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DEPENDENCE OF URBAN TEMPERATURE ELEVATION ON LAND COVER TYPES

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ABSTRACT: The purpose of this study is to evaluate the use of Landsat7 enhanced thematic mapper plus (ETM+) data for indicating temperature differences in urban areas and compare the relationships between urban surface temperature and land cover types. The study area is located at Singapore and part of Johor of Malaysia. The ETM+ data acquired on April 28, 2000 was used to derive the urban temperature and the merged temperature color map was generated from the derived surface temperature and the IKONOS image, which is useful for interpretation. The relationships between urban surface temperature and land cover types were analysed afterwards. Our results demonstrate that the image data provide the detailed micro-scale temperature variation. The urban temperature distribution map and the analyses of thermal-to-land-cover relationships can be used as the reference for urban planning and the heat island effect reduction.

1. INTRODUCTION

"Urban Heat Island" is studied to determine how the urban environment modifies the local climate. This phenomenon affects energy demand, human health and environmental conditions. Satellite imagery has been used for the study of urban heat island to analyse and determine how and why certain city areas contribute to heat island (Franca et al. 1994, Goldreich 1985, Roth et al. 1989, Nichol 1996). Accurate and spatially detailed urban heat island information would be useful to the urban planner.

Surface temperature can be daily estimated using thermal bands of NOAA/AVHRR; however, the 1.1km spatial resolution of the data was found suitable only for urban temperature mapping at the macro-level, which does not allow the recognition of different land cover types included within the pixels.

TM thermal infrared data with 120m spatial resolution were also used to derive surface temperature. But the spatial resolution of the TM thermal band is still inadequate to capture all the complex temperature changes of the urban environment. The Landsat-7 satellite, which was launched in April 1999, carries the enhanced thematic mapper plus (ETM+) sensor with eight bands. The spatial resolutions of the ETM+ sensor are 15 meters in the panchromatic band; 30 meters in the 6 visible, near and shortwave infrared bands; and 60 meters in the thermal infrared band. The increased spatial resolution of the thermal infrared band makes it possible to do the more detailed analysis of the urban microclimate than that of the TM data.

The objective of this study is to evaluate the use of Landsat7 ETM+ data for indicating temperature differences in urban areas; to analyse and compare the relationship between urban surface temperature and land cover type.

2. STUDY AREA AND DATA ACQUISITION

The study area is located at Singapore and part of Johor in Malaysia, which is the tropical area with high temperature, high humidity and low wind speed. Therefore, it is important to study the method of reducing the heat island effect. The data (Landsat TM, ETM+ and Ikonos images) used for this study is shown in Table 1.

Table 1. Data Used for This Study.

Data Type	Acquisition Date	The Local Time of Overpass	Sun Azimuth (degree)	Sun Elevation (degree)	Norminal Collection Azimuth (degree)	Norminal Collection Elevation (degree)
TM	14/4/1992					
ETM+	28/4/2000	11:09am	63.82	59.47		
IKONOS	29/4/2000	11:17am	61.55	60.93	208.11	61.03
IKONOS	29/5/2000	11:11am	51.28	56.18	41.69	71

3. METHODOLOGY

The following procedure was carried out in this study to derive the surface temperature, generate the temperature color map and analyse the data.

3.1 Conversion of the Digital Number (DN) to Spectral Radiance (L_l) (USGS, 2001):

L_λ = ((LMAX-LMIN)/(QCALMAX-QCALMIN)) * (QCAL-QCALMIN) + LMIN

Where: QCALMIN = 1, QCALMAX = 255, and QCAL = Digital Number

The LMINs and LMAXs are the spectral radiances for band 6 at digital numbers 1 and 255 respectively.

