VIIRS RSB Calibration for Ocean Color Applications

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Outline

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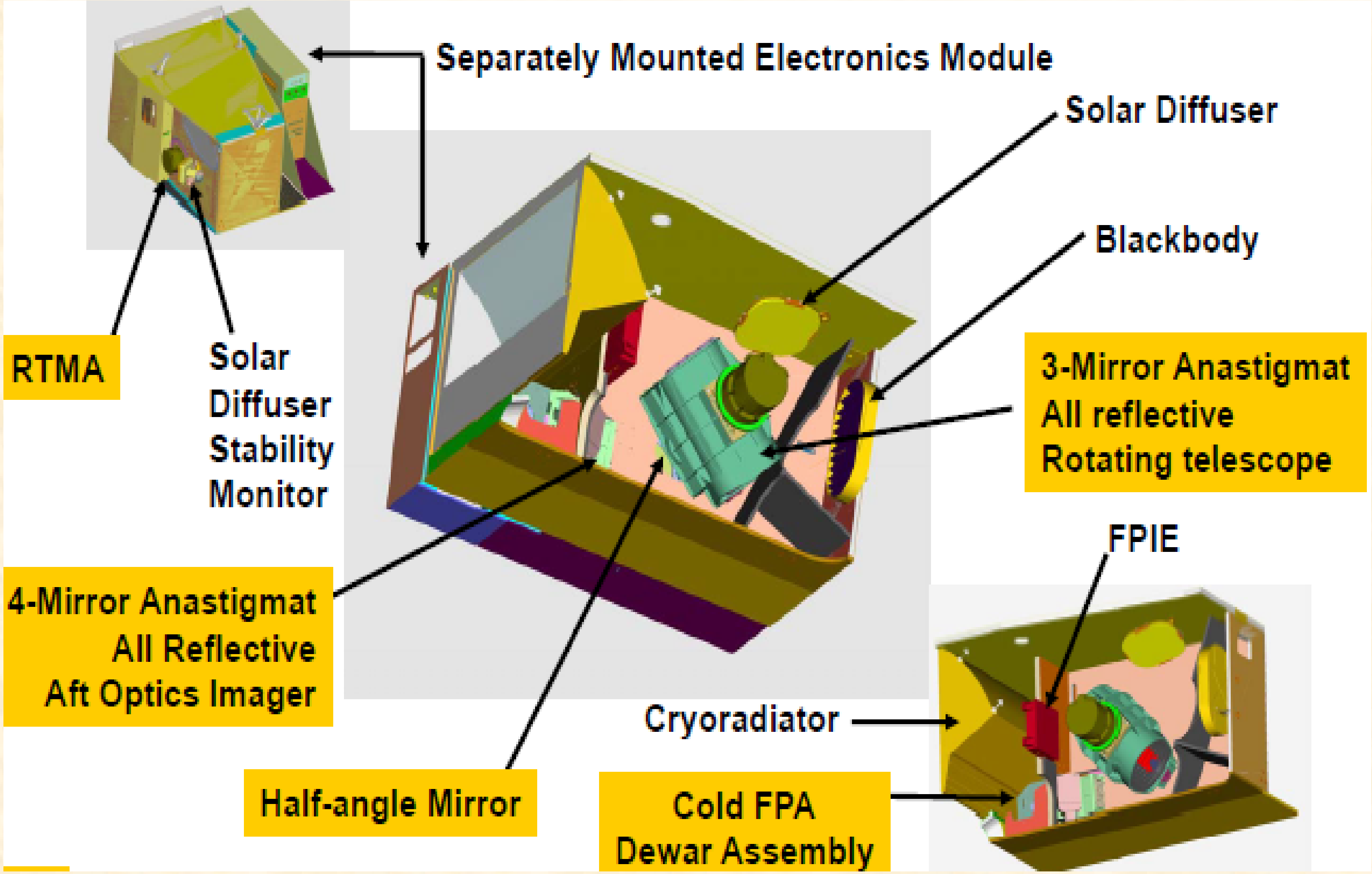
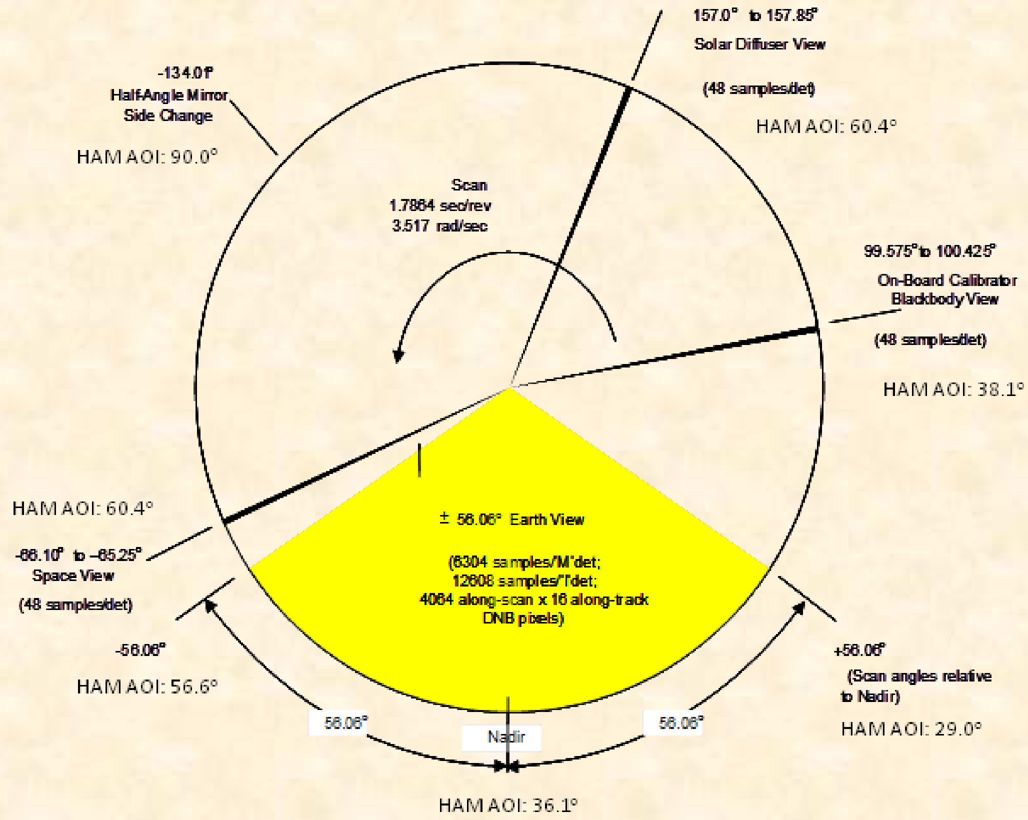
  - Reflective Solar Bands (RSB) On-Orbit Calibration
- SDSM Calibration
  - Algorithms, data analysis, and performance
- SD Calibration
  - Algorithms, data analysis, and performance
- Lunar Calibration
  - Algorithms, data analysis, and performance
- Hybrid Approach
  - Algorithms and hybrid calibration coefficients
- Improvements in Ocean Color Products
- 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%; For ocean color EDR products, the ocean bands (M1-M7) are required to be calibrated with an uncertainty of ~0.1-0.3%.

