Multi-temporal cross-calibration of Terra MODIS and Landsat 7 ETM+ reflective solar bands

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  – African PICS site
• Methodology
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  – BRDF correction
  – Spectral mismatch correction using EO-1 Hyperion (comparison with SCIAMACHY and MODTRAN)
• Results
  – Long-term stability
  – Comparison after BRDF correction
• Summary and Future Work

Sensor Overview

Images obtained from NASA’s Earth Observing System website

Landsat 7 (Apr 15, 1999)

Terra (Dec 18, 1999)

Earth Observing 1 (Nov 21, 2000)

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Sensor Overview

<table>
<thead>
<tr>
<th>Platform</th>
<th>Terra</th>
<th>Landsat 7</th>
<th>EO-1</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sensor</td>
<td>MODIS</td>
<td>ETM+</td>
<td>Hyperion</td>
</tr>
<tr>
<td>Number of bands</td>
<td>36</td>
<td>8</td>
<td>220</td>
</tr>
<tr>
<td>Spatial resolution</td>
<td>250 m, 500 m, 1 km</td>
<td>15 m, 30 m, 60 m</td>
<td>30 m</td>
</tr>
<tr>
<td>Swath</td>
<td>2330 km</td>
<td>187 km</td>
<td>7 km</td>
</tr>
<tr>
<td>Spectral coverage</td>
<td>0.4~14 µm</td>
<td>0.4~12.5 µm</td>
<td>0.4~2.5 µm (10 nm)</td>
</tr>
<tr>
<td>Launch date</td>
<td>Dec 18, 1999</td>
<td>April 15, 1999</td>
<td>Nov 21, 2000</td>
</tr>
<tr>
<td>Altitude</td>
<td>705km</td>
<td>705km</td>
<td>705 km at launch</td>
</tr>
</tbody>
</table>

L7 ETM+ (B1) and Terra MODIS (B3)

L7 ETM+ (B3) and Terra MODIS (B1)

L7 ETM+ (B5) and Terra MODIS (B6)
Motivation

• Why Use Ground Targets?
  – Not all sensors have on-board calibrators
  – On-board calibrators degrade (need a stability monitor)
  – On-board calibrators may not be sufficient (difference between on-orbit calibration and EV observations, full-aperture versus partial aperture, OBC and EV data view angle difference)

• Selection of Ground Targets
  – Data availability
  – Site accessibility (ideally with ground “truth”)
  – Stability (temporal)
  – Uniformity (spatially)
  – Well-defined spectral characteristics
  – Others (reflectance level, atmospheric conditions, ...)

Hardly any single ground target can meet all the “requirements”
Multiple sites should be considered, depending on the specific applications
Libya 4 Site Overview

- L7 Repeat Cycle is 16 days
- Near-simultaneous pairs (same-day)
- ROI is close to nadir angle for Terra
- After May 31, 2003, the L7 ETM+ SLC-off products were used
Methodology

• MRTSwath Reprojection was used on Terra MODIS 5min-Swath to match ETM+ L1T UTM product format
  – MODIS Collection 6 data and ETM+ products downloaded from MODAPS LAADS and USGS EarthExplorer in Feb, 2015
• Co-located areas (CNES specified ROI: Lacherade et.al) extracted for each MODIS and ETM+ image pair
  – ROI chosen from \((28.45^\circ,23.29^\circ)\) to \((28.65^\circ,23.49^\circ)\)
  – Near-nadir observations are chosen (minimal BRDF impact)
  – Only same-day scenes are considered
  – Brightness Temperature thresholds used to eliminate cloud contaminated pairs
• At-sensor reflectance were computed for all scenes, and a semi-empirical BRDF correction was derived
• RSR difference compensated using EO-1 Hyperion spectral signatures of Libya 4
  – Lifetime spectral difference factors were computed
TOA reflectance trending result

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BRDF Correction

• Since only near-nadir acquisitions (within 30 min) are chosen, a solar/sensor geometry based correction was developed

• Using the first 3-years of Terra MODIS measurements over the Libyan desert, a semi-empirical bi-directional reflectance function (BRDF) consisting of two kernel-driven components (Roujen et.al) was used:

\[
\hat{\rho} = k_0 + k_1 f_1(\theta_s, \theta_v, \phi) + k_2 f_2(\theta_s, \theta_v, \phi)
\]

• The derived coefficients applied to lifetime MODIS and ETM+ measurements
  – Applying MODIS-based coefficients to ETM+ also provides an estimate of the spectral mismatch (due to RSR differences) between the two sensors

BRDF Correction

Libya4: ETM+ B1 & MOD B3

Libya4: ETM+ B4 & MOD B2

Libya4: ETM+ B2 & MOD B4

Libya4: ETM+ B5 & MOD B6

Libya4: ETM+ B3 & MOD B1

Libya4: ETM+ B7 & MOD B7
Long-term stability

Libya4: ETM+ B1 & MOD B3
- Terra multi-year drift: 0.71% ±/-1.25%
- L7 multi-year drift: 0.03% ±/-1.45%

Libya4: ETM+ B2 & MOD B4
- Terra multi-year drift: 0.43% ±/-0.97%
- L7 multi-year drift: 0.61% ±/-1.25%

Libya4: ETM+ B3 & MOD B1
- Terra multi-year drift: 1.44% ±/-1.03%
- L7 multi-year drift: 0.67% ±/-1.14%

