

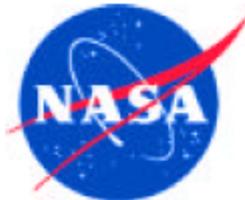


MODIS Reflective Solar Bands On-Orbit Calibration, Performance, and Polarization Issues

MODIS Characterization Support Team (MCST)

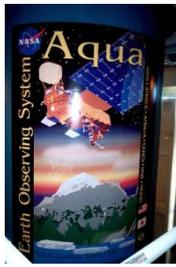


MODIS Polarization Working meeting (January 6, 2011)

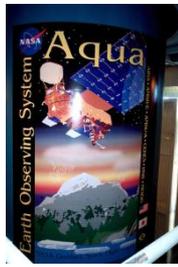




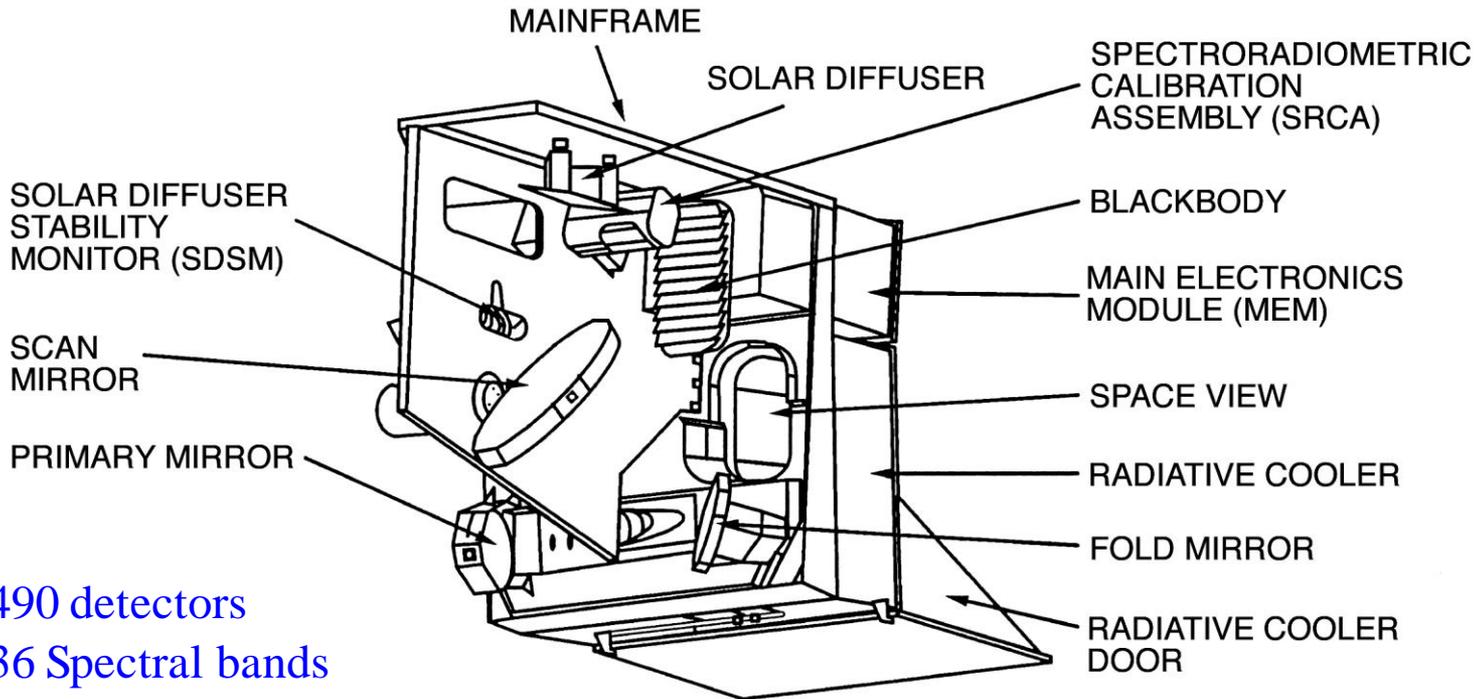
Outline



- Introduction
- Reflective solar bands (RSB) calibration algorithm
- RSB on-orbit performance
- Impact of polarization on RSB
- Summary



Introduction



490 detectors

36 Spectral bands

- 20 reflective solar bands (RSB)

- 16 thermal emissive bands (TEB)

Spatial resolution (36 bands) at nadir

- 250m(2), 500m(5), and 1km (29)

Wavelength range from 0.4 to 14.5 μm

Two sided paddle wheel scan mirror

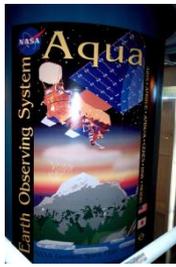
- 10 km (nadir) along track

by 2330 km cross track swath

- 1.478 second each scan



MODIS RSB L1B Products



EV Reflectance:

$$\rho_{EV} \cdot \cos(\theta_{EV}) = m_1 \cdot dn_{EV}^* \cdot d_{Earth_Sun}^2$$

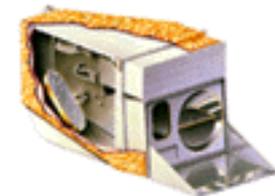
EV Radiance:

$$L_{EV} = \frac{E_{Sun} \cdot \rho_{EV} \cdot \cos(\theta_{EV})}{\pi \cdot d_{Earth_Sun}^2}$$

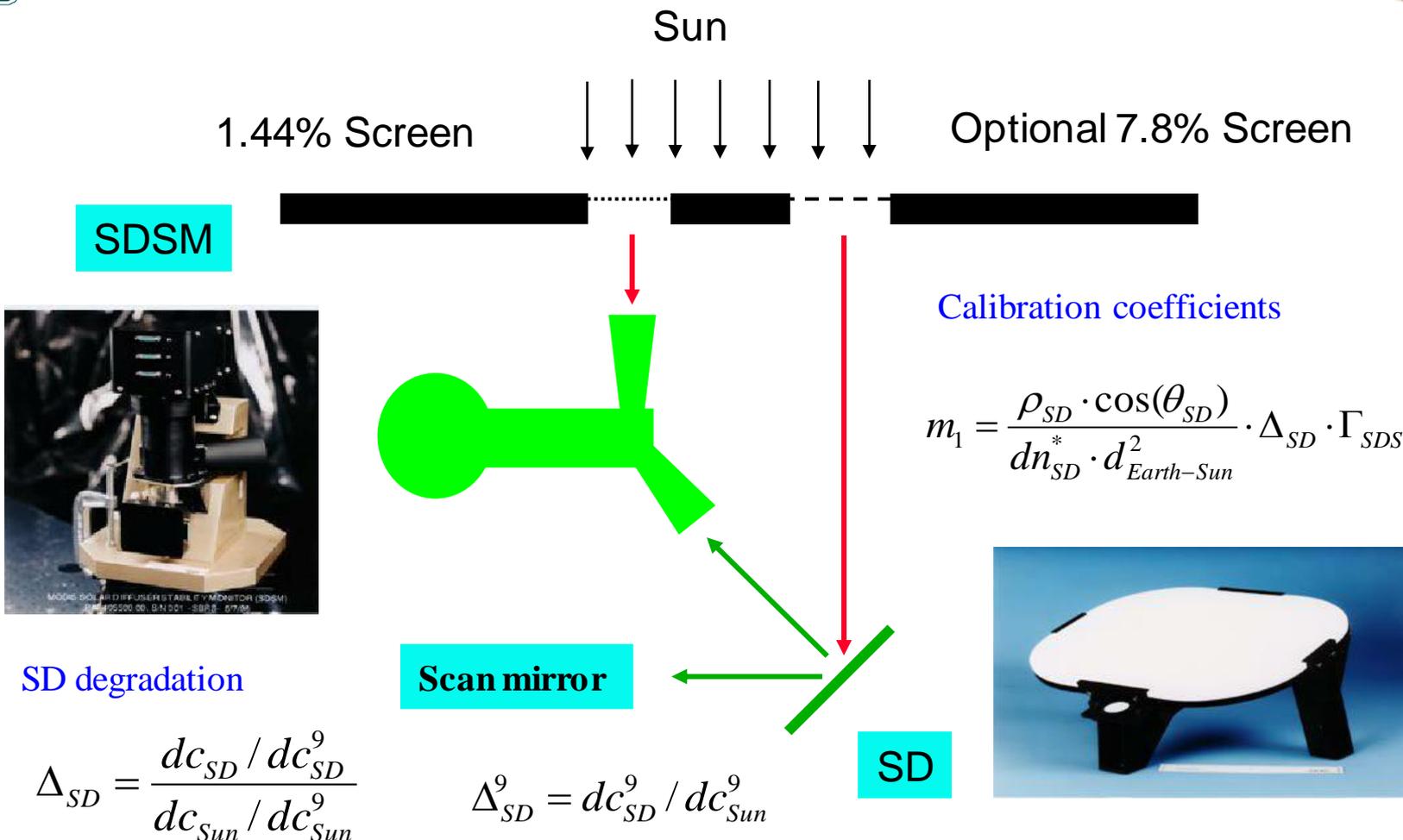
where

$$dn_{EV}^* = dn_{EV} \cdot (1 + k_{Inst} \cdot \Delta T_{Inst}) / RVS_{EV}$$

- *A linear approximation is applied for relationship between the instrument's response and reflectance/radiance of the incident light*
- *Two sets of coefficients, m1 and RVS, are regularly updated*
- *No correction for polarization effect in the L1B products*



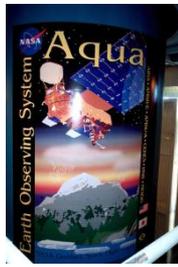
RSB SD Calibration



SD degradation at wavelength 936 nm measured by SDSM D9 is included in Collection 6 through the entire mission and also included in Collection 5 for Terra after Jan. 1, 2009 and Aqua after March 1, 2009.



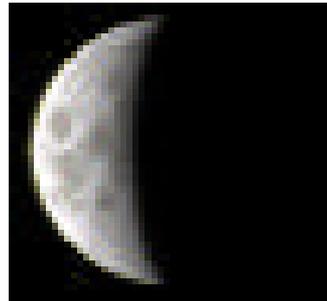
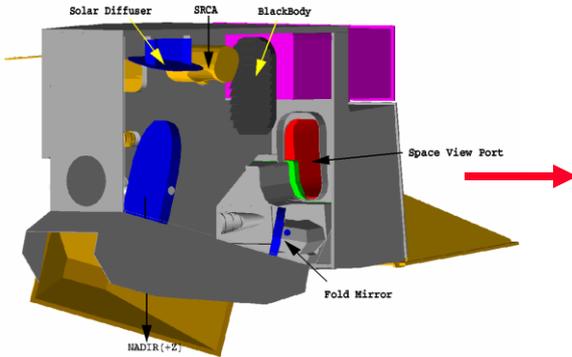
RSB lunar calibration



MODIS

Moon

Lunar coefficients



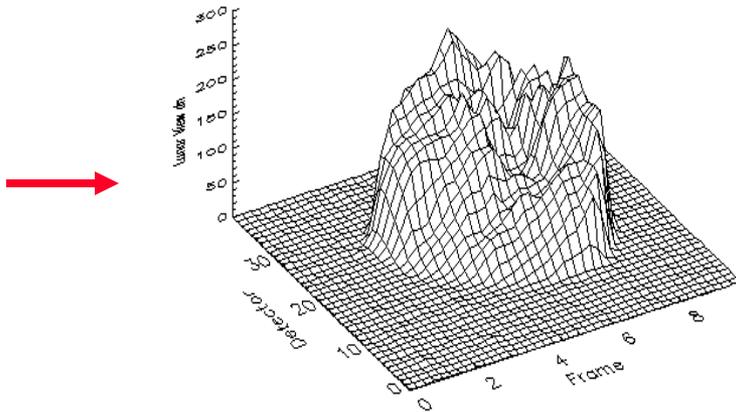
Bands 1-4, 8-12 and 17-19

$$m_1^{moon} = \frac{f_{vg}}{\langle dn_{Moon}^* \rangle}$$

Bands 13-16 (Saturated)

$$m_1^{moon} = m_{1,B18}^{moon} \cdot \frac{\langle dn_{Moon,B18}^* \rangle}{\langle dn_{Moon}^* \rangle}$$

MODIS Response



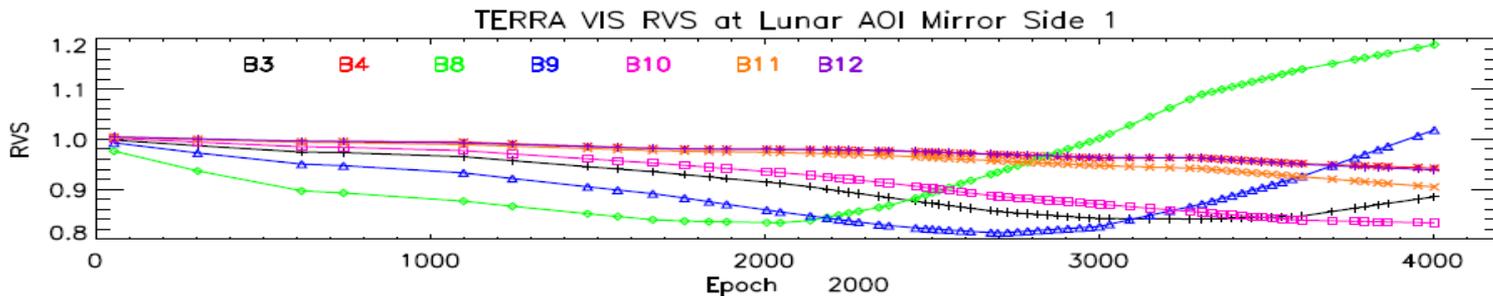
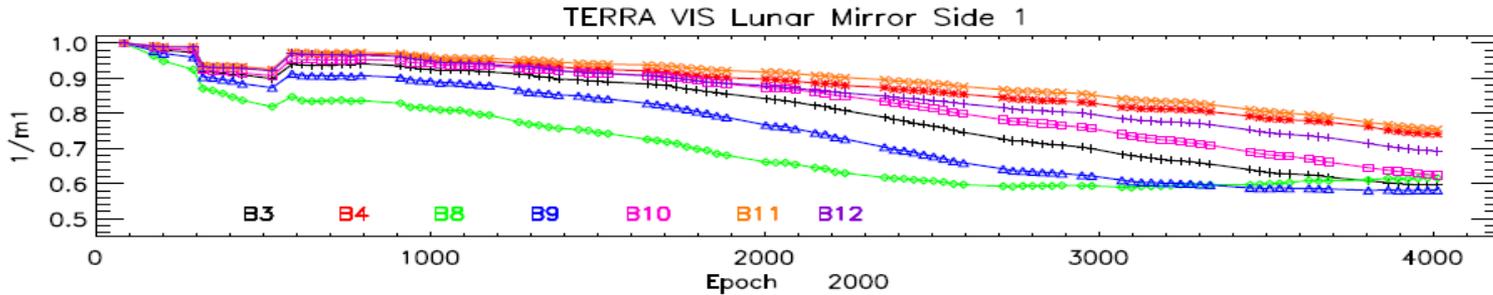
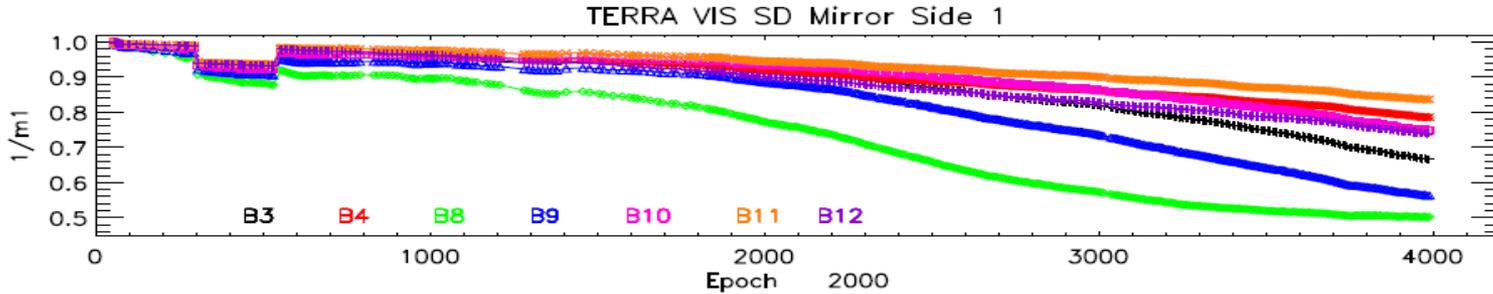
View geometry correction

$$f_{vg} = \frac{f_{phase-angle} \cdot f_{libration}}{d_{Sun-Moon}^2 \cdot d_{Moon-MODIS}^2}$$



