The North American ASTER Land Surface Emissivity Database (NAALSED) Version 3.0

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HyspIRI Science Workshop, Pasadena, CA, 24-26 August 2010
HyspIRI TIR Land Surface Temperature (LST) and Emissivity Relevance

• Physical: Emissivity error 1.5% = 1 K LST error
• Split-window: Emissivity error 0.5% = 1 K LST error
• LST Required for:
  – Measurements of fire parameters (Giglio, Csaszar)
  – Evapotranspiration models (Anderson)
  – Ecosystem function and Biodiversity (Asner, Townsend, Serbin, Roberts)
  – Modeling Urban heat islands (Weng)
  – Volcano monitoring, lava flows (Abrams, Realmuto, Vaughan, Wright)
  – Climate models (CDR’s) (Huemmrich, Minnett)
  – Surface composition, soil moisture (Ramsey, Scheidt)
Station Fire, Angeles National Forest, California

Temperature Emissivity Separation (TES) Algorithm
- Physical retrieval of LST and emissivity
- ASTER standard products

MODIS Split-window
- Emissivity assigned according to land cover classification
- Does not capture dynamic land cover changes
HyspIRI TIR Product ATBD’s

HyspIRI Level-2 TIR Surface Radiance Algorithm Theoretical Basis Document, Version 1.0

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Pasadena, California

Jan 2010

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HyspIRI Level-2 TIR Land Surface Temperature and Emissivity Algorithm Theoretical Basis Document, Version 1.0

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# ASTER and HyspIRI TIR Product Characteristics

<table>
<thead>
<tr>
<th></th>
<th><strong>ASTER</strong></th>
<th><strong>HyspIRI</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td>Calibration</td>
<td>&lt;0.3 K</td>
<td>&lt;0.2 K</td>
</tr>
<tr>
<td>LST&amp;E Algorithm</td>
<td>TES Calibration Curve</td>
<td>TES Calibration Curve</td>
</tr>
<tr>
<td>Atmospheric Correction</td>
<td>Water Vapor Scaling + MODTRAN</td>
<td>Water Vapor Scaling + MODTRAN</td>
</tr>
<tr>
<td>LST Product Accuracy</td>
<td>1.5 K</td>
<td>1 K</td>
</tr>
<tr>
<td>Product versions</td>
<td>Version 3</td>
<td>n/a</td>
</tr>
<tr>
<td>Temporal sampling</td>
<td>16 day repeat (1030 AM/PM)</td>
<td>5 day repeat (1030 AM/PM)</td>
</tr>
<tr>
<td>Spatial resolution</td>
<td>90 m</td>
<td>60 m</td>
</tr>
<tr>
<td>Spectral resolution</td>
<td>5 TIR bands (8-12 μm)</td>
<td>8 TIR bands (4-12 μm)</td>
</tr>
<tr>
<td>Swath Width</td>
<td>60 km</td>
<td>600 km</td>
</tr>
</tbody>
</table>
The North American ASTER Land Surface Emissivity Database (NAALSED)

Mapping Earth’s emissivity at 100 m

- ASTER produces L-2 LST/emissivity products at 90m (AST 05, 08)
- Scenes (60 x 60 km) produced on demand, limited repeat (16 days) => no L-3 gridded datasets!
- **Solution:** Produce an ASTER seasonal surface emissivity map for North America (NAALSED) and extend to Global product
  - Summertime (Jul-Sep), 2000-2009
  - Wintertime (Jan-Mar), 2000-2009
- **Applications:**
  - Evaluating emissivity products from coarser resolution sensors: eg. MODIS (5 km), AIRS (45 km)
  - Geological mapping and resource exploration
  - Inputs to Climate and Ecology Models
  - Validation dataset and simulation of future sensors, eg. HyspIRI
  - Generate a long-term LST climate data record from Landsat
North American Land Surface Emissivity Project

Welcome to the website for the North American Land Surface Emissivity Project. The goal of the project is to create a seamless database of emissivity from standard ASTER emissivity products for use in climate research. The Earth emits energy at wavelengths we cannot normally see, that energy is a function of the temperature and the emissivity of the surface. The surface emissivity primarily depends on the composition of the surface. Thus as the surface composition changes through, for example, land cover land use change, so does the surface emissivity. The land surface emissivity is measured by several instruments mounted on satellites and aircraft. Some of the most well known satellite sensors are AIRS, ASTER and MODIS.

