Calibration Techniques for NASA's Remote Sensing Ocean Color Sensors

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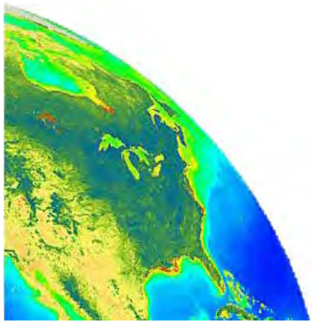
NASA Code 614.2

Ocean Biology Processing Group

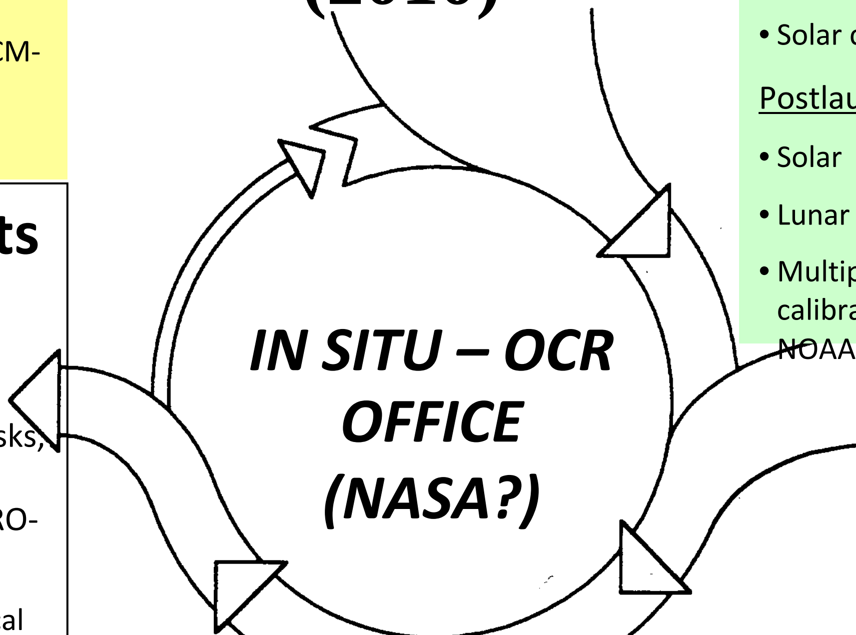
October 21st, 2010



Ocean Biology Processing Group:

- NASA Code 614.2, Ocean Sciences Research, Hydrospheric and Biospheric Sciences Research, Goddard Space Flight Center
- Responsible for producing Ocean Color (OC) products at NASA (CZCS, SeaWiFS, MODIS Aqua and Terra, MERIS, etc.)
- Website: oceancolor.gsfc.nasa.gov

Satellite Data from Calibrated Sensors (2010)



Mission Feedback

- Science community input (ESA CCI)
- Comparison with other appropriate products
- New Missions (Sentinel 3 OLCI, OCM-2)
- Protocol development

Improved Products & Algorithms

- Reprocessing due to improvements in calibration, masks, binning schemes, product compatibilities, etc. (ESA CCI; ISRO-NASA-NOAA JST)
- New products from bio-geochemical fields, atmospheric fields, etc.
- Data distribution interface

SeaDAS, ODESA, BEAM…

- Satellite data processing software (ACE, OCM-2, MERIS, OLCI, SGLI, GOCI, …..)

Calibration Strategy

Prelaunch

- Lab. characterization & calibration (SI-traceable)
- Solar calibration (transfer-to-orbit)

Postlaunch (operational adjustments)

- Solar calibration (daily)
- Lunar calibration (monthly)
- Multiple sites L_{wn} time series for vicarious calibration – (ISRO Arabian Sea Kavaratti; NOAA's MOBY-C)

In Situ Data

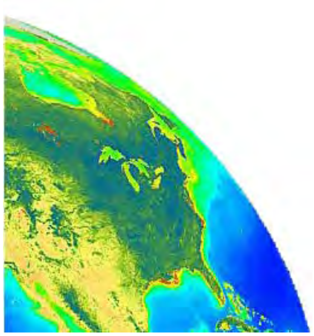
- Collection of required bio-optical and atmospheric measurements (INSITU-OCR PIs; ESA Aero. N. Africa)
- *in situ* instrument calibration (Project round robin SI-traceable, IOPs, AOPs; ESA Radiance Project)
- Data collection following NASA Ocean Optics protocols (ISRO Kavaratti)
- Archive of calibrated QC *in situ* data (NASA SeaBASS)
- Calibrated instrument pool
- Develop new instrumentation

Product & Algorithm Validation

- Atmospheric & bio-optical algorithm validation development (INSITU-OCR PIs,office staff, ESA CCI OC)
- Match-up analysis via Aeronet-OC sites, satellite QC, time series evaluation, Bio-Argo , ChloroGIN, etc.
- Earth System/Climate Model data assimilation

Overview of calibration techniques:

- Lunar calibration
- Solar diffuser calibration
- Striping corrections
- Crosscalibration to other sensors
- Vicarious calibration



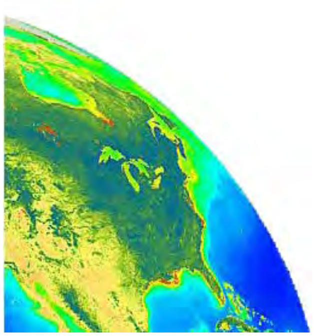
Lunar calibration:

Advantages:

- Reflectance stability (0.1-0.3%, limited by sensor)
- Low cost
- Available for all OC wavelengths

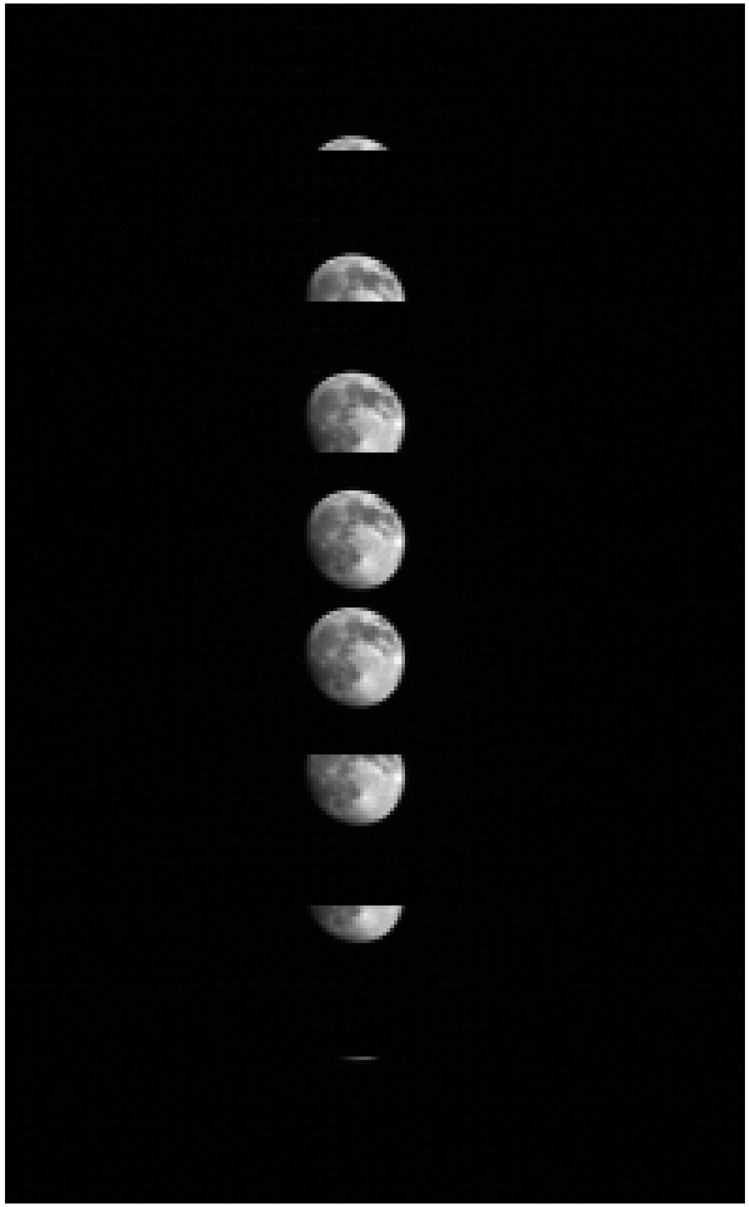
Disadvantages:

- Radiance variations (ROLO model)
- Brighter than typical OC radiances (MODIS saturates in red/NIR)
- Small source, →
  - size of source effects
  - FOV only partially illuminated in some sensor designs
  - single measurements are noisy, long time series required
- Uncertainty of absolute calibration rather high (>5%)
- Viewing geometry (requires maneuvers and oversampling correction for most sensors)

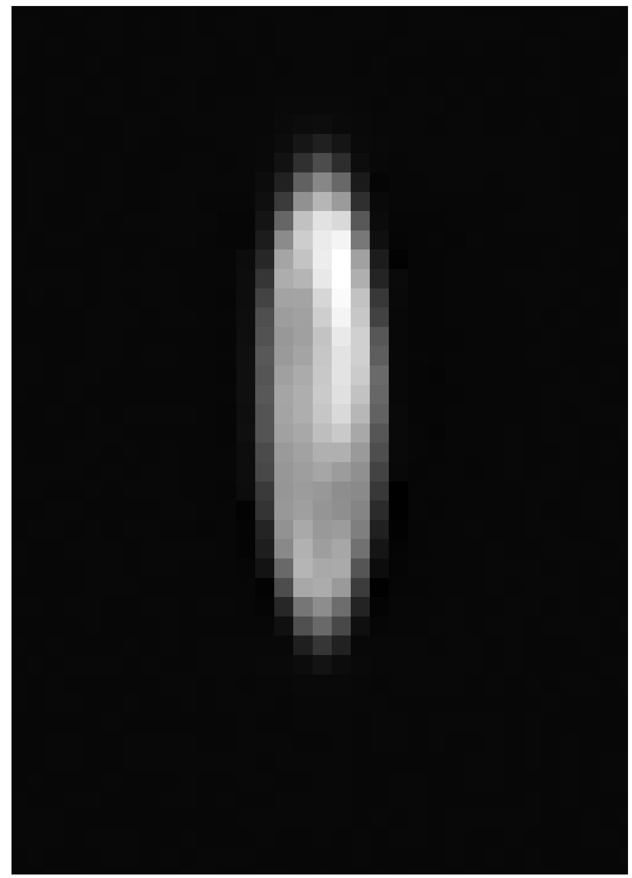


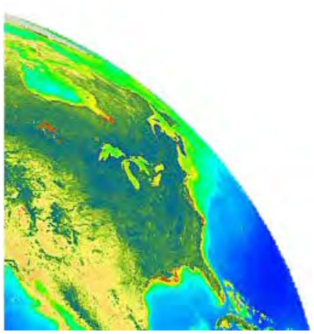
Lunar images may be oversampled:

MODIS band 1:
(image from
presentation
by J. Butler)



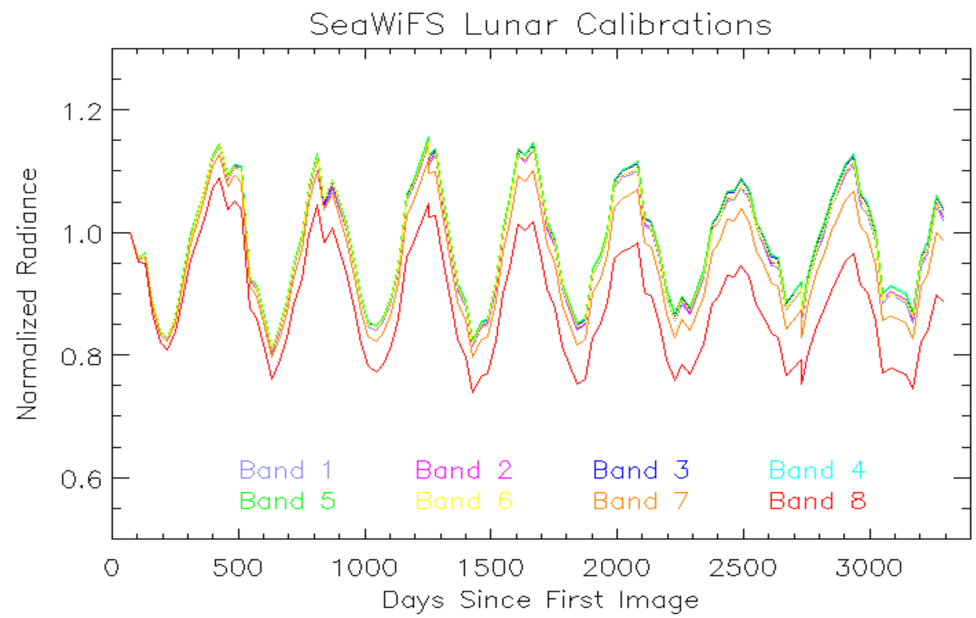
SeaWiFS:





Lunar calibration: SeaWiFS

SeaWiFS measured lunar irradiances:



SeaWiFS gain drift:

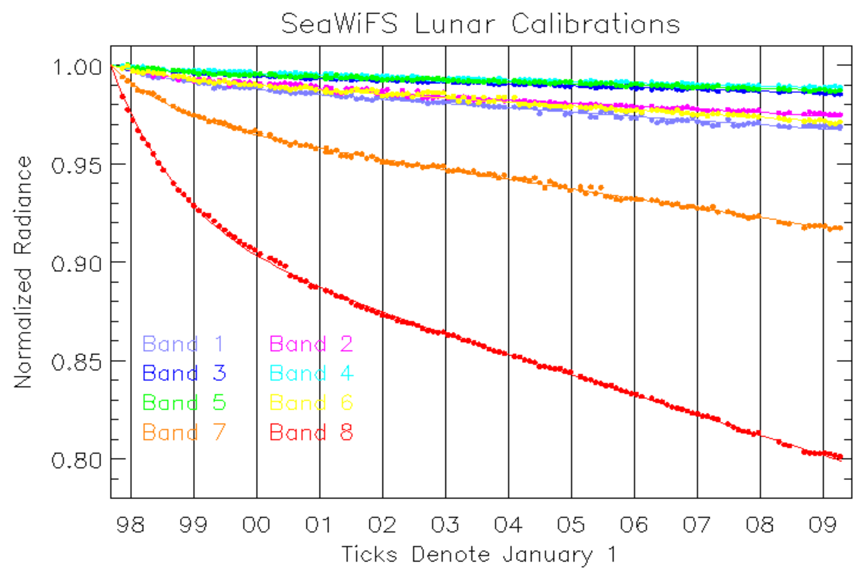


Fig. created by G. Eplee, OBPG

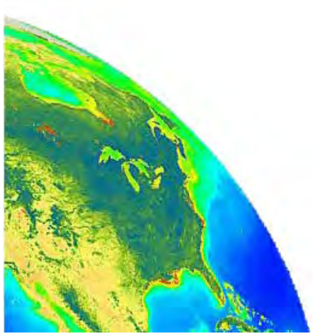
Solar diffuser calibration:

Advantages:

- Easy to fill iFOV
- Moderate cost
- Available for all OC wavelengths
- Low noise

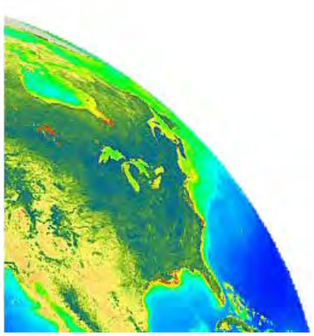
Disadvantages:

