Validation of Satellite AIRS LST/LSE Products Using Aircraft Observations

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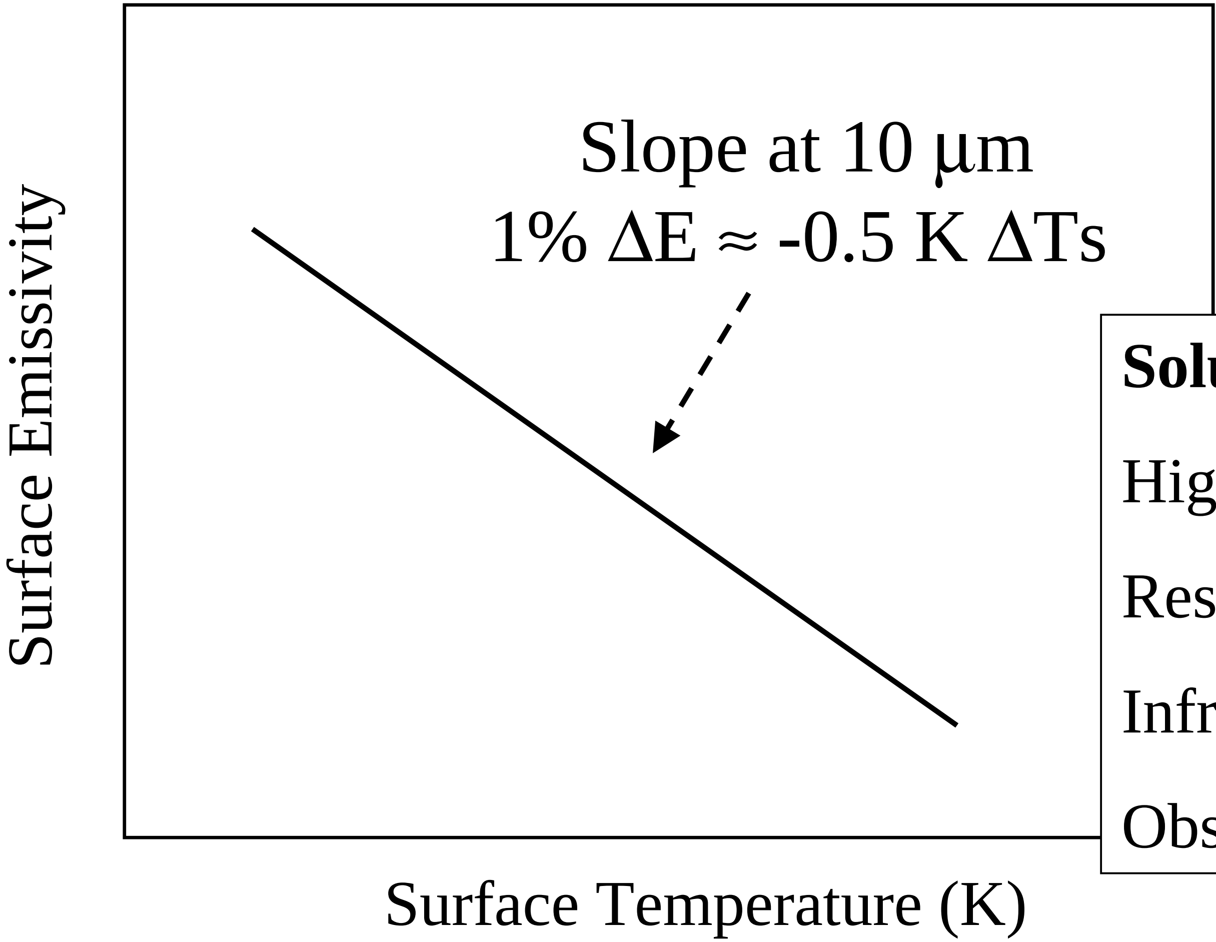
Topics:

- Importance of IR surface reflection at high spectral resolution.
- Importance of vegetation fraction in explaining the variations in IR emissivity.

30 October 2003 ITSC-13, Sainte-Adele, Canada

The Correlation Problem:

For broad-band sensors, such as HIRS, GOES, MODIS, errors in the IR emissivity and surface temperature are highly correlated.



Solution:

High Spectral

Resolution

Infrared

Observations

Infrared Radiative Transfer Equation (lambertian surface)

$$N_\nu^{\uparrow} = \underbrace{\int B_\nu(T(P))\,d\tau_\nu}_{N_\nu^{atm\uparrow}} + \underbrace{\tau_\nu^{tot} \cdot e_\nu \cdot B_\nu(T_S)}_{\text{Surface Emission}} + \underbrace{\tau_\nu^{tot} \cdot (1 - e_\nu) \cdot \overline{N}_\nu^{\downarrow}}_{\text{Surface Reflection}}$$

Formal Solution

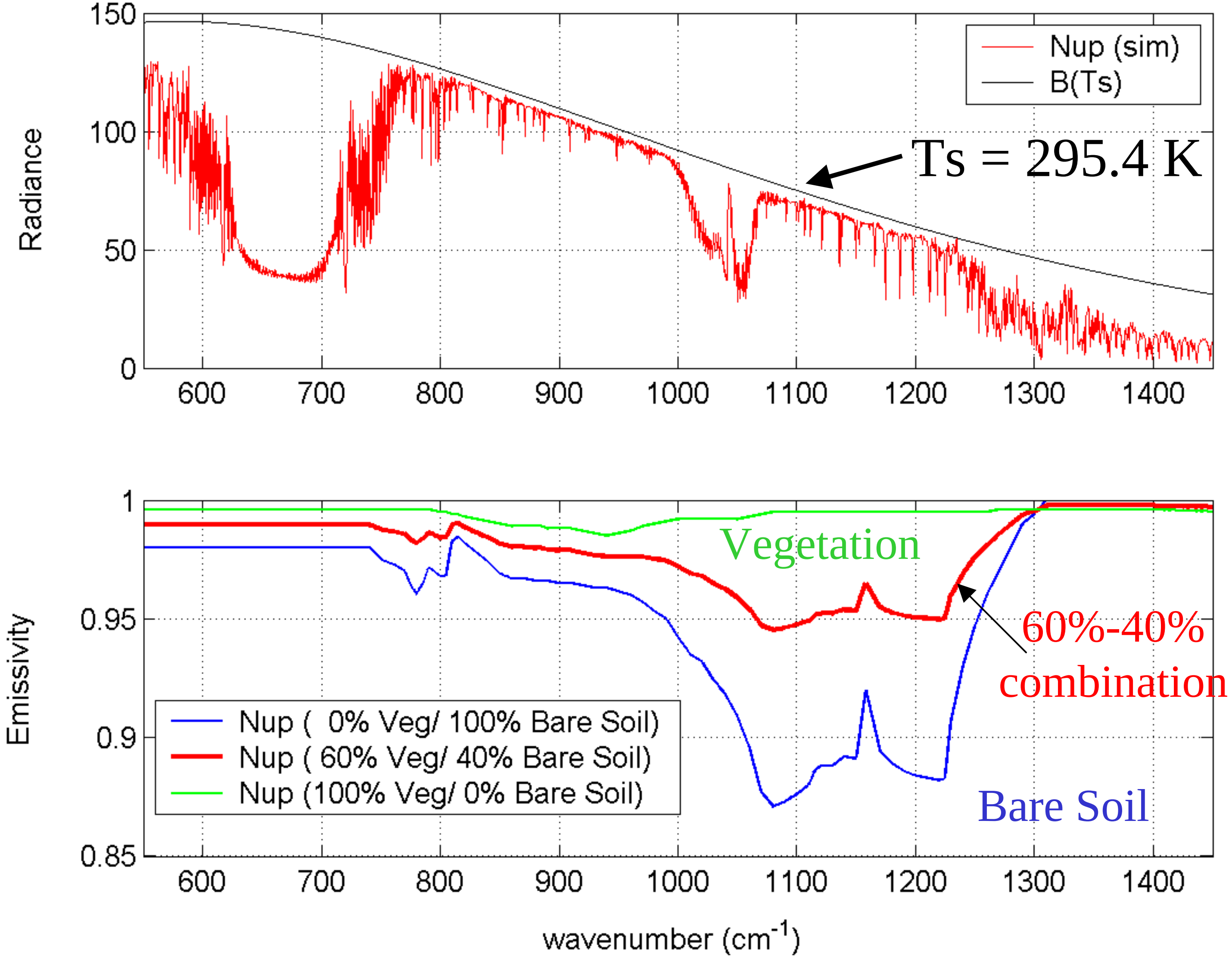
$$e_\nu = \frac{(N_\nu^{obs\uparrow} - N_\nu^{atm\uparrow}) / \tau_\nu^{tot} - \overline{N}_\nu^{\downarrow}}{B_\nu(T_S) - \overline{N}_\nu^{\downarrow}}$$

