MODIS and SeaWiFS: the On-orbit Experience

Jim Butler, Jack Xiong, and Chuck McClain
NASA's GSFC

Bob Barnes
SAIC, Inc.

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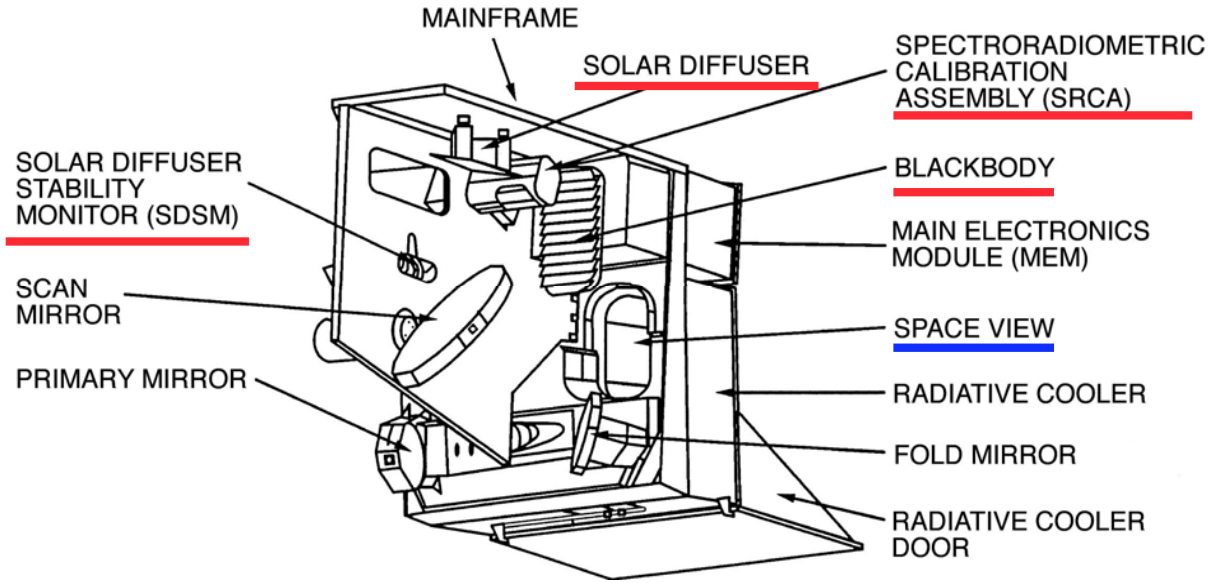
- MODIS Instrument
- MODIS On-orbit Calibration Approaches
- SeaWiFS Instrument
- SeaWiFS On-orbit Calibration Approaches
- CLARREO and the Calibration of Filter-based Instruments

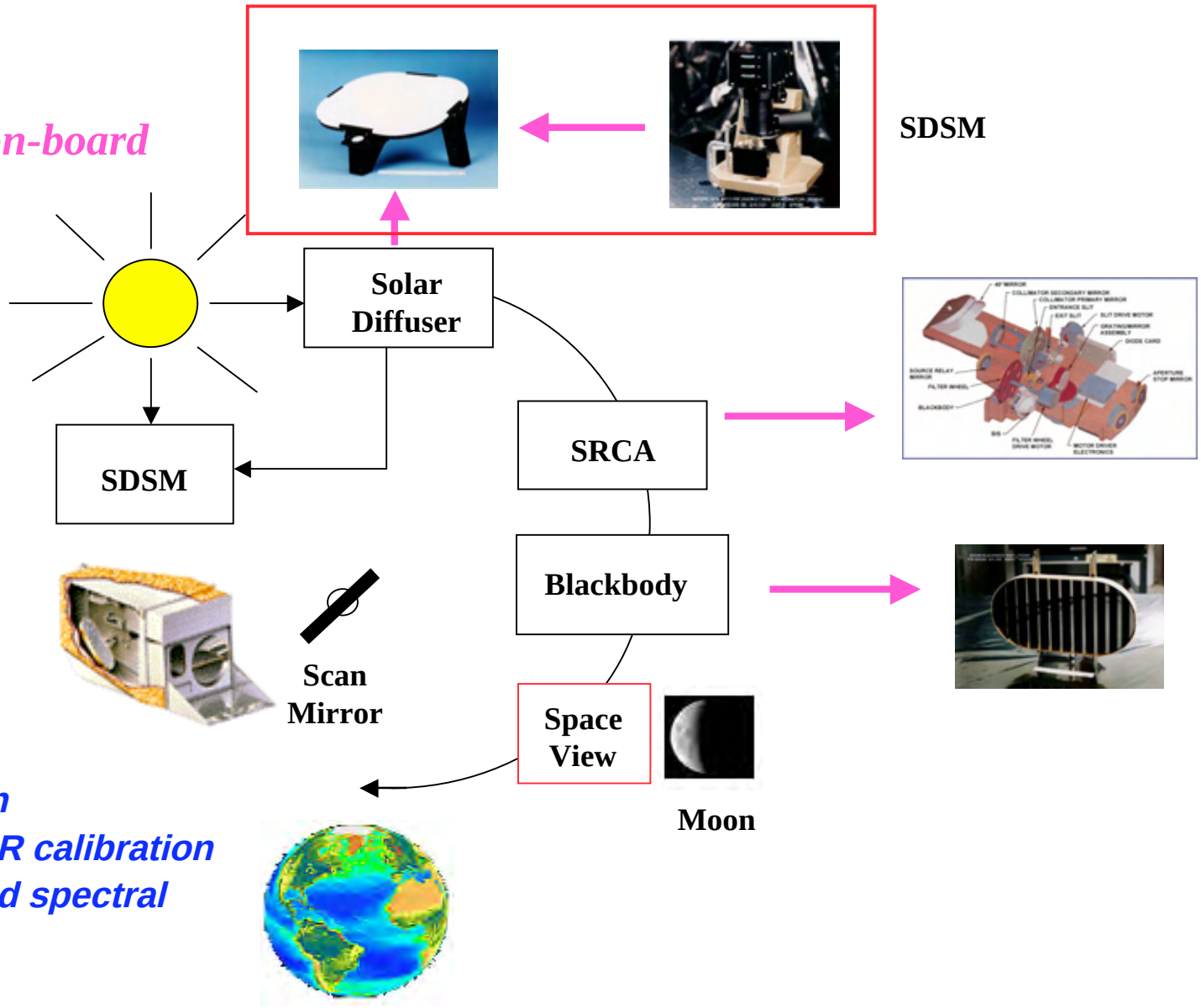
MODIS Instrument



- MODIS Terra: December 1999 to present; Aqua: May 2002 to present
- Terra: 10:30 sun-sync descending; Aqua: 13:30 sun-sync ascending
- 20 Reflective solar bands (RSB): 0.41-2.2μm
- 16 Thermal emissive bands (TEB): 3.7-14.4μm
- 3 spatial resolutions at nadir: 250m, 500m and 1000m
- 4 Focal Plane Assemblies (FPA): VIS, NIR, SMIR, LWIR
- 5 On-Board Calibrators: SD, SDSM, SRCA, BB, and SV port
- Two MODIS instruments: Complementary morning and afternoon observations
- A broad range of applications: land, oceans, cryosphere, and atmosphere