- On-orbit reflectance degradation
- Brighter than typical OC radiances in VIS and NIR (MODIS uses screen, which introduces additional problems)
- Adds complexity to sensor design
- BRDF needs to be well characterized and monitored
- Viewing the solar diffuser at different angles for different sensor elements may lead to striping (MODIS)



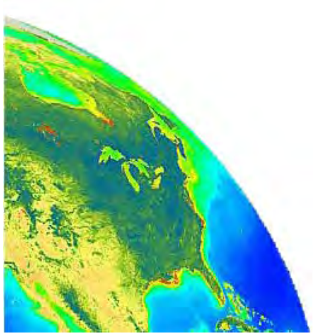
Solar diffuser calibration:

- Main problem is SD reflectance stability
- MODIS uses separate sensor (Solar Diffuser Stability Monitor, SDSM) to look at SD and at sun directly (through screen)
- Results insufficient for short wavelengths after long SD exposure to solar radiation
- MERIS approach of using two SD (keeping one protected most of the time) may be superior

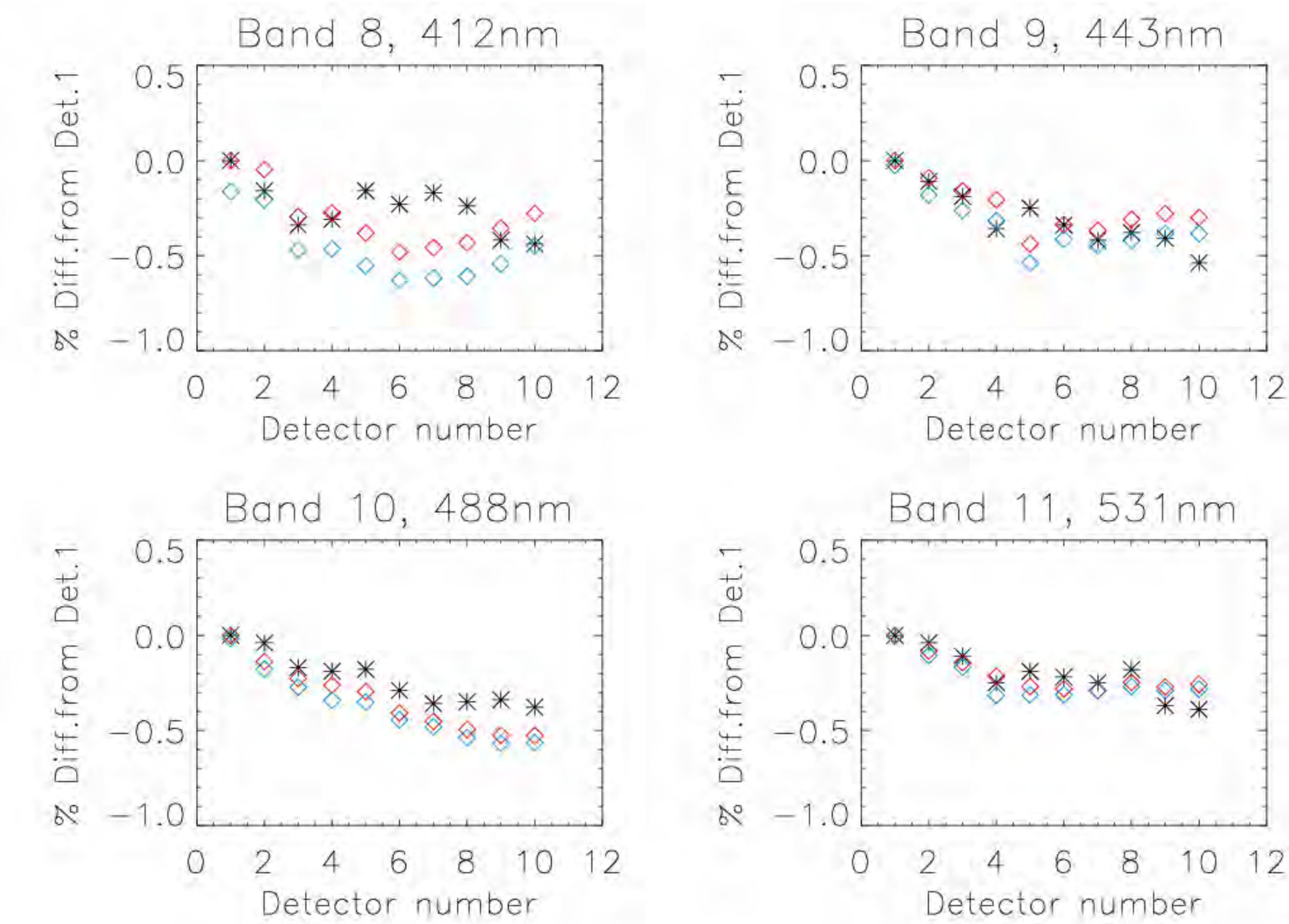


Striping correction:

- Very small calibration inaccuracies of different sensor elements (detectors, mirror sides, cameras) can lead to noticeable striping in OC products
- Uses assumption that adjacent pixels have identical global average water-leaving radiances
- SeaWiFS needs a mirror side correction (about 0.1%), MODIS Aqua and Terra need detector and mirror side corrections (very large for MODIS Terra)