MODIS RSB MS1 Gain and RVS

Detector Averaged

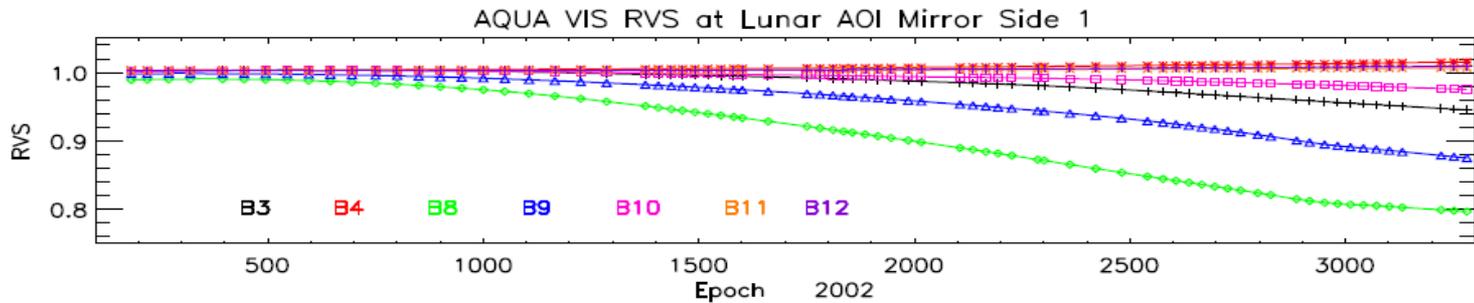
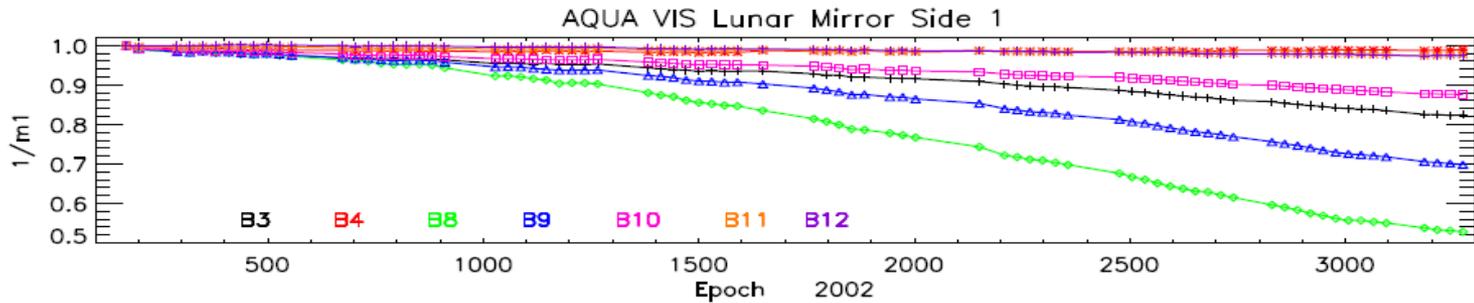
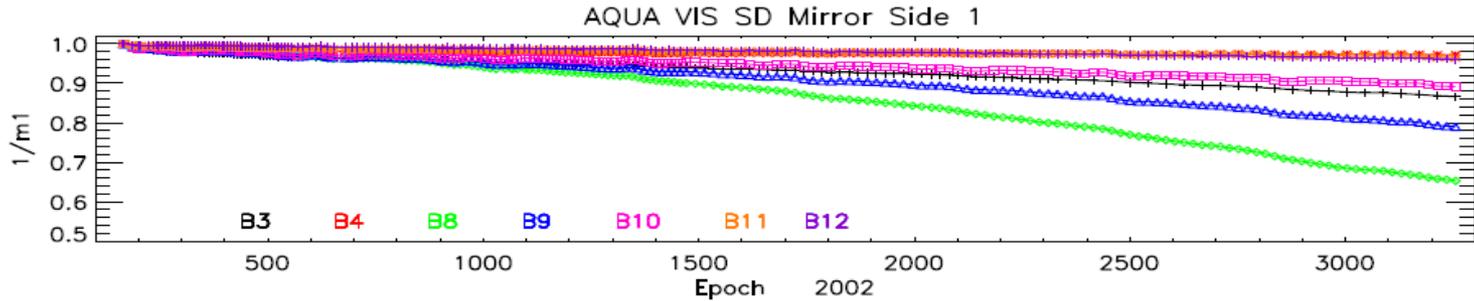


- RVS at SV AOI is derived from SD and lunar observations.
- RVS at other AOI are obtained from a linear interpolation of the RVS at AOI of SD and SV.
- Terra band 8 MS1 RVS at AOI of the SV has changed about 26% in last few years



MODIS RSB MS1 Gain and RVS

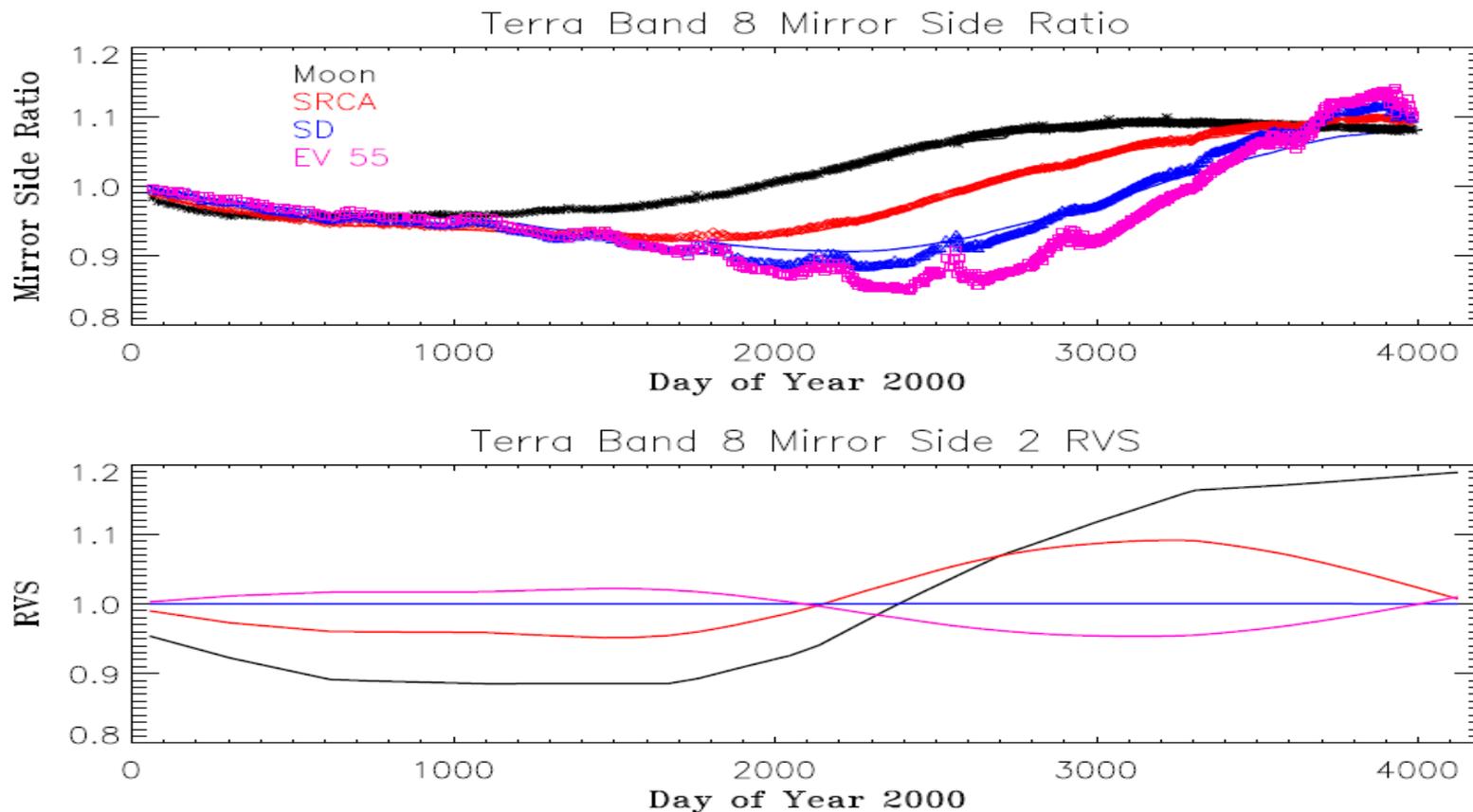
Detector Averaged



Aqua band 8 RVS at AOI of the SV has decreased about 19% since launch



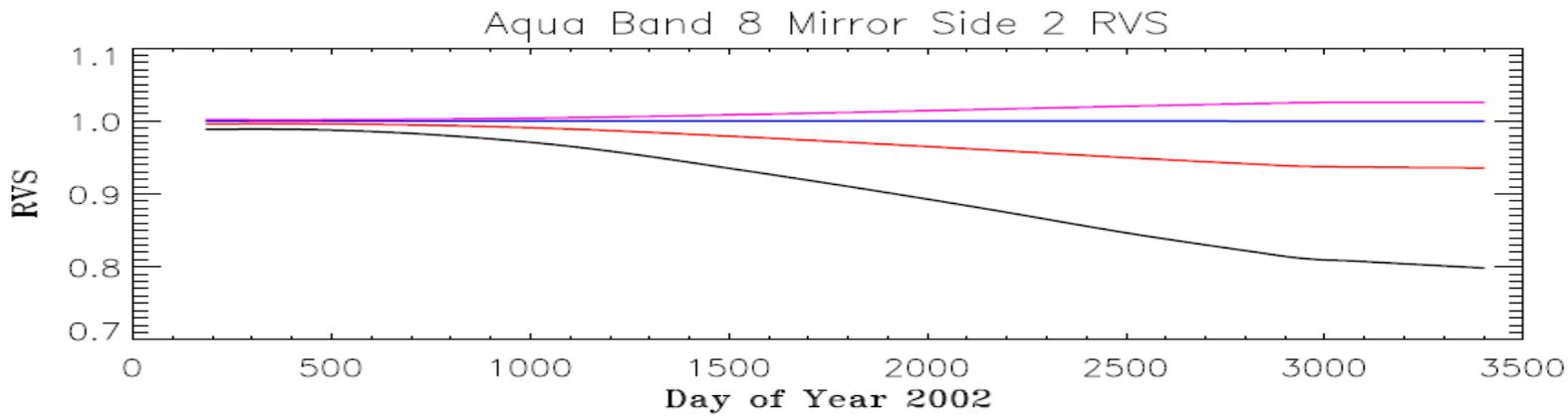
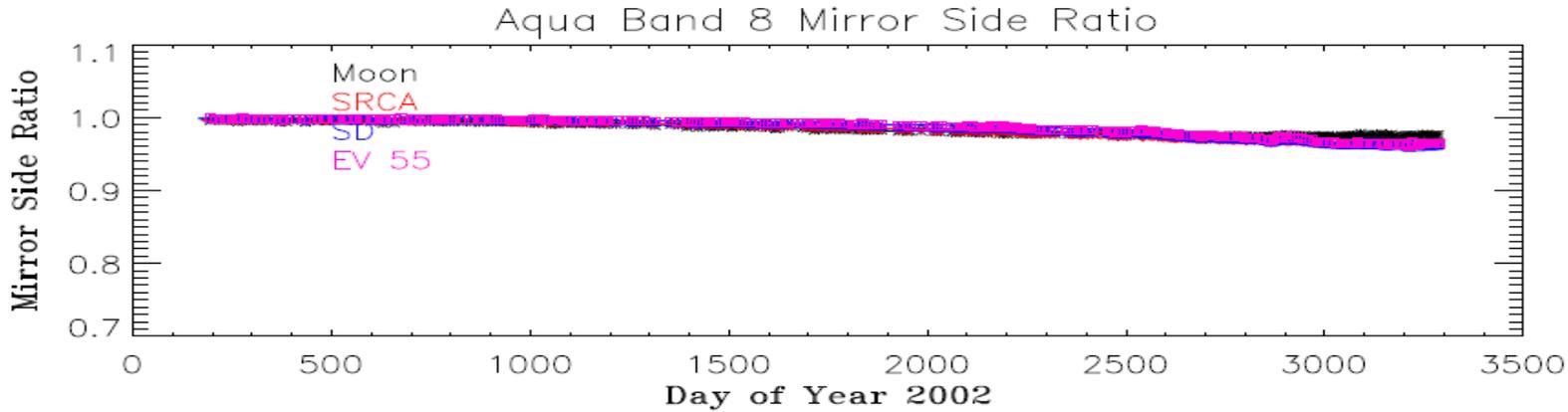
MODIS RSB MS Ratio and MS2 RVS



- **MS2 RVS** is derived from MS1 RVS and instrument response MS ratios (SD, lunar, and EV observations) with a quadratic approximation
- Terra band 8 MS2 RVS at AOI of the SV has changed about 29% in last few years



MODIS RSB MS Ratio and MS2 RVS



Aqua band 8 MS2 RVS at AOI of the SV has changed about 19% in last few years



MODIS Polarization Effect



- TOA (Top-of-Atmosphere) reflectance

$$[\rho_{EV} \cos(\theta_{EV})]_{L1B} = \rho_{EV} \cos(\theta_{EV}) \{1 + f \cdot a_{BDM\theta} \cos[2(\mu + \delta_{BDM\theta})]\}$$

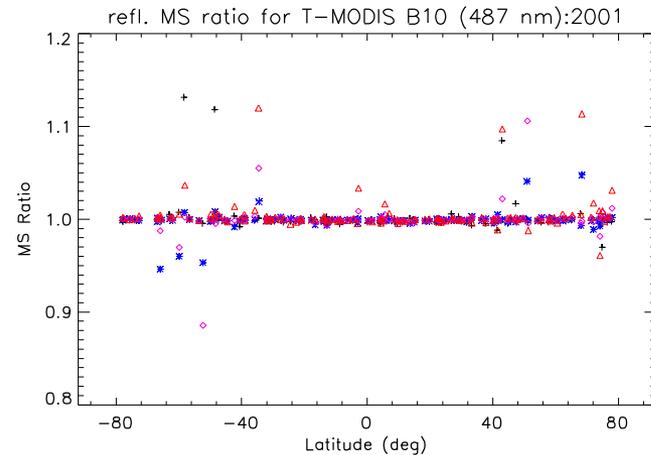
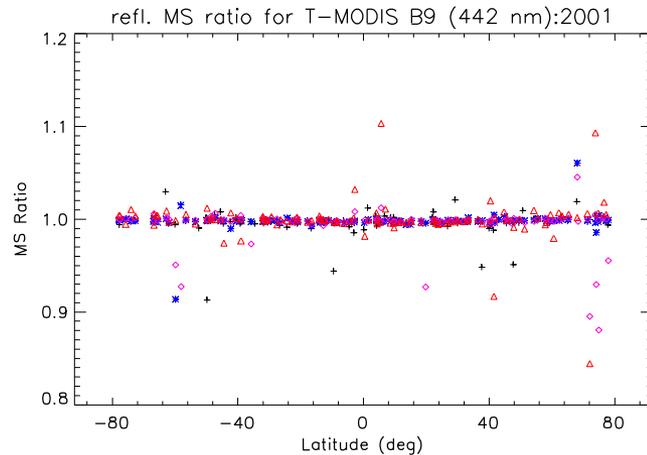
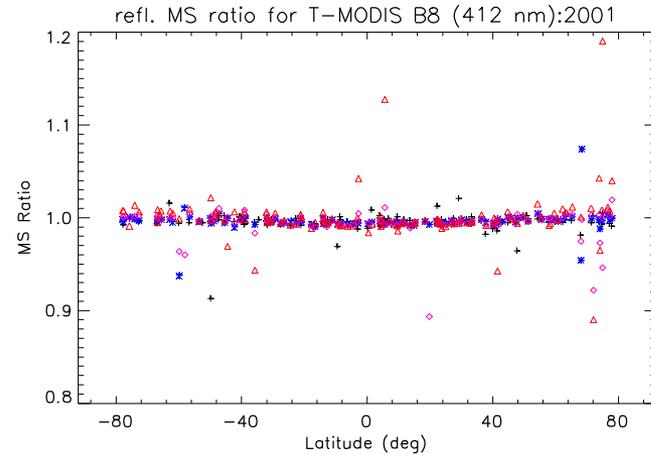
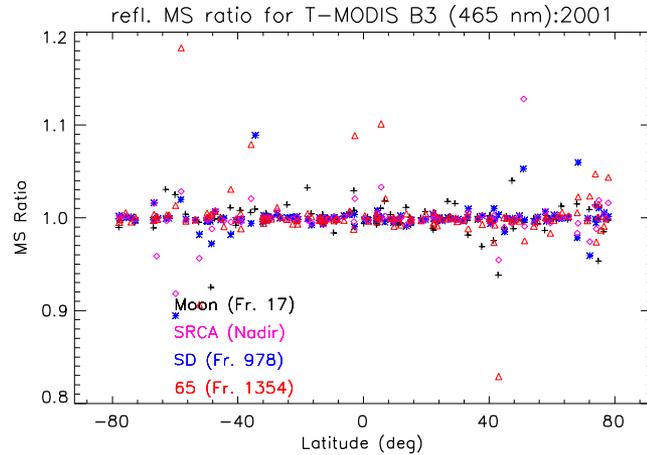
- B, D, M, and θ are band, detector, mirror side, and angle of incidence
- a and δ are instrument's polarization factor and phase angle, which were measured prelaunch but change on orbit
- f and μ are degree of the incident light's polarization and the direction of larger axis of the incident light's polarization

- EV mirror side ratio

$$\frac{[\rho_{EV} \cos(\theta_{EV})]_{L1B,MS1}}{[\rho_{EV} \cos(\theta_{EV})]_{L1B,MS2}} = \frac{\{1 + f \cdot a_{BD1\theta} \cos[2(\mu + \delta_{BD1\theta})]\}}{\{1 + f \cdot a_{BD2\theta} \cos[2(\mu + \delta_{BD2\theta})]\}}$$

