The use of a pseudo-invariant target for the calibration of thermal infrared data by split-window and single-channel methods

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Land Surface Temperature (LST) is a key parameter in the physics of terrestrial surface processes. Hence, many efforts have been devoted to establishing methods for LST retrieval from remote sensing data. The split-window (SW) methods use two channels in the thermal infrared region (TIR), typically located in the atmospheric window between 10 and 12 µm. The single-channel (SC) methods use the radiance measured by the satellite sensor in a single band, chosen from the atmospheric window. Both correct the atmospheric attenuation, which is one of the main problems in the TIR remote sensing to obtain reliable estimates of LST. Due to their simplicity and precision, SW methods are more popular. However, SC methods may be more accurate as long as they have sufficient data of the atmosphere state and robust techniques. Thus, this work aimed to compare SW and SC methods for obtaining LST from a Landsat 8 OLI/TIRS image. In order to validate the results, the Atmospheric Correction Parameter Calculator (ACPC) was used. The ACPC provides specific atmospheric parameters required as input into the Radiation Transfer Equation (RTE). Data from a meteorological station near the study area were used as input in the ACPC for generating the variables: transmittance, downwelling and upwelling radiance. Both methodologies demonstrated similar performance and good agreement when compared to ACPC results, nevertheless, the SC approach was the most suitable for the region studied.

Introduction

Land surface temperature (LST) is an essential parameter in the physics of land surface processes on regional as well as a global scale (Li and Jiang, 2018). In addition, it is a key variable to be retrieved from the Thermal Infrared (TIR) data (Cristóbal et al., 2009) because is widely used in many fields including evapotranspiration, climate change, hydrological cycle, vegetation monitoring, urban climate and environmental studies, among others (Li et al., 2013).

Remote sensing in the TIR region provides an opportunity to obtain information about the LST, since most of the energy detected by the sensor in this spectral region is directly emitted by the land surface (Jiménez-Muñoz et al., 2008; Yu et al., 2014).

Several efforts have been devoted to establishing methods to retrieve the LST from remote sensing data. These algorithms can be roughly grouped into three categories according to Du et al., (2015): (i) single-channel (SC) (ii) multichannel, and (iii) multi-time methods. The split-window (SW) methods are included in the group (ii).

The SW methods uses two TIR bands typically located in the atmospheric window between 10 and 12 µm. The basis of the technique is that the radiance attenuation for atmospheric absorption is proportional to the radiance difference of simultaneous measurements at two different wavelengths (Jiménez-Muñoz et al., 2014).

On the other hand, SC methods uses the radiance measured by the sensor in a single channel and corrects the radiance for residual atmospheric attenuation using atmospheric transmittance/radiance code that requires input data on the atmospheric profiles. These profiles are obtained by launching in situ radiosondes. Then, the LST is retrieved from the radiance measured in this channel by inverting the Radiative Transfer Equation (RTE).

Nevertheless, atmospheric profiles data hardly ever are available for specific conditions in the real world (Wang et al., 2015) and to be suitable they need to be launched simultaneously with the satellite overpass, which is a challenge (Sobrino et al., 2004). In order to avoid the radiosonde dependence SC algorithms were developed in the last three decades.

Given that the atmosphere is the main problem in the TIR remote sensing, to acquire reliable estimates of LST from satellite measurements, atmospheric, angular and emissivity effects must be compensated (Li et al., 2013). SW methods are more popular due to its simplicity and precision. However, SC methods may be more accurate as long as they have sufficient data relative to the atmosphere (Dash et al., 2002) and robust techniques.

This paper aims to compare a SW and a SC method to retrieve LST from a Landsat 8 OLI/TIRS image. To validate the results obtained, the *Atmospheric Correction Parameter Calculator* (ACPC) (Barsi et al., 2005) was used. ACPC provides specific atmospheric parameters for the Landsat 5 TM, Landsat 7 ETM+ and Landsat 8 TIRS thermal bands, which are required as input to solve the RTE. Data from a meteorological station near the study area were also used as input data in the ACPC for generating the variables: transmittance (τ), downwelling ($L\downarrow$) and upwelling radiance ($L\uparrow$).

Method

Physical basis

The land surface is not a perfect blackbody for thermal emittance. Therefore, the LST retrieval from the observed thermal radiance in space is more complicated. The atmosphere and ground effects must be considered (Li et al. 2013; Wang et al. 2015). The RTE which represents the basis of the SC methods is applied to a certain sensor channel and wavelength interval according to:

$$L_{sensor,\lambda} = [\varepsilon_\lambda B_\lambda(Ts) + (1-\varepsilon_\lambda)\, L_{atm}\downarrow]\, \tau_\lambda + L_{atm\uparrow} \qquad (1)$$

where Lsensor is the at-sensor radiance in $Wm^{-2}\ \mu m^{-1}\ sr^{-1}$, ε is the land surface emissivity (LSE), $B\lambda(Ts)$ is the Planck's law, $L\downarrow$ is the downwelling atmospheric radiance in $Wm^{-2}\ \mu m^{-1}\ sr^{-1}$, $L\uparrow$ is the upwelling atmospheric radiance in $Wm^{-2}\ \mu m^{-1}\ sr^{-1}$, and τ is the atmospheric transmitance.

