SNPP VIIRS SDR Calibration for Improvement of Ocean Color Products

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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

- 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

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)


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

\[ H(\lambda_D) = \left( \frac{dc_{SD,D}}{\rho_{SD,SDSM}(\lambda_D)\tau_{SD}\cos(\theta_{SD})} \right)_{Scan} \left( \frac{dc_{SV,D}}{\tau_{SV}} \right)_{Scan} \]

**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.

SDSM Calibration Results

Sun view response trending

SDSM can accurately track the SD degradation for SDSM direction

SDM degradation

SDM 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
  \[ L_{SD}(\lambda) = I_{Sun}(\lambda) \cdot \tau_{SD} \cdot \cos(\theta_{SD}) \cdot \rho_{SD,RTA}(\lambda) \cdot h(\lambda) / d_{VS}^2 \]
  - \( \rho_{SD,RTA}(\lambda) \): 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
  \[ F(B, D, M, G, t) = \frac{RVS_{B,SD} \cdot \int RSR_B(\lambda, t) \cdot L_{SD}(\lambda) \cdot d\lambda}{\sum_i c_i(B, D, M, G) \cdot dn^i \cdot \int RSR_B(\lambda, t) \cdot d\lambda} \]
  - \( B, D, M, G \): 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

SD Calibration Results

**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

Lunar Planning and Calibration Results

Roll maneuver

Lunar and SD F Factors

Symbols: Moon
Lines: SD

- 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 \([-56^\circ, -55^\circ]\) to \([-50.5^\circ, 51.5^\circ]\)
- Size of the moon
- Oversampling effect
- Scans seeing full lunar image

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

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

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

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

\textit{F-Factors Ratios are fitted to quadratic polynomials of time}

Hybrid Calibration Coefficients

Calibration coefficients Ratios

Calibration Coefficients (M1)

Symbols: Hybrid
Lines: SD

Calibration Coefficients (M4)

Symbols: Hybrid
Lines: SD

Calibration Coefficients

Symbols: Hybrid
Lines: SD
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!

Some Other Challenges

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

- S-NPP orbit drift

- 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
• 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

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

SDM normal vector

Sun

RTA

SD

SDSM

D1 D2 D3 D4 D5 D6 D7 D8

Slopes

Degree Since Launch

0.00000

0.00010

0.00000

-0.00000

-0.00010

-0.00015

0

360

720

1080

1440

Day Since Launch

SDM and RTA views

SDM normal vector

Sun

RTA

SD

SDSM

D1 D2 D3 D4 D5 D6 D7 D8

Slopes

Degree Since Launch

0.00000

0.00010

0.00000

-0.00000

-0.00010

-0.00015

0

360

720

1080

1440

Day Since Launch
# VIIRS RSB Specification

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>
<th>CW* (nm)</th>
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</table>

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