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Normalizing land surface temperature for environmental parameters in mountainous and urban areas of a cold semi-arid climate

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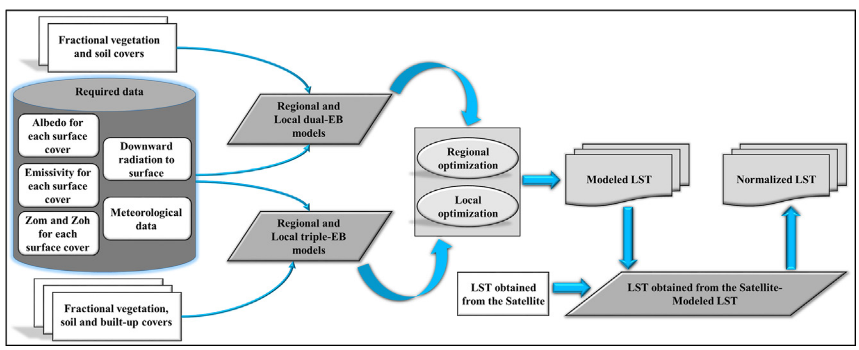
HIGHLIGHTS

- Normalization of LST relative to environmental parameters is significant in climate.
- Triple-EB model f\or modeling LST increased the accuracy over the Dual-EB model.
- Local optimization was more efficient than regional optimization to normalize LST.
- The developed protocol was applicable both to mountainous and urban areas.

GRAPHICAL ABSTRACT



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ABSTRACT

Normalization of land surface temperature (LST) relative to environmental factors is of great importance in many scientific studies and applications. The purpose of this study was to develop physical models based on energy balance equations for normalization of satellite derived LST relative to environmental parameters. For this purpose, a set of remote sensing imagery, meteorological and climatic data recorded in synoptic stations, and soil temperatures measured by data loggers were used. For modeling and normalization of LST, a dual-source energy balance model (dual-EB), taking into account two fractions of vegetation and soil, and a triple -source energy balance model (triple-EB), taking into account three fractions of vegetation, soil and built-up land, were proposed with either regional or local optimization strategies. To evaluate and compare the accuracy of different modeling results, correlation coefficients and root mean square difference (RMSE) were computed between modeled LST and LST obtained from satellite imagery, as well as between modeled LST and soil temperature measured by data loggers. Further, the variance of normalized LST values was calculated and analyzed. The results suggested that the use of local optimization strategy increased the accuracy of the normalization of LST, compared to the regional optimization strategy. In addition, no matter the regional or local optimization strategy was employed, the triple-EB model out-performed consistently the dual-EB model for LST normalization. The results show the efficiency of the local triple-EB model to normalize LST relative to environmental parameters. The correlation coefficients were close to zero between all of the environmental parameters and the normalized

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LST. In other words, normalized LST was completely independent of the environmental parameters considered by this research.

1. Introduction

Land surface temperature (LST) is a very important biophysical variable as it reflects the amount of radiation emitted from the surface and sub-surface of the earth, and the exchange of energy between the earth surface and atmosphere. In recent studies, it has been possible to calculate the LST for large areas by using thermal infrared data obtained from thermal remote sensing images and by using physical and quantitative models. LST obtained from thermal remote sensing have been used in numerous studies, including ground and underground thermal sources (Jia et al., 2017; Mansor et al., 1994), environmental monitoring (Wan et al., 2004), energy balance (Friedl, 2002; Weng et al., 2014), geological structure (Ma et al., 2010), climate change and urban phenomena (Okalebo et al., 2016; Voogt & Oke, 2003; Berger et al., 2017; Weng et al., 2004; Firozjaei et al., 2018; Panah et al., 2017), evapotranspiration, soil moisture and water resources management (Jia et al., 2017; Harris et al., 2017; Lievens et al., 2017), and identification of various objects/phenomena (Bellaoui et al., 2017; Eckmann et al., 2008).

The set of environmental parameters, such as temporal and geographical settings, inherent thermal characteristics, biophysical properties, climatic parameters and sub-surface conditions, can cause the heterogeneous spatial and temporal distribution of LST. Normalization of LST relative to environmental parameters is of great importance in many scientific studies and accurate management decisions such as identifying geothermal resources, monitoring the trend of changes in the faults and volcanoes activities, the trend of thermal anomalies and their relationship with earthquake and management and planning of energy consumption in urban environment (Coolbaugh et al., 2007; Gutiérrez et al., 2012; Malbéteau et al., 2017; Mattar et al., 2014). For the earth surface under different conditions, energy balance components include net radiation flux and geothermal sources flux as heaters factors, and soil heat fluxes, sensible heat flux and latent heat flux as surface cooling agents. The energy balance is directly related to the surface environmental parameters. The ultimate goal for normalizing LST relative to environmental parameters is to eliminate and modulate the effect of the net radiation flux, sensible heat flux, and latent heat flux.

