

**Investigations with
High Spectral Resolution Data
from AIRS**

Lectures in Krakow
May 2006

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NOAA/NESDIS/ORA



Investigations with High Spectral Resolution Data from AIRS

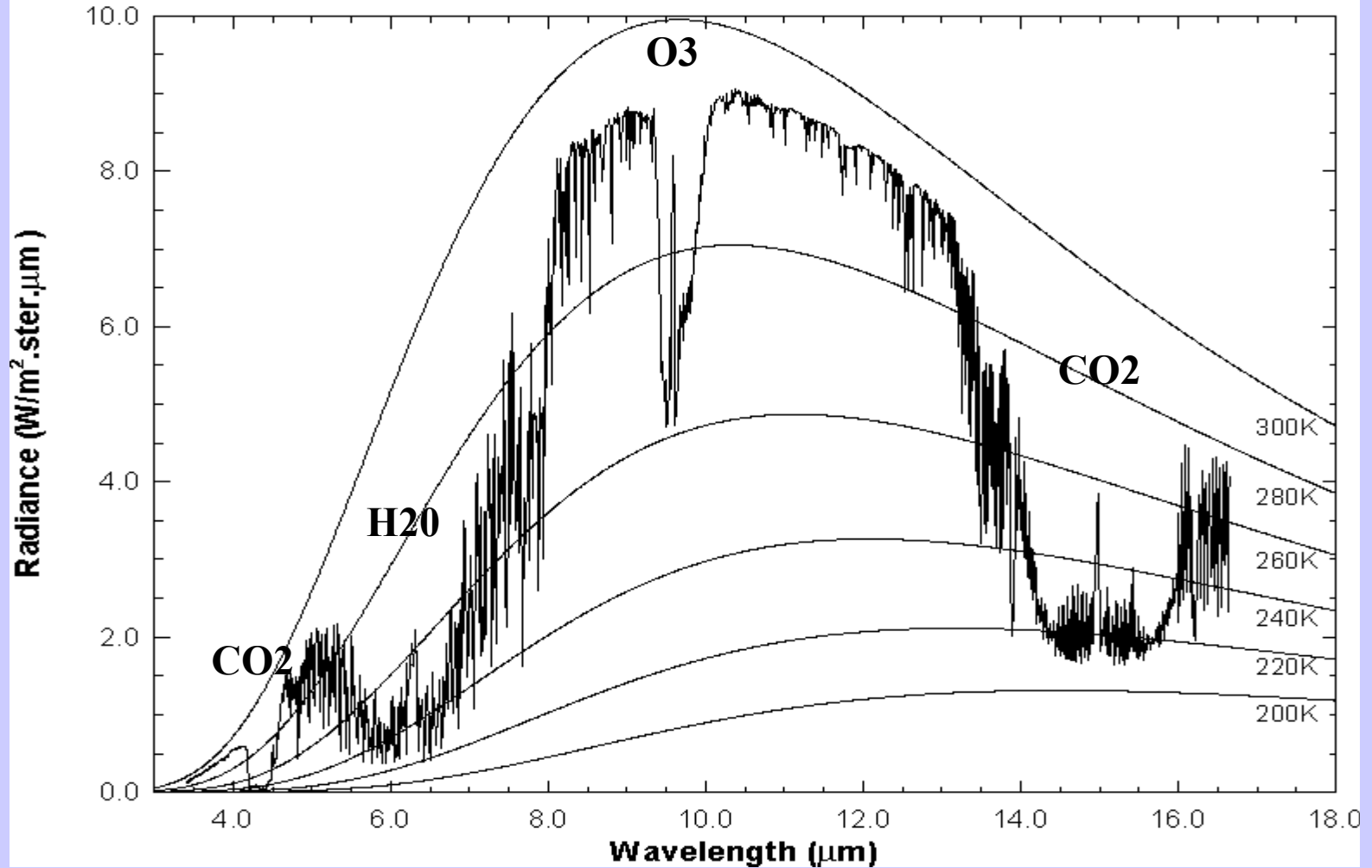
Paul Menzel
NOAA/NESDIS

in collaboration with
Tim Schmit, Jun Li, Yuri Plokhenko,
Dave Tobin, Hank Revercomb
and colleagues at CIMSS

