High Spectral Resolution IR Observing & Instruments

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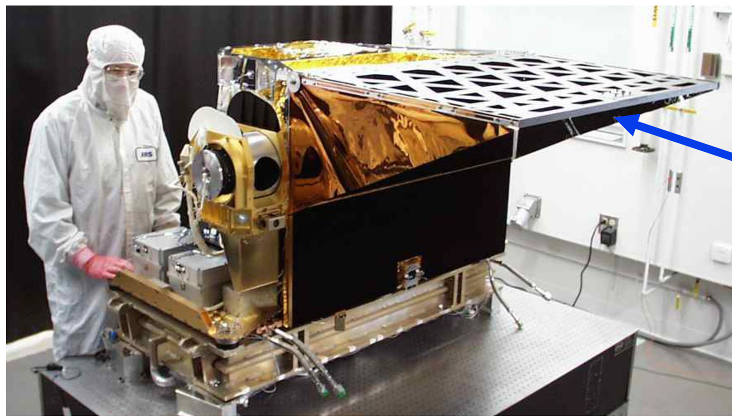
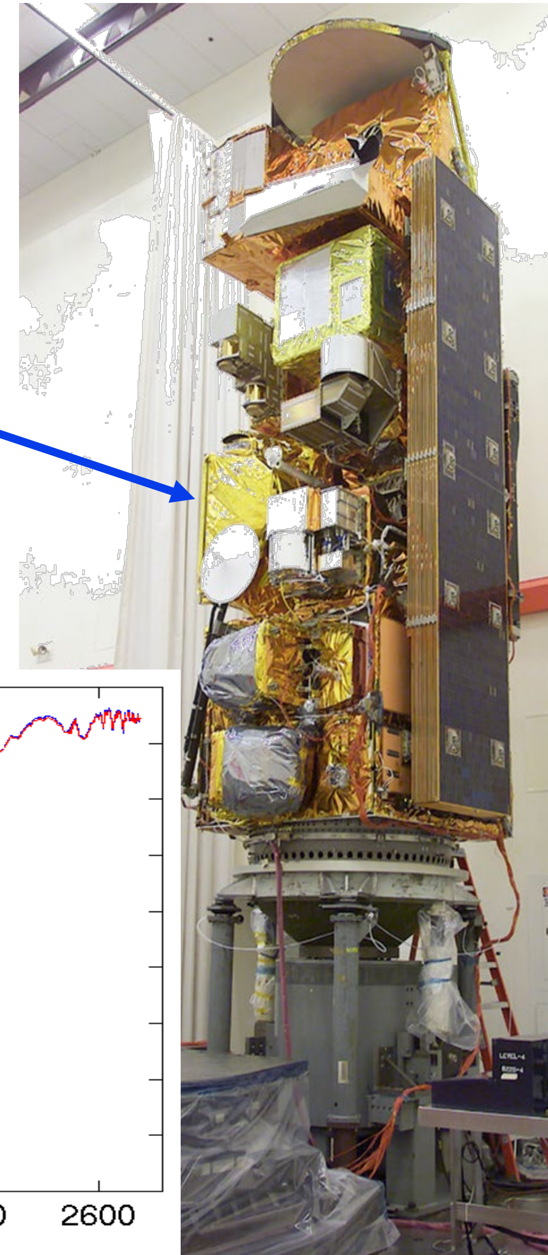
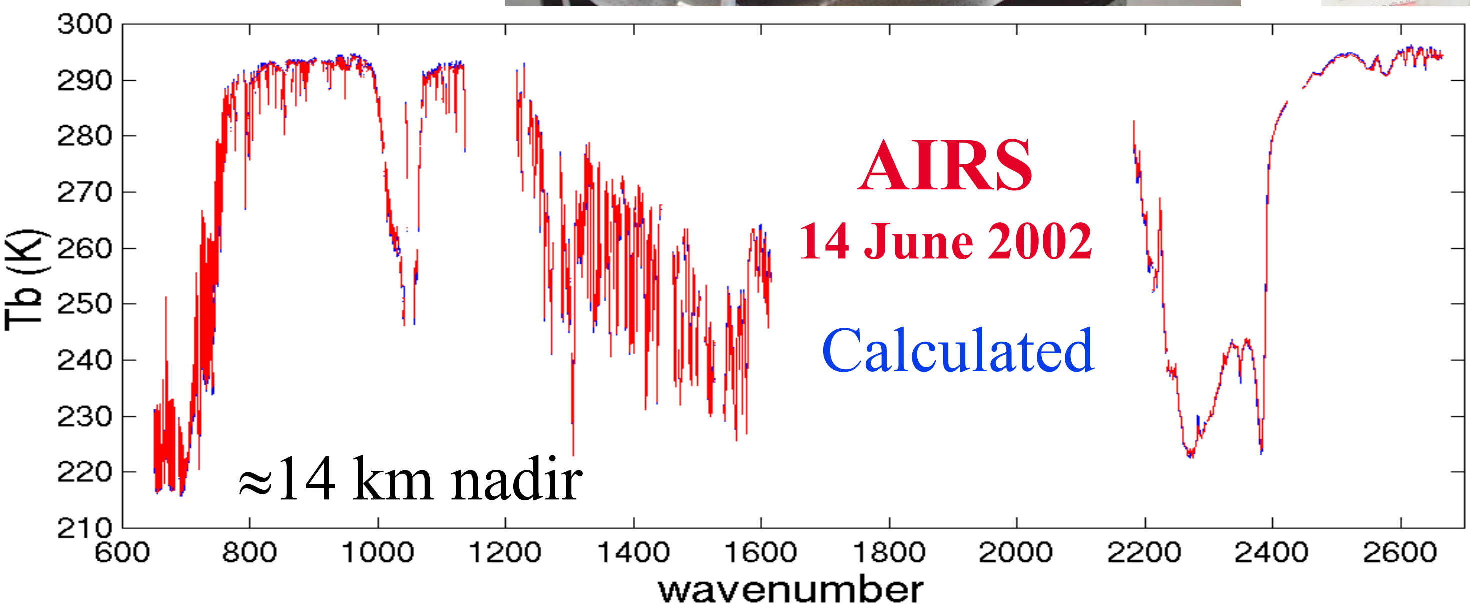
Supported by CNR-IMAA(Potenza) & EUMETSAT(Darmstadt)

AIRS: *Begins the era of High Spectral Resolution Global Sounding (4 May 2002 Launch)*

NASA Aqua







AIRS-AMSU-HSB

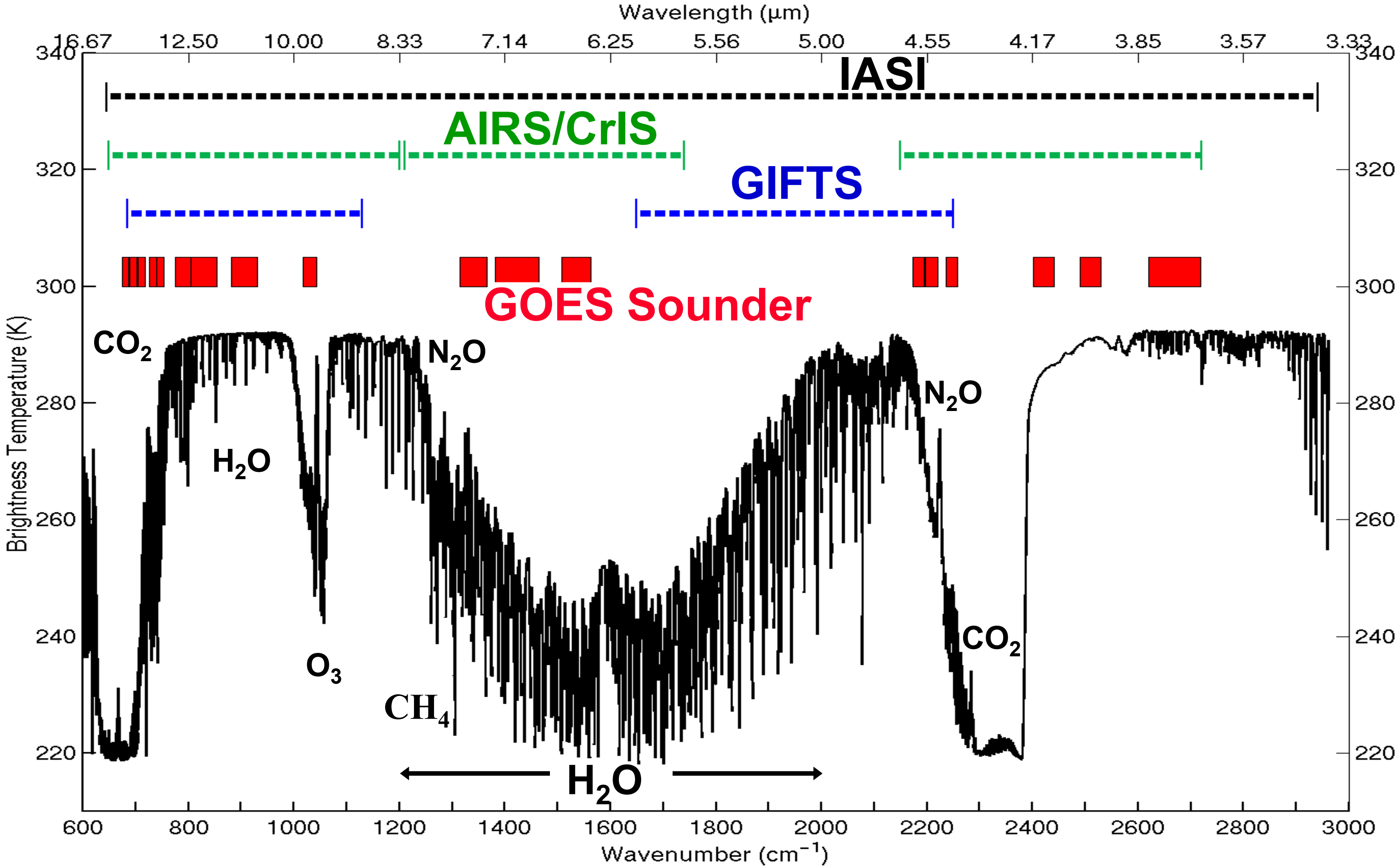
Atmospheric Infrared Sounder

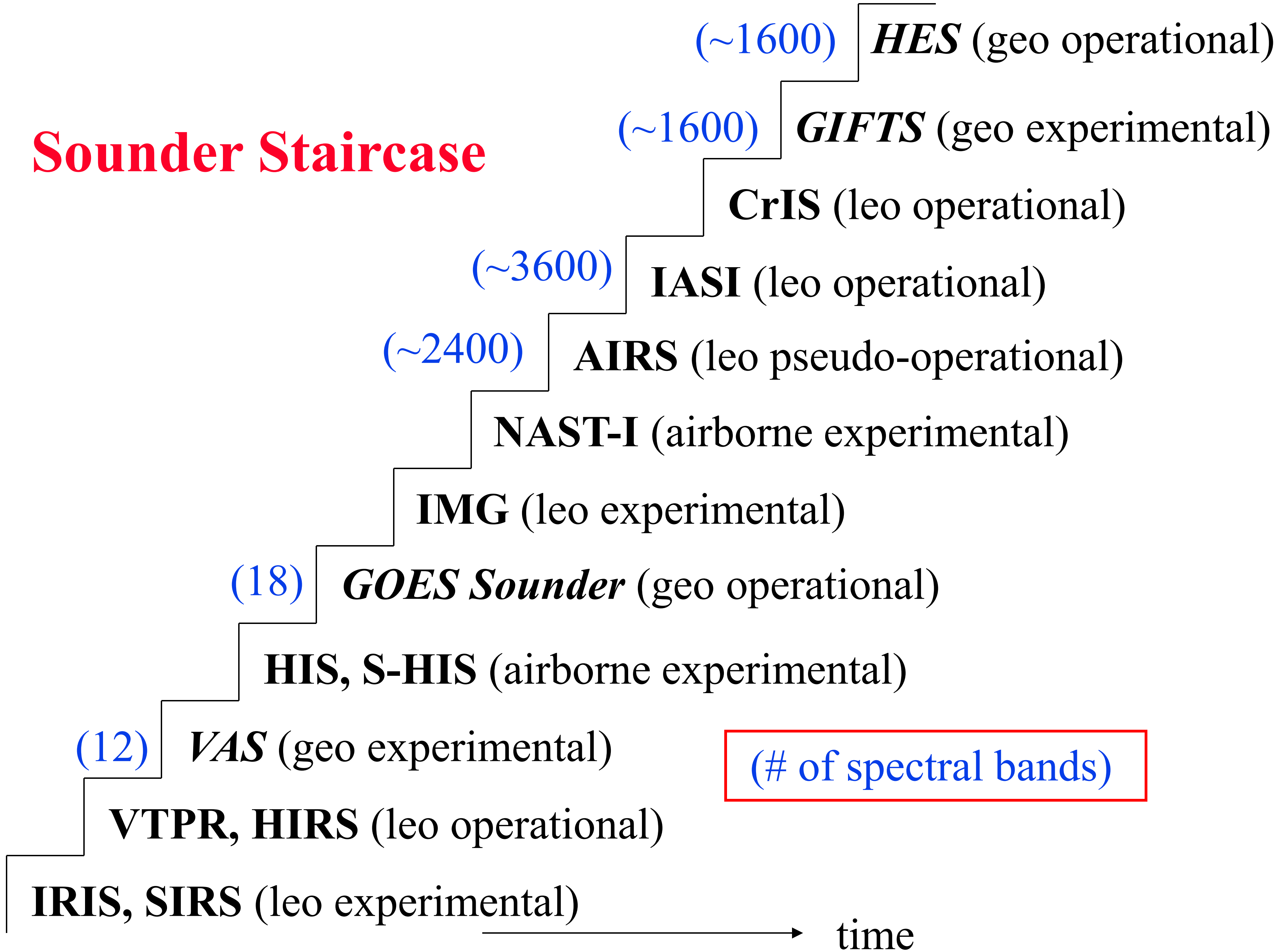
Advanced Microwave Sounding Unit

Humidity Sounder for Brazil

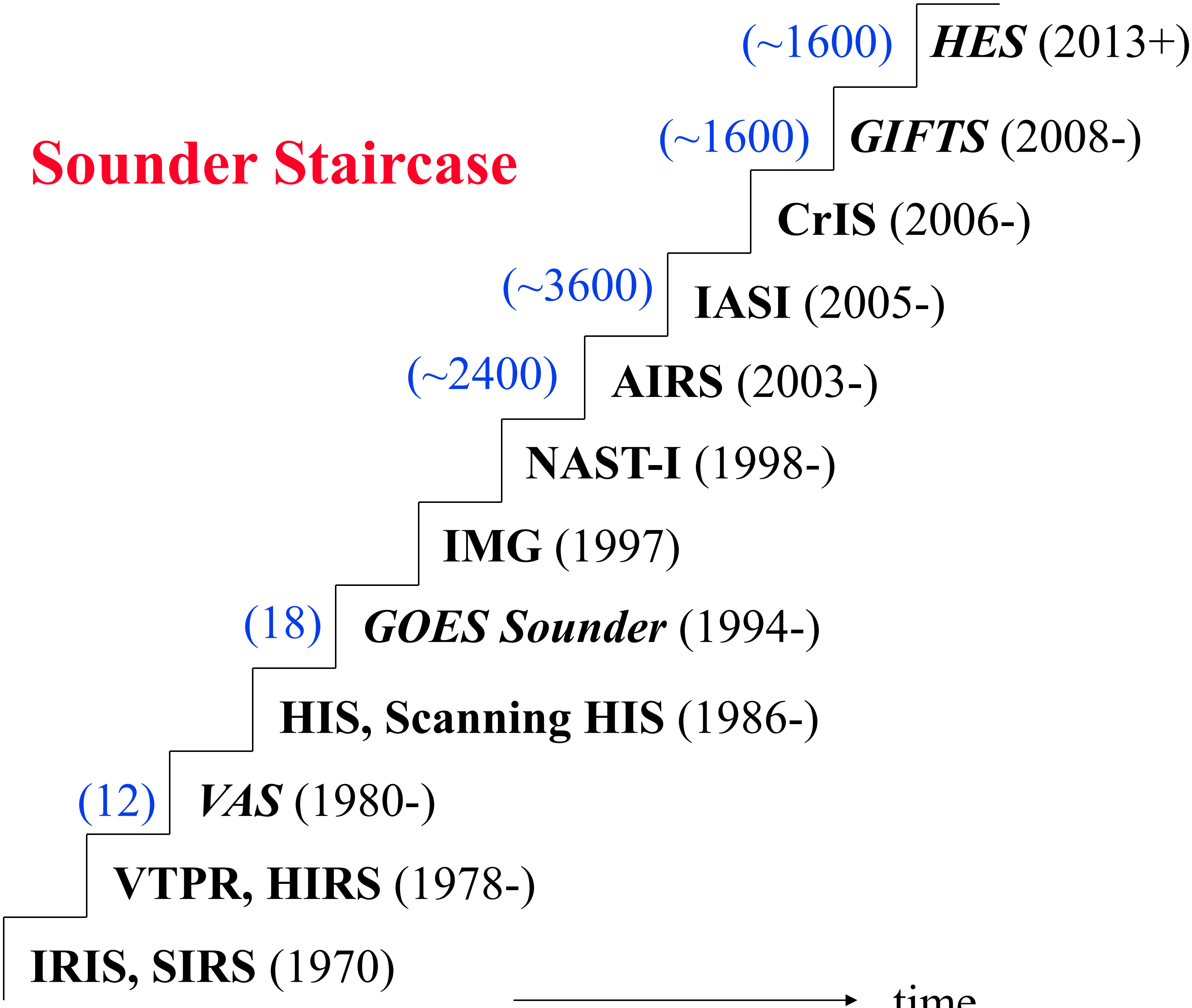
New Era: Spaceborne High-resolution IR

AIRS/CrIS/IASI (LEO) to GIFTS/HES (GEO)




Sounder Staircase
(~1600) HES (geo operational)
(~1600) GIFTS (geo experimental)
CrIS (leo operational)
(~3600) IASI (leo operational)
(~2400) AIRS (leo pseudo-operational)
NAST-I (airborne experimental)
IMG (leo experimental)
(18) GOES Sounder (geo operational)
HIS, S-HIS (airborne experimental)
(12) VAS (geo experimental)
VTPR, HIRS (leo operational)
IRIS, SIRS (leo experimental)
(# of spectral bands)
time

Sounder Staircase

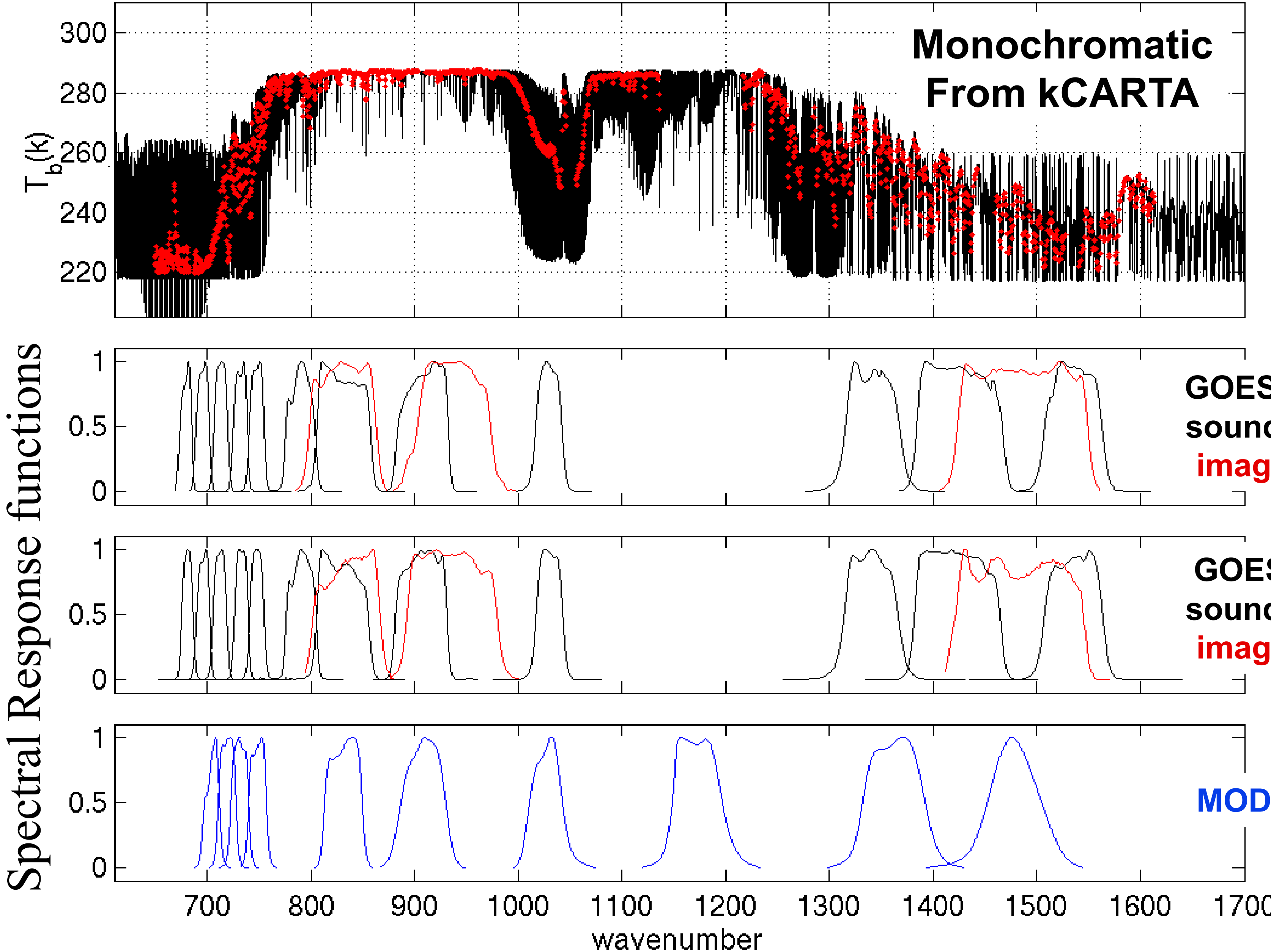


Higher Spectral Resolution Offers Significantly Less Vertical Smearing

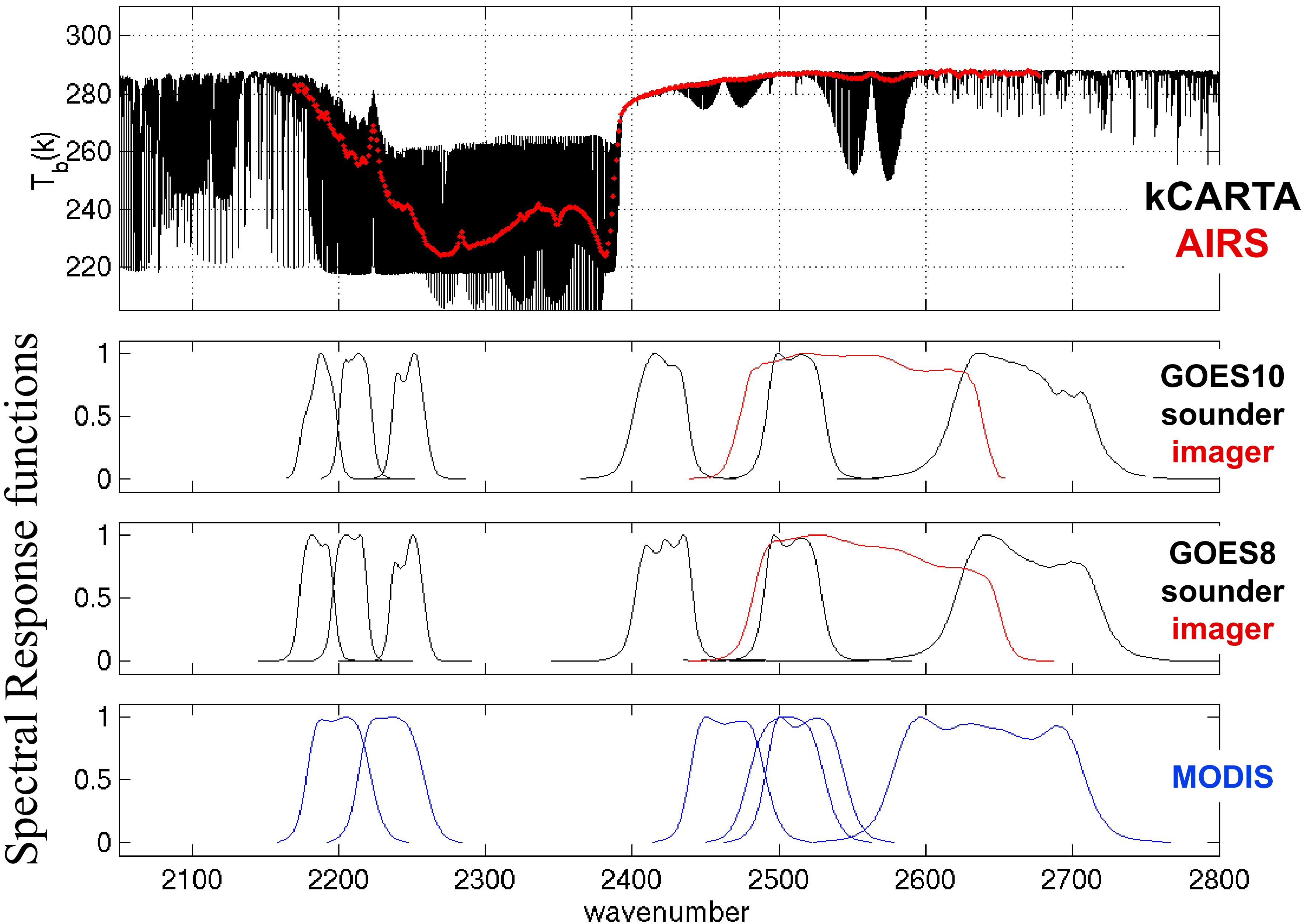
- Viewing Surface and Clouds between absorption lines reduces contamination from atmospheric absorption
  → Better Sea Surface Temperature & Cloud Properties
- Resolving absorption lines reduces smearing from on-line, off-line, and variable line strength atmospheric transmission variations
  → Better Vertical Resolution for T & WV Sounding
- Resolving lines also allows the contributions from different trace gas species to be separated
  → Possible to detect CO, Methane, and many other trace gases, if the spectral resolution is high enough
- On-line/Off-line techniques give sensitivity to separating the effects of surface emissivity from surface temperature
  → Better Land Surface Tempertures and Soundings over land
- Similar On-line/Off-line techniques apply to clouds

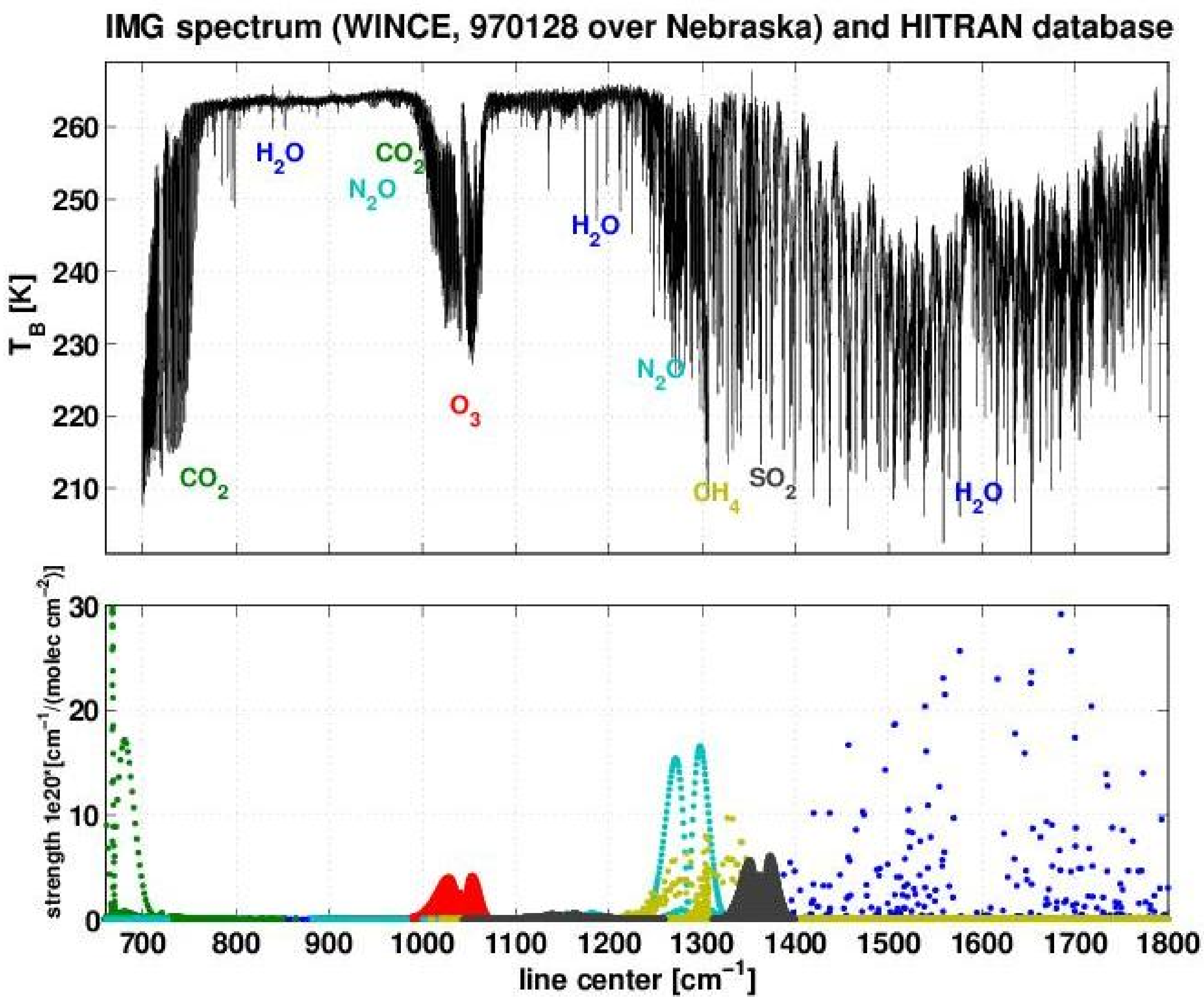
Resolving Individual Absorption Lines is Key

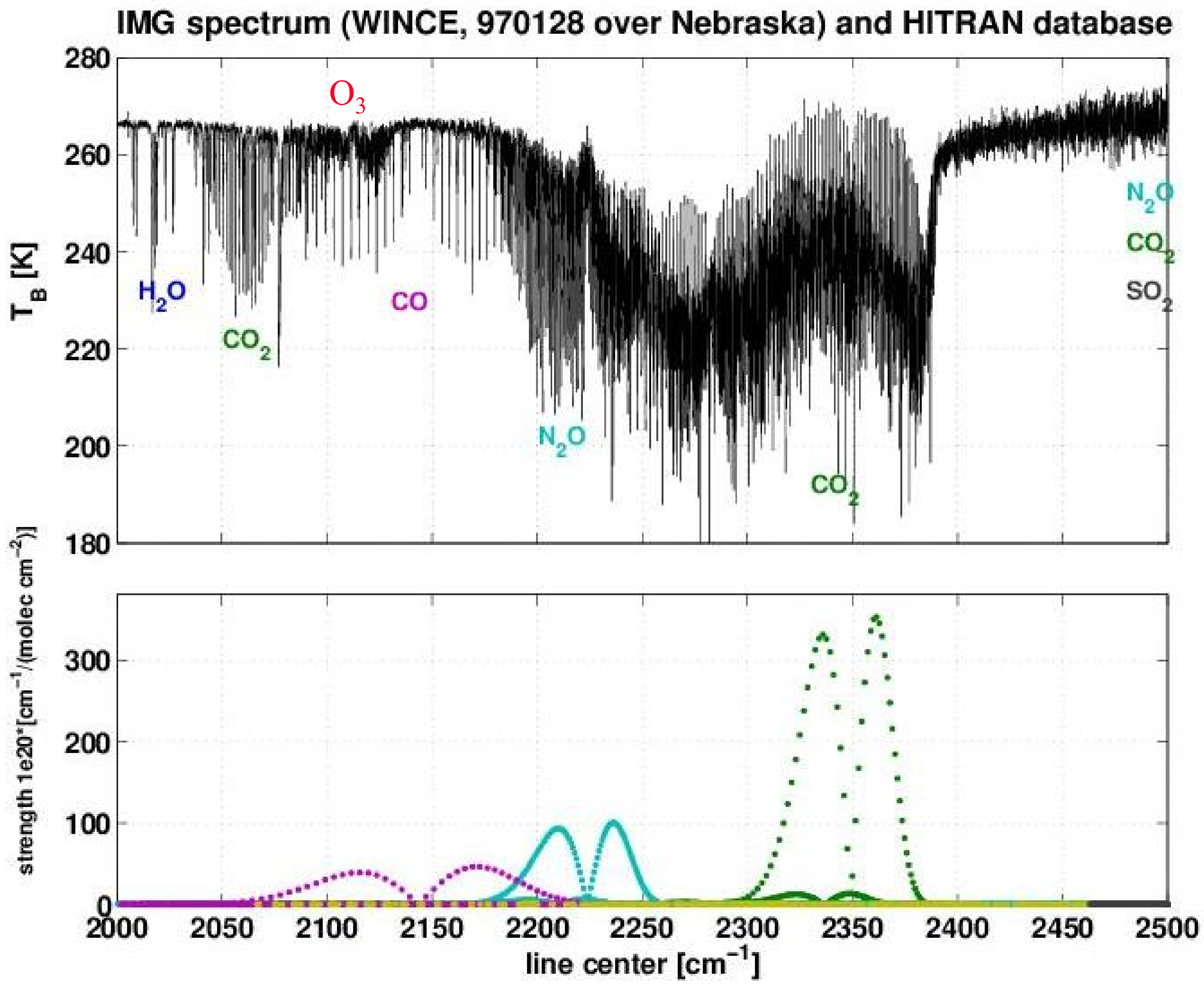
AIRS Spectrum Compared to Monochromatic



AIRS Spectrum Compared to Monochromatic



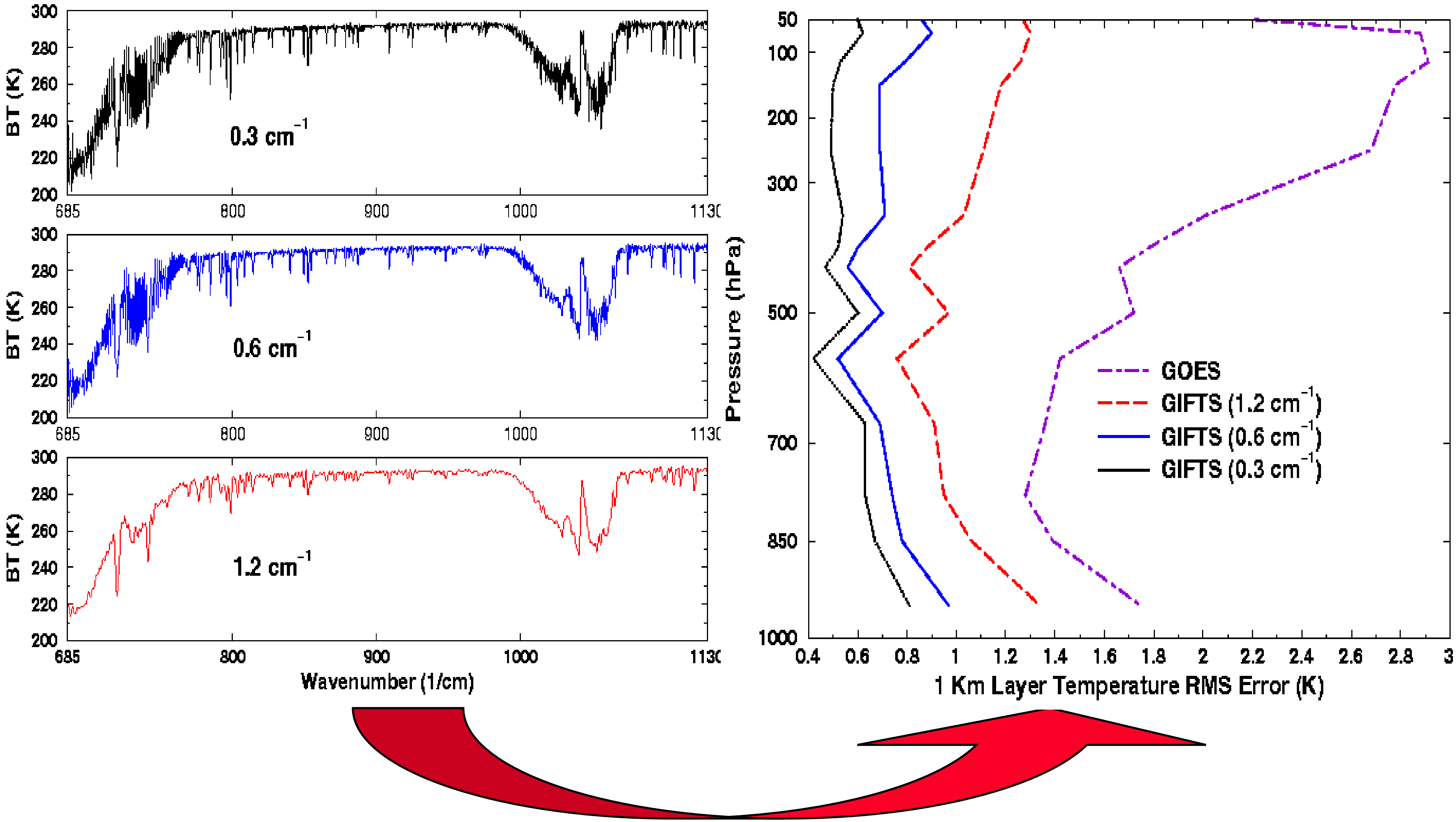

IMG spectrum (WINCE, 970128 over Nebraska) and HITRAN database
T_B [K]
260
250
240
230
220
210
H2O
CO2
N2O
H2O
N2O
O3
CO2
CH4
SO2
H2O
strength 1e20*[cm^-1/(molec cm^-2)]
30
20
10
0
700
800
900
1000
1100
1200
1300
1400
1500
1600
1700
1800
line center [cm^-1]



