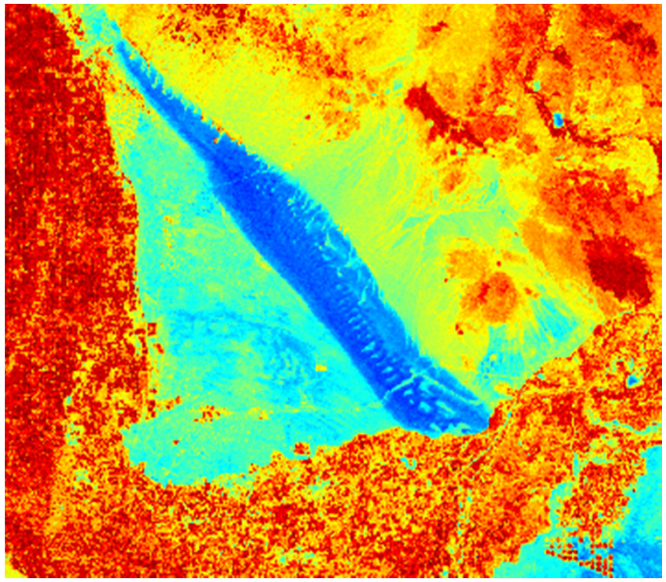
National Aeronautics and Space Administration

A Land Surface Temperature (LST) Product for Landsat



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Landsat CalVal Meeting, Sioux Falls, May 10, 2011

Introduction

- Land Surface Temperature (LST) has been identified as an important Earth System Data Record (ESDR) by NASA
  - Long-term climate trend analysis
  - Water and drought monitoring tool for agricultural applications
  - Used in Ecological models, e.g. evapotranspiration, soil moisture

- Reflectance data derived from visible, shortwave bands:
  - Determine biophysical parameters (e.g. using vegetation indices)
  - Monitor land cover changes, and derive land cover classification maps

- LST data derived from thermal infrared data:
  - Provide information on land water use
  - Assist in land cover mapping

- Thermal data has been largely under-utilized due to problems with deriving the land surface emissivity (difficult with 1 band)

- ***Goal:*** Develop Landsat LST product for Landsat-7 and extending back to Landsat-4 (1982) using an ASTER gridded emissivity product (NAALSED).

Landsat LST Status

- Progress:
  - ✓ Downloaded ~9500 TM scenes for California/Nevada (1984-2011) for initial algorithm testing
  - ✓ Landsat LST algorithms developed for TM and EMT+ data:
    - Classification-based emissivities
    - NAALSED-based emissivities
  - ✓ Comparisons between two methods completed for several scenes covering broad range of different land cover types
- Next Steps:
  - ✓ Generate monthly or annual LST maps of California/Nevada using both approaches
  - ✓ Makes assessment of which approach is best, in terms of accuracy and computationally
  - ✓ Generate North American Landsat LST product

The North American ASTER Land Surface Emissivity Database (NAALSED)

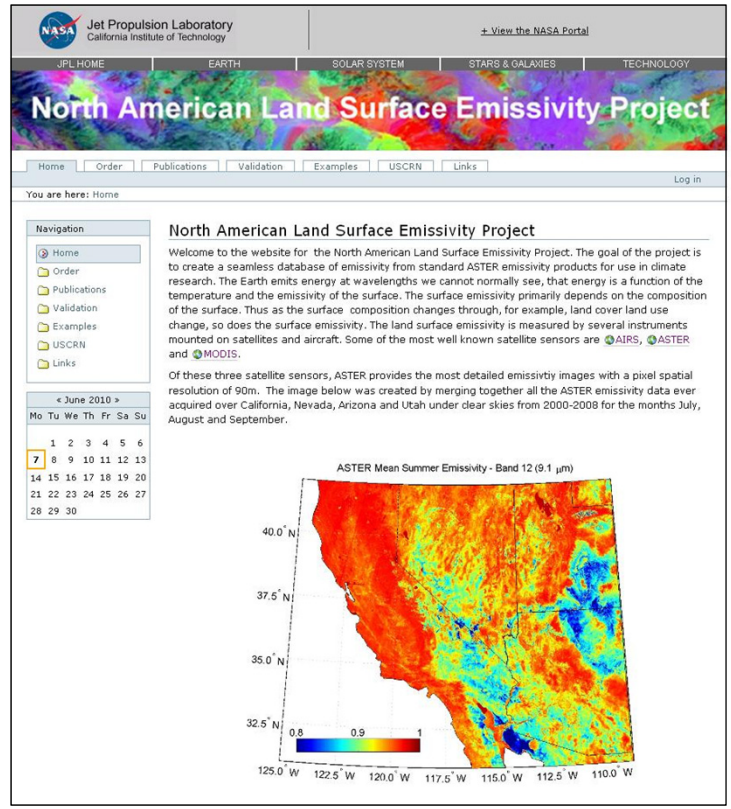
- Mean, seasonal emissivity product at 100m using all clear-sky ASTER scenes acquired since launch (2000-2010)

- Summer product: (Jul-Aug-Sep)
- Winter product: (Jan-Feb-Mar)

