Radiometric Scaling and Stability Assessment of MODIS and SNPP-VIIRS

Raj Bhatt, David Doelling, Benjamin Scarino, Arun Gopalan, and Conor Haney
CERES Imager and Geostationary Calibration Group

May 7, 2019
CERES Science Team Meeting
Outline

• Background
  • MODIS and VIIRS relevance to CERES
  • CERES Imager and Geostationary Calibration Group

• MODIS and VIIRS Calibration stability assessment
  • Temporal radiometric stability
  • Response versus scan-angle (RVS) dependency

• Radiometric scaling of VIIRS to MODIS
• Radiometric scaling between MODIS collections and VIIRS versions

• Geostationary imager calibration
• Summary
Background

• Why calibration of MODIS and VIIRS matter to CERES?
  • CERES relies on coincident measurements from onboard imagers (MODIS, VIIRS) for proper scene identification needed to convert CERES radiances into radiative fluxes
  • SYN1deg products utilize GEO derived broadband (BB) fluxes and cloud properties
  • To ensure that the GEO BB fluxes and cloud properties are consistent across GEO sensors, the GEO radiances are radiometrically scaled to MODIS

• Consistent retrievals of cloud properties requires
  • Individual imager records are temporally stable in their calibration
  • MODIS and VIIRS imagers are radiometrically consistent

• Any radiometric drift in MODIS manifests itself in both the MODIS and GEO cloud retrievals

• On-orbit changes in scan-mirror reflectivity and solar diffuser (SD) necessitates independent evaluation of MODIS radiometric quality

• CERES imager and geostationary calibration group (IGCG) performs calibration assessment of MODIS, VIIRS, and GEO imagers in real-time using multiple approaches
MODIS and VIIRS stability assessment based on Earth invariant targets

<table>
<thead>
<tr>
<th>Dome-C</th>
<th>Libya-4</th>
<th>Deep Convective Cloud</th>
</tr>
</thead>
<tbody>
<tr>
<td>• Near nadir measurements</td>
<td>• Near-nadir measurements</td>
<td>• ±40° VZA, Look-up table BRDFs</td>
</tr>
<tr>
<td>• Pre and post solstice directional</td>
<td>• Forward/backward scattering directional</td>
<td>• Large ensemble statistical</td>
</tr>
<tr>
<td>models (DM)</td>
<td>models (DM)</td>
<td>statistical approach</td>
</tr>
<tr>
<td>• Construct the DM from stable</td>
<td>• Construct the DM from stable</td>
<td>• PDF mode and Mean tracks</td>
</tr>
<tr>
<td>part of the record</td>
<td>part of the record</td>
<td>stability</td>
</tr>
</tbody>
</table>

**Dome-C**

- Pre-Dec 21: 283.703, Post-Dec 21: 297.806
- Offset: -5.608, -14.849
- MEAN: 121.044, 118.790
- StdErr %: 0.83, 0.78

**Libya-4**

- Pre-Dec 21: 32.770, Post-Dec 21: 42.974
- Offset: 172.299, 186.695
- MEAN: 1.027, 0.920

**Deep Convective Cloud**

- ±40° VZA, Look-up table BRDFs
- Large ensemble statistical approach
- PDF mode and Mean tracks stability
MODIS C6.1 and VIIRS V1 temporal stability

- All reflective solar bands (RSB) of SNPP-VIIRS and Aqua-MODIS are stable within 1%
- Terra-MODIS 0.65-µm band is stable within 1%
- Terra-MODIS SWIR bands exhibit trends and discontinuity in calibration after 2016 when Terra entered into safe mode (will be discussed later)

Available at: https://cloudsway2.larc.nasa.gov/cgi-bin/site/showdoc?mnemonic=STABILITY-MODIS
https://cloudsway2.larc.nasa.gov/cgi-bin/site/showdoc?mnemonic=STABILITY-SNPP-VIIRS
RVS improvements in Terra-MODIS C6.1

- Scan-mirror reflectance is a function of AOI
- Solar Diffuser (SD) and lunar view can calibrate at two fixed AOIs
- C5 used linearly-interpolated SD/lunar measurements for RVS characterization
- C6 and C6.1 use SD, lunar, and Saharan Desert sites measurements for RVS characterization
- C5 RVS drifts < 6% for band 1
- C6.1 RVS drifts within ~1.5% for band 1

This work is a collaboration with Jack Xiong’s calibration group

MODIS Earth View

Terra-MODIS Band 1 (0.65µm)
RVS improvements in Aqua-MODIS C6.1

- C5 and C6 (until Jul 2016) used SD and lunar measurements for RVS characterization
- C6 (Jul 2016 onwards) and C6.1 use SD, lunar, and Saharan Desert sites for RVS characterization
- C6 RVS drifts <3% for VIS/NIR
- C6.1 RVS drifts <1% for VIS/NIR
Calibration anomalies in Terra-MODIS C6.1