IMG spectrum (WINCE, 970128 over Nebraska) and HITRAN database
O3
H2O
CO2
CO
N2O
CO2
N2O
CO2
SO2
T_B [K]
280
260
240
220
200
180
strength 1e20*[cm^-1/(molec cm^-2)]
300
200
100
0
2000
2050
2100
2150
2200
2250
2300
2350
2400
2450
2500
line center [cm^-1]

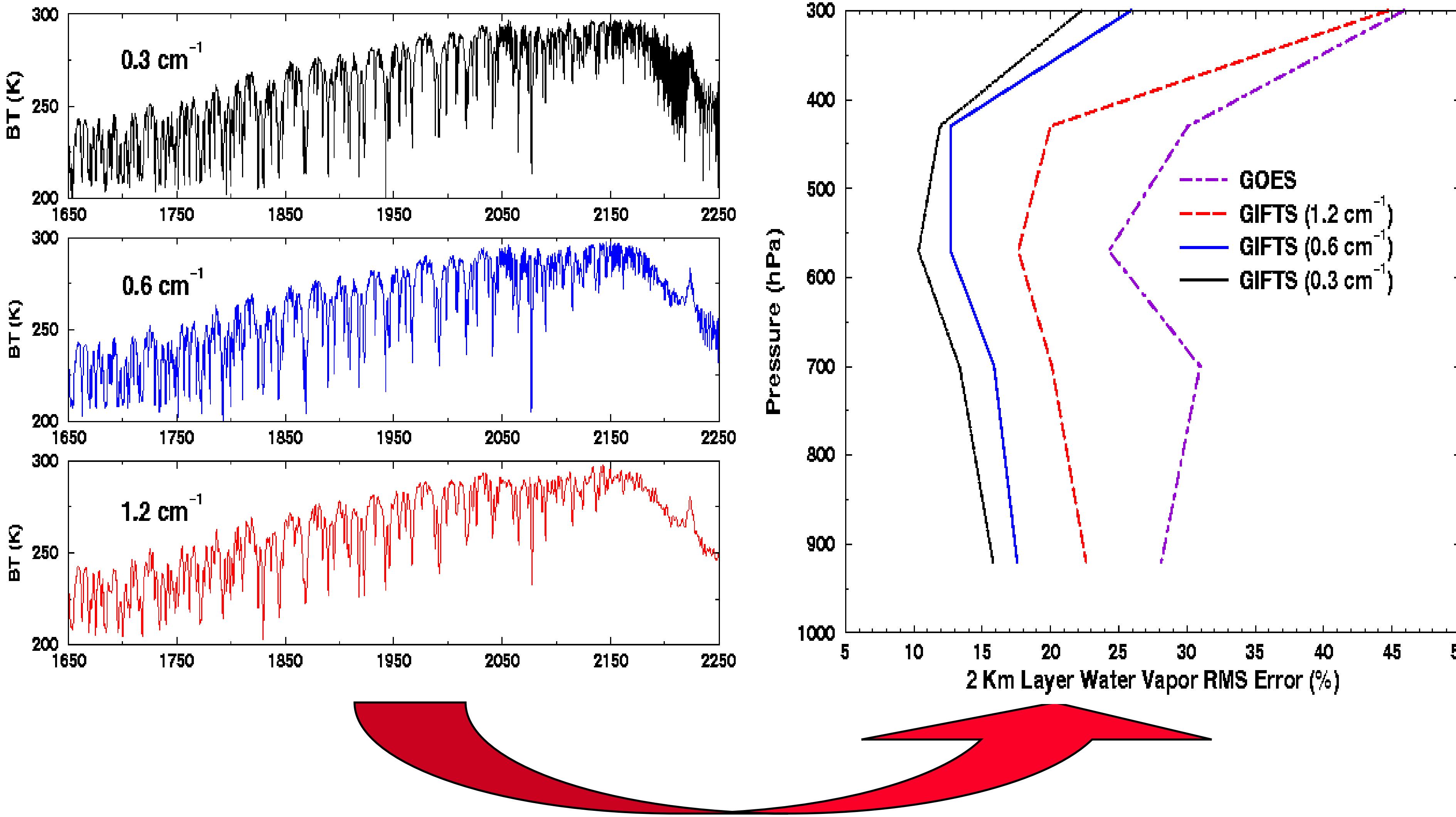
GIFTS Spectral Resolution Trade

Objective for LW Band - 0.6 cm^{-1}



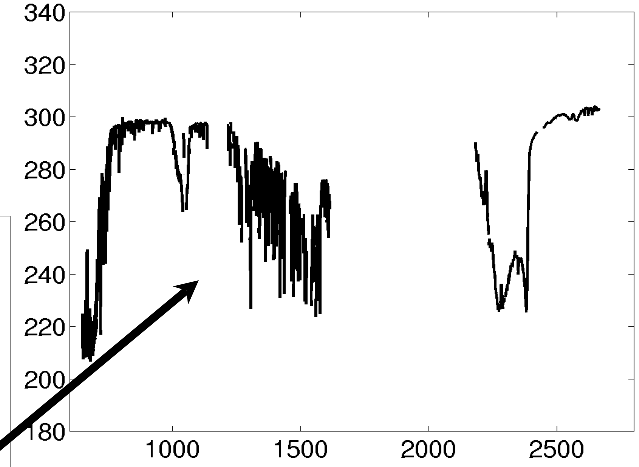
GIFTS Spectral Resolution Trade

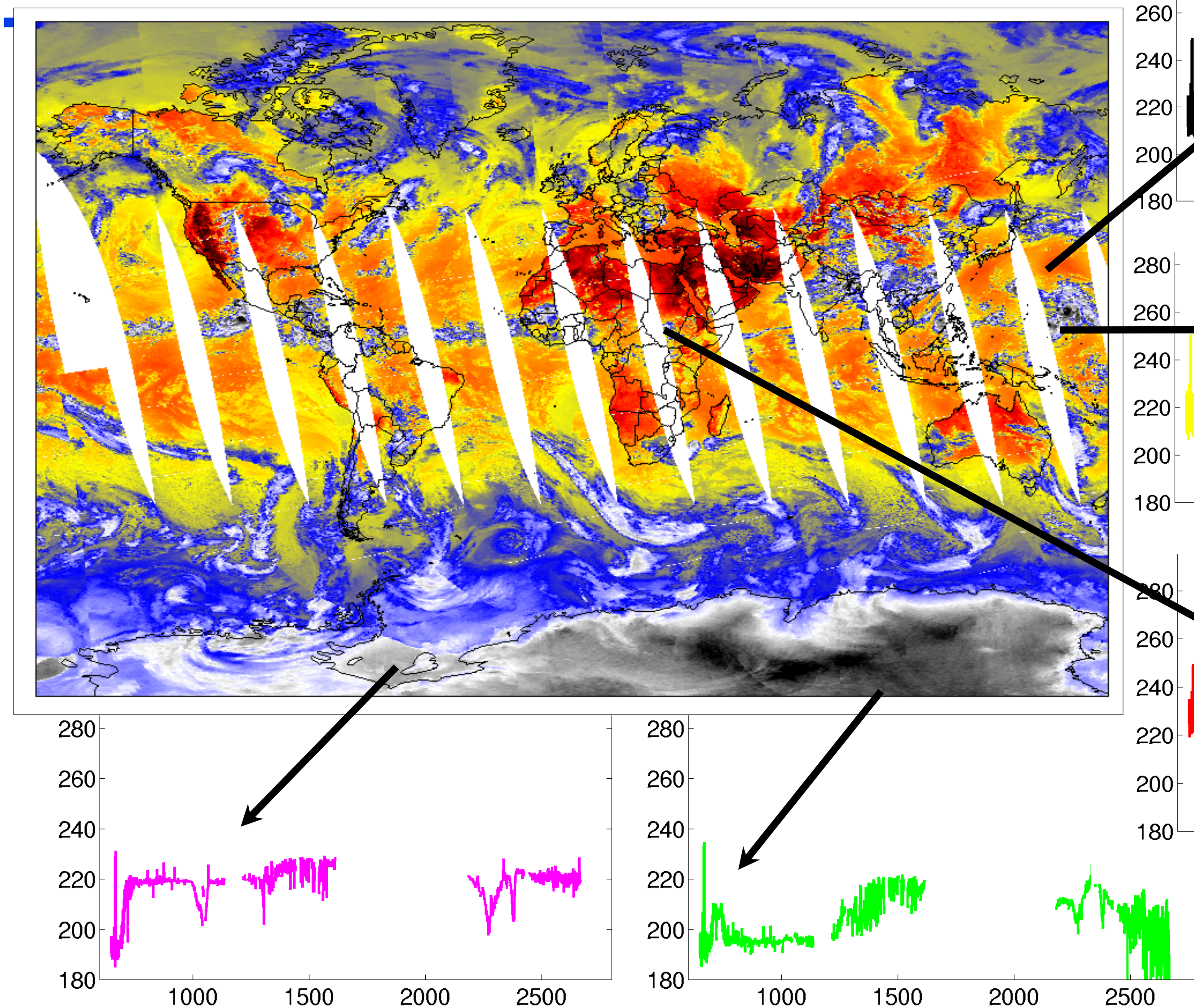
Objective for MSW Band - 0.6 cm^{-1}

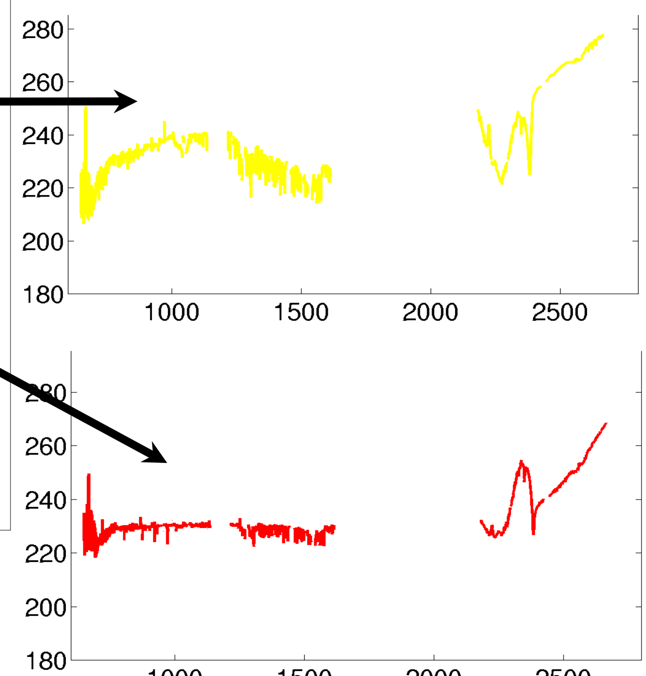


AIRS Global Coverage

20 July 2002 Ascending, LW Window







Vertical Resolution Improvement

Factor of 2-3 improvement for Temperature and Water Vapor vertical profiling!

Weighting Function: Sensitivity of spectrum to atmospheric T or composition changes at a given level

Mathematically,

Weighting Function = dR/dx_l or dT_b/dx_l (Jacobian),

where x_l is the atmospheric variable at level l

(e.g. T or *mixing ratio*)

or

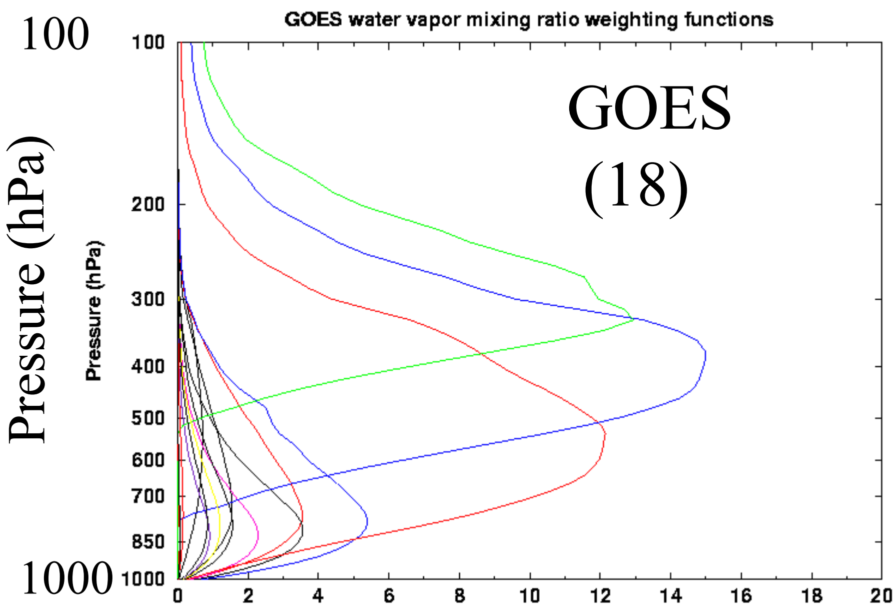
Specifically, in what follows we use Brightness Temperature instead of Radiance & atmospheric variables T & $\ln q$, э:

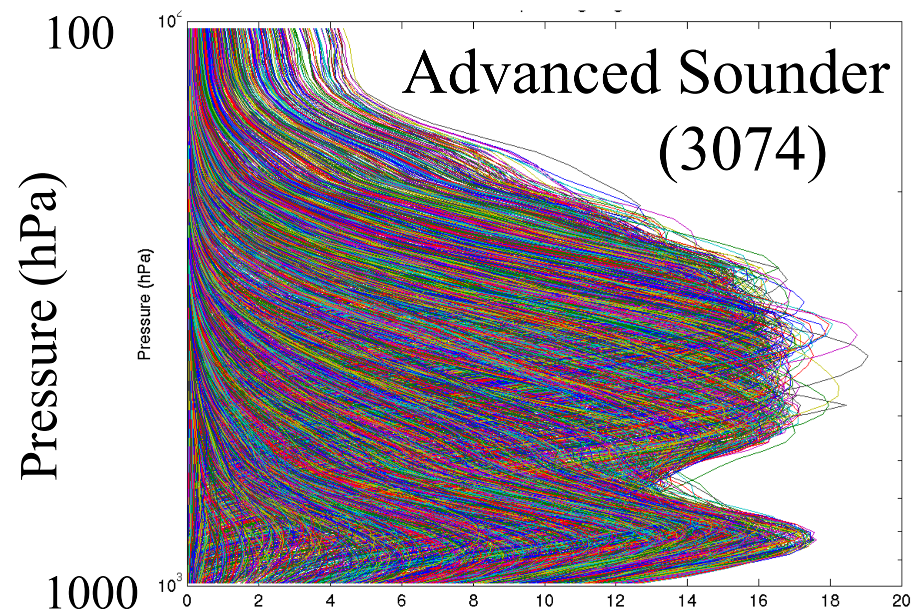
Weighting Functions = dT_b/dT & $dT_b/d\ln q$

For actual discrete models, weighting functions are discrete differences, like the radiative transfer equation itself & often shown scaled by $\delta \ln P$

$$R_\nu = \varepsilon_s B_\nu(T_s) + \int_0^1 B_\nu(T)\,d\tau_\nu = \varepsilon_s B_\nu(T_s) + \sum_{\ln P_s}^{-\infty} B_\nu(T)\frac{\delta\tau_\nu}{\delta \ln P}\delta \ln P$$

Where τ is the atmospheric transmission, equal to 1 at TOA

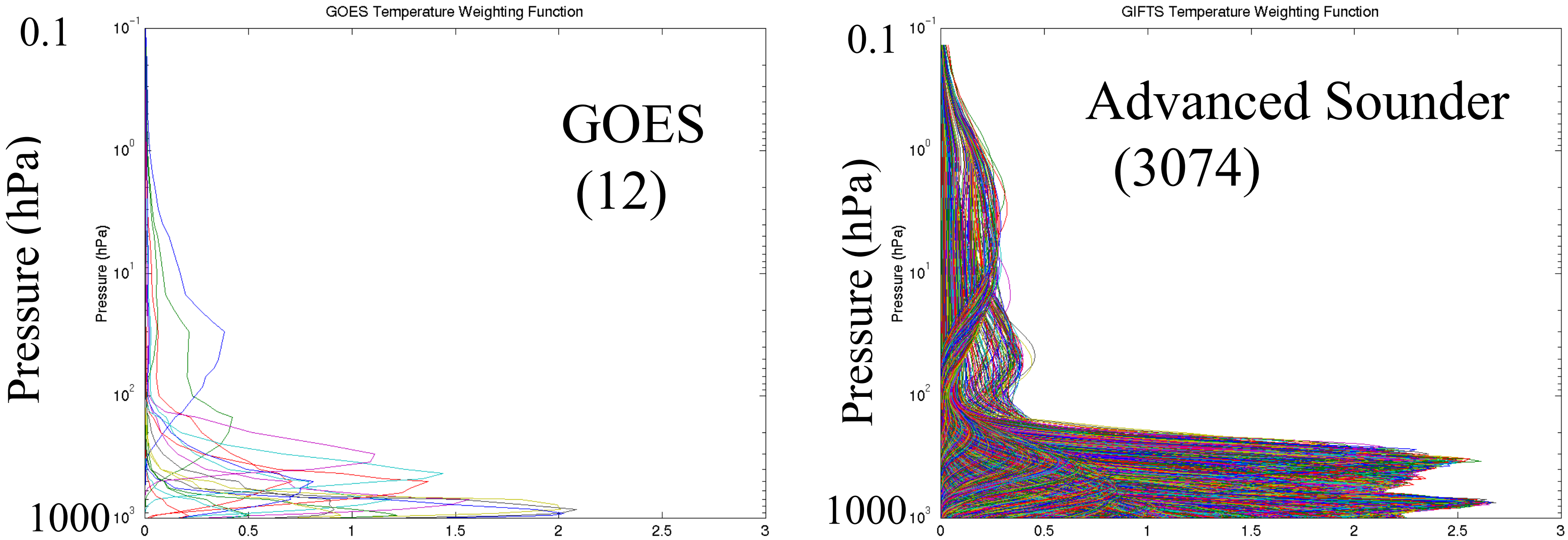




Moisture Weighting Functions

High spectral resolution advanced sounder will have more and sharper weighting functions compared to current GOES sounder. Retrievals will have 2-3 x better vertical resolution.

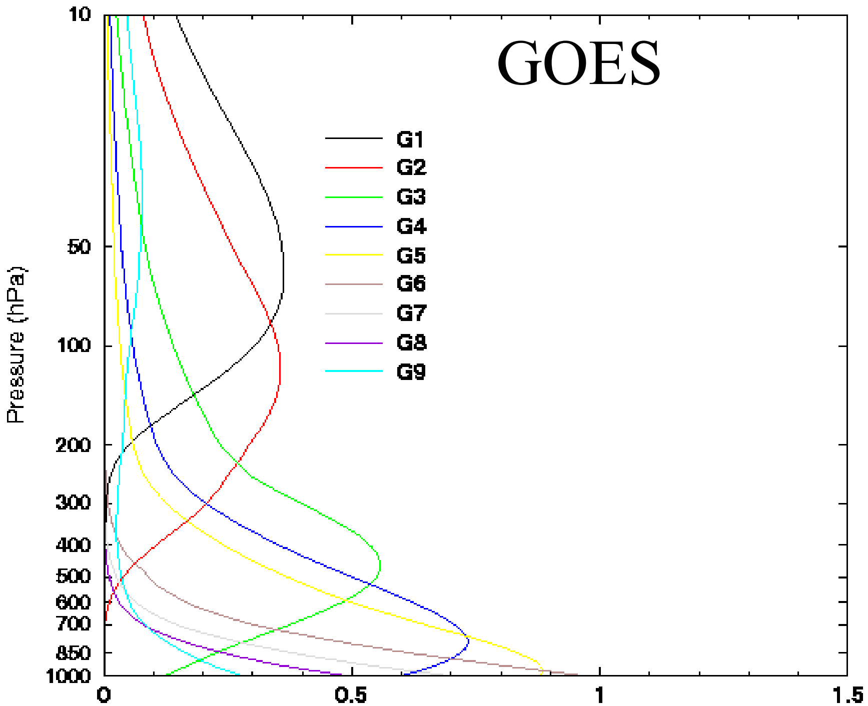
UW/CIMSS

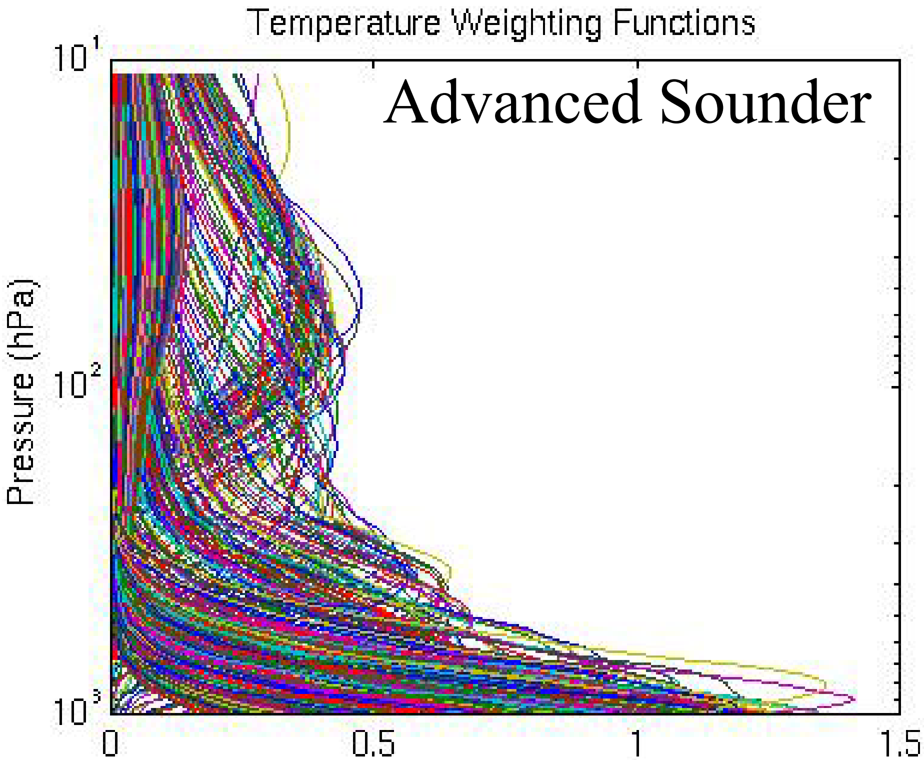


Temperature Weighting Functions

A high spectral resolution advanced sounder will have both more and sharper weighting functions compared to the current GOES sounder. This leads to retrievals with 2-3 x better vertical resolution.

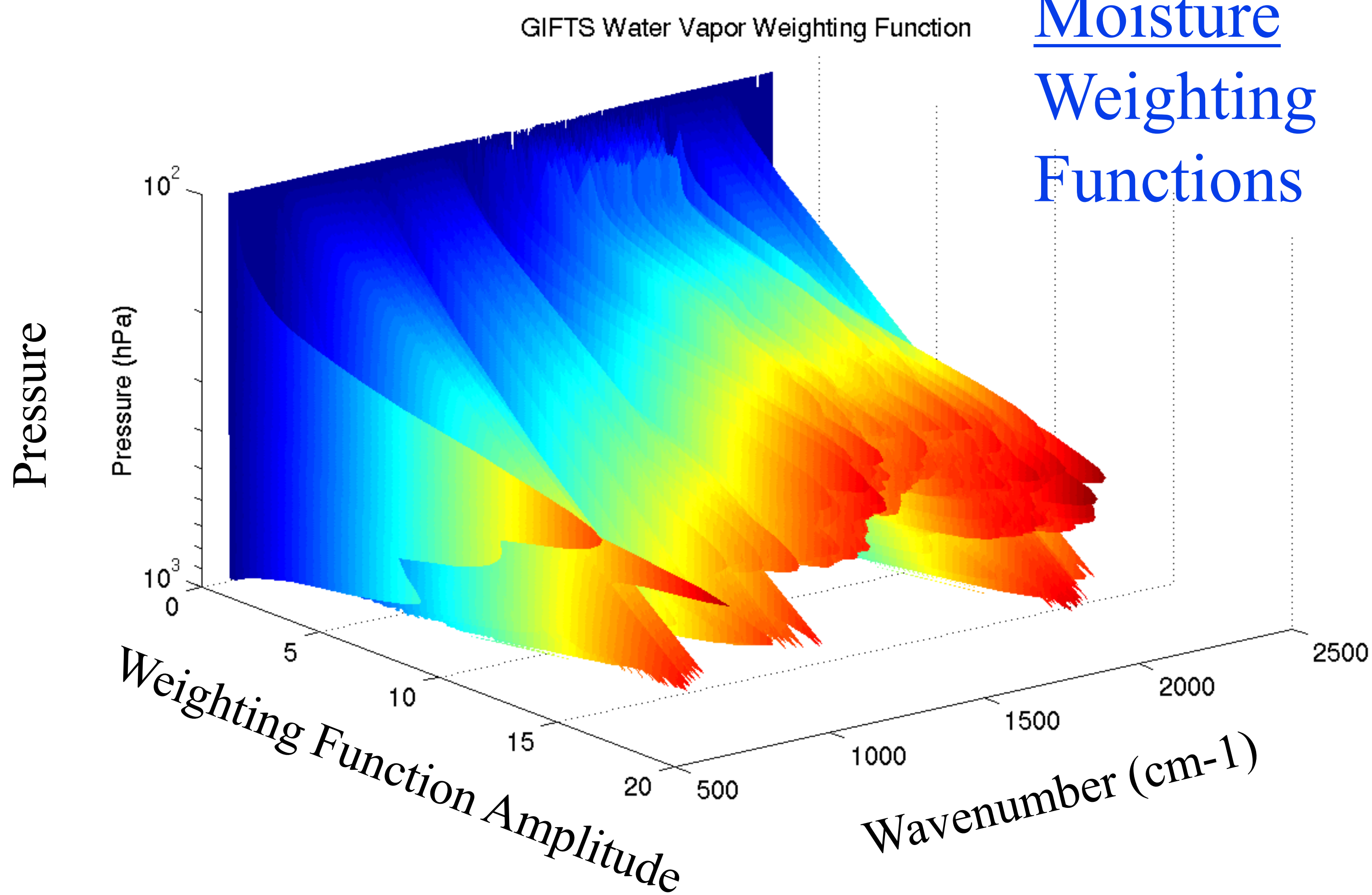
Tropospheric Temperature Weights: a Closer View





Longwave IR Sounder Temperature WFs (Jacobians scaled by dlnp)

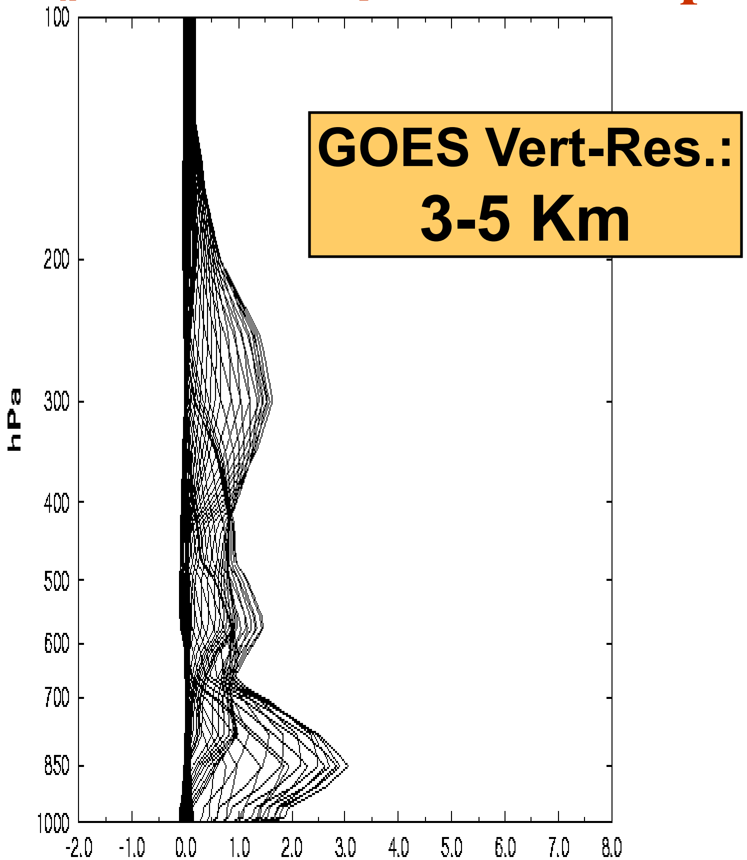
Advanced Sounder <u>Moisture</u> Weighting Functions



The advanced sounder has both more and sharper weighting functions.