Analytic Derivative

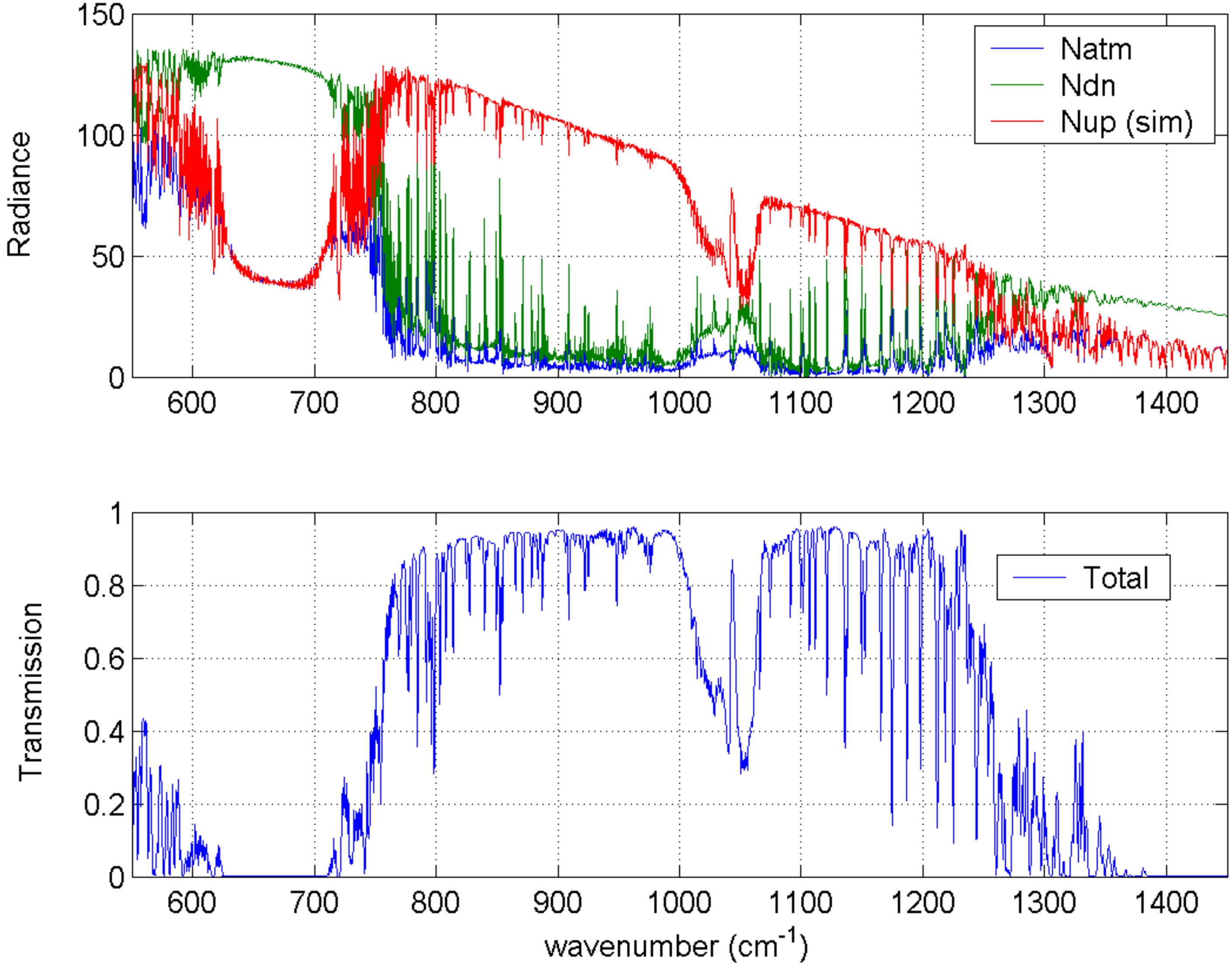
$$\frac{de_\nu}{e_\nu} = \frac{-B_\nu(T_S)}{B_\nu(T_S) - \overline{N}_\nu^{\downarrow}} \bullet \frac{dB_\nu(T_S)}{B_\nu(T_S)dTs} dTs$$

Varies on/off spectral lines !!!

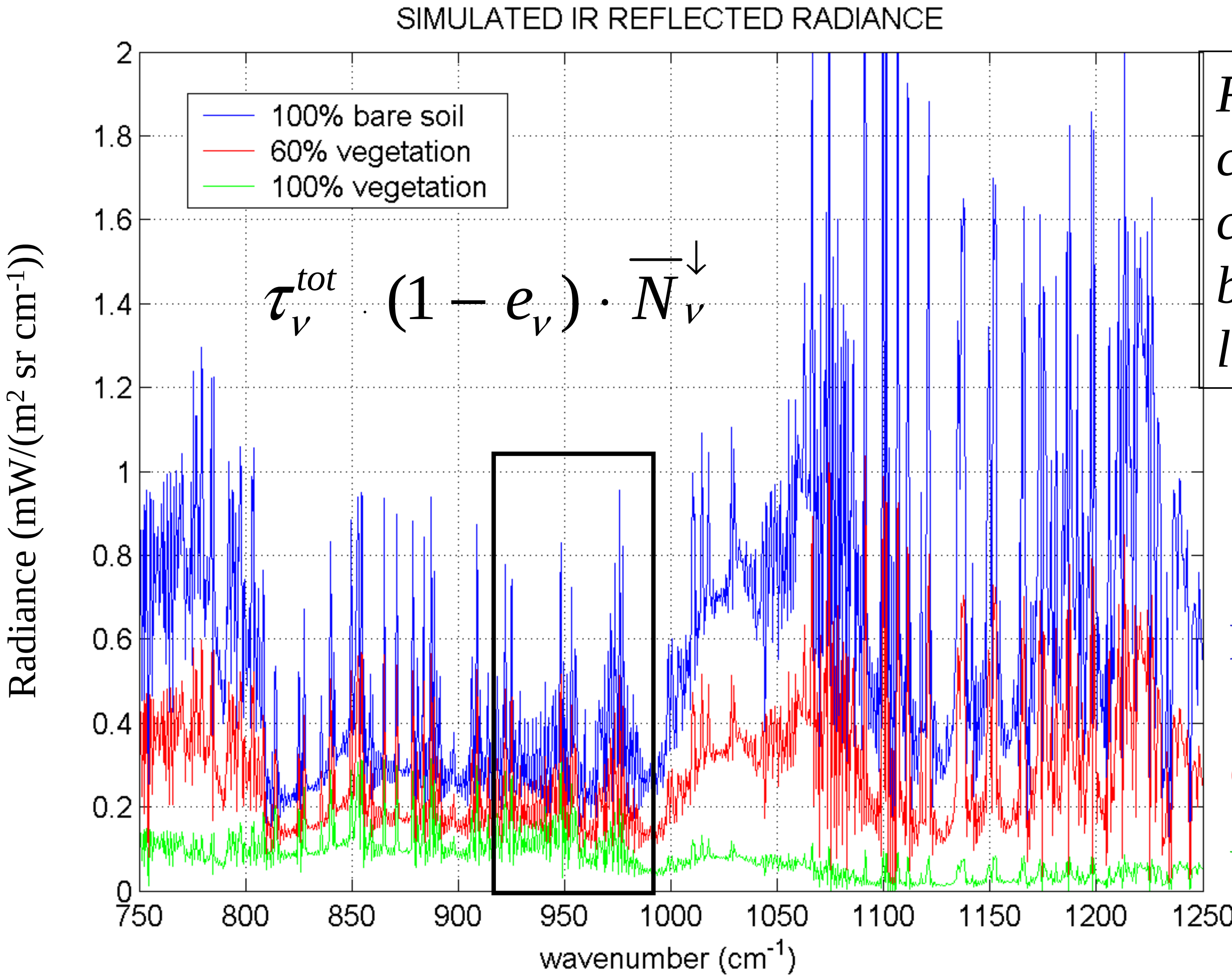
Simulated Radiance (Using measured emissivity spectrum)



Simulated Radiance (S-HIS resolution = 1 cm^{-1} apodized)



Simulated IR Reflected Radiance Contribution to TOA Radiance



Reflected contribution can be large !

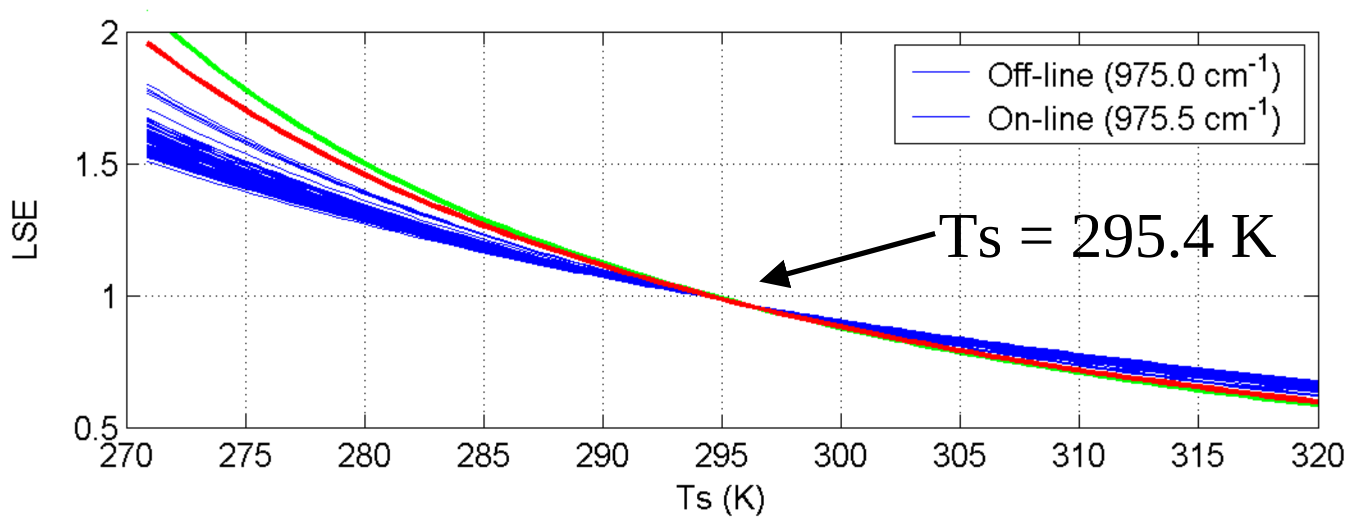
Bare Soil

60% Veg.

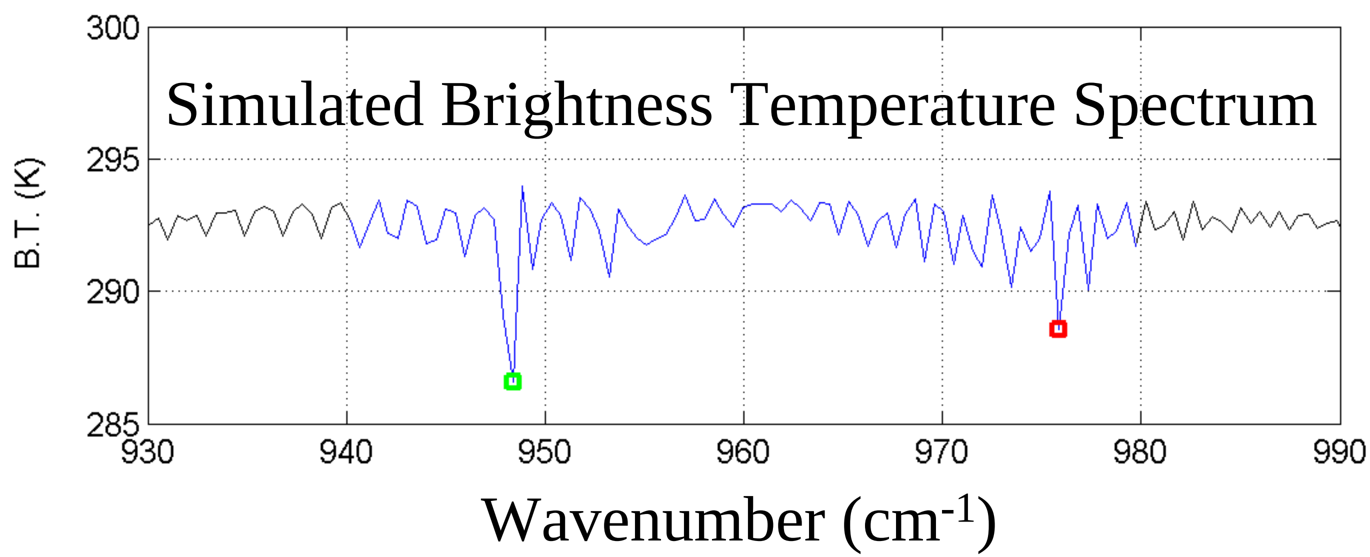
Vegetation

On-line channels have a greater rate of change, dE/dTs !

