SNPP VIIRS SDR Calibration for Improvement of Ocean Color Products

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8/27/2015 9:00-9:15 AM

Star JPSS 2015 Annual Science Team Meeting

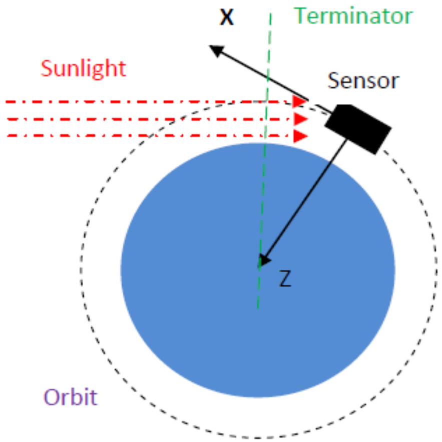
24-28 August 2015, College Park, Maryland

Key Points

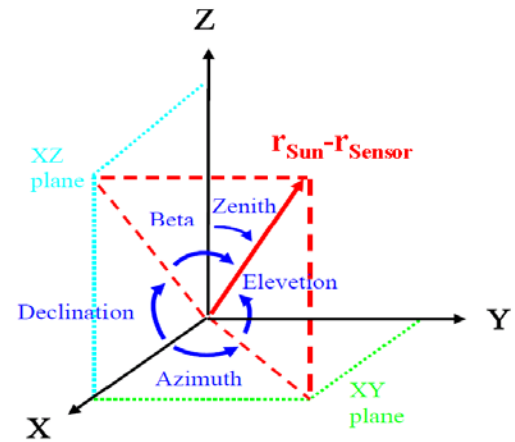
- **Ocean color products are highly sensitive to details in processing algorithms and calibration.**
- VIIRS RSB uncertainty specification is 2%; For ocean color EDR products, the ocean bands (M1-M7) are required to be calibrated with an uncertainty of ~0.1-0.3%.
- Solar diffuser (SD) degrades non-uniformly, resulting in long-term bias in calibration results, especially for short wavelength bands
- A 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:
  - Lunar calibration provides long-term baseline
  - SD calibration provides smoothness and frequency
- **Every component must itself be accurately characterized!**
  - SDSM calibration/SD calibration; Lunar calibration; Hybrid approach
- Challenges and potential issues

