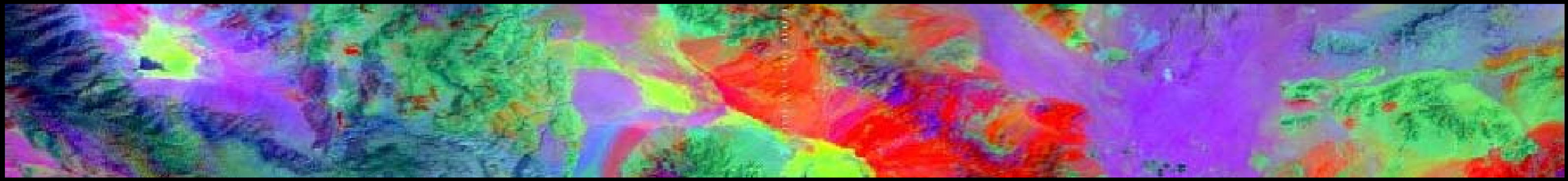
HyspIRI Level-2 TIR Products
Surface Radiance
Land Surface Temperatrue
Land Surface Emissivity



Simon Hook, Glynn Hulley

Jet Propulsion Laboratory, California Institute of Technology, Pasadena, CA

HyspIRI - ASTER - MODIS

TIR Product Characteristics

	HyspIRI	Terra ASTER	Terra MODIS
Sensor Calibration:	0.1-0.2 K	< 0.3 K	< 0.2 K
Cloud Contamination:	Cloud Detection	Cloud Detection	Cloud Detection
Retrieval Type:	TES + WVS	TES	Day/Night (V4) Split-Window(V5)
Temporal Sampling:	11:00 AM, PM 5 days	10:30 AM, PM 16 days	10:30 AM, PM Twice daily
Spatial Resolution:	60 m	90 m	1 km
Swath Width	600 km	60 km	2300 km
View angle:	25	8.55	55
MTIR Bands:	8 bands	5 bands	7 bands

HyspIRI TIR Level-2 Products

1. Cloud Mask
   a. Approach
   b. ASTER examples
2. Surface Radiance
   a. Infrared Radiative Transfer
   b. Atmospheric Correction
   c. Validation
3. Land/Ocean Surface Temperature and Surface Emissivity (LST&E)
   a. Algorithm Development
   b. TES examples
   c. Validation

1. Cloud Mask

- Accurate, reliable and automatic cloud detection is critical
- Use same approach as the New ASTER Cloud Mask Algorithm (NACMA)
- Hybrid algorithm, clear-sky conservative:
  - Landsat-7 two pass approach
  - MODIS shadow test
  - AVHRR thin cirrus test
- HyspIRI VSWIR repeat is 19 days, but TIR is 5 days
- Propose using VIIRS for visible data (250 m) when VSWIR not available

** **Hulley G.C., S.J. Hook,** 2008, A New Methodology for Cloud Detection and Classification with Advanced Spaceborne Thermal Emission and Reflection (ASTER) Data , *Geophys. Res. Lett.*, 35, L16812, doi:10.1029/2008GL034644

ASTER 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)

