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Assessing the potential of parametric models to correct directional effects on local to global remotely sensed LST

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ABSTRACT

Land surface temperature (LST) values retrieved from satellite measurements in the thermal infrared (TIR) may be strongly affected by spatial anisotropy. Different parametric approaches have been proposed to simulate such effects. These are relatively simple models requiring few input data and therefore appropriate to simulate directional effects in satellite LST retrievals over large areas. The purpose of this study is to consistently evaluate the performance of two parametric models (the so-called Kernel and Hotspot models), and to assess their respective potential to correct directional effects on LST for a wide range of surface conditions, in terms of tree coverage, vegetation density, surface emissivity. We also propose an optimization of the correction of directional effects through a synergistic use of both models. The Kernel model allows an effective simulation of LST directionality associated with shadowing effects and emissivity anisotropy, but results show that it significantly underestimates the amplitude of the angular corrections. The Hotspot model performs better in simulating anisotropy related to shadowing effects. However, it is unable to account for emissivity anisotropy, showing lower performance than the Kernel model for nighttime data and for low tree coverage. The combined Kernel-Hotspot model provides corrections on LST directionality with reliable quality, with particularly improved performance during nighttime and for low tree densities.

1. Introduction

Satellite-based Thermal Infrared (TIR) observations have proven useful to estimate land surface temperature (LST) over large areas and on a regular basis (Lacaze et al., 2011; Trigo et al., 2011; Wan, 2014) and are therefore a valuable source of input data when deriving surface fluxes (e.g. Wang et al., 2014; Xu et al., 2011). Retrieved LST values correspond to a mean radiometric surface temperature within the sensor footprint and, therefore, remotely sensed LST is in general highly anisotropic. As such, a scene viewed by the same sensor from different viewing angles would lead to different LST retrievals. This effect contributes to increase the LST variability among datasets.

Several methodologies have been developed to simulate LST directionality, either through physically-based formulations such as those relying on radiative transfer modeling, geometric and 3-D models, or by means of parametric models (see, e.g., Verhoef et al., 2007 for a review of the various methods). For scenes such as forests and shrublands, the physical models simulate the canopy physical properties and the radiative transfer between the different layers of the media, soil background inclusive. As a result, they provide accurate simulations of the radiometric temperature for the canopy-soil system. However, those physical models require detailed knowledge of surface characteristics, which is not readily available at the continental or global scale. Parametric models, on the other hand, are computationally more efficient and require few input data, which makes them particularly appropriate for operational use in satellite LST retrieval.

A proposed methodology to simulate LST anisotropy based on a parametric approach is the one developed by Vinnikov et al. (2012). The model follows a kernel approach that has successfully been used to describe the Bidirectional Reflectance Distribution function (BRDF) in the optical domain (e.g. Jupp, 2000). Here the LST directionality is modeled by two kernels composed of trigonometric functions of the viewing and sun geometries. Previous studies have shown the potential of the approach to retrieve satellite LST (Ermida et al., 2017; Scarino et al., 2016; Vinnikov et al., 2012).

Another approach is the one proposed by Lagouarde and Irvine (2008) that is engendered by the hot spot formulation proposed by Roujean (2000) for the optical domain where reflectance is formally replaced by surface temperature. The model has been successfully evaluated against radiative transfer models and experimental setups

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that revealed its potential to properly describe directional LST for both urban and vegetated areas (Duffour et al., 2016; Lagouarde and Irvine, 2008).

The two approaches are worth being compared in a systematic way. For instance, the model by Vinnikov et al. (2012) allows an effective simulation of LST directionality associated not only to shadowing effects but also to emissivity anisotropy. However, Duffour et al. (2016) have pointed out a possible underestimation by the model of the LST anisotropy near the hot-spot geometry. In turn, the model by Lagouarde and Irvine (2008) performs better in simulating anisotropy related to shadowing effects (Duffour et al., 2016), but the model is unable to account for emissivity anisotropy and could potentially fail for surfaces with low vegetation cover.

The aim of this study is threefold: 1) to consistently evaluate the performance of the models proposed by Vinnikov et al. (2012) and by Lagouarde and Irvine (2008); 2) to assess their respective potential to correct directional effects on LST for a wide range of surface conditions (tree coverage, vegetation density, surface emissivity); and 3) to optimize the correction of directional effects by proposing an approach based on a synergistic use of both models.

For this purpose, we first generate a dataset of synthetic time-series of directional LST, considering a wide range of surface conditions in terms of vegetation density and emissivity anisotropy. It may be emphasized that the synthetic dataset is based on brightness temperature values measured in Évora (Portugal) at the validation station maintained by the Karlsruhe Institute of Technology (KIT) within the framework of the EUMETSAT Satellite Application Facility on Land Surface analysis (LSA-SAF; Trigo et al., 2011). Synthetic values of directional LST are then generated using a geometric model, following the methodology proposed by Ermida et al. (2014). This geometric model together with the observations gathered at Évora constitute the baseline to generate different scenarios of LST anisotropy. The parametric models are then calibrated using those synthetic datasets and an assessment is made of their capability to reproduce the different scenarios of LST anisotropy.

