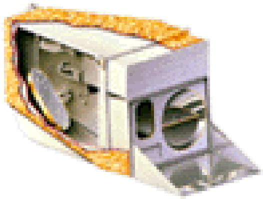


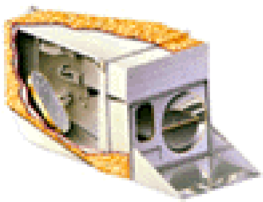
MODIS Calibration and Characterization for the Reflective Solar Bands (RSB)

Jack Xiong and Bill Barnes (NASA/GSFC)

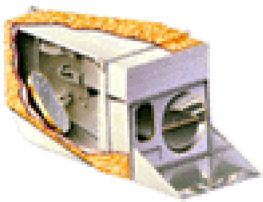
RSB Group (MODIS Characterization Support Team)

Ocean Color Calibration and Characterization Review Meeting, February 11-12, 2004

Outline

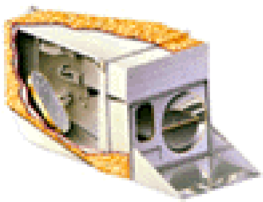


- Instrument Background
- Reflective Solar Bands (RSB) Calibration Overview
  - Pre-launch calibration activities
  - On-orbit calibration algorithm
- Calibration Results and Discussions
  - Solar diffuser (SD) bi-directional reflectance factor (BRF)
  - Temperature correction coefficients
  - Response versus scan angle (RVS)
  - SD screen (SDS) vignetting function (VF)
  - SD degradation using SD stability monitor (SDSM)
  - m1 trending results

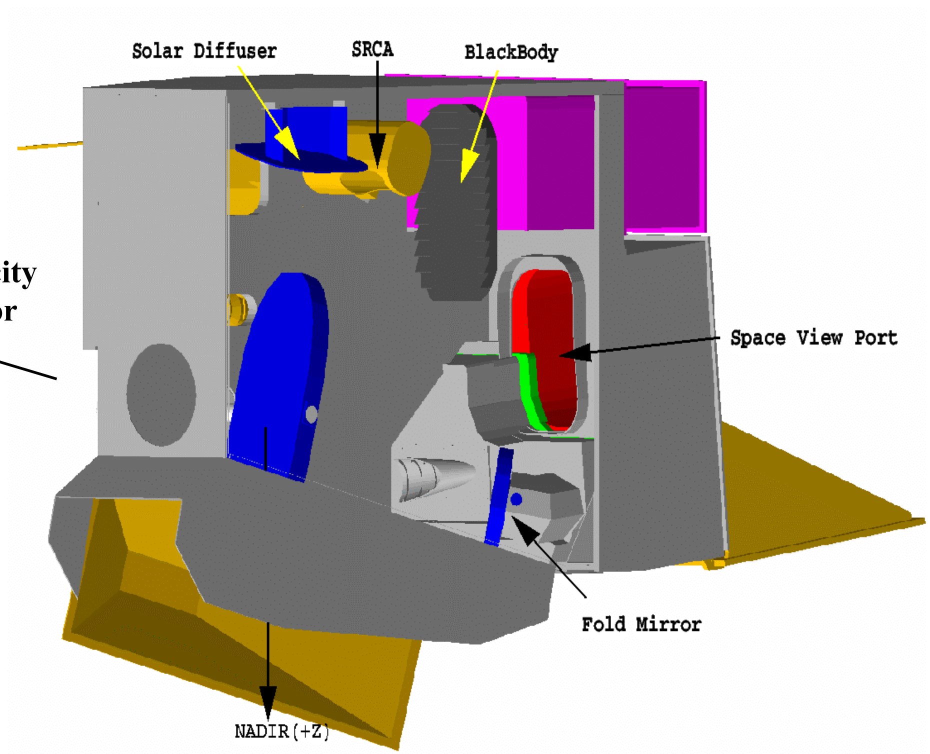


Outline

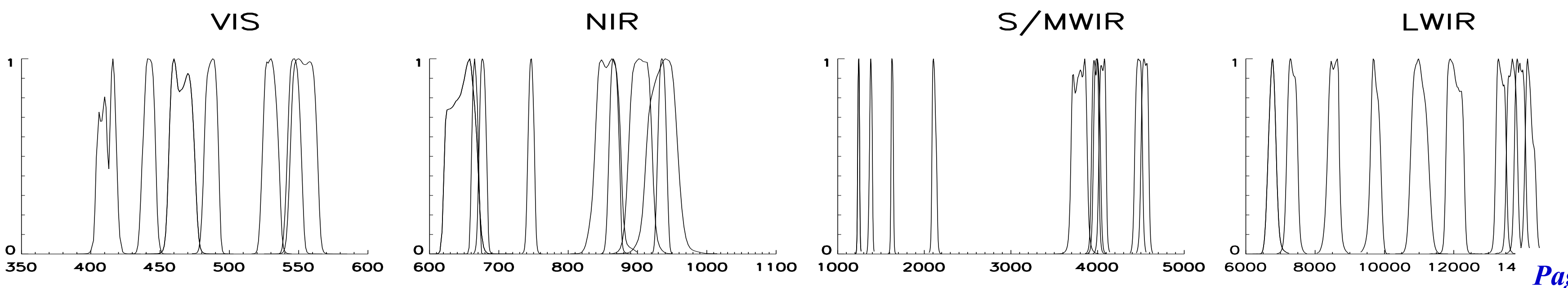
- Challenging Issues and Concerns
  - BRF error’s impact on RSB calibration
  - Instrument and focal plane temperature effects
  - On-orbit RVS characterization limits
  - Polarization (SBRS/MCST/Miami)
  - SD screen vignetting effect – observations and simulation results (Xiong/Waluschka)
  - Scattering (SBRS/Waluschka)
  - Earth shine (Wolfe)
  - Calibration (detector’s response) stability



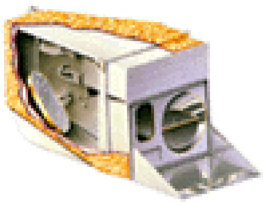
Instrument Background



- 36 spectral bands with wavelengths from 0.4 to 14.5 µm
- Spatial resolution at nadir: 250m (2 bands), 500m (5 bands) and 1000m
- 4 FPAs: VIS, NIR, SMIR, LWIR
- On-Board Calibrators: SD/SDSM, SRCA, and BB (plus space view)
- 12 bit (0-4095) dynamic range
- 2-sided paddle wheel scan mirror scans 2330 km swath in 1.47 sec (1354 data frames, ±55º)
- Day data rate = 10.6 Mbps; night data rate = 3.3 Mbps (100% duty cycle, 50% day and 50% night)



Instrument Background



MODIS Design Parameters and Specifications

Orbit:	705 km, 10:30 a.m. descending node or 1:30 p.m. ascending node, sun-synchronous, near-polar, circular
Scan Rate:	20.3 rpm, cross track
Swath Dimensions:	2330 km (across track) by 10 km (along track at nadir)
Telescope:	17.78 cm diam. off-axis, afocal (collimated), with intermediate field stop
Size:	1.0 x 1.6 x 1.0 m
Weight:	250 kg
Power:	225 W (orbital average)
Data Rate:	11 Mbps (peak daytime)
Quantization:	12 bits
Spatial Resolution:	250 m (bands 1-2)
(at nadir):	500 m (bands 3-7), 1000 m (bands 8-36)
Design Life:	5 years

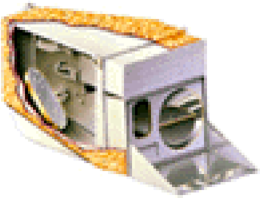
Primary Use	Band	Bandwidth[1]	Spectral Radiance[2]	Required SNR[3]
Land/Cloud Boundaries	1	620-670	21.8	128
	2	841-876	24.7	201
Land/Cloud Properties	3	459-479	35.3	243
	4	545-565	29.0	228
	5	1230-1250	5.4	74
	6	1628-1652	7.3	275
	7	2105-2155	1.0	110
Ocean color/ Phytoplankton/ Biogeochemistry	8	405-420	44.9	880
	9	438-448	41.9	838
	10	483-493	32.1	802
	11	526-536	27.9	754
	12	546-556	21.0	750
	13	662-672	9.5	910
	14	673-683	8.7	1087
	15	743-753	10.2	586
	16	862-877	6.2	516
Atmospheric Water Vapor	17	890-920	10.0	167
	18	931-941	3.6	57
	19	915-965	15.0	250

Primary Use	Band	Bandwidth[1]	Spectral Radiance[2]	Required NEΔT(K)[4]
Surface/Cloud Temperature	20	3.660-3.840	0.45	0.05
	21	3.929-3.989	2.38	2.00
	22	3.929-3.989	0.67	0.07
	23	4.020-4.080	0.79	0.07
Atmospheric Temperature	24	4.433-4.498	0.17	0.25
	25	4.482-4.549	0.59	0.25
Cirrus Clouds	26	1.360-1.390	6.00	150[3]
Water Vapor	27	6.535-6.895	1.16	0.25
	28	7.175-7.475	2.18	0.25
	29	8.400-8.700	9.58	0.05
Ozone	30	9.580-9.880	3.69	0.25
Surface/Cloud Temperature	31	10.780-11.280	9.55	0.05
	32	11.770-12.270	8.94	0.05
Cloud Top Altitude	33	13.185-13.485	4.52	0.25
	34	13.485-13.785	3.76	0.25
	35	13.785-14.085	3.11	0.25
	36	14.085-14.385	2.08	0.35

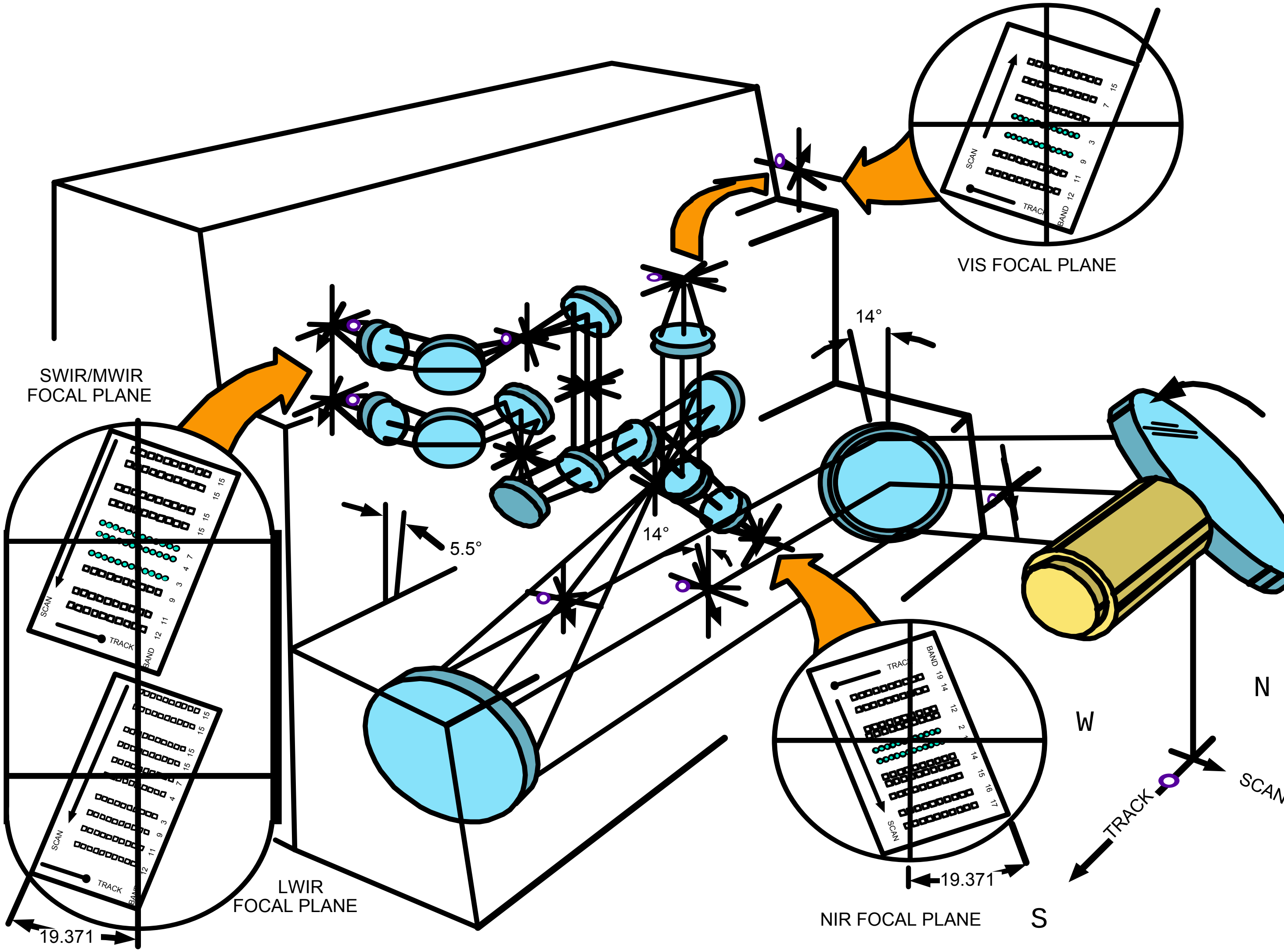
[1]Bands 1 to 19, nm; Bands 20-36, µm
[2](W/m^2-µm-sr)
[3]SNR=Signal-to-noise ratio
[4]NEΔT=Noise-equivalent temperature difference