Solar Illumination and Sweet Spot

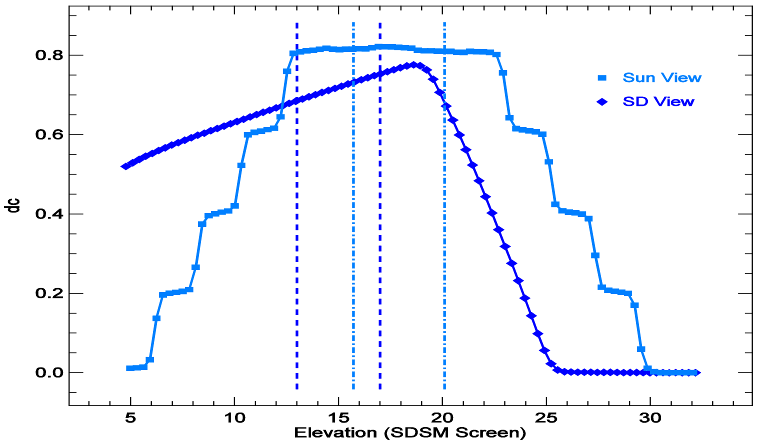
Illumination of SD and SDSM Aperture



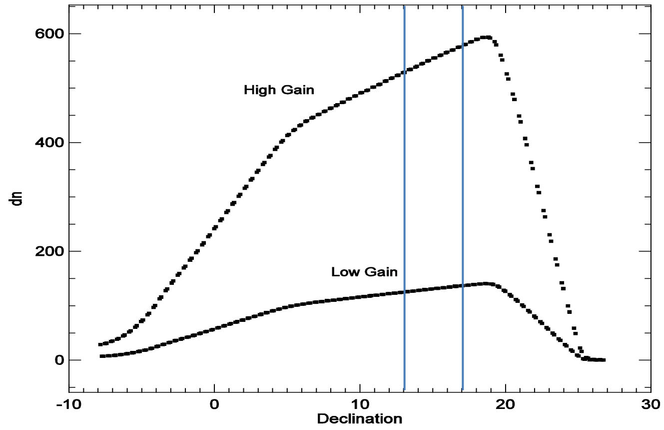
Solar angles



SDSM response

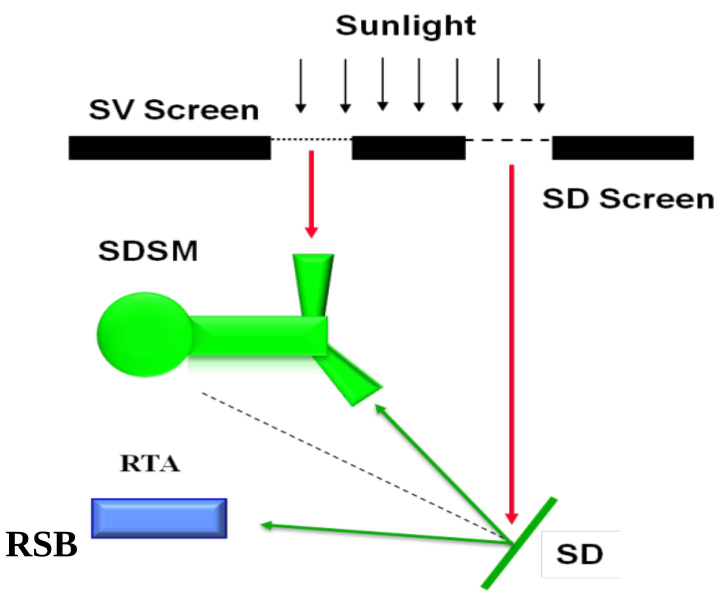


Band M1 Detector 1 response



Good selections stabilizes results, reduce noise – Different from ATBD

Prelaunch BRFs of the SD and the VFs of SD and SDSM Screens



The author carefully made yaw planning in 2012 with NASA colleagues for on-orbit validation of BRDF and VF.

We have carefully re-derived BRFs and VFs from the yaw measurements (removes seasonal variation artifacts and noises)

- SD and SDSM sun view screens:
  - Prevent RSB and SDSM saturation
  - Vignetting functions (VFs)
  - VFs measured prelaunch and validated by yaw measurements
- 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

J. Sun and X. Xiong, "Solar and lunar observation planning for Earth-observing sensor", Proc. SPIE, ***8176****, 817610, (2011).*

J. Sun and M. Wang, "On-orbit characterization of the VIIRS solar diffuser and solar diffuser screen," Appl. Opt., 54, 236 -252(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

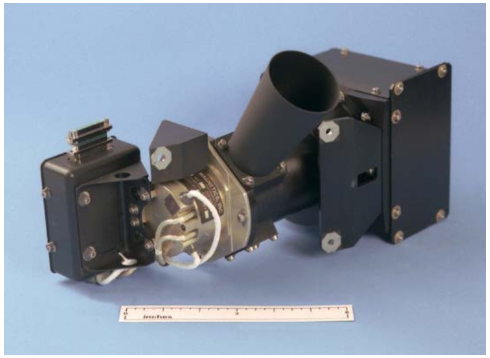
$$BRF_{SD,SDSM}(\lambda) = \rho_{SD,SDSM}(\lambda) H(\lambda)$$

  - $\rho_{SD,SDSM}(\lambda)$: Prelaunch BRF for SDSM view direction
  - $H(\lambda)$ is solar diffuser degradation since launch

- SD degradation, H factors, for SDSM view direction at the wavelength of the SDSM detector D

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

- ***Improvements***
  - *Carefully re-derived the VFs and BRFs from yaw measurements*
  - ***Ratio of the averages (different from ATBD!)***
  - *Sweet spots selection*

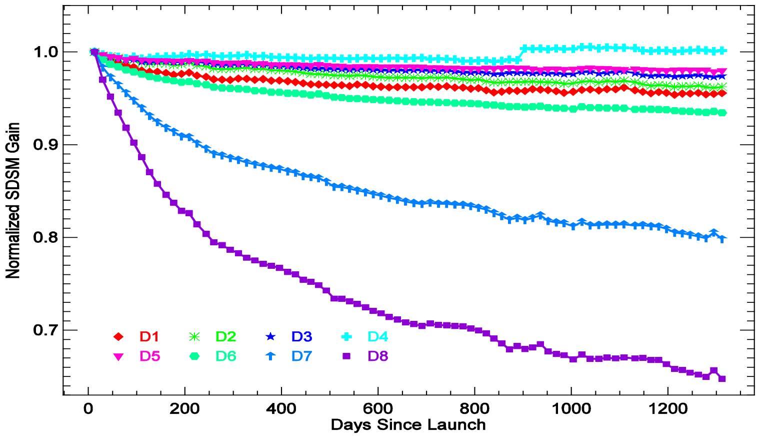


SDSM operations: Every orbit first few months, then once per day for about two years, and once per two days since May, 2014.

