High Spectral Resolution Infrared Data

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Monteponi, September 2008
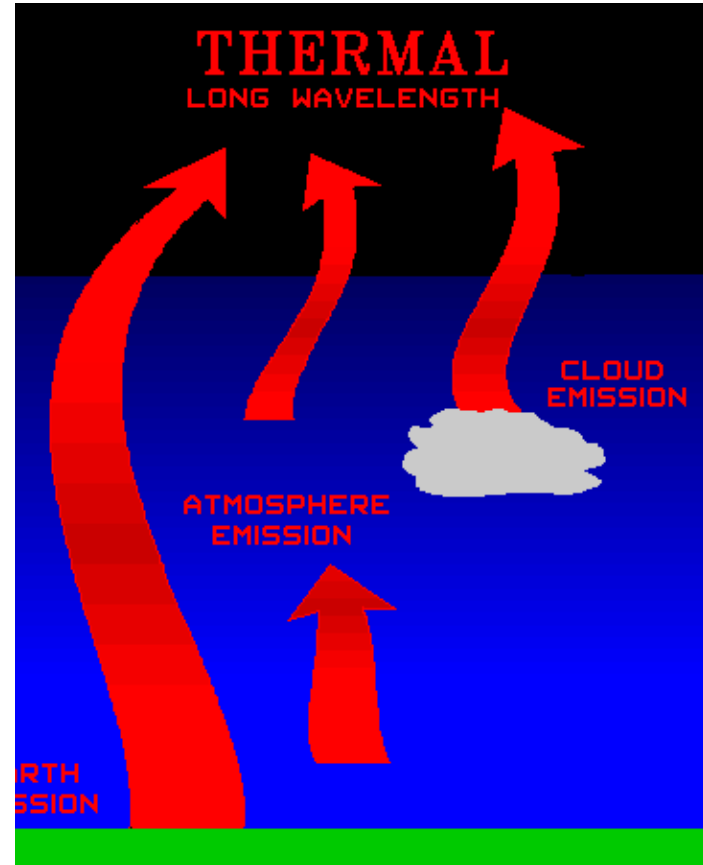
Outline

IR at High Spectral Resolution
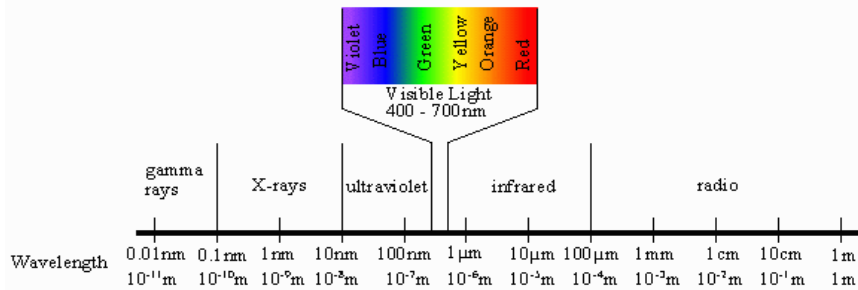
- Basic Principles

- Limits in IR remote sensing

Infrared
(Emissive Bands)

High Spectral Resolution

High Spectral Resolution

Electromagnetic Spectrum

Violet Blue Green Yellow Orange Red

Visible Light
400 - 700nm

| gamma rays | X-rays | ultraviolet | infrared | radio |

Wavelength

| 0.01nm | 0.1nm | 1nm | 10nm | 100nm | 1μm | 10μm | 100μm | 1mm | 1cm | 10cm | 1m |

| 10^{-11}m | 10^{-10}m | 10^{-9}m | 10^{-8}m | 10^{-7}m | 10^{-6}m | 10^{-5}m | 10^{-4}m | 10^{-3}m | 10^{-2}m | 10^{-1}m | 1m |

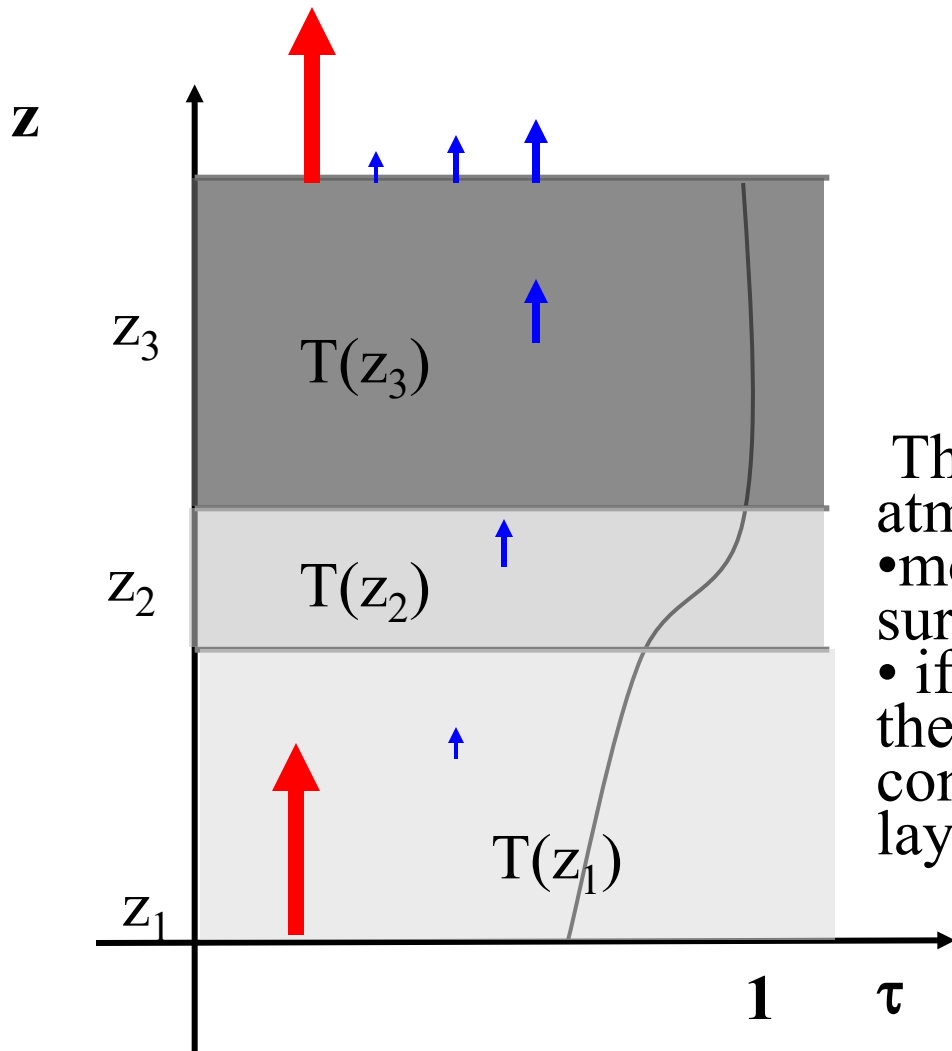QuickTime™ and a
decompressor
are needed to see this picture.

High Spectral Resolution   High Vertical Resolution

Radiative Transfer Equation
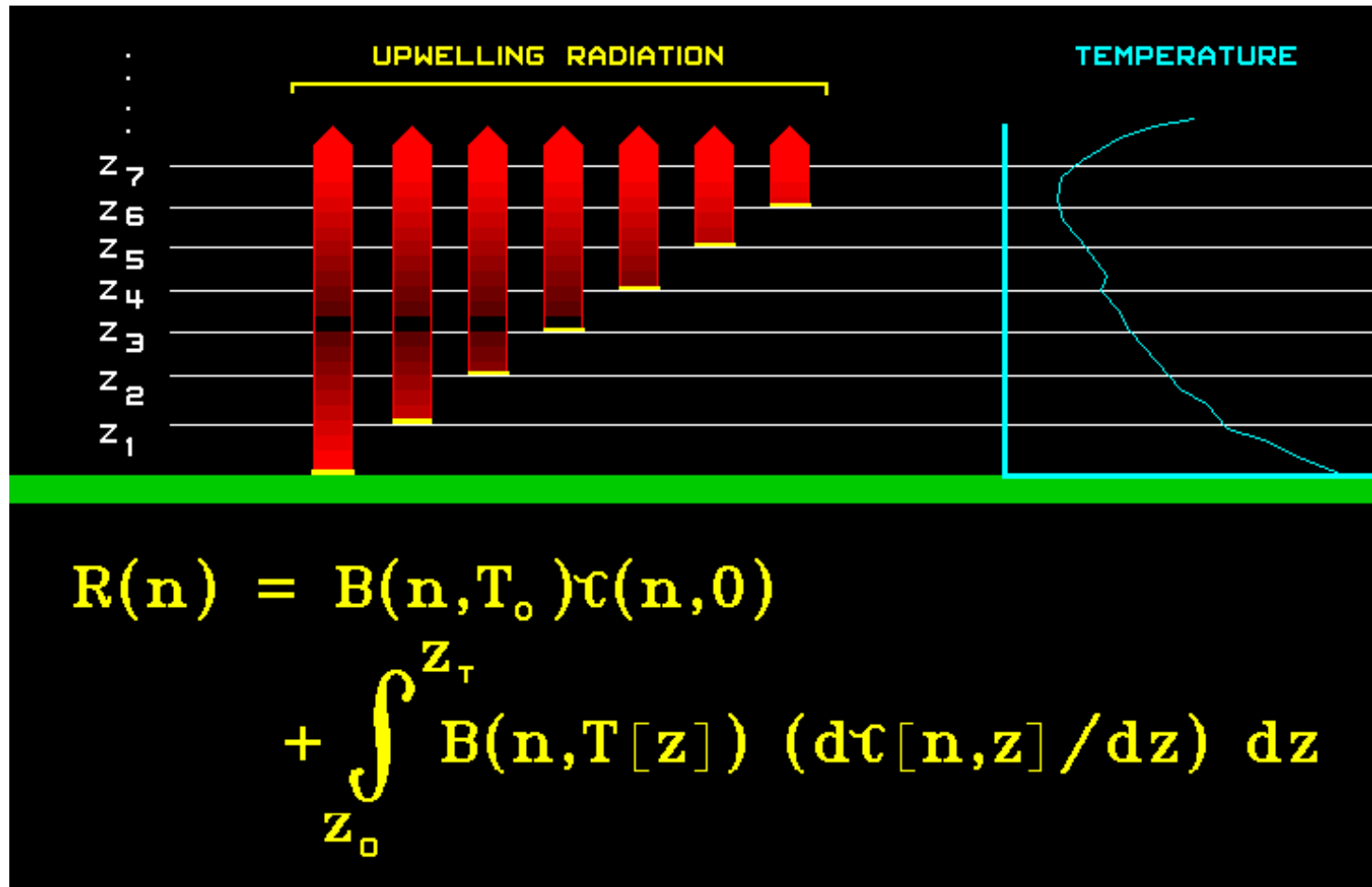
Transmittance for an off-line Channels

$$\tau + a + \cancel{r} = 1$$

τ close to 1
a close to 0

z

z_3 $T(z_3)$
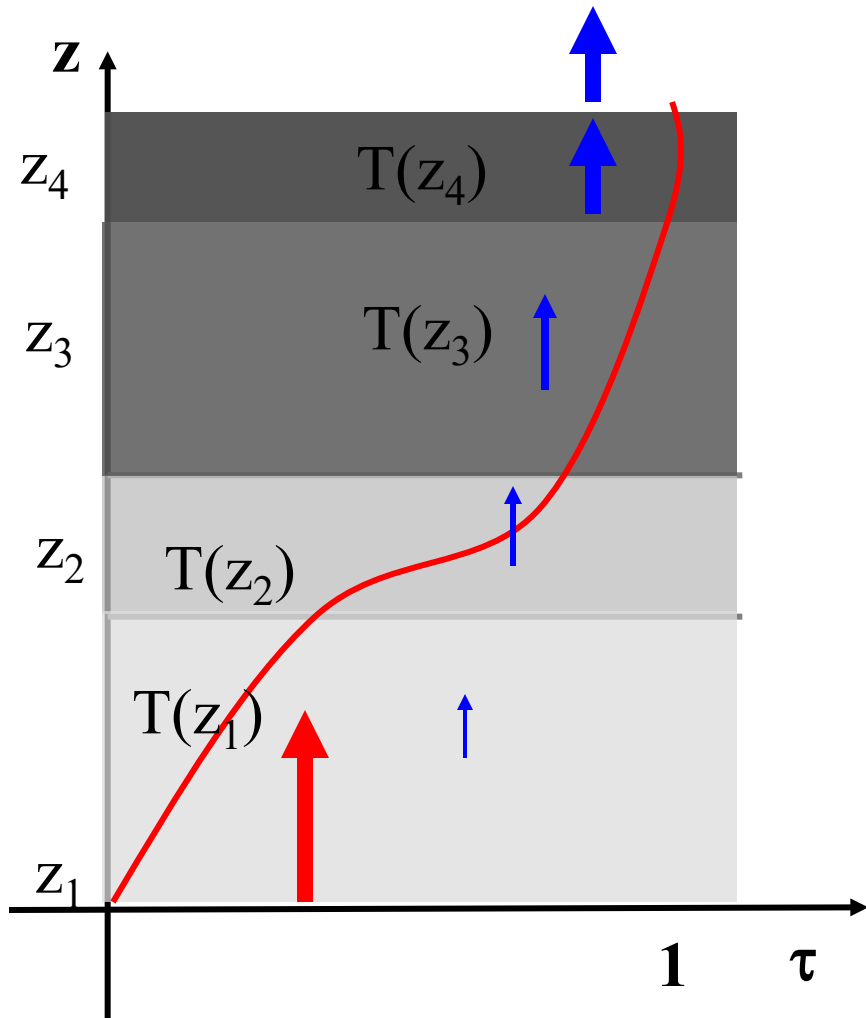
z_2 $T(z_2)$

$T(z_1)$

z_1

1 τ

The molecular species in the atmosphere are not very active:
• most of the photons emitted by the surface make it to the Satellite
• if a is close to 0 in the atmosphere then ε is close to 0, not much contribution from the atmospheric layers

Surface emission
Atmospheric emission

Trasmittance on an Absorption Line

Absorption Channel:
τ close to 0
a close to 1

One or more molecular species in the
atmosphere is/are very active:
• most of the photons emitted by the surface will not make it to the Satellite (they will be absorbed)
• if a is close to 1 in the atmosphere then ε is close to 1, most of the observed energy comes from one or more of the uppermost atmospheric layers

Weighting Functions
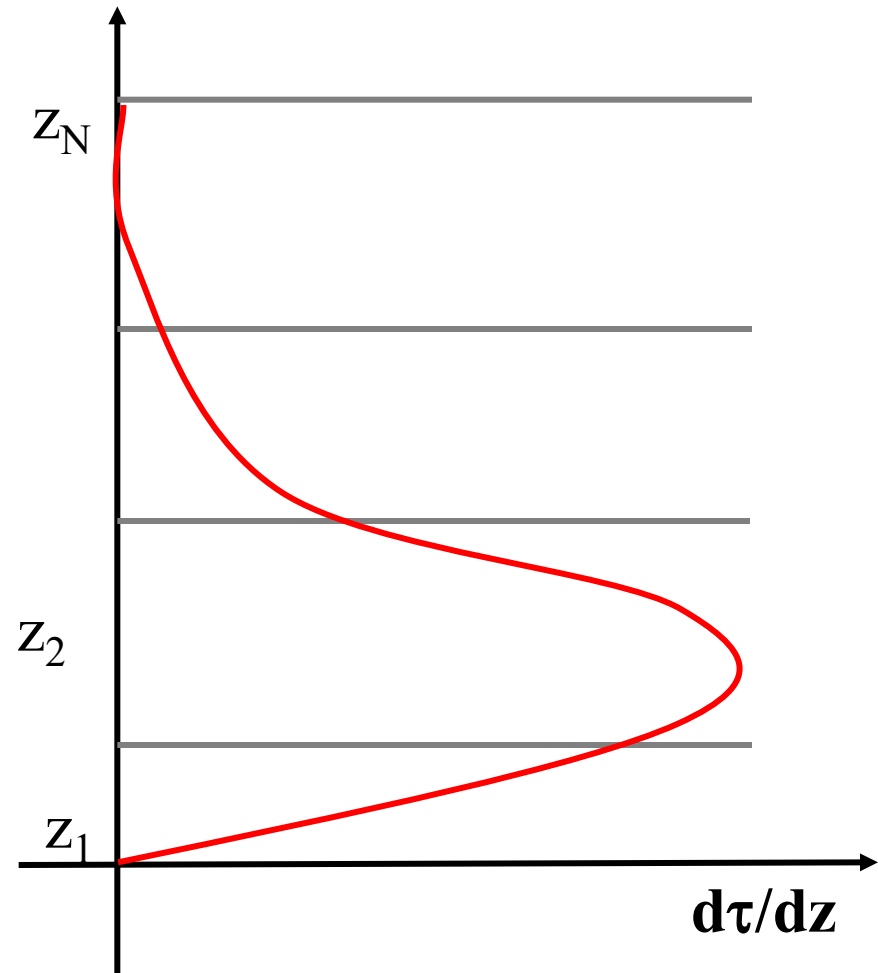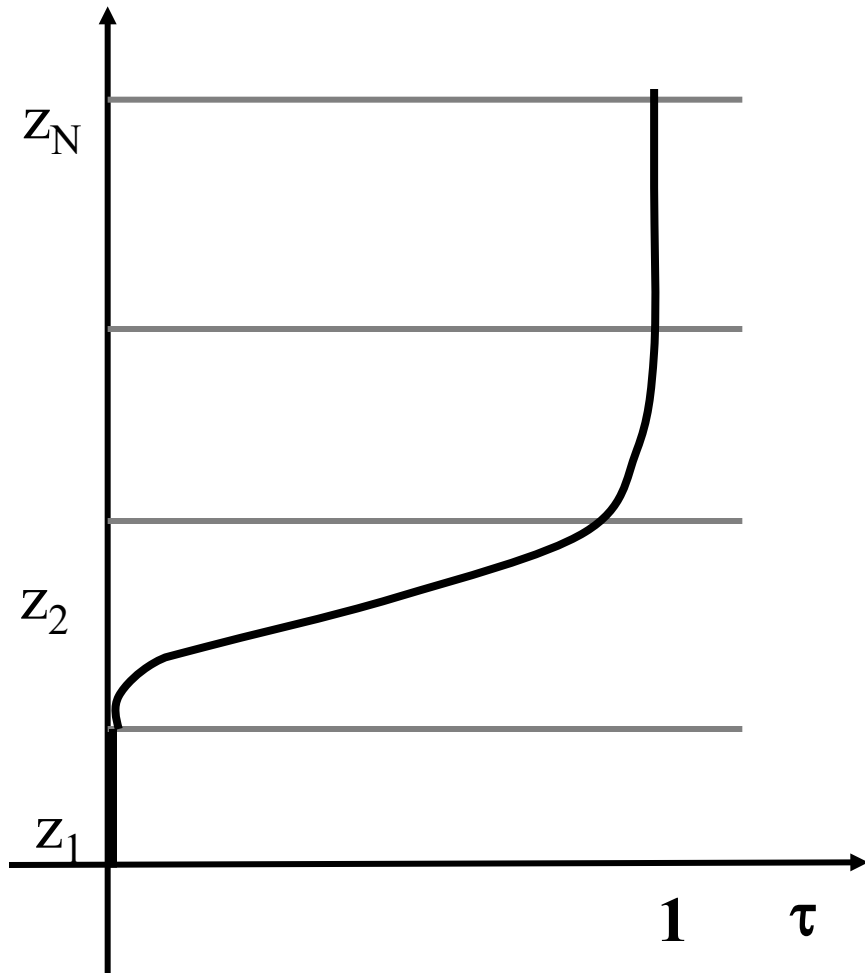
What Causes Absorption?

Molecules in the Atmosphere.