3.2 Conversion of the Spectral Radiance to Temperature:

The ETM+ thermal band data can be converted from spectral radiance to a more physically useful variable under an assumption of unity emissivity (USGS, 2001).

$$T = K2 / \ln(K1 / L_\lambda + 1)$$

Where:
T = Effective at-satellite temperature in Kelvin
$K1$ = Calibration constant 1 in watts/(meter squared * ster * µm) (666.09)
$K2$ = Calibration constant 2 in K (1282.7)
L_λ = Spectral radiance in watts/(meter squared * ster * µm)

3.3 Emissivity Correction:

The ETM+ image was first classified into different land cover types through unsupervised classification, then the corrections for emissivity differences were carried out according to the land cover type. The emissivity corrected surface temperature can be computed as follows (Artis and Carnahan 1982):

$$Ts = T / [1 + (\lambda T / \alpha) \ln \varepsilon]$$

Where:
λ= wavelength of emitted radiance,
$\alpha = hc/K$ (1.438×10^{-2} mK),
h = Planck's constant (6.26×10^{-34} J·sec),
c = velocity of light (2.998×10^{8} m/sec),
K = Stefan Bolzmann's Constant (1.38×10^{-23} J/K).

The following surface emissivity (ε) values were used for the correction:

- Non-vegetation (soil/asphalt/sand/mixed pixels) (emissivity = 0.96)
- vegetation (emissivity = 0.97)
- water (emissivity = 0.98)

3.4 The Merged Temperature Color Map:

The surface temperature data was color-coded to generate a thermal pattern distribution map (Figure 1). Blue to red of the map represents cooler to warmer temperatures. Red and yellow identify hot spots while blue and green mark cooler areas. The temperature pattern of the image indicates that which parts of the city contribute the most to the heat island. As our aim is to analyse the relative temperature difference of the land cover type, the image has not been calibrated to absolute temperature.

The IKONOS image was used as the ground truth data to examine the relationships between temperature and the land cover type as well as its characteristics such as the building height, building geometry, vegetation density and roof material etc. In order to do this analysis, the ETM+ image was registered to the IKONOS image. The temperature color map was up-sampled to 3 meter's pixel resolution by the nearest neighbor method while the IKONOS image was resampled to 3 meter's pixel resolution by the cubic convolution method. The "IHS" transformation was used afterwards to generate the merged temperature color map, which uses the IKONOS image's higher resolution intensity and the color of the thermal map. Two sub-areas of the map are shown in Figure 2.