- Cloud detection methodology adapted from Landsat ACCA

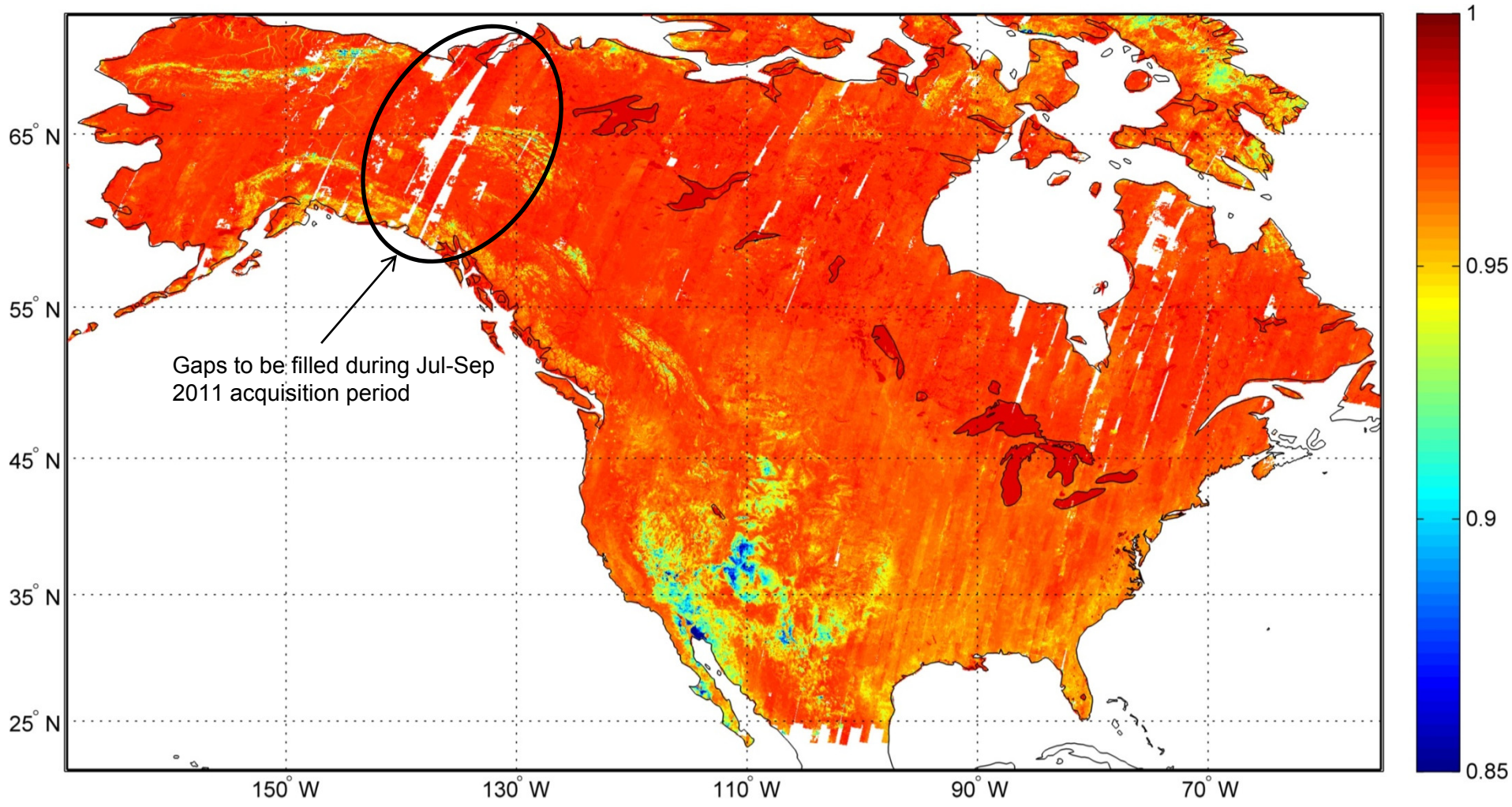
- USA (22-49º N)
  - Total Scenes: 29,653
  - Usable Scenes: 21,860 (74%)

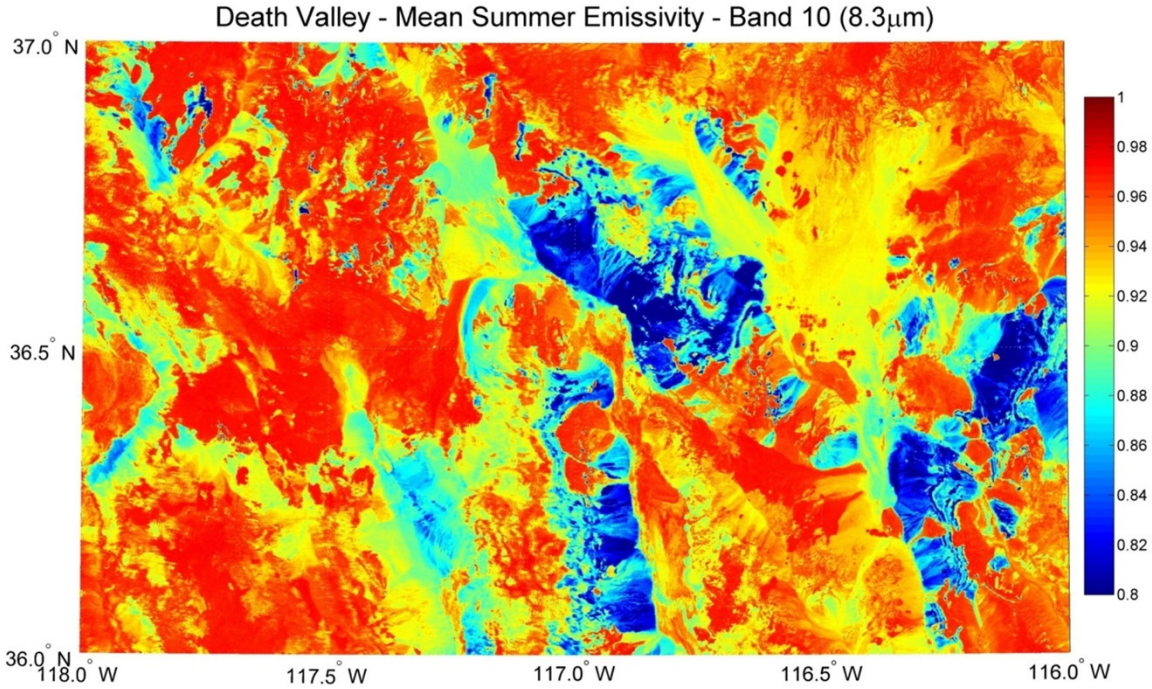
- Canada (49-71º N)
  - Total Scenes: 34,496
  - Usable Scenes: 17,988 (52%)