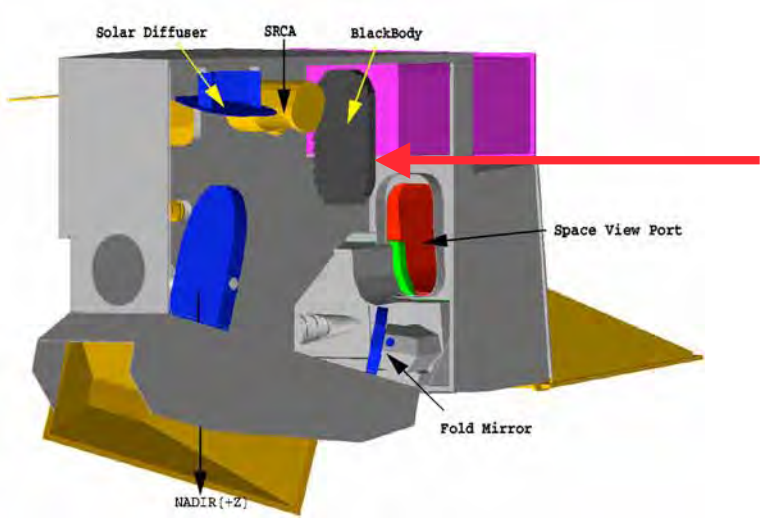
MODIS On-orbit Calibration

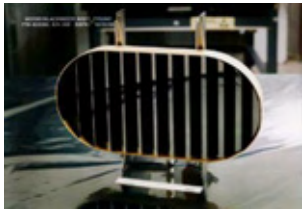
Important:
A complete set of on-board calibrators



BB for IR calibration
SD/SDSM for VIS/NIR calibration
SRCA for spatial and spectral
Lunar observations

On-board Blackbody

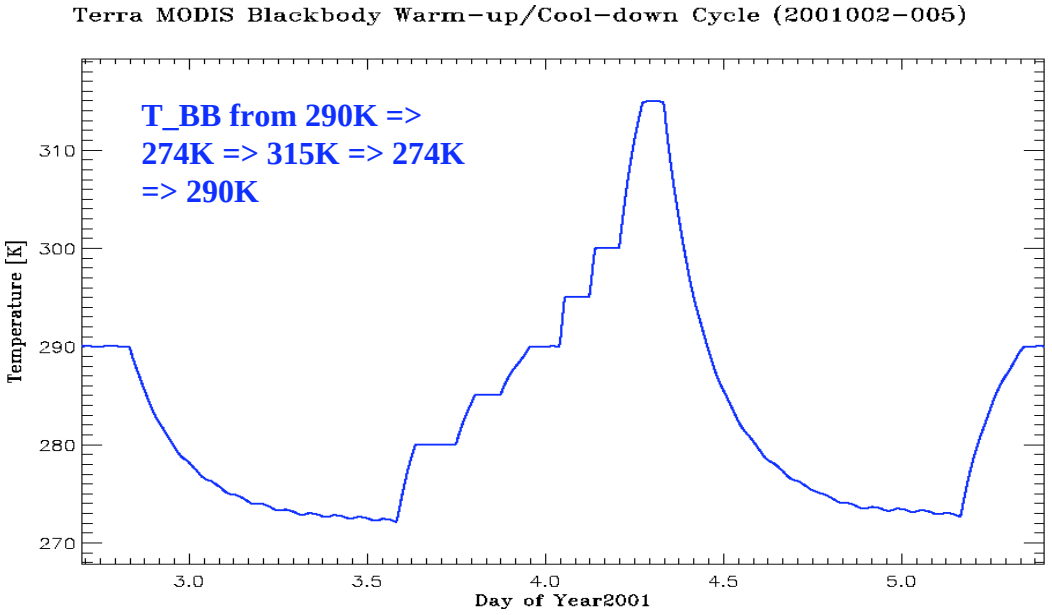




Range: 274 – 315K
Nominal: 290K

On-board blackbody (BB)

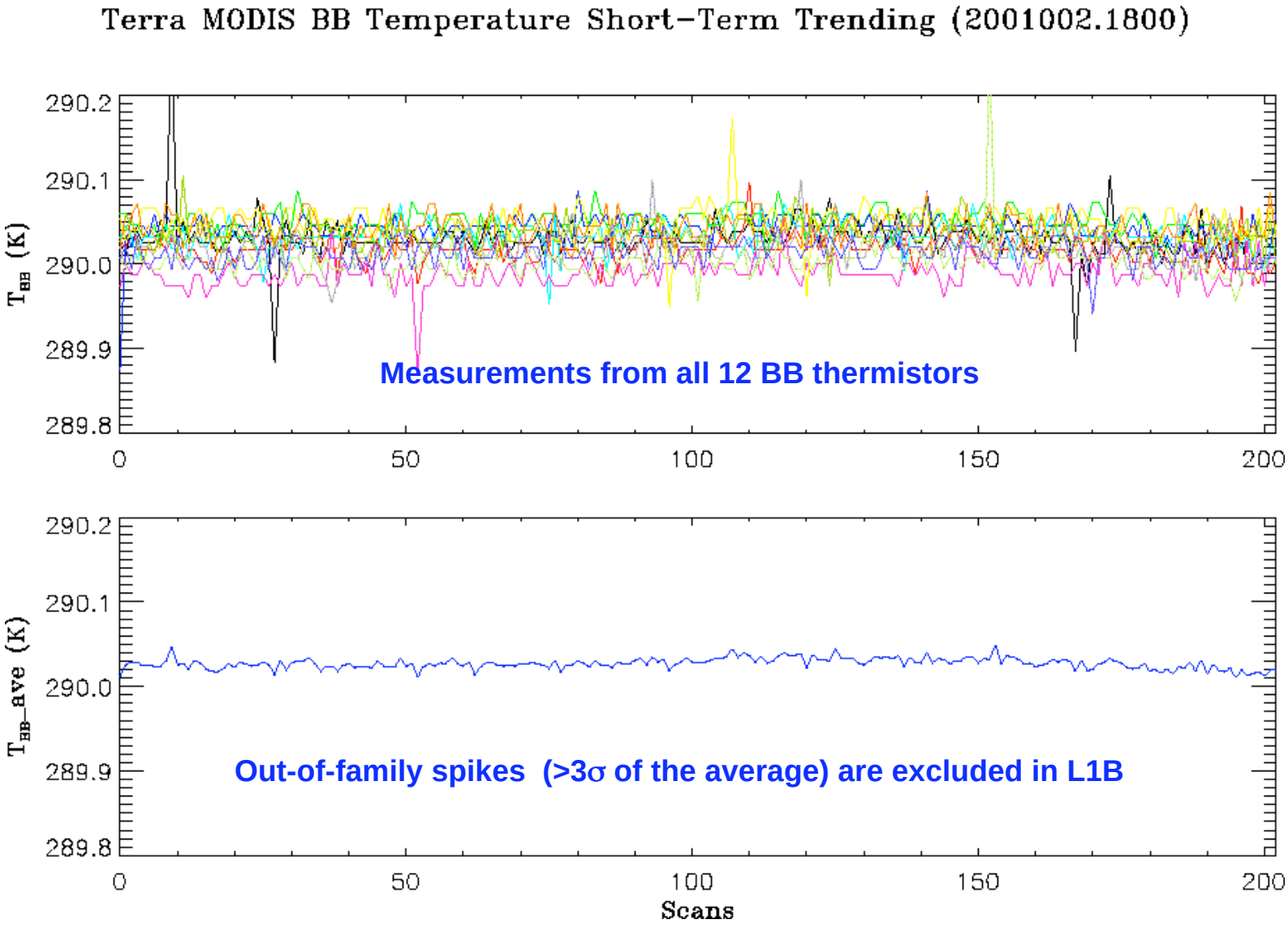
v-grooved panel
high emissivity
12 thermistors (PRT)
traceable to NIST temperature scale



