A LAND SURFACE TEMPERATURE PRODUCT

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A Land Surface Temperature Product

Goals – Develop a methodology applicable to entire Archive (L4, L5 & L7) (L3?)

– Deliver methodology, software as appropriate and validation results/test sites to USGS for implementation.

A Land Surface Temperature Product

Approach – Focus initial efforts on north America to take advantage of available data

- NAALSED (N.A. Emissivity maps)
- NARR (N.A. Met data)

– Use North America to clarify how to do Globe

- Same approach with more interpolation of atmospheres & lower resolution emissivities
- Identify/develop better global reanalysis
- Build higher resolution global emissivity maps

A Land Surface Temperature Product

Implement Approach

Calibrate data base: Goddard, JPL, RIT

- L4, L5, L7 Updated trusted calibrations available – final error assessment ongoing

Atmospheric Compensation: RIT with JPL, USGS & Goddard

Emissivity values: JPL with RIT, USGS & Goddard

A Land Surface Temperature Product

Timeline: Year 1 Define Approach

- identify limitations
- identify filters
- perform sensitivity analysis
- identify QC issues

Implement & Test methodology

Year 2 Refine Algorithms and extend approach to Global database.

Evaluate initial products.

- compare to ASTER/MODIS
- compare to truth
- user evaluation

Year 3 Refine Global Algorithm based on Year 2 results

- validate at range of trusted sites
- deliver final tools to USGS

Calibrate Archive

Table 1: Residual Uncertainties in the data from the USGS Landsat Archive expressed in apparent temperature [K]. Values in parenthesis are the number of points included in the analysis.

	Uncertainty in Predicted Radiance S_P	Instrument Noise S_I	Modeled Uncertainty in Sensed Radiance S_L	Observed Variability About Best Fit Calibration Line S_{RMS}	Observed Variability Unaccounted Uncertainty S_u
Aerial (A) (0.31)					
Surface Temperature (RIT) (0.34)					
Surface Radiometers & Thermistors (JPL) (0.35)					
Subsurface Temperatures (NOAA Buoys) (0.41)					
Landsat 7 (composite) (324)		0.21[1]	0.41	0.48[2]	0.25
RIT(51)			0.40	0.32	
JPL(234)			0.41	0.48	
NOAA Buoys (39)			0.46	0.59	
Landsat 5		0.17-0.3			
1984-1998 NOAA Buoy (102)			0.44-0.51	0.53[2]	0.24
1997-2010 Composite (285)			0.41-0.48	0.66[2]	0.49
RIT (29)			0.38-0.45	0.48	
JPL (149)			0.39-0.46	0.73	
NOAA Buoy (107)			0.44-0.51	0.60	
Landsat 4		0.22-0.32			
1982-2983 NOAA Buoy (9)			0.47-0.52	0.98[2]	0.86
1987-1992 NOAA Buoy (19)			0.47-0.52	0.43[2]	

[1] $NE\Delta T$ for the low gain is $(0.26K)$

[2] These are the best values to use for the expected uncertainty in the radiance values.

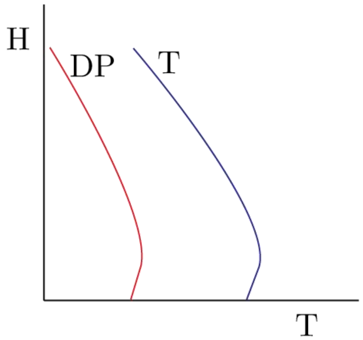
R·I·T

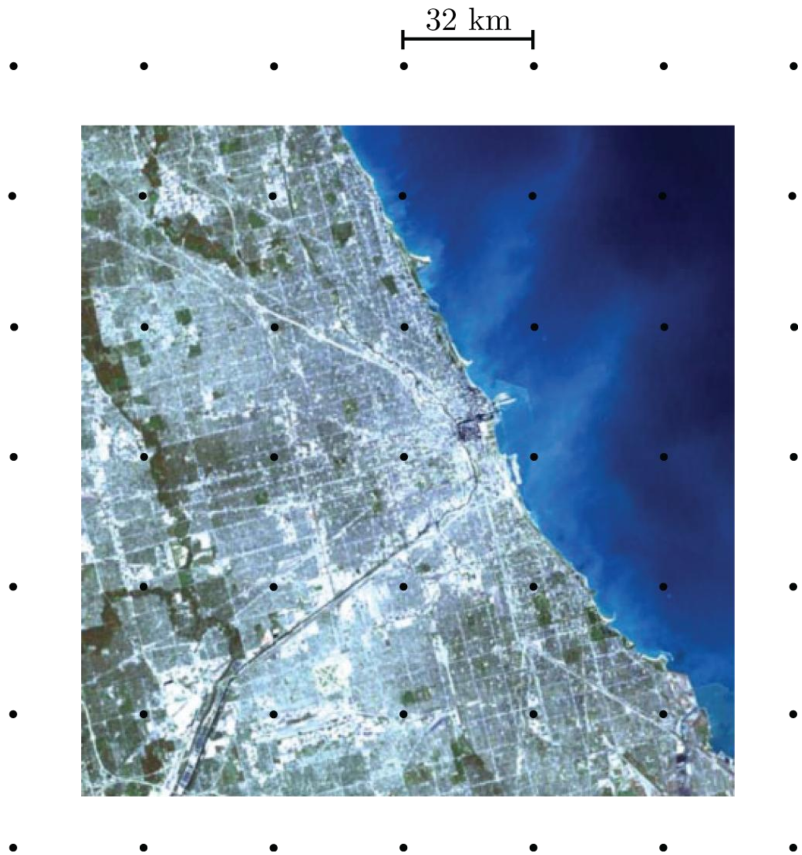
Chester F. Carlson CENTER for IMAGING SCIENCE

ATMOSPHERE

North America Regional Reanalysis (NARR) program

- 32 km. grid
- 3 hr temporal samples
- 29 atmospheric layers
- Spans entire Landsat time period