For any layer of the atmosphere,
molecular absorption
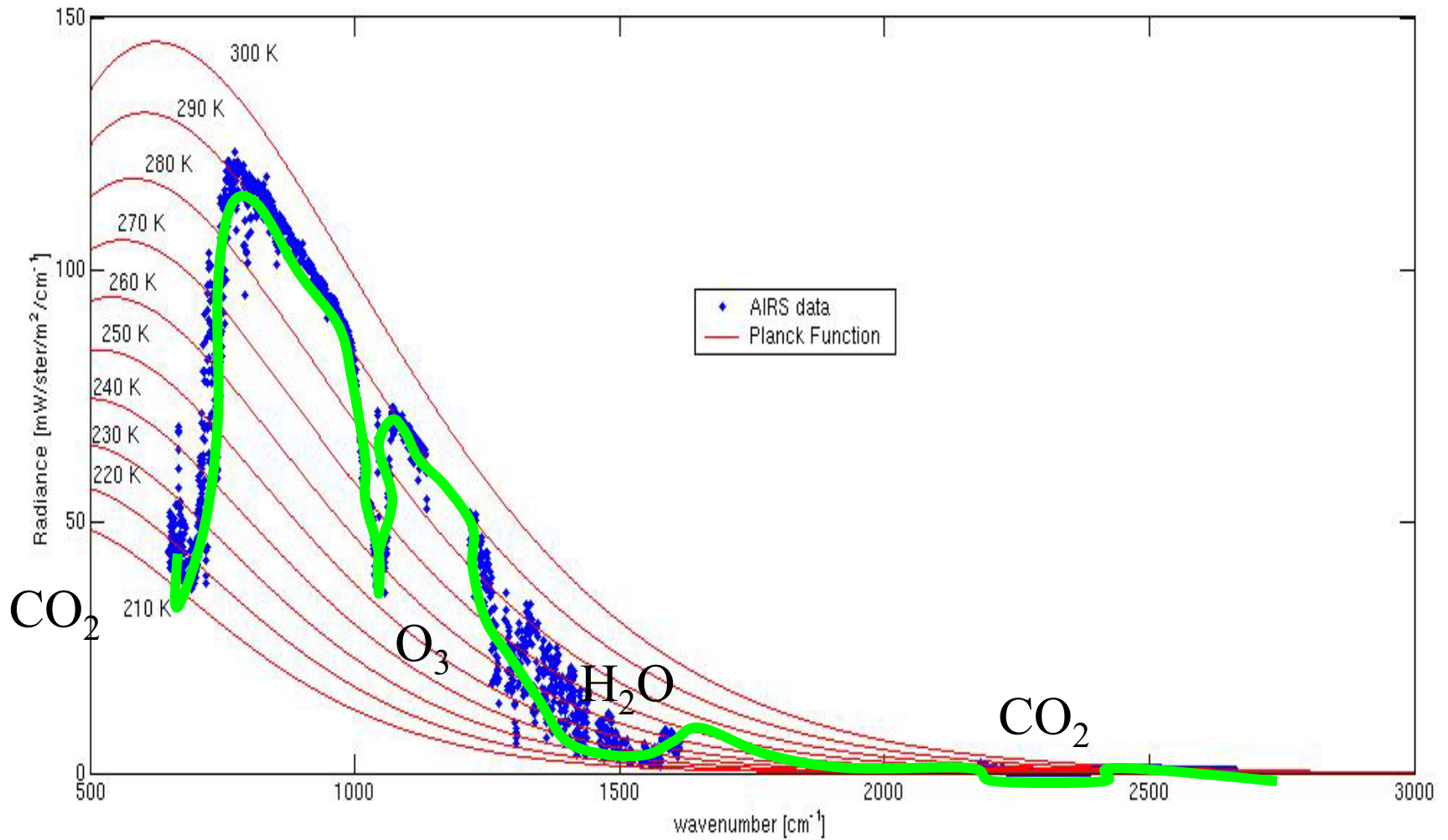determines the layer emissivity
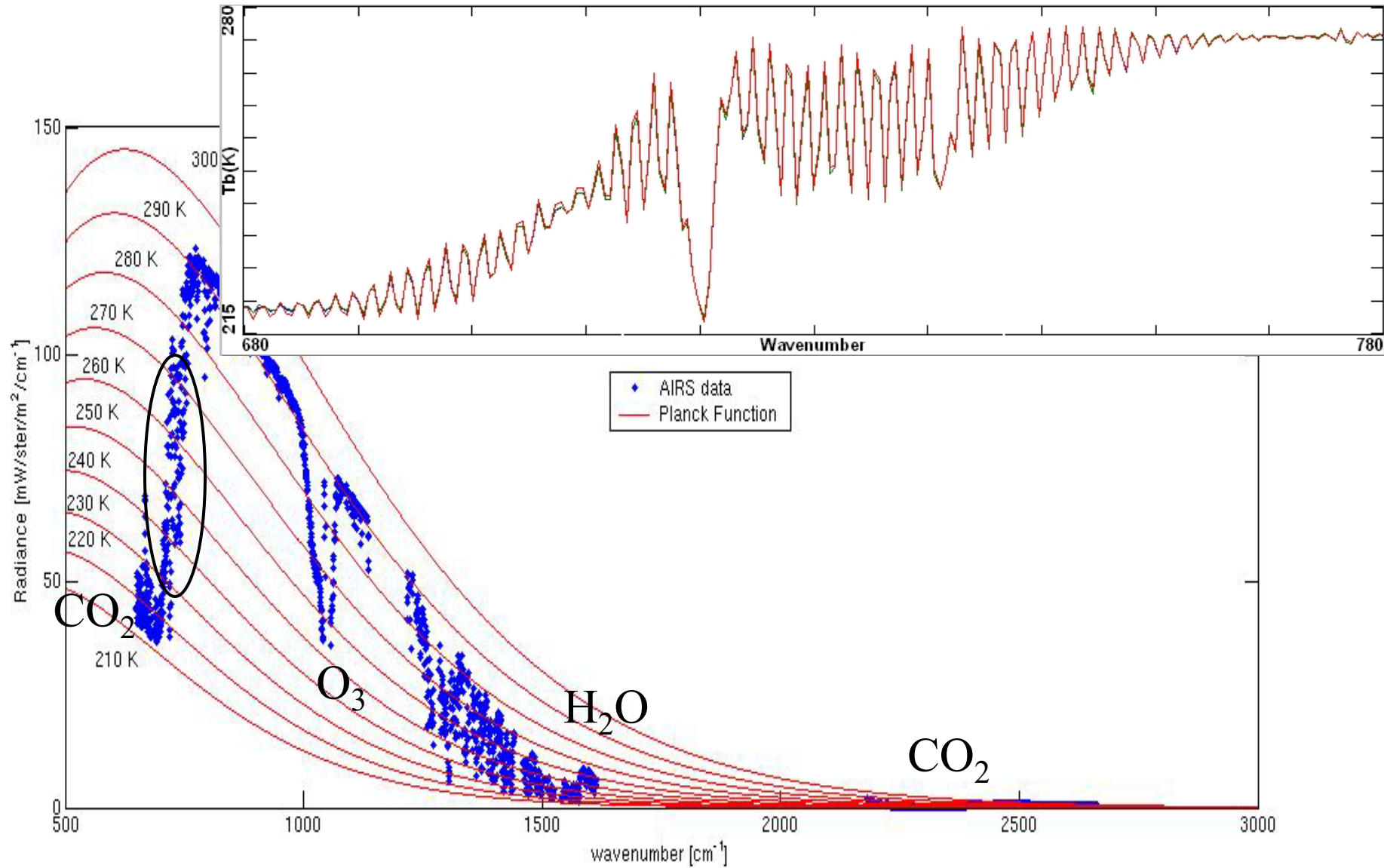and trasmittivity

CO$_2$ Lines
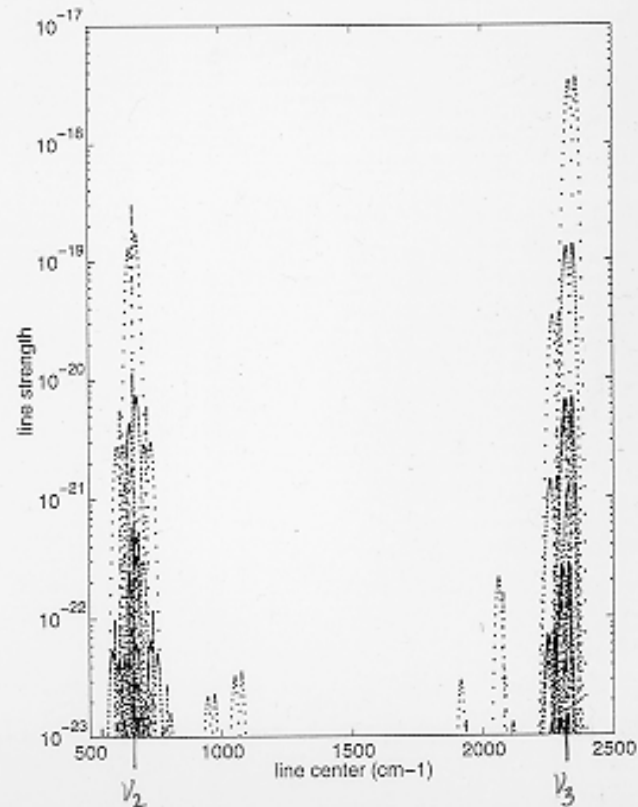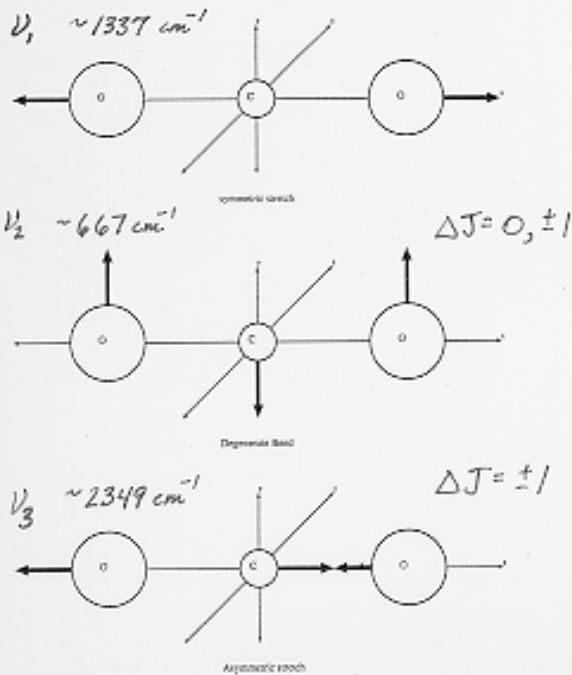
H$_2$O Lines
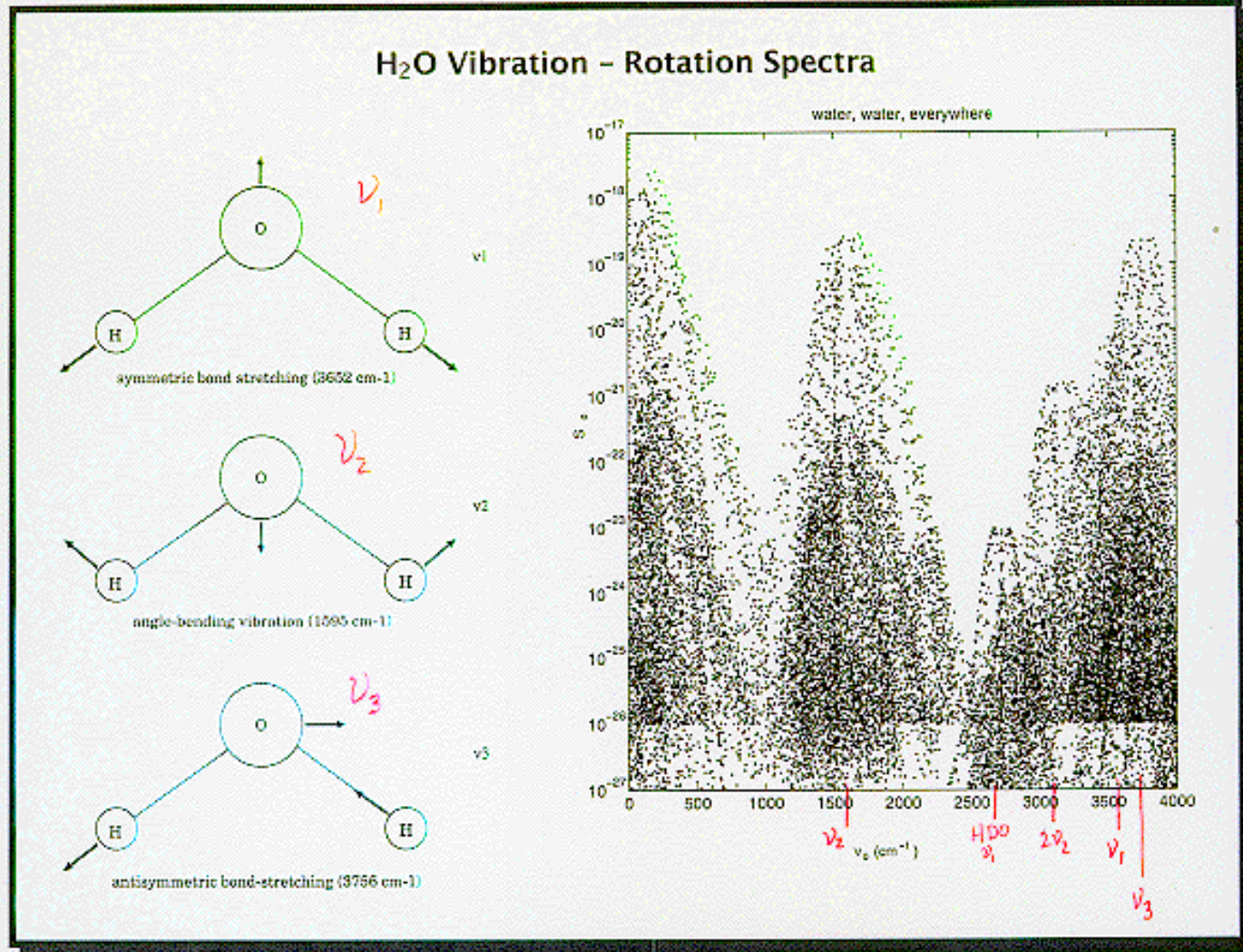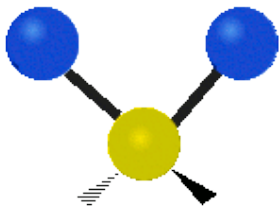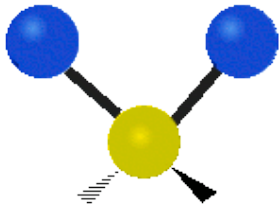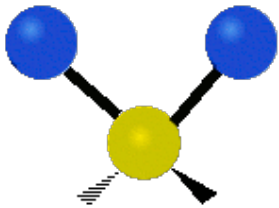
Energy State Transitions
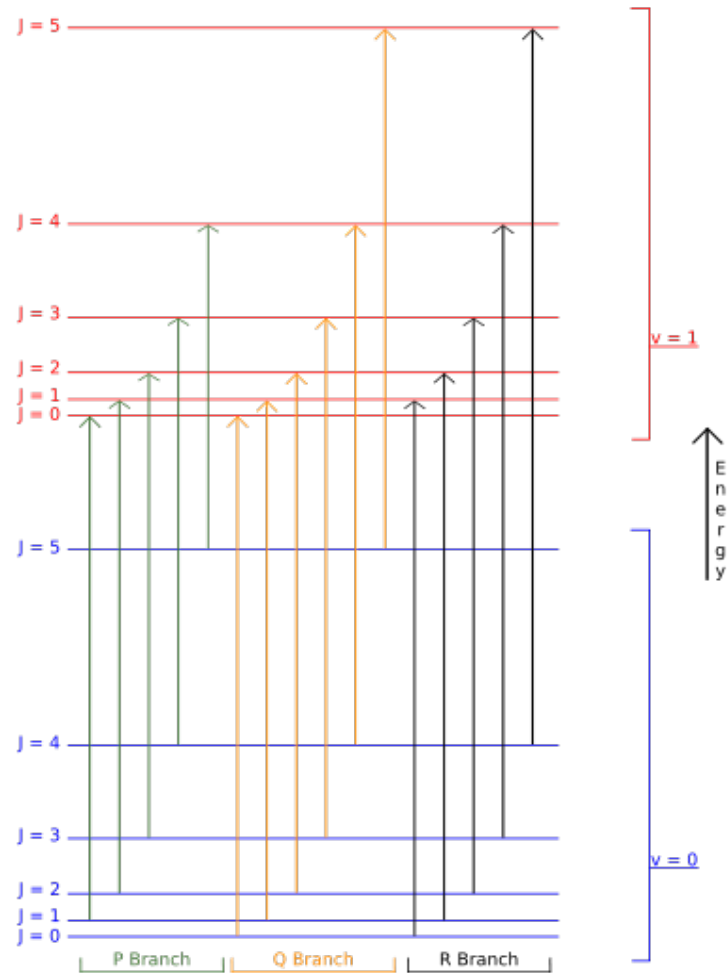
Vibrational Bands

Rotational Lines

Weighting Functions

A b s o r p t i o n

$k(\nu - \nu_0)$

$\alpha_L = 0.0125 \ cm^{-1}$
$p = 0.25 \ bar$

$\alpha_L = 0.025 \ cm^{-1}$
$p = 0.5 \ bar$

$\alpha_L = 0.05 \ cm^{-1}$
$p = 1 \ bar$

-0.05   0   +0.05

Wavenumber

H e I g h t

Energy Contribution

Broad Band

window

window

CO_2

O_3

H_2O

Samplig of vibrational bands
Integration over rotational bands
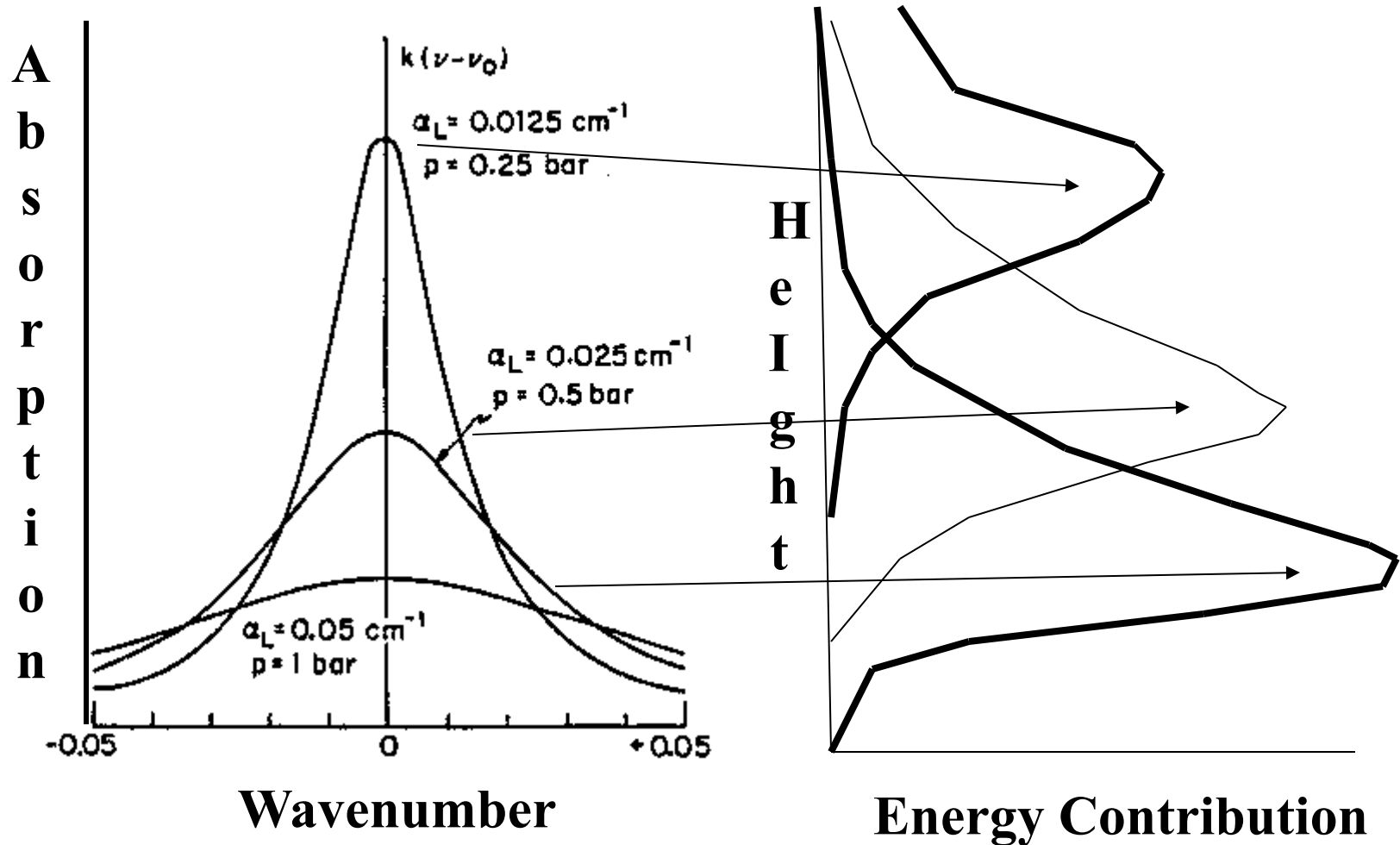
… in Brightness Temperature
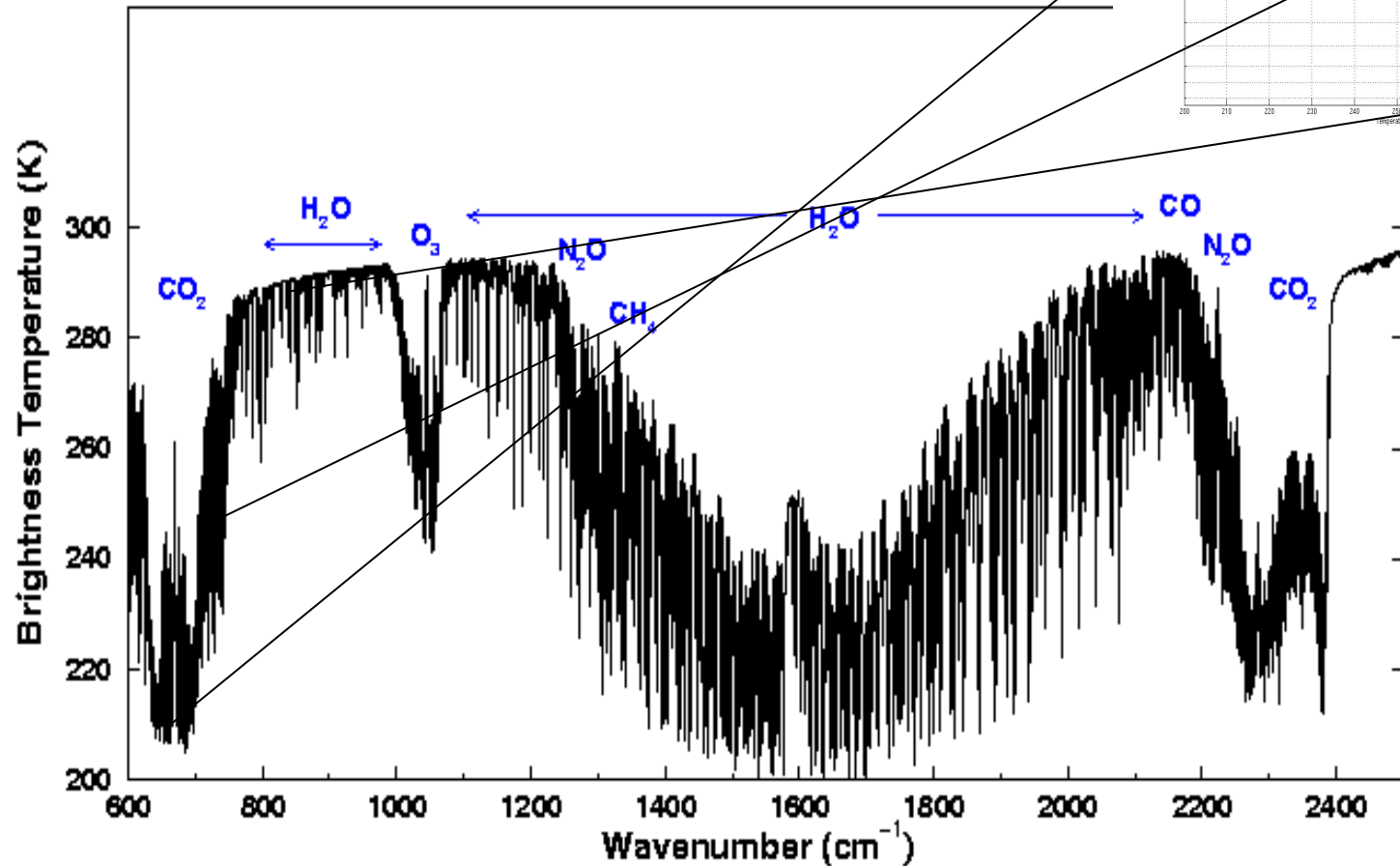
High Spectral Resolution
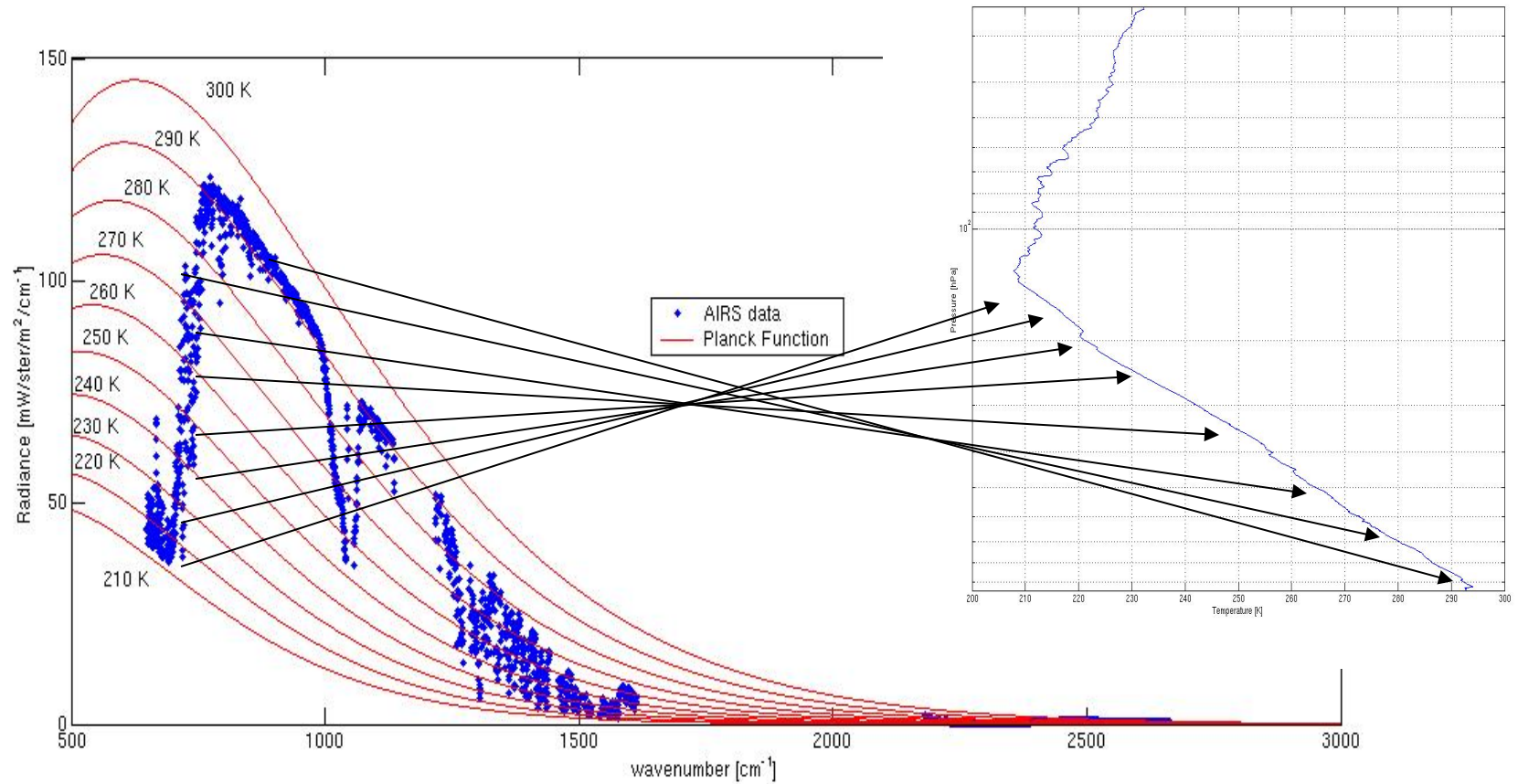
Samplig over rotational bands