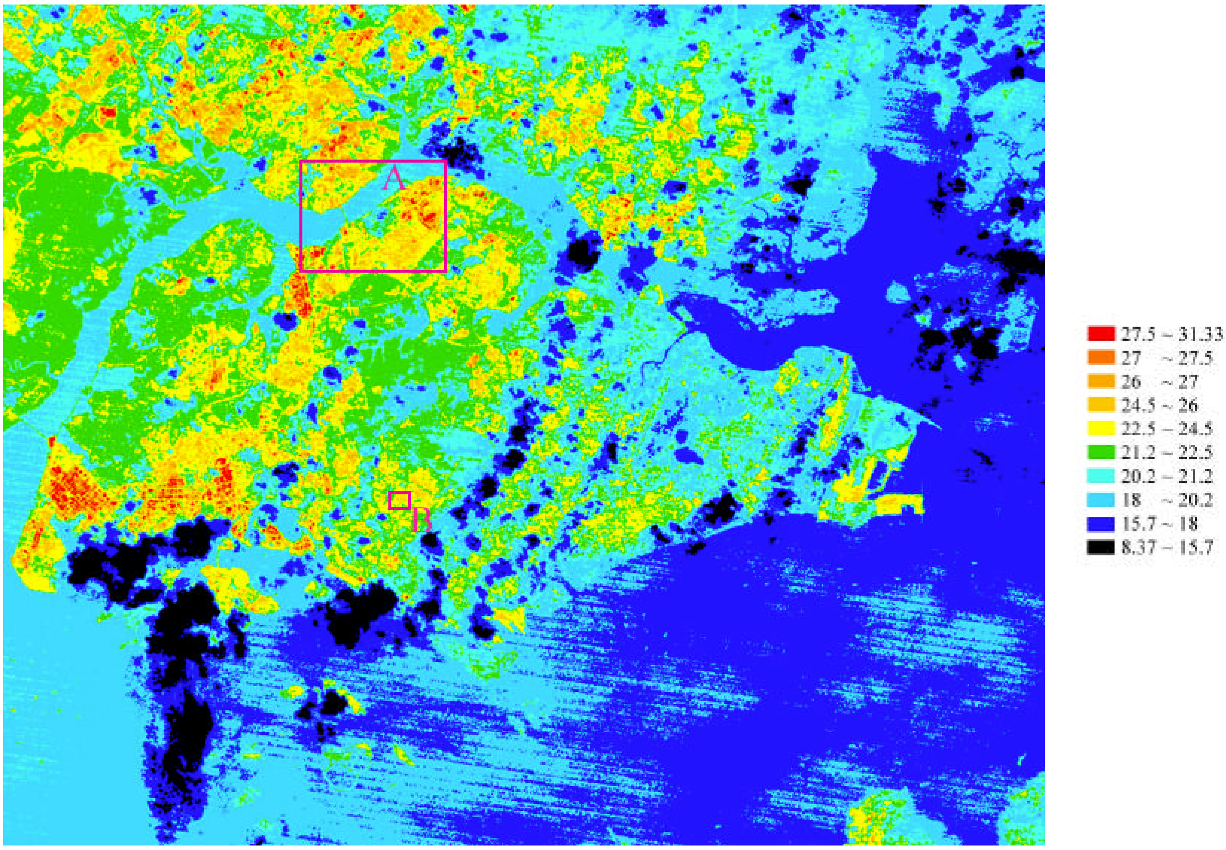


Figure 1. The thermal pattern distribution map of the study area.

3.5 Calculate the surface temperature by land cover type:

Eight land use/cover types are identified and used in this study. They are forest, grass (golf course), water (the Johor Strait and the Singapore Strait), high rise building, barren land/reclaimed land, container port, industrial estate and high density low rise residential areas. In order to examine the spatial relationships between land use/cover types and the surface temperature, the representative polygon of each land cover type was manually delineated from the ETM+ image. The mean temperature values and standard deviations of these polygons were calculated from the derived thermal data. The relationship between surface temperature and land use/cover type is shown in Figure 3.

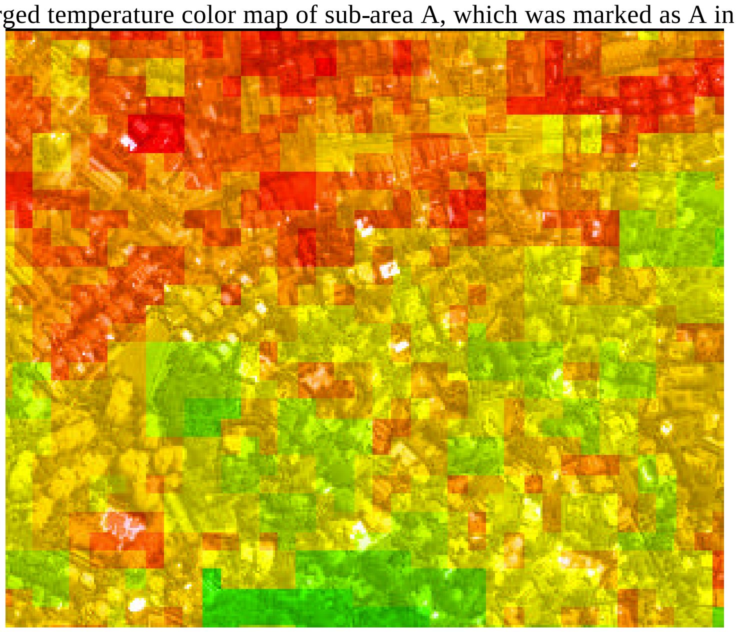
4. RESULTS AND DISCUSSIONS

Our results show that the maximum temperature difference of different land cover type is more than 5°C in the study area. The linear features such as the road and lines of trees along roadsides can be recognized clearly from Figure 1. The land and water of the eastern part is cooler than that of the western part in the image.

The merged temperature color map is useful for interpretation, and visualizing the impact of land use/cover type on surface temperature and to analyse how the urban environment modifies the local climate.