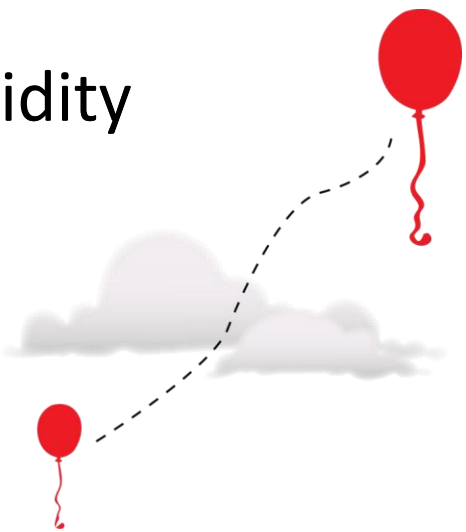


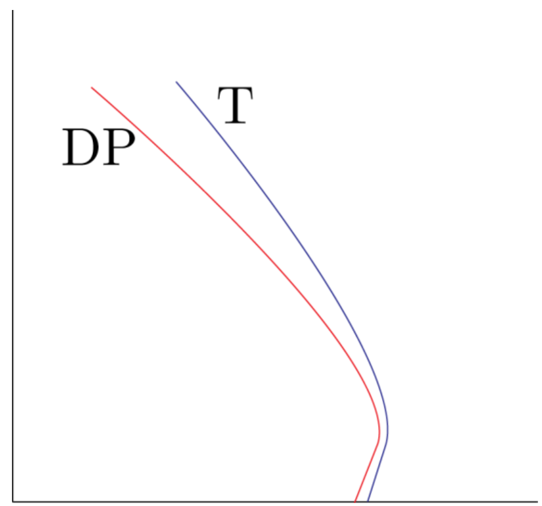


Filters

- Clouds
- Bad data
- High humidity

H	T
	⋮
	27
	25
	9999
	9999
2000	⋮
1000	
0	

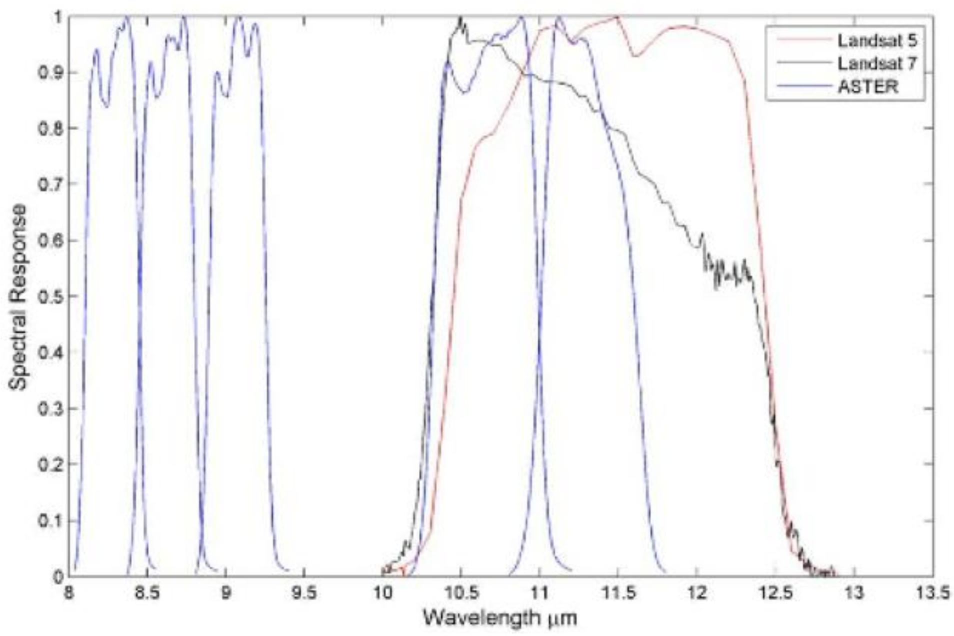




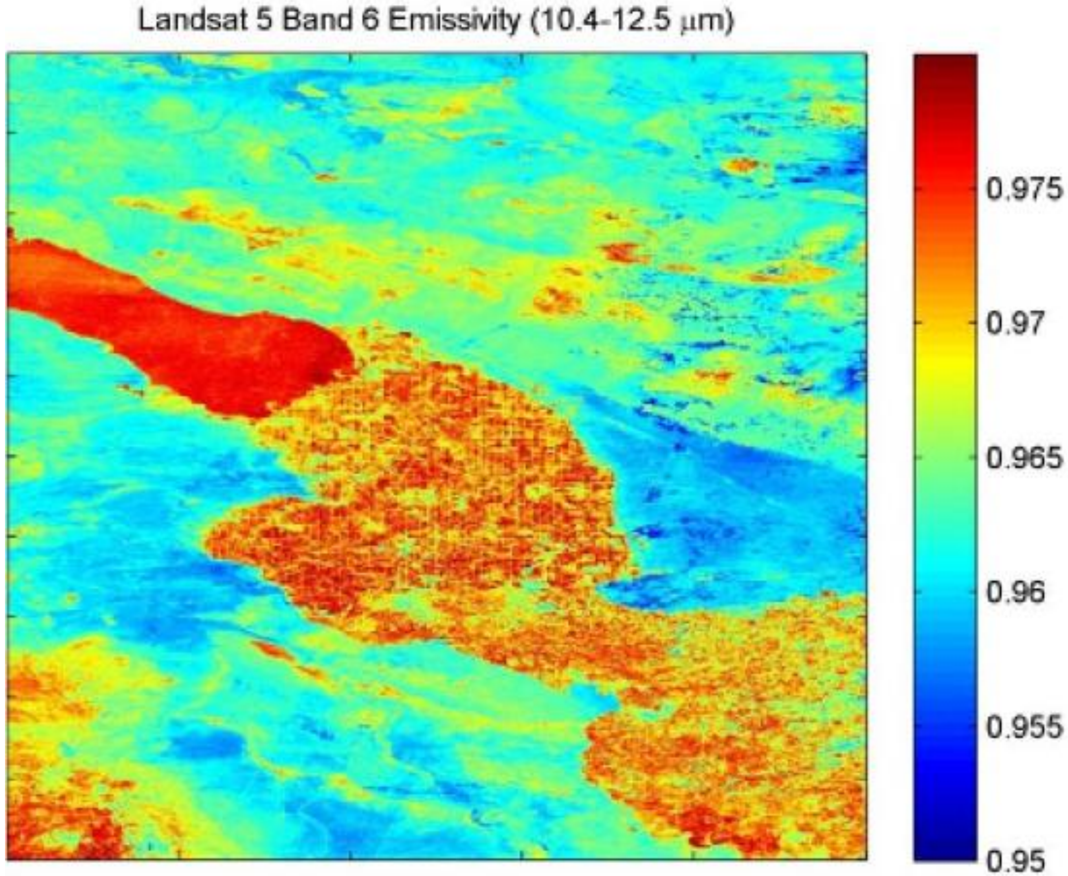
EMISSIVITY

- Extract Bare Earth Emissivity from the North American Aster Land Surface Emissivity Database (NAALSED)
  - Emissivities (ε_{13}, ε_{14}) and regression coefficients (JPL)

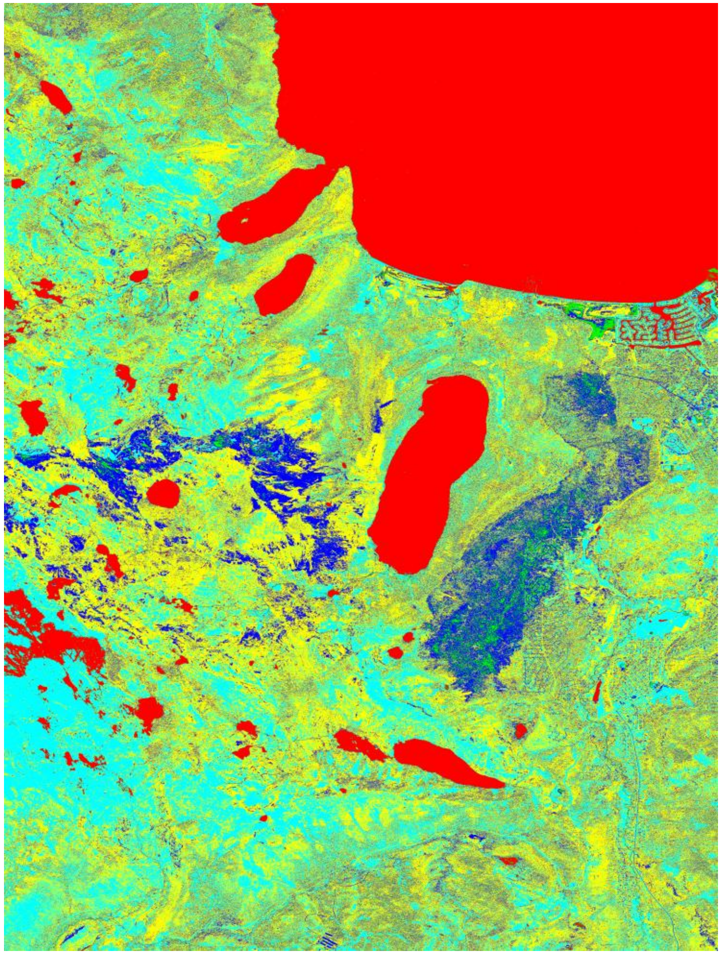
$$\varepsilon_{landsat} = C_{13}\,\varepsilon_{13} + C_{14}\,\varepsilon_{14} + C$$



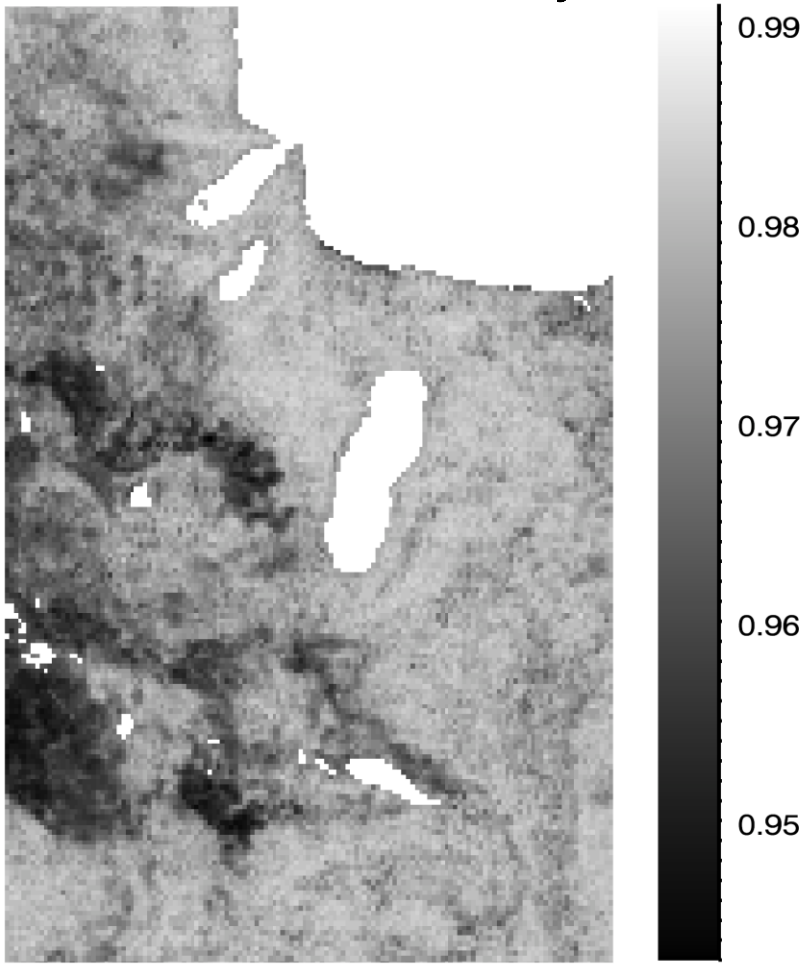
LANDSAT 5 derived emissivity from NAALSED bands 13 & 14 over the Salton Sea and Imperial Valley, CA.(JPL)