http://emissivity.jpl.nasa.gov

NAALSED v3 Summer Emissivity (Jul-Aug-Sep 2000-2010), Band 12 (9.1 μm), 5km

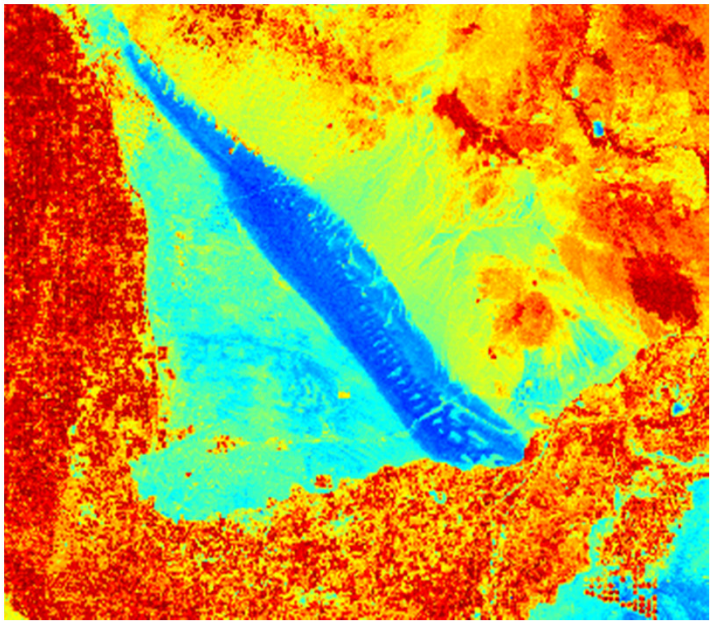




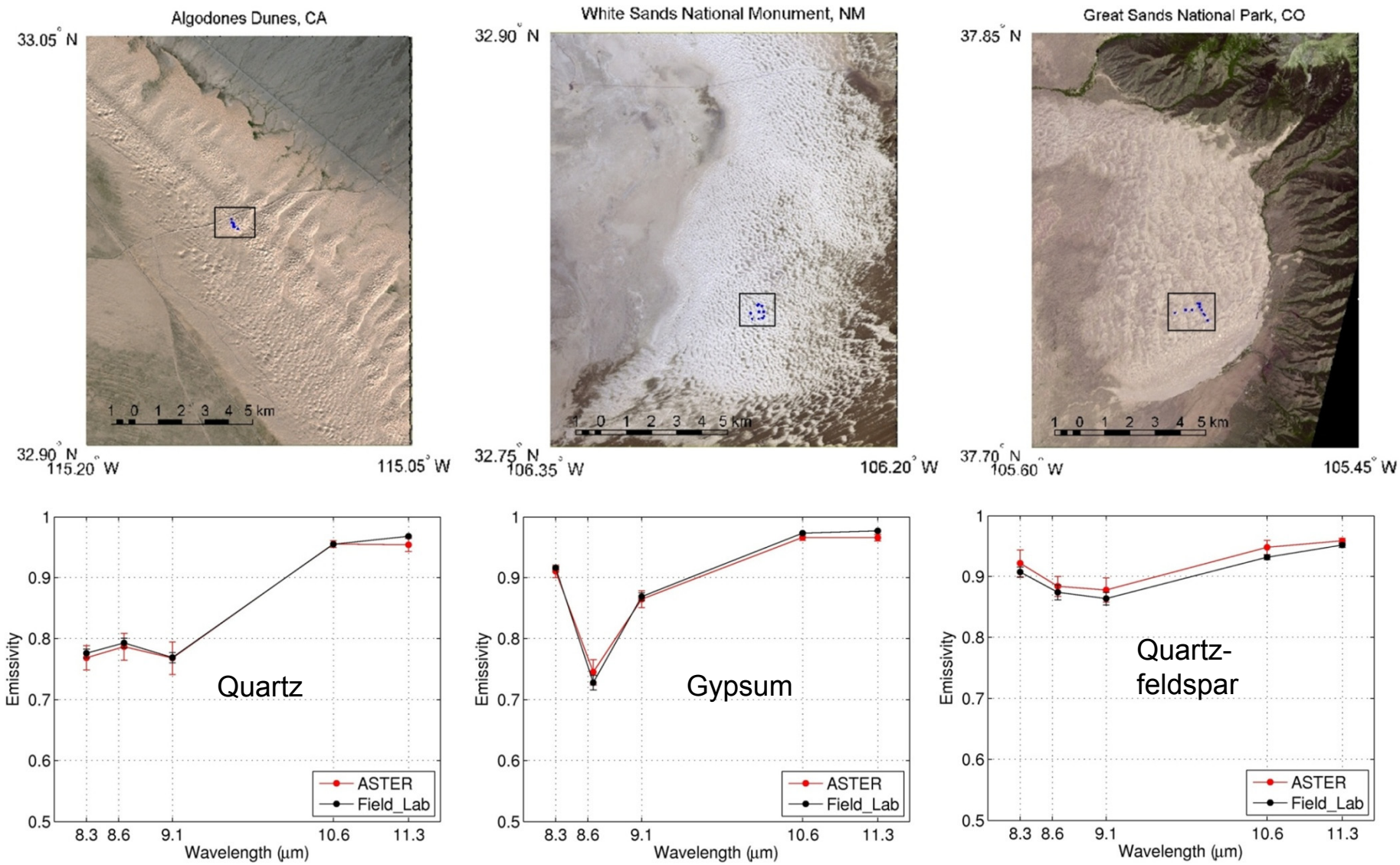
Death Valley

(Classification would assign one emissivity class to most of this region)

Algodones Dunes

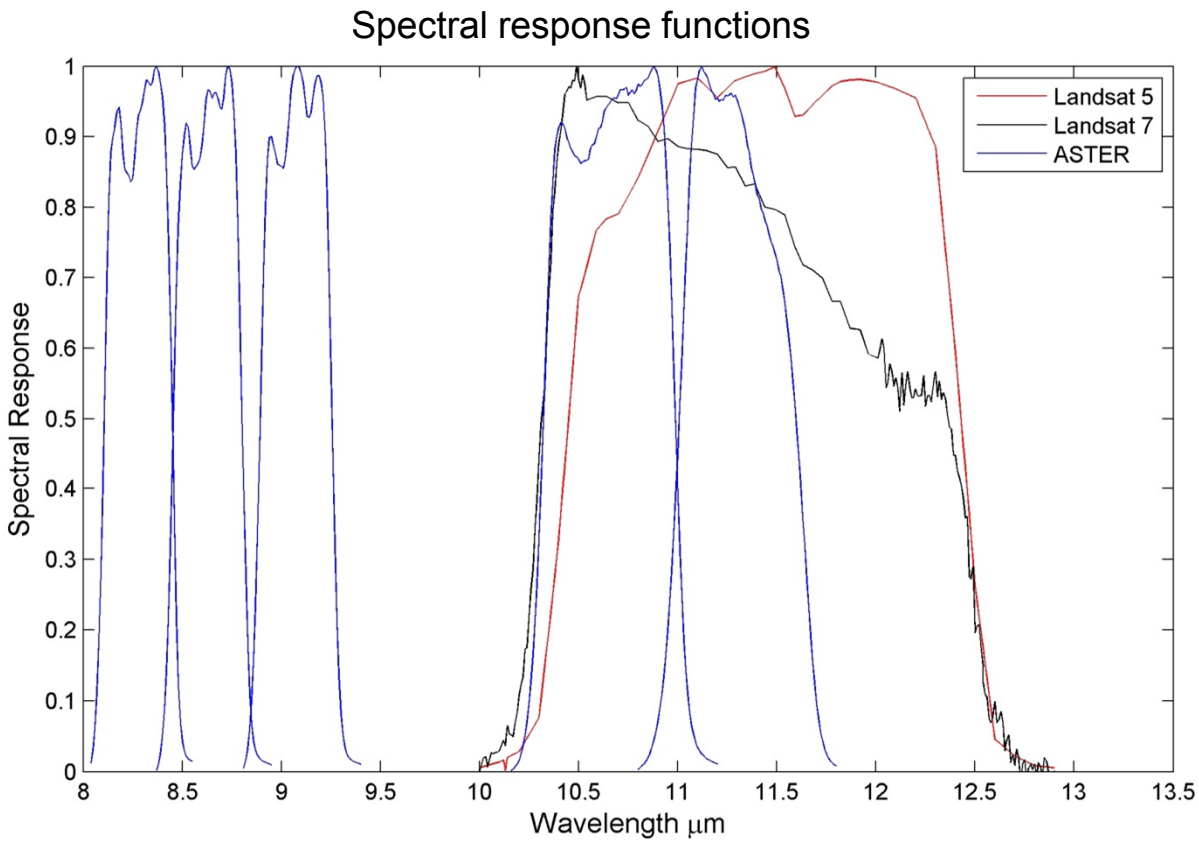


NAALSED validation at pseudo-invariant sand dune sites



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

Landsat emissivity from NAALSED



Landsat-5: $\epsilon_{10.4-12.5} = 0.305\ \epsilon_{13} + 0.468\ \epsilon_{14} + 0.223$

Landsat-7: $\epsilon_{10.4-12.5} = 0.44\ \epsilon_{13} + 0.4\ \epsilon_{14} + 0.156$

Coefficient regressed from 150 lab spectra consisting of rocks, soils, vegetation, water and ice and convolved to appropriate spectral responses.