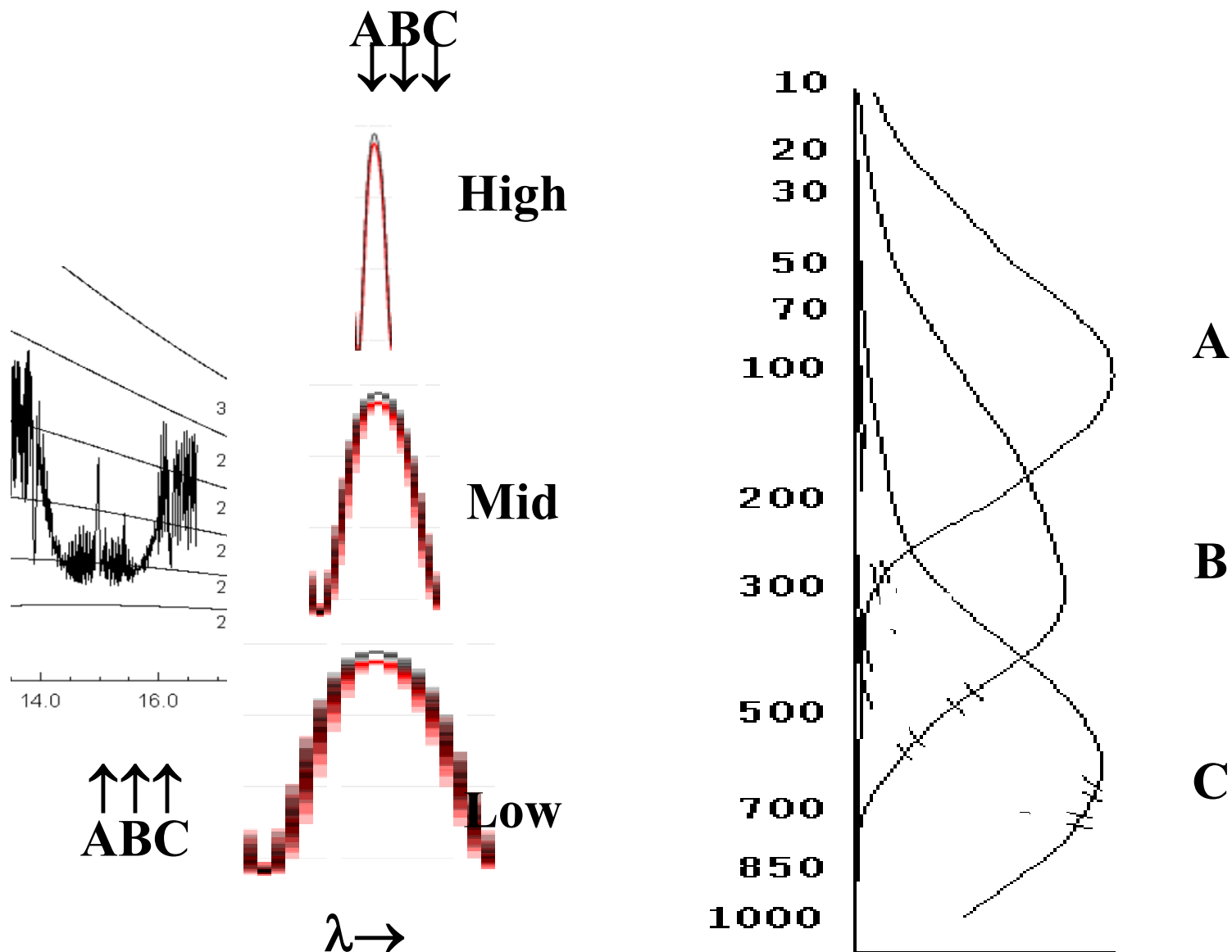


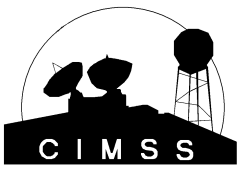
Earth emitted spectra overlaid on Planck function envelopes