Emissivity
vs.
Surface
Temperature

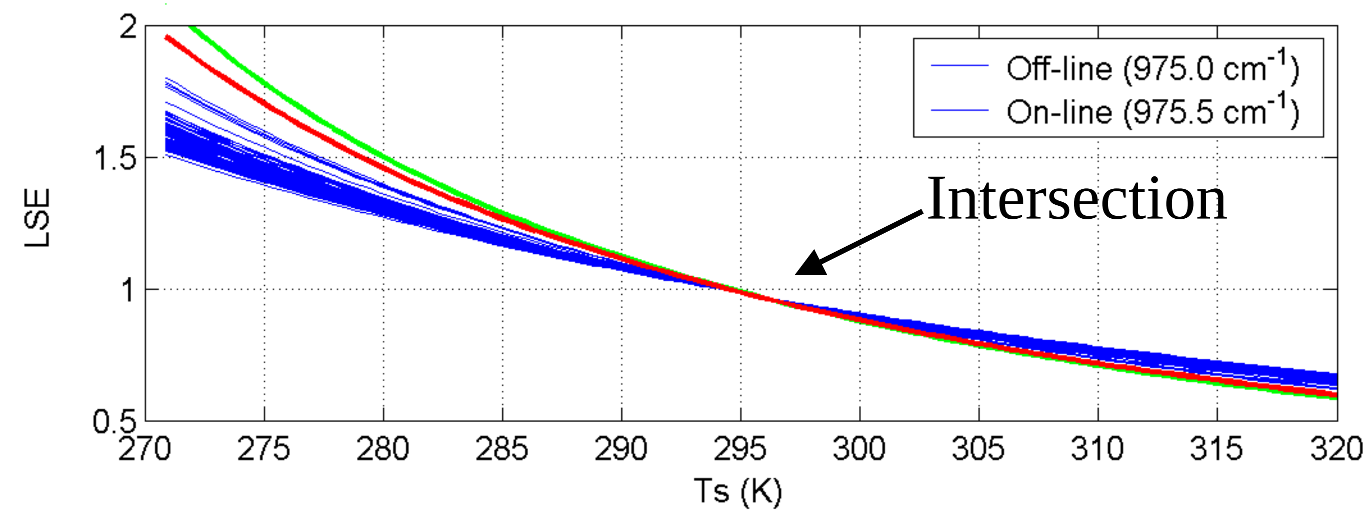


B.T. (K)

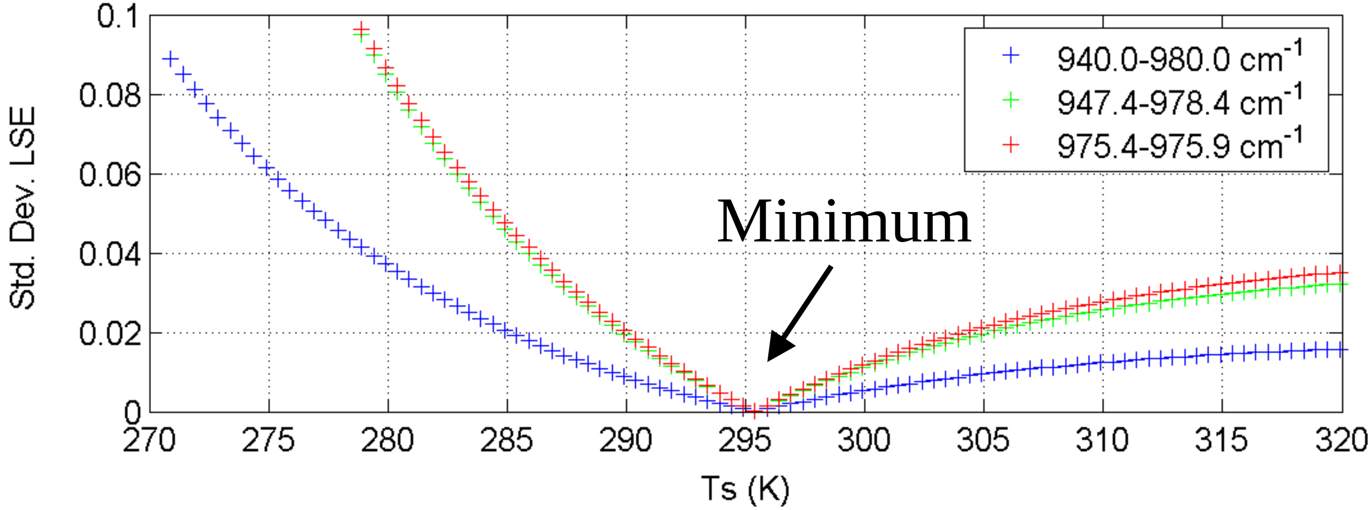


The value of Ts can be determined from the variance of emissivity as a function of surface temperature !!!

Emissivity vs. Surface Temperature



Std. Dev. E(Ts)

