VIIRS Reflective Solar Bands On-Orbit Calibration and Performance

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- Hybrid Approach
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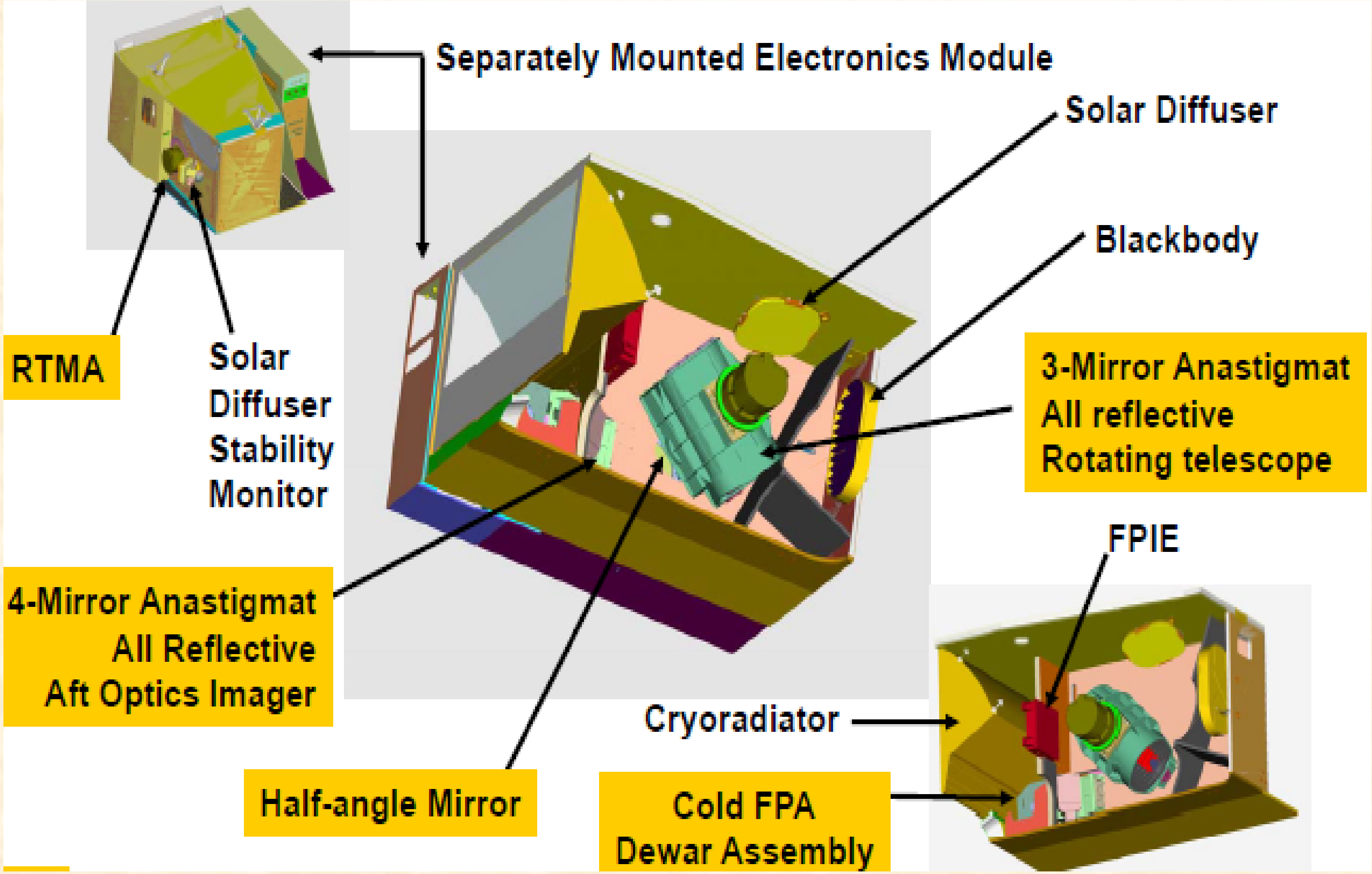
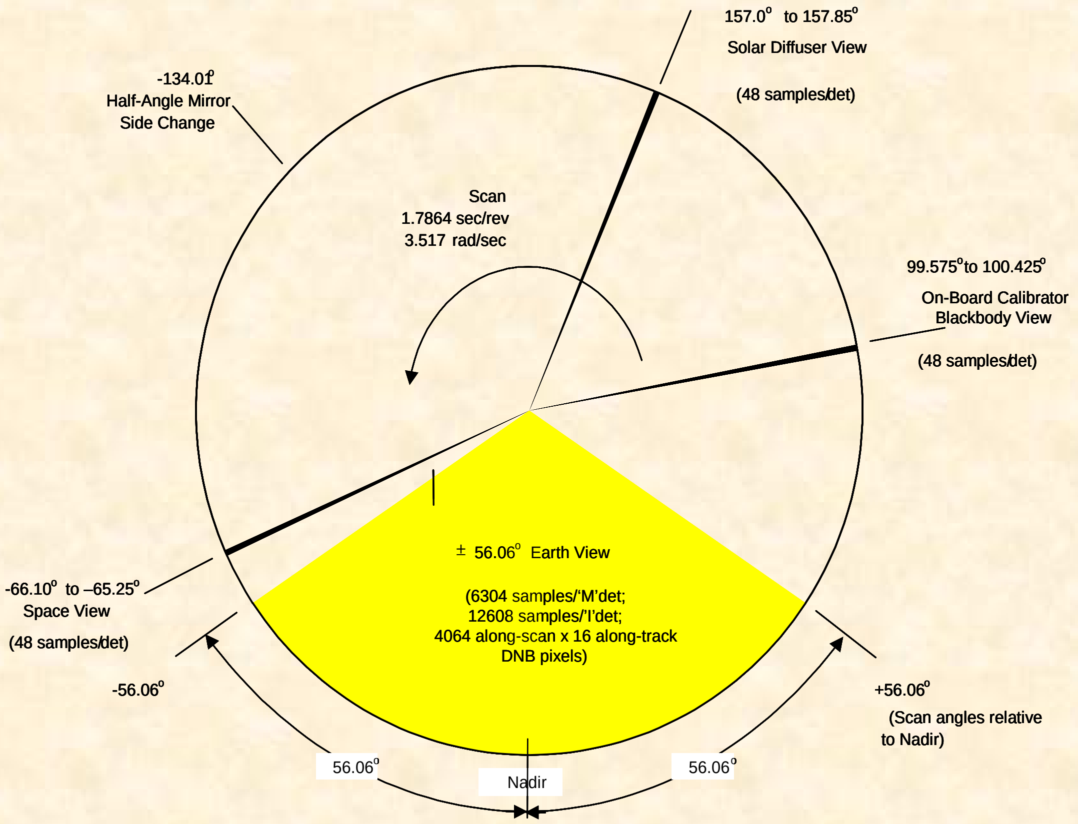
VIIRS Background



