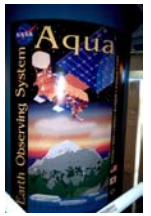


Inter-comparison Study of Terra and Aqua MODIS Reflective Solar Bands Using Lunar Observations

J. Xiong

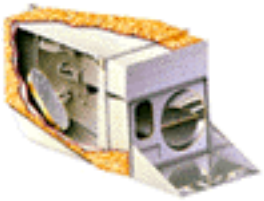
Earth Sciences Directorate, NASA/GSFC, Greenbelt, MD 20771

J. Sun

Science Systems and Applications, Inc., Lanham, MD 20706

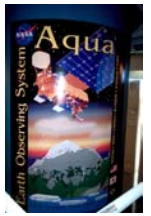
W. Barnes, B. Guenther

University of Maryland, Baltimore County, Baltimore, MD 21250



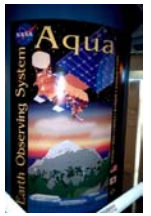
NEWRAD 2005, Davos, Switzerland (17-19 October, 2005)

Outline

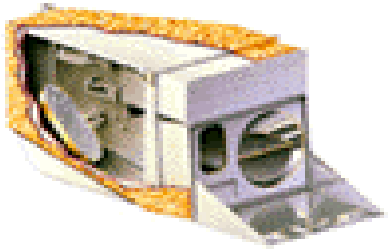


- Introduction
  - Instrument Background
- MODIS On-orbit Calibration
  - Reflective Solar Bands (RSB) Calibration
- Inter-comparison of Terra and Aqua MODIS RSB Calibration Using Lunar Observations
  - MODIS Lunar Observations and Applications
  - Inter-comparison Methodology
  - Results and Discussions
- Summary

Introduction



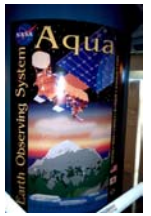
- Moderate Resolution Imaging Spectroradiometer (MODIS)
  - Terra (EOS AM) MODIS launched on 12/18/99 (first light 02/24/00)
  - Aqua (EOS PM) MODIS launched on 05/04/02 (first light 06/24/02)
- Objective
  - Inter-compare Terra and Aqua MODIS RSB calibration
  - Build inter-comparison time series for future sensors (e.g. VIIRS)
- Approach
  - Lunar observations



Terra Launch

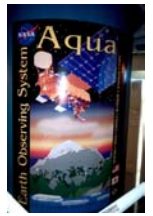
Aqua Launch

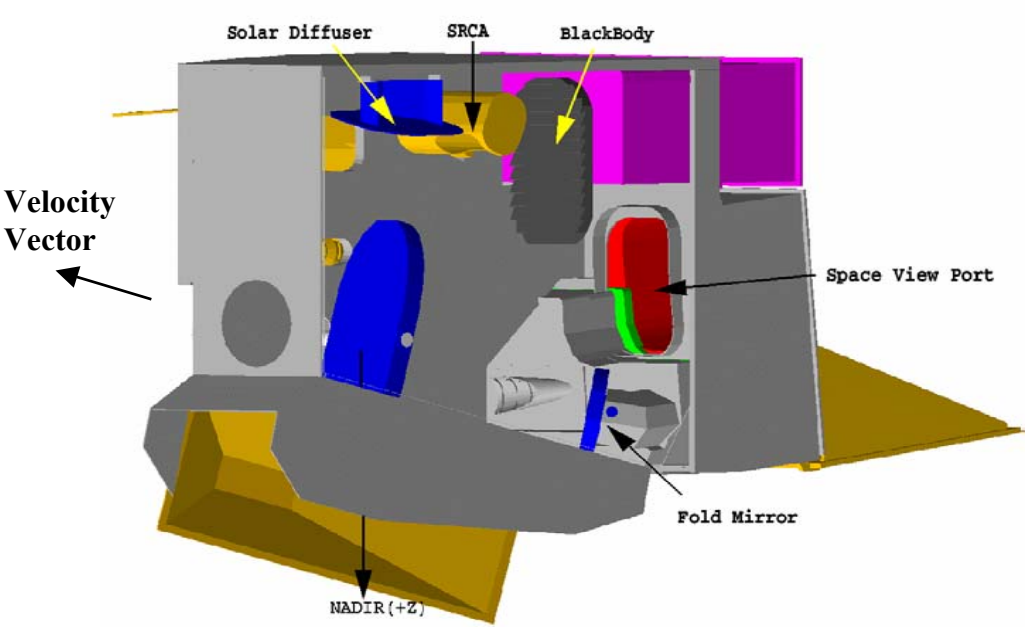
Instrument Background



- The MODIS was designed by NASA/GSFC with Improved Spatial and Spectral Resolution and Frequent Global Coverage Over Its Heritage Sensors
- It was built by SBRS (Santa Barbara Remote Sensing, Goleta, California) for NASA EOS (Earth Observing System) mission
- MODIS observations have been used for many applications
  - Earth's system of land, oceans, atmosphere
  - Climate and environmental changes
  - Morning & afternoon observations over the same targets
- Extensive pre-launch and on-orbit calibration and characterization
  - Radiometric, spatial, and spectral
- Additional information
  - *http://terra.nasa.gov/ and http://eos-pm.gsfc.nasa.gov/*

