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Detection of urban expansion and land surface temperature change using multi-temporal landsat images

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ABSTRACT

Rapid urbanization in China has attracted the attention of researchers from different countries and regions due to its potential influence on the environment and local climate. In this study, Nanjing City was chosen as a research site to demonstrate the process of urban expansion as well as the associated land surface temperature change in a long time period. Multi-temporal Landsat TM/ETM+ satellite images acquired in April or May in 1985, 1991, 1996 and 2009 were used to document changes in land cover and land surface temperature (LST) using the support vector machine method and thermal image processing. Results showed that Nanjing City rapidly expanded over the study period, with impervious surface area replacing soil and vegetated land. Increasing LST was mostly due to the conversion of LULC change. This study provided an approximately quantification of the magnitude and spatial patterns of urbanization in Nanjing City, and urbanization was shown to be associated with the conversion of vegetative land cover, with likely negative consequences for biodiversity and local climate change.

1. Introduction

Due to the complicated relationship between land use land cover (LULC) and environmental factors that influence human livelihoods, LULC change detection and mapping has relevance to many disciplines including urban planning, climate change, and environment monitoring (Sexton et al., 2013, 2015; Senf et al., 2015; Ogashawara and Bastos, 2012; Dewan and Yamaguch, 2009; Amiri et al., 2009; Qian et al., 2006; Rogan and Chen, 2004; Carlson and Arthur, 2000). LULC changes from one type of land use to another, such as from farmland to urban land, influenced the process of energy exchange between the terrestrial surface and the atmosphere (Tonkaz and Çetin, 2007; Chen et al., 2006). Thus, the expansion of urban areas, partially due to rapid population growth, has lead to significant changes in local climate and the environment (Ogashawara and Bastos, 2012; Dewan and Yamaguchi, 2009; Yuan et al., 2005). These rapid and spatially extensive changes motivate further work to map and quantify changes in land cover over time, particularly in regions of the world experiencing the greatest rates of change.

One particularly important effect of urbanization is its impact on land surface temperature (LST)and local air temperature (Roberts et al., 2015; Rinner and Hussain, 2011; Amiri et al., 2009; Qian et al., 2006). LST is a key physical characteristic of the land surface directly influenced by LULC with implications for the study of climate change and related environmental impacts (Sobrino and Jimenez-Munoz, 2014; Feng et al., 2014; Li et al., 2013; Almazroui et al., 2013). For example, the cover of vegetation and bare soil influenced the partitioning of sensible and latent heat fluxes. Despite being a critical physical property of the Earth's surface, LST is difficult to measure over large areas without the use of remote sensing. With the advent of thermal images obtained from satellites, it is now possible to monitor changes in LST over time and compare with changes in LULC (Feng et al., 2014; Ding and Shi, 2013; Almazroui et al., 2013; Rinner and Hussain, 2011; Amiri et al., 2009).

The greatest rates of recent LULC change have been observed during urbanization in developing countries (Zhang et al., 2009; Hu and Jia, 2009; Deng et al., 2009; Tonkaz and Çetin, 2007; Rogan and Chen, 2004). This is especially relevant in China, where urbanization has become one of the most significant results of economic and social development (Ding and Shi, 2013; Gao et al., 2011; Hu and Jia, 2009; Zhang and Zhang, 2007; Qian et al., 2006; Chen et al., 2006). Remote sensing data from a variety of sources, including Landsat Thematic Mapper (TM), Landsat Enhanced Thematic Mapper Plus (ETM+), Moderate Resolution Imaging Spectroradiometer

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(MODIS)(Zhang et al., 2008; Zhan et al., 2002), NOAA's Advanced Very High Resolution Radiometer (AVHRR) and SPOT sensors have been used to study the extent and spatial pattern of these changes (Li et al., 2013; Patino and Duque, 2013). These data have been used for real-time monitoring, long term, and rapid assessment of natural hazard risk.

LST is often found to be closely related to the percentage of impervious surface area (ISA) in urban areas (Yuan and Bauer, 2007), suggesting that LST might be moderated by reducing impervious surface. Conversely, water and vegetation have been found to be negatively related to LST, indicating that the urban heat island effect can be relieved by increasing vegetation and water area in cities (Ogashawara and Bastos, 2012; Rinner and Hussain, 2011; Jusuf et al., 2007; Yuan and Bauer, 2007). However, there is also variation in LST among different types of impervious surface (Roberts et al., 2015; Feng et al., 2014; Li et al., 2013; Ding and Shi, 2013). For example, it was found that commercial regions usually have the highest LST followed by residential areas. However, more work is warranted in this area, including management options for reducing LST in urban areas while maintaining economic development.

Rapid urban expansion has been observed in China especially in those cities located in Pearl River Delta and Yangtze River Delta. Over the past decade, the pressure exerted by urbanization motivated city planners and managers to evaluate the magnitude of urban expansion and the associated urban heat island effect (Han and Xu, 2013; Zhang et al., 2009; Qian et al., 2006). The current study was motivated by large observed changes in land use land cover in Nanjing City (Feng et al., 2014; Han and Xu, 2013; Almazroui et al., 2013; Rinner and Hussain, 2011; Amiri et al., 2009; Tonkaz and Çetin, 2007).

