S-NPP VIIRS On-orbit Calibration and Performance

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Outline

- **Background**
  - Instrument and On-board Calibrators
- **On-orbit Operation and Calibration**
  - Operation and Calibration Activities
  - Calibration Methodologies
- **On-orbit Performance**
  - On-board Calibrators
  - Changes in Spectral Band Responses (Detector Gains)
  - Changes in Relative Spectral Response (RSR)
  - Detector SNR/NEdT
- **Summary**

Background

- **Visible/Infrared Imager Radiometer Suite (VIIRS)**
  - Key instrument for S-NPP (L: 2011) and future JPSS missions
  - 14 reflective solar bands (RSB), 7 thermal emissive bands (TEB), and 1 day night band (DNB)
  - Spectral wavelengths: 0.4-12.4 mm
  - Spatial resolution: 375 m for DNB and I bands and 750 m for M bands
  - Sensor Data Records (SDR): equivalent of MODIS L1B
  - 22 Environmental Data Records (EDR): equivalent of MODIS science data products
- **Strong MODIS Heritage**
  - Spectral band selection
  - On-board calibrators
  - Calibration strategies
  - Calibration scheduling and data analysis tools

VIIRS Spectral Bands and Data Products

VIIRS 22 Bands (16 M-Band, 5 I-Band and 1 DNB)

VIIRS Band	Spectral Range (um)	Nadir HSR (m)	MODIS Band(s)	Range	HSR
DNB	0.500 - 0.900				
● M1	0.402 - 0.422	750	8	0.405 - 0.420	1000
● M2	0.436 - 0.454	750	9	0.438 - 0.448	1000
● M3	0.478 - 0.498	750	3 10	0.459 - 0.479 0.483 - 0.493	500 1000
● M4	0.545 - 0.565	750	4 or 12	0.545 - 0.565 0.546 - 0.556	500 1000
I1	0.600 - 0.680	375	1	0.620 - 0.670	250
● M5	0.662 - 0.682	750	13 or 14	0.662 - 0.672 0.673 - 0.683	1000 1000
M6	0.739 - 0.754	750	15	0.743 - 0.753	1000
I2	0.846 - 0.885	375	2	0.841 - 0.876	250
● M7	0.846 - 0.885	750	16 or 2	0.862 - 0.877 0.841 - 0.876	1000 250
M8	1.230 - 1.250	750	5	SAME	500
M9	1.371 - 1.386	750	26	1.360 - 1.390	1000
I3	1.580 - 1.640	375	6	1.628 - 1.652	500
M10	1.580 - 1.640	750	6	1.628 - 1.652	500
M11	2.225 - 2.275	750	7	2.105 - 2.155	500
I4	3.550 - 3.930	375	20	3.660 - 3.840	1000
M12	3.660 - 3.840	750	20	SAME	1000
● M13	3.973 - 4.128	750	21 or 22	3.929 - 3.989 3.929 - 3.989	1000 1000
M14	8.400 - 8.700	750	29	SAME	1000
M15	10.263 - 11.263	750	31	10.780 - 11.280	1000
I5	10.500 - 12.400	375	31 or 32	10.780 - 11.280 11.770 - 12.270	1000 1000
M16	11.538 - 12.488	750	32	11.770 - 12.270	1000

● Dual gain band

Similar MODIS bands

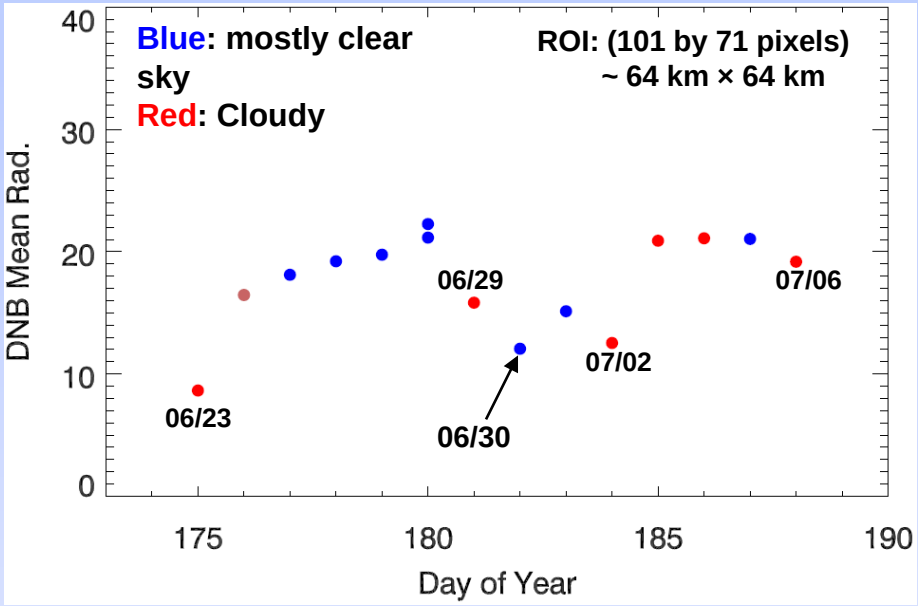
VIIRS 20 EDRs (Land, Ocean, Cloud, Snow)

Name of Product	Group	Type
Imagery *	Imagery	EDR
Precipitable Water	Atmosphere	EDR
Suspended Matter	Atmosphere	EDR
Aerosol Optical Thickness	Aerosol	EDR
Aerosol Particle Size	Aerosol	EDR
Cloud Base Height	Cloud	EDR
Cloud Cover/Layers	Cloud	EDR
Cloud Effective Particle Size	Cloud	EDR
Cloud Optical Thickness/Transmittance	Cloud	EDR
Cloud Top Height	Cloud	EDR
Cloud Top Pressure	Cloud	EDR
Cloud Top Temperature	Cloud	EDR
Active Fires	Land	Application
Albedo (Surface)	Land	EDR
Land Surface Temperature	Land	EDR
Soil Moisture	Land	EDR
Surface Type	Land	EDR
Vegetation Index	Land	EDR
Sea Surface Temperature *	Ocean	EDR
Ocean Color and Chlorophyll	Ocean	EDR
Net Heat Flux	Ocean	EDR
Sea Ice Characterization	Snow and Ice	EDR
Ice Surface Temperature	Snow and Ice	EDR
Snow Cover and Depth	Snow and Ice	EDR