Landsat emissivity from Land Classification

Use an estimate of vegetation fraction (fv) computed from NDVI to estimate effective emissivity from IGBP land cover classification maps.

$$ee = e_{veg} * fv + e_{bare}(1 - fv)$$

ee = effective emissivity
fv = fractional vegetation cover
e_{veg} = vegetation emissivity (assigned from land cover map)
e_{bare} = soil/rock emissivity (assigned according to vegetation type)

$$fv = 1 - (NDVI_{max} - NDVI)/(NDVI_{max} - NDVI_{min})$$

NDVI = Normalized Difference Vegetation Index
$NDVI_{max}$ = 0.9
$NDVI_{min}$ = 0.0

$$NDVI = (r4 - r3)/(r4 + r3)$$

r4 = Landsat band 4 Reflectance
r3 = Landsat band 3 Reflectance
* Reflectances derived using methods defined in Irish (2000).

Landsat emissivity from Land Classification

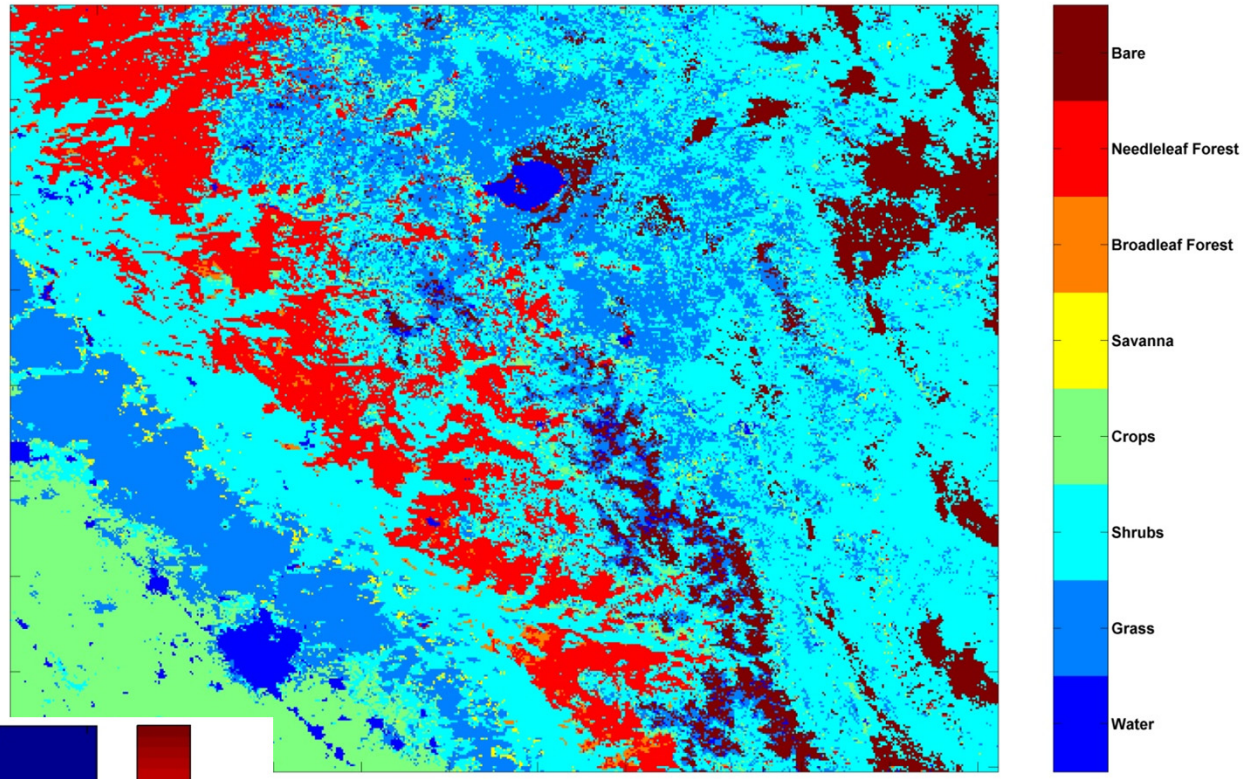
IGBP Class Type	Veg	Bare
Grasslands	0.953	0.971
Shrublands	0.972	0.958
Crops	0.983	0.971
Woody Savannas	0.982	0.971
Broadleaf Forest	0.981	0.971
Needleleaf Forest	0.989	0.971
Wetlands	0.992	0.971
Urban	0.990	0.950
Bare	0.970	0.958

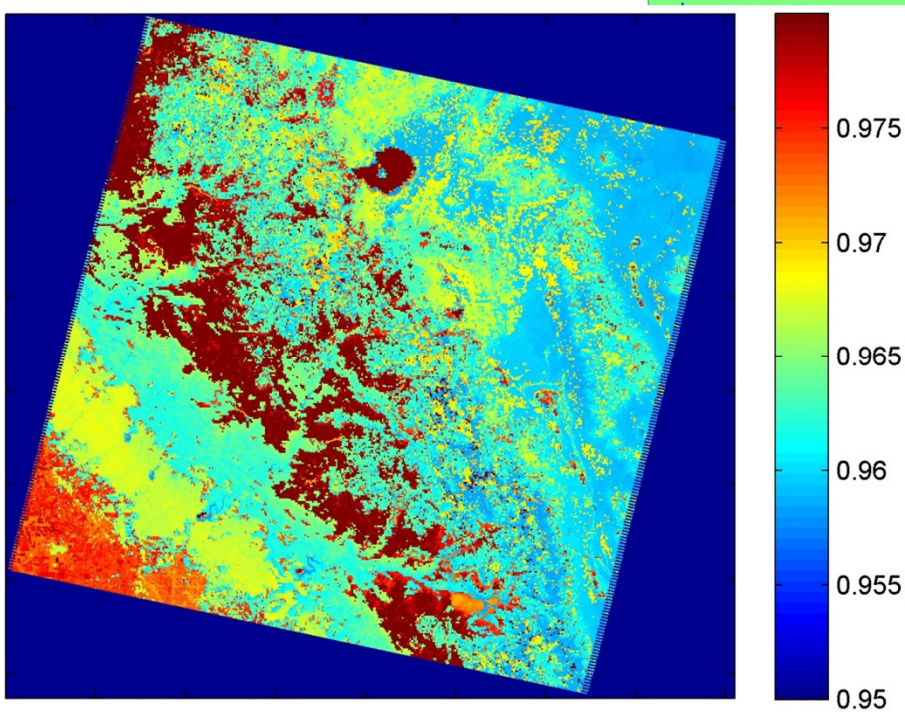
** 0.971 = typical soil emissivity for Landsat Band 6
0.958 = typical rock/sand emissivity for Landsat Band 6

