise buildings.

Climate is classified as tropical humid (Aw: tropical savanna climate). Thus, the intra-annual air temperature changes are small and precipitation rates divides into a wet and a dry season. Dry season is considered from November to April while the wet season is between May and October with highest precipitation rates (300–350 mm/month) from June to September (Garcia et al., 2006). Monthly air temperature is always above 20 °C. However differences between municipalities are registered and influenced by the urban development, the topographic altitude and the wind pattern. Thus, mean air temperature vary ~1.5 °C between Santa Tecla (936 m.a.s.l.) and Ilopango (619 m.a.s.l.) and even 5 °C between the highest and lowest urbanized areas of MASS (e.g. Santa Tecla and Apopa at 434 m.a.s.l.) (Cetella et al., 1998; Garcia et al., 2006). Highest air temperatures are registered in April and July and lowest between November and February. Daily air temperature variation is higher during the dry season when clear skies and higher solar radiation and a reduction in wind speed increases surface heat accumulation and daily maximum air temperature. Also during the dry season the presence of vegetation is reduced which increases the night-time surface cooling rate and lower minimum air temperature are registered (Garcia et al., 2006).

3. Methodology

3.1. Data

During this study satellite images from LANDSAT were used to derive Surface Emissivity (ϵ) and Land Surface Temperature (LST) in MASS. Data from years 2000 and 2015 were analyzed corresponding to LANDSAT5 and LANDSAT8 respectively. Four images for each climatic season (wet & dry) were selected each year. On the whole, 16 images of MASS were processed, all with cloud cover < 10%. Dates of the imagery can be found in Table 1. All images where taken during the mid-morning period at MASS (i.e. 10:18 (GMT-6) and 9:56 (GMT-6) for the LANDSAT5 and LANDSAT8 respectively).

Data were downloaded from USGS Earth Resources Observation and Science (EROS) which provides free LANDSAT surface