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Research Paper

A mixture emissivity analysis method for urban land surface temperature retrieval from Landsat 8 data

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ABSTRACT

Land surface temperature (LST) retrieval from satellite imagery is one of the most practical ways to consistently monitor urban thermal environment. Given the heterogeneous nature of urban landscape, an implicit assumption should be considered in remotely sensed LST determinations that a mixed urban land cover aggregation is the combination of its constituent components. Currently, the common LST retrieval method which utilize emissivity measures estimated by NDVI threshold method (NDVI^{THM}), including mono window (MW), single channel (SC), and split window algorithms (SW), does not take into account heterogeneity of pixels. While in this study, a new approach, the mixture analysis of emissivity (MAoE), is proposed to calculate temperature by estimating pixel emissivity from mixed land cover classes. We conduct a comparison of six approaches by the combinations of three LST retrieval algorithms with NDVI^{THM} and MAoE respectively. The differences among strategies are characterized and analyzed by comparing LST estimates from Landsat 8 thermal images. The LST gradients derived from transect analysis are found consistently similar for combinations of two LST algorithms (MW and SC) and the two emissivity estimation algorithms (MAoE and NDVI^{THM}). LSTs derived from SW algorithms using band 10 have the highest mean values, while the SC algorithms have moderate mean values and the MW algorithms have the lowest values. Standard deviations of estimated LST from MAoE are smaller compared with NDVI^{THM} methods, SC retrieval algorithm with MAoE has the smallest standard deviation, and NDVI^{THM} temperature estimation could be more impacted by different land use land cover types.

1. Introduction

Land surface temperature (LST) is an indispensable parameter highly responsive to Earth surface energy fluxes (Zhan et al., 2013). As the result of surface-atmosphere interactions, LST is often regarded as an indicator of the thermodynamic state (Wang, He, & Hu, 2015). It is crucial to estimate LST, because it can be used to assess the effect of surface energy and water exchange with the atmosphere (Yu, Guo, & Wu, 2014). Since field observations are costly and only limited to certain sites, the requirement of accurate and effective temperature measurements makes the thermal infrared (TIR) remote sensing of LST a prevailing topic. Over the past decades, a variety of new theories and influential algorithms have been developed and used for retrieving LST (Sobrino, Li, & Becker, 1996; Qin, Karnieli, & Berliner 2001, Jiménez-Muñoz & Sobrino, 2003). Most approaches used for the determination of LST were based on principles of fluid dynamics, thermo-dynamics and atmospheric physics (Li & Yu, 2008; Sinha et al., 2014). Attempts to estimate LST are usually carried out in three ways depending on the number of TIR bands. One way is by mono window (MW) algorithm, which relies on an individual atmospheric parameter and is applicable for handling single channel TIR data (Qin et al., 2001; Wang et al., 2015). A second approach is the single channel (SC) algorithm (Jiménez-Muñoz & Sobrino, 2003). The advantage of SC algorithm is its simplicity because it only needs two parameters for LST retrieval: the ground emissivity (ε) and the water vapor content (w) (Yu et al., 2014). However, SC algorithm shows a significant overestimation of LSTs (Zhou, Li, Liu, Jia, & Ma, 2015). The third one can be carried out by utilizing two thermal bands, which is also known as split window (SW) algorithm (Jiménez-Muñoz & Sobrino, 2008; Sobrino et al., 1996). Generally, the first two algorithms depend on a single TIR channel, while the third algorithm requires two adjacent TIR channels.

Emissivity is commonly referred to as the ratio between the radiative flux of an existing object and a theoretical blackbody at the same temperature. It is always applied to convert heat energy into radiant energy when the temperature is retrieved. Therefore, emissivity measurement is critical to the derivation of temperature, and explicitly thermal analysis requires accurate estimates of emissivity from surface coverages (Dash, Göttsche, Olesen, & Fischer, 2002). Ground emissivity

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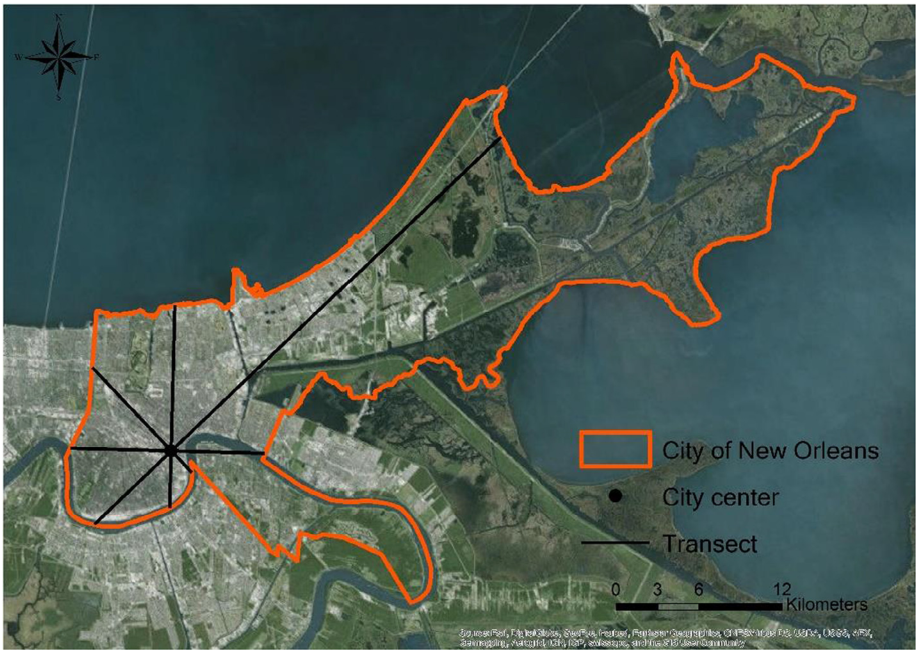