Study site

The study area is a dune located in the North Coast of Rio Grande do Sul state, Brazil (Figure. 1). The site has a large stock of fine quartz sand (125 to 250 μm), composed by quartz (99.53%) and heavy minerals (0.47%), with grains varying among sub-rounded (68%), rounded (18%), subangular (14%).

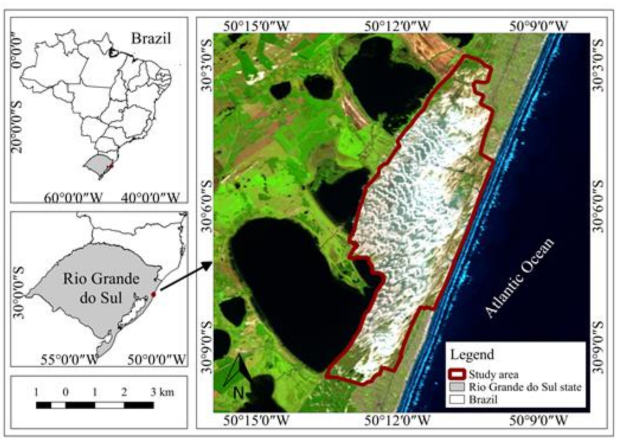

Figure 1. Study area location in Southern Brazil. Dune mask shown by the red line (Landsat 8 OLI - color composite RGB: 432).

The sand dune is a test area, where is possible to perform field campaigns, mostly because it is considered a pseudo-invariant target, and therefore suitable for the terrestrial calibration of LST retrieval by remotely sensed data (Hulley and Hook, 2009).

Data acquisition

Landsat 8 OLI/TIRS image was downloaded over the study area from the US Geological Survey website in Level 1 product. Landsat Level 1 data are radiometric, geometric and terrain corrected. To obtain the *normalized difference vegetation index* (NDVI), which is used in the LSE derivation, Landsat 8 OLI surface reflectance product was also downloaded from the Landsat Data collection.

Landsat 8 TIRS has two spectrally adjacent channels. For LST retrieval using the SW algorithm, the two thermal radiance bands were used. In contrast, for the application of the SC method the band 10 was chosen as input because it is in a lower atmospheric absorption region (high atmospheric transmissivity values) (Jiménez-Muñoz et al., 2014), providing superior results (Yu et al., 2014).

LST calculation

The SW algorithm applied in this paper is proposed by Jiménez-Muñoz et al., (2014) based on the mathematical structure proposed by Sobrino et al., (1996). The SC algorithm is based on the RTE (Eq. 1) and was originally developed by Jiménez-Muñoz et al., (2003) and improved in Cristóbal et al., (2018) by adding a new parameter to the model: the atmospheric mean temperature (*Ta*). (See the papers for the equations and more details).

SW and SC methods need the water vapor content (*w*) in the atmosphere as input. Thus, we used Leckner method proposed by Iqbal (1983) to obtain this variable. The input data required in the methodology were taken from a nearby atmospheric observation station of the Brazilian National Institute of Meteorology (INMET- http://www.inmet.gov.br/portal/) located 6 km away from the study area (station coordinates: 30.010268º; -50.135887º and 5 m a.s.l.)

Land surface emissivity (LSE) is also required in both algorithms. An operational way to estimate LSE is the *NDVI threshold method* ($NDVI^{THM}$) (Sobrino et al. 2008). This method is based on the principle that there is a relationship between the NDVI and the emissivities of terrestrial materials (Van de Griend and Owe, 1993).

$NDVI^{THM}$ considers that the surface is composed only of soil and vegetation. For NDVI values lower than 0.2, pixels are entirely of soil. As in this study the region is composed of 99.53% quartz, the emissivity attributed in the $NDVI^{THM}$ was based on a spectrum acquired from the Aster Spectral Library Version 2.0, available in <http://speclib.jpl.nasa.gov>.

For NDVI values higher than 0.5, the pixel is considered to be fully vegetated, thus assuming the typical emissivity value of 0.99 (Sobrino et al., 2008). For NDVI values within the described range (0.2 ≤ NDVI ≤ 0.5) the pixels are considered as mixing pixels, and their emissivity is calculated a simplified equation (Sobrino et al. 2004)

Data analysis and validation

As in situ data were not available for the region studied, the RTE (Eq. 1) was assumed as ground truth. We applied the web-based ACPC tool available in: <https://atmcorr.gsfc.nasa.gov/> to generate the atmospheric parameters $L\downarrow$, $L\uparrow$ and τ, and solve the RTE.

The ACPC tool takes the National Centers for Environmental Prediction modeled atmospheric profiles as input to the MODTRAN radiative transfer code (Barsi et al. 2005). Furthermore, studies have reported that ACPC validation demonstrated that it can achieve satisfactory results in the LST retrieval (Barsi et al. 2005; Jiménez-Muñoz et al. 2010; Zhang et al. 2016).