The overall aim of this work was to detect the process of urban expansion and the associated variation of LST in the past thirty years. The use of time series Landsat TM/ETM+ images to measure LULC and LST change represents a useful application of novel technologies to a globally important environmental problem.

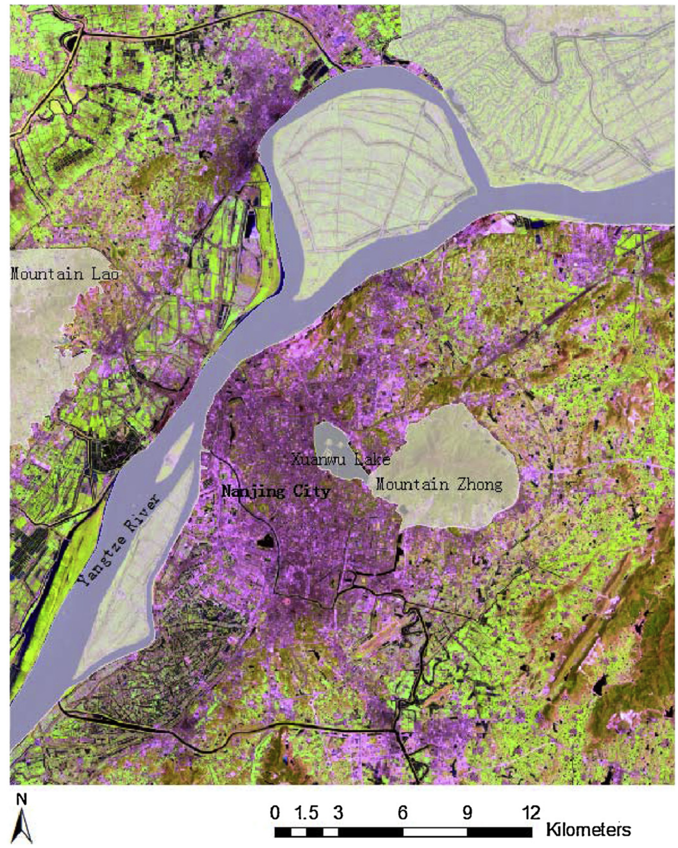

Fig. 1. Landsat TM image of Nanjing City (Path/row:120/38, April 22, 1996), shown with the band combination R:band 5,G:band 4, B: band 3.

2. Study site and data sources

Nanjing City, which is located mainly on the south side of the Yangtze River (Fig. 1), has experienced rapid urbanization over the past thirty years. Following the reformation and opening policy implemented in 1980s, rapid urbanization has been observed in many cities of China, especially those cities located in the Pearl River Delta and the Yangtze River Delta regions (Han and Xu, 2013; Zhang et al., 2009; Qian et al., 2006). As the capital of Jiangsu Province, Nanjing city has prime economic development opportunities, and population has increased due to migration of rural residents to the city in search of better opportunities and an increased standard of living.

Urbanization of Nanjing City could be observed in the social-economic statistics of the past thirty years. Population of Nanjing City in 1985, 1990, 1995, 2000, 2005 and 2011 were 2.24, 2.49, 2.65, 2.89, 5.13, 5.51 million, and the population density in these years were 2595, 2637, 2723, 2822, 1087, 1165.35 people per square kilometers (Statistics, 2011). Abrupt increase of population and decrease of population density has been found from 2000 to 2005 due to the expansion of administration region of Nanjing City. Actually, in this period, several counties around Nanjing City were allocated and managed by Nanjing government. Area of Nanjing City in those years were 121, 129, 151, 201, 513 and 637 square kilometers, while the GDP (Gross Domestic Product) in those years were 10.52, 14.85, 44.00, 77.55, 223.51 and 533.89 billion Yuan.

Landsat TM images on April 24, 1985 (Day of year (DOY) 114),April 25, 1991 (DOY 115), April 22, 1996 (DOY 113), and Landsat ETM$^+$ (Scan Lines Corrector) SLC-Off image on May 4, 2009 (DOY 124), were downloaded from online resources (www.USGS.gov) and used as the primary data for this work. Landsat images have been extensively used for urban planning, urban heat island, and impervious surface studies, owing to the useful characteristics of moderate spatial resolution and shorter revisit time (Senf et al., 2015; Nutini et al., 2013; Sexton et al., 2013; Bagan and Yamagata, 2012; Lasanta and Vicente-Serrano, 2012; Yuan and Bauer, 2007). A subset of IKONOS images of Nanjing City and Google Earth images were used as guidance when interpreting the Landsat images and to find reference samples during classification training and assessment. Air temperature data of Nanjing City for every day from 1980 to 2010 was utilized in this study to get the trend of mean air temperature.

Preprocessing of the datasets included: geographical registration, radiometric calibration and atmospheric correction. Geographical registration was implemented by aligning the coordinate values of the four corners of an image from associated metadata such that these images had same coordinates. Radiometric calibration was performed using the parameters in the metadata file to convert the DN value of the pixels to the reflectance values. Atmospheric correction was made in the ENVI platform using the FLASSH model to eliminate the impact of atmospheric disturbance on the pixel values.

3. Methodology

3.1. Image classification

Support vector machine (SVM) is a classification algorithm based on statistical learning theory (Gu and Sheng, 2016; Colgan et al., 2012; Nemmour and Chibani, 2006). Through structural risk

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