** All estimates derived from MODIS and SEVIRI land classifications at 11 micron (may need to be refined for Landsat)

Sierra Nevadas, Mono Lake region

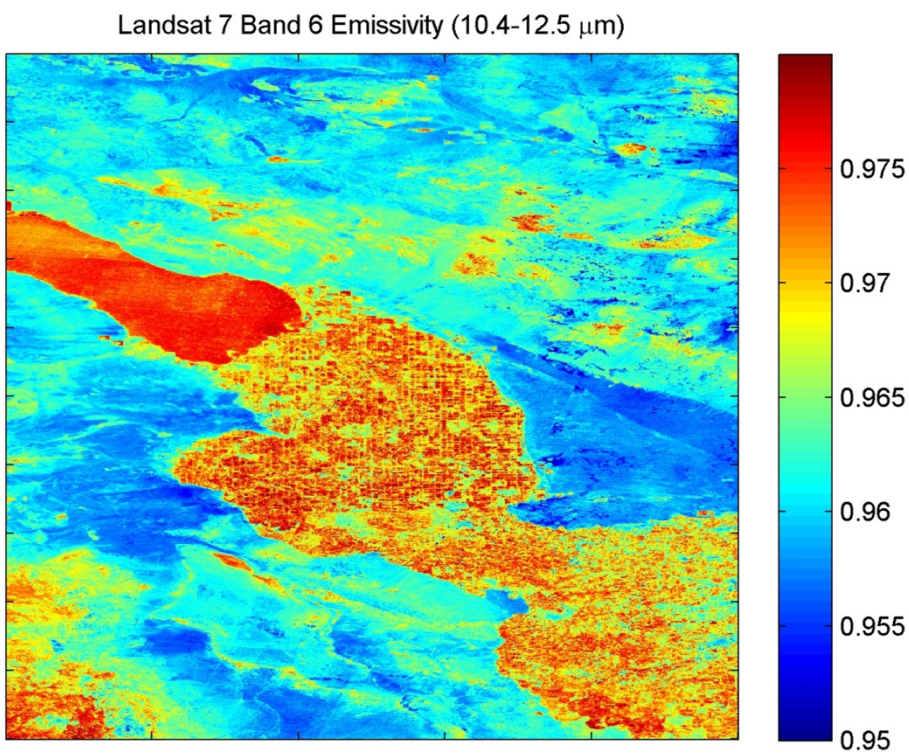
IGBP Land Cover Classification (MOD12 Product)

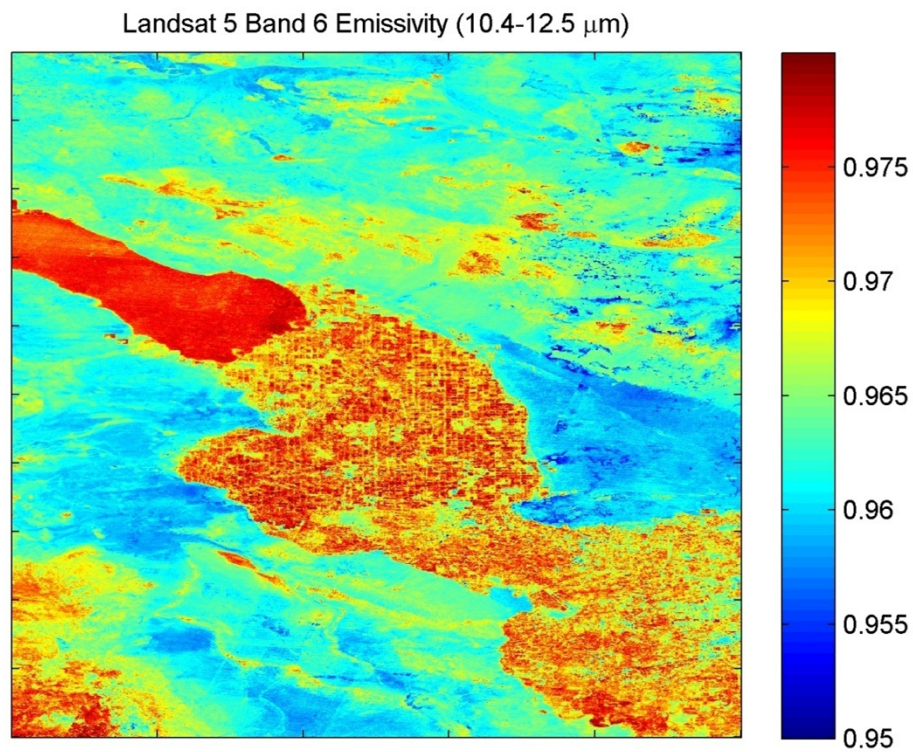




Classification Emissivities using Fractional Vegetation Cover Approach

Landsat emissivity from NAALSED





- Max emissivity: ~0.98 (Salton Sea, Crops)
- Min emissivity: ~0.94 (Algodones dunes)

Worst case scenario: $\delta e = 0.04 \Rightarrow \delta T = 2.85$ K (for surface at 11 μm, 300 K)

Single-band Temperature Inversion

Surface Radiance:

Observed Radiance

$$L_{surf,i} = e_i \cdot B_i(T_S) + (1 - e_i) \cdot \boxed{\overline{L}_i^{\downarrow}} = \frac{L_i(\theta) - \boxed{L_i^{\uparrow}(\theta)}}{\boxed{\tau_i(\theta)}}$$

- **Atmospheric Parameters:** $\tau_i(\theta),\ L_i^{\uparrow}(\theta),\ L_i^{\downarrow}(\theta)$

  Estimated using radiative transfer code such as MODTRAN with Atmospheric profiles and elevation data

Surface emitted radiance

$$B_i(T_S) = \frac{1}{e_i}\left(\frac{L_i(\theta) - L_i^{\uparrow}(\theta)}{\tau_i(\theta)} - (1 - e_i) \cdot \overline{L}_i^{\downarrow}\right)$$