Data processing was made through the development of the algorithms in MATLAB environment. The comparisons between the LST retrieved by the algorithms and the ACPC results were performed by through an analysis of the minimum, maximum and mean values and standard deviation (σ) of LST.

Results and discussion

The web-based ACPC is a very useful tool for the atmospheric correction of TIR Landsat data because it allows to obtain the needed parameters to solve RTE (Eq. 1). Thus, it was used as reference in this work. As the RTE is considered a SC method, the radiance measured by the sensor also was taken from the band 10.

The choice of band 10 is associated to the fact that it is expected that the band 11 has more uncertainties, since this region is more affected by the continuous absorption of water vapor content (*w*) in the atmosphere, being more sensitive to errors (Coll et al. al., 2012; Yu et al., 2014).

When comparing maximum, minimum and mean values of LST retrieved with the LST calculated by the RTE (Table 1), it is seen that both methods present similar results and slightly overestimate the LST.

Table 1. LST retrieved using SW and SC methods. Minimum, maximum, means and standard deviation values are shown.

Method	LST Min (K)	LST Max (K)	LST Mean (K)	*Δ (K)*	*σ (K)*
SW	297,02	307,00	301,23	3,04	1,25
SC	298,02	304,80	301,14	2,95	1,16

The SC algorithm was able to produce results closer to the RTE. The difference consisted of 2.95 K (σ of 1.16) for the SC method, while the SW algorithm showed a higher difference of 3.04 K (σ of 1.25) relative to the reference.

A greater variability (higher σ) in the LST values is observed when the SW algorithm is used, which is also mentioned by Weng et al., (2018) who also applied a SC and a SW algorithm. However, when the method was compared to a SC method, a SW and the RTE with parameters of atmospheric profiles, the SW method demonstrated a better performance than SC in LST determination.

It is important to mention that the SC methodology applied by the authors in the paper was previous to the improvements made in the algorithm by Cristóbal et al., (2018). In this context, in Cristóbal's work the authors compared the previous methodology with the new approach, and they concluded that the algorithm presents a significant improvement in the accuracy. The same result was also observed in Käfer et al. (2019).

The input parameters required for the calculation of *w*, used in both algorithms applied, were obtained from measurements of air temperature (*To*) (299.15 K) and relative humidity (60%) for the study area, provided by the meteorological station of INMET-National Institute of Meteorology located in the municipality of Tramandaí. These parameters resulted in a *w* of 2.26 g.cm^{-2}. It can be considered that none of the methodologies was effectively affected by *w* in the retrieval of LST, since the amount of *w* in the atmosphere is within the accuracy of the algorithms tested here (Jiménez-Muñoz et al., 2014).

When using a SC method, Souza e Silva (2005) claimed that it is possible to assume average values of *Ta* for a given region since there are small differences between the characteristics of the types of soil that compose the surface.

As the region evaluated in this work is highly homogeneous and the meteorological station very close, there was probably good accuracy of the input data used in the SC algorithm, especially *Ta*, which may have been the reason for its superior performance compared to the SW method that does not need this input parameter. In Figure 2 the LST maps generated by the two methodologies can be seen.

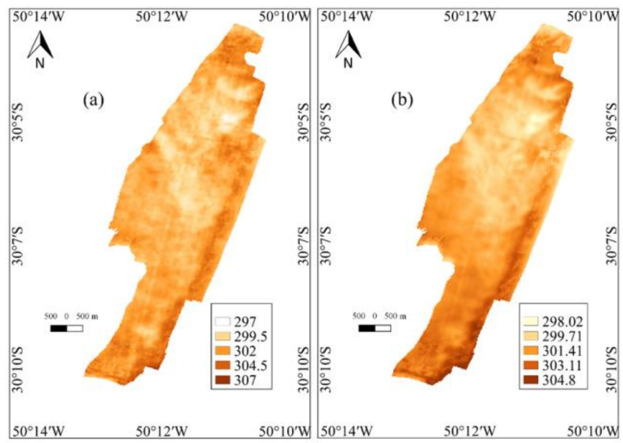

Figure 2. Maps of LST retrieved from the study area.

Conclusions

This paper explores two operational methods of LST retrieval from Landsat 8 image using a pseudo-invariant target. The methodologies here tested require the parameters *w*, *Ta* and LSE as input data, which can be obtained only from image data and measurements of meteorological stations.

When comparing the methods in a Landsat 8 image, both showed good agreement when confronted with the reference. The SC method is the most suitable for the region studied with an average accuracy of 2.95 K (1.16 σ) relative to the RTE with the parameters generated using the ACPC (Barsi et al. 2005).

The single-channel (SC) method is a LST retrieval method that has recently been improved by the insertion of a new parameter on its calculation (Ta). In further study we intend to analyze the performance of the algorithms in a great number of scenes. In addition, in situ LST and LSE measurements are required for more accurate validation.

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