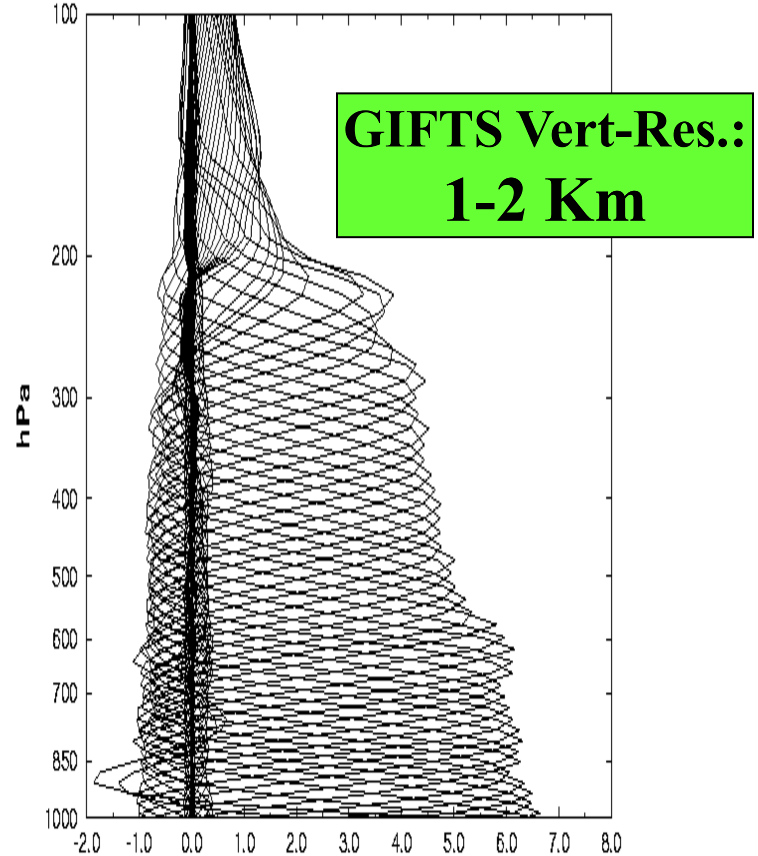
GIFTS Vertical Resolution Analysis for T

Objective: Improved Temperature Information



Current - GOES

~3 Pieces

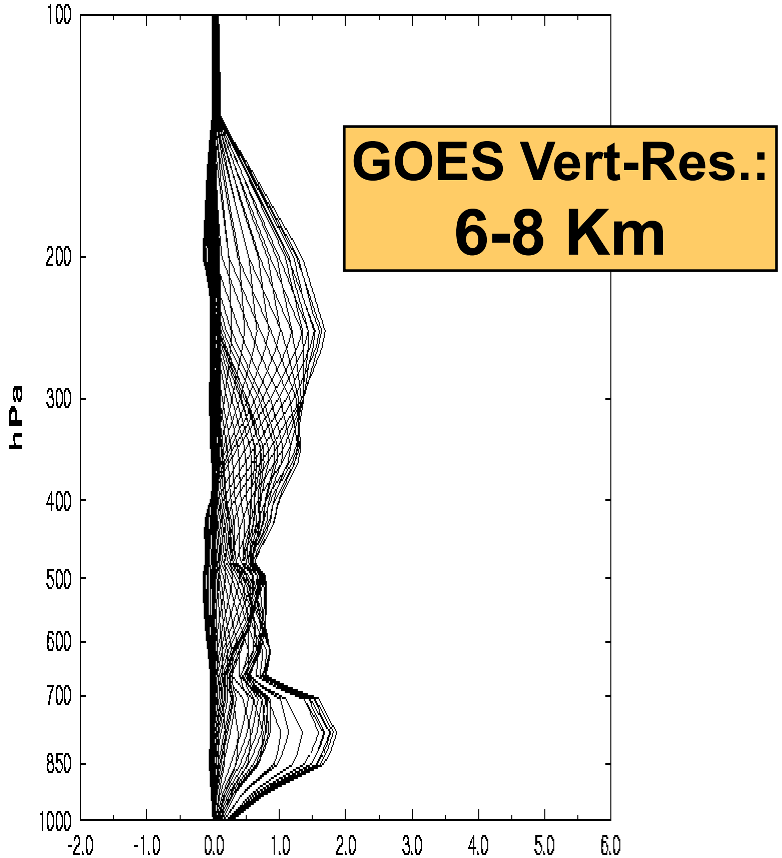


GIFTS

10-12 Pieces

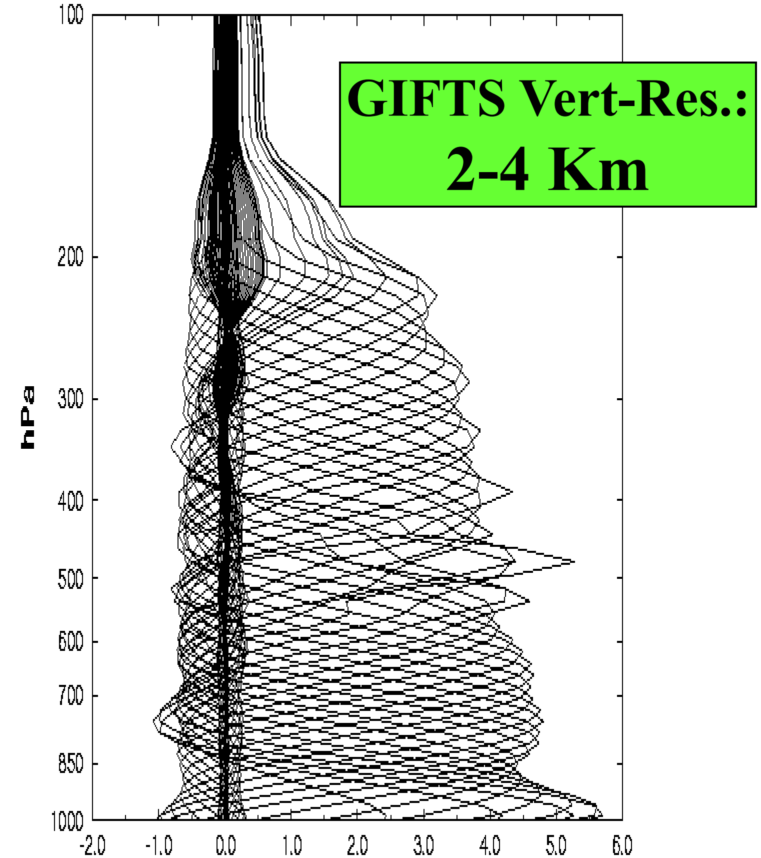
GIFTS Vertical Resolution Analysis for WV

Objective: Improved Water Vapor Information



Current - GOES

~2 Pieces

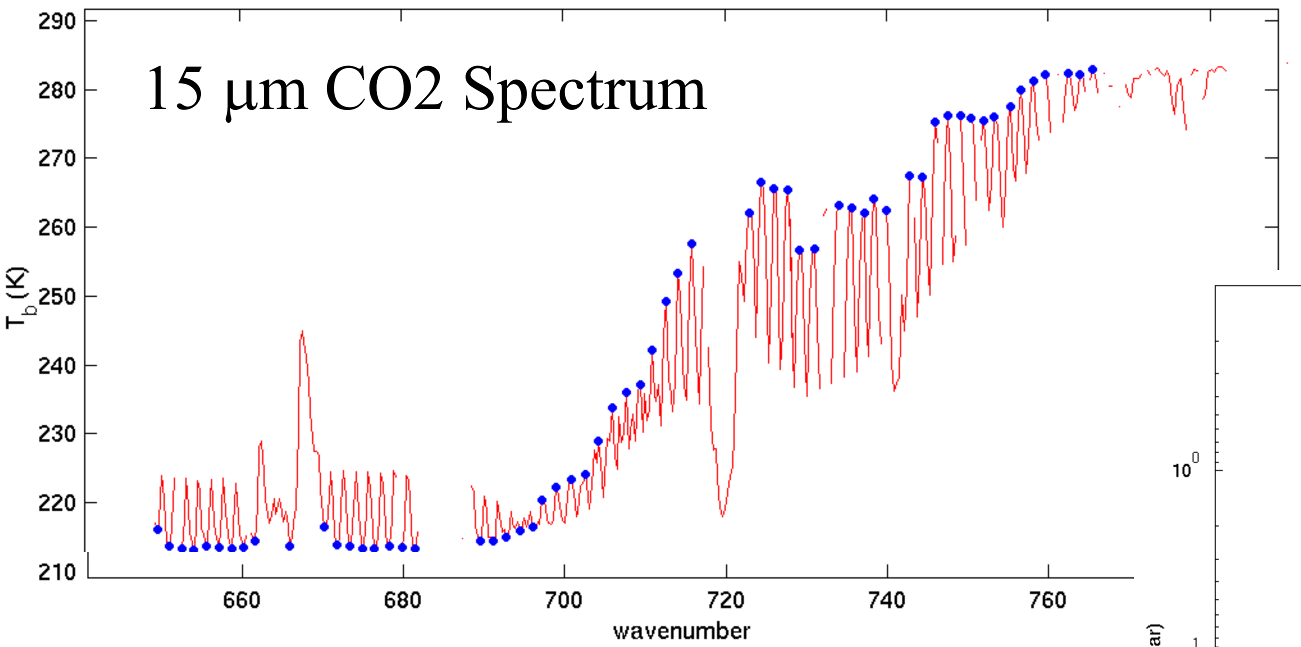


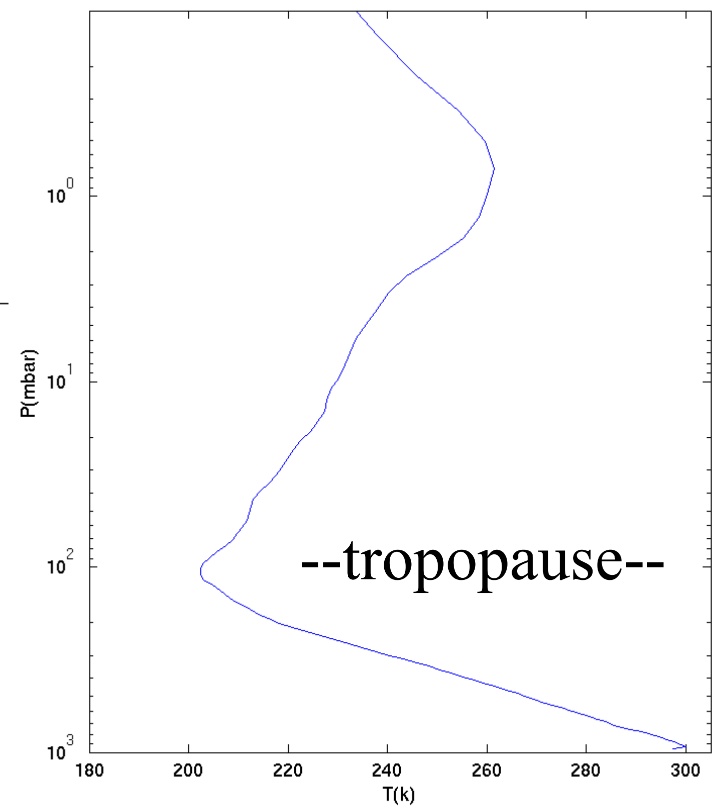
GIFTS

8-9 Pieces

Twisted Ribbon formed by CO_2 spectrum:

Tropopause inversion causes On-line & off-line patterns to cross





Blue between-line T_b

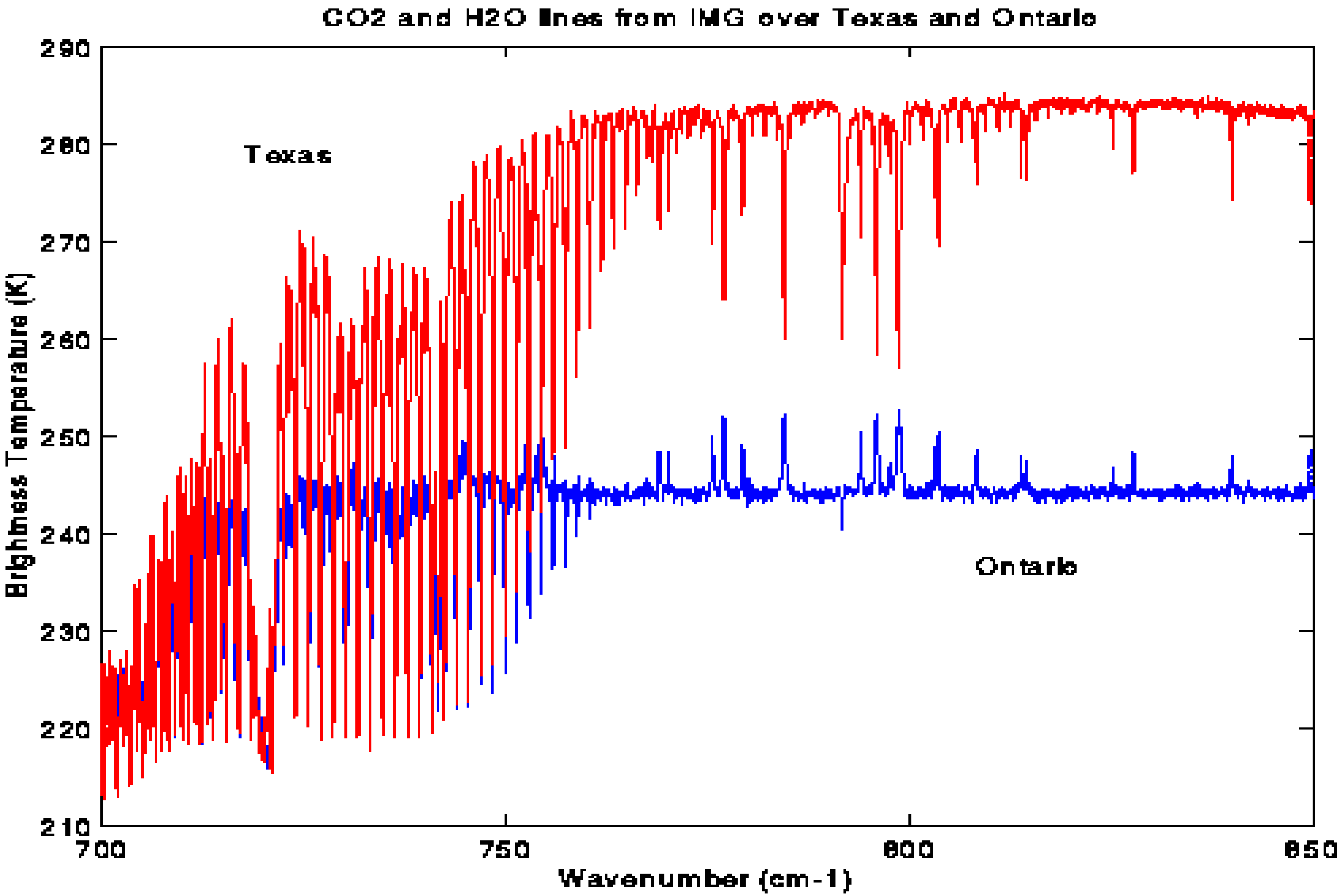
<u>warmer</u> for tropospheric channels,

<u>colder</u> for stratospheric channels

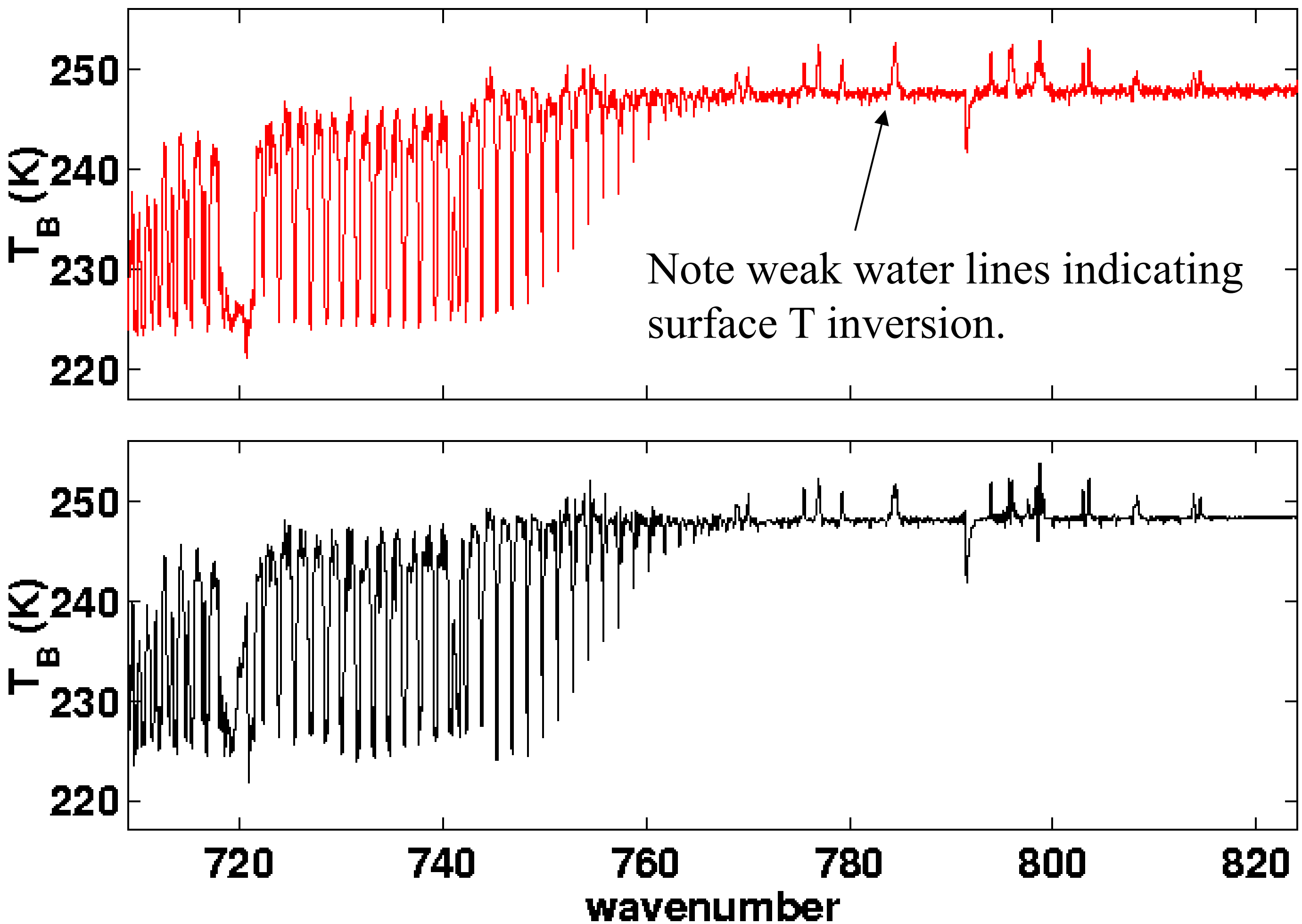
Signature not available at low resolution

Sensitivity of High Spectral Resolution to Boundary Layer Inversions and Surface/atmospheric Temperature differences

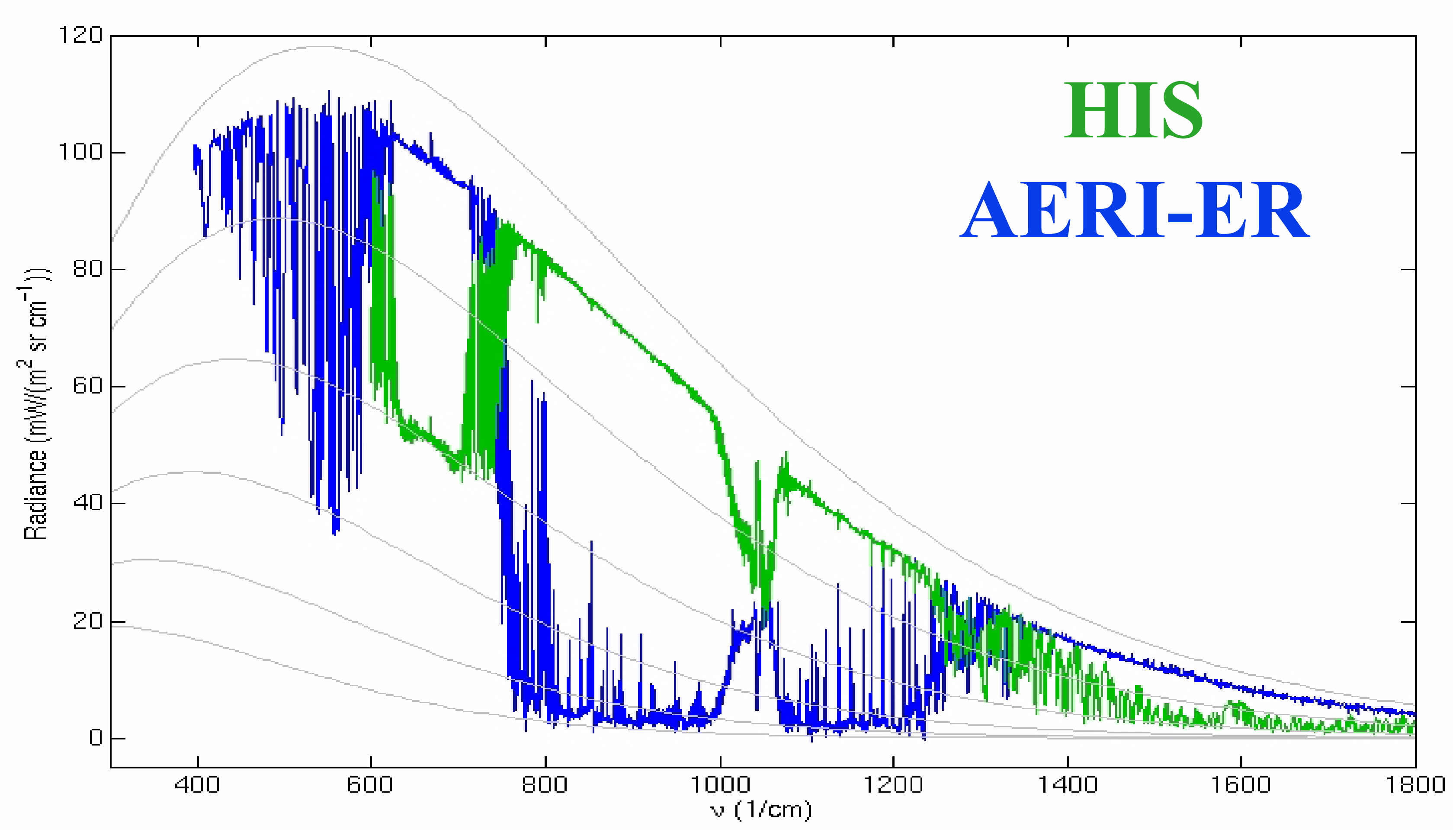
(from IMG Data, October, December 1996)



IMG spectrum from 11 Dec 1996 over Point Barrow, AK with LBLRTM calculation



View from below as well as above: FIRE ACE, 20 May 1998

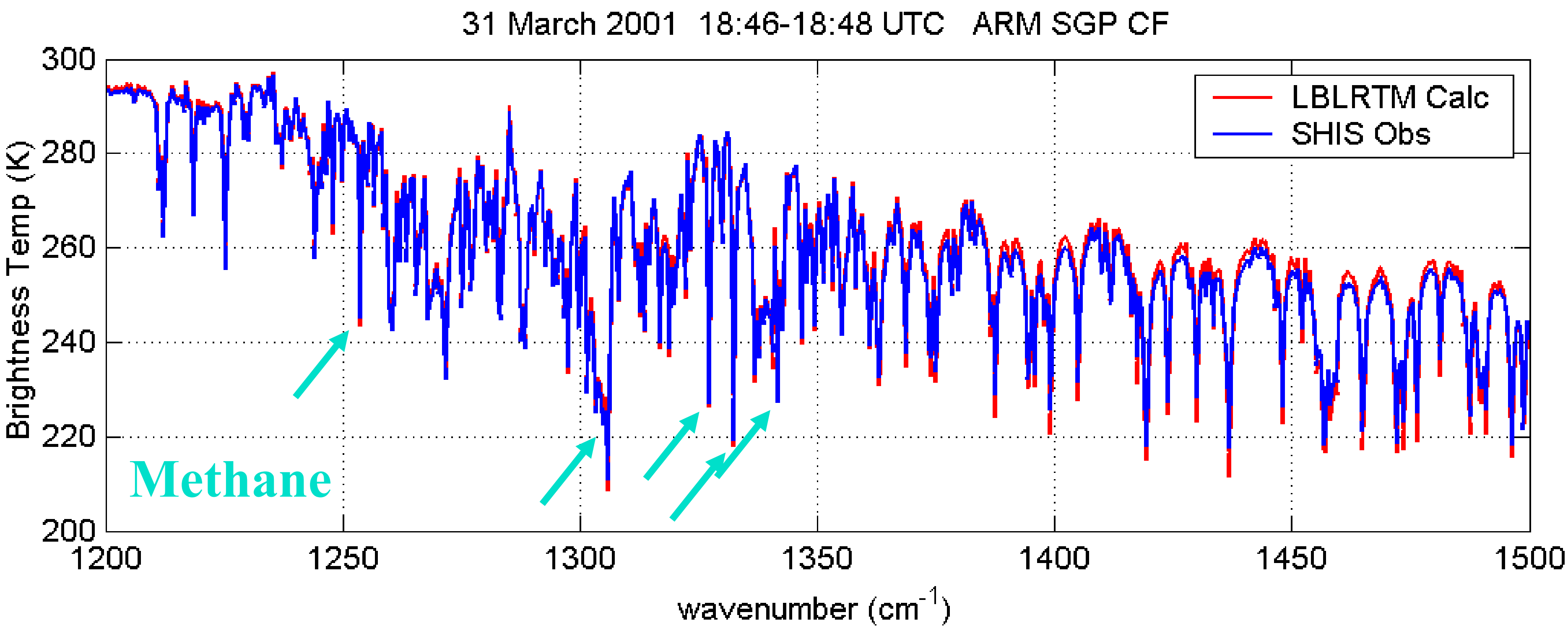


Trace Gas Sensitivity

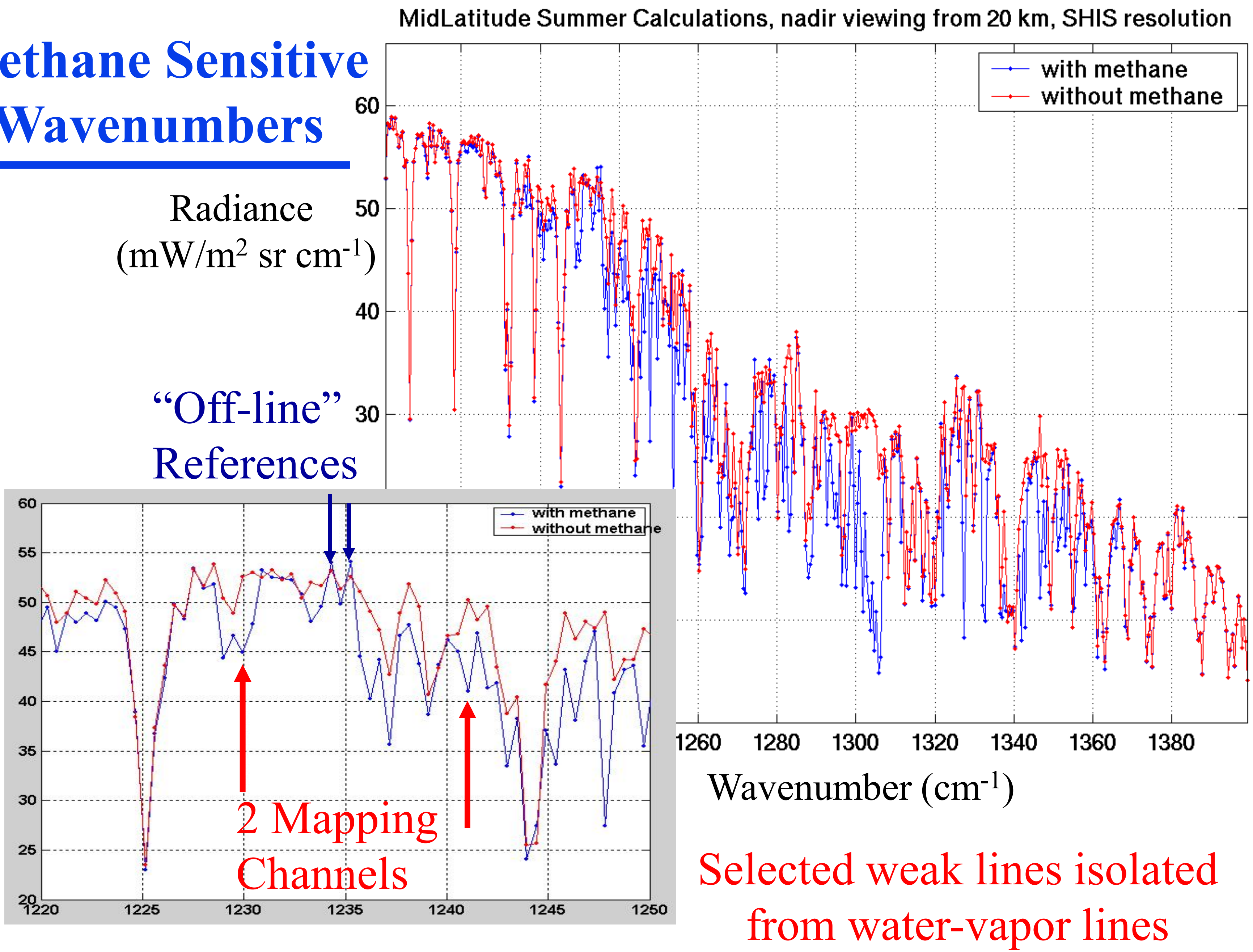
New things can be done with O_3, CO, and probably CH_4 at AIRS/CrIS/IASI resolution.

Most other gases require higher resolution or active approaches

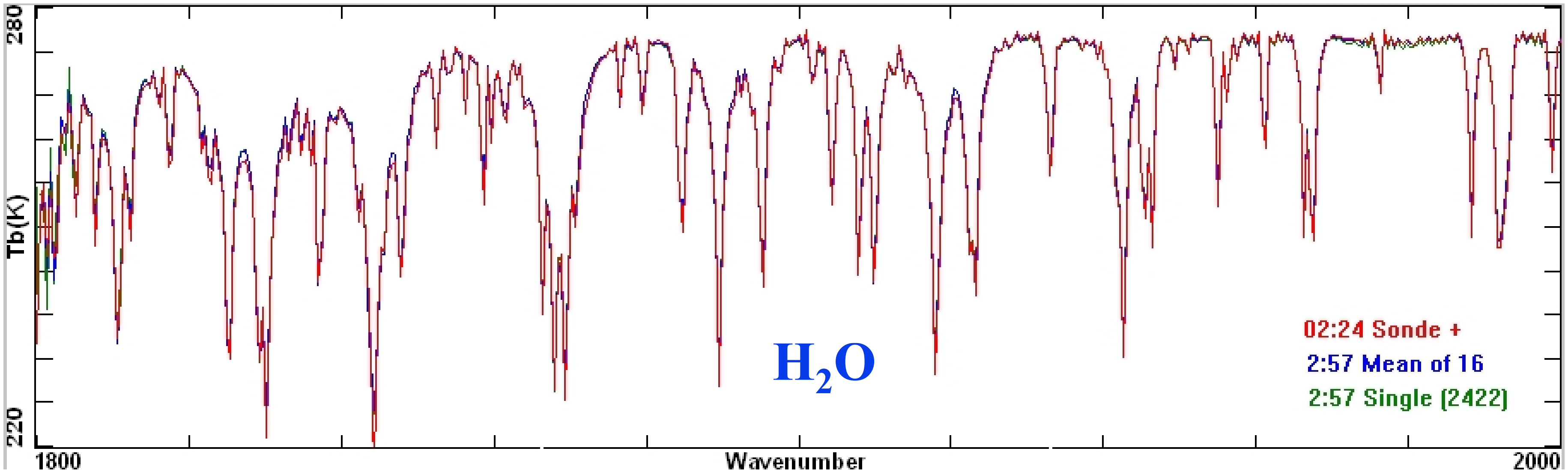
Methane region: S-HIS and Line-by-line Calculation

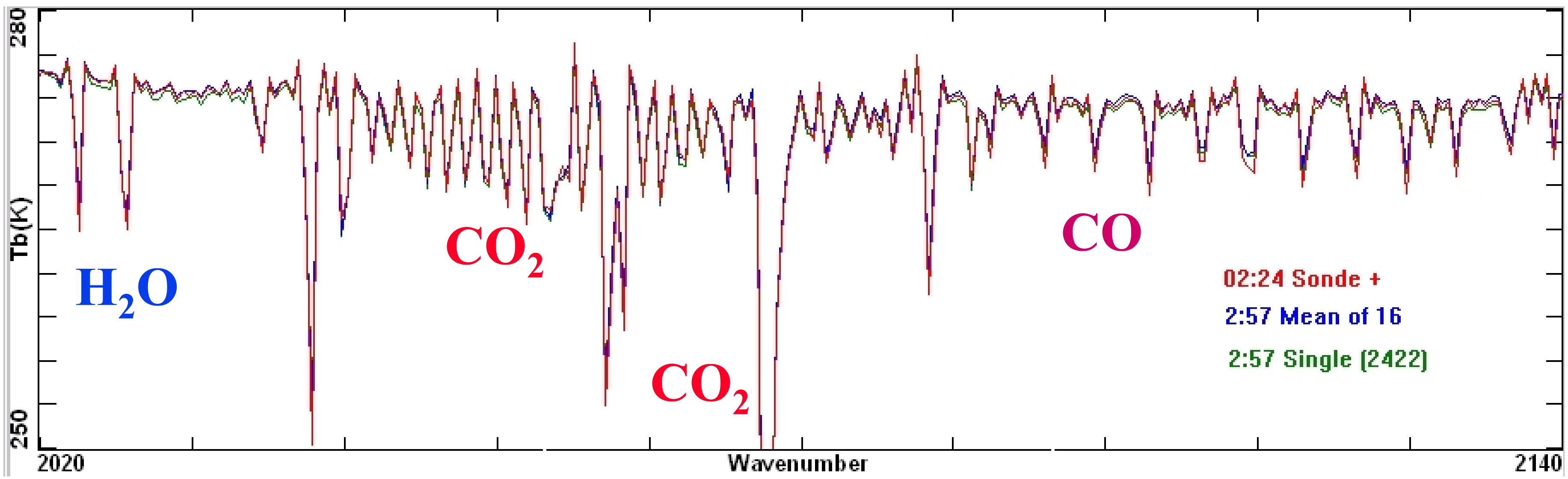


Methane Sensitive Wavenumbers



CO Region: Calculation from Sonde Compared to S-HIS Brightness T Spectra

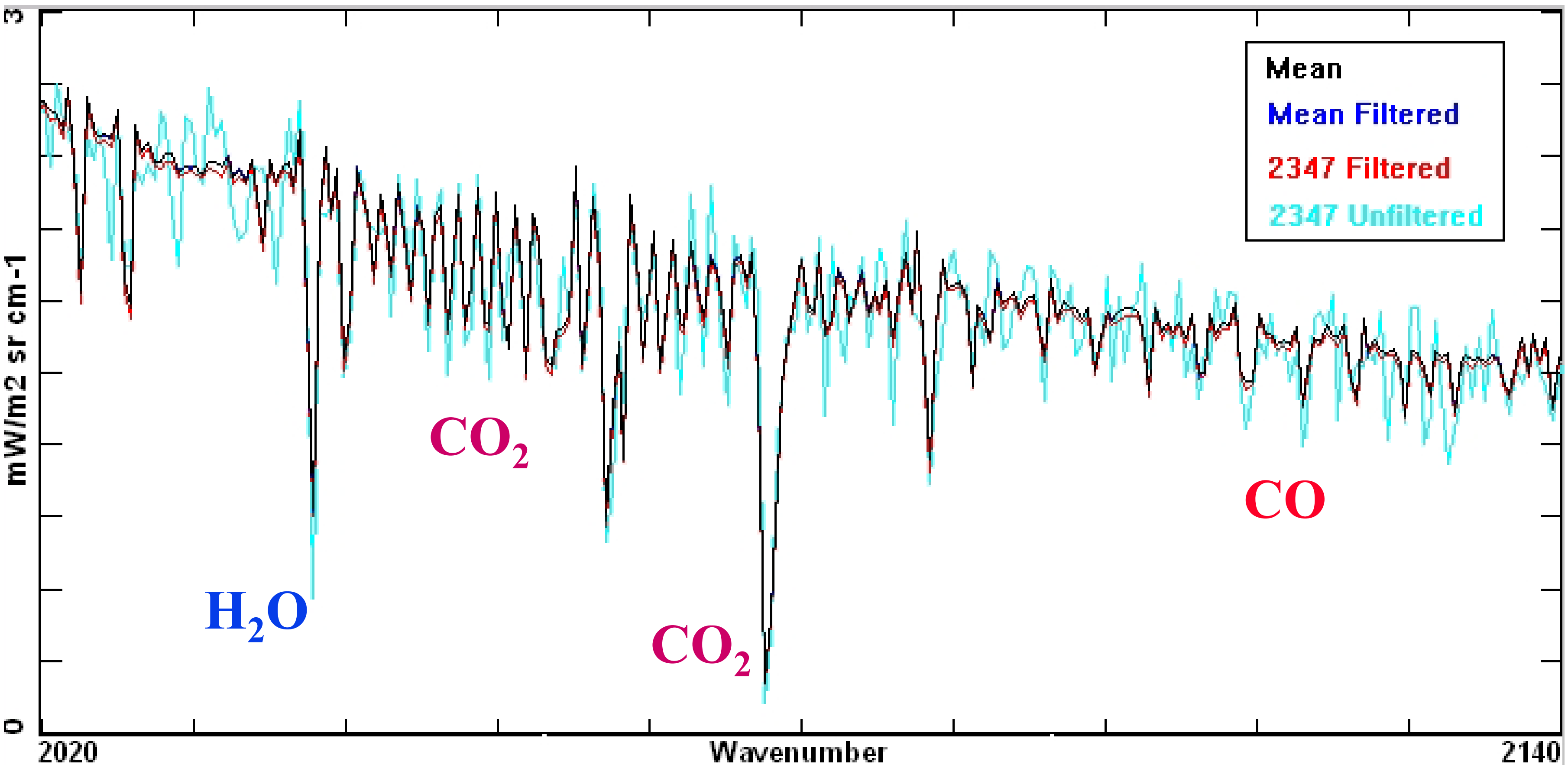




12-10-00 AFWEX

CO: S-HIS PCA-Filtered Radiances

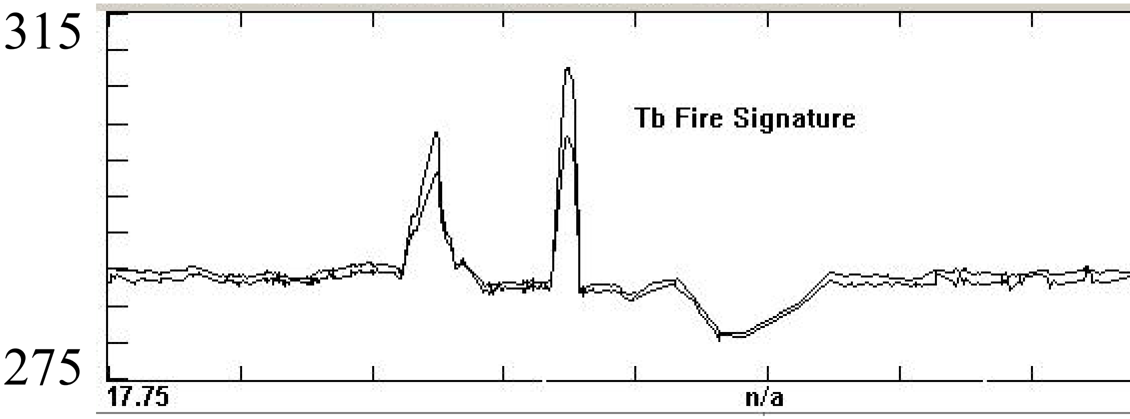
Shortwave Band (2020-2140 cm^{-1})