Key Improvements: Overview

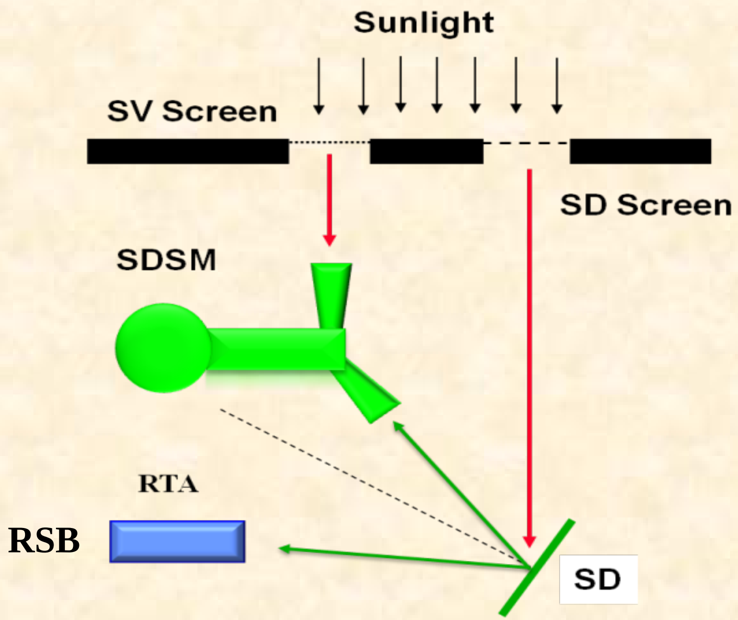
- BRF and VF from yaw measurements
  - Modified procedure
  - Proper data selection
- H-factors (SD degradation from SDSM)
  - Correct initial characterization
  - Identified “SD degradation nonuniformity effect”
- F-factors (RSB Calibration Coefficients)
  - time-dependent relative-spectral-response
- New: Hybrid Coefficients
  - Improved lunar results – geometrical factor
  - Combination algorithm

(*Each step has been thoroughly described in publication*)

Part 1: Standard RSB Calibration with Solar Diffuser

- Solar Diffuser provides quantifiable illumination on orbit
- Currently the official calibration baseline

SD/SDSM Calibration Overview



- ***Key assumption: SD degrades uniformly with respect to both incident and outgoing directions***

Fist step: Carefully derive BRFs and VFs from the yaw measurements

- ***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 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

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

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

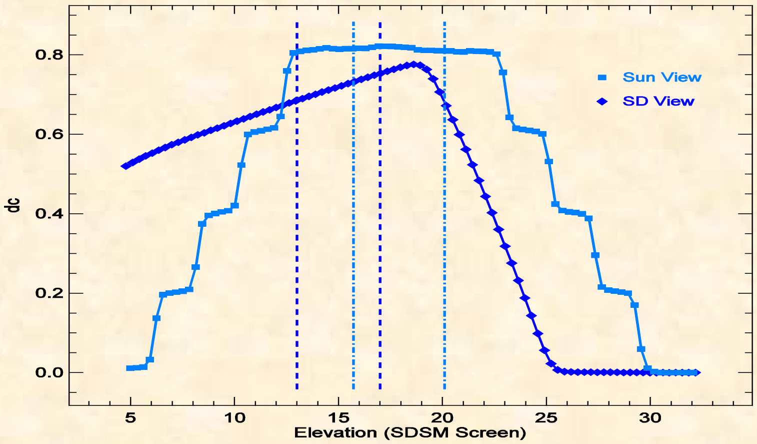
- ***Improvements***
  - ***Carefully derived the VFs and BRFs from yaw measurements***
  - ***Ratio of the averages***
  - ***Sweet spots selection***

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).

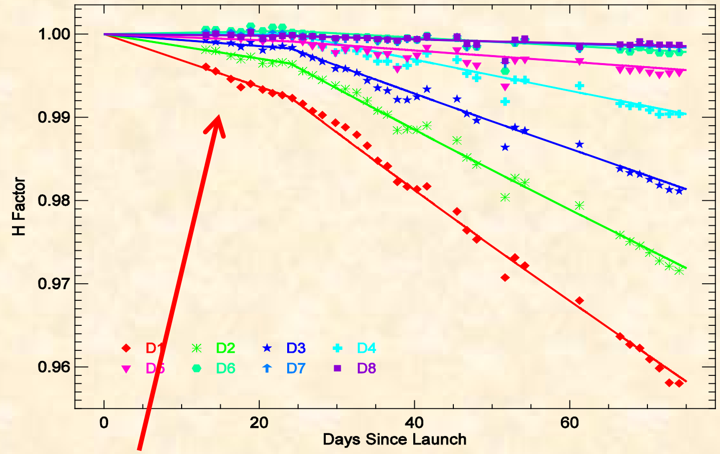
SDSM Calibration Results

SD Degradation (H-Factors)