RSB On-Orbit Calibration

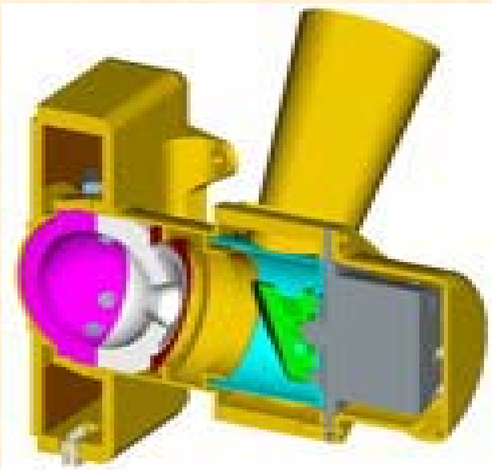
- **VIIRS on-board the Suomi NPP satellite launched on October 28, 2011**
- **VIIRS has 22 spectral bands covering a spectral range from 412 nm to 12.013 µm**
- **14 Reflective Solar Bands (RSB) : three image bands, I1-I3, and eleven moderate bands, M1-M11**
- **The VIIRS RSB are calibrated on orbit by SD/SDSM calibration**
- **VIIRS has also been scheduled to view the moon monthly through its Space View (SV) since launch.**
- **For VIIRS, the Angle of Incidence (AOI) of the SV is exactly the same as that of the SD. Lunar observations should provide identical on-orbit gain change for VIIRS RSB.**

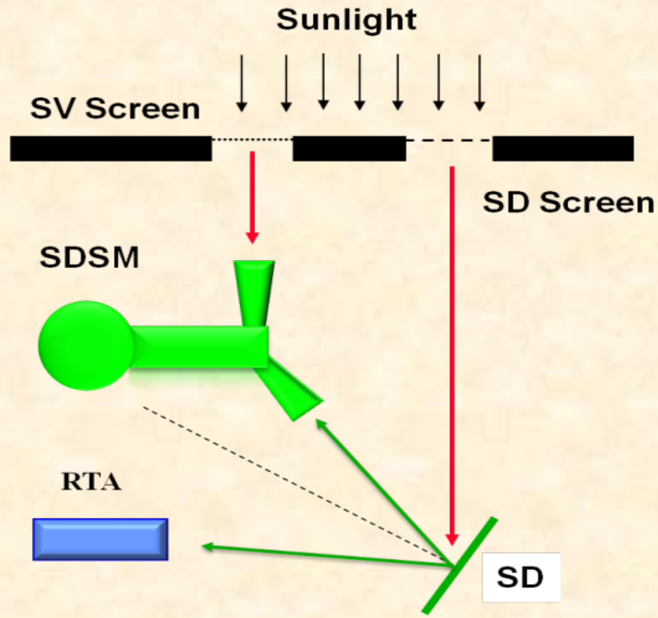


RSB uncertainty specification is 2%; For ocean color EDR products, the ocean bands (M1-M7) is expected to be calibrated with an uncertainty ~0.1%.