High resolution atmospheric absorption spectrum and comparative blackbody curves.



line broadening with pressure helps to explain weighting functions

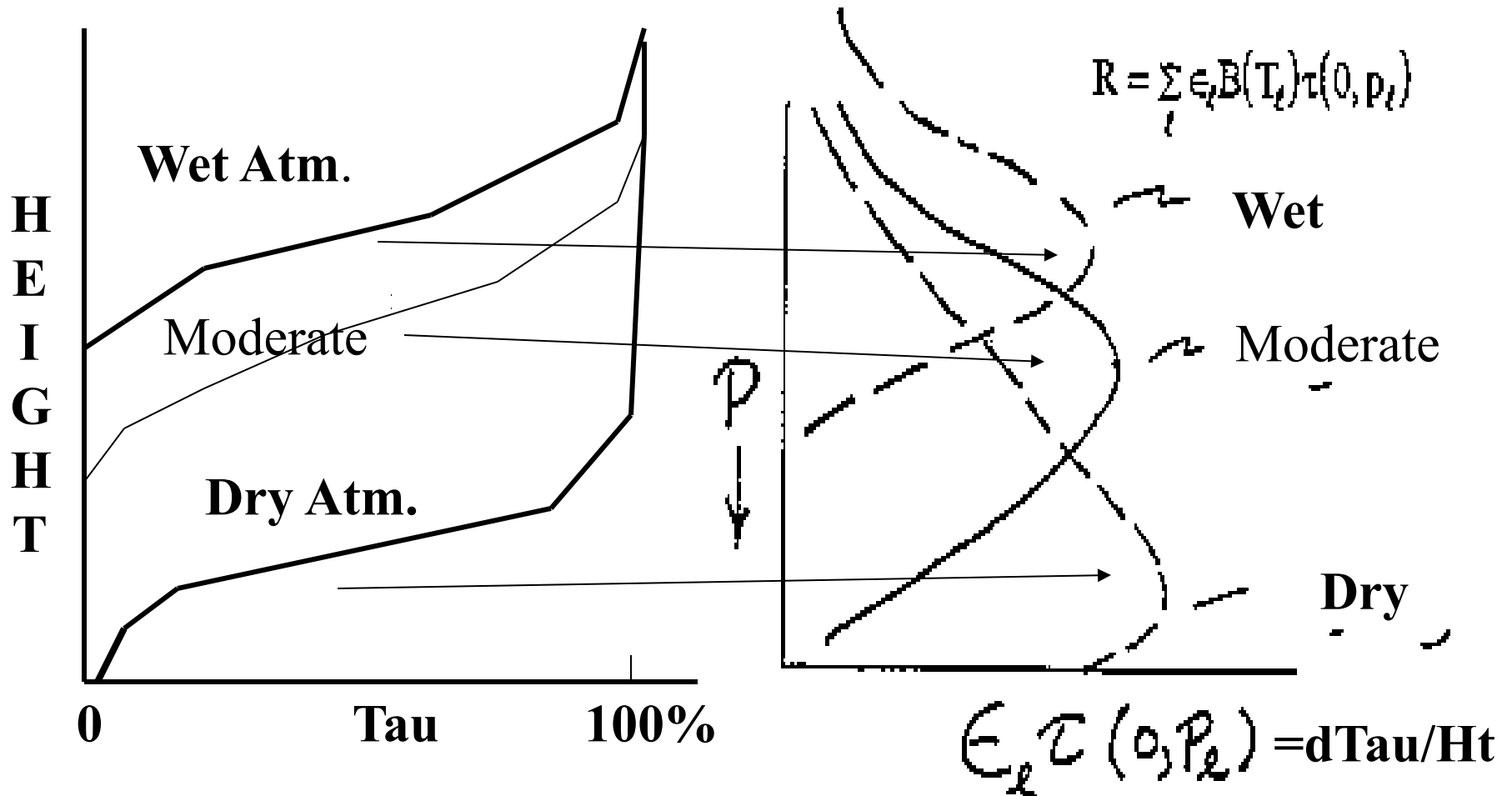


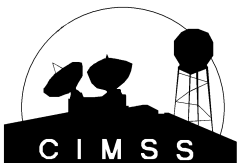


Fourier Transform Spectroscopy Infrared Atmospheric Sounding