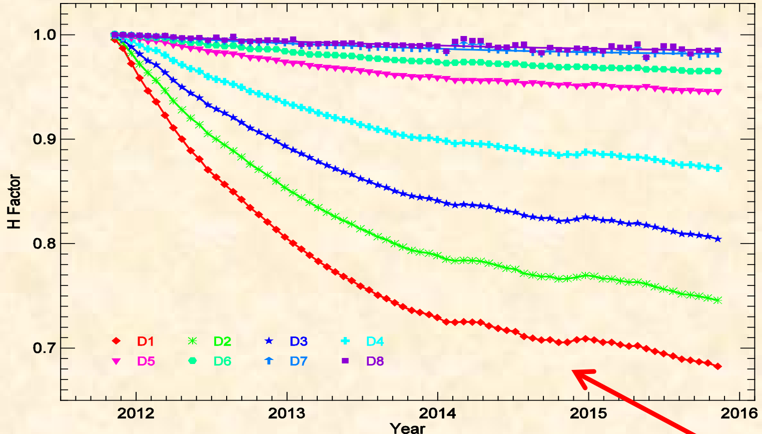
Sweet spots



SD Degradation – First 70 days



SD degradation



- ***First 25 days must be done right, or 1% error!***
- ***Results very stable, very accurate, no average over orbit, no smoothing, actual measurements***
- ***SDSM can accurately track the SD degradation for SDSM direction***
- ***But in different direction from RSB view direction – KEY ISSUE***
- ***Unexpected but real degradation (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).

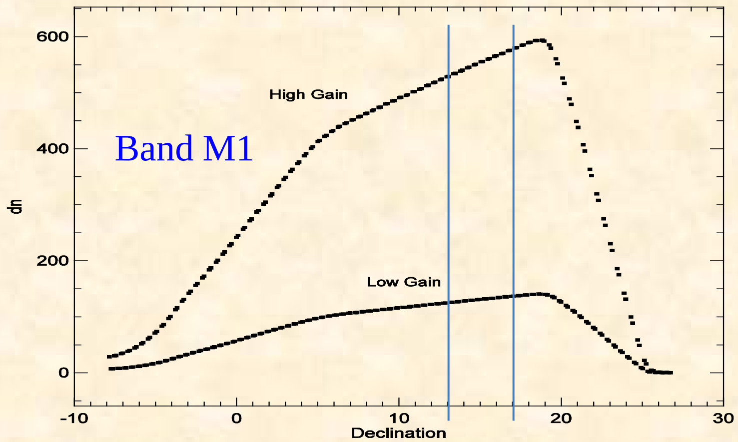
SD Calibration: Every orbit

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

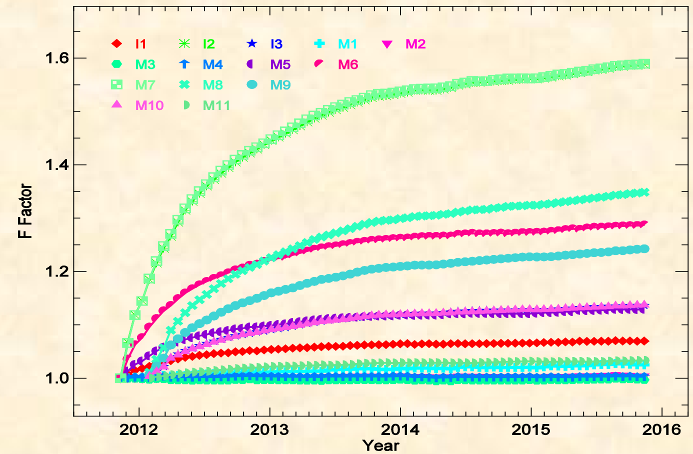
SD Calibration Results

RSB Calibration Coefficients (SD F-Factors)

