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Evaluation of the S-NPP VIIRS land surface temperature product using ground data acquired by an autonomous system at a rice paddy

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ABSTRACT

The S-NPP VIIRS Land Surface Temperature (LST) product attained the stage V1 of validation maturity (provisional validated) at the end of 2014. This paper evaluates the current VIIRS V1 LST product versus concurrent ground data acquired at a rice paddy site from December 2014 to August 2016. The experimental site has three different seasonal and homogeneous land covers through the year, which makes the site interesting for validation activities. An autonomous and multiangular system was used to record continuous ground data at the site. The data acquired at zenith angles similar to the VIIRS viewing angles were used for the validation to avoid possible differences between satellite and ground views due to angular dependences of the LSTs. Concurrently to surface data, downwelling sky radiances were measured at different incidence angles by the system, which were used to improve the cloud screening of the validation dataset, since cloud leakage was identified in previous validation studies as an important issue for further improvement. The validation results show good performance for the VIIRS V1 LST product at zenith angles $\leq 40°$, with systematic uncertainties within ±0.5 K and accuracies around 1.2 K. These values are within the threshold requirements established for the VIIRS LST product, and they are better than the validation results published previously for the beta version of the product or using VIIRS data reprocessed with the calibrated algorithm coefficients implemented from April 2014. As the VIIRS LST algorithm has regression coefficients dependent on land cover type, the impact of land cover misclassifications on VIIRS LST data accuracy was also evaluated. It was expected that changing the surface type assigned by the VIIRS product to more appropriate types at the site pixels should improve the validation results. However, the improvement was limited, likely due to the reduced range of variability of the emissivities considered for the different land cover types in the regression process of the VIIRS LST algorithm coefficients. The results reveal the difficulties and uncertainties involved in the LST retrieval when using a LST algorithm with surface type dependent coefficients.

1. Introduction

Land surface temperature (LST) and emissivity are key variables to assess the longwave flux exchange between land surfaces and the atmosphere, and therefore they are essential variables in meteorology, climatology and hydrology (Weng, 2009; Ghent et al., 2010; Schneider and Hook, 2010; Anderson et al., 2012; Sánchez et al., 2015).

The aim of this paper is to evaluate the LST product of the Suomi National Polar-Orbiting Partnership (S-NPP) Visible Infrared Imaging Radiometer Suite (VIIRS) using concurrent ground measurements. The VIIRS LST product is generated with a split-window algorithm with different sets of coefficients for daytime and nighttime overpasses and for 17 surface land cover types, which are assigned to each VIIRS pixel according to classification maps (Yu et al., 2005; VIIRS LST ATBD, 2013). The threshold requirements for VIIRS LSTs are bias between satellite and ground-based LSTs of 1.4 K and standard deviation (SD) of 2.5 K, although the objective is to attain bias of 0.8 K and SD of 1.5 K (Justice et al., 2013; Joint Polar Satellite System (JPSS) Program, 2014). In this paper, the current V1 version of the product (i.e., JPSS defined "provisional validated") was evaluated from mid-December 2014 to mid-August 2016 using data acquired by an autonomous and multiangular system deployed on a permanent station in a ~100 km^2 flat and homogeneous area of rice fields (39.274°N, −0.317°E in

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WGS-84; 2.5 m above sea level) near Valencia city, Spain. Due to changes in crop phenology, the site has different seasonal land covers throughout the year (water, bare soil and full vegetation cover), all of them being thermally homogeneous (Coll et al., 2005, 2007; Niclòs et al., 2015).

There exist several methods for the validation of satellite-derived LSTs. One is the temperature-based method, which directly compares satellite LSTs with concurrent ground measurements in a test site. In this case, the test site must be thermally homogeneous at the spatial scales of the ground measurements (m^2) and the satellite data (km^2), a condition which is difficult to meet for most land surfaces. Another validation method is the radiance-based method (Wan and Li, 2008; Coll et al., 2009) where ground-measured LSTs are not necessary, but requires emissivity estimates and atmospheric profiles over the validation site concurrent with the satellite overpass, together with an atmospheric radiative transfer model. Although the radiance-based method does not strictly provide a direct LST validation, it can be applied to much more surface types than the temperature-based method. However, the efficiency of the radiance-based method depends on the quality of the emissivity data and the atmospheric profiles required. Finally, LST estimates from a satellite under study can be compared to LSTs provided by another well documented, validated satellite sensor, what is known as the cross-validation method (Tang et al., 2015; Duan et al., 2017). However, when comparing LST products from different satellites, there are important sources of discrepancies (overpass times, view angles, cloud cover, resolutions and spectral response functions) that can affect the performance evaluations.

The characterization of uncertainties on existing LST products is not possible without independent and traceable sites (Hulley et al., 2012). Thus, accurate in situ LST measurements at dedicated, homogeneous validation sites provide the most reliable validation results (Guillevic et al., 2014).