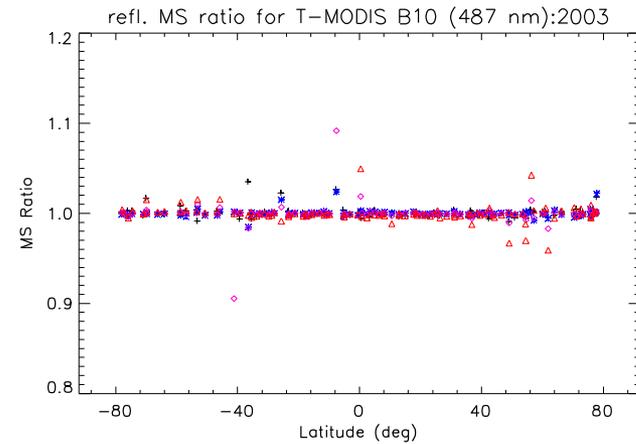
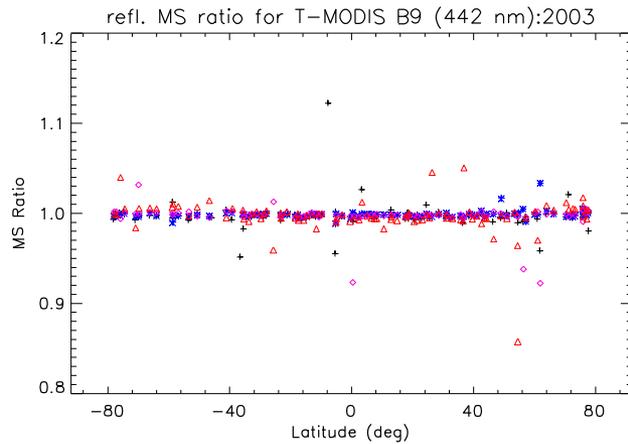
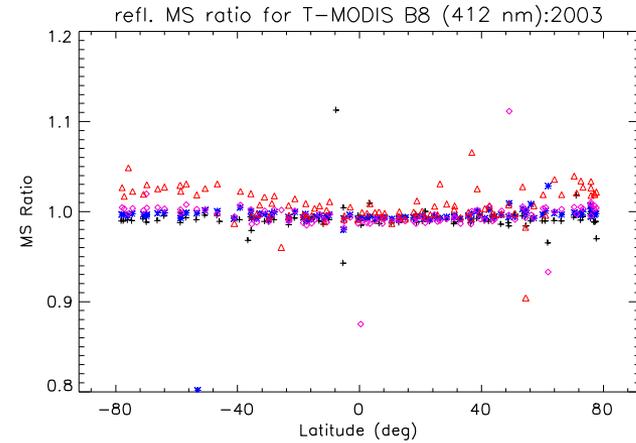
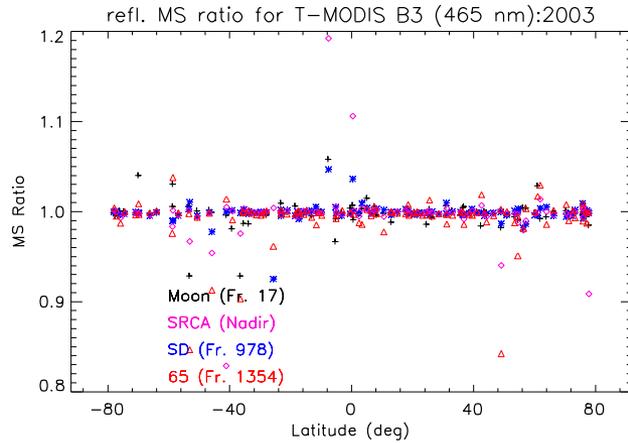


Terra L1B MS Ratio at Different Latitudes



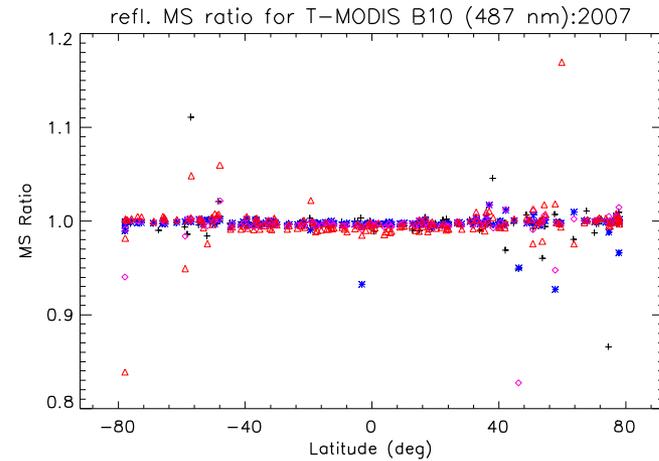
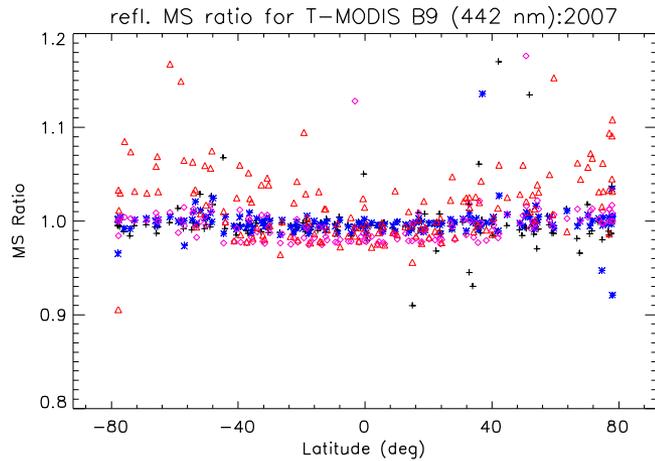
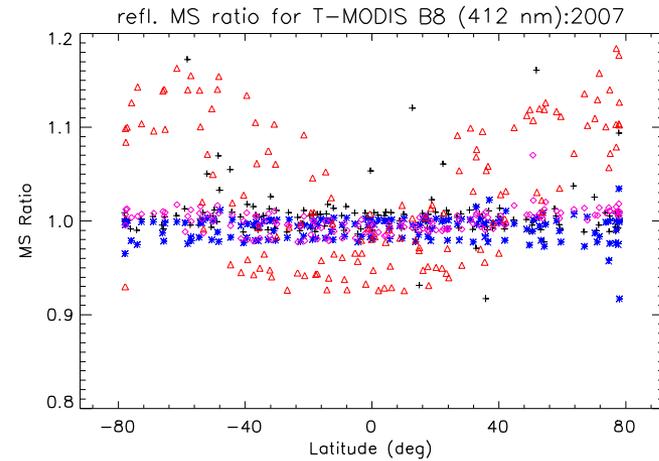
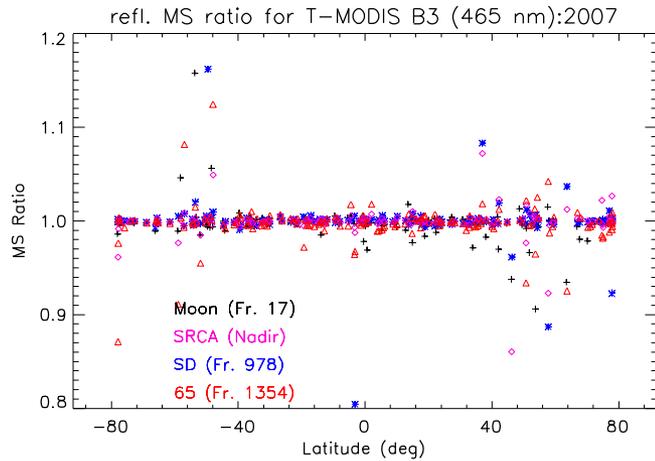


Terra L1B MS Ratio at Different Latitudes



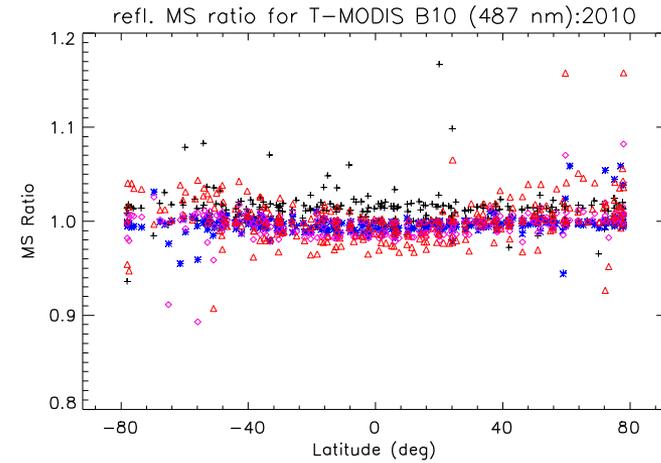
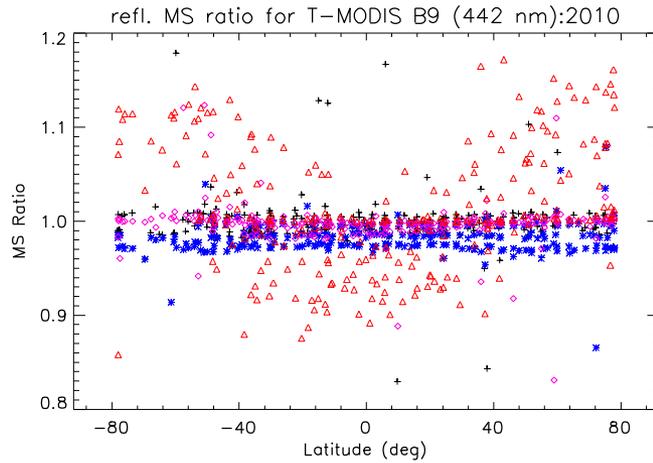
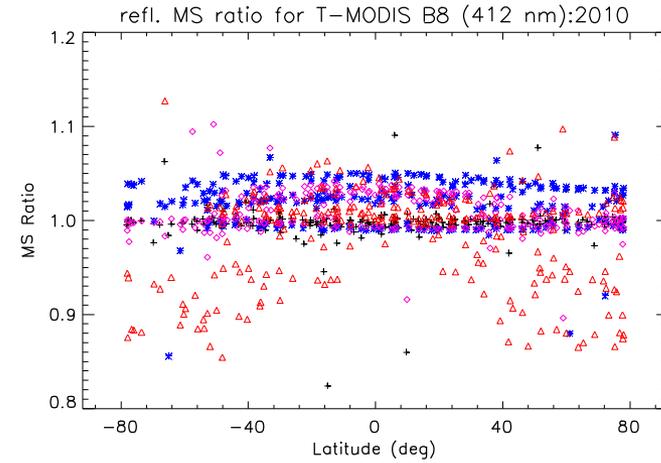
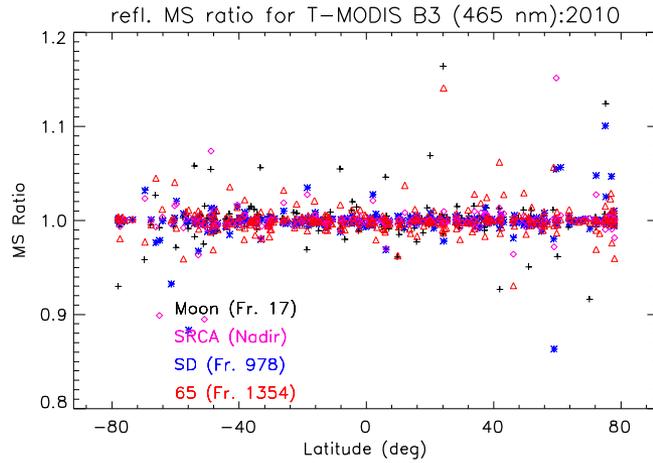


Terra L1B MS Ratio at Different Latitudes



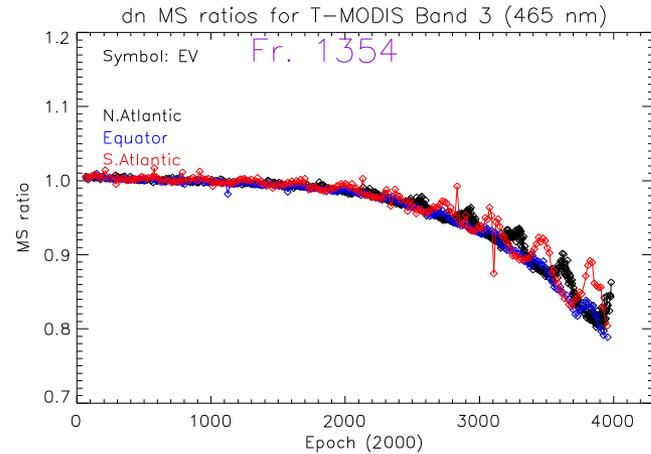
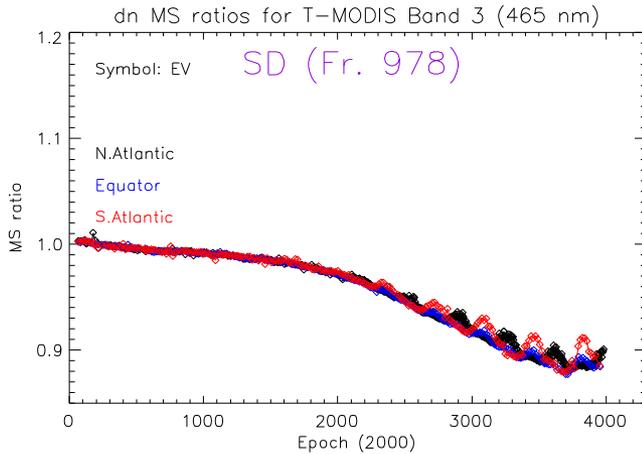
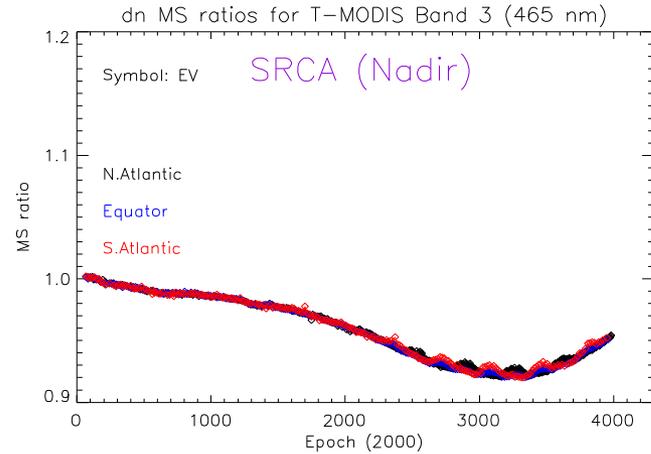
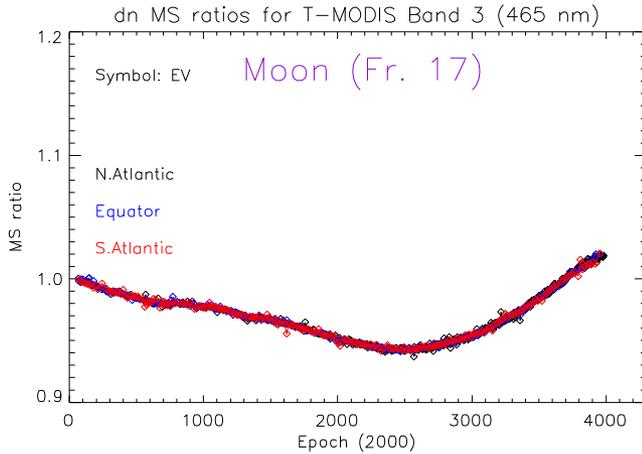