Of these three satellite sensors, ASTER provides the most detailed emissivity images with a pixel spatial resolution of 90m. The image below was created by merging together all the ASTER emissivity data ever acquired over California, Nevada, Arizona and Utah under clear skies from 2000-2006 for the months July, August and September.
<table>
<thead>
<tr>
<th>Product/Service</th>
<th>NAALSED v2.0</th>
<th>NAALSED v3.0</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Temporal coverage</strong></td>
<td>2000-2008</td>
<td>2000-2010</td>
</tr>
<tr>
<td><strong>Products</strong></td>
<td>Emissivity</td>
<td>Emissivity</td>
</tr>
<tr>
<td>2000-2008</td>
<td>Temperature</td>
<td>Temperature</td>
</tr>
<tr>
<td>2000-2010</td>
<td>NDVI</td>
<td>NDVI</td>
</tr>
<tr>
<td>2000-2008</td>
<td>Land/Water Map</td>
<td>Land/Water Map</td>
</tr>
<tr>
<td>2000-2010</td>
<td></td>
<td>DEM</td>
</tr>
<tr>
<td><strong>Cloud mask</strong></td>
<td>v1.0</td>
<td>v3.2</td>
</tr>
<tr>
<td><strong>Atmospheric Profiles</strong></td>
<td>NCEP GDAS</td>
<td>Terra MODIS (MOD07)</td>
</tr>
<tr>
<td>- Temporal interpolation</td>
<td>- Temporal interpolation</td>
<td>- Coincident</td>
</tr>
<tr>
<td>- 100 km</td>
<td>- 100 km</td>
<td>- 5 km</td>
</tr>
<tr>
<td>- TOMS ozone</td>
<td>- TOMS ozone</td>
<td>- MOD07 ozone</td>
</tr>
<tr>
<td><strong>Atmospheric Correction</strong></td>
<td>Standard MODTRAN™3.5</td>
<td>Water Vapor Scaling (WVS)</td>
</tr>
<tr>
<td></td>
<td>(Tonooka, 2005)</td>
<td>(Tonooka, 2005)</td>
</tr>
<tr>
<td></td>
<td>MODTRAN™5.2</td>
<td>MODTRAN™5.2</td>
</tr>
<tr>
<td></td>
<td>(Berk et al. 2005)</td>
<td>(Berk et al. 2005)</td>
</tr>
<tr>
<td><strong>Temperature Emissivity Separation</strong></td>
<td>Standard TES</td>
<td>Standard TES</td>
</tr>
<tr>
<td><strong>(TES) algorithm</strong></td>
<td>(Gillespie et al. 1998)</td>
<td>(Gillespie et al. 1998)</td>
</tr>
</tbody>
</table>
NAALSED Summertime Emissivity (Jul-Sep 2000-2009), Band 12 (9.1 µm)
Degraded from 100 m to 5 km

Total Scenes: 64,149
Usable: 39,848 (Cloud<80%)
NAALSED Summertime Emissivity (Jul-Sep 2000-2009), Band 14 (11.3 µm)

Cloud: scenes with no SWIR band

Scenes with high PWV values greater than 5 cm

Water too low
Solution: use water mask to replace values with library spectra
NAALSED Total Summertime Observations (Jul-Sep 2000-2009)
Salton Sea
Death Valley/Cuprite
White Sands
ARM CART
EROS
LPDAAC
USDA-ARS
Hydrology Remote Sensing Lab
Manitoba Mining Activities?
Mount St. Helens
Tahoe
Death Valley/Cuprite
White Sands
Salton Sea
USDA-ARS
Hydrology Remote Sensing Lab
Pseudo-invariant Sand Dune Emissivity Validation Results

