SNPP VIIRS Reflective Solar Bands On-Orbit Calibration: Improvements, Updates and SDR Reprocessing

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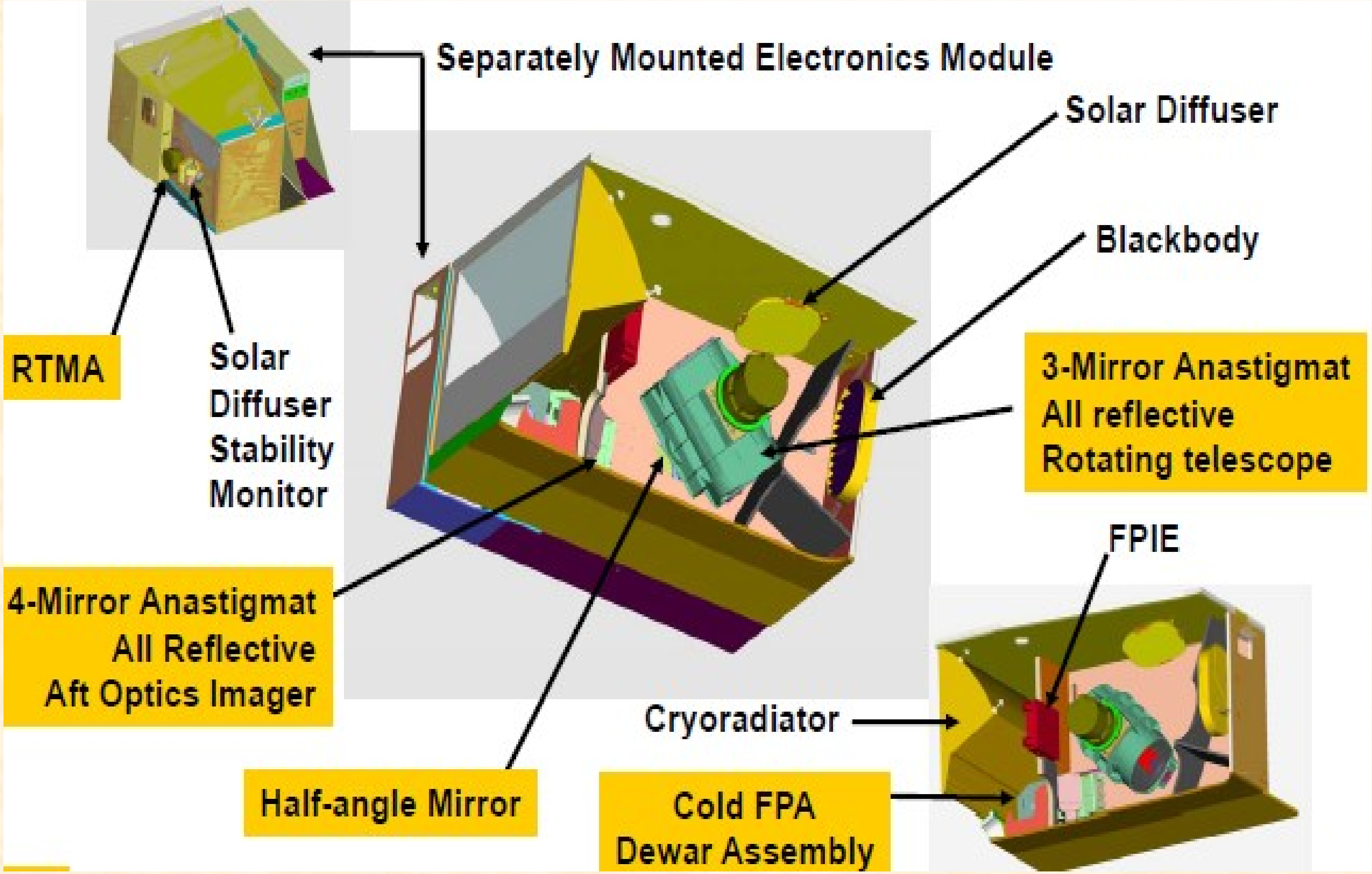
Outline

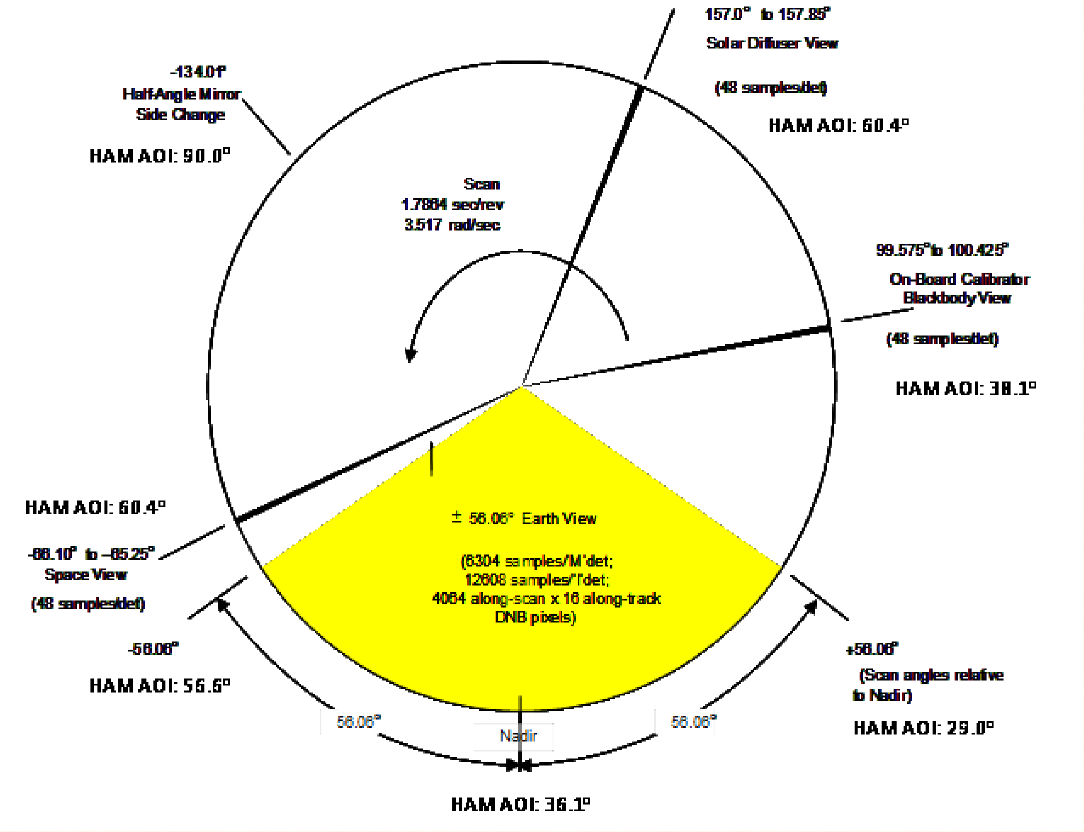
- Introduction
- Solar Diffusor Stability Monitor (SDSM) Calibration (H-factor)
  - Algorithms, data analysis, and performance
- Solar Diffusor (SD) Calibration (SD F-factor)
  - Algorithms, data analysis, and performance
- Lunar Calibration (Lunar F-factor)
  - Algorithms, data analysis, and performance
- Hybrid Approach (Hybrid F-factor)
  - Algorithms and hybrid calibration coefficients
- Inter-sensor and In-situ Comparison
- Ocean Color Products Performance
- Summary

