NPP VIIRS LAND SURFACE TEMPERATURE PRODUCT VALIDATION USING WORLDWIDE OBSERVATION NETWORKS

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ABSTRACT

Thermal infrared satellite observations of the Earth's surface are key components in estimating the surface skin temperature over global land areas. This work presents validation methodologies to estimate the quantitative uncertainty in Land Surface Temperature (LST) product derived from the Visible Infrared Imager Radiometer Suite (VIIRS) onboard Suomi National Polar-orbiting Partnership (NPP) using ground-based measurements currently made operationally at many field and weather stations around the world. Over heterogeneous surfaces in terms of surface types or biophysical properties (e.g., vegetation density, emissivity), the validation protocol accounts for land surface spatial variability around the ground station. Over sparse vegetation canopies, the methodology accounts for viewing directional effects and sun configuration when validating VIIRS LST products.

Index Terms— Land Surface Temperature, NPP VIIRS, validation, ground-based LST, spatial heterogeneity.

1. INTRODUCTION

NOAA will soon use the new Visible Infrared Imager Radiometer Suite (VIIRS) on the Suomi National Polar-orbiting Partnership (NPP) and future Joint Polar Satellite System (JPSS) platforms as its primary polar-orbiting satellite imagers. NOAA will generate a series of Environmental Data Records (EDRs) – or level 2 products – from VIIRS data. For example, the VIIRS Land Surface Temperature (LST) EDR will estimate the surface skin temperature over land surfaces and provide key information for monitoring Earth surface energy and water fluxes. Because both VIIRS and its processing algorithms are new, NOAA is conducting a rigorous calibration and validation program to understand and improve LST product quality.

The objective of this work is to evaluate quantitative uncertainties in LST products derived from VIIRS using ground-based measurements currently made operationally at many field and weather stations around the world, and contributes to improving the retrieval algorithm. Until now, validation of thermal infrared satellite products at moderate resolution was mostly performed over homogeneous surfaces such as lakes and deserts. Actually, for most vegetated landscapes composed of various land cover types or soils, the LST measured by a station at one specific location – i.e., a point measurement – does not represent the surrounding area that is part of the coarser satellite sensor pixel (Fig. 1). Furthermore, depending on illumination and viewing directional configurations, satellites measure different surface radiometric temperatures, especially over sparsely vegetated regions with directionally varying radiometric contributions from soil and vegetation. Here, we present new methodologies to account for both spatial variability of LST around ground stations [7] and directional viewing and illumination configuration effects [8] when validating LST satellite products.

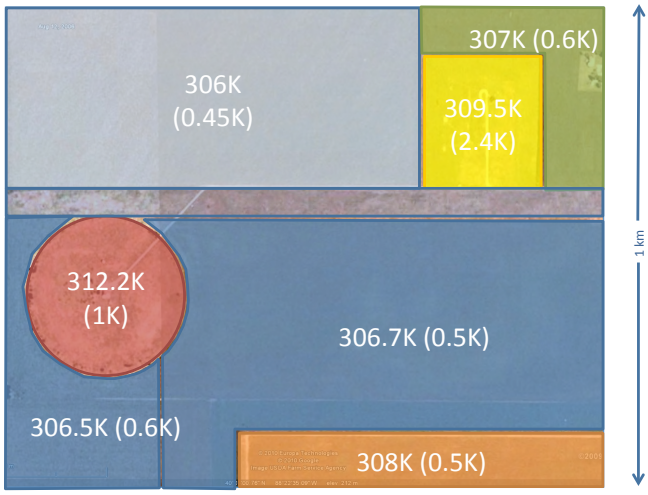

Figure 1: How to compare satellite data at moderate resolution and field measurements due to spatial variability of the LST around a station? Here, distribution of LST within a 1km^2 area derived from ASTER (90m resolution) data over Bondville, IL. Mean and STD are represented for each cover type.

2. DATA AND METHODS

The VIIRS instrument acquires data in 16 spectral channels from visible to thermal infrared domains at moderate spatial resolution, i.e. spatial resolution of around 750m at nadir. It scans around ±60° from nadir and provides daytime and nighttime imaging of any point on the Earth everyday. The LST retrieval algorithm for VIIRS is based on a viewing angle dependent generalized split-window algorithm [14] to correct for absorption and re-emission of radiation by atmospheric gases, predominately water vapor, and derive LST products from channels 15 (T_{15}) and 16 (T_{16}) centered on 10.8 and 12.0µm, respectively (Eq. 1).

$$LST=a_1+a_2T_{15}+a_3(T_{15}-T_{16})+a_4(\sec\theta_v-1)+a_5(T_{15}-T_{16})^2 \quad (1)$$

where θ_v is the viewing zenith angle, and a_i (i=1,5) are the algorithm coefficients. Day and nighttime sets of coefficients are defined for each of the 17 International Geosphere Biosphere Program (IGBP) surface types.