Lake Tahoe
5 Class Classification Map

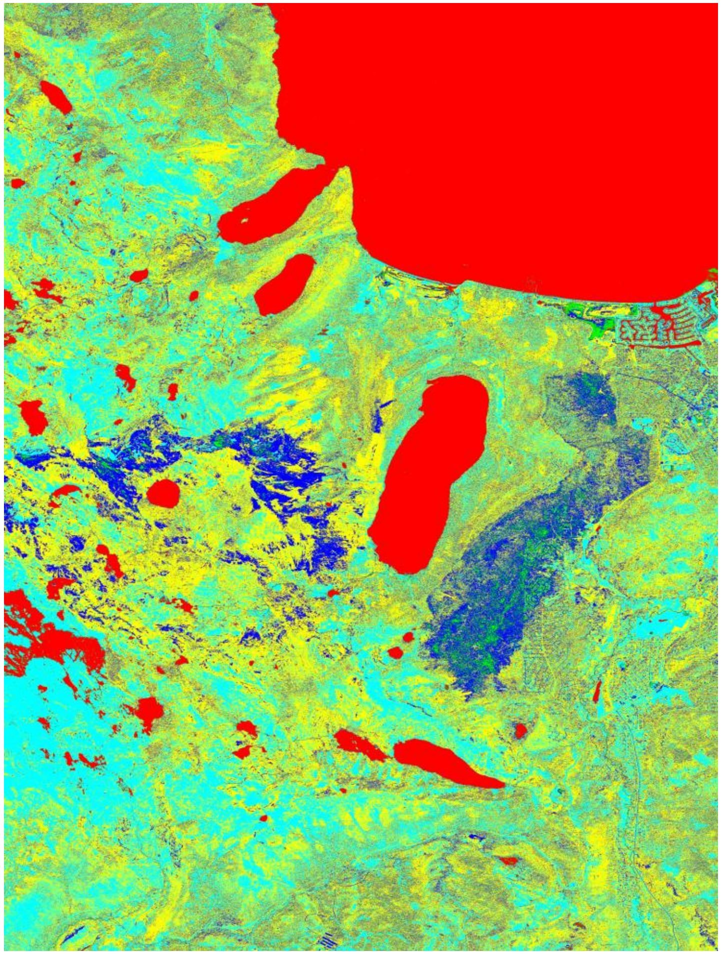


Aster Band 13
Lake Tahoe Emissivity Data

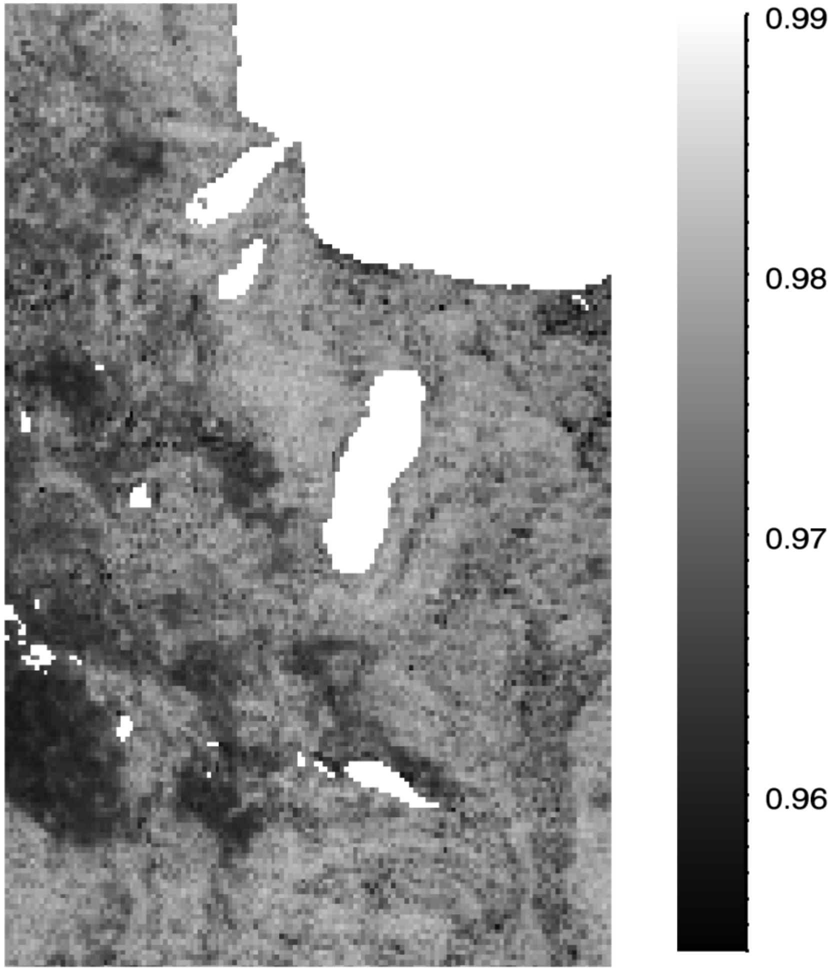


Class 1	Average Emissivity	0.988	SD	0.00736
Class 2	Average Emissivity	0.976	SD	0.00698
Class 3	Average Emissivity	0.975	SD	0.00748
Class 4	Average Emissivity	0.975	SD	0.00681
Class 5	Average Emissivity	0.972	SD	0.00890