Several studies have evaluated the previous versions of the VIIRS LST product (Justice et al., 2013; Li et al., 2014; Guillevic et al., 2014). Guillevic et al. (2014) presented validation results against ground measurements for the version previous to V1 (with the JPSS defined "beta maturity stage", i.e., minimally validated) of the VIIRS LST product. They used VIIRS LST data from August 2012 to October 2013, provided by both the NOAA's Comprehensive Large Array-data Stewardship System (CLASS) and the NASA's Land Product Evaluation and Analysis Tool Element (LPEATE), which contains subsets of the VIIRS data. Ground data were acquired from 8 stations (7 from the SURFace RADiation (SURFRAD) network and the Karlsruhe Institute of Technology (KIT) Gobabeb station in Namibia) and by NASA JPL at Lake Tahoe, California. The validation showed that the VIIRS beta LST product performed accordingly to the threshold requirements over most vegetated and inland water surfaces, with overall mean differences lower than ±0.8 K and SD values from 0.4 to 2.7 K depending on the site. However, stronger biases and SDs were obtained when results were analyzed separately for nighttime and daytime overpasses. Moreover, an overall bias of −4.6 K, with SD of 2.5 K, was obtained for the Gobabeb station. Other studies over arid and semi-arid validation sites (Justice et al., 2013; Li et al., 2014) also showed a systematic underestimation of the VIIRS beta LST product by up to 5 K.

Liu et al. (2015) used ground measurements acquired by the SURFRAD observing network to evaluate the product with new calibrated algorithm coefficients implemented from April 2014 (those of the current version V1). They also used ground data acquired by the Gobabeb station in Namibia for the evaluation, similarly to that shown by Guillevic et al. (2014). The SURFRAD stations provide ground data of upwelling and downwelling thermal infrared (TIR) irradiances measured by pyrgeometers in the spectral range from 3.5 to 50 μm (Augustine et al., 2005). These irradiances were used in the abovementioned references to estimate ground LSTs. According to Guillevic et al. (2012), the SURFRAD instrumental error alone gives rise to a LST uncertainty less than 1 K. Ground observations at Gobabeb, Namibia, are collected with a thermal infrared radiometer in the 9.6–11.5 μm spectral domain set up in a permanent station located at a homogeneous gravel plain sparsely covered by dry grass. There, the downwelling thermal radiance is estimated using another radiometer facing the sky at an effective angle of 53° (from zenith). However, the effective angle depends on the atmospheric conditions and the measurement spectral band; so the use of a fixed angle can introduce uncertainties (Niclòs et al., 2005a; Guillevic et al., 2014). The main uncertainties in the derived ground LSTs are due to the accuracy of the surface emissivity and the downwelling radiance (Hook et al., 2007). In general, directional measurements of sky downwelling radiance are not routinely sampled in the field, yielding LST uncertainties, especially for humid and warm atmospheres. However, directional sky downwelling data are measured by our autonomous and multiangular system, avoiding this problem.

Liu et al. (2015) showed validation results for the VIIRS LST data obtained from LPEATE. They reprocessed a dataset of VIIRS LST data (from February 2012 to April 2015) by using the calibrated algorithm coefficients implemented from April 2014. An overall bias of −0.4 K and SD of 2.4 K were shown in the case of the reprocessed dataset when compared with ground LSTs derived from the SURFRAD data. Better results were obtained at nighttime (bias of −0.2 K and SD of 2.0 K) compared to daytime (bias of −0.7 K and SD of 2.9 K). Liu et al. (2015) also showed a VIIRS LST overall bias of −1.6 K and a SD of 2.1 K when comparing with ground LSTs from the Gobabeb station. Therefore, the VIIRS reprocessed data provided better results for such arid area, but an underestimation was still observed.

Additionally, previous studies evaluated the VIIRS LST product performance by comparing with other satellite LST products, like the MODIS one (Guillevic et al., 2013, 2014; Liu et al., 2015), showing both large biases and SDs (e.g., larger than 3 K in Guillevic et al. (2014)).

The paper follows with a brief description of the S-NPP VIIRS LST product in Section 2. Section 3 shows the ground measurements acquired by the system and a new cloud screening procedure based on the system data. In Section 4, the product (version V1) validation is shown and compared with the results from Liu et al. (2015), together with an evaluation of the effect of assigning different surface types and thus different coefficient sets in the VIIRS LST algorithm at the rice paddy site. Finally, the main conclusions of the study and some suggestions for future algorithm refinements are summarized in Section 5.

2. S-NPP VIIRS land surface temperature product

The VIIRS Environmental Data Record (EDR) LST product is derived at pixel level (spatial resolution of ~750 m at nadir and around 1.5 km at the edge of the swath) using the following split-window algorithm (Yu et al., 2005):

$$LST = a_0 + a_1 T_{15} + a_2(T_{15} - T_{16}) + a_3(sec\theta_v - 1) + a_4(T_{15} - T_{16})^2 \tag{1}$$

which uses brightness temperatures (T_i) measured in two VIIRS spectral bands: M15 placed at 10.76 μm (i = 15) and M16 placed at 12.01 μm (i = 16). Different sets of coefficients (a_j, with j = 0–4) are used for daytime and nighttime and for 17 surface types of the International Geosphere-Biosphere Programme (IGBP) classification maps (VIIRS LST ATBD, 2013; Guillevic et al., 2014; Liu et al., 2015). The coefficient sets were obtained using simulations with the MODTRAN radiative transfer model (Berk et al., 2006)