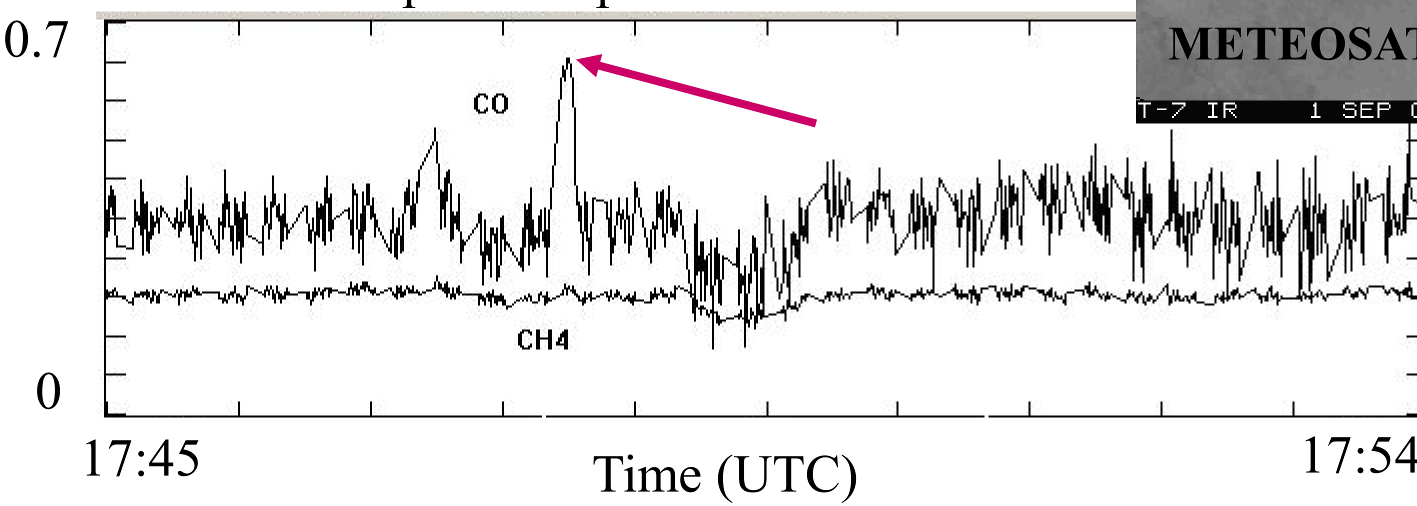
CO Detection over Fire

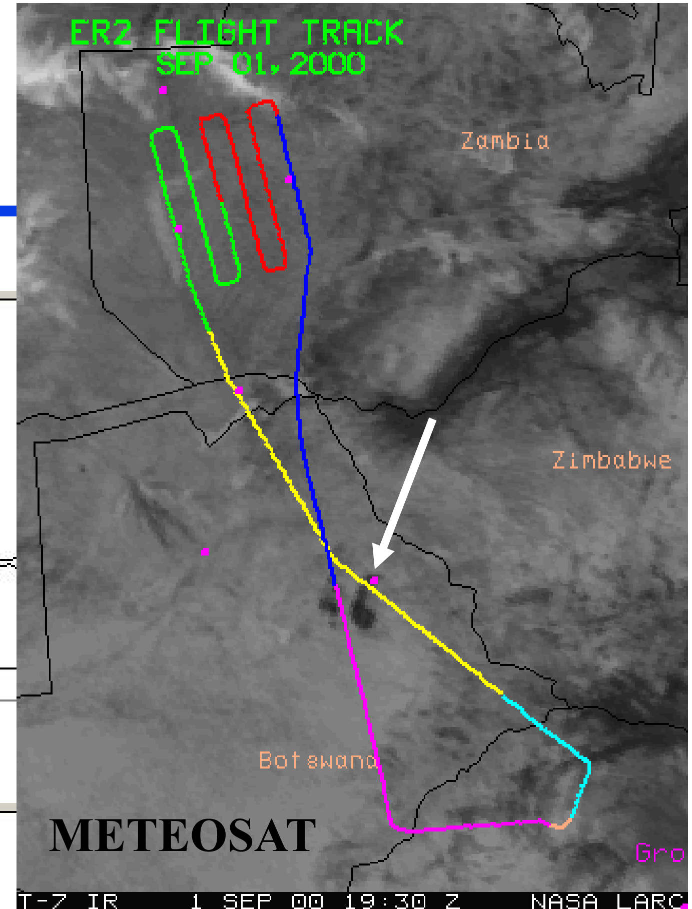
(1 Sept Night Flight)

Brightness Temperature (4.09, 4.66 µm)



Optical Depth Estimate



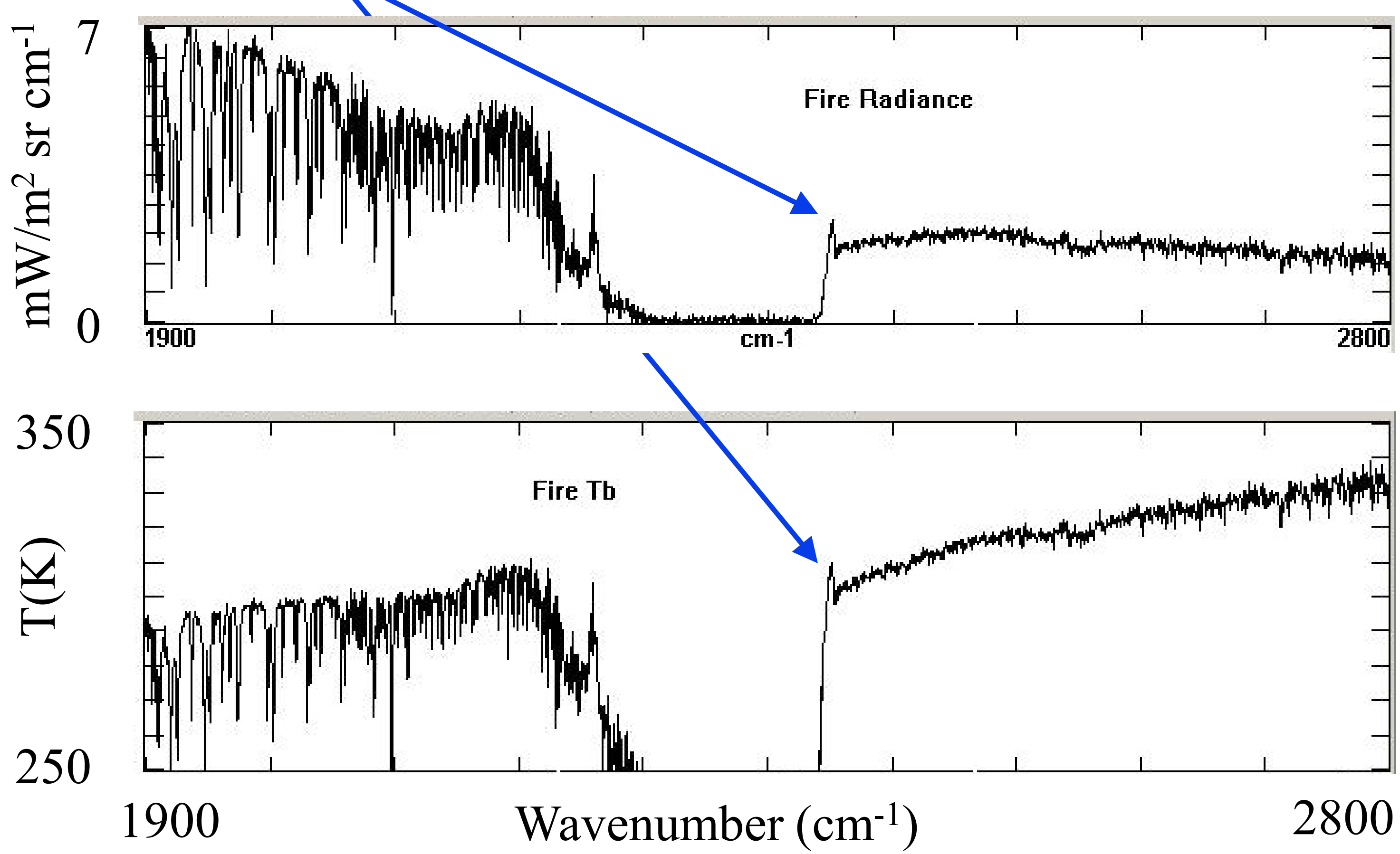


Column CO doubles over the fire

Fire Radiometric Signature

(1 Sept Night Flight, 7 Sept Controlled Burn)

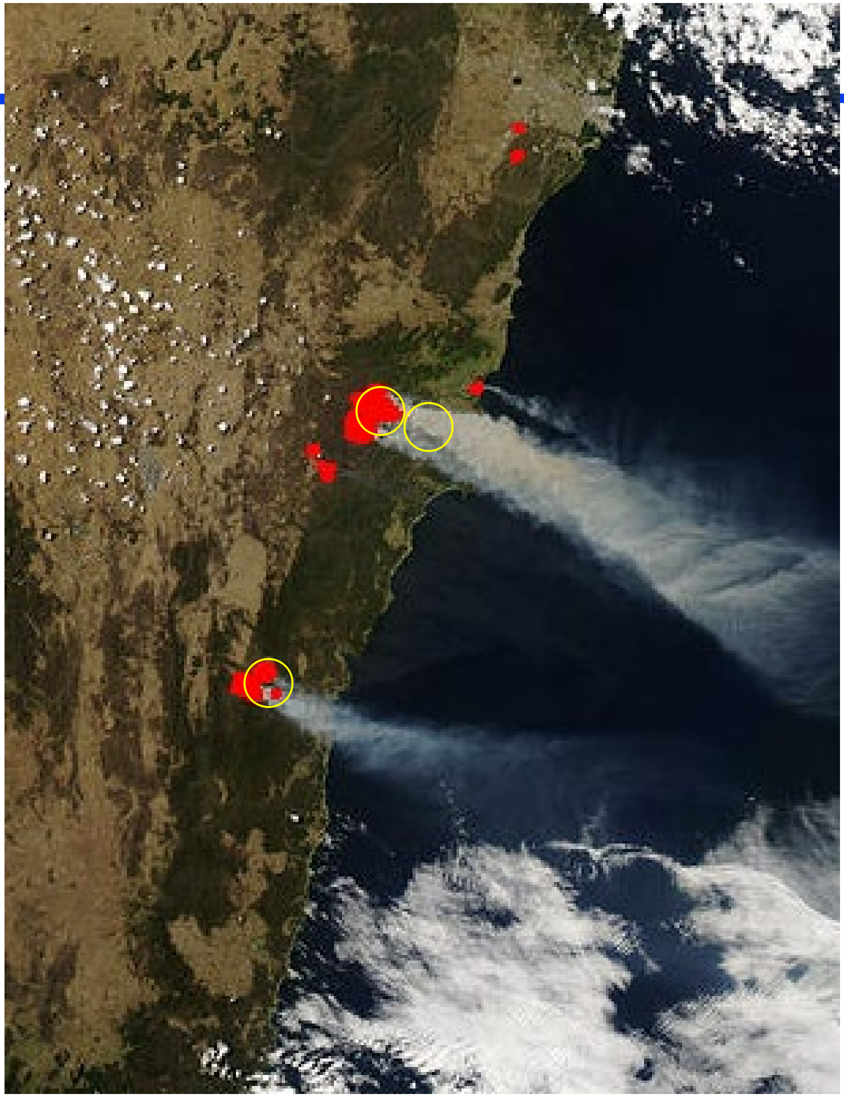
- High temperature and enhanced CO_2 provide a unique "**blue Spike**" signature in high resolution spectra



MAS

Bluespike observed with AIRS

Extensive Wild Fires in SE Australia, 4 December 2002



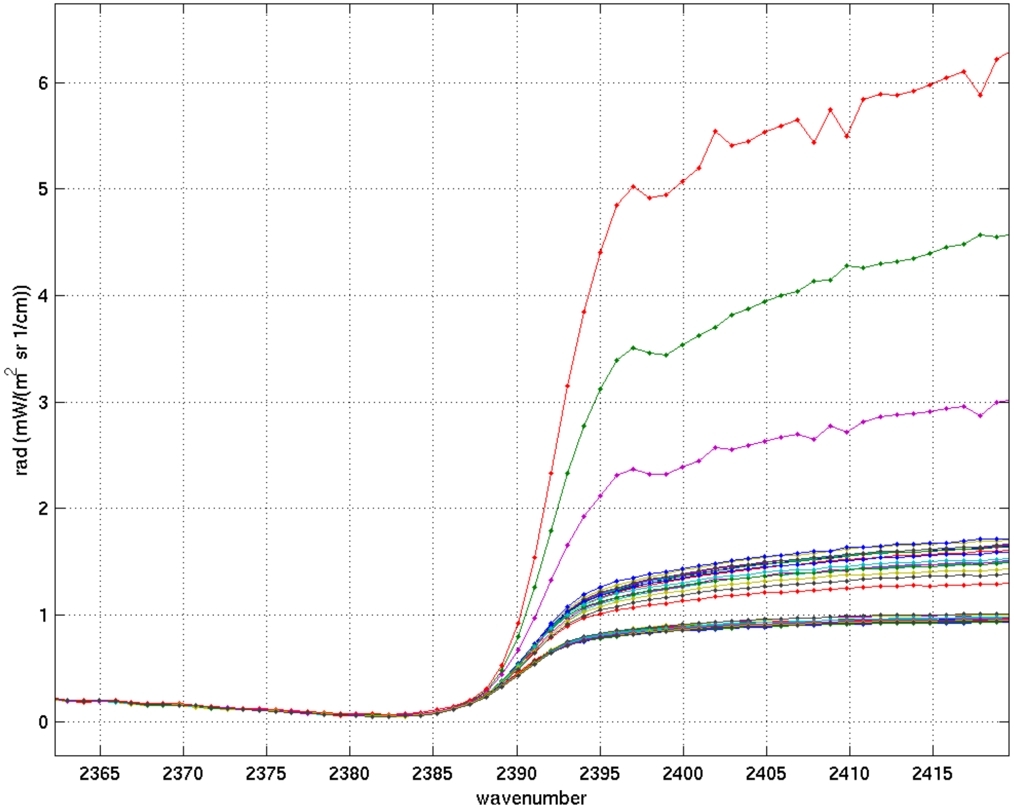


image source: MODIS Land Rapid Response System

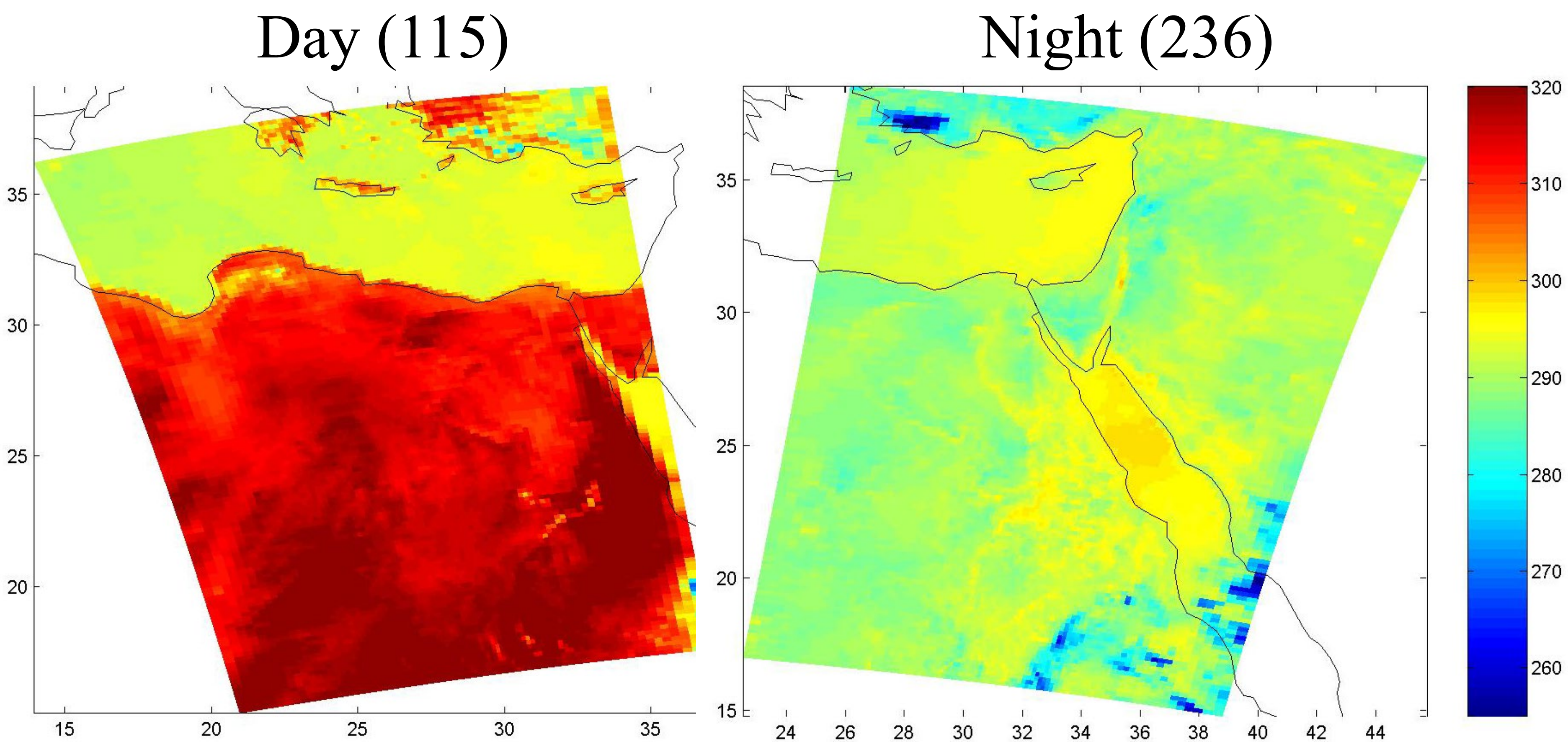
Surface Emissivity from on-line/off-line techniques

Great potential for land surface temperatures and accurate soundings over land

AIRS Surface Emissivity Survey

Granules 105, 115, 236; 14 June 2002

Day-Night Thermal Contrast

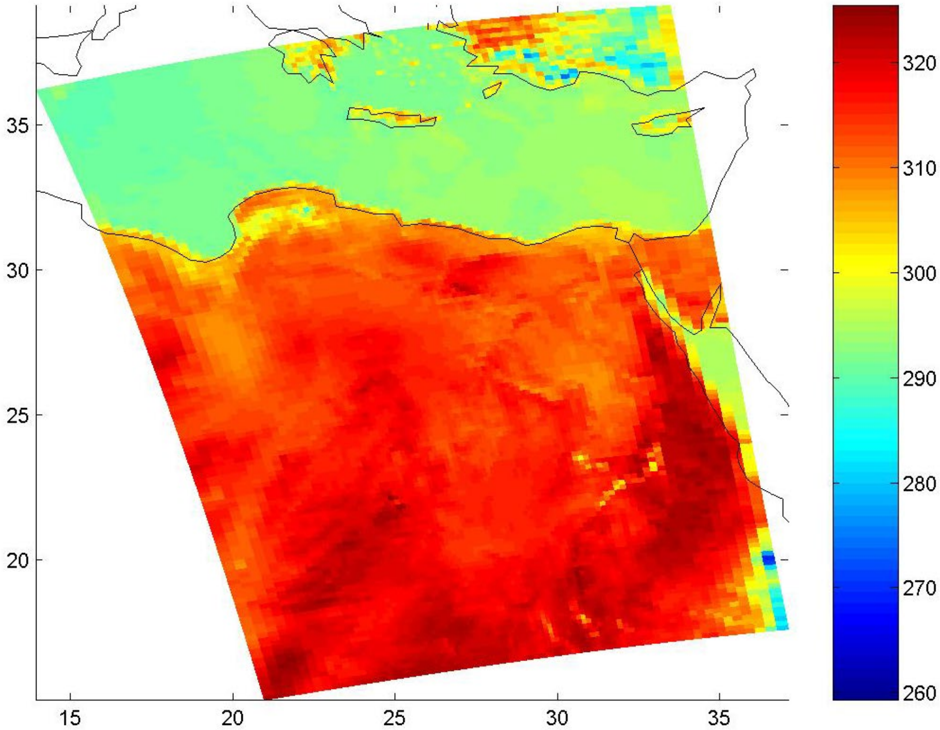


981 cm^{-1} Brightness Temperature

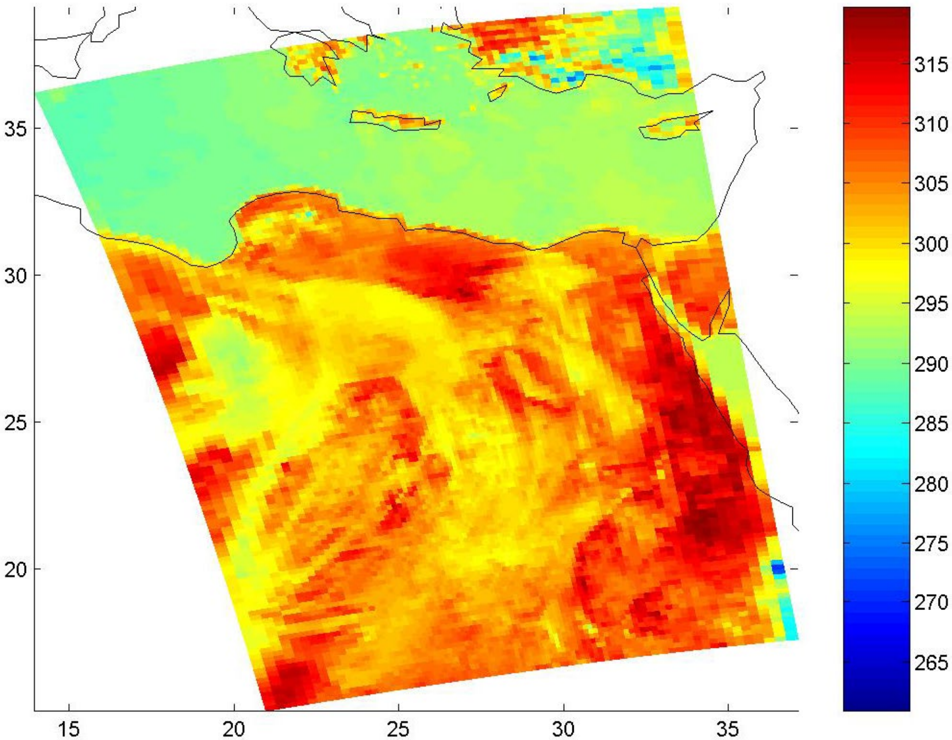
981 & 1086 cm^{-1} Brightness Temperatures

Granules 115, Day, 14 June 2002

981 cm^{-1}

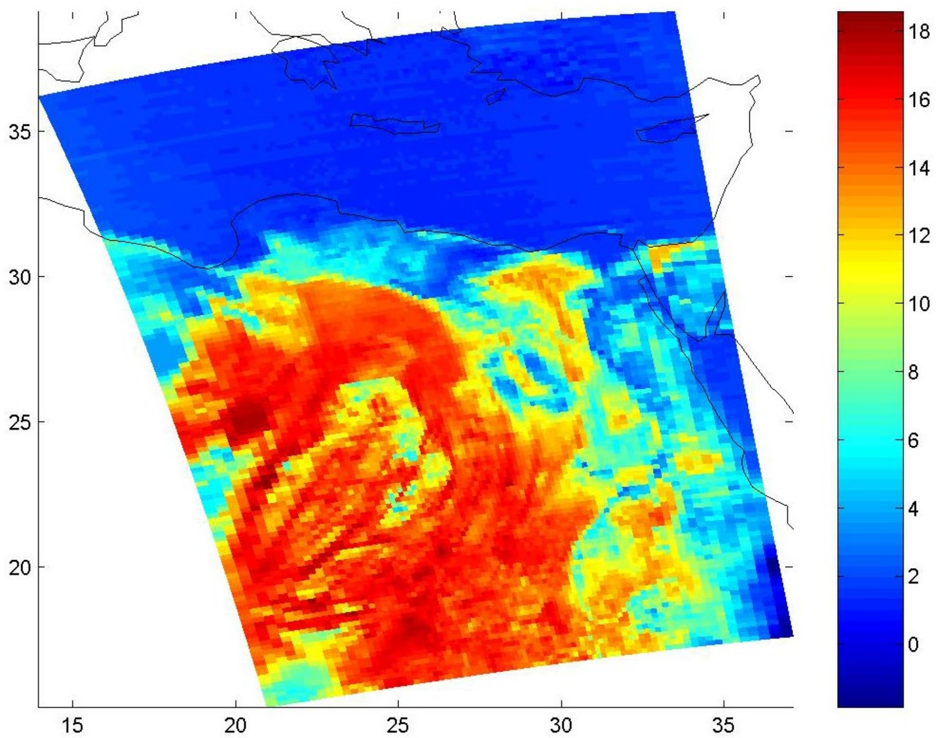


1086 cm^{-1}

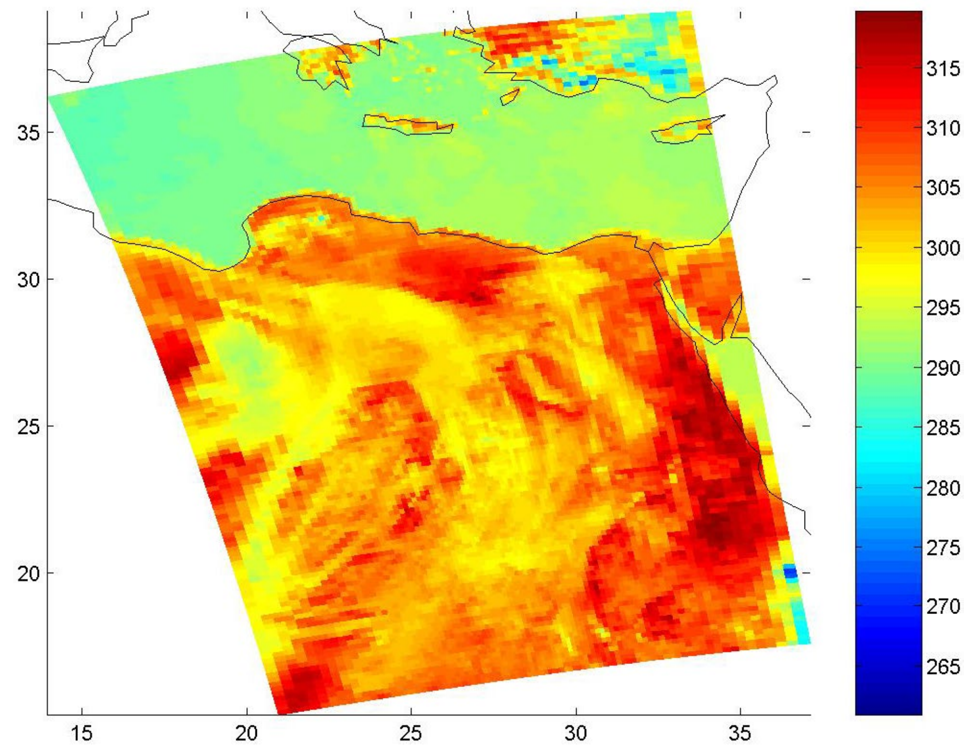


981-1086 cm^{-1} as Barren Region Detector
Granule 115, Day, 14 June 2002

T(981)-T(1086)

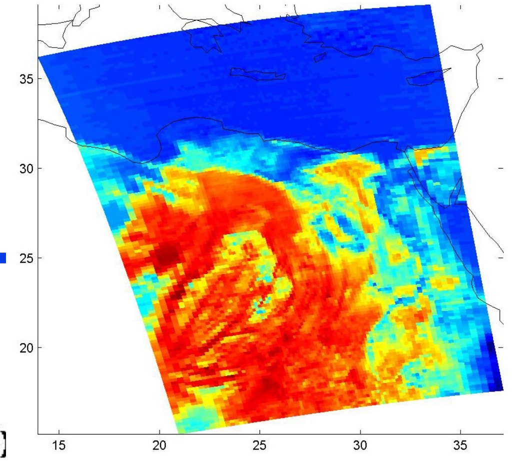


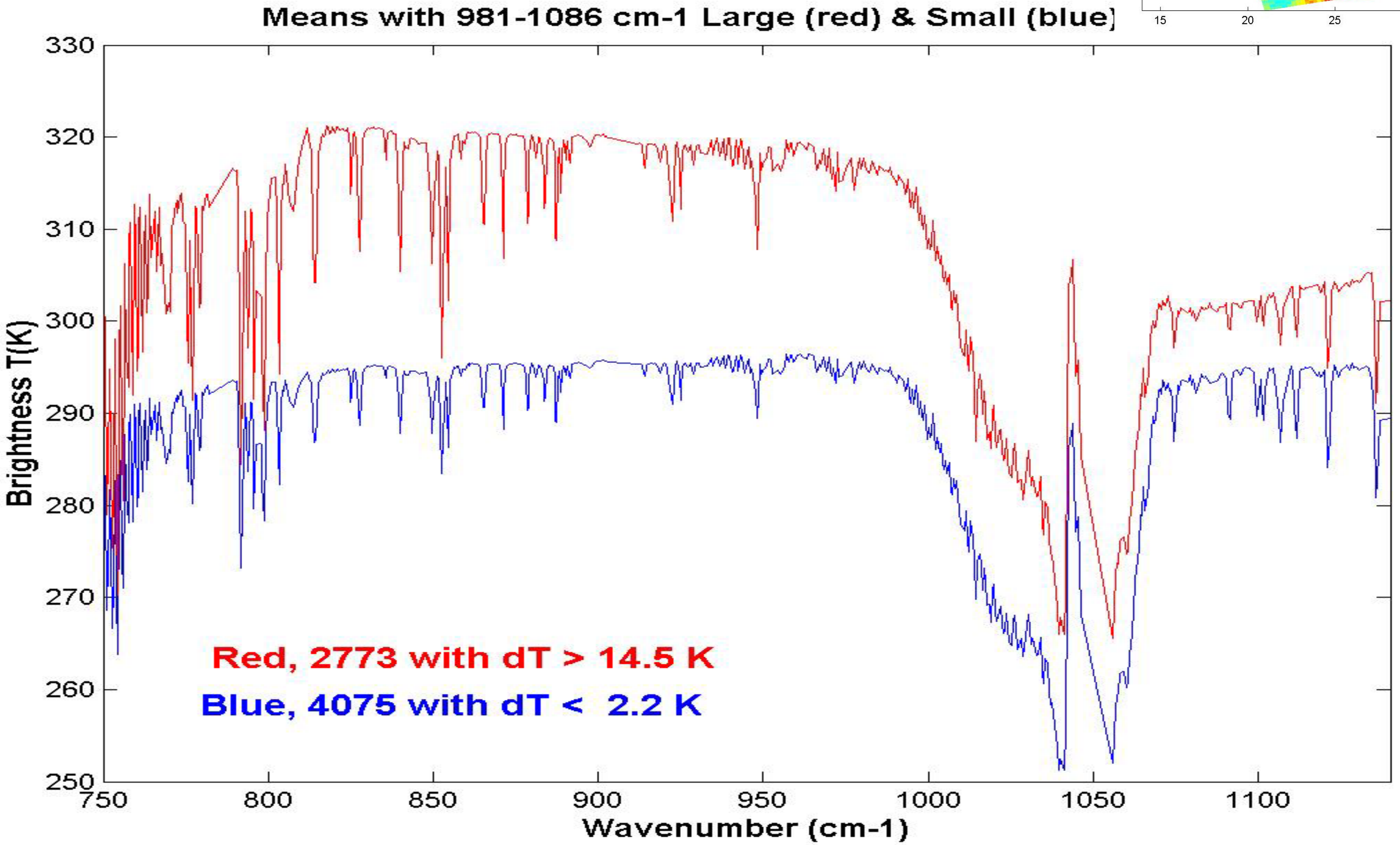
T(1086 cm^{-1})



Barren vs Water/Vegetated Surface

Granule 115, Day, 14 June 2002

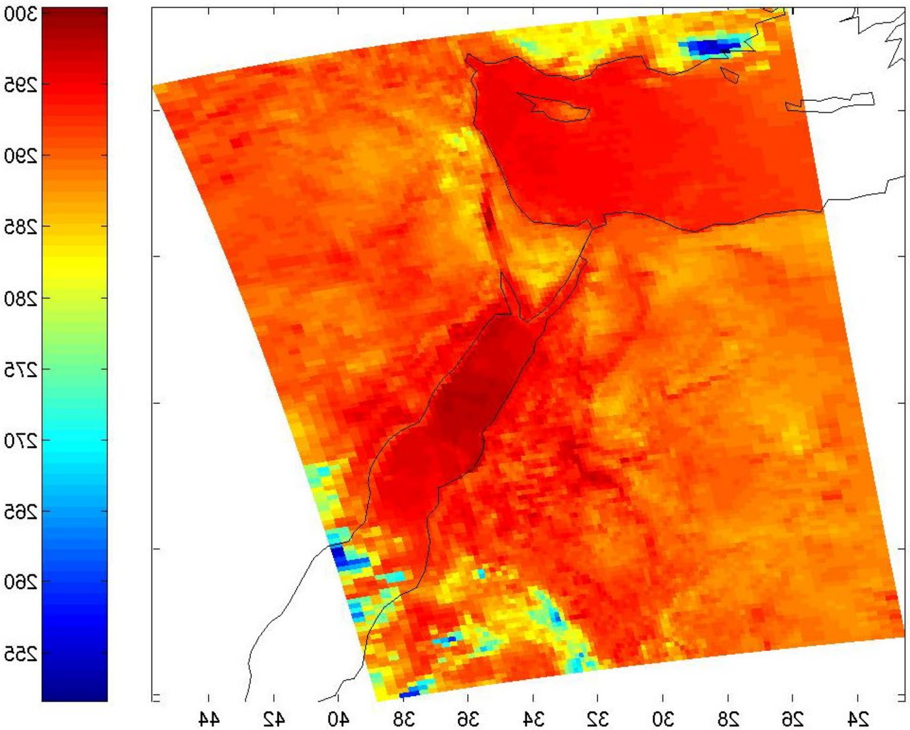




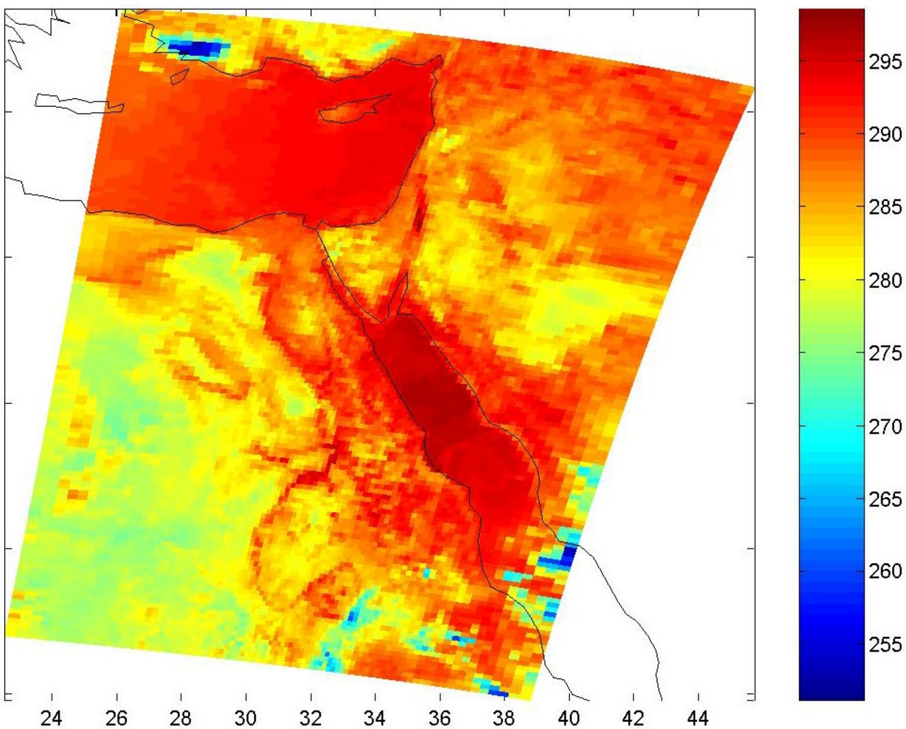
981 & 1086 cm^{-1} Brightness Temperatures