Instrument Background

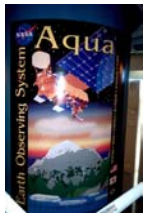




- 2-sided paddle wheel scan mirror
  - (10km by 2330 km swath per 1.478 sec)
  - Day data rate = 10.6 Mbps, night data rate = 3.3 Mbps (100% duty cycle, 50% day and 50% night)

- 36 spectral bands
  - Reflective solar bands (1-19, and 26)
  - Thermal emissive bands (20-25, 27-36)
- 3 nadir spatial resolutions
  - 250m (1-2), 500m (3-7), and 1km (8-36)
- 4 focal plane assemblies
  - VIS, NIR, SMIR, and LWIR
- On-board calibrators:
  - Solar diffuser (SD)
  - SD stability monitor (SDSM)
  - Blackbody (BB)
  - Spectro-radiometric calibration assembly (SRCA)
  - Space View (SV)

Instrument Background



Spectral Bands: Primary Applications and Specifications

Primary Use	Band	Bandwidth[1]	Spectral Radiance[2]	Required SNR[3]
Land/Cloud/Aerosols Boundaries	1	620 - 670	21.8	128
	2	841 - 876	24.7	201
Land/Cloud/Aerosols Properties	3	459 - 479	35.3	243
	4	545 - 565	29	228
	5	1230 - 1250	5.4	74
	6	1628 - 1652	7.3	275
	7	2105 - 2155	1	110
Ocean Color/ Phytoplankton/ Biogeochemistry	8	405 - 420	44.9	880
	9	438 - 448	41.9	838
	10	483 - 493	32.1	802
	11	526 - 536	27.9	754
	12	546 - 556	21	750
	13	662 - 672	9.5	910
	14	673 - 683	8.7	1087
	15	743 - 753	10.2	586
	16	862 - 877	6.2	516
Atmospheric Water Vapor	17	890 - 920	10	167
	18	931 - 941	3.6	57
	19	915 - 965	15	250

[3] SNR = Signal-to-noise ratio

Primary Use	Band	Bandwidth[1]	Spectral Radiance[2]	Required NEΔT(K)[4]
Surface/Cloud Temperature	20	3.660 - 3.840	0.45 (300K)	0.05
	21	3.929 - 3.989	2.38 (335K)	0.2
	22	3.929 - 3.989	0.67 (300K)	0.07
	23	4.020 - 4.080	0.79 (300K)	0.07
Atmospheric Temperature	24	4.433 - 4.498	0.17 (250K)	0.25
	25	4.482 - 4.549	0.59 (275K)	0.25
Cirrus Clouds Water Vapor	26	1.360 - 1.390	6	150 [3]
	27	6.535 - 6.895	1.16 (240K)	0.25
	28	7.175 - 7.475	2.18 (250K)	0.25
Cloud Properties	29	8.400 - 8.700	9.58 (300K)	0.05
Ozone	30	9.580 - 9.880	3.69 (250K)	0.25
Surface/Cloud Temperature	31	10.780 - 11.280	9.55 (300K)	0.05
	32	11.770 - 12.270	8.94 (300K)	0.05
Cloud Top Altitude	33	13.185 - 13.485	4.52 (260K)	0.25
	34	13.485 - 13.785	3.76 (250K)	0.25
	35	13.785 - 14.085	3.11 (240K)	0.25
	36	14.085 - 14.385	2.08 (220K)	0.35

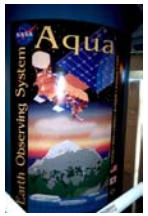
[1] Bands 1 to 19 are in nm; Bands 20 to 36 are in μm

[2] Spectral Radiance values are (W/m^2-μm-sr)

[4] NEΔT = Noise-equivalent temperature difference

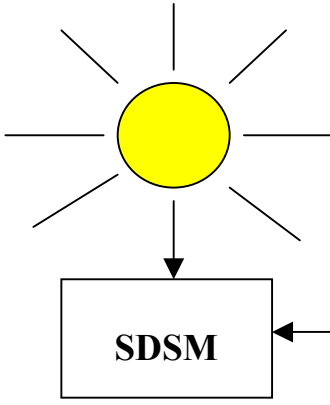
20 Reflective Solar Bands Calibrated On-orbit by a SD/SDSM System

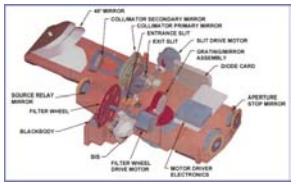
MODIS On-orbit Calibration



SD/SDSM (weekly first year to bi-weekly) for RSB calibration
BB (scan by scan with quarterly warm-up and cool-down) for TEB calibration
SRCA for RSB and TEB spatial (bi-monthly) and RSB spectral (quarterly) characterization
Moon (~monthly) for RSB radiometric stability monitoring