VIIRS Background



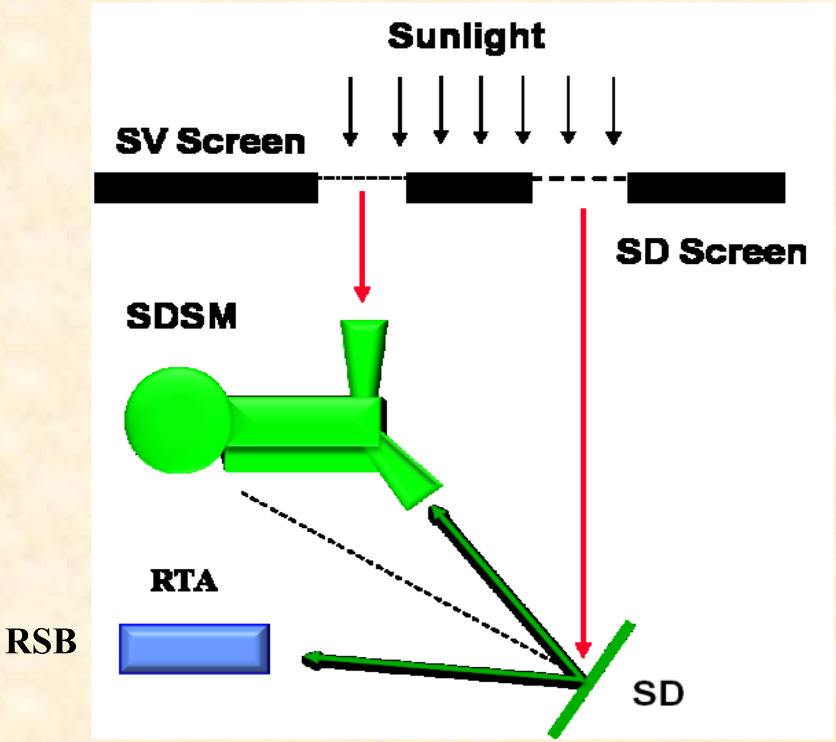
RSB On-Orbit Calibration

- 22 spectral bands - 410 nm to 12.013 µm spectral range
- 14 Reflective Solar Bands (RSB) : 3 image bands, I1-I3, and 11 moderate bands, M1-M11
- The VIIRS RSB are calibrated on orbit by SD/SDSM calibration
- Monthly lunar observation 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 as SD/SDSM calibration.



VIIRS RSB uncertainty specification is 2%, but ocean color EDRs (using M1-M7, NIR; also M8, M10, and M11, NIR-SWIR; recently I1) need to achieve ~0.2%.   This has been achieved.

