DRAFT

MODIS–T CALIBRATION HANDBOOK

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MODIS Science Team Meeting, Oct. 1 - 3, 1991. Attachment U

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1. Introduction

1.1 Overview

This document is intended as an introduction to the results of the radiometric, geometric, and spectral calibration/characterization of the MODIS–T instrument scheduled for launch on the EOS–A platform in 1998. Readers of the document are expected to be those in the EOS program who are concerned with calibration, but not concerned primarily with the MODIS–T calibration efforts. This document provides these readers with sufficient information so they will have a clear picture of MODIS–T calibration/characterization plans. Every attempt will be made to make this handbook succinct yet complete. It is the intent to maintain and up-date this document as part of the information mode available to both EOS and non-EOS scientists through the EOSDIS's (EOS Data and Information Systems) DADS (Data Analysis and Distribution Sytem).

MODIS-T is a single pass grating type reflecting Schmidt imaging spectrometer. It is designed to view the Earth with a nadir footprint of 1.1 km in 32 wavelength channels of 13 to 14.5 nm from 400 to 800 nm. An interline CCD detector is used, which signal is converted to a 12 bit signal. A thirteenth bit indicates for each pixel the gain used which is different for ocean and land surfaces. This method of operation is called the dual composite mode.

Optically the instrument has a 34 mm entrance aperture and is an f/3.0 system. The CCD detector is curved in one direction to reduce spatial distortion. All metal components are aluminum except the beryllium scan mirror.

Mechanically there are four moving mechanisms. The scan, which covers 45 degrees is controlled by a continuously rotating single speed double sided mirror. The scan mirror rotates at 6.6 rpm, so each Earth scan takes 4.54 seconds. The tilt mirror rotates the scan mirror assembly about the center of the scan mirror. This direct drive mechanism allows tilts up to 55 degrees for and aft to be made. A diffuser plate is deployable on an arm and is visible to the detector when the platform is crossing the equator provided the tilt angle is less than 30 degrees. The fourth and final mechanism is an aperture wheel with 3 open aperture settings and a closed aperture which is used with a solar integrating sphere to control its radiance level.

1.2 Science Calibration/Characterization Objectives

The MODIS–T specifications call for a radiometric calibration accurate to ±5% at typical spectral radiance levels outlined by the instrument specifications. Over two weeks, a ±0.5% stability is required. The on-board diffuser plate shall be used to achieve an absolute radiometric reflectance accuracy of 2% relative to the sun. A spectral calibrator will be used to test the wavelength stability of the instrument.

1.3 Organizations and Responsibilities

The MODIS Characterization Support Team (MCST) provides the overall planning and coordination of the MODIS–T calibration efforts under the direction of the MODIS Science Team. The MODIS-T calibration team (Code 700), does the ground calibration and characterization and demonstrates that the specifications are met.

2. Pre–Launch Calibration/Characterization

2.1 Objectives/Rationale

Before launch, tests will be conducted to characterize the properties of MODIS–T. These plans call for the testing of the following radiometric properties: Gain, offset, signal versus radiance, linearity, signal-to-noise ratio, on–board calibrator performance, spectral matching, coherent noise, scan modulation, and band-to-band stability. The Modulation Transfer Function (MTF) will be measured along-track and across-track. Spectral band shapes will be measured. The transient response including rise time and overshoot or undershoot will be tested. Polarization sensitivity will be measured. The spectral band registration along-track and crosstrack will be measured. Most of these tests will be made under ambient conditions and under vacuum conditions.

As part of EOS calibration planning, MODIS–T and all EOS–A platform instruments will be cross–calibrated using a common known source and/or using a traveling standard radiometer. These activities are in early planning stages and will be summarized when they become public.

The results summarized in this section come from two sources. The primary input comes from the MODIS-T calibration team (Code 700) at NASA's Goddard Space Flight Center in Greenbelt, MD. A parallel calibration and characterization effort has been provided by the MODIS Characterization Support Team (MCST) also at NASA's Goddard Space Flight Center. Initial drafts of this document carry requirements prior to the availability of results.

2.2 Radiometric Calibration

Before launch, tests will be conducted to characterize the properties of MODIS–T. Characterization tests include component level tests on the CCD detector, the compound elliptical concentrator, the grating, the integrating sphere, the silicon photodiodes, the spectral line source, the transmission diffuser, and the solar diffuser. The tests will assure that the instrument specifications have been met and theat the calibration in orbit can be derived and maintained.

2.2.1 Absolute Calibration

A minimum absolute radiometric calibration accuracy of ± 5% is required in the visible and near-infrared.