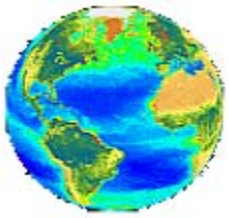
SDSM





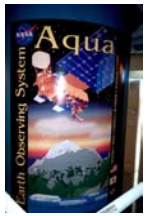
Scan
Mirror

Moon



RSB Calibration Using SD/SDSM

Reflectance $\rho_{EV} \cdot \cos(\theta_{EV}) = m_1 \cdot dn^*_{EV} \cdot d^2_{Earth-Sun}$



Sun

1.44% Screen

Optional 7.8% Screen

$\Delta_{SD} = \dfrac{\overline{dc_{SD}}}{dc_{Sun}}$

SDSM

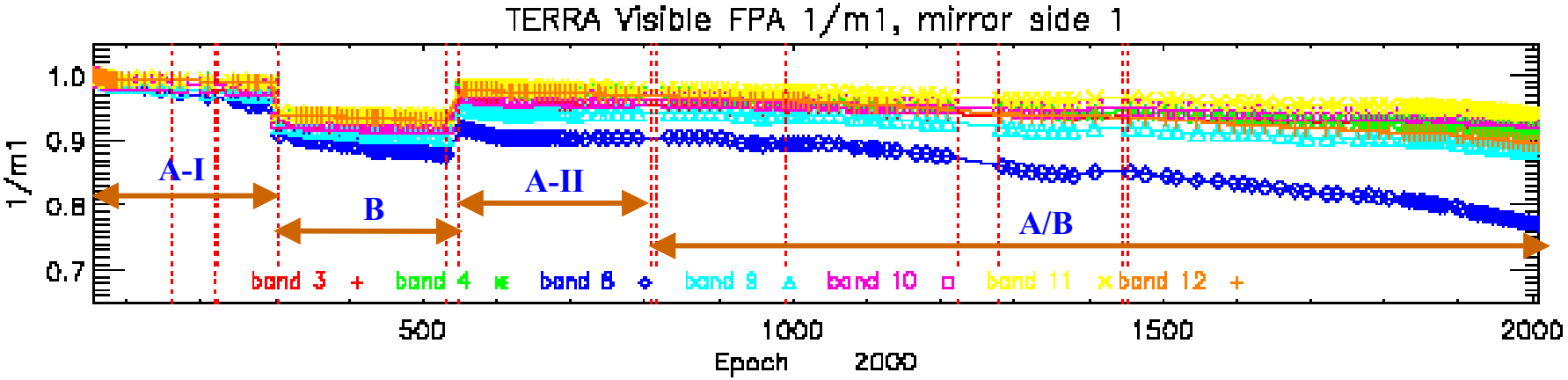
$m_1 = \dfrac{BRF_{SD} \cdot \cos(\theta_{SD})}{< dn^*_{SD} > \cdot d^2_{Earth-Sun}} \cdot \Gamma_{SD} \cdot \Delta_{SD}$

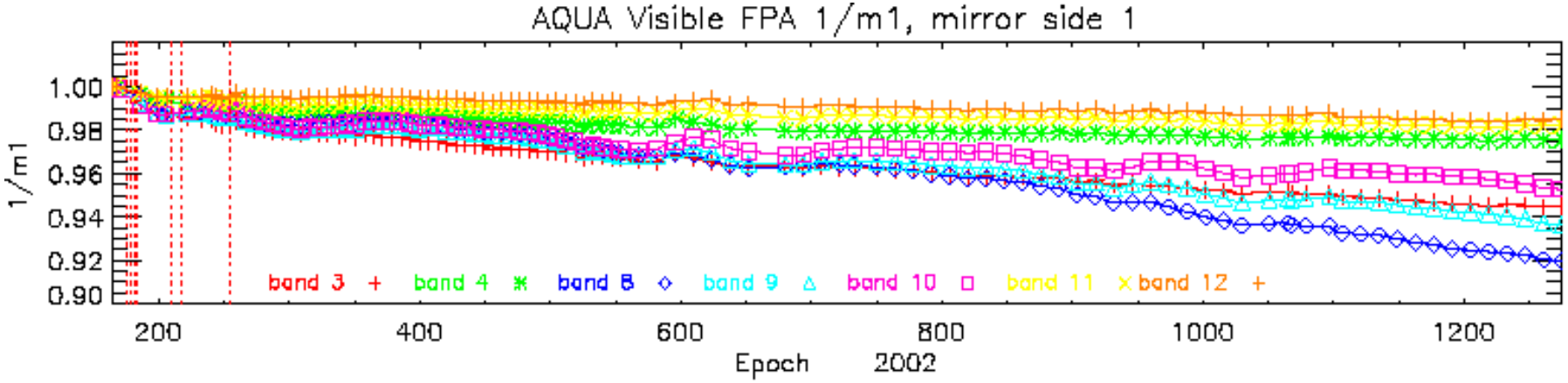
Scan Mirror (MODIS)

SD

Δ_{SD}: SD degradation factor;
Γ_{SD}: SD screen vignetting function
d: Earth-Sun distance
dn*: Temperature and RVS corrected digital number;
dc: Digital count of SDSM