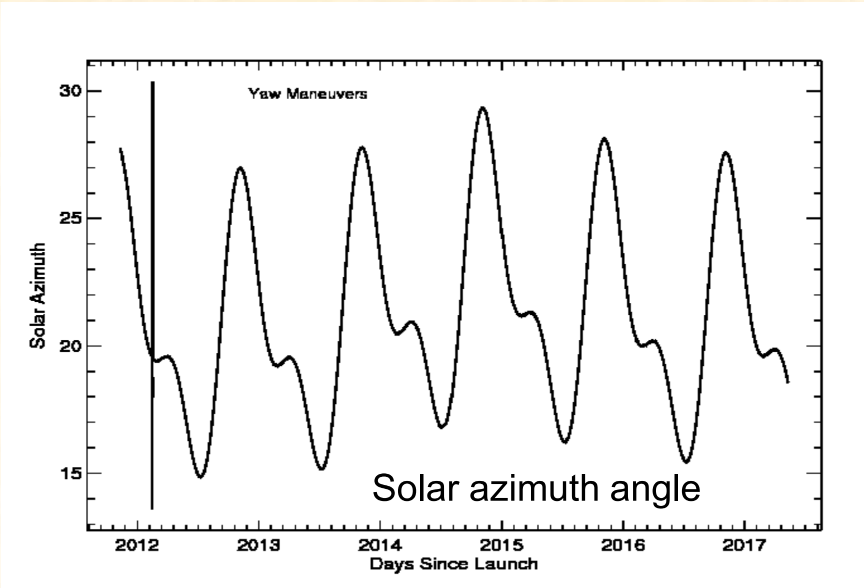
SD/SDSM Calibration Overview

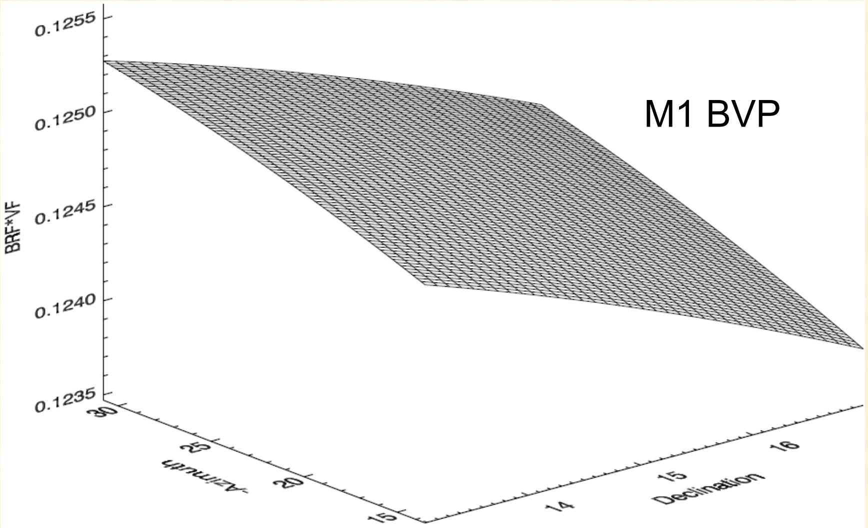


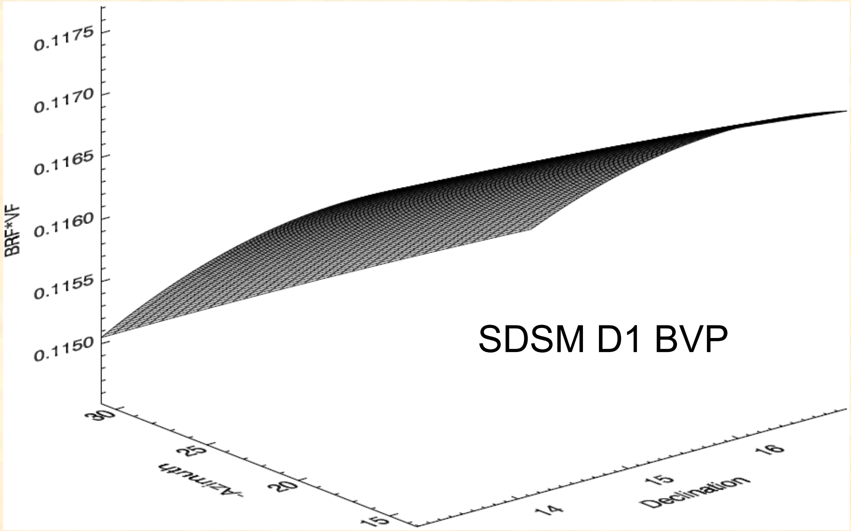
- *SD and SDSM sun view screens:*
  - *Prevent RSB and SDSM saturation*
  - *Vignetting functions (VFs)*
  - *VFs measured prelaunch and validated by yaw measurements*
  - *SD bidirectional reflectance factors (BRFs)*
- *BRFs measured prelaunch and validated by yaw measurements*
  - *SD on-orbit degradation is tracked by the SDSM measurements at 8 wavelength from 412 nm to 935 nm*
- ***Key assumption: SD degrades uniformly with respect to both incident and outgoing directions***
- *SDSM measures H-factors*
- *F-factors, or RSB calibration coefficients, are the final calibration product*

SD BRF and SDS VF

BRF-VF Product (BVP)





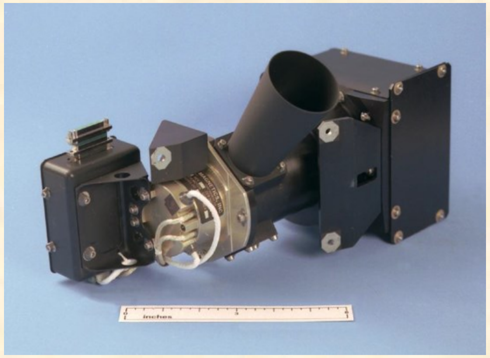


- Yaw carefully planned, cover all solar angle range for SD/SDSM calibration.
- Carefully derive BRFs and VFs from the yaw measurements is the crucial 1st step.
- **Need to do it right just one time from yaw data.**

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

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

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

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

- 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***
  - ***Robust and accurate VFs and BRFs from yaw measurements***
  - ***Ratio of the averages***
  - ***Sweet spots selection***

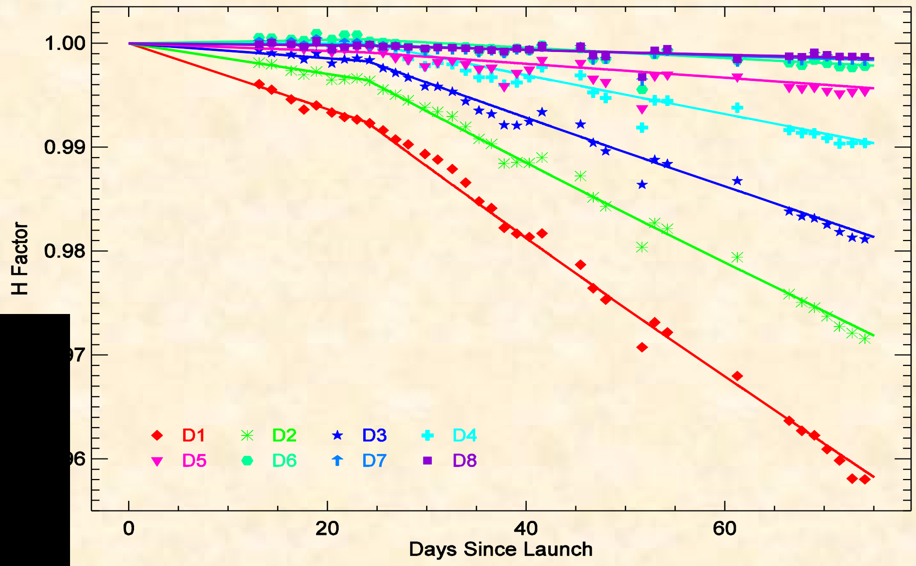
J. Sun and M. Wang, "Visible infrared image radiometer suite solar diffuser calibration and its challenges using solar diffuser stability monitor," Appl. Opt., 53, 8571-8584 (2014).

