NASA CERES Strategy for radiometric scaling between SNPP and NOAA-20 VIIRS reflective solar bands

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Outline

• Background
  • SNPP and NOAA-20 VIIRS radiometric consistency importance to CERES
  • CERES Imager and Geostationary Calibration Group

• Radiometric scaling of VIIRS instruments
  • Methods:
    • All-sky tropical ocean (ATO) ray-matching with a GEO imager
    • Simultaneous Nadir Overpass (SNO) with Aqua-MODIS
    • PICS invariant target approach (Saharan desert)
    • Deep-convective clouds (DCC) invariant target approach
  • Spectral differences and spectral band adjust factor (SBAF)

• SNPP and NOAA-20 VIIRS radiometric scaling results
  • Consistency among methods

• Conclusions
Background

• Why consistent calibration of two VIIRS instruments 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
  • Consistent retrievals of cloud properties requires
    • Individual imager records are temporally stable in their calibration
    • Both VIIRS imagers are radiometrically consistent
  • 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.
  • CERES imager and geostationary calibration group (CIGC) performs calibration assessment of MODIS, VIIRS, and GEO imagers in real-time using multiple approaches
Background (contd.)

• Three independent cross-calibration approaches are used to estimate radiometric biases between the reflective solar bands (RSB) of SNPP and NOAA-20 VIIRS instruments:
  • Ray-matching with a GEO imager and Aqua-MODIS over ATO
  • DCC invariant target
  • Pseudo-invariant ground site (Libya-4 PICS)

• Datasets used are
  • Aqua-MODIS Collection 6.1 level 1B product
  • SNPP VIIRS V1 and NOAA-20 VIIRS V2 datasets generated by the NASA VIIRS Land Science Investigator-led Processing System (Land SIPS).
ATO-RM with a GEO imager

- Both VIIRS instruments are calibrated against Himawari-8 AHI imager over all-sky tropical ocean targets (0.5° grids)
- Himawari-8 AHI is a transfer radiometer
- Calibrate full dynamic range of sensor
- Matches within 15 minutes
  - $\mathrm{VZA}, \mathrm{SZA}<40^\circ; \quad \Delta \mathrm{VZA}=5^\circ-15^\circ$
  - $10^\circ<\mathrm{RAA}<170^\circ; \quad \Delta \mathrm{RAA}=5^\circ-15^\circ$
- Linear regression of the matched data on a monthly-basis
- Ratio of the two regression slopes gives radiometric biases between SNPP and NOAA-20 VIIRS

### Graphs

- **SNPP-VIIRS M5 vs AHI band 3, January 2018**
  - SNPP: SLOPE 0.3092, XoffPC 22.5, RS 0.9944, STDerr% 3.06, NORM 616
  - NOAA-20: SLOPE 0.3023, XoffPC 24.5, RS 0.9942, STDerr% 2.98, NORM 530

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Ray-matching with Aqua-MODIS

- Coincident, co-located, and co-angled radiance pairs for all comparable channels of Aqua-MODIS and SNPP/NOAA-20 VIIRS are acquired between 30°N and 30°S.
- Ray-matching is performed over ATO scenes, when the two orbits overlap in time (every 2.5 days)
  - pixels averaged within a shared 50-km diameter constitutes one ray-matched radiance pair
  - VZA/SZA differences < 3°, RAZ difference <10°
- A linear regression forced through zero is fitted to the radiance pairs on a monthly basis and the forced-slope is used as the cross-calibration ratio.

NOAA-20 VIIRS M5 radiances are darker compared to SNPP-VIIRS
PICS Method

- Libya-4 PICS (28.6°N, 23.4°E, 0.5° x 0.5° ROI)
- Only near-nadir observations (VZA < 10°) are considered
- PICS TOA radiance is modeled as a function of SZA (2nd order regression)
  - Libya-4 directional models (DM) stratified by scattering direction (back/forward)
  - 7-year data from SNPP-VIIRS are used to construct DM
- DM can predict TOA radiance for a given SZA of a target LEO (NOAA-20 VIIRS).
Baseline DCC method

- DCC pixel selection criteria:
  - BT11μm < 205.0K, SZA < 40°, VZA < 40°, 10° < RAA < 170°, σ(BT11μm) < 1.0° K, and σ(VIS) < 3%
  - DCC pixels are compiled into monthly probability distribution functions (PDFs) and their modes are tracked over time.
  - Anisotropic correction using the angular distribution model by Hu et al 2004.
  - Suitable for wavelengths <1 μm
Improved DCCT for SWIR bands

- At SWIR wavelengths,
  - DCC reflectivity is affected by ice particle size
  - results in large seasonal cycles
  - DCC response is highly dependent on the IR BT threshold

- Channel and seasonal specific empirical BRDFs are constructed using the SNPP-VIIRS DCC reflectances from 2012-2016

- VIS-NIR BRDFs are similar to Hu model

- Cirrus Channel (1.38 μm)
  - Ground PICS are inapplicable for vicarious calibration
  - Radiation is mostly absorbed by atmosphere, except for high altitude ice clouds

- SWIR band BRDFs reduces temporal variability of DCC response by up to 65%.