2.2.2 Relative Calibration

A ± 2% accuracy relative to the Sun is required. Over two weeks, a ± 0.5% stability is required. Section 3 is devoted to in-orbit calibrations.

2.3 Geometric Calibration

The pointing accuracy of MODIS–T will be sufficient to locate any pixel on the Earth's surface to with ± 0.5 times the length or width of the pixel. Registration of pixels to 0.1 pixel or better will be made, but a pointing knowledge of 30 arc seconds and alignment changes of 60 arc seconds will reduce the overall pointing knowledge to 0.5 pixels. Section 4 is devoted to in–orbit geometric calibrations.

2.4 Spectral Calibration

The spectral response of MODIS–T as a function of time must either be stable or measured with sufficient accuracy so that the overall radiometric calibration goals are reached. Section 5 is devoted to in–orbit spectral calibrations.

3. In–Orbit Radiometric Calibration/Characterization

3.1 Objectives/Rationale

The characterization efforts before launch and the use of known radiation sources in orbit will allow the initial in–orbit calibration to be measured and maintained within specifications during the mission life. Multiple calibration techniques and sources will be used to obtain the necessary calibration accuracy. Sections 3.2 through 3.5 describe different calibration techniques. Section 6 discusses the approach to synthesizing the multiple approaches into a single official calibration algorithm.

3.2 Instrument-Based Calibration Methods

Radiometric calibration of MODIS–T will be made through the use of known sources to establish the instrument's response. These known sources include the Sun, the moon, space, and an incandescent line source.

3.2.1 Internal Sources

On each scan, the MODIS-T detectors view an integrating sphere which is illuminated by the sun. The radiance level of the solar illuminated sphere is monitored by two silicon photodiodes. A dark target is also viewed during each scan, so these two targets allow the gain and offset of the instrument to be determined for each scan. The linearity of the system can be checked by using three apertures which allow the level of illumination to be controlled. The gain and/or offset may also be functions of such variables as the detector temperature monitored by thermistors.

This method of calibration is a secondary method since the entire optical path of the instrument is not tested. To insure the method's stability over time, it is periodically compared to a primary method of calibration.

In addition to measuring the sensor gain, the zero offset must also be determined. Under routine operating conditions, the zero offset will be measured by scanning across an internal dark target. Two other methods of measuring the zero offset include deep space looks and views of the darkside of the Earth. These latter two approaches require the instrument to be placed in non-routine modes of operation. The deep space looks occur only when MODIS-T is tilting by 50^{o} or more so it will seldom be used. In addition, only a portion of the scan mirror will be sampled, although the portion sampled will be different from that sampled by normal operations when the internal dark target is used. The darkside of the Earth is not normally viewed since no data is taken at these times. The zeros measured by using the internal dark target, deep space, and the darkside of the Earth should all agree if the instrument is behaving correctly.

3.2.2 External Solar

A deployable solar diffuser plate is part of the MODIS–T design. The diffusing plate will be deployed on an arm about 50 cm in length when the satellite is crossing the equator. Assuming the material in the diffusing plate maintains its characteristics, the plate provides a stable repeatable source. The diffuser plate consists of three separate sections - two sections are composed of Spectralon (~10% and ~80% reflectance) and one section is composed of roughened aluminum. The aluminum will be used to provide a stable source over time to check the degradation of the Spectralon panels.

Since the diffuser plate is subject to contamination and other changes with time, particularly if exposed to solar ultraviolet radiation, under normal conditions it will be stowed in a protective opaque housing. The frequency of deployment will be kept to a minimum, perhaps once per month, to assure that a stable repeatable source is available over the five years of the mission. When the diffuser is deployed, it will cover part of the Earth as seen by the instrument. Thus, the data collection procedure remains the same as when it is not deployed and the only requirement in the data processing is to recognize the instrument mode and analyze the data properly.

This method of calibration is a primary method of calibration since the entire optical path of the instrument is monitored.

3.2.3 External Lunar

When MODIS-T tilts by 50° or more, it is capable of viewing deep space. At such times it is also cable of viewing the full moon. The moon is a relatively stable radiation source, which potentially allows it to be used for calibration. Only six of the 32 detector are exposed to lunar radiation when the moon is viewed and the intensity of the source is low compared to the Earth, so the signal-to-noise ratio may not be high. The moon is a relatively stable radiation source, which potentially allows it to be used for calibration. The intensity of the lunar disk will vary during the year as the Earth–Sun distance changes and will also vary with the lunar libration angle. Given the precise illumination and observation geometry, a high spatial resolution model of the spectral radiance from the moon will be calculated. This radiometric image will then be transforms to match the resolution and orientation of MODIS-T. Periodically then, MODIS-T will be exposed to a stable radiometric source, allowing the long-term stability of the instrument to be monitored. Hugh Kieffer of the USGS-Flagstaff is the principal investigator for lunar calibration.