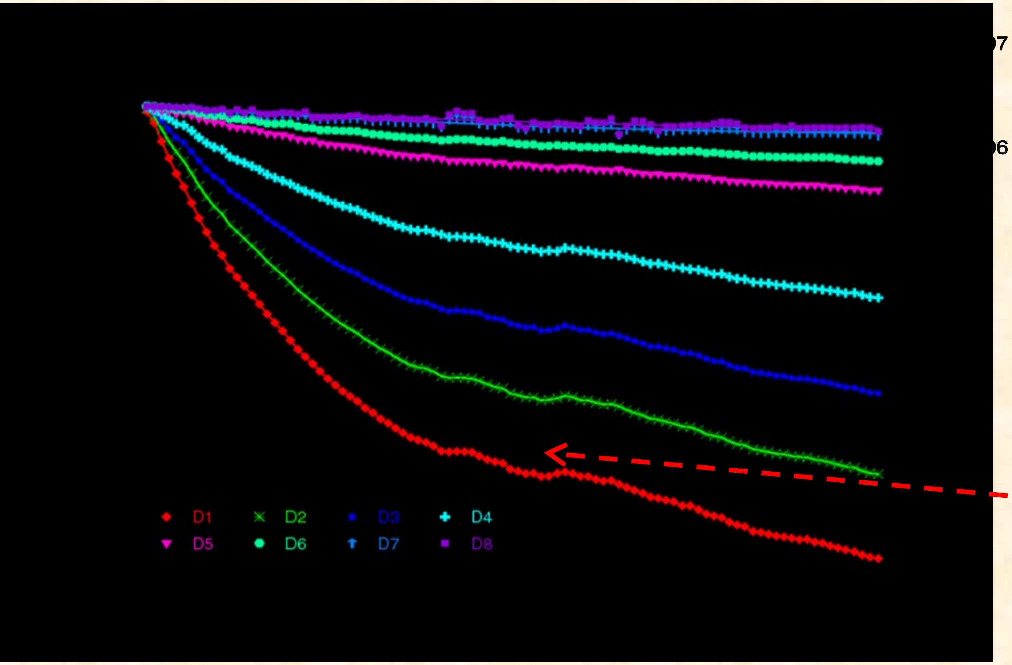
SDSM Calibration Performance

SD Degradation (H-Factors)

- ***Very stable***
- ***SDSM is very accurate!***
- ***Results are all actual measurements***
  - No averaging over orbits, no smoothing, NO FANCY TRICKS

SD Degradation – First 70 days





- ***First 25 days behaved differently.***
- ***But H-factor is in different direction from RSB view direction – KEY ISSUE***
- ***Unexpected but real degradation features (Nov 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).

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

- RSB calibration coefficients, F factors

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

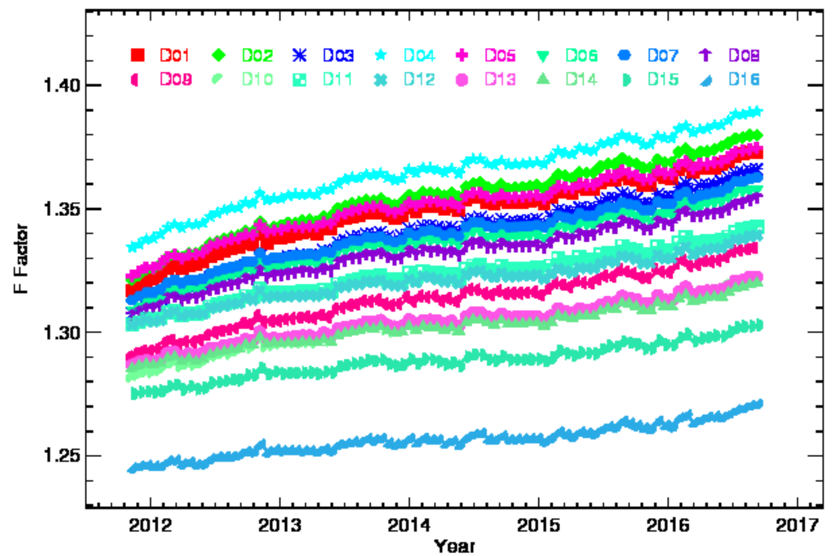
  - *B, D, M, G*: Band, Detector, HAM side, and gain status

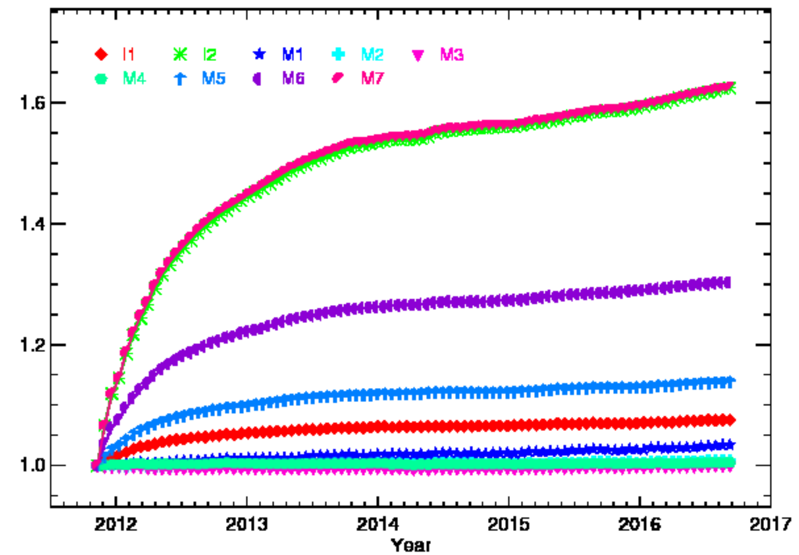
J. Sun and M. Wang, "On-orbit calibration of Visible Infrared Imaging Radiometer Suite reflective solar bands and its challenges using a solar," Appl. Opt., 54, 7210-7223 (2015).

