Instrument Characterization for Ocean Color Remote Sensing

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My background:

- Phd in 2000, 'BRDF of Urban Areas'
- Joined SIMBIOS in 2000, then OBPG
- SIMBIOS Radiometric Intercomparisons
- MODIS and SeaWiFS calibration and characterization analysis
- VOST: VIIRS prelaunch and on-orbit characterization
- ORCA: instrument design support, PI of Instrument Incubator Program; candidate for PACE mission
- ACE, CLARREO, and HyspIRI: mission definition support
- MERIS Quality Working Group (ESA)
- Instrument development for GeoCAPE
- NASA civil servant since 2010

Overview:

1. Ocean color requirements
2. Sensor requirements
3. Sensor characterization prelaunch
4. Sensor characterization on-orbit

Calibration and Characterization:

Calibration: convert dn to radiance L for ideal conditions

L = f(dn)

L = gain * dn

Characterization: what adjustments need to be made for non-ideal conditions:

L = g(P, S, T, etc.) * f(dn)

g can depend on polarization, neighboring bright targets, temperature, etc.

Derivation of ocean color products

Measurement of TOA Radiances
(calibration and characterization)

↓

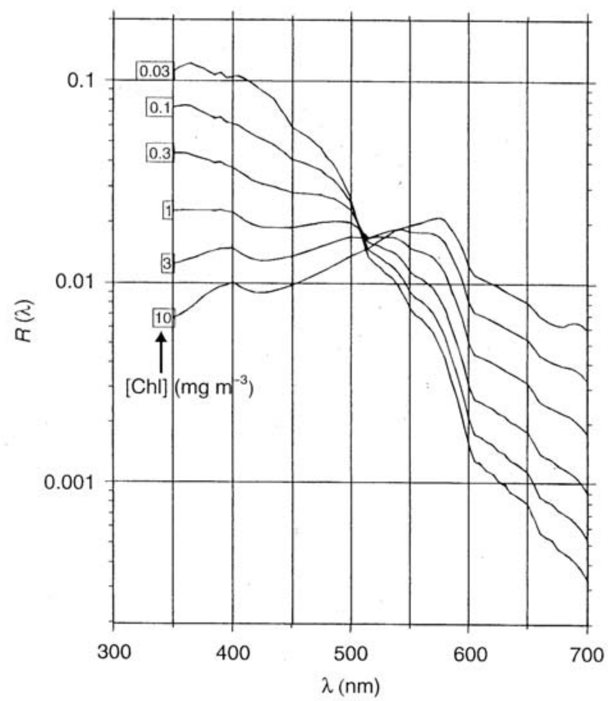
Conversion to water-leaving radiances
(atm. corr., vic. cal., glint, etc.)

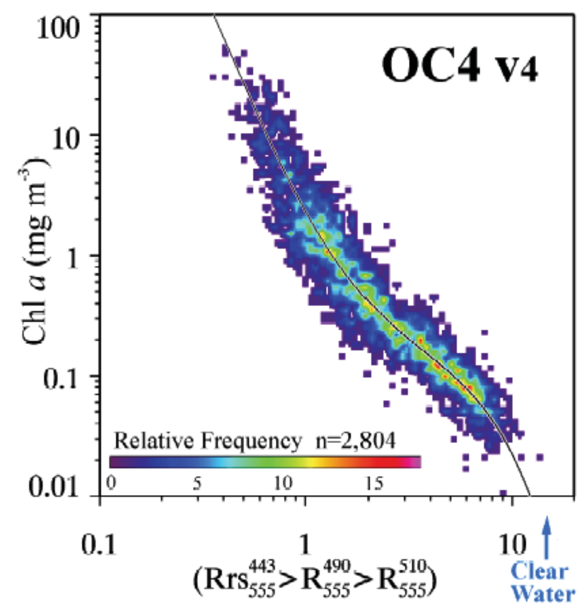
↓

Derivation of ocean color products
(chlorophyll concentration, attenuation coef., fluorescence line height, etc.)

1. Ocean color requirements

- Basic quantity: normalized water-leaving radiance nLw
- Some oceanographic variables can be expressed as function of nLw (chlorophyll concentration, suspended matter, attenuation coef., etc.)





1. Ocean color requirements

- Only 1%-15% of TOA signal is scattered within ocean
- If 5%, then 1% error in TOA signal leads to 20% relative error in nLw

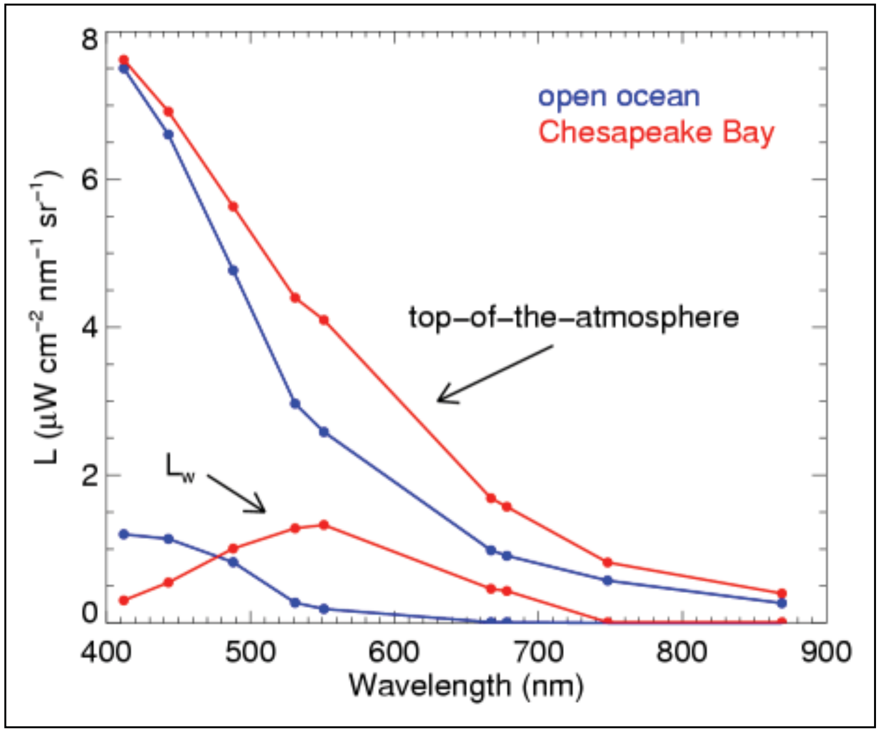


Fig. provided by B. Franz, OBPG

1. Ocean color requirements

How can we achieve high radiometric accuracy ?

1) Design and specifications

2) Prelaunch characterization and calibration

3) On-orbit monitoring

1. Ocean color requirements

- Historically: 5% goal for nLw at 443nm
- Requires better than 0.5% absolute calibration accuracy, unattainable from space (MODIS: about 2% in reflectance)
- Vicarious calibration (MOBY) adjusts absolute radiance level, so only relative calibration errors are important for ocean color
- Current relative accuracy is about 0.5% or more, goal for future missions probably about half that

2. Sensor requirements

- Ocean color requirements lead to sensor requirements, e.g. ACE Science Traceability Matrix (STM)

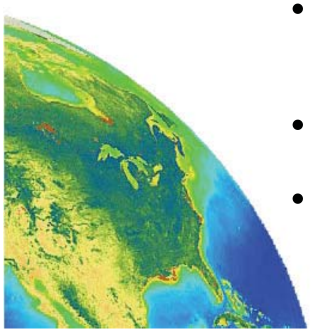
Ocean Biology STM — Goddard Space Flight Center

ory	Focused Questions*	Approach	Maps to Science Question	Measurement Requirements	Instrument Requirements	Platform Requir'ts	Other Needs
n gy	1 What are the standing stocks, composition, & productivity of ocean ecosystems? How and why are they changing? [OBB1]	Quantify phytoplankton biomass, pigments, optical properties, key (functional) phytoplankton groups, and productivity using bio-optical models and chlorophyll fluorescence	1 2 6	Water-leaving radiances in near-ultraviolet, visible, & near-infrared for separation of absorbing & scattering	Ocean Radiometer • 5 nm resolution 350 to 755 nm • 1000 – 1500 SNR for 15 nm aggregate bands UV & visible • 1000 SNR for 10 nm fluorescence bands (667, 678, 748 nm band center)	Orbit permitting 2-day global coverage of ocean radiometer	Global data sets from missions, models, or field observations:
		Measure particulate and dissolved					

- Sensor requirements should be
  1) strict enough to ensure quality of data product
  2) achievable at reasonable cost
  3) testable

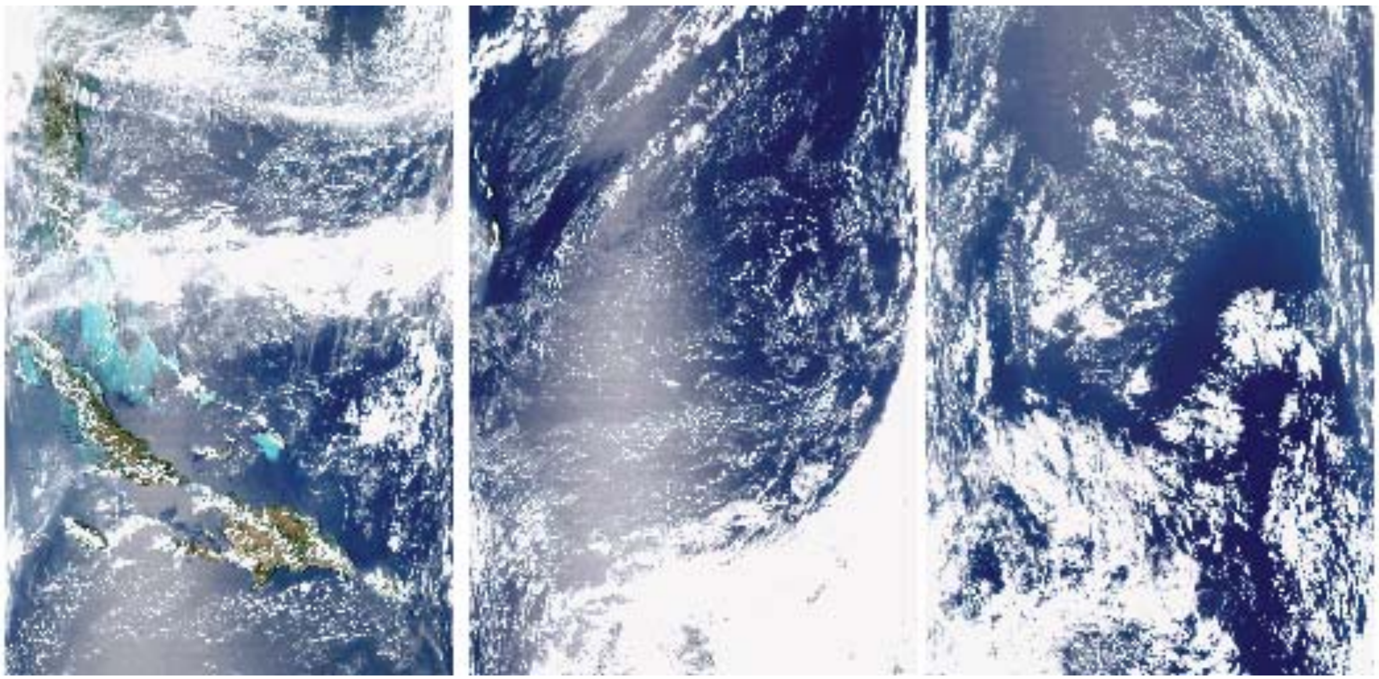
Specific calibration and characterization issues:

- **Polarization** (Meister et al., Applied Optics, 2005 (cover article); Kwiatkowska et al., Applied Optics, 2008; Waluschka et al., SPIE, 2007)
- **Straylight** (Meister et al., SPIE, 2008; Meister et al., ISPRS, 2005; Zhong et al., SPIE, 2007)
- **Gain trending, lunar** (Barnes et al., Applied Optics, 2004; Sun et al., SPIE, 2008; Eplee et al., SPIE, 2008; Patt et al., SPIE, 2005)
- **Gain trending, solar diffuser** (Meister et al., SPIE, 2008; Meister et al., SPIE, 2005)
- **Response versus scan** (Franz et al., JARS, 2008; Kwiatkowska et al., Applied Optics, 2008)
- **Striping** (Meister et al., SPIE, 2007, Meister et al., SPIE, 2006, Xiong et al., SPIE, 2007)
- **Linearity** (Meister et al., SPIE, 2007)
- **Absolute calibration** (Meister et al., Metrologia, 2003; et al.; Meister et al., NASA-TM, 2003, Meister et al., NASA-TM, 2002; Johnson et al., Metrologia, 2003)
- **Temperature** (Eplee et al., SPIE, 2007)
- **Crosstalk, Spectral response, Sensor noise, Field-of-view, etc.**



Sensor requirements not strict enough: VIIRS

- Straylight contaminates high contrast scenes:



- MODIS Aqua: masking 2-3km away from cloud, removes about 50% of the ocean pixels

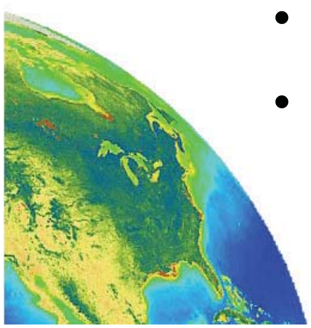
Sensor requirements not strict enough: VIIRS

- VIIRS structured scene (straylight) spec

TABLE 20. Structured Scene requirements

Band	Center Wavelength (nm)	Angular separation from bright target (milliradian)	Maximum allowed ratio of scattered radiance to typical radiance
M1	412	6	0.01
M2	445	6	0.01
M3	488	6	0.01
M4	555	6	0.01
M5	672	12	0.02
M6	746	12	0.02
M7	865	12	0.02

- Cloud size is 12mrad x 12mrad
- 12mrad ~ 10km, 6mrad ~ 5km
- SeaWiFS would pass VIIRS spec in the NIR (SeaWiFS has correction, VIIRS will not; VIIRS straylight performance much better than SeaWiFS, comparable to MODIS)



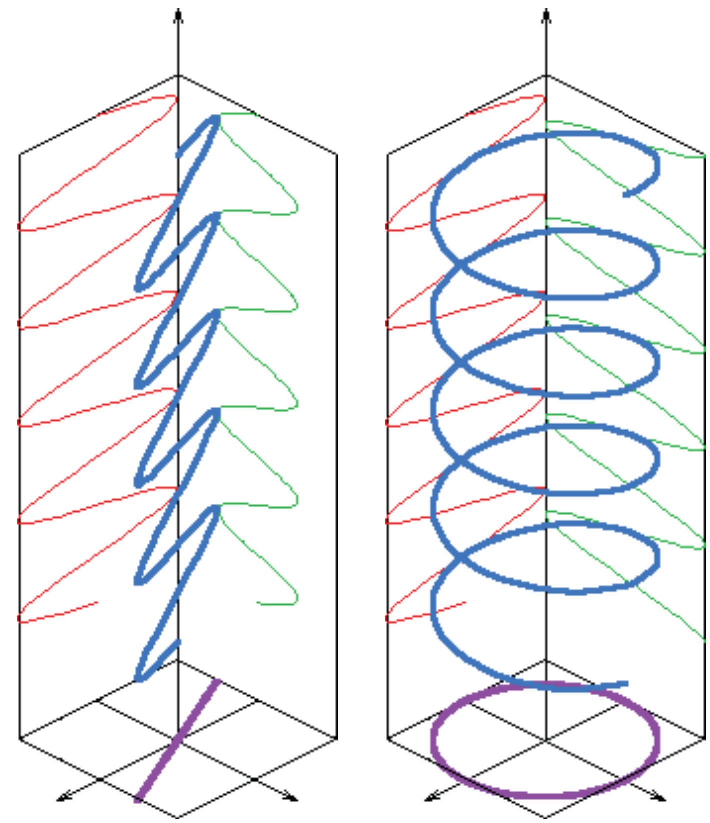
3. Sensor Characterization: Overview

- Polarization:
  setup documentation (MODIS and VIIRS)

- MODIS striping:
  1) horizontal (detectors)
  2) vertical (subframes)

Linear Polarization: Electric Field Vector

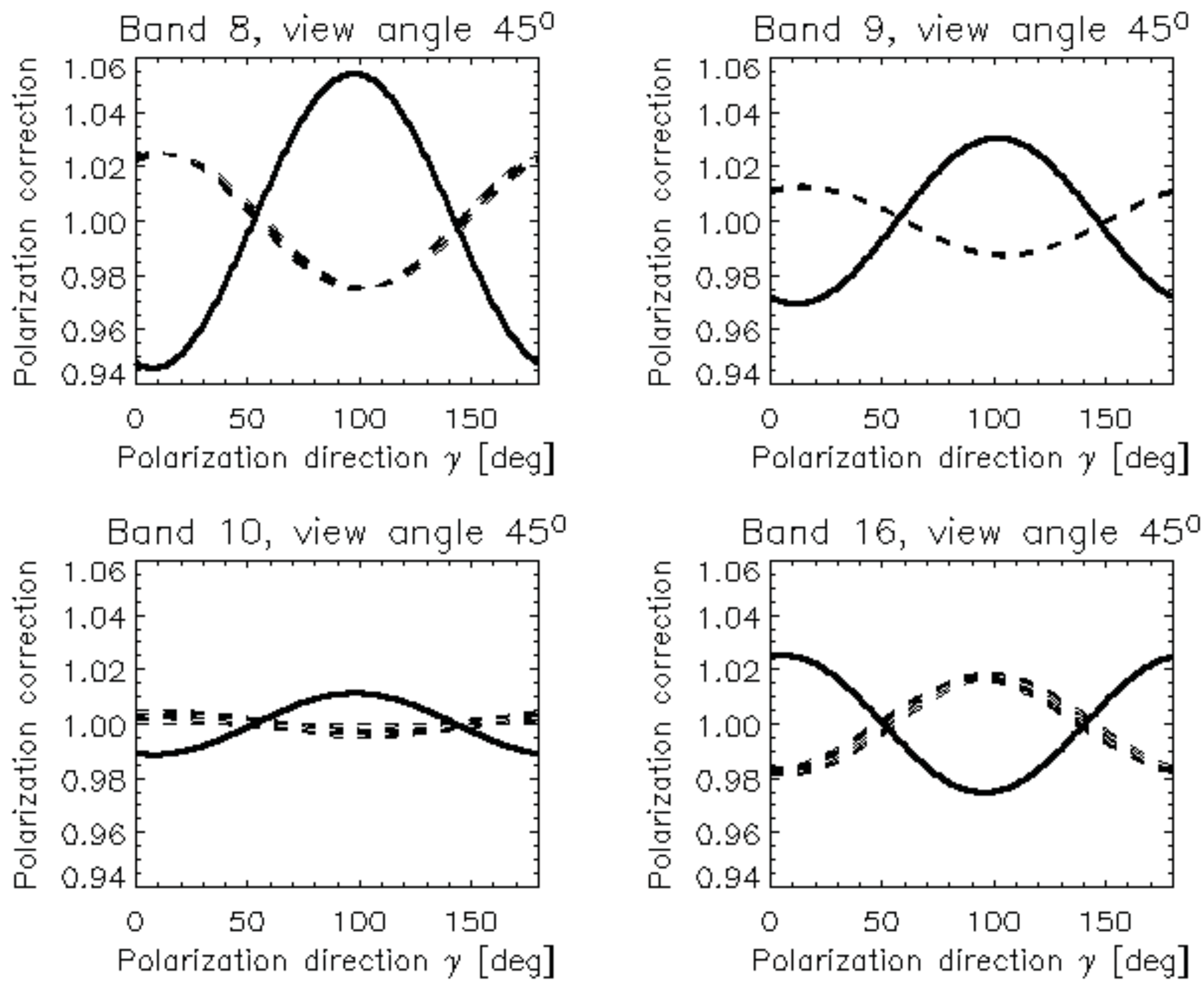
- There are two types of polarization: linear and circular
- TOA radiances are partly (0-70%) linearly polarized
- Prelaunch characterization: send 100% linearly polarized into sensor, varying polarization angle from 0^0-180^0 (15^0 steps for MODIS Aqua)



