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Near-real time retrievals of land surface temperature within the MODIS Rapid Response System

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Abstract

The MODIS Rapid Response (RR) System was developed to meet the near real time needs of the applications community. Generally, its products are available online within hours of the satellite overpass. We recently adapted the standard MODIS land surface temperature (LST) split-window algorithm for use in the RR System. To minimize latency, we eliminated the algorithm's dependency on upstream MODIS products. For example, although the standard MODIS LST requires prior retrieval of air temperature and water vapor from the MODIS scene, the RR LST employs a climatological database of atmospheric values based on a 25-year record of NOAA TOVS observations. The standard and RR algorithms also differ in upstream processing, surface emissivity determination, and use of a cloud mask (RR product does not contain one). Comparison of the MODIS RR and standard LST products suggests that biases are generally less than 0.1 K, and root-mean-square differences are less than 1 K despite the presence of some larger outliers. Initial validation with field data suggests the absolute uncertainty of the RR product is below 1 K. The MODIS RR land surface temperature algorithm is a stand-alone computer code. It has no dependencies on external products or toolkits, and is suitable for Direct Broadcast and other processing systems.

Keywords: Land surface temperature; MODIS; Rapid Response System; Direct broadcast

1. Introduction

Through the first 2 years of Terra satellite operations, the Earth Observing System (EOS) Data Information System (DIS) – designed for processing, distributing and archiving EOS data – suffered various problems that limited product generation rates. In that period, product generation lagged data acquisition by up to 2 months. To address the needs of applications user communities – especially the U.S. Forest Service in their efforts to combat the devastating wildfires of 2000 – the MODIS Land Discipline Team developed the Rapid Response (RR) System at NASA's Goddard Space Flight Center, in collaboration with the University of Maryland. Initial emphasis was on delivering MODIS corrected reflectance and active fire products within 2 to 4 h of acquisition (Justice et al., 2002).

The initial RR project successes, coupled with early challenges in producing and using standard MODIS products (e.g., uncommon projections and data formats, extensive metadata and quality assurance information, up to 50 days latency), led to RR product requests from other users. The RR mission thus evolved into developing and distributing modified MODIS land products within hours of the satellite observation, at accuracies rivaling the standard products and catered to the needs (e.g., data products, projections, formats, content, subsets) of (primarily) application-oriented users. The project's flexibility (e.g., subsetting, multiple projections) facilitates production of custom products for high volume data users that are not available via standard MODIS processing.

Although current latency for standard MODIS products is typically less than 2 days, operational, emergency and media communities, such as the U.S. Forest Service, the National

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Interagency Fire Center (NIFC) and the U.N. Global Fire Monitoring Center, continue to rely extensively on RR system's capabilities. Through early 2004, the RR product suite consisted of active fire distribution, Normalized Difference Vegetation Index (NDVI) and atmospherically-corrected reflectance imagery and products.

Recently, we developed and implemented a land surface temperature (LST) product within the RR system. Our algorithm was adapted from that of the MODIS Level 2 "swath" product (MOD11_L2 for Terra, MYD11_L2 for Aqua), hereafter referred to as the standard LST product. The RR LST algorithm provides day and night products at 1-km spatial resolutions globally in swath format. LST is a key variable needed to describe the energetic state of the Earth's surface, and its availability in near real time can benefit various hydrological, ecological, and biogeochemical applications.

The objective of this paper is to describe the implementation the LST product within the MODIS RR System and to detail the changes in the standard algorithm as required for near-real time production. We first introduce the MODIS sensor and the standard MODIS LST product. Then we describe the MODIS RR System, focusing on the LST algorithm. We explain the assumptions inherent to our approach and describe the TOVS climatology input field. We evaluate the RR product against the standard product and field measurements. Finally, we present a discussion and conclusions.

2. Background

2.1. Moderated Resolution Imaging Spectroradiometer (MODIS) sensor

The Moderated Resolution Imaging Spectroradiometer (MODIS) is an Earth Observing System (EOS) instrument on board the Terra and Aqua platforms, launched in December 1999 and May 2002, respectively. The sensor scans ±55° from nadir in 36 spectral bands. During each scan, 10 along-track detectors per spectral band simultaneously sample the earth. From its polar orbit, MODIS provides daytime and nighttime global coverage every 1 to 2 days.

MODIS has 16 bands in the emissive portion (3–15 μm) of the spectrum. The bands have a ground instantaneous field of view of about 1 km at nadir and a radiometric resolution of 12 bits. The detectors sample onboard calibration before and after each scan of the Earth (Guenther et al., 2002). The absolute calibration accuracy is within 1% for the thermal infrared bands, except for band 36 (Justice et al., 2002). In this article, we focus on the two longwave thermal infrared bands, 31 and 32, used in the split-window LST retrieval. Mean band characteristics are provided in Table 1.

Table 1
MODIS emissive bands for surface temperature retrievals

Band	Band width (μm)	Central wavelength (μm)	Required NeΔT (K)
31	10.780 – 11.280	11.0186	0.05
32	11.77 – 12.27	12.0325	0.05

2.2. MODIS land surface temperature swath product

The standard MODIS LST product suite is composed of both swath products, which cover areas sampled by MODIS in a 5-min period (about 2030 km along-track, and 2330 km cross-track), and gridded 'tile' products (about 10° × 10° at the equator), which are typically composed of data from multiple swaths and amenable to compositing and aggregation.

The MODIS standard LST product is generated using a generalized split-window algorithm, which is derived from a (typically) 1st order Taylor Series expansion of the radiative transfer equation. The coefficients for the algorithm are determined through regression analysis of radiative transfer simulations (prescribed LSTs vs. simulated top-of-atmosphere brightness temperatures) for a wide range of surface and atmospheric conditions. The split window method uses two spectrally-close bands in the thermal infrared wavelengths, and assumes that the differential radiance between these bands is a linear function of the atmospheric absorption at those wavelengths (due primarily to water vapor). However, to estimate the kinetic (skin) temperature, surface emissivity values are typically required for one or more terms in a split window formulation. Surface emissivity is the ratio of the radiation emitted by an object at a given temperature to the radiation emitted by a backbody (perfect emitter) at the same temperature and in the same spectral wavelength.

6. Conclusions

We modified the standard MODIS land surface temperature (LST) processing algorithm, used to generate product MOD11_L2/MYD11_L2, as needed for implementation within the MODIS Rapid Response (RR) System. To achieve near-real time retrievals of this variable we removed dependencies on external products that would create latency in product generation. Specifically, we adopted a 1° × 1° TOVS climatology for air temperature and water vapor to substitute the equivalent MODIS variables from MOD07_L2. Minor modifications were also made in the estimation of top-of-atmosphere brightness temperature and land emissivity determination. Comparisons of the new product against the standard MODIS LST product show that this is a reasonable assumption and that, for most cases, the biases created by this method are small (<0.1 K) for most granules studied, and are, in general, within the accuracy to MODIS standard product itself. Comparisons against field data from sites in Europe and North America suggest the absolute uncertainty is less than 1 K — approximately the same uncertainty attributed to the standard LST product. Comparisons against the MODIS LST standard product suggest the RR LST tends to be slightly higher (biases < 0.1 K) and that product differences are lowest for daytime data (versus nighttime data). These differences are more pronounced around the Equator than at mid latitudes.

The new code allows for a stand-alone processing algorithm for retrievals of MODIS land surface temperature fields and can be implemented in Direct Broadcast or similar systems. This capability is relevant for any user community that requires MODIS LST within a few hours of satellite overpass. All RR software system is written in C code and is available at no cost to any user.