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

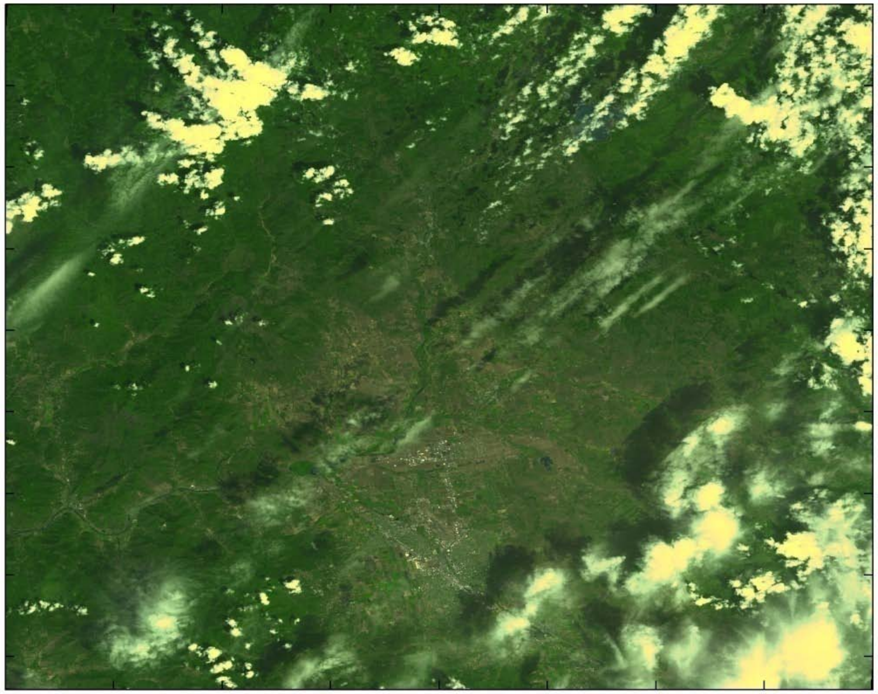
Thin cloud/cirrus test

Table 2. Brightness Temperature Thresholds for the Thin Cloud/Cirrus Test

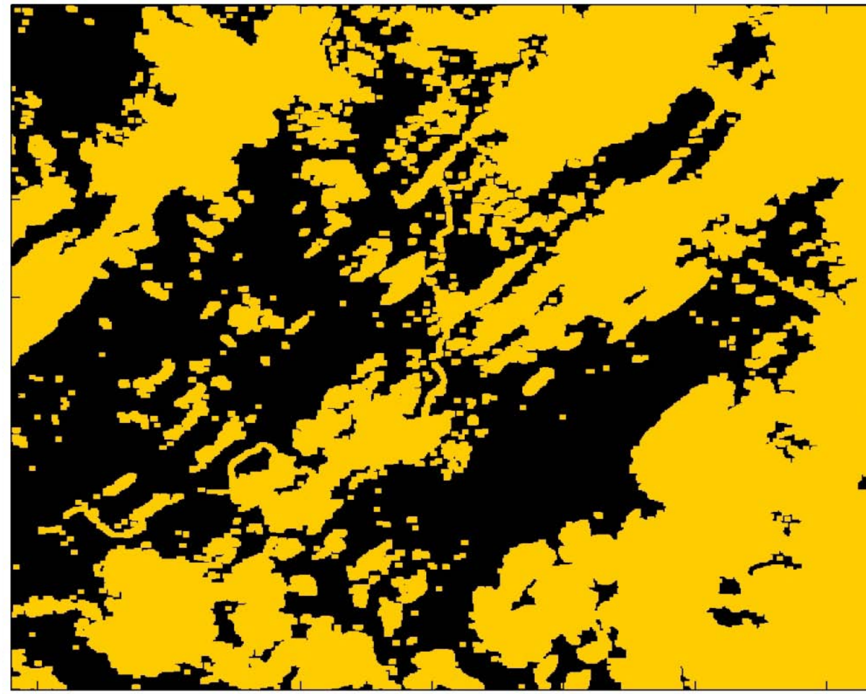
	$BT_{10.6-11.3}$ (K)	
$BT_{10.6}$ (K)	Snow > 50%	Snow < 50%
260	0.55	0.50
270	1.00	0.51
280	1.20	0.53
290	1.30	1.00
300	1.50	2.00
310	3.00	3.00
320	4.00	4.00
330	5.00	5.00

Cumulus + thin cirrus example

ASTER visible image



ASTER Cloud Mask + Fill



Shadow – **Cyan**

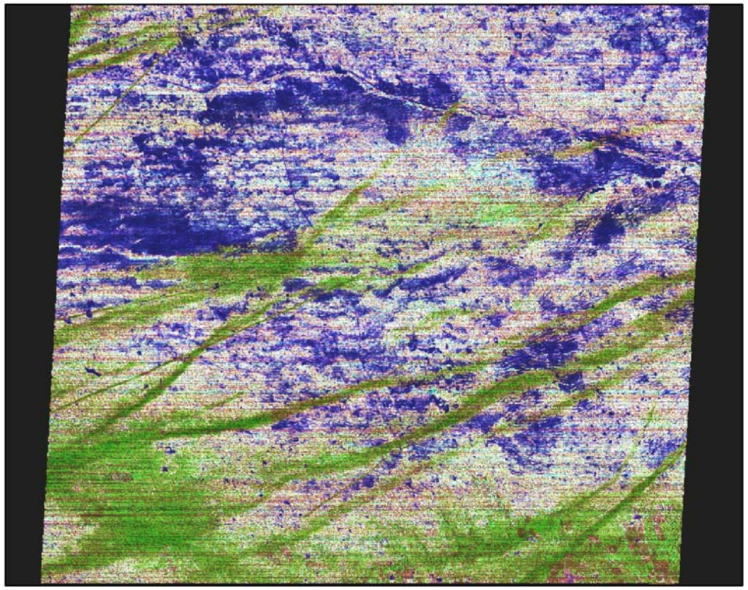
Cloud – **Gold**

Clear – **Black**

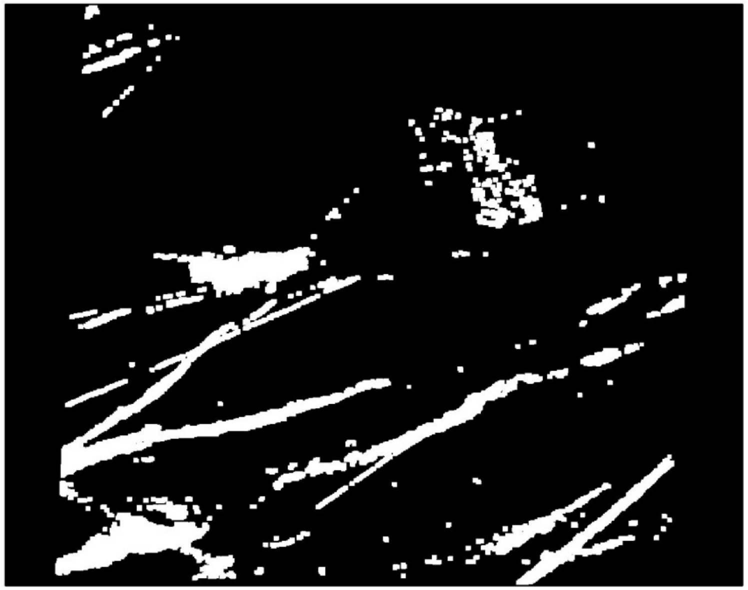
ASTER Visible image

Jet Contrails
Sub-visible cirrus

Emissivity (R=10, G=12, B=14)