### ASTER validation with pseudo-invariant sand dune sites

<table>
<thead>
<tr>
<th>Dune site</th>
<th>Band 10</th>
<th>Band 11</th>
<th>Band 12</th>
<th>Band 13</th>
<th>Band 14</th>
<th>Mean</th>
</tr>
</thead>
<tbody>
<tr>
<td>Algodones</td>
<td>0.68</td>
<td>0.60</td>
<td>0.13</td>
<td>0.02</td>
<td>1.40</td>
<td><strong>0.57</strong></td>
</tr>
<tr>
<td>Stovepipe Wells</td>
<td>0.17</td>
<td>0.77</td>
<td>1.02</td>
<td>0.34</td>
<td>0.37</td>
<td><strong>0.53</strong></td>
</tr>
<tr>
<td>White Sands</td>
<td>0.34</td>
<td>2.76</td>
<td>0.16</td>
<td>0.92</td>
<td>1.08</td>
<td><strong>1.05</strong></td>
</tr>
<tr>
<td>Kelso Dunes</td>
<td>1.57</td>
<td>1.04</td>
<td>1.33</td>
<td>1.91</td>
<td>0.81</td>
<td><strong>1.33</strong></td>
</tr>
<tr>
<td>Great Sands</td>
<td>1.44</td>
<td>0.97</td>
<td>1.42</td>
<td>1.64</td>
<td>0.69</td>
<td><strong>1.23</strong></td>
</tr>
<tr>
<td>Moses Lake</td>
<td>0.69</td>
<td>0.52</td>
<td>0.42</td>
<td>0.61</td>
<td>1.01</td>
<td><strong>0.65</strong></td>
</tr>
<tr>
<td>Sand Mountain</td>
<td>7.74</td>
<td>6.47</td>
<td>9.01</td>
<td>1.82</td>
<td>1.10</td>
<td><strong>5.23</strong></td>
</tr>
<tr>
<td>Coral Pink</td>
<td>7.48</td>
<td>6.44</td>
<td>7.32</td>
<td>2.50</td>
<td>1.70</td>
<td><strong>4.90</strong></td>
</tr>
<tr>
<td>Little Sahara</td>
<td>3.55</td>
<td>2.39</td>
<td>2.60</td>
<td>0.96</td>
<td>0.19</td>
<td><strong>1.94</strong></td>
</tr>
<tr>
<td>Killpecker</td>
<td>2.34</td>
<td>1.99</td>
<td>2.26</td>
<td>1.33</td>
<td>0.81</td>
<td><strong>1.75</strong></td>
</tr>
</tbody>
</table>

< 1.6% (1 K)
NAALSED Band 14 (11.3 µm) minus MODIS Band 31 (10.8 µm)

- MODIS emissivity of rivers and estuaries are too low by ~3%.
- ASTER emissivity of lakes too low by ~2%
- Distinct differences between the two products based on land cover type.
HyspIRI Cloud Detection Methodology

• Accurate and reliable cloud masking is critical for generating high quality HyspIRI Level-2 and Level-3 data products
• Daytime Cloud masking relies heavily on thresholding VSWIR reflectance tests
• HyspIRI VSWIR swath (150 km) and TIR swath (600 km) will not overlap
• HyspIRI Cloud Detection Options:
  – Generate separate VSWIR-only and TIR-only cloud masks?
  – Use external data source to fill in VSWIR gap in TIR swath?
  – Use NAALSED-based cloud detection (Landsat methodology)?
    • Pass-1: Uses combined VSWIR reflectances and TIR data to develop cloud signature
    • Pass-2: Use thermal classification to identify remaining clouds on TIR-only swath
NAALSED/Landsat Pass-1 Cloud Spectral Tests

Table 1. Pass-1 Filters and Threshold Tests Using Reflectance, $r_i$ and Temperature, $T_{sat}$, Values From Equations (1) and (2)