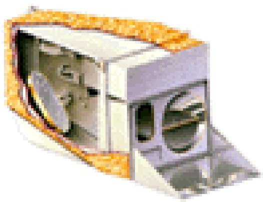
} Performance goal is 30%-40% better than required

Instrument Background



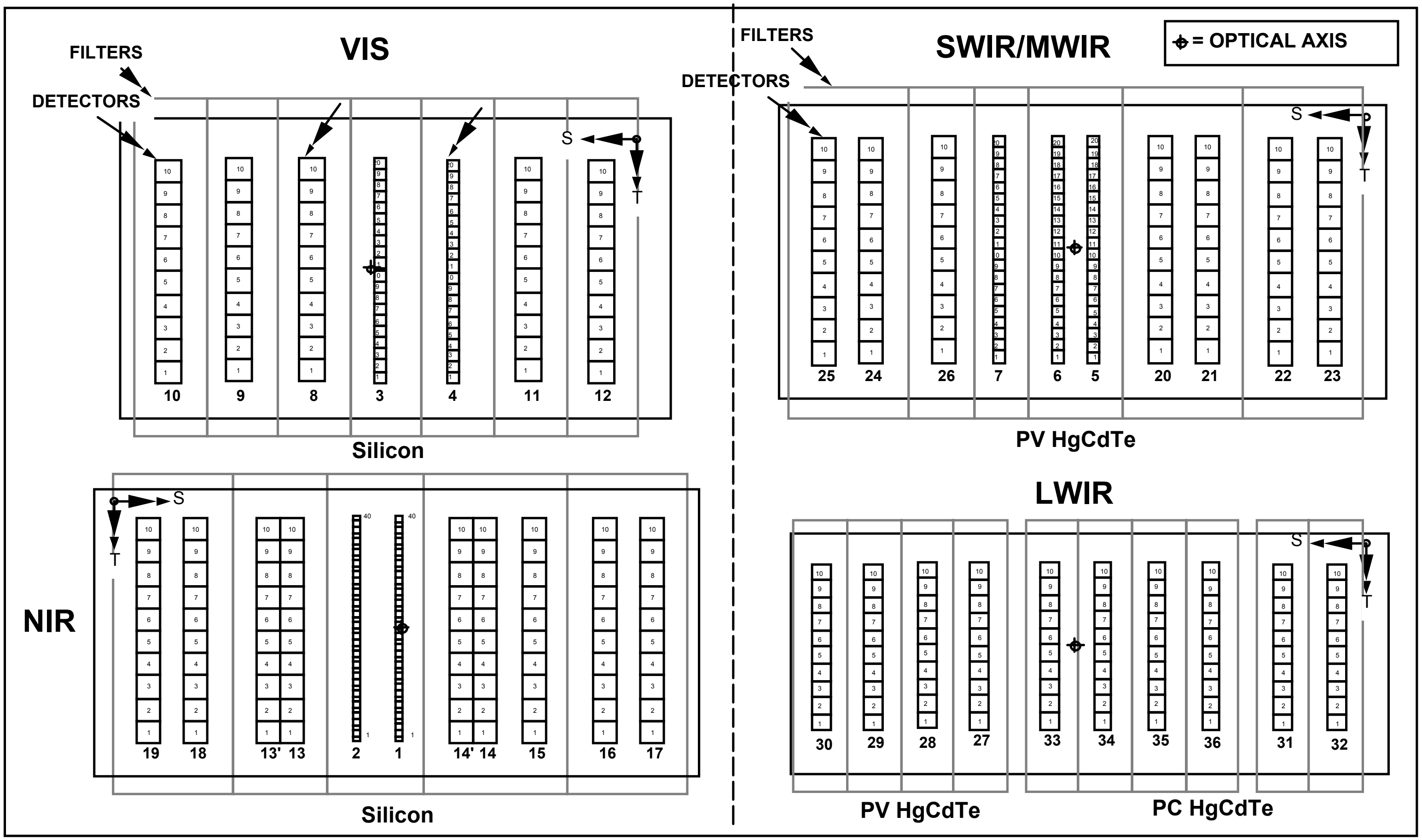
MODIS Optics System





Instrument Background

MODIS Four Focal Planes (36 bands, 490 detectors)



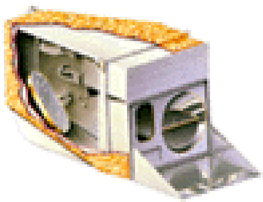
Instrument FPA Main Frame Temperature

Cold FPAs: (80. 83, 85k)

S: scan direction; T: track direction

B13 and B14 have 2 columns of detectors for TDI high and low gain outputs

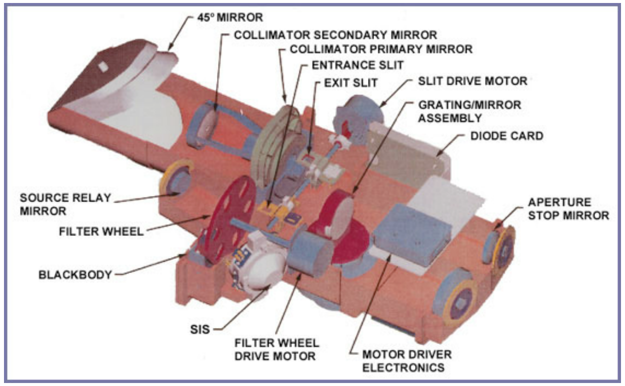
Instrument Background



On-board Calibrators (OBCs)

Blackbody (BB)

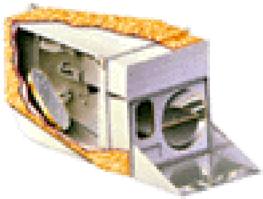
Spectro-Radiometric Calibration Assembly (SRCA)



Solar Diffuser (SD)

Solar Diffuser Stability Monitor (SDSM)

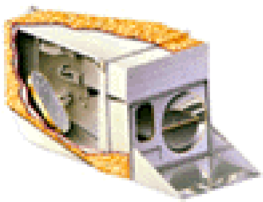
- BB for thermal emissive bands (TEB) calibration
- SD for reflective solar bands (RSB) calibration
- SDSM for monitoring SD degradation
- SRCA for spatial and spectral (RSB only) monitoring



Calibration Overview

Pre-launch Calibration

- Calibration and Characterization:
  - SIS100 (Spectral Integration Sphere) used for RSB radiometric calibration in thermal vacuum (TV)
    - Calibration performed at three instrument temperature plateaus (hot, nominal, and cold)
    - Calibration parameters derived (detector's response and its temperature dependence, noise characterization, non-linearity)
  - Spectral and spatial characterization (RSR; BBR)
  - Response versus scan angle measurements (RVS)
  - SD BRF measurements
  - Polarization characterization



Calibration Overview

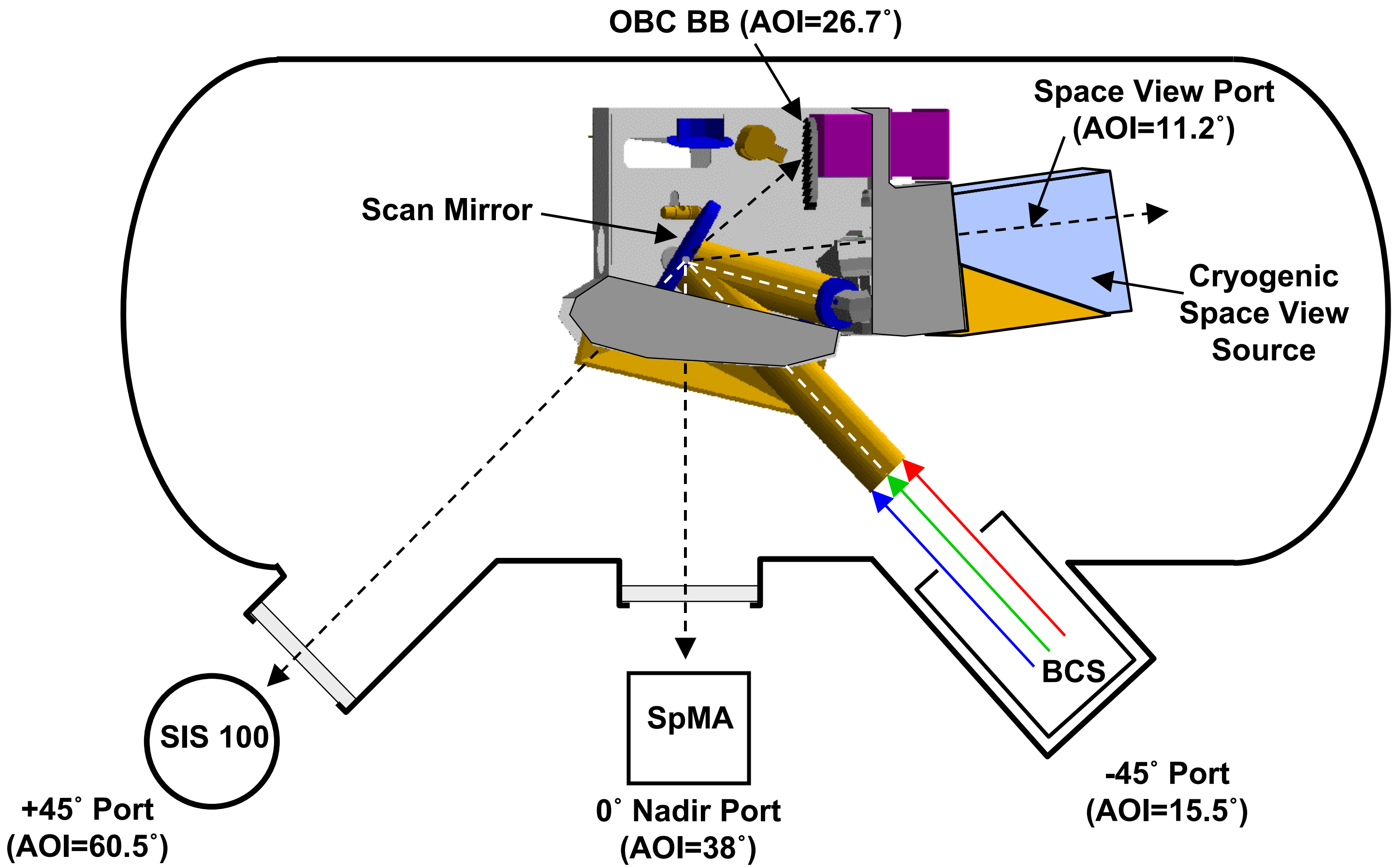
MODIS Calibration Accuracy Requirements (RSB)

- 0.3Ltyp to 0.9Lmax; within ±45° of scan angle range:
  - Reflectance: 2%; Radiance: 5%
  - Polarization: 2% (except for B8 at 412nm)

Band	CW (nm)	BW (nm)	IFOV (m)	Ltyp (W/m^2/sr/ μ)	Lmax (W/m^2/sr/ μ)	Lcloud (W/m^2/sr/ μ)	SNR
1	645	50	250	21.8	685	457	128
2	858	35	250	24.7	285	293	201
3	469	20	500	35.3	593	570	243
4	555	20	500	29.0	518	559	228
5	1240	20	500	5.4	110	138	74
6	1640	24	500	7.3	70	68	275
7	2130	50	500	1.0	22	27	110
8	412	15	1000	44.9	175	573	880
9	443	10	1000	41.9	133	585	838
10	488	10	1000	32.1	101	539	802
11	531	10	1000	27.9	82	538	754
12	551	10	1000	21.0	64	528	750
13L	667	10	1000	9.5	32	471	910
14L	678	10	1000	8.7	31	440	1087
15	748	10	1000	10.2	26	373	586
16	869	15	1000	6.2	16	286	516
17	905	30	1000	10.0	185	252	167
18	936	10	1000	3.6	256	267	57
19	940	50	1000	15.0	189	244	250
26	1375	30	1000	6.0	90	113	150
13H	667	10	1000	9.5	32	471	910
14H	678	10	1000	8.7	31	440	1087

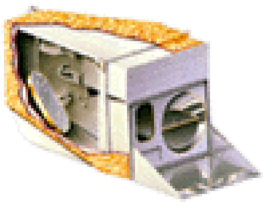
Calibration Overview

Pre-launch: Thermal Vacuum Chamber



Instrument Temperature Plateaus, SMIR and LWIR FPAs Temperatures (TEB)