SD/SDSM Calibration

SDSM





SD and SDSM sun view screens:

- ***Avoid RSB and SDSM saturation***
- ***Vignetting functions (VFs)***
- ***VFs measured prelaunch and validated by yaw measurements***

SD

SD bidirectional reflectance factors (BRFs)

- ***BRFs measured prelaunch and validated by yaw measurements***
- ***SD on-orbit degradation is tracked by the SDSM measurements at 8 wavelength from 412 nm to 935 nm***
- ***SD degradation for the RTA direction can be approximately by that for the SDSM view direction***

J. Sun and M. Wang, "On-orbit characterization of the VIIRS solar diffuser and solar diffuser screen," Appl. Opt., 54, 236 (2015).

SDSM Calibration Algorithm

- SDSM is a ratio radiometer, which views SD, Sun, and an internal dark scene successively in three-scan cycles.
- SD BRF for SDSM view direction

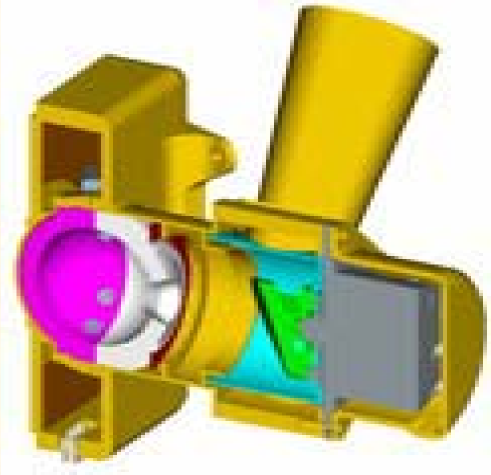
$$BRF_{SD,SDSM}(\lambda) = \rho_{SD,SDSM}(\lambda_D) H(\lambda_D)$$

  - $\rho_{SD,SDSM}(\lambda_D)$: BRF before launch
  - $H(\lambda_D)$ is solar diffuser degradation since launch

- SD degradation, H factors, for SDSM view direction

$$H(\lambda_D) = \left\langle \frac{dc_{SD,D}}{\rho_{SD,SDSM}(\lambda_D)\tau_{SDS}\cos(\theta_{SD})} \right\rangle_{Scan} \Big/ \left\langle \frac{dc_{SV,D}}{\tau_{SVS}} \right\rangle_{Scan}$$

  - $dc_{SD,D}$ and $dc_{SV,D}$ are the background-subtracted digital count for SD and sun view (SV)
  - τ_{SDS} and τ_{SVS} are VFs of SD and SV screens
  - θ_{SD} is the solar-zenith angle to the SD



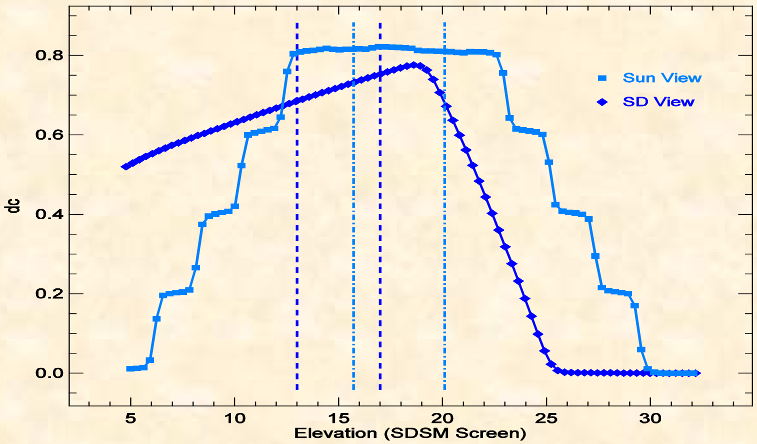
- ***Improvements***
  - ***Carefully derived the VFs and BRFs from yaw measurements***
  - ***Ratio of the averages***
  - ***Sweet spots selection***

SDSM operations: Every orbit first few months, then once per day for about two years, and once per two days since May, 2014.

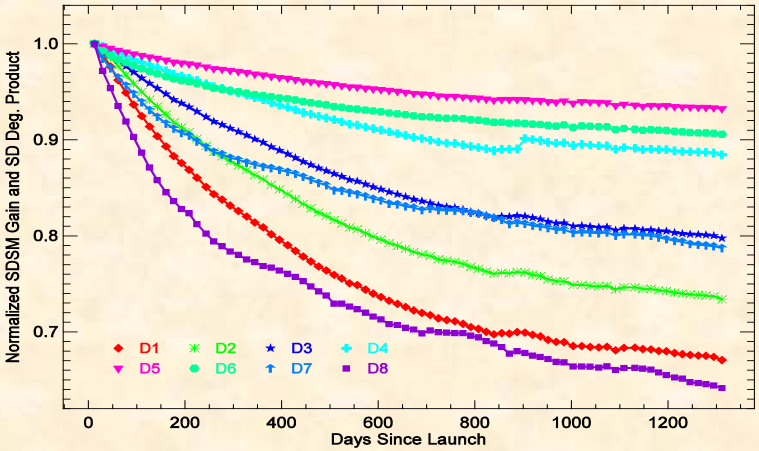
J. Sun and M. Wang, "Visible infrared image radiometer suite solar diffuser calibration and its challenges using solar diffuser stability monitor," Appl. Opt., 36, 8571-8584 (2014).