<table>
<thead>
<tr>
<th>Filter</th>
<th>Threshold Test</th>
<th>Function</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 Brightness Threshold</td>
<td>$r_2 &gt; 0.08$</td>
<td>Eliminates low reflectance, dark pixels</td>
</tr>
<tr>
<td>2 Snow Threshold</td>
<td>NDSI = $(r_1 - r_4)/(r_1 + r_4) &lt; 0.7</td>
<td>Eliminates snow</td>
</tr>
<tr>
<td>3 Temperature Threshold</td>
<td>$T_{sat} &lt; 300$</td>
<td>Eliminates warm surface features</td>
</tr>
<tr>
<td>4 Band 4/5 Composite</td>
<td>$(1 - r_4)T_{sat} &lt; 240 \Rightarrow$ snow present</td>
<td>Eliminates cold surfaces - snow, tundra</td>
</tr>
<tr>
<td></td>
<td>$(1 - r_4)T_{sat} &lt; 250 \Rightarrow$ snow absent</td>
<td></td>
</tr>
<tr>
<td>5 Growing vegetation</td>
<td>$\frac{r_2}{r_2} &gt; 2$</td>
<td>Eliminates reflective growing vegetation</td>
</tr>
<tr>
<td>6 Senesescing vegetation</td>
<td>$\frac{r_2}{r_1} &lt; 2.3$</td>
<td>Eliminates reflective senescing vegetation</td>
</tr>
<tr>
<td>7 Rocks and Sand</td>
<td>$\frac{r_2}{r_4} &gt; 0.83$</td>
<td>Eliminates reflective rocks and sand</td>
</tr>
<tr>
<td>8 Warm/Cold Cloud</td>
<td>$(1 - r_4)T_{sat} &gt; 235 \Rightarrow$ warm cloud</td>
<td>Warm and cold cloud classification</td>
</tr>
<tr>
<td></td>
<td>$(1 - r_4)T_{sat} &lt; 235 \Rightarrow$ cold cloud</td>
<td></td>
</tr>
<tr>
<td>Cloud Shadow</td>
<td>$r_3 &lt; 0.05$ and $\frac{r_2}{r_1} &gt; 1.1$</td>
<td>Detects cloud shadows</td>
</tr>
</tbody>
</table>

NAALSED/Landsat Pass-2 Cloud Spectral Tests

- Pass-2 is applied to all ‘uncertain/ambiguous’ pixels identified from Pass-1 processing
- Thermal cloud signature is developed from Pass-1 clouds and new thermal thresholds determined based on statistical analysis (e.g. Max, min and mean cloud temperature, skewness etc.)
**Mean Temperature:** 292.22 K  
**Max Temperature:** 299.96 K  
**Min Temperature:** 287.89 K  
**Standard Deviation:** 2.2 K  
**Skewness:** 0.848

**ASTER visible RGB**

**HyspIRI Simulated Pass-1**

**HyspIRI Simulated Pass-2**

**HyspIRI Pass-1 + Pass-2 clouds**

**Mean Temperature:** 292.22 K  
**Max Temperature:** 299.96 K  
**Min Temperature:** 287.89 K  
**Standard Deviation:** 2.2 K  
**Skewness:** 0.848
Mean Temperature: 252.42 K
Max Temperature: 299.88 K
Min Temperature: 231.52 K
Standard Deviation: 10.7 K
Skewness: 0.357
Future Work

• Acquire remaining scenes needed to fill gaps in NAALSED
• Release NAALSED v3.0 for North America
• Extend NAALSED to global coverage: North Africa – AIRS/IASI/MODIS products have large uncertainties in emissivity here
• Continue developing HyspIRI thermal infrared product ATBD’s
• Continue developing HyspIRI cloud detection methodology
The End
ASTER L1-B
Radiance at Sensor

Cloud Masking (NACMA)

Terra MODIS Atmospheric Product (MOD07)

TIR Destriping algorithm

Cloud Masking (MOD35)

Atmospheric Correction
MODTRAN 5

τ - Transmissivity
L↑ - Path radiance
L↓ - Sky irradiance

Water Vapor Scaling (WVS)
- Tonooka (2005)

EMC/WVS Coefficients
Vegetation Indices (MOD13A2)
Land/Water map (MOD44)

ASTER Output: (16-day 90 m)
- Emissivity (5 TIR bands)
- Land Surface Temperature (LST)

TES
Temperature/Emissivity Separation

Data Fusion Model (STARFM)

MODIS Output: (Daily 1 km)
- Emissivity (3 TIR bands)
- Land Surface Temperature (LST)

Co-I Roses 2009 Proposal:
Detection and Monitoring of Irrigated Agriculture

Unified Emissivity Product: (Daily, 90 m)
Warm clouds over cold surface?
Pass-2 Processing
(Landsat-7 Approach)