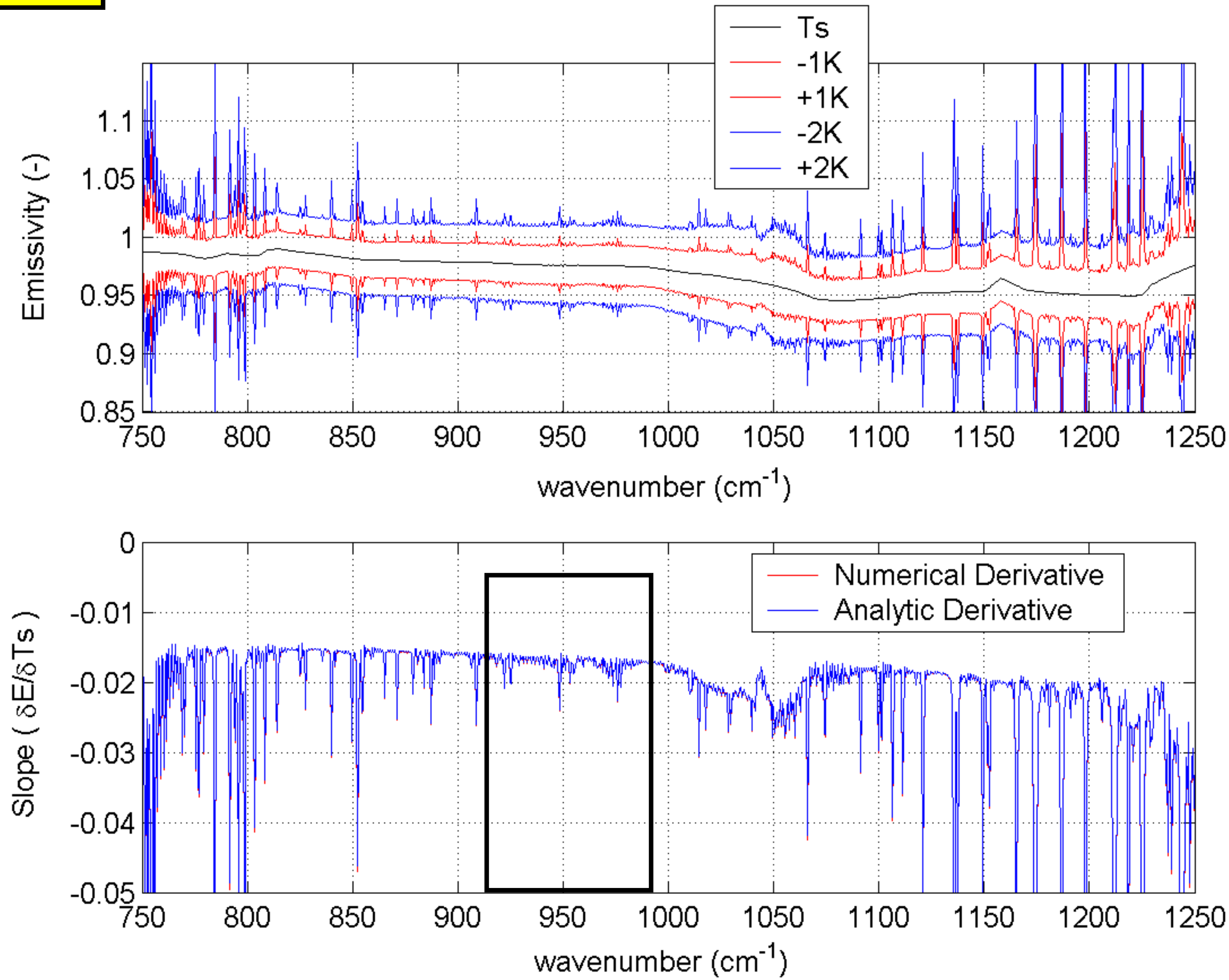


KEY RESULT

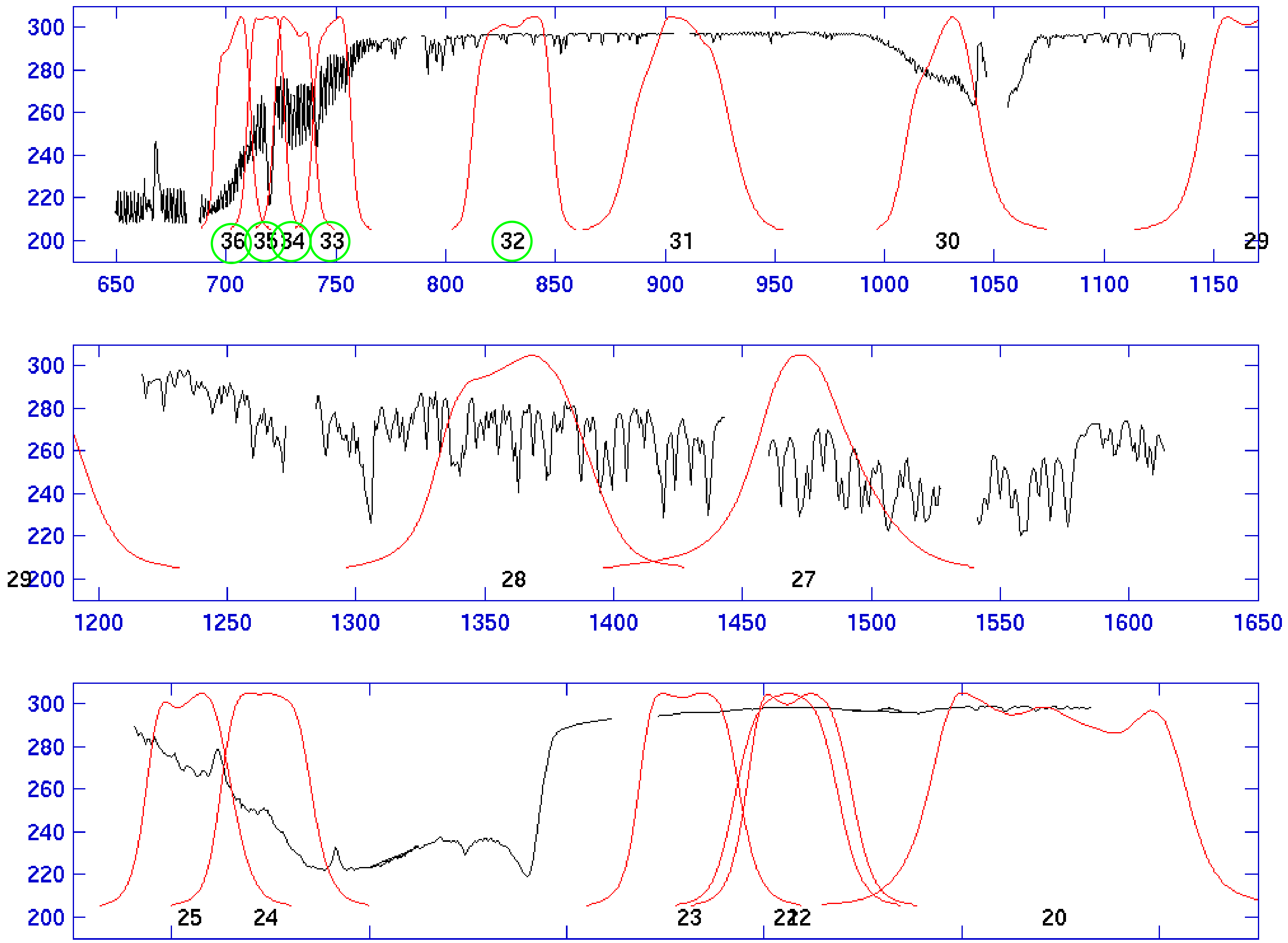
The change in emissivity with Ts varies on and off atmospheric absorption lines!

E_ν

$\frac{dE_\nu}{dTs}$



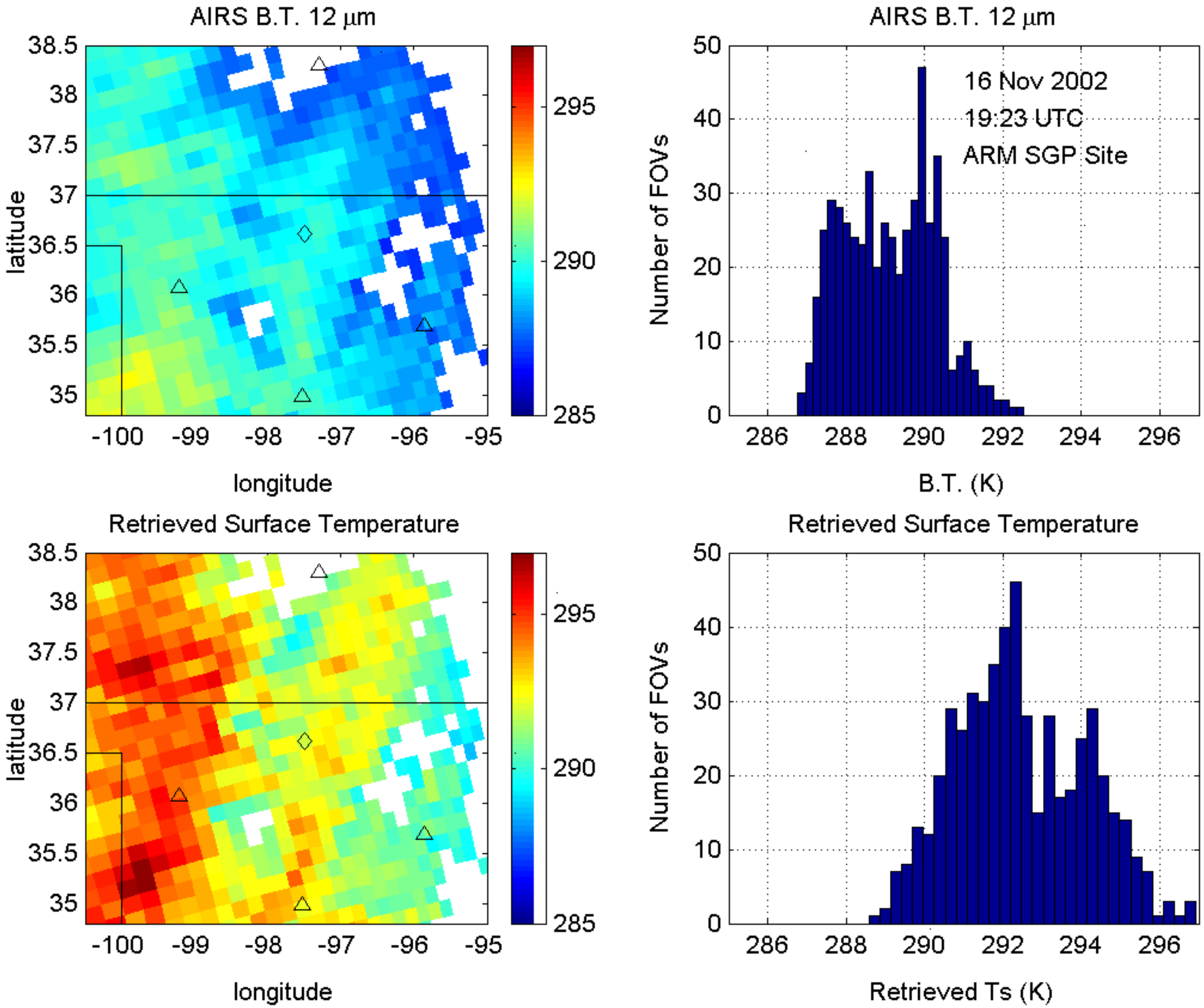
AIRS Spectrum compared to MODIS Bands



LST is 2 to 4 degrees warmer than 12 μm brightness temperature.

AIRS
12 μm
B.T.
(K)

LST
(K)



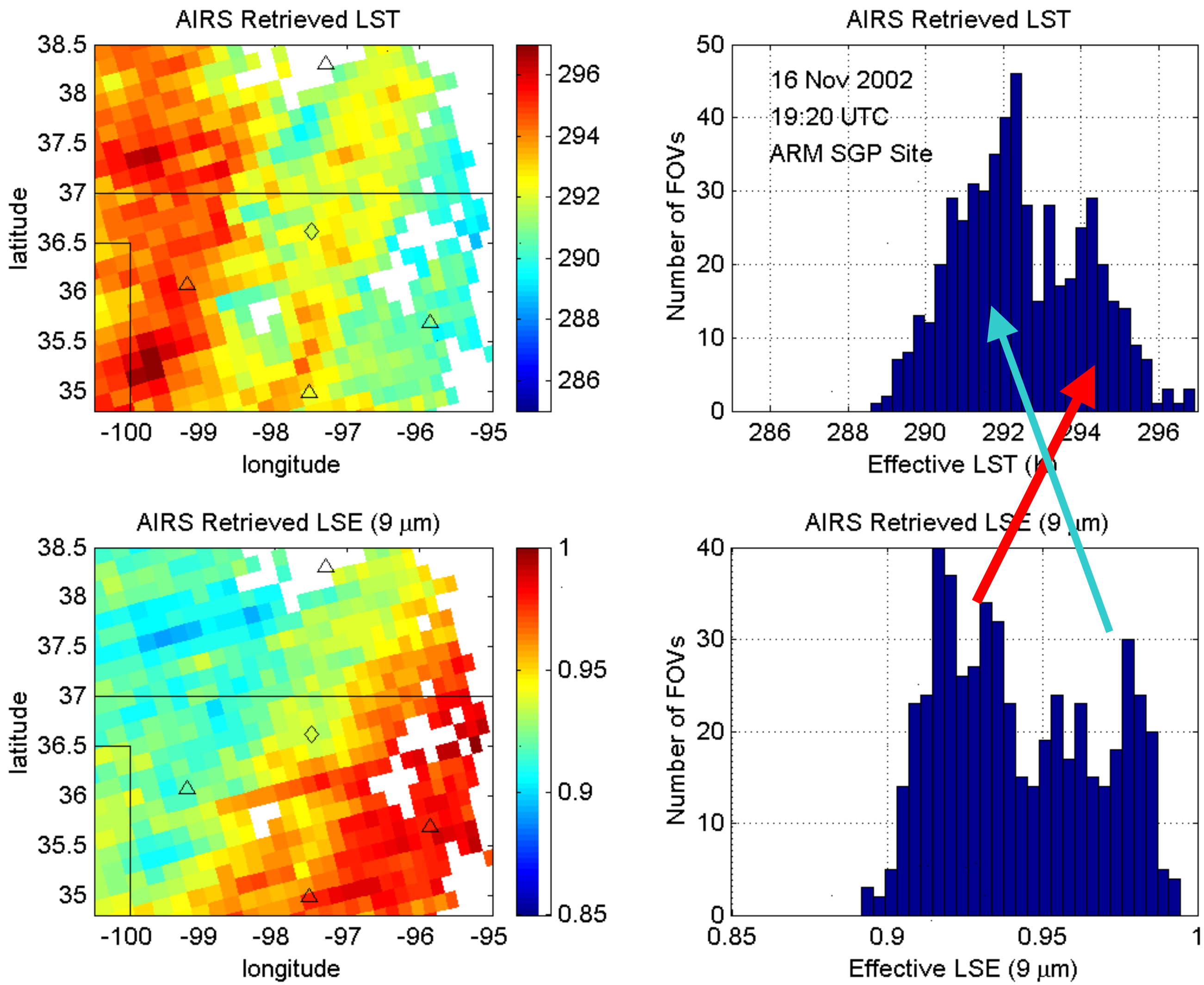
Research
Product

AIRS Observation from 16 Nov. 2002 of DOE ARM Site

High emissivity (grass) is cooler than low emissivity (exposed soil).