AIRS and MODIS
(mt Etna, Sicily, 28 Oct 2002)

QuickTime™ and a
Microsoft Video 1 decompressor
are needed to see this picture.

Broad Band vs High Spectral

GOES water vapor mixing ratio weighting functions

GOES
(18)

NAST-I Band 2 Weighting Function

U.S. Standard Atmosphere (1976)
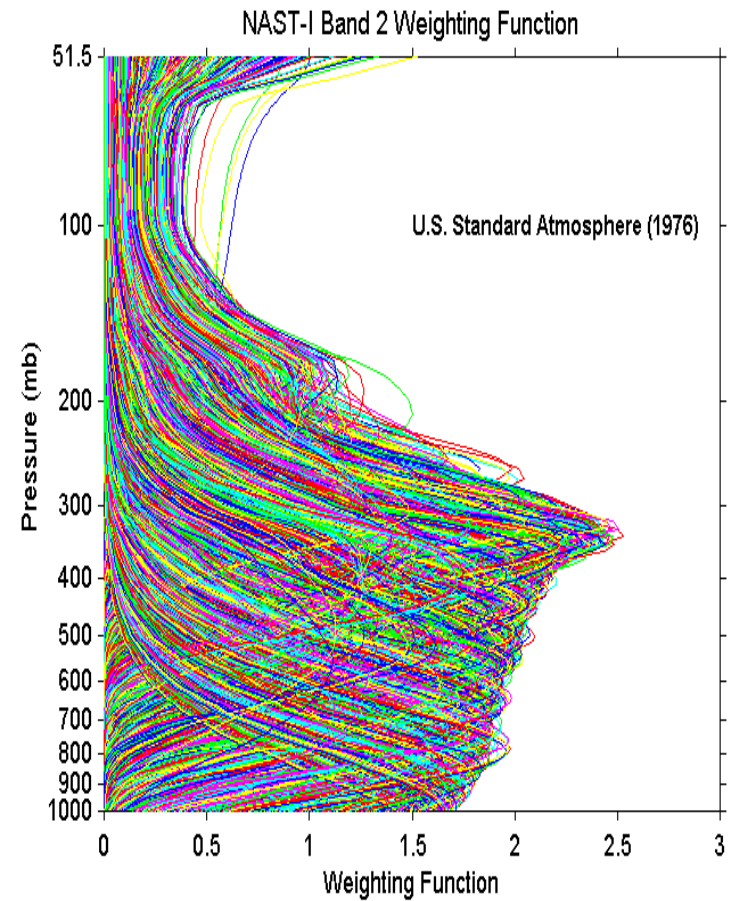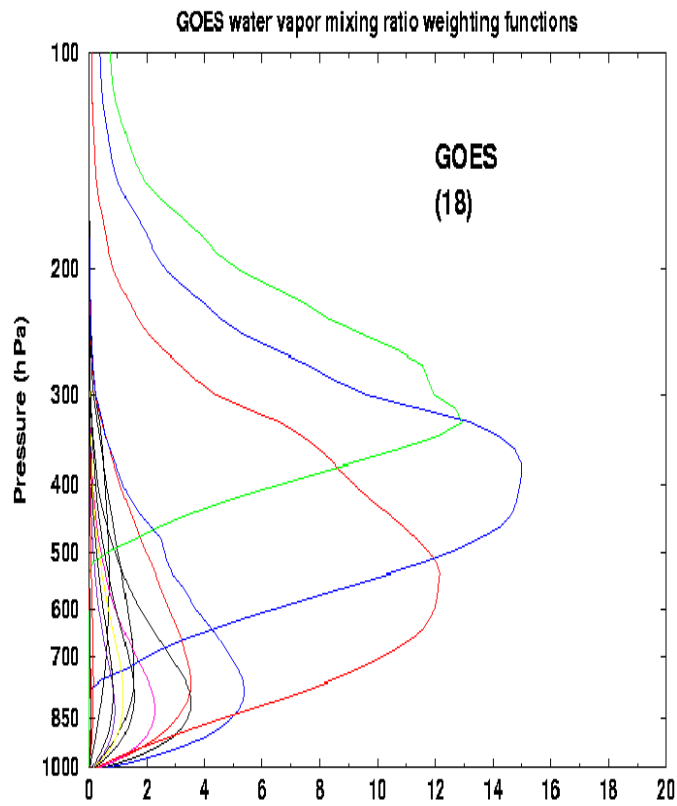
Questions

For a given water vapor line what happens to its weighting function
When the amount of upper tropospheric water vapor increases?

Weighting Function

For a given water vapor spectral channel

Wet Atm.

Moderate

Dry Atm.

H
E
I
G
H
T

Wet

Moderate

Dry

Tau   **0**

100%
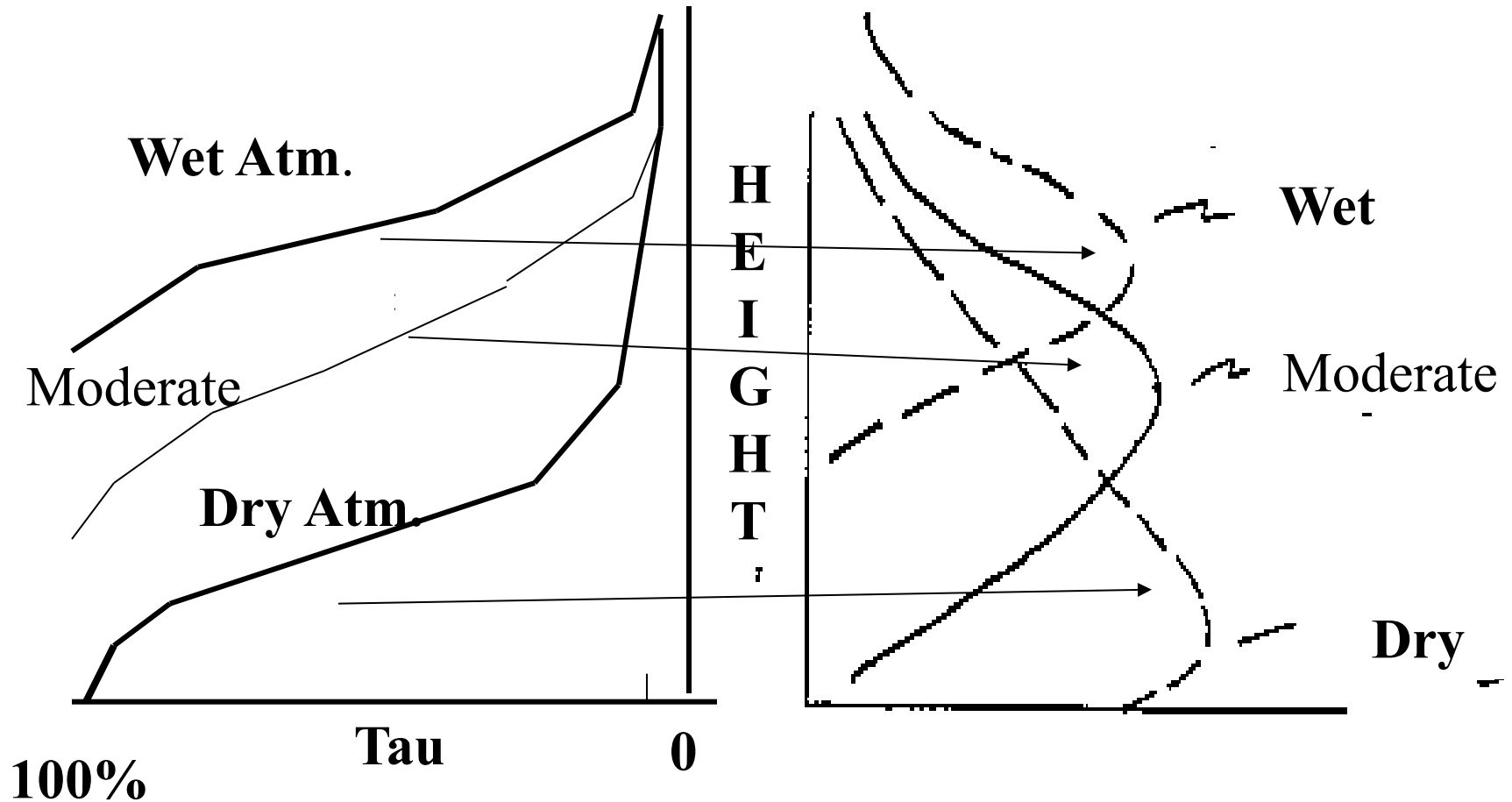
Questions

How does it look the observed spectrum for high thick water vapor cloud ?

Thick Cloud Opacity
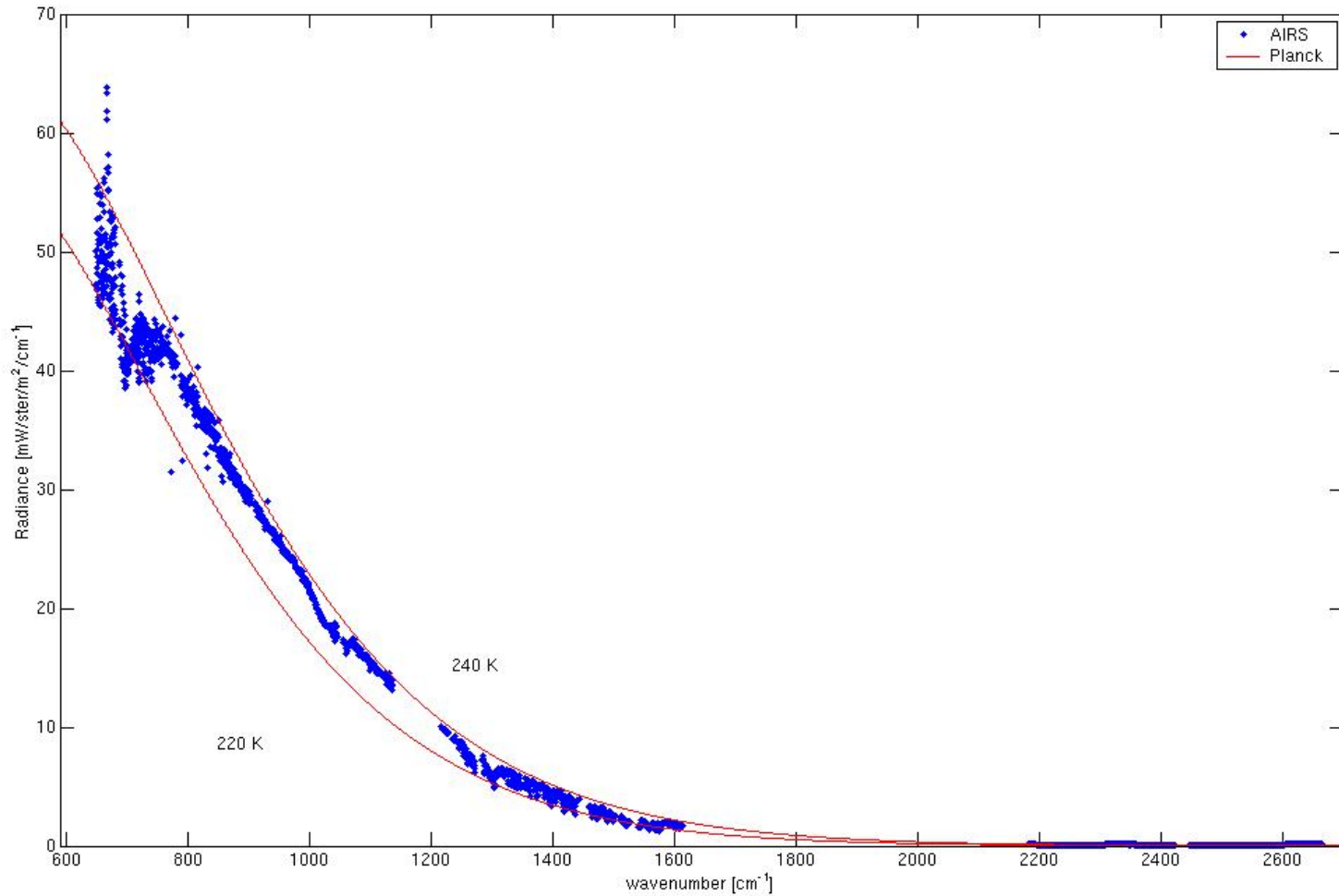
Questions

Moving deeper and deeper into an absorption line the observed BT tends do decrease, why?

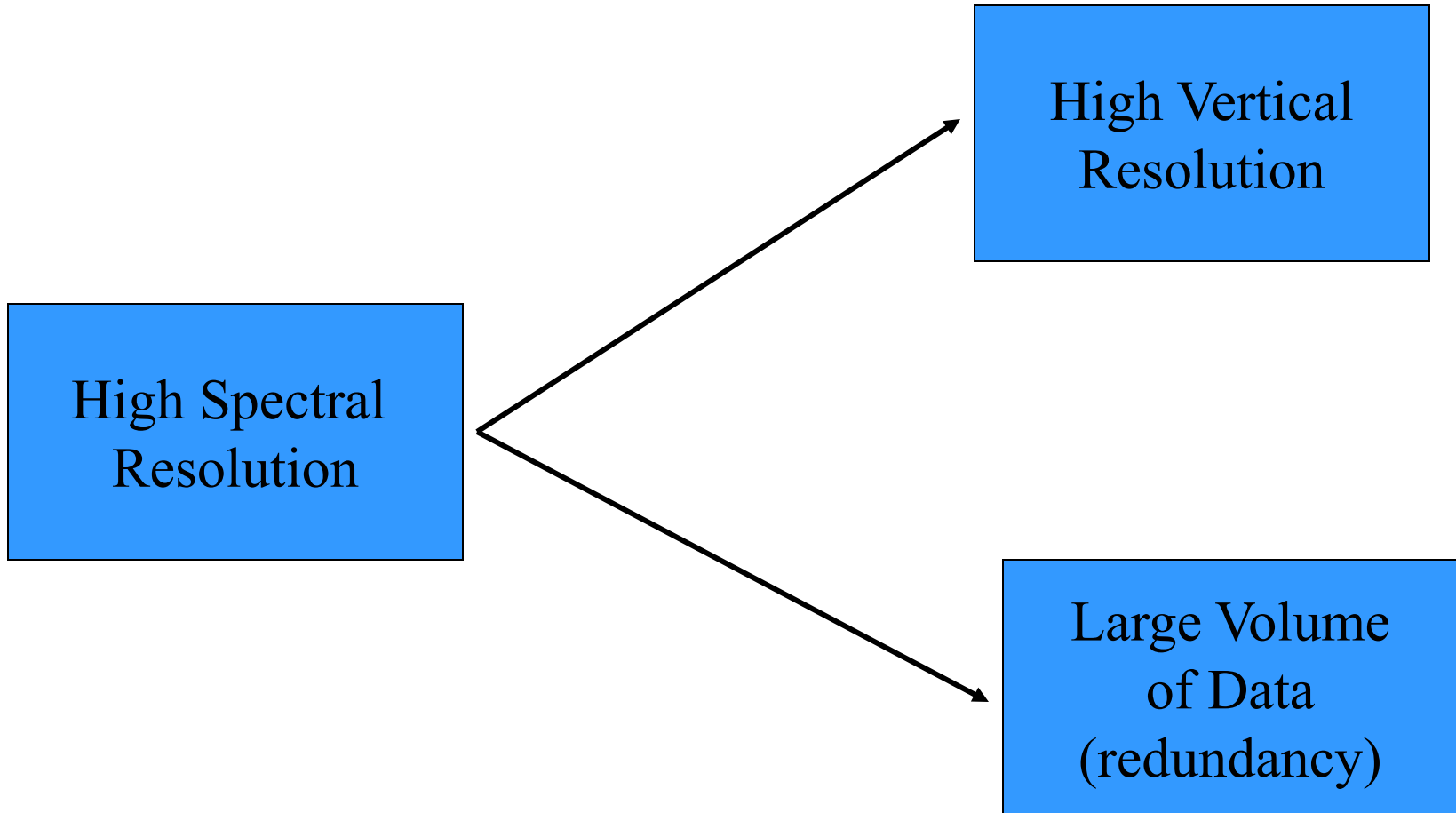Is it always true that the BT decreases going deeper into the absorption band?