Terra L1B MS Ratio in at Different Latitudes



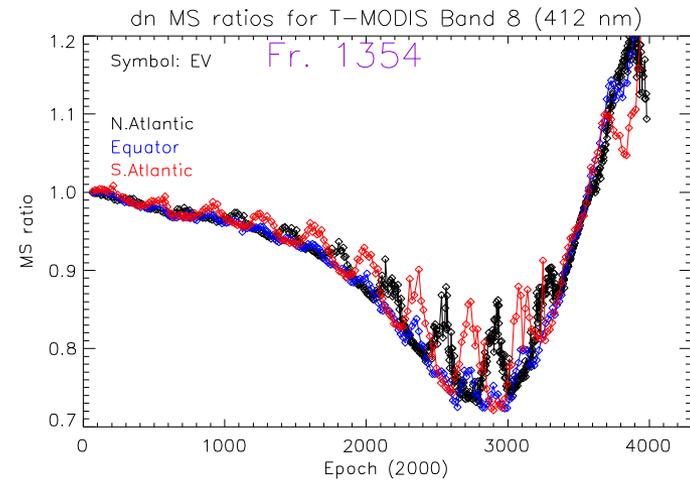
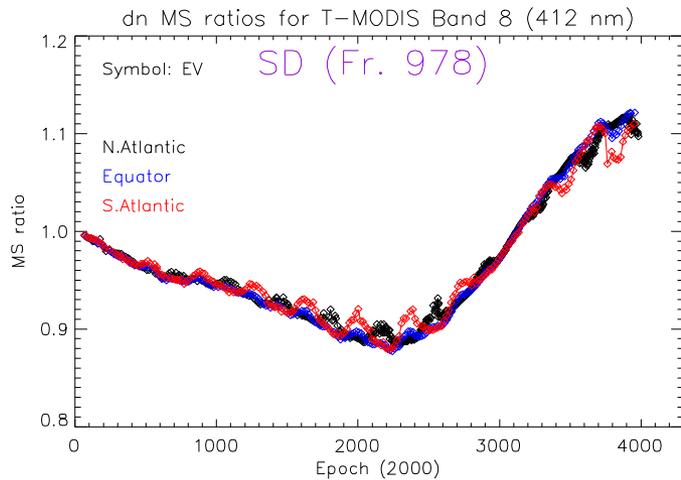
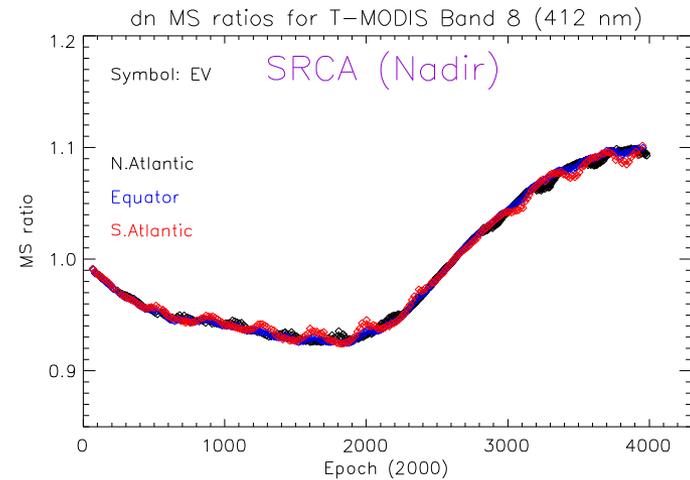
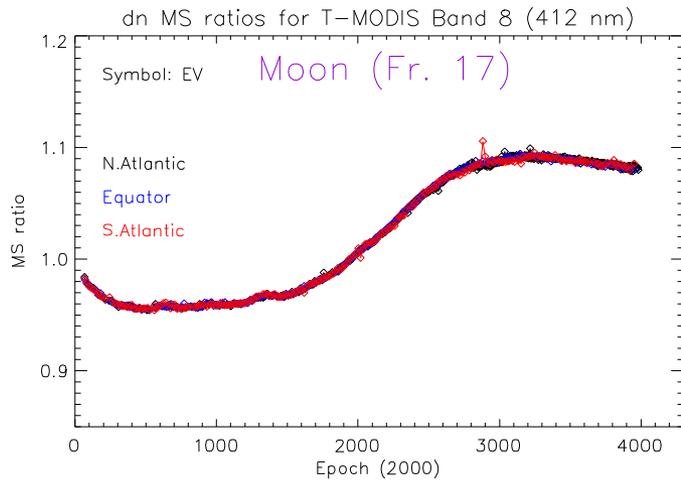
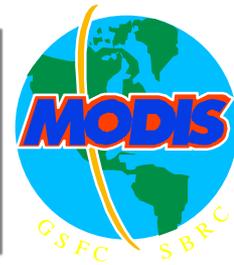


Terra Instrument Response MS Ratio



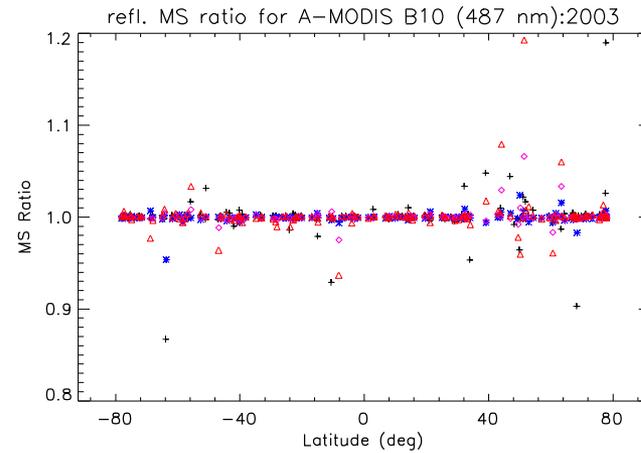
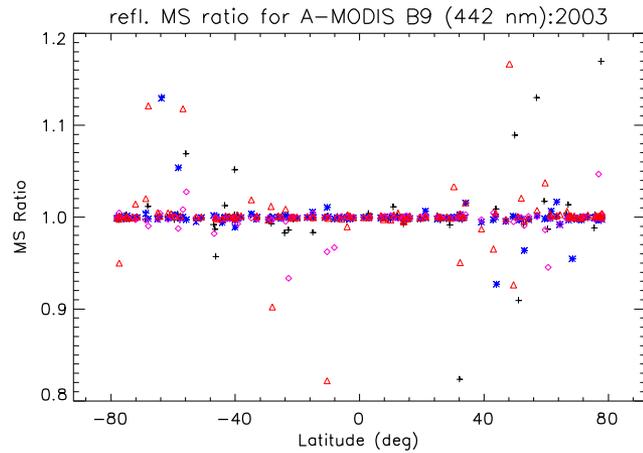
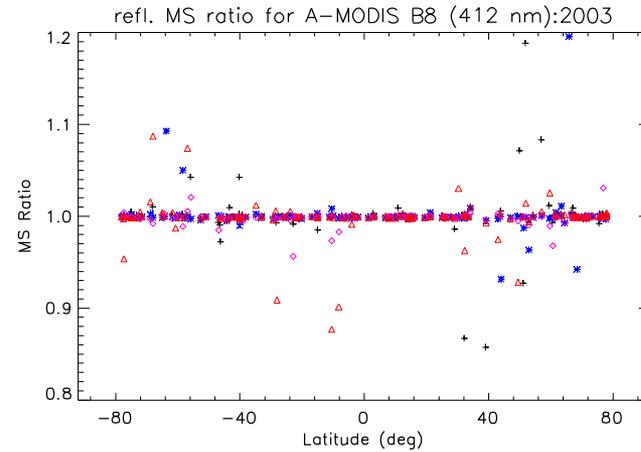
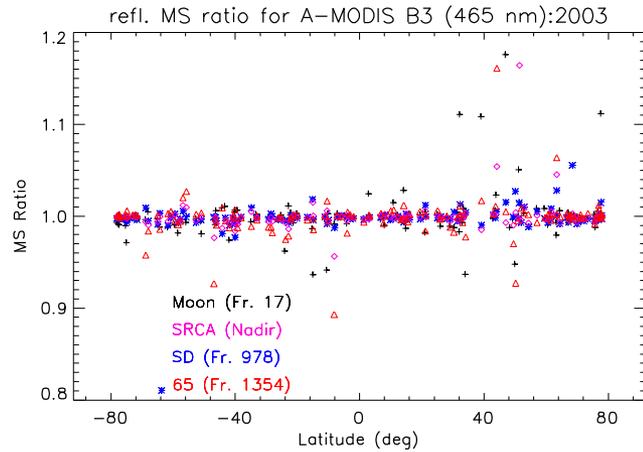


Terra Instrument Response MS Ratio



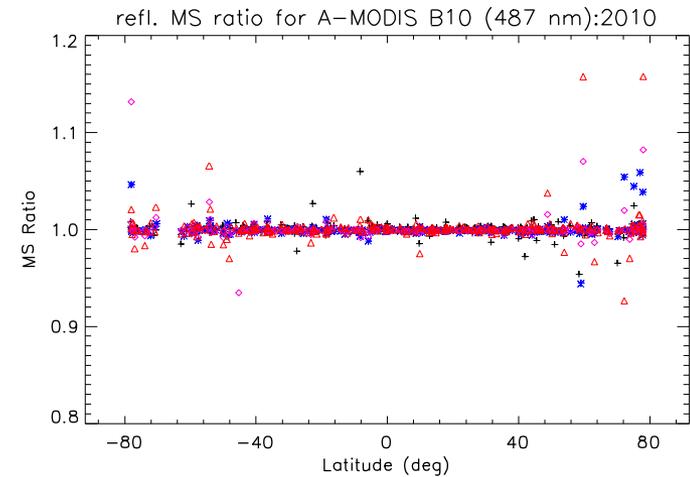
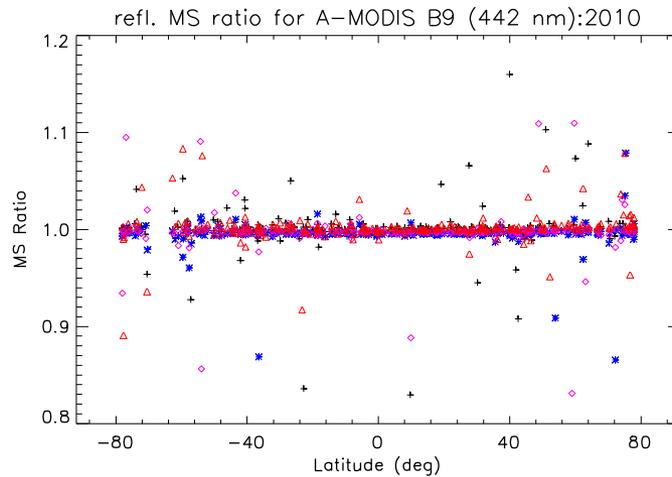
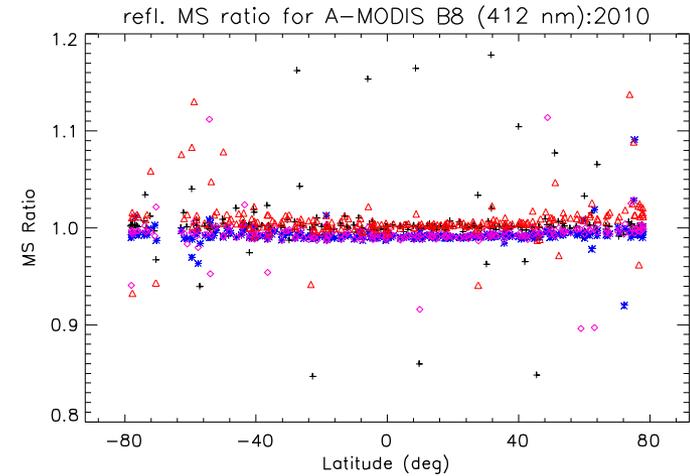
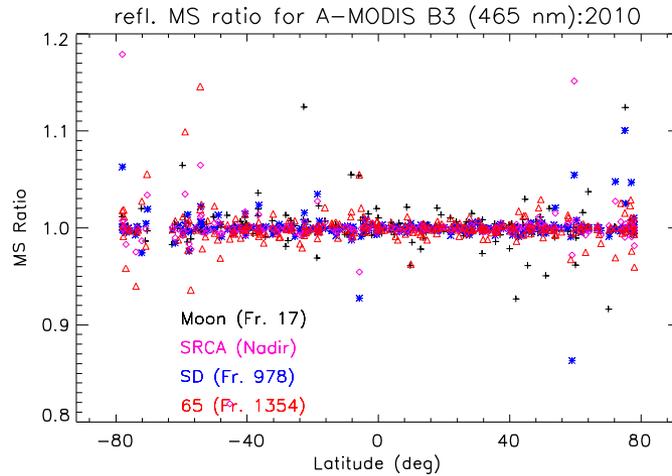


Aqua L1B MS Ratio at Different Latitudes



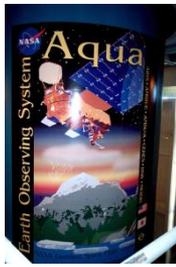


Aqua L1B MS Ratio at Different Latitudes





Summary of RSB overall Performance



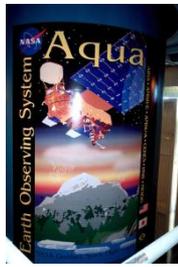
- **Terra MODIS (11 years)**
 - Band 8 responses at the SD AOI has decreased about 50% and 46% in mirror side 1 and 2, respectively.
 - The band 8 RVS at the SV AOI has changed about 26% and 29% for MS1 and MS2 in the last few years.
- **Aqua MODIS (8.5 years)**
 - Band 8 responses at the SD AOI has decreased about 35% and 37% in mirror side 1 and 2, respectively
 - The band 8 RVS at SV AOI has changed 19% for both mirror sides since launch.
- **Polarization Effect**
 - Significant impacts on Terra MODIS RSB (shorter wavelength bands) due to polarization property change on-orbit in last few years, especially at large angle of incidence (AOI).
 - Polarization effect evident in recent Aqua Band 8 EV L1B products.
 - MODIS RSB are calibrated using non-polarized light and the polarization effect is not accounted for in MODIS L1B products



Backup



MODIS RSB Noisy & Inoperable Detectors



Terra

Day/Year	Band	5										6			7		
	SNR Spec	74										275			110		
	Detector	2	4	6	11	13	16	17	18	19	20	3	7	8	1-10	11-13,15-20	14
055/2000	Nadir Dorr Open	0	0	60	80	0	30	0	0	80	0	0	0	100	100	110	0
160/2000	CFPA Lost Control	95	95	60	80	80	30	80	80	80	80	0	0	100	100	110	0
232/2000	Back from FPA recycle	75	95	50	0	80	50	80	0	70	0	0	0	100	100	110	0
304/2000	B Side	85	20	85	80	80	60	80	80	80	80	350	350	275	90	100	100
183/2001	A Side	95	10	90	90	90	90	90	90	90	90	380	380	380	100	110	110
259/2002	A Side B Formatter	100	10	100	100	100	100	100	100	100	100	380	380	380	100	110	110

Aqua

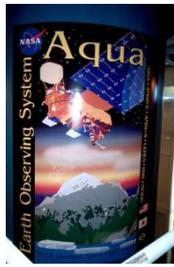
Day/Year	Band	5	6									
	SNR Spec	74	275									
	Detector	20	2	4	5	6	7	9	10	12-16	17	18-20
175/2002	Nadir Dorr Open	0	0	0	0	0	470	470	0	0	100	0
189/2002	Back from Safe Mode	0	0	470	470	0	470	470	0	0	470	0
255/2002	Back from Safe Mode	0	0	0	0	0	470	470	0	0	470	0
266/2002	Back from Safe Mode	0	0	0	0	0	150	400	0	0	470	0
110/2003		0	0	0	0	0	260	470	0	0	320	0
160/2003		0	0	0	0	0	290	400	0	0	470	0
265/2003		0	0	150	0	0	290	400	0	0	275	0
360/2003		0	0	200	0	0	290	275	0	0	270	0
080/2006		0	0	200	0	0	0	350	0	0	270	0
314/2006		0	0	200	0	0	472	350	0	0	270	0