LST (K)

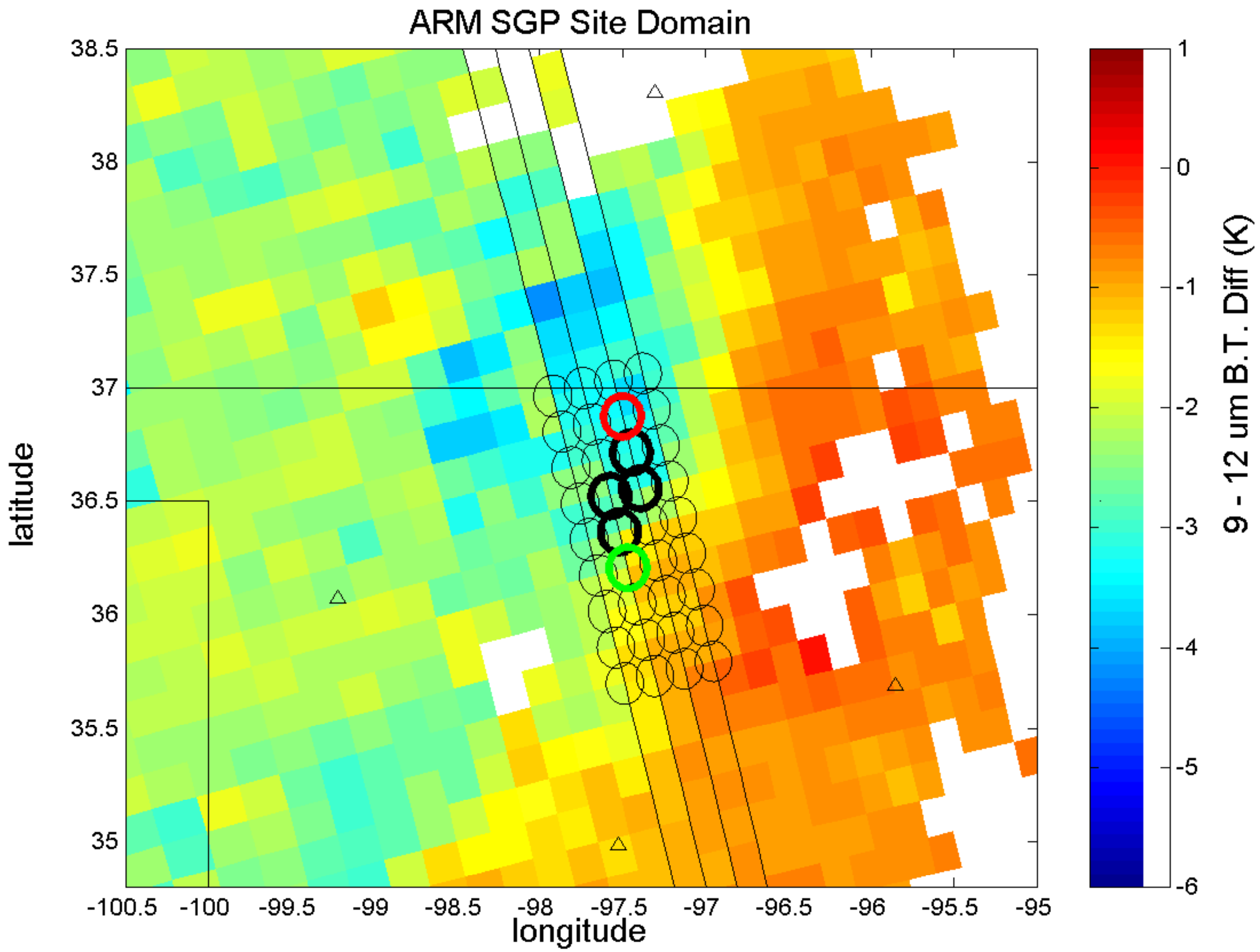
LSE (9 µm)



Research Product

Surface Temperature and Emissivity from UW "research" Product

DOE ARM central facility is near the pasture/wheat transition.
Inspect emissivity spectra near the site derived from AIRS data.



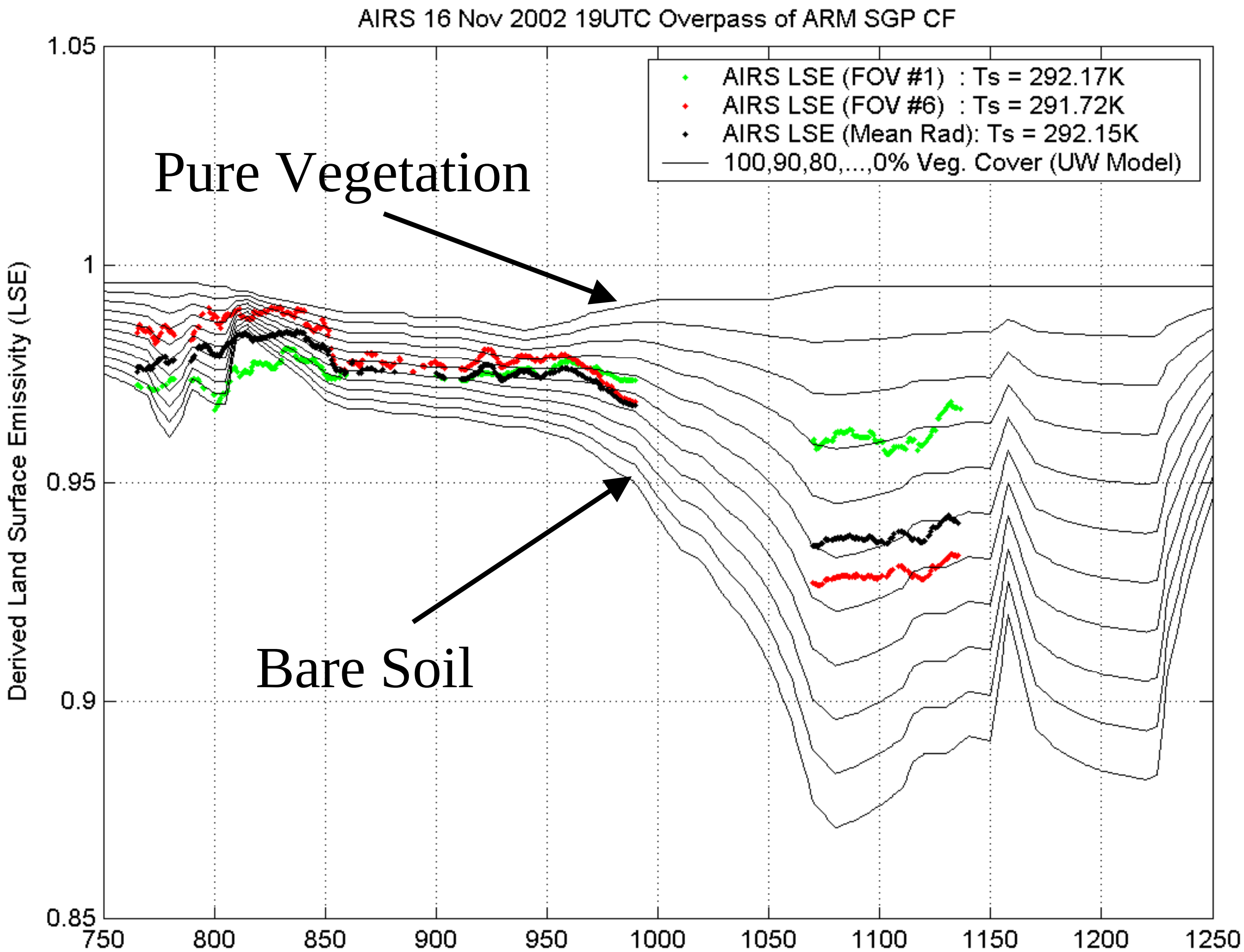
B.T.
Diff
9-12 μm

ARM SGP 16 Nov 2002 19 UTC Case Study

KEY RESULT

AIRS emissivity is consistent with a linear combination of pure scene types. This implies a single vegetation fraction can explain most of the variation in the IR spectra over land.