The results indicate that the strong relationship exists between urban temperature and land cover features. The temperature of various land cover types was distributed from low to high as follows: sea surface water, inland water (river/reservoir), forest, grass, reclaimed land/barren land, high rise building, low rise residential area (low density / high density) and industrial estate. The micro-scale temperature variation is due to the variations in surface materials, the coverage of vegetation, residential density, building geometry and building height. Figure 2(a) show that the areas of industry, commercial and services like MRT stations and schools which is in red color exhibit the highest temperature due to the aluminum roof material, while water and forest in blue and green color the lowest. Vegetation in a neighborhood reduces the ambient temperature by evapotranspiration. High rise areas in light orange color marked as C are significantly cooler than low rise areas in dark orange color marked as D due to the lag effect in heating of large concrete masses, the shadow and the building geometry. There are three MRT stations in this sub image, which are Marsiling, Woodlands and Admiralty MRT stations marked respectively as circle E, F and G in Figure 2(a). The temperature of two of them (E and G) is high while the other one (F) is comparatively lower because of its different roof materials and the light-colored surface results in a lower ambient temperature. Figure 2(b) shows that the temperature of residential area varies with the residential density and the tree cover. In addition, the sea surface temperature distribution is same as the results of (Chia et al. 1991). The sea surface temperature in the Johor Straits is higher than that of the Singapore Straits (Figure. 3) and the water temperature increases progressively from the East to West Johor Straits. It can also be found that for the grassy surface like sports field, its temperature depends on the coverage density of vegetation and the temperature of the barren land/reclaimed land is associated with its soil moisture.

(a). The merged temperature color map of sub-area A, which was marked as A in Figure 1.



(b). The merged temperature color map of sub-area B, which was marked as B in Figure 1.

Figure 2. The merged temperature color map in sub-area A and B.

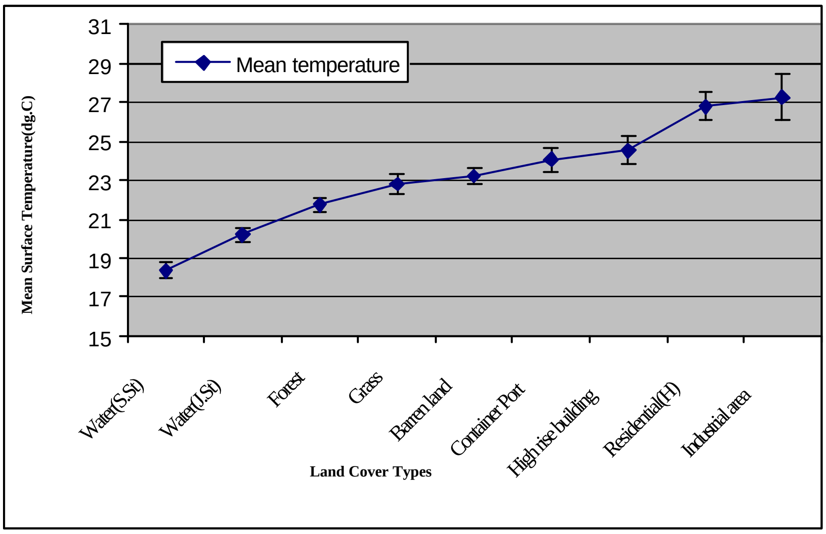


Figure 3. Thermal signature of land use/cover types.
Water (S.St): water of the Singapore Straits, Water (J.St): water of the Johor Straits, Residential(H): low rise residential area with high density.

5. CONCLUSION

The ETM+ data derived surface temperature provides the low cost and time-synchronous coverage in the whole city. By comparison of ETM+ and TM thermal infrared band, the ETM+ data derived surface temperature provides more detailed temperature variations and more accurate estimation of the urban temperature than that of the TM data. The method for generating the merged temperature color map is an effective way for analysing the temperature pattern of the image from which the relationships between the temperature and land cover type can be identified easily. The results in this paper demonstrate the usefulness of the Landsat ETM+ data for mapping the thermal pattern distribution, which can be used as the reference for urban planning. The analyses of thermal-to-land-cover relationships would help guide the planning strategies for heat island reduction.

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