SD Calibration: Every orbit

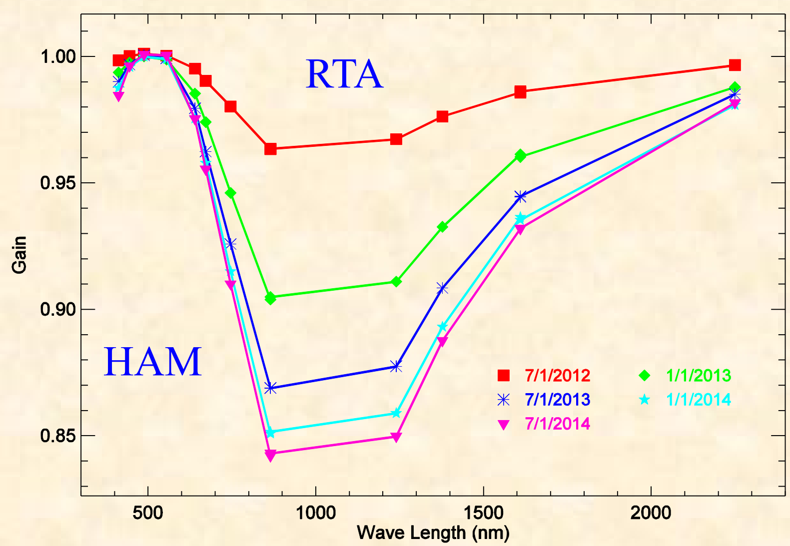
- ***Improvements***
  - ***Robust VFs and BRFs from yaw measurements***
  - ***Improved H factors***
  - ***Sweet spot selection***
  - ***Time-dependent RSR***

SD Calibration Performance





On-orbit Gain Change



- ***Very stable and smooth***
- ***Different from MODIS: Much less degradation of the scan mirror***
- ***But the input H-factor measured by the SDSM is for the SDSM view direction – KEY ISSUE***

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***

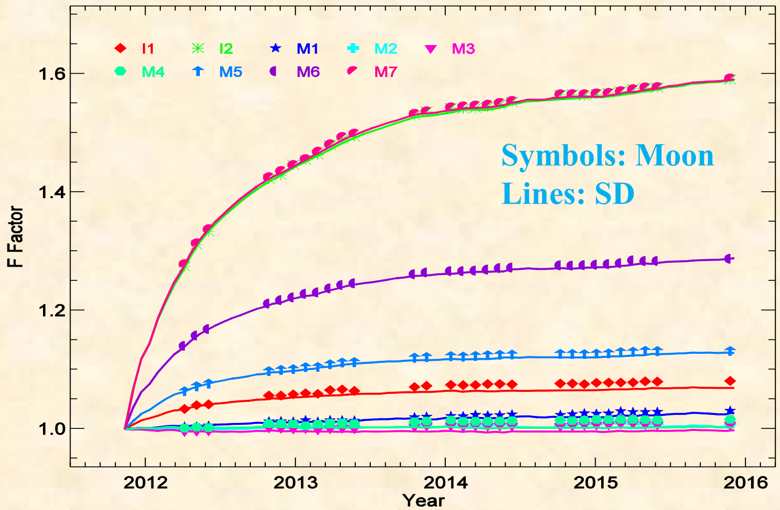
J. Sun, X. Xiong, and J. Butler, "NPP VIIRS on-orbit calibration and characterization using the moon", Proc. SPIE, 8510,85101I, (2012).

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., **54**, 1052-1061, (2016).

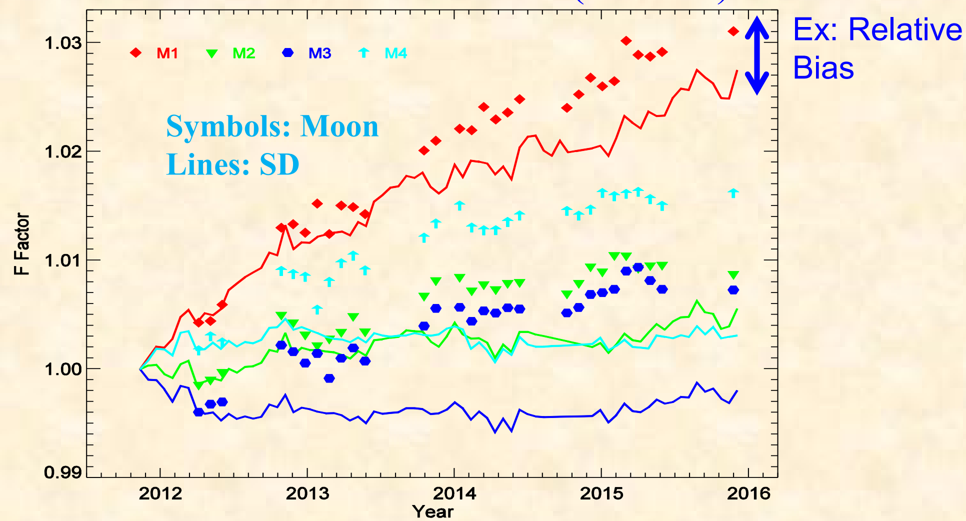
Lunar Calibration Performance

RSB Calibration Coefficients (Lunar F-Factors)

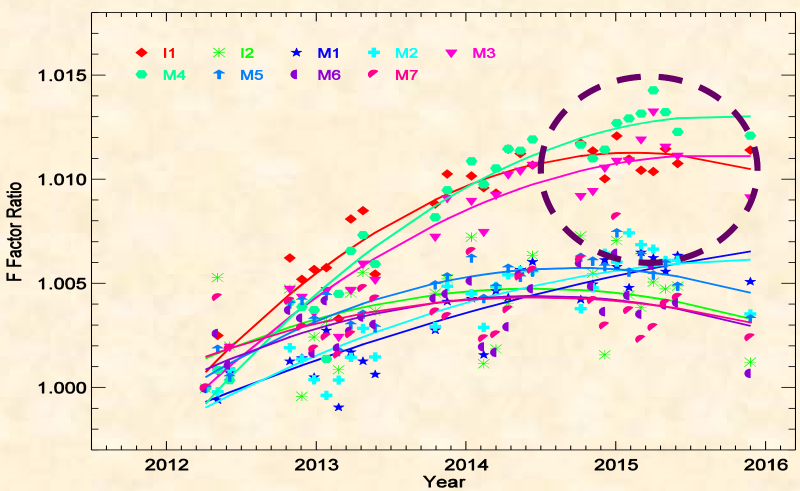
Lunar and SD F Factors



Lunar and SD F factors (M1-M4)



