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Validating MODIS land surface temperature products using long-term nighttime ground measurements

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Abstract

The Moderate Resolution Imaging Spectroradiometer (MODIS), onboard the NASA Terra and Aqua Earth Observing System satellites, provides multiple land surface temperature (LST) products on a daily basis. However, these products have not been adequately validated. This paper presents preliminary results of validating two MODIS Terra daily LST products, MOD11_L2 (version 4) and MOD07_L2 (version 4), using the FLUXNET and Carbon Europe Integrated Project (CarboEurope-IP) long-term ground measurements over eight vegetated sites. Since ground-measured LSTs were only available over one fixed point in each validation site, the study was carefully designed to mitigate the scale mismatch issue by using nighttime ground measurements concurrent to more than 1800 MODIS Terra overpasses.

The preliminary results show that MOD11_L2 LSTs have smaller absolute biases and root mean squared errors (RMSE) than those of MOD07_L2 LSTs in most cases. The match of MOD11_L2 LSTs with ground measurements in the Brookings, Audubon, Canaan Valley, and Black Hills sites is good, yielding absolute biases less than 0.8 °C and RMSEs less than 1.7 °C. In the Fort Peck, Hainich, Tharandt, and Bondville sites, MOD11_L2 LSTs were underestimated by 2–3 °C. Biases in MOD11_L2 LSTs correlate to those in MOD07_L2 LSTs. Since the MOD07_L2 LST product is one of the input parameters to the MOD11_L2 LST algorithm, biases in MOD11_L2 LSTs may be influenced by biases in MOD07_L2 LSTs. The errors in both products depend weakly on sensor view zenith angle but are independent of surface air temperature, humidity, wind speed, and soil moisture.

Keywords: Land surface temperature; MODIS; Validation; FLUXNET; CarboEurope-IP

1. Introduction

Land surface temperature (LST) is a key variable in climatological and environmental studies (Liang, 2001; Peres & DaCamara, 2004; Pinheiro et al., 2004; Wan, 1999; Wan & Dozier, 1996; Wan & Li, 1997a,b). Multiple daily LST products (on a global scale) are generated by the science team of the Moderate Resolution Imaging Spectroradiometer (MODIS) onboard the NASA Terra and Aqua Earth Observation System satellites. Table 1 lists the product name, spatial resolution, stated accuracy, and algorithm principle of the Terra MODIS daily LST products. These products are referred to as MOD11_L2, MOD11A1, MOD11B1, and MOD07_L2 in the rest of the paper. MOD11_L2 is retrieved using a generalized split-window algorithm by MODIS land team (Wan, 1999; Wan & Dozier, 1996). MOD11A1 is a gridded version of MOD11_L2, generated by projecting MOD11_L2 pixels to Earth locations on a sinusoidal mapping grid. MOD11B1, another LST product from the MODIS land team, is retrieved using a day/night algorithm (Wan, 1999; Wan & Li, 1997a,b). MOD07_L2 LST is produced using a statistical regression-based method by the MODIS atmosphere team (Seemann et al., 2003). Similar products are available from MODIS Aqua observations.

Meteorological, hydrological, and agricultural research communities require an accuracy of 0.5–2 °C for LST retrieved from satellite observations at 1–10 km spatial resolution (CEOS & WMO, 2000; GCOS, 2006). MODIS LST products have been validated in previous studies (Coll et al., 2005; Menzel et al., 2002; Wan et al., 2004a,b, 2002). The accuracy of MOD11_L2 and MOD11B1 LST products is reported to be 1 °C for the surfaces with known emissivity (Wan et al., 2002). However, the reported accuracy cannot be applied to the

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Table 1
Summary of Terra MODIS daily LST products

Product short name	Product full name	Stated accuracy (°C)	Spatial resolution (km)	Algorithm principle	References
MOD11_L2	Land surface temperature/emissivity daily 5-min L2 swath 1 km	1	1	Generalized split-window algorithm; statistical-based	Wan and Dozier (1996), Wan (1999)
MOD11A1	Land surface temperature/emissivity daily L3 global 1 km SIN grid	1	1	Reprojected from MOD11_L2 to a sinusoidal mapping grid	Wan and Dozier (1996), Wan (1999)
MOD11B1	Land surface temperature/emissivity daily L3 global 5km SIN grid	1	5	Day/night algorithm; physics-based	Wan and Li (1997a,b), Wan (1999)
MOD07_L2	Temperature and water vapor profiles 5-min L2 swath 5 km	N/A	5	Statistical regression	Menzel et al. (2002), Seemann et al. (2003)