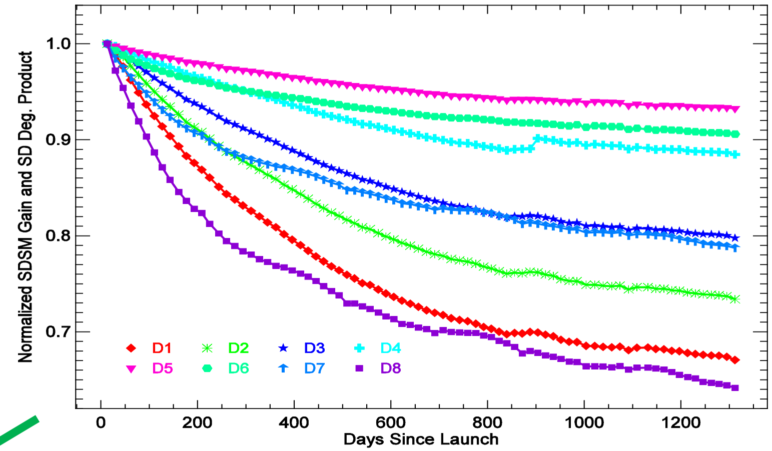
J. Sun and M. Wang, "Visible infrared image radiometer suite solar diffuser calibration and its challenges using solar diffuser stability monitor," Appl. Opt., 53, 8571-8584 (2014).

SDSM Calibration Results

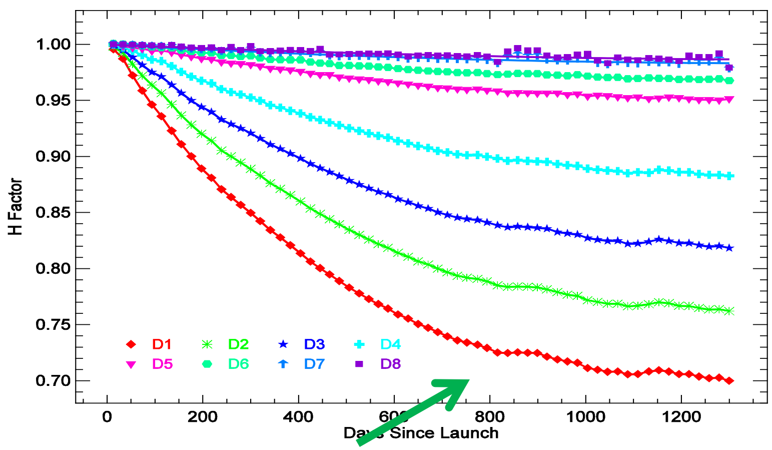
Sun view response trending



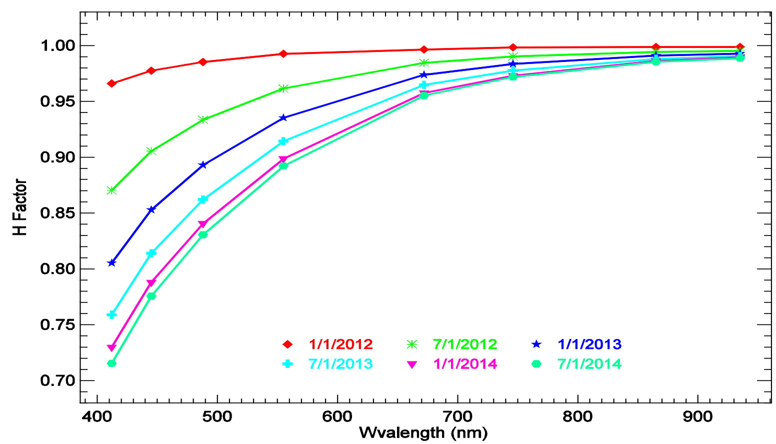
SD view response trending



SD degradation



SD degradation



Unexpected but real degradation (Nov., 2014)

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

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

  - $\rho_{RSD,RTA}(\lambda)$: Prelaunch BRF for RTA view direction
  - $h(\lambda)$: SD degradation for SDSM view direction is used as the SD degradation for the RTA direction

SD Calibration: Every orbit

- RSB calibration coefficients, F factors

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

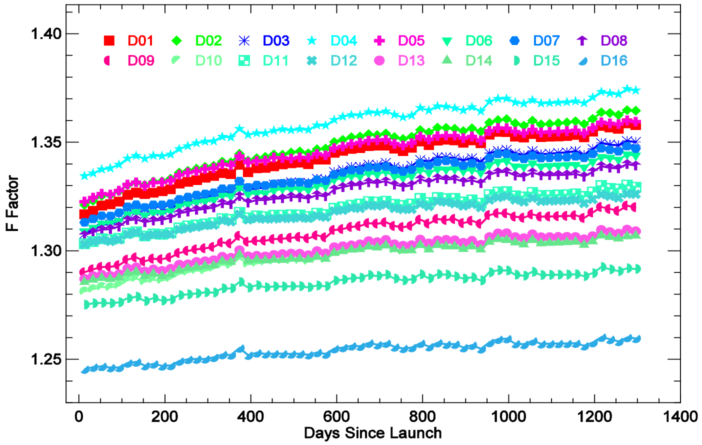
  - *B, D, M, G*: Band, Detector, HAM side, and gain status