SD Degradation

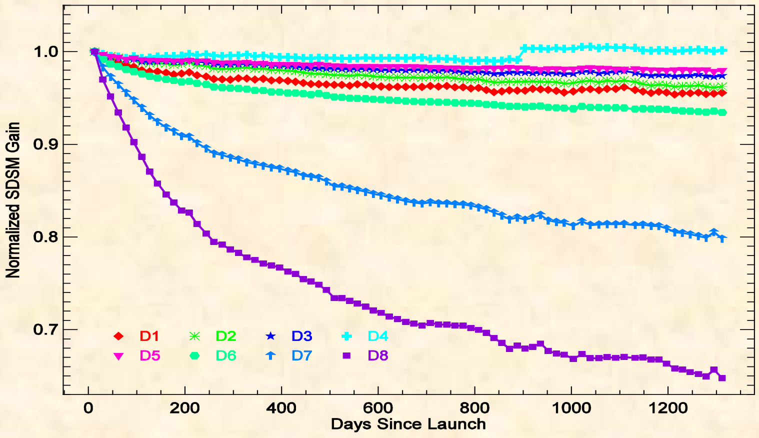
Sweet spots



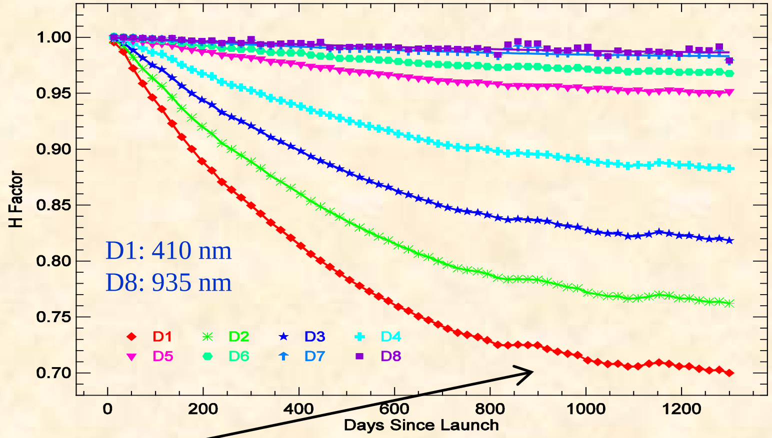
SD response trending



Sun view response trending



SD degradation



Unexpected but real degradation

SDSM can accurately track the SD degradation for SDSM direction

SD Calibration Algorithm

- SD is made of Spectralon®, near Lambertian property
- Solar radinace reflected by the SD

$$L_{SD}(\lambda) = I_{Sun}(\lambda) \cdot \tau_{SDS} \cdot \cos(\theta_{SD}) \cdot BRF_{RTA} \cdot h(\lambda) / d_{VS}^2$$

  - I_{Sun}: Solar radiance
  - BRF_{RTA}: BRF for RTA view direction
  - $h(\lambda)$: SD degradation for RTA direction, for which the SD degradation for SDSM direction is used
- RSB calibration coefficients, F factors

$$F(B,D,M,G) = \frac{RVS_{B,SD} \cdot \int RSR_B(\lambda) \cdot L_{SD}(\lambda) \cdot d\lambda}{\sum_i c_i(B,D,M,G) \cdot dn^i \cdot \int RSR_B(\lambda) \cdot d\lambda}$$

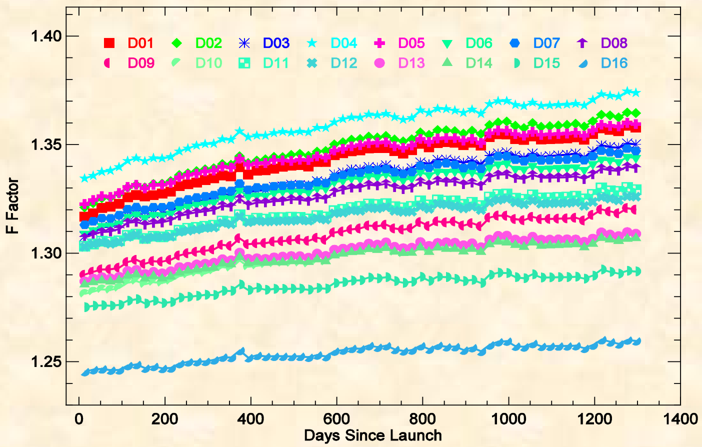
  - *B, D, M, G*: Band, Detector, HAM side, and gain status
  - $RVS_{B,SD}$: Response versus Scan angle
  - RSR_B: Relative spectral response for band B
  - $C_i(B,D,M,G)$: Prelaunch calibration coefficients