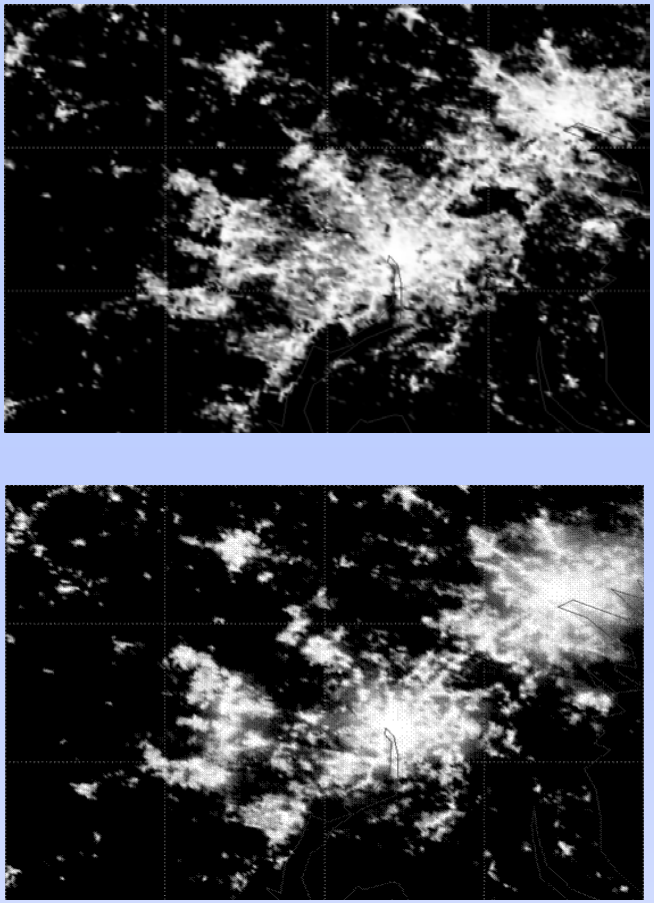
* Product is a Key Performance Parameter (KPP)

DNB: Power Outage Monitoring

- The Day/Night Band has been used to detect a major power outage in the Washington, DC on the night of the Direcho storm on June 29, 2012.
- An analysis of the data after the storm showed that most areas had power restored within 3 days.



VIIRS DNB radiance time series before and after the power outage (6/29) shows that most of the power was restored in three days.

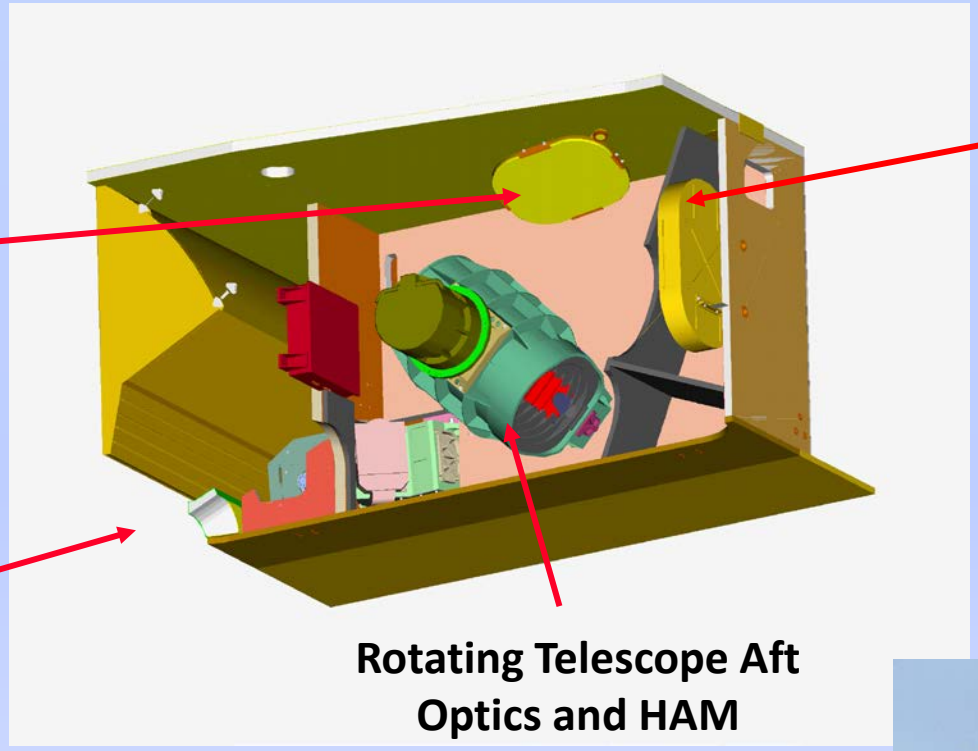


VIIRS DNB of the Washington/Baltimore area on June 26th (top)and June 30th.
The suburbs west of DC and Baltimore, in particular show dark areas.

