An Intercomparison of AIRS, MODIS, and ASTER Land Surface Temperature and Emissivity (LST&E) Measurements

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# MODIS, AIRS, ASTER LST&E Climate Product Characteristics

## Potential Sources of Bias

<table>
<thead>
<tr>
<th></th>
<th>Terra/Aqua MODIS</th>
<th>Aqua AIRS</th>
<th>Terra ASTER</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Cloud Contamination</strong></td>
<td>Cloud Detection</td>
<td>Cloud Clearing</td>
<td>Cloud Detection</td>
</tr>
<tr>
<td><strong>Algorithm</strong></td>
<td>Day/Night</td>
<td>Multi-spectral</td>
<td>Calibration Curve</td>
</tr>
<tr>
<td><strong>Land Cover Class</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Temporal Sampling</strong></td>
<td>Clear only; 10:30 AM, PM</td>
<td>Partly Cloudy; 1:30 AM, PM</td>
<td>Clear only; 10:30 AM, PM</td>
</tr>
<tr>
<td></td>
<td>1:30 AM, PM</td>
<td></td>
<td>every 16 days</td>
</tr>
<tr>
<td></td>
<td>Twice daily</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Spatial Sampling</strong></td>
<td>1 km Clear Only</td>
<td>45 km CC</td>
<td>90 m Clear only</td>
</tr>
<tr>
<td>and Resolution</td>
<td>(1 km -&gt; 5 km)</td>
<td>(15 km -&gt; 45 km)</td>
<td></td>
</tr>
<tr>
<td><strong>Scan angle</strong></td>
<td>55</td>
<td>45</td>
<td>8.55</td>
</tr>
</tbody>
</table>
**ASTER Gridded L3 Emissivity Product**

- Mean Summer (July, Aug, Sep) and Winter (Jan, Feb, Mar) emissivity from 2000-2008
- ASTER Land Surface Emissivity Aggregation Algorithm (ALSEA)
- Use New ASTER Cloud Mask (NACMA) to screen out cloudy pixels (MODIS/AVHRR/Landsat)
- Determine all intersecting granules on 1 x1 given grid
- Output mean and temporal SDev for all clear obs on each pixel
- 100 m spatial resolution
- States completed:
  - California, Nevada, Arizona, Utah, New Mexico, Oklahoma, Texas
- Complete USA by end of year??

ASTER Validation Sites

- Rocks and Sand

10 samples at each site over 500m² area

2x2 ASTER pixels (100 m) averaged over each sample
Quartz - Algodones Dunes, CA

- ASTER
- Field_Lab

<0.5%
~0.3 K

Carbonte - Cuprite, NV

- ASTER
- Field_Lab

<0.5%
~0.3 K

Stovepipe Wells Dunes - Death Valley, CA

- ASTER
- Field_Lab

0.5-1%
~0.5 K
ASTER Validation Sites
- Vegetation and Water

Redwood National Park – Conifer Forest

Lake Tahoe - Water

Stevens Creek Oak Forest - Deciduous
MODIS UCSB spectral library

Vegetation - Redwood National Park, CA

- Emissivity: <1%
- Temperature: ~0.5 K

Water - Lake Tahoe, CA

- Emissivity: <2-3%
- Temperature: ~2 K

Deciduous Oak - Upper Stevens Creek Park, CA

- Emissivity: <1%
- Temperature: ~0.5 K
** 80% of pixels have less than 1.5% emissivity difference (~1 K)
** Low emissivity areas have differences up to 7% (6.5 K)

**But** could be due to AIRS overestimating nighttime emissivities over barren areas
ASTER and AIRS Emissivity Comparisons for all 5 TIR bands

The images show scatter plots for each of the 5 TIR bands (8.3 µm, 8.6 µm, 9.1 µm, 10.6 µm, 11.3 µm) comparing ASTER and AIRS emissivity values. The plots are accompanied by histograms showing the distribution of the differences between ASTER and AIRS emissivity values for each band.
** 80% of pixels have less than 1% emissivity difference (~0.8 K)

** Low emissivity areas have differences up to 6% (~4.5 K)
ASTER minus MODIS (MYD11C3 V5) Mean Summer Emissivity Difference

- MODIS (v5) uses Day/Night combined with Split-Window Land Cover type
- Up to 10% emissivity difference in arid/semi-arid areas!! (~7 K)
ASTER and MODIS (v4) Emissivity Comparisons for all 5 TIR bands
ASTER and MODIS (v5) Emissivity Comparisons for all 5 TIR bands
** ~80% of pixels <2% emissivity difference (~1.4 K)