- Pass-2 involves using a thermal analysis to classify ‘ambiguous’ pixels from Pass-1 processing
- Thermal cloud signature is developed based on warm/cold cloud class identified in Pass-1 processing (eg. Max T, min T, mean T, skewness etc..)
- New temperature thresholds set for Pass-1 warm and cold cloud signatures based on statistical analysis (eg. Threshold adjusted for skewness)
- Decision tree used to accept one or both of cloud populations in final mask

- HyspIRI Cloud Processing Option:
  - Use VSWIR and TIR data to classify clouds using Pass-1 filters for VSWIR swath (150 km)
  - Set remaining pixels falling outside swath to ambiguous (600 km)
  - Use Pass-2 processing to classify remaining clouds on TIR swath
Easily distinguishable land cover types due to dependence on split-window land classification algorithm
Distinct differences between the two products based on land cover type.
Relevance to Future JPL Missions

**HyspIRI** – Tier 2 (2015-2020)  
Hyperspectral Infrared Imager

- Ecosystem response to natural and human-induced changes
- Monitoring natural hazards
- Land surface composition

- North American ASTER Land Surface Emissivity Database (NAALSED) – proxy HyspIRI dataset

- Algorithm development (thermal IR)
  - What is the appropriate temperature/emissivity separation algorithm for HyspIRI?
  - What atmospheric correction technique, and profiles to be used?
  - Cloud detection methodology?

- Level-2 Product Definition and ATBD’s
Sand samples collected in field

Reflectance measured using Nicolet 520 FTIR spectrometer

JPL LAB MEASUREMENTS

spectral range: 2.5 – 15 μm
spectral resolution: 4 cm⁻¹
1000 scans in 10 minutes

\[ \varepsilon = 1 - r \]
# Pseudo-Invariant Sand Dune Sites

Summary of the major characteristics of each dune site including locality, elevation, surface area, dune height, grain size, sand source and bulk mineralogy.

<table>
<thead>
<tr>
<th>Dune site</th>
<th>Locality</th>
<th>Surface area (km²)</th>
<th>Elevation/max dune height (m)</th>
<th>Grain size</th>
<th>Sand source</th>
<th>Mineralogy (XRD)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Algodones (32.95° N, 115.07° W)</td>
<td>Southeast CA, Eastern margin of the Salton Trough</td>
<td>720</td>
<td>94/80</td>
<td>Medium to coarse sand</td>
<td>Beach sand from Lake Cahuilla</td>
<td>Major: quartz</td>
</tr>
<tr>
<td>Coral Pink (37.04° N, 112.72° W)</td>
<td>Sand Valley, just north of UT–AZ border, west Kanab</td>
<td>13.6</td>
<td>1780/10</td>
<td>Medium sand</td>
<td>Navajo, Page and Estrada Jurassic sandstones of the Vermillion Cliffs</td>
<td>Major: quartz</td>
</tr>
<tr>
<td>Great Sands (37.77° N, 105.54° W)</td>
<td>San Luis Valley, CO, adjacent to Sangre de Cristo, NE of Alamosa</td>
<td>104</td>
<td>2560/230</td>
<td>Medium to coarse sand</td>
<td>Quartz and volcanic fragments derived from Santa Fe and Alamosa formations, recent fluvial (Rio Grande) deposits</td>
<td>Major: potassium feldspar, Major: quartz</td>
</tr>
<tr>
<td>Kelso (34.91° N, 115.73° W)</td>
<td>Mojave Desert, CA, southeast of Baker</td>
<td>115</td>
<td>800/195</td>
<td>Medium sand</td>
<td>Derived from sedimentary, metamorphic, igneous terrains from Mojave River alluvial apron</td>
<td>Major: quartz, Minor: potassium feldspar, Trace: magnetite</td>
</tr>
<tr>
<td>Killpecker (41.98° N, 109.10° W)</td>
<td>Southwest WY, from Eden across Rock Springs into Red Desert</td>
<td>550</td>
<td>2000/45</td>
<td>Medium sand</td>
<td>Sandstone and siltstone of the Laney member of the Green River Formation</td>
<td>Major: quartz, Trace: magnetite, Minor: plagioclase feldspar, epidote</td>
</tr>
<tr>
<td>Little Sahara/Lynndyl (39.7° N 112.39° W)</td>
<td>West-central UT, Sevier River drainage basin, west of Lynndyl</td>
<td>575</td>
<td>1560/200</td>
<td>Fine sand</td>
<td>Deltaic and shoreline sediments from the Provo shoreline of Lake Bonneville</td>
<td>Major: quartz, Minor: plagioclase feldspar, pyroxene, carbonate, magnetite</td>
</tr>
<tr>
<td>Stovepipe Wells (36.62° N, 117.11° W)</td>
<td>Central Death Valley, CA, near Stovepipe Wells</td>
<td>7.7</td>
<td>– 12/40</td>
<td>Medium sand</td>
<td>Mixed lithic fragments and quartz from Emigrant Pass to the west and Furnace Wash to the east</td>
<td>Major: quartz, Minor: plagioclase feldspar, potassium feldspar</td>
</tr>
<tr>
<td>Moses Lake (47.05° N, 119.31° W)</td>
<td>Quincy Basin in central WA</td>
<td>40</td>
<td>345/18</td>
<td>Fine sand</td>
<td>Basaltic sand from the east bank of the Columbia River</td>
<td>Major: quartz, albite</td>
</tr>
<tr>
<td>White Sands (32.89° N, 106.33° W)</td>
<td>South-central NM, Tularosa Valley</td>
<td>704</td>
<td>1216/10</td>
<td>Fine sand</td>
<td>Paleo-lake Otero, present playa Lake Lucero to the southwest</td>
<td>Major: gypsum</td>
</tr>
</tbody>
</table>