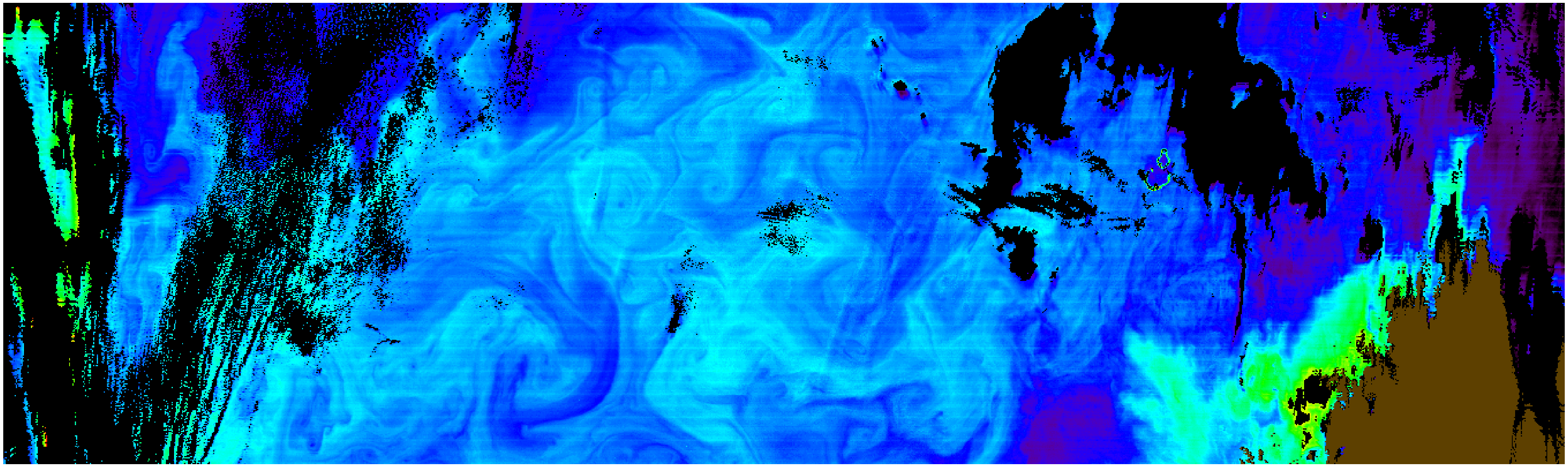


Residuals of TOA and lunar analysis:

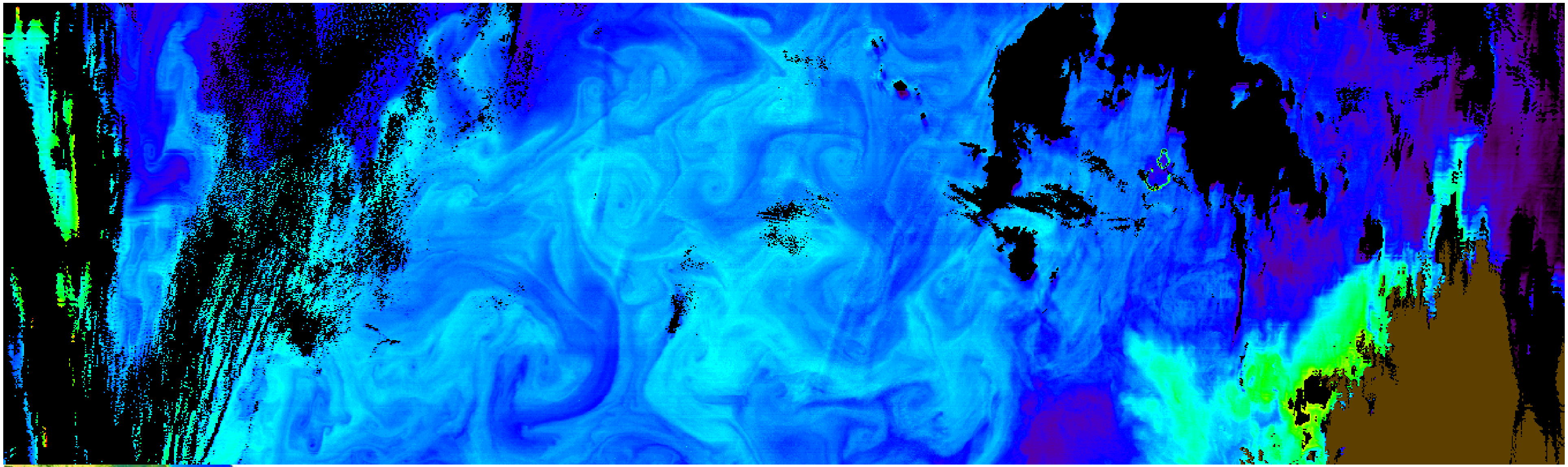


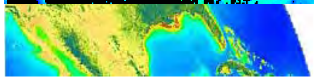
Stars: lunar, blue/red diamonds: TOA MS 1/2

MODIS Aqua nLw 412nm, before correction:



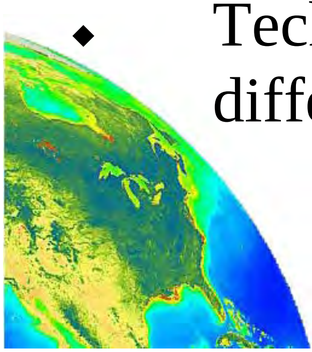
After correction:





Crosscalibration:

- Uses truth field of water-leaving radiances from another sensor
- Propagates L3 truth data to TOA for viewing and solar geometry of sensor whose radiometric properties (gain and polarization) are adjusted as a function of scan angle
- Corrections for MODIS Terra and Aqua result in very consistent global time series for all sensors
- Polarization change for MODIS Terra has been dramatic at 412nm and 443nm, MODIS Terra OC products are unusable without crosscalibration
- Technique may prove beneficial for merging datasets from different sensors (e.g. MODIS Aqua and MERIS)



Modeling of TOA Stokes vector over oceans

air aerosol whitecap glint water gas

$$\begin{bmatrix} L_t \\ Q_t \\ U_t \\ 0 \end{bmatrix} \quad L_t(\lambda) = [\, L_r(\lambda) + L^a(\lambda) + tL_f(\lambda) + TL_g(\lambda) + t_d(\lambda)L^w(\lambda) \,] \cdot t_g(\lambda)$$

from MODIS NIR
assumes MCST NIR band characterization

$\lambda' \rightarrow \lambda$
fit based on bio-optical models

SeaWiFS
4-day mean

$L^{wn}(\lambda')$

Crosscalibration approach:

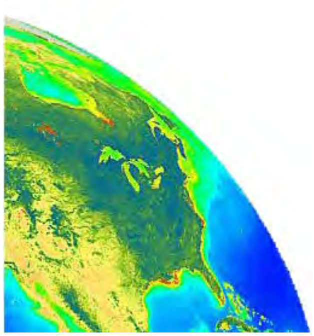
$$L_m/M_{11} = L_t + m_{12}*Q_t + m_{13}*U_t$$

L_m: measured TOA radiance (MODIS)

L_t: true TOA radiance (from SeaWiFS)

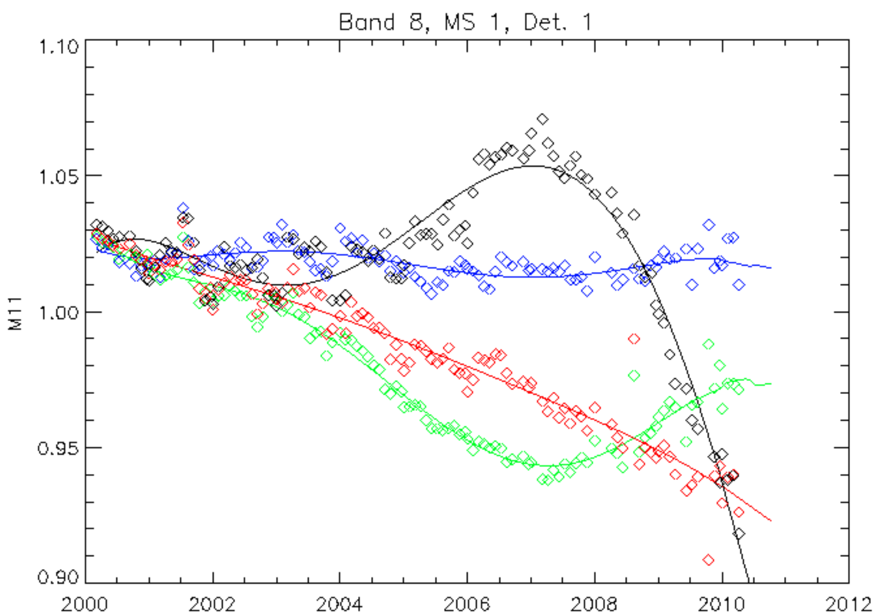
Q, U : linear Stokes vector components, modeled from Rayleigh and glint

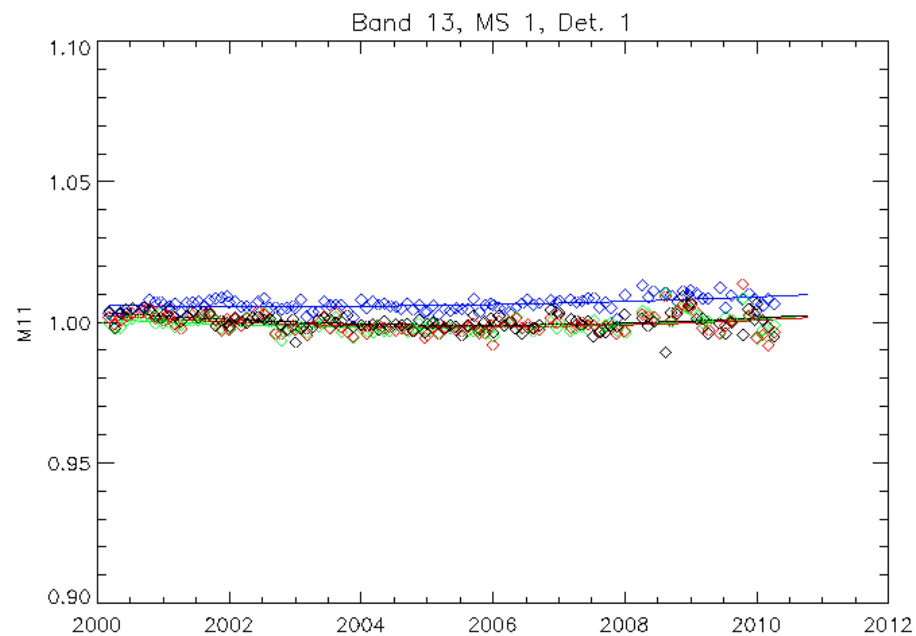
M_{11}, m_{12}, m_{13} : fitted instrument characterization parameters (depend on band, MS, detector, scan angle)