Lake Tahoe
5 Class Classification Map

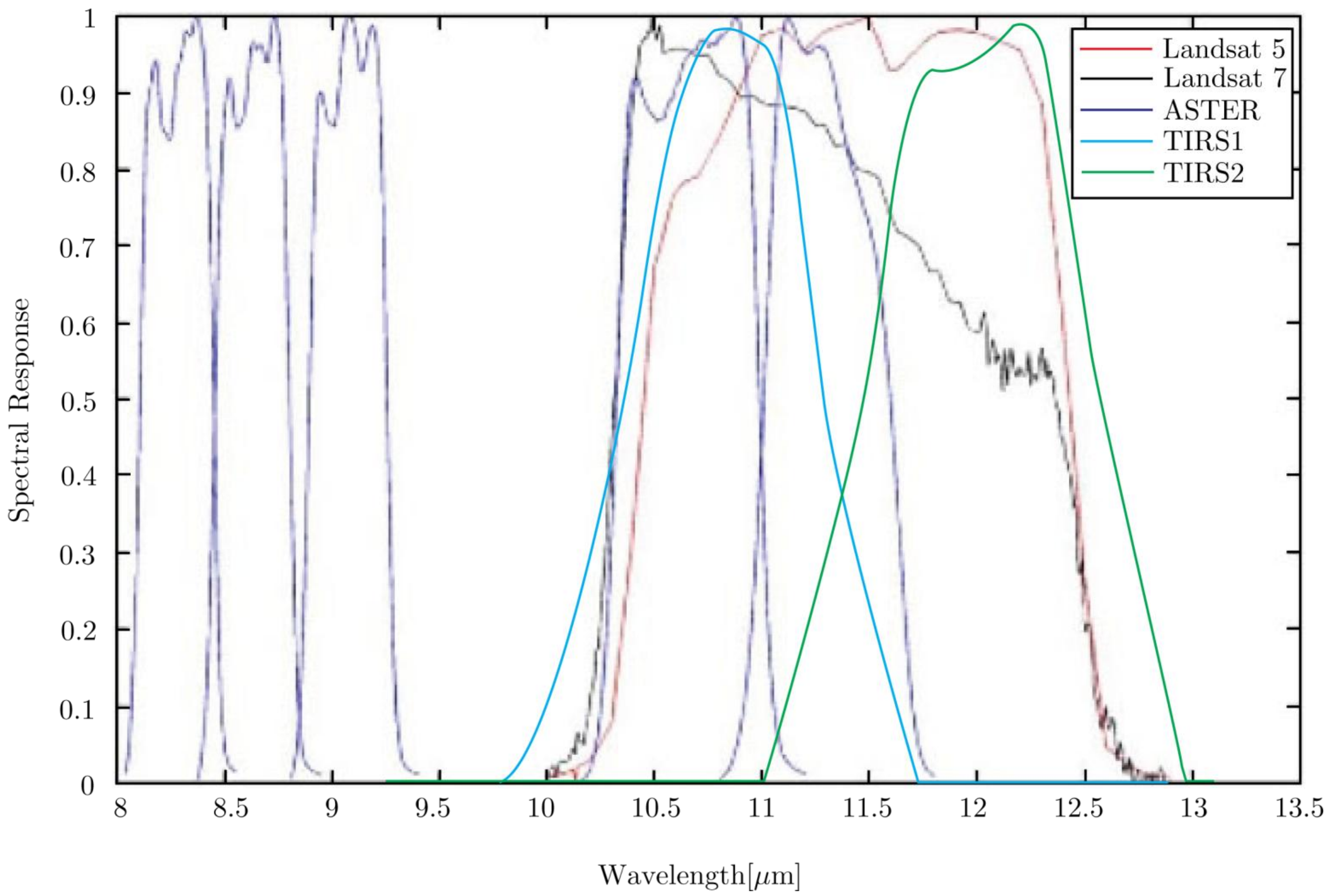


Aster Band 14
Lake Tahoe Emissivity Data



Class 1	Average Emissivity	0.988	SD 0.00644
Class 2	Average Emissivity	0.974	SD 0.00476
Class 3	Average Emissivity	0.974	SD 0.00477
Class 4	Average Emissivity	0.974	SD 0.00472
Class 5	Average Emissivity	0.972	SD 0.00572

Spectral Response Functions
TIRS and the Future



A Land Surface Temperature Product

Validation

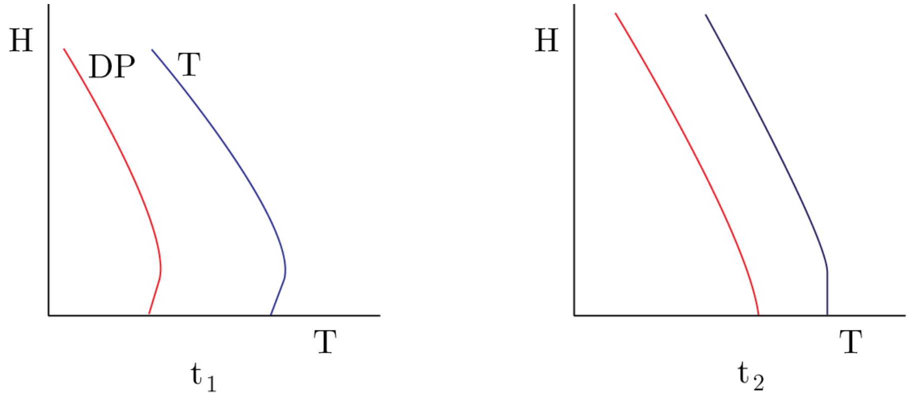
- Use calibration sites – Atm. Compensation
    - Salton Sea (below sea level and hot)
    - East & West Coast (sea level – wide range of atmosphere)
    - Great Lakes (≈ 0.2 km)
    - Lake Tahoe (≈ 1.4 km)
  - Covers all dates, all instruments
  - Only tests atmospheric compensation since all targets are water
- Cross calibrate with other instruments
    - ASTER-MODIS
        - » Need to account for time difference and any errors in alternate emissivity retrieval
    - Field sites?
        - » Historical?
        - » New???

Status_(RIT)

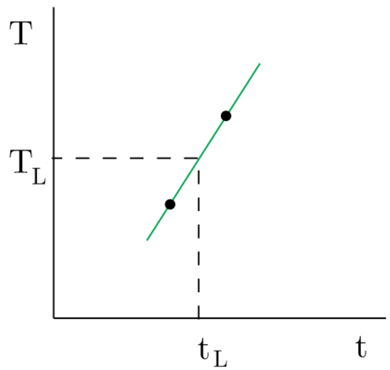
- Reading NARR GRIB files
- Converting NARR data to MODTRAN input files
- Generating Landsat passband atmospheric parameters from Modtran
- Evaluating height interpolators
- Learning about filtering issues
- Learning that atmosphere may be harder and emissivity easier than we thought

Questions? Help!

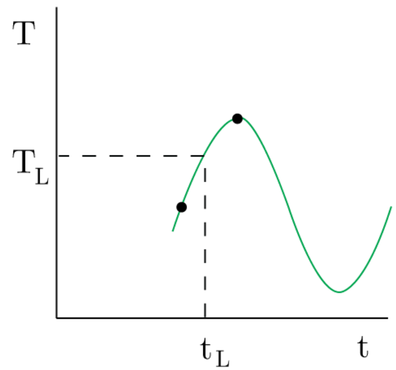
- Interpolate in time
  - Linear
  - Diurnal