Thermal emissive bands (TEB) calibration

Quadratic algorithm
Scan-by-scan calibration for linear coefficients,
Warm-up and cool-down for nonlinear coefficients

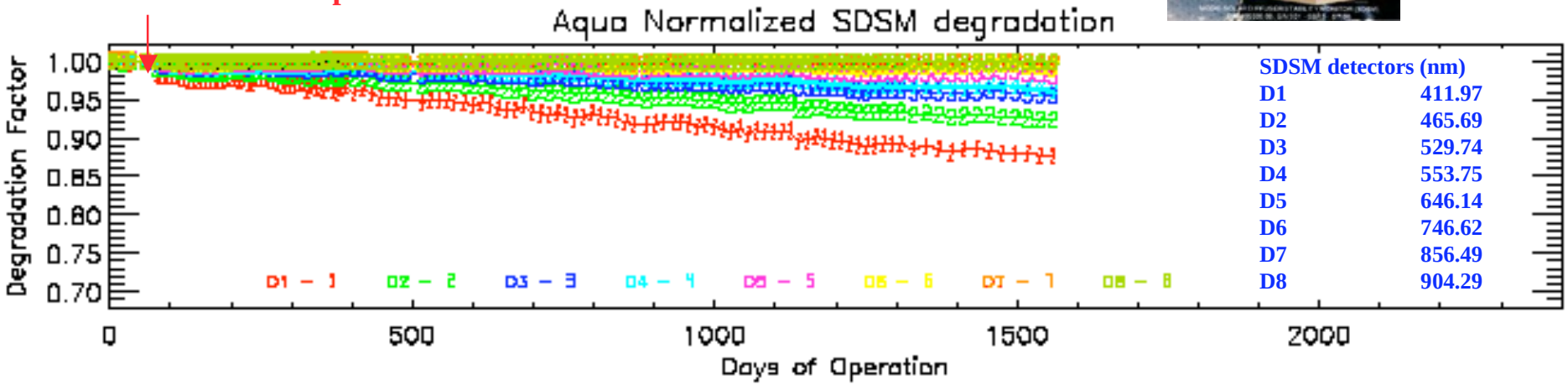
BB Short-term Stability



Solar Diffuser Stability Monitor

- A solar diffuser (SD) with and without a screen regularly used for VIS/NIR calibration
- A solar diffuser stability monitor (SDSM), working as a ratioing radiometer, used to track SD BRF changes on-orbit

SD door left open for 5 days due to a command drop

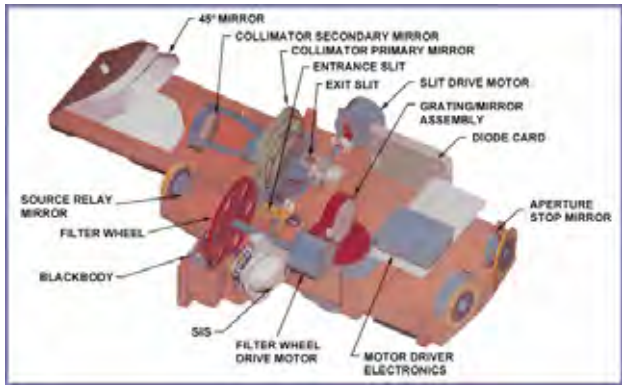


Similar SD degradation in Terra and Aqua MODIS when operated under the same conditions

SRCA: Unique Device for Spatial and Spectral Characterization

$$\bar{x}(b,d) = \frac{\sum_{x=0}^{N_x} dn(b,d,x)\cdot x}{\sum_{x=0}^{N_x} dn(b,d,x)}$$

