VALIDATION OF MODIS-DERIVED TOP-OF-ATMOSPHERE SPECTRAL RADIANCES BY MEANS OF VICARIOUS CALIBRATION

submitted to the EOS Validation Office by

S. F. Biggar, P. N. Slater, P. R. Spyak, K. J. Thome, and E. F. Zalewski

Remote Sensing Group, Optical Sciences Center, University of Arizona

Version 1.2

September 1996

INTRODUCTION

The EOS Validation Office has requested these viewgraphs to summarize vicarious validation activities:

MODIS products to be validated

MODIS specifications relevant to vicarious calibration

Calibration data to be validated

Vicarious calibration methodologies and instrumentation

Steps to establish scientific validity

Confirmation of accuracy and precision

Proposed improvements in instrumentation and techniques

Recommendations for EOS and non-EOS experimental activities

Required operational activities

Archival plans for validation information

Appendix: MODIS Science Team members and other U.S. calibration scientists likely to contribute to MODIS calibration/validation activities

References

MODIS PRODUCTS TO BE VALIDATED

Top-of-atmosphere (TOA) radiances in the MODIS spectral bands.

TOA radiances are produced by applying the MODIS calibration coefficients to the digital counts obtained from the image of a given site.

Calibration coefficients are derived from the MODIS Level-1B algorithm[1] using data from the on-board calibrators (OBCs) as input.

The Level-1B algorithm is being designed and will be implemented by the MODIS Calibration Support Team (MCST).

MODIS SPECIFICATIONS RELEVANT TO VICARIOUS CALIBRATION

10:30 a.m. descending sun-synchronous polar orbit: launches in 1998 and 2004

1:30 p.m. ascending sun-synchronous polar orbit: launches in 2000, and 2006

Designed for a 6-year lifetime

Mechanical scanner, altitude 705 km, swath 2,330 km

36 spectral bands covering the range 0.41 to 14.4 µm, 16 spectral bands in the visible and near infra-red (VNIR), 4 in the short wave infra-red (SWIR), and 16 in the thermal infra-red (TIR)

Ground instantaneous fields of view (GIFOVs) at nadir:

Bands at 0.645 and 0.858 µm have GIFOVs of 250 m

Bands at 0.469, 0.555, 1.24, 1.64, and 2.13 µm have GIFOVs of 500 m

All other bands have GIFOVs of 1000 m

Spectral resolutions vary from 10 nm, for many of the 1000-m GIFOV bands in the VNIR, to 500 nm for the “fire bands” in the TIR

Employs 12-bit digitization

MODIS ON-BOARD CALIBRATORS[2]

SpectroRadiometric Calibration Assembly (SRCA):

- Spectral mode (0.41- 2.13 µm) -- band centroid within 1-nm uncertainty, 0.5-nm precision
- Radiometric mode -- within-orbit stability in solar-reflective range
- Geometric mode -- determines band-to-band mis-registration to within 1/10 th of a 1-km pixel; also provides some data on MTF change

Solar Diffuser/Solar Diffuser Stability Monitor (SD/SDSM)

- Two levels of diffusely scattered solar irradiance from panel
- Panel reflectance changes monitored by ratio of panel radiance to that of attenuated sun

On-board blackbody (BB)

- Temperature usually “floats” with instrument but BB can be heated to 315 K

Space-view: For offset determination

CALIBRATION DATA TO BE VALIDATED

The MODIS-derived TOA spectral radiances are to be validated periodically in the 16 visible and near infra-red (VNIR), 4 short-wave infra-red (SWIR), and 16 thermal infra-red (TIR) bands of MODIS. The MODIS specifications for calibration uncertainty in these bands are as follows:

VNIR and SWIR: less than 5% uncertainty in radiance, and 2% in reflectance with respect to the sun.

TIR: less than 1% uncertainty in radiance, with the exception of the following bands:
3.75 µm -- 0.75% in radiance
3.959 µm -- 10% in radiance
11.03 and 12.02 µm -- 0.5% in radiance for the lower dynamic ranges of these bands
11.03 and 12.02 µm -- 10% in radiance for the upper dynamic ranges of these bands

Note: the 3.959-µm, and the upper dynamic ranges of the 11.03-µm and 12.02-µm bands constitute the so-called "fire bands" whose response is higher than the maximum output of the on-board blackbody at 315 K.

VICARIOUS CALIBRATION METHODOLOGIES AND INSTRUMENTATION

Vicarious calibration[3] is the use of calibrated sources external to MODIS in order to validate the on-board calibrator-derived radiances.