Sweet spot



Band averaged HAM 1 HG F-factors

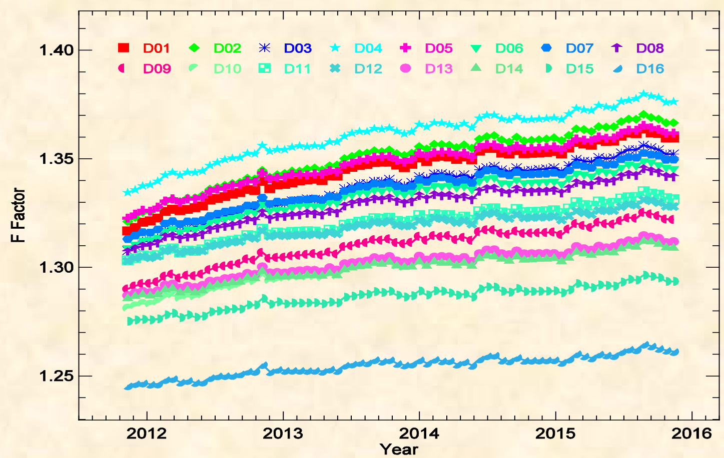


HG = High Gain

LG = Low Gain

Band M1 HAM 1 HG F-factors

Band averaged gains



- ***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.***
- ***Stable and smooth***

Part 2: Lunar Calibration

- Not an official part of the RSB official calibration algorithm
- Not in IDPS processing
- Important calibration baseline

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)

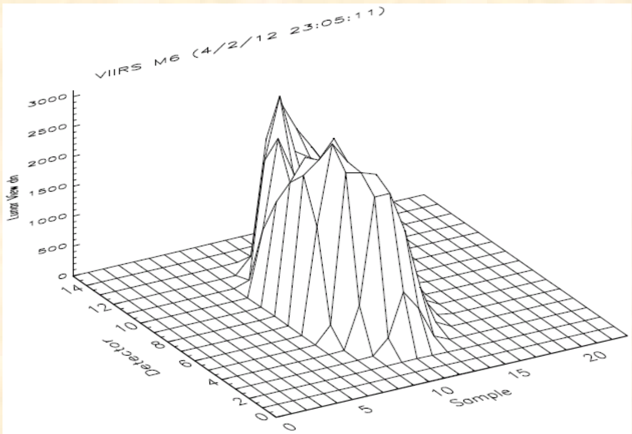
- ***Advantages***
  - ***Lunar surface reflectance has no observable degradation***
  - ***Can be used for inter-comparison***

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).

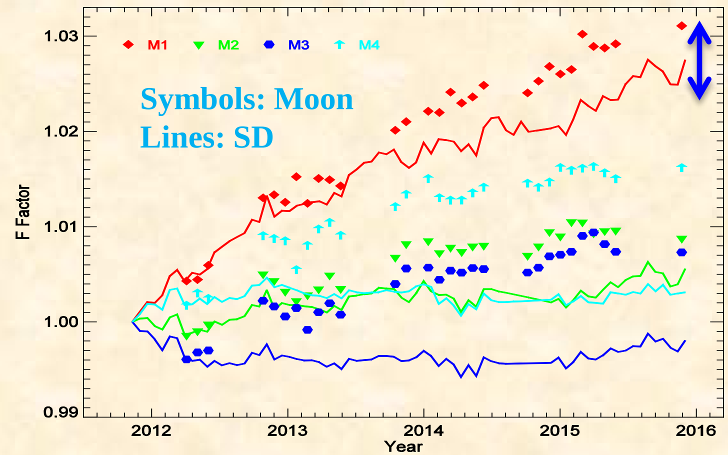
Lunar Calibration Results

RSB Calibration Coefficients (Lunar F-Factors)

Lunar image (M6 in April, 2012)

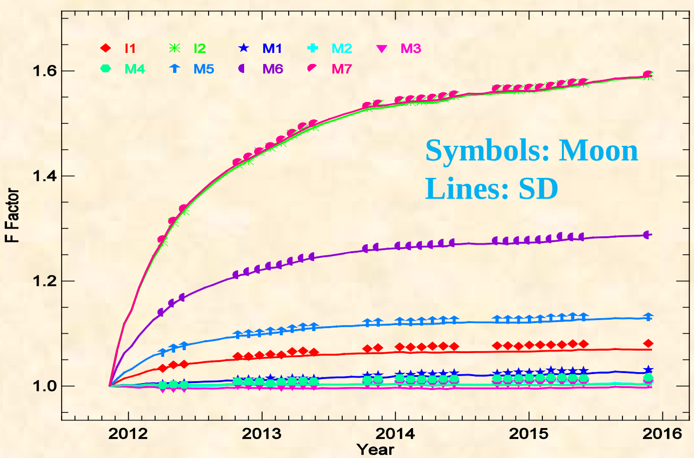


Lunar and SD F factors (M1-M4)