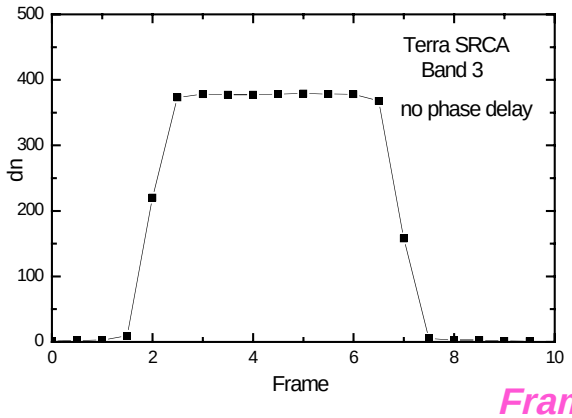
Spatial

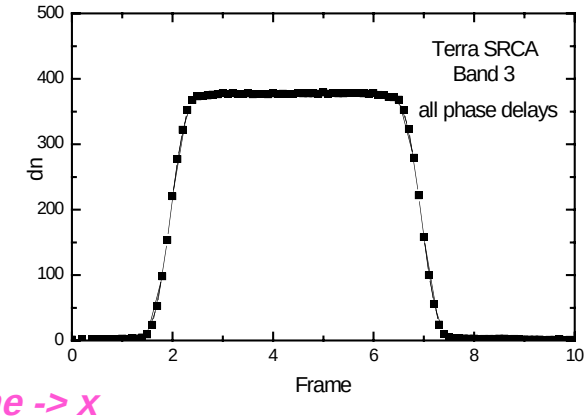


Spectral

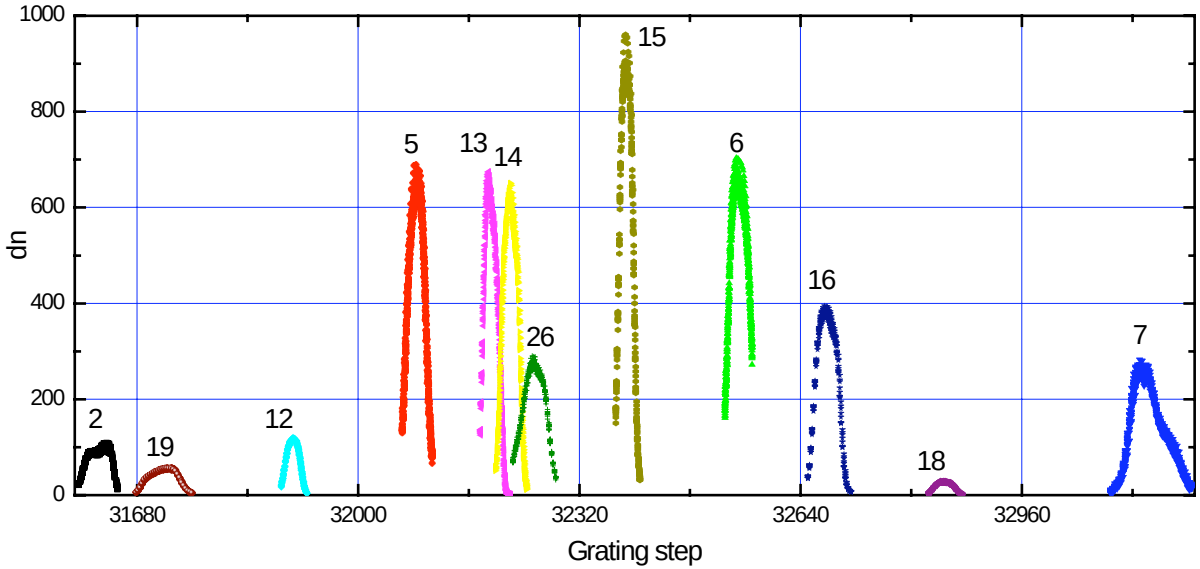
$$\lambda_C = \frac{2A}{m}\cdot\sin(\theta_C + \theta_{off})\cdot\cos\beta$$

Grating step -> θ





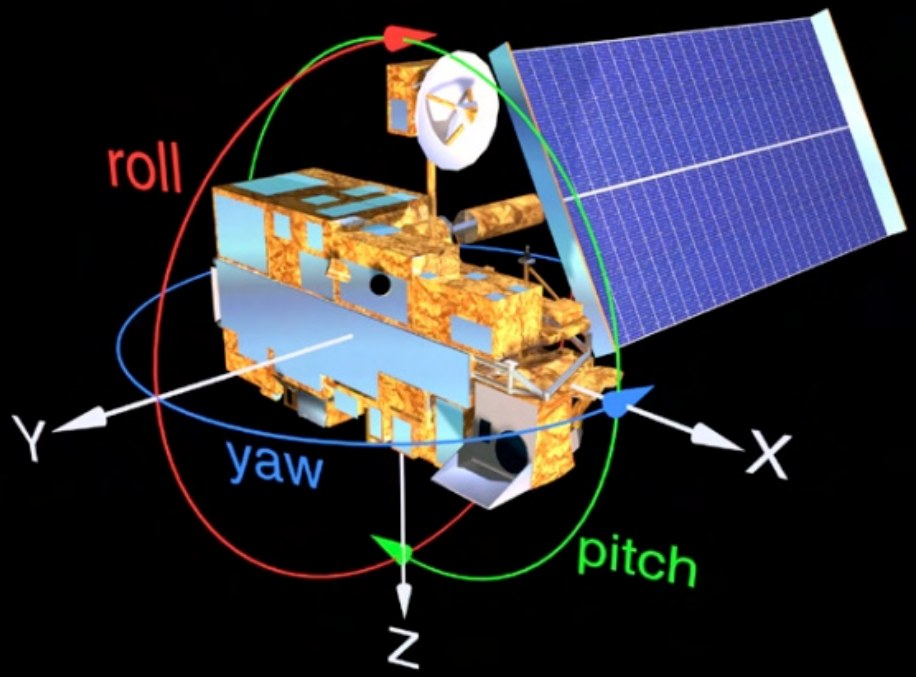
Frame -> x



Stable spatial and spectral performance validated on-orbit

S/C Maneuver Capability

Spacecraft Maneuvers



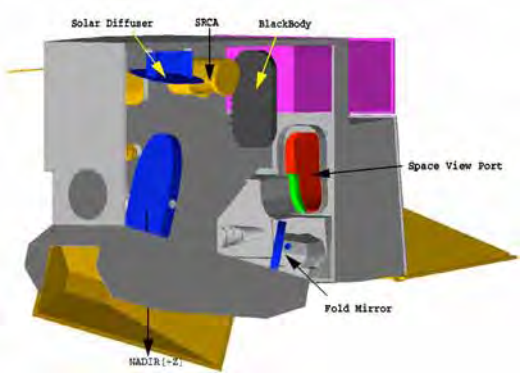
Tasks that were not completed pre-launch (didn't do or couldn't be done due to various reasons); tasks that can only be performed on-orbit (lunar observations)

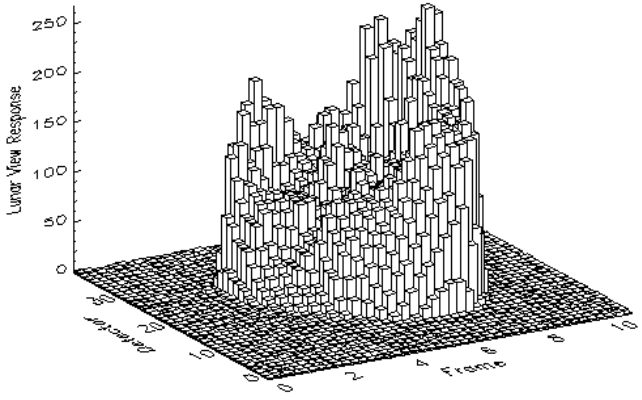
- **Yaw maneuvers:** MODIS SD BRF and SD screen vignetting function
- **Roll maneuvers: Lunar observations** for RSB radiometric stability, Spatial characterization, Optical leak and electronic cross-talk, Sensor calibration inter-comparison
- **Pitch maneuvers:** MODIS TEB response versus scan angle (RVS)