Invert Planck function to get LST $\longrightarrow$ $T_S = B_i^{-1}$

Atmospheric Correction

- NCEP atmospheric profiles (6 hourly, 1ºx1º)
  - Spatially interpolated to 10 km across scene
  - Temporally interpolated to Landsat observation time
- MODTRAN 5.2 Radiative Transfer Model
- GTOPO30 Elevation model (USGS)
- To minimize computation time, downwelling sky radiation was modeled from path radiance using regression with RT simulations.
  - CLAR radiosondes used for radiative transfer (380 global sondes)

$$Lsky = a + b*Lpath + c*Lpath^2$$

Lsky = Downwelling sky irradiance

Lpath = Path radiance

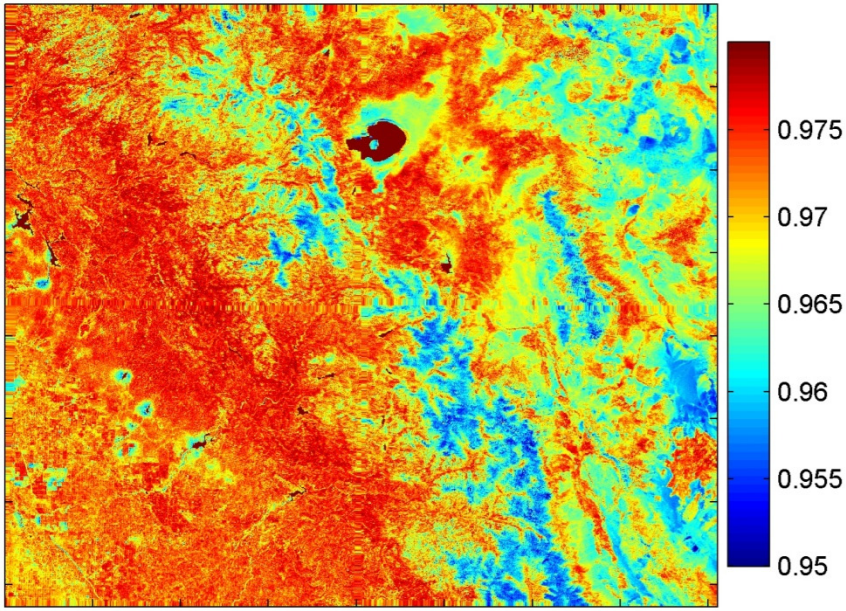
a = 0.0194

b = 0.5469

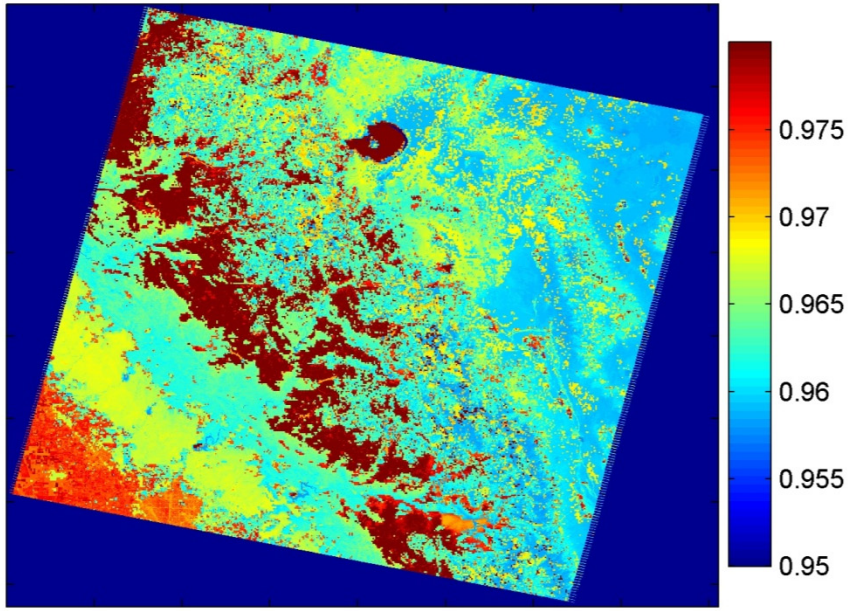
c = 0.0254

Sierra Nevada, Mono Lake, CA.

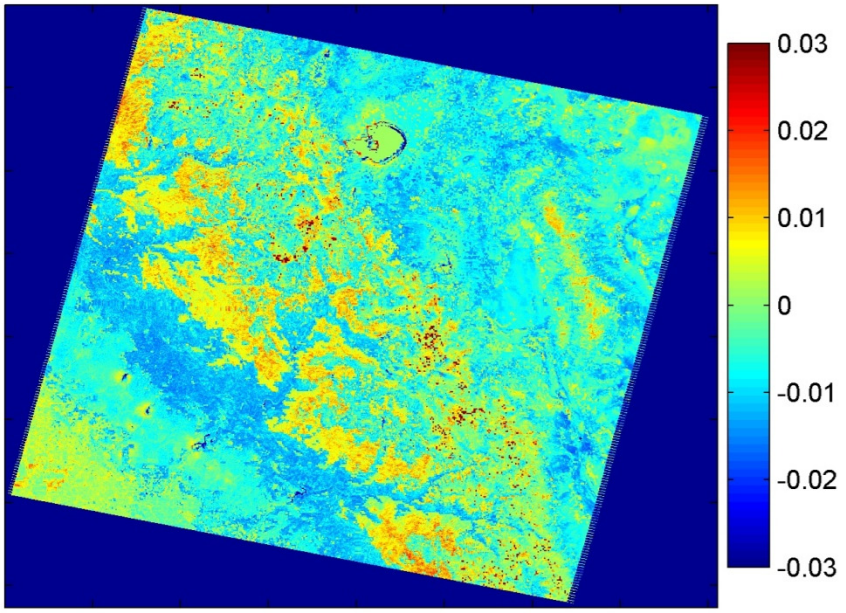
Landsat5 Band6 Emissivity (NAALSED)