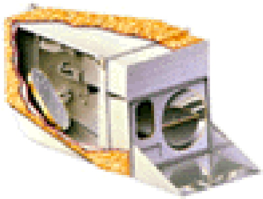
Calibration Overview



Pre-launch

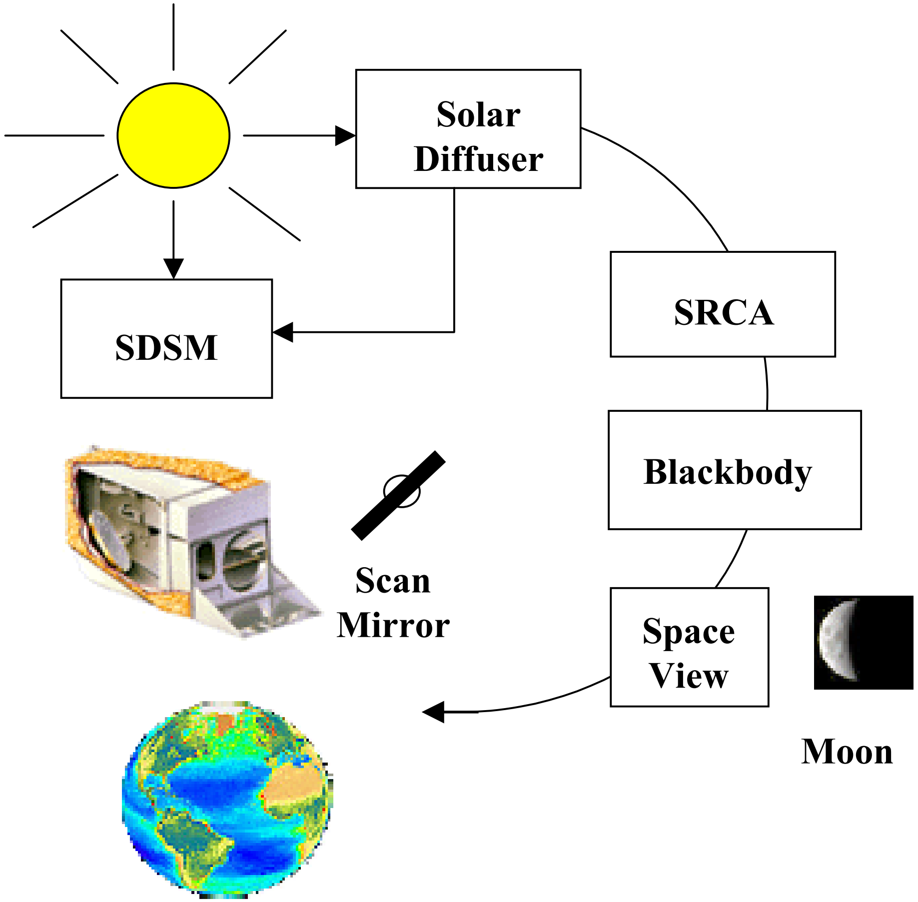
- Pre-launch calibration and characterization Results
  - Previous workshops
    - Examples from FM1 Pre-launch Calibration (pages 29-41,56-64)
  - Science meeting briefings
  - Decisions for the on-orbit approach
    - Use on-board SD reflectance based calibration
    - Apply a simple linear algorithm (offset = 0)
    - Apply pre-launch RVS and temperature coefficients
    - Track SD degradation with SDSM
    - Derive and validate SD screen (SDS) vignetting function (VF) on-orbit
    - Use lunar observations to track the response stability

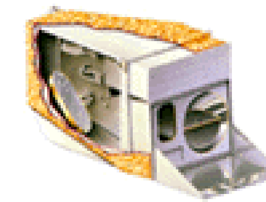
Calibration Overview



On-orbit Calibration

- Radiometric
  - Thermal emissive bands (TEB) by BB
  - Reflective solar bands (RSB) by SD/SDSM
- Spatial and Spectral
  - Spatial for RSB and TEB by SRCA
  - Spectral for RSB by SRCA
- Lunar Observations (support)
  - Instrument characterization
  - RSB response trending
  - RSB RVS

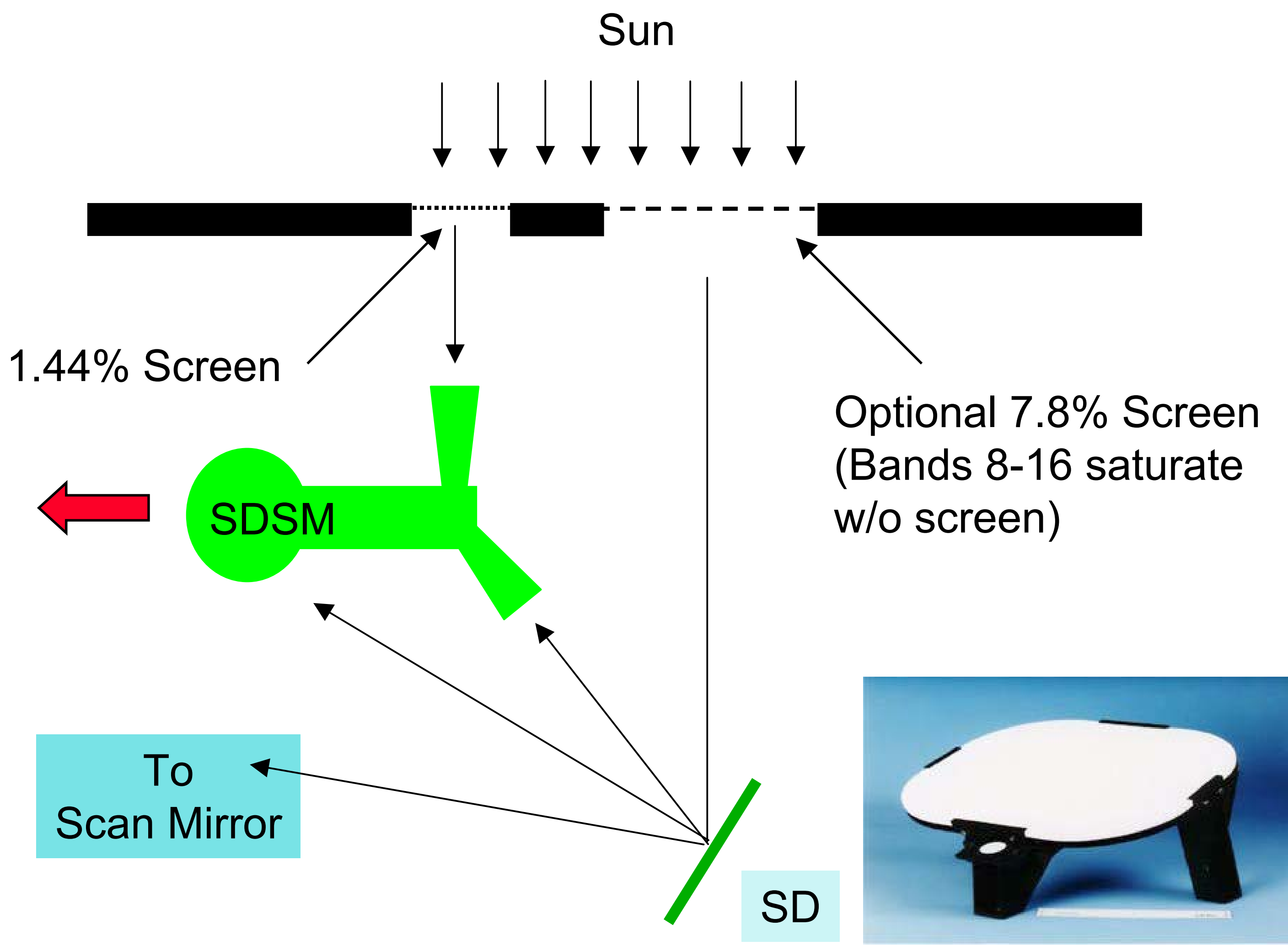


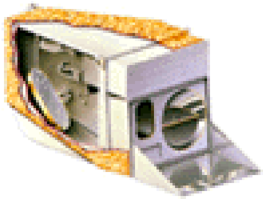


Calibration Overview

On-orbit Calibration Schematic

SDSM Views:
Sun, SD, Dark





Calibration Overview

Calibration Algorithm

SD Reflectance based linear approach:

$$\frac{\rho_{EV} \cdot \cos\left(\theta_{EV}\right)}{\rho_{SD} \cdot \cos\left(\theta_{SD}\right)} = \frac{dn^*_{EV} \cdot d^2_{Earth-Sun(EV)}}{dn^*_{SD} \cdot d^2_{Earth-Sun(SD)}}$$

$$dn^*_{EV} = (DN_{EV} - \langle DN_{SV} \rangle) \cdot \{1 + k_{INST} \cdot (T_{INST(EV)} - T_{REF})\} / RVS_{EV}$$

$$dn^*_{SD} = (\langle DN_{SD} \rangle - \langle DN_{SV} \rangle) \cdot \{1 + k_{INST} \cdot (T_{INST(SD)} - T_{REF})\} / RVS_{SD}$$

ρ_{EV}·cos(θ_{EV}): EV pixel reflectance factor (ρ is the BRF and θ is the solar zenith angle)

dn^*_{EV}: Detector’s EV “corrected” digital number

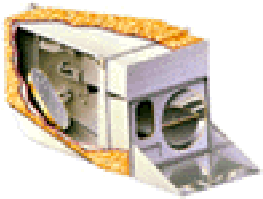
$d_{Earth\text{-}Sun(EV)}$: Earth-Sun distance at the time of EV observation

$T_{INST(EV)}$: Instrument temperature at EV observation

T_{REF} : Instrument reference temperature

k_{INST} : Instrument temperature correction coefficients

DN: Detector’s response (raw DN)



Calibration Overview

Calibration Algorithm

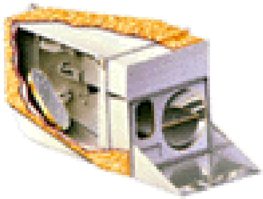
EV Reflectance factor: $$\rho_{EV} \cdot \cos(\theta_{EV}) = m_1 \cdot dn^*_{EV} \cdot d^2_{Earth-Sun(EV)}$$

SD calibration coefficient: $$m_1 = \frac{\rho_{SD} \cdot \cos(\theta_{SD})}{dn^*_{SD} \cdot d^2_{Earth-Sun(SD)}}$$

Consider SD degradation (Δ_{SD}) and SD screen effect (Γ_{SDS}):

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

ρ_{SD}: SD pre-launch Bidirectional Reflectance Factor (BRF_{SD})
Δ_{SD}: SD on-orbit degradation (determined by SDSM)
Γ_{SDS}: SD screen vignetting function (1 for open mode)



Calibration Overview

Calibration Algorithm

EV Radiance:

$$L_{EV} = \frac{E_{Sun} \cdot \rho_{EV} \cdot \cos(\theta_{EV})}{\pi \cdot d^2_{Earth\_Sun(EV)}}$$

Solar Irradiance E_{SUN}:

0.4-0.8 µm Thuillier et al., 1998;
0.8-1.1 µm Neckel and Labs, 1984;
Above 1.1 µm Smith and Gottlieb, 1974

Others:

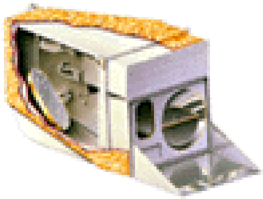
Thermal leak applied for SWIR bands (B5-7, B26)

Leak coefficients determined from EV night time data

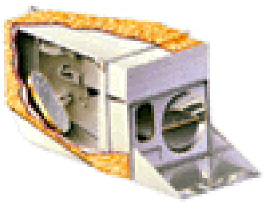
B26 de-striping algorithm added (from C. Moeller of Wisconsin)

Results and Discussions

(SD BRF characterization)



$$\boxed{m_1 = \frac{\rho_{SD} \cdot \cos\left(\theta_{SD}\right)}{dn^*_{SD} \cdot d^2_{Earth-Sun(SD)}} \cdot \Delta_{SD} \cdot \Gamma_{SDS}}$$



Results and Discussions

(SD BRF characterization)

- **Pre-launch** characterization performed by Santa Barbara Remote Sensing (SBRS)
- A scattering goniometer used in a comparison mode
- Traceability maintained from standard reference (characterized at NIST) => secondary reference (characterized at SBRS) => MODIS SD
- BRF calibrations performed at 400, 500, 600, 700, 900, and 1700nm over a two-dimensional grid of nine incident directions
- 2100nm BRF derived from Total Integrated Scatter (TIS) and BRF at other wavelengths
- Quadratic fitting applied to the BRF surfaces at characterized wavelengths
- Interpolation used to obtain BRF for MODIS spectral bands

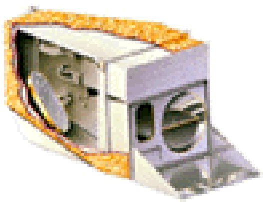
$\boxed{\rho_{SD}}$

$$BRF_{\lambda}^{PL}(\theta_{SD},\phi_{SD}) = a_0 + a_1\theta_{SD} + a_2\phi_{SD} + a_3\theta_{SD}^2 + a_4\phi_{SD}^2 + a_5\theta_{SD}\phi_{SD}$$