Reflectance calibrated sites
Radiance calibrated sites, including the moon[4]
Temperature/emissivity calibrated sites

Measurements made at the surface or aboard aircraft simultaneously with MODIS imaging

Cross comparisons made with other sensors

Highest accuracy obtained with large areas of uniform high radiance

Vicarious calibration methodologies and instrumentation

PARAMETER	INSTRUMENTATION
Radiance **Surface**	Aircraft-mounted or surface-traversed radiometers
TOA	Predicted from RTCs using inputs below
Surface properties $\rho(\lambda)$	Aircraft, buoy & surface radiometers.Reflectance panels
BRDF(λ)	PARABOLA and BRDF radiometers and camera
$\epsilon(\lambda)$	µFTIR, blackbody sources, TIR filter radiometers
Temperature	Thermocouples in buoys, µFTIR, TIR filter radiometers
Atmospheric properties[A]	
OD(λ)	Solar radiometers, e.g., Reagan and Cimel
Aerosol & O_3 OD	As above
Aerosol size distn.	As above
Ängstrom coef.	As above
H_2O- vapor OD	Three-band solar radiometer
Phase function	Aureole camera (will not be ready until late 1999)
Aerosol complex index	Diffuse/global irradiance, almucantar scans
General **Rayleigh OD**	Barometric pressure -- meteorological station
Line-of-sight monitor	Narrow-field, pointable, radiometer
Total irradiance down	Pyranometer, all-sky camera
Pressure, temp, R.H.	Meteorological station, radiosonde

[A] **OD stands for optical depth. Some of the instrumentation is under development.**

STEPS TO ESTABLISH SCIENTIFIC VALIDITY

Preflight calibration validation

In-flight VC, and AM-1 sensor cross comparisons

OBC validation during the operational phase

Non-AM-1 sensor cross comparisons

Comparisons with calibration-sensitive Level-2 products

PREFLIGHT CALIBRATION VALIDATION

Laboratory cross comparisons of the VNIR/SWIR calibration sources used by:

- ASTER
- MISR
- MODIS

Laboratory cross-comparison radiometers:

- GSFC
- NIST
- NRLM
- Univ. of Arizona

Comparisons of TOA radiances predicted by joint field campaigns

- ASTER (Japan)
- ASTER (JPL)
- MISR (JPL)
- ASTER and MODIS (Univ. of Arizona)
- South Dakota State University

IN-FLIGHT VC AND AM-1 SENSOR CROSS COMPARISONS

VCs performed by Remote Sensing Group, University of Arizona

- **Schedule several VCs at various sites during intensive A&E phase**

- **Change locations to obtain**
  - **the maximum number of nadir (<5°) and near-nadir (<30°) opportunities,**
  - **surfaces of different reflectances to optimize calibrations in different bands**

- **Initial AM-1 sensor cross comparisons (CCs) simultaneous with VC campaigns,**
  - **follow-on CCs do not require detailed ground-site characterizations**

- **Night overpasses for TIR VC and AM-1 cross comparisons**

Steps to establish scientific validity

PROPOSED INTENSIVE FIELD CAMPAIGN DURING A&E

Launch (June 30, '96)	x								
Check-out	xxxxxxx	xxxxxxx	xxxxxxx	xxxxxxx					
Ivanpah Playa					n				o n
Lunar Lake/ Railroad Playa						o o N		O N o	
Lake Tahoe							O N O	O	
Week:	1	2	3	4	5	6	7	8	9

n & N are for nadir views for reflectance-based, and reflectance- plus radiance-based
o & O are as above for off-nadir views

OBC VALIDATION DURING THE OPERATIONAL PHASE

Periodic VC campaigns by the RSG at various sites depending on success of previous campaign(s) and MODIS stability:

- **White Sands as well as those already mentioned**
- **Two calibrations each campaign at two-month intervals**
- **One intensive campaign each year**

VC campaigns by other groups at US and non-US sites[5]

AM-1 sensor cross comparisons, usually concurrent with VC campaigns

Lunar[2] VC

VC via other aircraft-mounted radiometers:

AIR-MISR	**MAS**
AVIRIS	**MASTER**
HAUCSS	**TIMS**

POTENTIAL NON-AM-1 SENSOR CROSS COMPARISONS WITH MODIS

Examples:

Landsat-7	**OCTS**
SPOT-4	**VEGETATION**
SeaWiFS	**GOES**
ATSR-2	**EO-1**

OBC VALIDATION VIA CALIBRATION-SENSITIVE LEVEL-2 DATA PRODUCTS

Level-2 data products selected by MODIS Science Team and MCST

Examples:

- **Sea surface temperature**
- **Reflectance/radiance retrieval**

For these and other examples, see appendix.

CONFIRMATION OF ACCURACY AND PRECISION

Peer review of uncertainty estimates

Multiple VC paths:

- **reflectance-based for solar-reflective bands**
- **radiance-based for all bands**
- **temperature/emissivity for TIR bands**

Joint field campaigns to compare TOA radiances

Cross comparisons of radiometric standards used by each VC group

Ground-based VC versus aircraft VC comparisons

Comparisons of radiative transfer codes

PROPOSED IMPROVEMENTS IN INSTRUMENTATION AND TECHNIQUES

Propose to improve:

- **Atmospheric characterization**
  - **Scattering phase function**
  - **Aerosol index of refraction**
  - **Solar radiometer operating in the SWIR**
- **On-site surface characterization**
  - **Directional-hemispherical reflectance**
  - **Two-dimensional simultaneous BRF**
- **TIR measurements**
  - **Stable, well-characterized airborne TIR radiometer**

RECOMMENDATIONS FOR EOS AND NON-EOS EXPERIMENTAL ACTIVITIES

That an international collaborative VC program be established for EOS sensors. This to include non-EOS sensors where possible, for example the French VEGETATION and the Japanese Ocean Color and Thermal Scanner (OCTS).

