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Spatio – temporal variations of urban heat island over Delhi

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ABSTRACT

Temporal and spatial trends of the surface urban heat island (UHI) formation over Delhi are examined with respect to aerosol load and land-cover variations. The study reveals that temperatures over Delhi are higher than those over the surrounding regions almost through-out the year during the night time. The nocturnal heat island intensity is minimum (0–2 K) during the monsoon months and maximum during the month of March (4–6 K). The UHI trends during the day-time are however, significantly different. It is observed that a day-time cool island forms over Delhi twice during the year in the months of May–June and October–December. Analysis of temporal variations in urban heat island intensity (UHII) and aerosol load over Delhi reveals a significant negative correlation between UHII and aerosol optical depth (AOD). Spatial analysis of LST, land-cover and AOD for the months of March, May and November confirms the significant role of AOD along with land-cover variables such as percentage area under the classes built-up, rock, vegetation and bare soil. Comparative analysis of LST in the regions lying north, south, east and west of Delhi in relation to the prevailing land-cover suggests that thermal inertia is also a very important factor determining the urban-rural thermal structure.

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1. Introduction

Urbanization brings about significant changes in the land-cover and land-use of a place. These changes include replacement of soil and vegetation cover by concrete/asphalt surfaces, low rise rural structures being replaced by high-rise complex urban structures and predominantly agricultural activities in the rural areas being replaced by large-scale commercial and industrial activities in the urban areas. This often results in reduced soil moisture, decreased evapo-transpiration, low sky-view factors (SVF) (Oke, 1981; Svensson, 2004) and emission of large quantities of waste heat in the urban atmosphere. These changes influence the local energy budget significantly (Oke, 1981; Arnfield, 1982), thus causing a modification in the local climate. Formation of urban heat island (UHI) is one of the most obvious manifestations of these changes. Traditionally, UHI's have been studied by evaluating urban and rural temperature differences obtained from ground based measurements of air temperature (e.g. Oke and Maxwell, 1975; Morris, 2001; Gaffin et al., 2008; Saaroni and Ziv, 2010; Shao et al., 2011; Oswald et al., 2012). Though observations from ground based stations are generally accurate and reliable, these are not sufficiently representative of the large variety of land surfaces, especially in regions where network of ground based stations is still sparse. Thermal remote sensing is an alternative approach which overcomes this limitation. Satellite based sensors that make use of thermal band data, provide information on land surface temperature (LST) for vast areas, enabling researchers to study the spatio-temporal trends in the formation of Surface Urban Heat Island (e.g. Roth and Oke, 1989; Gallo et al., 1993; Owen et al., 1998; Nichole, 2005; Buyantuyev and Wu, 2010; Schwarz et al., 2011). A comprehensive discussion on the application of thermal remote sensing in studying urban climate may be found in Voogt and Oke (2003).

Due to their relevance in regional climate, human comfort/health and urban air quality, UHI's have been studied extensively worldwide over the last few decades viz. Kuwait City (Nasrallah, 1990), Johannesburg (Goldreich, 1992), Mexico City (Jauregui, 1997), Houston (Streutker, 2002), Phoenix (Hawkins et al., 2004), Singapore (Chow and Roth, 2006), Brussels (Weverberg et al., 2008), London (Jones and Lister, 2009; Bohnenstengel et al., 2011) and Shanghai (Jin et al., 2011). In the Indian context, research on the UHI formation has picked up momentum only during the last decade (Deosthali, 2000; Badarinath et al., 2005; Mallick et al., 2008; Pandey et al., 2012). A thorough discussion on the UHI research during the 1980s and 1990s in different parts of the world, may be found in Arnfield (2003). However, most of the studies on UHI pertain to examining the magnitude of UHI with respect to surface/land-cover parameters. Very few studies till date have examined the role of aerosols in UHI formation. Regional studies (Kaiser and Qian, 2002; Ramanathan et al., 2005) suggest that aerosols could cause surface cooling due to dimming of incoming solar radiation. Wang et al. (2007) argue that human activity in urban areas tends to put more aerosols in the atmosphere and report 23 W/m^2 less surface solar shortwave radiation received in Beijing during September, 2001 as compared to the rural areas. They, however, suggest that reduced surface albedo over urban areas results in nearly equal surface net solar radiation. But, Jin et al. (2010) report that aerosols may reduce surface insolation by 40–100 W/m^2 and skin temperatures over urban areas by 1–2 K as compared to surrounding rural areas. Pandey et al. (2012) also report a reduction in the intensity of surface solar radiation over Delhi as compared to rural areas and the formation of day time 'cool island' over Delhi during the months of November and December. Traditionally however, the formation of day time urban cool islands has been attributed to the large thermal inertia of urban materials and shadow effect (Carnahan and Larson, 1990; Hafner and Kidder, 1999; Nichole, 2005; Peña, 2008; Cai et al., 2008). The present study investigates the decade long temporal trends of monthly day and night time surface UHII obtained from MODIS satellite data in the context of Delhi along with the trends obtained from decade long sun-photometer based measurements of AOD to examine the role of AOD and land-cover variations in the surface thermal structure over Delhi and surrounding areas in different seasons.