SD Calibration: Every orbit

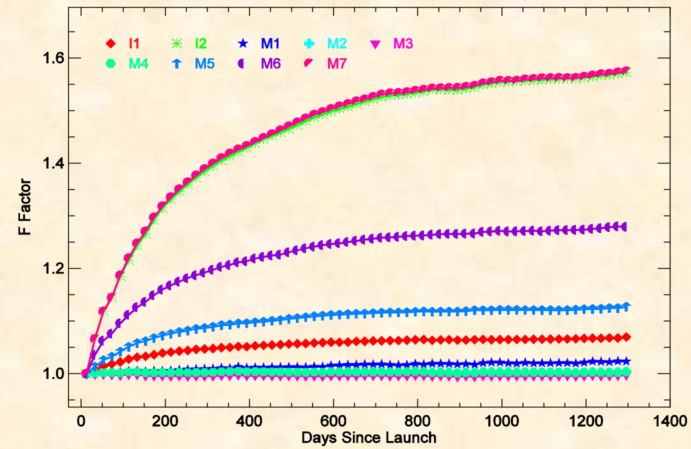
- Issues
  - Prelaunch c_0 and c_2
  - RSR on-orbit change
  - Correction for solar angle error
- ***Improvements***
  - ***Carefully derived the VFs and BRFs from yaw measurements***
  - ***Improved H factors***
  - ***Sweet spot selection***

RSB Calibration Coefficients

M1 HAM 1 HG F factors

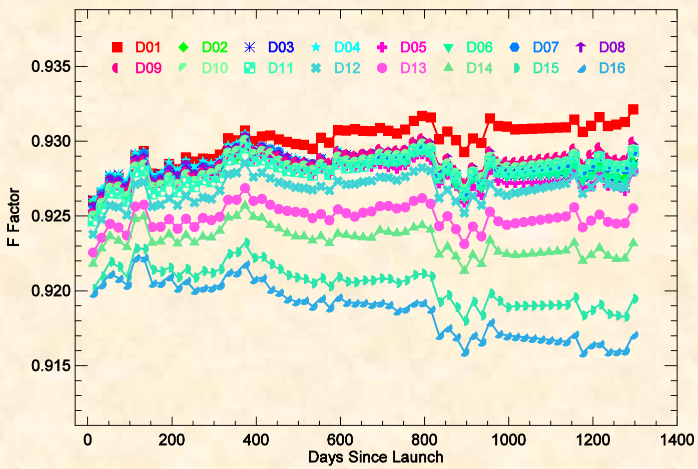


Band averaged HAM 1 HG F factors

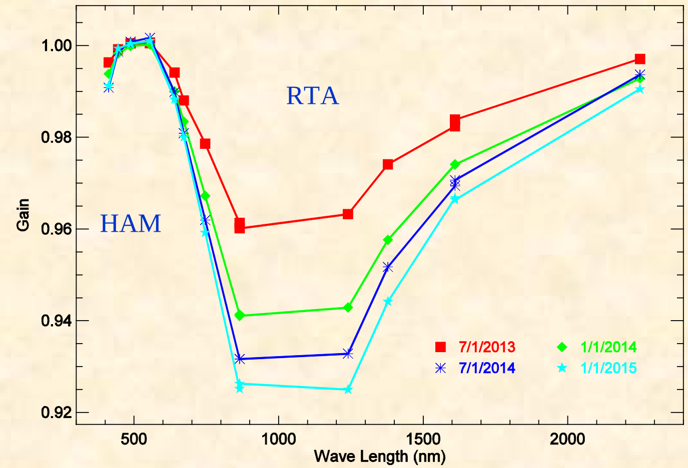


HG = High Gain
LG = Low Gain

M4 HAM 1 HG F factors



Band averaged gains



M1: 410 nm
M4: 551 nm

SD can accurately track the RSB gain change as long as SD degradation for the RTA view can be approximated as that for the SDSM view.

Lunar Calibration Algorithm

- Moon is very stable in its reflectance
- Lunar irradiance

$$I(B) = \sum_{D,S,N} L(B,D,S,N) w_B / N_t ,$$

  - N_t: Number of the scans which view a whole moon
  - w_B = (0.742 km)*(0.259 km)*g_B/(824 km)^2 is the solid angle (in steradians)
  - g_B: 1 and 1/4 for for M and I bands in SV sector, respectively; 1 for dual gain M bands, 3 for single gain M bands, and ¾ for I bands in EV sector, respectively.
- RSB calibration coefficients , F factors, from lunar observations

$$F(B,M) = \frac{g(B) N_{t,M}}{\sum_{D,S,N} L_{pl}(B,D,S,N)\delta(M,M_N)},$$

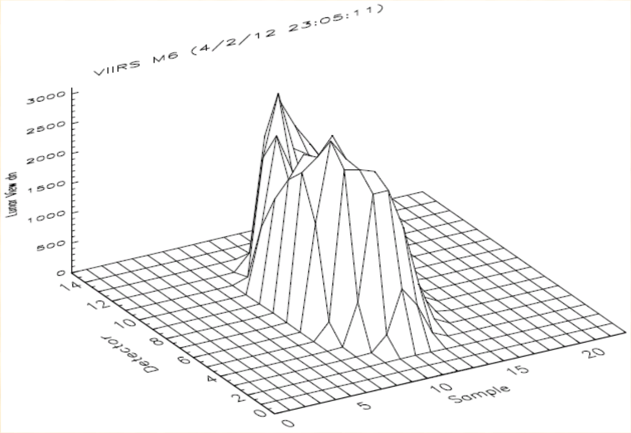
  - $g(B)$: View geometric effect correction (ROLO lunar model and extra correction)
  - $N_{t,M}$: number of the scans view a whole moon with HAM side M
  - M_N: HAM side for scan N