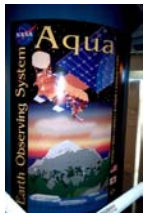
Terra and Aqua RSB (VIS Bands) Response Trending





- Terra MODIS has been operated in a number of configurations; Aqua has been operated in the same configuration
- B8 (0.41μm) response with mirror side 1 of scan mirror have changed approximately 4.5%/year for Terra MODIS and 2.6%/year for Aqua MODIS

Inter-comparison of Terra and Aqua MODIS RSB Calibration Using Lunar Observations



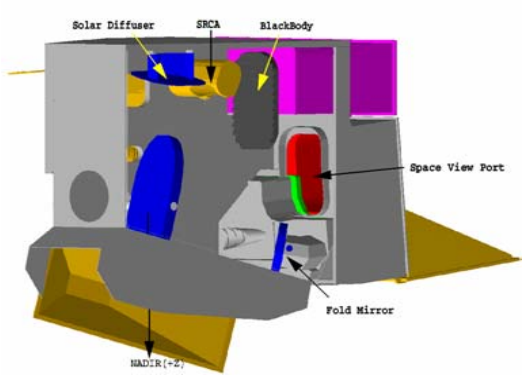
- MODIS Lunar Observations and Applications
  - MODIS lunar observations (8-10/year) have been made through instrument space view (SV) port **at a nearly fixed phase angle** (54.5±0.5° waning for Terra and waxing for Aqua) via spacecraft roll maneuvers
  - Applications
    - RSB radiometric calibration stability
    - Optical leak (Terra MODIS PC bands) and SWIR band xtalk characterization
    - Spatial band-to-band registration
    - **Inter-comparison of Terra and Aqua MODIS RSB**
- Inter-comparison Methodology
  - Compare Terra and Aqua MODIS measured lunar irradiance with each normalized to the model (Kieffer/Stone) predicted lunar irradiance
- Results and Discussions

MODIS Lunar Observations

SD Calibration

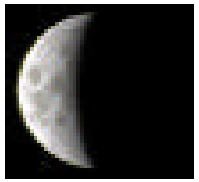
$$m_1 = \frac{BRF_{SD} \cdot \cos(\theta_{SD})}{< dn^*_{SD} > \cdot d^2_{Earth-Sun}} \cdot \Gamma_{SD} \cdot \Delta_{SD}$$

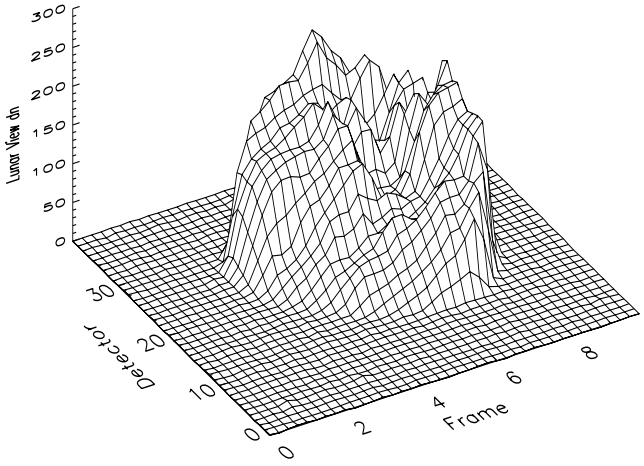
Moon can be used to track RSB calibration stability



Moon Calibration

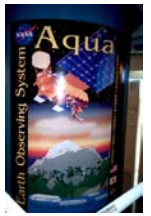
$$m_1 = \frac{f(view\_geometry)}{< dn^*_{Moon} >}$$





$$f = \frac{f_{phase-angle} \cdot f_{libration} \cdot f_{over-sampling}}{d^2_{Sun-Moon} \cdot d^2_{Modis-Moon}}$$