- ***Improvements***
  - *Carefully rederived the VFs and BRFs from yaw measurements*
  - ***Improved H factors***
  - *Sweet spot selection*
  - ***Time-dependent RSR***

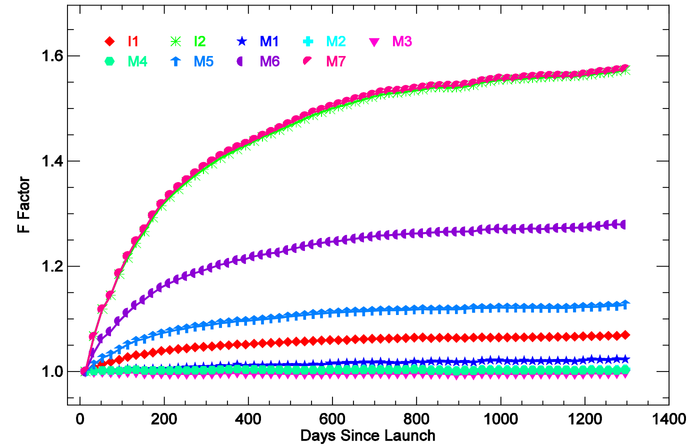
J. Sun and M. Wang, "On-orbit calibration of Visible Infrared Imaging Radiometer Suite reflective solar bands and its challenges using a solar," Appl. Opt., 54, 7210-7223 (2015).

SD Calibration Results

Band M1 HAM 1 HG F-factors

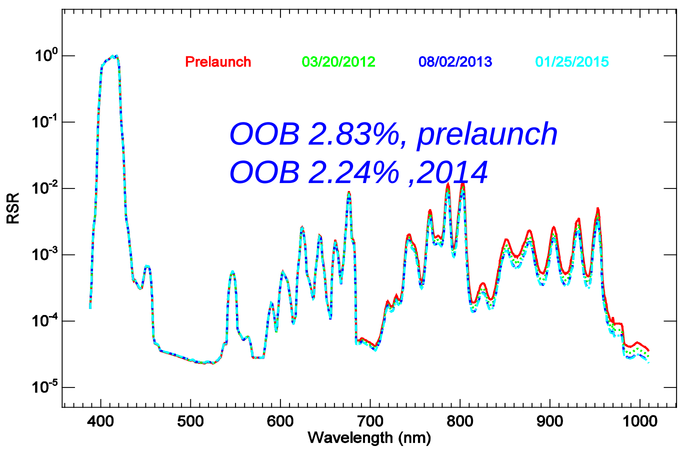


Band Averaged HAM1 HG F-factors

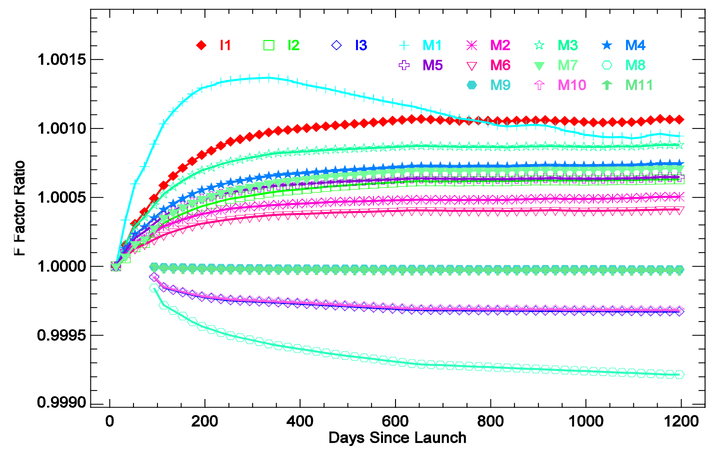


HG = High Gain
LG = Low Gain

Time-dependent RSR



Impact of RSR on F-factors



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
- 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)

SNPP VIIRS is scheduled to view the Moon approximately monthly (about nine months every year)

- *Advantages*
  - *Lunar surface reflectance has no observable degradation*
  - *Can be used for inter-comparison*

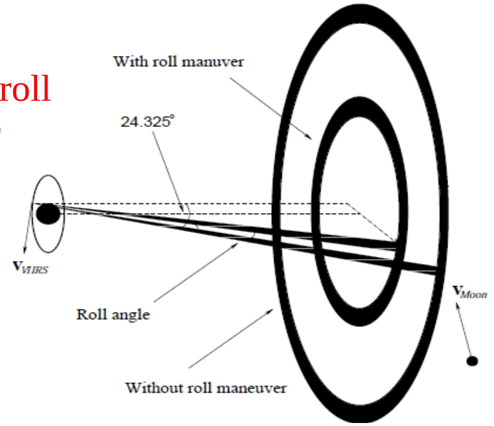
J. Sun, X. Xiong, and J. Butler, "NPP VIIRS on-orbit calibration and characterization using the moon", Proc. SPIE, 8510,85101I, (2012).