Temperature Inversions

AIRS (20 July 2002)
calculation

AIRS (K)
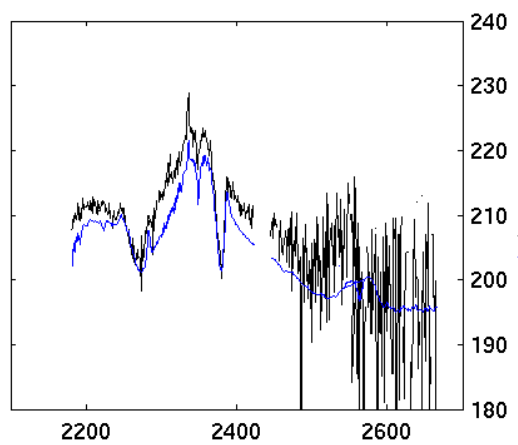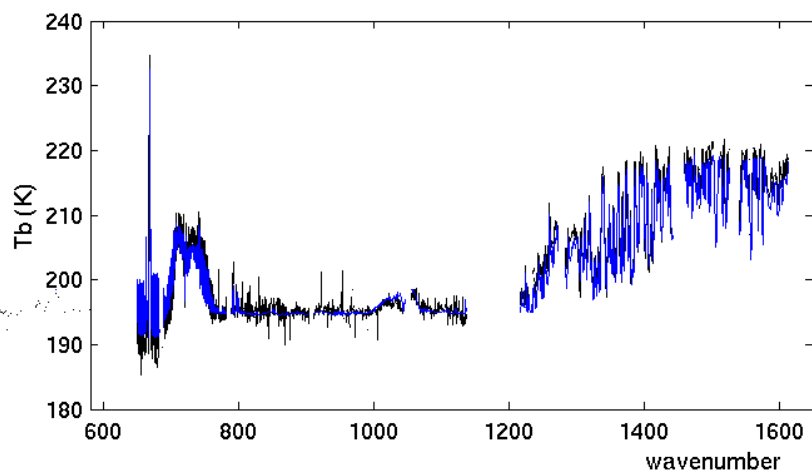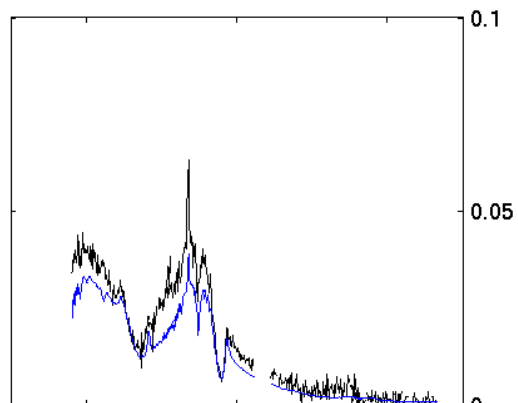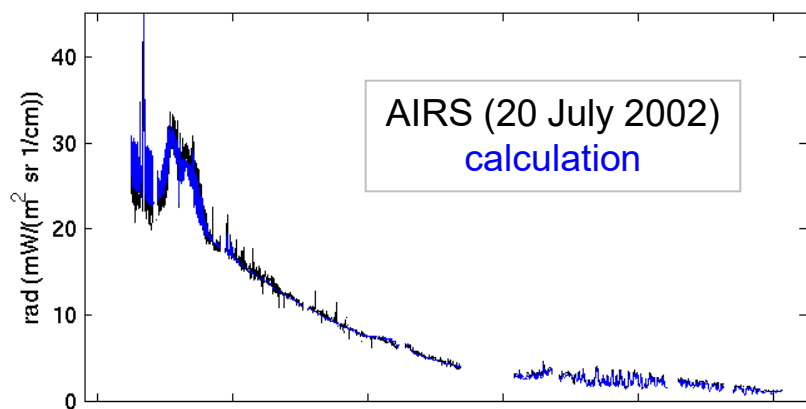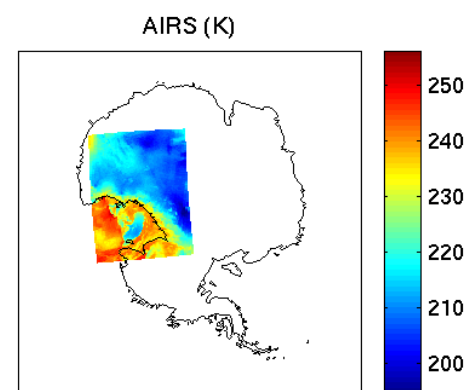
Sub-Arctic Winter
May 2001 S. Pole radiosonde
profile used in calculation
(0.365 mm H_2O)
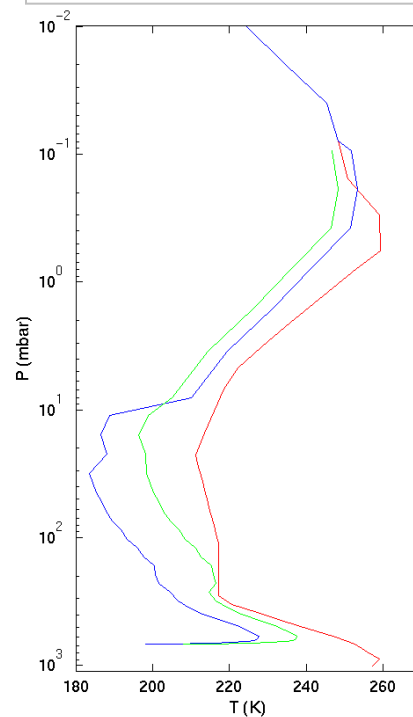
Conclusions

High Spectral Resolution → High Vertical Resolution

High Spectral Resolution → Large Volume of Data (redundancy)

High Spectral Resolution: Products

- Sounding (T,WV) at high vertical resolution

- Surface Properties (Emissivity, T)

- Cloud properties (Top Pressure, Optical Thickness, Effective Emissivity)

- Wind Profiling

- Noise Filtered Observations

Airborne Instruments

- MAS: moderate spectral resolution, high spatial resolution

- NAST-I, S-HIS: high spectral resolution, lower spatial resolution

Airborne FTS Instruments

- **NPOESS Atmospheric Sounder Testbed** Interferometer (NAST-I) Microwave (NAST-M)
- **Far-Infrared Sensor for Cirrus (FIRSC)**
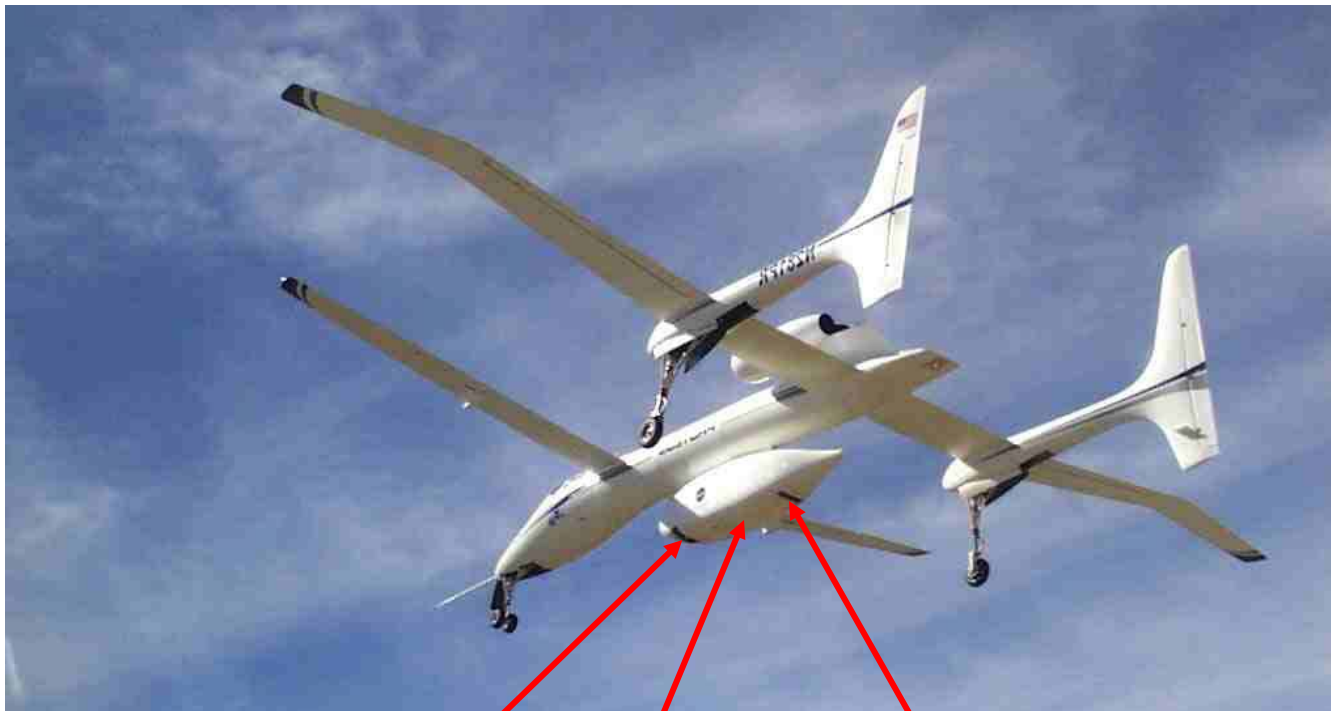
NAST-M
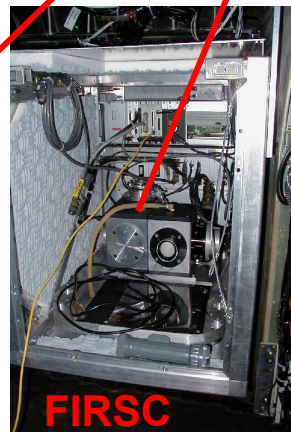
FIRSC

NAST-I

Scanning-HIS Aircraft Instrument

Quicklooks

Infrared Window (1123 – 1136 cm^{-1})

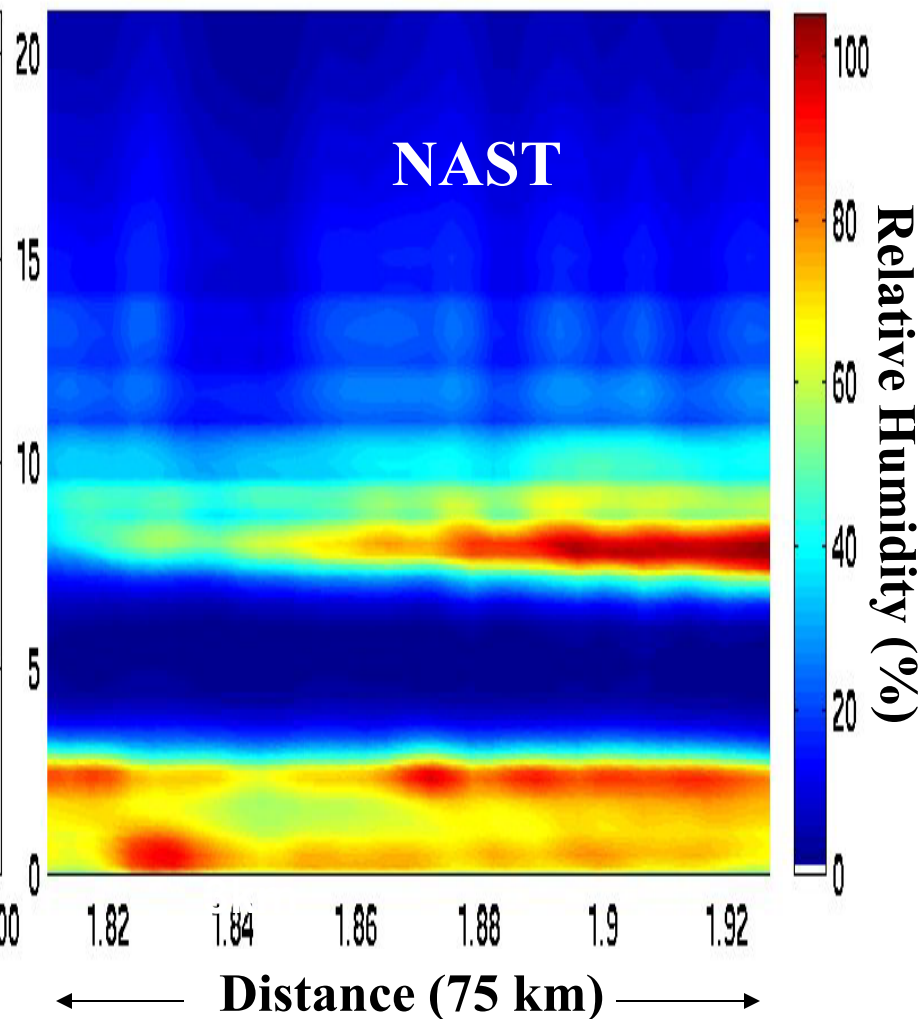Brightness Temperature (Kelvin)