- Terra-MODIS SWIR bands are contaminated by electronic crosstalk from thermal bands.
- Crosstalk issue amplified after 2016 safe-mode event, resulting in discontinuities.
- 1.24-µm trend rate increased after 2016.
- 1.38-µm band reveals positive trend in left-side scans:
  - Invariant ground sites are inapplicable for RVS characterization.
  - DCC approach is still applicable.
- 1.6-µm band reveals 1% calibration jump.
- 2.1-µm band shows ~3% calibration discontinuity.
To scale VIIRS to MODIS

Spectral Band differences

- SCIAMACHY spectral band adjustment factor (SBAF)
- Specific to scene type

1.6% reflectance difference between VIIRS I1 and Aqua-MODIS Band 1 over Libya-4

SBAF Tool: https://cloudsway2.larc.nasa.gov/cgi-bin/site/showdoc?mnemonic=SBAF
To scale VIIRS to MODIS

Reference Solar Spectrum

- MODIS and VIIRS are calibrated on Reflectance scale
- \[ \text{Radiance} = \text{Reflectance} \times E_{\text{SUN}} \times \cos(SZA) / d^2 \]
- Terra and Aqua MODIS uses mix of Thuillier, Neckel and Labs, and Smith and Gottlieb solar spectra
- SNPP-VIIRS uses Kurucz solar spectra
- NOAA-20 VIIRS uses Thuillier spectra
- Biases are different for radiance and reflectance
- Difference in reference solar spectra can induce additional radiance bias

4% difference in \( E_{\text{sun}} \) for 1.24-\( \mu \text{m} \) band

Solar constant tool: https://cloudsway2.larc.nasa.gov/cgi-bin/site/showdoc?mnemonic=SOLAR-CONSTANT-COMPARISONS
Scaling of SNPP-VIIRS V01 to Aqua-MODIS C6.1

- All-sky tropical ocean ray-matching
- Matches within 15 minutes
- VZA, SZA < 40°; \( \Delta VZA, \Delta SZA < 3° \)
- 10°<RAA<170°; \( \Delta RAA = 3° - 10° \)

MODIS = VIIRS*0.9848

Scaling factors available at: [https://cloudsway2.larc.nasa.gov/cgi-bin/site/showdoc?mnemonic=TIMELINE-AQUA6_1-SNPP_1](https://cloudsway2.larc.nasa.gov/cgi-bin/site/showdoc?mnemonic=TIMELINE-AQUA6_1-SNPP_1)
### SNPP-VIIRS to Aqua-MODIS scaling validation

#### DCC Ray-matching
- Coincident DCC footprints
- Minimal SBAF corrections

#### DCC-Invariant Target
- Large ensemble statistical approach
- Comparison of monthly mode and mean
- LUT BRDFs

#### Libya-4 and Dome-C
- **Forward/backward** scattering directional models (DM)
- VIIRS radiances are compared against MODIS DM

---

#### SNPP-VIIRS I1 radiance vs. Aqua-MODIS Band 1 radiance

**Graph:**
- DC30, NPP-V, Aqua-AVE, 377.70, 376.89
- SDV: 56.78, 56.11
- MAX: 478.34, 481.50
- MIN: 223.43, 222.59
- NIN: 255.91, 258.91

#### Libya-4 DM for 0.65 µm
SNPP-VIIRS and Aqua-MODIS biases

- ATO-RM primary method, other methods are used for validation
- SNPP-VIIRS reflectance values are brighter than those from Aqua-MODIS
- 1.38-µm has largest bias
- Larger inconsistency seen in 1.6-µm band using Libya-4 (working with MCST on this)

**Bias** = \( 100\% \times \frac{\text{VIIRS}-\text{MODIS}}{\text{VIIRS}} \)

### Reflectance Bias (%)

<table>
<thead>
<tr>
<th>Band pair</th>
<th>ATO-RM</th>
<th>DCC-RM</th>
<th>DCC-IT</th>
<th>Libya-4</th>
<th>Dome-C</th>
</tr>
</thead>
<tbody>
<tr>
<td>B3/M3 (0.48 µm)</td>
<td>+1.2</td>
<td>+2.8</td>
<td>+2.4</td>
<td>+2.9</td>
<td>+2.8</td>
</tr>
<tr>
<td>B4/M4 (0.55 µm)</td>
<td>+2.5</td>
<td>+2.7</td>
<td>+1.9</td>
<td>+2.4</td>
<td>+2.5</td>
</tr>
<tr>
<td>B1/M5 (0.65 µm)</td>
<td>+2.3</td>
<td>+2.7</td>
<td>+1.9</td>
<td>+2.0</td>
<td>+1.9</td>
</tr>
<tr>
<td>B1/I1 (0.65 µm)</td>
<td>+1.1</td>
<td>+1.2</td>
<td>+0.3</td>
<td>+1.0</td>
<td>+1.0</td>
</tr>
<tr>
<td>B2/M7 (0.86 µm)</td>
<td>+2.1</td>
<td>N/A</td>
<td>N/A</td>
<td>+2.7</td>
<td>+2.0</td>
</tr>
<tr>
<td>B5/M8 (1.24 µm)</td>
<td>+3.3</td>
<td>+3.7</td>
<td>+3.3</td>
<td>+3.2</td>
<td></td>
</tr>
<tr>
<td>B26/M9 (1.38 µm)</td>
<td>+4.7</td>
<td>+5.4</td>
<td>+4.9</td>
<td>N/A</td>
<td></td>
</tr>
<tr>
<td>B6/M10 (1.6 µm)</td>
<td>+2.0</td>
<td>+1.8</td>
<td>+1.1</td>
<td>+4.6</td>
<td></td>
</tr>
<tr>
<td>B6/I3 (1.6 µm)</td>
<td>+3.4</td>
<td>+3.4</td>
<td>+2.6</td>
<td>+6.4</td>
<td></td>
</tr>
</tbody>
</table>
Scale MODIS C6 to C5