X. Xiong, J. Sun, J. Fulbright, Z. Wang, and J. Butler, "Lunar Calibration and Performance for S-NPP VIIRS reflective Solar Bands", IEEE Trans. Geosci. Remote Sens., accepted.

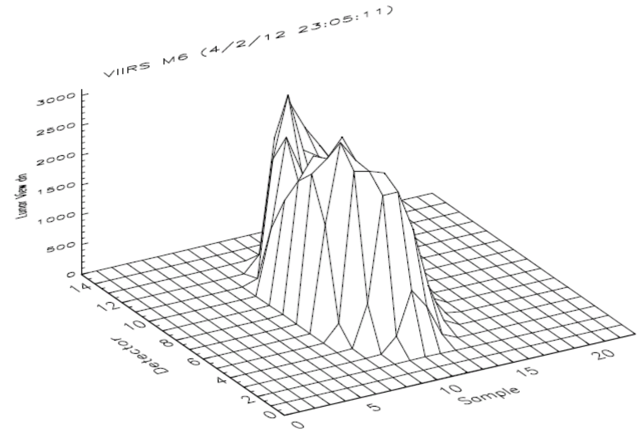
Lunar Planning and Calibration Results

Roll maneuver

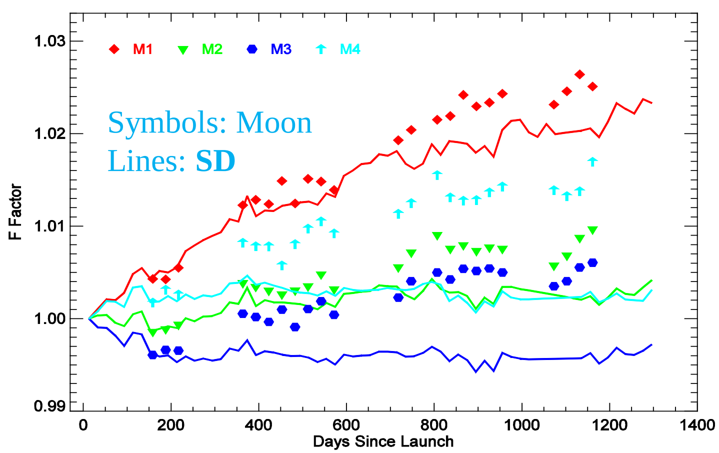
Required roll maneuver



Lunar image (M6 in April, 2012)



Lunar and SD F Factors



- View geometry dependence
- ***Planning is important starting point – made lunar planning tool and planned lunar observations in early mission***
- However, the phase angle range change from [-56º, -55º] to [-50.5º, 51.5º]
- Size of the moon
- Oversampling effect
- Scans seeing full lunar image

*J. Sun and X. Xiong, "Solar and lunar observation planning for Earth-observing sensor", Proc. SPIE, **8176**, 817610, (2011).*

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 year
- Hybrid Approach

F-Factors Ratios are fitted to quadratic polynomials of time

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

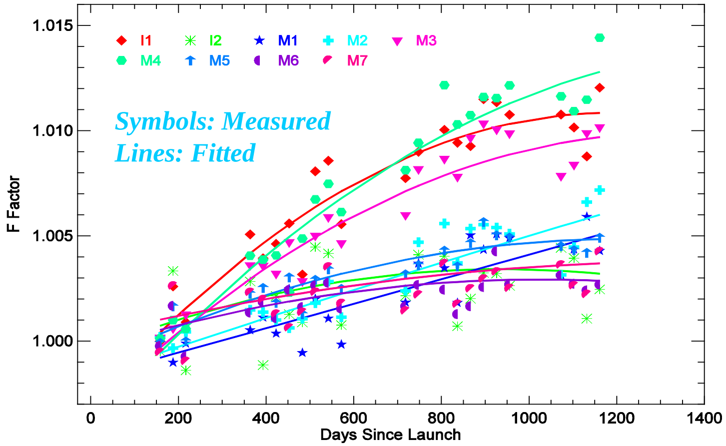
$$R(B,t) = \left\langle f(B,M,t)\right\rangle_M / \left\langle F(B,D,M,0,t)\right\rangle_{D,t-15<t_i<t+15,M}$$