We have selected 51 validation sites worldwide to represent a large range of climate regimes and land cover types, including forests and mixed vegetated areas. The stations are part of operational networks, e.g. the Surface Radiation Budget (SURFRAD) network [1], US Climate Reference Network (USCRN) [11] (Fig. 2), and Ameriflux, or are specifically designed for the validation of LST products derived from other satellite sensors: the Moderate Resolution Imaging Spectroradiometer (MODIS) [10], the Spinning Enhanced Visible and Infrared Imager (SEVIRI) [5] and [13] or the Along Track Scanning Radiometers (ATSR) [4]. Depending on spectral characteristics of the thermal infrared sensors, different protocols are defined to retrieve precise LST values from thermal infrared radiances collected by different ground stations [12].

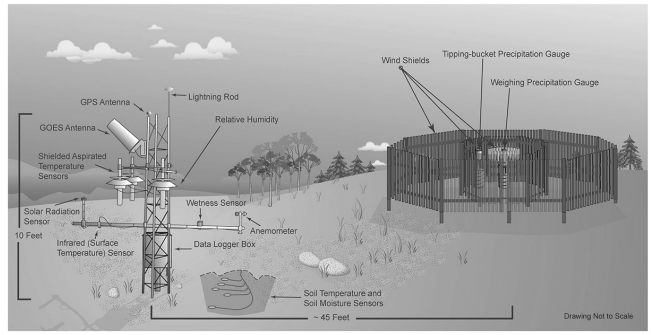

Figure 2: Schematic description of a US Climate reference Network station. Each station has the same design.

Over heterogeneous areas, the LST spatial variability is mainly due to changes in surface types, biophysical parameters, or soil moisture. The validation methodology employs a physically-based approach to scaling up in situ measurements. We use vegetation density information at higher resolution than the thermal infrared data (e.g., MODIS NDVI at 250m) and surface emissivity from ASTER at 100m [9] to describe the spatial variability in surface biophysical parameters (Fig. 3).

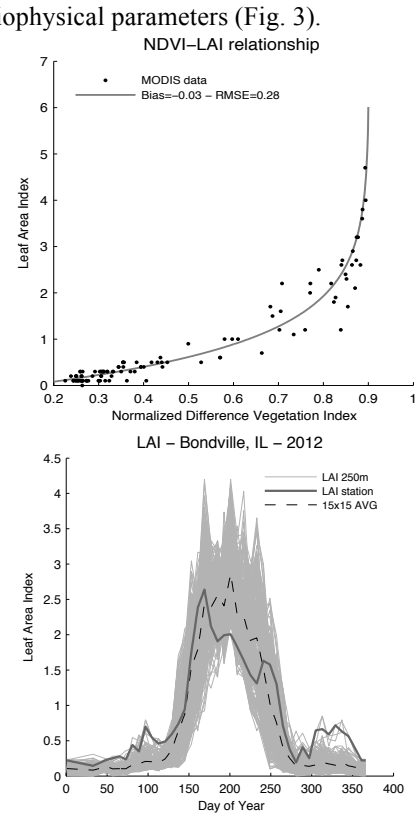

Figure 3: Relationship between NDVI and LAI MODIS standard-products at 1 km resolution for Bondville, IL. The

relationship at 1km is applied to high-resolution NDVI data to derive LAI values at 250m.

Then, we use the SETHYS land surface model [2] (Fig. 4) to merge information collected at different spatial resolutions, describe the LST distribution around the station, and fully characterize large area (km x km scale) satellite products [7].

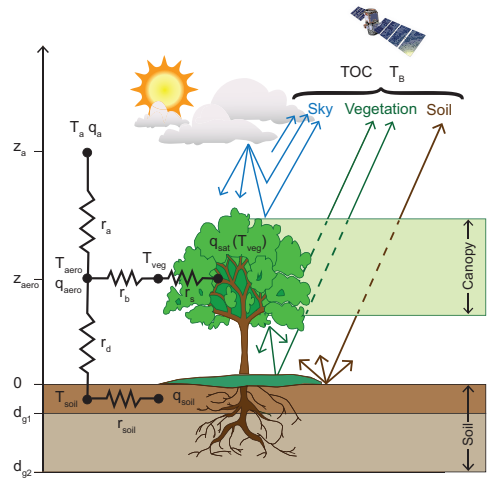

Figure 4: Schematic representation of the turbulent transfer regimes and the radiative transfer model used in the SETHYS land surface model. The measured long wave radiation, and the simulated soil (T_{soil}) and canopy (T_{veg}) temperatures are used to simulate the surface directional Top of Canopy (TOC) radiometric temperature (T_B).

The approach can be used to explore scaling issues over terrestrial surfaces spanning a large range of climate regimes and land cover types, including forests and mixed vegetated areas. For sparsely vegetated areas, such as woodlands or open forests with low tree coverage, the approach combines local field radiometric measurements and a 3-D radiative transfer model to characterize illumination and viewing directional effects on LST standard products. We use the Discrete Anisotropic Radiative Transfer (DART) model [3] and [6], to estimate the radiometric contribution of the different surface components, i.e. tree canopy and understory/soil fractions in shaded and sunlit areas, for a given illumination and viewing geometry [8]. Remotely sensed data are then represented by a linear combination of surface component ground-based radiometric temperatures weighted by the fraction of each component viewed by the sensor.