Inter-comparison Methodology

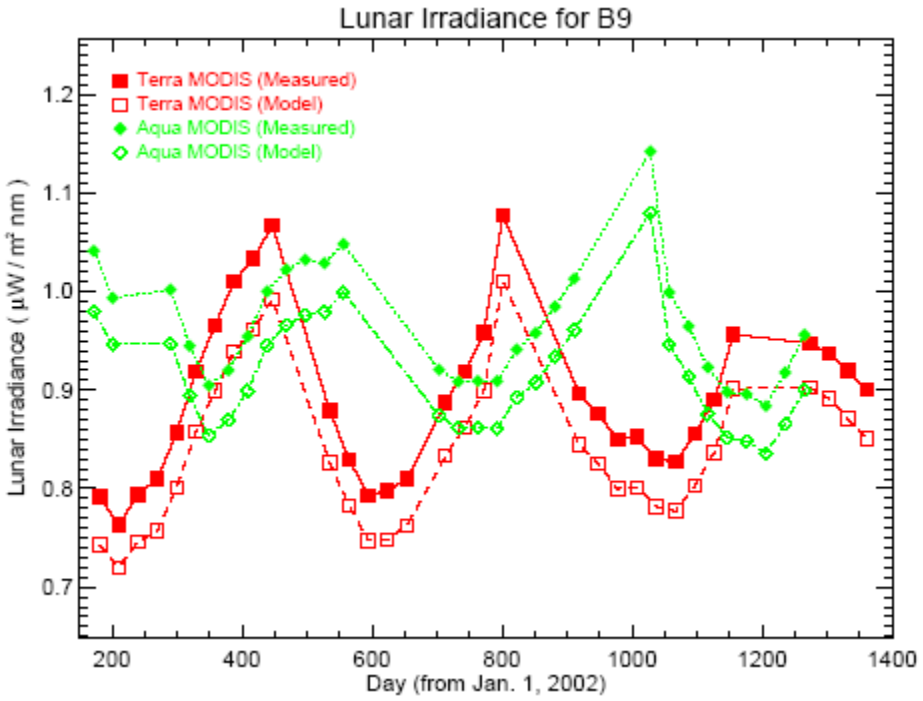


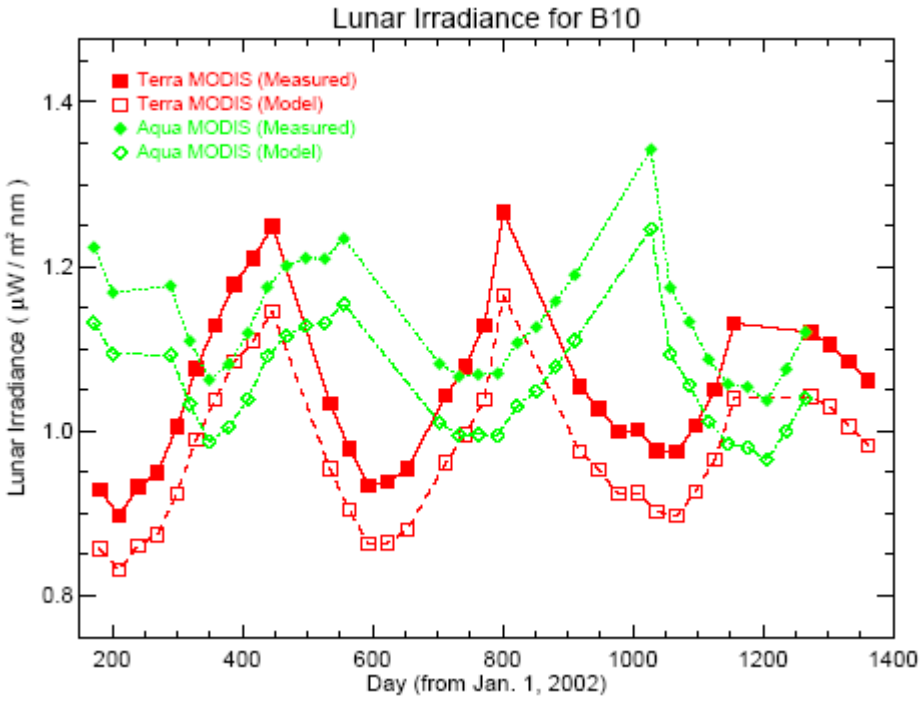
- Measured lunar irradiance computed using sensor's on-orbit calibration coefficients
- Model predicted lunar irradiance obtained from Kieffer/Stone (USGS)
- Compare Terra MODIS (sensor_A) and Aqua MODIS (sensor_B) measured lunar irradiance with each normalized to the model predicted lunar irradiance
  - Normalization removes effects due to lunar viewing geometry differences and sensor relative spectral response differences

$$\frac{I_{Sensor\_A} / I_{Model\_A}}{I_{Sensor\_B} / I_{Model\_B}}$$

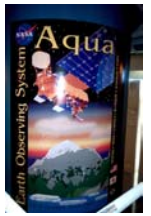
Inter-comparison Results

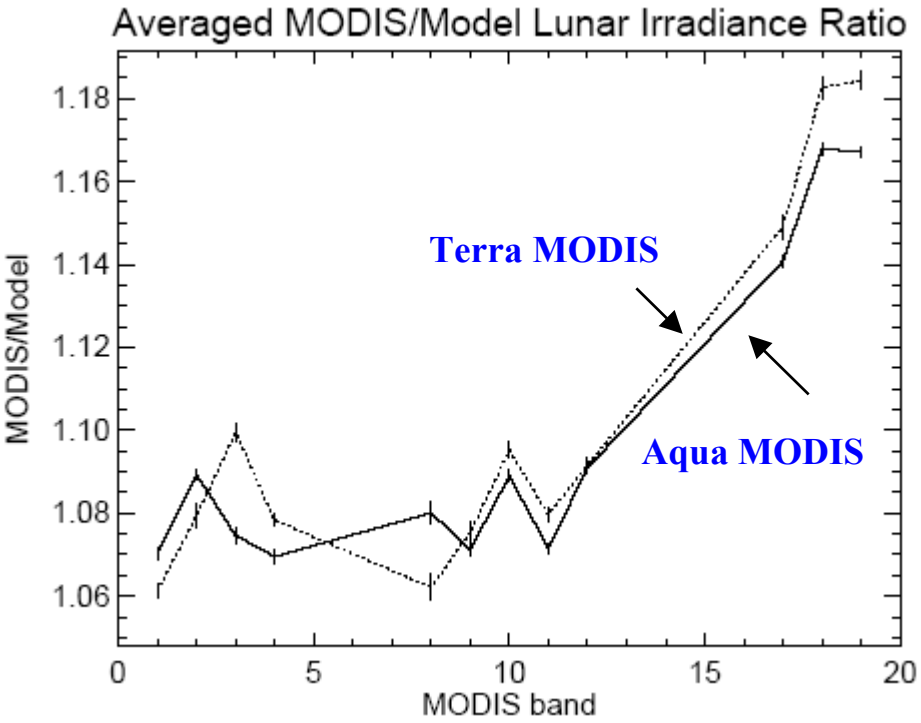
Examples of Sensor Measured Lunar Irradiance and Model Predicted Lunar Irradiance (Terra MODIS: Red; Aqua MODIS: Green)