Ocean Spectra
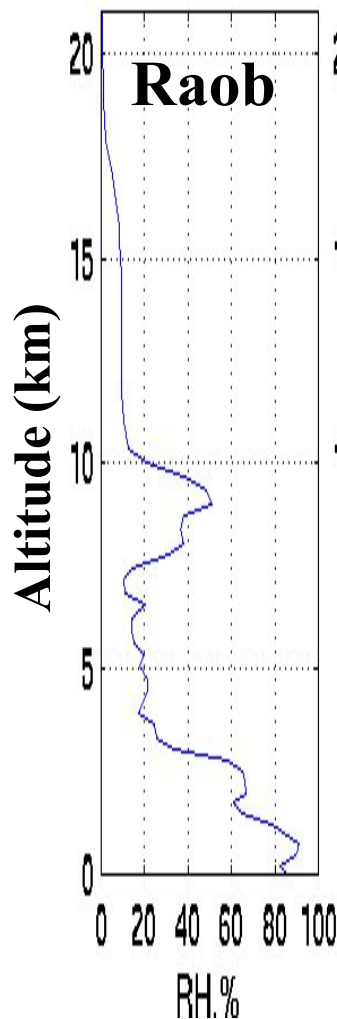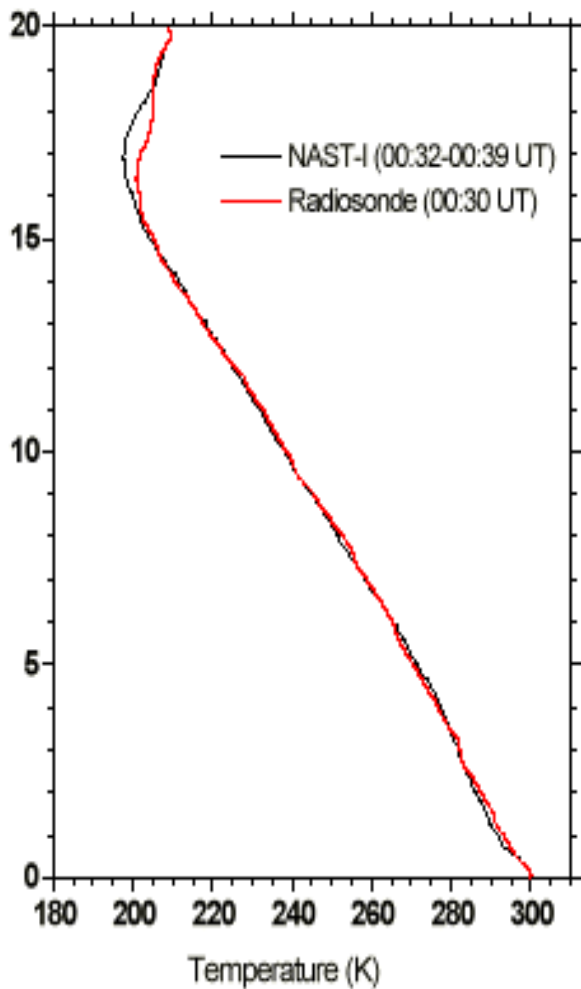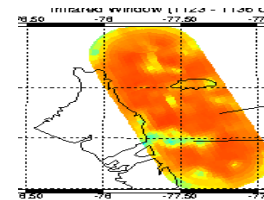
Land Spectra
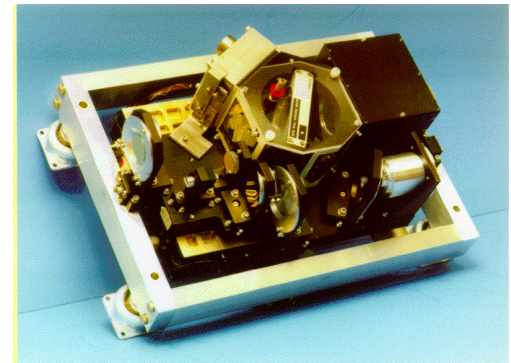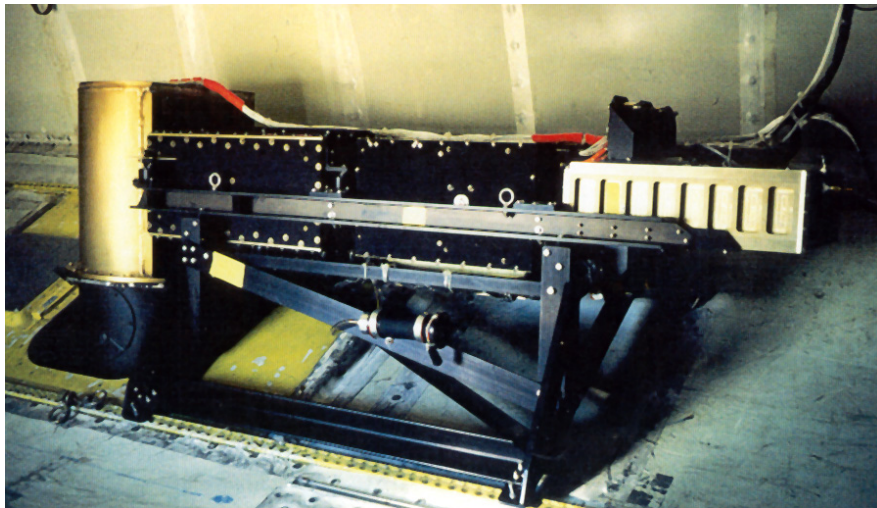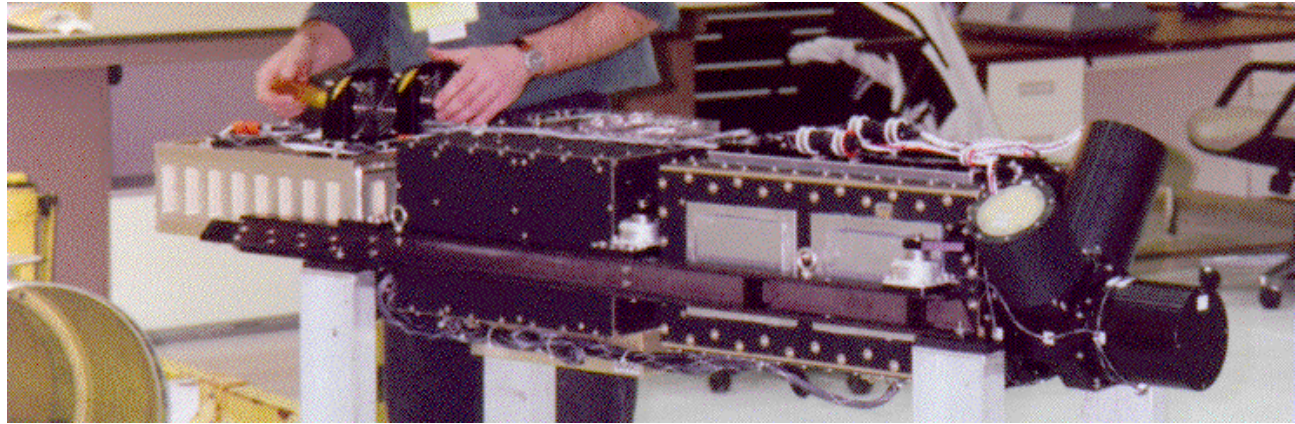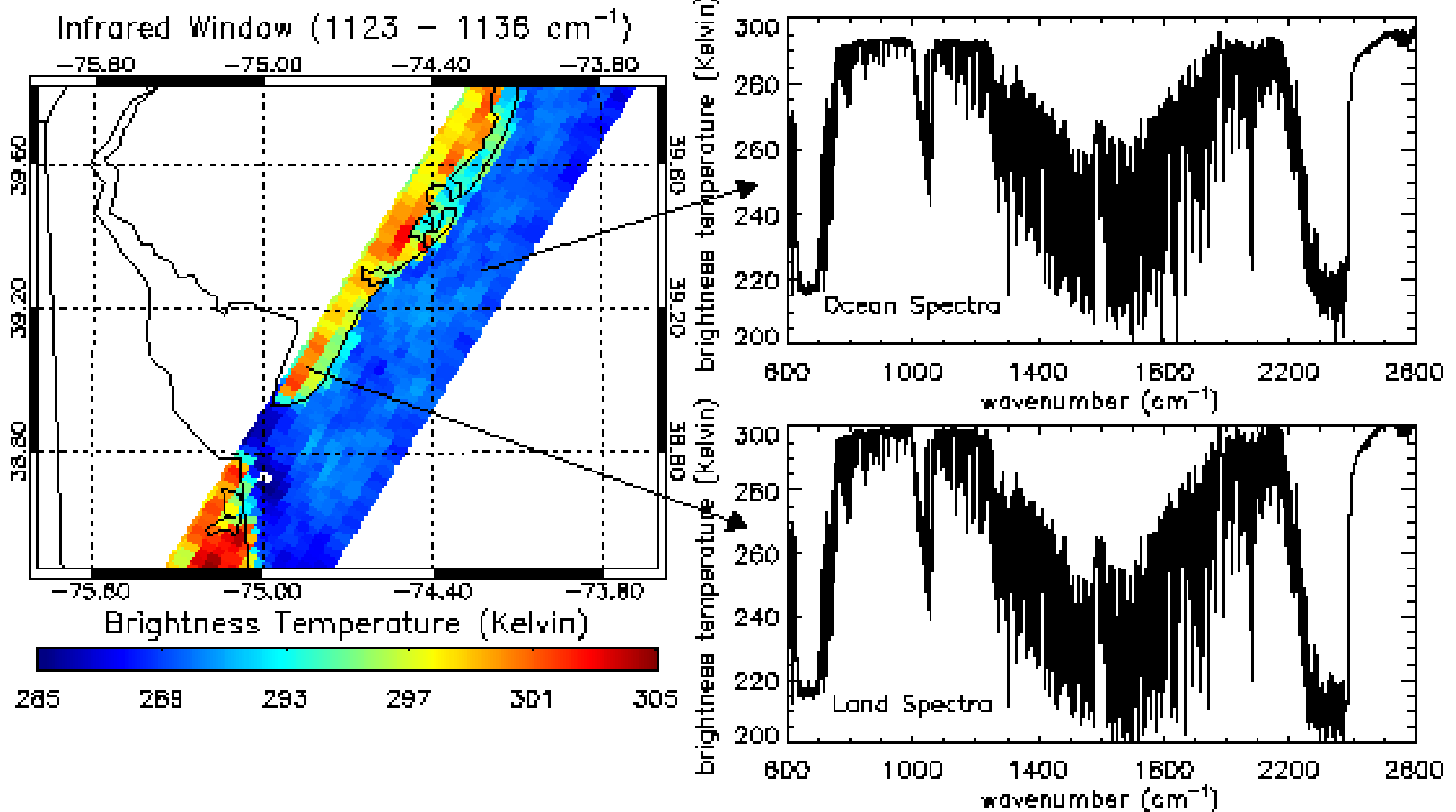
Spectral Coverage
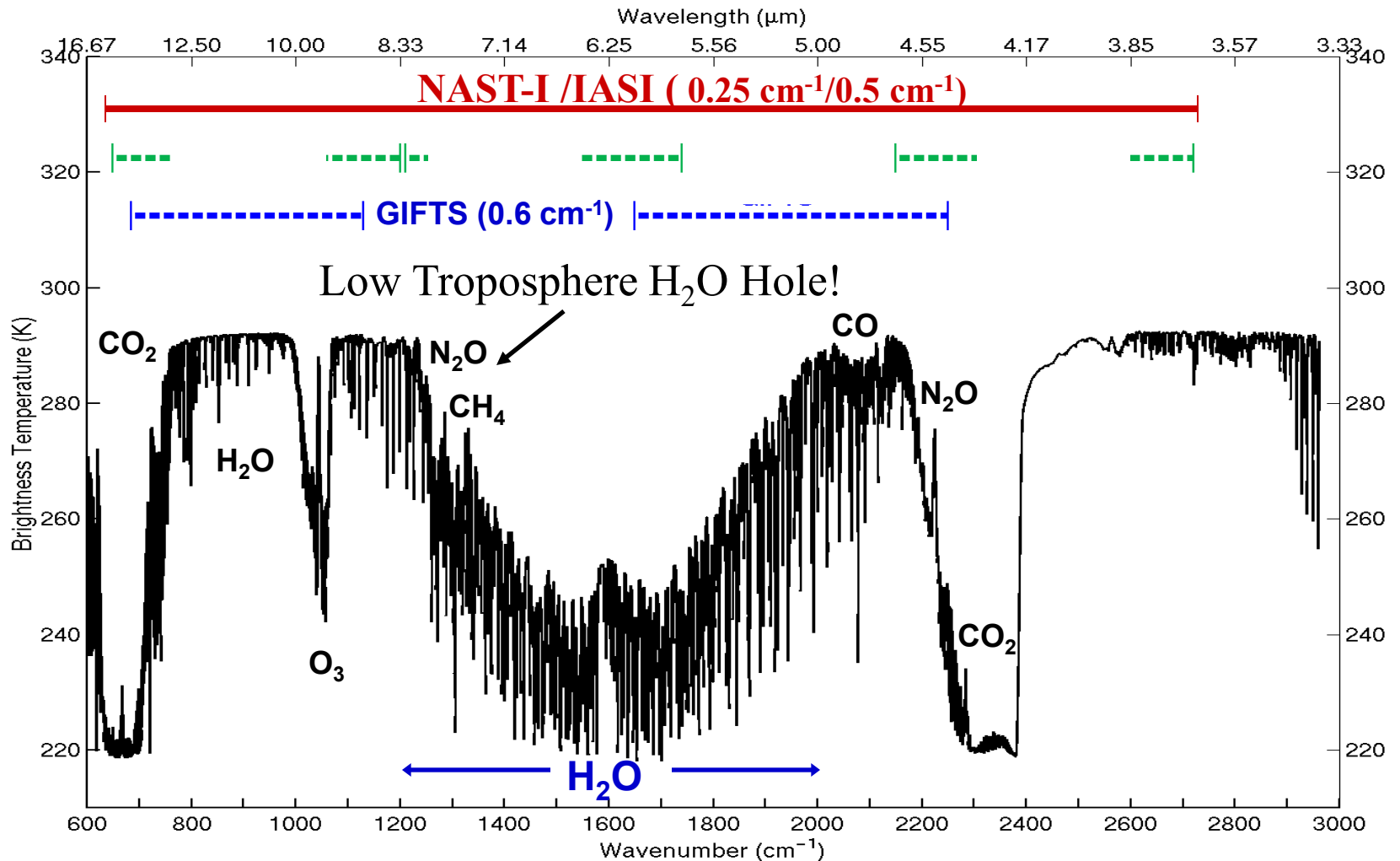
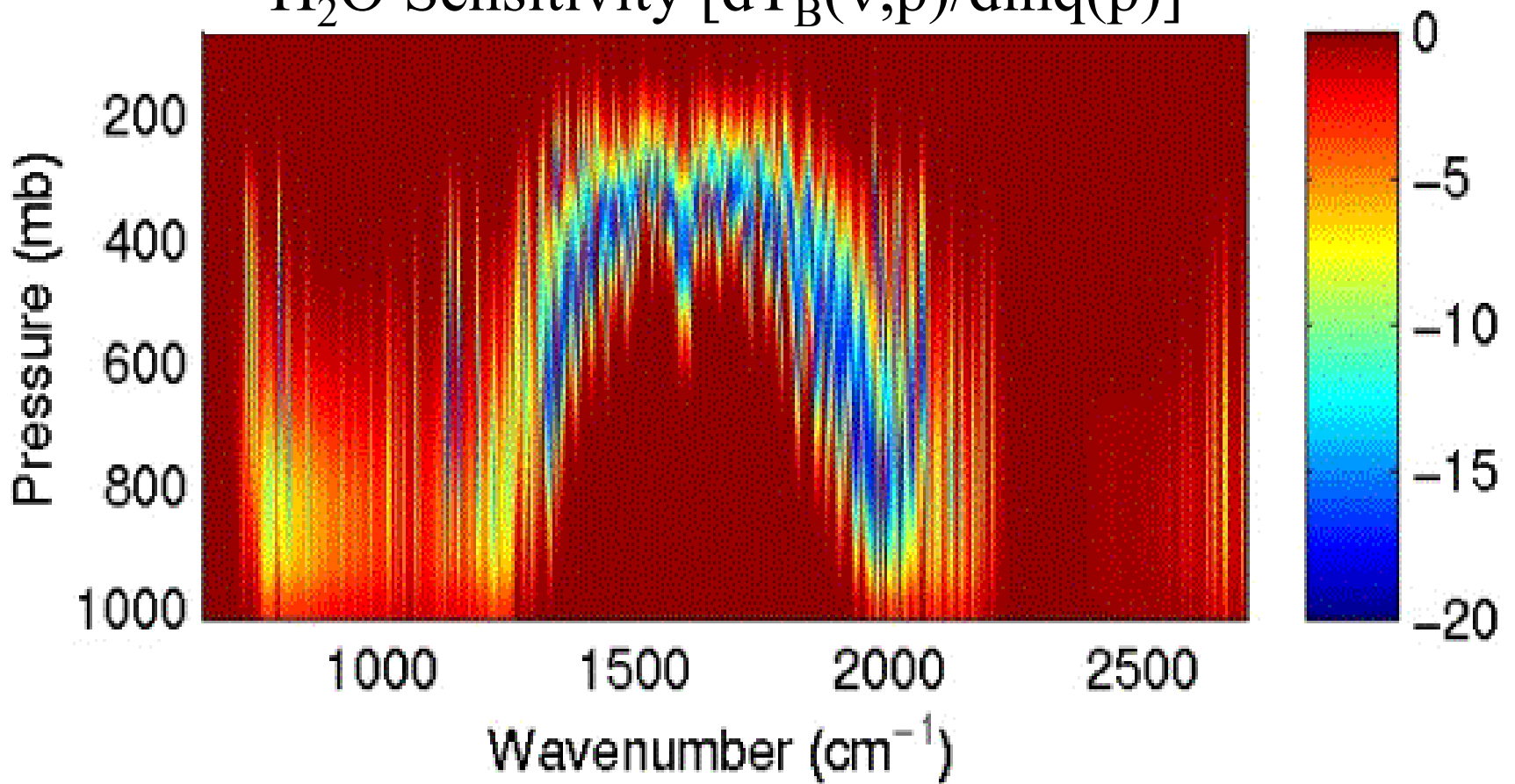# Regression Retrieval: Channel Selection
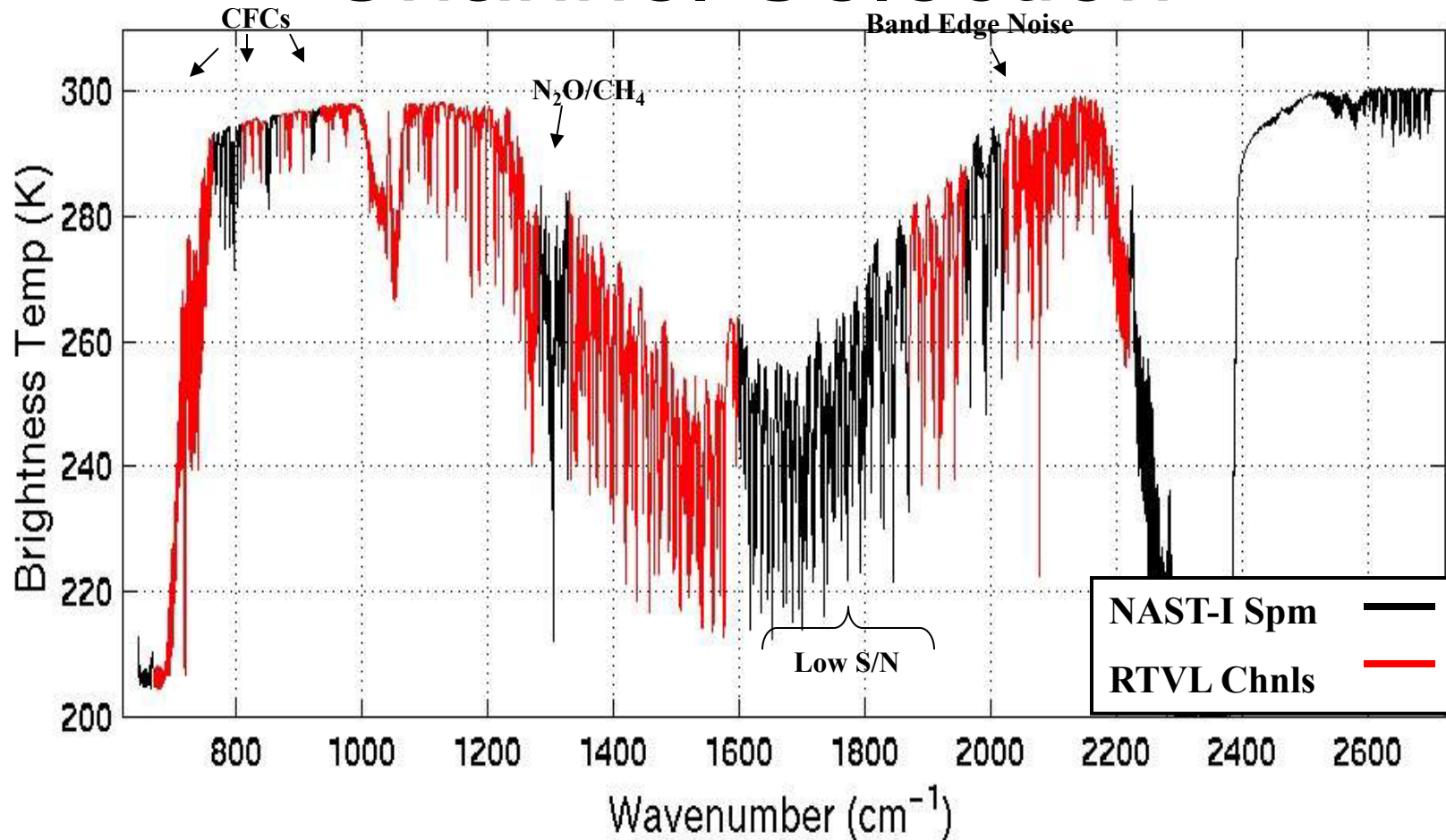
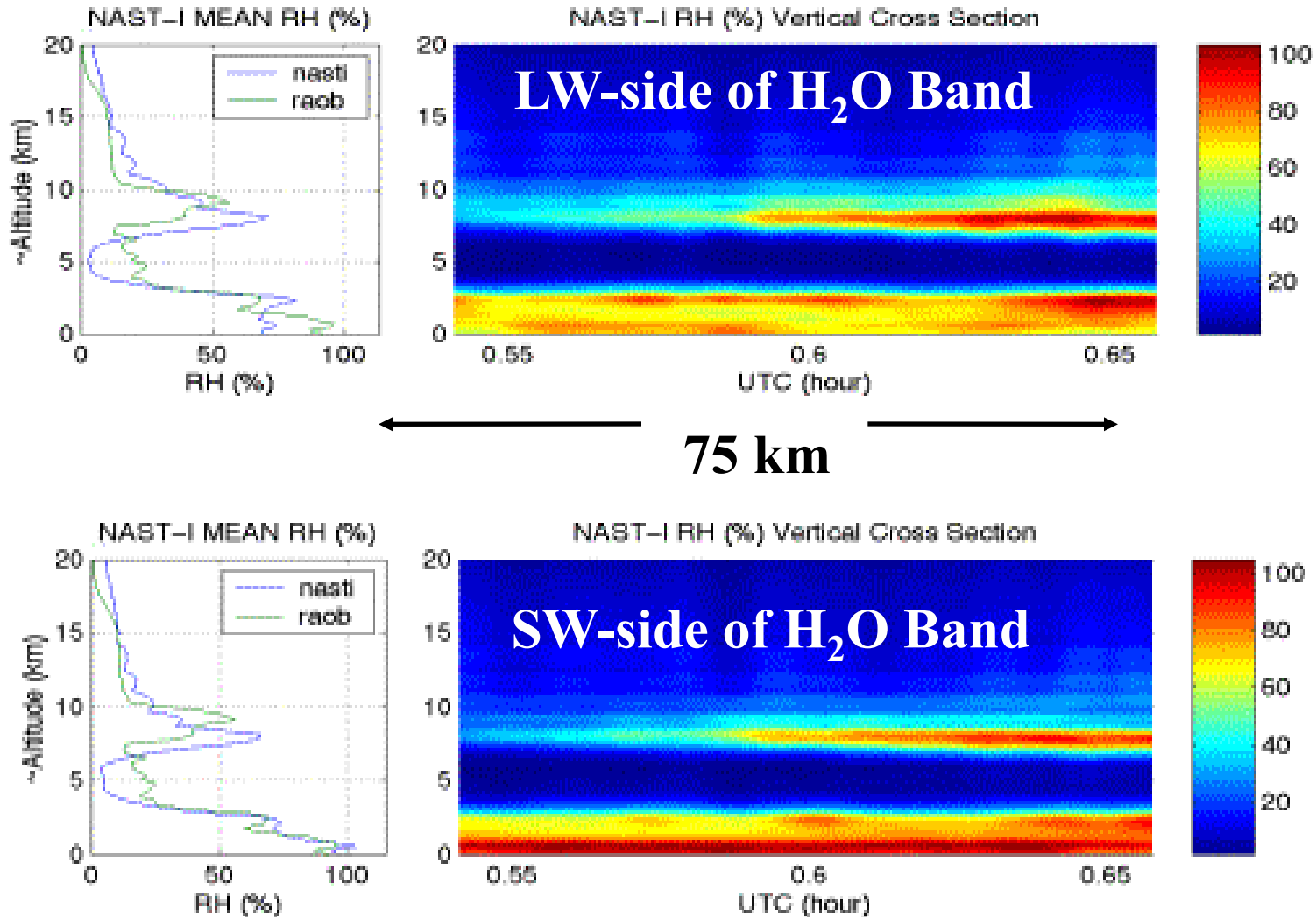# Water Vapor and Temperature Retrievals
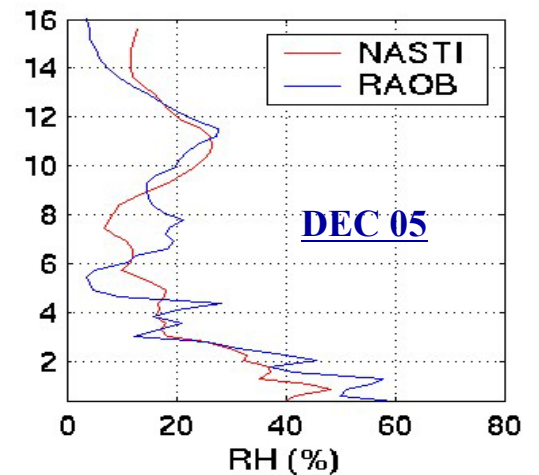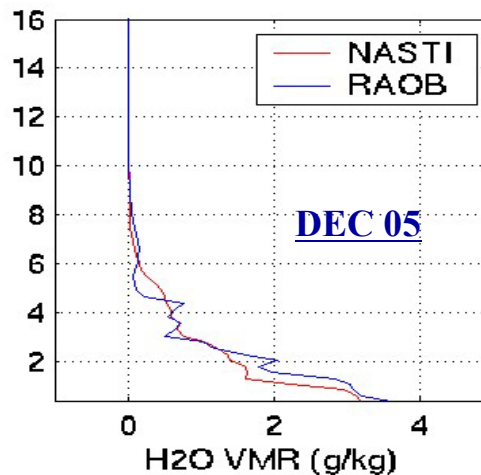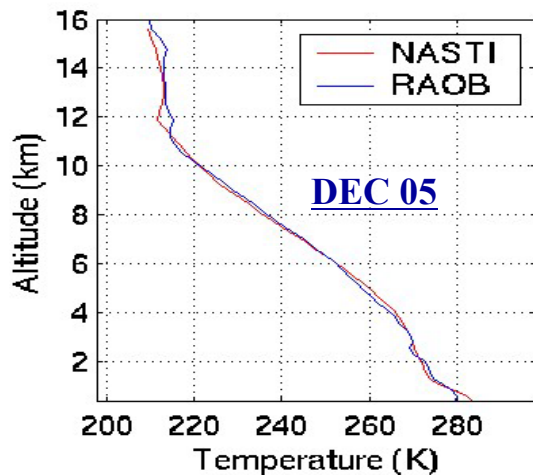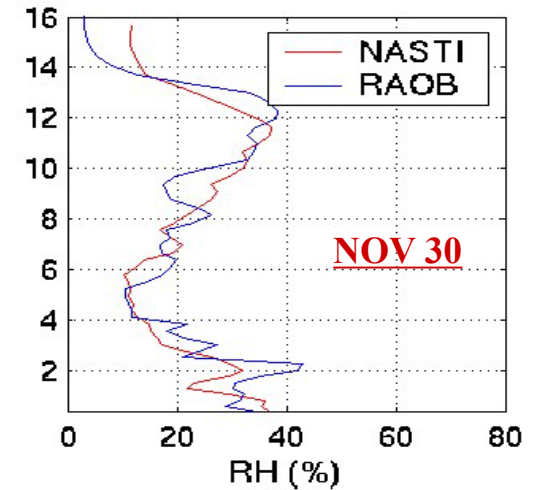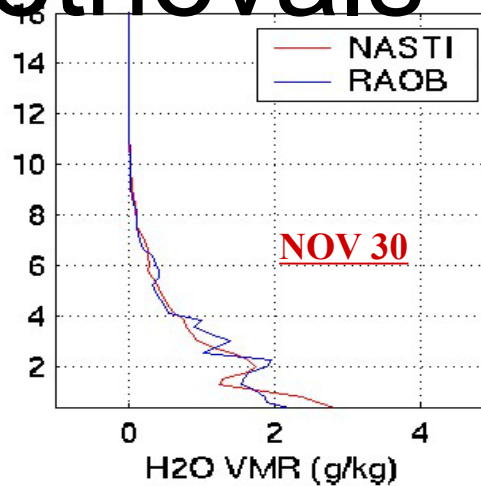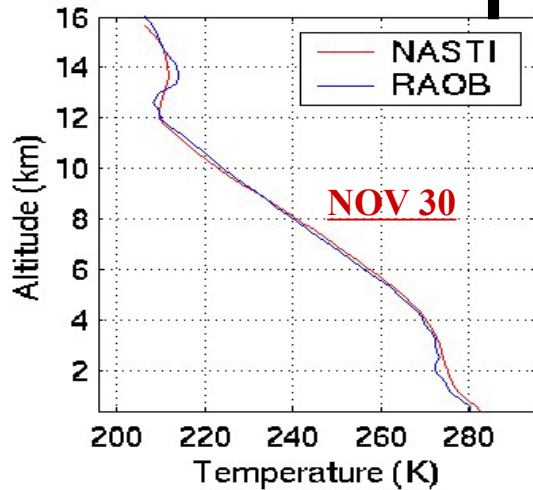
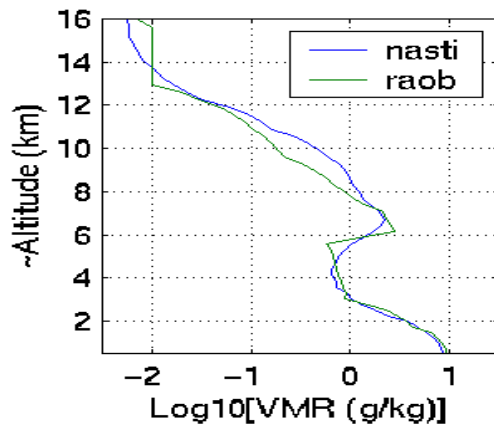# Andros Is. Bahamas, Sept 12,1998

Water Vapor Sensitivity
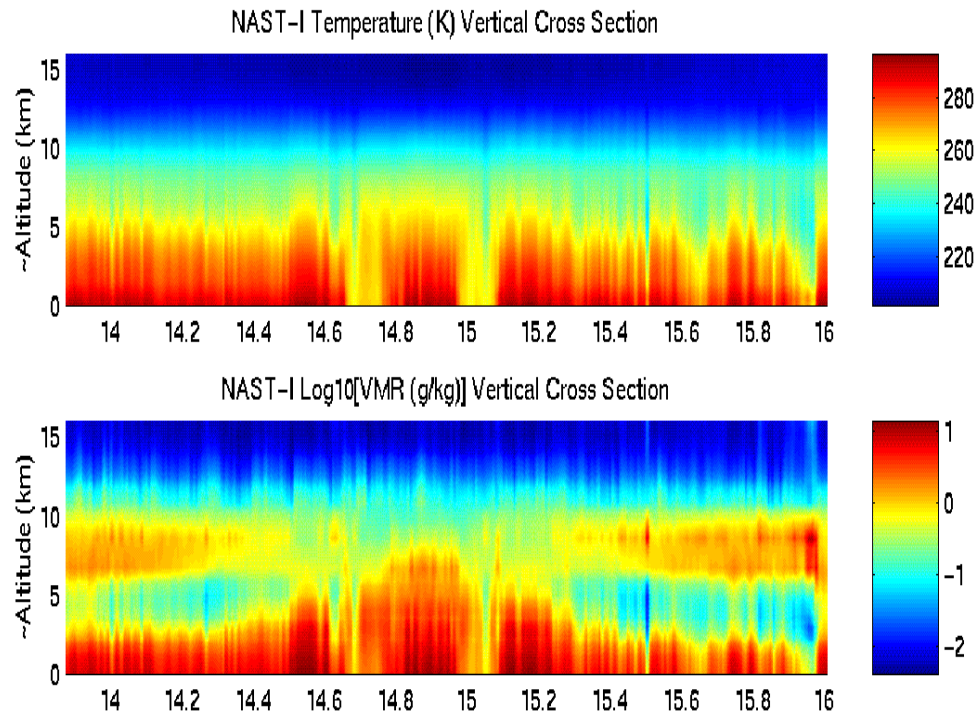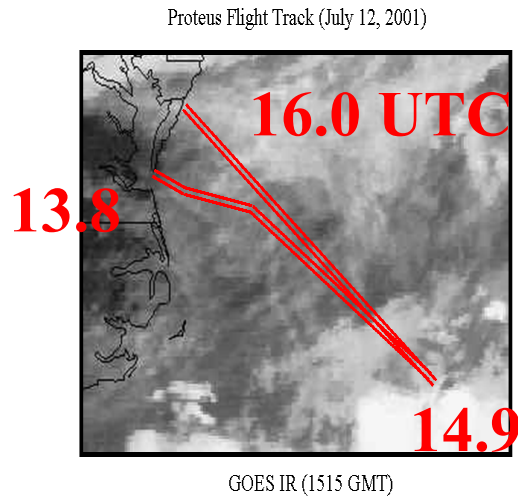