This method of calibration is a primary method of calibration since the entire optical path of the instrument is monitored.

3.3 Instrument Cross–Comparison Methods

3.3.1 Cross–Sensor/Within Platform

Several passive remote sensors using visible radiation are planned for the EOS–A platform. Each instrument will be independently calibrated. After corrections for differences in footprint size, spectral resolution, and pointspread functions are made, the radiances measured by the separate should agree to within their stated accuracies. If they do agree, it tells us that any biases, whether the bias is zero or not, are the same. If they do not agree, an opportunity exists to investigate the reasons for the disagreements. The more instruments that agree, the more confidence we can have that correct measurements are being made. Potential comparison instrument include MODIS-N (am and pm), AIRS, EOSP, and MISR. Several of these potential configurations are discussed below.

AIRS (Atmospheric Infrared Sounder) has a 56 km nadir footprint with five channels in the visible region from 0.4 to 1.1 microns. Inter–comparison to MODIS–T will consist of combining many MODIS pixels, weighted by the AIRS pointspread function, to form an image like a single AIRS pixel. Because MODIS–T also appears to have better spectral resolution in the visible, several appropriately weighted MODIS–T bands will be required to match the AIRS resolution. Comparison of many hundreds of AIRS pixels with MODIS–T simulated AIRS pixels should give a reasonable indication of the amount of agreement.

EOSP (Earth Observing Scanning Polarimeter) has a 10 km nadir footprint and several spectral bands in the visible region. MODIS–T radiances can be spatially re–mapped, using the EOSP pointspread function, and spectrally re–mapped, using the EOSP filter transmission functions, to match the EOSP radiance observations.

MISR (Multi–angle Imaging Spectro–radiometer) has eight viewing angles which can be duplicated by MODIS–T. Both MISR and MODIS-T have spectral bands centered at 440 and 860 nm. The wavelength resolution for MISR is not available, but probably is less than MODIS–T. By spatially re–mapping MISR, a matching image for the two instruments appears possible which will allow them to be inter–compared.

3.3.2 Cross–Platform In–Orbit

Using sensors on other satellites for inter–comparison proceeds much like the inter–comparisons described above. The major difficulty and drawback in comparisons between two satellites is that seldom are both satellites over the same region at the same time so matching satellite and solar geometries can be obtained. Without the geometry and temporal match, the inter–comparison become considerably more involved. Some potential comparison instruments are AVHRR, SPOT, and Landsat as discussed below. Other potential comparisons with MERIS, SeaWiFs, GOES, and other satellites are also possible.

AVHRR (Advanced Very High Resolution Radiometer) has a 1.1 km. nadir footprint, which is close to the 1 km nadir footprint for some MODIS–T channels. AVHRR has a lower spectral resolution than MODIS–T. AVHRR's channel 1 measures in the range of about 560 to 700 nm. Weighting the MODIS–T bands centered at 545, 560, 575, 590, 605, 620, 635, 650, 665, 680, 695, and 710 nm by the filter transmission of the AVHRR channel 1 interference filter should allow an AVHRR type scene to be constructed from the MODIS–T observations. The initial pre–flight filter transmissions for AVHRR are known, but because filters of this type change their properties in flight, it is not clear that using the pre–flight transmission functions will give correct results. Another drawback with the AVHRR/MODIS–T inter–comparison is that the AVHRR sensors are not well calibrated. It is also not clear if the present AVHRR design will be flying in the MODIS–T era. Finally comparison between the two sensors will be limited to those times when both are crossing the same scene at the same time or nearly the same time.

SPOT has a 10 meter nadir footprint and several visible bands which offer opportunities for inter–comparison with MODIS–t. SPOT images can be spatially re–mapped and MODIS–T images can be spectrally re–mapped to achieve common images which can be inter–compared.

Landsat has a 30 meter nadir footprint and visible bands covering 450–520, 520–600, 630–690, and 760–900 nm which offer opportunities for inter–comparison with MODIS–T. Landsat images can be spatially re–mapped and MODIS–T images can be spectrally re–mapped to achieve common images which can be inter–compared.

3.3.3 Target Related/Aircraft

MODIS–T radiances will be compared to the radiances measured from high flying aircraft. Except for small corrections for the atmosphere above the aircraft, co–located radiances from these two sensors should be nearly the same. Since the aircraft radiometer can be re–calibrated in the laboratory and its calibration can be maintained over many years, this technique will allow the MODIS–T observations to be maintained to within several percent over the entire 15 years of the EOS experiment.

