Remote Sensing To Study Urban Heat Island Effects in Bangkok Metropolitan Region

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Abstract: This study focuses on monitoring the surface UHI in a tropical city of Bangkok in both spatial and temporal dimensions based on MODIS- and TM-derived land surface temperature (LST). The spatial extension and magnitude of the surface UHI are explored for days and nights as well as its variations through the dry (least-clouded) season. Surface UHI growth between 1993 and 2002 is mapped using high-resolution LANDSAT TM thermal bands. UHI patterns are, then, analyzed in association with land/vegetation covers derived from high-resolution ETM+ and ASTER satellites and ancillary data.

Keywords: Thermal remote sensing, Urban Heat Island, Urbanization, Bangkok

1. Introduction

Bangkok, one of fastest growing Asian Metropolis agglomerations with population of more than 10 million, is a primate city of Thailand. Rapid urban development involving a large volume of population with increased energy consumption and dense urban infrastructure leads to an inevitable decline in the quality of life as well as urban environment. One of the most well known forms of anthropogenic modification is the phenomenon of urban heating or urban heat island (UHI) effect, causing the local air and surface temperatures to rise several degrees higher than the simultaneous temperatures of the surrounding rural areas. Boonjawat *el al.* (2000) found an increase of 1.23^{0}C in lowest air temperature in the UHI of Bangkok in the last 50 years. To date, the vast majority of climatologic studies of UHI's have been performed using in-situ data, which have the advantage of a high temporal resolution and a long data record, but have poor spatial resolution. In recent years, the field of remote sensing, which offers higher spatial distribution, has lent itself well to the study of UHIs. The objective of this paper is to document the application of remote sensing (MODIS, TM, ASTER) data to study UHIs in the tropical city of Bangkok and to analyze its temporal and spatial variations in relation to urban surface characteristics.

2. Data and Methods

The study area covers whole Bangkok Metropolitan Region (BMR) located between 99º 52' – 100º 58' E and 13º 27' – 14º 17' N (Fig. 1). 16 relatively cloud-free MODIS level 1b images during September 2001 – March 2002 are obtained from the IIS's data archive. Radiant temperatures for each MODIS thermal band are calculated from emitted spectral radiance (R_i) using Plank's equation and land surface temperature (LST) is derived, then, using split-window algorithm (Tran *et al.*, 2003) to construct time series of daytime LSTs. As seen in Fig. 2, the daytime urban-rural differences between CBD and rural areas are not varying much during the dry season with maximum of 6^{0}C observed in February and minimum of 5^{0}C in December, suggesting that we could focus our study on significant surface UHIs in dry season. LANDSAT TM images acquired on December 25, 1993 and January 08, 2002 are used to map the UHI growth in the 120-m resolution. High correlation ($r = 0.85$, $p < 0.0001$) found between LST derived from MODIS and that aggregated from TM images indicate the high possibility of satellite-data fusion to study UHI's phenomena (Dousset and Gourmelon, 2003). To quantify the change in UHI's measurements during 1993-2002 period, magnitude and spatial extent are estimated using methods of Gaussian surface approximation described in Streuker (2003). ASTER images acquired during 2001 is used for detailed land use classification, which is then used to analyze the association of surface characteristics with UHI patterns.

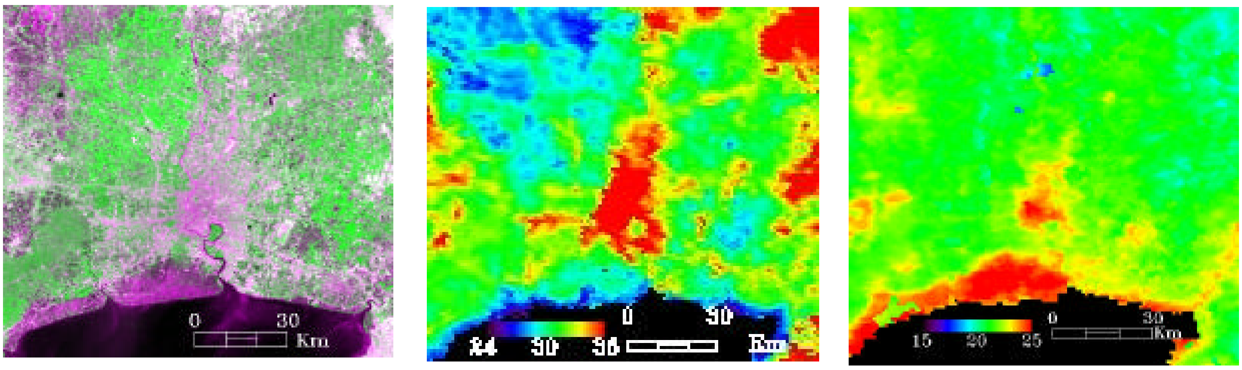

Fig. 1 MODIS 1/2/1 composite images and corresponding day and night LST maps of BMR acquired on 10 February 2001