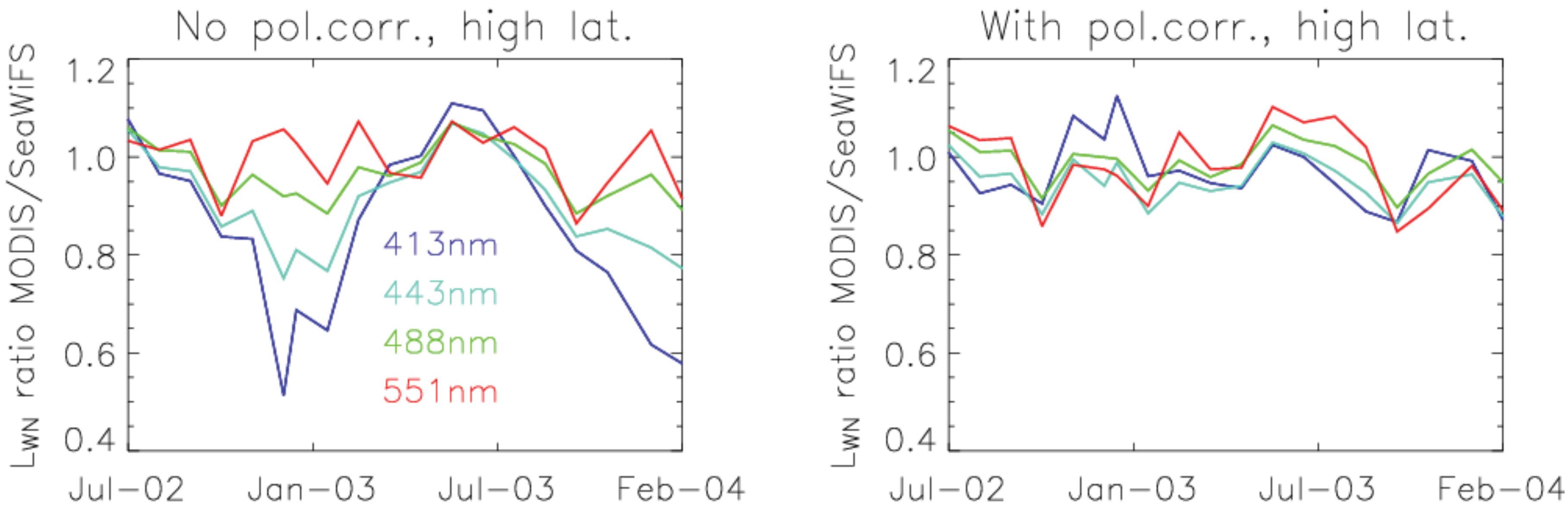
MODIS Polarization Characterization: Setup documentation

Solid line:
Correct
polarization
Correction

Dashed line:
Previous
polarization
correction

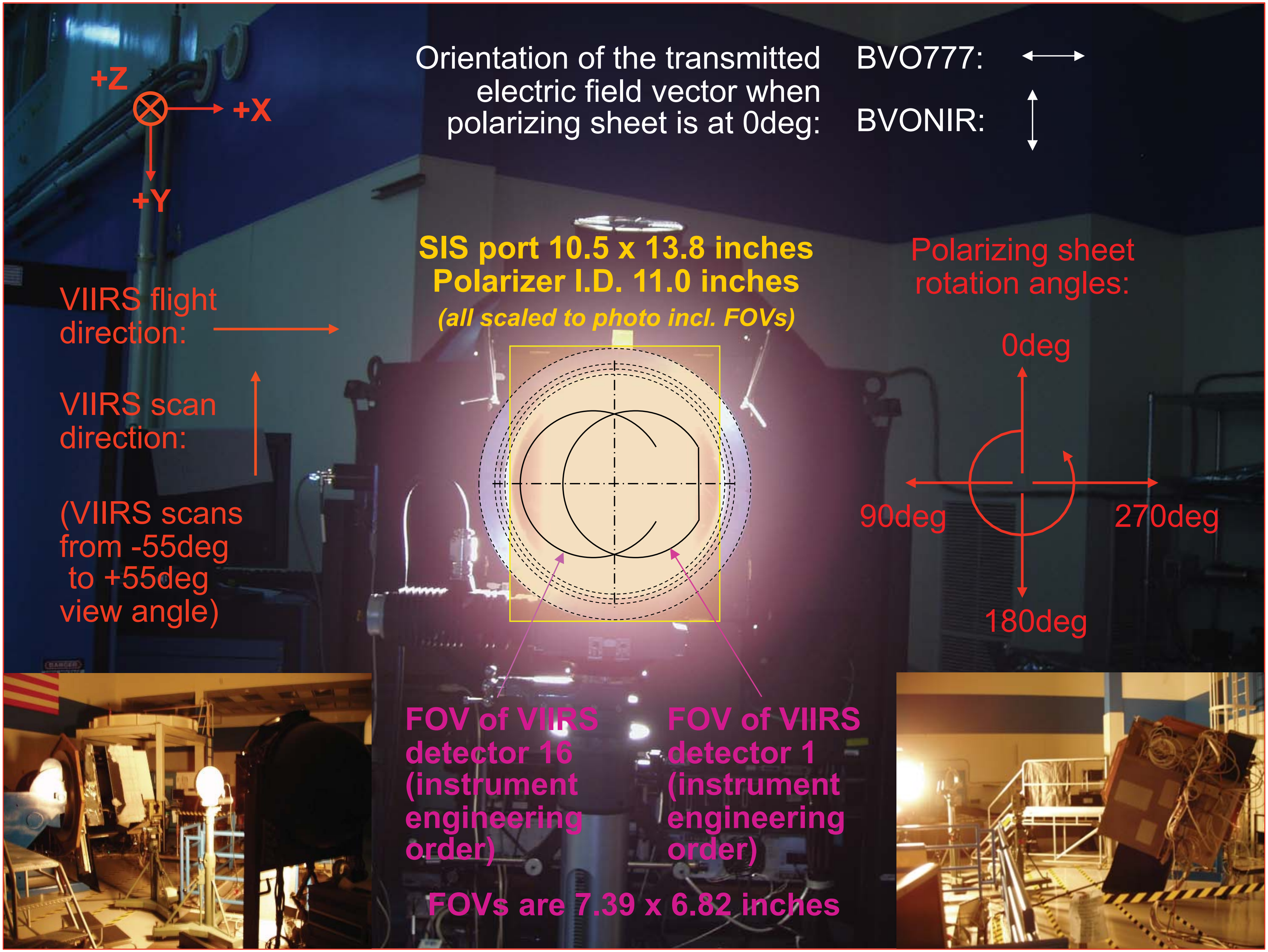


Impact of MODIS Polarization Characterization



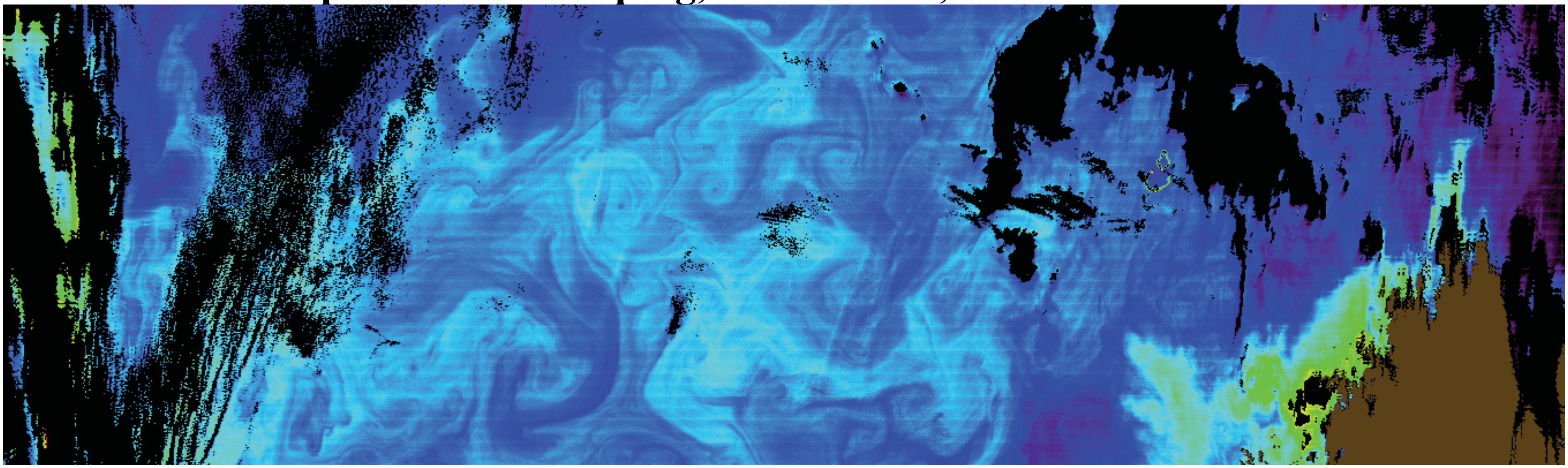
nLw ratios MODIS/SeaWiFS for northern pacific

Fig. from Meister et al., 2005, Applied Optics

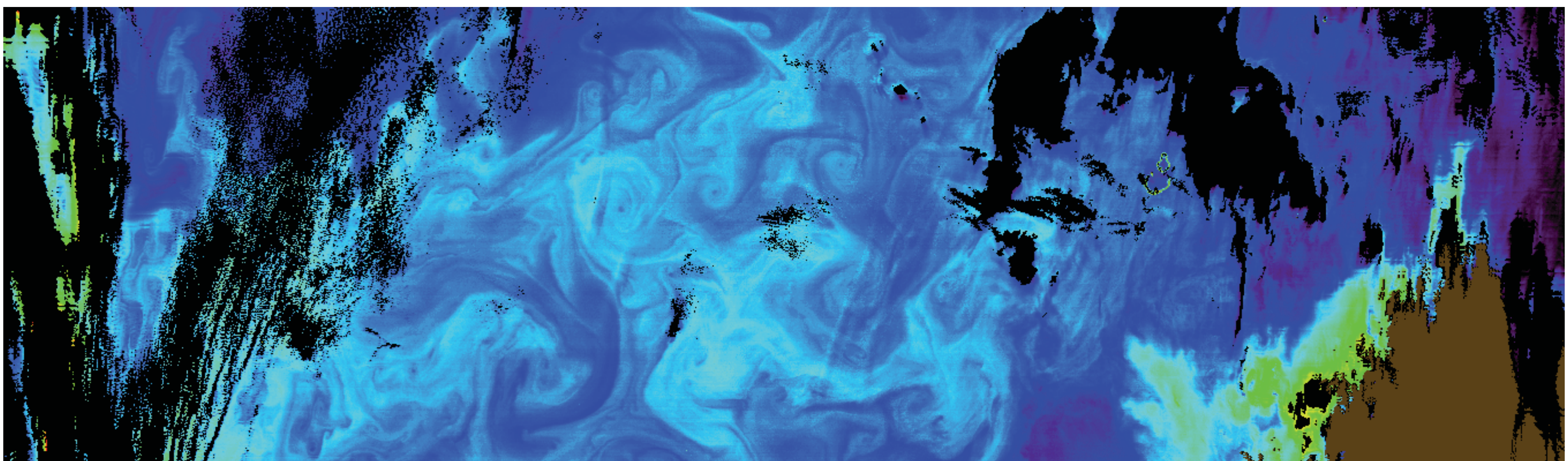


Orientation of the transmitted electric field vector when polarizing sheet is at 0deg:
BVO777:
BVONIR:
+Z
+X
+Y
SIS port 10.5 x 13.8 inches
Polarizer I.D. 11.0 inches
(all scaled to photo incl. FOVs)
Polarizing sheet rotation angles:
0deg
90deg
270deg
180deg
VIIRS flight direction:
VIIRS scan direction:
(VIIRS scans from -55deg to +55deg view angle)
FOV of VIIRS detector 16 (instrument engineering order)
FOV of VIIRS detector 1 (instrument engineering order)
FOVs are 7.39 x 6.82 inches

MODIS Aqua detector striping, nLw 412nm, before correction:

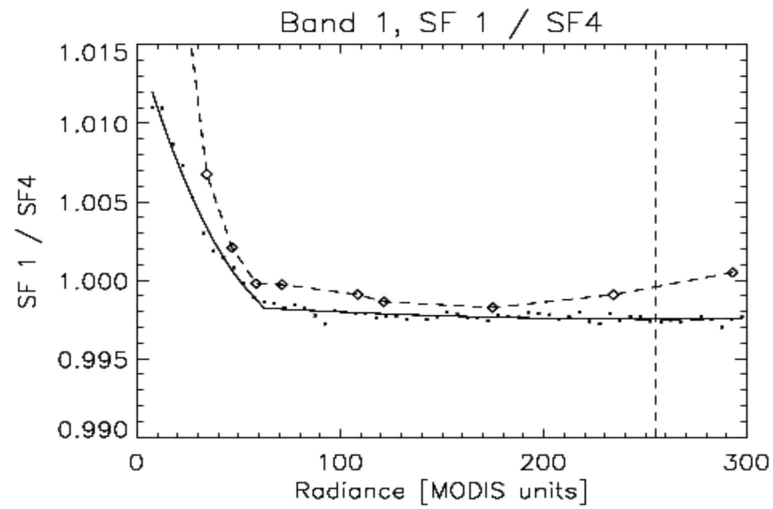


After correction:



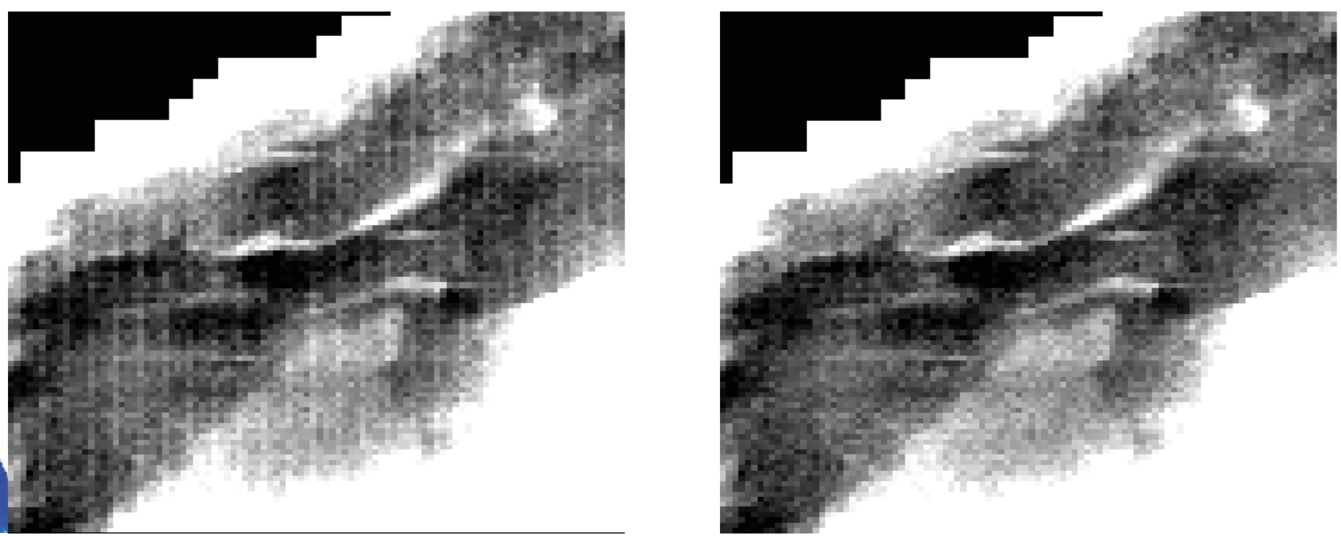
MODIS subframe striping correction

- Subframes not linear versus radiance, prelaunch and on-orbit:

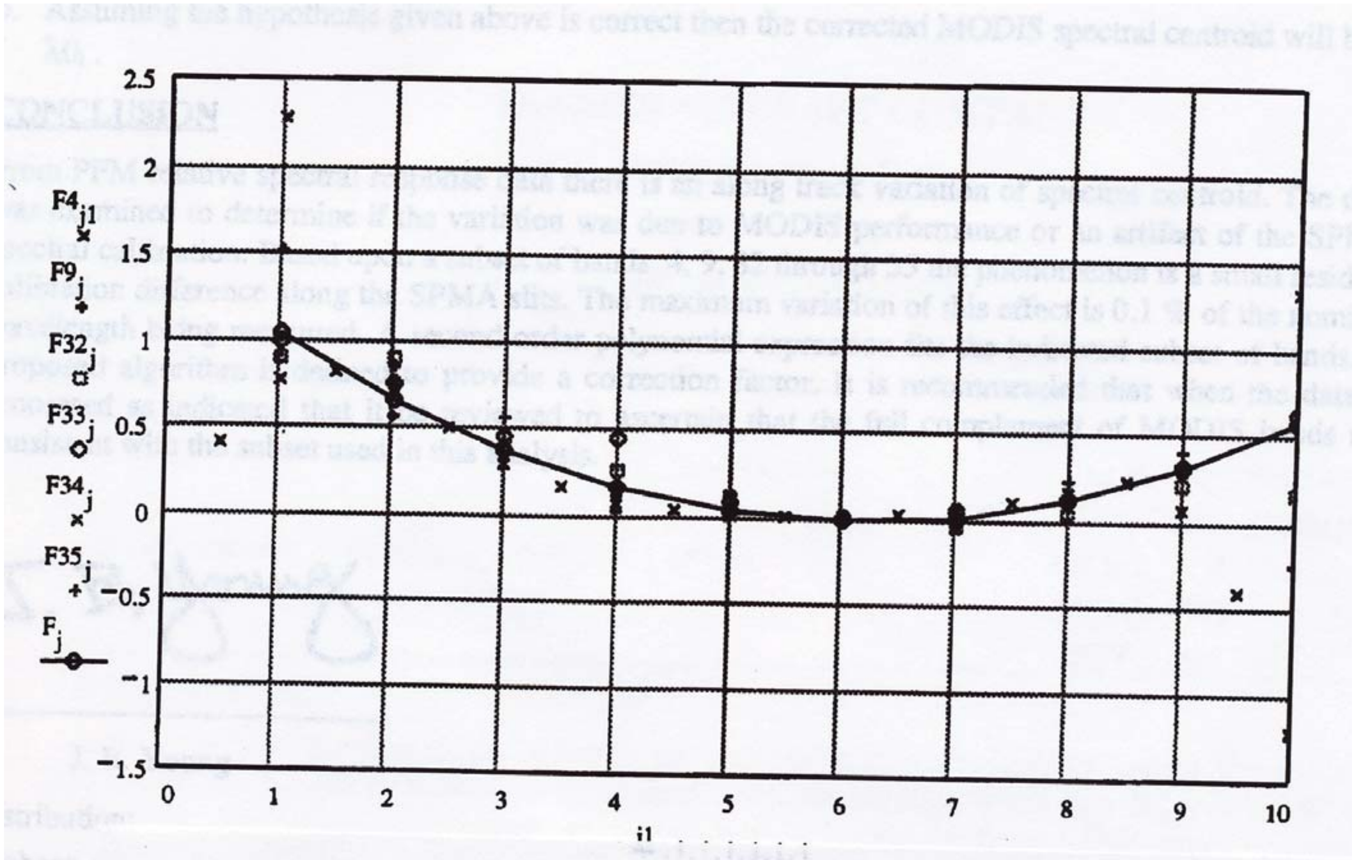


Figures from Meister et al., SPIE, 2007

- nLw 645nm (before/after correction):



MODIS Relative Spectral Response:



- Issues: detector dependence (real and smile correction), source intensity (low and not well known)

4. Sensor calibration on-orbit

- Problem: how to calibrate sensor several hundred miles away ?
- Solution 1: carry calibration sources (solar diffuser, blackbody, spectral targets)
- Solution 2: use natural sources (moon, deserts, clouds, atmospheric absorption lines)

Sensor calibration: SeaWiFS

- SeaWiFS optics based on a telescope design, with well protected half-angle mirror
- SeaWiFS optics + detectors have degraded consistently => one analytical function sufficient to model sensor degradation
- Error of individual lunar measurements (~1%) does not affect calibration accuracy of SeaWiFS

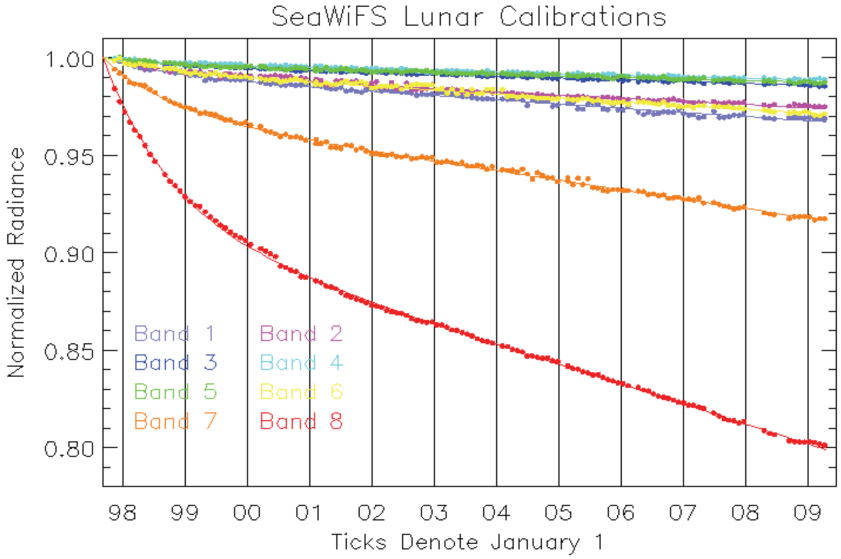
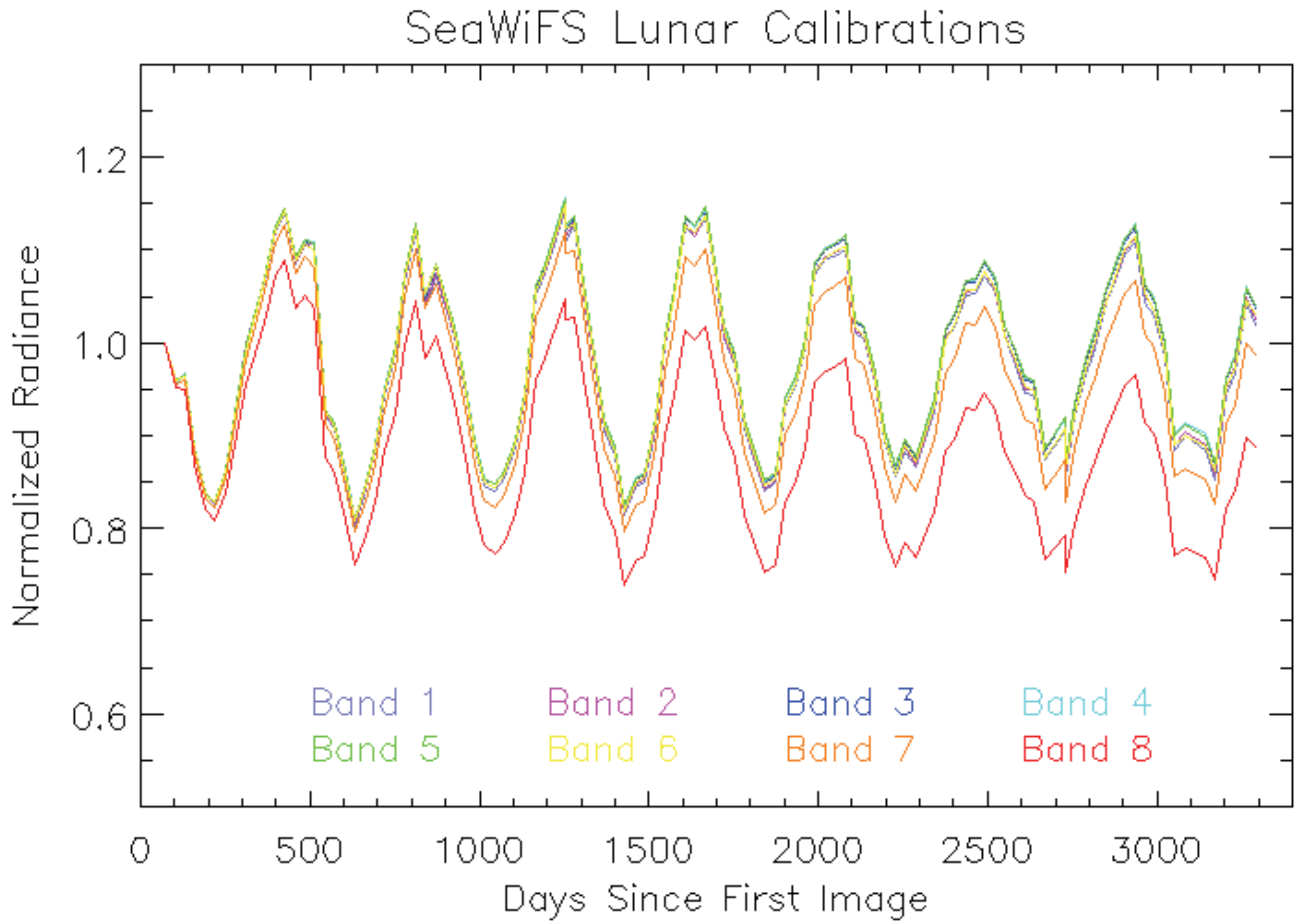


Fig. created by G. Eplee, OBPG

SeaWiFS Lunar Image

First step: Sum all lunar pixels (radiance to irradiance)

Monthly SeaWiFS lunar irradiance measurements



Lunar Calibration

- Application to space-based instruments requires using a photometric model
  - to accommodate unrestricted observation (illumination and view) geometry
- Currently, the radiometric quantity utilized is spatially-integrated irradiance
  - improved signal-to-noise through summation of pixels
  - enhanced freedom in model development
- USGS lunar irradiance model was built from database of spatially resolved images of the Moon acquired by the RObotic Lunar Observatory (ROLO)
  - 6+ years in operation, >85,000 individual Moon images (many $\times 10^5$ star images)
  - twin telescopes, 32 wavelength bands, 350–2450 nm

USGS campus
Flagstaff, AZ

Using the Moon — Lunar Irradiance Model

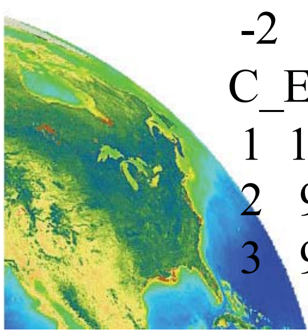
- described in: H.H. Kieffer and T.C. Stone "*The Spectral Irradiance of the Moon*", Astronomical Journal 129, 2887-2901 (2005 June)
- empirically-derived analytic function in the geometric variables of phase and libration, for disk-equivalent reflectance ***A***:

$$\ln A_k = \sum_{i=0}^{3} a_{ik} g^i + \sum_{j=1}^{3} b_{jk} \Phi^{2j-1} + c_1\theta + c_2\phi + c_3\Phi\theta + c_4\Phi\phi$$
$$+ d_{1k} e^{-g/p_1} + d_{2k} e^{-g/p_2} + d_{3k} \cos((g - p_3)/p_4)$$

g = phase angle
θ = observer selenographic latitude
ϕ = observer selenographic longitude
Φ = selenographic longitude of the Sun

Example of ROLO input file: Sirad

```
SECTION = Observation Info
Instrument = SeaWiFS
User = Gene Eplee
Process = multimoon
Version = 2002apr03
Run_Time = 2005Jan05 14:00:00
BEGIN_FREE
    This is ROLO exchange SCT MOF Irradiance  file.
    Prelaunch calibration with best time correction applied.
    The irradiances are integrated over pixels above 1% of maximum.
Col_0 = Obs_index   Col_1+ = Irradiance in bands
Units are: uW / m^2 / nm
Format = (i2,8f8.4)
 -1   1        2        3        4        5        6        7       8
 -2   412.     443.     490.     510.     555.     670.     765.    865.
C_END
 1  10.23306  12.39135  14.35401  14.27165  15.17209  14.61134  12.98814  10.44421
 2   9.78679  11.85517  13.73272  13.66103  14.54734  14.01934  12.44731  10.01145
 3   9.91586  12.00497  13.88532  13.80062  14.66388  14.08408  12.49814  10.04028
```



Example of ROLO input file: Sgeom

SECTION = Observation Info
Instrument = SeaWiFS
User = Gene Eplee
Process = multimoon
Version = 2002apr03
Run_Time = 2005Jan05 14:00:00
BEGIN_FREE
    This is ROLO exchange SCT MOF Geometry file.
    The Moon_Y_Size is defined by the 1% of maximum pixels.
Col_0 = Obs_index   Col_1 = Image_time   Col_2,3,4 = Spacecraft_X,Y,Z
Col_6 = Moon_Y_Size <mrad>   [Col_7=Miss_Frac   Col_8=Clip_angle]
Format = (i2,a19,3f7.1,f6.3.f7.4,f4.1)
C_END

1	1997-11-14T22:50:09	4122.0	5570.3	1480.1	31.931	0.0000	0.0
2	1997-12-14T12:18:26	945.1	6757.2	1912.9	31.517	0.0000	0.0
3	1998-01-13T01:44:52	-2527.0	6418.3	1631.4	30.775	0.0000	0.0

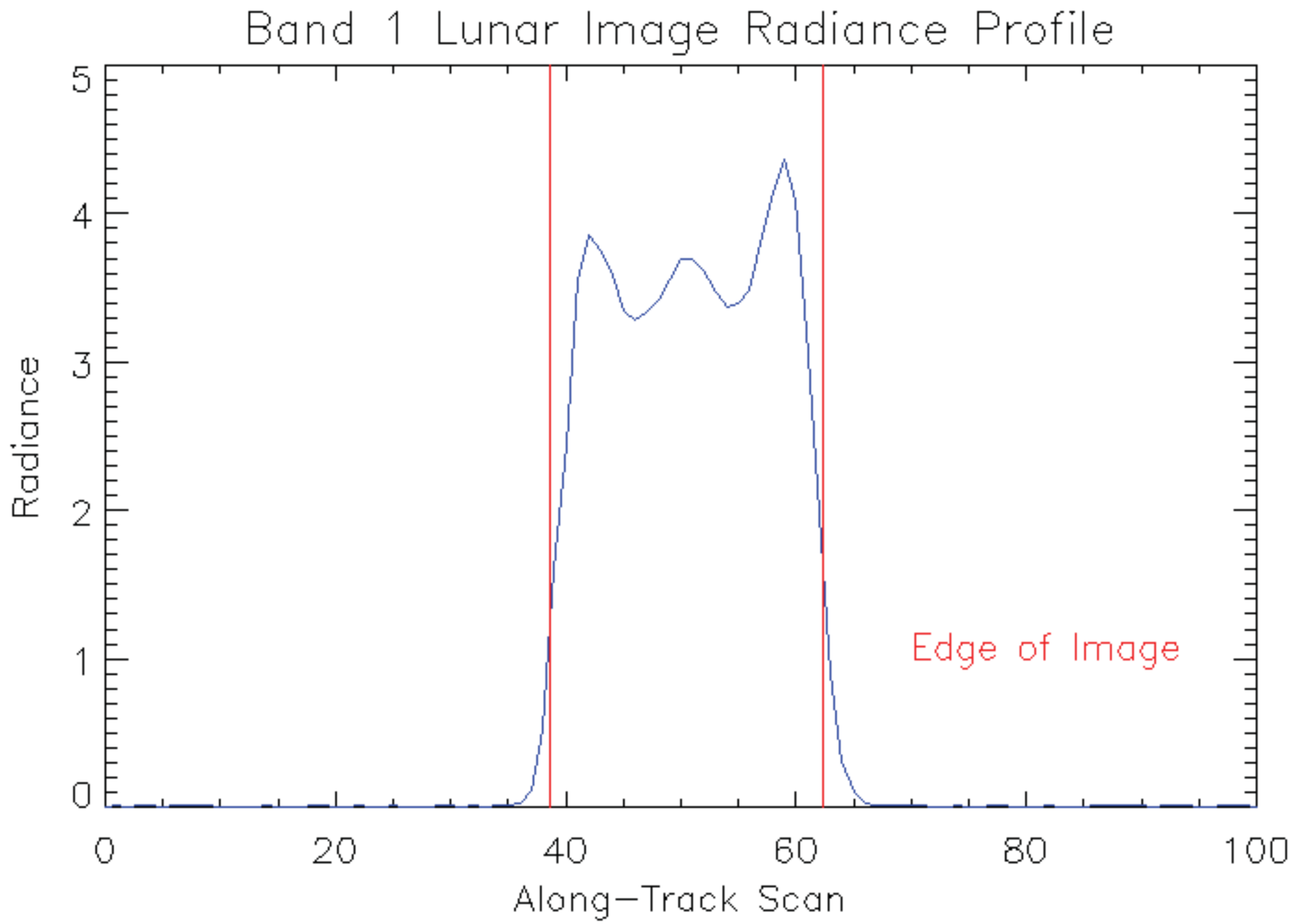
Example of ROLO output file: Lgeom

```
SECTION = Observation info             ! ---------------------- Begin a section
Instrument = SeaWiFS                   ! Instrument makeing the observation
User = Gene Eplee                      ! Person submitting the calibration request
Source_Date = 2005Jan05 14:00:00       ! Run Date/Time of primary input file
Process = 2004jun24T12:14 & multimoon ! Name of process that generated this file
Version = 2005jul24                    ! Processing version
Run_Time = 2006Mar21 08:52:49          ! Local Date/Time of these calculations
BEGIN_FREE     ! Begins a free-form section describing the table section
    This is a ROLO exchange for:   LCT MOF geometry
GUIDE to columns below:
Col          Key   units  Description
  0          Row       -  Observation Count
  1  TDB-2451545     day  Dynamical barycentric Days -2451545.
  2       SunLon  degree  Selenographic longitude of the Sun
  3       SunLat  degree  Selenographic latitude of the Sun
  4       SC_Lon  degree  Selenographic longitude of spacecraft
  5       SC_Lat  degree  Selenographic latitude of spacecraft
  6     SC_Dist.      km  Distance of spacecraft from center of Moon
  7   Sun_M_Dist      AU  Heliocentric range of the Moon
  8      DistFac       -  Factor to correct irradiance to standard distances
  9     PhaseAng  degree  Signed phase angle
 10    Moon_mrad    mrad  Angular Diameter of the Moon from SC
 11     Axis_Ang  degree  Position Angle of lunar axis, ccw from N
Format = (I3,1x,f13.6,1x,f8.2,1x,f5.2,1x,f6.2,1x,f6.2,1x,f8.1,1x,F9.7,1x,f9.6,1x,F8.3,1x,f8.4,1x,f8.3)
Row   TDB-2451545  SunLon SunLat SC_Lon SC_Lat SC_Dist. Sun_M_Dist  DistFac PhaseAng Moon_mrad Axis_Ang
C_END  End of label section
  1   -777.547791    -0.40  1.42   4.46   6.16 361263.7 0.9915820  0.868439    6.780   9.6185  -13.242
  2   -747.986450     0.03  1.53   5.27   6.31 371926.9 0.9867886  0.911584    7.085   9.3427   -0.551
  3   -718.426453     0.64  1.18   4.93   4.61 383036.8 0.9860848  0.965479    5.485   9.0717   11.964
```