** Low emissivity areas have differences up to 6% (~4.5 K)
** ~49% of pixels <2% emissivity difference (~1.4 K)

** Low emissivity areas have differences up to 10%! (~7 K)
Algodones Dunes – MODIS v4 and v5 Differences

>10% difference
MODIS (v5) and MODIS (v4) Emissivity Difference at 8.3 µm

>10% difference
Low-Emissivity (Quartz)

All pixels with ASTER $\varepsilon$ at 8.3 $\mu$m <0.85

10 pixels
Mid-Emissivity (Mixed)

All pixels with $0.85 < \text{ASTER} \varepsilon \text{ at } 8.3 \mu m < 0.95$

240 pixels
High-Emissivity (Vegetation/Water)

All pixels with ASTER $\varepsilon$ at 8.3 $\mu$m > 0.95

259 pixels
Barren land shows MODIS cold bias (collection 005) up to 8 degrees.

*Knuteson*
Barren land shows MODIS cold bias (collection 005) up to 10 degrees.

* Knuteson
Use Land Classes (IGBP) to group the global data by land type for statistical analysis.

<table>
<thead>
<tr>
<th>IGBP CLASS ID</th>
<th>IGBP CLASS DESCRIPTION</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>Water Bodies</td>
</tr>
<tr>
<td>1</td>
<td>Evergreen Needleleaf Forest</td>
</tr>
<tr>
<td>2</td>
<td>Evergreen Broadleaf Forest</td>
</tr>
<tr>
<td>3</td>
<td>Deciduous Needleleaf Forest</td>
</tr>
<tr>
<td>4</td>
<td>Deciduous Broadleaf Forest</td>
</tr>
<tr>
<td>5</td>
<td>Mixed Forest</td>
</tr>
<tr>
<td>6</td>
<td>Closed Shrublands</td>
</tr>
<tr>
<td>7</td>
<td>Open Shrublands</td>
</tr>
<tr>
<td>8</td>
<td>Woody Savannas</td>
</tr>
<tr>
<td>9</td>
<td>Savannas</td>
</tr>
<tr>
<td>10</td>
<td>Grasslands</td>
</tr>
<tr>
<td>11</td>
<td>Permanent Wetlands</td>
</tr>
<tr>
<td>12</td>
<td>Croplands</td>
</tr>
<tr>
<td>13</td>
<td>Urban and Built-Up</td>
</tr>
<tr>
<td>14</td>
<td>Cropland/Natural Vegetation Mosaic</td>
</tr>
<tr>
<td>15</td>
<td>Snow and Ice</td>
</tr>
<tr>
<td>16</td>
<td>Barren or Sparsely Vegetated</td>
</tr>
<tr>
<td>17</td>
<td>Missing Data</td>
</tr>
</tbody>
</table>

* Knuteson
Snow/Ice Covered Land

Warm clouds over cold snow/ice contaminate the AIRS LST monthly product.

* Knuteson
AIRS and MODIS (collection 004) agree to within 0.5 K at night !!!
MODIS (collection 005) is 0.5 – 2.5 K colder than collection 004?
AIRS and MODIS (collection 004) agree to between 0 and -1.5 K in the Day.
MODIS DAY Collection 005 minus AIRS(v5) DAY

MODIS (collection 005) is 0.5 – 3 K colder than collection 004?
Summary and Future Work

• ASTER validation results
  – <0.5 % rocks/sand, 1-3% over vegetation/water
• AIRS (v5) and ASTER emissivity differences
  – <1.5% over vegetated and mixed areas
  – Up to 7% over desert areas.
• MODIS (v4) and ASTER emissivity differences
  – 80% < 2%
  – Low < 6%
• MODIS v5 and ASTER emissivity differences
  – 50% < 2%
  – Low < 10%
• MODIS v4 and AIRS
  – < 0.5K
• MODIS v5 and AIRS
  – 0.5-3K
EXTRAS
MODIS (MYD11C3 V5) minus AIRS Mean Summer Emissivity Comparisons
LST&E Intercomparison Goals

• International Workshop on the Retrieval and Use of Land Surface Temperature: Bridging the Gaps – Asheville, NC, 7-9 April `08

• What are the natural spatial and temporal scales of the natural variability of the relevant quantities (LST&E)?