From GSICS presentation (Cao and Xiong)

VIIRS On-board Calibrators (MODIS Heritage)

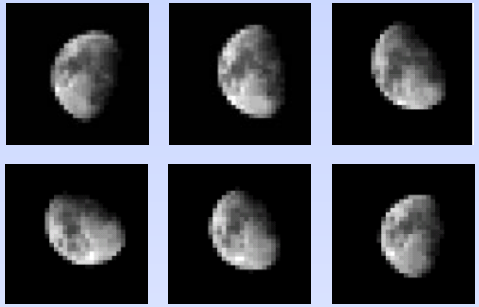
Solar Diffuser with Fixed Screen



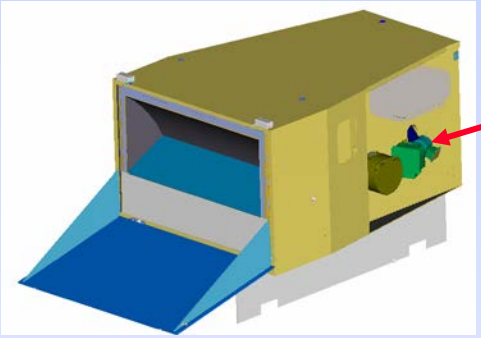
Rotating Telescope Aft Optics and HAM

Blackbody

Extended SV Port



S-NPP VIIRS I1 Lunar Images



Solar Diffuser Stability Monitor

On-orbit Operation and Calibration

Operation and Calibration Activities (Key Events)

- Launch: 10/28/11
- Instrument turn-on: 11/8/11
- Nadir door open: 11/21/11 (first image from VIS/NIR)
- RTA stow (4 times): 12/9/11 – 1/2/12
- Cryo-cooler door open: 1/18/12 (observations from all bands)

- Roll maneuvers: started from 1/4/12 (nearly monthly, 12 since launch)
- Yaw maneuvers; 2/15/12 – 2/16/12 (SD/SDSM screen transmission)
- Pitch maneuvers: 2/20/12 (TEB response versus scan angle)

- BB nominally set at 292 K, quarterly warm-up and cool-down (WUCD)
- SD calibration performed in each orbit
- SDSM operated on a daily basis

Calibration Methodologies

- **Solar Calibration (RSB)**
  - Quadratic calibration algorithm
  - Linear calibration coefficients derived from SD observations
  - SD degradation tracked by SDSM
- **Lunar Calibration (RSB)**
  - Regularly scheduled at nearly the same phase angle, implemented via S/C roll maneuvers, observed through SV port with a data sector rotation
  - Calibration reference provided by the lunar model
- **BB Calibration (TEB)**
  - Quadratic calibration algorithm
  - Linear calibration coefficients derived from BB observations

Solar Calibration (RSB)

RSB Calibration: F and H Factors

$$L_{EV} = F \cdot \left(c_0 + c_1 \cdot dn_{EV} + c_2 \cdot dn_{EV}^2\right)$$

$$L_{SD_Meas} = F \cdot \left(c_0 + c_1 \cdot dn_{SD} + c_2 \cdot dn_{SD}^2\right)$$

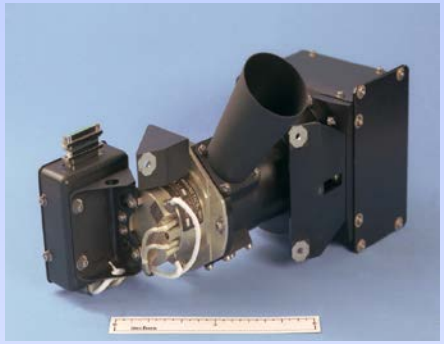
$$L_{SD_Comp} \propto E_{SUN} \cdot BRDF_{SD}(t) \cdot \tau_{SDS}$$

$$F = \frac{L_{SD_Comp}}{L_{SD_Meas}}$$

$$BRDF_{SD}(t) = H_{SD}(t) \cdot BRDF_{SD}(t_0)$$

$$H_{SD}(t) = H(t) / H(t_0)$$

$$H(t) \propto \frac{dc_{SD} \cdot \tau_{SDSMS}}{dc_{SUN} \cdot \tau_{SDS}}$$



The dn and dc are VIIRS and SDSM detector "corrected" responses

Lunar Calibration (RSB)

- Integrated lunar irradiance (or radiance) from sensor observations

$$J(B,M,G)=\sum_{s,d}[c_0(B,M,G)+c_1(B,M,G)dn(s,d)+c_2(B,M,G)dn(s,d)^2]$$

  - *B*: Band; *M*: HAM side; *G*: Gain stage; *d*: Detector; *s*: Sub-frame;
  - dn: Background subtracted response
  - c_0, c_1, and c_2: calibration coefficients

- Relative lunar F-factor

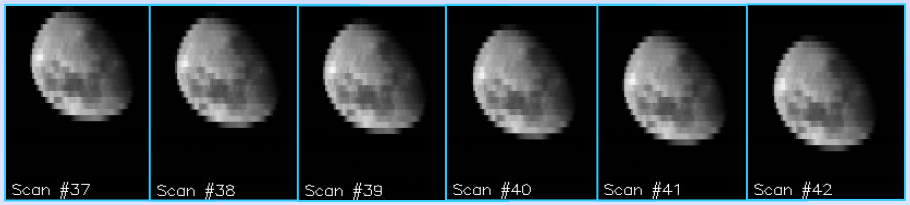
$$F(B,M,G)=J_{Model}(B)/J(B,M,G)$$

  - J_{Model}(B) from USGS ROLO model

SD F-factor

$$F=\frac{L_{SD_Comp}}{L_{SD_Meas}}$$

Examples of band I1 lunar images (Jan 4, 2012)



BB Calibration (TEB)

TEB Calibration: F Factor

$$\Delta L_{EV} = F \cdot \left(c_0 + c_1 \cdot dn_{EV} + c_2 \cdot dn_{EV}^2\right)$$

From BB observations

$$F = \frac{\Delta L_{\det_computed}}{\Delta L_{\det_retrieved}}$$

$$\Delta L_{\det_retrieved}(B) = \sum_{i=0}^{2} c_i dn_{BB}^i$$

$$\Delta L_{\det_computed}(B) = RVS_{BB}(B)\Delta L_{ap}(B) + \Delta L_{bckgr}(B)$$

$$\Delta L_{ap}(B) = \varepsilon L_{BB} + (1-\varepsilon)(F_{RTA}L_{RTA} + F_{SH}L_{SH} + F_{CAV}L_{CAV})$$