3. RESULTS

Here, we have evaluated the precision and accuracy of one year of VIIRS LST products (from March 2012 to March 2013) over SURFRAD sites. The SURFRAD network mainly represents short vegetation covers: grassland, cropland and arid/desert areas. We ran a similar analysis for MODIS LST to be able to compare both VIIRS and MODIS algorithms performance. First results show that VIIRS LST products verify JPSS program quality requirements over most validation sites. The bias and precision specifications of LST products are 1.4K and 2.5K, respectively. At daytime, VIIRS and MODIS LST agree better with scaled-up field data than with non-scaled field observations over mixed vegetation areas (Fig. 5 and 6). Nevertheless, observed biases between ground and satellite-based LST obtained over heterogeneous areas are strongly reduced when using nighttime data since effects of structural shading, evaporative cooling and surface-air temperature differences are smaller.

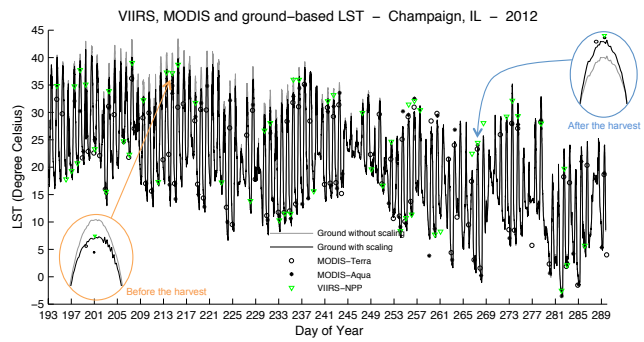

Figure 5: LST derived from VIIRS and MODIS sensors and from ground-based measurements with and without scaling over Bondville/Champaign, IL.

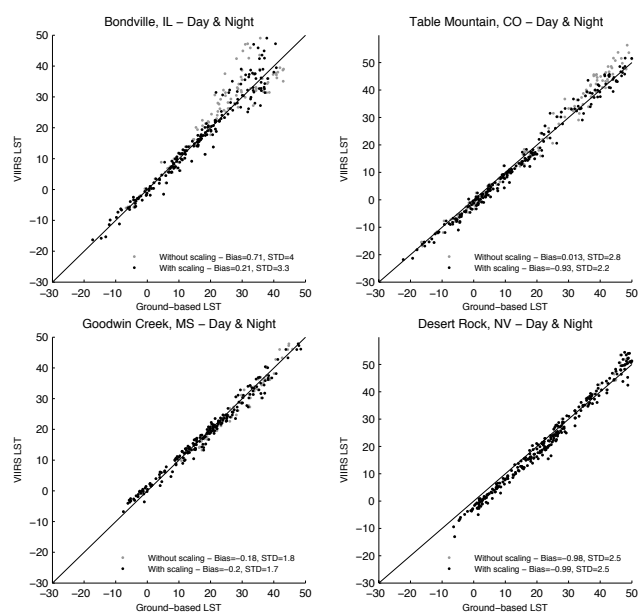

Figure 6: VIIRS LST validation results over 4 SURFRAD sites. Bias and Precision specifications of VIIRS LST are 1.5K and 2.5K.

For two of the SURFRAD sites (Bondville, IL and Fort Peck, MT), the STD of the difference between satellite and ground LST is higher than JPSS requirements. The validation

sites located at Desert Rock, NV is an arid area with very small shrubs. The landscape is very homogeneous in terms of land cover types and vegetation density, and the scaling does not affect the results. However, results show that over desert areas, MODIS and VIIRS LST products are in good agreement but are lower than the ground-based LST by around 2.5K for VIIRS and 3.0K for MODIS at nighttime. Both VIIRS and MODIS LST tend to underestimate LST at night and overestimate the LST during the day.

4. CONCLUSION

Users of satellite products put a high priority on the provision of product accuracy. In this paper we demonstrate the difficulty in validating satellite LST products over homogeneous or relatively sparse vegetation canopies using *in situ* measurements. In this context, we have developed a validation methodology to monitor the quality of polar-orbiting satellite LST products in terms of accuracy and precision and evaluate retrieval algorithms performance. First results clearly illustrate that validation of satellite LST products over heterogeneous landscapes should be performed at nighttime only if no scaling is accounted for. Ultimately, this validation approach should lead to an accurate and continuously-assessed VIIRS LST products suitable to support weather forecast, hydrological applications, or climate studies. Readily adaptable to other moderate resolution satellite systems, this work is part of the EarthTemp initiative which main goal is to develop more integrated, collaborative approaches to observing and understanding Earth's surface temperatures.

5. ACKNOWLEDGEMENT

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