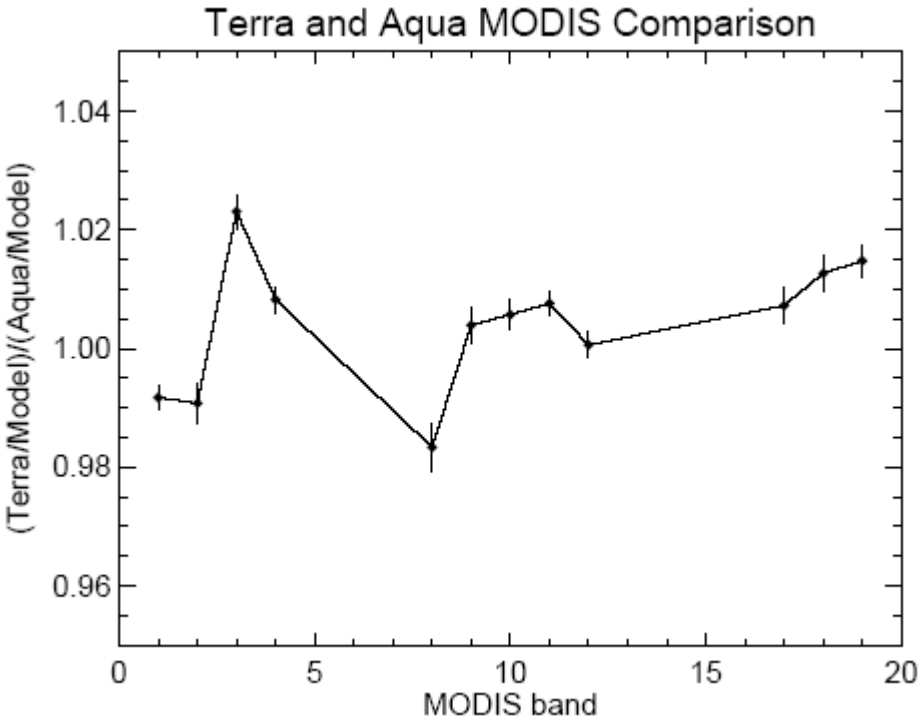




Inter-comparison Results



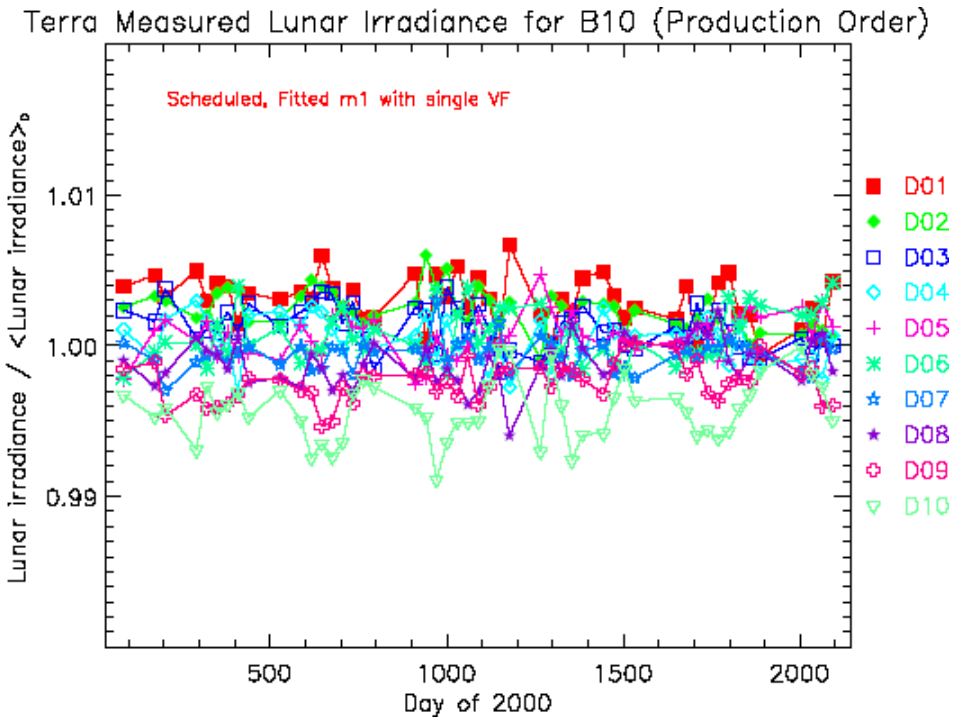


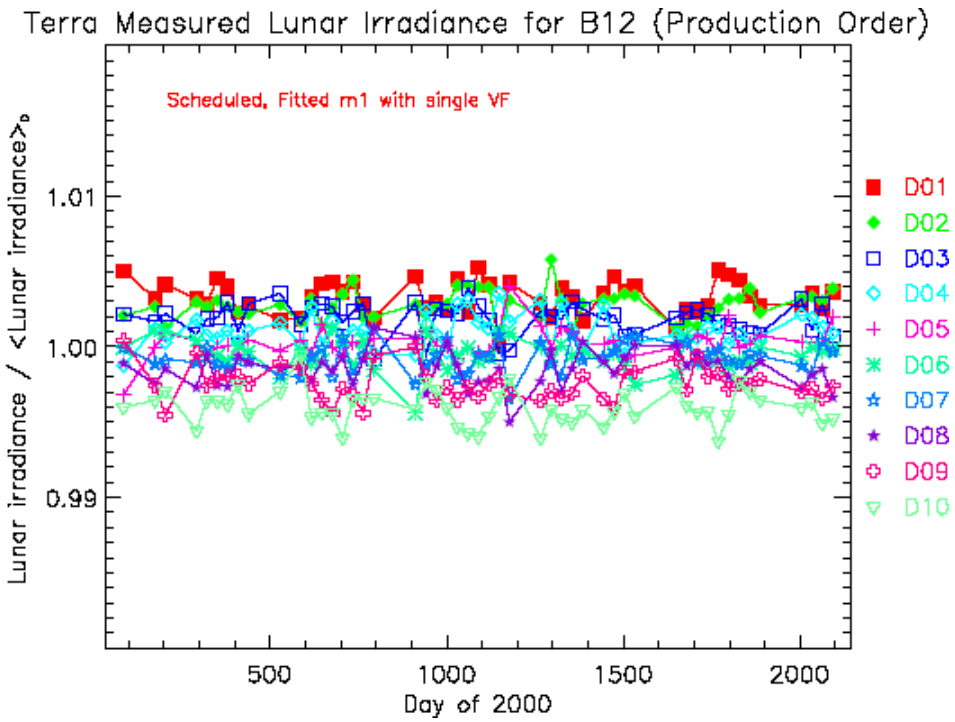


MODIS measured lunar irradiance versus modeled predicted
Large difference at NIR (910-970nm)
