Using Hyper-Spectral SCIAMACHY Radiances to Uniformly Calibrate Contemporary Geostationary Visible Sensors

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Inter-calibration and Validation of Operational Sensors -- Oral Session
Outline

• Motivation/Objective
• Background
  – SCIAMACHY/MODIS/MET-9
  – Inter-calibration techniques
• Spectral Band Adjustment Factors (SBAF)
• Direct calibration transfer using SCIAMACHY
• Before/After SBAF results
• Conclusions
Motivation

- Geostationary satellites (GEOsat) sensors do not have on-board radiometric calibration sources for visible channels
- Need exists to develop absolute inter-calibration techniques capable of use with GEOsat sensors
- Cross-calibration is plagued by the differences in the sensor spectral response functions (SRFs)

Objective

- Develop inter-calibration-target-dependent Spectral Band Adjustment Factors (SBAFs) using SCIAMACHY hyperspectral visible radiances
- Validate for accuracy using SCIAMACHY and GEOsat direct comparisons
Background

• Global Space-Based Inter-Calibration System (GSICS)
  – Goal is to monitor/improve data quality from operational environmental satellites
  – Use IASI Hyper-spectral instruments to account for IR SRF differences
  – Aqua-MODIS is reference for GEO visible channels

• Key instruments used in this research
  – MODerate resolution Imaging Spectroradiometer (MODIS)
    • Collection 6, L1B, 1-km (subset to 2-km)
  – Meteosat-9 (Met-9)
    • 3-km
  – SCanning Imaging Absorption spectroMeter for Atmospheric CartograpHY (SCIAMACHY or SCIA)
    • Level-1b, Version-7.03
Background- SCIAMACHY Specifications

- Onboard ESA Environmental Satellite (Envisat)
- Launched on 1 March 2002
- 10:00 AM LST sun-synchronous orbit
- 35-day repeat cycle
- Shared scan duty between nadir and limb measurements
- Four 30-km along-track by 240-km across-track nadir-like footprints
  - Two nadir-like footprints on either side of ground track within a 30° view angle
  - Total nadir scan width of 960 km
Background- InterCalibration Methods

• MODIS-with-Met-9 ray-matching
  – Transfer calibration using co-incident, co-angled, and co-located ocean regions

• Deep Convective Clouds (DCC)
  – Treated as invariant targets
  – DCC model referenced to Aqua-MODIS

• Libyan Desert
  – Invariant target
  – Employs a kernel-based bidirectional reflectance distribution function (BRDF) model referenced to Aqua-MODIS

• SBADF necessary to account for spectral differences in all three methods
Visible-channel spectral corrections are dependent on target and reference SRFs

- MODIS: 0.65-μm (CH1)
- Met-9: CH1 and High Resolution Visible (HRV)

Scene-specific corrections for independent inter-calibration techniques (i.e., separate correction for DCC, Desert, and Ray-matching)
Spectral Band Adjustment Factors

- Spectra from each SCIAMACHY scene-appropriate footprint are convolved with imager SRFs to compute imager equivalent radiances.

- Regression of the two convolved SCIAMACHY radiances constitutes a Spectral Band Adjustment Factor (SBAF).
  - Applied to the reference sensor (MODIS) radiance \( L_{ref} \) to arrive at the predicted target sensor (Met-9) radiance \( L_{tar} \).

\[
L_{ref} \times SBAF_{tar/ref} = L_{tar}
\]
Narrowband-to-Narrowband SBAFs

Regressions well-behaved for narrowband-to-narrowband case
Corrections are small but not insignificant
Narrowband-to-Broadband SBAFs

Specific scene selection critical for obtaining representative Spectral Band Adjustment Factors when calibrating narrowband to broadband.
Direct SCIAMACHY Calibration Transfer

• Inter-calibrate SCIAMACHY and Aqua-MODIS 0.65µm channel using Near-SNOs
  – Determine SCIAMACHY stability compared against Aqua-MODIS
  – Determine relative calibration difference
• Inter-calibrate GEO with SCIAMACHY using ray-matching
• Can be used to validate the SBAF corrections for the other inter-calibration methods

Aqua-MODIS 0.65 micron \(\rightarrow\) Near SNO \(\rightarrow\) SCIAMACHY \(\rightarrow\) Ray-Match \(\rightarrow\) MET-9 0.65 micron
SCIAMACHY Aqua-MODIS 0.65µm, Jul 2010

- coincident within 15 minutes
- ~1300 1-km sub-sampled MODIS pixels are averaged into a 30x240km SCIAMACHY footprint
- limited to <70° SZA
Nearly Simultaneous Nadir Overpass Comparisons with Aqua-MODIS

SCIAMACHY Radiance is stable to within -0.6% per decade compared to Aqua-MODIS.
SCIAMACHY-with-Met-9 Ray-Matching

- Average Met-9 10-bit count computed within SCIA footprint bounds
  - 4-km pixels
  - Count $\propto$ radiance
  - Match within 15 min
- Three-monthly gains found by regressing SCIA convolved radiances with Met-9 average counts
  - Regression forced through the Met-9 space count
  - SCIA radiances scaled to Aqua-MODIS using NSNO comparisons
- Figure: Jan – Mar 2008 SCIA-with-Met-9 CH1 gain = 0.557
Standard error of 0.52% means absolute calibration coefficients are well-represented by the linear trend.
Before and After: Narrow-to-Narrow

