Assessment and Comparison of MODIS and VIIRS SD On-orbit Degradation

X. Xiong\textsuperscript{1}, J. Butler\textsuperscript{1}, J. Fulbright\textsuperscript{2}, A. Angal\textsuperscript{2}, H. Chen\textsuperscript{2}, and Z. Wang\textsuperscript{2}

\textsuperscript{1}Sciences and Exploration Directorate, NASA/GSFC, Greenbelt, MD
\textsuperscript{2}Science Systems and Applications Inc., 10210 Greenbelt Road, Lanham, MD

(J. Fulbright: currently with Columbus Technologies and Services, Inc., Greenbelt, MD)
Outline

• **Background**

• **Characterization of SD On-orbit Degradation**
  – On-board Calibrator - Solar Diffuser Stability Monitor
  – Characterization Methodologies

• **Results and Discussion**
  – Changes in SD Bi-directional Reflectance Factor (BRF)
  – Changes in SDSM Detector Responses
  – Challenging Issues

• **Concluding Remarks**
**Background**

**MODIS**
- **Spectral range:** 36 bands between 0.4 µm and 14.5 µm
  - 20 RSB and 16 thermal emissive bands (TEB)
- **Focal plane assemblies (FPA):** VIS, NIR, SMIR, and LWIR
- **Spatial resolution:** 250, 500, 1000 m
- **On-board Calibrators:** SD, SDSM, BB, SV, SRCA

**VIIRS**
- **Spectral range:** 22 bands between 0.4 µm and 12.5 µm
  - 15 RSB, including 1 day night band (DNB), and 7 TEB
- **Focal plane assemblies (FPA):** VIS/NIR, SMIR, and LWIR
- **Spatial resolution:** 375 and 750 m
- **On-board Calibrators:** SD, SDSM, BB, SV
- **Pixel aggregations and bowtie deletion**

**MODIS**
- Terra 1999-present
- Aqua: 2002-present

**VIIRS**
- S-NPP 2011-present
- JPSS-1: 2017
Reflective Solar Bands (RSB) Calibration
(Similar for MODIS and VIIRS)

MODIS RSB On-orbit Calibration Coefficients ($m_1$)

\[
m_1 = \frac{BRF_{SD} \cdot \cos(\theta_{SD})}{<dn^*_{SD} > \cdot d_{Earth-Sun}^2} \cdot \Gamma_{SD} \cdot \Delta_{SD}
\]

\[
\Delta_{SD} \propto \frac{dc_{SD}}{dc_{Sun}}
\]

$\Delta_{SD}$: SD degradation factor
$\Gamma_{SD}$: SD screen vignetting function
$d$: Earth-Sun distance
$dn^*$: Corrected digital number (sensor)
$dc$: Corrected SDSM digital count
Characterization of SD On-orbit Degradation

On-board Calibrator - Solar Diffuser Stability Monitor (SDSM)

MODIS has 9 SDSM detectors

VIIRS has 8 SDSM detectors

SDSM detector wavelengths (unit: μm)

<table>
<thead>
<tr>
<th>SDSM Detector</th>
<th>D1</th>
<th>D2</th>
<th>D3</th>
<th>D4</th>
<th>D5</th>
<th>D6</th>
<th>D7</th>
<th>D8</th>
<th>D9</th>
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<tbody>
<tr>
<td>MODIS</td>
<td>0.412</td>
<td>0.466</td>
<td>0.530</td>
<td>0.554</td>
<td>0.646</td>
<td>0.747</td>
<td>0.857</td>
<td>0.904</td>
<td>0.936</td>
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<tr>
<td>VIIRS</td>
<td>0.412</td>
<td>0.445</td>
<td>0.488</td>
<td>0.555</td>
<td>0.672</td>
<td>0.746</td>
<td>0.865</td>
<td>0.935</td>
<td></td>
</tr>
</tbody>
</table>
VIIRS SDSM Design Improvements