Terra and Aqua MODIS RSB calibration consistency is within ±2%
(RSB calibration uncertainty is ±2% in reflectance)

Inter-comparison Results

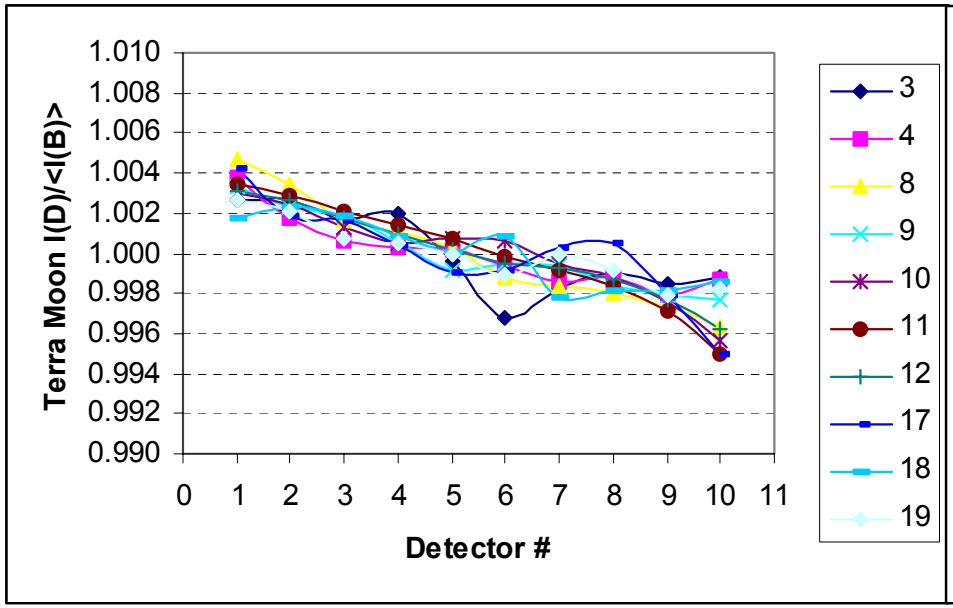
Examples of Sensor Measured Lunar Irradiance from Individual Detectors Within a Band (Normalized to Band Average)