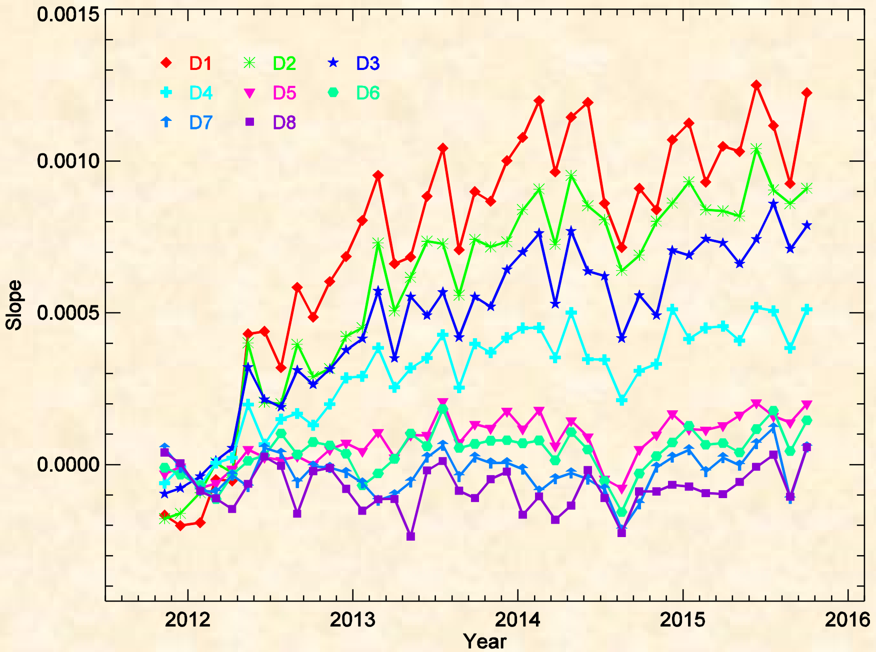
Calibration coefficients Ratios



- ***Own Lunar model and correction beyond ROLO model***
- ***New Lunar results much improved – smooth, no oscillation - 0.2% stability***
- ***SD F-factors and lunar F-factors diverge, especially for short wavelength RSBs.***
- ***SD F-factors have error***

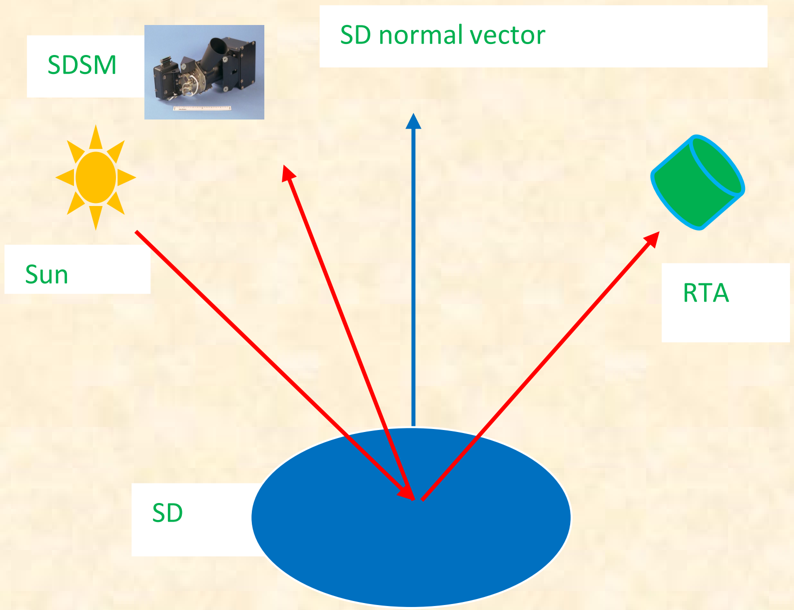
Non-Uniformity of the SD Degradation

Non-uniformity of SD degradation



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

SDSM and RTA views



- It was discovered by 2014 that SD degradation is not uniform
- Standard SD calibration brings non-negligible error into RSB characterization

J. Sun, M. Chu, M. Wang, "Degradation nonuniformity the solar diffuser bidirectional reflectance distribution factor," Appl. Opt., 55, 6001-6016 (2016).

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

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

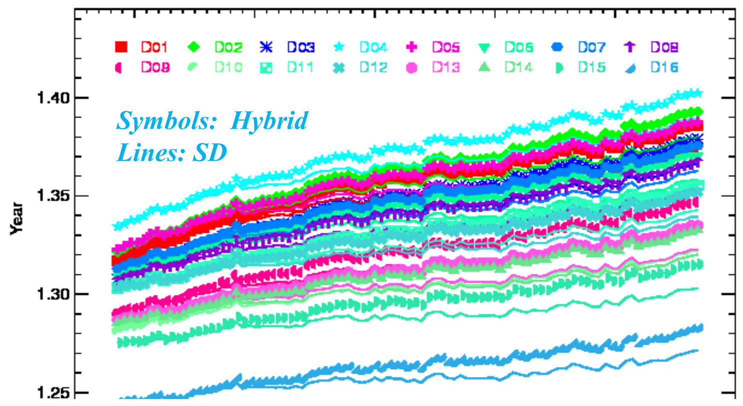
$$R(B,t) = \left\langle f(B,M,t)\right\rangle_M / \left\langle F(B,D,M,0,t)\right\rangle_{D,t-15<t_i<t+15,M}$$

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

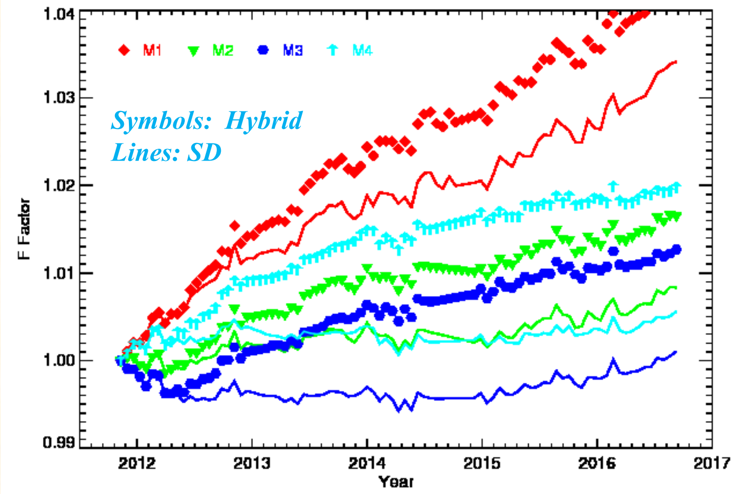
J. Sun and M. Wang, "Radiometric Calibration of the VIIRS Reflective Solar Bands with Robust Characterizations and Hybrid Calibration Coefficients," Appl. Opt., 54, 9331-9342 (2015).