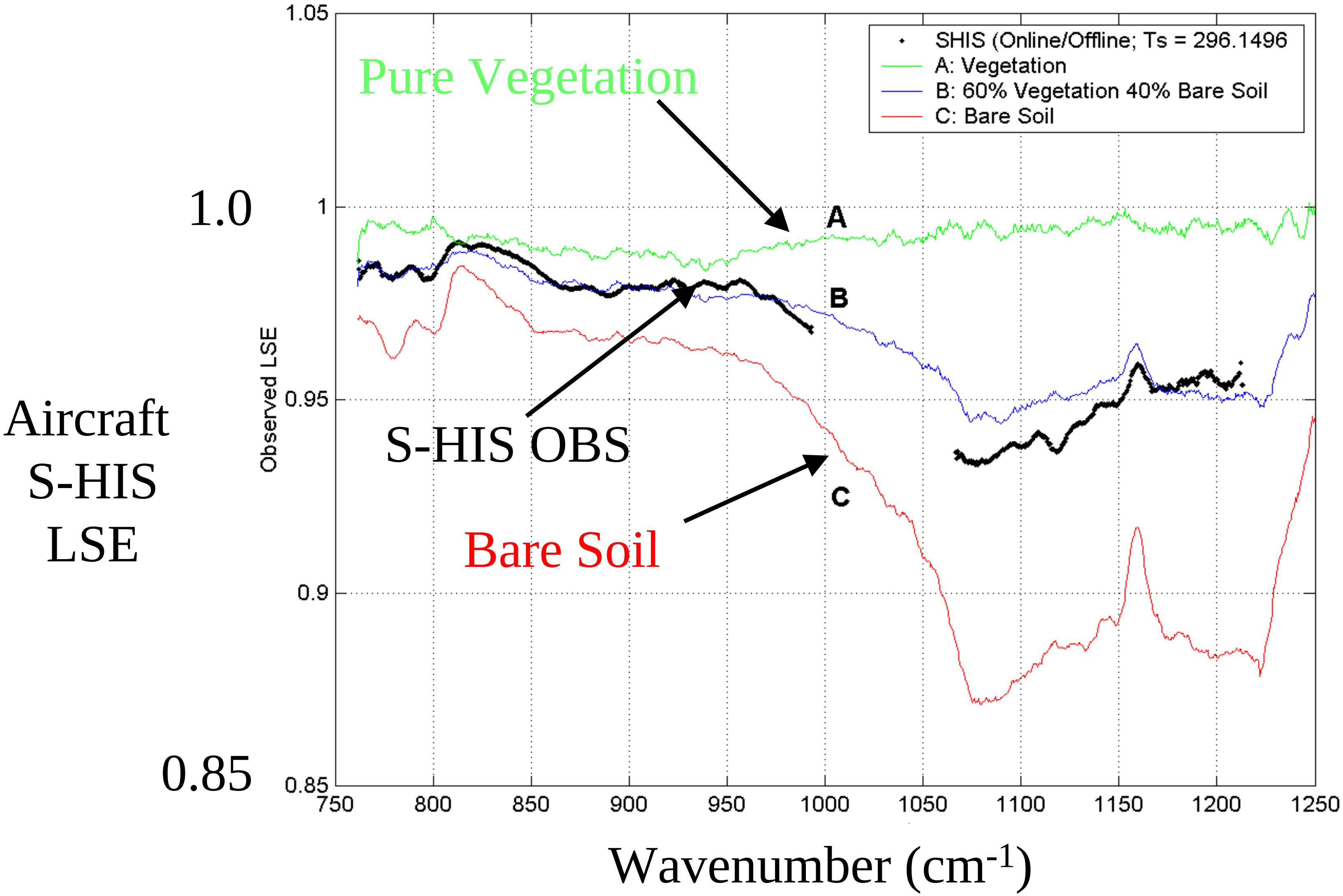
LSE from AIRS Radiance



Wavenumber (cm^{-1})

Research Product

Aircraft validation measurements are also consistent with a linear combination of vegetation and bare soil.



Key Results

1. The high spectral resolution structure of the surface reflection can be used to determine the value of Ts for which e_ν is constant across spectral absorption/emission lines (locally).

2. Using ground-based measurements at the ARM SGP site, area averaged emissivity can be accurately represented using a single parameter (vegetation fraction) and two pure scene types; vegetation (grass) and bare soil (quartz signature).

Study Questions

- What is the best way to make use of the variation of emissivity with respect to surface temperature across spectral absorption lines in retrieval and data assimilation?
    - Optimal channels to selection.
    - Error characteristics of chosen method.

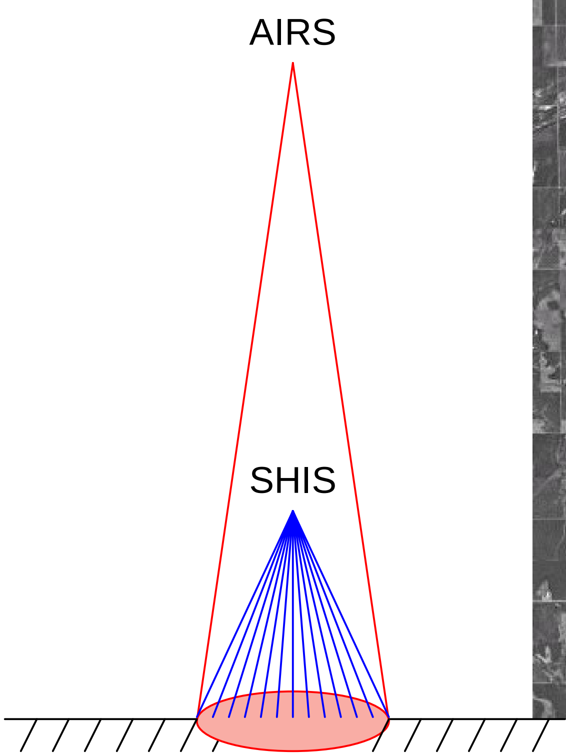
- What improvements are needed in radiative transfer models to take advantage of this high spectral information?
    - Spectroscopy of weak absorption lines (?<5%).
    - Accurate computation of IR reflected flux.

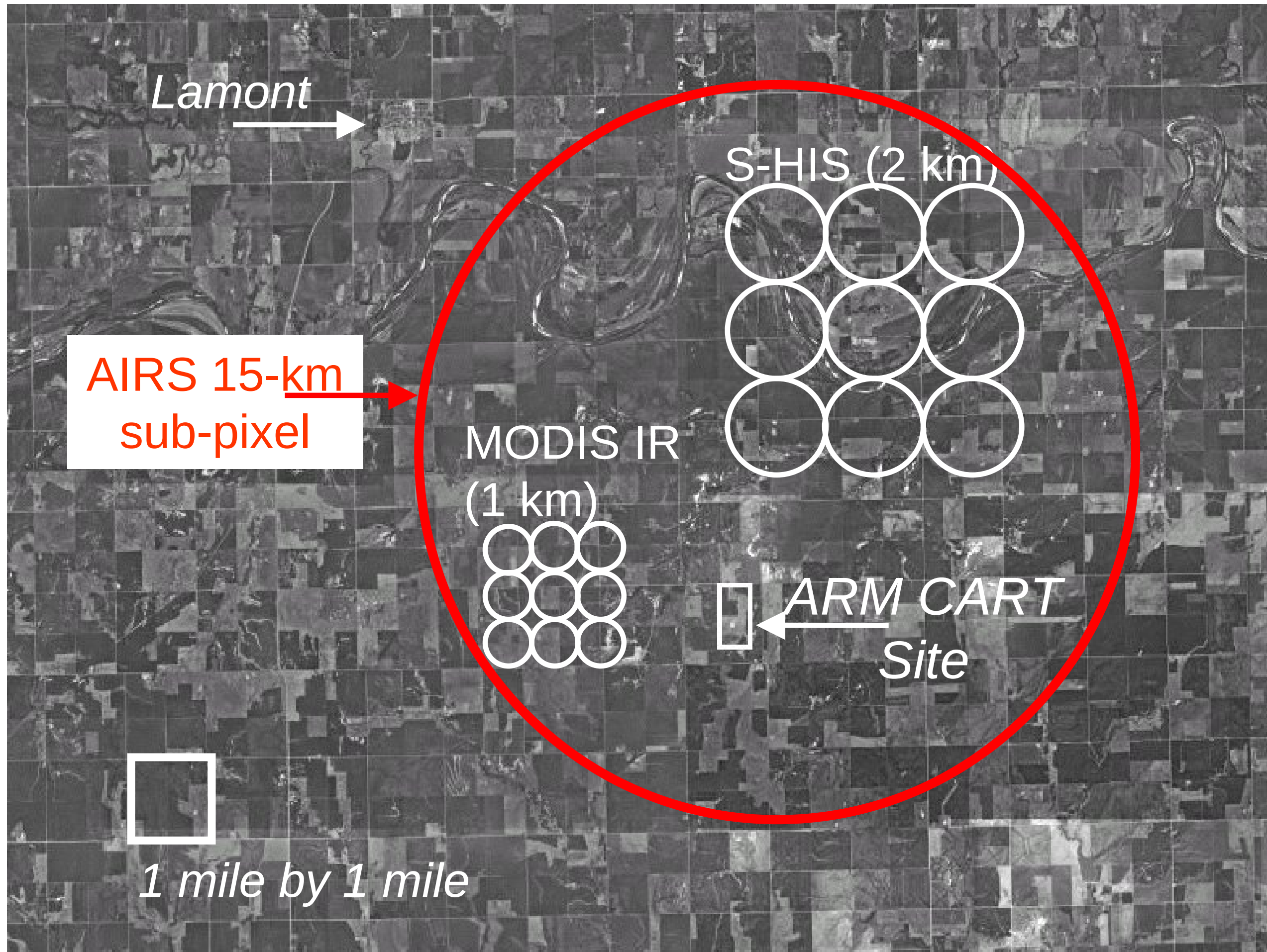
- Can the results from the ARM site be generalized?
    - Derive vegetation fraction from AIRS data globally?
    - Do we need more measurements of pure scene types?

Validation: The scale problem

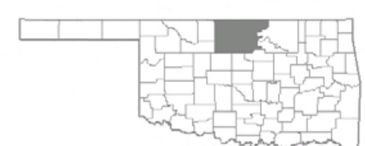
Farm Fields < 0.5 km; Aircraft ≈ 2 km; AIRS ≈ 15 km