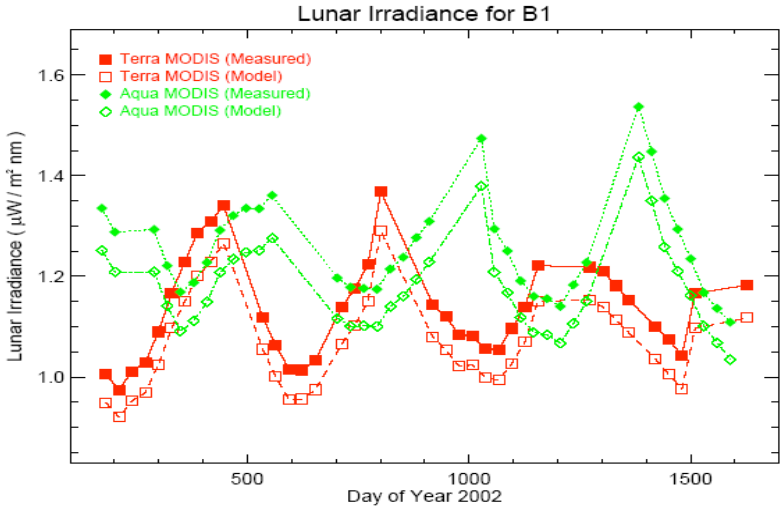
MODIS Lunar Observations

via space view; at fixed phase angle; during nighttime orbit

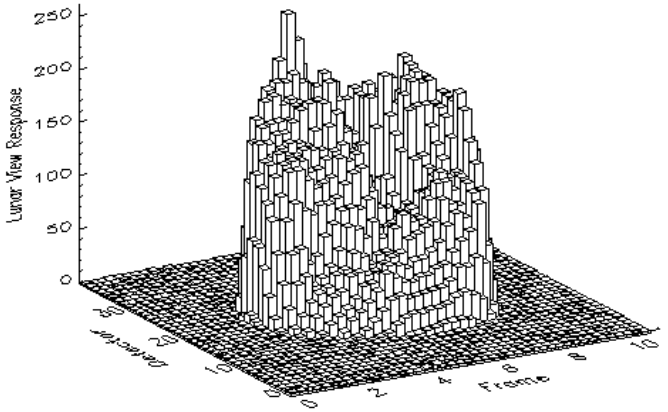
Terra MODIS B1







Aqua MODIS B1



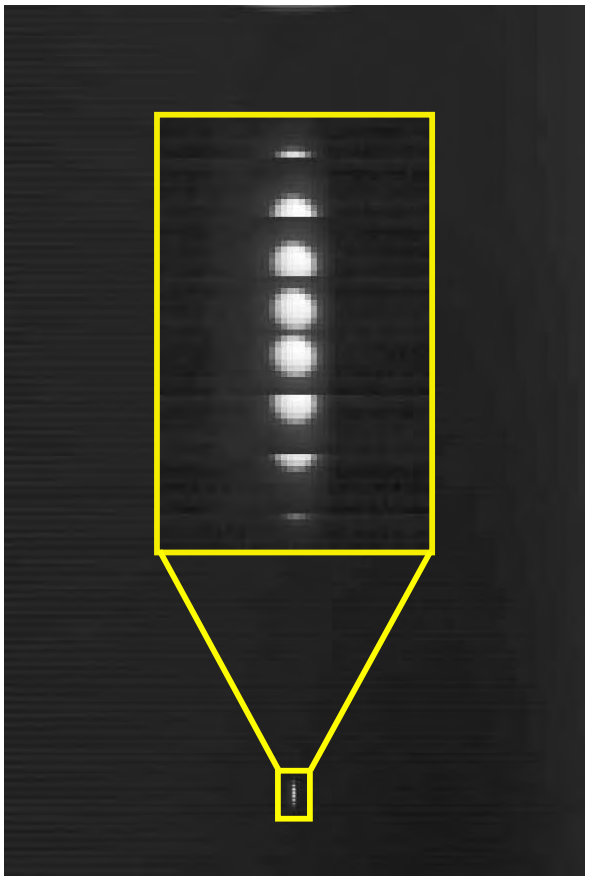
Applications:

stability, spatial characterization, xtalk characterization, cross-sensor calibration

Terra Spacecraft Pitch Maneuver

MODIS B31 - DSM (4/14/03 with Moon in Nadir View)

22:05-10



22:05:00 Terra nadir vector at the limb
22:09:28 MODIS see the first Moon image

Applications:

Deep space view for TEB response versus scan angle characterization

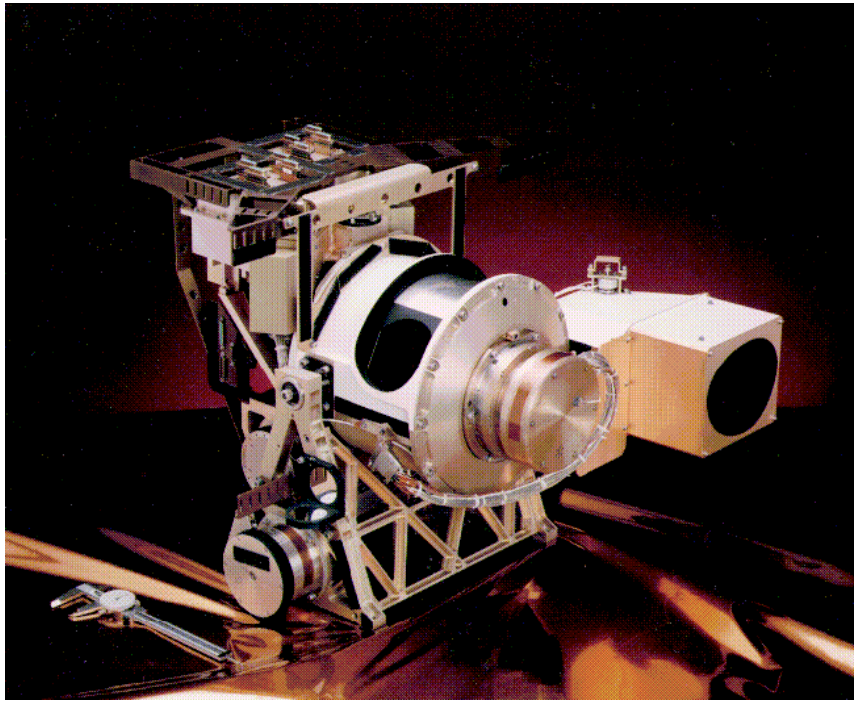
Lunar view for cross-sensor calibration (MODIS, MISR, ASTER, SeaWiFS, EO-1)