θ_{SD} : SD Zenith, ϕ_{SD} : SD Azimuth

Results and Discussions

(SD BRF characterization)



SBRS PFM BRF at 400nm (J. Young's memo, PL3095-N06370A**):**

Average of and difference between pre and post BRF scale transfer

BRF 400 nm		
1.012	1.006	0.995
1.007	0.999	0.987
0.999	0.991	0.979

BRF 400 nm		
-0.005	-0.005	-0.004
-0.005	-0.005	-0.004
-0.005	-0.005	-0.004

angles (deg) el - az		
17, -13	17, -23	17, -33
13.5, -13	13.5, -23	13.5, -33
10, -13	10, -23	10, -33

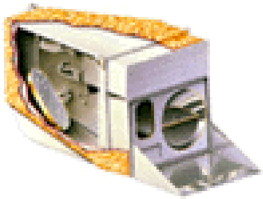
Spatial uniformity and repeatability

angle-deg	BRF spatial uniformity (400 nm)				
elev az		left	center	right	max dev
17, -13	1	1.007	1.010	1.005	0.005
-23	2	1.002	1.003	0.998	0.005
-33	3	0.993	0.992	0.988	0.005
13.5, -13	4	1.000	1.003	0.998	0.005
-23	5	0.995	0.995	0.991	0.004
-33	6	0.985	0.984	0.980	0.005
10, -13	7	0.992	0.995	0.990	0.005
-23	8	0.986	0.987	0.982	0.005
-33	9	**0.942**	0.975	0.970	0.033

angle - deg	BRF - repeatability					
elev az	400_1	400_2	400_3	avg.	Max. Dev	400_rpt
17, -13	1.009	1.009	1.009	1.009	0.000	1.007
-23	1.004	1.003	1.003	1.003	0.001	1.002
-33	0.994	0.993	0.992	0.993	0.001	0.992
13.5, -13	1.005	1.004	1.004	1.004	0.001	1.004
-23	0.997	0.996	0.997	0.997	0.001	0.996
-33	0.986	0.985	0.985	0.985	0.000	0.985
10, -13	0.997	0.997	0.996	0.997	0.001	0.997
-23	0.990	0.989	0.989	0.989	0.001	0.989
-33	0.977	0.976	0.976	0.977	0.001	0.977

Results and Discussions

(SD BRF characterization)

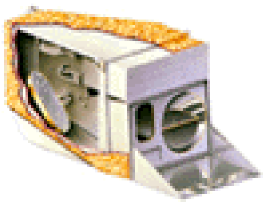


<u>SD Characterization Uncertainties</u> (J. Young's memo, PL3095-N06370A):

– NIST reference:	0.5%
– Characterization of SBRC scattering goniometer:	0.7%
– Transfer of NIST BRF scale to MODIS SD:	0.5%
– Solar diffuser characterization:	0.5%
– Solar diffuser spatial non-uniformities:	0.7%
– Interpolation angular / spectrally:	0.1%
– Prelaunch to orbit insertion BRDF change:	0.5%
– Characterization of 8.5% SD screen:	0.2%
– SDSM solar 2% attenuation and SDS impact:	0.5%
– On-orbit stray light elements during the use of the illuminated SD	
– Solar illumination of the SD surrounds	0.3%
– Earthshine through the SD door	0.3%
– Earthshine through nadir aperture door	0.1%

<u>Errors can be different at different illuminating/viewing angles</u>

RSS = 1.6%



Results and Discussions

(SD BRF characterization)

- **On-orbit** BRF validation performed using SD observation during yaw maneuvers at different azimuth angles
- Detector's solar response is proportional to the BRF
- Bands 1-4 and 17-19 used to validate the BRF (bands 8-16 saturate without SD screen; crosstalk in SWIR bands 5-7 and 26)
- Results (Terra MODIS) agree with pre-launch values to within ±0.25%* (consistency checked among different detectors within a band; * B2 differences vary from -0.21 to 0.41%)
- Pre-launch BRF is used in the m1 calculation

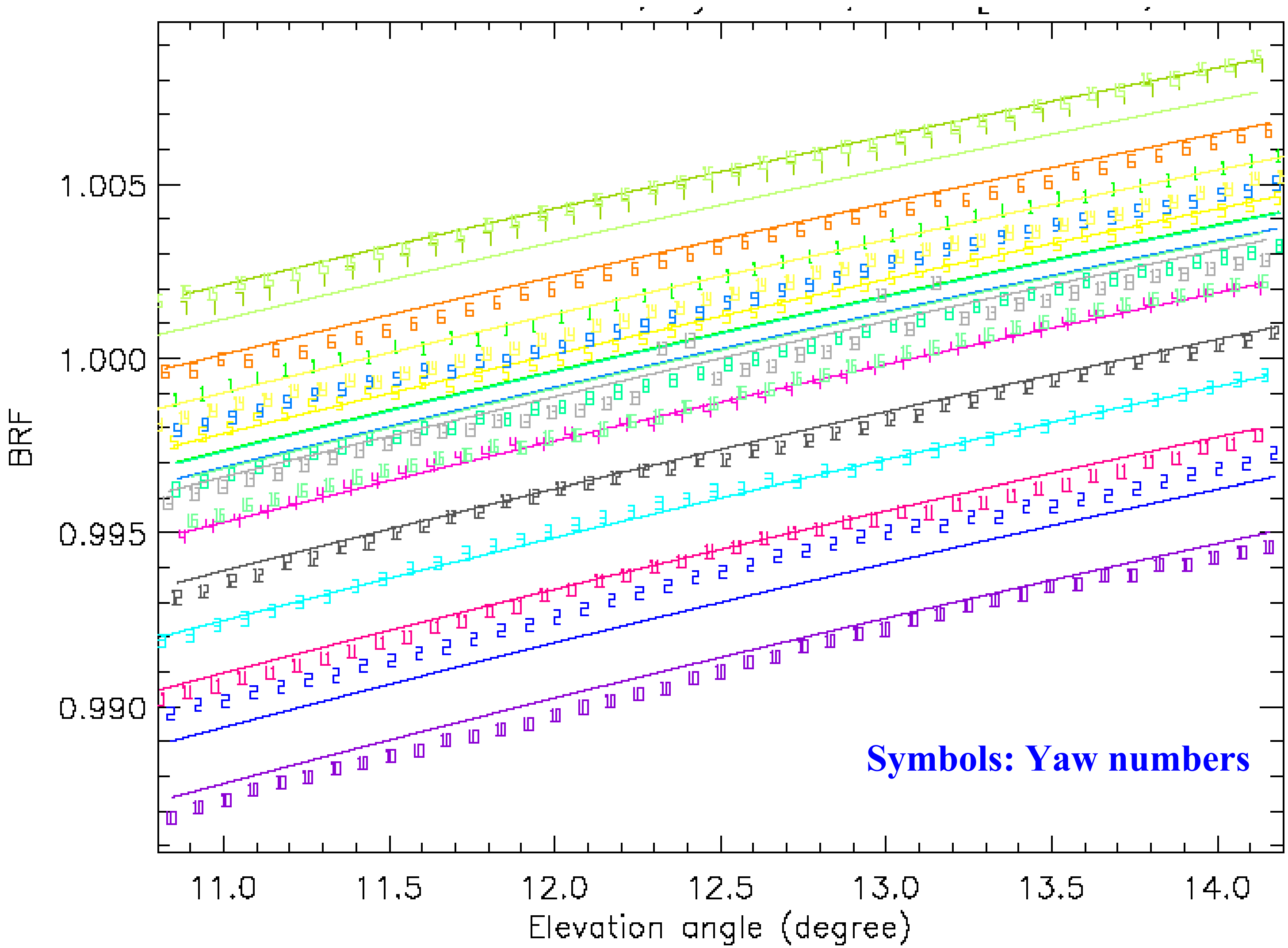
$$BRF_{SD} \propto \frac{dn^*_{SD}}{\cos(\theta_{SD})}$$

Band	Min_Diff	Max_Diff
1	-0.1309	0.2413
2	-0.2172	0.4130
3	-0.1624	0.1933
4	-0.1332	0.1747
17	-0.2045	0.2705
18	-0.1385	0.2491
19	-0.1590	0.2552

Results and Discussions

(SD BRF characterization)

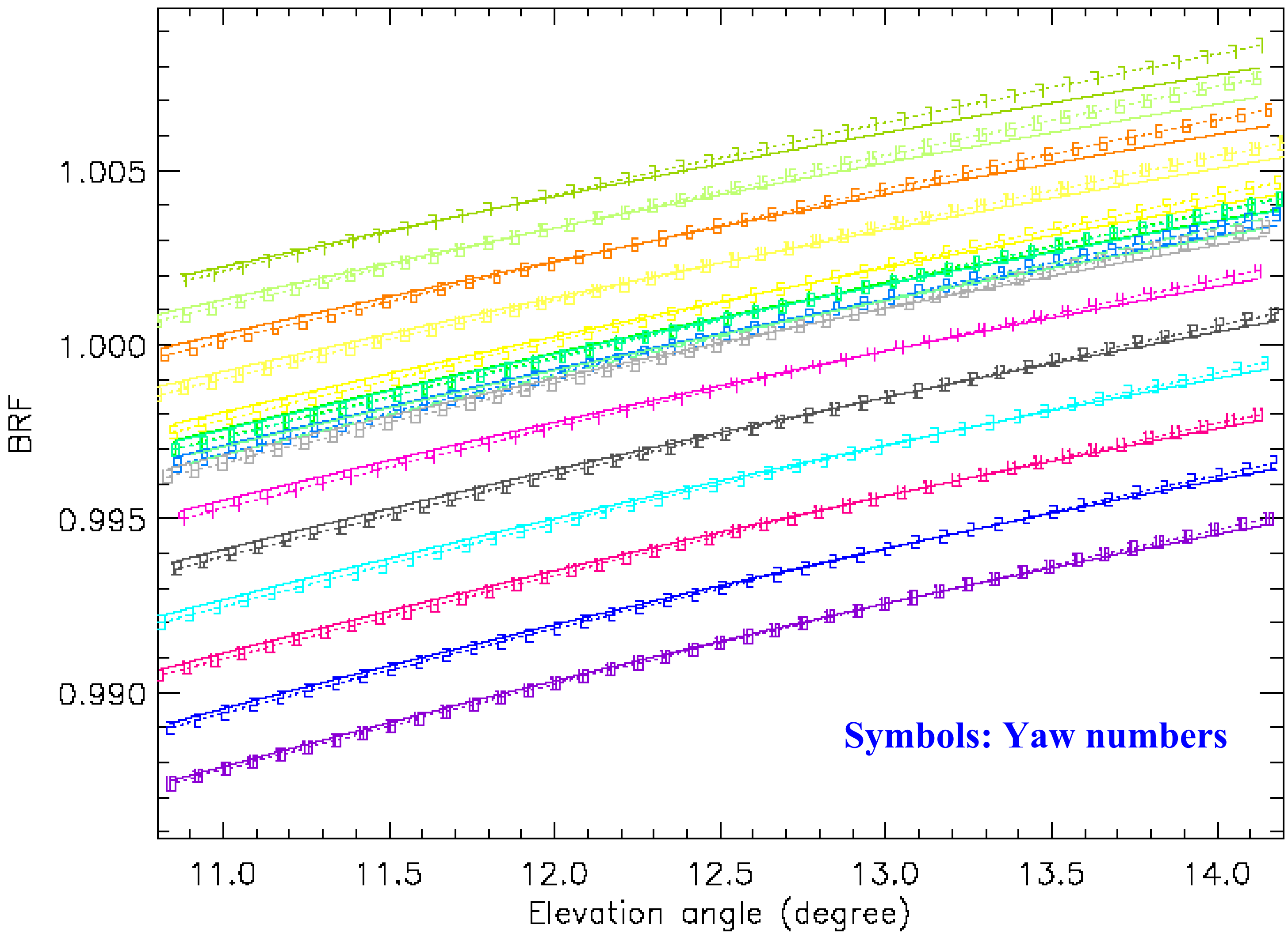
Terra B3 BRF: fitting (solid line); on-orbit data (symbols)

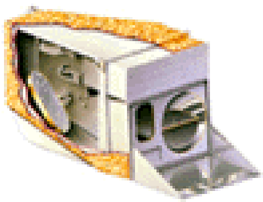


Results and Discussions

(SD BRF characterization)

Terra B3 BRF: pre-launch (solid line); on-orbit fitting (symbols)





Results and Discussions

(Temperature correction coefficients)

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

$$dn^*_{SD} = (< DN_{SD} > - < DN_{SV} >) \cdot \{1 + k_{INST} \cdot (T_{INST(SD)} - T_{REF})\} / RVS_{SD}$$