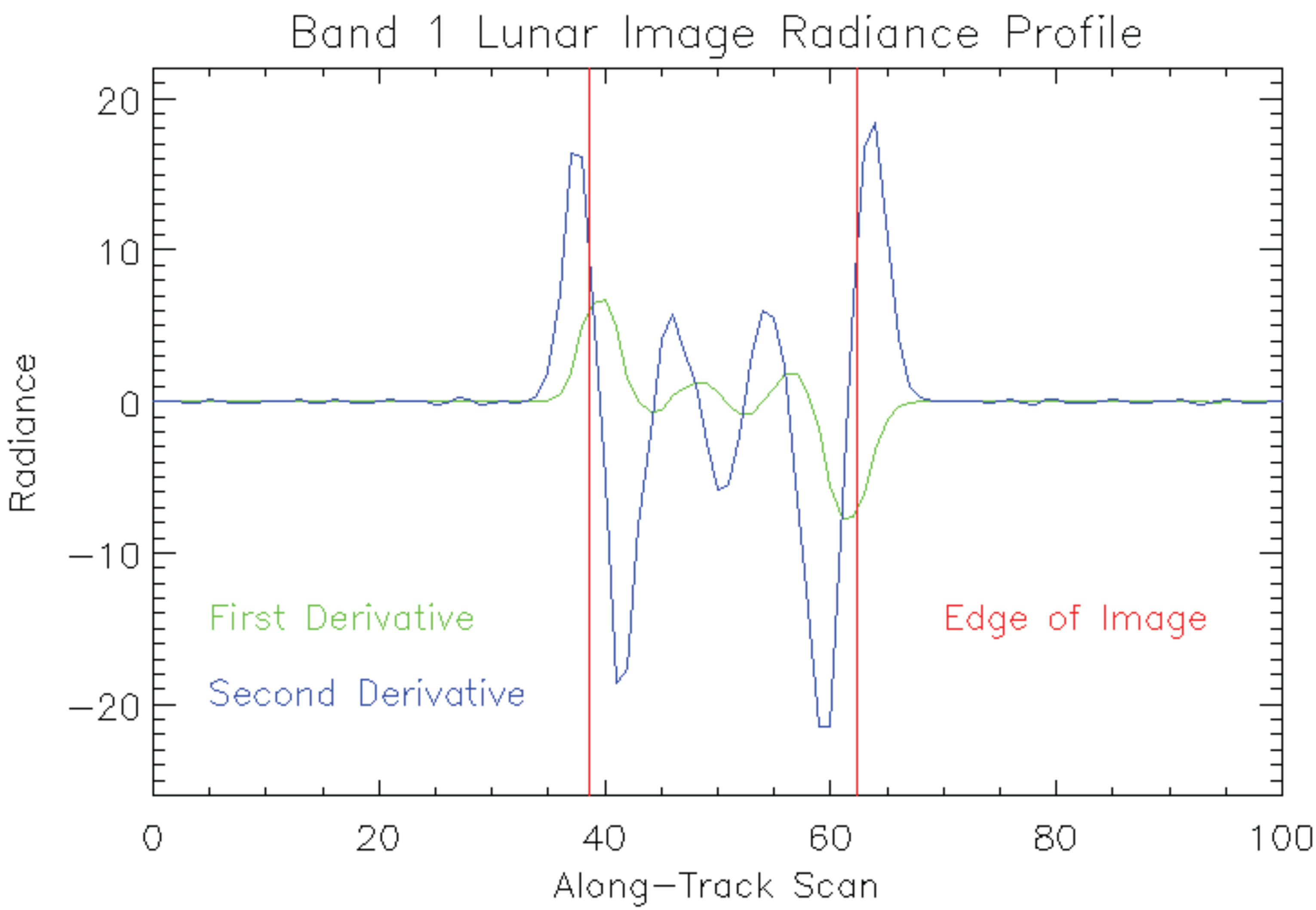
Example of ROLO output file: Lirad

```
SECTION = Observation info          ! ---------------------- Begin a section
Instrument = SeaWiFS                ! Instrument makeing the observation
User = Gene Eplee                   ! Person submitting the calibration request
Process = 2004jun24T12:14 & multimoon ! Name of process that generated this file
Version = 2005jul24                 ! Processing version
Run_Time = 2006Mar21 08:52:49       ! Local Date/Time of these calculations
Lunar_model = 311g = [coeff=r311g adjust=r311g05 ]
 !! Corrections:
BEGIN_FREE     ! Begins a free-form section describing the table section
   This is a ROLO exchange for:   LCT MOF Irradiance
      See matching  Geometry  file for comments
GUIDE to columns below:
Headers: Row-1=band
      Row-2=Nominal wavelength
      Row-3=Effective wavelength for the Moon
Table  : Col_0=count   Col_1=oversample factor.  Remaining columns are
      % disagreement, with a row for each observation
      (Spacecraft_Irradiance/ROLO_Irradiance -1.) in percent.
Format = (i3,f8.4,12f8.3)
 -1              1       2       3       4       5       6       7       8
 -2           412.    443.    490.    510.    555.    670.    765.    865.
 -3         414.50  444.71  491.91  510.20  556.40  668.37  766.85  863.61
C_END  End of label section
  1  3.3198   0.006   1.245   4.170   3.263   4.037   5.621   8.087   4.590
  2  3.3734   0.047   1.290   4.180   3.314   4.239   5.835   8.138   4.649
  3  3.3924  -0.991   0.331   3.235   2.353   3.158   4.714   7.136   3.635
```

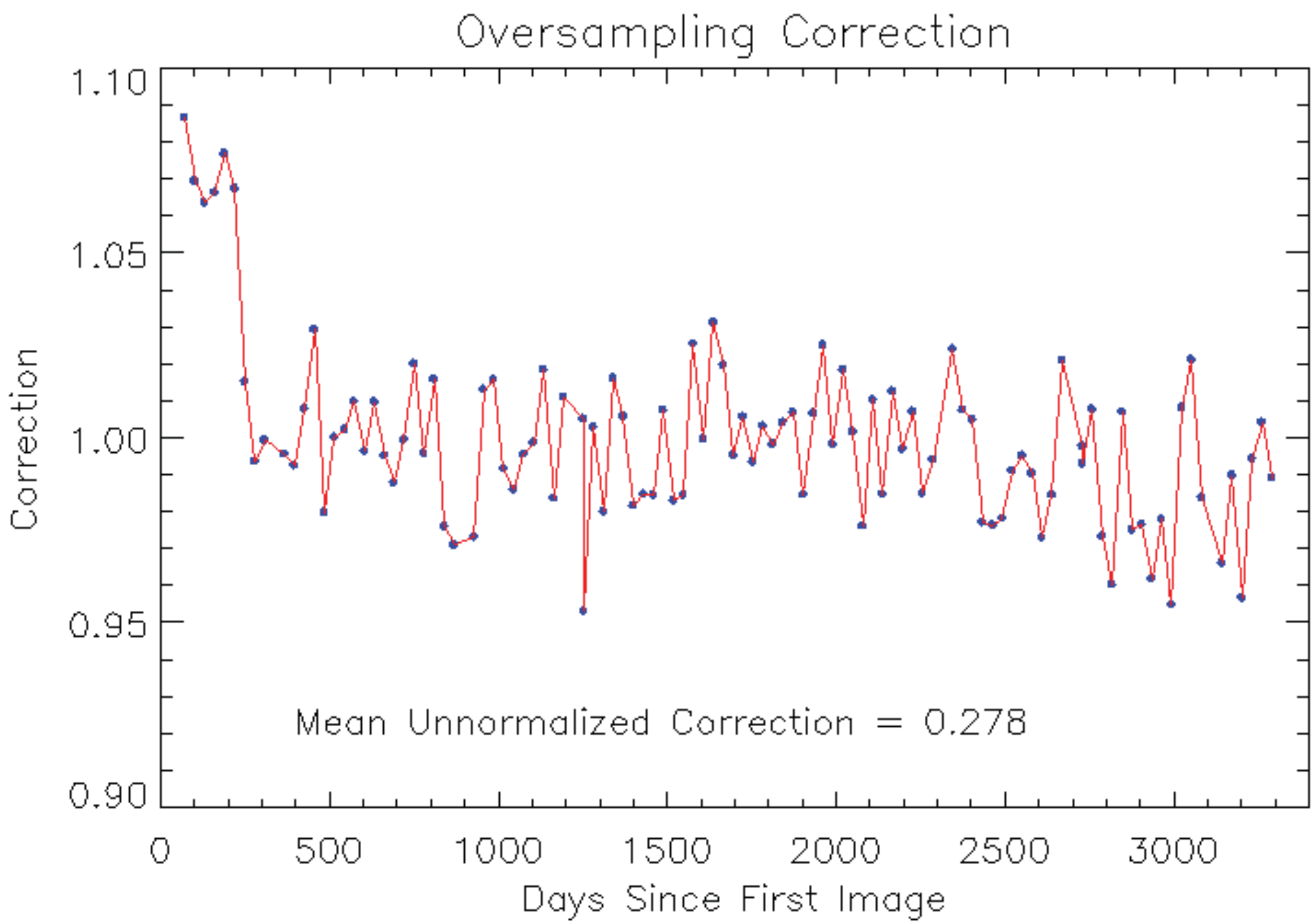
How to determine the apparent size of the moon:



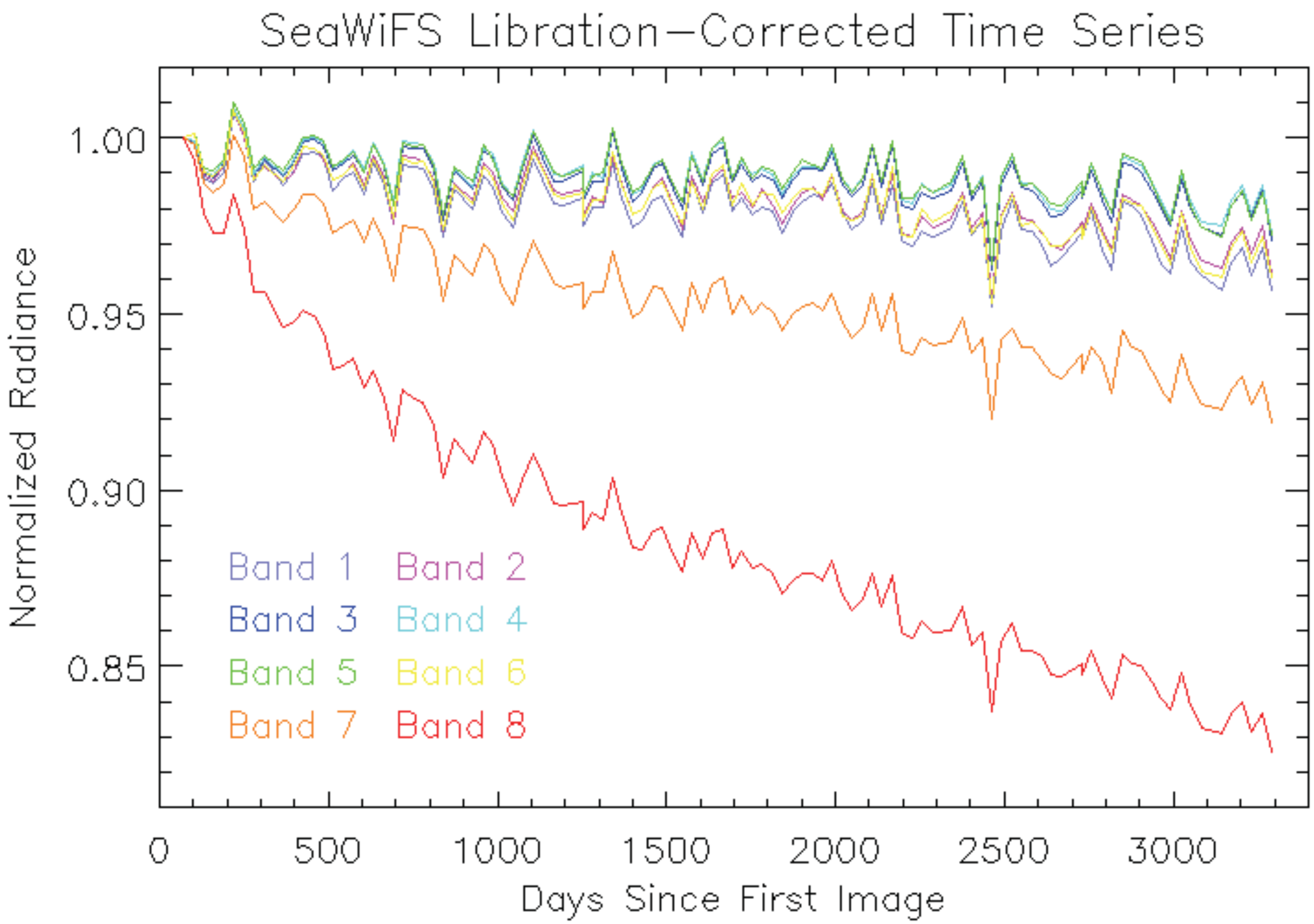
How to determine the apparent size of the moon:



Apparent size of the moon as a function of time:



Lunar irradiances after ROLO and oversampling correction:



SeaWiFS temperature correction

- SeaWiFS band 8 calibration temperature dependence on-orbit differs from prelaunch measurements
- Successfully corrected using lunar data
- Prelaunch Tvac different from on-orbit temperature environment
- Additional change since 2005 could be related to SeaWiFS orbit drift

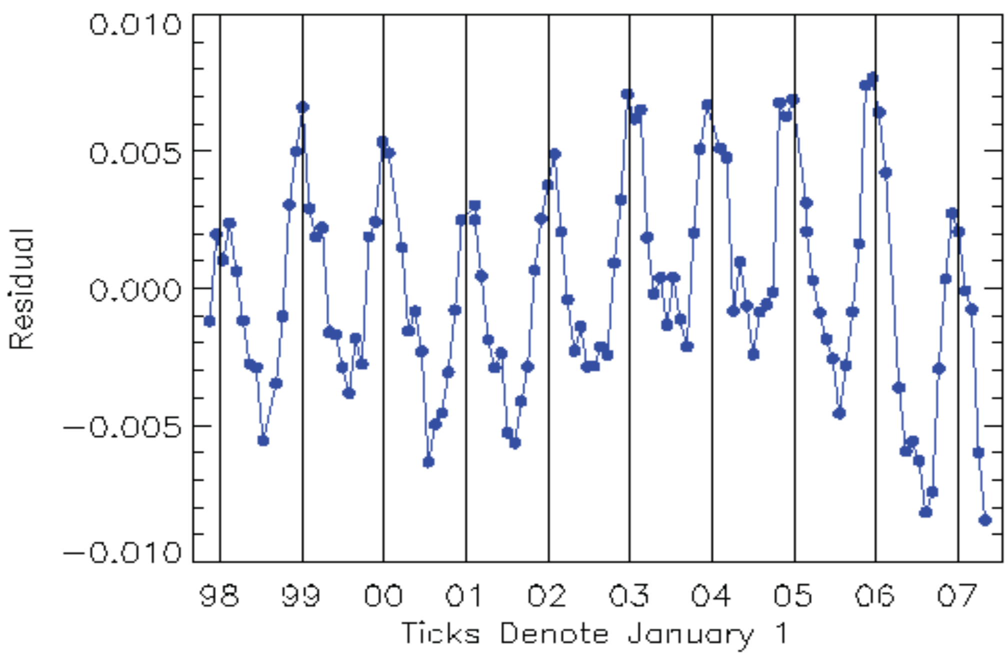
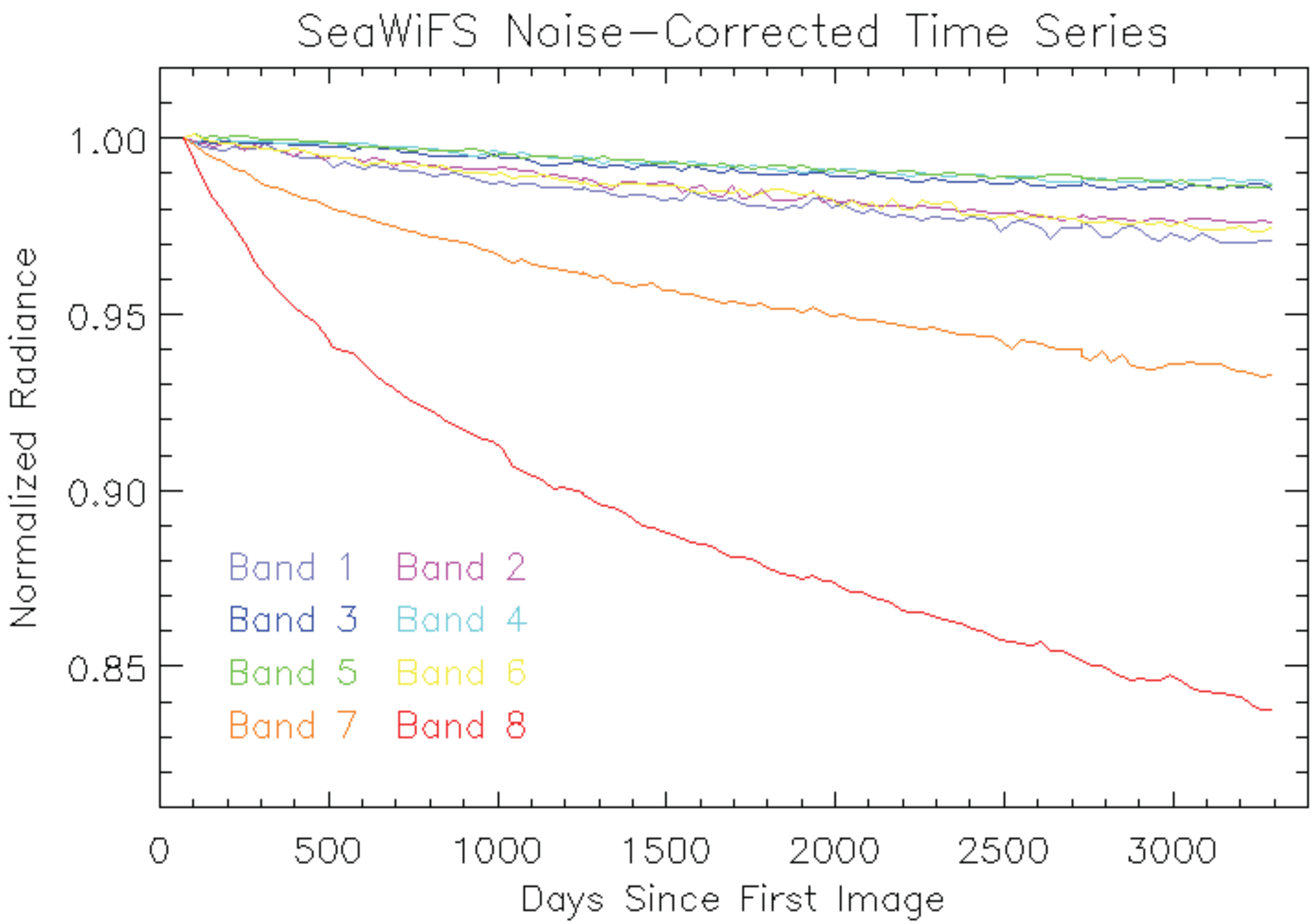