Section 2 describes the in situ data together with the methodology proposed to generate the synthetic LST data, as well as the parametric models being evaluated. In Section 3 we perform a detailed analysis of the dependence of model parameters and model performance on surface characteristics, including their seasonal behavior and sensitivity to data sampling. Finally, in Section 4 a brief discussion is presented while Section 5 concludes this study.

2. Data and methods

2.1. In situ measurements

The Évora anchor station is a validation site operated and maintained by the Karlsruhe Institute of Technology (KIT) within the framework of the LSA-SAF. Évora is located in Southern Portugal (8.00°W; 38.54°N) within an area of Quercus woodland. The area is characterized by high seasonality of understory vegetation, presenting strong temperature contrasts during the dry season (Fig. 1). The surface temperature and emissivity values at Évora anchor station exhibit noticeable seasonal cycles. Due to the inherent characteristics, a significant dependence on sun-view geometry occurs, thereby making this site an interesting testbed for the understanding of TIR directional effects and further LST retrieval based on remotely sensed measurements.

In situ measurements are collected every minute by three infrared radiometers (Heitronics KT-15.85 IIP), observing the sunlit background, a tree crown and the sky at 53° zenith angle, which is used to estimate down-welling reflective components (Göttsche et al., 2013). The radiometers provide measurements of brightness temperatures within the 9.6–11.5 μm spectral interval, with an absolute accuracy of 0.3 K (Göttsche et al., 2013). For this study, the full-year period from October 2011 to September 2012 is used. The original 1-minute sampling is degraded to match the observation time of the SEVIRI instrument, and SEVIRI's cloud mask is used to remove cloudy sky observations.

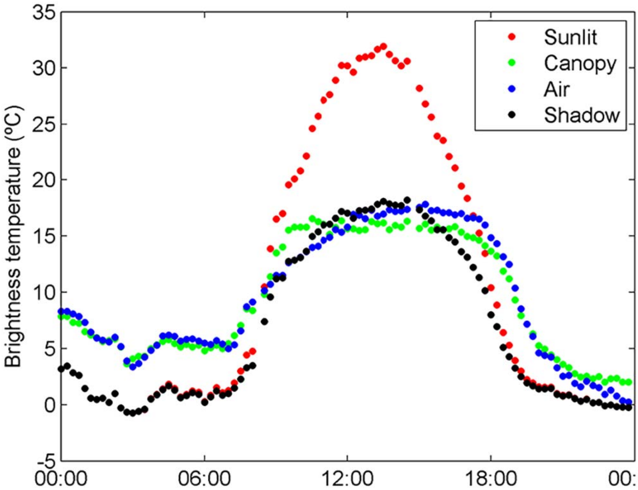

Fig. 1. Diurnal cycle of near-surface air, canopy, and sunlit ground temperatures (°C) measured at Évora, on the 20th of March 2011. The temperature of the shaded background (Shadow) was estimated from air temperature (Ermida et al., 2014).

The temperature of the shaded ground component is obtained following the procedure described in Ermida et al. (2014), where the air temperature is used with an additional phase correction to account for the time lag between ground temperature and near-surface air temperature (Fig. 1).

2.2. The geometric model

The Geometric model is used here to generate synthetic LST time-series for any given view and illumination geometries. The model allows estimating the scene fractions covered by sunlit ground, shaded ground and canopy, respectively, given the average shape of the trees within the scene (tree height, canopy height and canopy width) and tree density (Ermida et al., 2014). It is then assumed that the scene's radiance may be estimated as a linear combination of the radiances emitted by each component. The corresponding LST is obtained by inversion of Planck's Law, using an effective surface emissivity.

The Geometric model was originally designed to upscale in situ measurements from Évora's radiometers to areas of a few km^2, comparable to the footprint of a SEVIRI/MSG pixel (4–5 km sampling size), or MODIS (about 1×1 km^2). The same model is here used to upscale these measurements for a variety of scenes. In particular, we consider a set of LST synthetic time-series generated for Évora-like sites, but with Percentage of Tree Cover (PTC) varying from extremely sparse (in the limit with no trees, PTC = 0%) to extremely dense (PTC = 90%).

In order to generate the LST values of scenes corresponding to varying viewing geometry, 100 view angles are selected randomly for each data point, with zenith angles ranging between 0° and 70° and azimuth angles ranging between 0° and 360°. This procedure results in 100 full-year LST time-series with varying sun-view configurations. The procedure is repeated for PTC values of 0%, 5%, and 10–90% with intervals of 10%.

2.3. Emissivity parametrization

Effective emissivity is simulated for the wavelength range of the in situ radiometers using the Vegetation Cover method (Peres and DaCamara, 2005), where emissivity is given by a weighted average of a soil emissivity and a vegetation emissivity with weights defined by the fraction of green vegetation. Following results suggested by previous works (Göttsche et al., 2013; Peres and DaCamara, 2005), vegetation emissivity is assumed to be constant with view angle, taking a constant