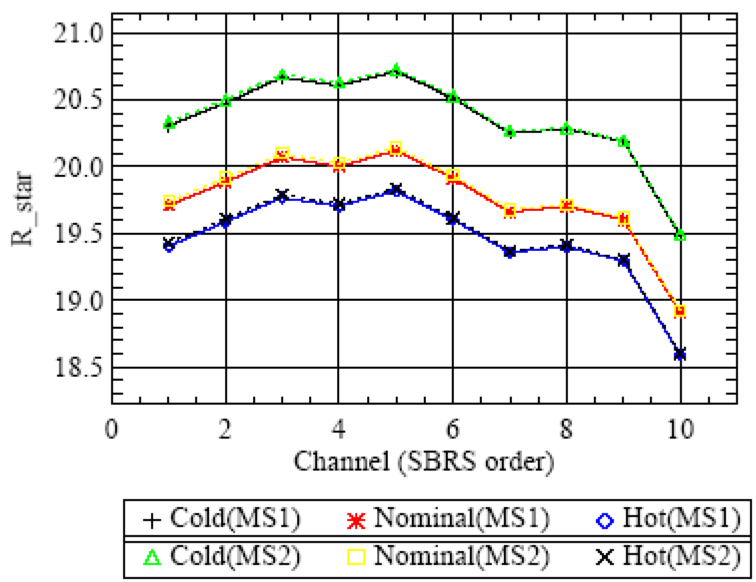
Results and Discussions

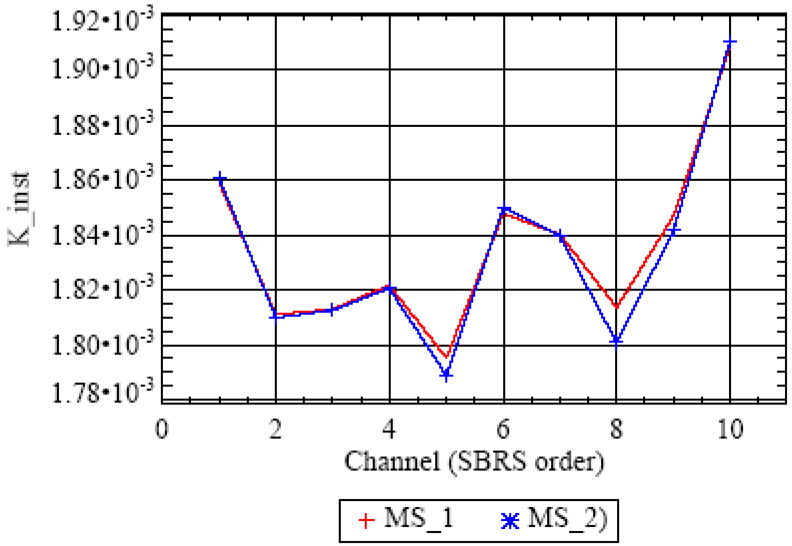
(Temperature correction coefficients)

Pre-launch characterization results

More examples in FM1 (Aqua MODIS) Pre-launch Calibration (pages 29-41)

TERRA MODIS R_star and K_inst, Electronic side A, Band 8

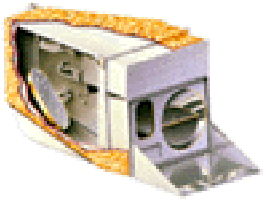




Pre-launch calibration: $$L_{SIS} = \frac{dn_{SIS}}{R^*}$$

Temperature correction coefficients:

$$k_{INST} = \{R^*(T_{REF}) / R^*(T_{INST}) - 1\} / (T_{INST} - T_{REF})$$



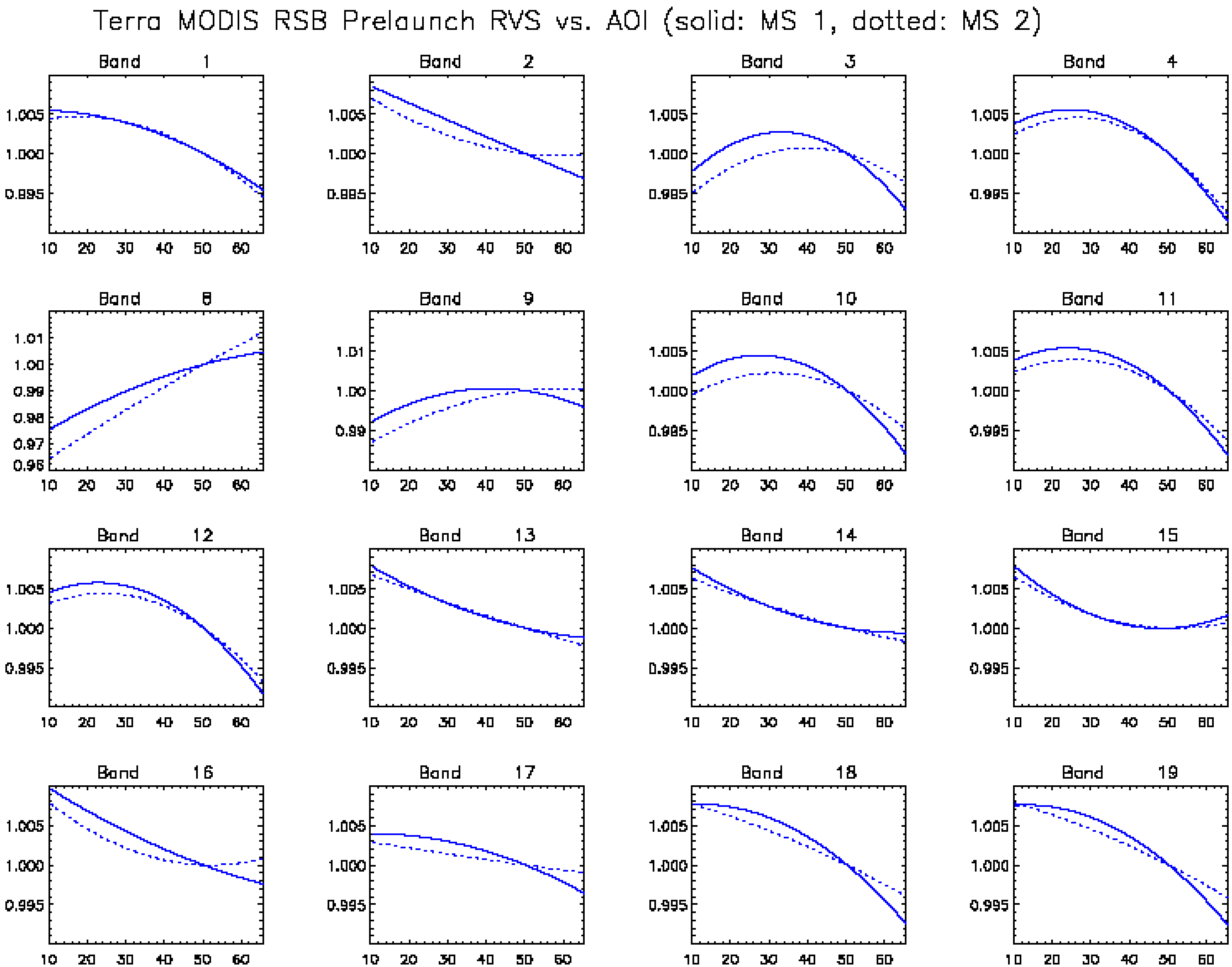
Results and Discussions

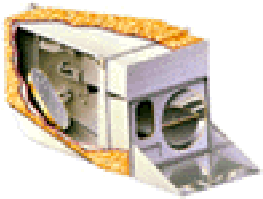
(Response versus scan angles)

- **Pre-launch** characterization and results
  - Examples in FM1 Pre-launch Calibration (pages 56-64)
- **On-orbit** RVS
  - Response trending from SD, SRCA, and Lunar observations
  - These three sectors have different angles of incidence (AOI) to the scan mirror
  - Results used to update pre-launch values (for VIS bands 8, 9, 3, and 10)
  - Ocean group applies “additional correction”

Results and Discussions

(Response versus scan angles)





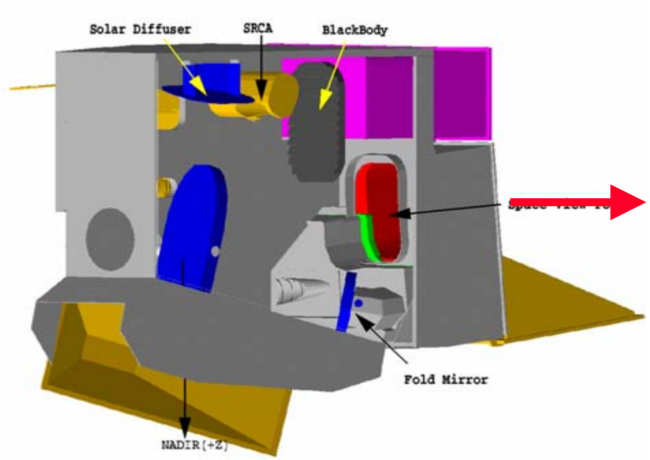
Results and Discussions

(Response versus scan angles)

RSB Calibration Using the Moon

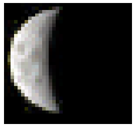
SD Calibration

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



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

Moon Calibration



Geometry factors corrected:

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

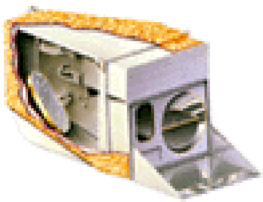
How:

Nighttime orbits, SV port

0-20° roll maneuvers, 55° phase angle

Why:

No SD degradation, different AOI

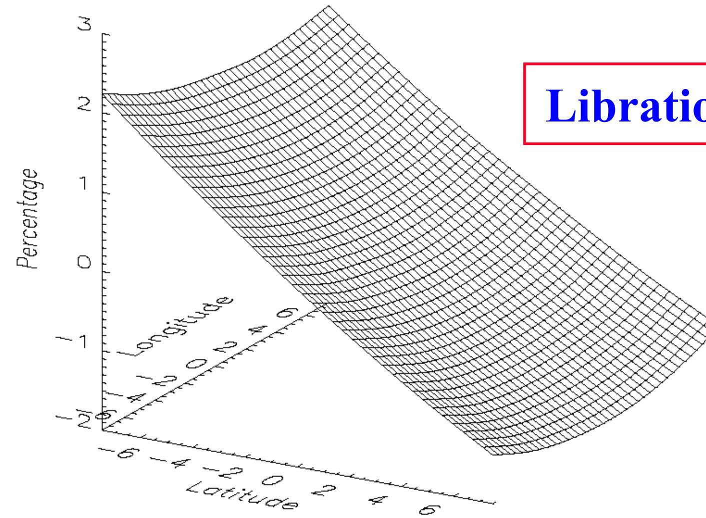


Results and Discussions

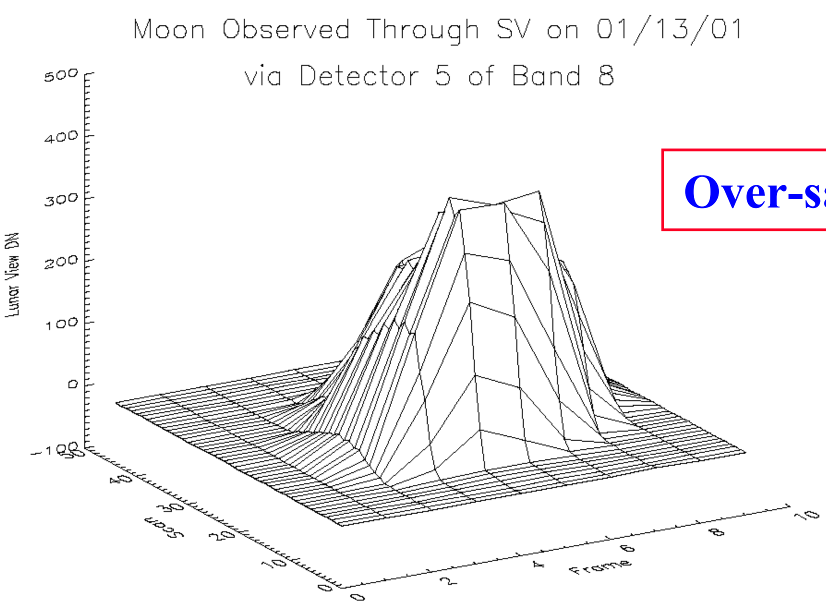
(Response versus scan angles)

Geometry factors corrected:

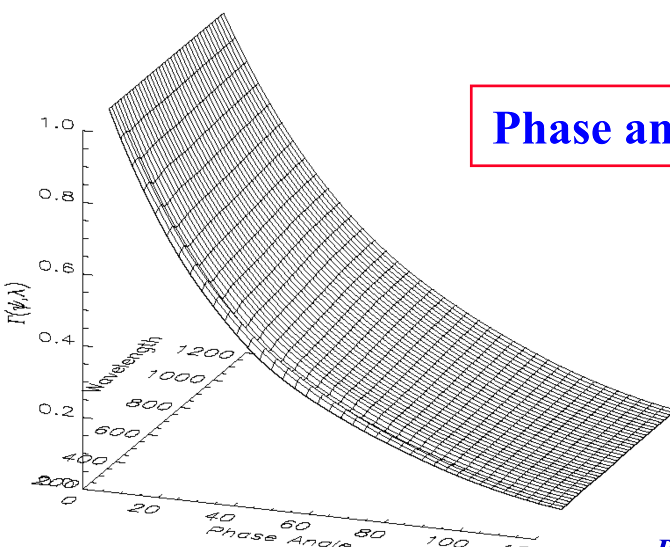
$$f = \frac{f_{phase-angle} \cdot f_{libration} \cdot f_{over-sampling}}{d^2_{Sun-Moon} \cdot d^2_{Modis-Moon}}$$