MODIS On-orbit Challenges

- SD and scan mirror reflectance degradation in Terra MODIS VIS spectral region
  - Several % per year degradation rate requires monthly updates
- Terra MODIS SD door operational anomaly in late 2003 led to a decision to permanently fix the SD door in the “open” position. This has contributed to a faster SD reflectance degradation.
- Multiple operational configurations involved in Terra MODIS (early in mission)
  - Required effort to assure calibration consistency/data quality
- Striping (10/20/40 detectors per spectral band, 2 mirror sides)
- Evaluating and monitoring calibration consistency between MODIS and other on-orbit sensors (radiance, reflectance, different science data products) over instrument/mission lifetime
  - Considerations required for spatial, spectral, and temporal differences, surface types; algorithm differences, etc.

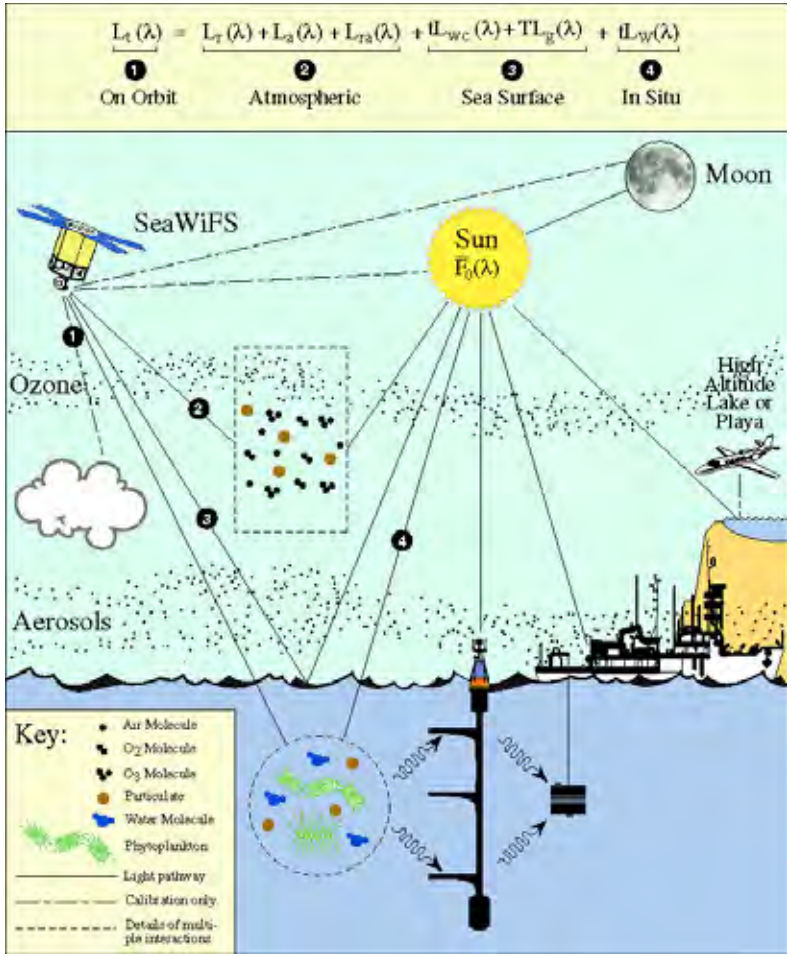
SeaWiFS Instrument

- September 1997 to present
- Orbit: Noontime, sun-synchronous descending
- Instrument Components & Spectral Bands;
  - Fore optics: rotating telescope
  - 8 wavelengths from 412 to 865 nm
  - 4 detectors/bands in TDI w/ bilinear gains
  - 4 commandable gain settings
  - Depolarizer: polarization sensitivity ~0.25%
  - 10 bit digitization
- Spatial Resolution
  - 1.1 km local area coverage
    - Swath: 2800 km
  - 4.4 km global area coverage
    - Swath 1500 km



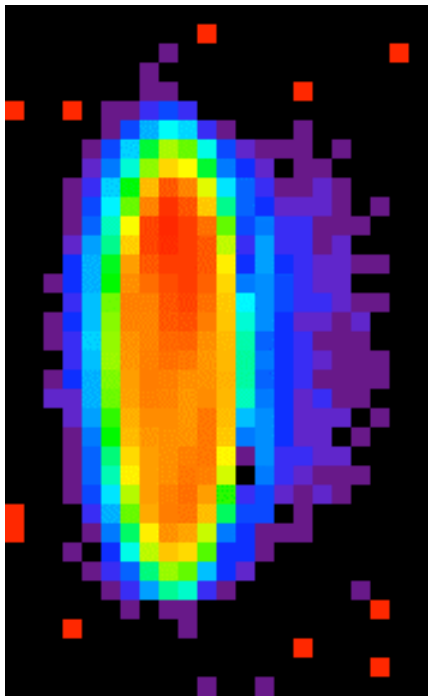
SeaWiFS Calibration: the Ocean Color Cal-val Paradigm

- SeaWiFS Project Calibration
  - Pre-launch laboratory
    - Linearity, T sensitivity, polarization sensitivity, spectral response functions, RVS function, bright target response, et al.
  - Post-launch on-orbit
    - Daily solar diffuser views to track short t sensitivity variations
    - Monthly lunar views at ~7° lunar phase to track long t sensitivity variations
    - Daily cal pulse to track instrument electronics stability
    - Vicarious cal gain adjustments using MOBY off Lanai, HI