Cloud Mask

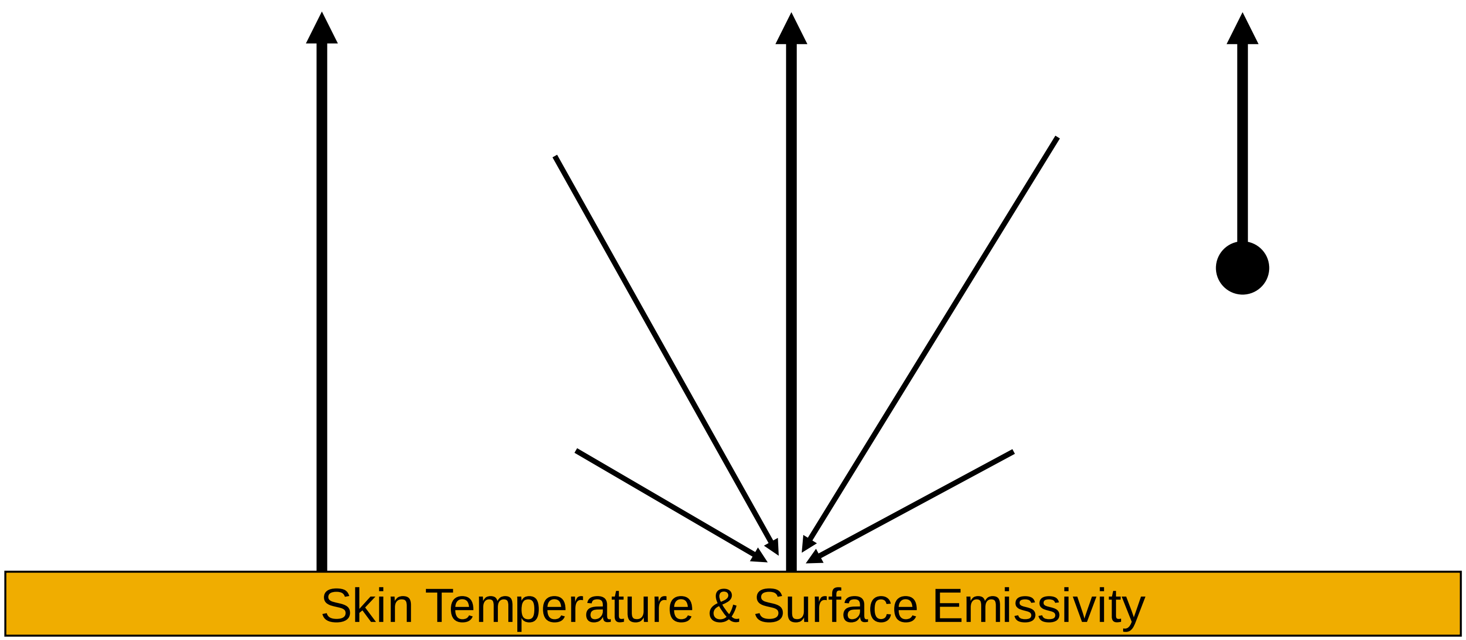


2. Surface Radiance

- Surface radiation is combination of direct surface emission and reflected radiance from sky and surrounding
- Atmospheric corrections necessary to isolate surface features, which are obscured by atmospheric attenuation
- Approach
  1. Choose a radiative transfer model to estimate magnitude of atmospheric emission, absorption and scattering
     - eg. MODTRAN 4, 5.3 (beta), CRTM – JCSDA
  2. Acquisition of atmospheric profiles (eg. Temperature, water vapor, ozone, aerosol) at time and location of observation
     - VIIRS (MODIS follow-on) or CrIS (AIRS follow-on) on NPP/NPOESS
     - NCEP GDAS as backup (currently used for ASTER)
     - OMI (ozone)

Infrared Radiative Transfer

$$L_i(\theta) = \overbrace{\underbrace{\tau_i(\theta)\cdot e_i \cdot B_i(T_S)}_{\text{Surface Emission}} + \underbrace{\tau_i(\theta)\cdot(1-e_i)\cdot \overline{L}_i^{\downarrow}}_{\text{Surface Reflection}}}^{\text{Surface Radiance}} + \underbrace{\int B_i(T(P))\,d\tau_i}_{L_i^{atm\uparrow}}$$



Radiative Transfer Model

- MODTRAN 5.3 (beta)
  - Finer spectroscopy: resolution down to 0.1 cm^{-1}
  - DISORT multiple scattering speed and accuracy improved
  - Option for including auxiliary molecules
  - Several tape5 input files can be processed with single execution
- Maintain close communication with developers on updates and improvements (Gail Anderson)
- Other radiative transfer models will be explored, eg. Community Radiative Transfer MODEL (CRTM) – open source through JCSDA