• Before the SBAF is applied, the maximum mean difference in gain between the three methods for Met-9 CH1 **0.4%**

• After the SBAF is applied, the difference reduces to within **0.2%**

• The mean difference in CH1 gains from before to after application of the SBAF is **+2.0%**

• SCIAMACHY-to-Met-9 CH1 gain is within **1.3%** of other methods after SBAF is applied
Before and After: Narrow-to-Broad

- Before the SBAF is applied, the maximum mean difference in gain between the three methods for Met-9 HRV **8.3%**
- After the SBAF is applied, the difference reduces to within **1.0%**; reduced spread
- The mean difference in HRV gains from before to after application of the SBAF is **-11.3%**
- SCIAMACHY-to-Met-9 HRV gain is within **0.2%** of other methods after SBAF is applied
Conclusions

- SCIAMACHY convolved radiances can account for sensor SRF differences
- SCIAMACHY-with-Met-9 gain within 0.2% – 1.3% of other methods after the SBAF is applied
- A unique SBAF is required for each scene type
  - After SBAF application, three inter-calibration methods within 0.2%-1.0%
  - Better than 7% improvement in narrowband-to-broadband calibration agreement, suggests SBAF is important in deriving a gain
Nearly Simultaneous Nadir Overpass Comparisons with Aqua-MODIS

- Establish the stability of SCIAMACHY by radiometrically scaling to Aqua-MODIS
- Accomplished using nearly simultaneous nadir overpass (NSNO) comparisons near the north pole during Apr-Sep
- Aqua-MODIS is chosen following recommendations from GSICS
- About 14 NSNOs per day (dependent on scan duty cycle) at 11:45 am LST
  - Minimal view angle difference
  - Near-symmetric solar conditions (corrections for SZA differences applied)
Nearly Simultaneous Nadir Overpass Comparisons with Aqua-MODIS

- MODIS CH1 2-km pixel radiances averaged within bounds of SCIA footprint

- Regressed with SCIA radiances that were convolved with the MODIS CH1 SRF

![Graph showing a linear relationship between SCIAMACHY CH1 Radiance and Aqua-MODIS CH1 Radiance](image)

- SLOPE: 0.9848
- OFF: 0.03846
- $R^2$: 0.9977
- STDerr%: 3.1802
- NUM: 375
- BIAS (X-Y): 1.1259
- FOR [0.0]: 0.9853
Nearly Simultaneous Nadir Overpass Comparisons with Aqua-MODIS

- Stability of SCIAMACHY assessed with timeline of yearly regressions
- Mean correction value between SCIAMACHY and Aqua-MODIS of 0.9838
- Degradation of SCIAMACHY of 0.6% per decade
- Low degradation and 0.23% standard deviation suggests that SCIAMACHY is stable
SCIAMACHY-with-Met-9 Ray-Matching

- Match VZA for Met-9 and SCIA FOV
- One ray-matched location per FOV, four SCIA FOVs
- Four ray-matched locations per GEOsat sub-satellite domain
- Match occurs when:
  - SCIA FOV is within 160 km of corresponding ray-matched location
  - Scan difference < 15 min
- Threshold of 160 km provides sufficient sampling; does not significantly increase standard error relative to a tight threshold
### Before and After: Summary

MODIS Characterization Support Team

- Met-9 CH1 / Aqua CH1 SC ratio = 1.013
- Met-9 HRV / Aqua CH1 SC ratio = 0.883

<table>
<thead>
<tr>
<th></th>
<th>Average Gain (CH1) Before SBAF</th>
<th>Average Gain x SC ratio (CH1)</th>
<th>Average Gain (CH1) After SBAF</th>
<th>Average Gain (HRV) Before SBAF</th>
<th>Average Gain x SC ratio (HRV)</th>
<th>Average Gain (HRV) After SBAF</th>
</tr>
</thead>
<tbody>
<tr>
<td>Terra-MODIS</td>
<td>0.540</td>
<td>(+1.3%) 0.547</td>
<td>(+0.7%) 0.551</td>
<td>0.633</td>
<td>(-11.7%) 0.559</td>
<td>(+1.3%) 0.566</td>
</tr>
<tr>
<td>Aqua-MODIS</td>
<td>0.539</td>
<td>(+1.3%) 0.546</td>
<td>(+0.9%) 0.551</td>
<td>0.619</td>
<td>(-11.6%) 0.547</td>
<td>(+2.9%) 0.563</td>
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<tr>
<td>DCC</td>
<td>0.541</td>
<td>(+1.3%) 0.548</td>
<td>(+0.5%) 0.551</td>
<td>0.631</td>
<td>(-11.7%) 0.557</td>
<td>(+3.2%) 0.575</td>
</tr>
<tr>
<td>Libya</td>
<td>0.539</td>
<td>(+1.3%) 0.546</td>
<td>(+1.1%) 0.552</td>
<td>0.675</td>
<td>(-11.7%) 0.596</td>
<td>(-4.5%) 0.569</td>
</tr>
</tbody>
</table>

Combination of surface reflectance and atmospheric absorption differences means that a single SBAF cannot account for all calibration methods.

SBAFs are impactful and add value.