Granules 236, Night, 14 June 2002

981 cm^{-1}



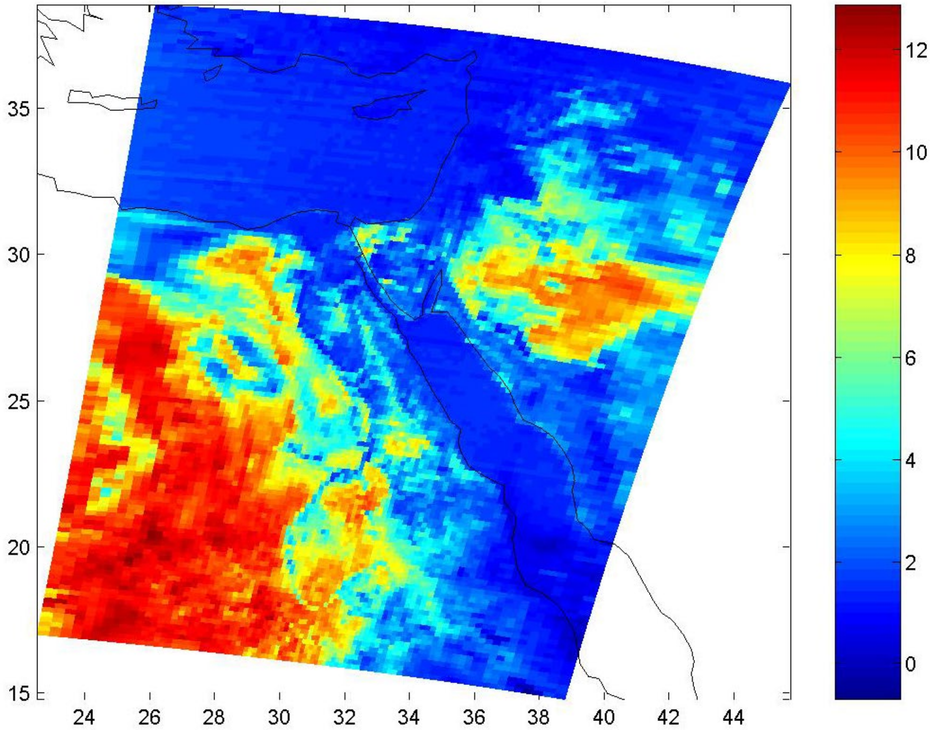
1086 cm^{-1}



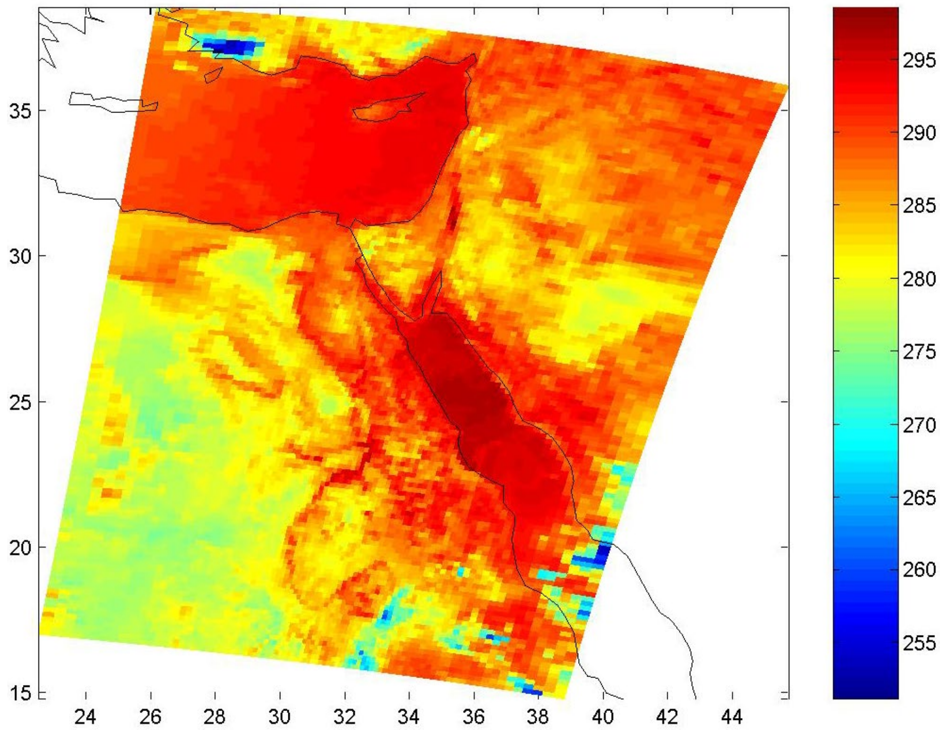
981-1086 cm^{-1} as Barren Region Detector

Granule 236, Night, 14 June 2002

T(981)-T(1086)

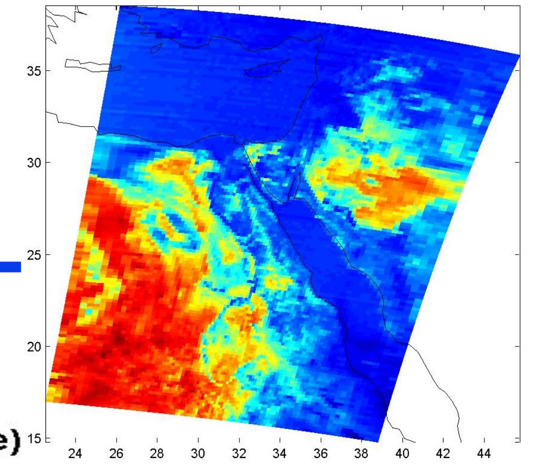


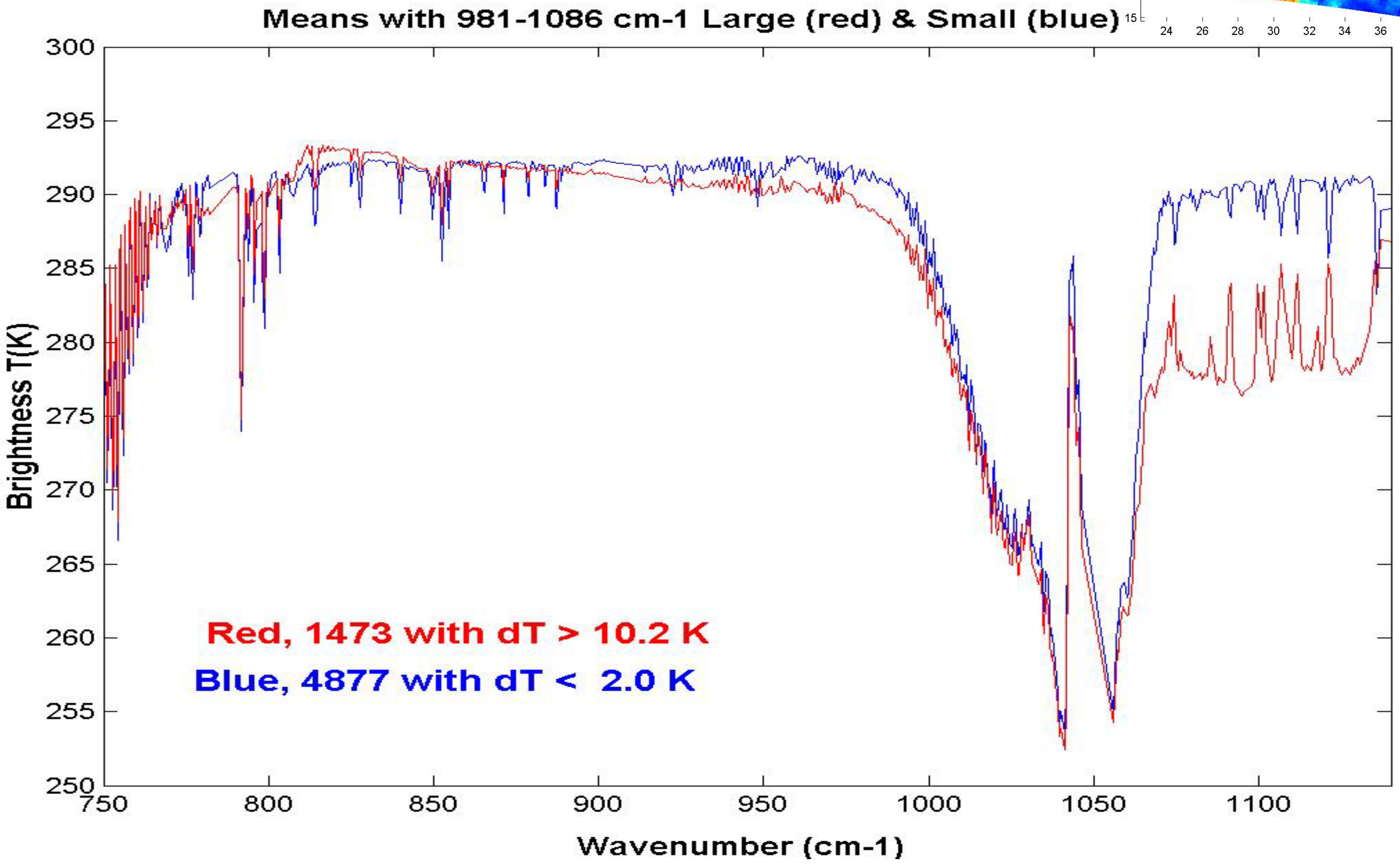
T(1086 cm^{-1})



Barren vs Water/Vegetated Surface

Granule 236, Night, 14 June 2002

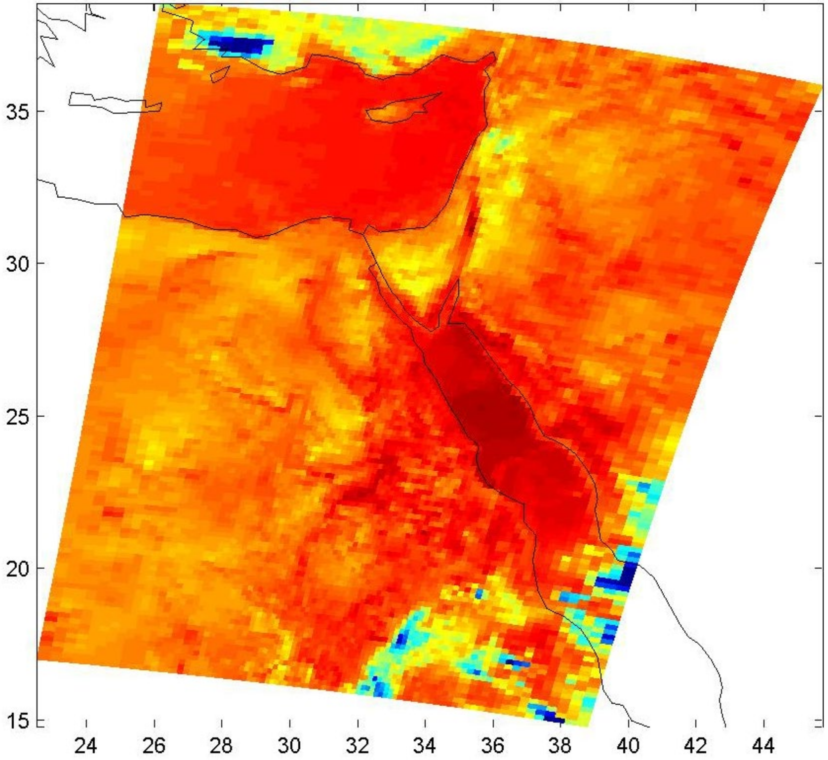




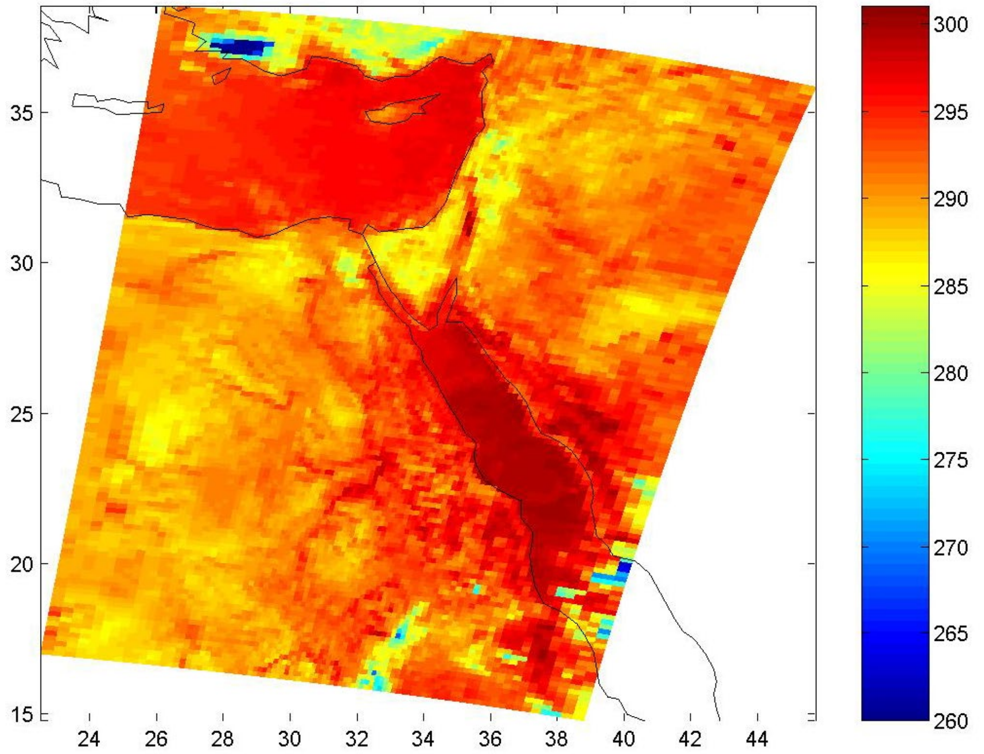
Single Channel "Surface" Temperatures

Granules 236, Night, 14 June 2002

960.27 cm^{-1}

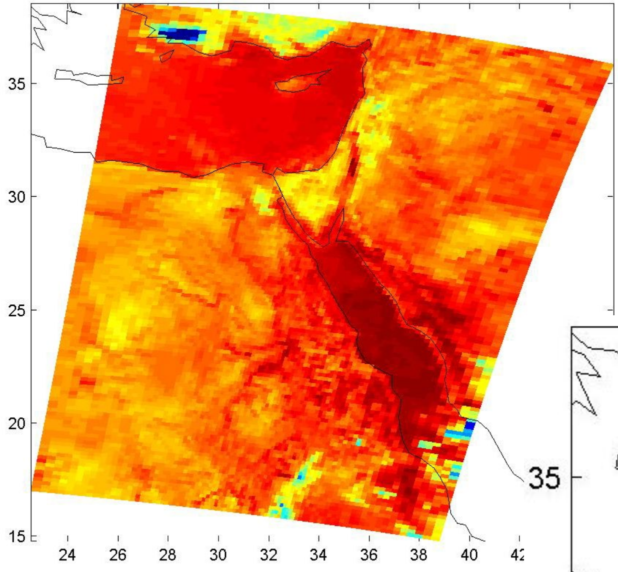


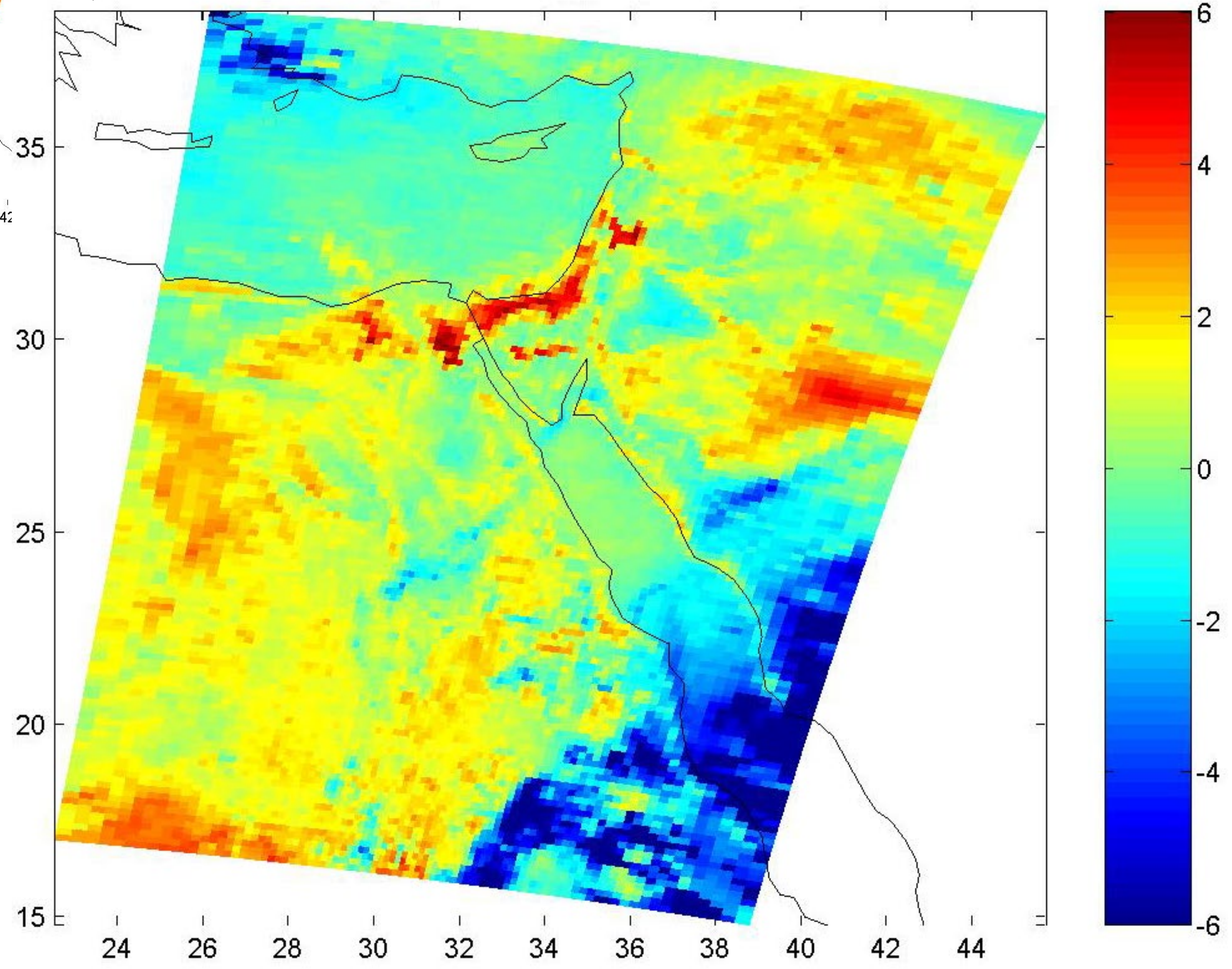
2616.38 cm^{-1}



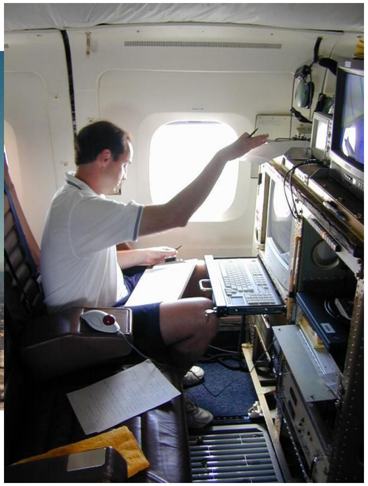
$T_b(960)$ - $T_b(2616)$

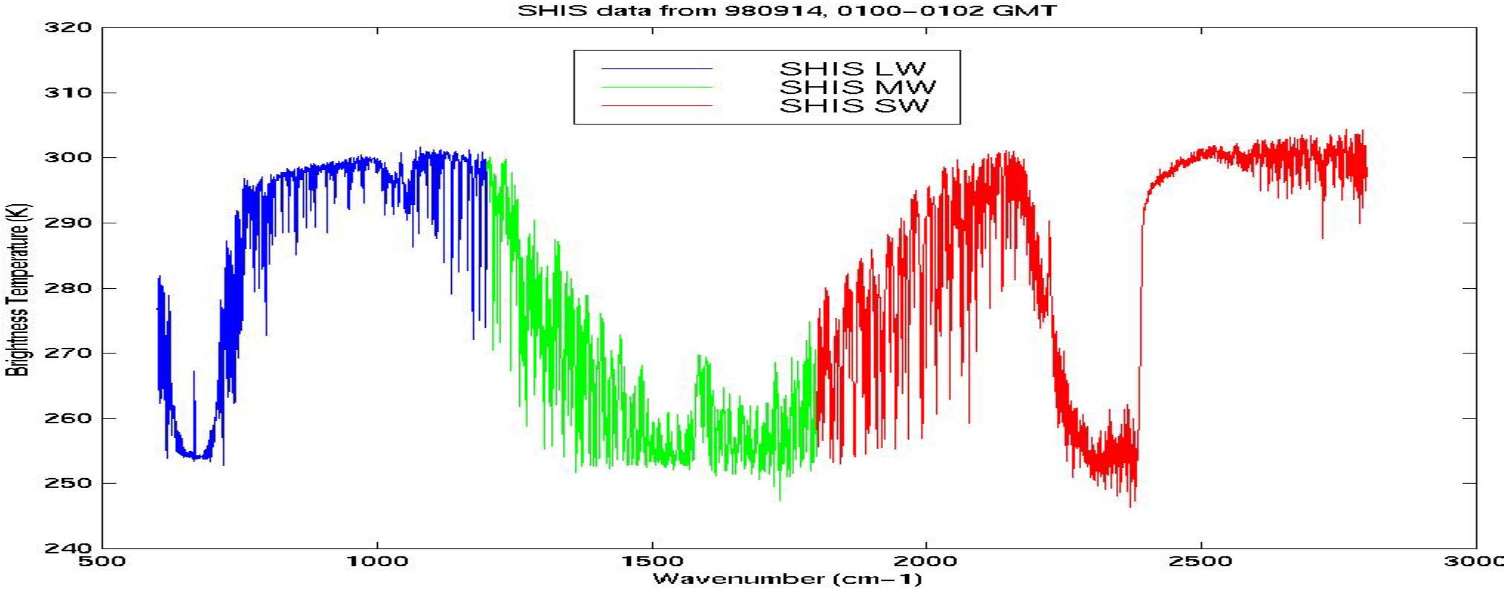
Granules 236, Night, 14 June 2002





More Surface Emissivity Examples: from the S-HIS Aircraft Instrument



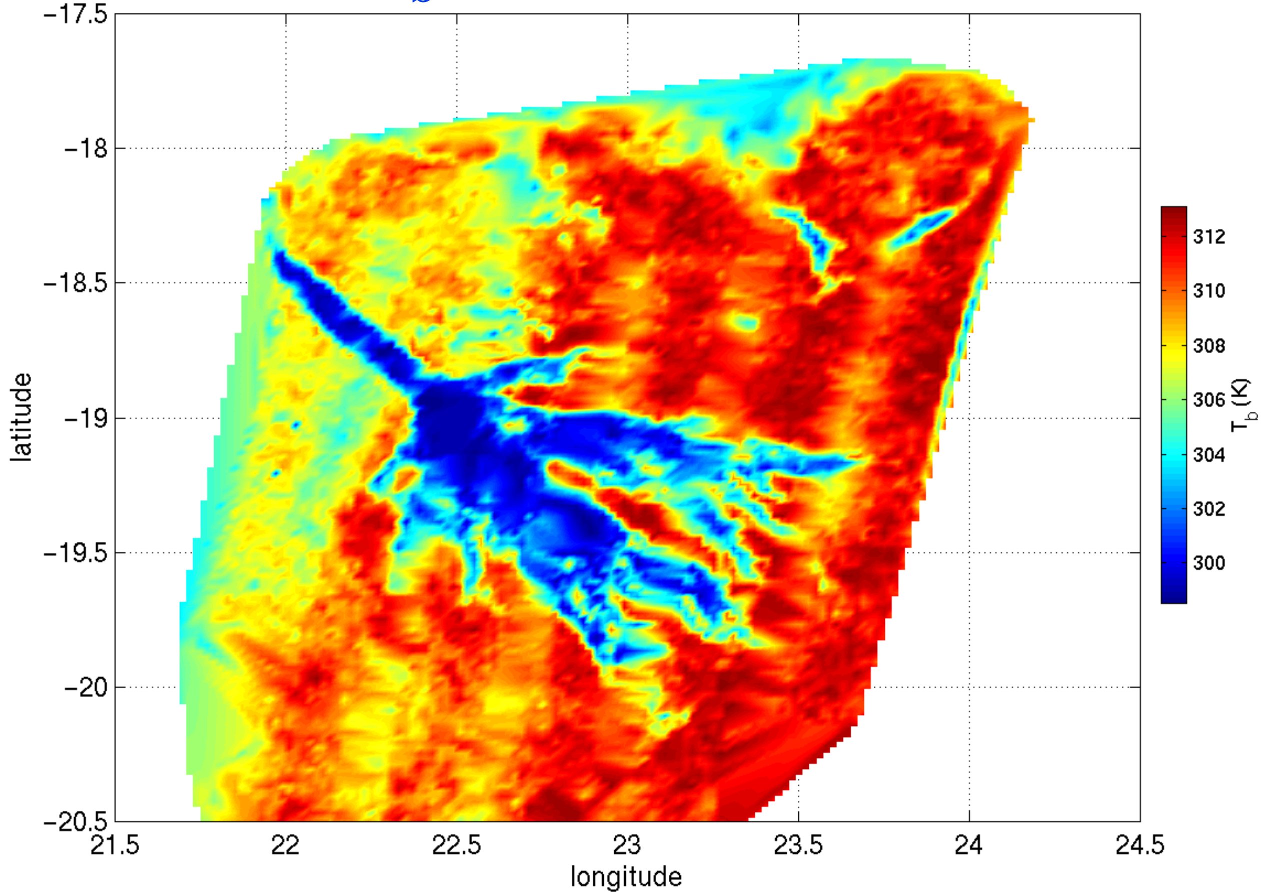


Okavanga Delta Mapping

from Scanning HIS, SAFARI, 27 Aug 2000

Scanning HIS: 2 km footprints

T_b (980-985 cm^{-1})

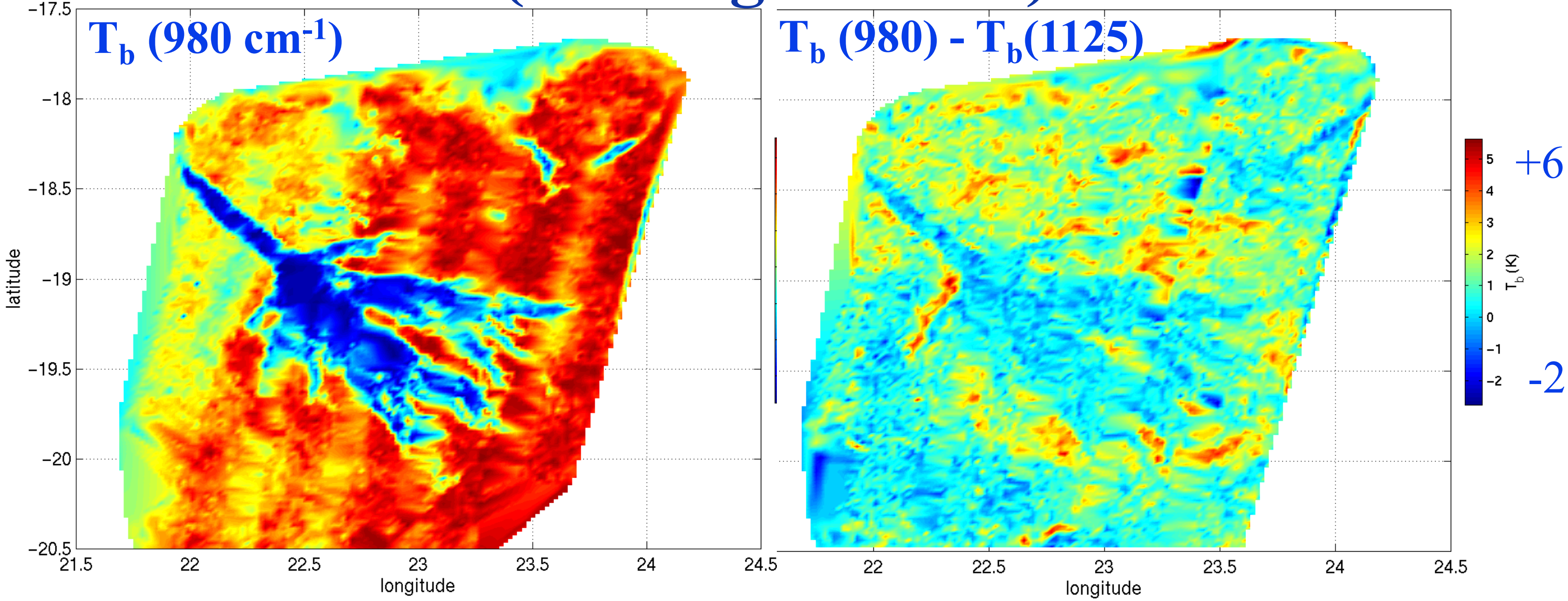


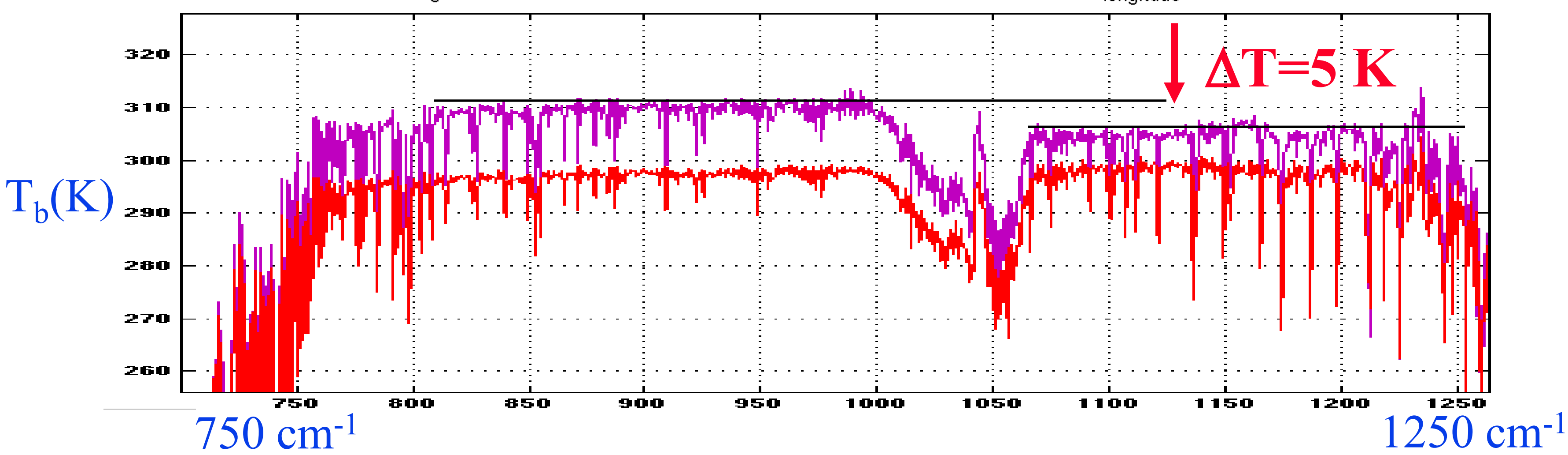
<u>MODIS</u>: 0.25 km

0.65 μm

Okavanga Delta Surface Emissivity

(27 August 2000)

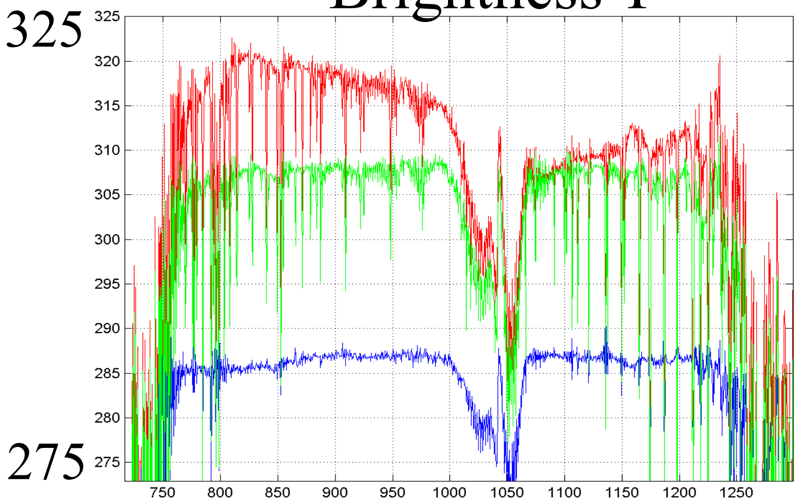




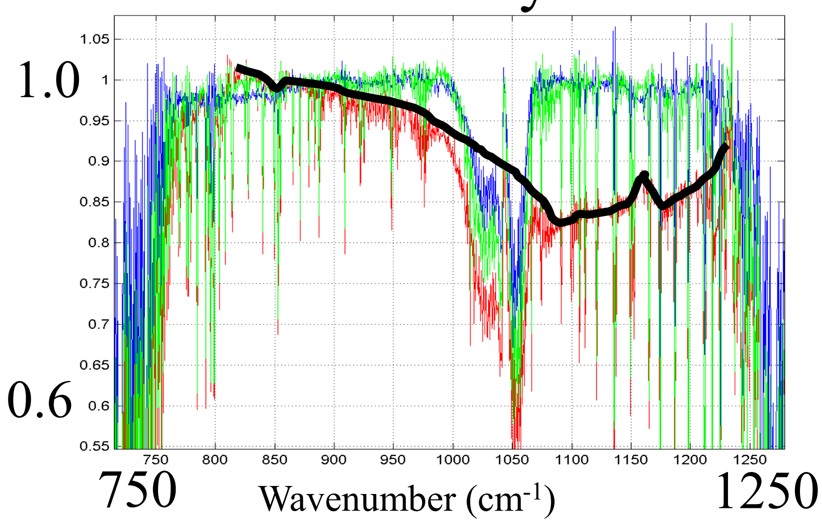
Surface Emissivity, a new emphasis

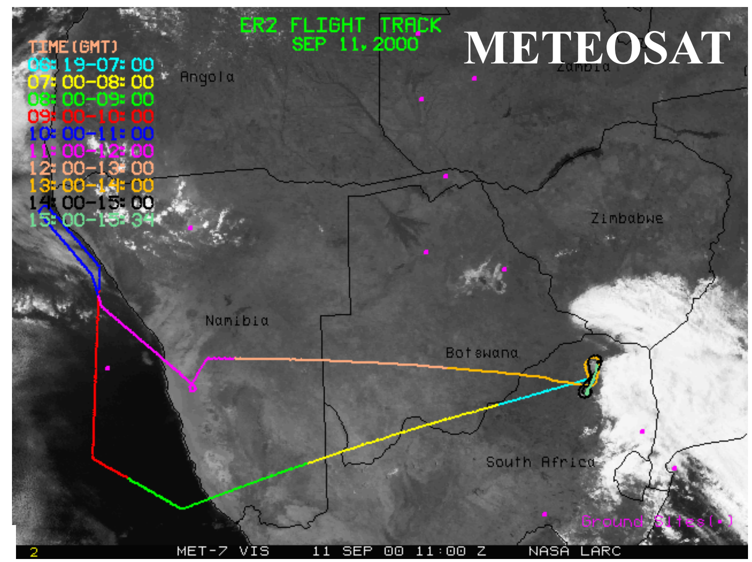
Namibian Land (11 September 2000)