SNPP VIIRS is scheduled to view the Moon approximately monthly

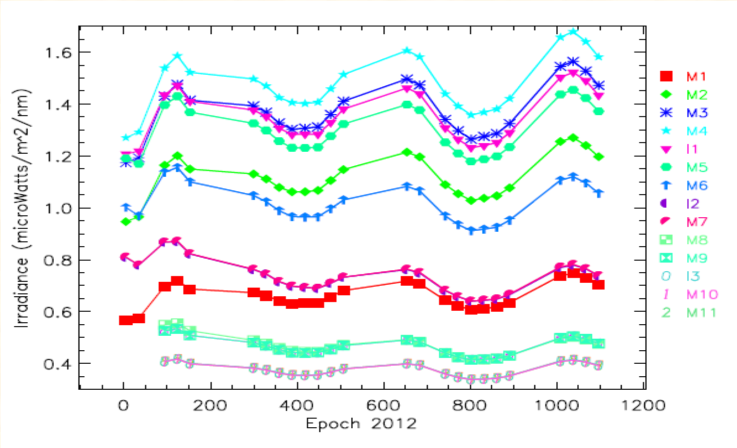
J. Sun, X. Xiong, and J. Butler, "NPP VIIRS on-orbit calibration and characterization using the moon", Proceedings of SPIE- Earth Observing Systems XVII, vol. 8510, no. 85101I, 2012.

Lunar Calibration Results

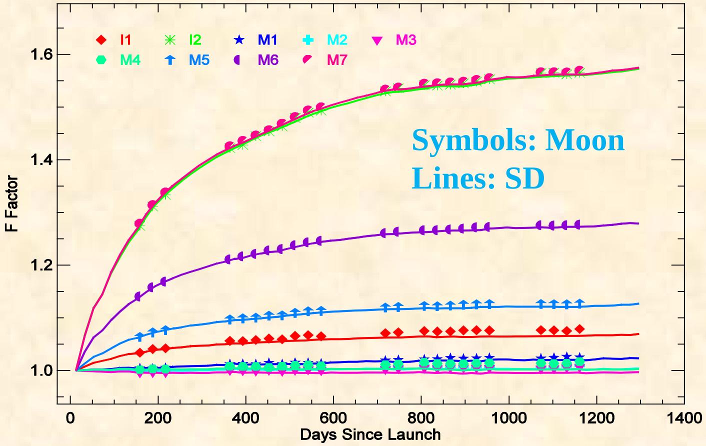
Lunar image (M6 in April, 2012)



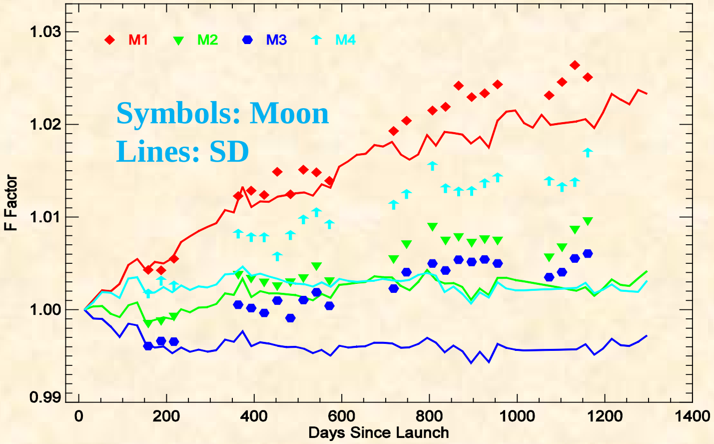
Lunar irradiance



Lunar and SD F Factors



Lunar and SD F factors



M1: 410 nm
M2: 443 nm
M3: 486 nm
M4: 551 nm

The SD F-factors and lunar F-factors diverge with time, especially for short wavelength RSB

Hybrid Approach

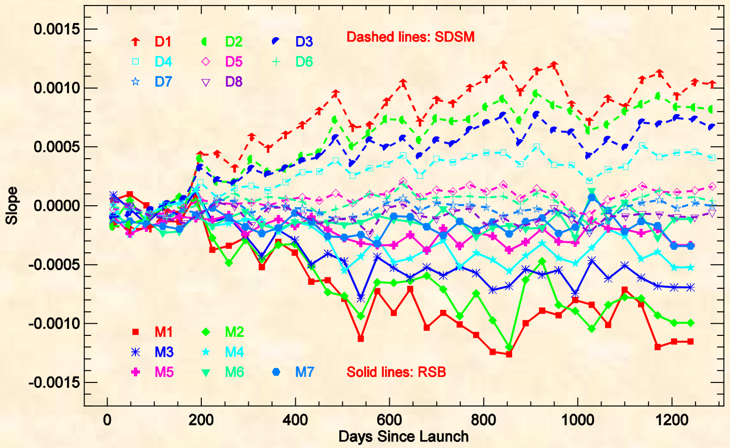
- SD Calibration
  - SD degrades non-uniformly, resulting long-term drifts
  - Results are stable and smooth
  - Observation in every orbit
- Lunar Calibration
  - No degradation issue
  - Infrequent and no observation in three months every
- Hybrid Approach

$$R(B,t) = \langle f(B,M,t) \rangle_M / \langle F(B,D,M,0,t) \rangle_{D, t-15<t_i<t+15, M}$$

$$\mathcal{F}(B,D,M,G) = R(B,t) \cdot F(B,D,M,G)$$

  - Lunar calibration provides long-term baseline
  - SD calibration provides smoothness and frequency