Surface Radiance: Validation

- Water Surface Targets:
  1. Lake Tahoe automatic Cal/Val facility (Cool, 0 - 25° C)
  2. Salton Sea (Hot, >30° C!)
- Land Surface Targets:
  1. DOME-Argus, Antarctica (high, and cold, <-60° C)
  2. Valencia site (>30 km^2), homogenous rice fields (cool)
  3. Sand dune sites in southwestern USA (hot)
     - Emissivity measured and well characterized
     - Multiple balloon launches to control temperature and water vapor
     - Sun photometer for aerosol optical depth and column water
- Airborne Instruments
  - HyTES, MASTER

3. Land Surface Temperature and Emissivity (LST&E)

- Key Earth System Data Records (ESDR) in climate change studies
  - Climate modeling, estimating heat radiation budgets
  - Surface-atmosphere interactions
  - Cryospheric studies and hydrology
  - Earth surface composition and change
- Emissivity is critical for determining LST (1.5% = 1 K error)
- Goals:
  1. Estimate accurate and precise LST (<1 K)
  2. Recover accurate emissivity for mineral exploration and geologic mapping (<1%)
  3. Produce seamless products, with no artificial discontinuities, which exist in split-window, land class approach.

LST&E Retrieval Algorithms

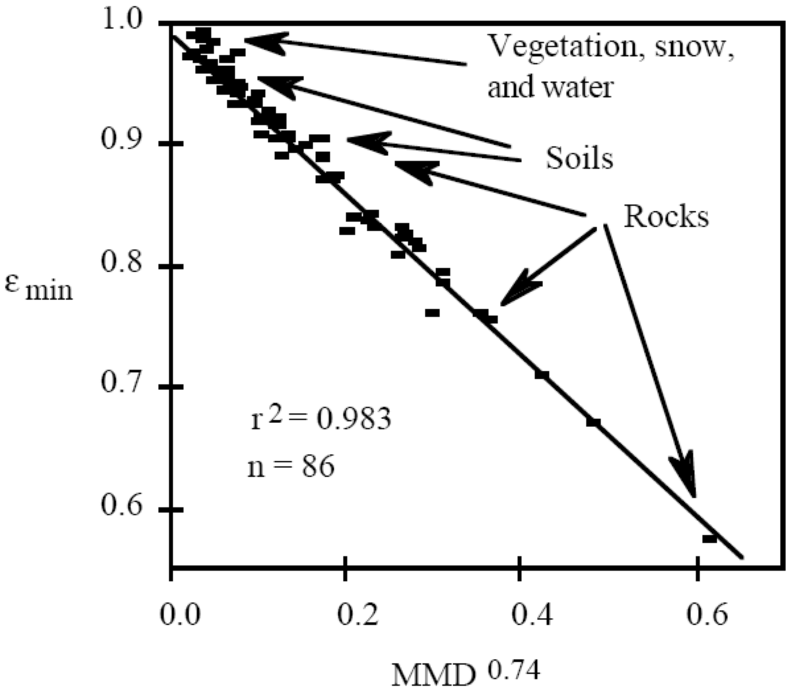
- Temperature Emissivity Separation (TES, ASTER)

Relies on empirical relationship between spectral contrast and minimum emissivity, determined independently from laboratory measurements

- PROS:
  - LST and emissivity in all bands are physically determined
  - High accuracy over low emissivity, high contrast areas (eg. Deserts)
  - Validated with ground truth using sand dune sites to 1.6%
- CONS:
  - Atmospheric profiles are required for atmospheric correction
  - Accuracy is dependent on atmospheric correction
  - Accuracy degraded over graybody surfaces as a result, since errors in atmospheric correction resulted in larger ‘apparent’ contrast

Temperature Emissivity Separation (TES)

- Inversion of T and ε are underdetermined
- Additional constraint arises from minimum emissivity vs spectral contrast
- Three error sources:
  - Reliance on empirical function
  - Atmospheric corrections
  - Radiometric calibration errors
- Reported accuracy for ASTER:
  - LST is 1.5 K
  - ε is 0.015 (1.5 %)