In Spec
 Near Spec
 Out Spec
 Inoperable

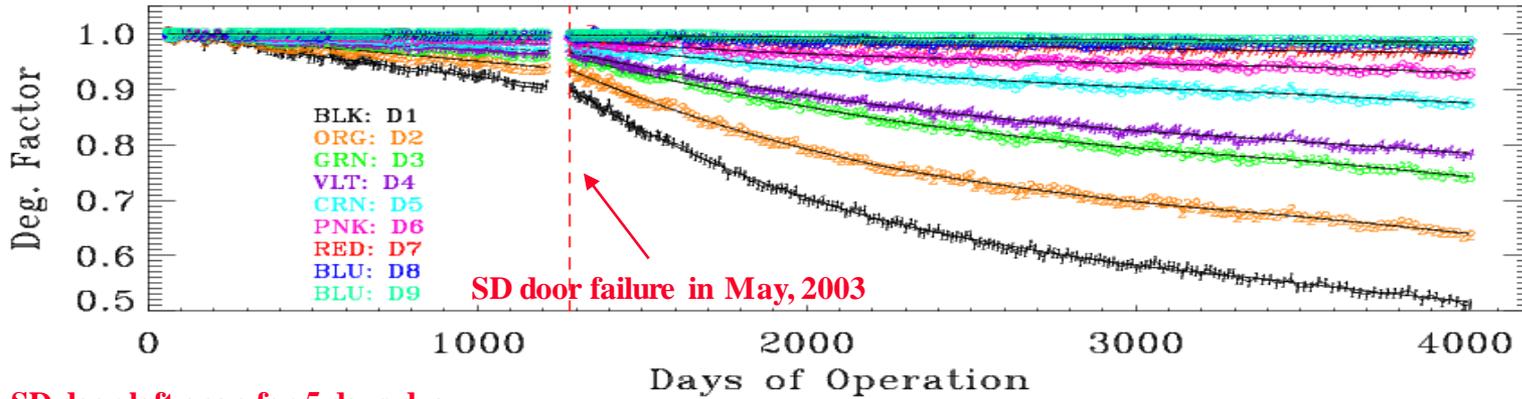
Detectors in Production order



MODIS SD Degradation Trending

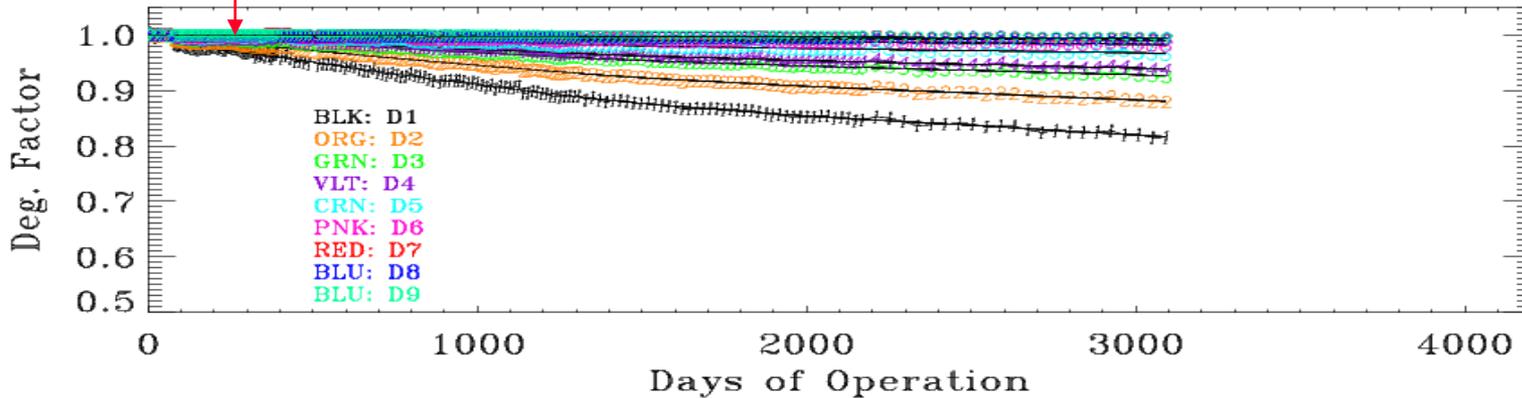


Terra SDSM tracking SD degradation

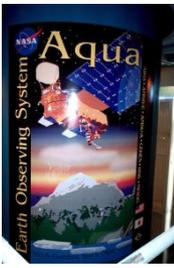


SD door left open for 5 days due to a command drop

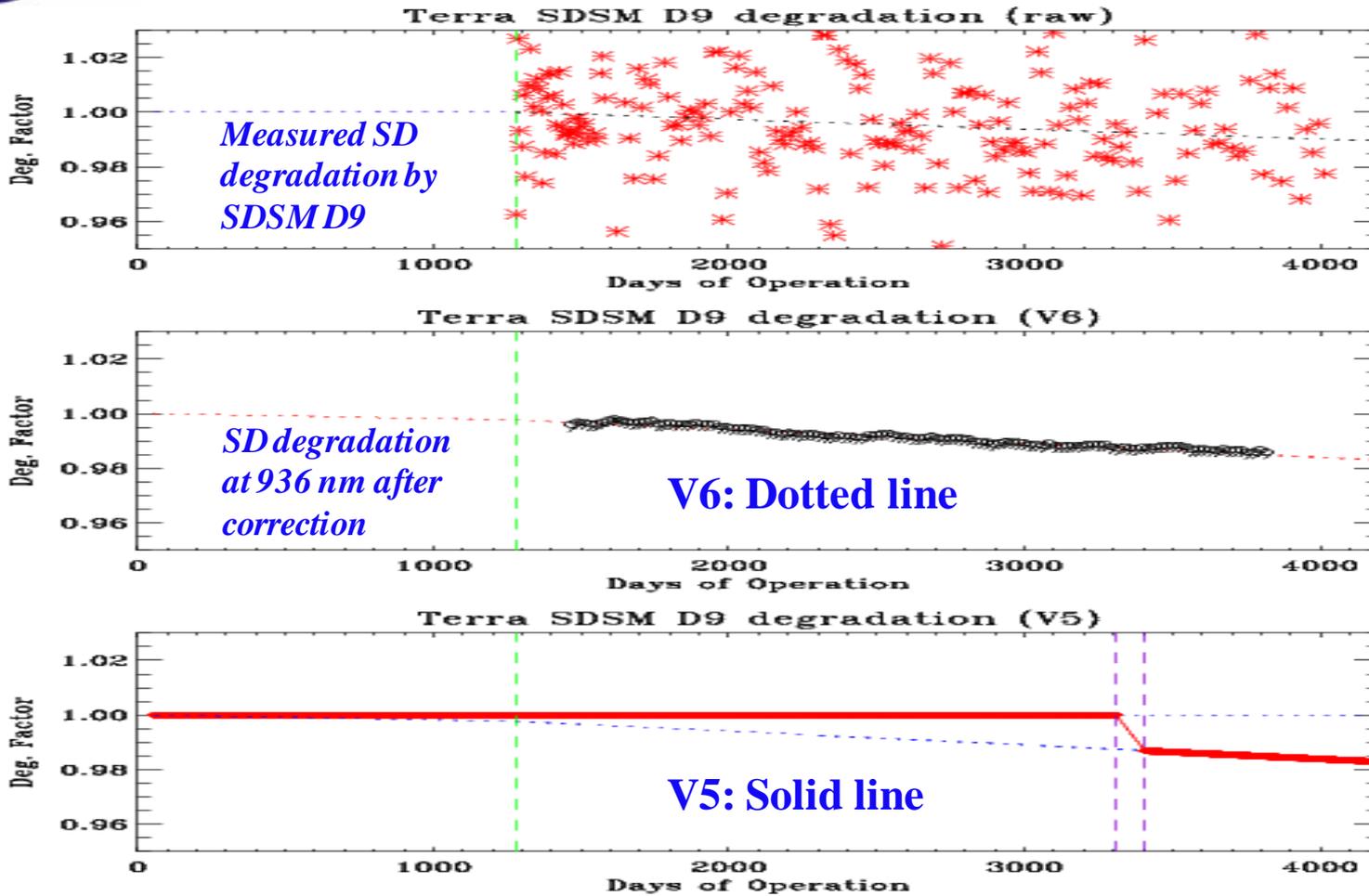
Aqua SDSM tracking SD degradation



Results are derived from normalization approach (to D9). Additional D9 corrections are applied to Collection 6 through the entire mission and to Collection 5 after Jan. 1, 2009 for Terra and after March 1, 2009 for Aqua, respectively.



MODIS SD Degradation Trending

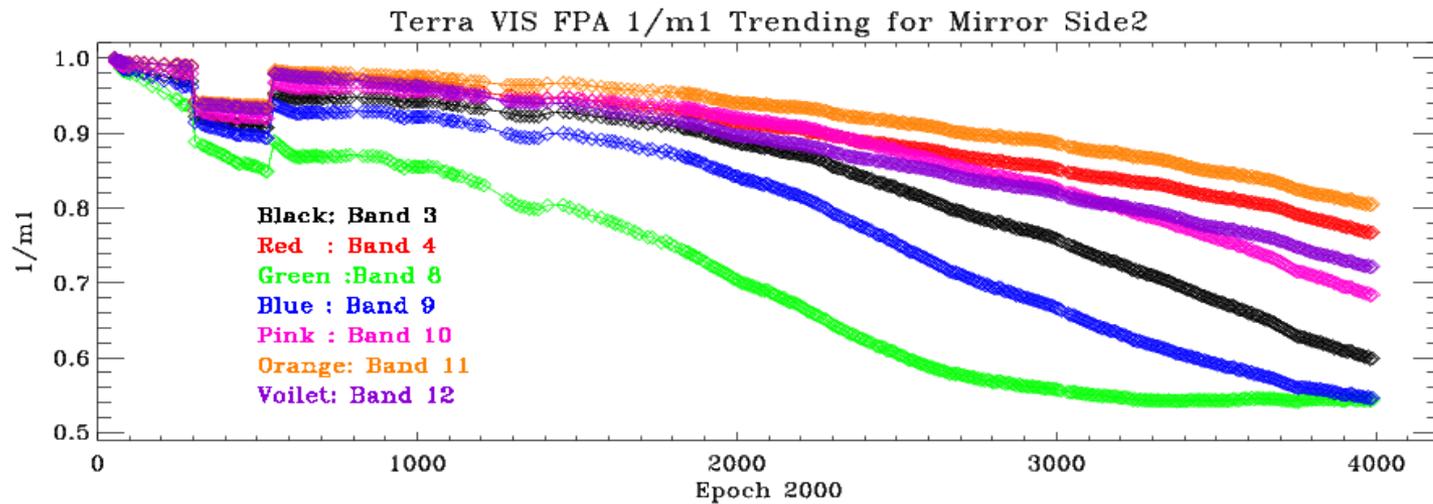
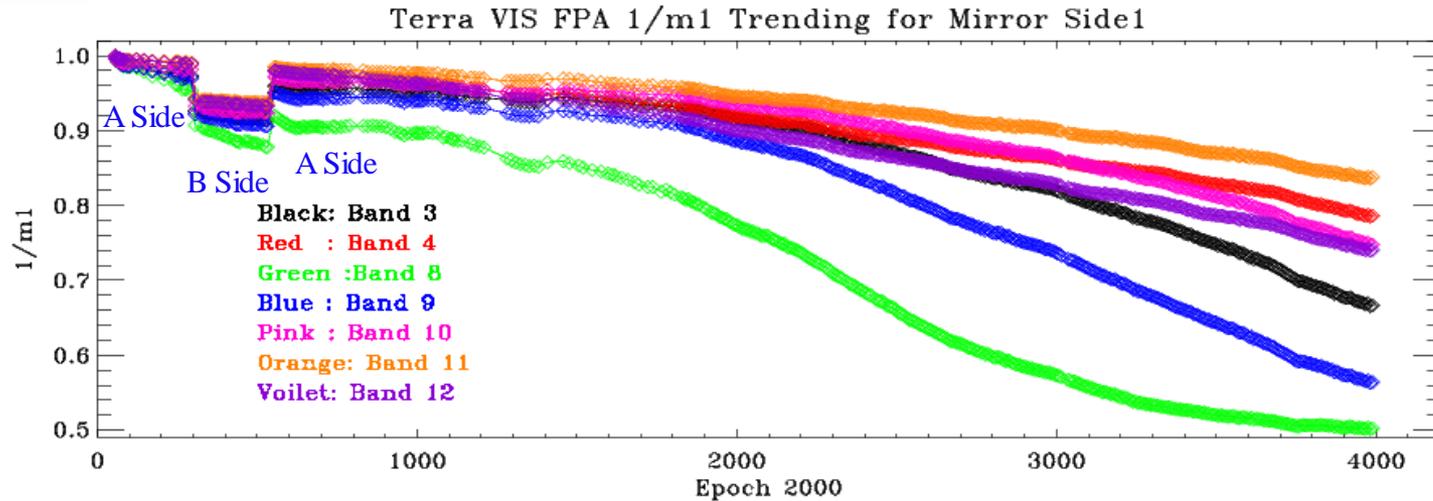


Additional D9 corrections are applied to Terra Collection 6 through the entire mission and to Collection 5 after Jan. 1, 2009.



MODIS RSB Response Trending

Detector Averaged

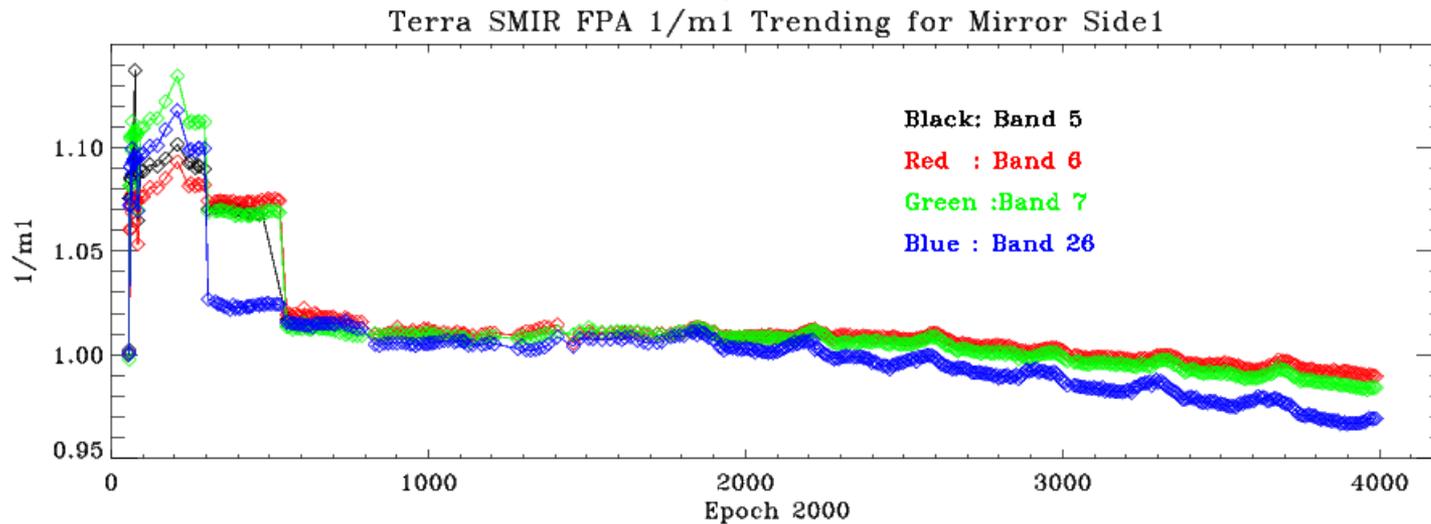
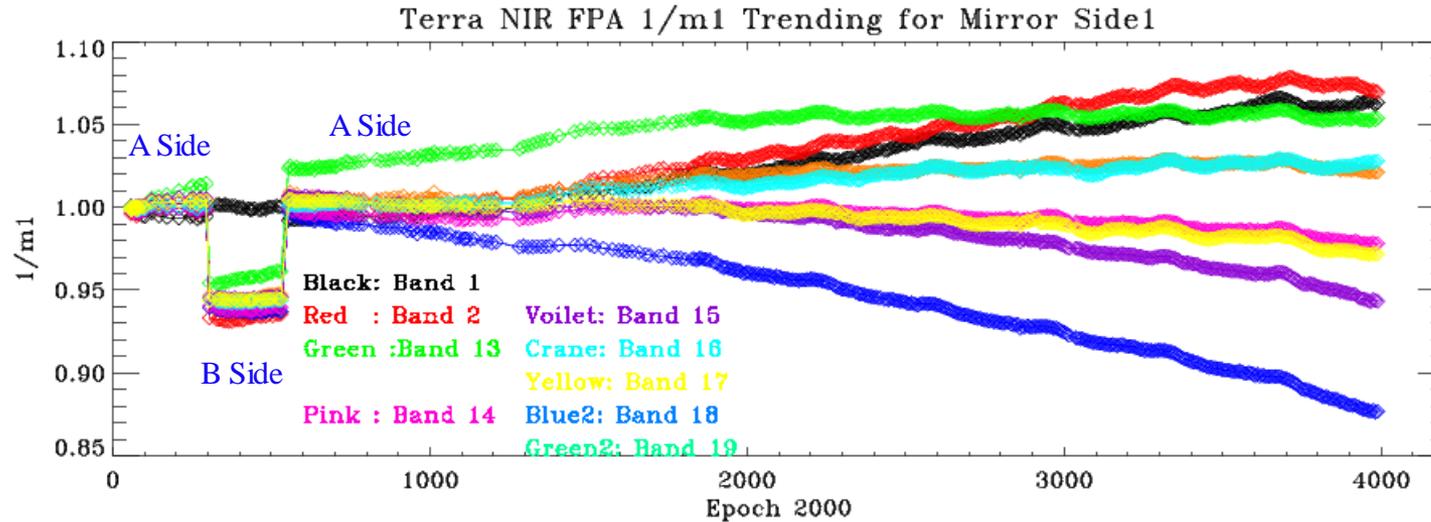


