Radiometric evaluation of the MODIS C6.1 reflective solar channels radiances and the need for C7

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

Feb 26, 2021
Outline

• Introduction
  • Why MODIS calibration important for CERES?
    • Consistent MODIS cloud retrievals and scene identification for the CERES ADM
    • MODIS as reference calibration for to provide consistent cloud retrievals and radiances across GEO imagers

• Evaluation Methodology
  • Tropical DCC calibration
  • Pseudo-invariant Earth sites (Dome-C and Libya-4)

• Terra and Aqua MODIS Results and Discussion

• Conclusions
Why MODIS calibration matters to CERES

- Clouds and the Earth's Radiant Energy System (CERES) relies on coincident measurements from onboard imagers (MODIS, VIIRS) for proper scene identification needed to convert CERES radiances into radiative fluxes.

- Consistent retrievals of cloud properties requires the MODIS calibration is temporally stable.

- CERES also utilizes geostationary (GEO) imager radiances to retrieve clouds and derive broadband fluxes that are used to account for the regional diurnal flux variation between the CERES measurements.

- To ensure that the GEO fluxes and cloud properties are consistent across sensors, the GEO radiances are radiometrically scaled to MODIS.

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

- CERES imager and geostationary calibration group (IGCG) performs an independent calibration assessment of MODIS and VIIRS L1B products using multiple approaches.
DCC-IT method

- DCC pixel selection criteria:
  - $BT_{11\mu m} < 205.0^\circ K$, $SZA < 40^\circ$, $VZA < 40^\circ$, $10^\circ < RAA < 170^\circ$, $\sigma(BT_{11\mu m}) < 1.0^\circ K$, and $\sigma(VIS) < 3\%$
  - DCC pixels are compiled into monthly probability distribution functions (PDFs) and their modes are tracked over time.
- Anisotropic correction
  - Hu ADM for VIS-NIR bands
  - Seasonal BRDFs for SWIR bands
- At SWIR wavelengths,
  - DCC reflectivity is affected by ice particle size
  - larger ice particles are more absorbing
  - results in large seasonal cycles
  - DCC response is highly dependent on the IR BT threshold

<table>
<thead>
<tr>
<th>DCC pixel radiance</th>
<th>Frequency</th>
</tr>
</thead>
<tbody>
<tr>
<td>225</td>
<td>0.00</td>
</tr>
<tr>
<td>225</td>
<td>0.02</td>
</tr>
<tr>
<td>275</td>
<td>0.04</td>
</tr>
<tr>
<td>325</td>
<td>0.06</td>
</tr>
<tr>
<td>375</td>
<td>0.08</td>
</tr>
<tr>
<td>425</td>
<td>0.10</td>
</tr>
<tr>
<td>475</td>
<td>0.00</td>
</tr>
<tr>
<td>525</td>
<td>0.00</td>
</tr>
</tbody>
</table>

Aqua-MODIS band 1

<table>
<thead>
<tr>
<th>Month</th>
<th>Pixels</th>
<th>MEAN</th>
<th>MODE</th>
</tr>
</thead>
<tbody>
<tr>
<td>Jul2002</td>
<td>816453</td>
<td>440.9</td>
<td>469.0</td>
</tr>
<tr>
<td>Apr2003</td>
<td>970795</td>
<td>449.5</td>
<td>471.0</td>
</tr>
<tr>
<td>Jan2004</td>
<td>951428</td>
<td>436.7</td>
<td>467.0</td>
</tr>
<tr>
<td>Oct2004</td>
<td>965880</td>
<td>445.2</td>
<td>471.0</td>
</tr>
<tr>
<td>Jul2005</td>
<td>1091550</td>
<td>442.8</td>
<td>465.0</td>
</tr>
<tr>
<td>Apr2006</td>
<td>928655</td>
<td>443.8</td>
<td>467.0</td>
</tr>
<tr>
<td>Jan2007</td>
<td>840847</td>
<td>439.9</td>
<td>467.0</td>
</tr>
<tr>
<td>Oct2007</td>
<td>922654</td>
<td>446.4</td>
<td>469.0</td>
</tr>
<tr>
<td>Jul2008</td>
<td>998476</td>
<td>439.5</td>
<td>467.0</td>
</tr>
<tr>
<td>Apr2009</td>
<td>916084</td>
<td>446.5</td>
<td>469.0</td>
</tr>
<tr>
<td>Jan2010</td>
<td>789066</td>
<td>435.9</td>
<td>465.0</td>
</tr>
<tr>
<td>Oct2010</td>
<td>928420</td>
<td>444.0</td>
<td>465.0</td>
</tr>
<tr>
<td>Jul2011</td>
<td>1036823</td>
<td>440.9</td>
<td>467.0</td>
</tr>
<tr>
<td>Apr2012</td>
<td>862973</td>
<td>446.5</td>
<td>467.0</td>
</tr>
<tr>
<td>Jan2013</td>
<td>893737</td>
<td>435.2</td>
<td>469.0</td>
</tr>
<tr>
<td>Oct2013</td>
<td>901300</td>
<td>441.9</td>
<td>465.0</td>
</tr>
<tr>
<td>Jul2014</td>
<td>1196150</td>
<td>438.5</td>
<td>465.0</td>
</tr>
<tr>
<td>Apr2015</td>
<td>922011</td>
<td>447.6</td>
<td>467.0</td>
</tr>
<tr>
<td>Jan2016</td>
<td>857374</td>
<td>442.0</td>
<td>467.0</td>
</tr>
<tr>
<td>Oct2016</td>
<td>1133094</td>
<td>442.9</td>
<td>465.0</td>
</tr>
<tr>
<td>Jul2017</td>
<td>1065877</td>
<td>441.4</td>
<td>469.0</td>
</tr>
<tr>
<td>Apr2018</td>
<td>965656</td>
<td>454.8</td>
<td>469.0</td>
</tr>
<tr>
<td>Jan2019</td>
<td>819824</td>
<td>435.9</td>
<td>471.0</td>
</tr>
<tr>
<td>Oct2019</td>
<td>977575</td>
<td>450.9</td>
<td>471.0</td>
</tr>
<tr>
<td>Jul2020</td>
<td>916852</td>
<td>441.3</td>
<td>466.3</td>
</tr>
</tbody>
</table>
Channel-specific BRDFs are constructed using the first 5-year MODIS record of tropical DCC pixels.