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

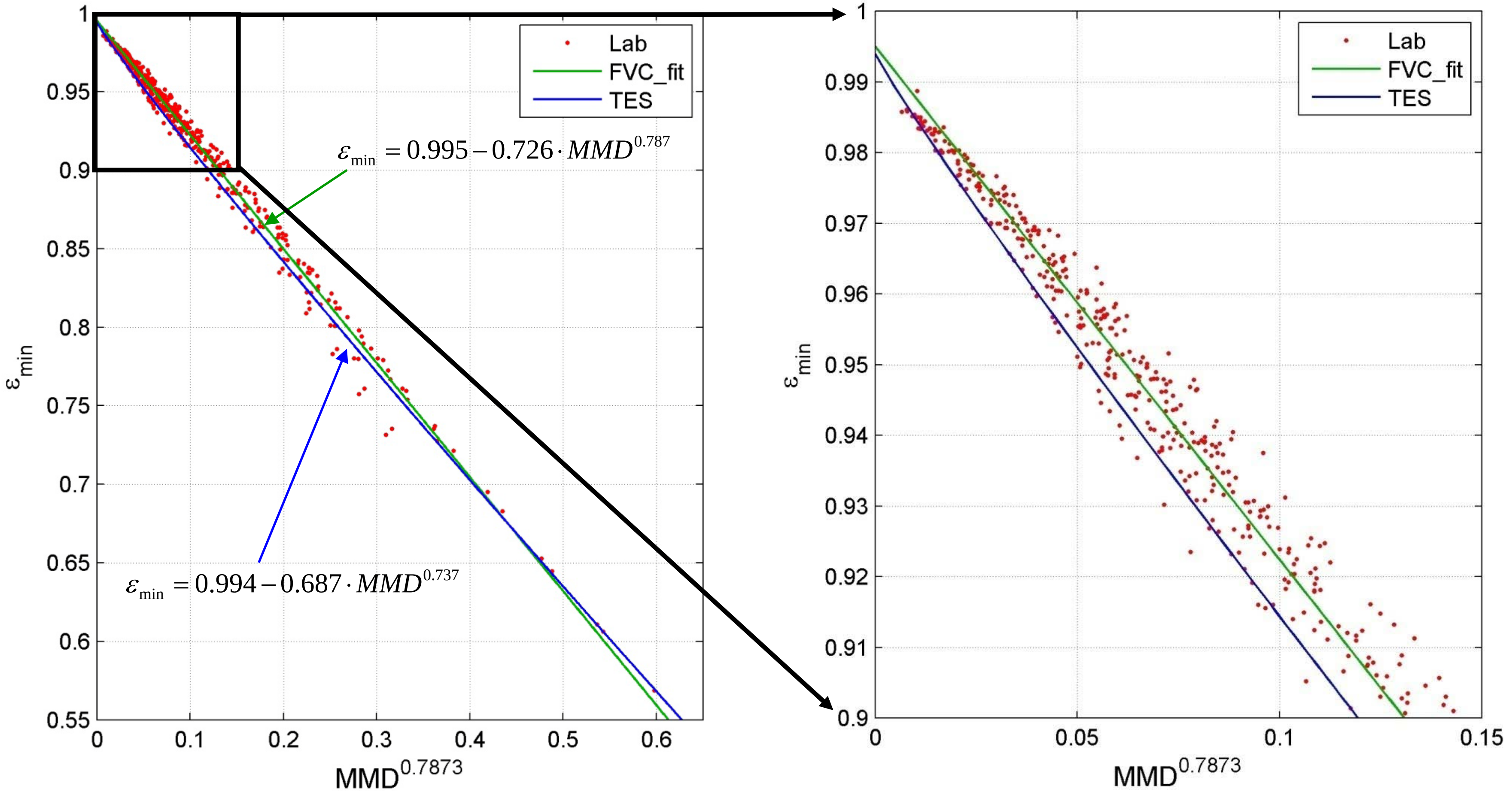
TES Vegetation Adjustment

$$\varepsilon_b = \varepsilon_b^{veg} \cdot FVC + \varepsilon_b^{soil} \cdot (1 - FVC)$$