3.4 Target-Based Calibration Methods

3.4.1 Target Related/Ground Reflectance

In–situ observations of radiance from the ground or from aircraft can be compared to satellite radiance observations by using radiative transfer models. These in–situ radiance measurements, in effect, become known sources suitable for calibration. The following sub–sections describe these techniques. Buoy observations of pigment concentration can also be compared to MODIS–T derived values for the same pigment concentration. A difference in the two determinations can indicate a calibration problem exists, which can be corrected by altering the calibration until the two pigment concentrations exists. This technique calibrates not just the spectrometer, but the spectrometer–radiative transfer–pigment concentration algorithm combination.

MODIS–T radiances can also compared to ground observations provided a good radiative transfer model is available and the composition and vertical structure of the atmosphere are well measured. Co–located ground and satellite measurements then allow the calibration of the satellite sensor to be checked much as is done using high flying aircraft.

Characterizing atmospheric composition requires measurements of total precipitable water, total ozone amount, and aerosol optical depth as a function of wavelength. Atmospheric water vapor can be measured using radiosondes, or total precipitable water vapor meters using either solar or microwave radiation. Dobson spectrometers can provide total ozone amounts. Aerosol properties can be measured using lidar, sunphotometers, aureole meters, combined pyranometers and pyrheliometers giving the diffuse–direct ratio, or pyrheliometers equipped with Schott glass filters. The combination and choice of instruments has not yet been made.

3.4.2 Bio–Optical Oceans

Water leaving radiances over the many ocean locations at wavelengths greater than about 700 nm are close to zero. An accurate radiative transfer model allows the path radiance to the satellite radiance to be determined. This path radiance therefore provides a known source which allows MODIS–T to be calibrated. This technique makes the instrument calibration and the radiative transfer model self–consistent.

Buoy measurements of pigment concentration can be compared with MODIS–T determined pigment concentrations. A discrepancy between the two may be solved by altering the calibration of the satellite. This technique can be introduced into the routine processing and is called bio–geochemical normalization.

3.5 Image Related

3.5.1 External Image Related Radiometric Rectification

Certain regions on Earth contain areas which are radiometrically stable. For example, exposures of bedrock may have a relative stable reflectance over long periods of time. These radiometrically stable areas within images can be used to correct other portions of an image so that they are internally self–consistent with the stable portions of the image. The technique is referred to as "within image radiometric rectification" and is generally applied to high resolution images such as those produced by Landsat or SPOT. The applicability of the technique to MODIS–T images will be researched and applied.

3.5.2 Class–specific Scene Equalization

A generalization of the within image radiometric rectification technique in which multiple scenes are used will also be employed for monitoring the MODIS–T stability.

4. In–Orbit Geometric Calibration

TBD

5. In–Orbit Spectral Calibration

An internal spectral line source will be used to provide in–orbit spectral calibration. The assembly consists of an incandescent lamp source which illuminates a double pass grating spectrometer that provides a light source of known wavelength to the detectors.

6 Official MODIS–T/MCST Calibration Algorithms/Models

6.1 Objectives/Rationale

During routine processing, one calibration algorithm will be used to determined the Level–1B radiances. This official algorithm may be one technique, but it is more likely to be a combination of methods. MCST has the responsibility of supplying this algorithm to convert the raw Level-1A quantized value to Level-1B radiances.

6.2 Algorithm Sensitivity/Simulation Studies

7. Definitions and References

7.1 Data Dictionary/Glossary

7.2 Acronyms

A	
AIRS	Atmospheric Infrared Sounder
ASTER	Advanced Spaceborne Thermal Emission and Reflection
AVHRR	Advanced Very High Resolution Radiometer
E	
EOS	Earth Observing System
EOSP	Earth Observing Scanning Polarimeter
G	
GOES	Geostationary Operational Environmental Satellite
I	
IFOV	Instrument field of view
M	
MCST	MODIS Characterization Support Team
MERIS	Medium Resolution Imaging Spectrometer
MISR	Multi–angle Imaging Spectro–radiometer
MODIS-N	Moderate Resolution Imaging Spectrometer – Nadir
MODIS-T	Moderate Resolution Imaging Spectrometer - Tilt
MTF	Modulation transfer function
N	
NASA	National Aeronautics and Space Administration
S	
SeaWiFs	Sea Viewing, Wide–Field–of–View Sensor

SBRC	Santa Barbara Research Center
SDSM	Solar Diffuser Stability Monitor
SRCA	Spectro–radiometric Calibration Assembly

7.3 References

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