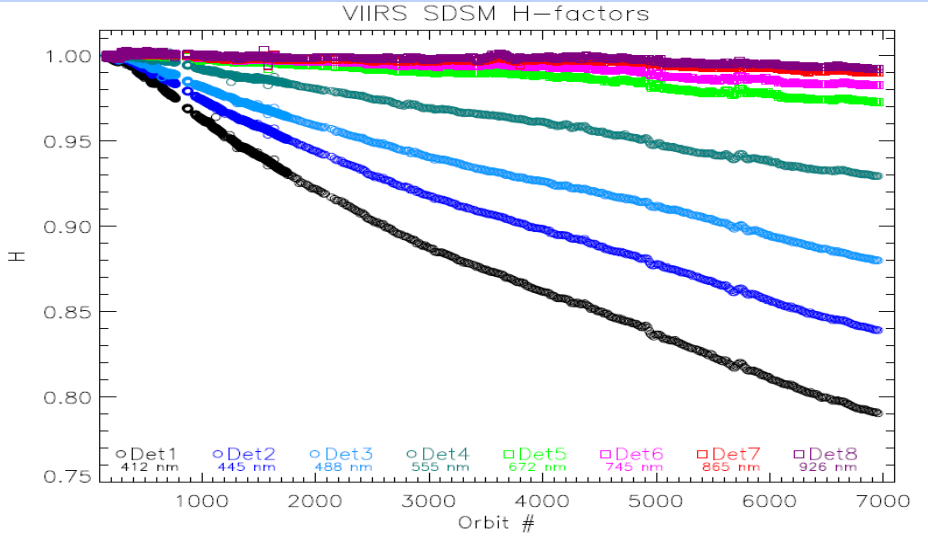
$$\Delta L_{bckgr}(B) = \frac{(RVS_{BB}(B) - RVS_{SV}(B))}{\rho_{RTA}(B)}[(1-\rho_{RTA}(B))L_{RTA} - L_{HAM}]$$

On-orbit Performance

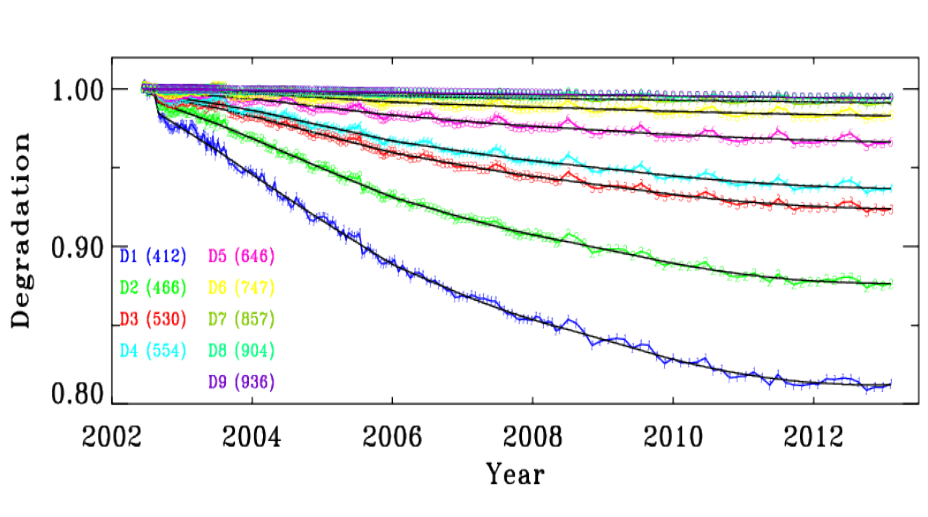
- **On-board Calibrators**
  - SD Degradation
  - BB Stability
- **Changes in Spectral Band Response**
  - Reflective Solar Bands (RSB)
  - Thermal Emissive Bands (TEB)
- **Changes in Relative Spectral Response (RSR)**
  - Modulated RSR for VIS/NIR Bands
- **Detector SNR and NedT**