ε_b^{veg} - Conifer spectra

ε_b^{soil} - 59 soil/sand spectra

FVC = 0:5:100%



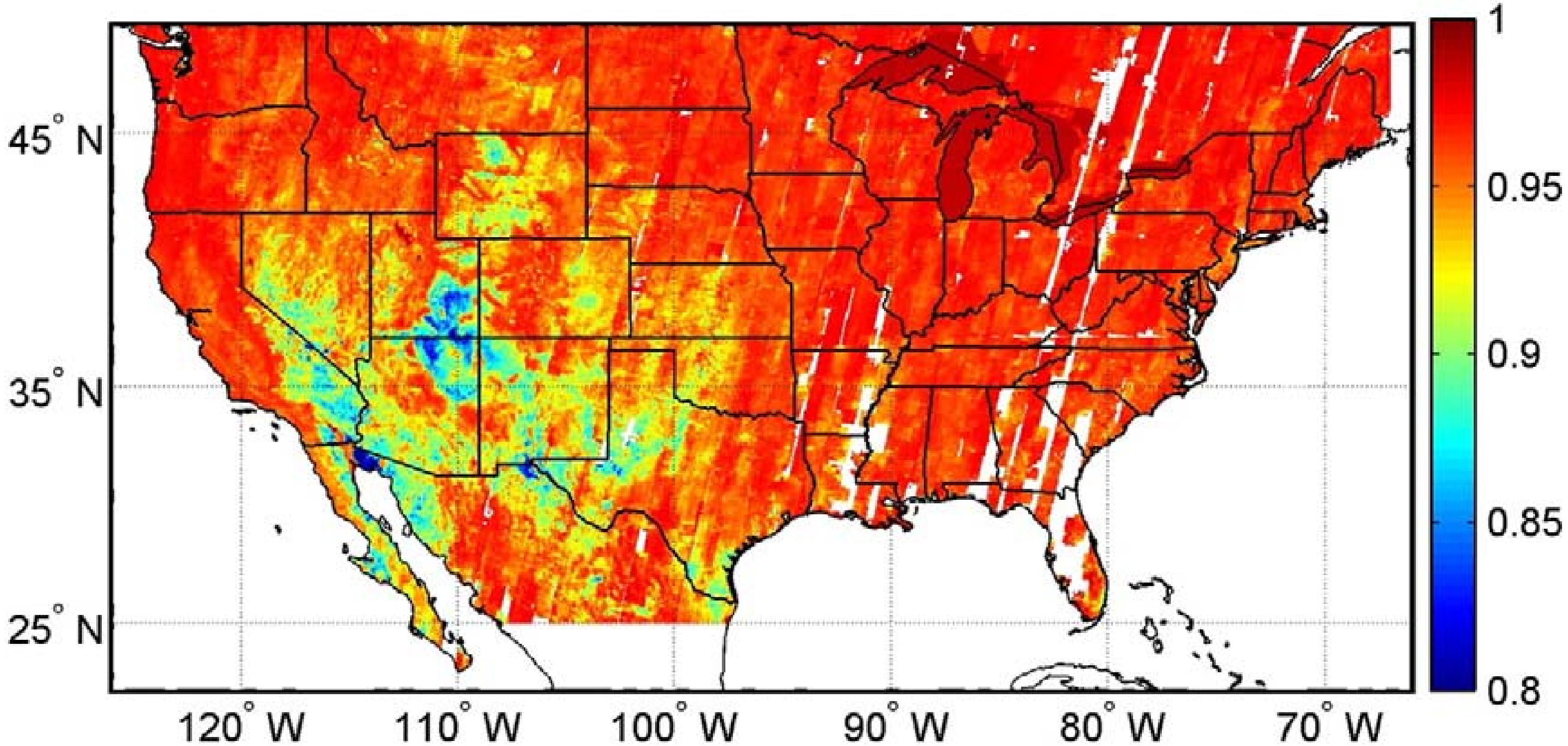
TES underestimates vegetation from 1.5-2% in emissivity

FVC curve reduces this down to <1% (~0.7 K)

NAALSED Mean Summer (Jul-Sep) Emissivity:

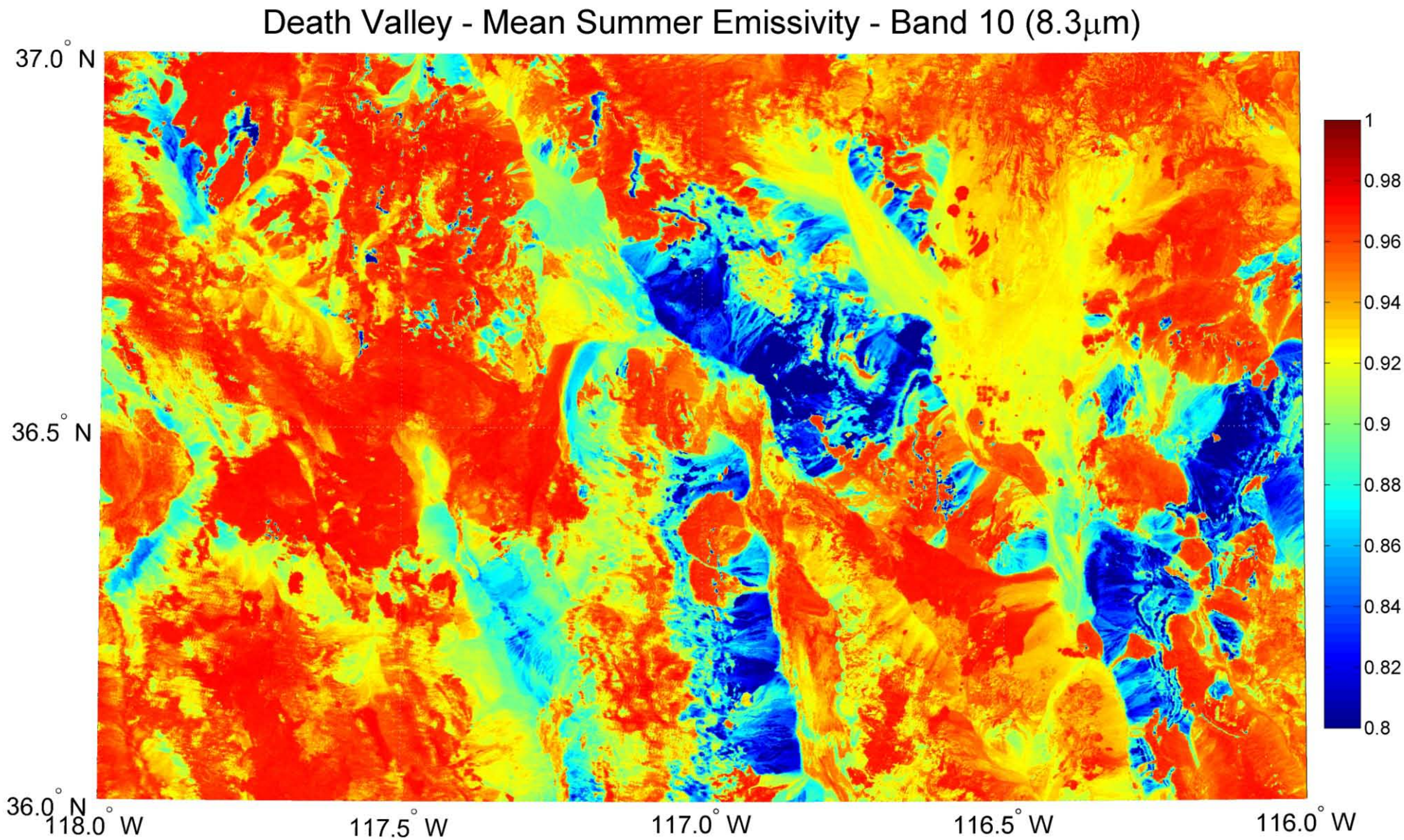
Band 12 (8.6 µm): 2000-2008: 50,075 scenes

