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Assessment of multi-resolution and multi-sensor data for urban surface temperature retrieval

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Abstract

Data from three thermal sensors with different spatial resolution were assessed for urban surface temperature retrieval over the Yokohama City, Japan. The sensors are Thermal Airborne Broadband Imager (TABI), Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER) and MODerate resolution Imaging Spectroradiometer (MODIS). Two algorithms were developed for land surface temperature (LST) retrieval from TABI image and ASTER thermal infrared (TIR) channels 13 and 14. In addition, ASTER LST and MODIS LST products were also collected. All the LST images were assessed by analyzing the relationship between LST and normalized difference vegetation index (NDVI) and by spatial distributions of LST profiles, derived from typical transects over the LST images. In this study, a strong negative relationship between LST and NDVI has been demonstrated although the degree of correlation between NDVI and LST varies slightly among the different LST images. Cross-validation among the LST images retrieved from the three thermal sensors of different spatial resolutions indicates that the LST images retrieved from the 2 channel ASTER data and a single band TABI thermal image using our developed algorithms are reliable. The LST images retrieved from the three sensors should have different potential to urban environmental studies. The MODIS thermal sensor can be used for the synoptic overview of an urban area and for studying urban thermal environment. The ASTER, with its TIR subsystem of 90-m resolution, allows for a more accurate determination of thermal patterns and properties of urban land use/land cover types, and hence, a more accurate determination of the LST. In consideration of the high heterogeneity of urban environment, the TABI thermal image, with a high spatial resolution of 2 m, can be used for rendering and assessing complex urban thermal patterns and detailed distribution of LST at the individual house level more accurately.

Keywords: LST retrieval; Thermal remote sensing; Urban environment; ASTER; TABI; MODIS

1. Introduction

Land surface temperature (LST) is one of the key parameters controlling the physical, chemical and biological processes of the Earth. It is an important factor for study of urban climate (Voogt & Oke, 2003). Surface and atmospheric modifications due to urbanization generally lead to a change of thermal physical properties over urban area that is warmer than the surrounding non-urbanized areas, particularly at night. This phenomenon is called urban heat island (UHI). The occurrence of UHIs represents human-induced urban/rural contrast (in physical characteristics of the surface, such as albedo, thermal capacity and heat conductivity), which is mainly caused by replacement of vegetated areas by non-evaporating and impervious materials such as asphalt and concrete. This UHI phenomenon leads to changes in radiative fluxes and in the near-surface flow (Dousset & Gourmelon, 2003; Kim, 1992; Oke, 1982). For example, in urban areas, the original higher

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level of latent heat flux over vegetated areas is changed into the higher level of sensible heat flux over the same areas due to land use and land cover changes; further, there obviously exist facts of reduced evapotranspiration and more rapid runoff of rain water. In the study of urbanization, the UHI phenomenon and monitoring of its physical processes have traditionally been conducted by ground-based observations taken from fixed thermometer networks or by traverses with thermometer mounted on vehicles (Voogt & Oke, 2003; Weng et al., 2004). The advent of remote sensing technology has made it possible to study UHIs using remote sensing data, especially thermal sensor data, taken from both satellite and aircraft platforms. However, in comparison with the application of thermal remote sensing to natural and agricultural surfaces, thermal remote sensing of urban areas has been slow to advance beyond qualitative description of thermal pattern and simple correlation analysis (Voogt & Oke, 2003). In addition, most existing studies of urban thermal remote sensing can only examine and map UHI phenomenon with single band (TM thermal image) or coarse spatial resolution (e.g., NOAA/AVHRR 1 km resolution) thermal images (Voogt & Oke, 2003).