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

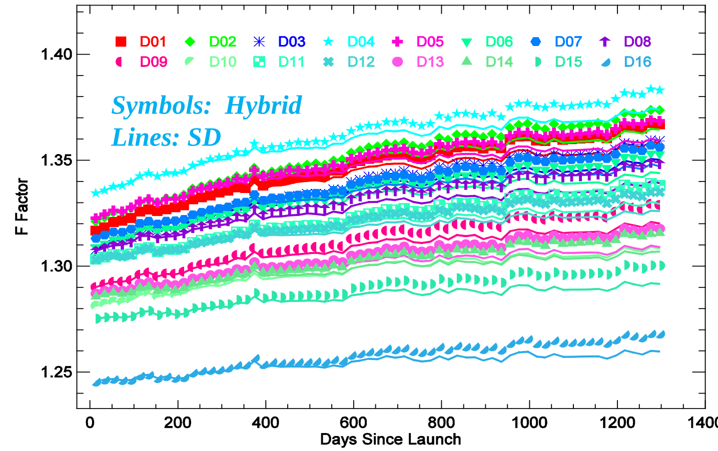
J. Sun and M. Wang, "Radiometric Calibration of the VIIRS Reflective Solar Bands with Robust Characterizations and Hybrid Calibration Coefficients," submitted to Applied Optics.

Hybrid Calibration Coefficients

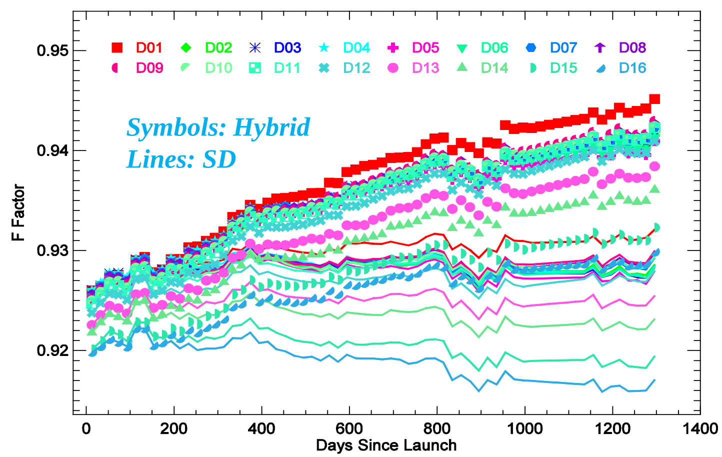
Calibration coefficients Ratios



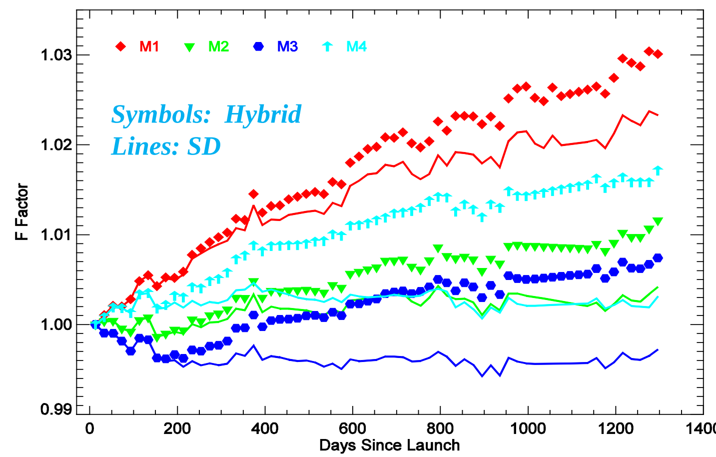
Calibration Coefficients (M1)



Calibration Coefficients (M4)