Libration



Over-sampling

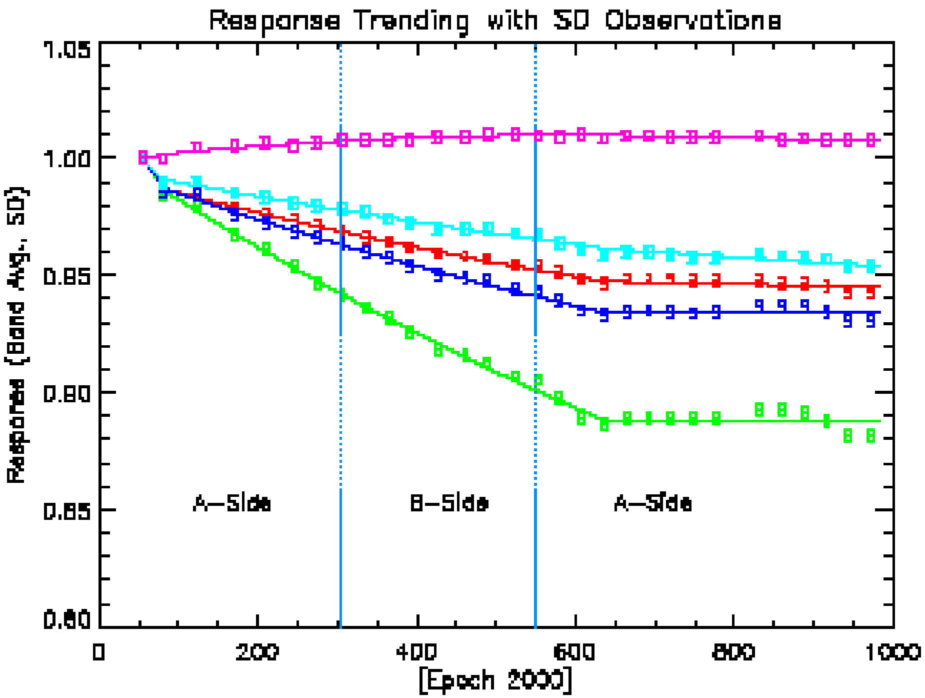


Phase angle

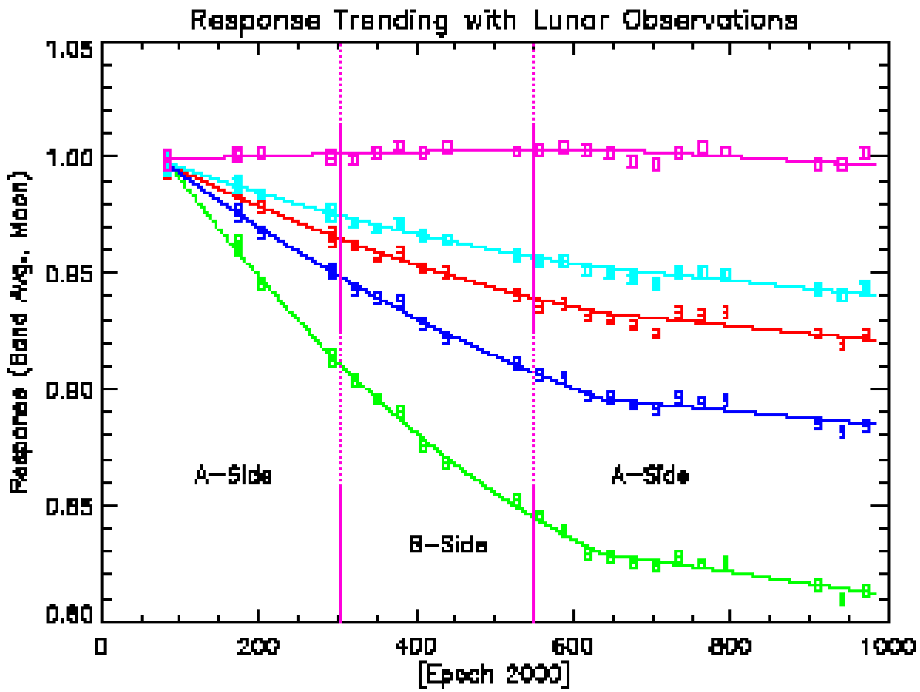
Results and Discussions

(Response versus scan angles)

SD AOI = 50.2°



Moon AOI = 11.2°



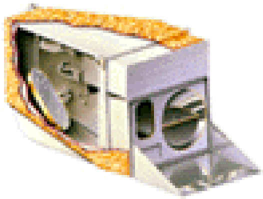
Symbols are the band numbers; B-side response normalized to the A-side

Optics (scan mirror) degradation at different AOI

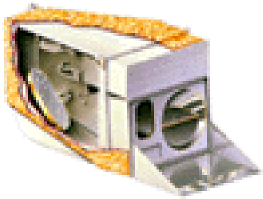
Time-dependent RVS implemented in MODIS L1B code using response trending results from SD, SRCA (AOI=38°), and the Moon

Results and Discussions

(SDS vignetting function)



$$\boxed{m_1 = \frac{\rho_{SD} \cdot \cos\left(\theta_{SD}\right)}{dn^*_{SD} \cdot d^2_{Earth-Sun(SD)}} \cdot \Delta_{SD} \cdot \Gamma_{SDS}}$$



Results and Discussions

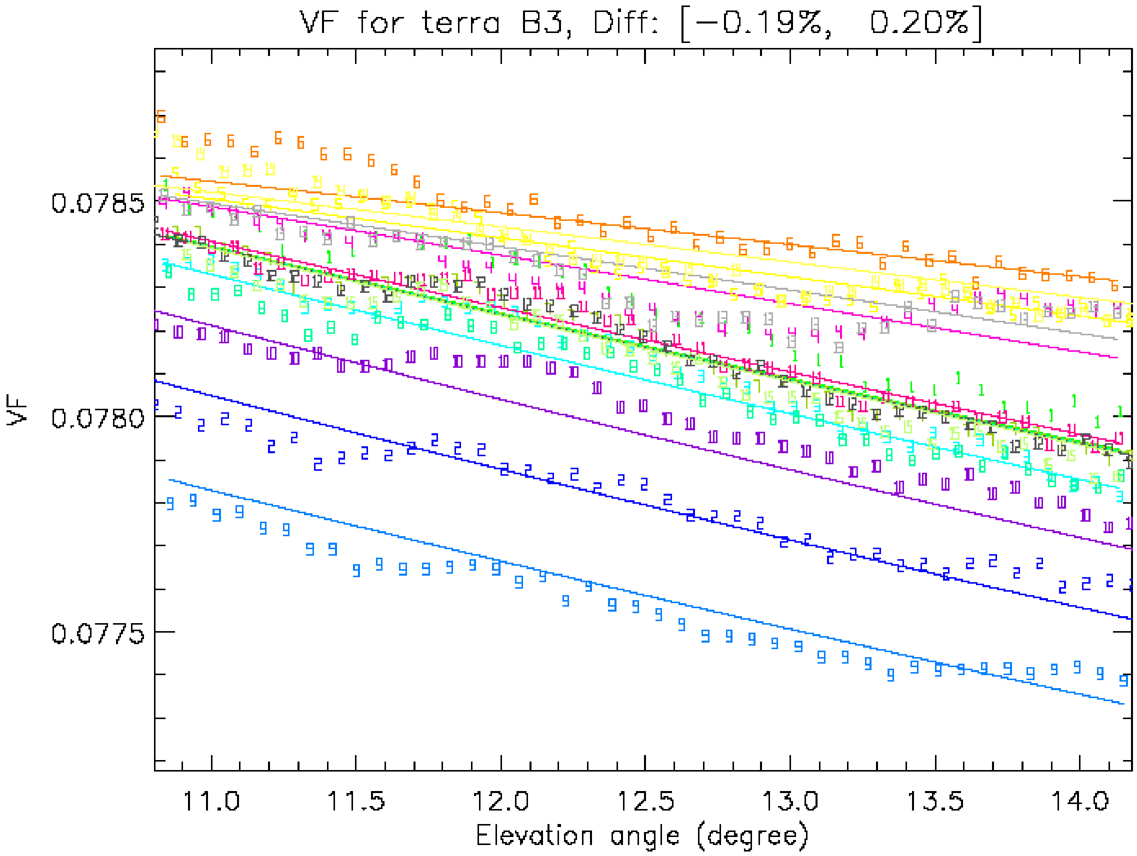
(SDS vignetting function)

- No pre-launch characterization activities
- On-orbit characterization using ratio of detector’s solar response with SDS to that without SDS; on-orbit yaw maneuver data sets
- VF determined from bands 3-4 and 17-19 and applied to bands 8-16 which saturate without SDS
- Fitting results agree with observations to within about ±0.30%
- Results of quadratic fitting coefficients used in m1 calculation

$$\Gamma_{SDS} = \left(\frac{dn^{*}_{SD}}{\cos(\theta_{SD})}\right)_{SDS\_Down} \div \left(\frac{dn^{*}_{SD}}{\cos(\theta_{SD})}\right)_{SDS\_Up}$$

Results and Discussions

(SDS vignetting function)

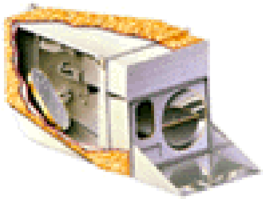


Band	Min_Diff	Max_Diff	RMS
1	-0.1623	0.1942	0.0619
2	-0.2086	0.2472	0.0874
3	-0.1936	0.1970	0.0686
4	-0.1647	0.2310	0.0686
17	-0.2301	0.2554	0.0800
18	-0.2887	0.3357	0.0992
19	-0.2089	0.2661	0.0884

(difference in %)

Results and Discussions

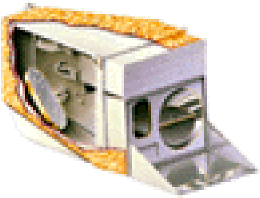
(SD degradation using SDSM)



$$\boxed{m_1 = \frac{\rho_{SD} \cdot \cos\left(\theta_{SD}\right)}{dn^{*}_{SD} \cdot d^{2}_{Earth-Sun(SD)}} \cdot \Delta_{SD} \cdot \Gamma_{SDS}}$$

Results and Discussions

(SD degradation using SDSM)



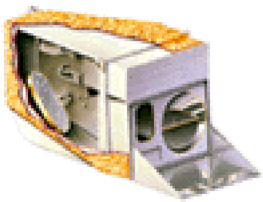
SD (BRF) degradation from SDSM

$$\Delta_{SD} = \frac{\overline{dc_{SD\_view}}}{\overline{dc_{Sun\_view}}}$$

SDSM detectors	Center wavelength (nm)
D1	411.97
D2	465.69
D3	529.74
D4	553.75
D5	646.14
D6	746.62
D7	856.49
D8	904.29
D9	936.23

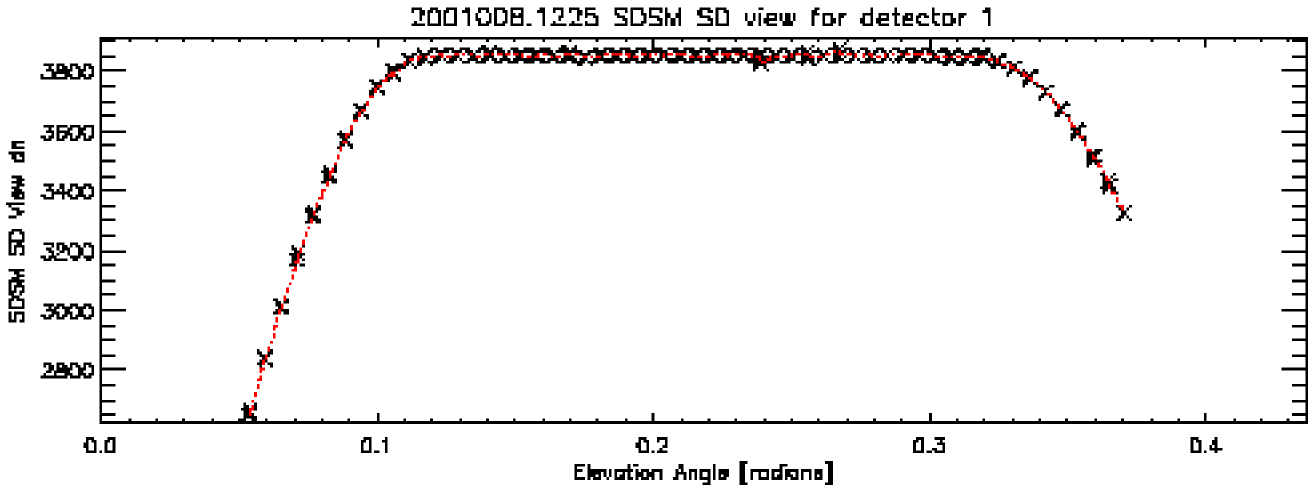
Large ripples seen from SDSM Sun view response
Ripples caused due to design error in a SDSM component
This approach did not work
Relative approach developed

dc_{Sun_view}: SDSM detector's Sun view digital count (DC) with dark signal subtracted
dc_{SD_view}: SDSM detector's SD view digital count (DC) with dark signal subtracted and SD BRF factor corrected

