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Land Surface Temperature Measurements from EOS MODIS Data

MODIS Team Member
PRINCIPAL INVESTIGATOR

ZHENGMING WAN

P.I.'s Address:

ZHENGMING WAN
Institute for Computational Earth System Science
University of California
Santa Barbara, CA 93106-3060

phone : (805) 893-4541
Fax no: (805) 893-2578
Internet: wan@icess.ucsb.edu

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Abstract

We made modifications to the linear kernel bidirectional reflectance distribution function (BRDF) models from Roujean et al. and Wanner et al. that extend the spectral range into the thermal infrared (TIR). With these TIR BRDF models and the IGBP land-cover product, we developed a classification-based emissivity database for the EOS/MODIS land-surface temperature (LST) algorithm and used it in version V2.0 of the MODIS LST code. Two V2.0 LST codes have been delivered to the MODIS SDST, one for the daily L2 and L3 LST products, and another for the 8-day 1km L3 LST product. New TIR thermometers (broadband radiometer with a filter in the 10-13 μm window) and an IR camera have been purchased in order to reduce the uncertainty in LST field measurements due to the temporal and spatial variations in LST. New improvements have been made to the existing TIR spectrometer in order to increase its accuracy to 0.2 °C that will be required in the vicarious calibration of the MODIS TIR bands.

Recent Papers Published and in Press

Z. Wan and Z.-L. Li, "A physics-based algorithm for retrieving land-surface emissivity and temperature from EOS/MODIS data", IEEE Trans. Geosci. Remote Sensing, vol. 35, pp. 980-996, 1997.

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1. New Developments for the MODIS LST Algorithm

Split-window LST methods need to use surface emissivity values in the two bands in the 10-13 µm window. It is well know that the surface emissivity of a scene at the pixel scale of satellite observations, approximately 1km for AVHRR and MODIS, depends on not only the optical properties of the surface materials bot also the surface roughness, structure, and proportions of all components in the scene. It is difficult over larger areas to measure the surface reflectance and/or emissivity of complex land cover types. This is especially true in the thermal infrared where both the reflected and emitted radiances are significant. We can find the spectral reflectance data of terrestrial materials in the literature and web sites. Most of these data are obtained from spectrometric measurements of small samples in laboratory such as by [Salisbury and D'Aria, 1992] and others. These include high-resolution spectra of single leaves, ice, water, snow, sand, different soil and rocks. In order to accurately estimate the scene emissivity from component emissivities and the parameters of surface structure and composition, we modified the linear kernel BRDF models [Roujean et al, 1992; Wanner et al, 1995] that were developed for the spectral range in visible and near infrared, and extend the spectral range into the thermal infrared. Because the details of the TIR BRDF kernel models are already described in a published paper [Snyder and Wan, 1998], we only summerize a few of its important features here. The model can reveal the angular variation in the scene emissivity. With foliage as modeled by the volumetric kernels, there is little angular dependence of the scene emissivity. On the other hand, the geometrical examples demonstrate that there may be a large angular dependence of the scene emissivity even with Lambertian components. This is because of structure - primarily because of the changing viewed proportions of the components. Another effect of going from components to the scene is that the spectral contrast is reduced because a mixture of components will have an averaging effect on the resulting spectrum.

With the combined use of the TIR BRDF kernel models and the IGBP land-cover classification, we developed a classification-based emissivity database for the MODIS generalized split-window LST algorithm [Wan and Dozier, 1996]. With the use of land-cover, snow-cover and vegetation index or time of year as inputs, our choice for combining and splitting 19 land-cover classes yields 14 emissivity classes. For example, we combine evergreen needle forest and green deciduous needle forest together into one emissivity class called green needle forest because it is not easy to discriminate these two types of forest with remote sensing data alone and they should have similar emissivity features. On the other hand, we need to split the land-cover type of spare shrublands into two emissivity classes, one for green spare shrubs and another for senescent spare shrubs because shrub has different emissivities when it changes from green to senescent. Based on several hundred spectra of natural materials, we believe that the 14 emissivity classes we chose can be discriminated and are a good balance between too many classes with similar emissivities, and too few, whereby emissivity accuracy is reduced. For each emissivity class, we designed a series of cases where the type of the components in the scene and the surface parameters can be changed in the appropriate ranges for this emissivity class. The band-averaged emissivities in the split-window bands can be estimated with the TIR BRDF kernel models for each cases. Finally, we can obtain the averaged values of the band emissivities at different viewing angles and their standard deviations for each emissivity class. Details are described in a paper in press [Snyder et al., 1998].