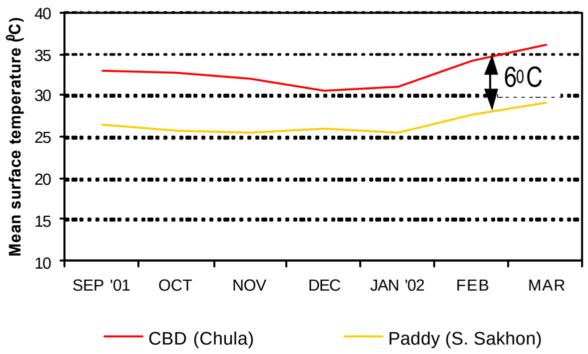

Fig. 2 Temporal variations of the daytime surface UHIs in Bangkok through dry season

3. Results

1) UHI patterns and magnitudes

Daytime surface UHIs mapped by MODIS data have spatial patterns closely resembled corresponding urbanized land surface as seen in Fig. 1. The urban areas, which are characterized by high albedo and dry (built) surfaces, have significantly higher daytime surface temperature as compared to those of the surrounding rural moist vegetated areas. LST maps show that the location of the maximum UHI intensity roughly coincides with densely built-up areas found in the center of cities (e.g., Sathon, Pathumwan). In February 2002, mean rural daytime temperatures are 29.5^{0}C and surface UHI intensity reaches 8^{0}C. During the night, the mean rural temperature is cooling down significantly to 22^{0}C and land-sea breeze circulations coupled with differences in surface cooling rates weaken surface UHI magnitude significantly to 3^{0}C as well as affect the UHI shape (Fig. 1). This well conforms air temperature observations at the center and seaside of the city (Fig. 3).

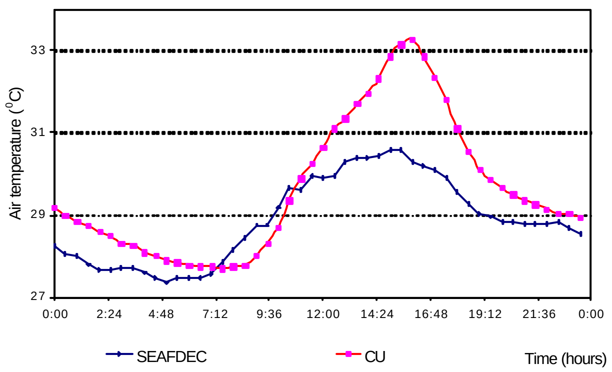

Fig. 3 Mean diurnal variations of the air temperature in February 2002 observed at CBD and seaside stations

2) Urban growth and UHI

Bangkok Metropolitan Region is reported to expand at 3% growth rate annually during the 1990s and population is grew from 8.9 millions in 1990 to 11 millions in 2000. As household size continues to dwindle the urbanized areas is expanding even faster. The area of surface UHIs is also significantly expanding as recorded by LANDSAT TM data between 1993 and 2002. The LST maps derived from thermal bands of TM images are aggregated to 1-km resolution and then fitted to a Gaussian surface to calculate the mean rural temperature, magnitude and spatial longitudinal and latitudinal extents (Tran *et al.*, 2003). A major advantage of this method for study of UHIs growth is that the quantity of interest is not absolute urban temperature, but the difference in temperature between urban and rural areas. Between 1993 and 2002 the surface UHI magnitude increases from 5^{0}C to 6^{0}C, spatial extents increases from 35 to 45 km in longitude and from 45 to 55 km in latitude, while the footprint area increases from 3679 to 4233 km^2 or an increase of 15%. Although UHI growth in magnitude found during 1993-2002 is just indicative as there is potential influences of meteorological conditions, the growth in spatial extents are much more reliable as it well conforms the mean extents derived from 5 MODIS scenes during January-February 2002. Moreover, daytime distribution of LST is significantly correlated to the increasing density of buildings from the suburbs to downtown as shown in Fig. 4. To construct this scatterplot, the percentage of built-up areas within 1-km resolution MODIS thermal pixels is computed from detailed land cover classification at 30-m resolution (Tachizuka *et al.*, 2002). However, residual in this relationships are relatively large presumably due to large fluctuations of the heat fluxes interacting within complex urban canopy structure under the strong and variable radiative forcing conditions, which should be addressed in further detailed study.