Generally, with the availability of thermal sensing data such as Landsat Thematic Mapper (TM6), Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER) thermal infrared (TIR) images, and the Advanced Very High-Resolution Radiometer (AVHRR) thermal channels, study of LST from thermal images has been a topic of great interest in the remote sensing community for the past three decades (e.g., Owen et al., 1998; Qin & Karnieli, 1999; Voogt & Oke, 2003; Wan & Dozier, 1996; Wan et al., 2002). Thermal data, covering TIR range 8–12 μm, can be acquired in single broadband (e.g., Thermal Airborne Broadband Imager, TABI) or multi-band images (e.g., five ASTER TIR channel images). Technically, for retrieving LST from thermal images, two types of methods have been developed: The single infrared channel method and the split-window method, depending on the number of bands used. The single-channel method (or mono-window algorithm, MWA) usually requires a good radiative transfer model and atmospheric profiles that must be provided by either satellite soundings or conventional radiosonde (Wan & Dozier, 1996). The split-window method (SWA) corrects for atmospheric effects based on the differential absorption in adjacent bands (Qin et al., 2001b). Because of the difficulties in correcting for atmospheric absorption, atmospheric emission, and surface emissivity, the development of accurate LST algorithm and correct application are not an easy job (Wan & Dozier, 1996). In addition, for retrieving LST from more than two thermal channel images, the third type of methods has been developed. For example, a temperature and emissivity separation algorithm (TES, Gillespie et al., 1998) was developed specially for LST and emissivity retrieved from five ASTER TIR channels.

Recently, Voogt and Oke (2003) reviewed most of previous research on UHI study using thermal sensor data. They listed three themes of research: Examination of the spatial structure of urban thermal patterns and their relation to urban surface characteristics (e.g., Balling & Brazel, 1988; Dousset & Gourmelon, 2003); thermal remote sensing for urban surface energy balances (e.g., Iino & Hoyano, 1996; Kim, 1992); and study on the relation between atmospheric heat islands and surface urban heat islands (e.g., Ben-Dor & Saaroni, 1997; Caselles et al., 1991). They suggested that research be made to examine the ability of applying advances made in the study of thermal remote sensing over vegetated surfaces to the study of urban areas, including retrieving appropriate LST and deriving structural parameters from thermal remote sensing data to better describe the urban surface.

A strong negative relationship between LST and NDVI (normalized difference vegetation index) has been extensively reported in thermal remote sensing for urban and rural environments (e.g., Dousset & Gourmelon, 2003; Gallo & Tarpley, 1996; Lo et al., 1997; Wilson et al., 2003). The basis of this relationship is that higher levels of latent heat fluxes are more representative of areas (e.g., forest and grass-land areas in this study) characterized by significant vegetation cover as compared to areas with sparse or no vegetation cover and low surface moisture availability (such as built-up and bare-soil types), where sensible heat exchange is favored (Oke, 1982; Wilson et al., 2003). Wilson et al. (2003), for example, used Enhanced Thematic Mapper Plus thermal channel (ETM+6) data to evaluate environmental influence of zoning in urban ecosystems of Indianapolis, IN, USA, and observed an inverse relationship between ETM+6 brightness temperature and NDVI across the city area as a whole and within almost every zoning category. Using Los Angeles and Paris metropolises as study cases to analyze physical processes that determine energy fluxes and their interaction at the urban surface with multi-sensor satellite data, Dousset and Gourmelon (2003) found a negative correlation between afternoon LST and NDVI, which confirms the cooling effect of urban parks. Lo et al. (1997) also reported notably inverse relationships between NDVI and radiant temperature associated with residential and agricultural land use in suburban areas of Huntsville, AL, USA, using high-resolution airborne data measured by the Advanced Thermal and Land Applications Sensor (ATLAS). In this study, we demonstrated the negative relationship between LST retrieval and the corresponding NDVI.

In this research, we proposed to examine and assess thermal data from three different sensors with various spatial resolutions for urban surface temperature (LST) retrieval. The three thermal sensors are TABI with 2-m resolution, ASTER TIR with 90 m and MODIS (MODerate resolution Imaging Spectroradiometer) with 1-km resolution. This research aims to retrieve LST from TABI data and two ASTER thermal images (ASTER channels 13 and 14) using methods developed by us and to assess all LST data including ASTER LST and MODIS LST products, covering Yokohama City, Japan, as a study area. More specific objectives include (1) evaluating the effectiveness of algorithms we developed for retrieving LST from TABI and ASTER data, and (2) assessing the characteristics of TABI, ASTER and MODIS thermal data for LST retrieval and the potential in studying urban environments with