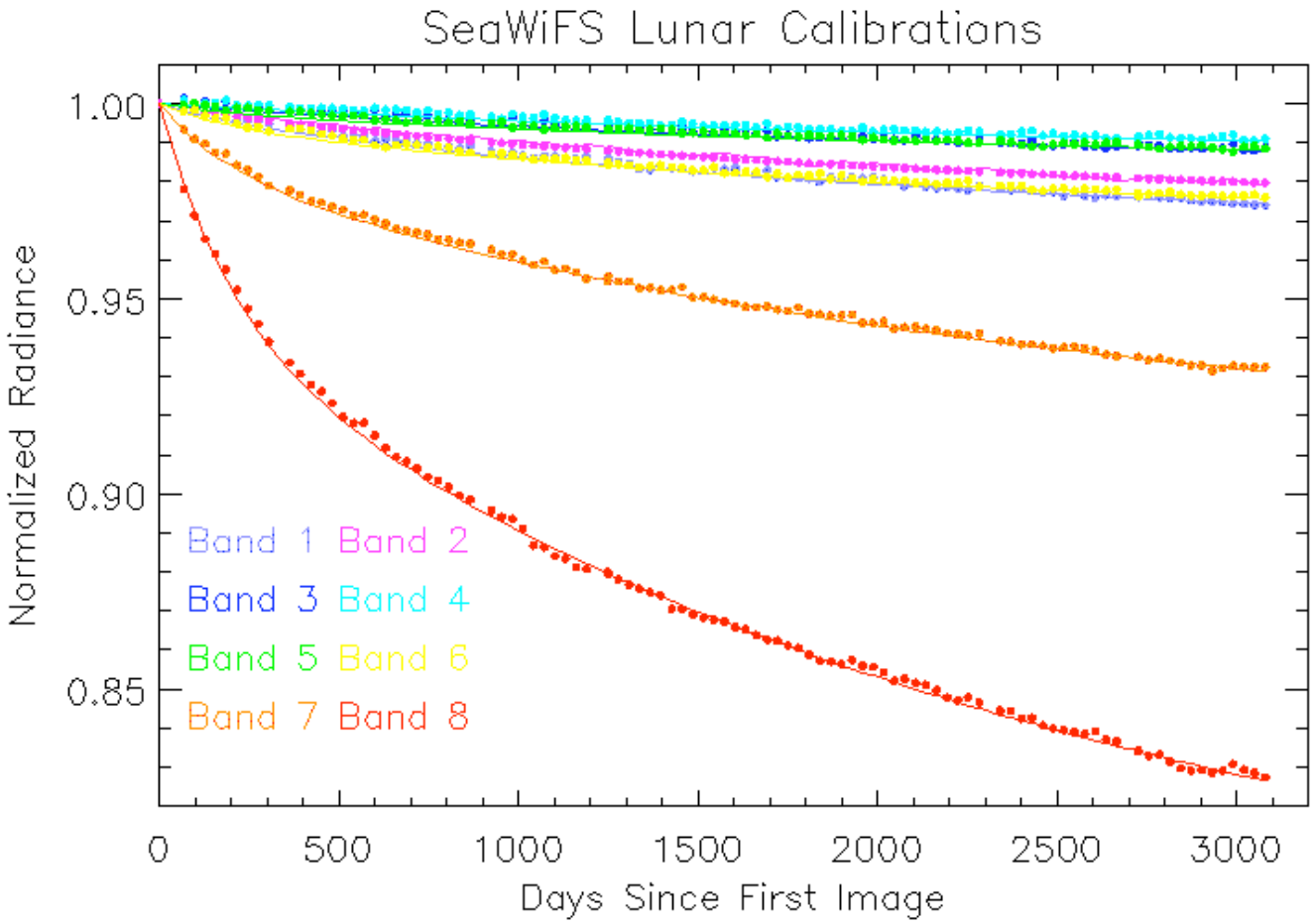
SeaWiFS Lunar Data Analysis

- Long t data series comprised of 163 lunar views over 9.5 years
- Radiance computation
  - Measurement over full SeaWiFS spectral response
  - Analysis of integrated lunar radiance (22 by 33 pixels)
- Corrections include
  - Sun-moon and moon-SeaWiFS distances
  - Normalize to 7° lunar phase angle (range within ±2°)
  - Elongation (over-sampling) variations due to differences in s/c rotation rate
  - Lunar libration



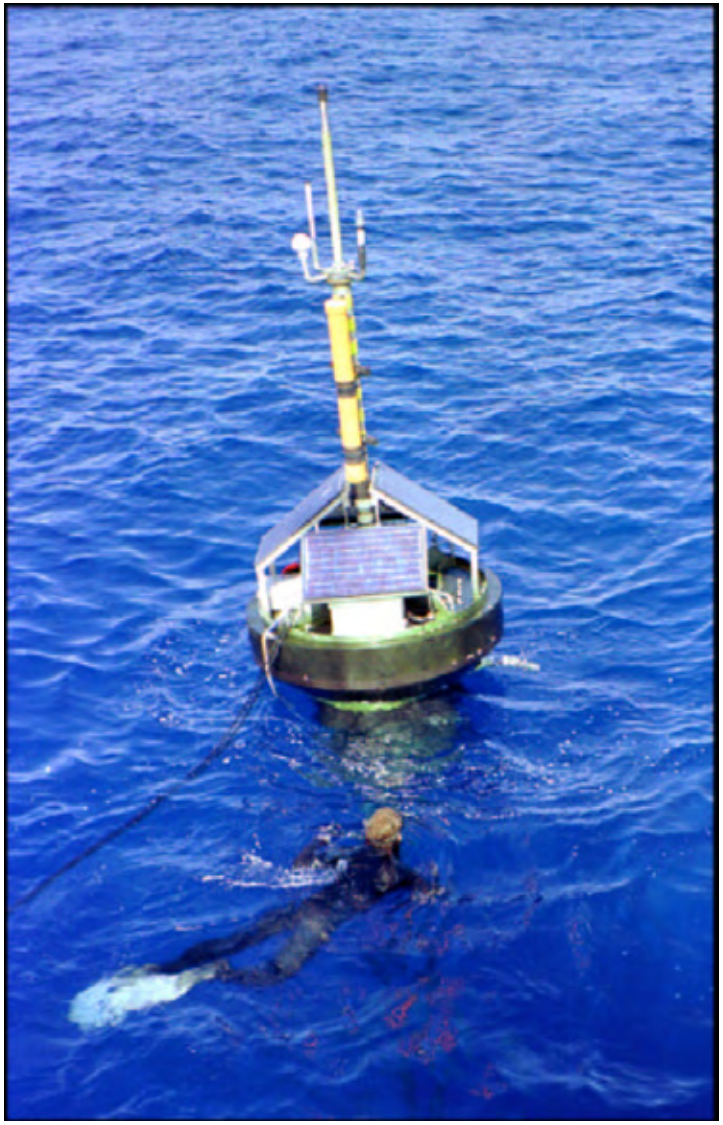
SeaWiFS Lunar-based Relative Calibration

Once a month, the SeaWiFS satellite (Orbview-2) is pitched to observe the Moon at a phase angle ~ 7°.