Thermal Infrared Radiative Transfer

TOA Radiance

\[ L_i(\theta) = \tau_i(\theta) \cdot e_i \cdot B_i(T_S) + \tau_i(\theta) \cdot (1-e_i) \cdot \bar{L}_i + \int B_i(T(P))d\tau_i \]

Surface Radiance

Surface Emission

Surface Reflection

Atmospheric Emission

Skin Temperature & Surface Emissivity

\[ L_i^\uparrow(\theta) \]

\[ L_i^\downarrow \]
NAALSED Users and Applications

- ~100 registered NAALSED users [http://emissivity.jpl.nasa.gov](http://emissivity.jpl.nasa.gov)
- Current projects and applications:
  - **Arizona State University**: JMARS (Java Mission-planning and Analysis for Remote Sensing) is a Java-based geospatial information system developed by Arizona State University
  - **UW-Madison**: NAALSED comparisons with MODIS baseline-fit emissivity product, used for retrieval of MOD07 profiles
  - **JPL**: AIRS (Atmospheric Infrared Sounder) and IASI (Infrared Atmospheric Sounding Interferometer) emissivity validation and intercomparison with NAALSED
  - **JPL**: Tropospheric Emission Spectrometer (TES) group will be using NAALSED as a first guess emissivity in retrieval of Ozone
  - **Beijing Normal University**: Developing an empirical relationship between NAALSED emissivity and NDVI products
  - **JPL**: Generate a land surface temperature product for Landsat
Atmospheric Correction

Surface Radiance:

\[ L_{\text{surf},i} = e_i \cdot B_i(T_S) + (1 - e_i) \cdot L_i \]

Observed Radiance:

\[ \frac{L_i(\theta) - L_i^\uparrow(\theta)}{\tau_i(\theta)} \]

- **Atmospheric Parameters:** \( \tau_i(\theta), L_i^\uparrow(\theta), \tau_i^\downarrow(\theta) \)
  
  Estimated using radiative transfer code such as MODTRAN with atmospheric profiles and elevation data

- Derivation of \( e_i \) and \( T_s \) is an undetermined problem
  
  The number of parameters (\( T_s, e_i \) in N channels) is always greater than the number of simultaneous equations needed to solve the problem (N)

=> Additional, independent constraint is needed
MODIS Baseline-Fit (MODBF) Emissivity Product