Profile samples at time 1 (t_1) and time 2 (t_2) for one sample location

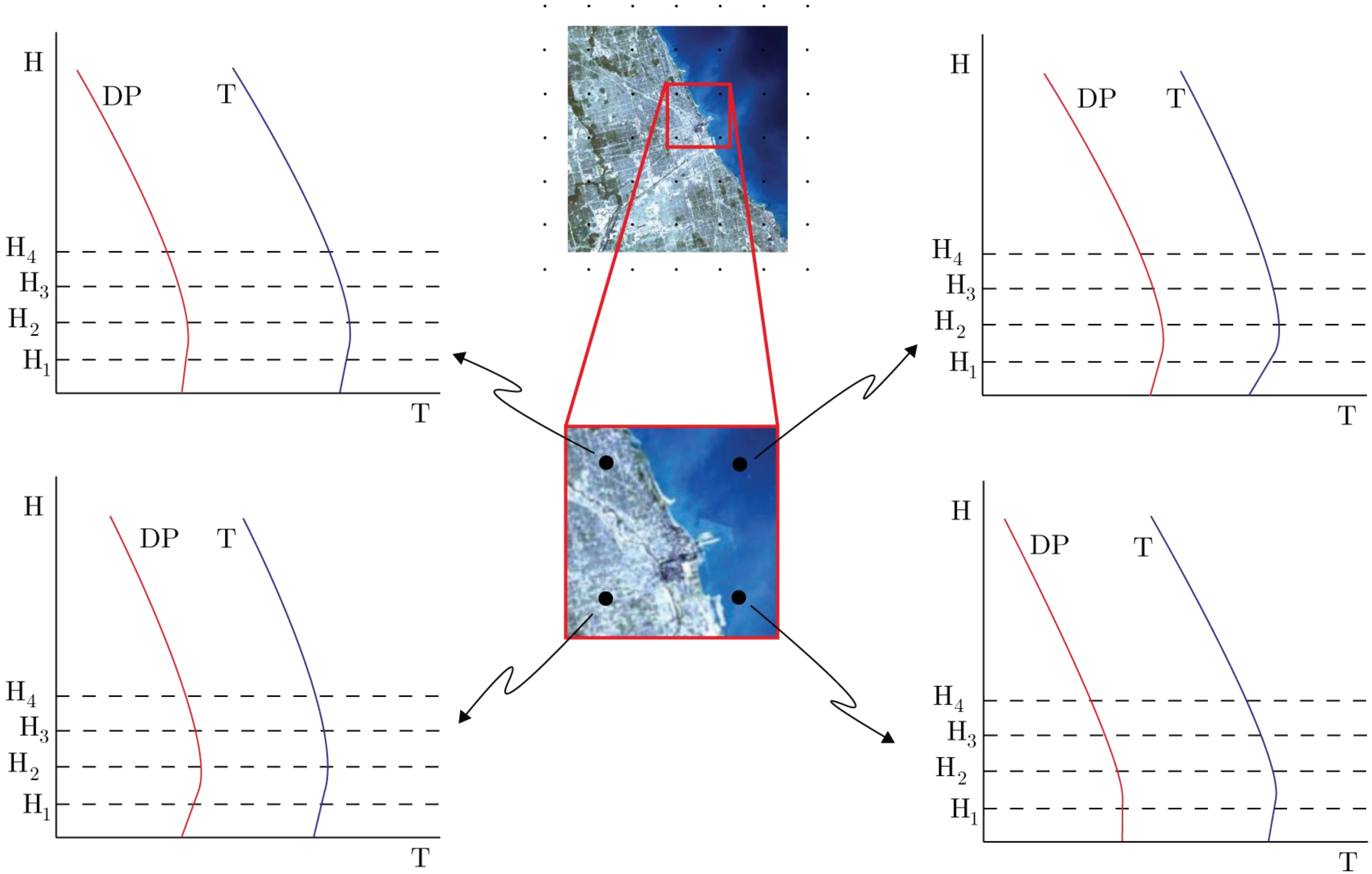


Linear Interpolation for T at each altitude

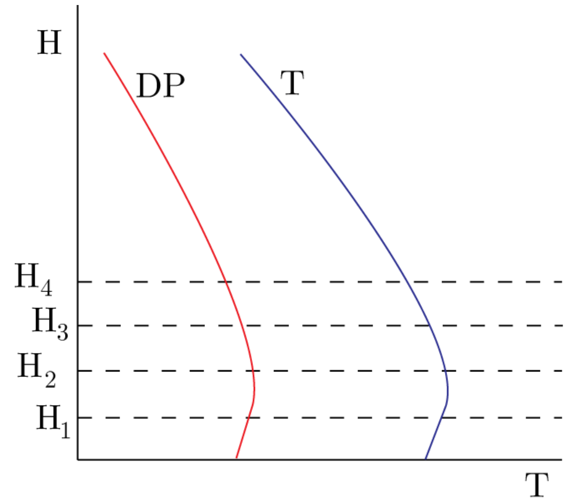


Diurnal Interpolation for T at each altitude

For each node we can estimate the atmospheric parameters
(τ, L_u, L_d)
associated with altitudes H_i from Modtran



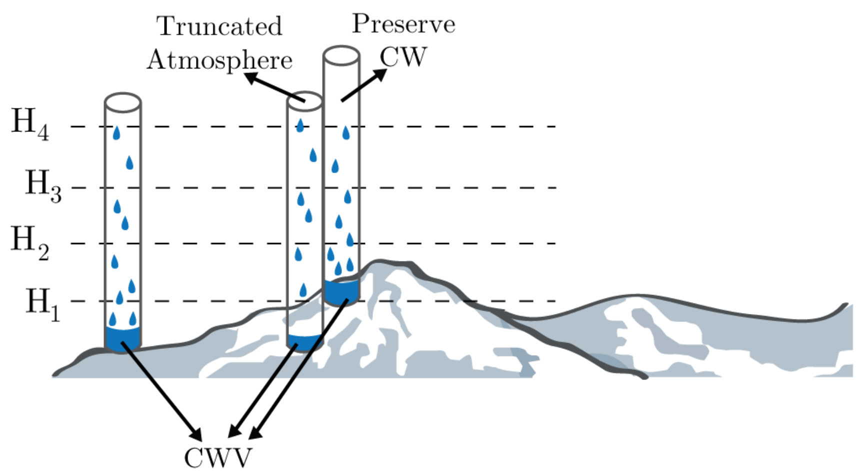
- Generate MODTRAN runs vs. Elevation(H) (H from USGS DEM)
  - Crop lower layers
  - Maintain CWV
  - Alternative logic?



Run Modtran for each altitude.

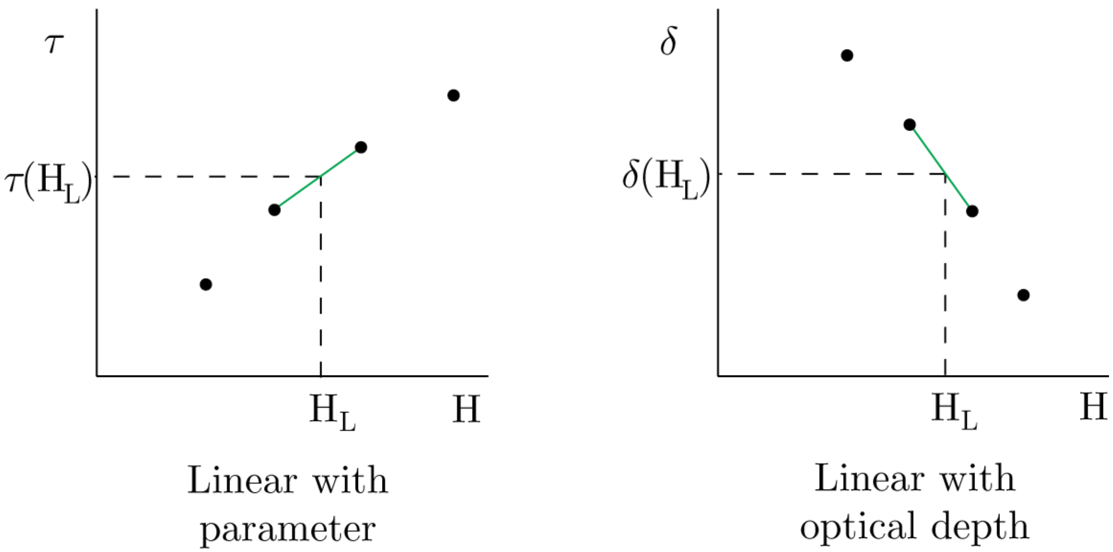
Output:

$$\tau(\mathrm{H}),\ \mathrm{L_u(H)},\ \mathrm{L_d(H)}$$



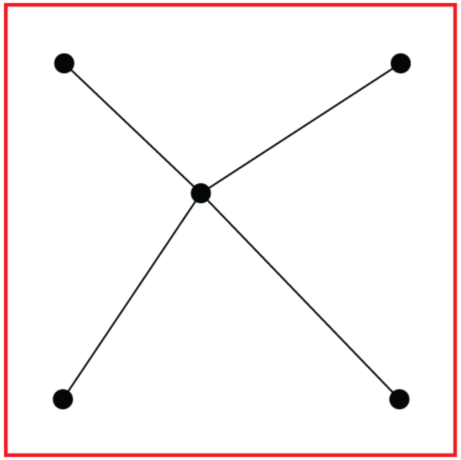
- Interpolate in parameter space (τ, L_u, L_d) on H for each profile site around the pixel of interest
  - Linear with H?
  - Linear in optical depth with H?

Interpolate to pixel height H_L

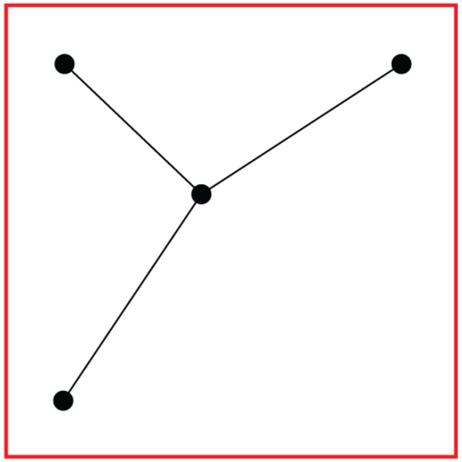


Output: $\tau(H_L,t_L)$, $L_u(H_L,t_L)$, $L_d(H_L,t_L)$

- Interpolate spatially in parameter space for fixed time and elevation at Nodes (profile sites)
  - Nearest neighbor?
  - Inverse distance (3 node, 4 node)?
  - Inverse exponential?