H_2O Sensitivity $[dT_B(\nu,p)/d\ln q(p)]$

Water Vapor Sensitivity

Sounding in presence of thin clouds

Proteus Flight Track (July 12, 2001)

16.0 UTC

13.8

14.9

GOES IR (1515 GMT)

NAST–I Temperature (K) Vertical Cross Section

NAST–I Log10[VMR (g/kg)] Vertical Cross Section

This flight demonstrates the ability to observe the spatial moisture structure below a scattered and semi-transparent Cirrus cloud cover

THORPEX 2003

THORPEX objectives are:
• to improve the use of various in situ and space-based observation systems in operational weather predictions
• to evaluate model sensitivity studies and test the impact of targeted observations
• to begin to develop intelligent observing systems along with forecast models capable of dynamical interaction through data assimilation systems
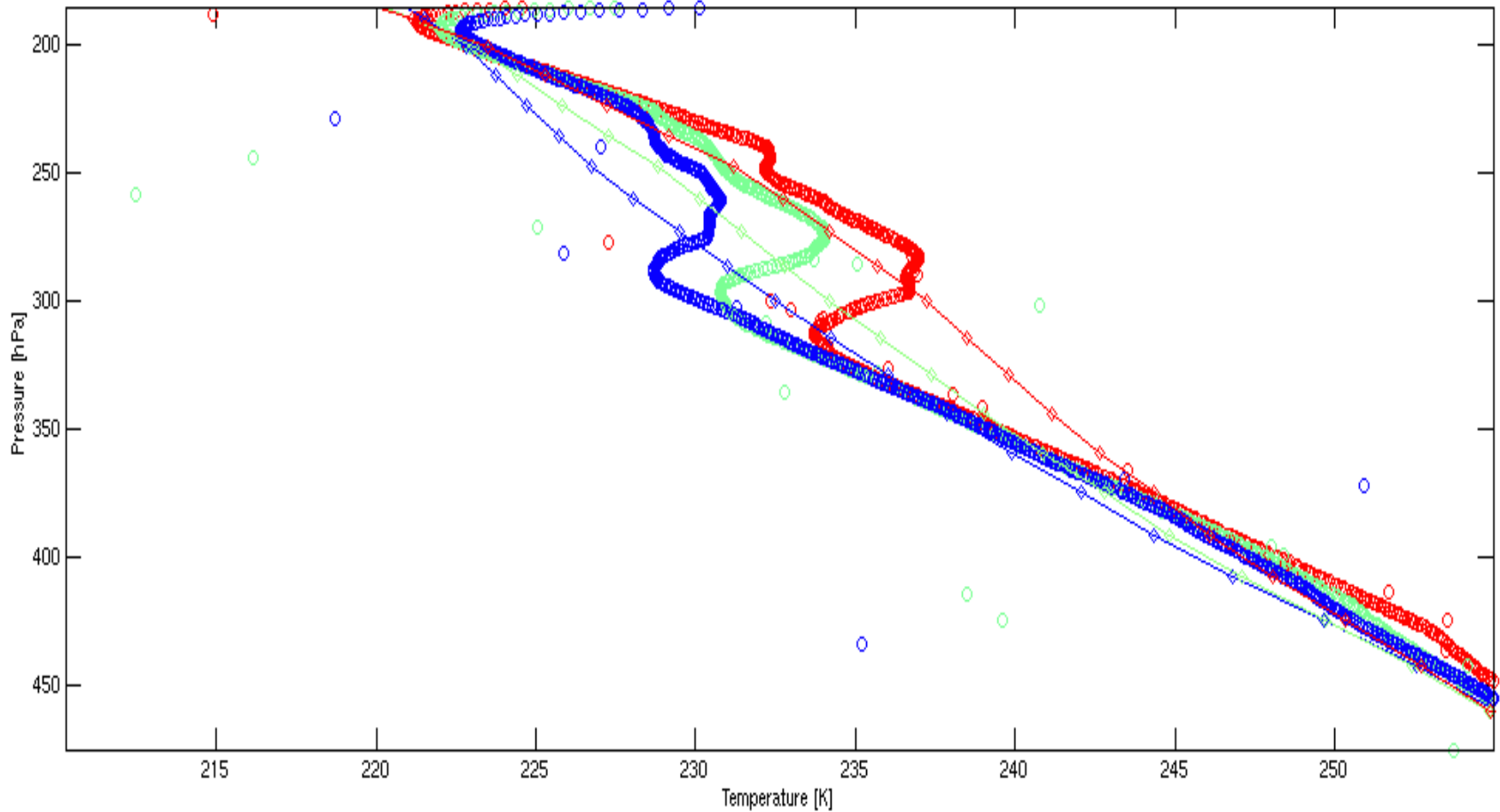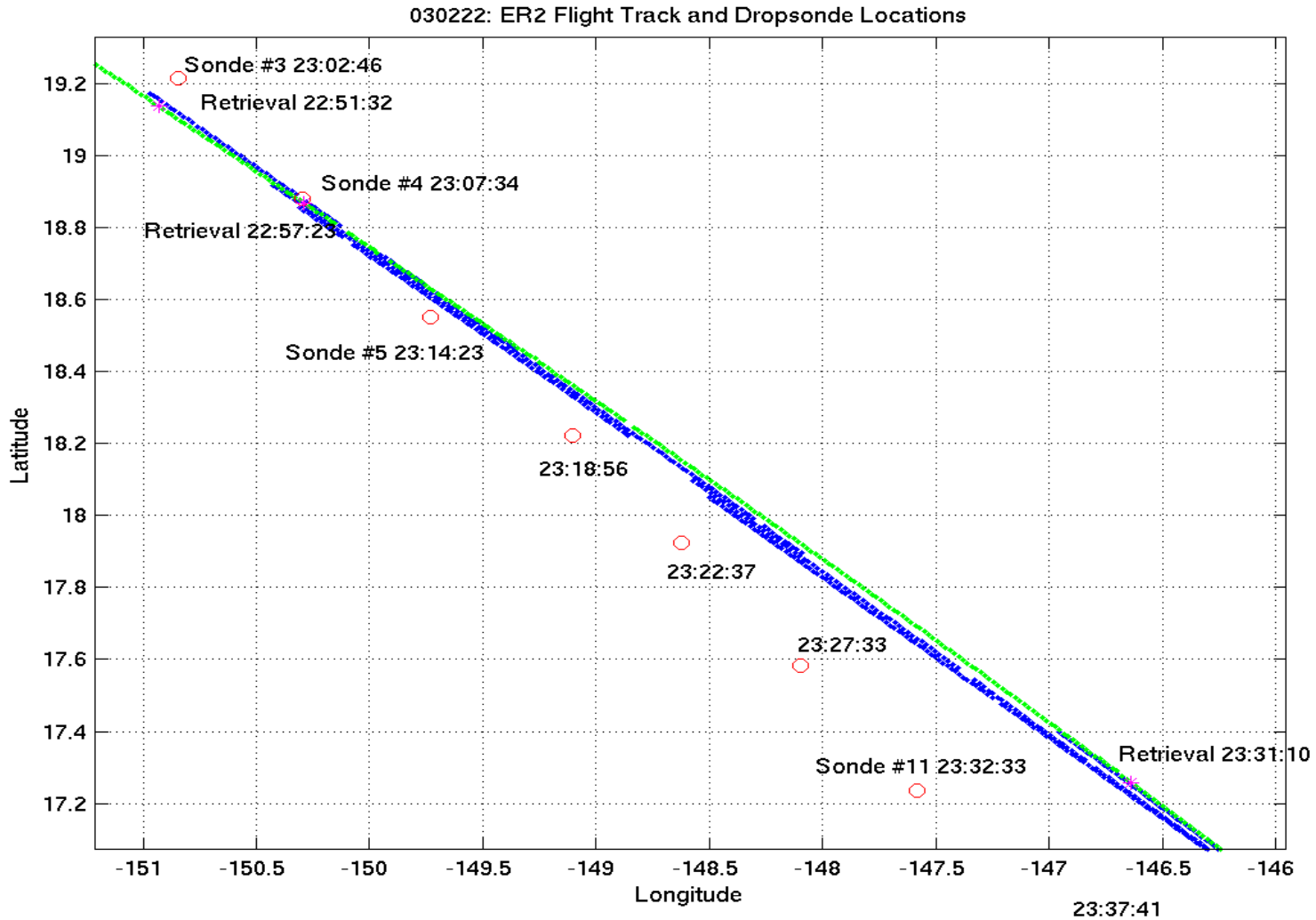
Soundings: 03 Mar 2003

030303: ER2 Flight Track and Dropsonde Locations

23:49:00

00:03:00
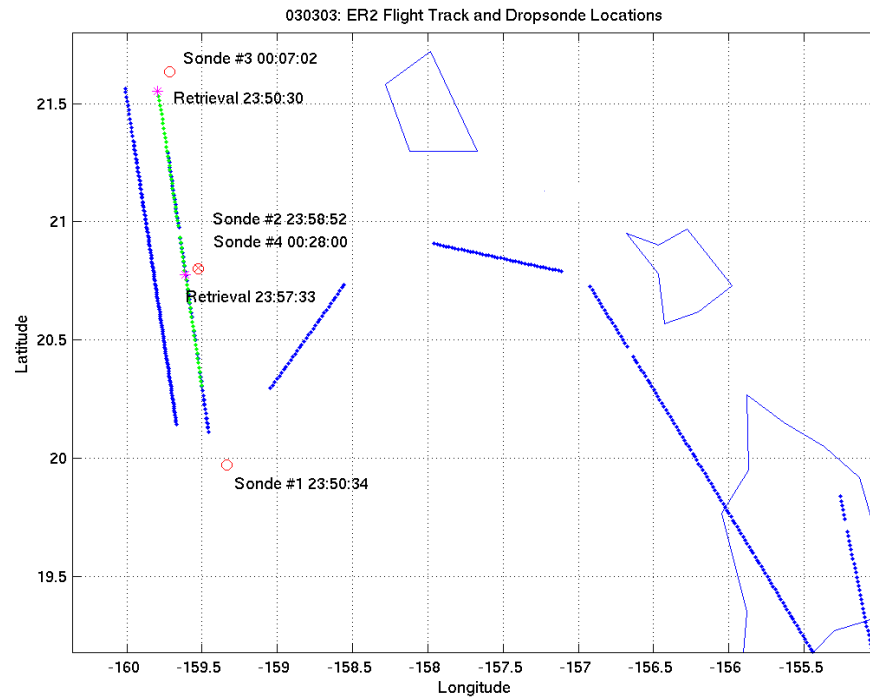
Temperature Sounding Validation
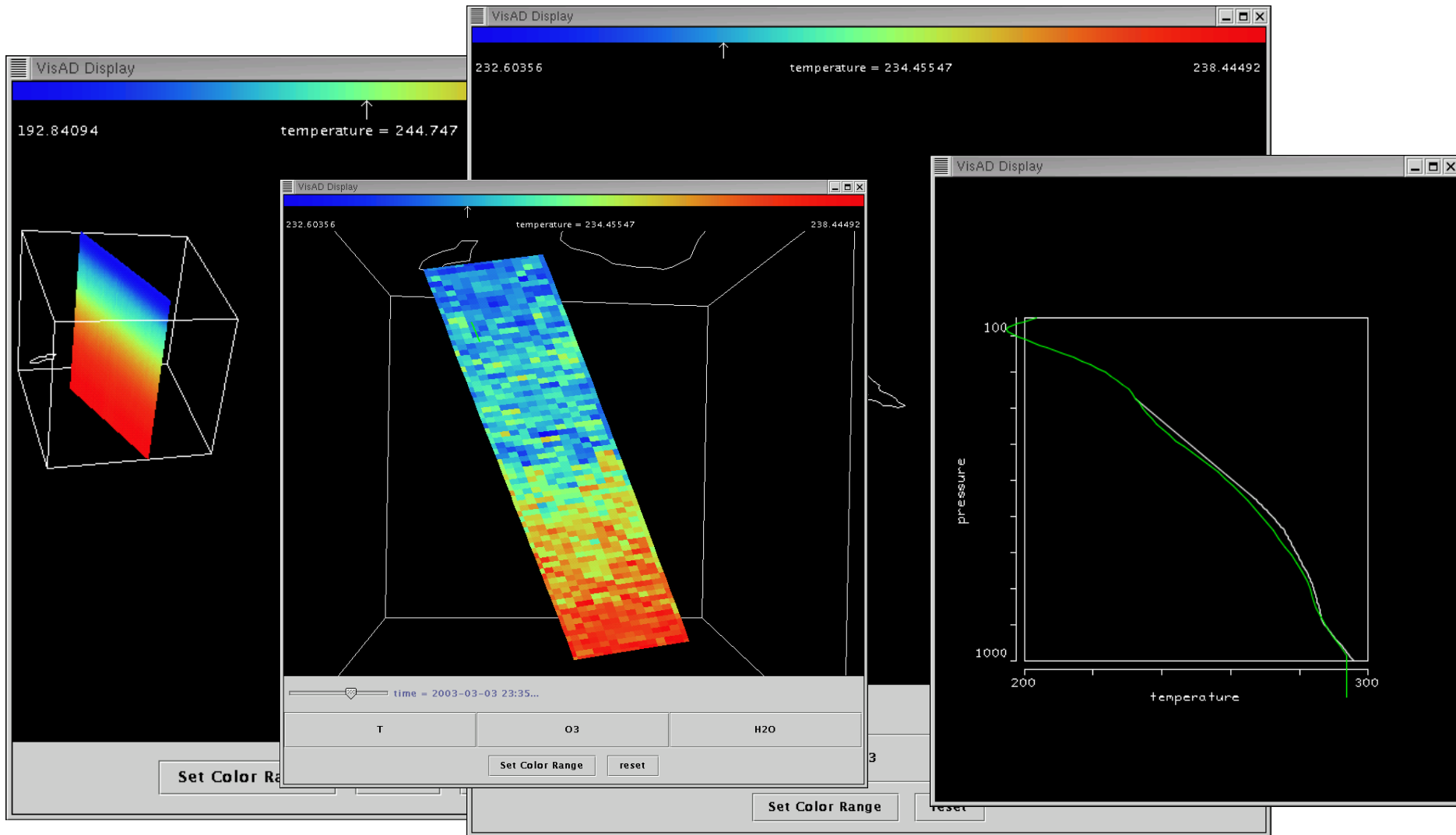
Temperature Sounding Validation: Dropsondes

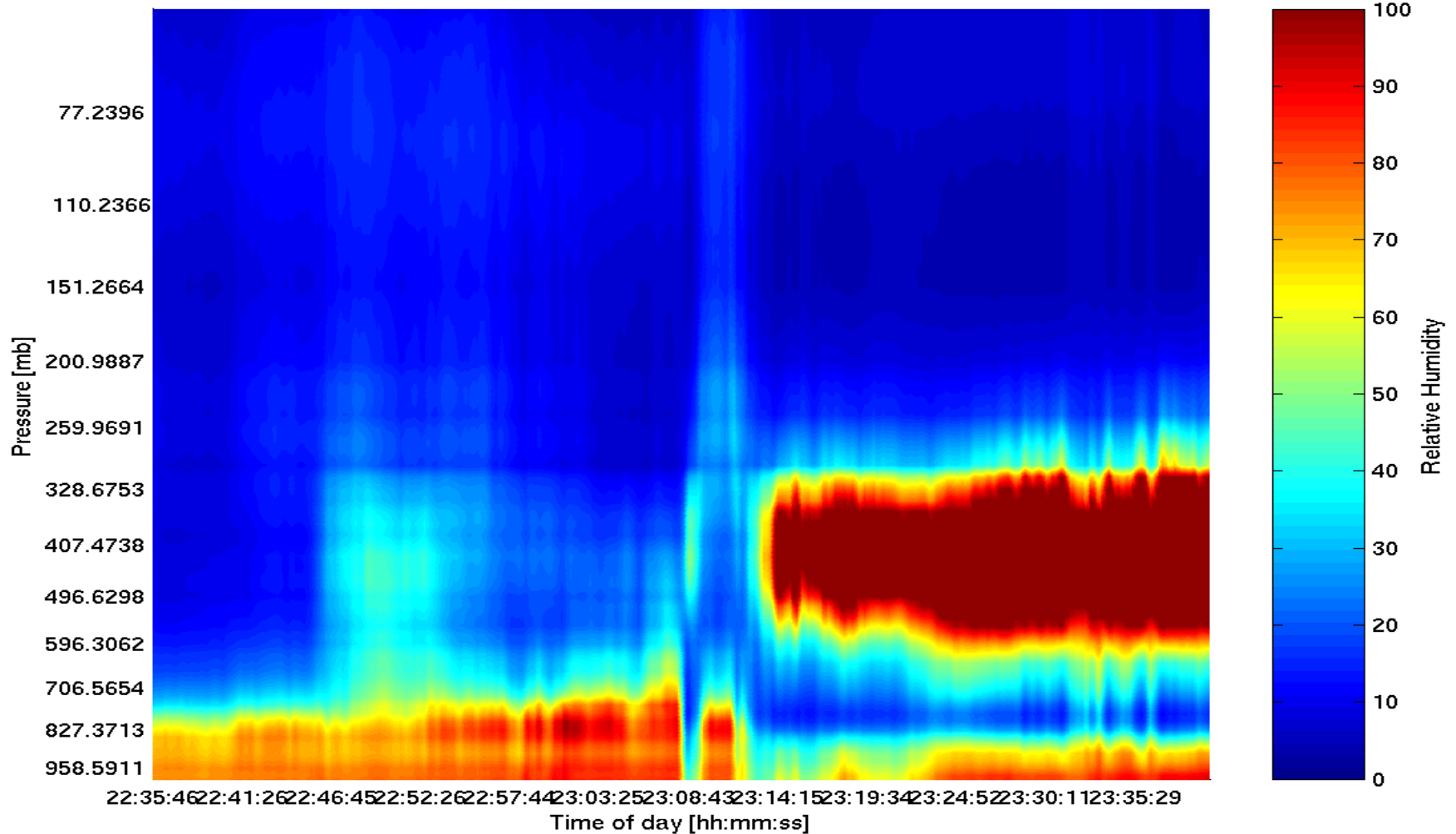# Sounding: 22 Feb 2003

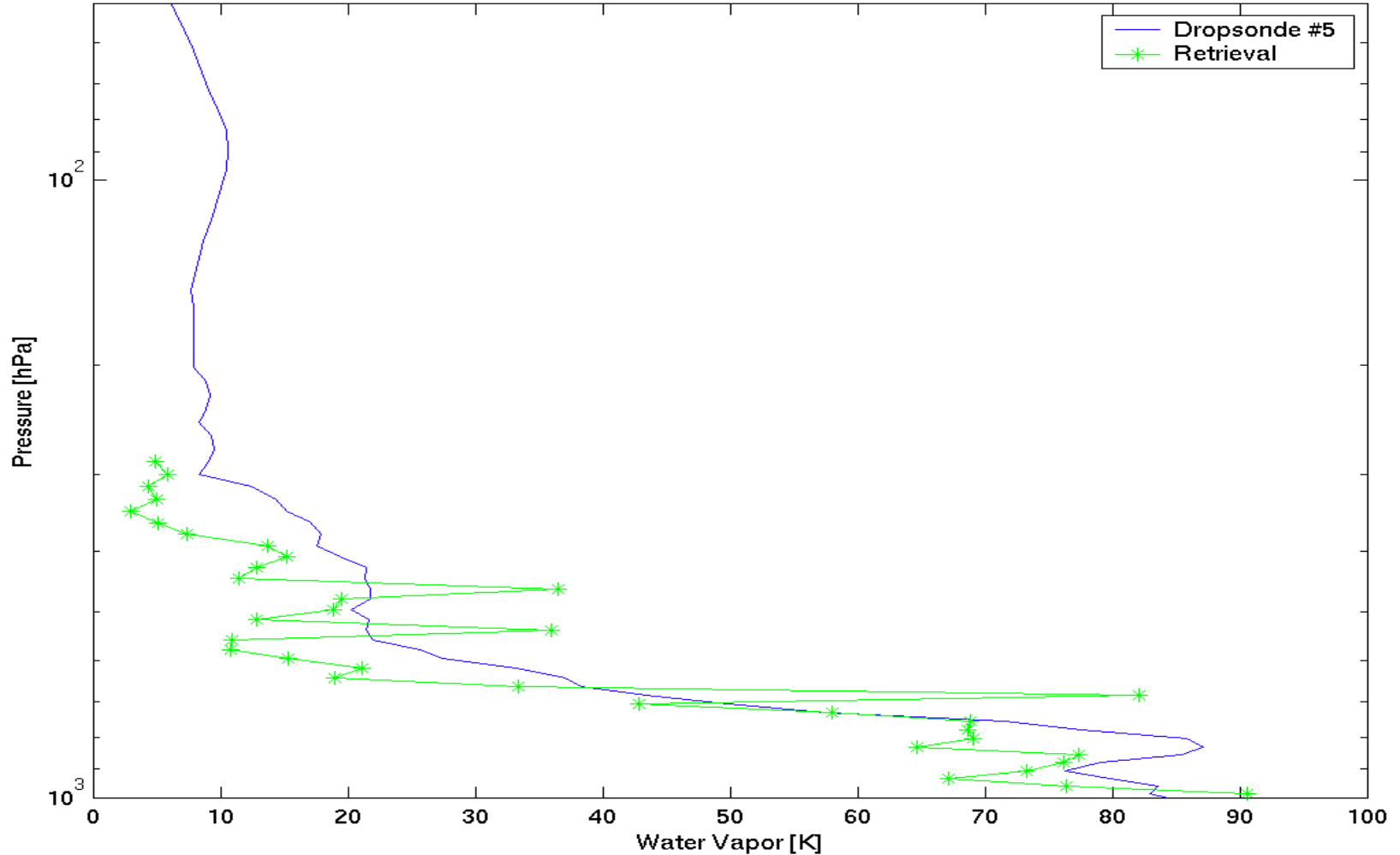030222: ER2 Flight Track and Dropsonde Locations