Hybrid Calibration Performance

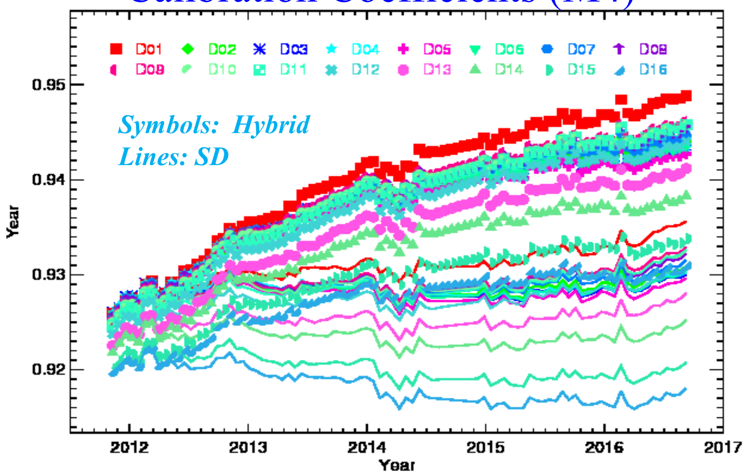
Calibration Coefficients (M1)



Band Averaged (M1-M4)



Calibration Coefficients (M4)

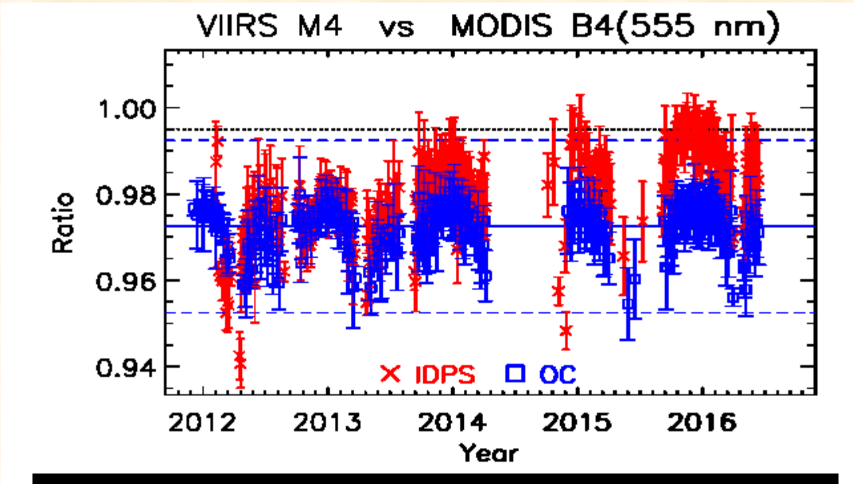


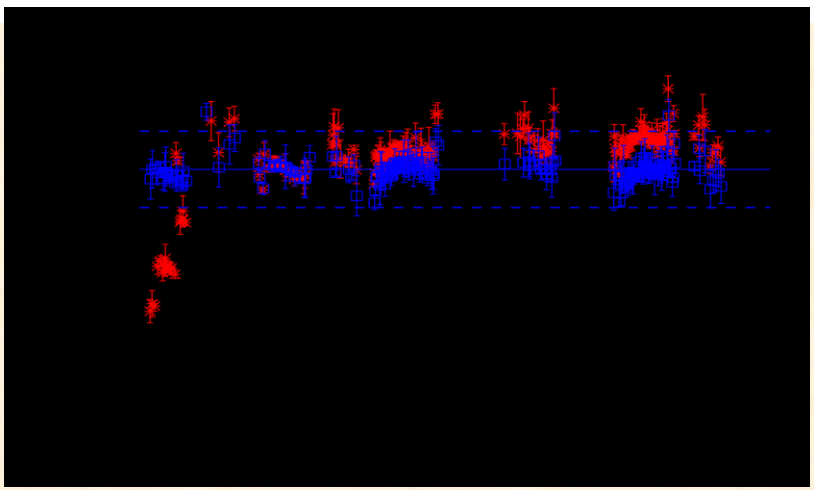
- Hybrid calibration coefficients (Hybrid F-factors) achieves long-term accuracy but also with short-term stability achieving ~0.2% level.
- Earth-based SDR studies show that Hybrid-method indeed mitigated the long-term defect and give stable time-series.

J. Sun and M. Wang, "VIIRS Reflective Solar Bands Calibration Progress and Its Impact on Ocean Color Products," Remote Sensing, 8, 194 (2016).