http://emissivity.jpl.nasa.gov



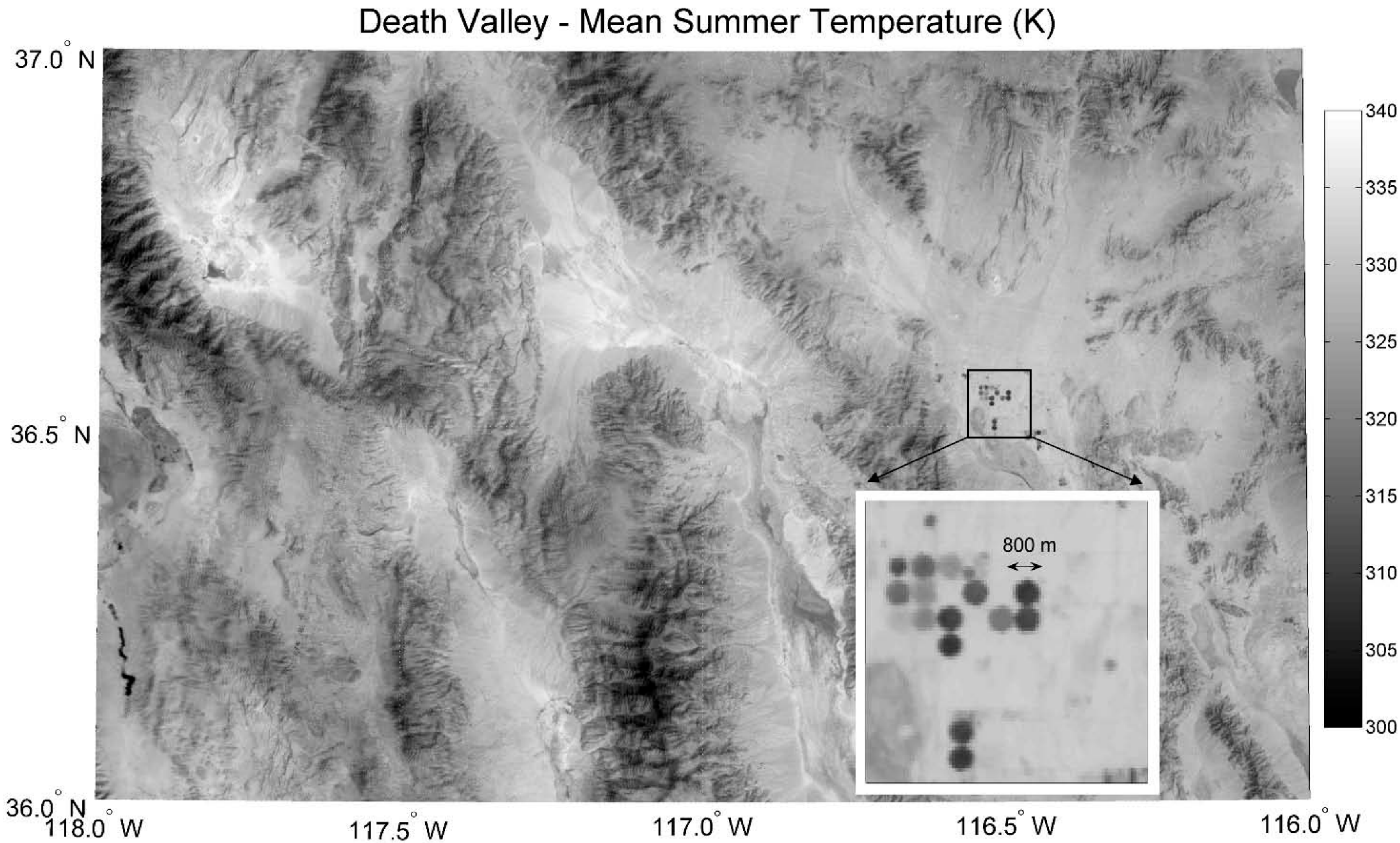
** Gaps plan to be filled during Jul-Sep 2009 ASTER acquisition

Hulley, G. C., & Hook, S. J., (2009),The North American ASTER Land Surface Emissivity Database (NAALSED) Version 2.0, *Remote Sensing of Environment*, doi:10.1016/j.rse.2009.05.005