Brightness T



Emissivity



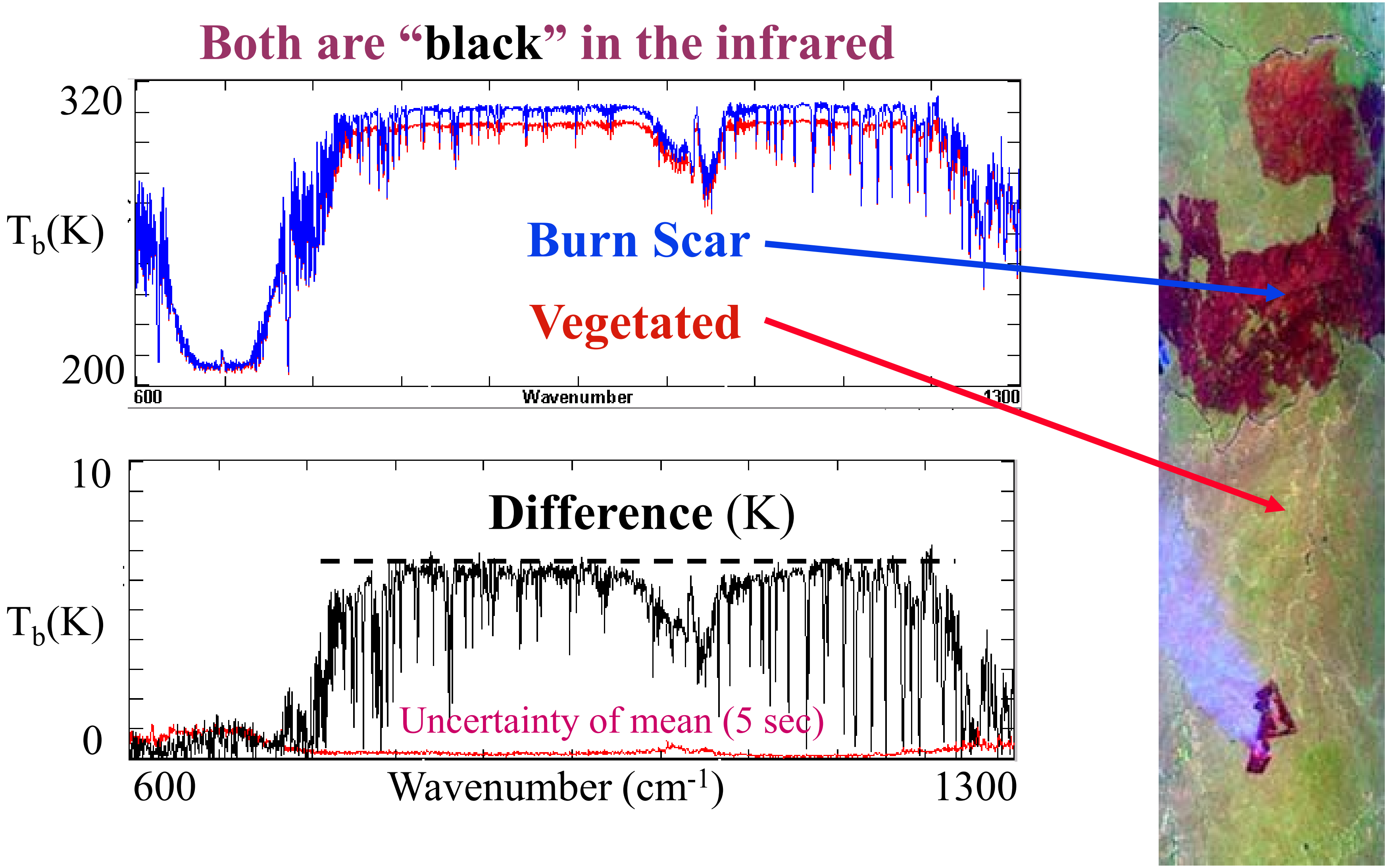


Namibian Coast

- Kuiseb River Canyon [Dunes (left)≈Desert pavement]
- Kalahari Desert (Vegetated)
- Ocean

Burn Scar Surface Characteristics

(7 September Controlled Burn)



Getting Quantitative: The on-line/off-line technique

Infrared Radiative Transfer Equation (lambertian surface)

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

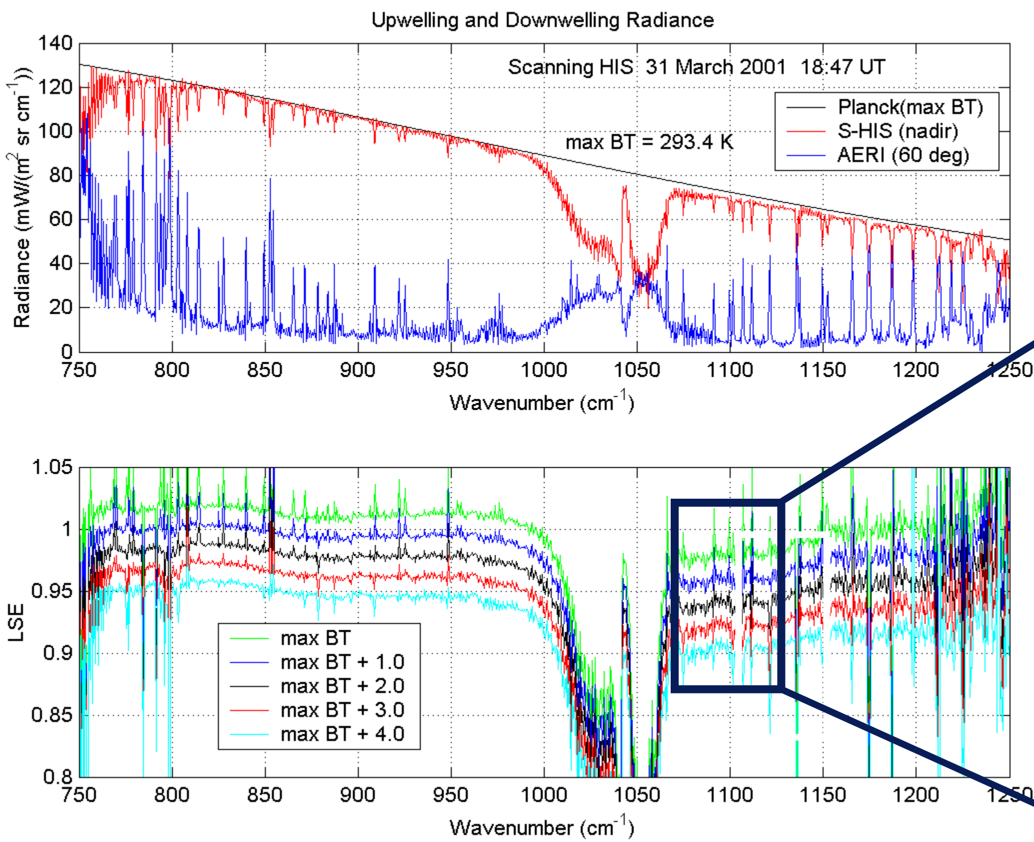
The effective skin temperature is obtained as the value of Ts that <u>minimizes the spectral variance</u> of the derived emissivity across atmospheric absorption lines. The effective emissivity is then computed using this skin temperature.

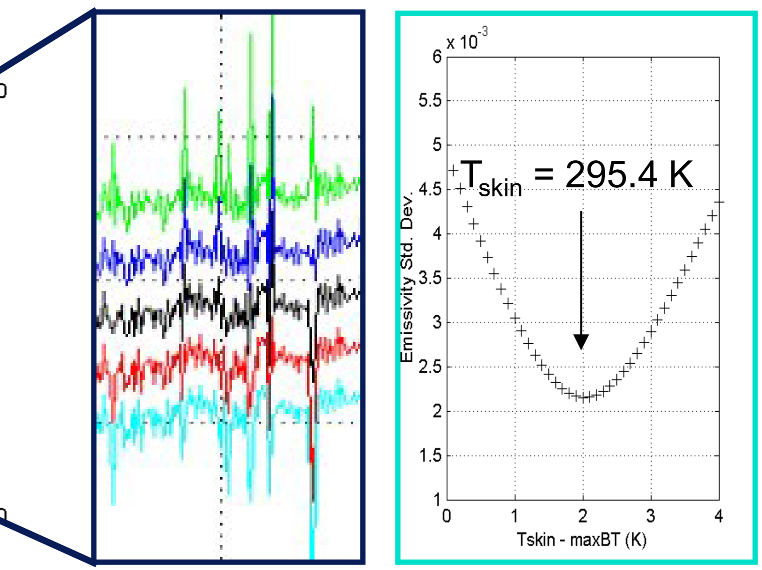
Formal Solution

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

Simultaneous Retrieval of Land Surface Emissivity and Temperature

$$e_\nu = \frac{\left(\dfrac{N_\nu^{obs\uparrow} - N_\nu^{atm\uparrow}}{\tau_\nu^{tot}}\right) - \overline{N_\nu^{\downarrow}}}{B_\nu\left(T_S\right) - \overline{N_\nu^{\downarrow}}}$$

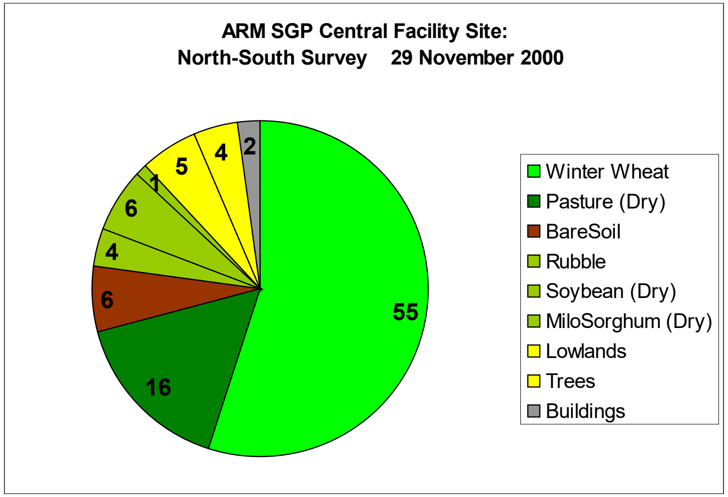


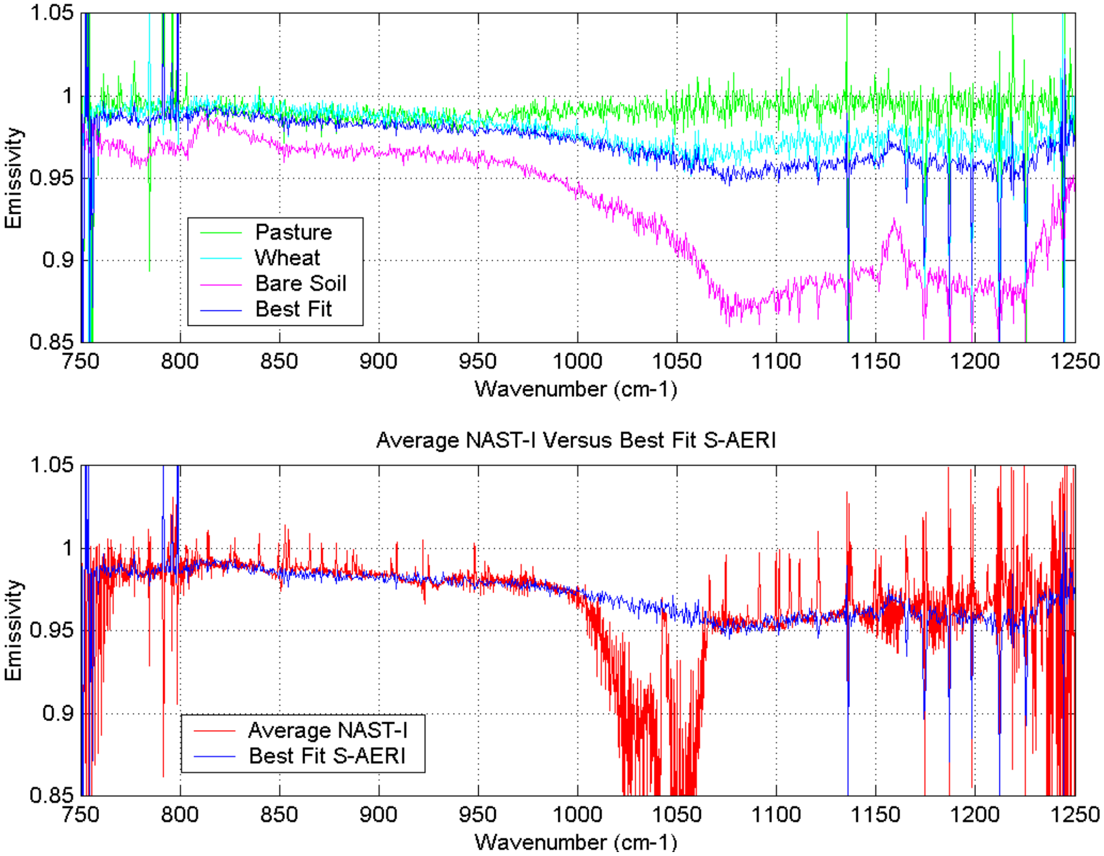


- CO2 “laser lines” in 970-980 cm^{-1} region used to minimize the standard deviation in derived emissivity.

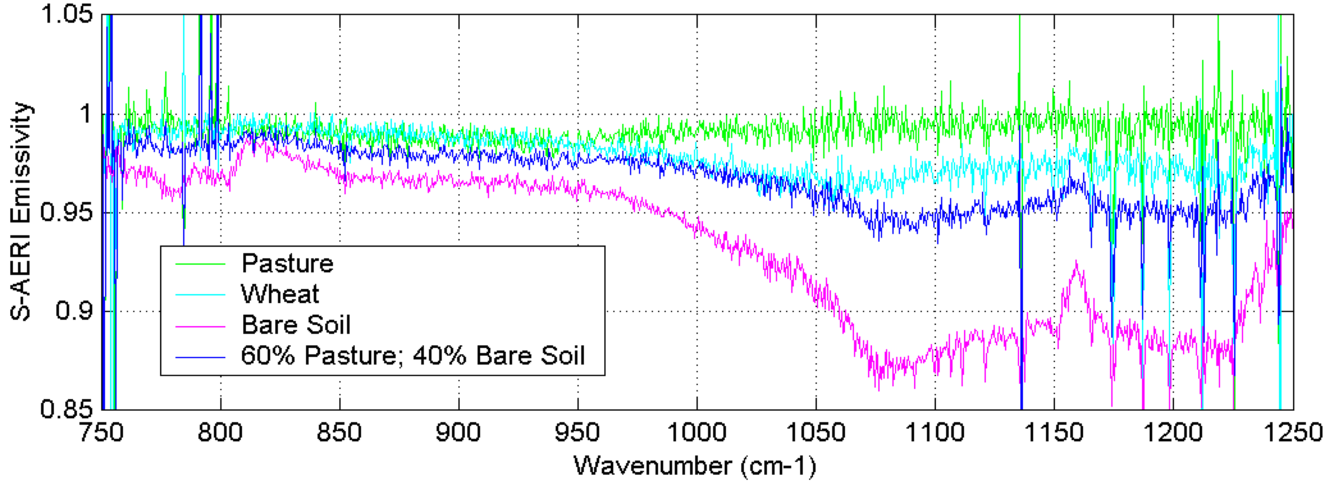
Surface Emissivity Validation with AERI

A survey was conducted on Nov 29 to characterize the surface type and spectral emissivity in the vicinity of the ARM SGP Central Facility site.

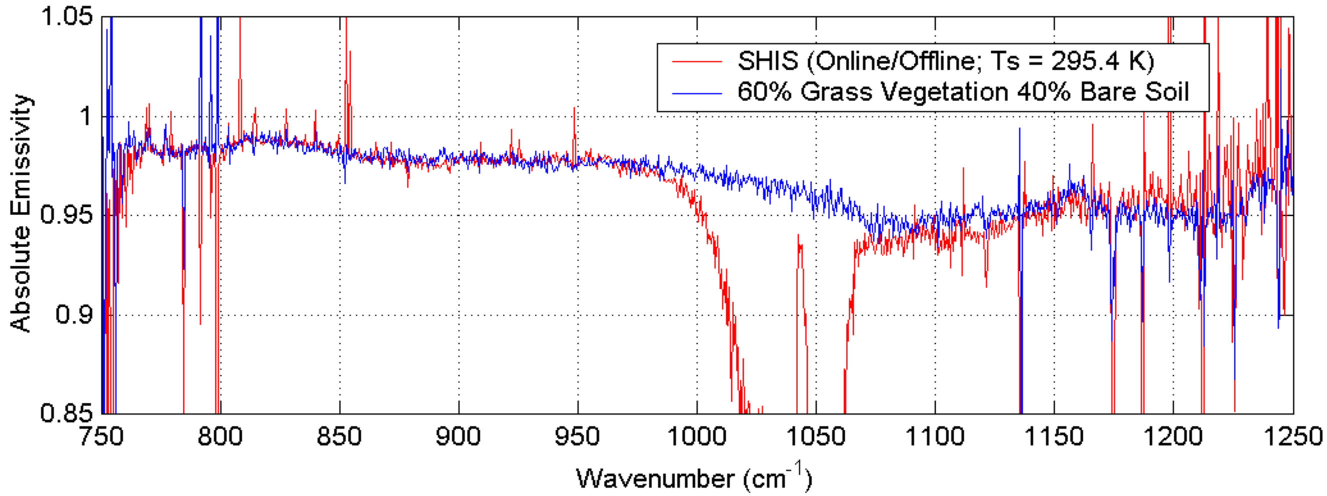




Effective Emissivity as a Linear Combination of Pure Scene Types



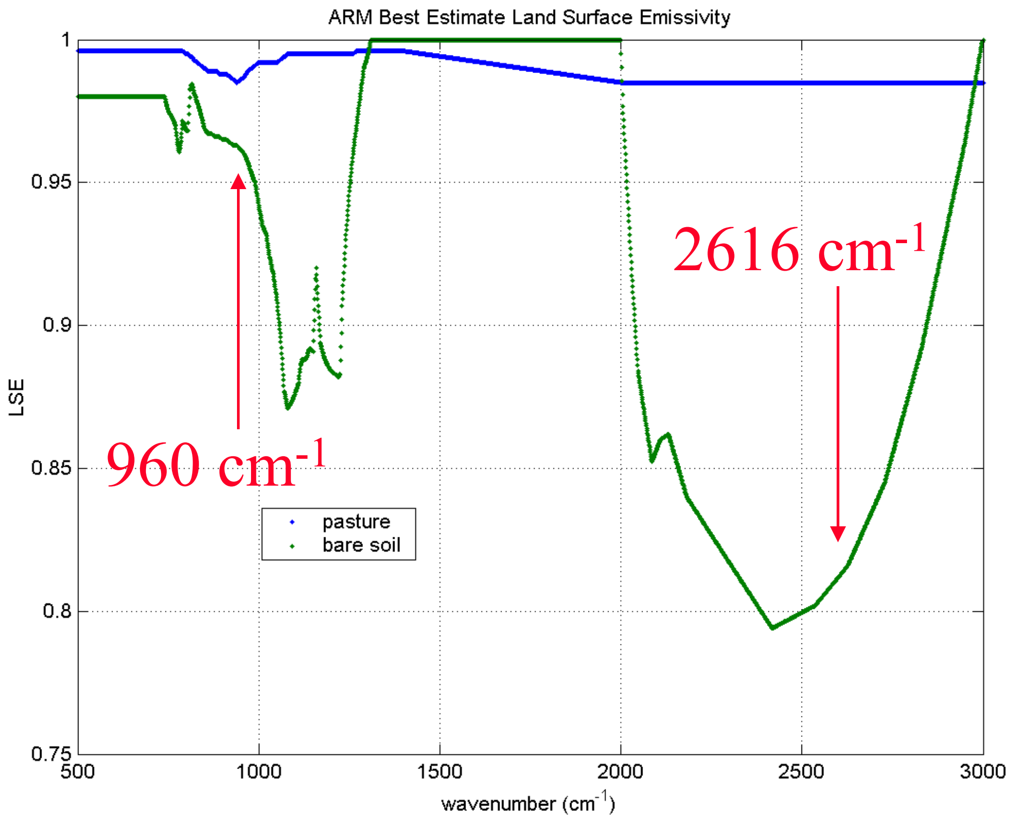
Ground-based Survey Results



Aircraft measurements can be fit by a weighted average of vegetation (60%) and bare soil (40%).

- Only <u>two</u> pure scene types are needed !!!

Fit to AERI Emissivity: LW & SW

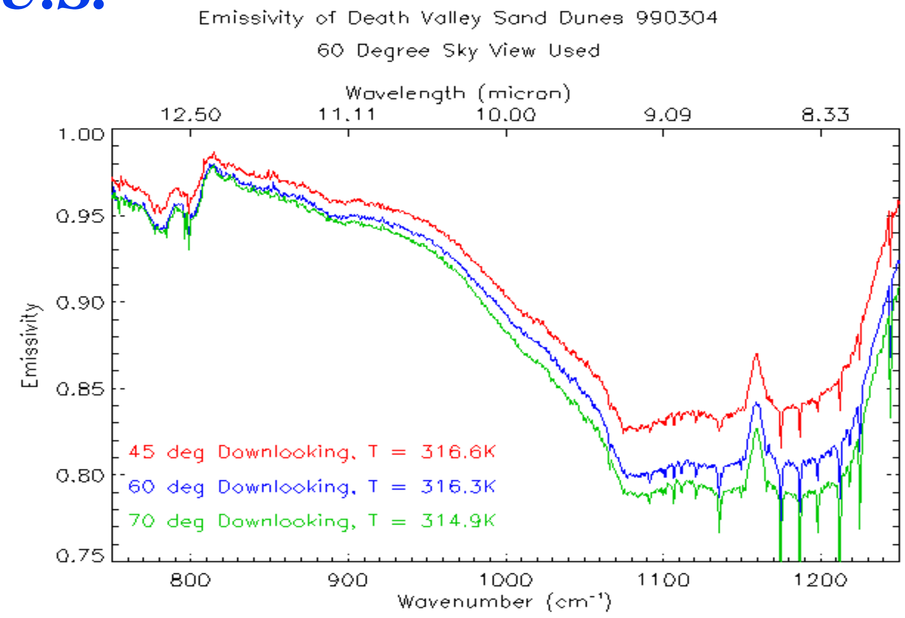


Remember the AIRS comparison between these 2 channels?

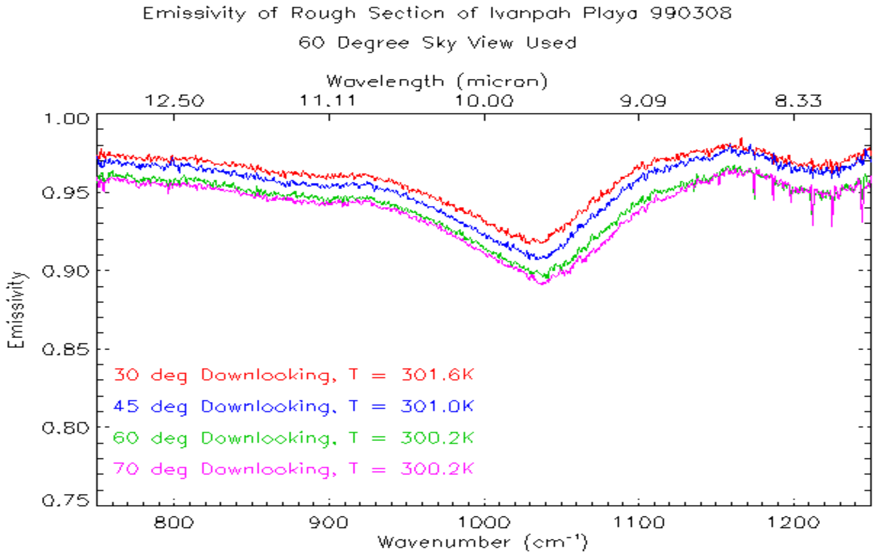
S-AERI: Desert Southwest U.S.

March 1999

Sand



Pan

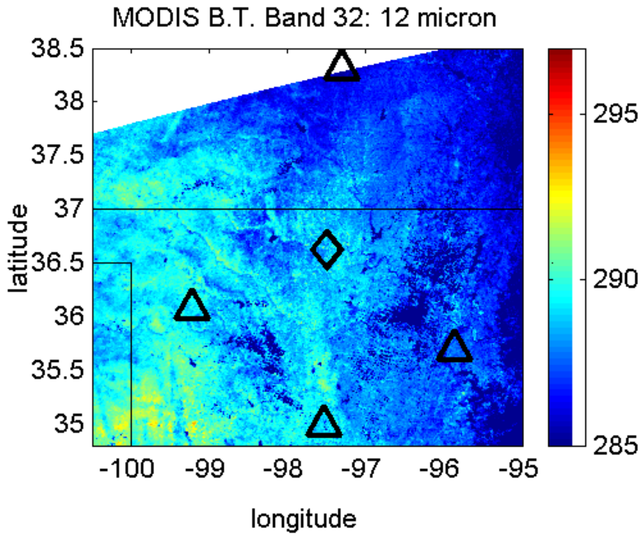


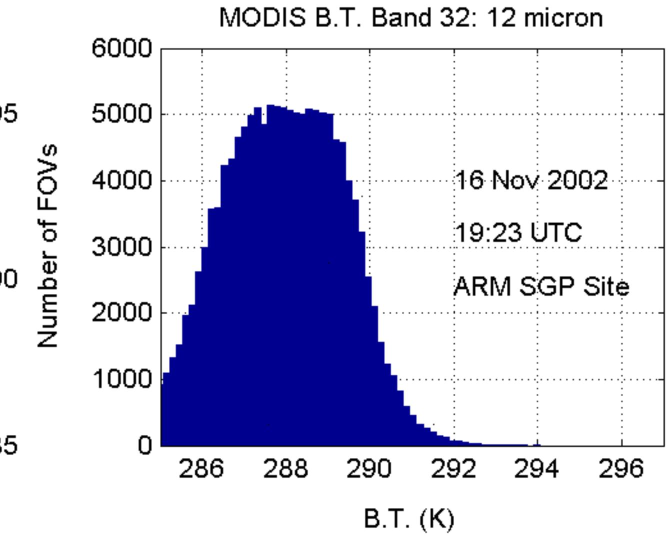
AIRS Emissivity Result

(Oklahoma, 16 November 2002)

MODIS Aqua and AIRS Brightness Temperatures

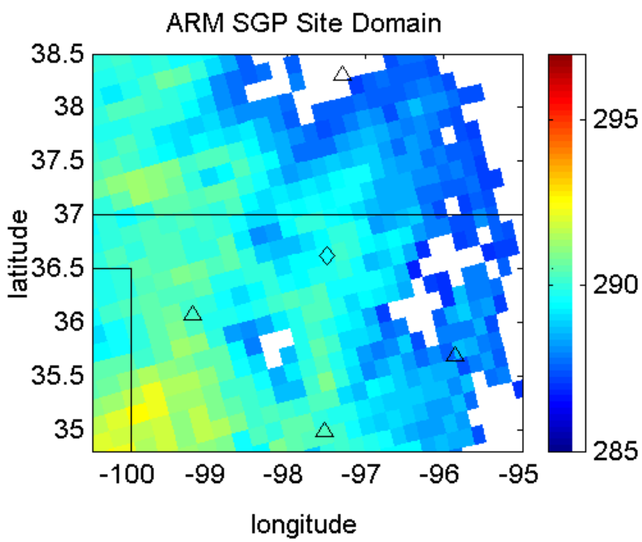
MODIS
12 µm
B.T.
(K)

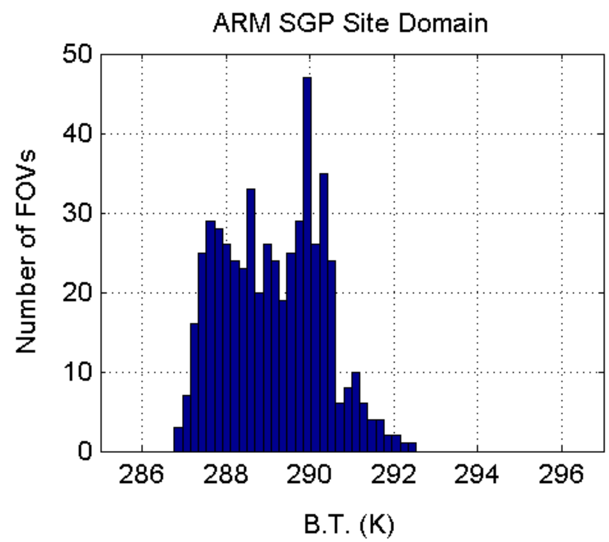




1 km

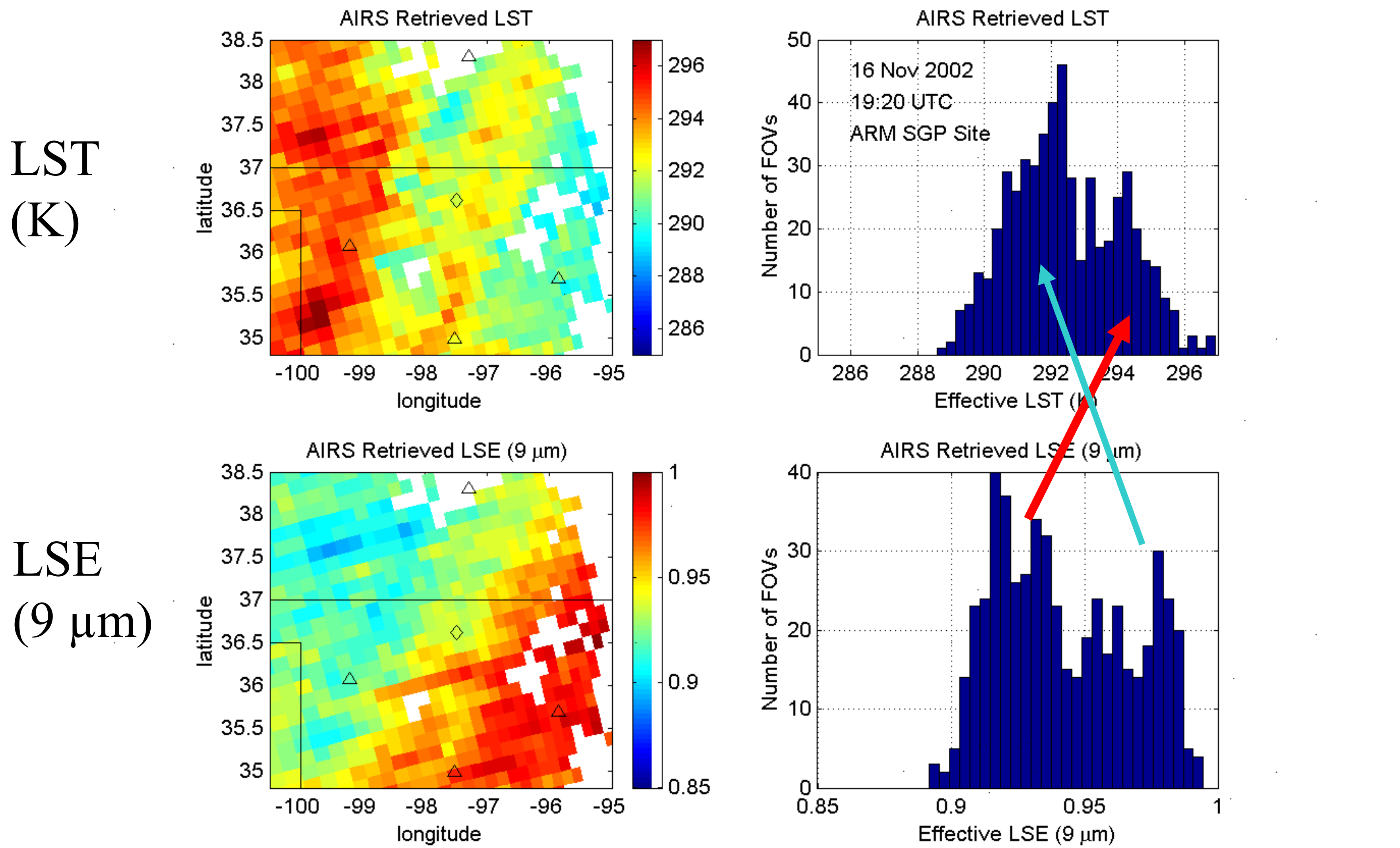
AIRS
12 µm
B.T.
(K)





16 km

Online/Offline Derived LST and LSE over ARM SGP Domain

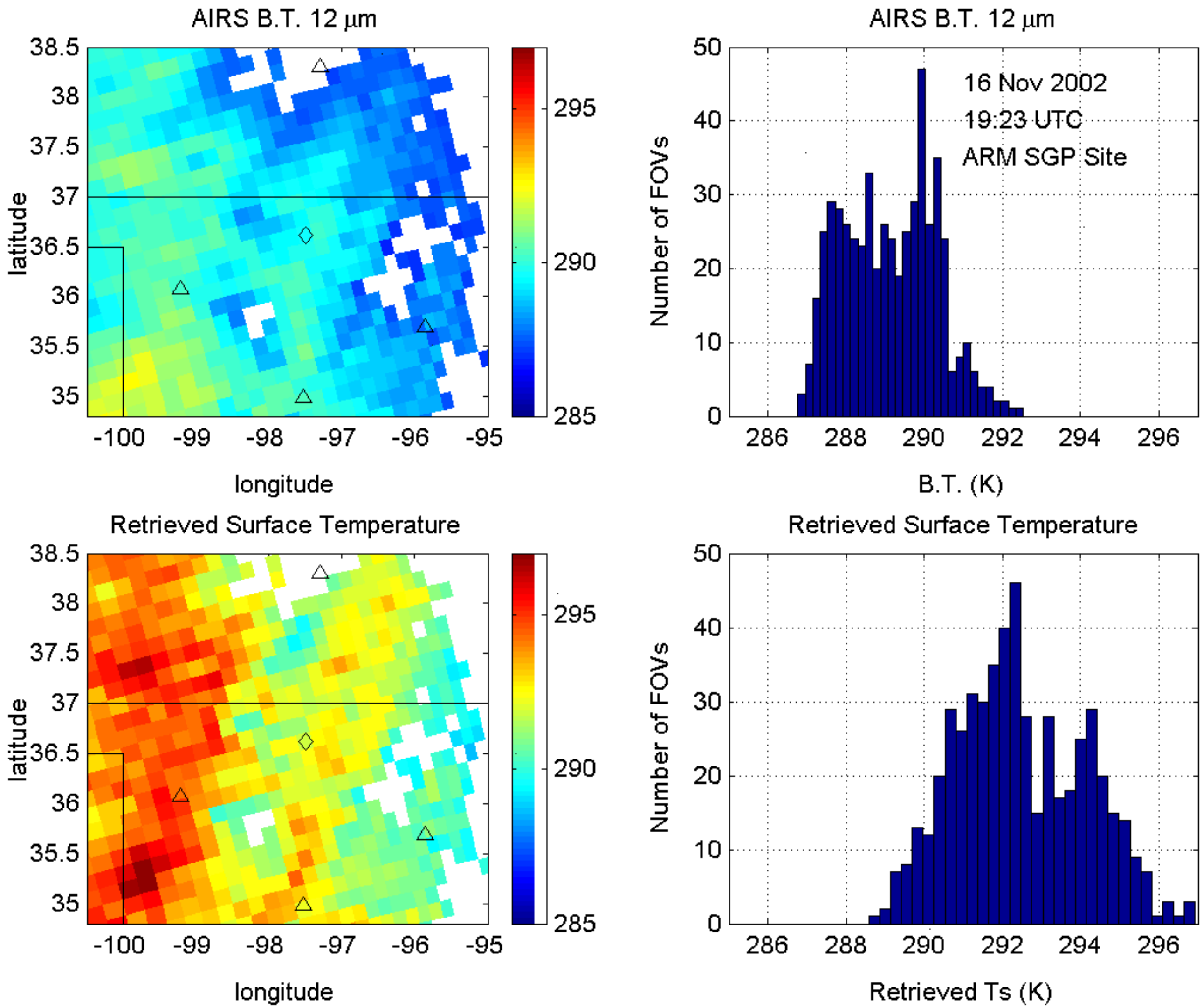


• Warm FOVs have lower absolute emissivity, i.e. more bare soil.