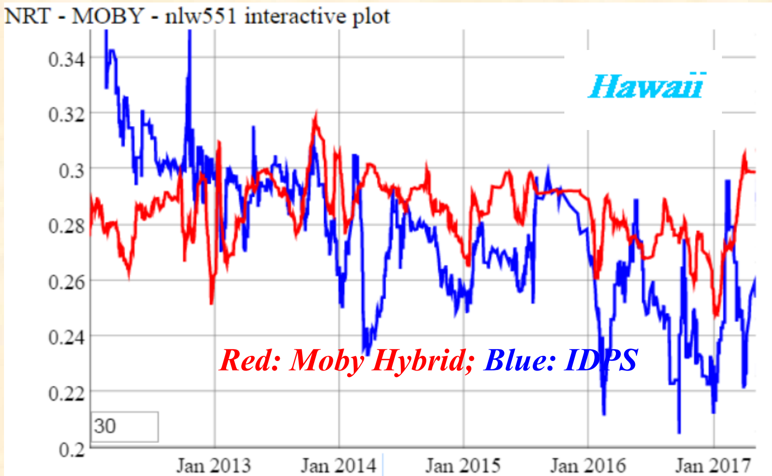
Inter-sensor and In-situ Comparison

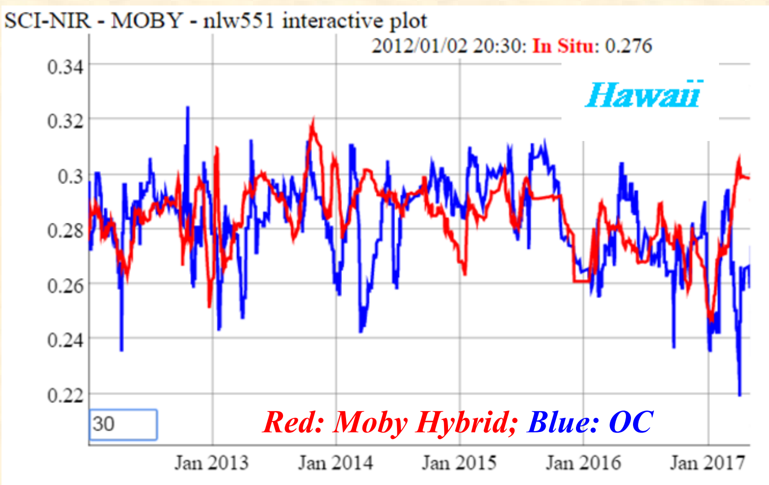
Aqua MODIS and VIIRS Radiance SNO Ratio





Water Leaving Radiance: nLw(551), M4

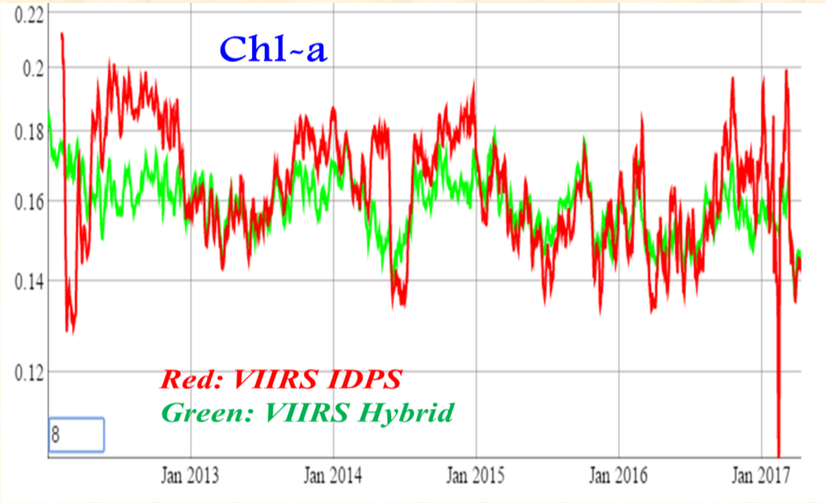


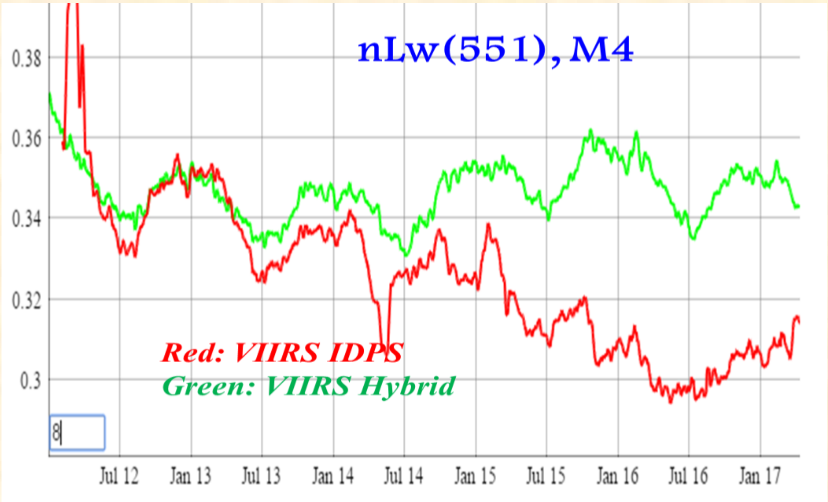


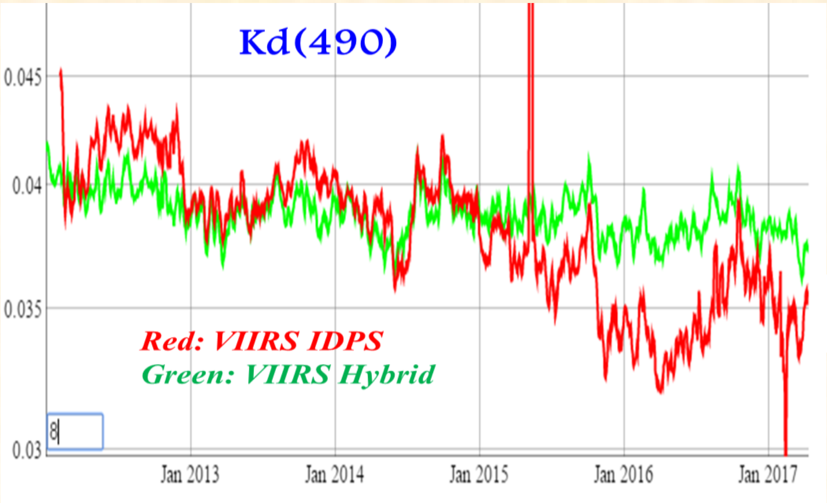
Chu, M., J. Sun, and M. Wang, "Radiometric evaluation of the SNPP VIIRS RSB sensor data records via inter-sensor comparison with Aqua MODIS", Proc. SPIE 9972, 99721R (2016).

Ocean Color Products Performance

Global Deep Water (Depth > 1km)







M. Wang, et al, "Evaluation of VIIRS ocean color products," Proc. SPIE 9261, 92610E (2014).

Charts were produced by X. Liu and S. Son.

Summary

- Rigorous calibration of every component is needed. Every component counts.
- RSB calibration to reach 0.2% is not easy but has been done. Results very clean, smooth and **stable**.
- "*SD degradation nonuniformity effect*" brings inherent errors in RSB SD calibration.
- "Hybrid-method" mitigation combining SD and Lunar calibration restores RSB calibration **accuracy**.
- The hybrid coefficients remove long-term bias in ocean color EDR products and enables the VIIRS ocean products for science quality applications. Similar issues is expected in J1-J4 VIIRS.
- VIIRS Ocean Color EDR mission-long data have been reprocessed a couple of times with Hybrid Coef. F-LUTs. Forward delivery of science quality EDR has been implemented since May 2016.
- **Our hybrid calibration coefficients for all RSB were delivered to VIIRS SDR team in September, 2016 for operational VIIRS SDR reprocessing.**
- *We anticipate more challenging issues to come and we are preparing*.

Backup

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