• To what degree can we identify BIASES in the LST&E products?

• When product algorithm changes are made (i.e. version changes), do we have a way of deciding if the intended improvements actually improve or degrade the product accuracy?

• More research and validation on low emissivities over barren areas

• Set of core validation LST&E sites over homogenous areas - set standard to which remote sensing LST&E measurements compared

• A possible Unified LST&E product for Earth Science Research?
ASTER Temperature Emissivity Separation (TES) Algorithm

- Inversion of T and ε are underdetermined
- In TES, additional constraint arises from minimum emissivity vs spectral contrast
- Observed maximum-minimum difference (MMD) used to obtain unknown emissivity value
- Three error sources:
  - Reliance on empirical function
  - Atmospheric corrections (~1 K)
  - Radiometric calibration errors (small)
- Reported accuracy:
  - T within 1.5 K and ε within 0.015 (1.5%)
  - **Strength:** low emissivity, high spectral contrast
  - **Weakness:** high emissivity, low spectral contrast

### ASTER TIR Bands

<table>
<thead>
<tr>
<th>Band</th>
<th>Wavelength Range</th>
</tr>
</thead>
<tbody>
<tr>
<td>Band 10</td>
<td>8.125 – 8.475 µm</td>
</tr>
<tr>
<td>Band 11</td>
<td>8.475 – 8.825 µm</td>
</tr>
<tr>
<td>Band 12</td>
<td>8.925 – 9.275 µm</td>
</tr>
<tr>
<td>Band 13</td>
<td>10.25 – 10.95 µm</td>
</tr>
<tr>
<td>Band 14</td>
<td>10.95 – 11.65 µm</td>
</tr>
</tbody>
</table>
## Low-Emissivity (Quartz)

All pixels with ASTER emissivity at 8.3 µm < 0.85

<table>
<thead>
<tr>
<th>Wavelength</th>
<th>8.3 µm</th>
<th>8.6 µm</th>
<th>9.1 µm</th>
<th>10.6 µm</th>
<th>11.3 µm</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Mean Bias</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>ASTER – AIRS (50 km)</td>
<td>-0.071</td>
<td>-0.067</td>
<td>-0.071</td>
<td>-0.015</td>
<td>-0.021</td>
</tr>
<tr>
<td>ASTER – MODIS (5 km)</td>
<td>-0.079</td>
<td>-0.056</td>
<td>-0.076</td>
<td>-0.009</td>
<td>-0.024</td>
</tr>
<tr>
<td>MODIS – AIRS (50 km)</td>
<td>0.005</td>
<td>-0.011</td>
<td>0.001</td>
<td>-0.007</td>
<td>0.003</td>
</tr>
<tr>
<td><strong>Std Dev</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>ASTER – AIRS (50 km)</td>
<td>0.028</td>
<td>0.028</td>
<td>0.033</td>
<td>0.009</td>
<td>0.012</td>
</tr>
<tr>
<td>ASTER – MODIS (5 km)</td>
<td>0.016</td>
<td>0.015</td>
<td>0.016</td>
<td>0.008</td>
<td>0.005</td>
</tr>
<tr>
<td>MODIS – AIRS (50 km)</td>
<td>0.022</td>
<td>0.024</td>
<td>0.023</td>
<td>0.011</td>
<td>0.016</td>
</tr>
</tbody>
</table>
## Mid-Emissivity (Mixed)

All pixels with $0.85 < \text{ASTER emissivity at } 8.3 \, \mu\text{m} < 0.95$

<table>
<thead>
<tr>
<th>Wavelength</th>
<th>8.3 $\mu$m</th>
<th>8.6 $\mu$m</th>
<th>9.1 $\mu$m</th>
<th>10.6 $\mu$m</th>
<th>11.3 $\mu$m</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Mean Bias</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>ASTER – AIRS</strong> (50 km)</td>
<td>-0.017</td>
<td>-0.023</td>
<td>-0.027</td>
<td>-0.002</td>
<td>-0.006</td>
</tr>
<tr>
<td><strong>ASTER – MODIS</strong> (5 km)</td>
<td>-0.038</td>
<td>-0.038</td>
<td>-0.050</td>
<td>-0.011</td>
<td>-0.021</td>
</tr>
<tr>
<td><strong>MODIS – AIRS</strong> (50 km)</td>
<td>0.018</td>
<td>0.013</td>
<td>0.022</td>
<td>0.009</td>
<td>0.015</td>
</tr>
<tr>
<td><strong>Std Dev</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>ASTER – AIRS</strong> (50 km)</td>
<td>0.022</td>
<td>0.019</td>
<td>0.020</td>
<td>0.009</td>
<td>0.011</td>
</tr>
<tr>
<td><strong>ASTER – MODIS</strong> (5 km)</td>
<td>0.018</td>
<td>0.015</td>
<td>0.016</td>
<td>0.005</td>
<td>0.005</td>
</tr>
<tr>
<td><strong>MODIS – AIRS</strong> (50 km)</td>
<td>0.018</td>
<td>0.017</td>
<td>0.018</td>
<td>0.010</td>
<td>0.010</td>
</tr>
</tbody>
</table>
## High-Emissivity (Vegetation/Crops)