Fig. from Eplee et al., SPIE, 2007

Lunar irradiances after noise correction:

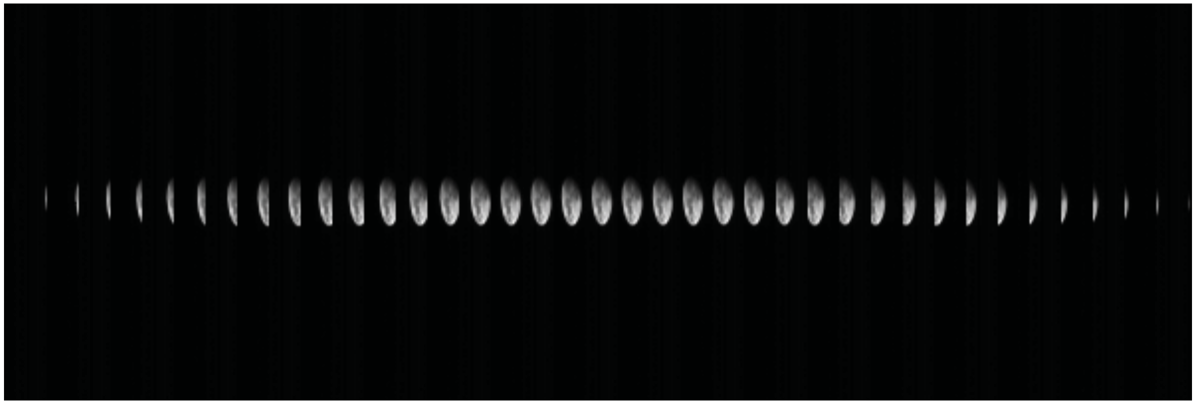


VIIRS On-Orbit Calibration:

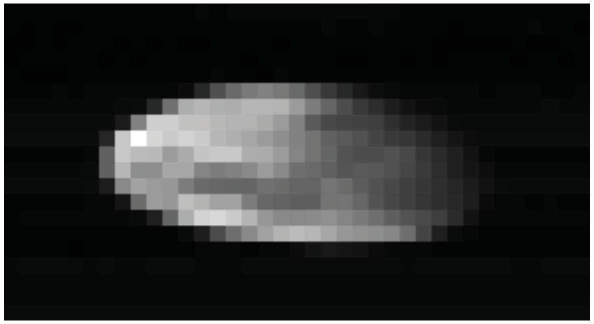
Lunar Time Series
Solar Time Series
Comparison

Slides provided by G. Eplee, SAIC

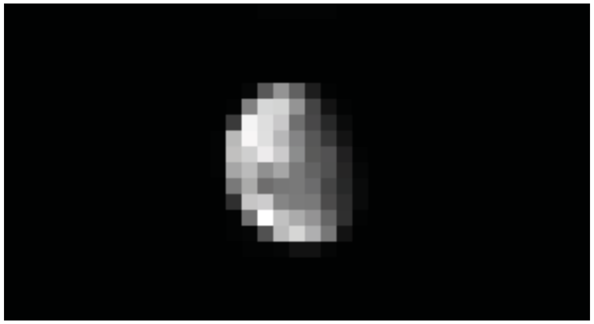
Lunar Calibration Data



M4 Lunar Calibration Image Sequence



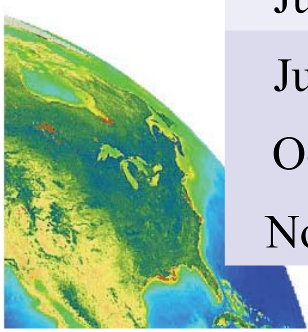
M4 Lunar Image
Unaggregated



M6 Lunar Image
Aggregated

Lunar Calibrations

Cal Date	Cal Type	Bands	Gains	Phase
Jan 4	Roll	M3-M7	High, Low	-55.4
Jan 5	Serendipitous	M1-M3	High, Low	-44.5
Feb 3	Roll	M6,M8-M11	High, Low	-56.2
Feb 3	Roll	M1-M5,M7	High, Low	-55.4
Mar 4	Serendipitous	M3,M5-M11	High, Low	-48.9
Apr 2	Roll/Sector Rot	M1-M11	High	-51.2
May 2	Roll/Sector Rot	M1-M11	High	-50.9
May 31	Roll/Sector Rot	M1-M11	High	-53.0
Jun 28	Serendipitous	M8, M9, M11	High, Low	-66.7
Jun 28	Serendipitous	M5-M7,M10	High , Low	-65.7
Jun 29	Serendipitous	M1-M4	High, Low	-64.8
Oct 25	Roll/Sector Rot	M1-M11	High	-51.0
Nov 23	Roll/Sector Rot	M1-M11	High	-50.7



Lunar Data Analysis

Analysis methodology:

- Calibrate lunar radiances, compute disk-integrated lunar radiances
- Use IFOV to convert radiances to irradiances: rectangular pixels
- Band aggregation is accounted for by oversampling correction
- ROLO Model is used to compute lunar residual time series

Observations:

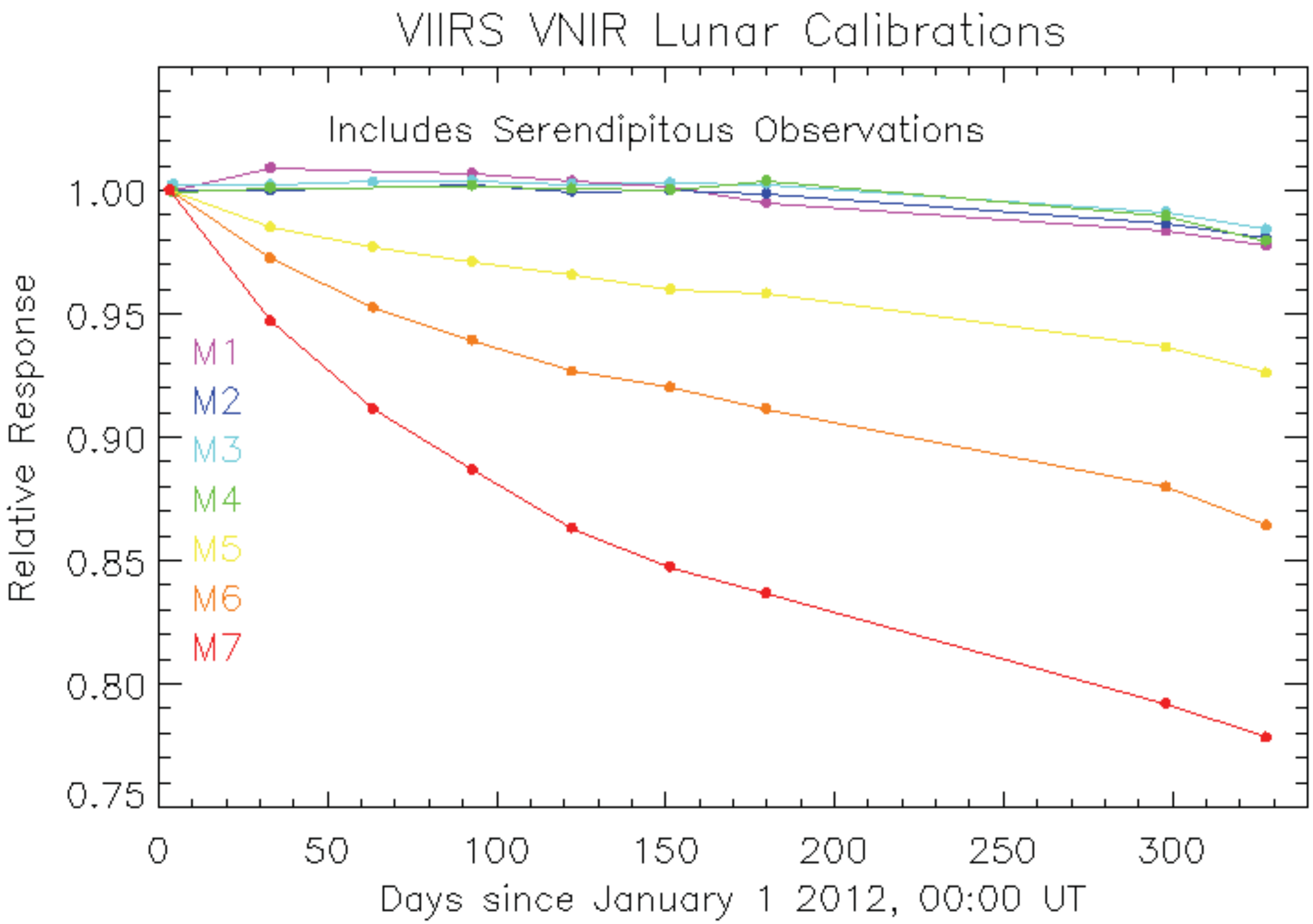
- Radiometric response degradation is strongest in the red (Bands M5-M7)
- Degradation in blue (Band M1) from “yellowing” of optics is observed

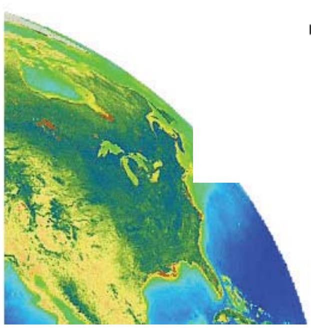
Concerns:

- Limited amount of low-gain calibration data
- Is observational noise low enough to allow a detector-specific calibration?

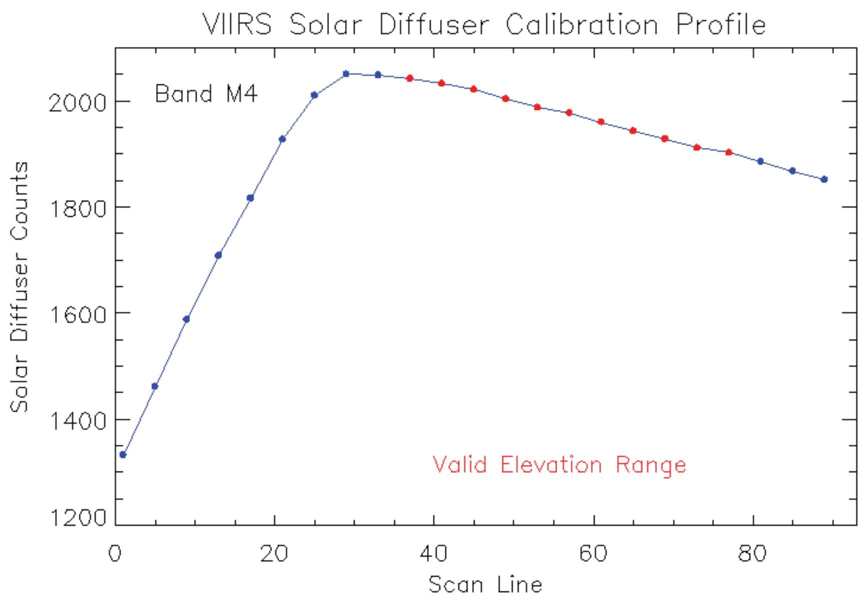
The following plots show the High Gain, Mirror Side 0 data.

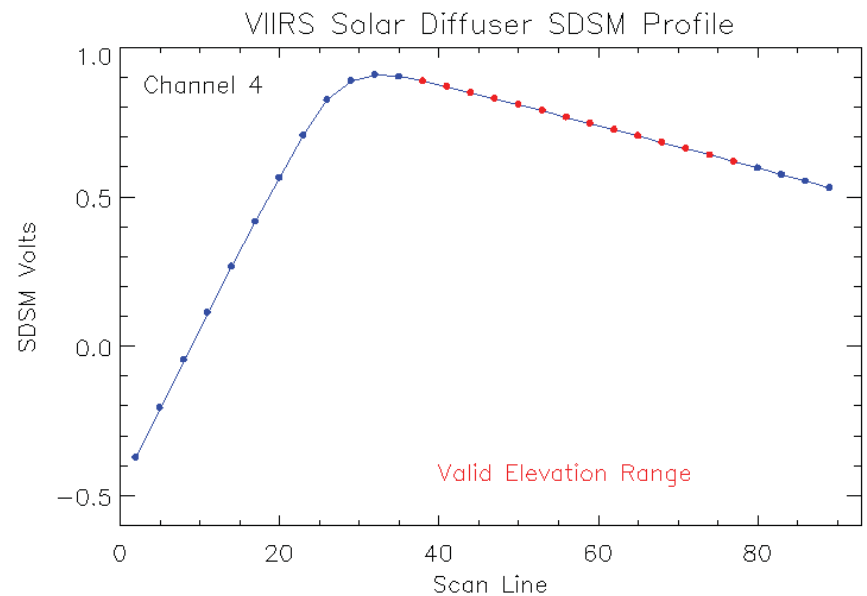
Lunar Time Series





Solar Calibration Data





Solar diffuser provides spatially homogeneous light, opposite of lunar image

Solar Diffuser Data Analysis

Analysis methodology:

- F-factor time series starting on January 2 are used for calibration
- SDSM-derived BRDF corrections are applied to F-factors
- Corrected F-factors are smoothed, then interpolated to a daily time basis
- Striping corrections are applied to corrected F-factors
- F-factors are interpolated between daily LUT entries in Ocean PEATE code

Observations:

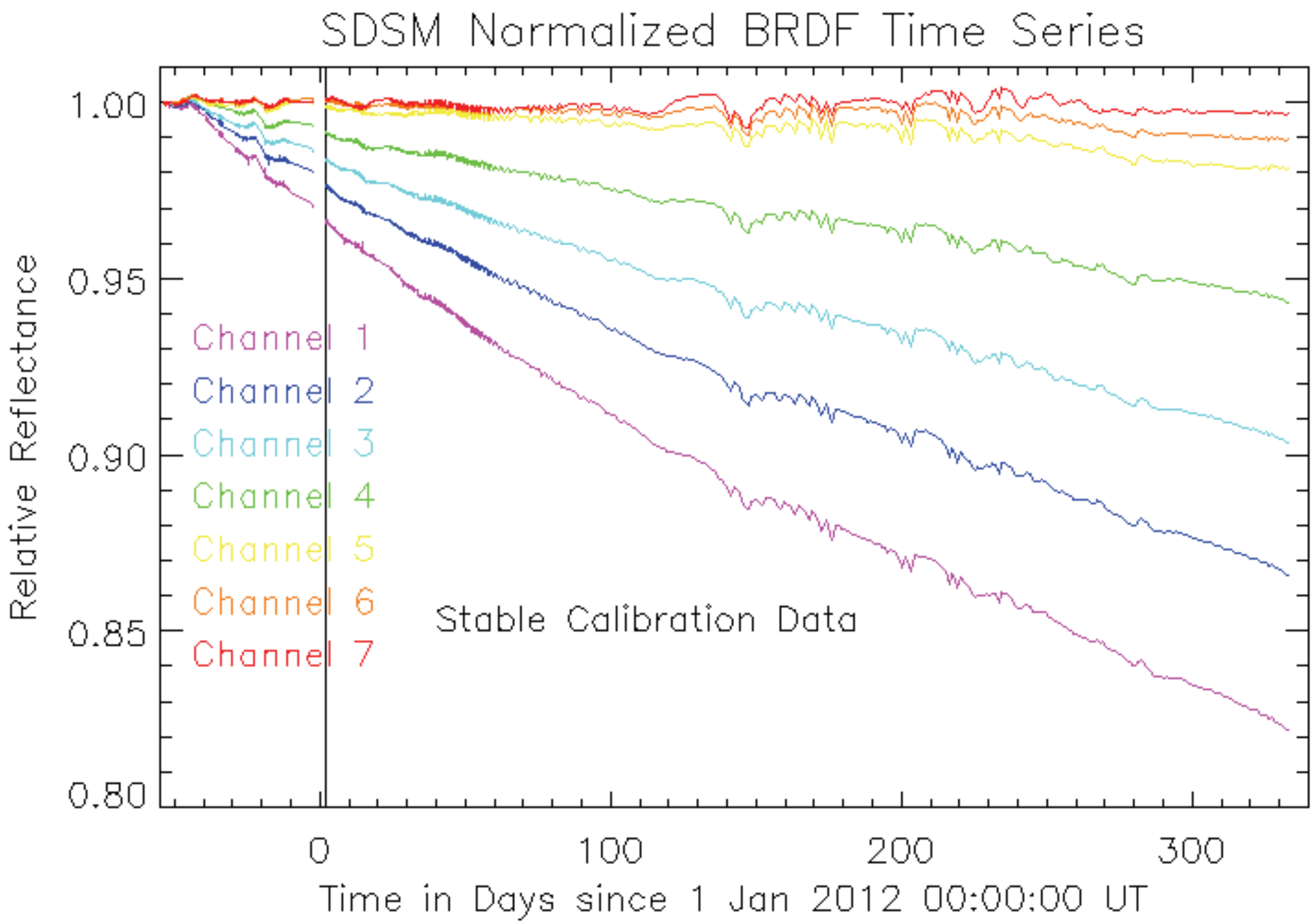
- Radiometric response degradation is strongest in the red, ~zero in the blue
- Size of uncorrected F-factors for bands M1-M3 is ~ size of BRDF corrections