S-HIS sounding

030222: SHIS Relative Humidity Retrieval 13 PCs

Relative Humidity Validation


030222: S-HIS Relative Humidity Retrieval Validation

Noise Reduction

- High Spectral Resolution means high redundancy

- Reducing the instrument noise without compromising the spatial and spectral resolutions is very expensive

- We can take full advantage of the high redundancy, to filter out part of the instrument noise

- PCA has been chosen to build a noise filter that takes advantage of the high redundancy
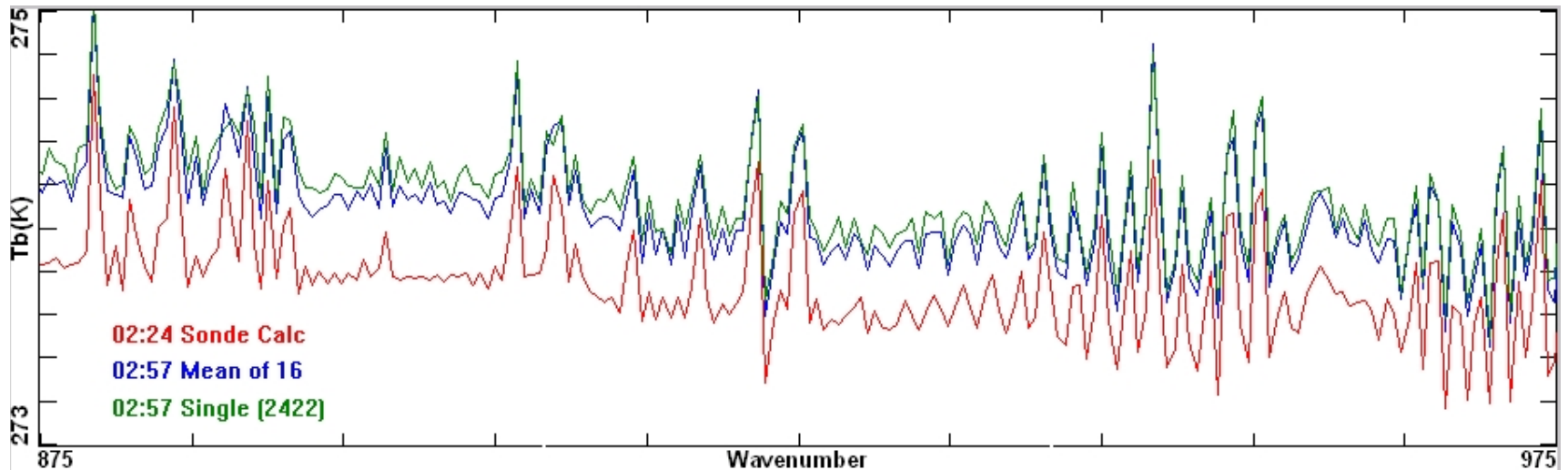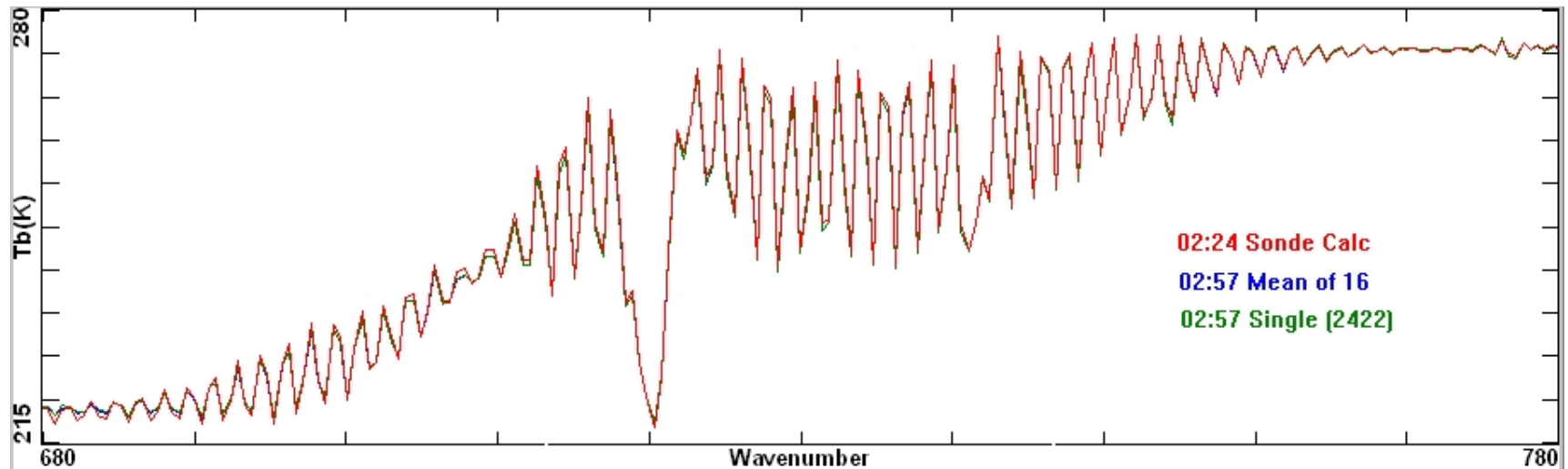
Noise Reduction
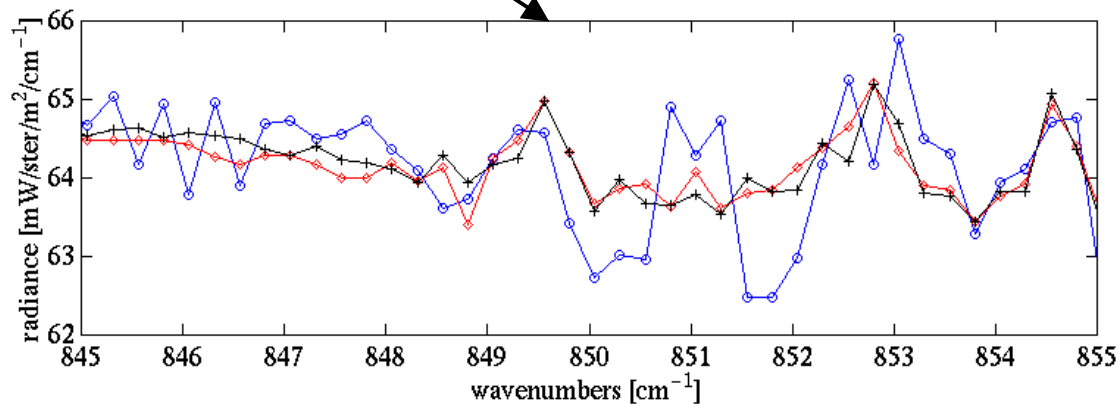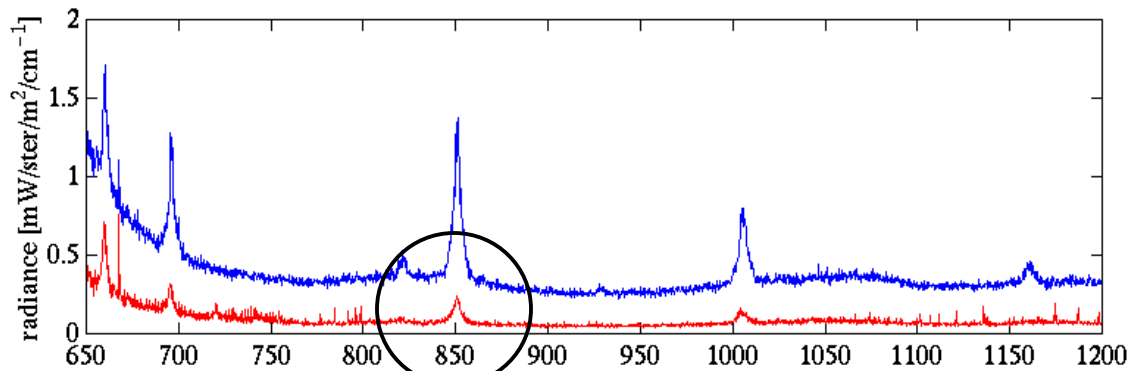
Uncorrelated Noise

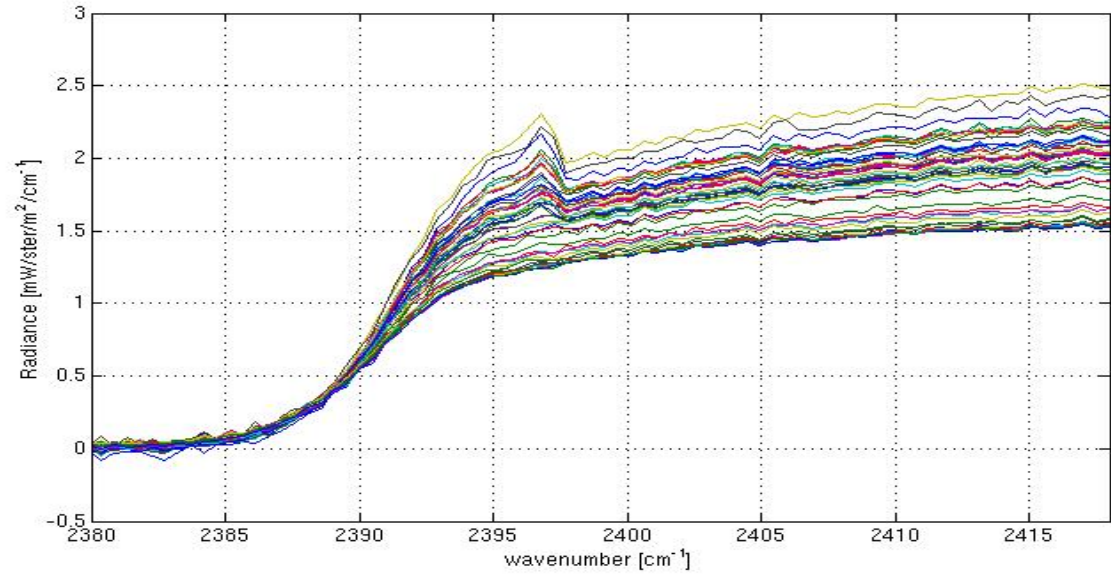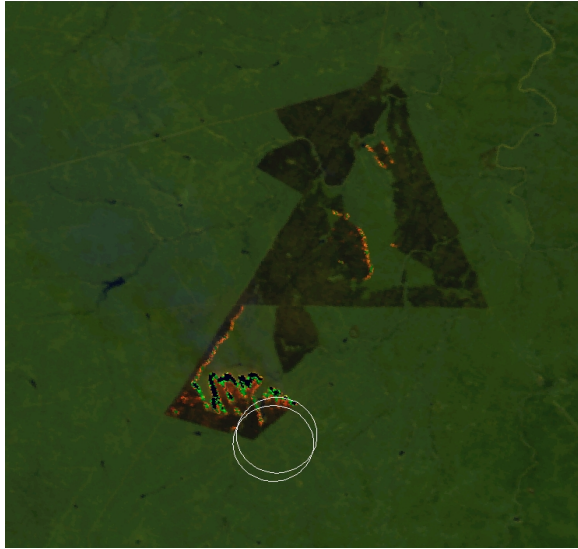Before Compression
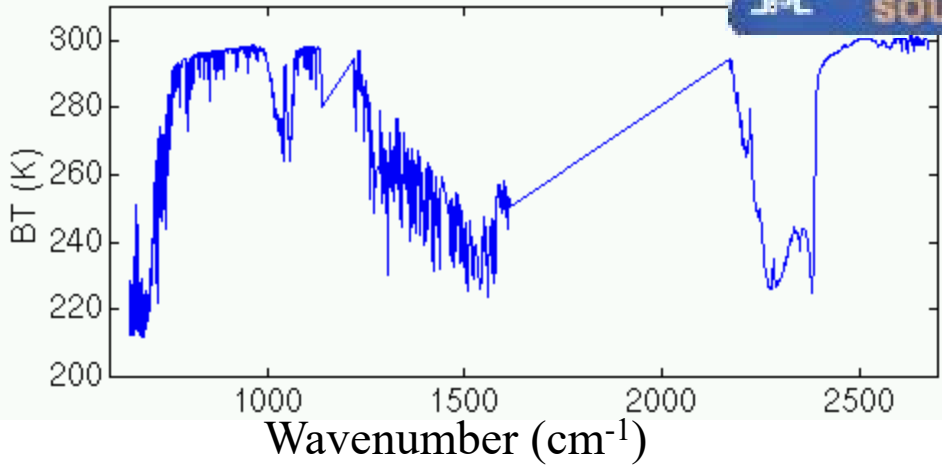After Compression

Single Recons. Spectrum

Averaged Spectrum

Noise Filter Validation: AFWEX

Upper panel legend:
02:24 Sonde Calc
02:57 Mean of 16
02:57 Single (2422)

Tb(K) axis: 280 to 215
Wavenumber axis: 680 to 780

Lower panel legend:
02:24 Sonde Calc
02:57 Mean of 16
02:57 Single (2422)

Tb(K) axis: 275 to 273
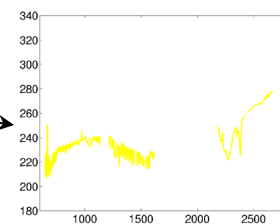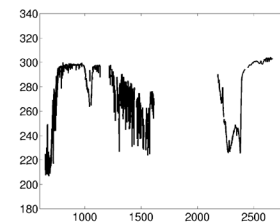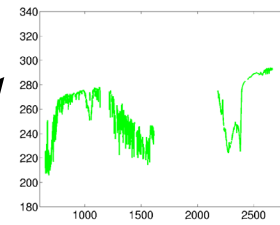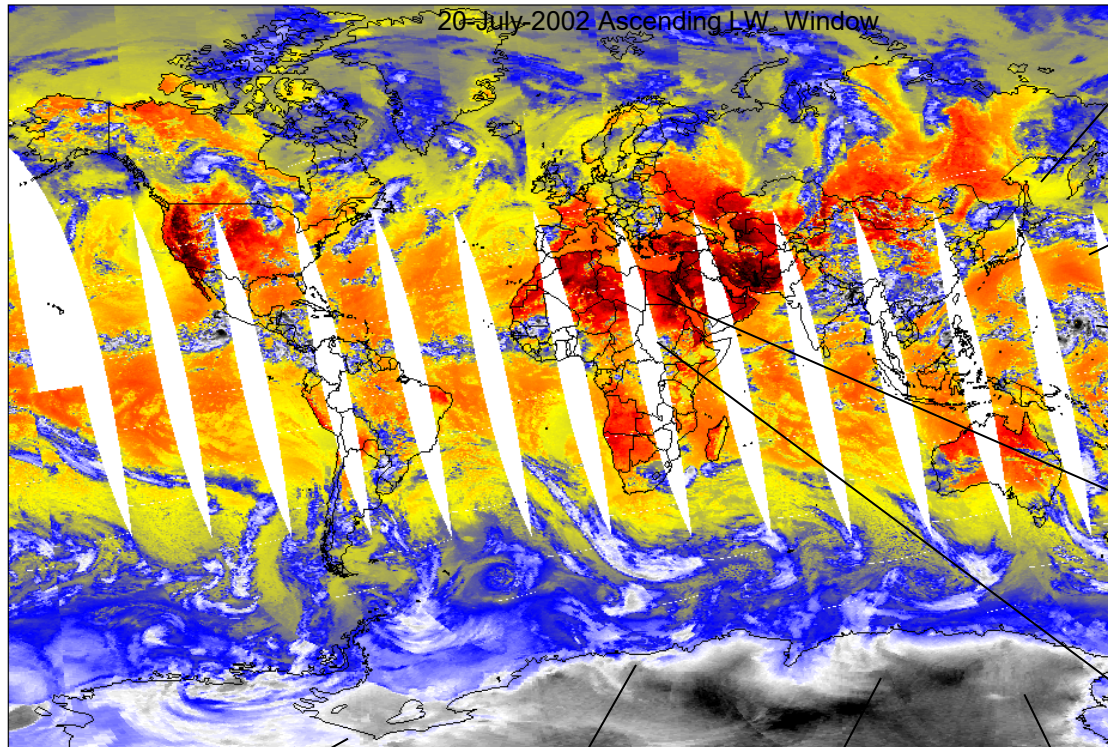Wavenumber axis: 875 to 975

S-HIS: Noise Filter

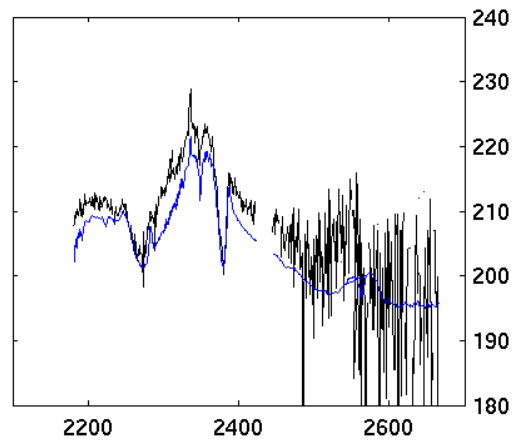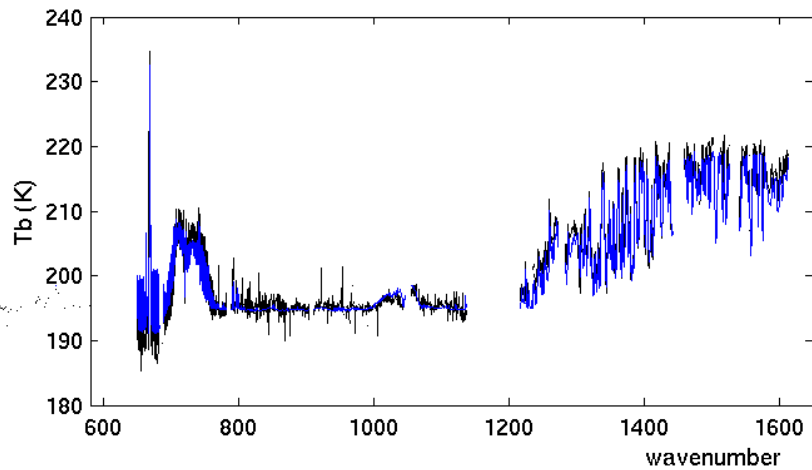# AIRS *before Aqua integration, Aqua shake test & simulated AIRS spectrum*

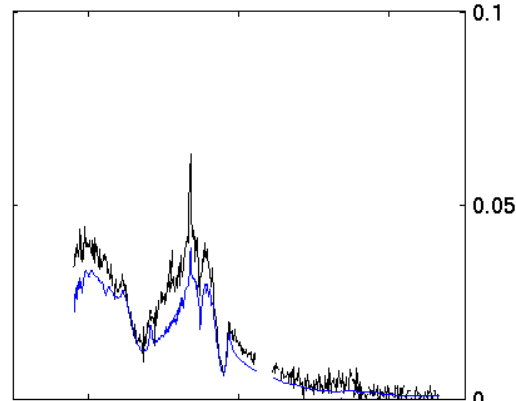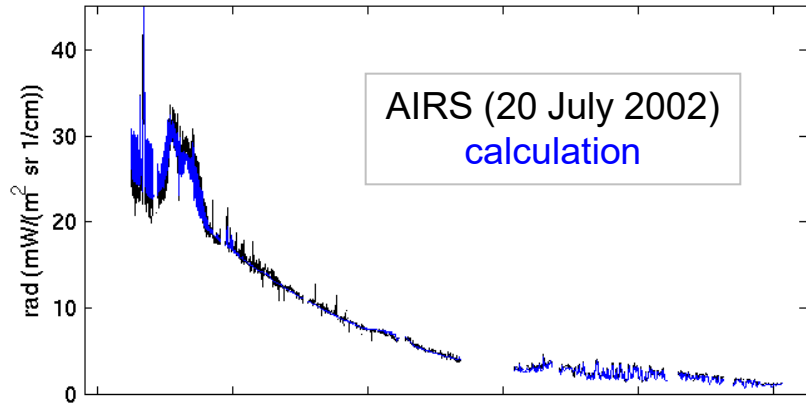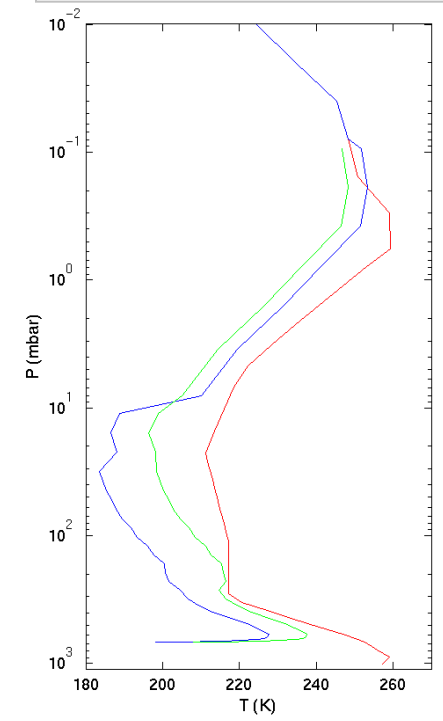# AIRS: High Spectral Resolution, Global!