Large mirror side differences are observed in short wavelength bands



MODIS RSB Response Trending

Detector Averaged

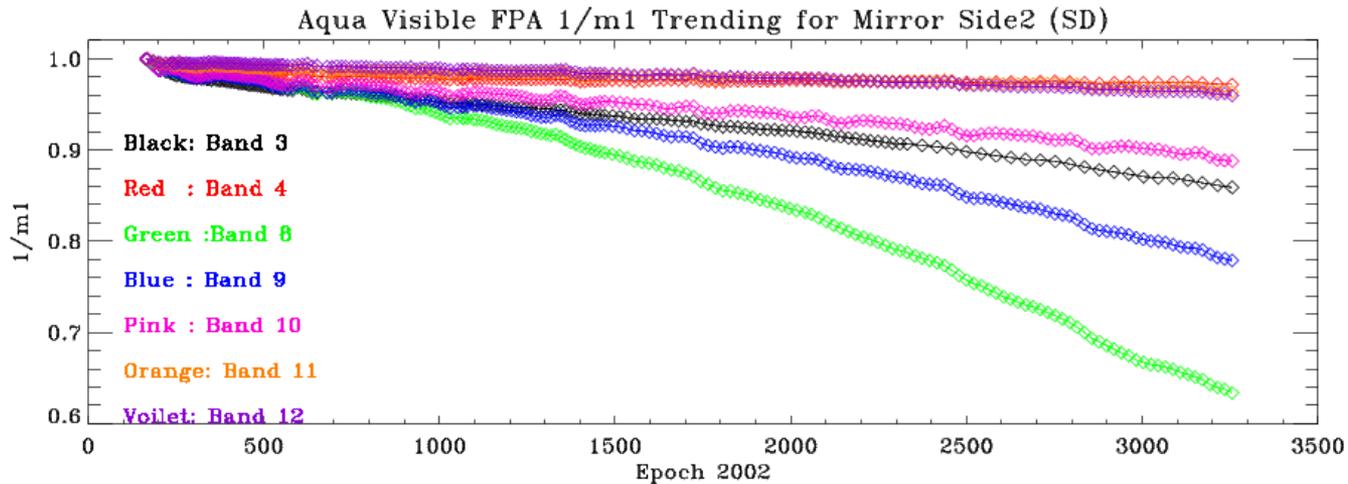
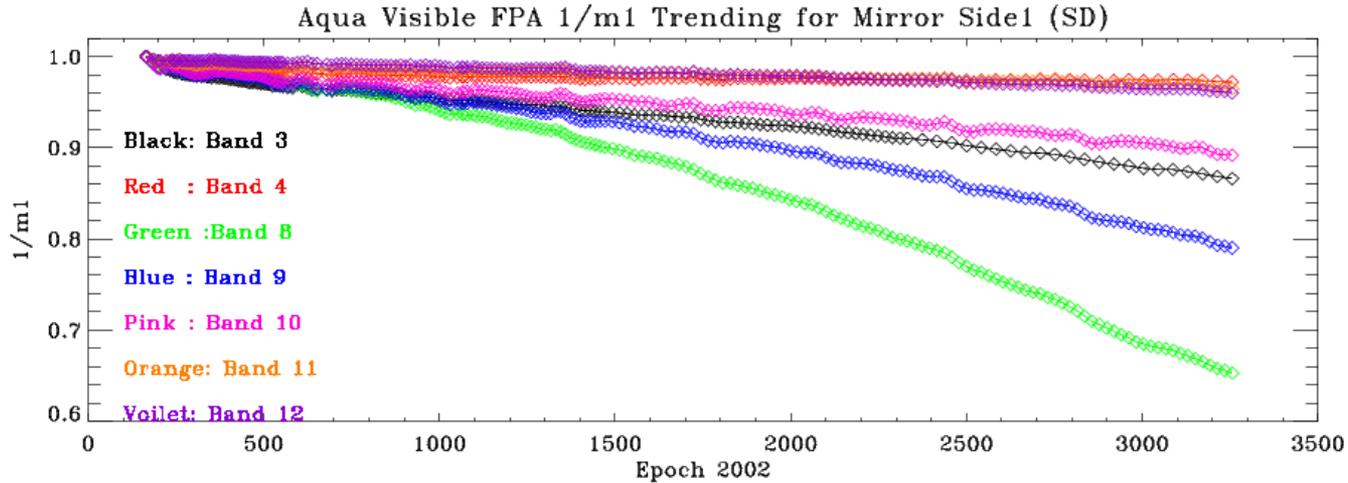
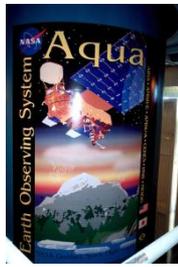


Mirror side differences are small in Terra NIR and SWIR bands



MODIS RSB Response Trending

Detector Averaged

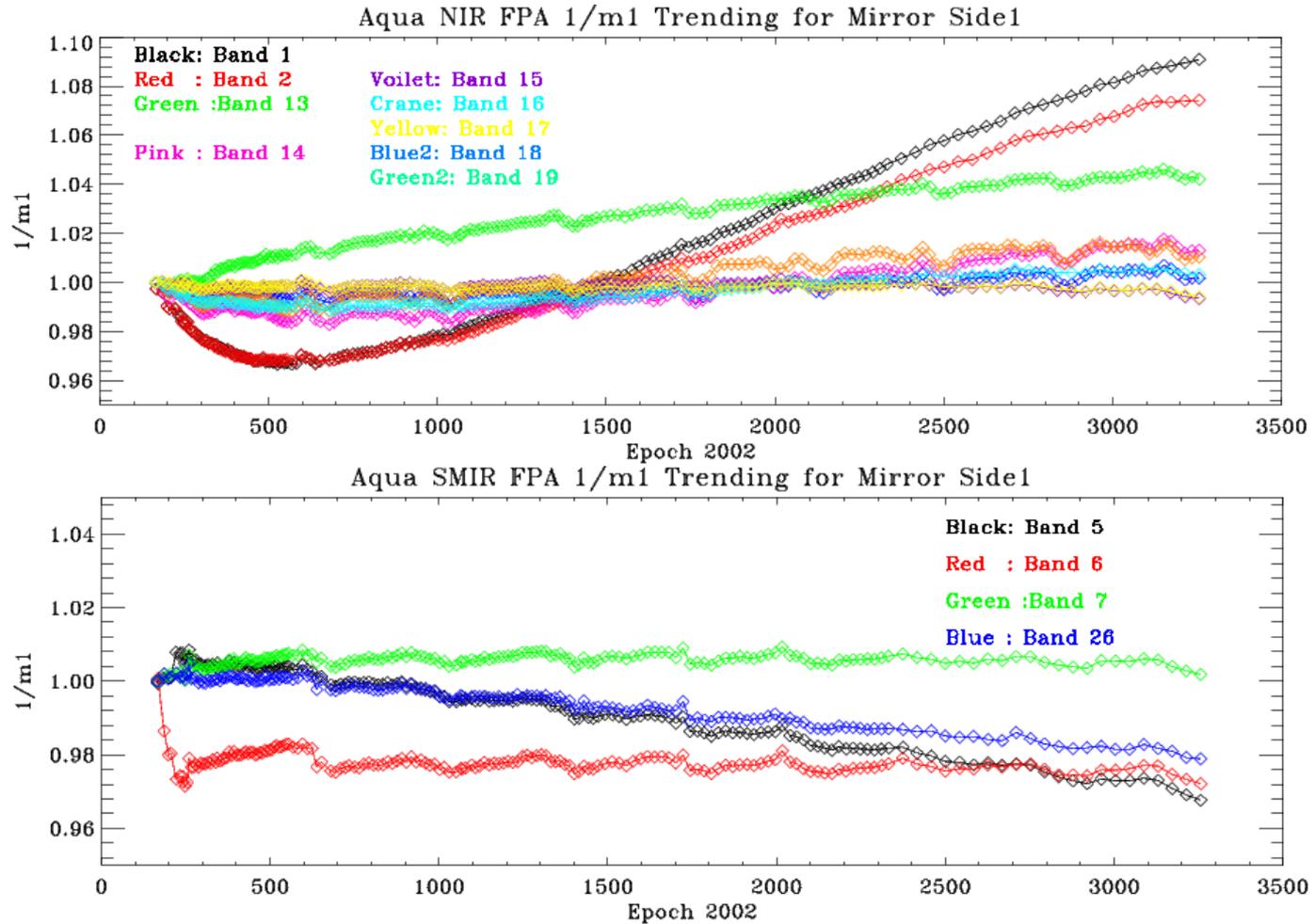
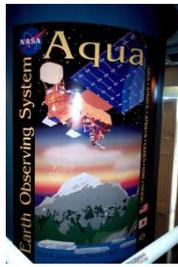


Much smaller mirror side differences in Aqua MODIS



MODIS RSB Response Trending

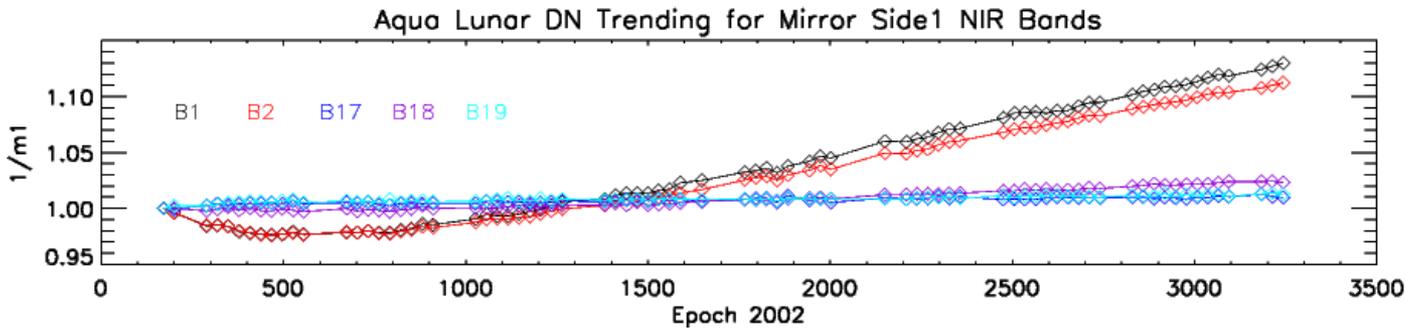
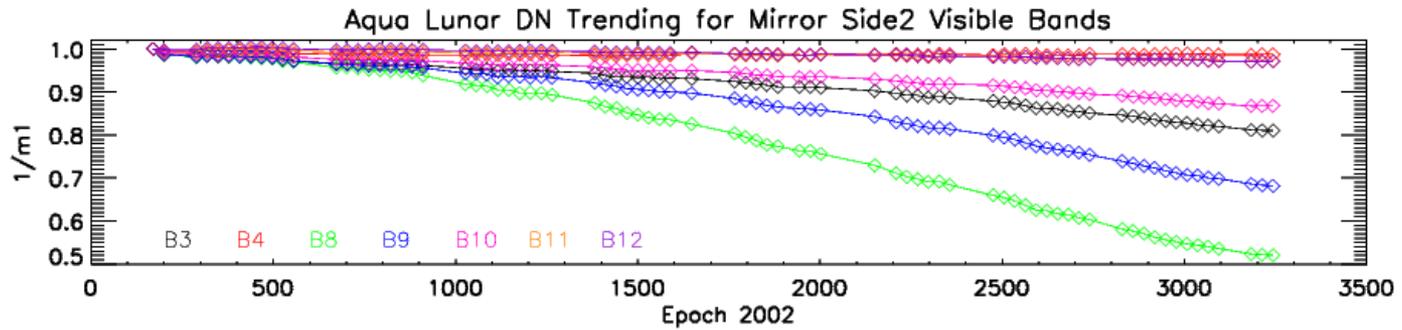
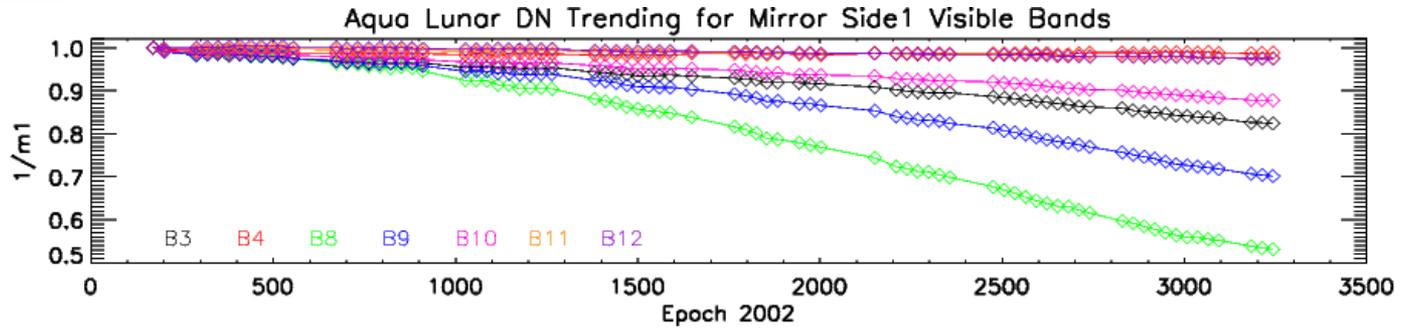
Detector Averaged





MODIS RSB Response Trending

Detector Averaged





MODIS RSB RVS Algorithms



- RVS is characterized by prelaunch measurement and on-orbit variation

$$RVS(B, D, M, \theta, t) = RVS^{pl}(B, M, \theta) RVS^{oo}(B, D, M, \theta, t)$$

- B, D, M, θ and t represent band, detector, mirror side, AOI and time
- dn is the background subtracted instrument signal. *pl*: prelaunch; *oo*: on-orbit.

- RVS on-orbit variation at AOI of the SV

$$RVS^{oo}(B, D, M, \theta_{SV}, t) = \frac{m_1^{moon}(B, D, M, t_0) m_1(B, D, M, t)}{m_1^{moon}(B, D, M, t) m_1(B, D, M, t_0)}$$

- Mirror side one RVS on-orbit variation – a linear function of AOI

$$RVS^{oo}(B, D, 1, \theta, t) = 1 + \frac{\theta - \theta_{SD}}{\theta_{SV} - \theta_{SD}} [RVS^{oo}(B, D, 1, \theta_{SV}, t) - 1]$$

- Mirror side two RVS

$$RVS(B, D, 2, \theta, t) = \frac{dn(B, D, 2, \theta, t)}{dn(B, D, 1, \theta, t)} \frac{m_1(B, D, 1, t)}{m_1(B, D, 2, t)} RVS(B, D, 1, \theta, t)$$

- Instrument response mirror side ratio is obtained from SD, lunar, SRCA, and EV observations

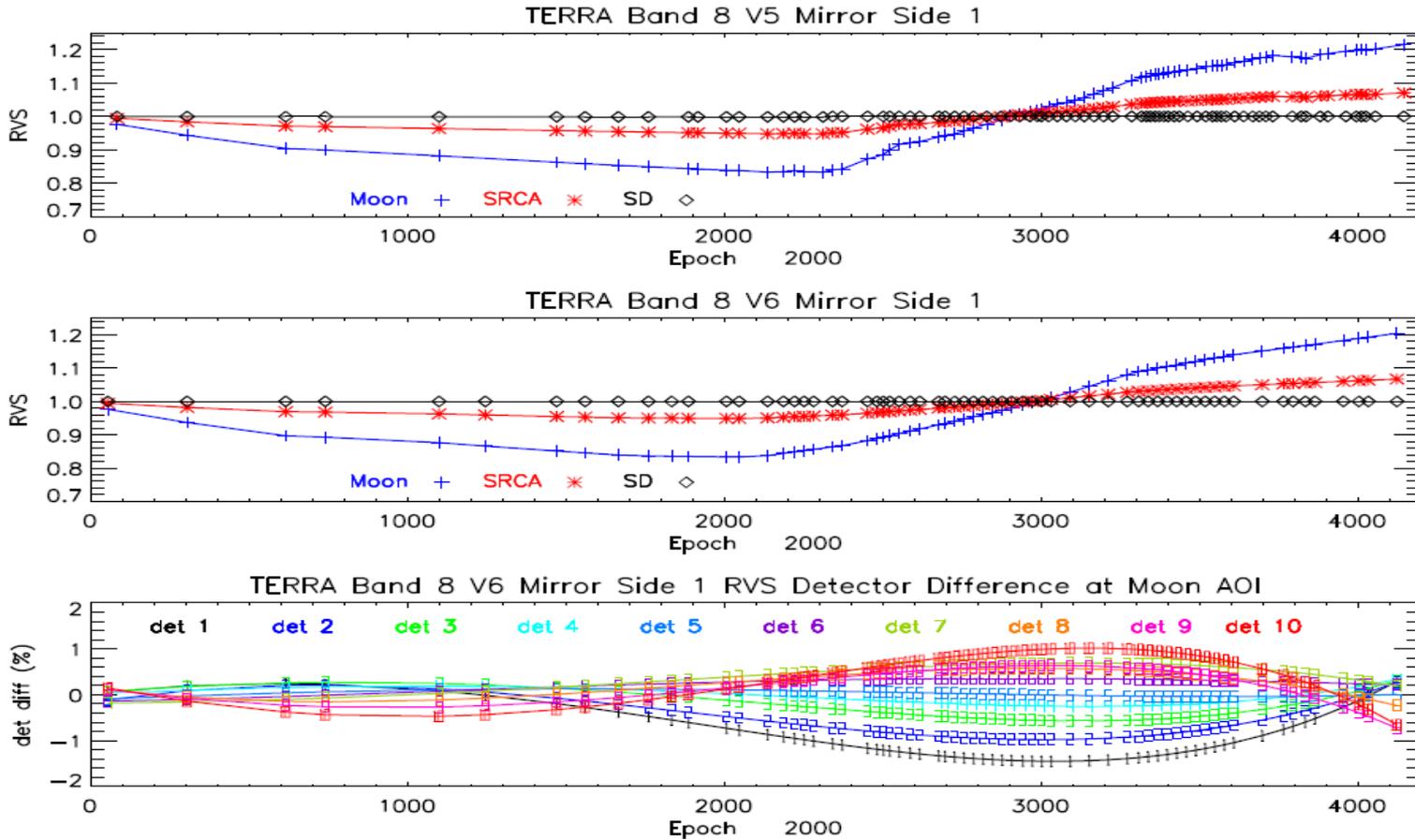
- The calculated RVS for 1354 frames are fitted to a quadratic form, and the fitted coefficients form a time dependent Look-Up Table (LUT) for MODIS RSB RVS