SD Degradation

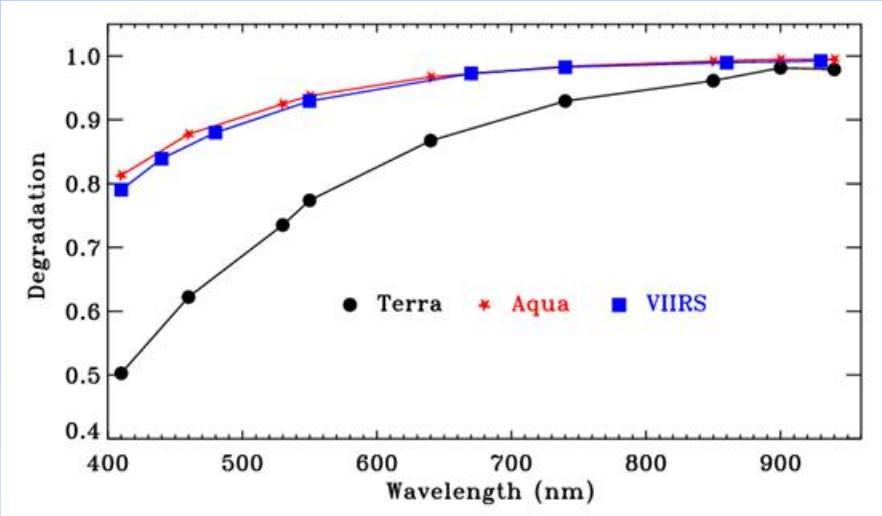
S-NPP VIIRS



Aqua MODIS



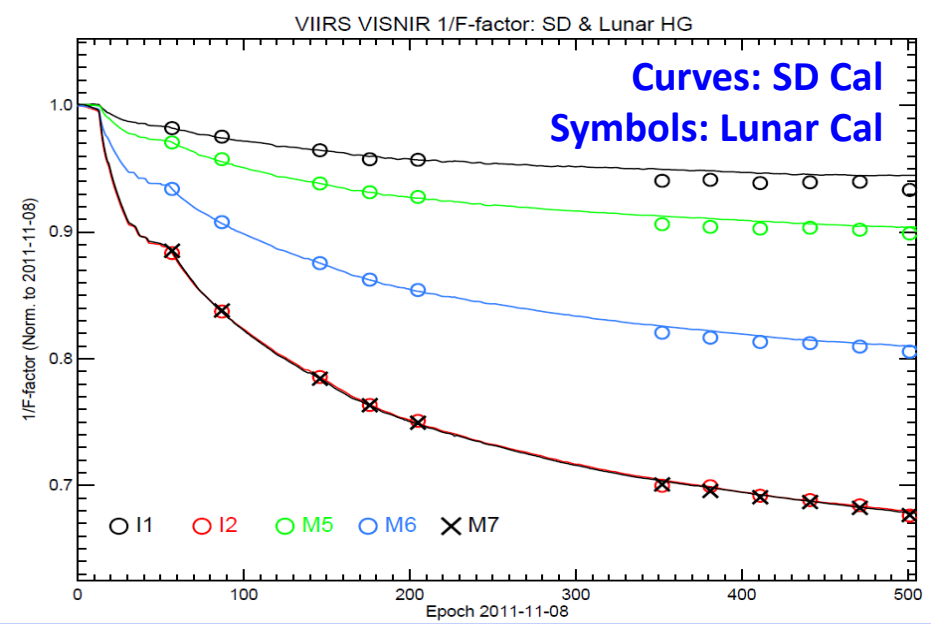
Similar to MODIS with strong wavelength dependence

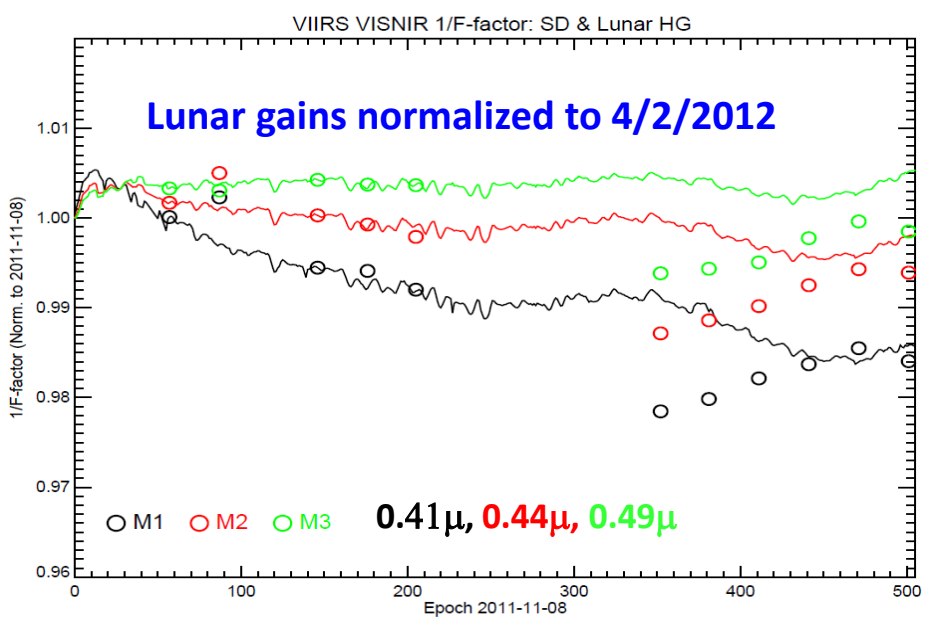


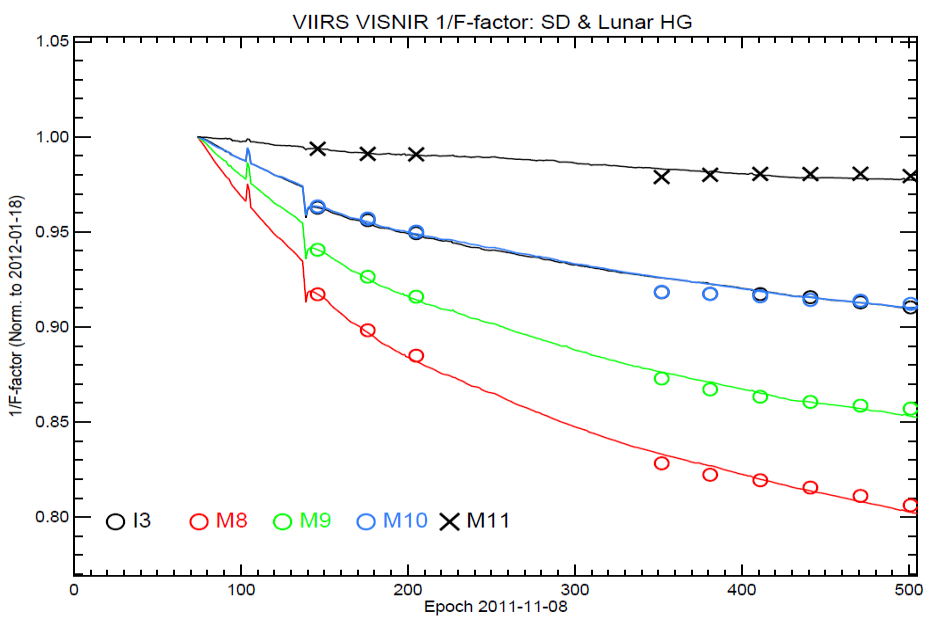
VIIRS has no SD door:

Large degradation in SD BRF at short wavelength

Changes in Spectral Band Response (RSB)







Little change for HAM side and AOI dependence

Large changes in NIR/SWIR response

Noticeable SD and Lunar calibration difference in VIS (M1-M3)

