



VIIRS SDR Calibration for Improvement of Ocean Color Products

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Outline



- Introduction
- Solar Diffusor Stability Monitor (SDSM) Calibration
- Solar Diffusor (SD) Calibration
- Lunar Calibration
- Hybrid Approach
- Inter-sensor and In-situ Comparison
- Ocean Color Products Performance
- Summary



VIIRS Background





- 22 spectral bands 410 nm to 12.013 µm spectral range
- 14 Reflective Solar Bands (RSB) : 3 image bands, 11-13, 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





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

J. Sun and M. Wang, "On-orbit characterization of the VIIRS solar diffuser and solar diffuser screen," Appl. Opt., 54, 236-252 (2015).

- 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
 - SDSM measures H-factors
 - *F*-factors, or *RSB* calibration coefficients, are the final calibration product



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

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



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

- Improvements
 - Robust and accurate VFs and BRFs from yaw measurements
 J. Sun and M. Wang
 - 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)



SD Degradation – First 70 days





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(λ): 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 diffuser," 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

RSB Calibration Coefficients (SD F-Factors)







Band-averaged HAM 1 HG F-factors



- 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, 8510,851011, (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)





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





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

- 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
- Hybrid Approach

• Lunar Calibration

- No degradation issue
- Infrequent and no observation in three months every year

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)



- 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 timeseries.

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.¹Son.



Summary



- Very rigorous RSB calibration has been achieved and demonstrated.
- "Hybrid-method" mitigation is the primarily important correction that removes the long-term worsening bias coming from within SD calibration at the SDR level.
- With our hybrid F-factor look-up-tables (LUTs), both the reprocessed mission-long and forward real-time VIIRS Ocean Color EDR products demonstrate very high quality performance.
- Forward delivery of publicly accessible science quality EDR with the hybrid F-factor LUTs has been implemented since May 2016.
- Our hybrid F-factor LUTs for all RSB have been adopted for the official operational VIIRS SDR reprocessing (as an option for high quality science quality EDRs).
- Per request, our hybrid F-factor LUTs have also been sent to NASA Ocean Biology and Biogeochemistry Program Group (OBPG) for their testing and processing.







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
l1	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
12	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
13	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



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). 18



RSB On-Orbit Calibration



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