Libya4: ETM+ B4 & MOD B2
- Terra multi-year drift: 1.50% ±/-1.16%
- L7 multi-year drift: 1.18% ±/-2.00%

Libya4: ETM+ B5 & MOD B6
- Terra multi-year drift: -0.62% ±/-1.00%
- L7 multi-year drift: 0.93% ±/-1.39%

Libya4: ETM+ B7 & MOD B7
- Terra multi-year drift: -0.63% ±/-2.31%
- L7 multi-year drift: 1.02% ±/-2.55%
Spectral Band Adjustment Factor (SBAF) to Correct Impact Due to RSR Difference

ENVISAT Sciamachy provides a hyperspectral signature of Libya 4 at 1 nm spectral resolution

Lifetime Sciamachy reflectance profiles over Libya 4 provided by Ben Scarino and Dave Doelling, NASA Langley

Spectral Band Adjustment Factor (SBAF) to Correct Impact Due to Sensor RSR Difference

Using all-available EO-1 Hyperion measurements to characterize the differences due to RSR mismatch.

Seasonal variations evident for some bands (BRDF, water-vapor variations).

Long-term drift (~2 %) evident in the SWIR band (Hyperion band 193-219).

Temporal SBAF is desirable, but due to lack of near-simultaneous collects, lifetime-average SBAF computed.
Spectral difference and atmospheric water-vapor impact

- RSR mismatch correction using MODTRAN 5.0 (mid-latitude desert profile)
- Impact of columnar atmospheric water-vapor on the observed differences
- Real-time columnar atmospheric water-vapor can be retrieved from MODIS MOD05_L2 product
Spectral difference
and atmospheric water-vapor impact

<table>
<thead>
<tr>
<th>Band pair</th>
<th>Hyperion SBAF</th>
<th>Sciamachy SBAF</th>
<th>MODTRAN SBAF</th>
<th>Sciamachy-Hyperion %</th>
<th>MODTRAN Hyperion %</th>
</tr>
</thead>
<tbody>
<tr>
<td>E-B1 &amp; M-B3</td>
<td>1.07</td>
<td>1.02</td>
<td>1.03</td>
<td>4.23</td>
<td>3.96</td>
</tr>
<tr>
<td>E-B2 &amp; M-B4</td>
<td>1.03</td>
<td>1.02</td>
<td>1.01</td>
<td>1.17</td>
<td>2.10</td>
</tr>
<tr>
<td>E-B3 &amp; M-B1</td>
<td>1.03</td>
<td>1.02</td>
<td>1.02</td>
<td>1.17</td>
<td>1.08</td>
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<tr>
<td>E-B4 &amp; M-B2</td>
<td>0.92</td>
<td>0.94</td>
<td>0.98</td>
<td>-2.56</td>
<td>-6.36</td>
</tr>
<tr>
<td>E-B5 &amp; M-B6</td>
<td>0.95</td>
<td>0.92</td>
<td>0.97</td>
<td>2.73</td>
<td>-2.41</td>
</tr>
<tr>
<td>E-B7 &amp; M-B7</td>
<td>0.87</td>
<td>N/A</td>
<td>0.86</td>
<td>N/A</td>
<td>0.68</td>
</tr>
</tbody>
</table>
MODIS-ETM+ Differences after correction (BRDF + SBAF)

Libya4: ETM+ B1 & MOD B3

MODIS-ETM+ difference: -0.48249133%

Libya4: ETM+ B4 & MOD B2

MODIS-ETM+ difference: -8.3105892%

Libya4: ETM+ B2 & MOD B4

MODIS-ETM+ difference: -4.9714894%

Libya4: ETM+ B5 & MOD B6

MODIS-ETM+ difference: 2.0059773%

Libya4: ETM+ B3 & MOD B1

MODIS-ETM+ difference: -4.0130635%

Libya4: ETM+ B7 & MOD B7

MODIS-ETM+ difference: -1.8780418%
Summary and Future Work (1)

- A methodology to monitor the long-term stability of Terra MODIS and Landsat 7 ETM+ RSB using PICS has been developed
  - Long-term drift for all bands within 2% over 14+ years
- EO-1 Hyperion collects were used to characterize the RSR differences between the two sensors
  - Results compared with Sciamachy and MODTRAN based SBAFs.
  - Columnar water-vapor retrieved from the MODIS MOD05_L2 product which is used as an input to MODTRAN
  - Most differences observed at the shortest wavelength with temporal variations (due to atmospheric water-vapor) observed in ETM+ band 4 and MODIS band 2
- After application of the SBAFs, difference between the two sensors is less than 5% for most bands (exception: MODIS band 2 and ETM+ band 4)
  - ETM+ band 4 RSR has a water-vapor absorption feature absent from MODIS RSR. Need a better understanding of the results
Summary and Future Work (2)

- EO-1 Hyperion provides an excellent resource to characterize the spectral differences between the two sensors
  - Lowering of the orbit reduces the number of near-simultaneous opportunities with ETM+ and MODIS collects
  - Long-term drift in the SWIR channels of EO-1 Hyperion adds more uncertainties to the SBAF computation
  - Spectral resolution of 10 nm can be inadequate especially in the regions of water-vapor absorption

- Similar methodology to be extended to other African PICS and other sites (covering different part of the dynamic range)

- Methodology to be extended to Landsat 8 OLI, Landsat 5 TM and Aqua MODIS comparison