BB Stability

Orbits: 4743, 4744, 4745

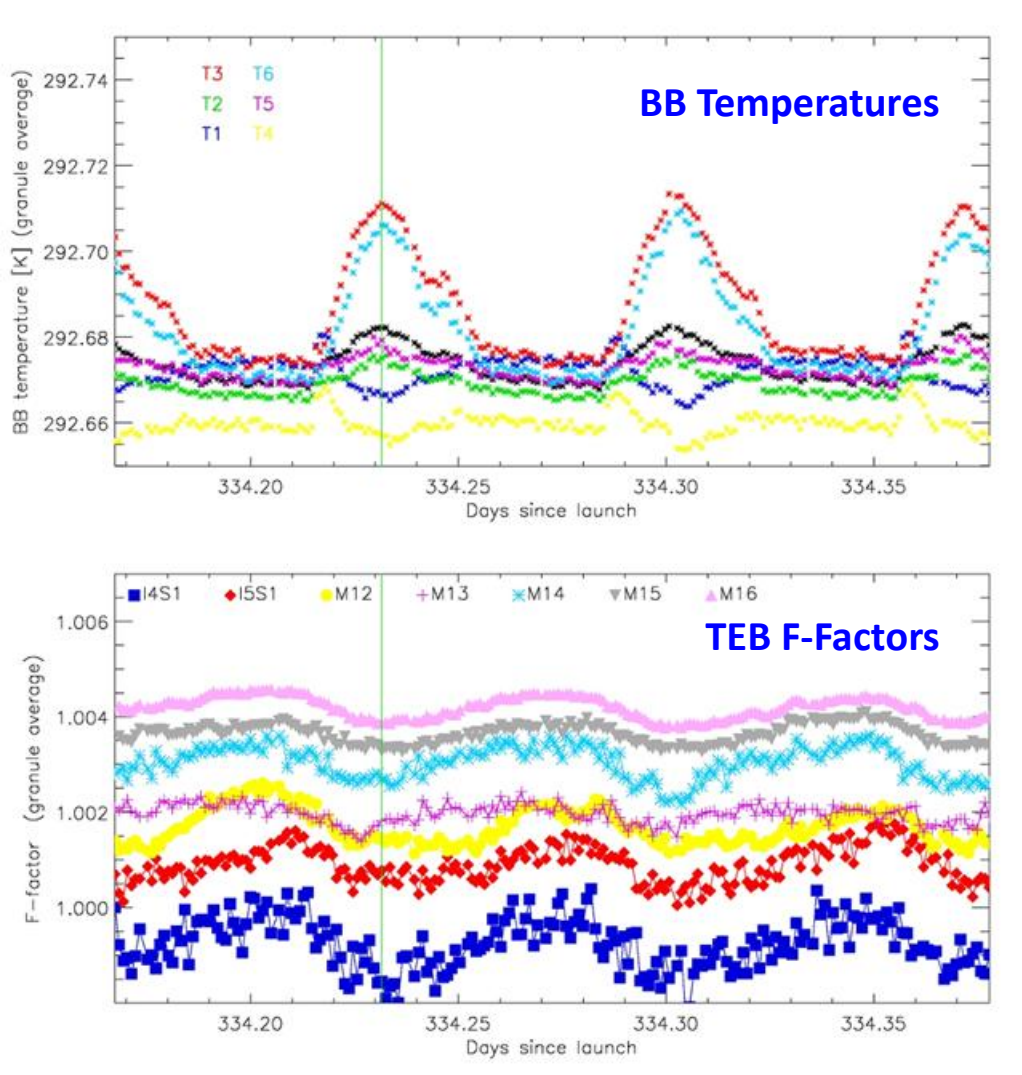
BB temperatures from individual thermistors show small orbital variation(with similar amplitude for thermistor pairs located at the same scan angle). Thermistors 3 and 6, which are located at the top of the BB (furthest from the EV), have the largest variation.