From hot to cold

20-July-2002 Ascending LW Window
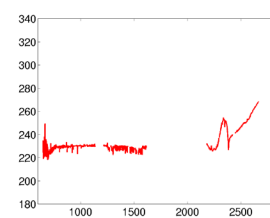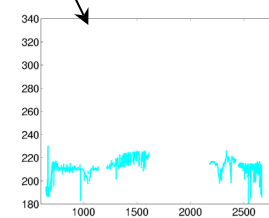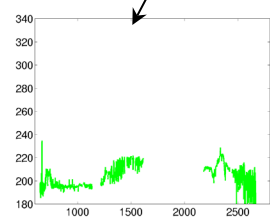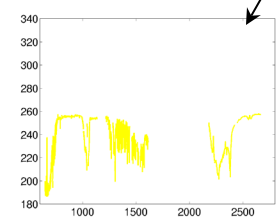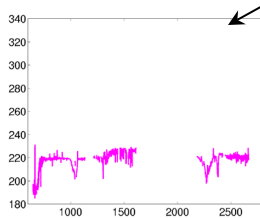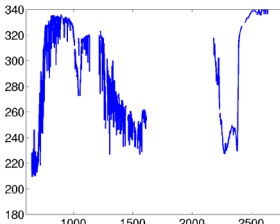
To Coldest …
Dome Concordia 20 July 2002
Obs-Calc

AIRS (20 July 2002)
calculation

AIRS (K)
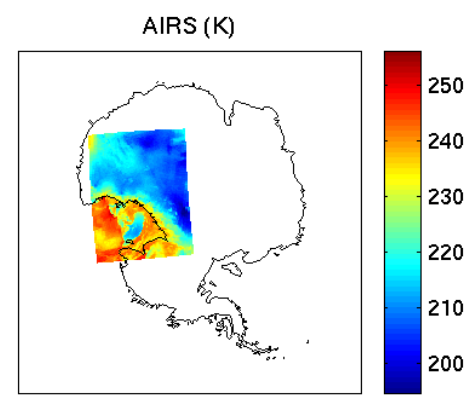
Sub-Arctic Winter
May 2001 S. Pole radiosonde
profile used in calculation
(0.365 mm H_2O)

Combining AIRS and MODIS
for cloud mask

Not Determined	Cloudy	Uncertain	Probably Clear	Confident Clear

$$\frac{\text{\# cloudy}}{\text{\# total}} = 1$$

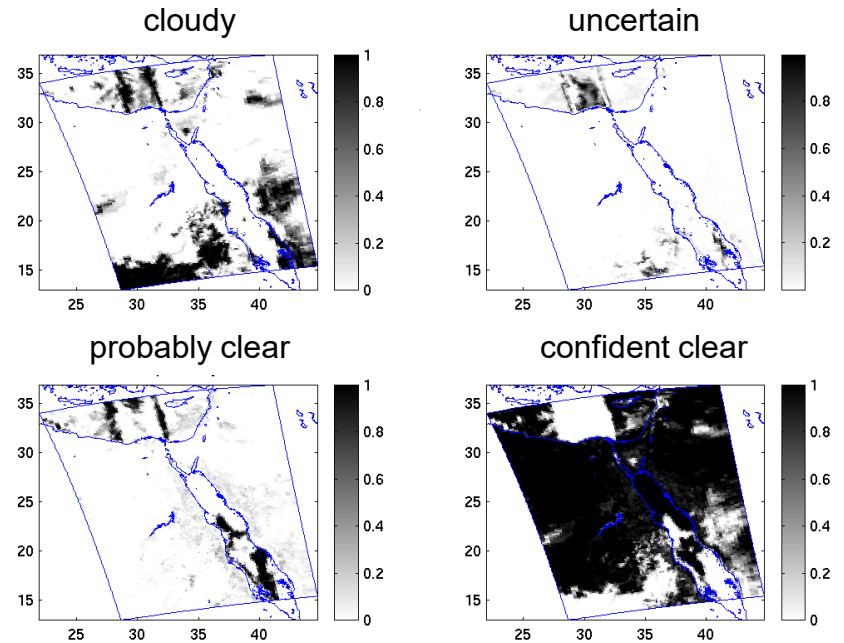$$\frac{\text{\# confident clear}}{\text{\# total}} = 1$$
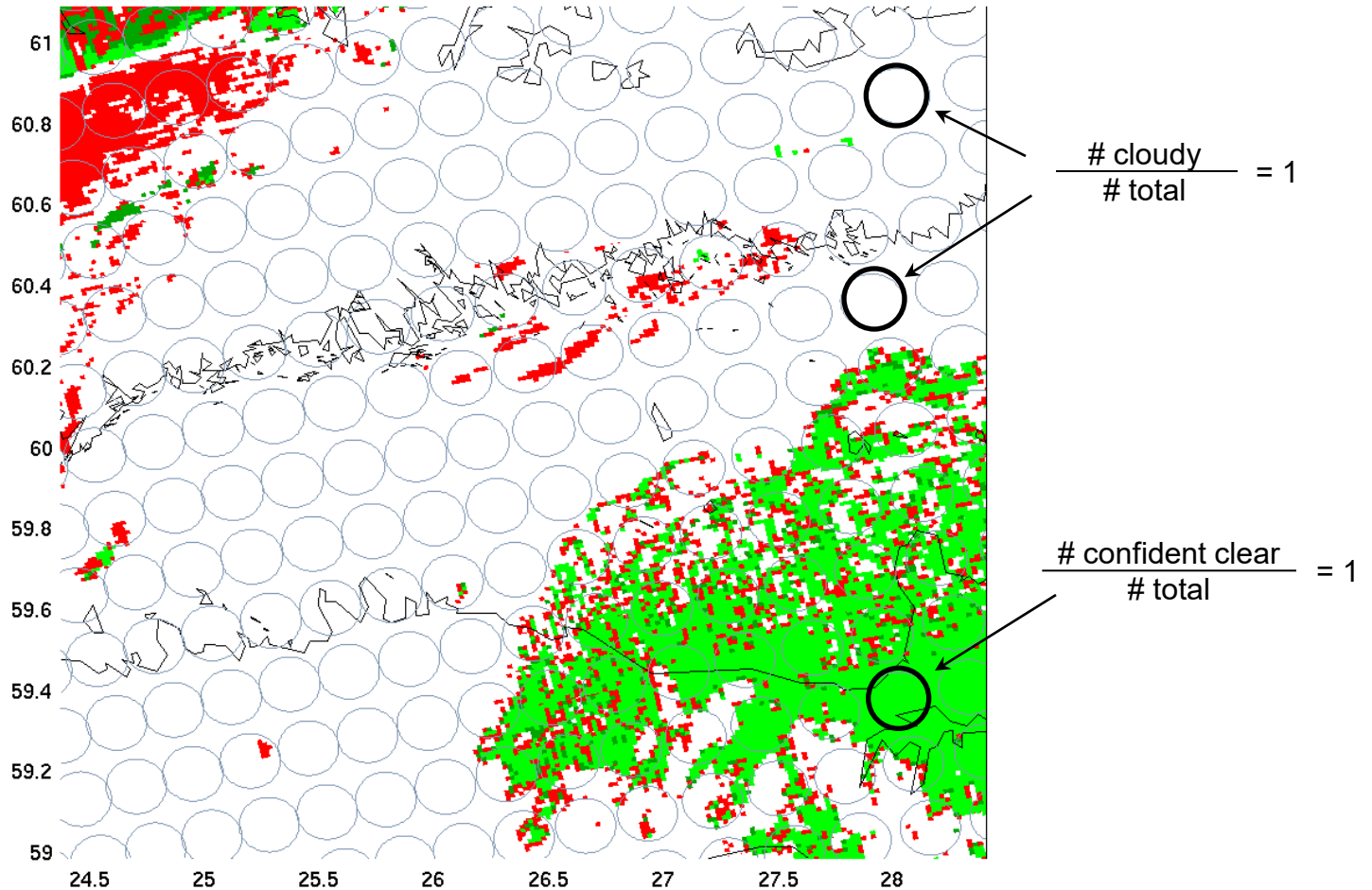
AIRS clear flag from MODIS cloud mask

MODIS cloud mask 20-July-2002

AIRS.2002.07.20.110.L1B.AIRS_Rad.v2.5.0.1.A02202051716
MYD35_L2.A2002201.1105.003.2002204063426.hdf

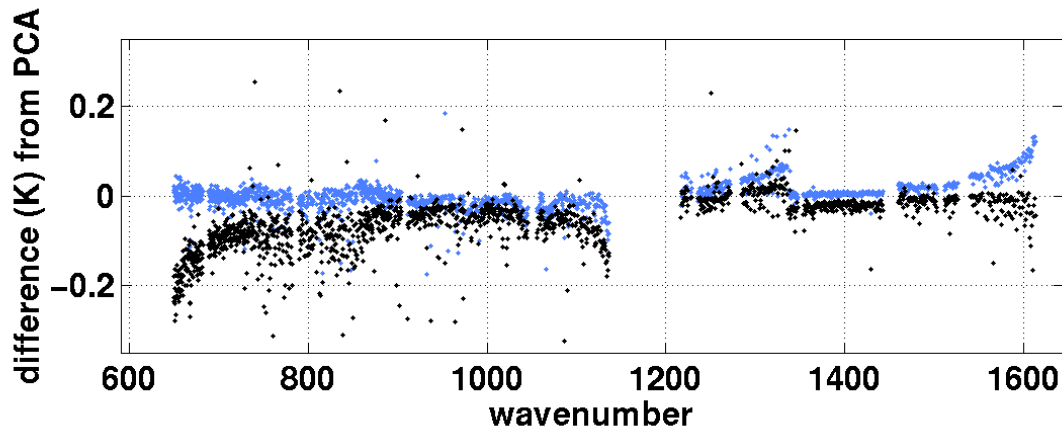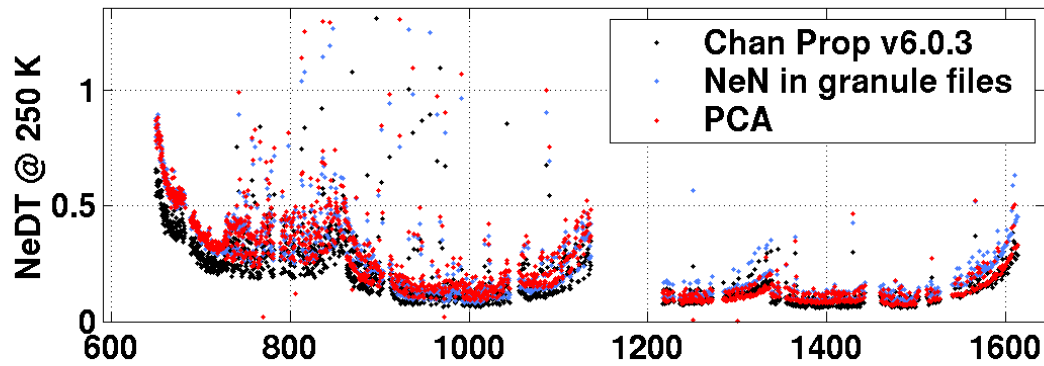| Not Determined | Cloudy | Uncertain | Probably Clear | Confident Clear |

cMODIS fractions

cloudy

uncertain

probably clear
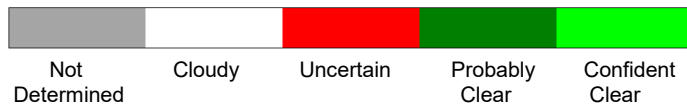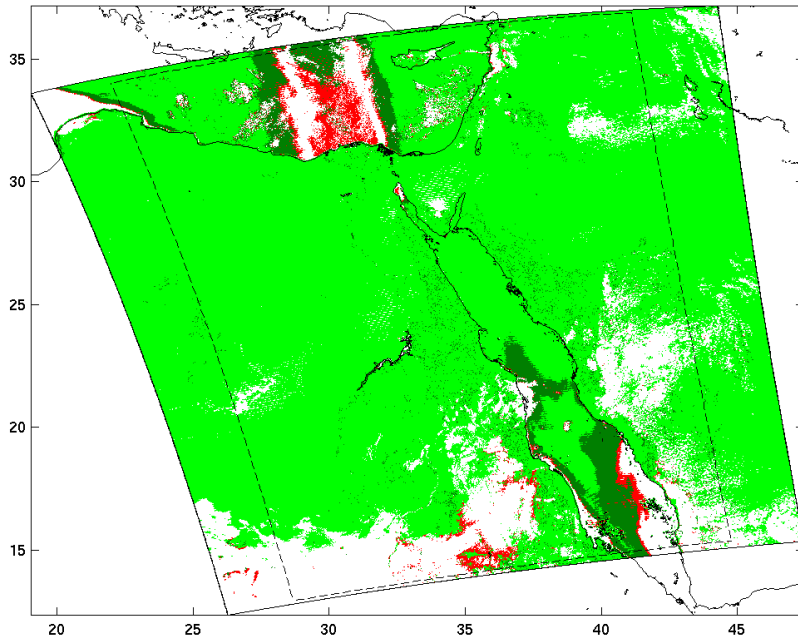
confident clear

AIRS cloud flag. All confident clear

clear

not clear
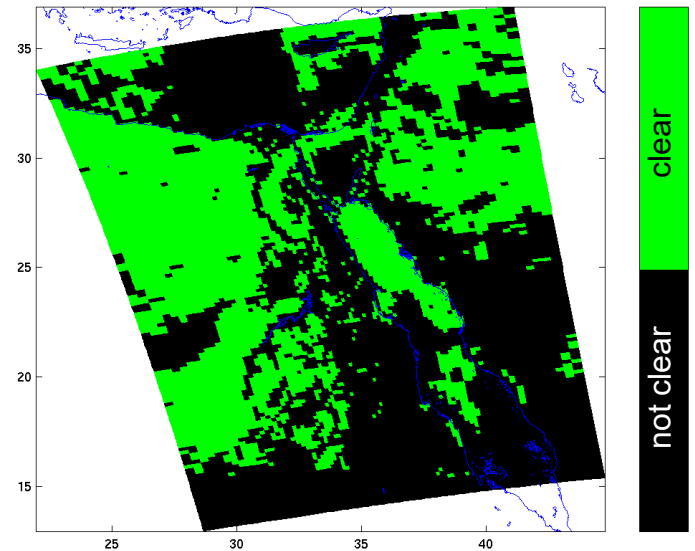
Noise Characterization using PNF
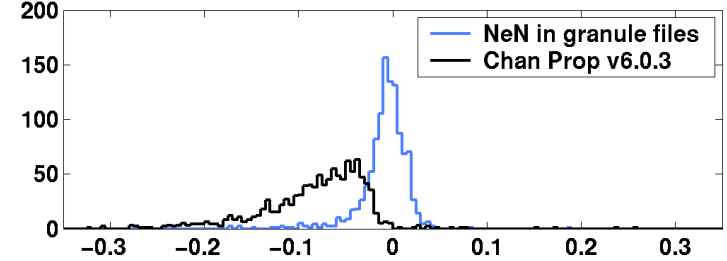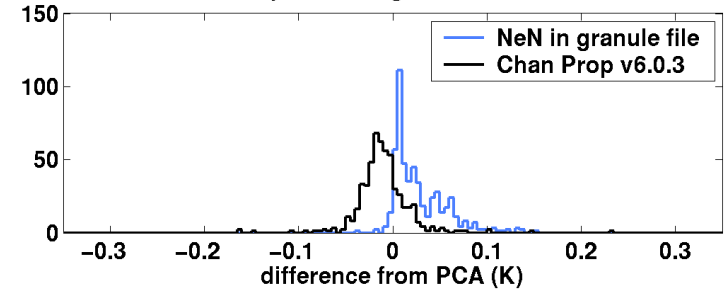
AIRS: Popping Noise
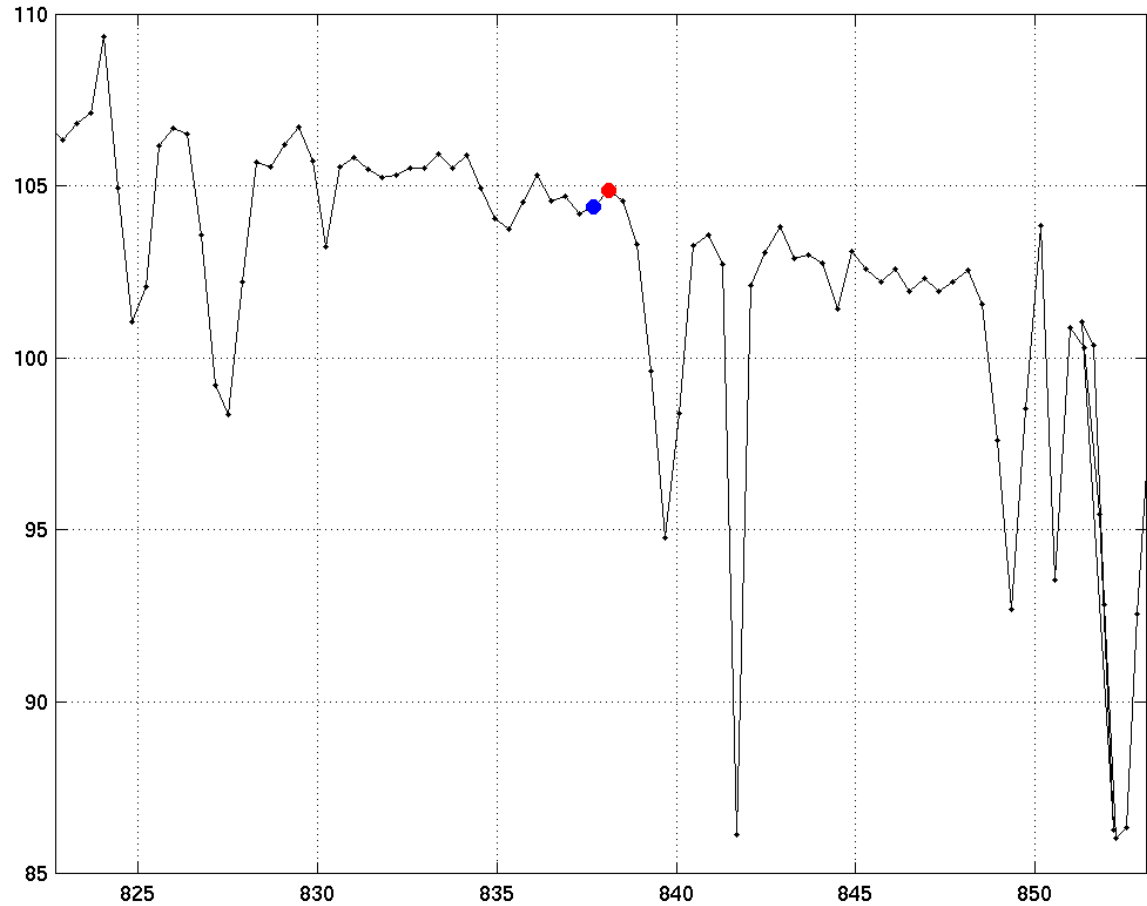
Granule 016
channels 572, 573
AB_State = [0,0], Rad_Qual = [0,0],
Bad_Flag = [0,0]

AIRS: PCA Noise Filter

Original

Filtered

AIRS.2002.07.20.016.L1B.AIRS_Rad.v2.5.0.1.A02202044234
L2.l.channel_prop.v6.0.0.anc
channel 573 minus channel 572
838.1 1/cm – 837.704 1/cm (K)

AIRS.2002.07.20.016.L1B.AIRS_Rad.v2.5.0.1.A02202044234
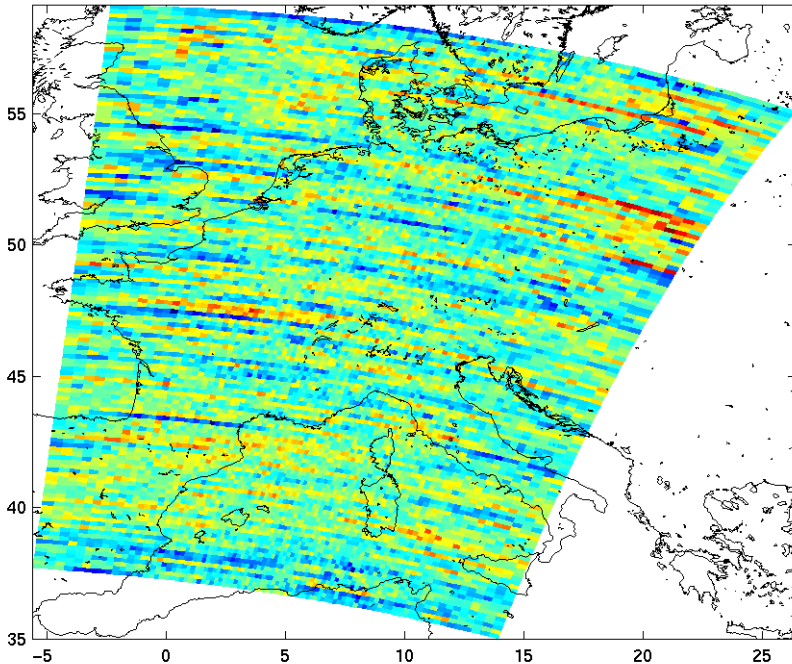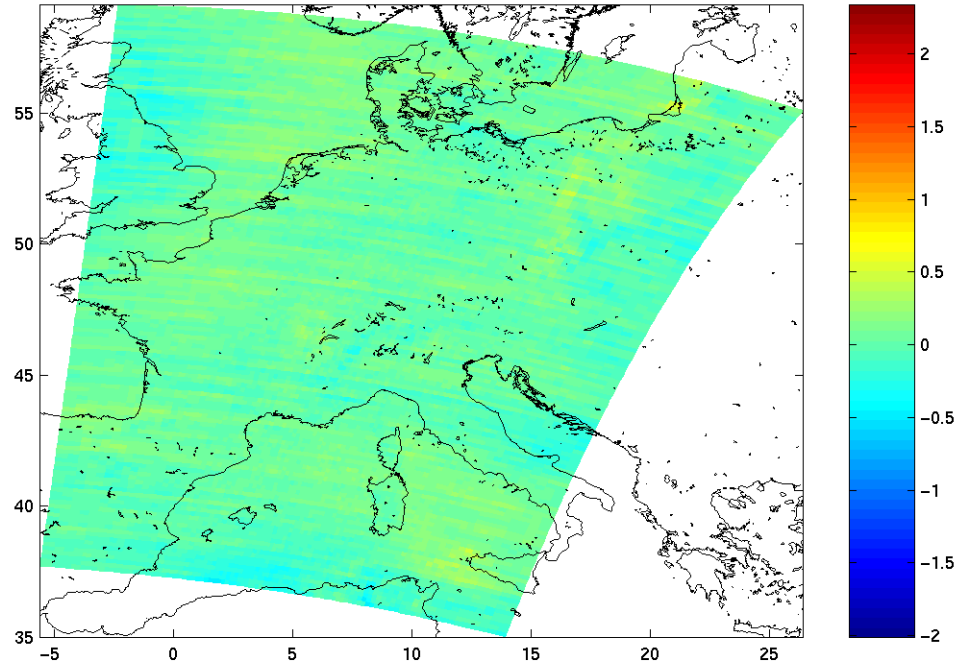L2.l.channel_prop.v6.0.0.anc
channel 573 minus channel 572
838.1 1/cm – 837.704 1/cm (K)

Channel 573 - Channel 572 Brightness Temperature Differences

Main Challenges of High Spectral Resolution

- Data volume
  - data transmission
  - data storage
  - data processing (calibration, inversion)

Data Volume

- The increased volume of data transmitted from the satellite to the ground, if not properly processed, will:

  - exceed the capacity of the current operational downlink technology

  - require expensive data systems to process the data on the ground

Data Volume: Transmission Rate