View Angles





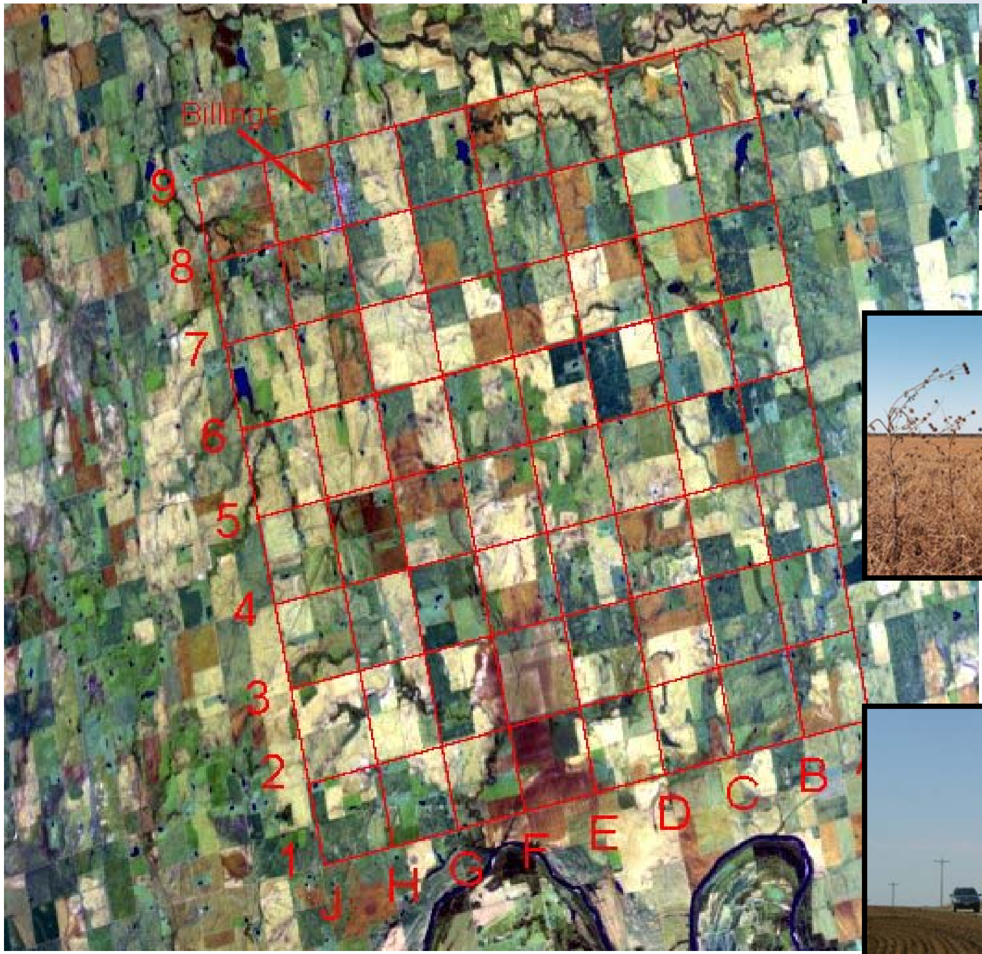
Aerial photo from http://terraserver.homeadvisor.msn.com/



U.S. Department of Energy ARM Site

Survey Grid

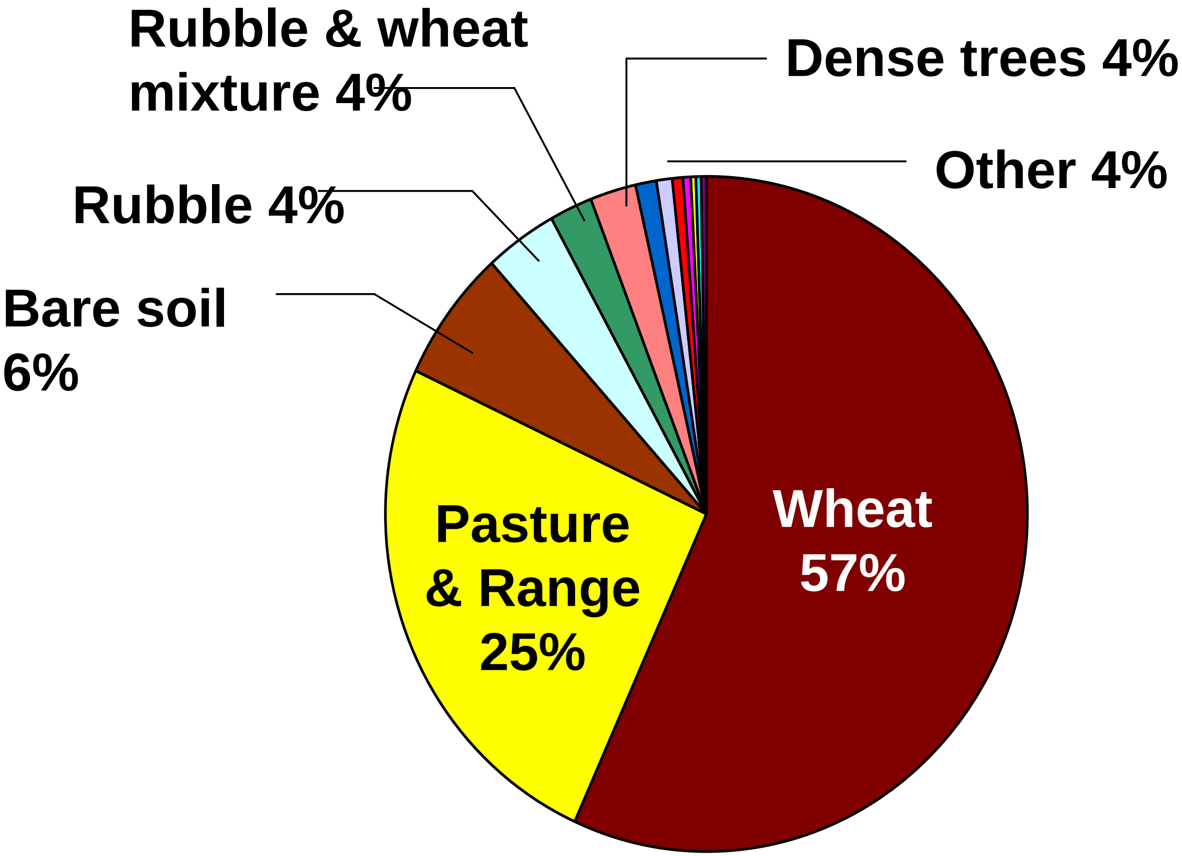
9 mile (15 km) square survey grid



NASA ER-2: 22 Nov 2002

ARM Site Land Use Survey

(Osborne, 2003)

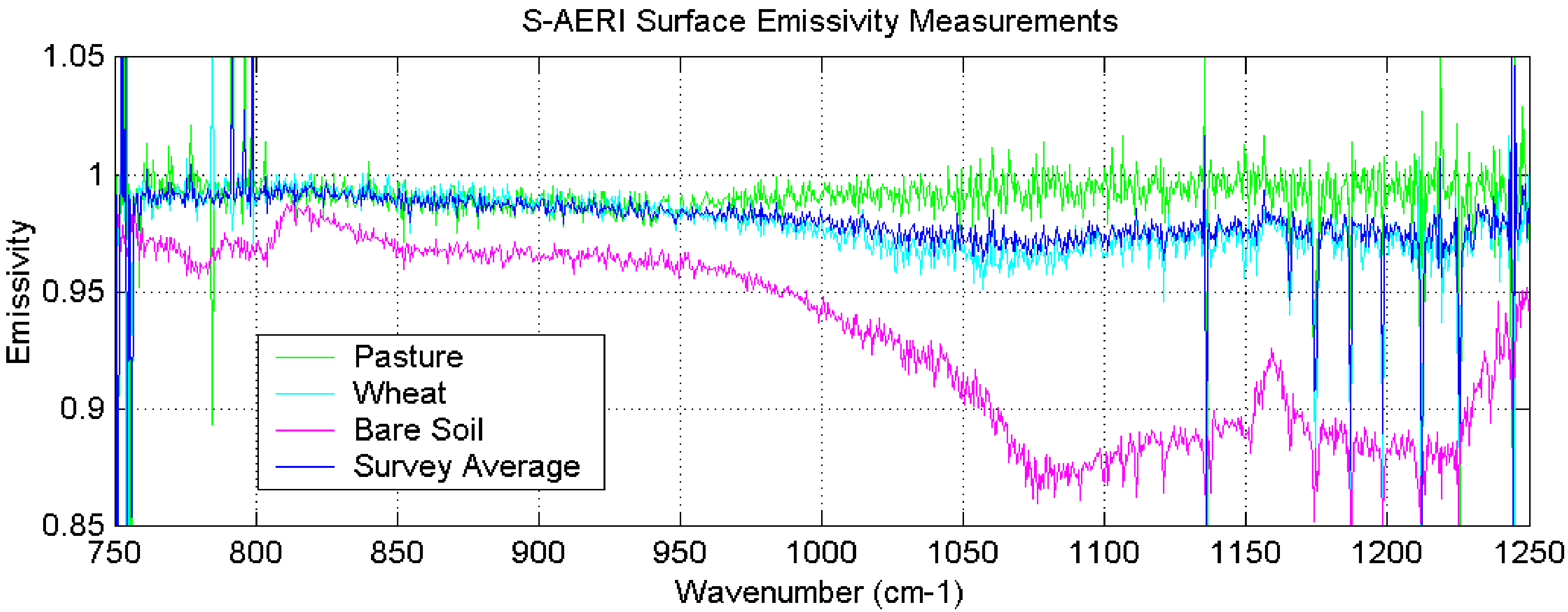


November 2002; 63 square mile area.

- Two land cover types dominate: wheat fields and pasture (grassland).

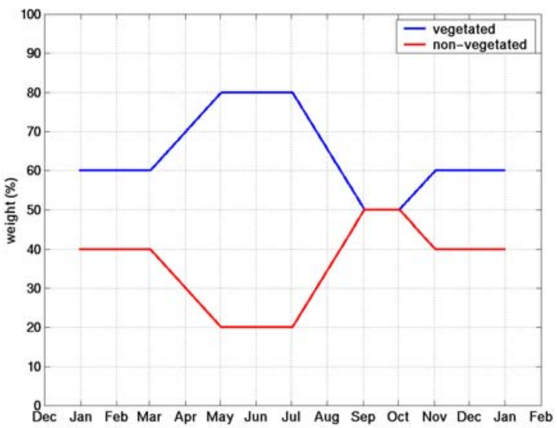
Emissivity Survey

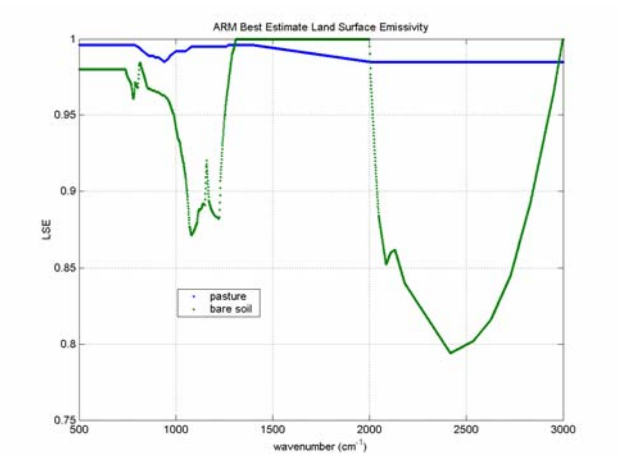
- ARM SGP site is dominated by two land cover types "pasture" and "wheat".
- We noticed that the measured wheat field emissivity can be approximated by a linear combination of pure scene types; bare soil and grass.