- CERES Ed4 switched to using MODIS C6 on Feb 2017
- Single granule from TWP domain (Nov 2016)
- Regress C5* and C6 pixel reflectance values
- C5* includes scaling adjustment implemented in Ed4 cloud properties to mitigate the impact of Terra-MODIS degradation in C5

\[ C5^* = 1.0272 \times C6 \]
\[ C5 = 0.99634 \times C6 \]
Collaboration with MCST/VCST

- Methodology sharing, independent validation, improvement suggestions, joint publications (7 journal articles and 2 conference proceedings)


GEO imager calibration

- All-sky tropical ocean ray-matching
- Calibrate full dynamic range of GEO sensor
- Matches within 15 minutes
- VZA, SZA<40°; \( \Delta VZA=5°-15° \)
  10°<RAA<170°; \( \Delta RAA=5°-15° \)
- Update calibration every 2 months
- MODIS calibration anomalies inherited to GEO

Realtime GEO calibration available at: https://cloudsway2.larc.nasa.gov/cgi-bin/site/showdoc?mnemonic=CALIB-UPRT
GEO imager calibration validation

- Three independent validation approaches
- Referenced to Aqua-MODIS C6.1

<table>
<thead>
<tr>
<th>DCC Ray Matching</th>
<th>DCC-Invariant Target (DCC-IT)</th>
</tr>
</thead>
<tbody>
<tr>
<td>• Coincident DCC matches with MODIS</td>
<td></td>
</tr>
<tr>
<td>• Spectral difference effects are minimal</td>
<td></td>
</tr>
<tr>
<td>• MODIS calibration anomalies inherited to GEO</td>
<td></td>
</tr>
<tr>
<td>• Utilizes tropical DCC as invariant targets</td>
<td></td>
</tr>
<tr>
<td>• Coincident matches not required</td>
<td></td>
</tr>
<tr>
<td>• Calibrate GEOs in the absence of MODIS</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>DERM (Desert approach)</th>
</tr>
</thead>
<tbody>
<tr>
<td>• Daily exo-atmospheric radiance models over deserts</td>
</tr>
<tr>
<td>• Benefit from consistent imaging schedules of GEOs</td>
</tr>
<tr>
<td>• Calibrate GEOs in the absence of MODIS</td>
</tr>
</tbody>
</table>

Realtime GEO calibration available at: https://cloudsway2.larc.nasa.gov/cgi-bin/site/showdoc?mnemonic=CALIB-UPRT
Summary

- SD and lunar measurements are inadequate to track on-orbit changes in optical properties of scan mirror in MODIS
- CERES IGCG works closely with MCST/VCST in monitoring the radiometric quality of MODIS and VIIRS L1B products
- CERES IGCG provides
  - independent assessment of MODIS and VIIRS stability (annual update) and RVS performance
  - VIIRS to MODIS scaling factors
  - MODIS Collection and VIIRS version scaling
  - GEO to MODIS scaling (bi-monthly update)
- Observed calibration anomalies in Terra-MODIS C6.1 may potentially influence cloud properties, particularly after 2016
- Plots and coefficients located at web site

https://cloudsway2.larc.nasa.gov/cgi-bin/site/showdoc?mnemonic=SAT_CALIB_USER
Additional slides
Polarization sensitivity

- Terra-MODIS has significant change in polarization sensitivity at short wavelengths
- Right-side scans are affected
- DCC and desert trends disagree due to difference in the strength of Rayleigh scattering over the scene types
• NASA Land SIPS distributes different versions of SNPP VIIRS sub-setted data for CERES.
• New version implements improved calibration algorithm and consistent LUT.
• Scaling between different versions is possible via direct comparison or F-factor ratio (provided by VCST).
• Version 2 will be available soon.

SNPP-VIIRS I1 (0.64µm) Reflectance
AS3110 = V001*0.9844
Jan 2016
Radiometric stability assessment

- Temporal stability
  - Pseudo-invariant Earth targets (deserts, polar icecap, DCC)
- Response versus scan-angle (RVS) dependency
  - Scan-angle response difference monitored on annual basis
  - Uses DCC and Saharan Deserts
- Kernel-based BRDFs for deserts and polar icecap
- Look-up table BRDFs for DCC
  - Channel-specific for SWIR bands
- Why multiple Earth targets
  - cover sensor dynamic range
  - cover all scan angles
  - channel-specific scenes
  - high confidence in results

---

**Diagram:**

- **DCC LUT BRDF**
  - Band 5 (1.24 µm)
  - Band 6 (1.6 µm)

---