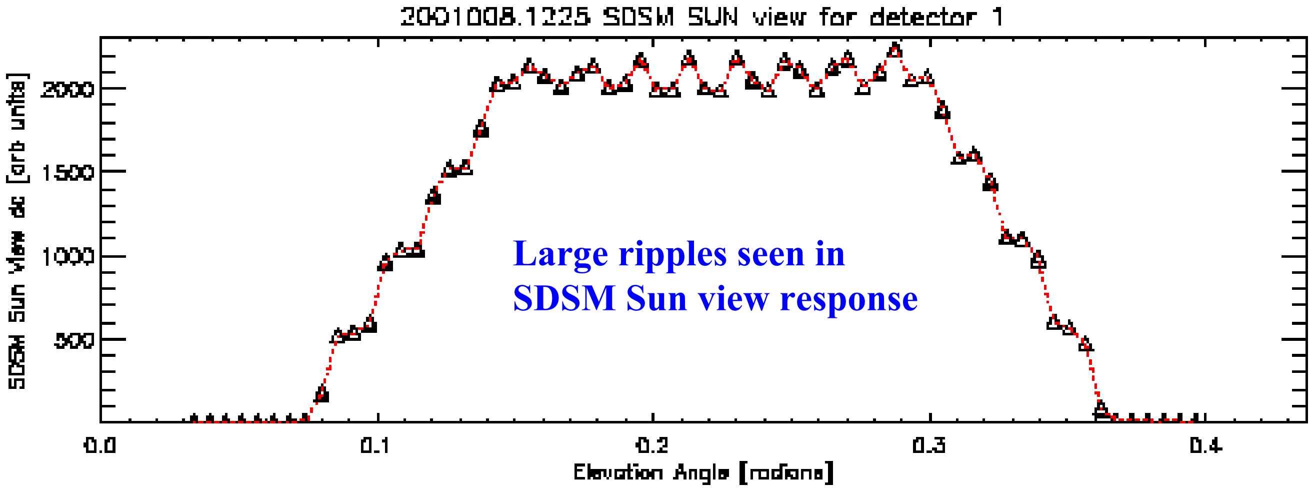


Results and Discussions

(SD degradation using SDSM)



$$\Delta_{SD} = \frac{\overline{dc_{SD\_view}}}{\overline{\overline{dc_{Sun\_view}}}}$$

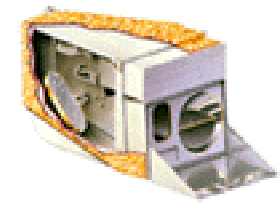


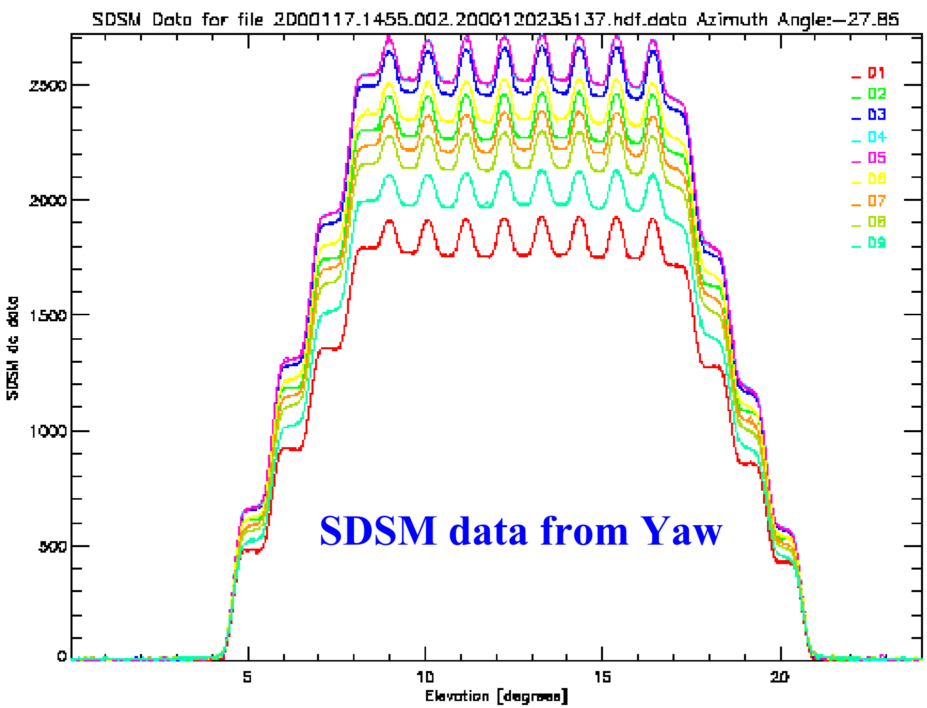
Original approach not working!!

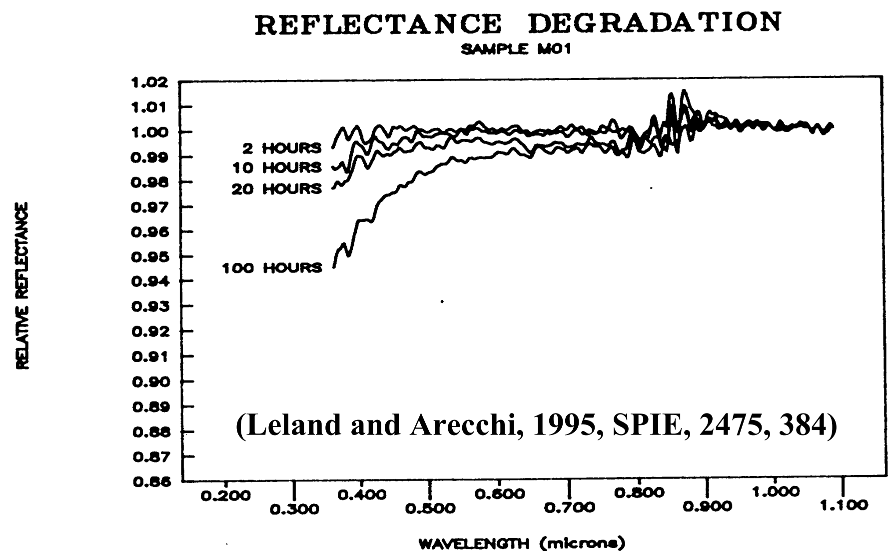
SDSM data during SD calibration

Results and Discussions

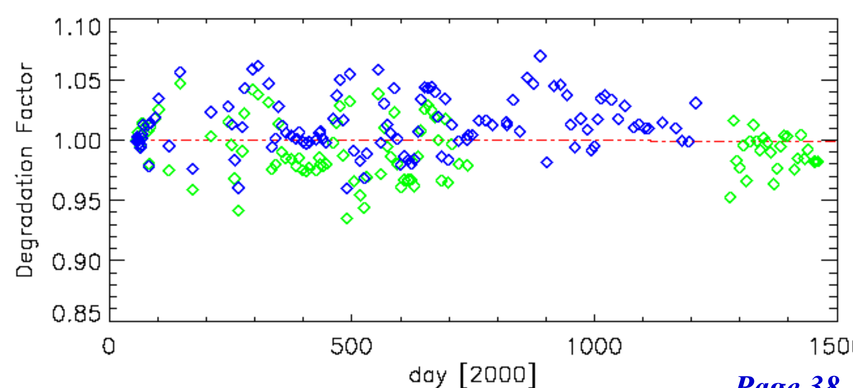
(SD degradation using SDSM)







Terra MODIS SDSM D9 degradation trending

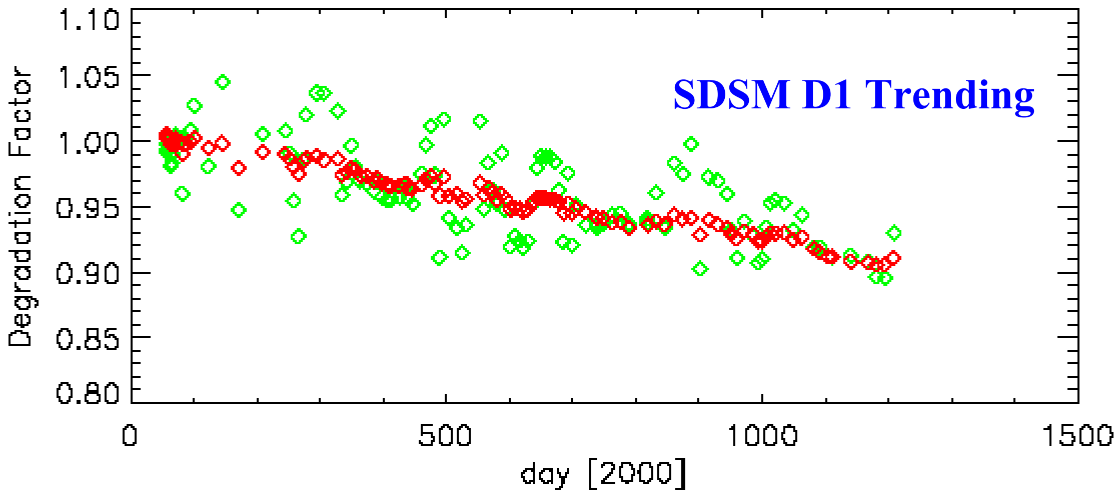


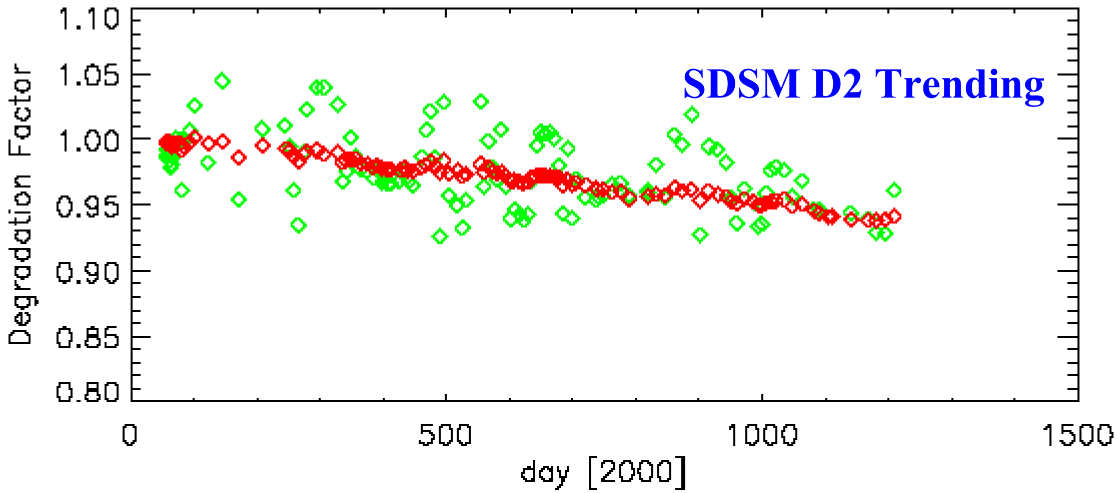
Normalize to SDSM D9 at 936nm

$$\Delta_{SD} = \frac{\overline{dc_{SD}}}{\overline{dc_{Sun}}} \Rightarrow \left\{ \frac{dc_{SD\_view}^{D1} / dc_{Sun\_view}^{D1}}{dc_{SD\_view}^{D9} / dc_{Sun\_view}^{D9}} \right\}$$

Results and Discussions

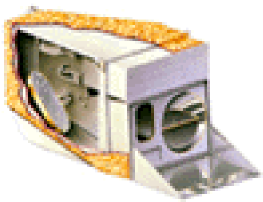
(SD degradation using SDSM)