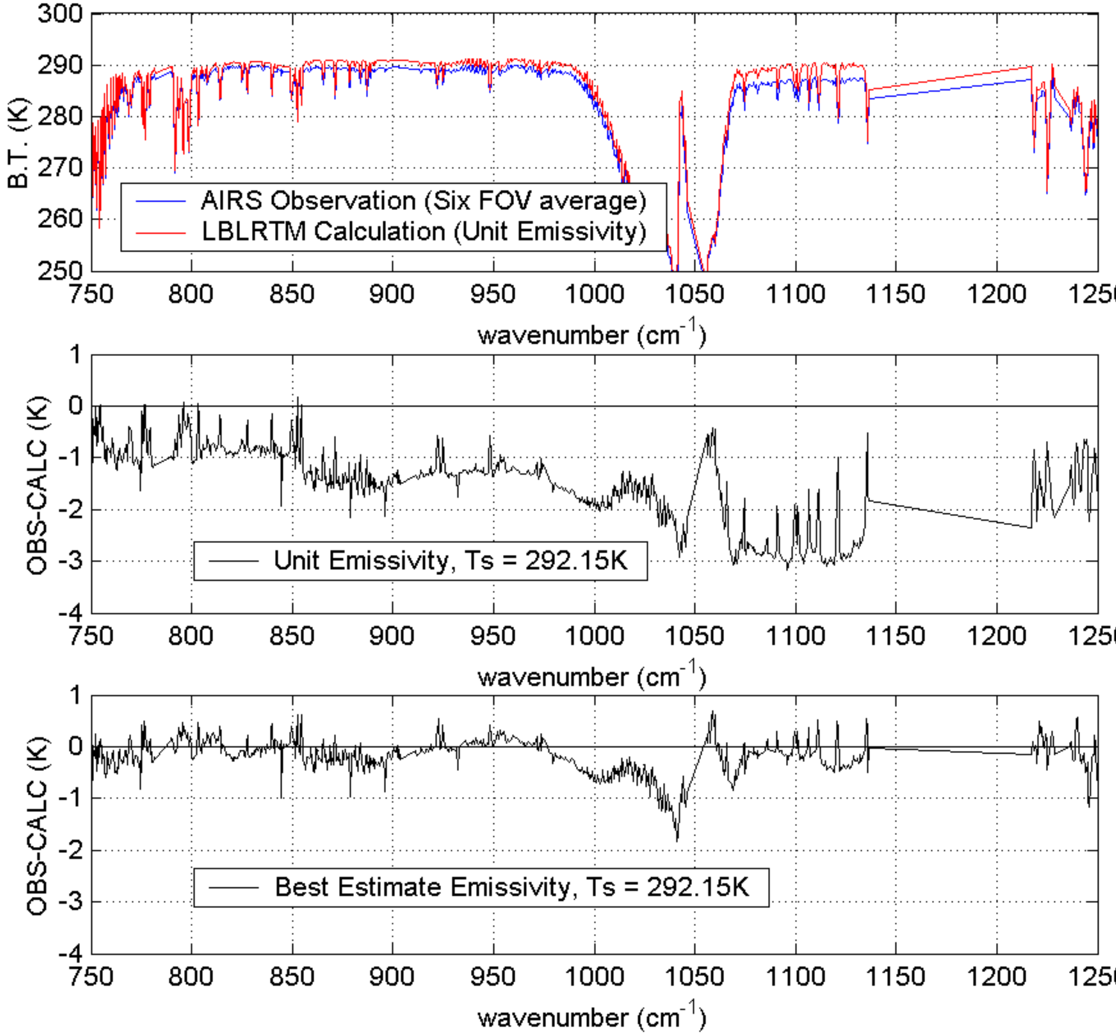


ARM SGP LST/LSE "Best Estimate"

- Formulated in April 2001 to supply the surface contribution to the ARM/AIRS validation product developed by D. Tobin.

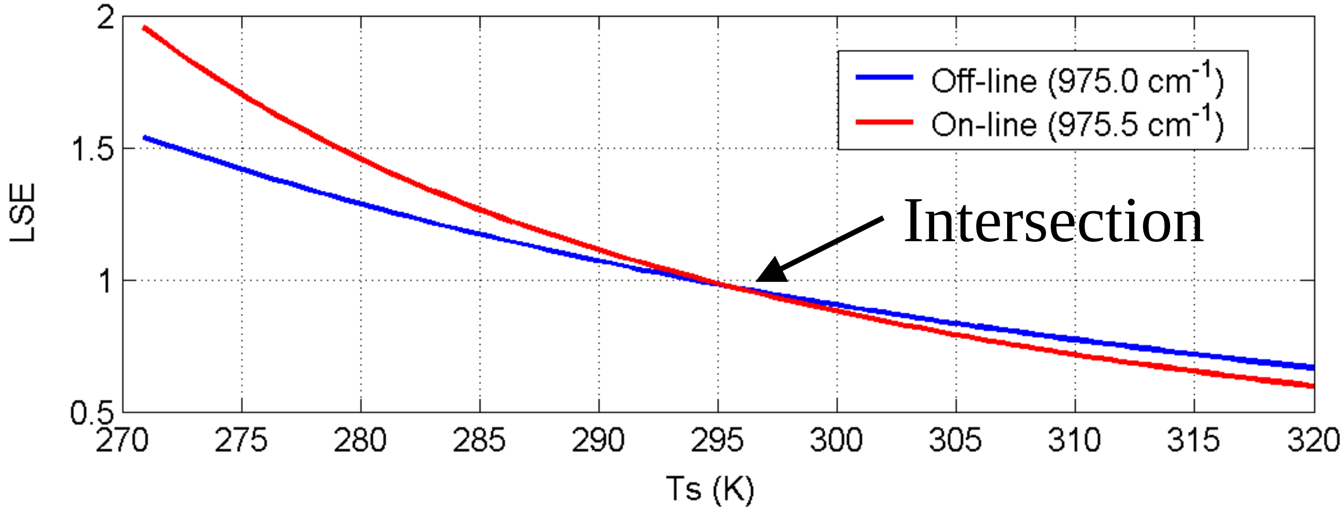




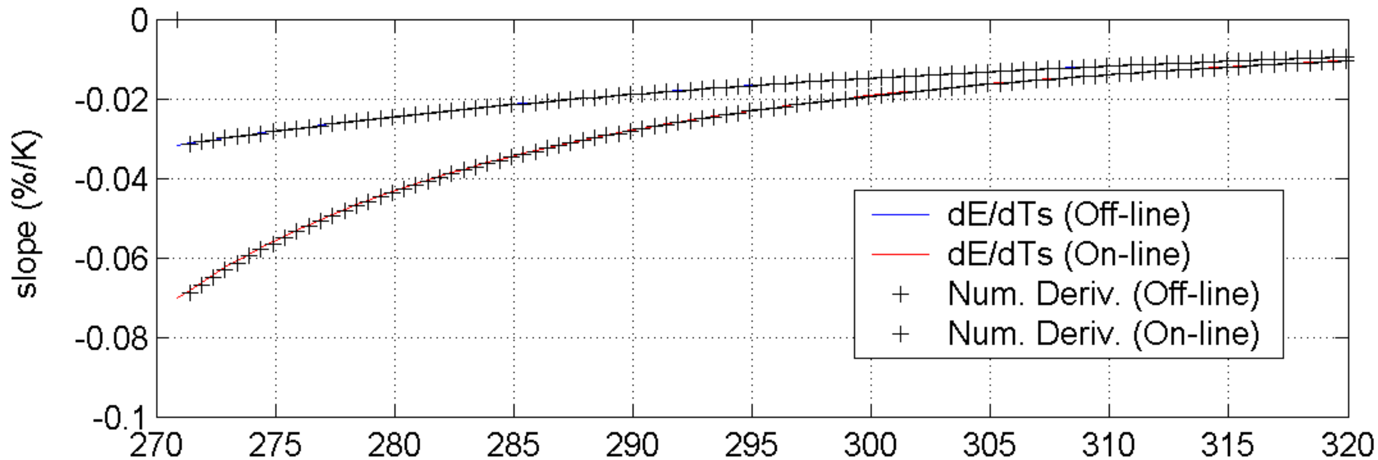


Note the slope difference "on-line" versus "off-line" !

Emissivity
vs.
Surface
Temperature



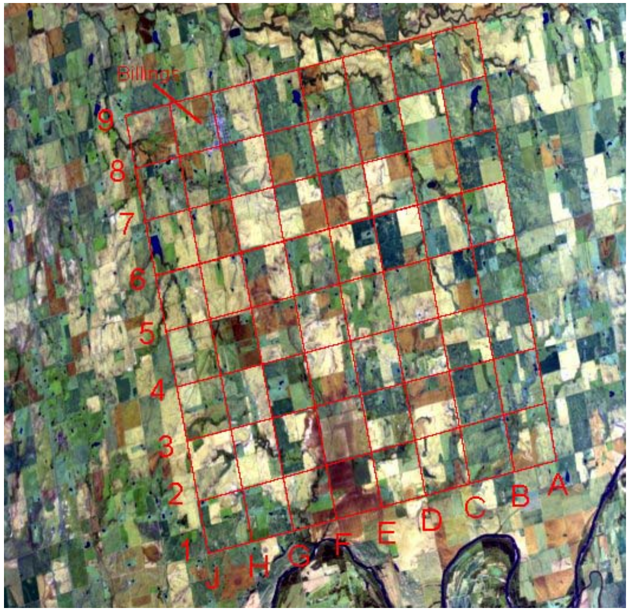
SLOPE
dE/dTs



Surface Temperature (K)

$$\frac{de_\nu}{e_\nu} = \frac{-B_\nu(T_S)}{B_\nu(T_S) - \overline{N}_\nu^{\downarrow}} \bullet \frac{dB_\nu(T_S)}{B_\nu(T_S)dTs} dTs$$

The Problem of Mixed Scenes



9 miles (15 km)

The observed radiance is a linear combination of uniform scenes.

$$R_\nu^{OBS} = \sum_{i,j} w_{i,j} \cdot I_{i,j,\nu} + S_\nu$$

Define an Effective Emissivity and Effective Surface Temperature such that

$$\hat{\varepsilon}_\nu = \sum_{i,j} w_{i,j} \cdot \varepsilon_{i,j,\nu}$$

$$\hat{\varepsilon}_\nu \cdot B_\nu(\hat{T}_S) = \sum_{i,j} w_{i,j} \cdot \varepsilon_{i,j,\nu} \cdot B_\nu(T_{i,j,S})$$