VIS-NIR BRDFs are similar to Hu model

BRDF for SWIR bands are channel-specific
Near nadir TOA radiance measurements are modeled as a function of Cosine of SZA.

- **Forward/backward** scattering directional models (DM) over Libya-4
- **Pre** and **post** solstice DM over Dome-C
- Construct DMs from the most stable part of the MODIS record (first 6 years)
Old Slide results of C5 and C6.1

- We use DCC to look at MODIS stability as function of frame intervals.
- Terra-MODIS C5 band 1 (0.65 µm) RVS were inconsistent
- MCST improved the RVS for this channel between C5 and C6.1
- We independently verified the improvement of C6.1
- The rest of the presentation will look at the C6.1 stability
Results, Band 1 (0.65µm) and 2 (0.86µm)

- MODIS bands 1 and 2 are stable within 1%

Statistics: Monthly (annual)

- Aqua
  - MODIS Band 1 (0.65µm)
    - DCC: SE% = 0.41 (0.22), Trend% = -0.3 (-0.3)
    - Libya-4: SE% = 0.72 (0.38), Trend% = 0.4 (0.4)
    - Dome-C: SE% = 1.04 (0.59), Trend% = 0.3 (0.0)
  - MODIS Band 2 (0.86µm)
    - Libya-4: SE% = 0.77 (0.37), Trend% = 0.4 (0.5)
    - Dome-C: SE% = 0.65 (0.34), Trend% = 0.6 (0.7)

- Terra
  - MODIS Band 1 (0.65µm)
    - DCC: SE% = 0.42 (0.27), Trend% = -0.7 (-0.8)
    - Libya-4: SE% = 0.84 (0.47), Trend% = 0.2 (0.3)
    - Dome-C: SE% = 1.15 (0.71), Trend% = -0.2 (-0.5)
  - MODIS Band 2 (0.86µm)
    - Libya-4: SE% = 0.92 (0.49), Trend% = -0.2 (0.0)
    - Dome-C: SE% = 0.85 (0.44), Trend% = 0.0 (0.2)
A positive trend (~1%) is shown by DCC and PICS time series in Terra-MODIS band 3.
Results, Band 5 (1.24µm) and 6 (1.6µm)

- Aqua-MODIS SWIR bands are stable within 1%
- Terra-MODIS band 5 response shows an upward drift after the 2016 safe mode incident.
Both bands 7 and 26 in Terra-MODIS C6.1 show upward trends.
Residual RVS in Terra-MODIS C6.1

- Terra-MODIS C6.1 exhibits some residual RVS dependencies.
- Band 3 RVS is due to a change in the polarization sensitivity of the scan-mirror over time. DCC and desert trends disagree in the right side of the scan.
- Band 5: DCC and PICS approach show an upward trend in the left-side frames and a downward trend in the right-side frames from 2001 through safe-mode incident in 2016.
Future Activities

- We have received the Terra and Aqua MODIS C6.1 to C7 conversion coefficients from MCST.
- We will redo the previous slides after applying the conversion coefficients.
  - Since they are mirror side and frame dependent all of the datasets will need to be rerun
- CERES will be migrating from Aqua to N20 in the future, when Aqua starts drifting outside of 15 minutes
  - Need to develop Aqua-MODIS to N20-VIIRS analogous channel radiometric scaling factors to provide consistent cloud properties
Conclusions

• CERES IGCG works closely with MCST/VCST in providing an independent evaluation of the radiometric quality of MODIS and VIIRS L1B products.

• Aqua-MODIS C6.1 calibration is stable within 1% for all RSB

• Terra-MODIS C6.1 calibration is stable within ~1% for bands 1 (0.65 µm), 2 (0.86 µm), and 4 (0.55 µm)

• Terra-MODIS band 3 (0.46 µm) suffers polarization sensitivity change over time, primarily affecting the response in the right side of the scan. The effect is scene specific.

• Terra-MODIS bands 5 (1.24 µm), 6 (1.6 µm), 7 (2.1 µm), and 26 (1.37 µm) exhibit noticeable calibration drifts (1-3%), especially after the 2016 Terra safe mode incident.

• Observed calibration anomalies in Terra-MODIS C6.1 may potentially influence cloud properties, particularly after 2016.