Lessons from MODIS led to improved design for VIIRS SDSM

- MODIS SDSM design artifact was eliminated in VIIRS
- Large ripples seen in MODIS SDSM Sun View responses no longer exist in VIIRS
\[ \frac{d}{dc} \text{At mission beginning} \]

\[ \Delta_{SD} \propto \frac{d_{SD}}{dc_{Sun}} \]

\[ \left\{ \frac{d_{SD_{view}}^{D1}}{d_{Sun_{view}}^{D1}} \right\} \]

\[ \text{Current implementation} \]

\[ \Delta_{SD}^{D9} \]

\[ \frac{d_{SD_{view}}^{D9}}{d_{Sun_{view}}^{D9}} \]

\[ \text{MODIS} \]

\[ \text{VIIRS} \]

\[ H(t) = \frac{d_{SD} \cdot \tau_{SDSM}}{d_{Sun} \cdot BRDF(t_0) \cdot \tau_{SD} \cdot \cos \theta_{inc}} \]

The normalized time series of \( \Delta \) (for MODIS) or \( H \) (for VIIRS) => SD degradation

Leland and Arecchi, 1995, SPIE, 2475

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Results and Discussion

- Changes in SD Bi-directional Reflectance Factor (BRF)
- Changes in SDSM Detector Responses
- Challenging Issues
  - SDSM detector OOB response
  - Wavelength-dependent degradation of SDSM detector
  - Wavelength-dependent degradation of SD BRF
SD Degradation

SD degradation as a function of time (day of mission operation)

SD degradation as a function of SD solar exposure time

Terra MODIS

Aqua MODIS

S-NPP VIIRS

Terra Normalized SD degradation

Aqua Normalized SD degradation

VIIRS Normalized SD degradation
SD Degradation

First 50 hrs in exposure time (Terra, Aqua, SNPP: 1500, 3400, 450 days in operation)

SD degradation as a function of SD solar exposure time
Changes in SDSM Detector Responses

MODIS SDSM Sun View Responses

VIIRS SDSM Sun View Responses

Terra MODIS

Aqua MODIS

S-NPP VIIRS

Wavelength Dependent Degradation

SD degradation

3.5 years

current

SDSM detector degradation

3.5 years

current
Is SD on-orbit degradation (*not the BRDF*) dependent on solar illumination angles? If so, how much?

With sufficient SDSM data over time, one can track and compare SD degradation at a number of fixed solar illumination angles (methodologies developed for MODIS but more useful for VIIRS)
SD Degradation at 5 Different Solar Azimuth Angles (17.5-26.5°)

Fits of the Form $H = \exp(A + B \cdot t + C \cdot t^2)$

**VIIRS SDSM D1**
(0.412 µm)

**VIIRS SDSM D3**
(0.488 µm)

**VIIRS SDSM D6**
(0.746 µm)

**VIIRS SDSM D8**
(0.935 µm)
Normalization to remove BRF differences at different illumination angles

VIIRS SDSM D1
(0.412 μm)

VIIRS SDSM D3
(0.488 μm)

VIIRS SDSM D6
(0.746 μm)

VIIRS SDSM D8
(0.935 μm)

0.5%
Similar Analysis Performed for Aqua MODIS

With changes in overall degradation trend:
pay attention to data (sample) distribution

Challenging issues for MODIS: SDSM and its operation frequency
Results and Discussion

• Changes in SD bi-directional reflectance factor (BRF)
• Changes in SDSM Detector Responses

• Challenging Issues
  – SDSM detector OOB response
    • Not enough information from pre-launch characterization
    • SD degradation could be under/over-estimated
  – Wavelength-dependent degradation of SDSM detector
    • Changes in SDSM detector’s RSR (OOB/IB) => SD degradation accuracy
    • Need initial SDSM detector’s RSR
  – Wavelength-dependent degradation of SD BRF
    • Need to be considered when deriving RSB calibration coefficients for bands with non-negligible OOB responses
Concluding Remarks

- SDSM operation and calibration performance has been satisfactory in support of sensor RSB on-orbit calibration
  - Improved design of VIIRS SDSM => better performance

- Larger SD degradation at shorter (VIS) wavelengths whereas larger SDSM detector degradation at longer (NIR) wavelengths
  - Different causes: exposure to solar UV vs exposure to high-energy protons

- Angular dependent SD degradation examined
  - Small for S-NPP and Aqua MODIS (±0.2% level < SD degradation UC)
  - More challenge for Terra MODIS (impact due to SD screen)

- Challenging issues to be examined for future improvements
  - OOB responses + wavelength-dependent SD and SDSM detector response degradation