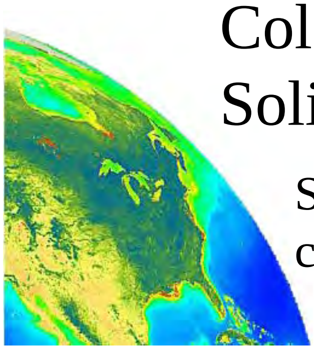


MODIS Terra radiometric gain corrections as a function of time at different view angles:

412nm: Gain at lunar view is stable
Gain at solar diffuser view changes by >6%





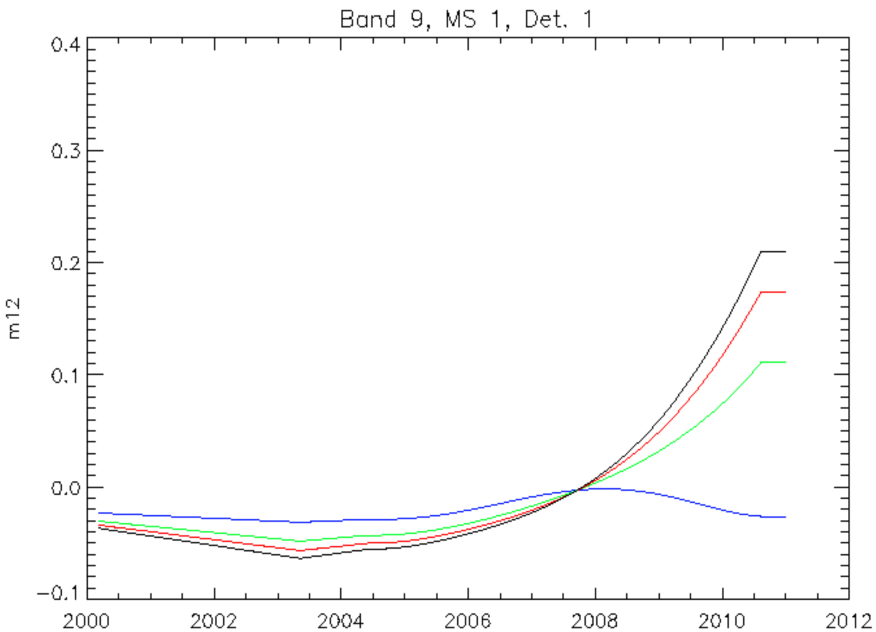


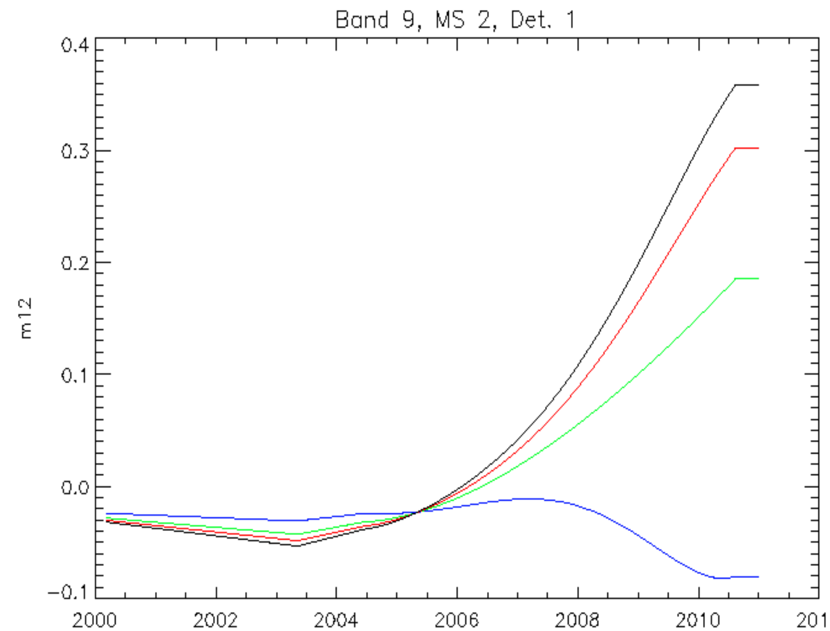
Color coding: Frames (pixels) 22 675 989, 1250 (out of 1354)
Solid line is a fit to the measurements of each month (diamonds)

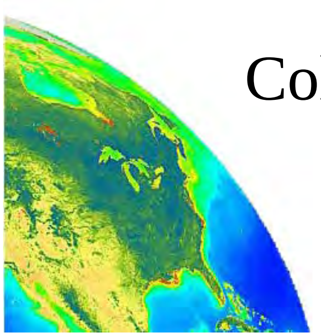
Significant corrections in the blue (up to 10% at 412nm (band 8)), very small corrections for the red (band 13 at 667nm)

MODIS Terra polarization sensitivity as a function of time at different view angles:

443nm: significant corrections to the polarization sensitivity, twice as large for mirror side 2 versus mirror side 1