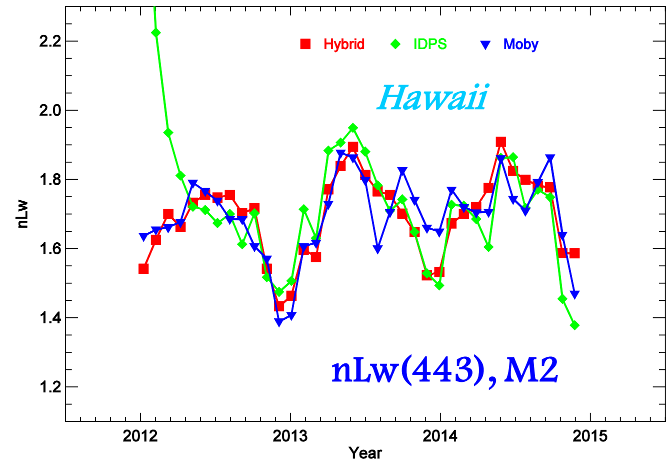


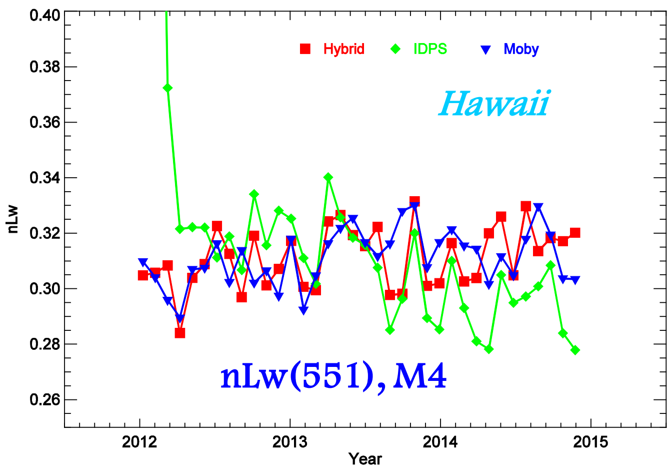
Calibration Coefficients

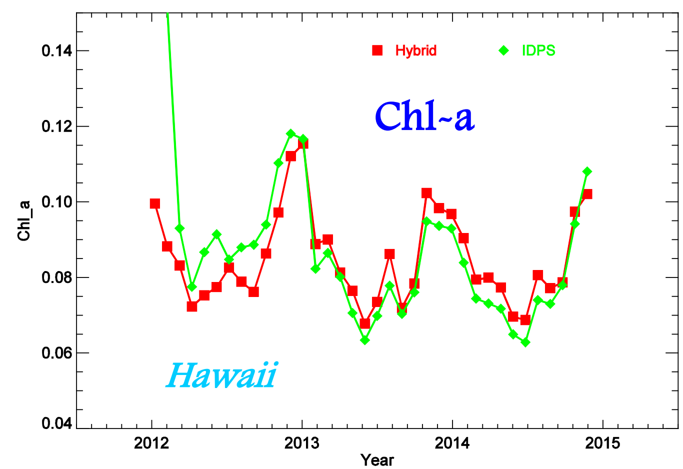


Improvements in Ocean Color Products

- VIIRS data were reprocessed using **MSL12** with SDR generated with updated hybrid calibration coefficients.
- NOAA ocean color products produced with the hybrid calibration coefficients have met validated maturity in March 2015.
- **Hybrid results agree with MOBY in situ!**





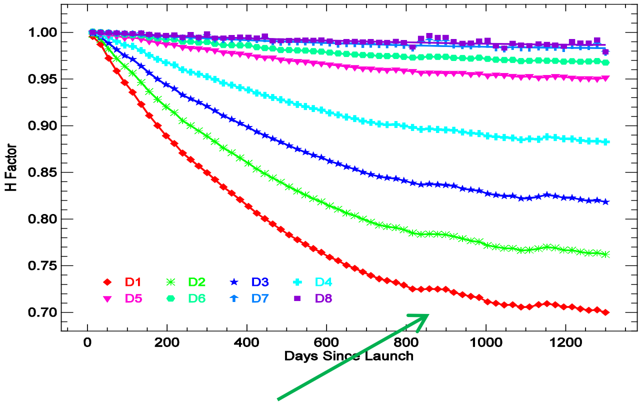


Green: VIIRS IDPS; Red: VIIRS Hybrid; Blue: Moby in Situ

- *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).*

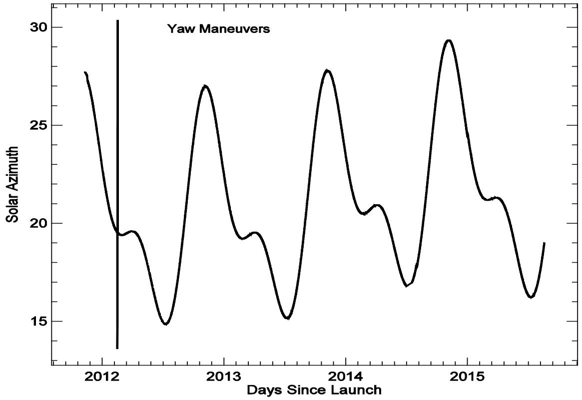
Some Other Challenges

- SD degrades abnormally



Unexpected but real degradation (Nov., 2014)

- S-NPP orbit drift

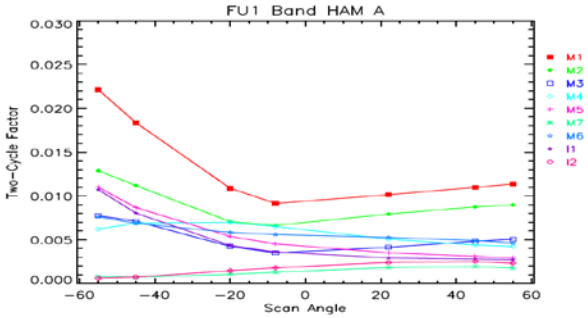


Azimuth angle in instrument coordinate system

- RVS may change on-orbit
  - Aqua and Terra MODIS RVS have changed more than 20% and 40%, respectively, at small AOI.