4 node

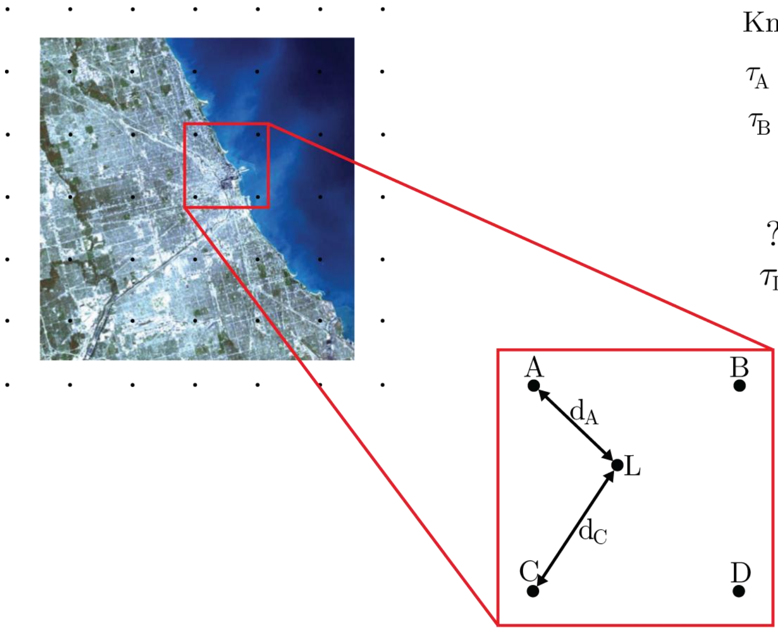


3 node

Output of Spatial Interpolation

$$L_{surf} = \frac{L_s - L_u}{\tau} = \varepsilon L_T + (1-\varepsilon) L_d$$

- Compute τ, L_u, L_d, $L_{surf} = (L_s - L_u)/\tau = \varepsilon L_T + (1-\varepsilon) L_d$



Know:

$\tau_A(H_L),\ L_{u_A}(H_L),\ L_{d_A}(H_L)$

$\tau_B(H_L),\ L_{u_B}(H_L),\ L_{d_B}(H_L)$

$\vdots$

?:

$\tau_L,\ L_{u_L},\ L_{d_L}$

Interpolate

Nearest neighbor → $\tau_L = \tau_A,\ L_{u_L} = L_{d_L}\ \ldots$

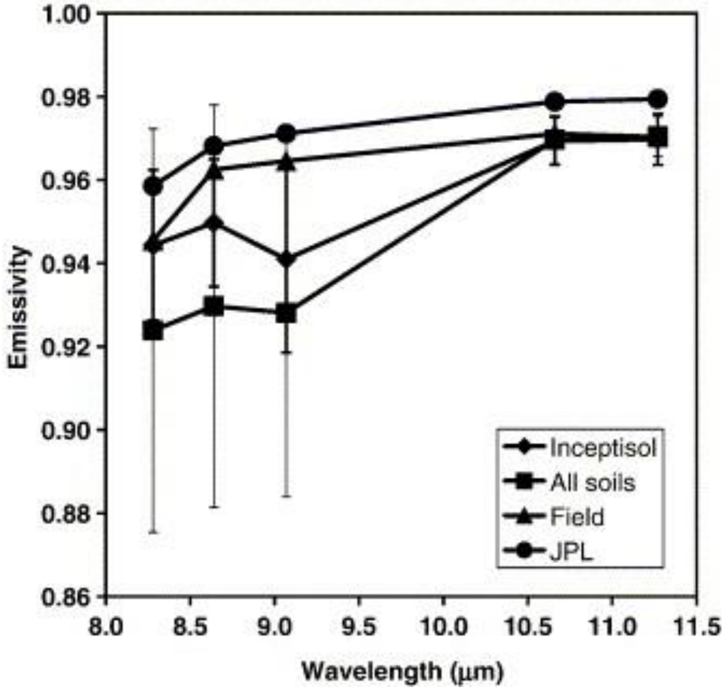
Linear in 1/d → $$\tau_L = \frac{\frac{\tau_A}{d_A} + \frac{\tau_B}{d_B} + \frac{\tau_C}{d_C} + \frac{\tau_D}{d_D}}{\sum_i \frac{1}{d_i}},\ \ldots$$

Linear in e^{-d} → $$\tau_L = \frac{\tau_A e^{-d_A} + \tau_B e^{-d_B} + \tau_C e^{-d_C} + \tau_D e^{-d_D}}{\sum_i e^{-d_i}},\ \ldots$$

Output: $\tau(H_L, t_L, L),\ L_u(H_L, t_L, L),\ L_d(H_L, t_L, L)$

$$L = \begin{bmatrix} x \\ y \\ H_L \end{bmatrix}$$

Correct Emissivity for High NDVI conditions
Note: an error in emissivity of 0.01 corresponds to 0.7K error in temperature in these bands.

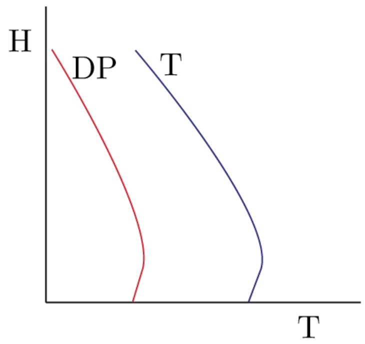


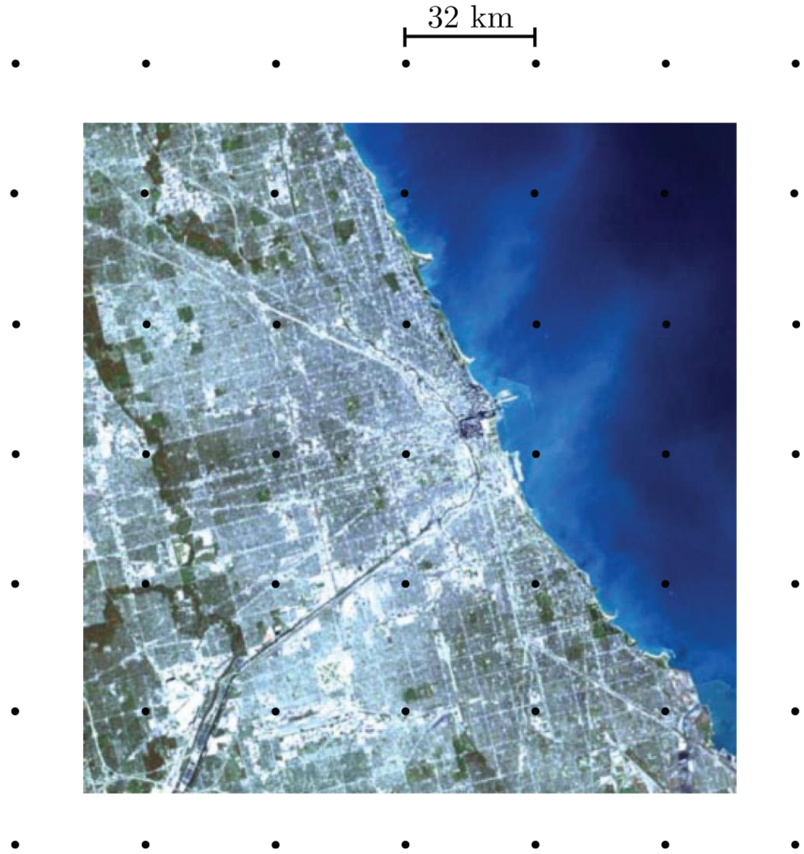
$$\varepsilon_{13} = 0.968 + 0.022\ P_V$$

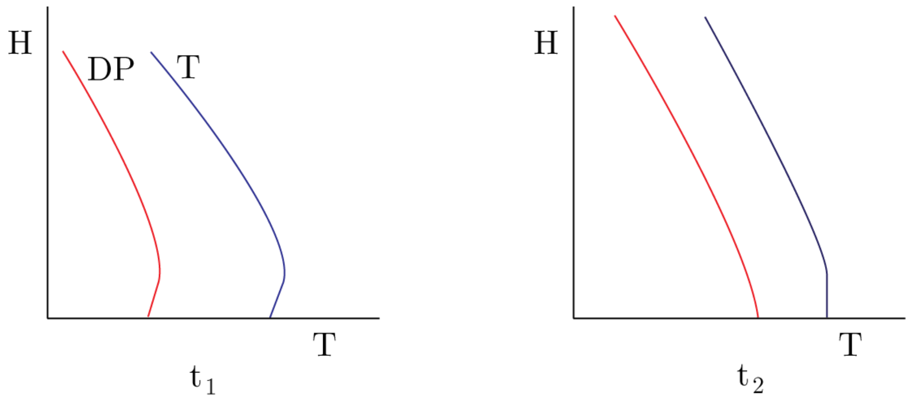
$$\varepsilon_{14} = 0.970 + 0.020\ P_V$$

$$P_V = \left(\frac{\mathrm{NDVI}-\mathrm{NDVI_s}}{\mathrm{NDVI_v}-\mathrm{NDVI_s}}\right)^2$$

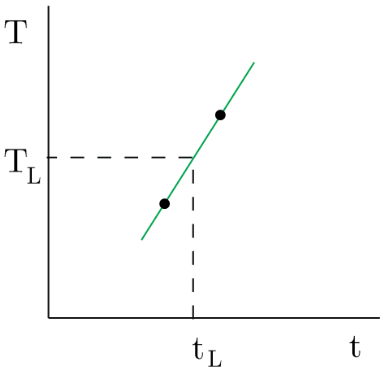
Fig. 3. Average emissivity spectra for different soil samples included in the ASTER spectral library (http://speclib.jpl.nasa.gov). 'Inceptisol' refers to the mean value for all the soil samples included in the ASTER library and classified as Inceptisol (7 samples). These values have been chosen a soil emissivities in the NDVI method. 'All soils' refers to the mean value for all the soil samples included in the ASTERlib (49 samples). Error bars refer to the standard deviation of the mean values. The emissivity spectrum obtained from field measurements (Field) and the one measured in the JPL are also given for comparison.[Munoz et al. (2006) RSofE V.103,#4, pp. 474-487].