Ex: Relative Bias

Lunar and SD F Factors



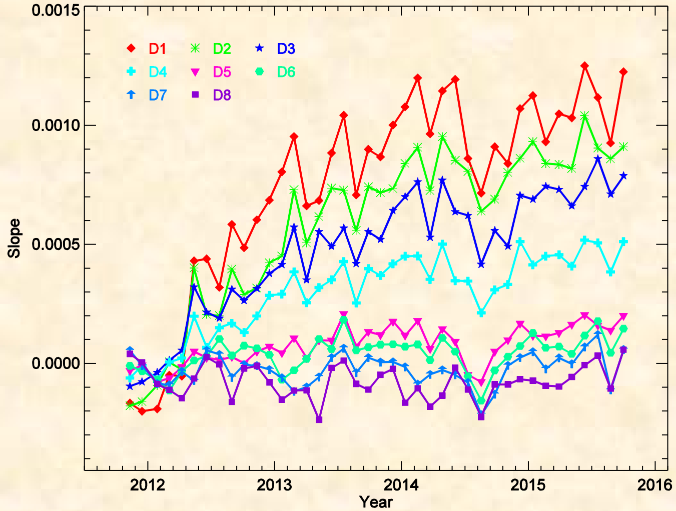
- ***Own Lunar model and correction beyond ROLO model***
- ***New Lunar results much improved – smooth, no oscillation***
- ***0.2% stability***
- ***The differences between the SD F-factor and lunar F-factors diverge, especially for short wavelength RSB***
- ***Which is correct?***

Part 3: Hybrid Methodology Mitigation

- Essential mitigation
- Takes full advantage of the strength in both SD/SDSM and Lunar Calibration Results

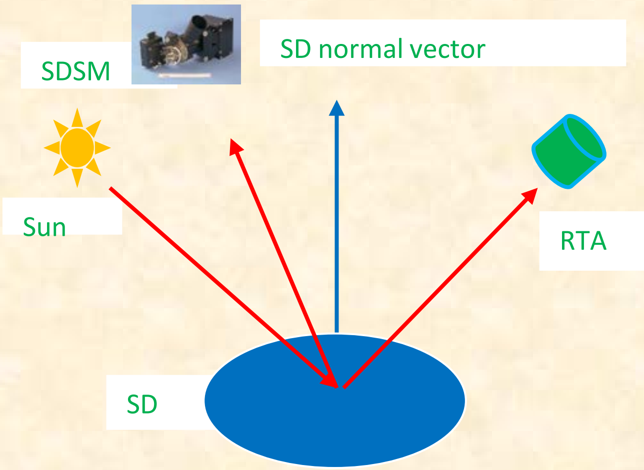
Non-Uniformity of the SD Degradation

Non-uniformity of SD degradation



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

SDSM and RTA views



- SD degrades non-uniformly with respect to the incident angle for SDSM view direction
- According to *optical reciprocity*, then SD also degrades non-uniformly with respect to the outgoing direction
- SD calibration is may bring non-negligible errors for 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

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

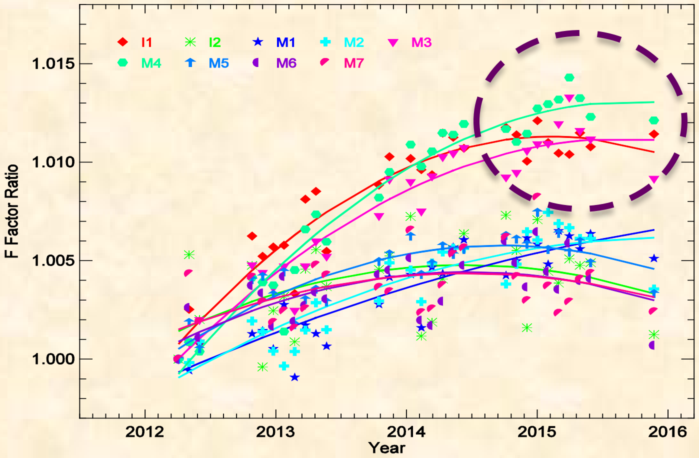
$$R(B,t) = \left\langle f(B,M,t)\right\rangle_M / \left\langle F(B,D,M,0,t)\right\rangle_{D,t-15<t_i<t+15,M}$$