All pixels with ASTER emissivity at 8.3 µm > 0.95

<table>
<thead>
<tr>
<th>Wavelength</th>
<th>8.3 µm</th>
<th>8.6 µm</th>
<th>9.1 µm</th>
<th>10.6 µm</th>
<th>11.3 µm</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Mean Bias</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>ASTER – AIRS (50 km)</td>
<td>-0.003</td>
<td>-0.008</td>
<td>-0.014</td>
<td>-0.001</td>
<td>-0.002</td>
</tr>
<tr>
<td>ASTER – MODIS (5 km)</td>
<td>-0.008</td>
<td>-0.013</td>
<td>-0.022</td>
<td>-0.010</td>
<td>-0.017</td>
</tr>
<tr>
<td>MODIS – AIRS (50 km)</td>
<td>0.006</td>
<td>0.007</td>
<td>0.010</td>
<td>0.010</td>
<td>0.015</td>
</tr>
<tr>
<td><strong>Std Dev</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>ASTER – AIRS (50 km)</td>
<td>0.012</td>
<td>0.011</td>
<td>0.012</td>
<td>0.008</td>
<td>0.009</td>
</tr>
<tr>
<td>ASTER – MODIS (5 km)</td>
<td>0.010</td>
<td>0.010</td>
<td>0.012</td>
<td>0.004</td>
<td>0.004</td>
</tr>
<tr>
<td>MODIS – AIRS (50 km)</td>
<td>0.017</td>
<td>0.016</td>
<td>0.018</td>
<td>0.009</td>
<td>0.009</td>
</tr>
</tbody>
</table>
ASTER Summer minus Winter mean emissivity
ASTER L3 Emissivity Validation

- High spatial resolution (100m) makes validation possible
- Homogenous areas with known composition needed
- Samples measured in lab using FTIR
- Reflectance converted to emissivity and convolved to ASTER bands
- Geologic Samples
  - Quartz-rich Algodones dunes, southeastern CA
  - Carbonate-rich fan deposit, Cuprite NV
  - Stovepipe Wells dunes, Death Valley, CA
- 10 samples taken in 500x500m grid
- 2x2 ASTER pixels (1 pixel = 180 m)
Outline

• ASTER overview
• New ASTER L3 Emissivity Product
• ASTER Emissivity Validation results
• AIRS and ASTER Emissivity Comparisons
• MODIS and ASTER Emissivity Comparisons
• AIRS and MODIS Global LST Comparisons
• AIRS and MODIS Global Emissivity Comparisons
• Summary and Future Work
- MODBF – Seemann Baseline Fit LSE Database
  • Characterized by model with inflection points at 8.3, 9.3, 10.8 and 12.1 µm in TIR

- MOD11 – MODIS LSE Product
  • Day-night emissivity retrieval with values at 8.6, 11 and 12 µm in TIR

- MOD11 values at 8.6 um are assigned to inflection points at 8.3 and 9.3 µm , while MOD11 emissivity values at 11 and 12 µm are used to extend line from hinge points 10.8 and 12.1 µm.

- MODBF can be linearly interpolated between inflection points for comparisons with other instruments, eg. ASTER
New ASTER Cloud Mask Algorithm (NACMA)
Sampling data with different spatial resolutions

Current:
\[
\bar{e} = \frac{1}{n} \sum_{k=1}^{n} e_k
\]

Proposed:
\[
\bar{e} = \left[ \frac{1}{n} \sum_{k=1}^{n} e_k B(T_k^*)}{B(T_{AIRS})} \right]
\]

** But ASTER product is mean, seasonal T and e

Work in progress.....