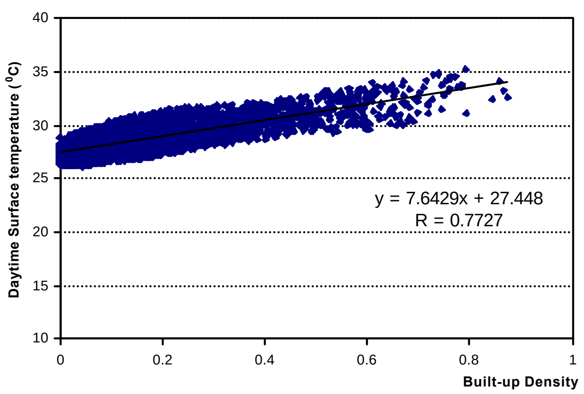

Fig. 4 Scatterplots of daytime LST versus built-up density at 1-km resolution, derived from 30-m resolution ETM+ classified images for Bangkok

3) UHI and urban surface characteristics

Fig. 5 represents the bivariate histograms of the daytime LST versus NDVI for BMR area derived from MODIS data over the 2001-2002 period. Strong negative correlations are seen for all images as the moisture availability from vegetation allowing a larger fraction of the net radiative flux to be balanced by evapo-transpiration and by the latent heat flux, thus lowering the sensible heat flux, hence LST. This again confirms the classic patterns of surface UHIs in tropical humid cities and indicates the universal cooling impacts of vegetation. It is also found the difference in heating and cooling rates for various land covers types over the diurnal cycle where wet paddy fields and perennial vegetations have smaller average day-night fluctuation (4 and 4.9^{0}C respectively) in surface temperature than urbanized areas (more than 5.5^{0}C) mainly due to high moisture availability. In the Bangkok city center, it is found a significant daytime thermal contrast between parks (Chatuchak and Lumpini parks) and its urban surroundings reaching 5-6^{0}C in February 2002.

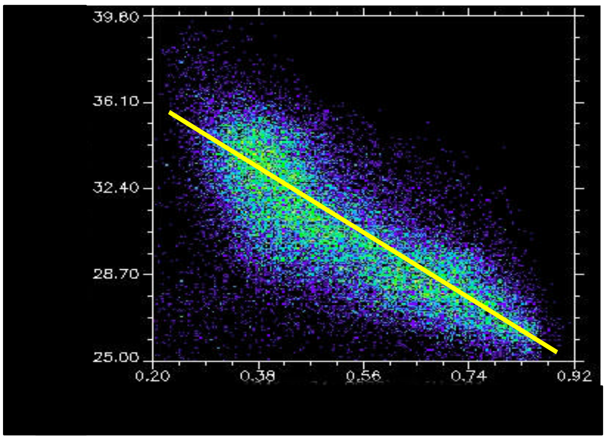

Fig. 5 Scatterplots of daytime LST versus vegetation index in February 2002

In addition, a Soil-Vegetation-Atmosphere Transfer (SVAT) model is applied to compute surface heat fluxes and surface moisture. The relationship between surface UHI pattern and urban surface characteristics is, then, further explored. These findings will be discussed in details during presentation.

4. Discussions and Conclusions

Urban climate studies require high spatial resolution data that can only be obtained from satellite. This study has demonstrated the use of thermal remote sensing at different resolution in observing and assessing surface UHIs in Bangkok Metropolitan Region. Using the statistics of LST images derived from MODIS day and night scenes acquired at the AIT MODIS-receiving station and archived at the IIS satellite database over the 2001-2002 period, the surface UHIs patterns and its seasonal and diurnal variation are explored in both magnitude and spatial extent. UHIs measurements are computed using Gaussian surface approximation indicating intense surface UHIs during the daytime in the range of 7-8^{0}C, reduced to 3^{0}C during the night and UHI footprint area of 4233 km^2 in 2002. A growth of 15% in surface UHI footprint area during the 1993-2002 period is recorded using thermal bands of LANDSAT TM images. At the first-order generalization, spatial variability of UHIs is a function of surface properties, which in turn is characterized by land-covers: most importantly by vegetation cover and built-up density. The combination with high-resolution satellite data (ASTER and ETM+) has explored more the relationship between surface properties and UHIs, confirming the importance of vegetation and in some degree urban density in the partition of sensible and latent heat fluxes in a humid tropical environment. The future progression of this work is to continuously monitor BMR's UHI and to quantify the relationship between population increase and UHI growth using high-resolution thermal data of ETM+ and ASTER.

This study is expected to provide inputs to subsequent land-surface modeling and meso-scale climatic modeling, whose ultimate goal is to provide deep understanding on the effects of rapid urbanization on local climate change in tropical cities.

Acknowledgement

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