SeaWiFS Calibration of Bands 1-6: MOBY

- The Marine Optical Buoy (MOBY)
  - In-water system moored off Lanai in “clear water”
  - Buoy refurbishment every 3-4 months
  - Time series since 1996
  - Hyperspectral data over VNIR
  - Calibration and characterization
    - Characterized using NIST’s travelling SIRCUS
    - NIST-traceable cals pre- and post-deployment
    - Monthly measurements with stable, diver-deployed lamps verified using NIST designed radiometers
    - Daily scans of 3 internal sources

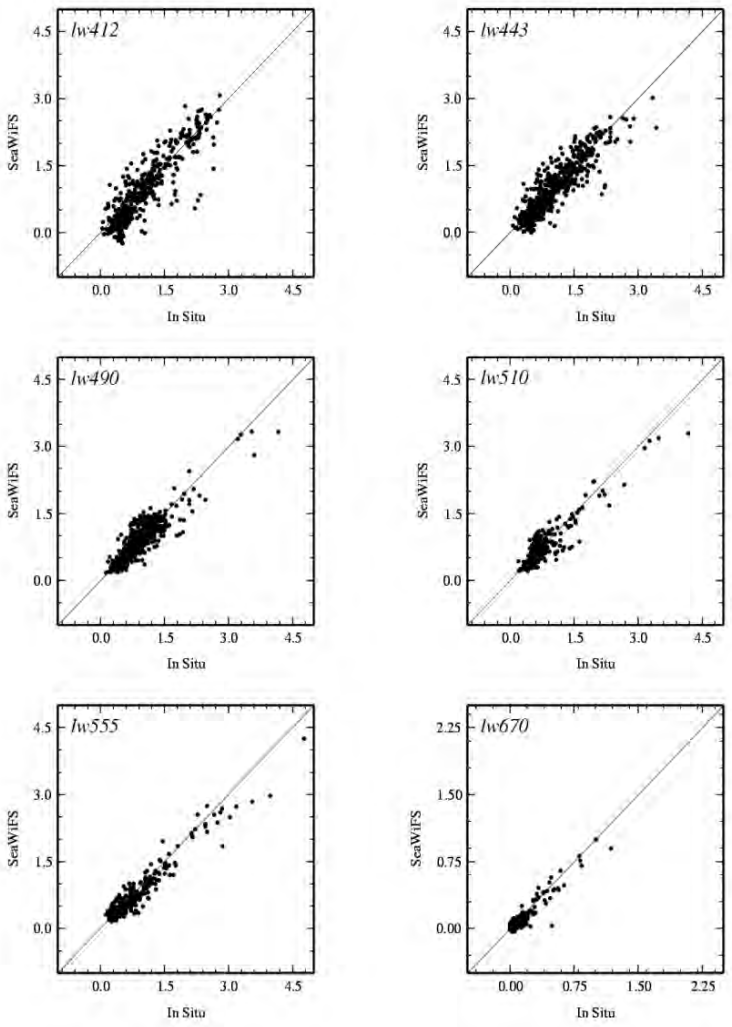


SeaWiFS NIR Bands 7 (765 nm) and 8 (865nm)

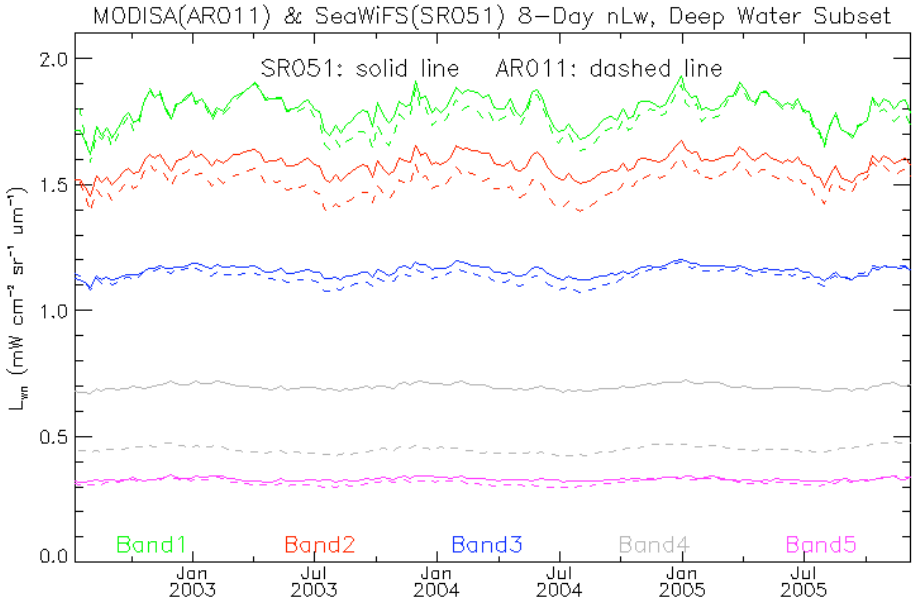
- **Bands 7 and 8 used to determine aerosol plus Rayleigh-aerosol term in $L_T(\lambda)$**
- **765 nm band calibration adjusted to match marine haze model and 865 nm aerosol radiances over open ocean. Aerosol type and single scattering reflectances for VIS/NIR bands derived from model.**
- **Aerosol type and 865 nm radiances (aerosol amount) used to determine aerosol + Rayleigh-aerosol term for VIS bands**
- **No vicarious calibration correction applied to band 8**
  - Use pre-launch gain with lunar time-dependent sensitivity adjustment

SeaWiFS Comparisons

- with ship-board in-situ Lwn's:



- with MODIS/Aqua Global Mean Lwn's:



CLARREO and the Calibration of Filter-based Satellite Instruments

- CLARREO: hyperspectral, high resolution instruments requiring state-of-the-art determination of image quality, spectral fidelity, and radiometric performance
- Requirements of pre-launch instrument calibration and characterization
  - RSRs, polarization responsivity, band-to-band registration, spatial oof, spectral oob, SNR, linearity et al.
  - Characterization of encircled energy response function (a.k.a. size of source effect) and its impact on instrument radiometry
  - Stability: establish confidence in instrument design and on-orbit operation through carefully designed testing
  - Commitment to employing new calibration/characterization technologies and methodologies
    - LED spheres: mimics spectral content of on-orbit scenes
    - CHIP (Calibrated Hyperspectral Image Projector): complements traditional integrating sphere/lamp & panel calibrations. Provides a calibrated target which reproduces on-orbit variegated scenes.
    - Intensity-stabilized lasers: tunable lasers such a SIRCUS providing a high SNR measurement of RSR, OOB, OOF, polarization et al.
- Requirements of on-orbit calibration and characterization
  - Determination (pre- and post-launch) of change in radiometric sensitivity of instrument from calibration at instrument builder's/sc integrator's facility to initial on-orbit operation (transfer to orbit measurements)
  - S/C maneuverability to enable frequent lunar views
    - Relative application in monitoring long t instrument responsivity degradation
    - Absolute application in cross-comparisons with other on-orbit instruments