That this international VC program be coordinated by the EOS Calibration Scientist through CEOS and/or by direct contact with other space agencies. It should thereby provide more frequent and appropriately spaced calibration up-dates than could otherwise be achieved.

Establishment of an EOS Calibration Panel sub-group to coordinate and oversee all EOS-related VC activities.

REQUIRED OPERATIONAL MEASUREMENTS

SPACE-BASED MEASUREMENTS

MODIS acquires data continuously, so there are no special requirements for data acquisitions when over selected surface calibration sites at the times VC campaigns are planned. The only special requirement is that MODIS acquires data at the appropriate Lunar phase (calibration maneuvers are still under discussion).

GROUND-BASED MEASUREMENTS

The requirements for the reflectance- and radiance-based methods and sensor-to-sensor comparison methods are described fully in the references, see the final viewgraph.

PLANS FOR ARCHIVING VALIDATION INFORMATION

Plans presently call for vicarious calibration/validation field measurement data to be archived at the Oak Ridge National Laboratory, which is the designated DAAC for field data and, in some cases, related aircraft data.

As a first step in this direction, the field data collected during the first VC joint field campaign in June 1996, are to be archived at Oak Ridge. We presently await recommendations from Richard J. Olson at Oak Ridge regarding formatting and other details.

APPENDIX

Appendix

MODIS SCIENCE TEAM MEMBERS AND OTHER U.S. CALIBRATION SCIENTISTS LIKELY TO CONTRIBUTE TO MODIS CALIBRATION/VALIDATION ACTIVITIES

Peter Abel (GSFC). Coincident VNIR spectrometer measurements from an ER-2 (HAUCSS)
William Barnes (GSFC). MODIS Instrument Scientist
Ian Barton (CSIRO). Sea surface temperature
Stuart Biggar (Univ. of Ariz.). Preflight cross- calibration of ASTER, MISR, MODIS, OCTS
Carol Bruegge (JPL). MISR Calibration Scientist
James Butler (GSFC). EOS Calibration Scientist
Otis Brown/ Peter Minnett (Univ. of Miami). Sea surface temperature
Dennis Clark (NOAA/NESDIS). Water-leaving and in-water radiance measurements, chlorophyll concentrations, etc.
James Conel (JPL) MISR Validation Scientist
Howard Gordon (Univ. of Miami). Water-leaving radiance and atmospheric optical properties
Bruce Guenther (GSFC). Head, MODIS Characterization Support Team (MCST)
Carol Johnson (NIST). Calibration scientist
Yoram Kaufman (GSFC). Aerosol properties over land and calibration data from cloud and ocean-glint studies

Appendix

MODIS SCIENCE TEAM MEMBERS AND OTHER U.S. CALIBRATION SCIENTISTS LIKELY TO CONTRIBUTE TO MODIS CALIBRATION/VALIDATION ACTIVITIES (Continued)

Hugh Kieffer (US Geological Survey). Lunar calibration
Paul Menzel/Dan Laporte (Univ. of Wisc.). Atmospheric TIR measurements
Frank Palluconi (JPL). ASTER team member measuring lake-surface temperatures
Philip Slater (Univ. of Ariz.). Vicarious calibration (VC) using ground and lake sites
Paul Spyak (Univ. of Ariz.). Preflight cross-calibration of ASTER and MODIS in the SWIR
Kurt Thome (Univ. of Ariz.). VC using ground and lake sites. Reflectance retrieval for ASTER and Landsat-7
Eric Vermote (Univ. of Md.). Reflectance retrieval for MODIS
Zhengming Wan (UC Santa Barbara). Land-surface temperature and emissivity
Edward Zalewski (Univ. of Ariz.). Calibration scientist and Head, Remote Sensing Group

Note that several ASTER, Landsat-7, MISR, and other MODIS Science Team members are expected to provide valuable VC results from time to time, but are not, in general, planning to collect and process VC data on a regular basis.

REFERENCES

1. Guenther, B., et al. 1995, “MODIS level 1B algorithm theoretical basis document.” NASA Tech. Memo. 104594, MODIS Tech. Rep Series, NASA/Goddard Space Flight Center, Greenbelt, MD, 45 pp.

2. Guenther et al., 1966, “MODIS calibration : a brief review of the strategy for the at-launch calibration approach” J. Atmos. and Oceanic Tech., 13, 274-285.

3. Slater, P.N., S.F. Biggar, K.J. Thome, D.I. Gellman, and P.R. Spyak, 1996, “Vicarious calibrations of EOS sensors," J. Atmos. and Oceanic Tech., 13, 349-359.

4. Kieffer, H.H., and R.L. Wildey, 1996, "Establishing the moon as a spectral radiance standard", J. Atmos. and Oceanic Tech., 13, 360-375.

5. Slater, P.N., and S.F. Biggar, 1996, “Suggestions for radiometric calibration coefficient generation,” J. Atmos. and Oceanic Tech., 13, 376-382.