- By implementing similar DCC thresholds and BRDF normalizations, inter-sensor comparison using mean and mode statistics is feasible.
Radiance and Reflectance biases

### Reference Solar Spectrum

- VIIRS instruments are calibrated on Reflectance scale (solar diffuser reference)
- \( \text{Radiance} = \text{Reflectance} \times E_{\text{SUN}} \times \cos(SZA)/d^2 \)
- SNPP (Modtran) and NOAA-20 (Thuillier) VIIRS use different solar irradiance models
- Biases will differ for radiance and reflectance
- Difference in reference solar spectra can induce additional (+/-) radiance/reflectance bias

### Impact on M4 band calibration

![Graph showing solar irradiance spectra for NPP-VIIRS and NOAA-20 VIIRS](image)

- ~2% difference in \( E_{\text{sun}} \) for M4 (0.55 µm) band

Solar constant tool: [https://cloudsway2.larc.nasa.gov/cgi-bin/site/showdoc?mnemonic=SOLAR-CONSTANT-COMPARISONS](https://cloudsway2.larc.nasa.gov/cgi-bin/site/showdoc?mnemonic=SOLAR-CONSTANT-COMPARISONS)
SRF differences and SBAF

- Mostly similar SRFs and all scene SBAFs are within 2%

Solar constant tool: https://satcorps.larc.nasa.gov/cgi-bin/site/showdoc?mnemonic=SBAF
- M4 radiance and reflectance biases differ by 2% (due to solar irradiance model)
Results

All methods agree within ~2%
### Bias table

<table>
<thead>
<tr>
<th>Band</th>
<th>HIM8 AHI RM</th>
<th>Aqua-MODIS RM</th>
<th>DCC-IT</th>
<th>Libya-4 PICS</th>
<th>Consistency within</th>
</tr>
</thead>
<tbody>
<tr>
<td>M3 (0.48µm)</td>
<td>+5.7 (+5.1)</td>
<td>+5.9 (+5.3)</td>
<td>+5.4 (+4.9)</td>
<td>+5.3 (+4.7)</td>
<td>0.6 (0.6)</td>
</tr>
<tr>
<td>M4 (0.55µm)</td>
<td>+6.7 (+4.9)</td>
<td>+7.0 (+5.2)</td>
<td>+6.4 (+4.5)</td>
<td>+6.2 (+4.4)</td>
<td>0.8 (0.8)</td>
</tr>
<tr>
<td>M5 (0.65µm)</td>
<td>+6.2 (+4.7)</td>
<td>+6.3 (+4.9)</td>
<td>+6.1 (+4.7)</td>
<td>+6.1 (+4.9)</td>
<td>0.2 (0.2)</td>
</tr>
<tr>
<td>I1 (0.65µm)</td>
<td>+5.6 (+4.5)</td>
<td>+5.6 (+4.5)</td>
<td>+5.2 (+4.3)</td>
<td>+5.8 (+4.7)</td>
<td>0.6 (0.4)</td>
</tr>
<tr>
<td>M7 (0.86µm)</td>
<td>+3.5 (+3.8)</td>
<td>+3.5 (+3.7)</td>
<td>+3.8 (+3.9)</td>
<td>+3.9 (+4.1)</td>
<td>0.4 (0.4)</td>
</tr>
<tr>
<td>M8 (1.24µm)</td>
<td>NA</td>
<td>+2.5 (+2.3)</td>
<td>+2.5 (+2.4)</td>
<td>+2.4 (+2.2)</td>
<td>0.1 (0.2)</td>
</tr>
<tr>
<td>M9 (1.38µm)</td>
<td>NA</td>
<td>+1.0 (+2.5)</td>
<td>+0.1 (+1.7)</td>
<td>NA</td>
<td>0.9 (0.8)</td>
</tr>
<tr>
<td>M10 (1.6µm)</td>
<td>0 (+2.0)</td>
<td>+0.7 (+3.0)</td>
<td>-0.2 (+2.2)</td>
<td>-0.3 (+1.6)</td>
<td>1.0 (1.4)</td>
</tr>
<tr>
<td>I3 (1.6µm)</td>
<td>+2.1 (+4.5)</td>
<td>+2.6 (+4.8)</td>
<td>2.0 (+4.6)</td>
<td>+3.3 (+4.6)</td>
<td>1.2 (0.3)</td>
</tr>
<tr>
<td>M11 (2.25µm)</td>
<td>-1.7 (+1.0)</td>
<td>NA</td>
<td>-1.0 (+1.7)</td>
<td>-1.7 (+1.1)</td>
<td>0.7 (0.7)</td>
</tr>
</tbody>
</table>

- Reflectance biases are provided in parenthesis
- ‘+’ indicates SNPP-VIIRS is brighter
- All methods consistent within 0.8%, except for M10
- For bands < 1µm NPP is brighter than NOAA20 VIIRS by 3.5-6%
Conclusions

• NPP and NOAA-20 VIIRS are radiometrically scaled using
  • NPP and NOAA-20 do not have any SNOs, since they are in the same orbit and altitude but are spaced by 45 minutes
  • Transfer radiometers with similar spectral response functions, Himawari-8 and Aqua-MODIS
  • Invariant Earth targets, Libya-4 and deep convective clouds
  • Spectral band adjustment factors are utilized to account for slight spectral response differences

• Both reflectance and radiance scaling factors are computed
  • Reflectance is based on solar diffuser observation. (assumes a EARTH reflected spectra that is flat over the band)
  • Radiance requires a solar spectra. NPP and NOAA-20 use differing solar constants, which are wrapped into the scaling factor.
  • Band spectral difference were taken into account using scene specific SBAFs

• The method specific NPP and NOAA-20 VIIRS radiometric scaling factors are within 0.8%
  • NPP-VIIRS is brighter by 3.5% to 5% for bands < 1µm

• CERES will radiometrically scale the VIIRS to Aqua-MODIS C5 reference to maintain a consistent calibration throughout the 20-year record.