Non-uniformity of SD degradation

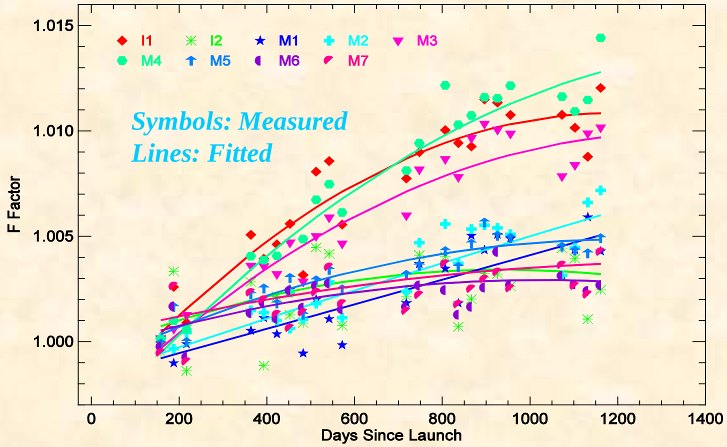


Slopes of H-factors and F-factors in each individual event with respect to solar declination

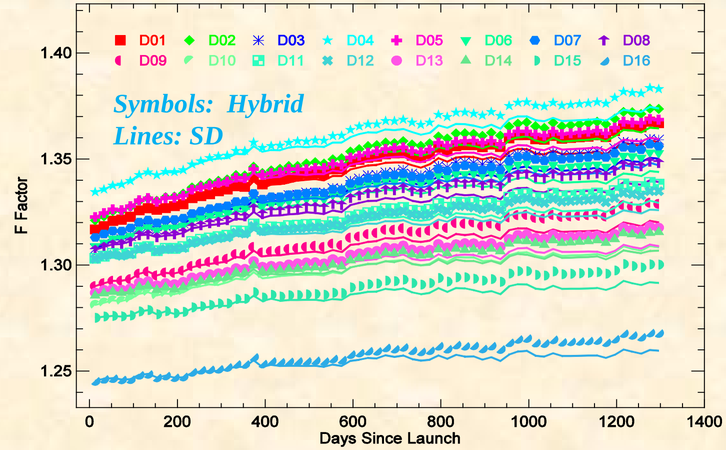
Ratios are fitted to quadratic polynomials of time