- *J. Sun, X. Xiong, A. Angal, H. Chen, A. Wu, and X. Geng, "Time dependent response versus scan angle for MODIS reflective solar bands," IEEE Trans. Geosci. Remote Sens., 52, 3159-3174 (2014).*
- *J. Sun and X. Xiong, "TMODIS polarization sensitiivity analysis", IEEE Trans. Geosci. Remote Sens., 45, 2875-2885 (2007).*

- Polarization sensitivity may change on-orbit



  - Terra MODIS polarization sensitivity changed dramatically on-orbit

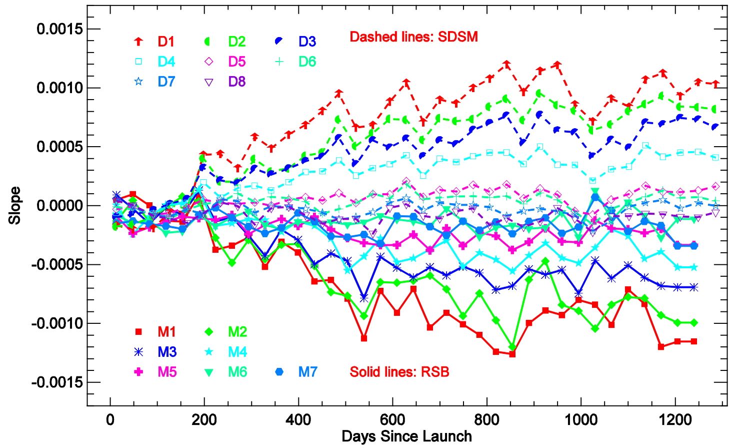
Summary

- Robust characterizations of essential calibration components have been completed
- A hybrid approach combining the SD and lunar calibration coefficients, along with robust inputs, achieves the highest accuracy up to date
- Hybrid calibration approach, using both solar and lunar calibrations, has significantly improved VIIRS ocean color products
- "Solar diffuser degradation uniformity condition" will be a key issue for all instruments such as VIIRS J1, VIIRS J2, etc, that use SD/SDSM for reflective solar bands calibration - Lunar calibration is necessary as a solution.
- There will be more challenge issues/problems when the instrument begins to age. Thus, more effort for instrument on-orbit calibration will be needed.

Backup

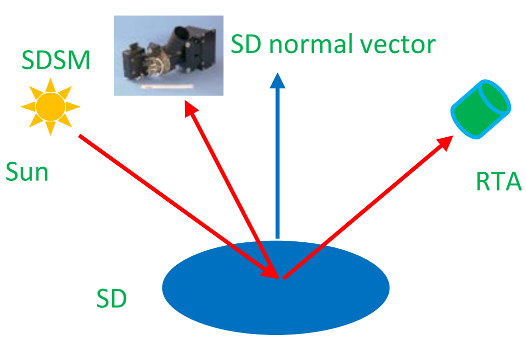
Non-Uniformity of the SD Degradation

Non-uniformity of SD degradation



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

SDSM and RTA views



- SD degrades non-uniformly with respect to the incident angle for SDSM view direction
- SD degrades non-uniformly with respect to the incident angle for rotating telescope assembly (RTA, RSB) view direction
- According to *optical reciprocity*, then SD also degrades non-uniformly with respect to the outgoing direction
- The different signs of the variation slopes of the H-Factors and F-Factors with respect to incident direction confirm that SD degrades non-uniformly with respect to outgoing direction

- *0.1% per degree; 1% per 10 degrees for 412 nm (D1 and M1)*
- *Angle between SDSM view direction and RTA view direction is larger than 100 degree?*
- ***SD calibration is not accurate enough for ocean color data processing***

VIIRS RSB Specification

Table 1. Specification for SNPP VIIRS RSBs and SDSM detectors.

VIIRS Band	CW* (nm)	Band Gain	Detectors	Resolution*	SDSD Detector	CW* (nm)
M1	410	DG	16	742m x 776m	D1	412
M2	443	DG	16	742m x 776m	D2	450
M3	486	DG	16	742m x 776m	D3	488
M4	551	DG	16	742m x 776m	D4	555
I1	640	SG	32	371m x 387m	NA	NA
M5	671	DG	16	742m x 776m	D5	672
M6	745	SG	16	742m x 776m	D6	746
M7	862	DG	16	742m x 776m	D7	865
I2	862	SG	32	371m x 387m	D7	865
NA	NA	N	16		D8	935
M8	1238	SG	16	742m x 776m	NA	NA
M9	1378	SG	16	742m x 776m	NA	NA
M10	1610	SG	16	742m x 776m	NA	NA
I3	1610	SG	32	371m x 387m	NA	NA
M11	2250	SG	16	742m x 776m	NA	NA

*CW: Center Wavelength; DG: Dual Gain; SG: Singla Gain; Resolution: Track x Scan at Nadir after aggregation