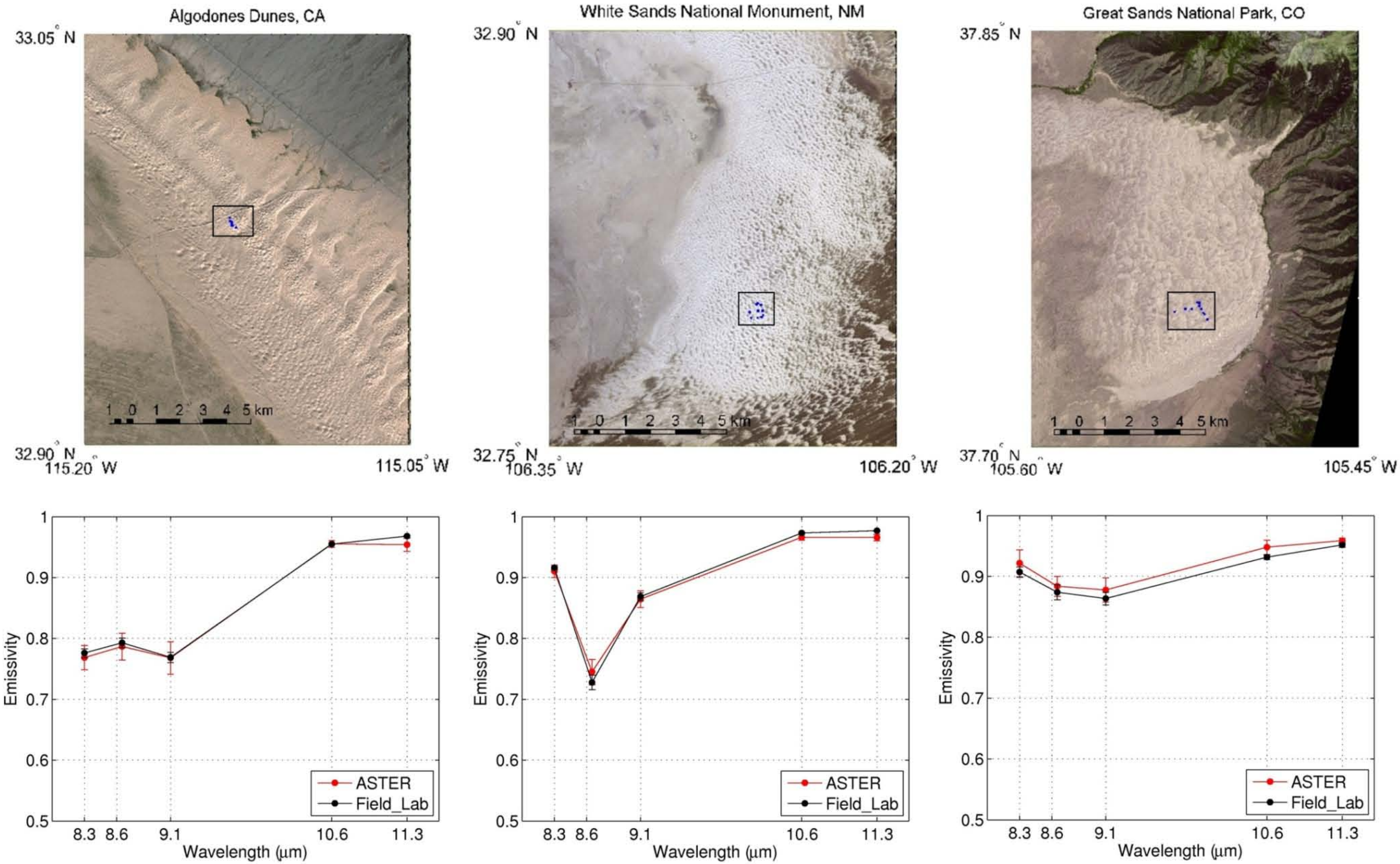
Death Valley - Mean Summer Emissivity - Band 10 (8.3μm)
37.0° N
36.5° N
36.0° N
118.0° W
117.5° W
117.0° W
116.5° W
116.0° W
1
0.98
0.96
0.94
0.92
0.9
0.88
0.86
0.84
0.82
0.8

NAALSED LST at 100 m – ASTER Emissivity Database



Rice crop spatially well resolved, as well as temperature differences between them

Validation of North American ASTER Emissivity Database (NAALSED)



Hulley, G. C., Hook, S. J., and A.M. Baldridge, (2009), Validation of the North American ASTER Land Surface Emissivity Database (NAALSED) Version 2.0, *Remote Sensing of Environment*, 113, 2224-2233

Conclusions

- Identified core L-2 Products
  - Surface Radiance
  - Land/water Surface Temperature
  - Land Surface Temperature
- Identified atmospheric correction scheme
  - MODTRAN 5*
  - Water-Vapor Scaling Atmospheric Correction
- Identified LST&E algorithm
  - Temperature Emissivity Separation (TES)
  - Investigate different calibration curves and atmospheric correction techniques (WVS)
- Core validation sites
  - Not discussed here but have started to identify sites.