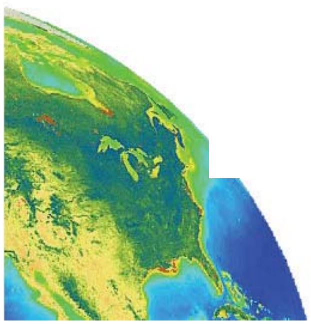
Concerns:

- NIR Degradation Anomaly for bands M5-M7
- BRDF Corrections for bands M1-M3
- Normalization of F-factor on January 2, at start of stable operations

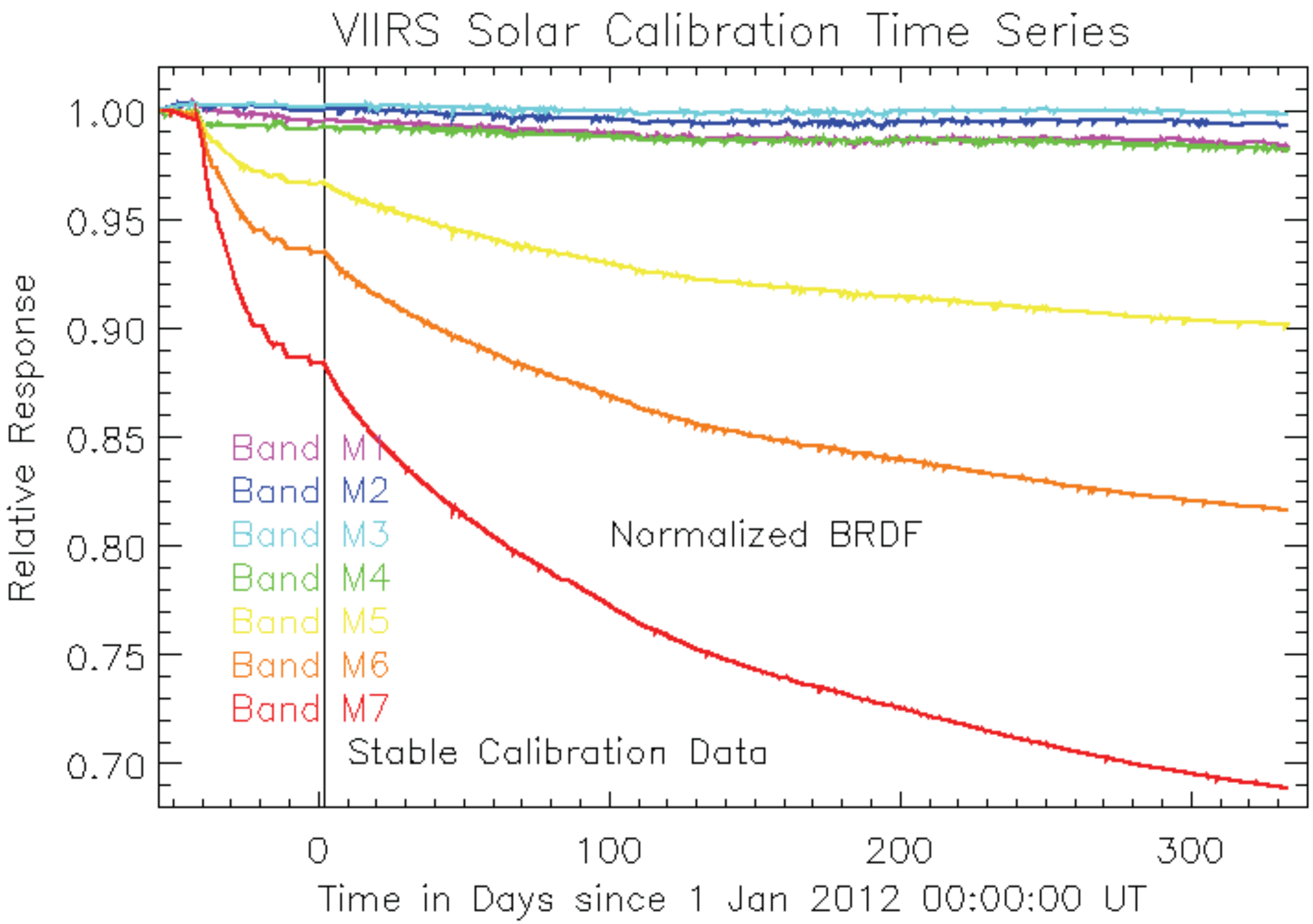
The following plots show the High Gain, Mirror Side 0 data.

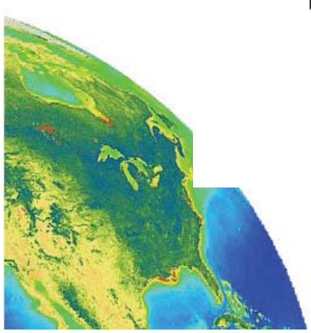
SDSM Time Series



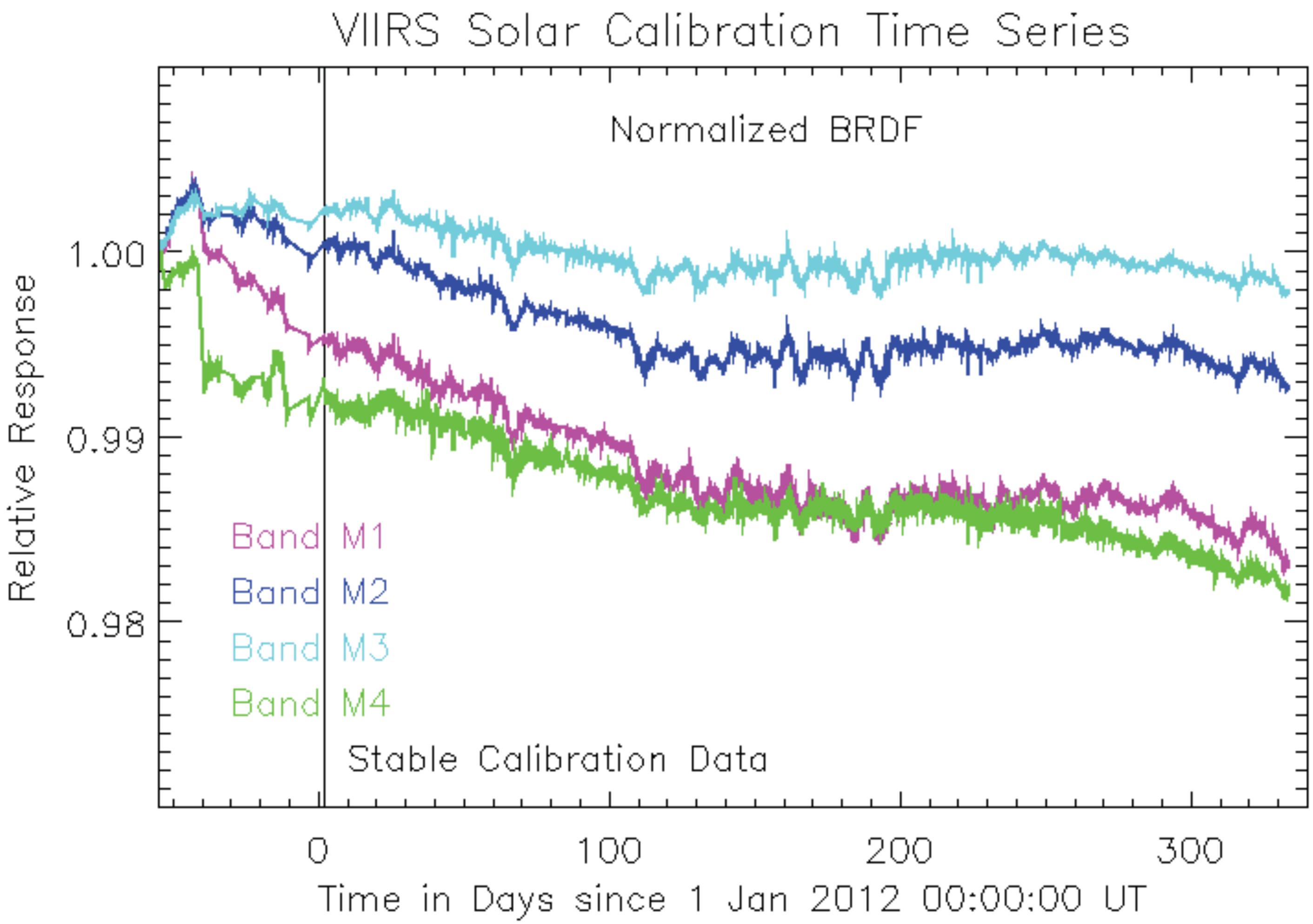


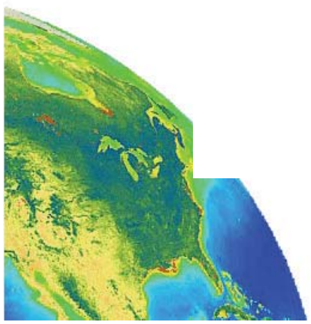
Solar Time Series





Solar Time Series





Solar / Lunar Cal Comparison

Comparison methodology:

- Lunar and solar observations are at the same AOI on the half-angle mirror
- Determine F-factor at time of 1st lunar calibration
- Use lunar trend for each band to predict F-factor at the of subsequent calibrations
- Comparison of predicted lunar-derived F-factors with solar-derived F-factors

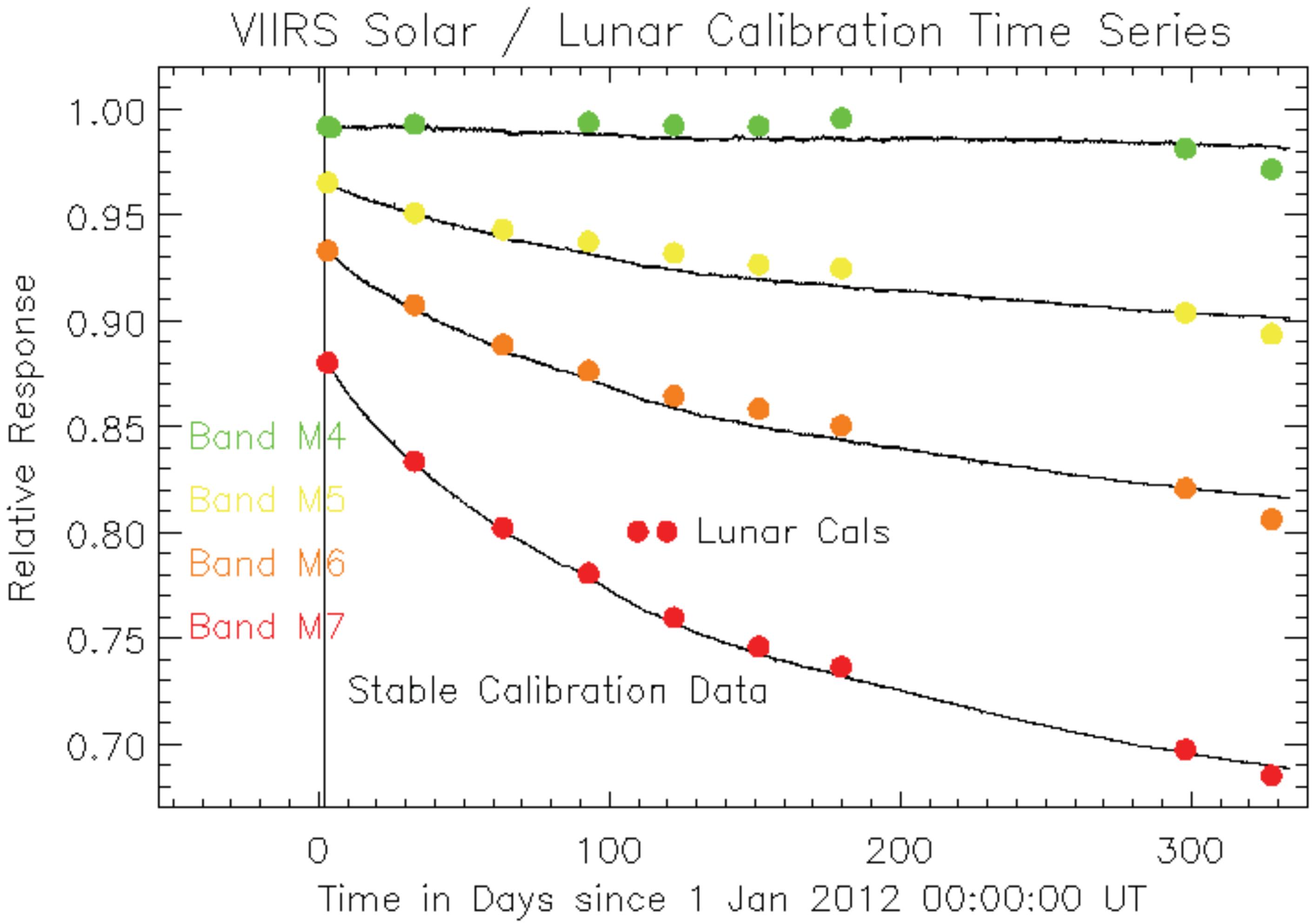
Observations:

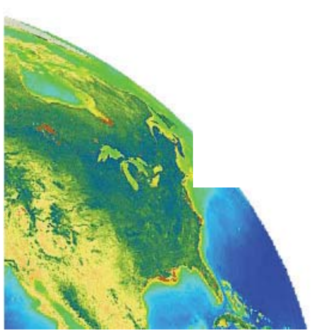
- Lunar trends imply a BRDF overcorrection which decreases with wavelength

Concerns:

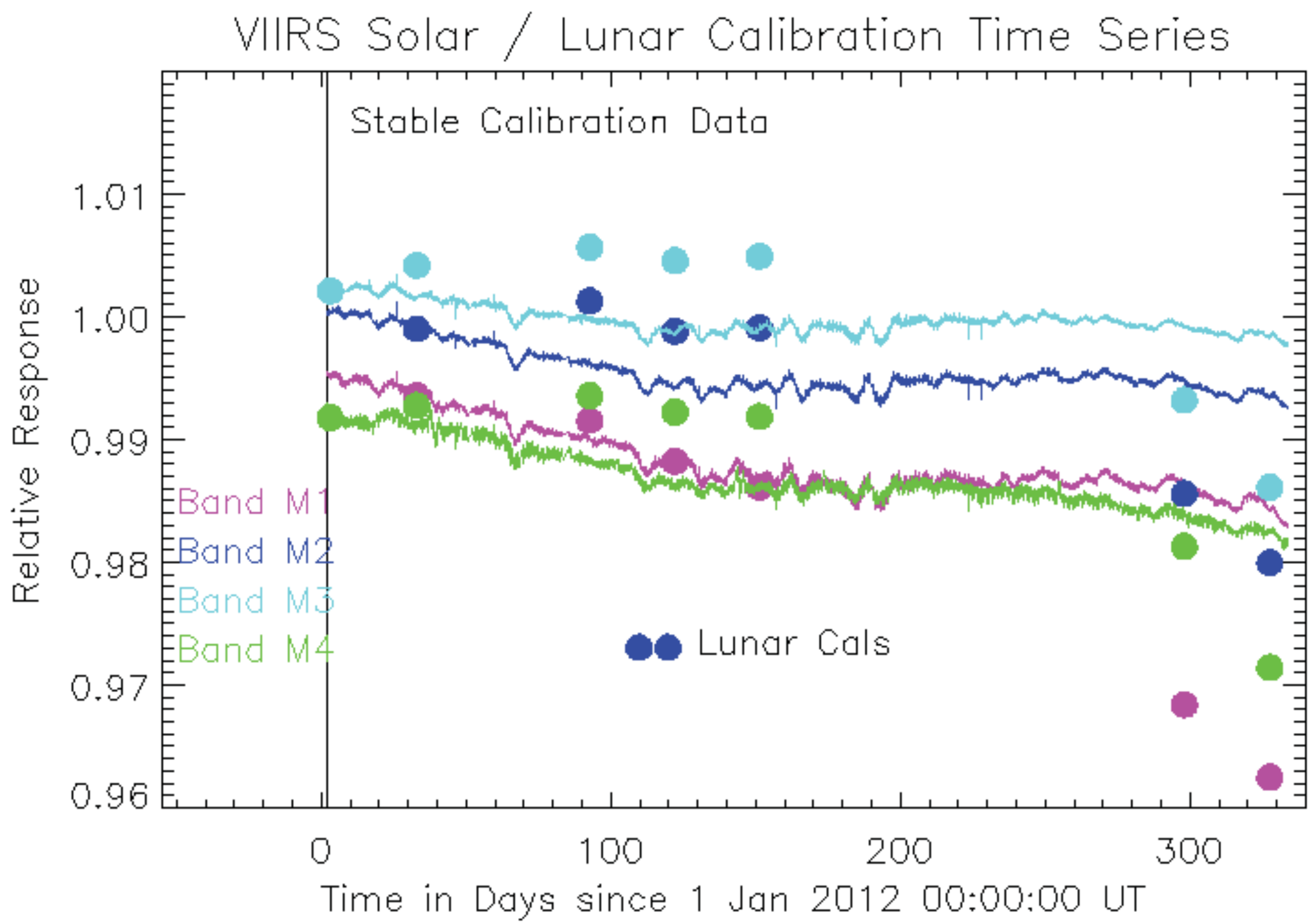
- Observational scatter in the lunar calibrations – at least a year of observations is required to assess the size of the scatter.
- Alternative F-factors are just now becoming practical