Comparison of AIRS LW Window B.T. and Online/Offline LST

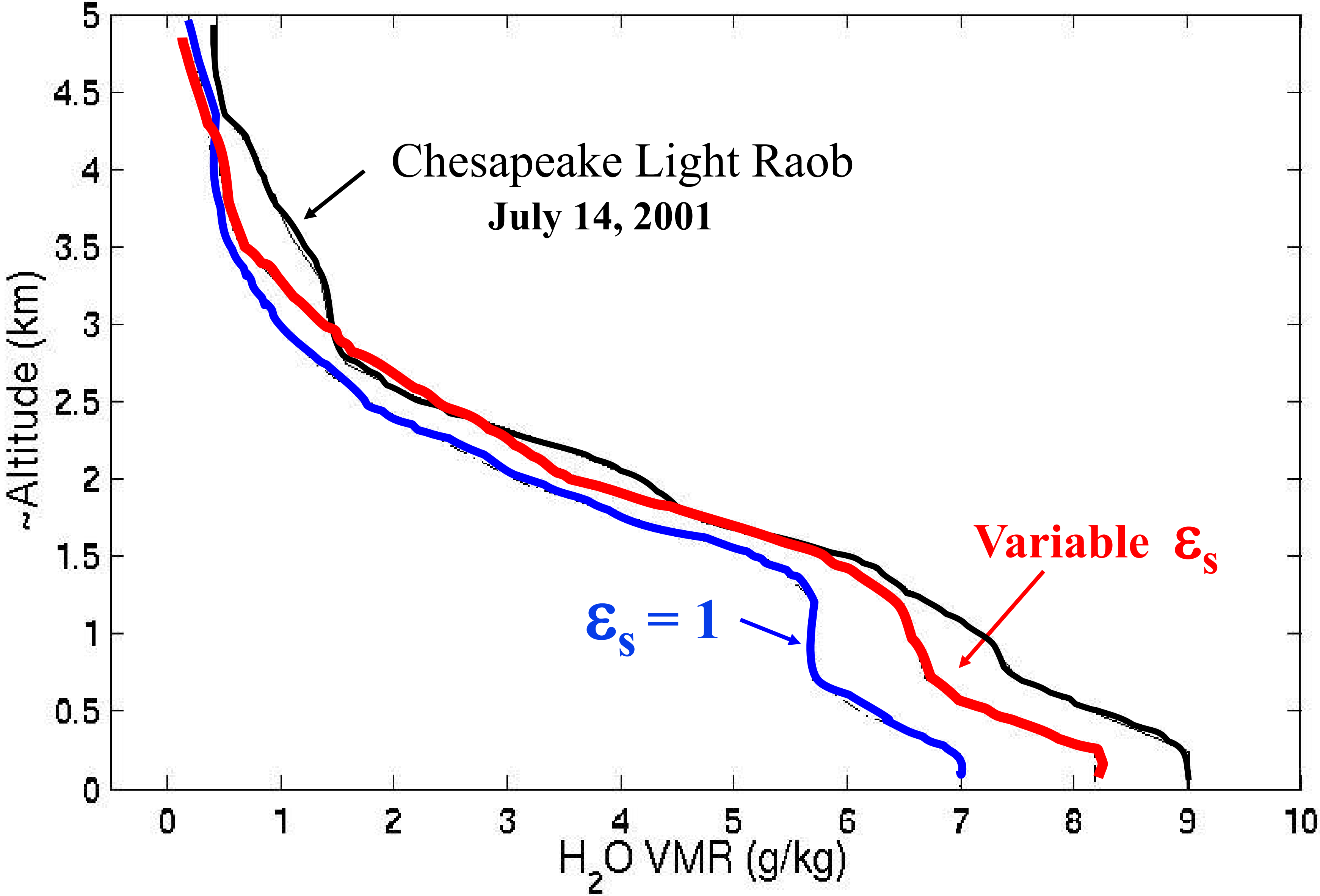
AIRS 12 µm B.T. (K)

LST (K)



Note: True variation of LST is almost double that of measured T_b!

Surface Emissivity Impact on PBL Moisture

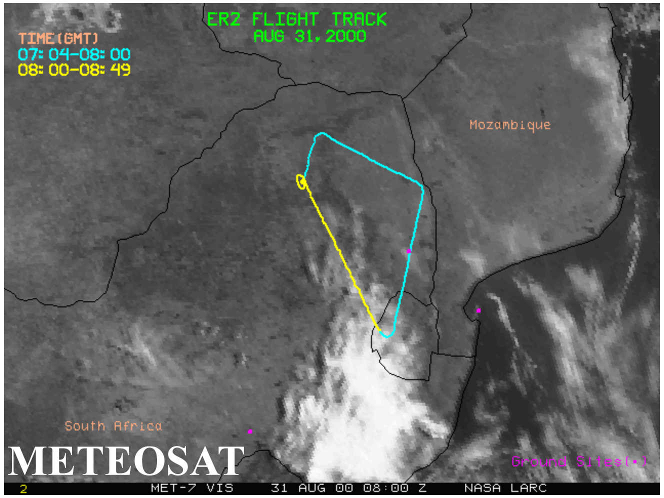


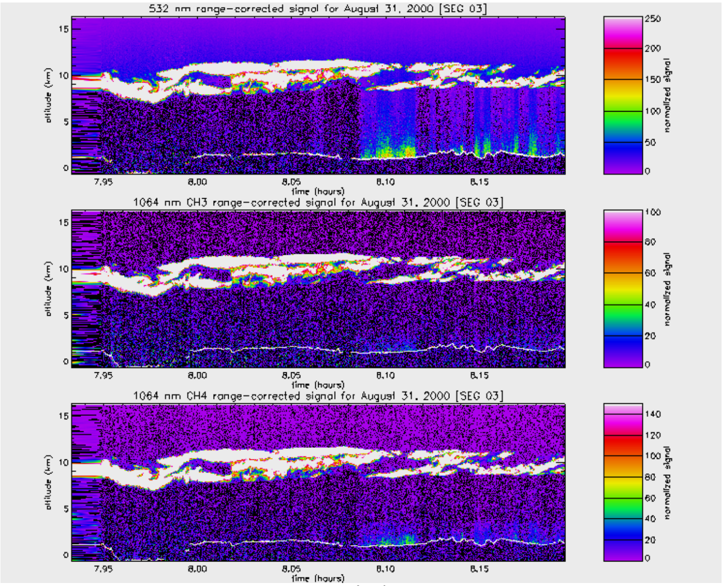
Cloud Properties

Some examples of new capabilities shown here

People are doing much more with determination of microproperties (effective radius and habit, or shape)

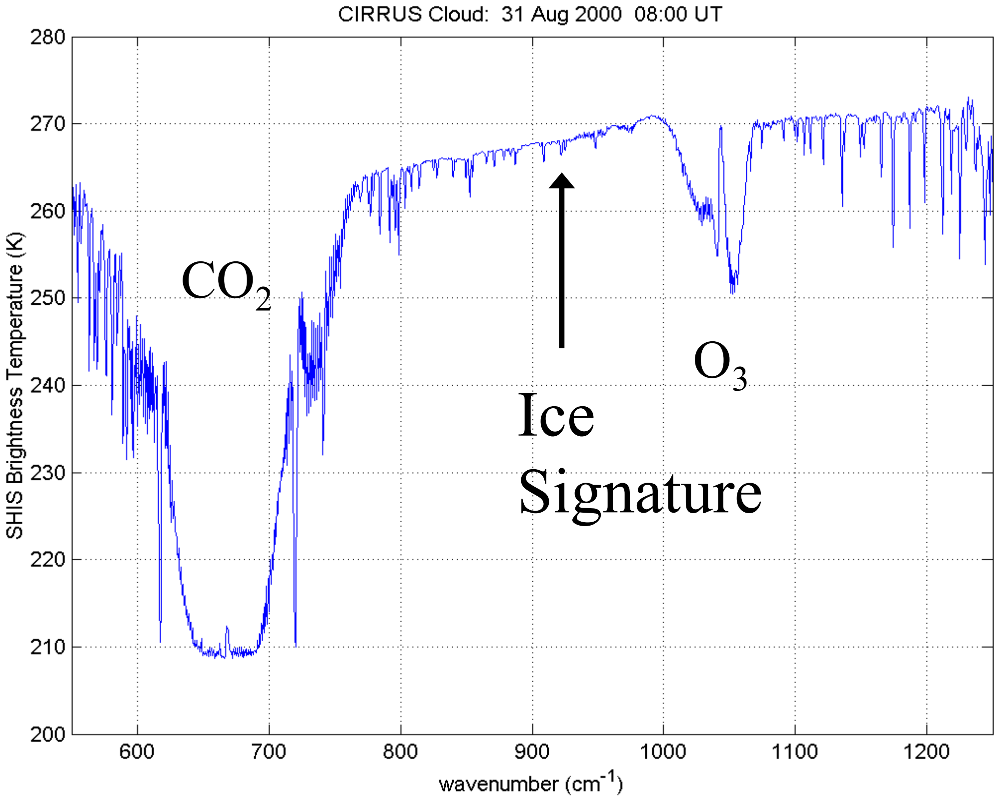
Cirrus Cloud Radiative Properties
(31 August 2000)



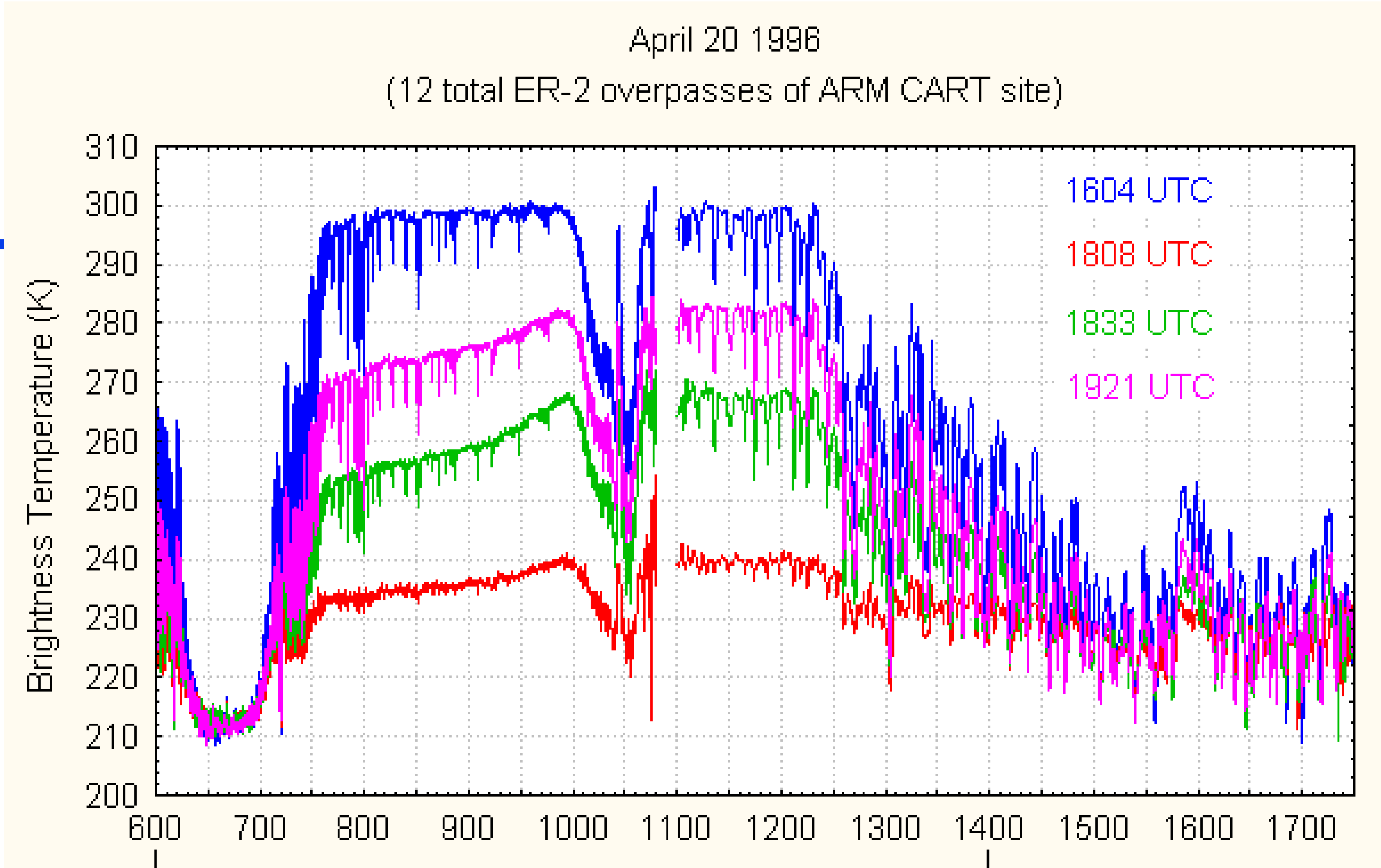


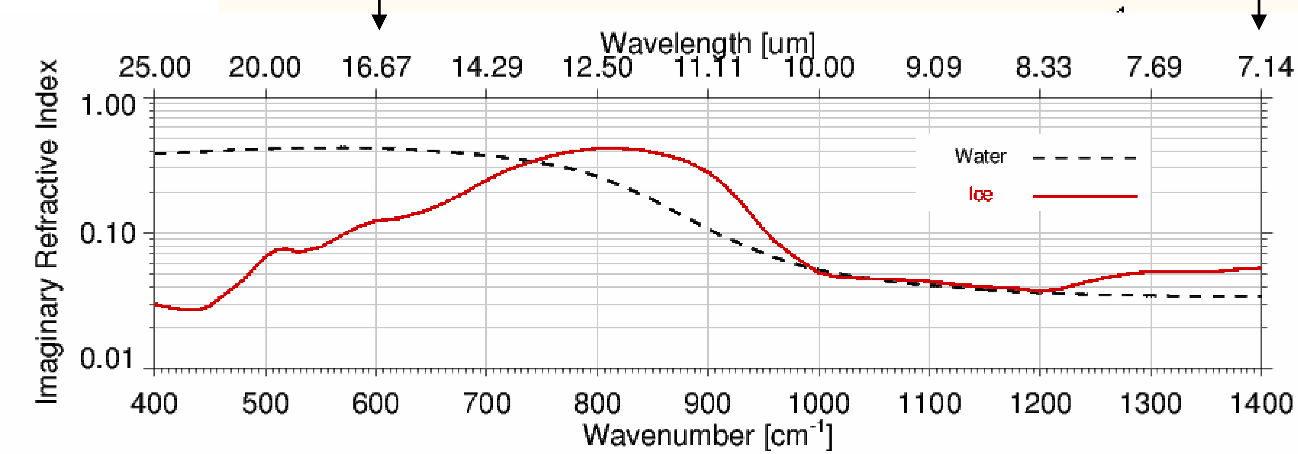
GSFC Lidar

- Small ice particles have absorption cross-sections that lead to "non-black" clouds.



Cirrus Cloud

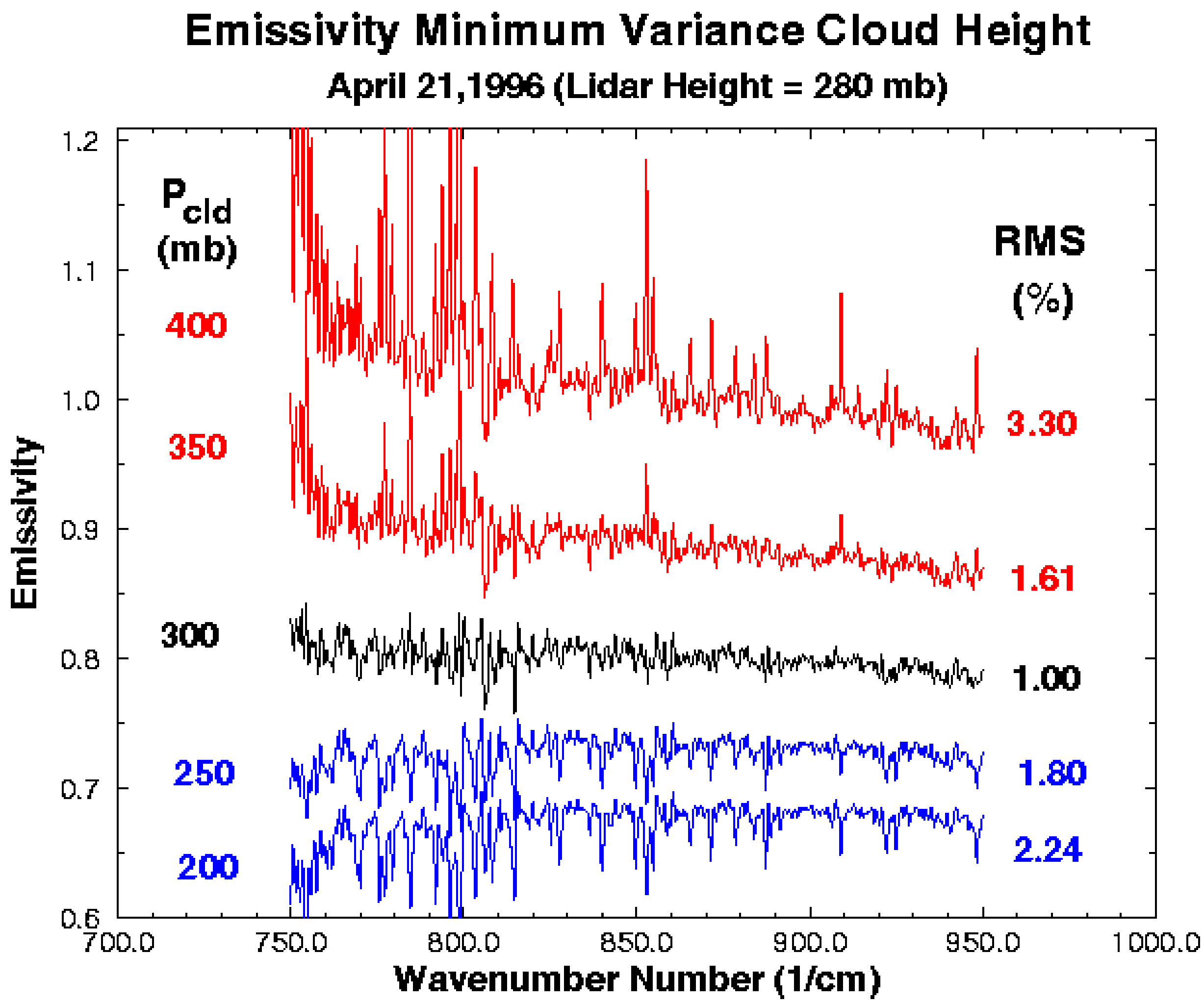




HIS Aircraft Data shows Ice Signature

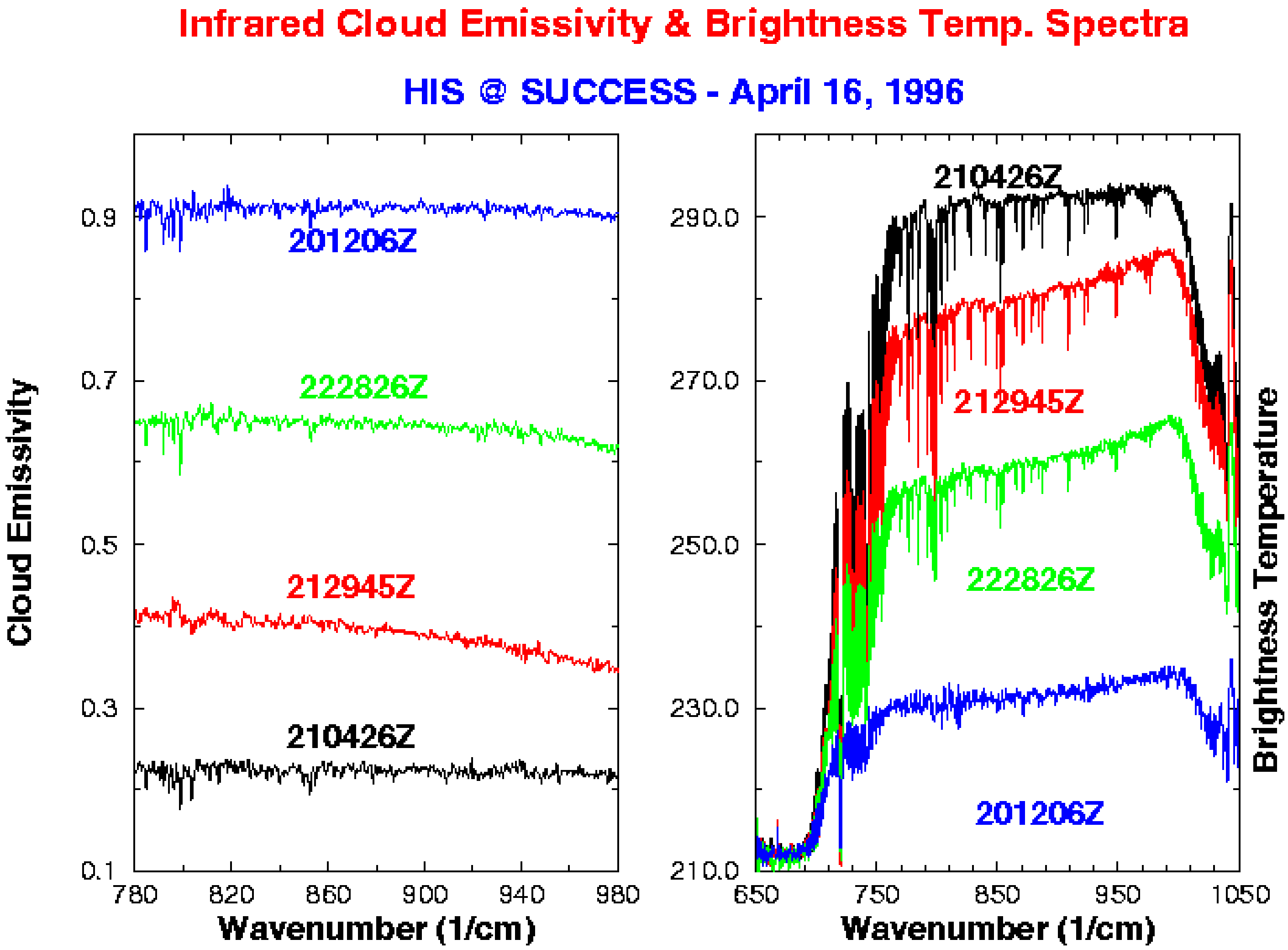
Cloud Emissivity and height from on-line/off-line technique

Cloud height
&
emissivity
simultaneous
retrieval
principal

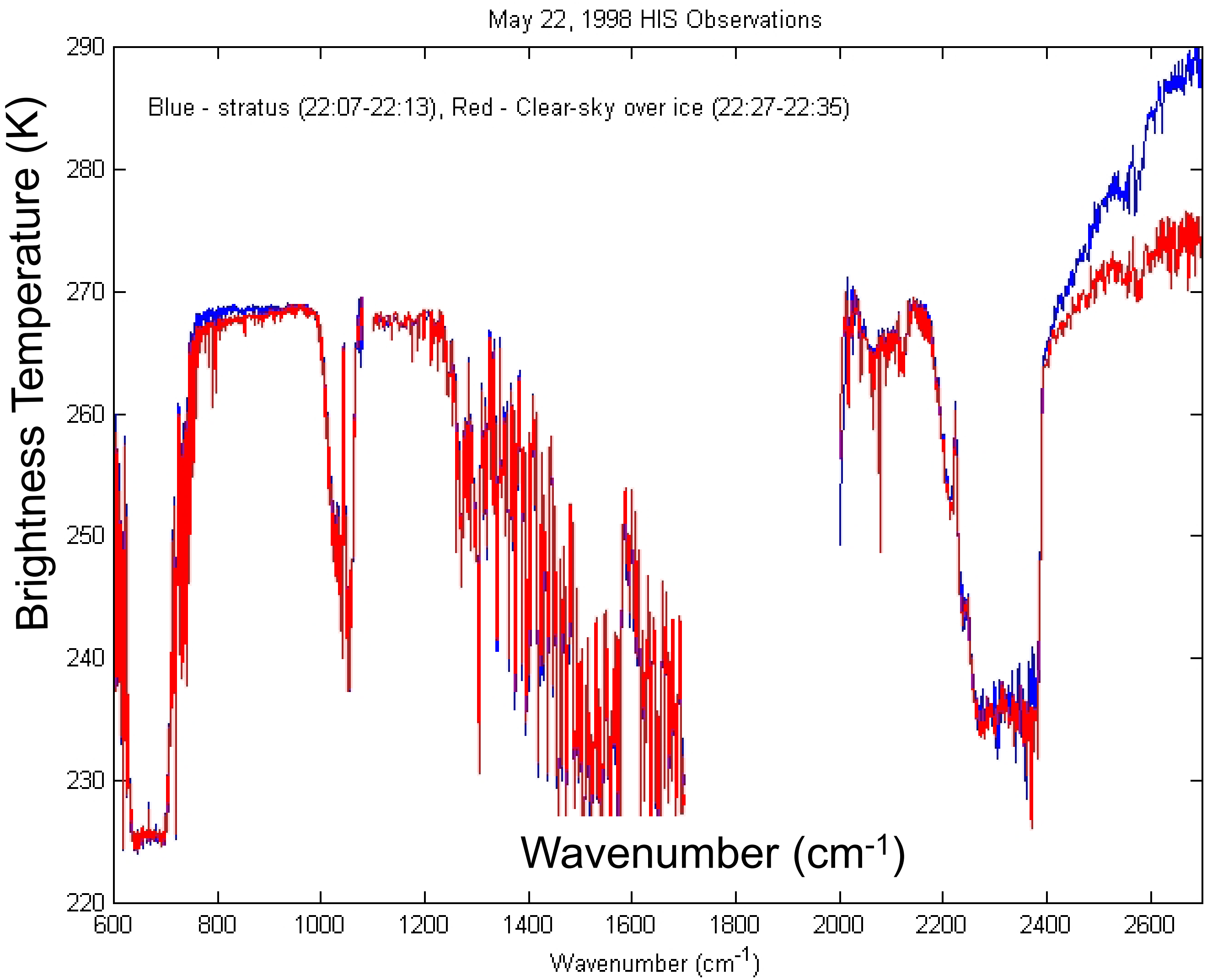


Emissivity is smooth when the cloud altitude is right

Cloud Emissivity Retrieval



Polar Stratus Cloud is “blacker” than the underlying ice and snow



Spectral Resolution:
0.5 - 1.0 cm^{-1}

Max OPD:
1.8 cm

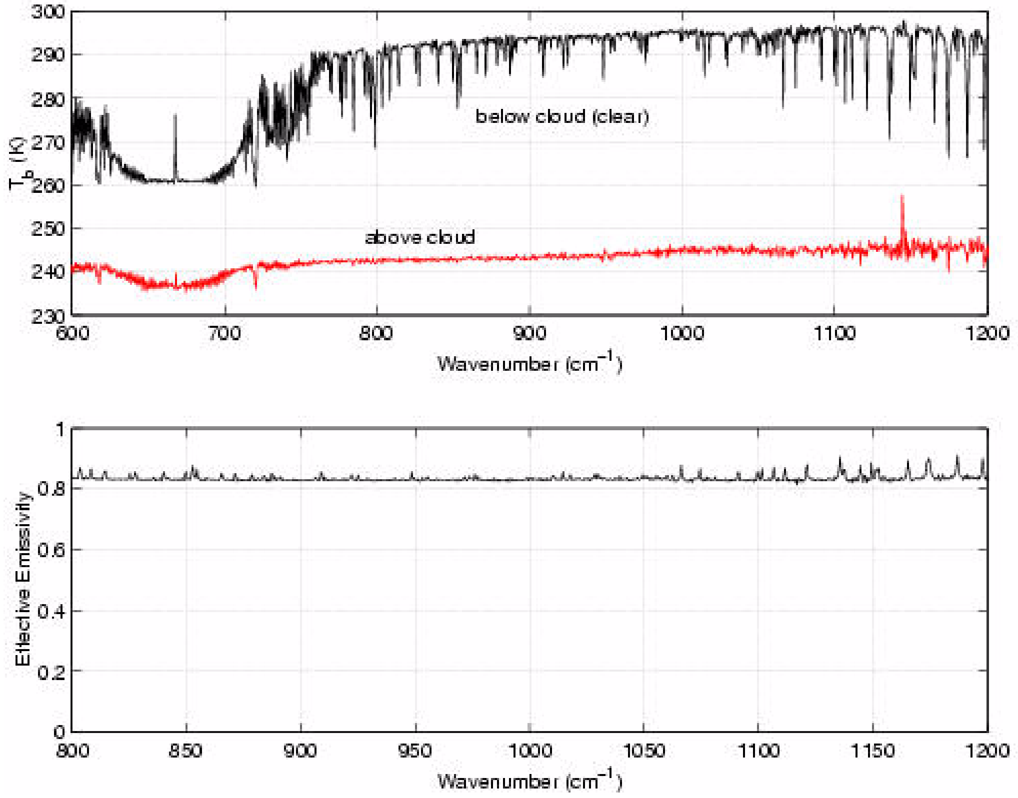
Dwell Period:
6 seconds

Altitude:
20 kilometers

Field of View:
2 kilometers at the surface

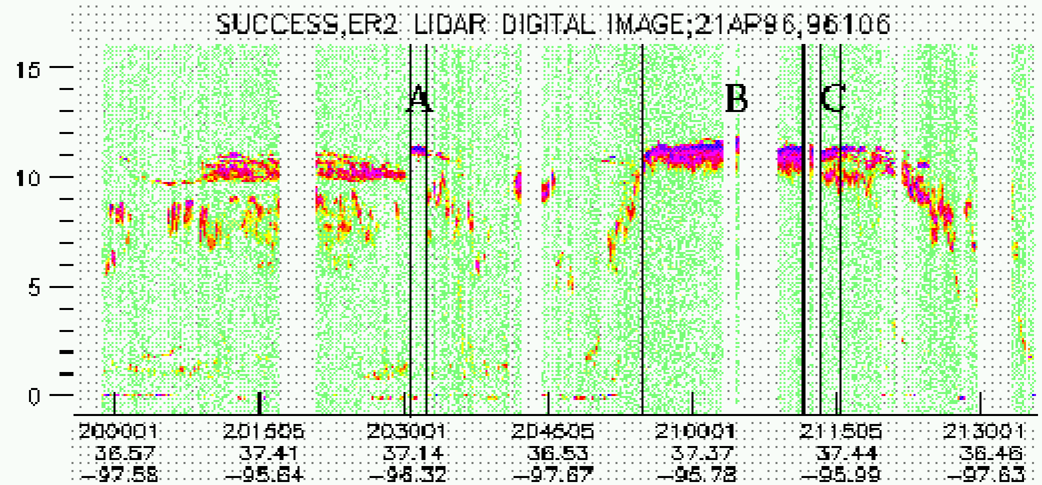
Tropical Cirrus:

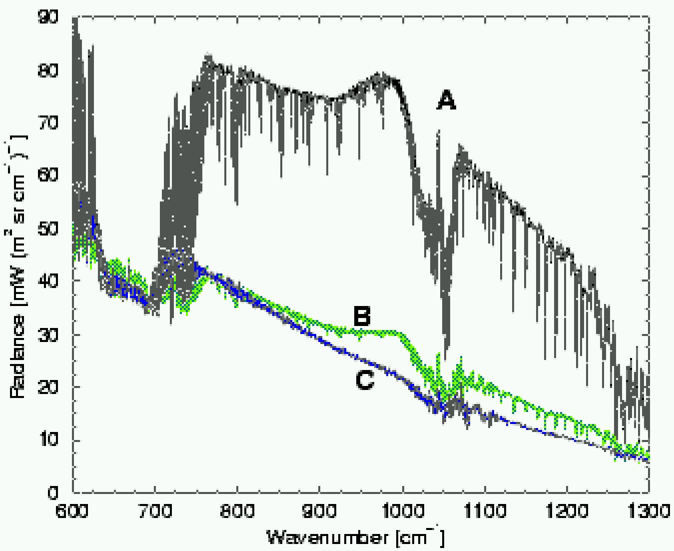
Direct measure of effect on upwelling radiance

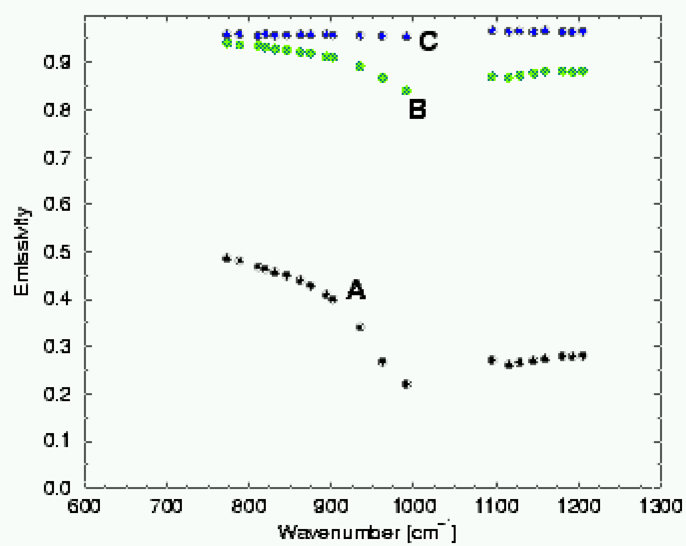


This figure shows the upwelling brightness temperature observed by the Scanning HIS during KWAJEX from above and below a cloud deck (upper panel) and a derived cloud top effective emissivity (lower panel). The spectrally uniform cloud emissivity, near 0.83 across the longwave window, is indicative of ice particles with effective radius greater than 50 microns (DeSlover et al., 1999). This is consistent with measurements from a 2D probe on the DC-8 aircraft.