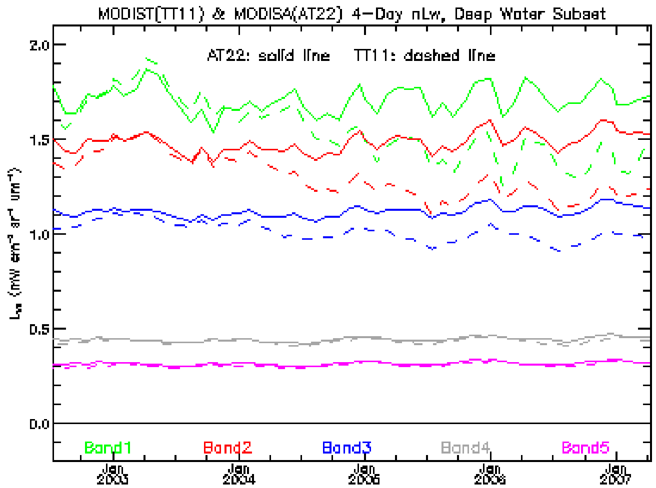


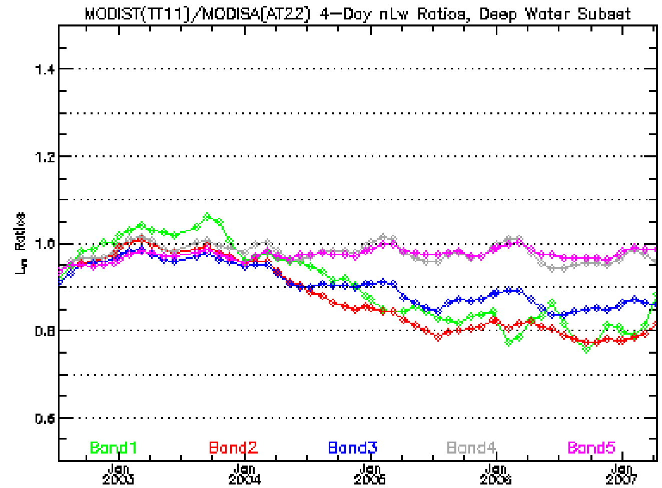
Color coding: Frames (pixels) 22 675 989, 1250 (out of 1354)

Polarization sensitivity is highest for 412nm, decreases with wavelength

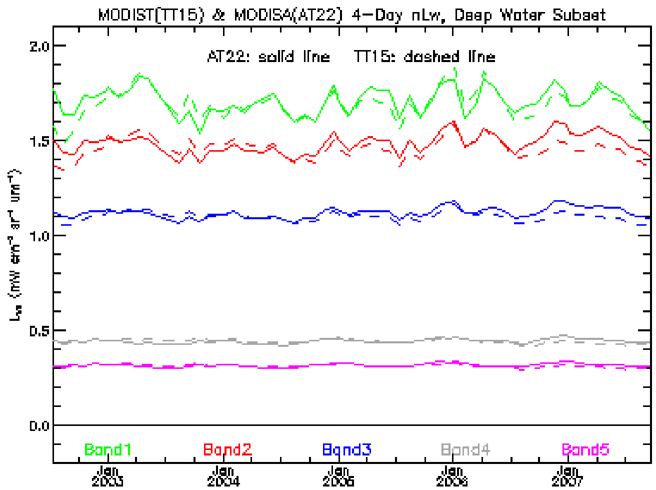
MODIS-Terra and MODIS-Aqua nLw

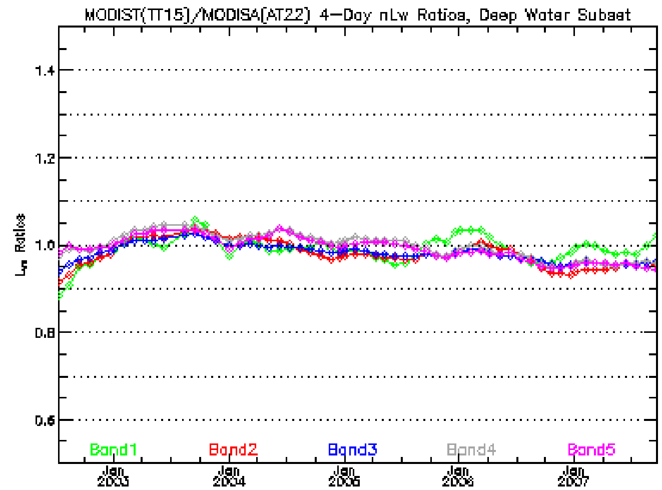
Before crosscalibration:





After crosscalibration:





Vicarious Calibration:

- NIR 870nm band: no adjustment to calibration (error mitigated by 750nm band calibration)
- NIR 750nm band: assuming maritime aerosol model (r70f10v01) in South Pacific
- VIS bands: MOBY at Hawaii
- Strict quality control
- Also applied after crosscalibration
- Advantage: calibrates both sensor and atmospheric correction algorithm, forces results to agree with in-situ measurements (most OC product algorithms are empirical fits to in-situ data)

Summary:

- Lunar trending is the most reliable calibration approach to produce climate data records for ocean color products, but requires long time series
- Solar diffuser calibration superior for short term gain variations and calibration of sensor elements relative to each other
- Crosscalibration is a powerful method to correct even severe instrument issues, but relies on truth sensor (only use when needed)