Solar / Lunar Comparison





Solar / Lunar Comparison

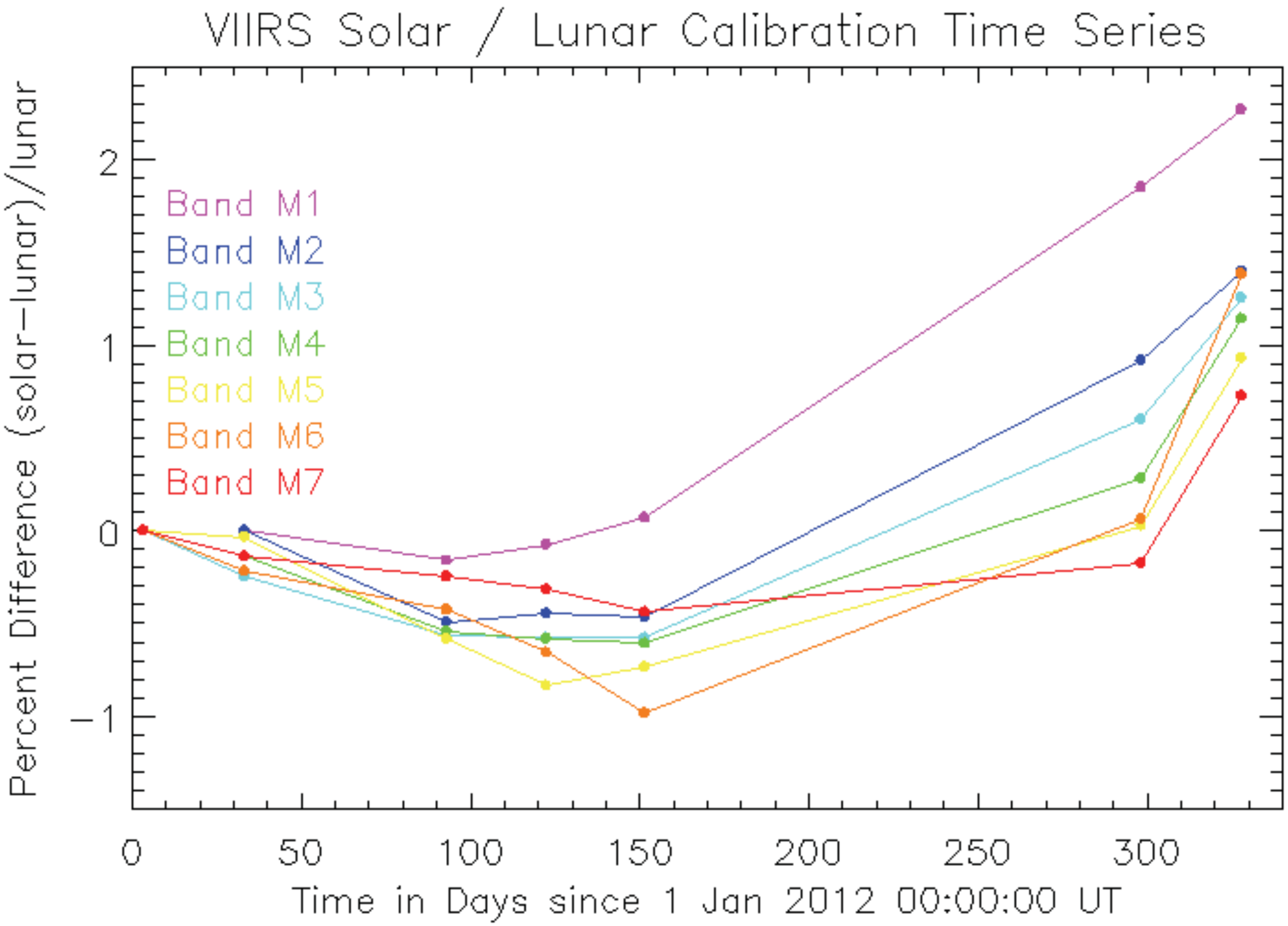


Conclusions:

- Ocean color requires relative accuracy better than 0.5% (goal for future sensors: 0.2%)
- This goal requires accuracy focused approach for
  1) sensor design and specifications
  2) prelaunch sensor characterization
  3) on-orbit monitoring
- NASA OBPG believes lunar measurements are most accurate for long term tending (depends on sensor design)
- In the past, each sensor had its own issues with regard to calibration/characterization, I expect that to continue for future sensors

Backup slides

Solar / Lunar Comparison



2. Sensor requirements: Summary

Sensor requirements should

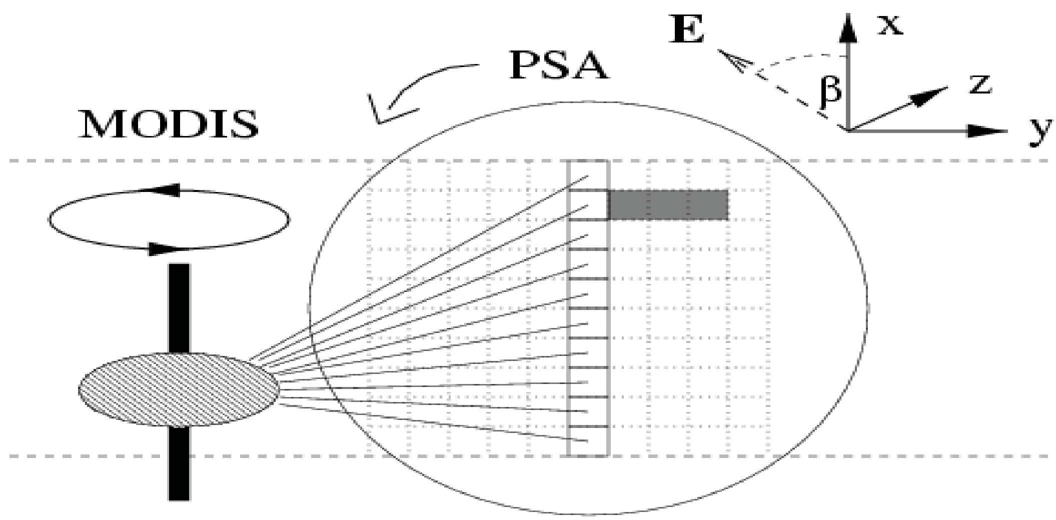
1) ensure quality of data product

2) be achievable at reasonable cost

3) testable

MODIS Polarization Characterization: Setup documentation

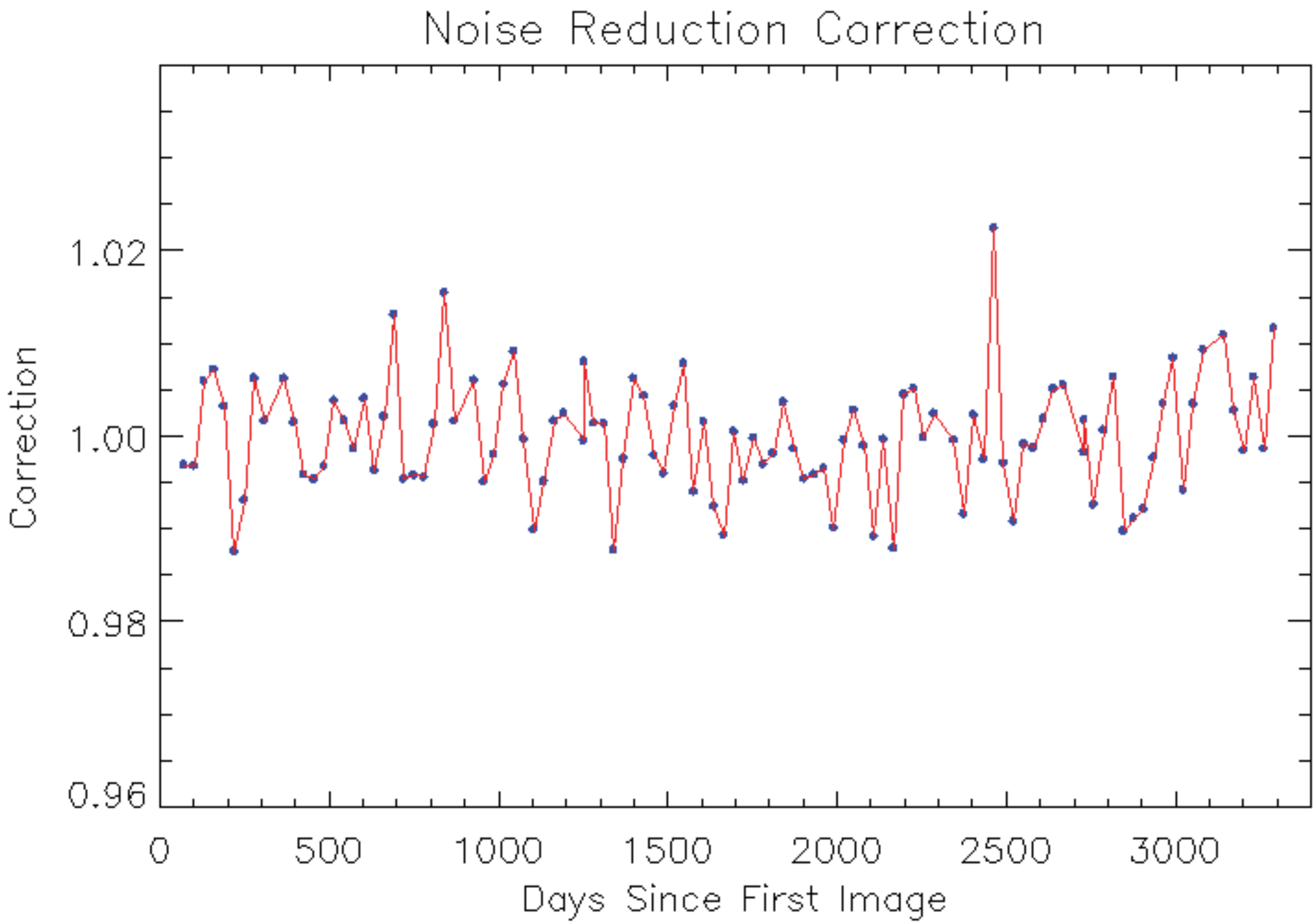
Orientation of polarization angle relative to MODIS leaving Polarization Source Assembly (PSA) not documented by Raytheon



Setup reconstructed with help of E. Waluschka

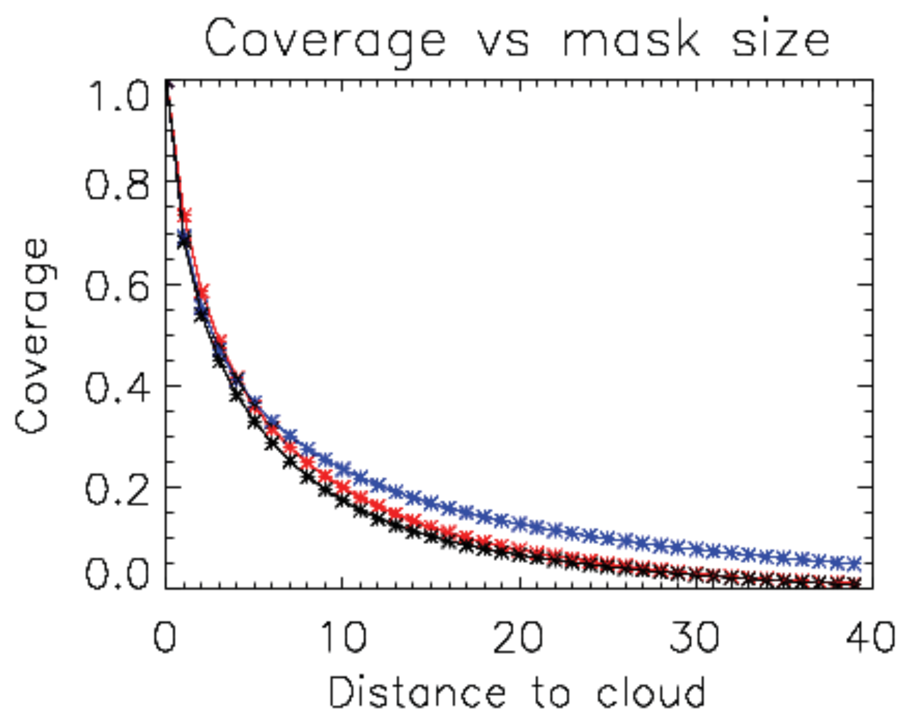
Fig. from Meister et al., 2005, Applied Optics

Band correlated noise:



Sensor requirements not strict enough: VIIRS

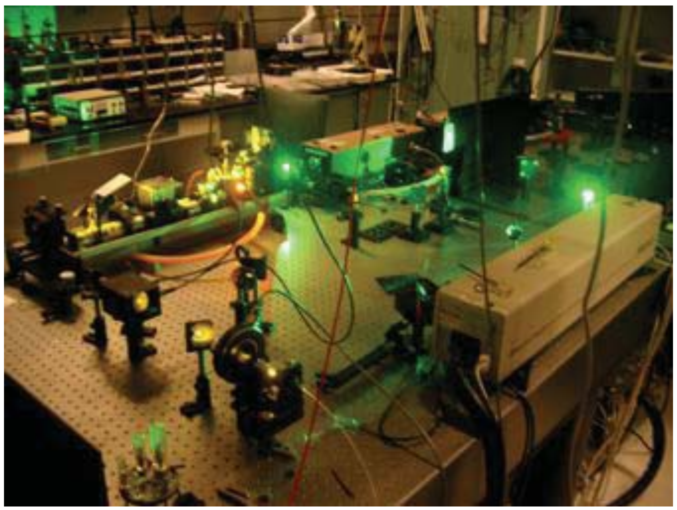
- Straylight masking influences global coverage
- Plot below shows reduction in coverage for masks around clouds for the 3 MODIS Aqua granules
- More straylight => larger mask => less coverage

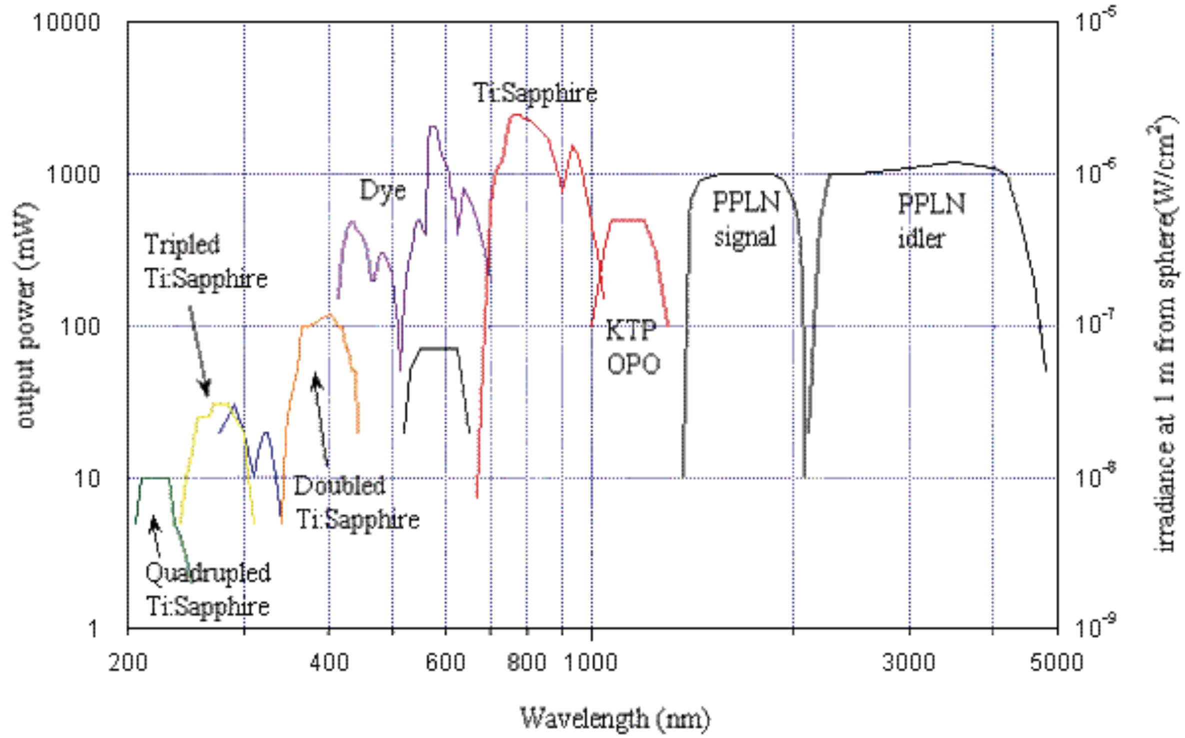


Relative Spectral Response:

- SeaWiFS characterization: mixture of piece-part and system level characterization
- MODIS: system level characterization (double monochromator)
- VIIRS: system level characterization (double monochromator and laser)
- If well characterized, OOB is manageable

VIIRS Relative Spectral Response:

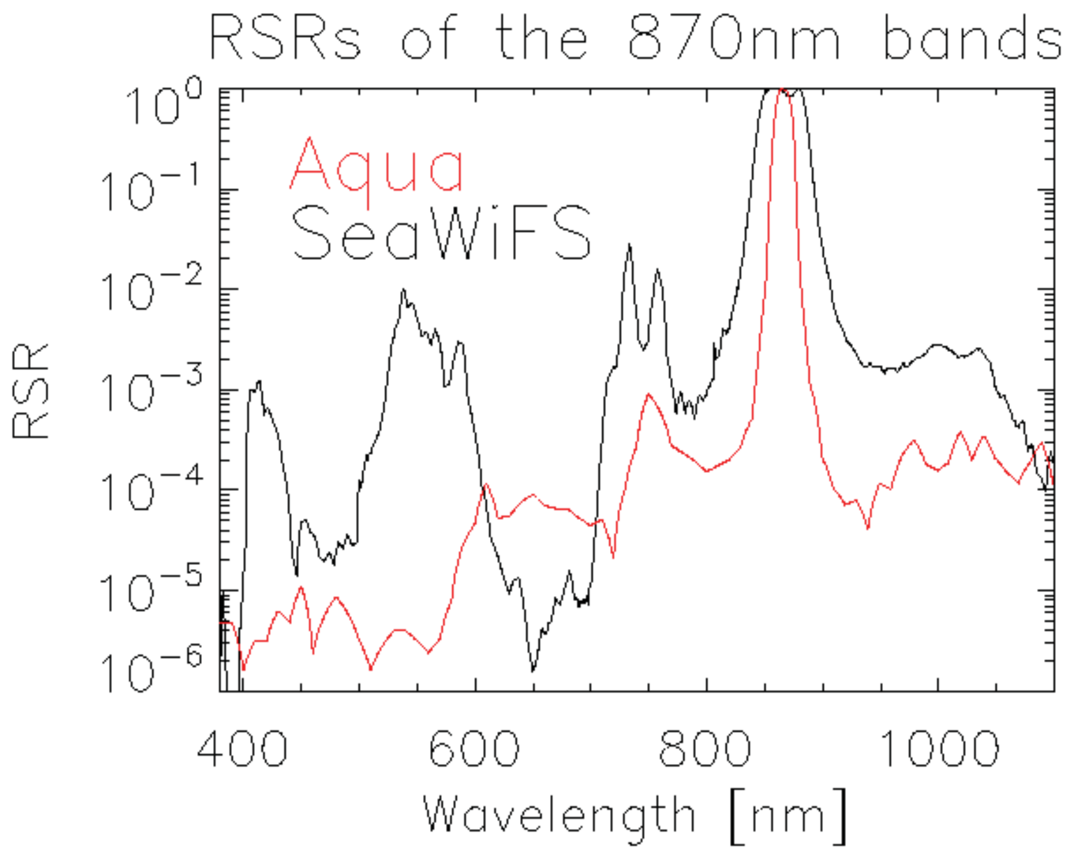




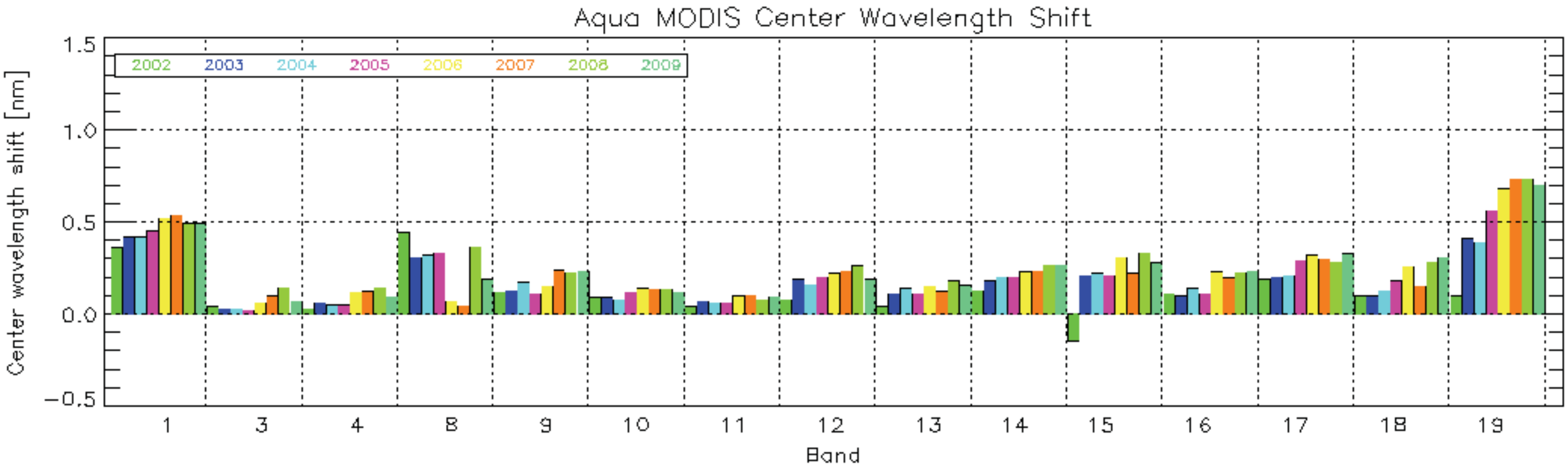
- Advantages: bright source, well calibrated
- Disadvantage: not continuous (delta lambda=0.1nm), flood illumination (crosstalk)

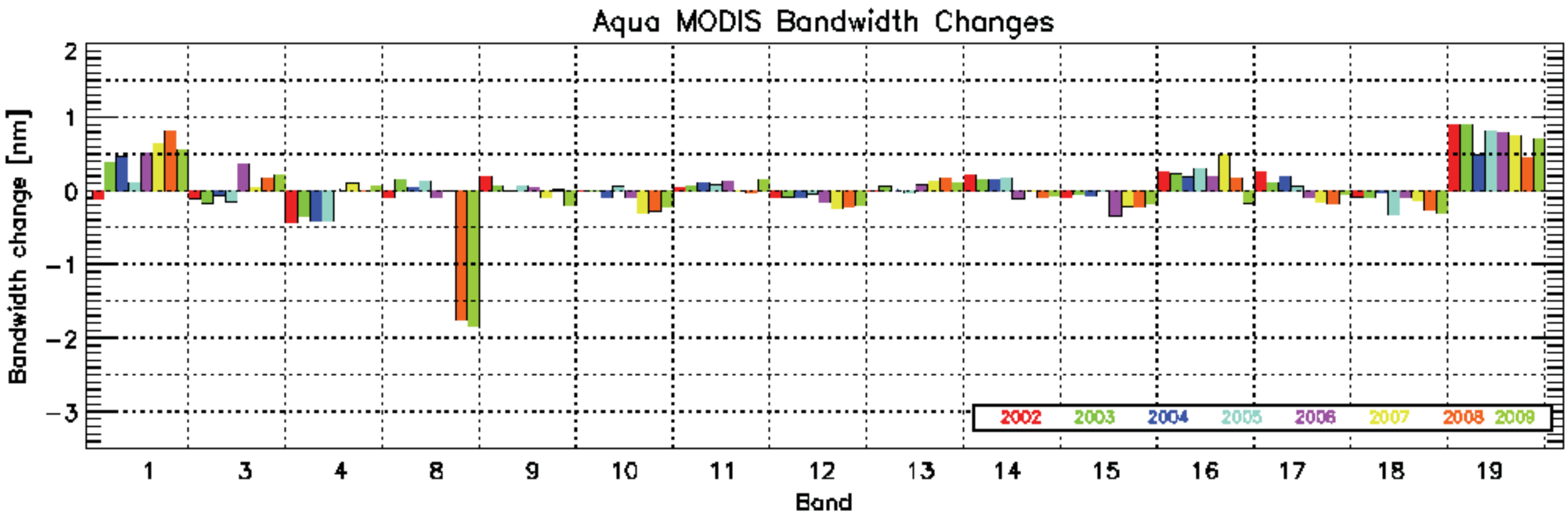
SeaWiFS RSR OOB for 870nm

- SeaWiFS spec: ratio out-of-band RSR to in-band RSR up to 5%
- Actual band 8 value : 3.7%



Spectral Response on-orbit (X. Xiong, MST 2010):





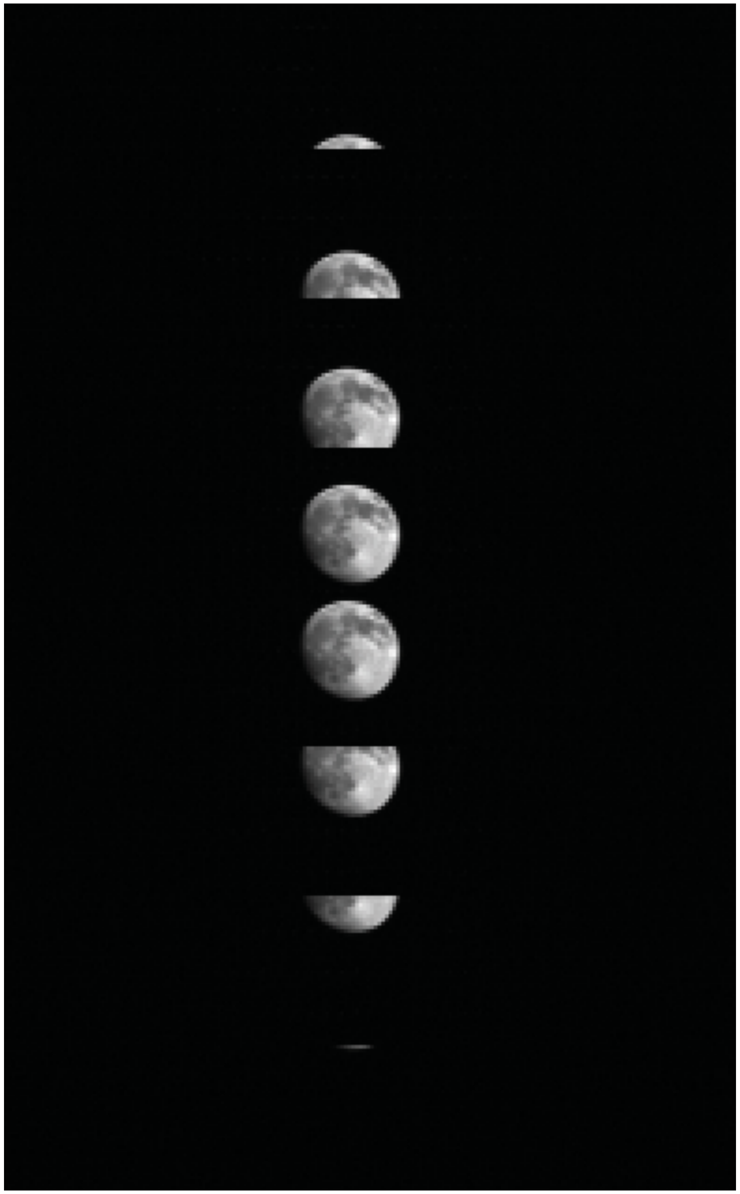
Oversampling Correction

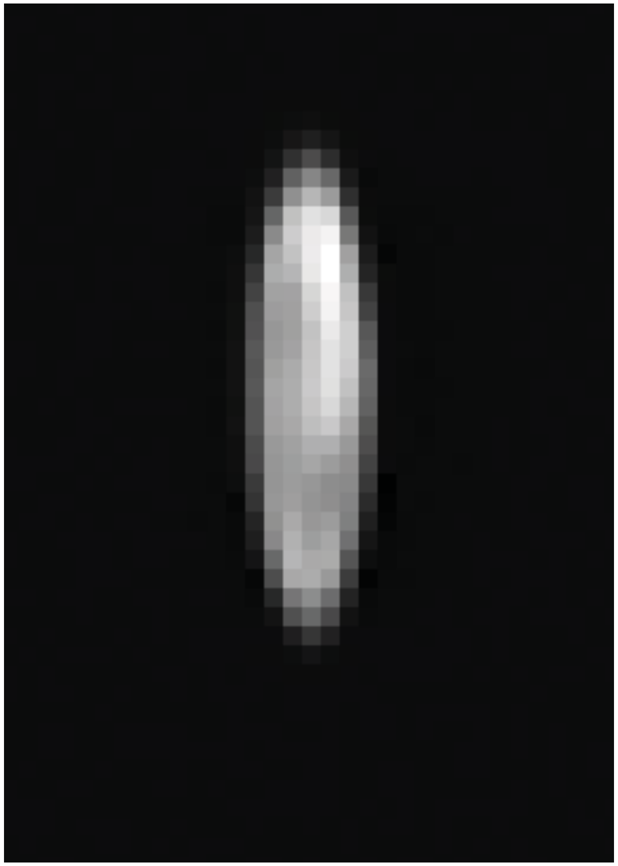
$$f(t,\alpha,\gamma) = \frac{1}{Y_{Moon}(\alpha,\gamma)} \arctan\left(\frac{D_{Moon}}{R_{Inst-Moon}(t)}\right)$$

Y_{Moon}	≡	angular size of Moon in image
D_{moon}	≡	diameter of Moon = 3476.4 km
$R_{Inst\text{-}Moon}$	≡	Instrument-Moon distance
t	≡	time of observation
α	≡	phase angle
γ	≡	track angle

Lunar images may be oversampled:

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





Sensor calibration: MODIS

- MODIS optics based on an (unprotected) rotating mirror
- Scan angle dependent degradation adds complexity to calibration approach

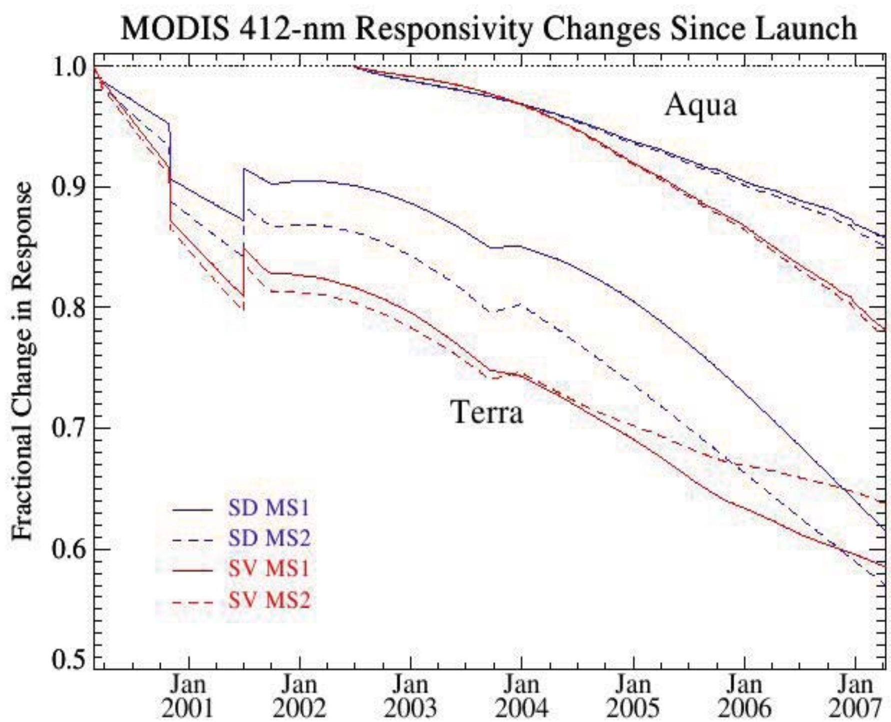


Fig. from Franz et al., 2008, Applied Optics

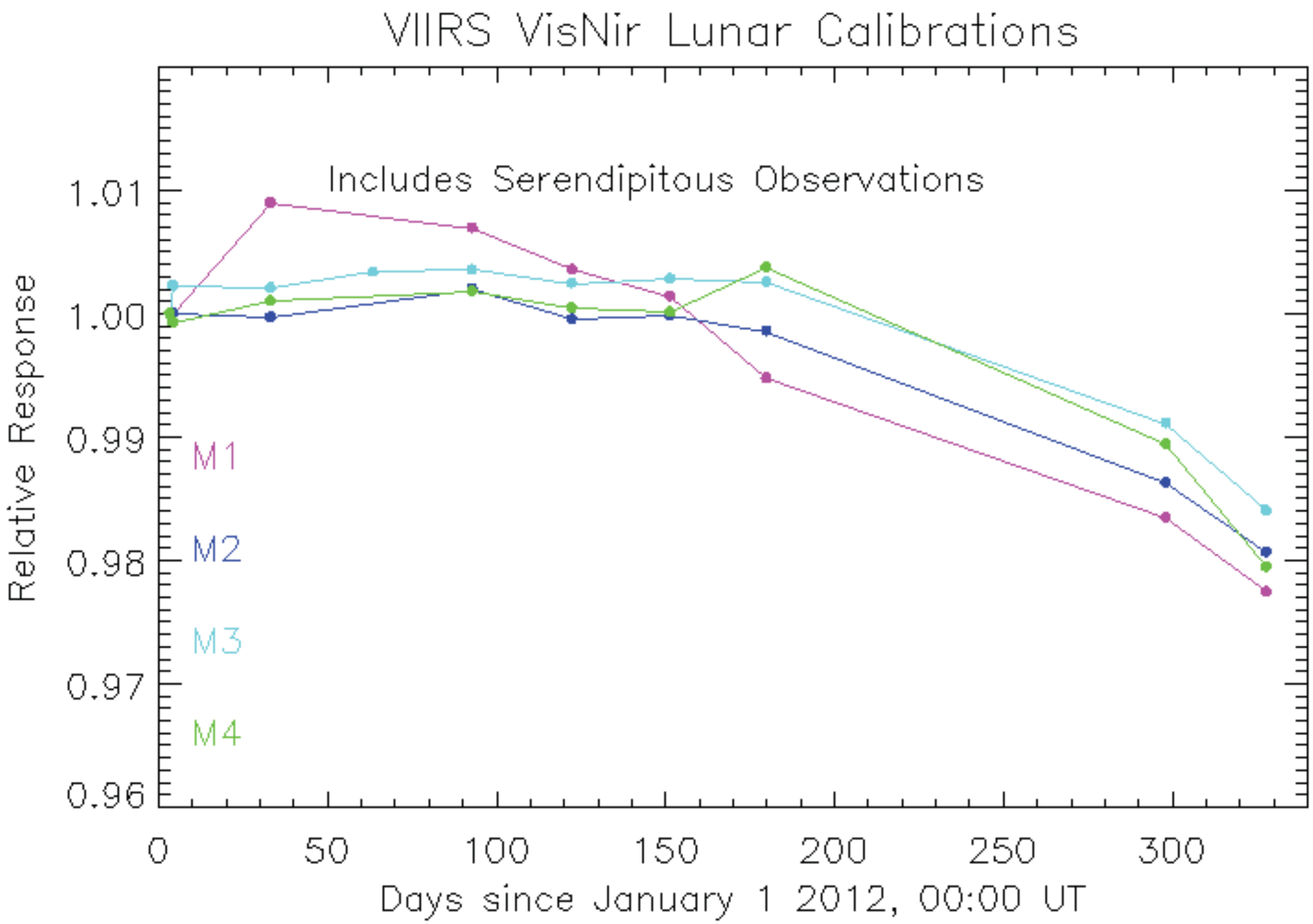
Sensor calibration: MODIS

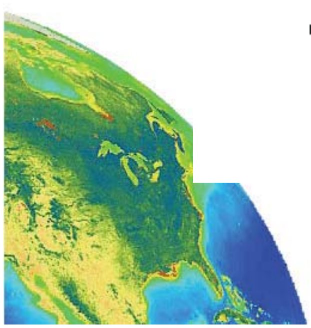
- MODIS uses two calibration sources: solar diffuser (SD) and moon (through space view (SV) port)
- Interpolation over $\Delta AOI=40^o$ and 10% gain change problematic, extrapolation even more

	Start	SV	Nadir	SD	End
Scan Pixel	1	23	677.5	979	1354
Scan Angle	-55.0	-53.2	0.0	24.5	55.00
Mirror AOI	10.5°	11.4°	38.0°	50.3°	65.5°

Table from Franz et al., 2008, Applied Optics

Lunar Time Series





Lunar Calibrations

Scheduled / Serendipitous Calibrations

- Moon below horizon for 3 months during the year

Lunar residuals from the USGS ROLO Photometric Model of the Moon

Comparison of Solar / Lunar Calibrations

- Same Angle of Incidence on Half-Angle Mirror

Alternate derivation of F-factor from lunar calibration time series

- Compensates for uncertainties in diffuser BRDF correction

Solar Calibrations

SDSM time series (H-factor): BRDF change:

Solar Diffuser time series (F-factor)

BRDF-corrected F-factor:

1. Ocean color requirements

OBPG produces different levels of data products, starting from level 0 (uncalibrated DN):

1) Level 1: calibrated radiances

2) Level 2: ocean color products (snapshot, no spatial averaging)

3) Level 3: ocean color products averaged over time and space (8-day, monthly, etc.)