$$RVS^{LIB}(F, t) = c_0(t) + c_1(t)F + c_2(t)F^2$$

- F : Frame



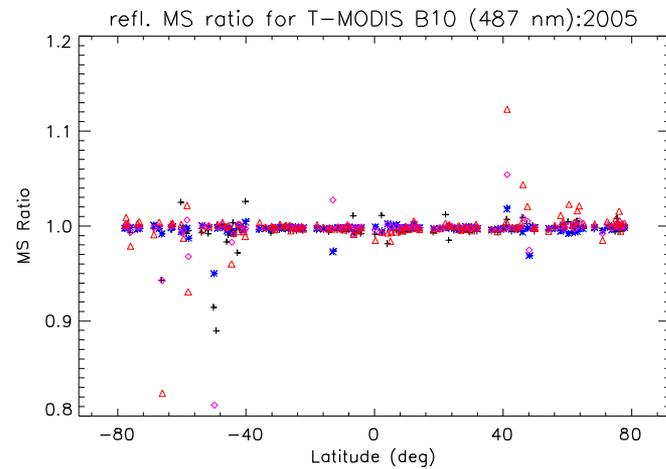
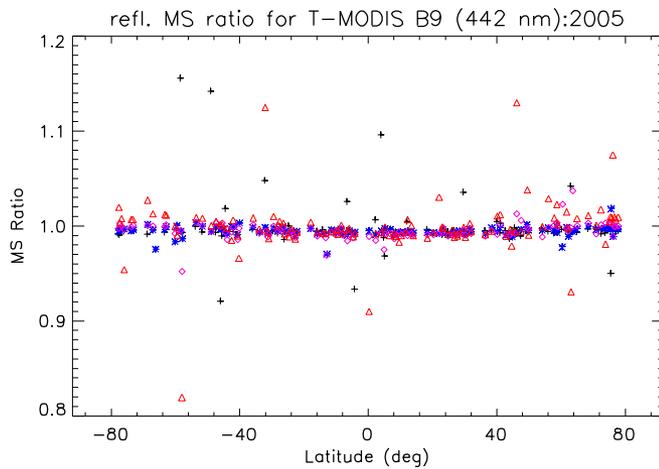
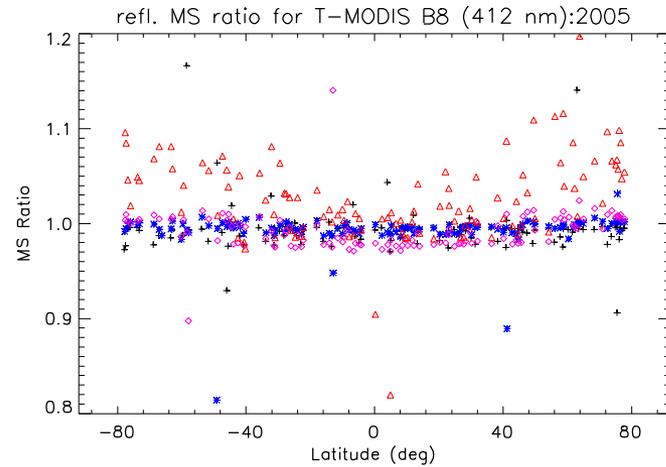
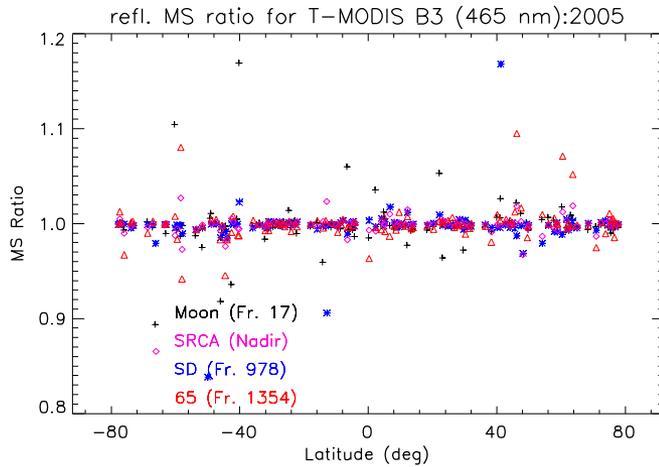
Terra MODIS Band 8 RVS Trending



The RVS detector difference can be as large as 2.5% for Terra band 8.

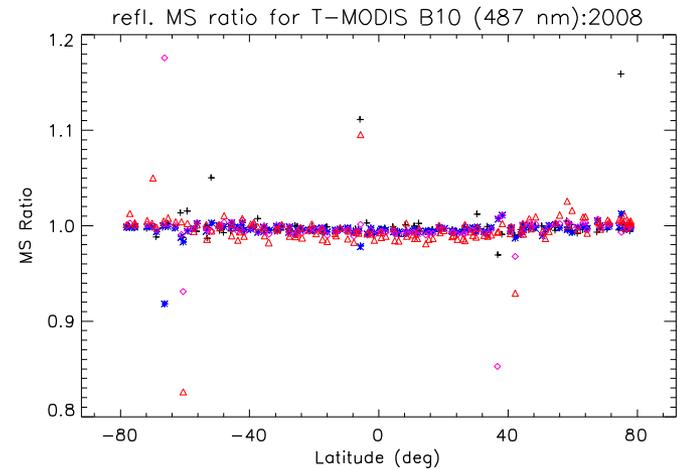
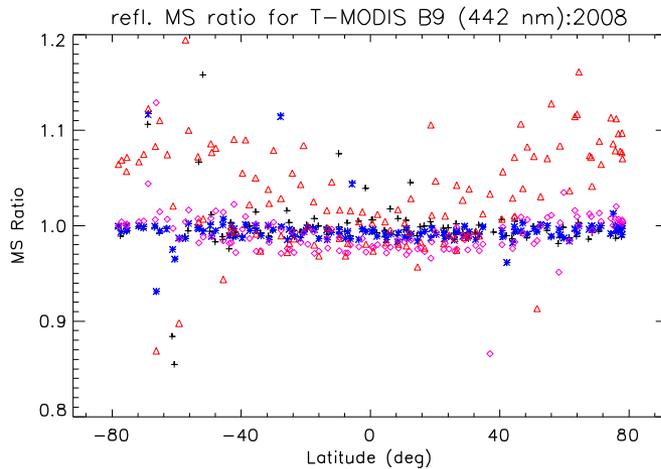
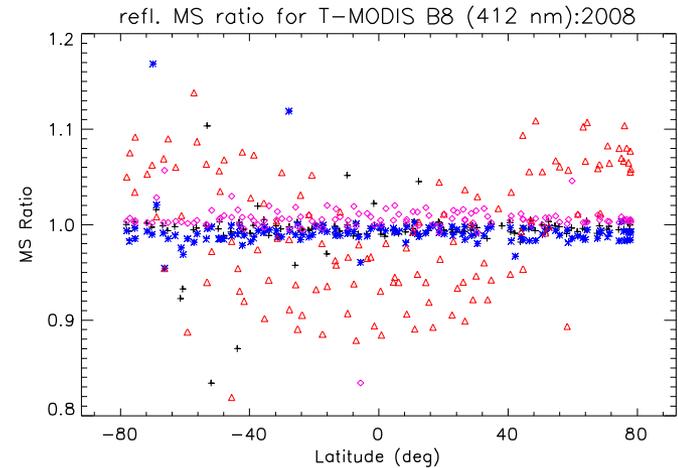
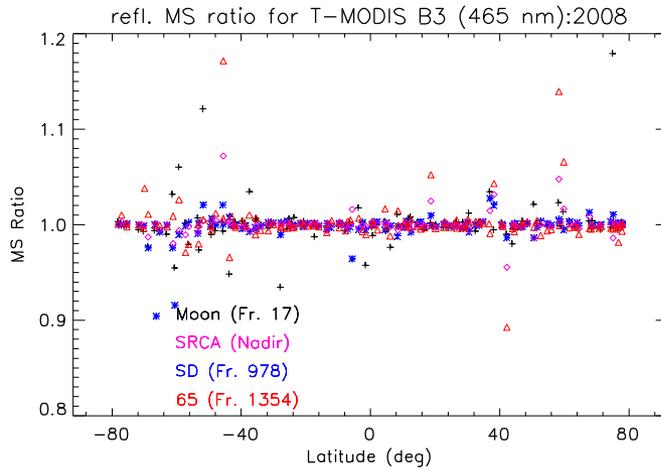


Terra L1B MS Ratio at Different Latitudes



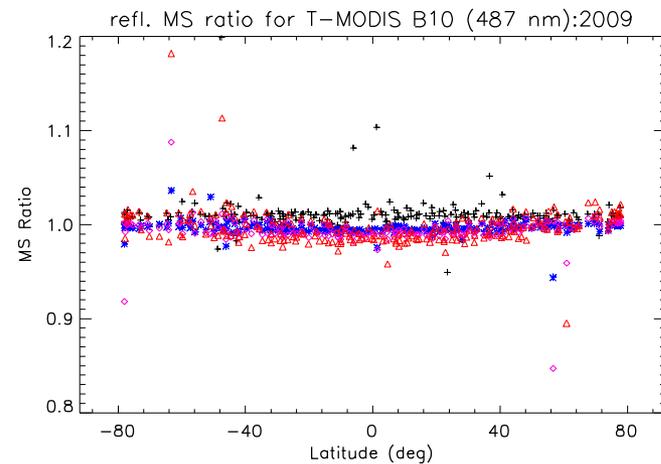
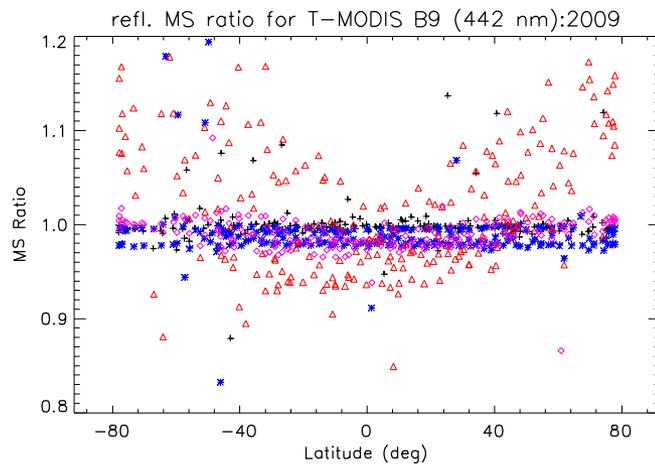
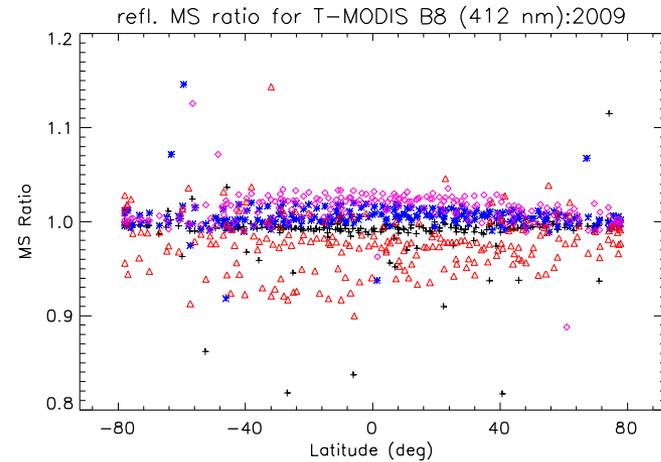
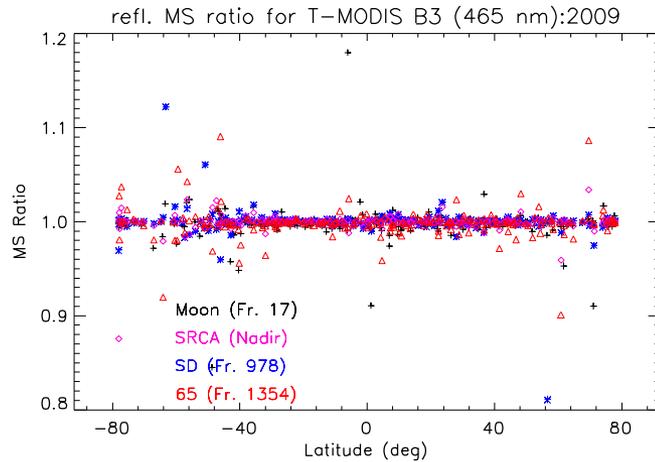


Terra L1B MS Ratio at Different Latitudes



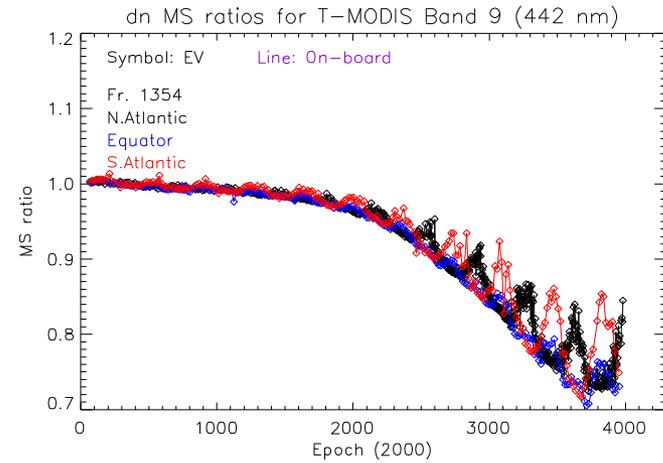
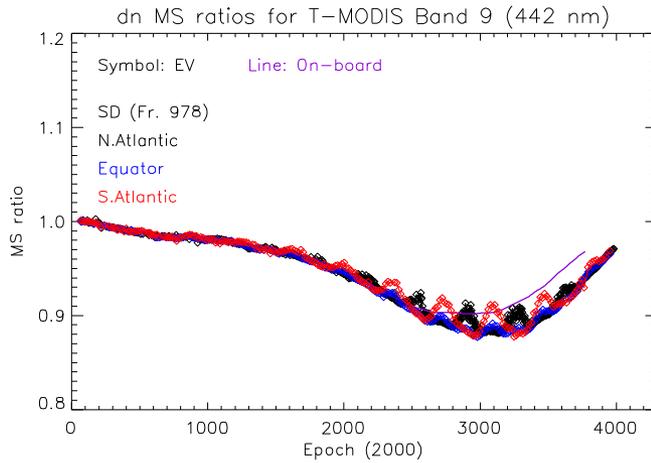
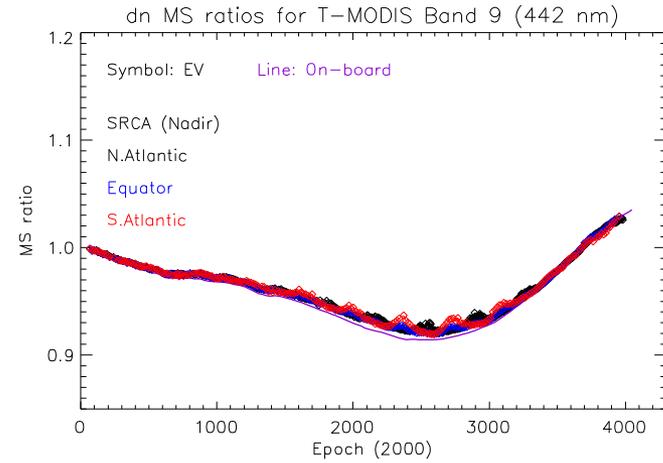
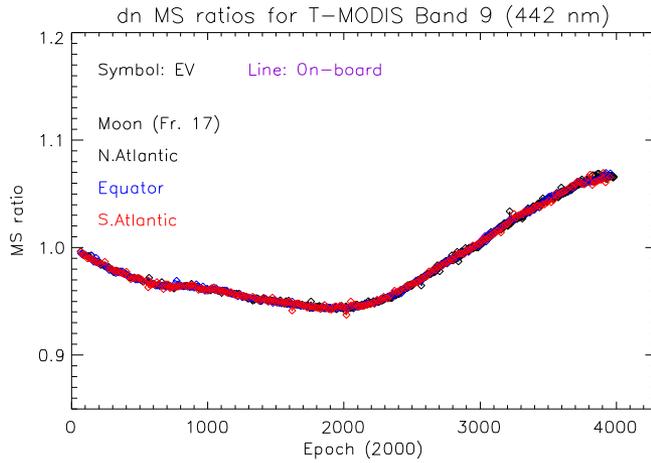