$$\Delta\overline{T}_{(T_3,T_6)} = 0.037\,K$$

$$\Delta\overline{T}_{(T_2,T_5)} = 0.011\,K$$

$$\Delta\overline{T}_{(T_1,T_4)} = 0.014\,K$$

$$\Delta\overline{T}_{(T_1,T_2,T_3,T_4,T_5,T_6)} = 0.014\,K$$

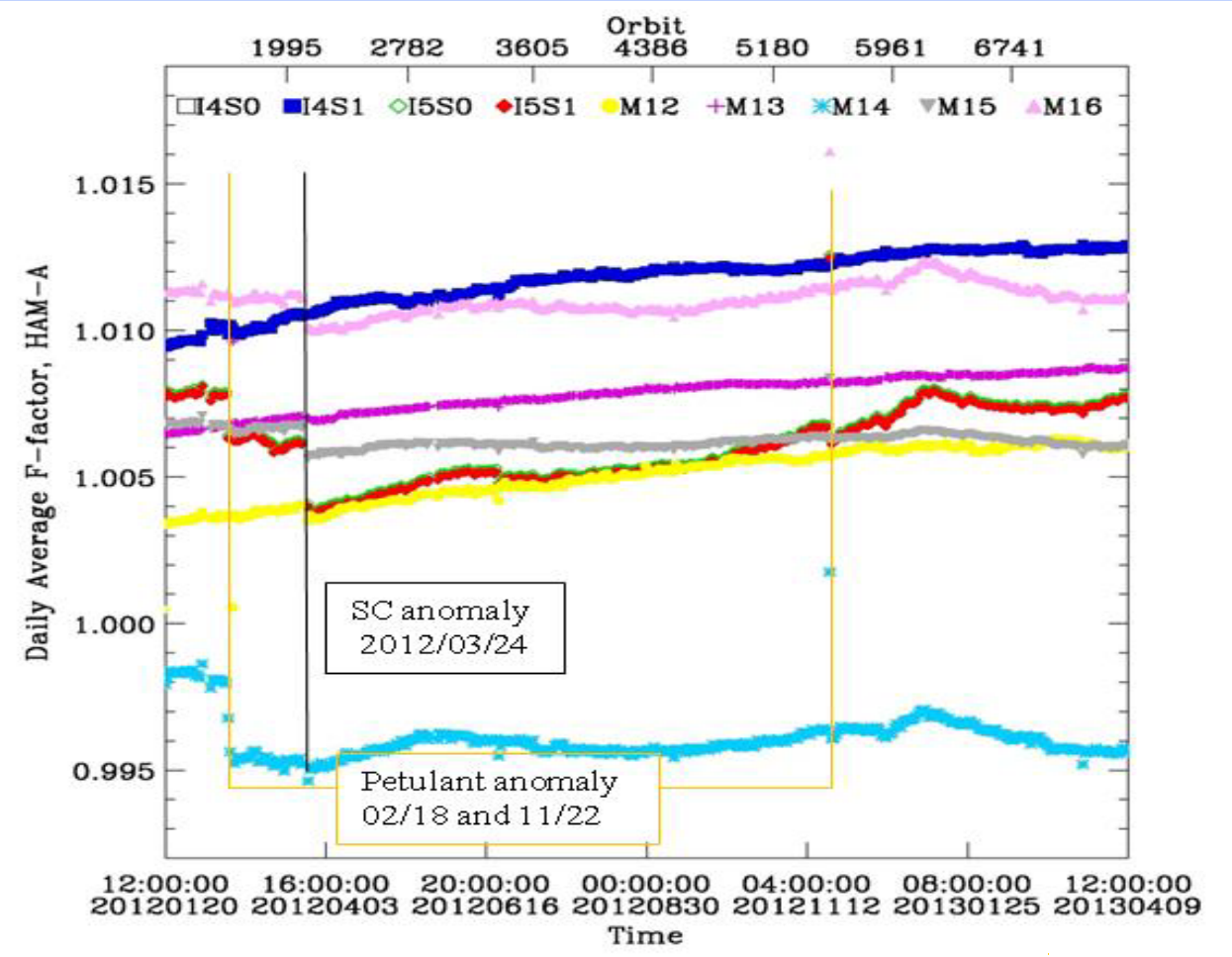


The F-factors at nominal temperature show periodic variations of 0.2%, which are correlated with the BB temperature variations.

*** For clarity the F-factors are shifted.**

Changes in Spectral Band Response (TEB)

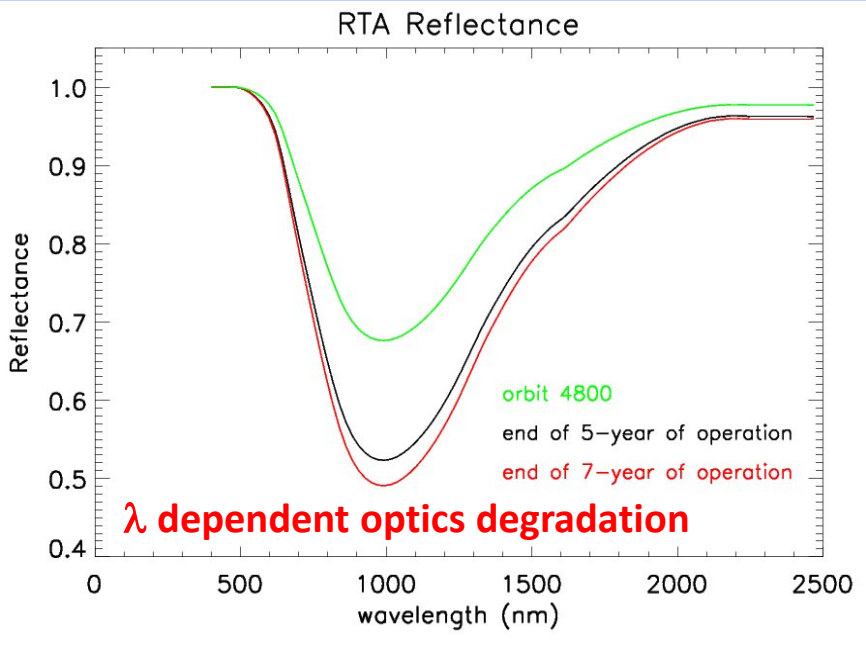
The discontinuities in the F-factor are coincident with spacecraft maneuvers and anomalies during which the cold FPA temperatures changed

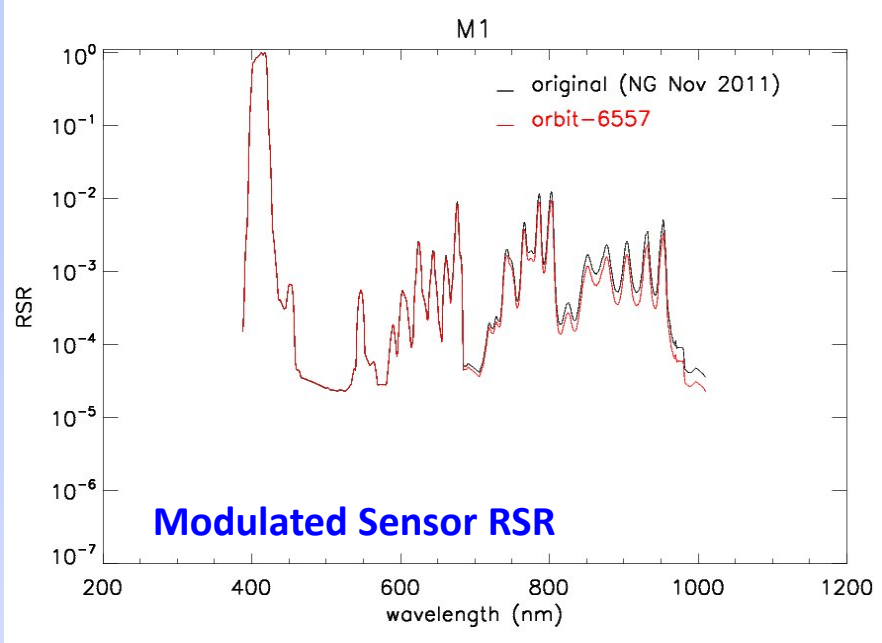


Band	I4	I5	M12	M13	M14	M15	M16
Band-Average (BA) Trends [%]	0.23	0.34	0.25	0.17	0.10	0.04	0.10
Standard Deviation of BA Trends [%]	0.10	0.10	0.03	0.05	0.09	0.03	0.02