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

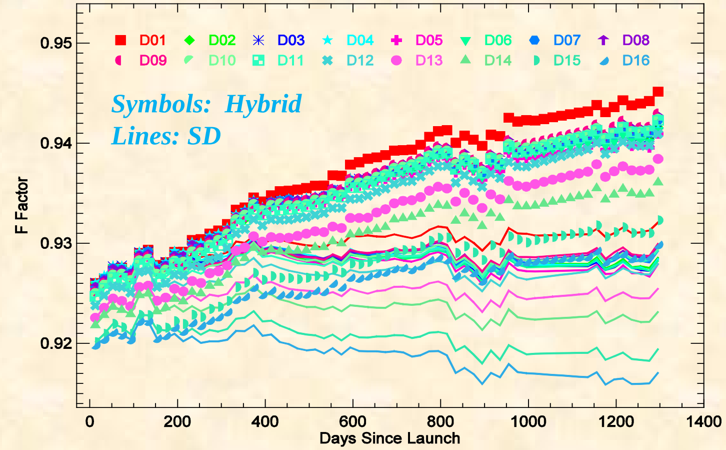
- *J. Sun and M. Wang, "Radiometric Calibration of the VIIRS Reflective Solar Bands with Robust Characterizations and Hybrid Calibration Coefficients," Appl. Opt., 54, 9331-9342 (2015).*
- *J. Sun and M. Wang, "VIIRS Reflective Solar Bands Calibration Progress and Its Impact on Ocean Color Products," Remote Sensing, 8, 194 (2016).*

Hybrid Calibration

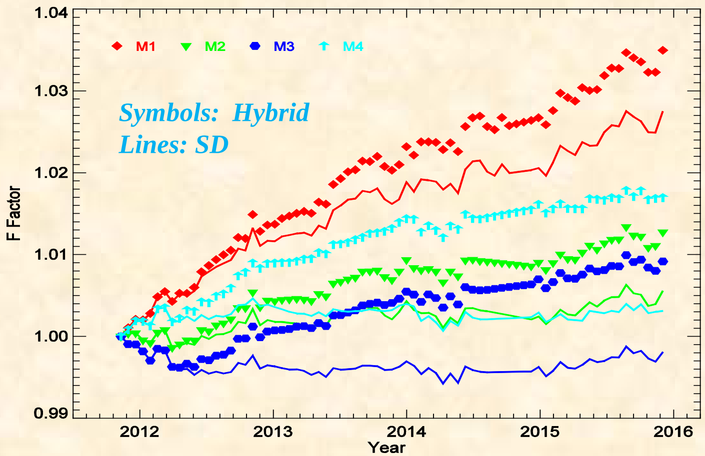
Calibration coefficients Ratios



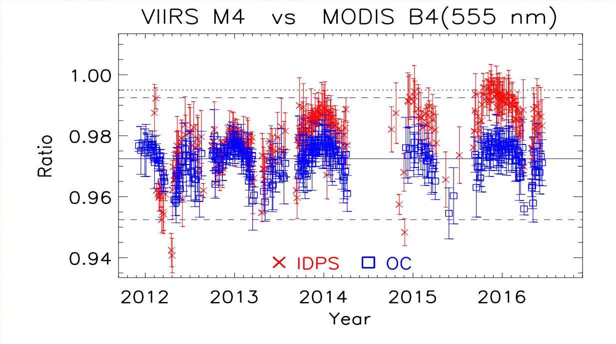
Calibration Coefficients (M4)