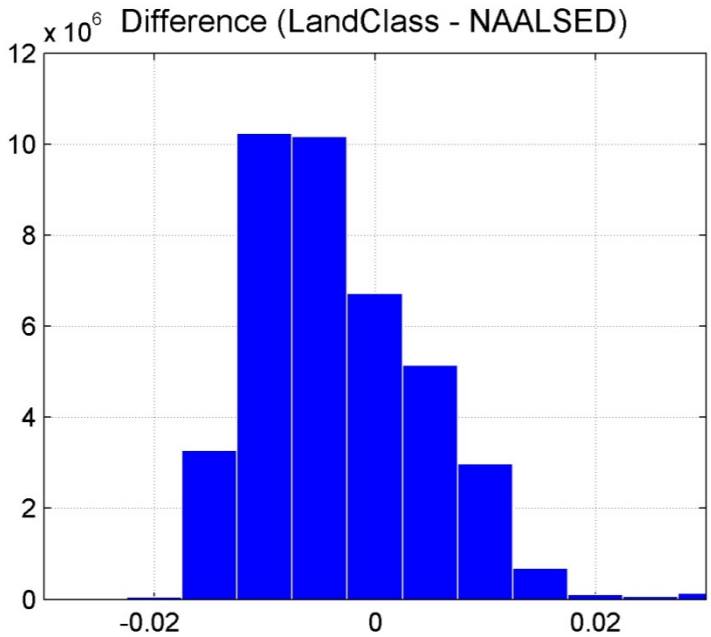


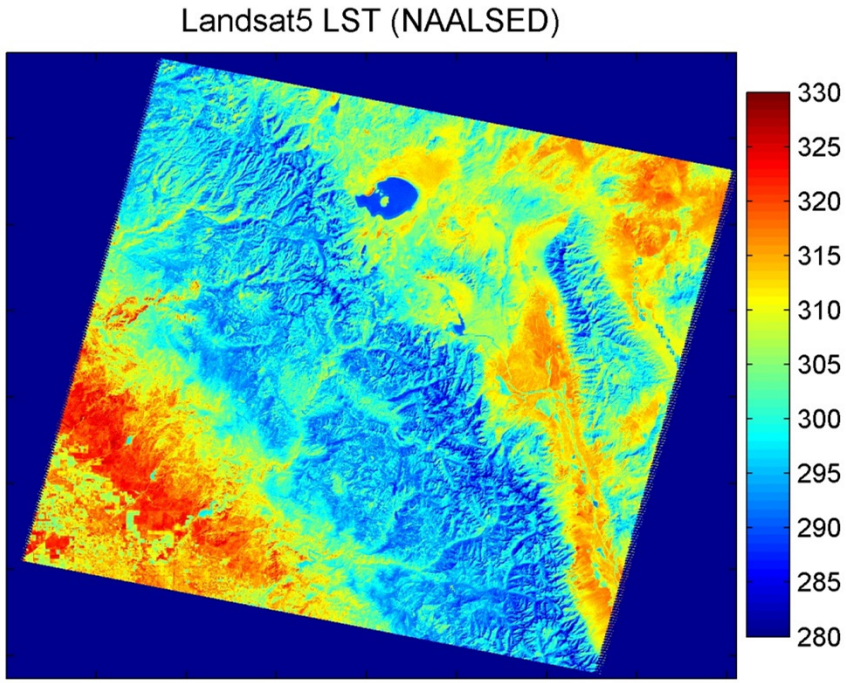
Landsat5 Band6 Emissivity (LandClass)

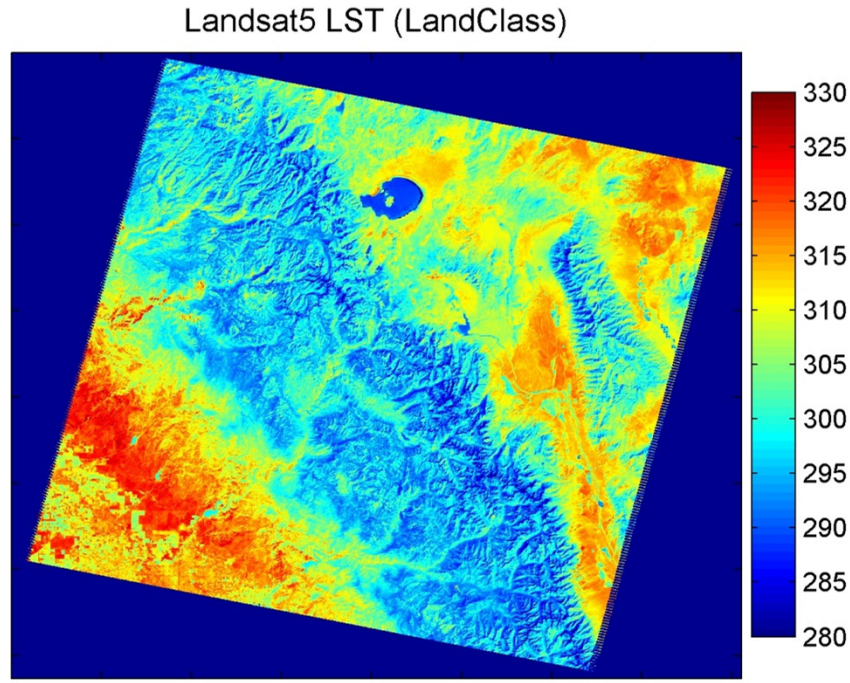


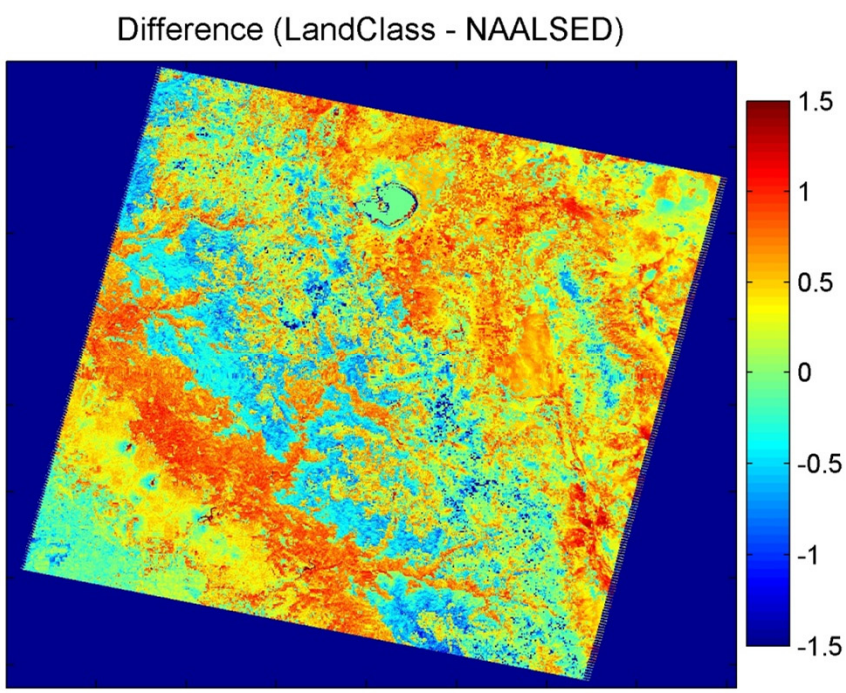
Difference (LandClass - NAALSED)

