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

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

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

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

- Improvements
  - Robust and accurate VFIs 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.
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)
SD Calibration Algorithm

- SD is made of Spectralon®, near Lambertian property
- Solar radinace reflected by the SD
  \[ L_{SD}(\lambda) = I_{Sun}(\lambda) \cdot \tau_{SDS} \cdot \cos(\theta_{SD}) \cdot \rho_{SD,RTA}(\lambda) \cdot h(\lambda) / d_{VS}^2 \]
  - \( \rho_{SD,RTA}(\lambda) \): 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
  \[ F(B, D, M, G) = \sum_i c_i(B, D, M, G) \cdot dn^i \cdot \int RSR_B(\lambda) \cdot L_{SD}(\lambda) \cdot d\lambda \]
  - \( B, D, M, G \): Band, Detector, HAM side, and gain status


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 M1 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

Band-averaged HAM 1 HG F-factors
• 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

Lunar Calibration Performance

RSB Calibration Coefficients (Lunar F-Factors)

Lunar and SD F Factors

Symbols: Moon
Lines: SD

- 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

Ex: Relative Bias

Lunar and SD F factors (M1-M4)
It was discovered by 2014 that SD degradation is not uniform.

Standard SD calibration brings non-negligible error into RSB characterization.

**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.

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

\[ F(B, D, M, G) = R(B, t) \cdot F(B, D, M, G) \]

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

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

*F-Factors Ratios are fitted to quadratic polynomials of time*

Hybrid Calibration Performance

Hybrid Calibration Coefficients (M1)

- Hybrid calibration coefficients (Hybrid F-factors) achieve 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.

Inter-sensor and In-situ Comparison

Aqua MODIS and VIIRS Radiance SNO Ratio

Water Leaving Radiance: nLw(551), M4

Ocean Color Products Performance

Global Deep Water (Depth > 1km)

nLw(443), M2

Chl-a

nLw(551), M4

Kd(490)

Red: VIIRS IDPS
Green: VIIRS Hybrid


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

<table>
<thead>
<tr>
<th>VIIRS Band</th>
<th>CW* (nm)</th>
<th>Band Gain</th>
<th>Detectors</th>
<th>Resolution*</th>
<th>SDSD Detector</th>
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</table>

*CW: Center Wavelength; DG: Dual Gain; SG: Single 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.

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