Calibration Coefficients



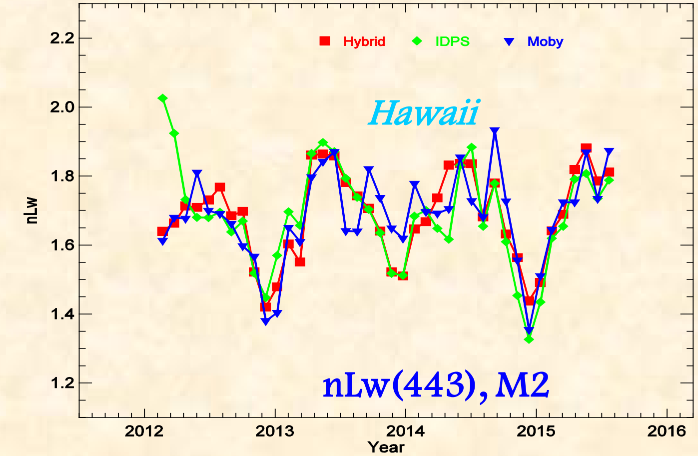
Earth-based SDR studies show that Hybrid-mitigated SDRs give correct time series

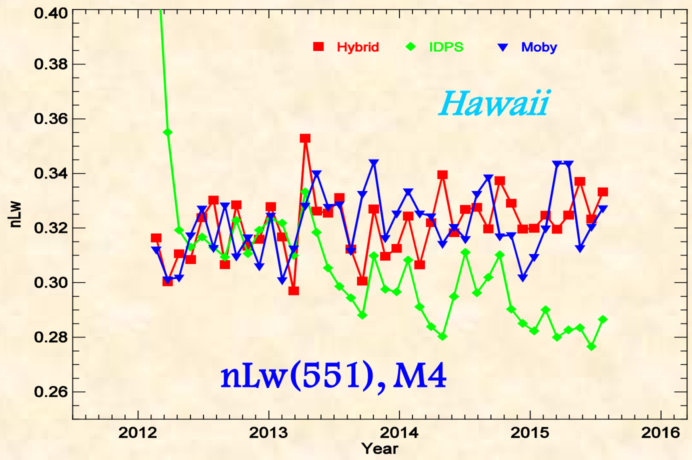


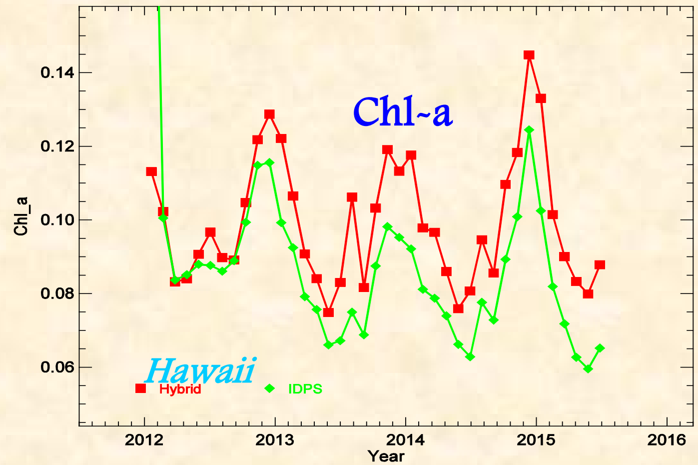
Poster: "Radiometric Comparison of the RSBs of the SNPP VIIRS and Aqua MODIS through SNO analysis" by M. Chu, J. Sun and M. Wang.

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!**
- **Hybrid LUTS have been used for forward science quality products since Dec 2015.**







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

- *J. Sun and M. Wang, "VIIRS Reflective Solar Bands calibration prog," Proc. SPIE, 9264, 92640L (2014).*
- *M. Wang, et al, "Evaluation of VIIRS ocean color products," Proc. SPIE 9261, 92610E (2014).*
- *M. Wang, et al, "VIIRS ocean color products: A progress update," Proc. IGARSS, Beijing, China (2016).*

Summary

- Robust RSB calibration of all components has been done to achieve ~0.2% stability – very clean, smooth result.
- The "*SD degradation nonuniformity effect*" has been discovered to impact RSB calibration, but "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 expected in J1-J4 VIIRS.
- Identity real and critical issues is a must
- **We have successfully completed VIIRS Ocean Color EDR mission-long data reprocessing with Hybrid Coef. F-LUTS this year, and have begun forward delivery of science quality EDR since May 2016.**
- ***We anticipate more challenging issues to come and we are preparing.***

******More technical discussions will be presented in Wednesday ocean color breakout session.***

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