Dozier and Outcalt (1979) used the energy balance equations to simulate LST in mountainous regions. In their model, the set of incoming radiation to the surface, albedo, surface roughness, wind speed, relative air humidity, air pressure, and vapor pressure in the air were considered. However, this model did not show effective for heterogeneous areas in terms of vegetation and surface moisture, and was suitable only for dry areas. In their study, direct and diffuse radiations reflected by nearby terrains were not considered for modeling of incoming radiation to the surface. Further, for modeling the environmental lapse rate (ELR), a standard value of 6.5 °C per km was used (Dozier & Outcalt, 1979). Rigon et al. (2006) used the GEotop model for modeling incoming radiation on the surface and its impact on LST. In the model, wind speed and air temperature for the whole region, direct incoming radiation for each pixel were considered according to the local incidence angle, diffuse radiation according to the atmospheric and cloudy transmissivity coefficient, shadow and radiations reflected by nearby terrains effects (Rigon et al., 2006). Jain et al. (2008) investigated the impact of ELR effect on LST in the Satluj River basin. In the study, MODIS and NOAA-AVHRR data were used. The surface area of the study was completely covered by snow. Therefore, surface emissivity coefficient was fixed with spatial variations. The results indicated an inverse linear relationship between LST and elevation parameters. The correlation between LST and elevation parameters for MODIS images showed a stronger correlation than that for AVHRR images, which was caused by the finer spatial resolution of MODIS compared to AVHRR. The correlation varied in different months of the year (Jain et al., 2008). Chen et al. (2009) reviewed the annual LST changes using the normal annual variation field (NAVF) model, and used solar incoming radiation, albedo, geographical location, and topographic conditions to model LST with this model. The relationship between LST and latitude in a specific longitude, in two independent states of elevation, showed very different results (Chen et al., 2009). In the case of altitude dependence, the relationship between LST and latitude along a particular longitude was very weak, but with the elevation independent of this relationship, the correlation coefficient can reach 0.97 (Chen et al., 2009). The results of the study indicated a strong relationship between LST and geographic location and high impact of elevation on LST (Chen et al., 2009). Peters et al. (2012) used the feature space between LST and the vegetation index (VI) to assess evapotranspiration. The results suggested that LST should be normalized to the elevation conditions of the study area in order to use the LST-VI feature space model to investigate evapotranspiration in heterogeneous topographic regions. In a study by Peters et al. (2012), a classified linear regression model was used to investigate the relationship between LST and elevation (Peters et al., 2012). Coolbaugh et al. (2007) used night and day thermal images to identify surface anomalies. In their study, LST obtained from thermal images was normalized relative to the effects of topography, albedo, emissivity and thermal inertia. The energy balance equation was used to normalize LST relative to different environmental parameters, regardless of sensible and latent thermal flux components. Therefore, the proposed model was ineffective for regions with variable biophysical properties (Coolbaugh et al., 2007). Malbéteau et al. (2017) proposed three models of soil and vegetation energy balance equations, multi-linear regression and slope of dry edges for normalization of LST relative to the elevation and illumination effects. In the energy balance model for normalization of LST, sensible and latent heat flux were considered, which was commonly ignored in previous studies due to the complexity of the model. The results of this study indicated that the energy balance equation model performed better than multi-linear regression and slope of dry edges models. In this study, to determine the unknown parameters of the various models, the ordinary least squares (OLS) and regional optimization were used. Moreover, the energy balance equation model for normalizing the LST proposed in the study considered only two fraction covers of vegetation and soil; and it was not suitable for regions with three fraction covers of vegetation, soil and built-up lands (Malbéteau et al., 2017).

The main objective of this study is to develop physical models based on energy balance equations for normalization of LST relative to environmental parameters, including solar radiation, topographic conditions, ELR effect, and surface biophysical characteristics such as albedo, greenness and wetness. The distinction between this study and the previous studies in the context of normalization of LST obtained from satellite images lies in three areas: (1) A physical model based on energy balance equations was presented for three fractions of vegetation, soil and built-up land covers; (2) For solving the unknown parameters in the normalization model, the local optimization strategy was proposed and calculated at the pixel scale; and (3) To solve the unknown parameters related to the LST normalization model in relation to the environmental parameters, the Partial least-squares (PLS) method was used.