Changes in Relative Spectral Response

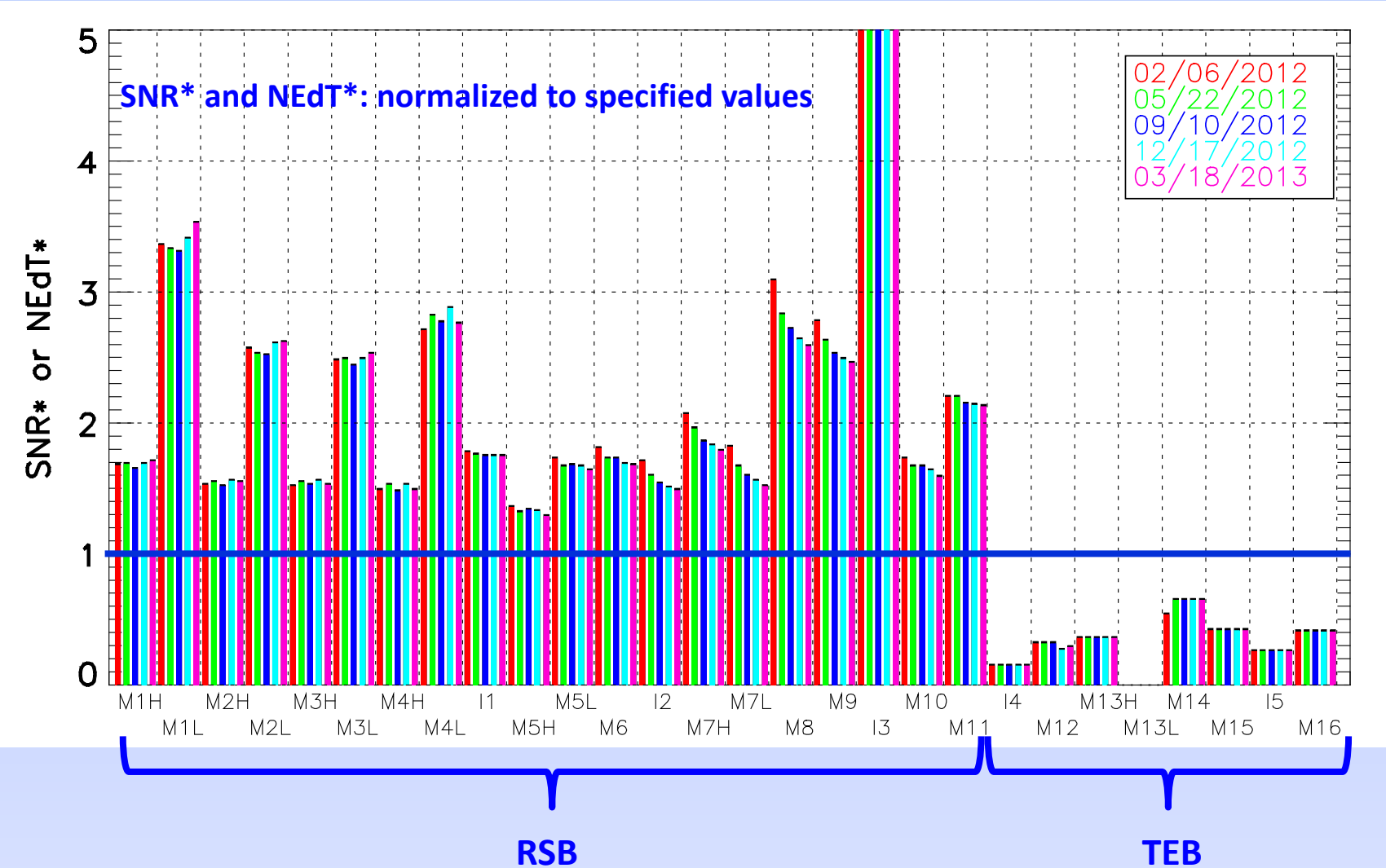
Mirror Degradation has impact on sensor relative spectral response and radiometric calibration quality





Modulate RSR has recently applied to SDR Calibration and Data Production

Detector SNR (RSB) and NEdT (TEB)



For RSB: SNR* > 1 means performance better than specified requirements

For RSB: SNR* > 1 means performance better than specified requirements

VIIRS SDR Data Access and Calibration Knowledge Base

- The VIIRS SDR team developed the Calibration Knowledge base at https://cs.star.nesdis.noaa.gov/NCC/VIIRS with a wealth of information including user's guide, relative spectral response, SNO predictions, image gallery, VIIRS Events, publication database, conference presentations, etc.

- VIIRS SDR data is available to the public on the NOAA CLASS archive at http://www.class.noaa.gov, and the ftp site: ftp://ftp-npp.class.ngdc.noaa.gov/

Reference:

Cao, C., F. Deluccia, X. Xiong, R. Wolfe, and F. Weng, 2013, Early On-orbit Performance of the VIIRS onboard the S-NPP Satellite, IEEE Transactions on Geoscience and Remote Sensing, in press.
DOI: 10.1109/TGRS.2013.2247768

Summary

- **VIIRS continues to operate and calibrate satisfactorily (as planned and expected)**
  - SD/SDSM, BB (warm-up and cool-down), and lunar calibration activities are regularly performed
  - Changes in sensor response are accurately tracked by the on-board calibrators
  - Calibration LUTs are frequently updated
- **Overall on-orbit performance meets the design requirements (such as SNR/NEdT)**
- **Continuous and dedicated calibration efforts are critical for maintaining SDR data and calibration quality**
- **The modulated RSR, as a result of mirror degradation, have been developed and applied to sensor SDR calibration and data production.**