MOD11_L2 and MOD11B1 products in their entirety, because land surface emissivity is usually unknown and retrieving it on a global scale is as challenging as LST retrieval. For vegetated sites, MOD11_L2 and MOD11B1 performances were validated using only limited ground measurements during the growing season. The MOD07_L2 LST product has been evaluated indirectly using ground measurements from the Southern Great Plains Atmospheric Radiation Measurement Cloud and Radiation Testbeds (SGP ARM-CART) site.

MODIS LST products have been used in various studies (Mostovoy et al., 2006; Nagler et al., 2005; Sun et al., 2005; Tran, 2006; Wan et al., 2004a,b; Wang et al., 2006, 2005). However, the errors caused by LST were mostly disregarded in these studies. While MODIS LSTs provide a potentially inexpensive means to validate and improve existing land surface and climate models, MODIS LST products have often been ignored by the modeling community until recently. The major concern is that the accuracy of these LST products has not been adequately assessed. To facilitate the use of MODIS LST products for broader application, more validation work is required.

The purpose of this study is to assess the accuracy of two MODIS LST products, MOD11_L2 LST and MOD07_L2 LST, using long-term continuous ground measurements over vegetated surfaces. MOD11A1 and MOD11B1 LST products were not considered in the current stage due to time limitations. MOD11_L2 LST has been used more frequently than MOD11B1 LST. MOD11A1 LST is reprojected from MOD11_L2 LST. MOD07_L2 LST is also validated because it is one of the input parameters for the MOD11_L2 LST algorithm. It is important to investigate whether the performance of the MOD07_L2 LST algorithm affects that of MOD11_L2 LST. Only nighttime observations were validated in this study because of the limitations of ground measurements. During nighttime, the Earth surface behaves almost as an isothermal and homogeneous surface. During daytime, surface temperatures under shadows are lower than surface temperatures in direct sunlight, giving rise to temperature differences as much as 20 °C (Wan & Dozier, 1996). Ground-measured surface temperatures are only available over one point in each site and cover a small area near the flux tower (about 2–5 m in diameter). Therefore, they may not represent the sunlight and shadow conditions within the MODIS footprint.

This validation study differs from previous MODIS validation works in four aspects. First, this is the first effort to validate MODIS LST products using ground measurements from long-term monitoring sites. The major advantage of using such data is that a large quantity of ground measurements is available. Ground measurements corresponding to more than 1800 MODIS Terra overpasses were used for statistical analysis. Second, the MODIS LST products over vegetated surfaces were evaluated during all seasons. In previous studies, the accuracy of MODIS LST products over vegetated surfaces was validated using ground measurements obtained during growing season only. Third, validation sites from a variety of geographic regions in the U.S. and Germany are used. Therefore, the statistics from the study are potentially more representative than those of previous validation work for vegetated surfaces. Finally, this is the first attempt to evaluate the accuracy of MOD07_L2 LST product by a team that is independent of the MODIS atmosphere team.

2. Data

2.1. Ground measurements

The ground-measured LSTs were obtained from two sources totaling eight sites (see Table 2). The first source of data is the FLUXNET Project, a global network of micrometeorological tower sites that measure the exchanges of carbon dioxide, water vapor, and energy between terrestrial ecosystems and the atmosphere. Some FLUXNET sites in the U.S. are equipped with thermal infra-red (TIR) sensors to continuously measure surface temperature at fixed points (AmeriFlux, 2006). Ground measurements from six FLUXNET sites were used in this study. The land cover types of these sites include grassland, forest, and cropland. The surface temperatures from these sites were measured by Apogee IRTS-P Infra-Red Temperature Sensor (Apogee Instruments Inc., 2005). The sensor is highly water resistant and designed for continuous outdoor use. It uses two type-K thermocouple outputs. The primary thermocouple is used to measure the target temperature. Sensor body temperature is measured using the secondary thermocouple and the sensor body temperature effect is corrected. The spectral range of the sensor is from 6.5 to 14 μm, with an optimal temperature range from − 10 °C