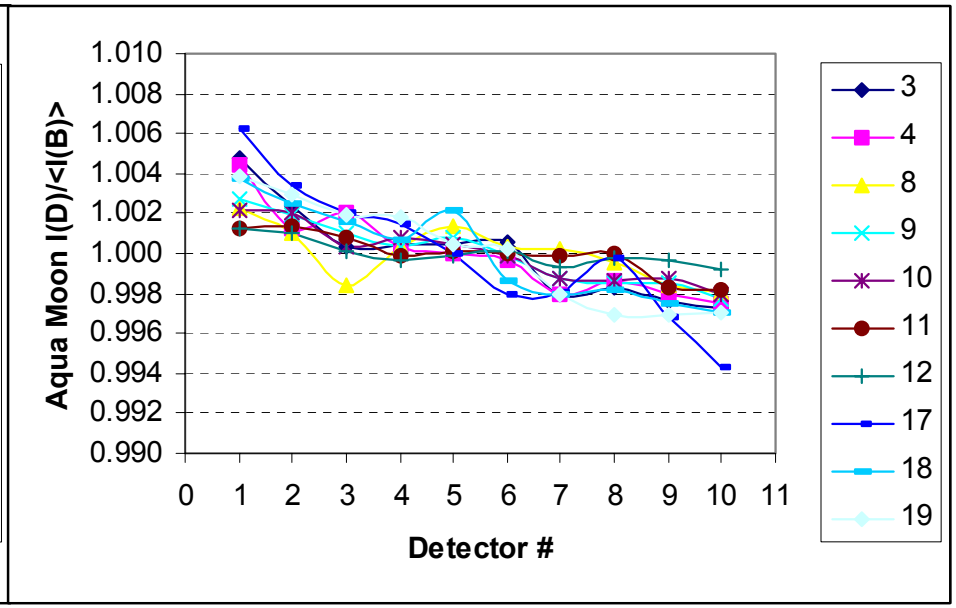


Inter-comparison Results

Examples of Detector to Detector Difference from Lunar Observations



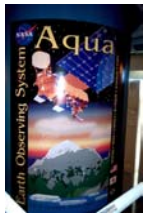
Terra MODIS B3, 4, 8-12, 17-19



Aqua MODIS B3, 4, 8-12, 17-19

Detector to detector differences (up to ±0.4%) could be due to
(1) SD calibration induced difference among detectors
(2) Scan mirror response versus scan angle difference among detectors

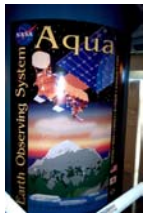
Inter-comparison of MODIS and SeaWiFS



- **SeaWiFS made a special lunar observation at nearly the same time as Terra spacecraft lunar observation during its deep space maneuver (April, 2003)**
- **Inter-comparison also made with MISR (agreement better than ±1% for all matching spectral bands)**

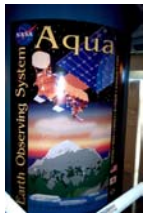
SeaWiFS				MODIS				
Band No.	Wavelength (nm)	Measured I μW/m^2/nm	Model I μW/m^2/nm	Band No.	Wavelength (nm)	Measured I μW/m^2/nm	Model I μW/m^2/nm	Ratio
1	412	1.790	1.757	8	412	1.805	1.714	0.97
2	443	2.190	2.130	9	442	2.143	2.026	0.97
				3	466	2.465	2.316	
3	490	2.574	2.437	10	487	2.526	2.319	0.97
4	510	2.589	2.458	11	530	2.617	2.463	0.99
5	555	2.776	2.631	12	547	2.704	2.523	0.98
5	555	2.776	2.631	4	554	2.663	2.539	1.01
				1	647	2.596	2.512	
6	670	2.744	2.556	1	647	2.596	2.512	1.04
7	765	2.480	2.266					
8	865	2.009	1.886	2	857	1.974	1.855	1.00
				17	904	1.912	1.705	
				18	935	1.822	1.574	
				19	936	1.815	1.572	

Summary (I)



- Lunar Observations
  - Support Sensor On-orbit Calibration
    - track calibration stability or monitor sensor on-orbit degradation
  - Inter-compare Sensors' On-orbit Calibration
    - sensors can be on different satellites (platforms)
    - on-orbit overlap is not necessary
    - normalization to lunar model removes lunar view geometry differences by different sensors and their relative spectral response differences

Summary (II)



- Applications of MODIS Lunar Observations
  - Designed for RSN Radiometric Stability Monitoring
  - Applied to Sensor Characterization (PC bands optical leak correction; SWIR bands cross-talk assessment; band to band registration)
  - Used for Inter-comparison of Terra and Aqua MODIS RSB Calibration
    - Consistency to within ±2% (help future calibration improvements)
    - Detector to detector differences of ±0.4% (SD calibration or detector dependent RVS) are currently being investigated
- Future Applications
  - Build Time Series to Inter-compare with Other Sensors (e.g. VIIRS)
  - Support Validation of Environmental or Climate Data Records (EDR or CDR) Derived from Different Sensors