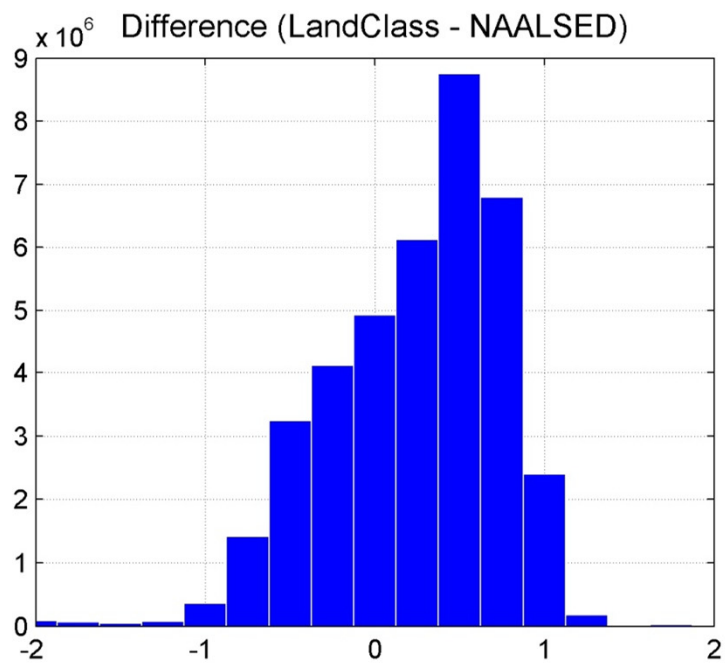


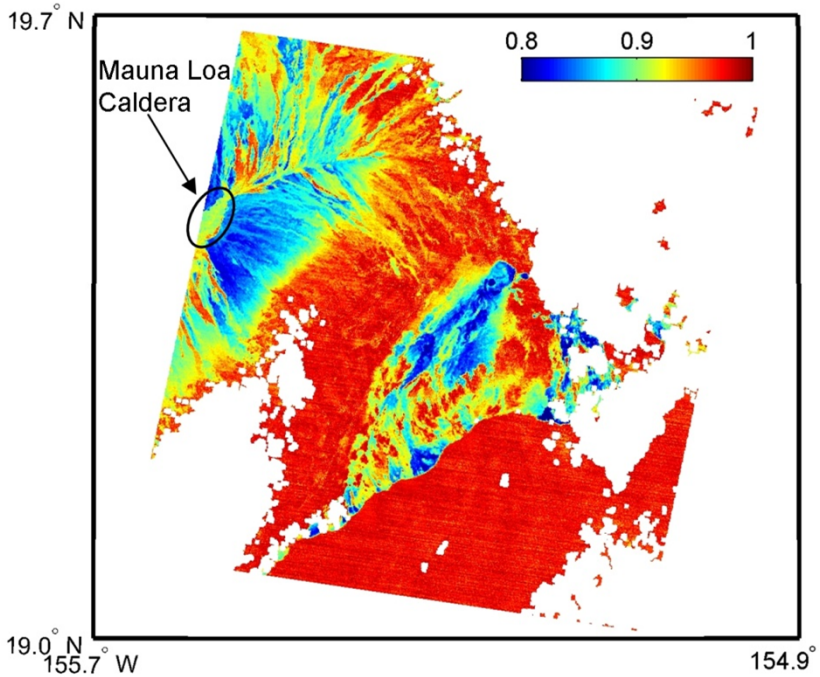



Landsat5 LST (NAALSED)
330
325
320
315
310
305
300
295
290
285
280


Landsat5 LST (LandClass)
330
325
320
315
310
305
300
295
290
285
280

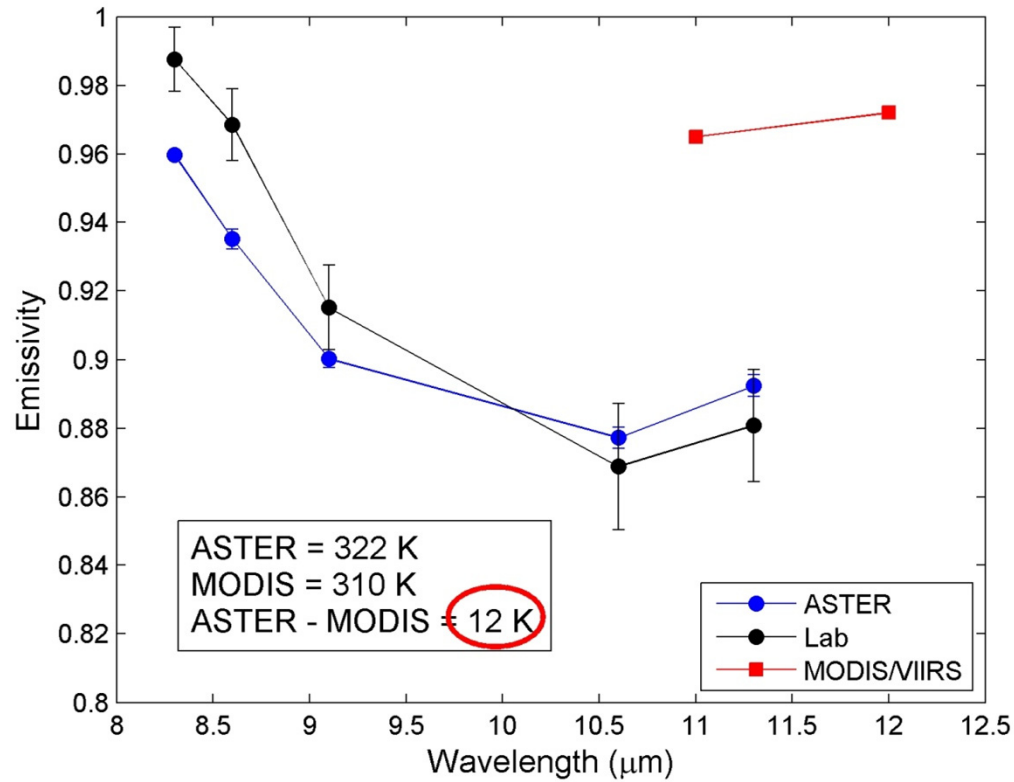

Difference (LandClass - NAALSED)
1.5
1
0.5
0
-0.5
-1
-1.5


Difference (LandClass - NAALSED)
x 10^6
9
8
7
6
5
4
3
2
1
0
-2
-1
0
1
2



Land Classification Emissivities could have large errors over certain geologic surfaces!

e.g. Mafic surfaces (basalt)



Summary

- Landsat LST algorithm developed for Landsat5 and Landsat7
  - Classification-based emissivities
  - NAALSED-based emissivities
- Scenes over California/Nevada downloaded for initial assessment of two algorithms
- Results show mean LST differences over diverse region (Sierra Nevadas) of 0.24 ± 0.51 K with max differences of ~2 K
- Shrublands and bare classifications tend to have largest errors >1 K with LST too high (emissivity too low)
- Analysis over mafic surfaces (e.g. Basalt) show classification errors could be as large as 12 K!!

The End

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