Terra L1B MS Ratio at Different Latitudes



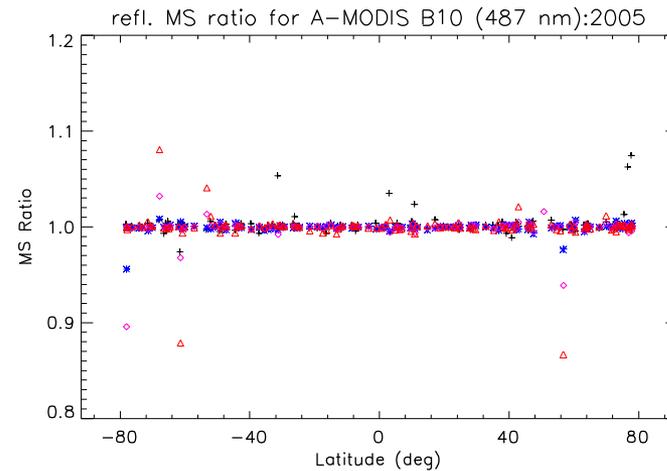
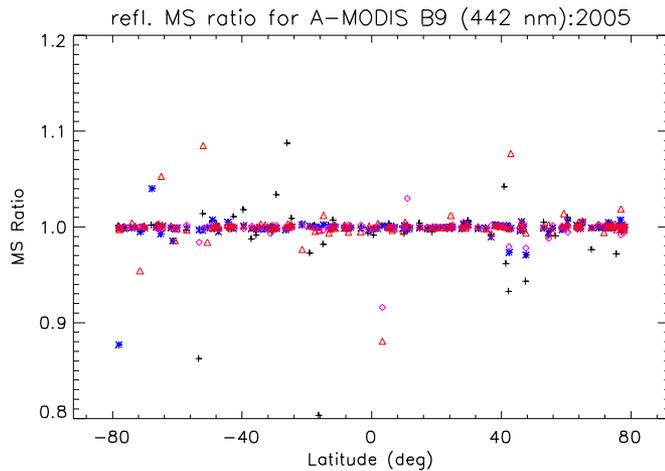
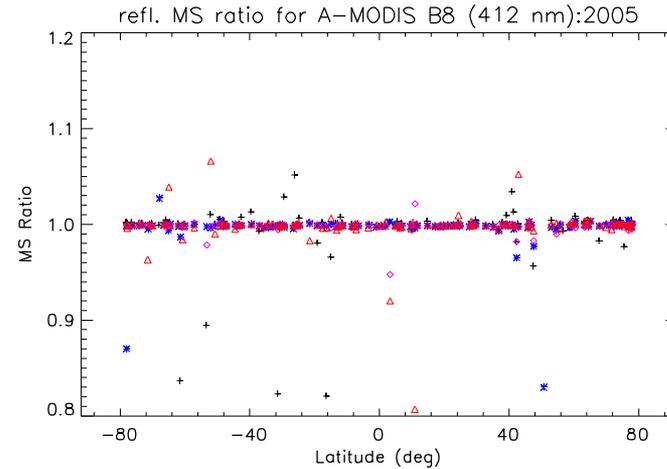
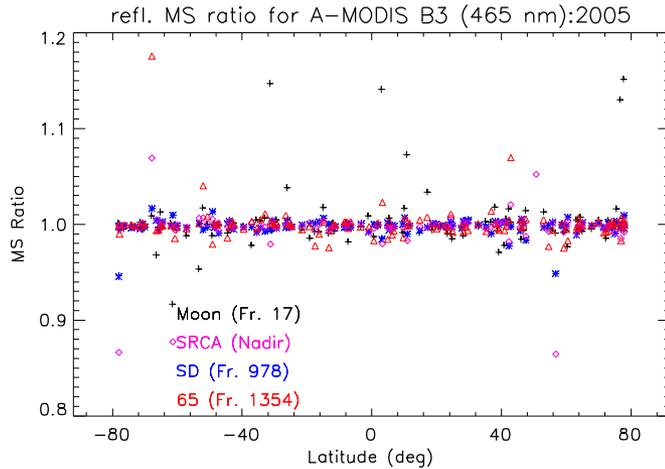


Terra Instrument Response MS Ratio



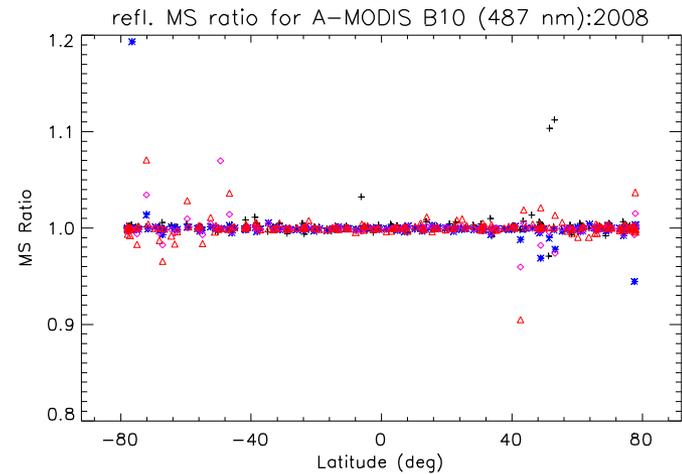
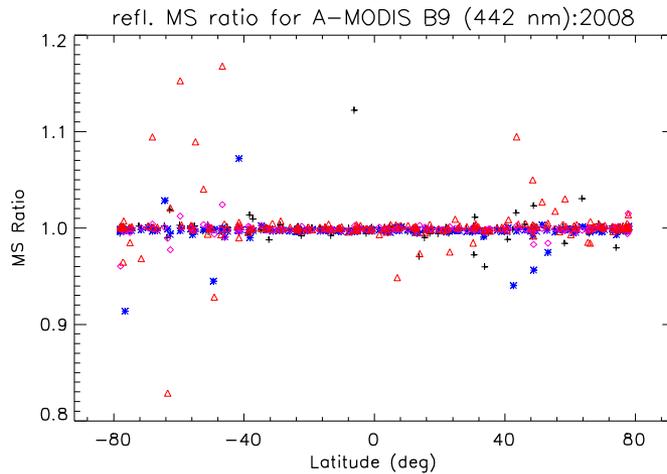
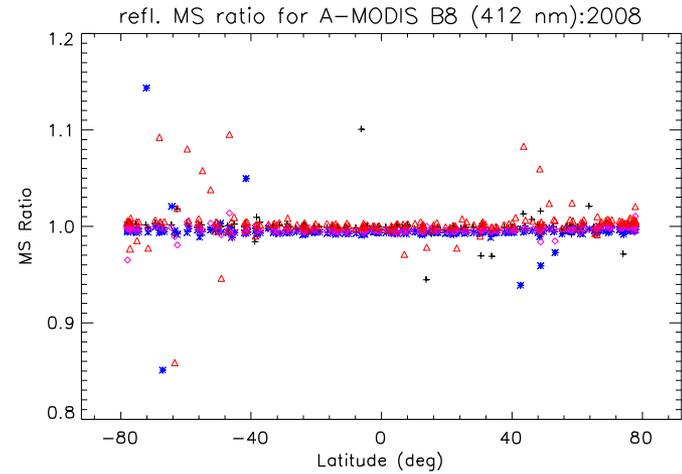
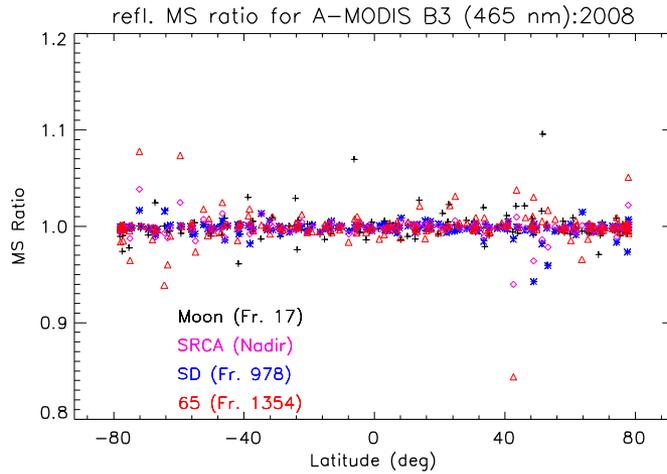


Aqua L1B MS Ratio at Different Latitudes



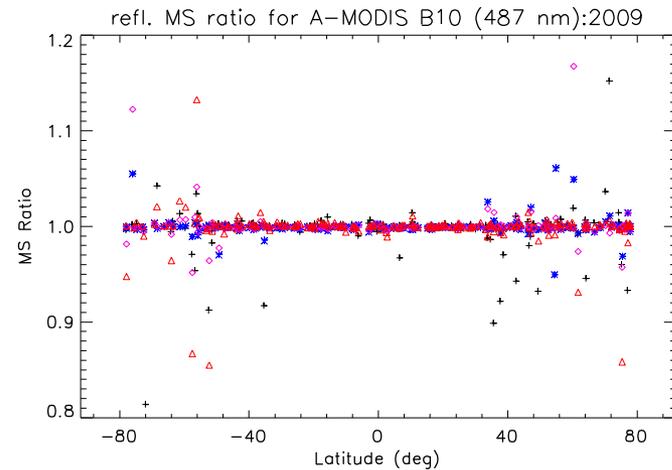
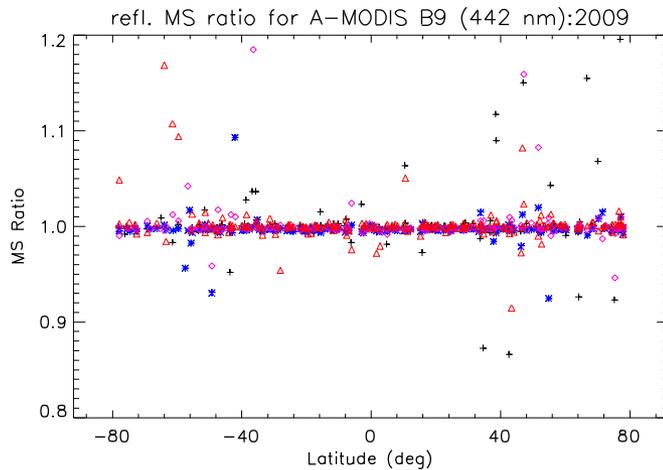
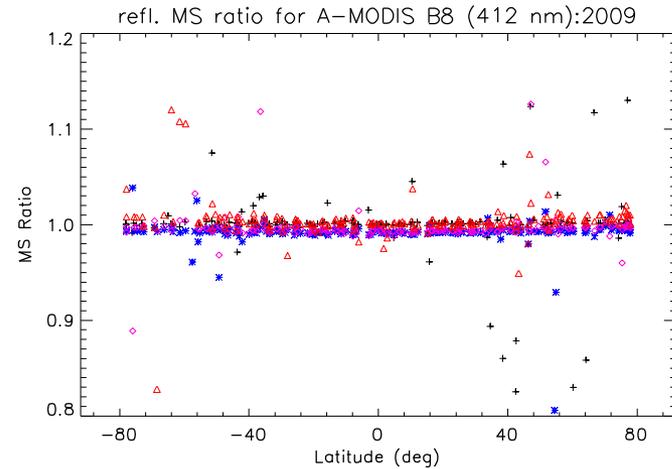
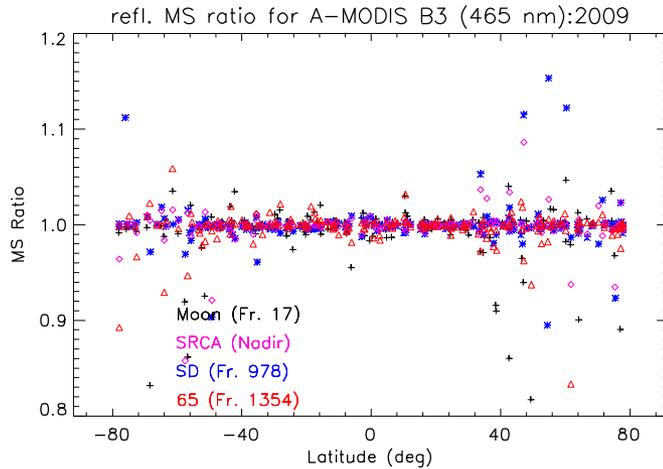


Aqua L1B MS Ratio at Different Latitudes



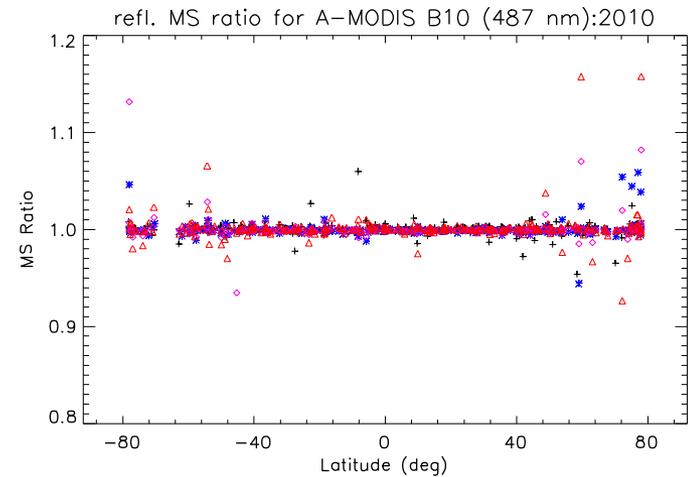
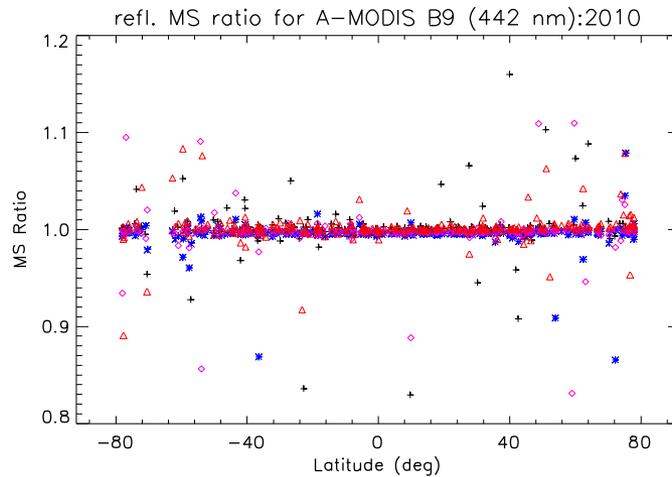
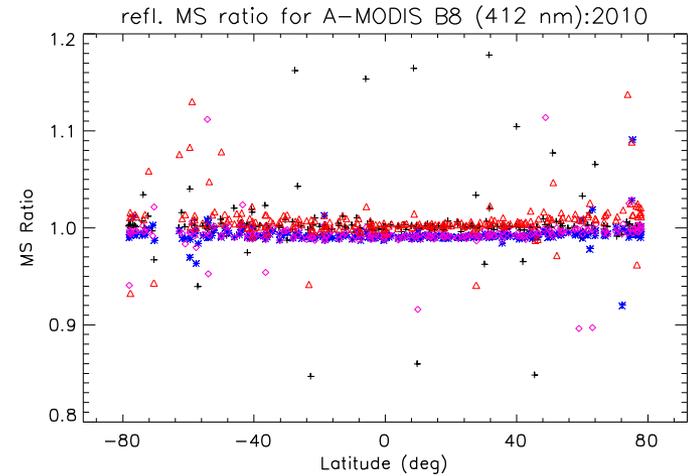
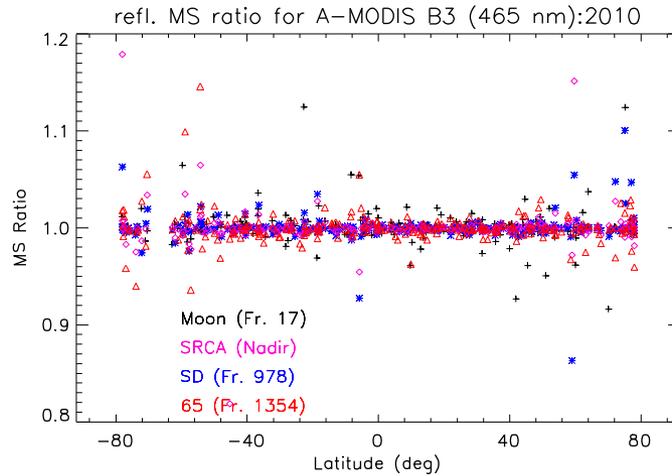


Aqua L1B MS Ratio at Different Latitudes





Aqua L1B MS Ratio at Different Latitudes

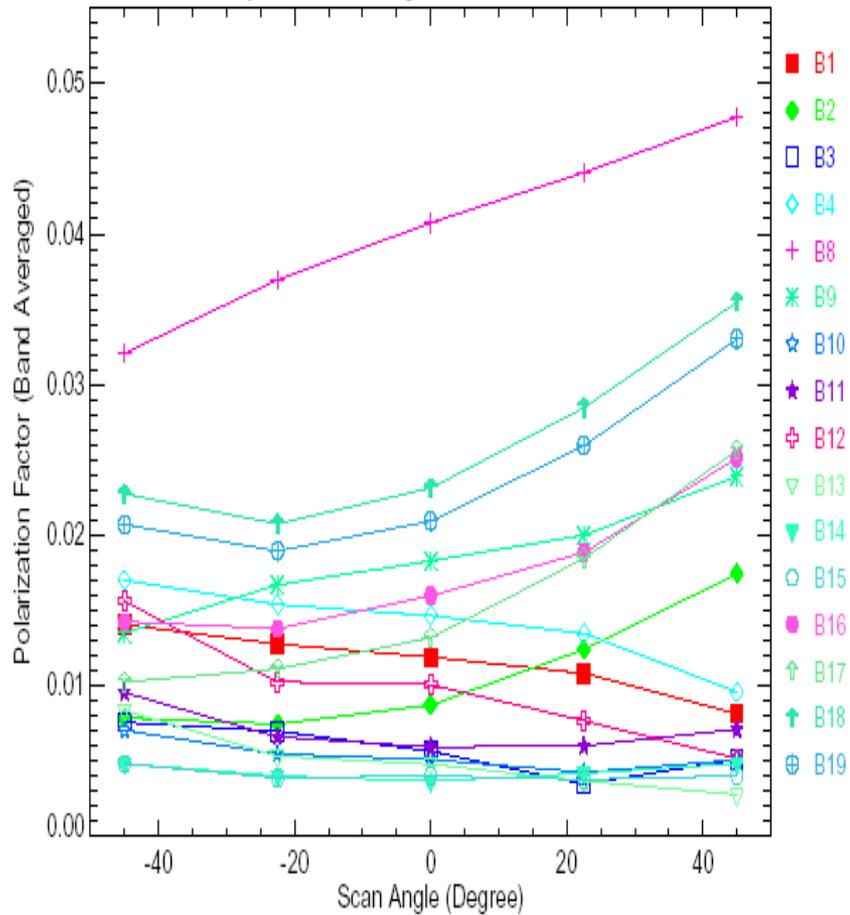




MODIS Band Averaged Polarization Factor



Aqua Band Averaged Polarization Factor



Terra Band Averaged Polarization Factor