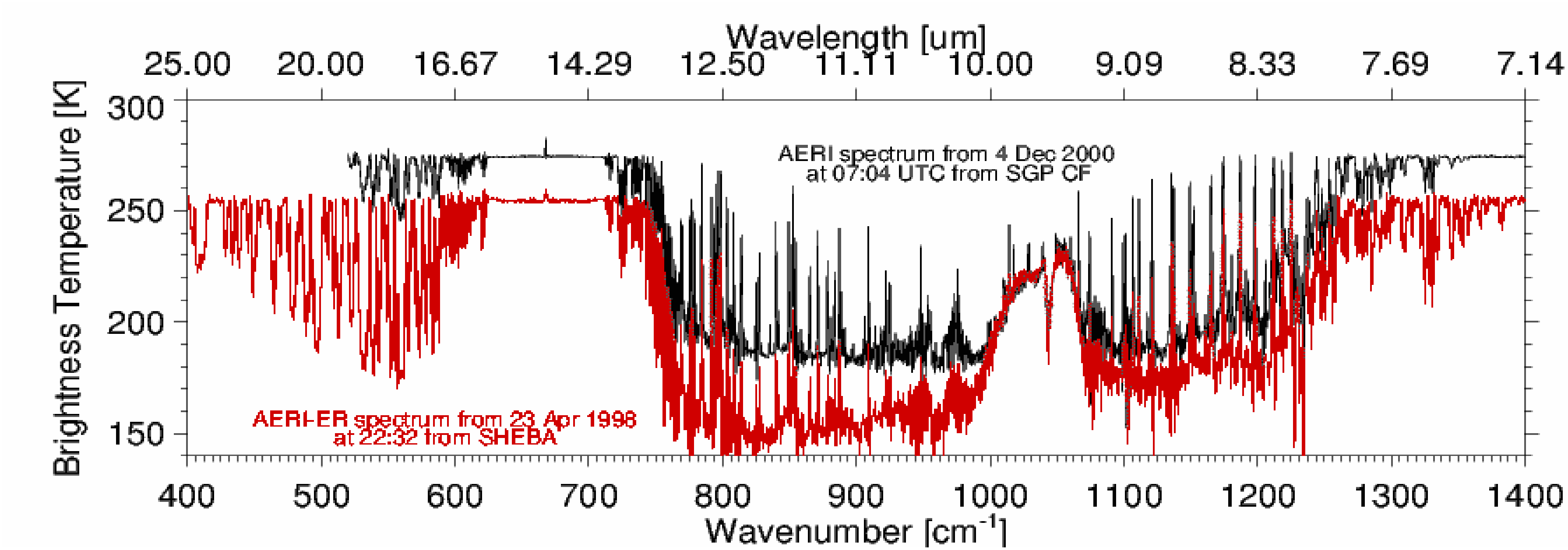
Aircraft-based Cirrus Cloud Emissivity Retrieval

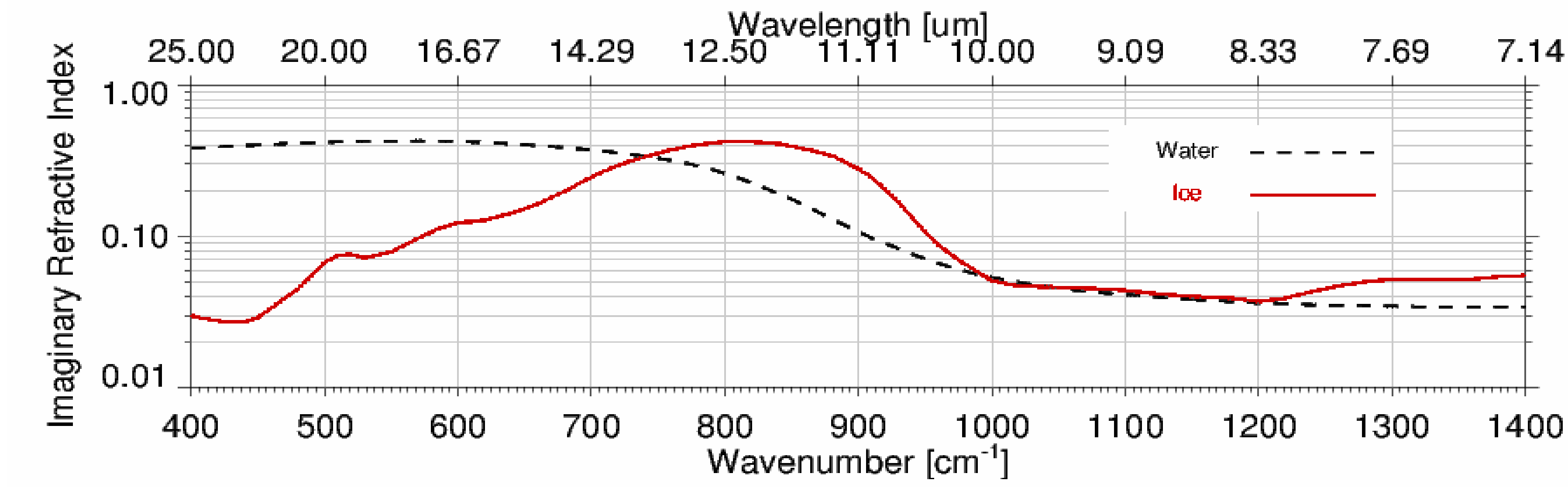




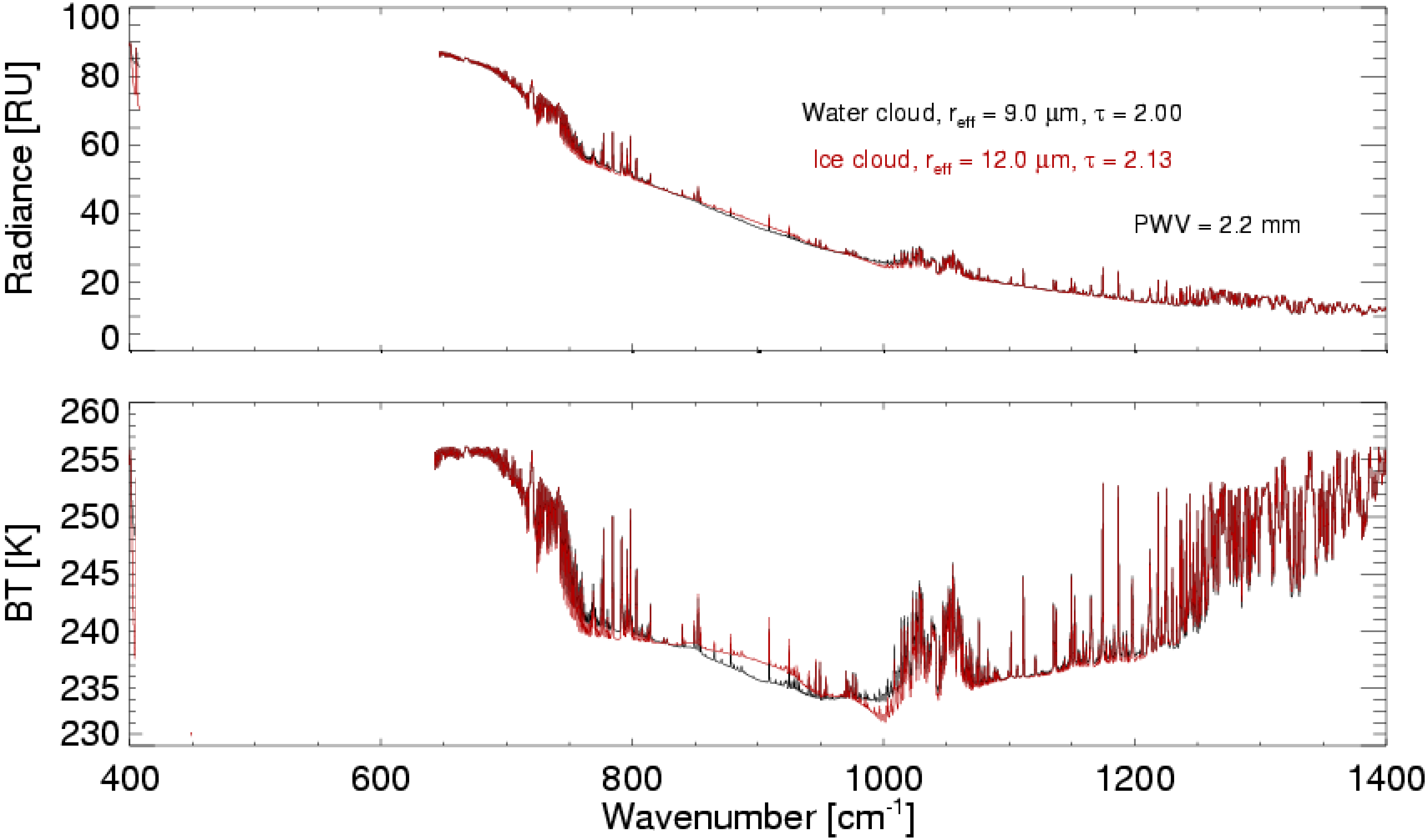


Cloud Phase Determination

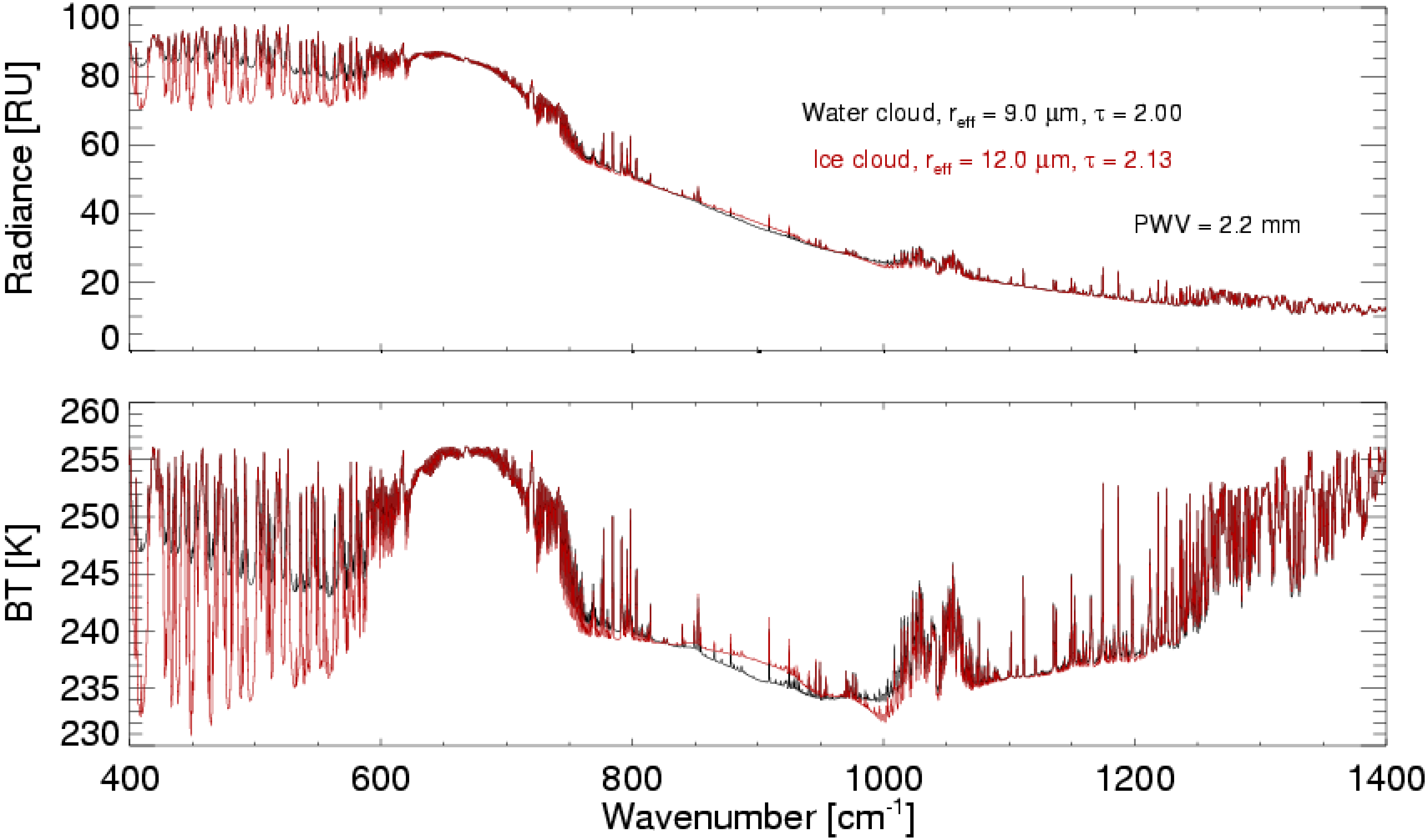




Importance of 16-25 μm data



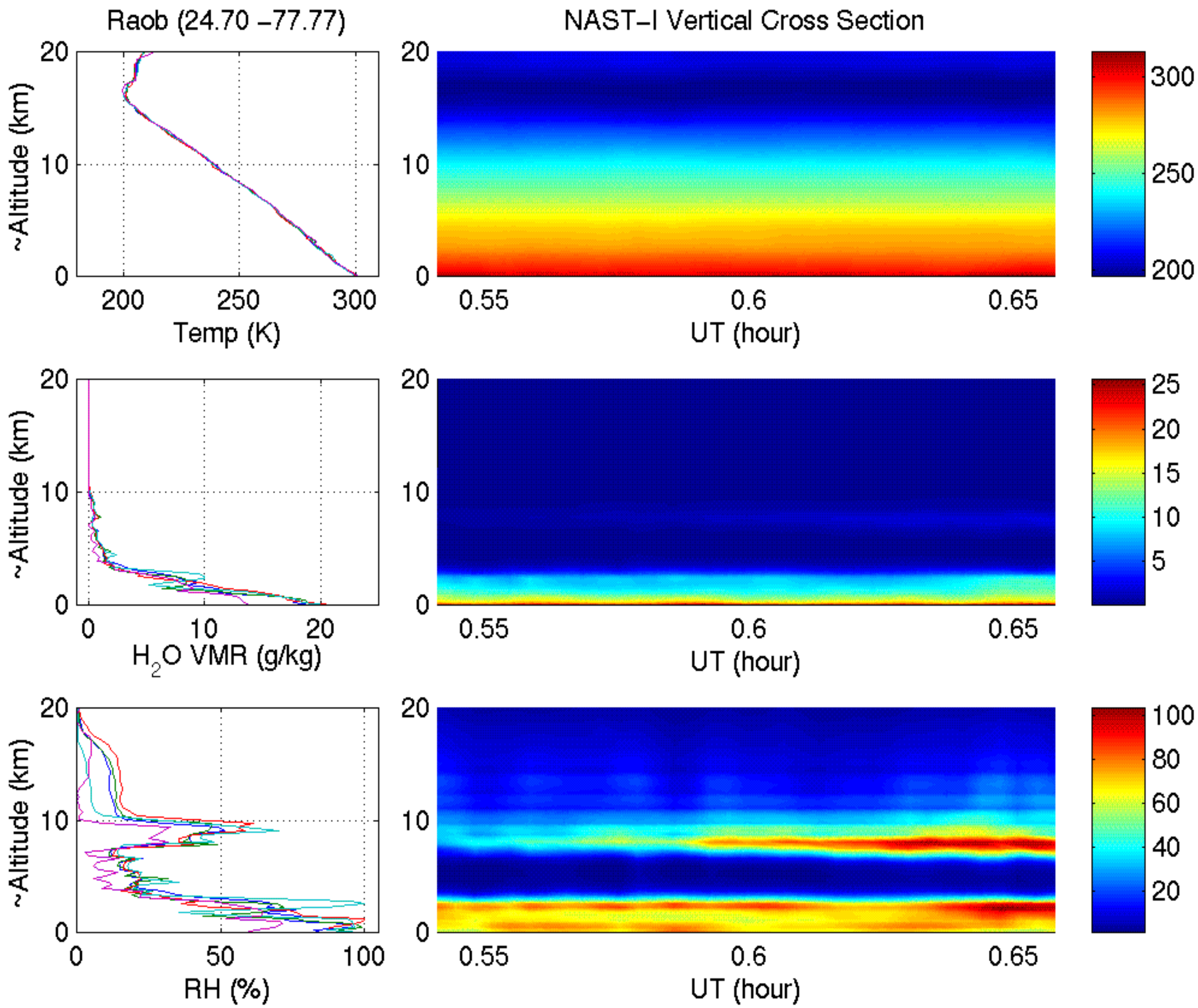
Importance of 16-25 μm data



End with T & Water Vapor Retrieval

Higher vertical resolution capability demonstrated by AIRS and even higher yet by NAST & S-HIS aircraft instruments

NAST-I Retrieval Sample
(Vertical Cross Section; Sept. 14, 1998)

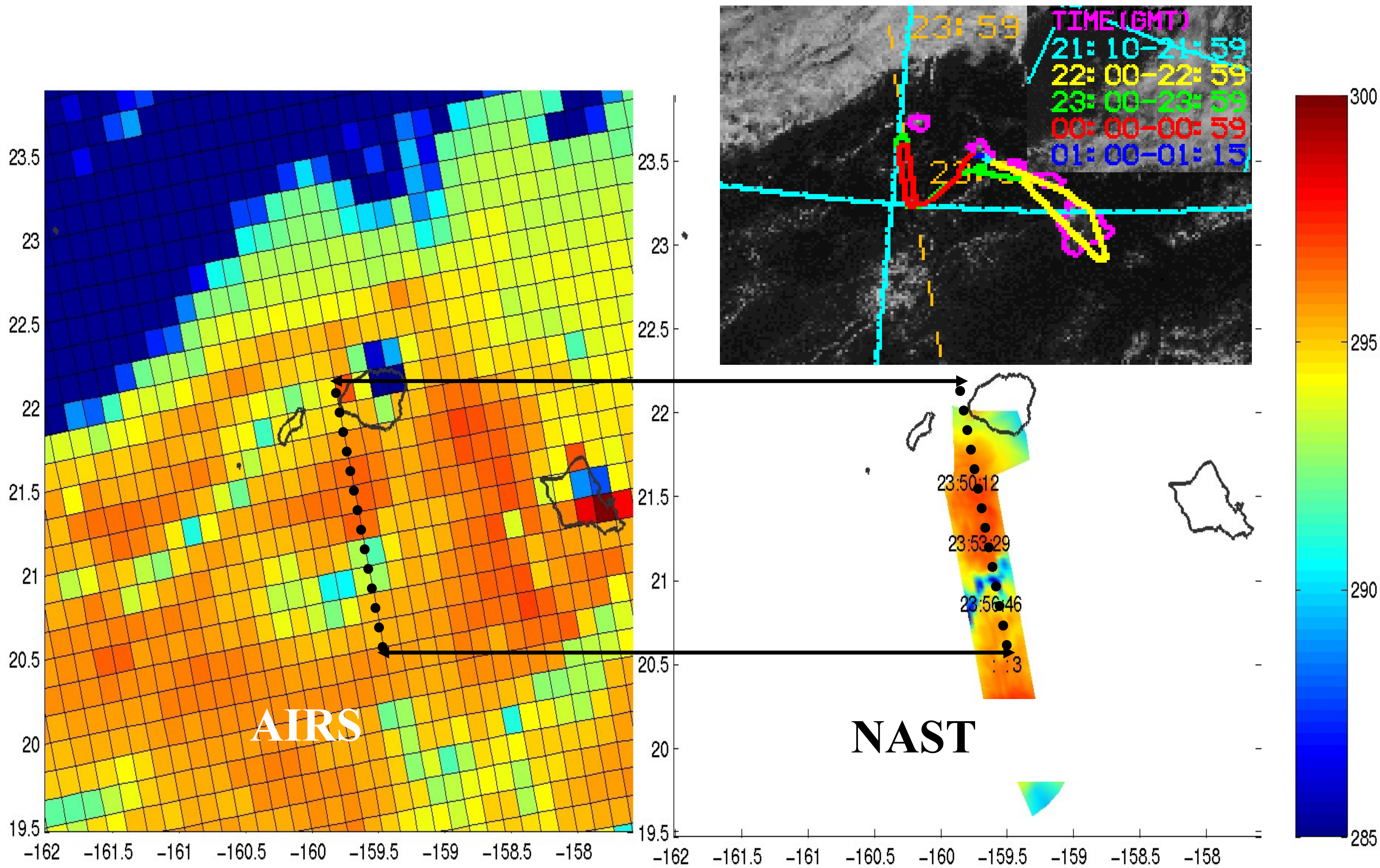


NAST-I retrieved vertical cross sections of temperature, abs water vapor, and relative water vapor distributions.

Five Radiosondes were plotted on the left panels for comparison.

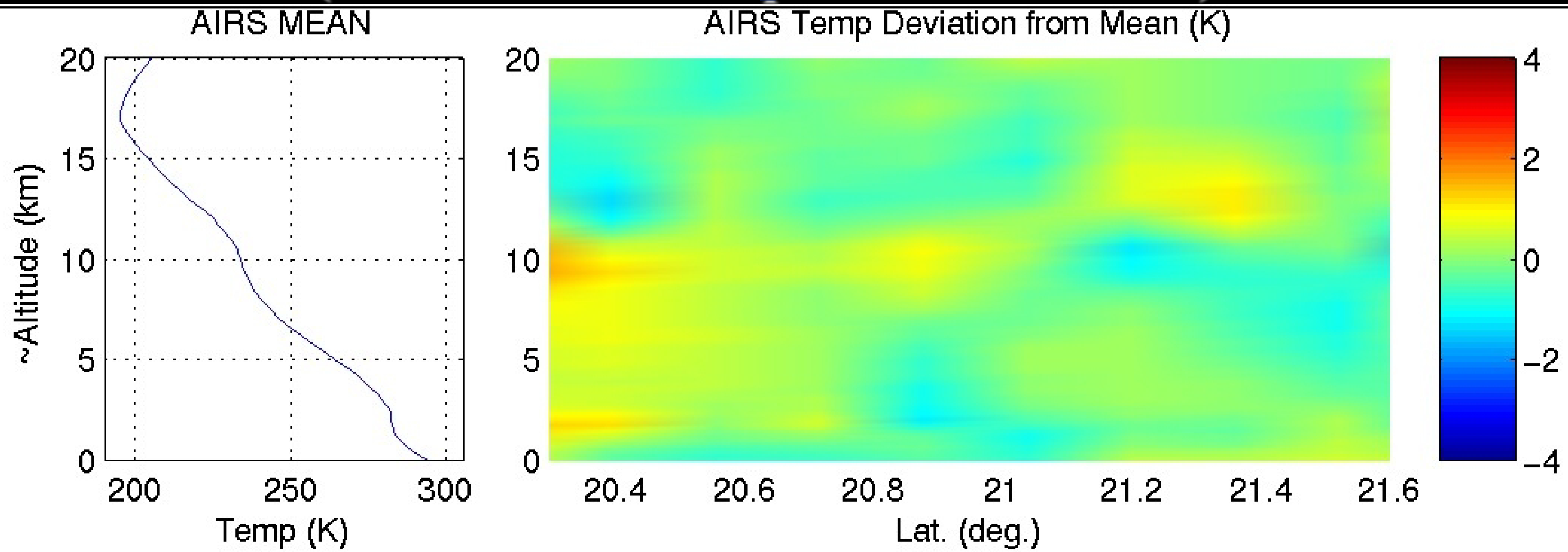
Note vertical structure in Relative Humidity

Thorpex AIRS and NAST Intercomparison (3-3-03)

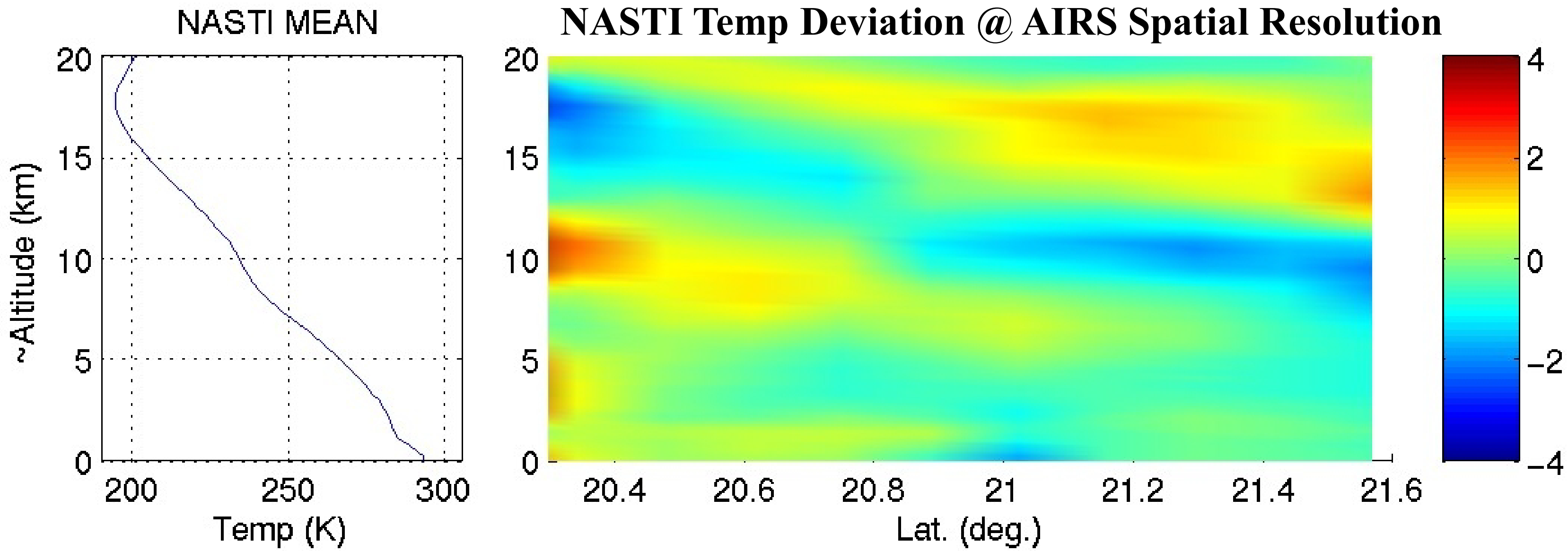


AIRS and NAST Retrieval Cross-section

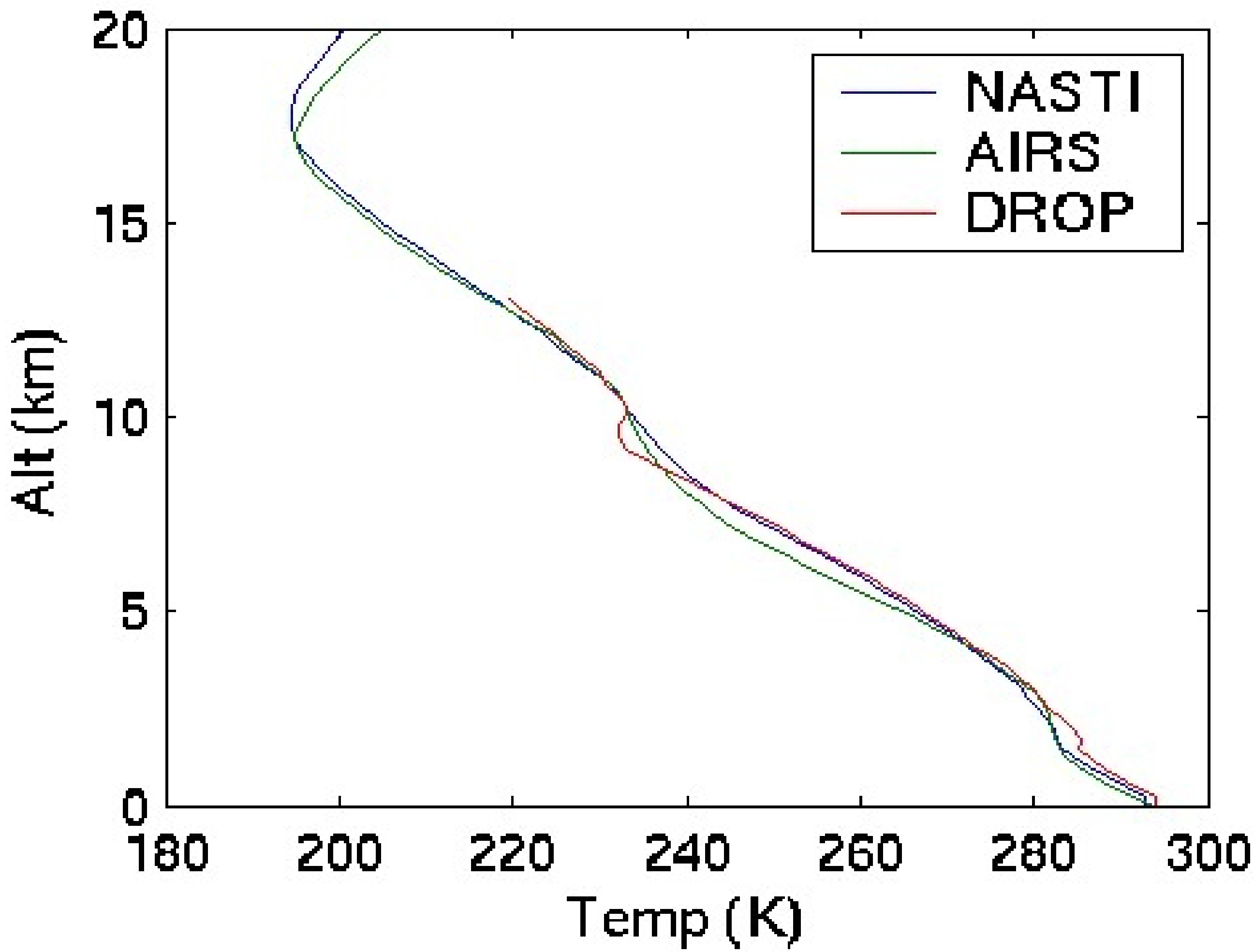
(NAST at AIRS Spatial Resolution)



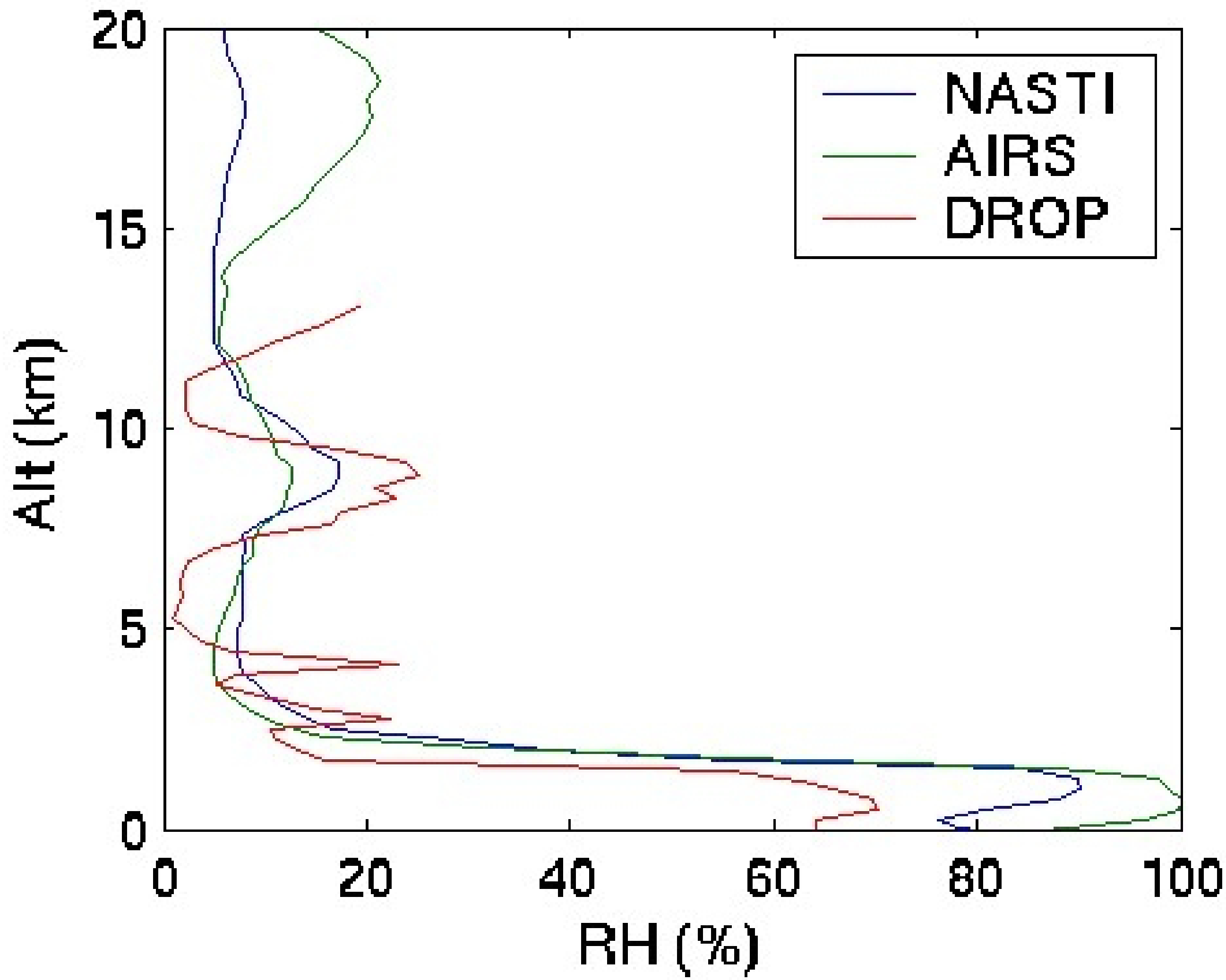
NAST validation provides higher vertical resolution from lower Noise & higher resolution.



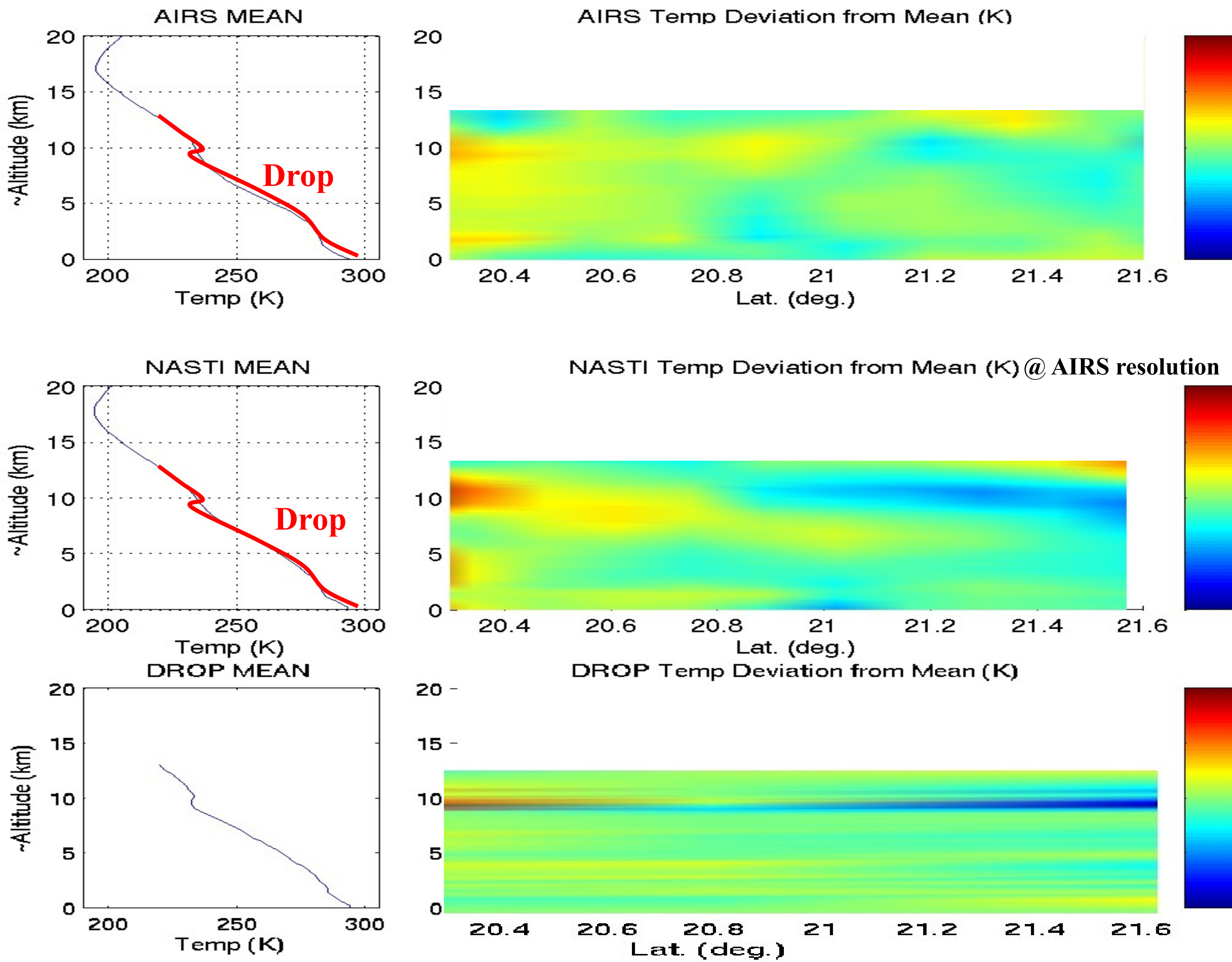
T Retrieval Comparisons With Dropsonde



RH Retrieval Comparisons With Dropsonde



Comparisons With Dropsonde Cross-section



Conclusions on Future
High Spectral Resolution Sounders

- Exciting Promise
- Major challenge will be dealing with clouds