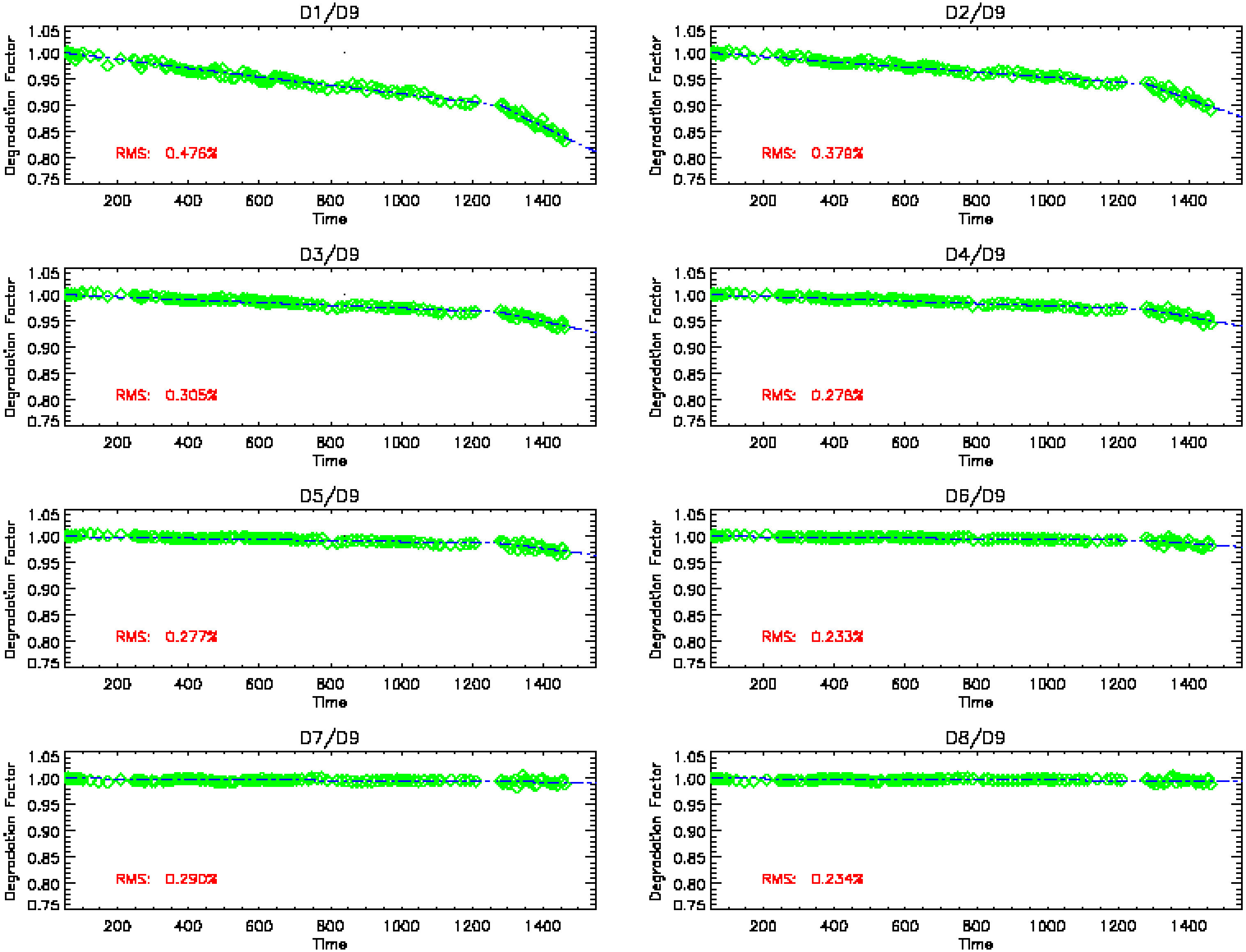
Green: no-normalization to D9

Red: normalize to D9 at 936nm



Results and Discussions

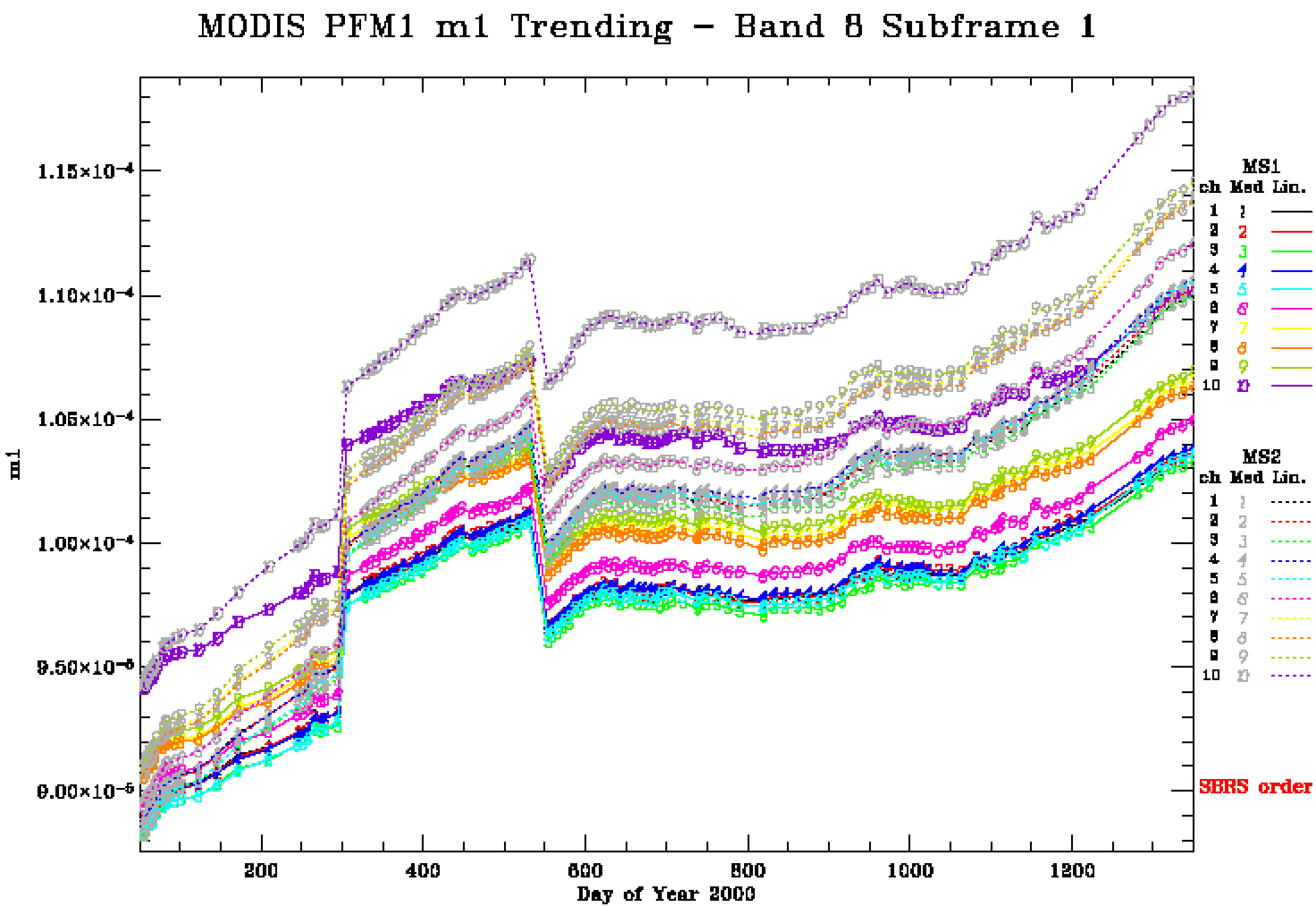
(SD degradation using SDSM)



Time: day from year 2000

Results and Discussions

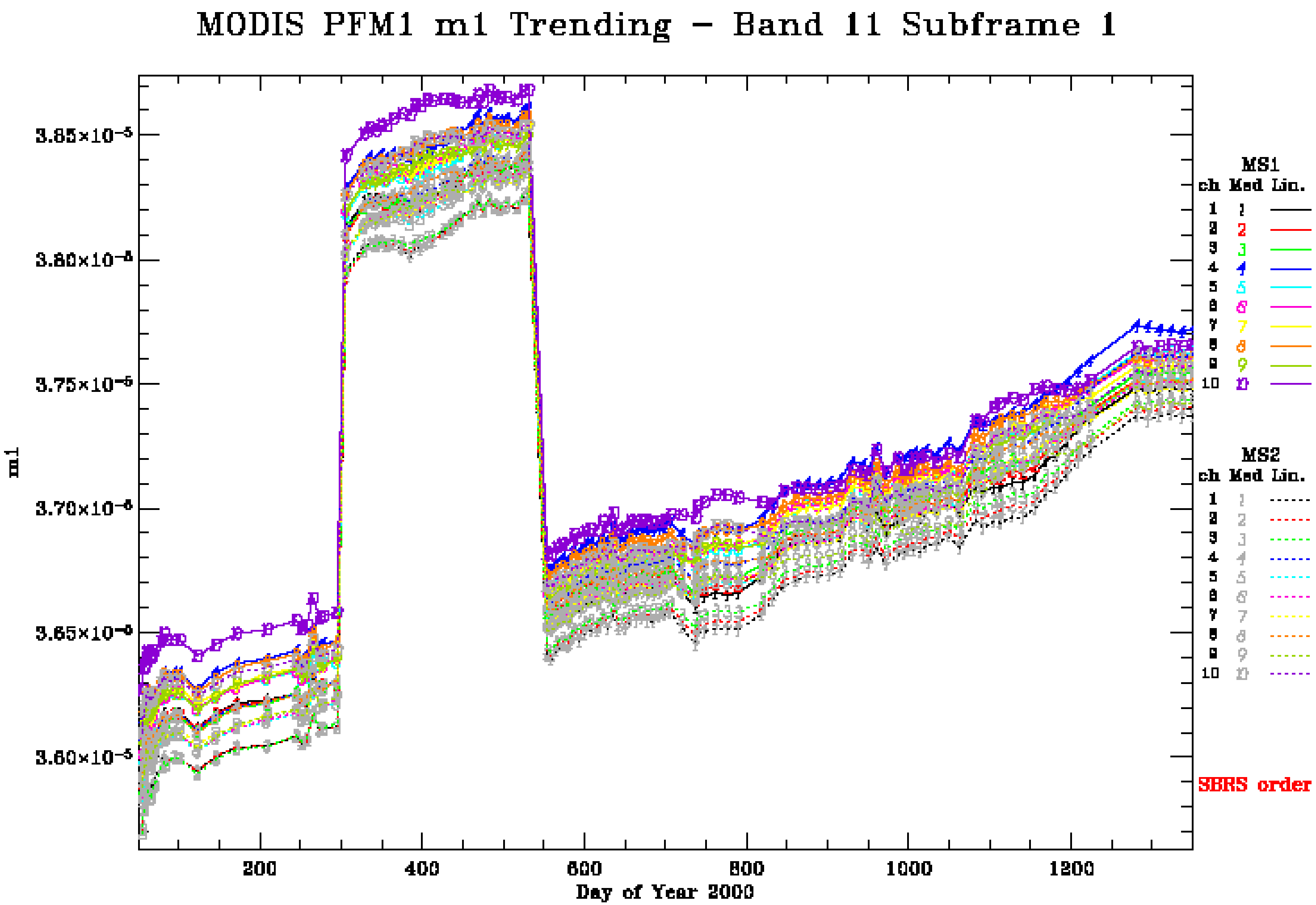
(m1 trending results)



Examples given for B8 and B11. All m1 trending results are available.

Results and Discussions

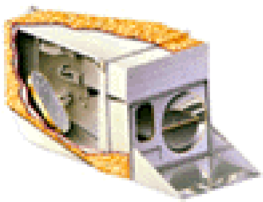
(m1 trending results)



Examples given for B8 and B11. All m1 trending results are available.

Results and Discussions

(Summary)



- MODIS RSB calibration error budget included
  - SD characterization errors (NIST reference, standard transfer, instrument effect, measurements errors
  - Pre-launch to on-orbit BRF change estimate
  - SD and SDSM screen impact
  - Stray light elements (e.g. Earthshine related)
- Considering all the factors identified in the calibration chain, the calibration is within the instrument specifications
  - Reflectance: ±2%; Radiance: ±5%
- Caveats
  - Polarization correction, if necessary, is used in the science application algorithm, not in the L1B calibration
  - RVS changes on-orbit, if not fully characterized, will cause additional errors (at different AOIs from that of the SD)

List of Acronyms and Abbreviations

AOI	**Angle of Incidence**
BB	**Blackbody**
BBR	**Band to Band Registration**
BCS	**Blackbody Calibration Source**
BRDF	**Bi-directional Reflectance Distribution Function**
BRF	**Bi-directional Reflectance Factor**
EV	**Earth View**
FPA	**Focal Plane Assembly**
IFOV	**Instantaneous Field Of View**
NAD	**Nadir Aperture Door**
OBC	**On Board Calibration**
OOB	**Out-of-Band**
RSB	**Reflective Solar Bands**
RSR	**Relative Spectral Response**
RVS	**Response Versus Scan Angle**
TEB	**Thermal Emissive Bands**
SD	**Solar Diffuser**
SDS	**Solar Diffuser Screen**
SDSM	**Solar Diffuser Stability Monitor**
SNR	**Signal to Noise Ratio**
SIS	**Spherical Integrating Source**
SpMA	**Spectral Measurement Assembly**
SRCA	**Spectro-Radiometric Calibration Assembly**
SVD	**Space View Door**
SVS	**Space View Source**
TDI	**Time Delayed Integration**
TOA	**Top of Atmosphere**
VF	**Vignetting Function**