Hybrid Calibration Coefficients

Calibration coefficients Ratios

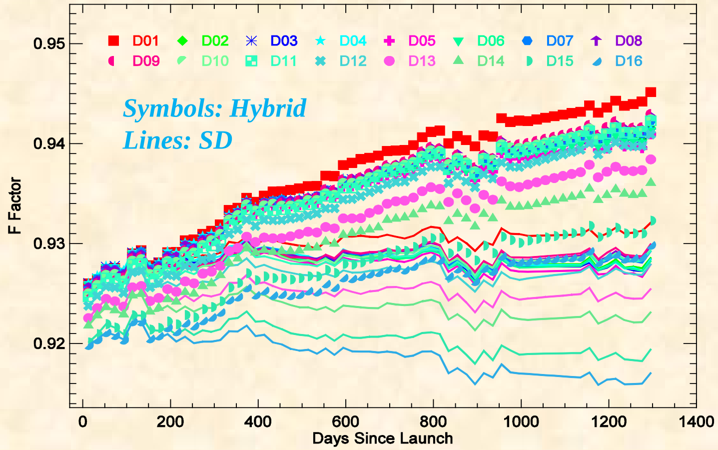


M1 Calibration Coefficients

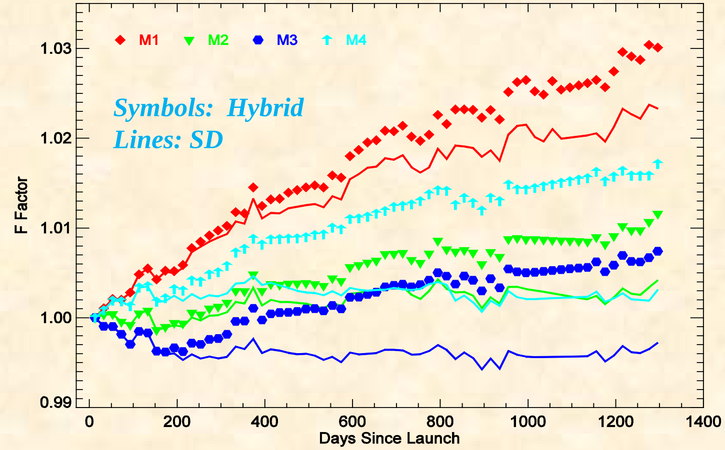


M1: 410 nm
M2: 443 nm
M3: 486 nm
M4: 551 nm
I1: 640 nm

M4 Calibration Coefficients

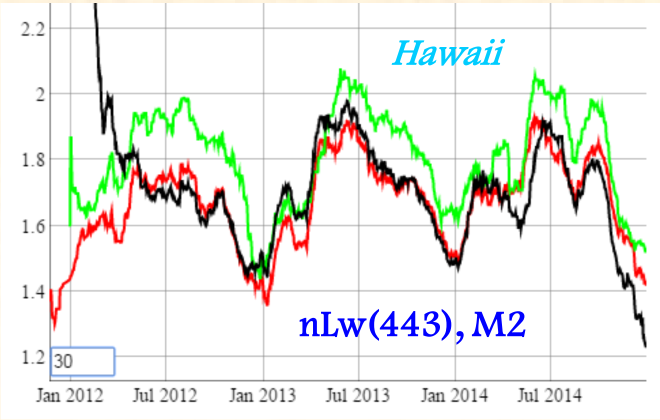


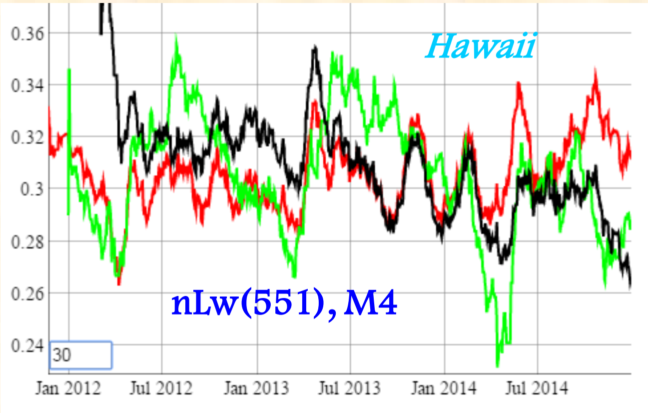
Calibration Coefficients

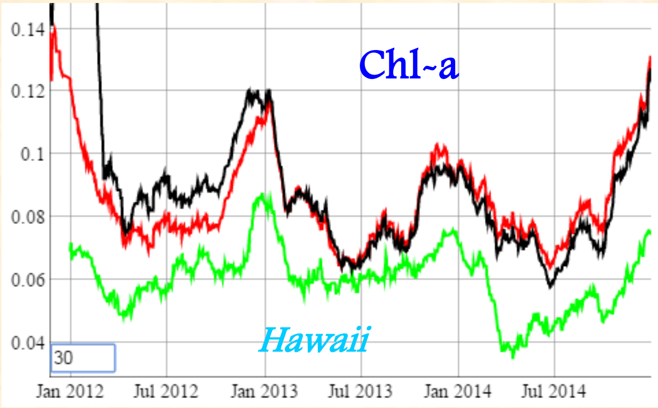


Improvements in Ocean Color Products

- The hybrid calibration coefficients were first applied in September 2014.
- VIIRS data were reprocessed using **MSL12** with SDR generated with updated hybrid calibration coefficients in February, 2015.
- NOAA ocean color products produced with the hybrid calibration coefficients has met the goals of the validated maturity in March 2015.







Black: VIIRS IDPS; Red: VIIRS Hybrid; Green: Aqua MODIS

- J. Sun and M. Wang, “VIIRS Reflective Solar Bands On-Orbit Calibration and Performance: A Three-Year Update,” Proc. SPIE, 9264, 92640L (2014).
- M. Wang, et al, “Evaluation of VIIRS ocean color products,” Proc. SPIE 9261, 92610E (2014).

Summary

- A timely update of the current progress in the calibration of the VIIRS reflective solar bands is presented.
- It is shown that SD/SDSM calibration can provide stable and clean calibration coefficients with all carefully derived input components.
- The "degradation uniformity condition", a key assumption in SD/SDSM calibration methodology, has recently proved to be untrue, which may result in a long-term bias into the calibration coefficients.
- Lunar observation can also provide stable and clean calibration coefficients without facing the surface degradation issue even though lunar observations are infrequent.
- An hybrid approach properly combining the SD and lunar calibration coefficients restores the accuracy of the calibration coefficients from the non-uniformity issue and other various effects.
- The hybrid calibration coefficients have significantly reduced the long-term drift in the ocean color EDR products and improved the VIIRS ocean products to high quality, capable to support of the science research and various operational applications.

Backup

SDSM RSB Specification

SDSD Detector	CW* (nm)	VIIRS Band	CW* (nm)	Band Gain
D1	412	M1	410	DG
D2	450	M2	443	DG
D3	488	M3	486	DG
D4	555	M4	551	DG
NA	NA	I1	640	SG
D5	672	M5	671	DG
D6	746	M6	745	SG
D7	865	M7	862	DG
D7	865	I2	862	SG
D8	935	NA	NA	NA
NA	NA	M8	1238	SG
NA	NA	M9	1378	SG
NA	NA	M10	1610	SG
NA	NA	I3	1610	SG
NA	NA	M11	2250	SG

*CW: Center Wavelength; DG: Dual Gain; SG: Singla Gain