H
DP
T
T

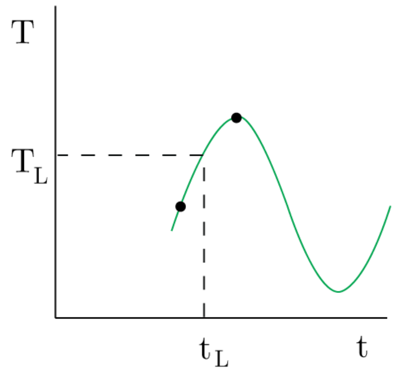

32 km



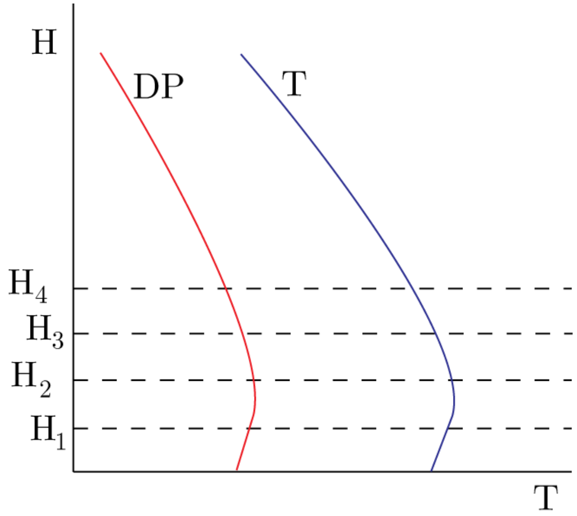
Profile samples at time 1 (t_1) and time 2 (t_2) for one sample location

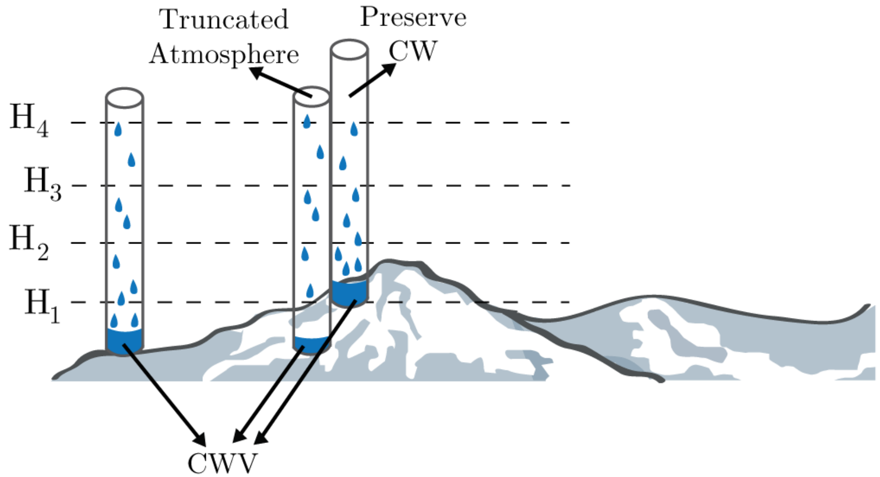


Linear Interpolation for T at each altitude



Diurnal Interpolation for T at each altitude



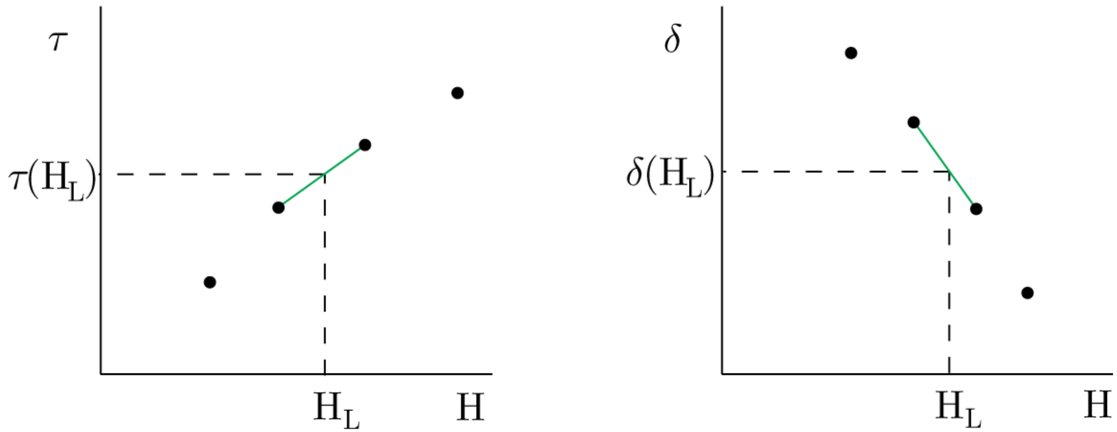


Run Modtran for each altitude.

Output:

$\tau(H)$, $L_u(H)$, $L_d(H)$

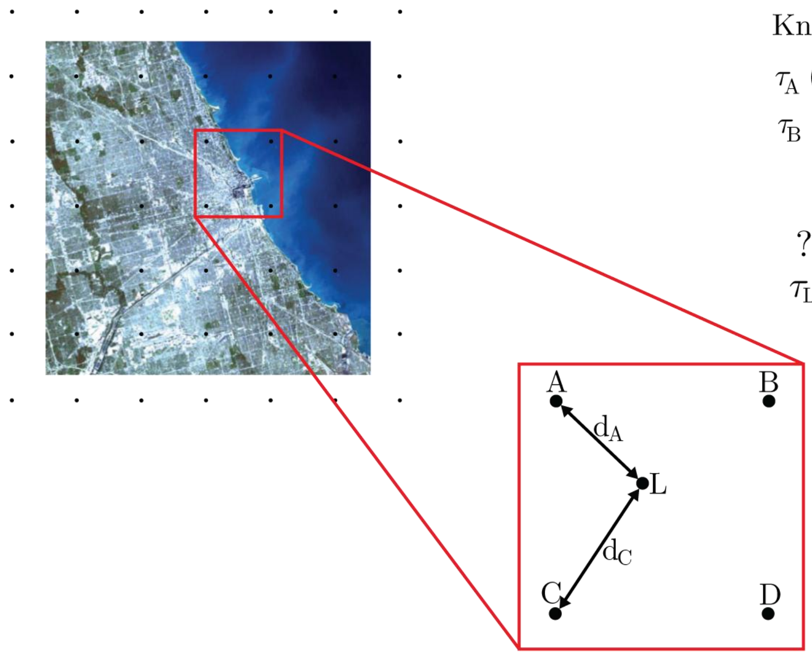
Interpolate to pixel height H_L



Linear with parameter

Linear with optical depth

Output: $\tau(H_L,t_L)$, $L_u(H_L,t_L)$, $L_d(H_L,t_L)$



Know:

$\tau_A\,(H_L),\ L_{u_A}(H_L),\ L_{d_A}(H_L)$

$\tau_B\,(H_L),\ L_{u_B}(H_L),\ L_{d_B}(H_L)$

$\vdots$

?:

$\tau_L,\ L_{u_L},\ L_{d_L}$

Interpolate

Nearest neighbor → $\tau_L = \tau_A,\ L_{u_L} = L_{d_L}\ \ldots$

Linear in 1/d → $$\tau_L = \frac{\frac{\tau_A}{d_A} + \frac{\tau_B}{d_B} + \frac{\tau_C}{d_C} + \frac{\tau_D}{d_D}}{\sum_i \frac{1}{d_i}},\ \ldots$$

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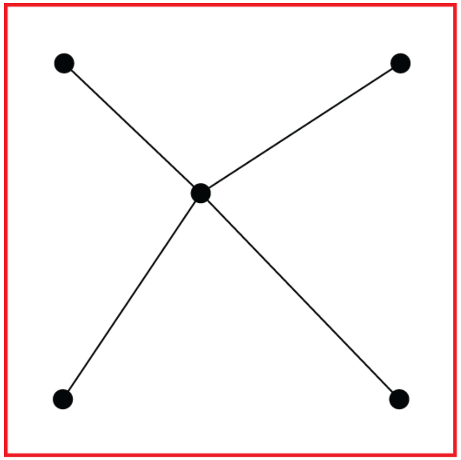
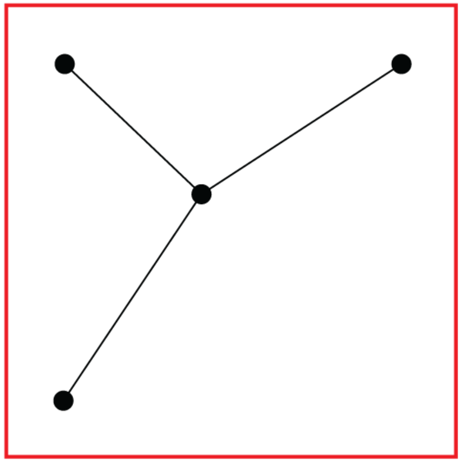
Output: $\tau(H_L, t_L, L),\ L_u(H_L, t_L, L),\ L_d(H_L, t_L, L)$

$$L = \begin{bmatrix} x \\ y \\ H_L \end{bmatrix}$$



4 node



3 node

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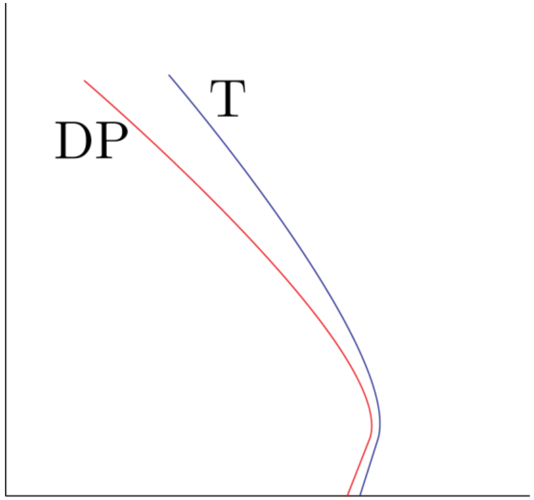
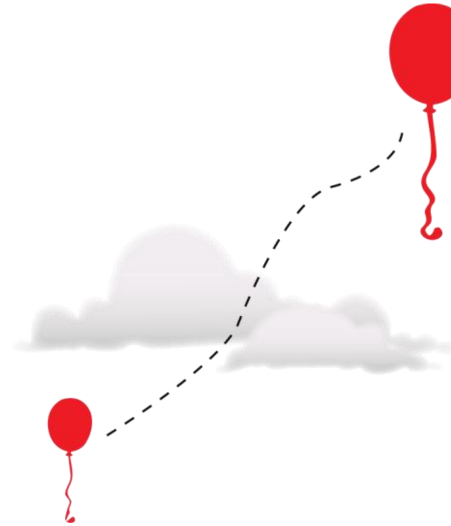
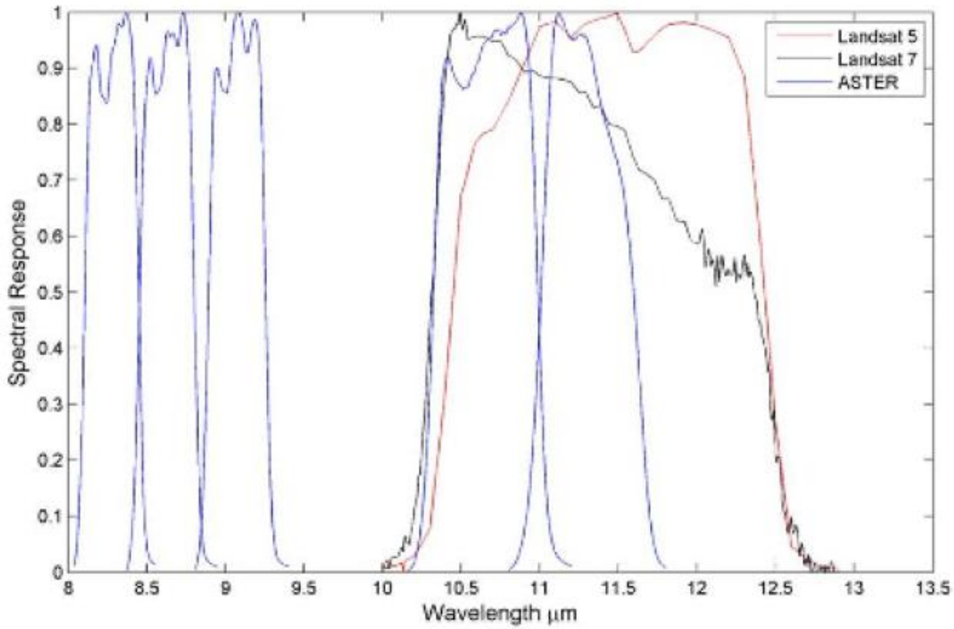
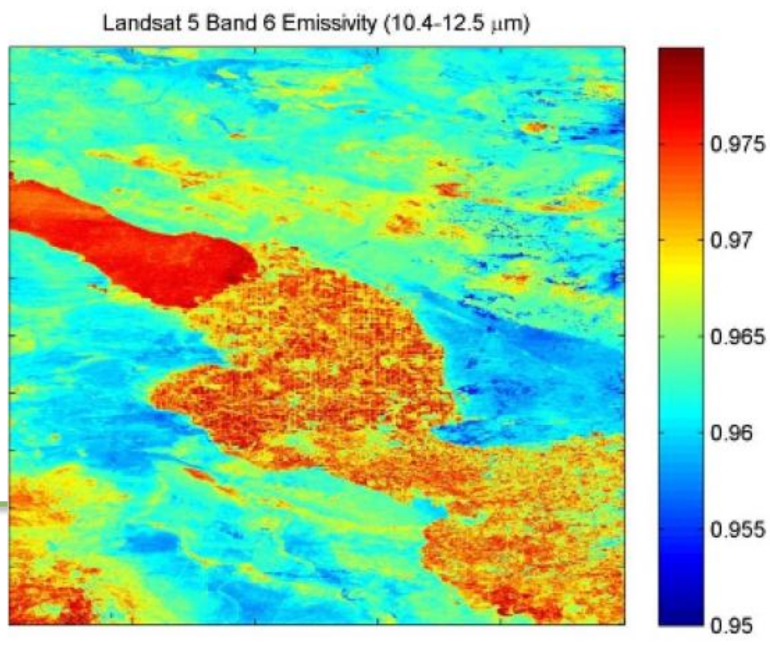




H	T
	⋮
	27
	25
	9999
	9999
2000	⋮
1000	
0	



Landsat 5
Landsat 7
ASTER
Spectral Response
Wavelength μm



Landsat 5 Band 6 Emissivity (10.4-12.5 μm)
0.975
0.97
0.965
0.96
0.955
0.95

A Land Surface Temperature Product

Timeline: Year 1 Define Approach

- identify limitations
- identify filters
- perform sensitivity analysis
- identify QC issues

Implement & Test methodology

Year 2 Refine Algorithms and extend approach to Global database.

Evaluate initial products.

- compare to ASTER/MODIS
- compare to truth
- user evaluation

Year 3 Refine Global Algorithm based on Year 2 results

- validate at range of trusted sites
- deliver final tools to USGS

A Land Surface Temperature "trial" Product

Timeline: Year 1 Define Approach

- identify limitations
- identify filters
- perform sensitivity analysis
- identify QC issues

Implement & Test methodology

Caveats: North America only

No cloud filter(Default to NAALSED emissivity)

May have no correction for current vegetation condition

QC map may be limited or non existent

Limited Formal Validation of Implementation