- Input data: MODIS MYD11 (Aqua) Day-night emissivity retrieval with values at 8.6, 11 and 12 µm in TIR
- MODBF is characterized by model with inflection points at 8.3, 9.3, 10.8 and 12.1 µm in TIR
- MOD11 values at 8.6 µm 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
- An eigenvector approach is used to produce emissivity at high spectral resolution from the inflection points for use with atmospheric retrieval algorithms
Motivation for Land Surface Temperature and Emissivity (LST&E) Products:

- Climate Modeling/Earth Surface Radiation Budget
  - Emissivity decrease of 0.1 results in 7 W/m² underestimation longwave radiation estimates (greenhouse gases, ~2 W/m²)

- Atmospheric Retrievals
  - Emissivity error of 0.15 leads to more than 3º C error in boundary layer air temperature and up to 20% in boundary moisture profiles

- Land use, Land cover change (LCLUC)
  - Increased demand for agricultural land, and significant land cover changes from extreme climatic events => increased demand for high spatial and temporal resolution LST&E products for monitoring these events

- Soil Moisture Mapping
  - Evapotranspiration models require LST&E to characterize surface energy balance
  - LST will be critical input for NASA’s future Soil Moisture Active & Passive (SMAP) mission
ASTER Temperature Emissivity Separation (TES) Algorithm

- Inversion of $T$ and $\varepsilon$ are underdetermined.
- In TES, additional constraint arises from minimum emissivity ($\varepsilon_{\text{min}}$) vs spectral contrast (MMD) using calibration curve derived from lab results (see plot).
- Requires atmospherically corrected surface radiance, and downward sky irradiance as input.
- Three error sources:
  - Reliance on empirical function
  - Atmospheric corrections
  - Radiometric calibration errors
- Reported accuracy:
  - $T$ within 1.5 K and $\varepsilon$ within 0.015 (1.5 %)

$$\varepsilon_{\text{min}} = 0.994 - 0.687 \times \text{MMD}^{0.74}$$

**ASTER TIR Bands**

<table>
<thead>
<tr>
<th>Band</th>
<th>Wavelength Range</th>
</tr>
</thead>
<tbody>
<tr>
<td>10</td>
<td>8.125 – 8.475 $\mu$m</td>
</tr>
<tr>
<td>11</td>
<td>8.475 – 8.825 $\mu$m</td>
</tr>
<tr>
<td>12</td>
<td>8.925 – 9.275 $\mu$m</td>
</tr>
<tr>
<td>13</td>
<td>10.25 – 10.95 $\mu$m</td>
</tr>
<tr>
<td>14</td>
<td>10.95 – 11.65 $\mu$m</td>
</tr>
</tbody>
</table>
NAALSED Status

• North America (22-71° N, 169-55° W)
  Summertime Product completed:
  (Jul- Aug) 2000-2009

• Products (100m):
  ➢ Emissivity (5 TIR bands)
  ➢ Surface Temperature
  ➢ NDVI
  ➢ Land/Water mask
  ➢ DEM
  ➢ Lat/Lon

<table>
<thead>
<tr>
<th></th>
<th>NAALSED v3.0</th>
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</thead>
<tbody>
<tr>
<td>Temporal coverage</td>
<td>2000-2009</td>
</tr>
<tr>
<td>Total ASTER Summertime Scenes</td>
<td>64,149</td>
</tr>
<tr>
<td>Usable Scenes (Cloud &lt;80%)</td>
<td>39,848</td>
</tr>
<tr>
<td>Cloud mask</td>
<td>v3.0</td>
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<tr>
<td></td>
<td>- Improved snow/cloud filter</td>
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<tr>
<td></td>
<td>- Elevation dependent brightness temperature thresholding (GTOPO30)</td>
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<tr>
<td></td>
<td>- Improved cirrus filter</td>
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<tr>
<td>Atmospheric Profiles</td>
<td>MODIS (MOD07)</td>
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<tr>
<td></td>
<td>- 5 km Coincident Obs</td>
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<tr>
<td></td>
<td>- MOD07 ozone</td>
</tr>
<tr>
<td>Atmospheric Correction</td>
<td>Water Vapor Scaling (Tonooka, 2005)</td>
</tr>
<tr>
<td></td>
<td>MODTRAN 5</td>
</tr>
<tr>
<td>TES algorithm</td>
<td>Standard TES (Gillespie, 1998)</td>
</tr>
</tbody>
</table>