Table I shows the classification-based emissivity database used in the MODIS generalized split-window LST algorithm. Where ε_{31} and ε_{32} are band emissivities in MODIS bands 31 (at 11 μm) and 32 (at 12 μm), respectively, rms_m_em is the root of mean square of the mean emissivity of these two bands, and rms_d_em is the root of mean square of the emissivity difference in these two bands. Three more emissivity classes are included in Table I in addition to the 14 classes used in the above paper. Two of them for the land-cover type classified as urban and built-up in the green season and dry season. The components and corresponding proportions of the urban and built-up class are buildings 25%, road and parking 25%, bare soils/rocks 15%, spare shrubs 10%, grass savanna 10%, broadleaf forest 10%, needle forest 5%. We also separate the emissivity class of snow/ice into two classes, one for dry/fine snow, another for medium and coarse snow and ice, for allowing the potential improvement to the LST algorithm if we can discriminate ice and dirty snow from dry/fine snow though it is not always possible. The values of ε_{31}, ε_{32}, rms_m_em and rms_d_em indicate that the split-window LST algorithm can retrieve LST accurately for water surface, dry/fine snow, dens vegetation areas in emissivity classes 4-8 because of the large emissivity values and small variations in the mean emissivities and the emissivity differences, and reasonable well for emissivity classes 3 and 10-12. However, the split-window LST algorithm cannot retrieve LST accurately for the last five classes, e.g., in the urban areas, and areas in the semi-arid and arid regions. In other words, for approximately one third of the global land surface, we will have real difficulty in the LST retrieval with the split-window method. For these areas, we will depend on the new day/night LST algorithm [Wan and Li, 1997] to retrieve the surface emissivities and temperatures simultaneously for improving the LST accuracy.

TABLE 1. The classification-based emissivity database for the MODIS split-window LST algorithm.

class	ε_{31}	ε_{32}	rms_m_em	rms_d_em	description
1	0.992	0.988	0.0049	0.0024	water surface
2	0.993	0.990	0.0023	0.0006	dry/fine snow
3	0.984	0.971	0.0069	0.0059	med/coarse snow & ice
4	0.989	0.991	0.0029	0.0005	green needle forest
5	0.987	0.990	0.0035	0.0015	green broadleaf forest
6	0.988	0.991	0.0039	0.0013	green doody savanna
7	0.987	0.991	0.0034	0.0014	green grass savanna
8	0.986	0.988	0.0040	0.0011	senescent needle forest
9	0.975	0.978	0.0095	0.0015	senescent woody savanna
10	0.977	0.982	0.0071	0.0022	organic bare soils
11	0.973	0.975	0.0115	0.0021	senescent grass savanna
12	0.968	0.971	0.0109	0.0038	senescent broadleaf forest
13	0.972	0.976	0.0134	0.0042	green sparse shrubs
14	0.970	0.975	0.0132	0.0044	senescent sparse shrubs
15	0.970	0.976	0.0139	0.0074	green urban & built-up
16	0.966	0.972	0.0117	0.0075	senescent urban & built-up
17	0.965	0.972	0.0148	0.0063	arid bare soil & rocks

2. V2 LST Code Delivery

We have delivered two V2.0 LST codes to the MODIS SDST (Science Data Support Team), one for the daily L2 and L3 (1km and 5km) LST products, and another for the 8-day 1km L3 LST product. New toolkits sdptk5.2v1.00, HDF4.1r1 and mapi2.2.1 were used in the code development for this delivery. Metadata and QA (quality assurance) attributes were also implemented in the V2 code. After new look-up tables are established with the final spectral response functions at the MODIS system level, we will deliver V2.1 codes for the at-launch LST processing.

3. Improvements in TIR Instruments for the LST Validation

The experience gained from the field campaigns conducted for the validation of MODIS LST algorithms in 1995-1997 (some details shown in the paper to be presented at the 7th JPL Airborne Earth Science Workshop, January 12-15, 1998, in appendix A) shows that the temporal and spatial variations in the field measurements of LST are the major uncertainty in the LST validation. Recently we have made a great effort to reduce this uncertainty. We purchased 12 Heimann radiometers with a special window filter of 10-13 μm. The effect of the large variation in emissivity below 10 μm can be reduced by the use of this filter. We expect that the accuracy of the LST measurements can be improved by averaging the LST values from 12 Heimann radiometers well distributed over an area of 100 by 100m or 1 by 1km for comparison with LST values retrieved from MAS or MODIS data. We also purchased an IR camera from AGEMA Infrared Systems. There are 240 by 320 elements in this uncooling microbolometer-based IR camera. So we can easily place this IR camera on towers, low-level aircraft or balloons for measuring the temporal spatial LST distribution over test sites. Further improvements have been made to the existing scanning TIR spectrometer. The number of blackbodies in the front of the spectrometer is increased from two to four. One of the blackbodies is at the ambient temperature (T_{am}), the second one at a temperature approximately 10 °C above T_{am}, the third one at 20 °C above T_{am}, and the fourth one at 10-15 °C below T_{am}. In this way, we can reduce the calibration error due to the non-linearity in the spectrometer response and reach the accuracy of 0.2 °C in the spectral ranges where the seven MODIS bands used in the MODIS LST algorithm are located. The spot size of the field-of-view of the scanning spectrometer is increased to 36cm from 12cm by placing it on a support structure 3m above the ground instead of 1m so that the surface sample measured by the spectrometer will better represent the surface condition of the test sites.

4. Anticipated Future Actions

In the first half of 1998, we will deliver all V2 codes for the at-launch LST processing, and will conduct a field campaign with MODIS Airborne Simulator flights and ground-based measurements at sites in Death Valley and Mammoth Lake area, California.

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Appendix A

A paper to be presented at

The 7th JPL Airborne Earth Science Workshop

Pasadena, CA, January 12-15, 1998