Fig. 1. The study area of New Orleans, Louisiana, USA.

is commonly associated with surface temperature and a relationship between them has long been exploited. For instance, the emissivity of impervious surfaces is slightly lower than that of vegetation, through which impervious surfaces are modulated into higher LSTs (Zhan et al., 2013). Depending on the established relationship between ground emissivity and surface temperature, many LST retrieval algorithms were carried out by using ground emissivity to model the radiative transfer process and the accuracy of the retrieved LST is primarily dependent on the accurate ground emissivity information (Wang, He, & Hu, 2015).

However, in LST estimations, scholars barely attempt to identify the mixture effect of emissivity; rather, it was assumed that entities with the same value of emissivity are composed of the same material. One major reason is that the non-uniform and heterogeneous surface limits the development of the emissivity retrieval algorithms at the satellite pixel scale (Li et al., 2013). The algorithm which has been widely used to obtain ground emissivity is to calculate emissivity value based on its correlation with visible and near-infrared (NIR) bands. One common approach is based on Normalized Difference Vegetation Index (NDVI) (Sobrino & Raissouni, 2000). $\mathrm{NDVI}^{\mathrm{THM}}$ (NDVI threshold) algorithm is conventionally implemented by NDVI thresholds, which are used to distinguish land cover types and therefore could differentiate emissivity of these land covers. This algorithm is however not always reliable as it might not be applicable for water, rocks or impervious surfaces (Sobrino et al. 2008; Li et al., 2013). Given the complexity of land surfaces, the emissivity of land, can differ significantly from unity and vary with wavelength, soil composition, vegetation, surface moisture, roughness, and viewing angles (Yu et al., 2014). Considering the combination of soil and vegetation for emissivity, $\mathrm{NDVI}^{\mathrm{THM}}$ might bias the estimate of LST as it oversimplifies the heterogeneity of emissivity in infrared spectrum ranges (Li et al., 2013; Yu et al., 2014). Moreover, it was also believed that vegetation could lead to misunderstanding in identifying land cover characteristics as it is generally limited by the similarity of vegetation reflectance spectra in visible and near-infrared (VNIR) bands (Snyder, Wan, Zhang, & Feng, 1998; Ullah, Schlerf, Skidmore, & Hecker, 2012). Therefore, it might be difficult for NDVI to distinguish ground emissivity between land covers especially in urban landscape, and a correction on emissivity retrieval becomes necessary in regard to the nature of land surfaces (Zhan et al., 2013).

The urban thermal environment is frequently complex in nature and the complexity depends on numerous factors such as the heterogeneous structure of land surface. Due to the heterogeneity in land surface features, LST was believed to significantly vary within a satellite pixel area (Yu et al., 2012). Moreover, since emissivity could change over short distance, Rozenstein, Qin, Derimian, and Karnieli (2014) suggested that it is important to estimate emissivity value for every pixel before applying it to LST estimation algorithms. The motivation for this research stems from a need to estimate surface temperature over heterogeneous urban landscapes. Our major concern is the feasibility of considering the mixture of emissivities when estimating LSTs given the heterogeneity of urban land surfaces. The application of mixture analysis of emissivity (MAoE) is designed based on the fact that the land surface is heterogeneous in land use and land cover types, which result in spectral mixtures inherent in pixels of remote sensing data (Lu & Weng, 2006; Powell, Roberts, Dennison, & Hess 2007). In other words, common temperature estimation methods do not consider the composition of land use and land cover (LULC) in each pixel; in fact, pixels that contain more than one type of LULC are mixed pixels, which exist often in urban remote sensing imagery, and thus MAoE has the potential to improve urban temperature retrieval by identifying and quantifying LULC types in each pixel for emissivity estimation. Emissivity estimates derived from MAoE act as inputs of LST retrieval algorithms (i.e., MW, SC, and SW) subsequently. This study is organized as follows. In Section 2, we introduce the remote sensing datasets and the study area – New Orleans, which has heterogeneous landscape. In Section 3, we first propose the new emissivity retrieval method of MAoE and then summarize $\mathrm{NDVI}^{\mathrm{THM}}$; three temperature retrieval algorithms of SC, SW and MW are also summarized so that other researchers can utilize all the LST retrieval approaches mentioned in this study. We summarize results, which were tested by the $\mathrm{NDVI}^{\mathrm{THM}}$ -based and MAoE-based MW, SC and SW methods in Section 4, and discussions are presented in Section 5. Section 6 is a concise conclusion.

2. Study area and data source

The study area is the city of New Orleans, Louisiana, USA, geographically situated between 29.865605 N and 30.174805 N latitudes and 89.627781 W – 90.140031 W longitudes (Fig. 1). This region predominantly experiences a humid subtropical climate with year-round temperature varying between 14 °C and 20 °C. The city is covered by a