For a given water vapor spectral channel

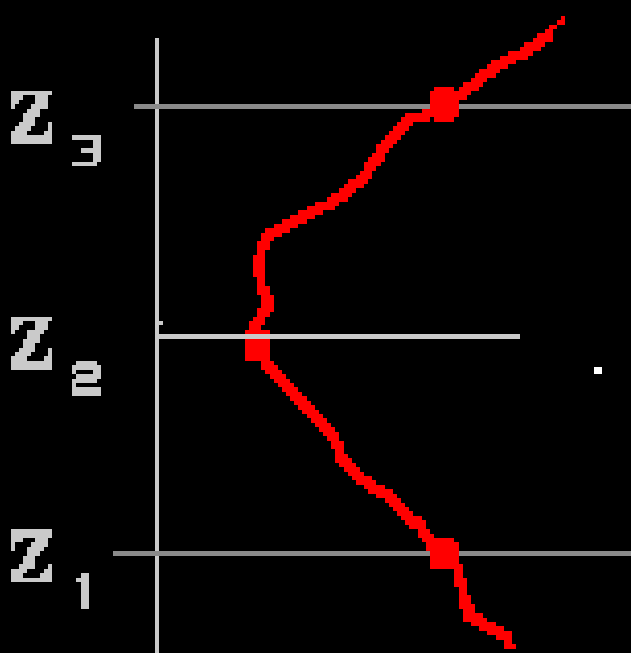




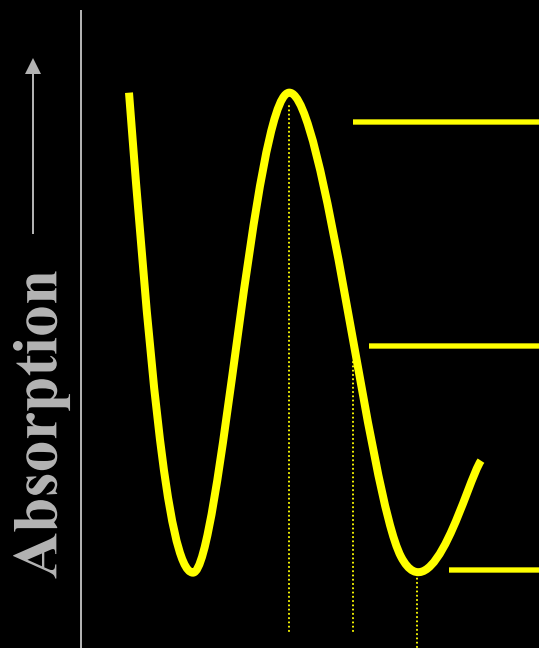
Fourier Transform Spectroscopy Infrared Atmospheric Sounding



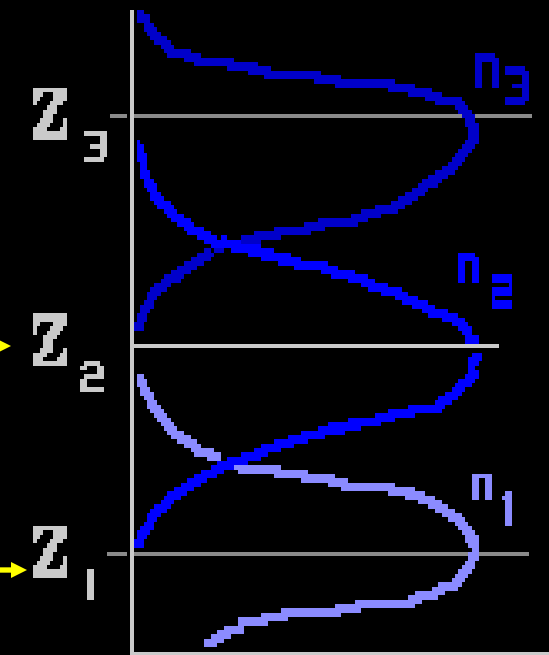
Wavelength Converts to Altitude



$T(z)$

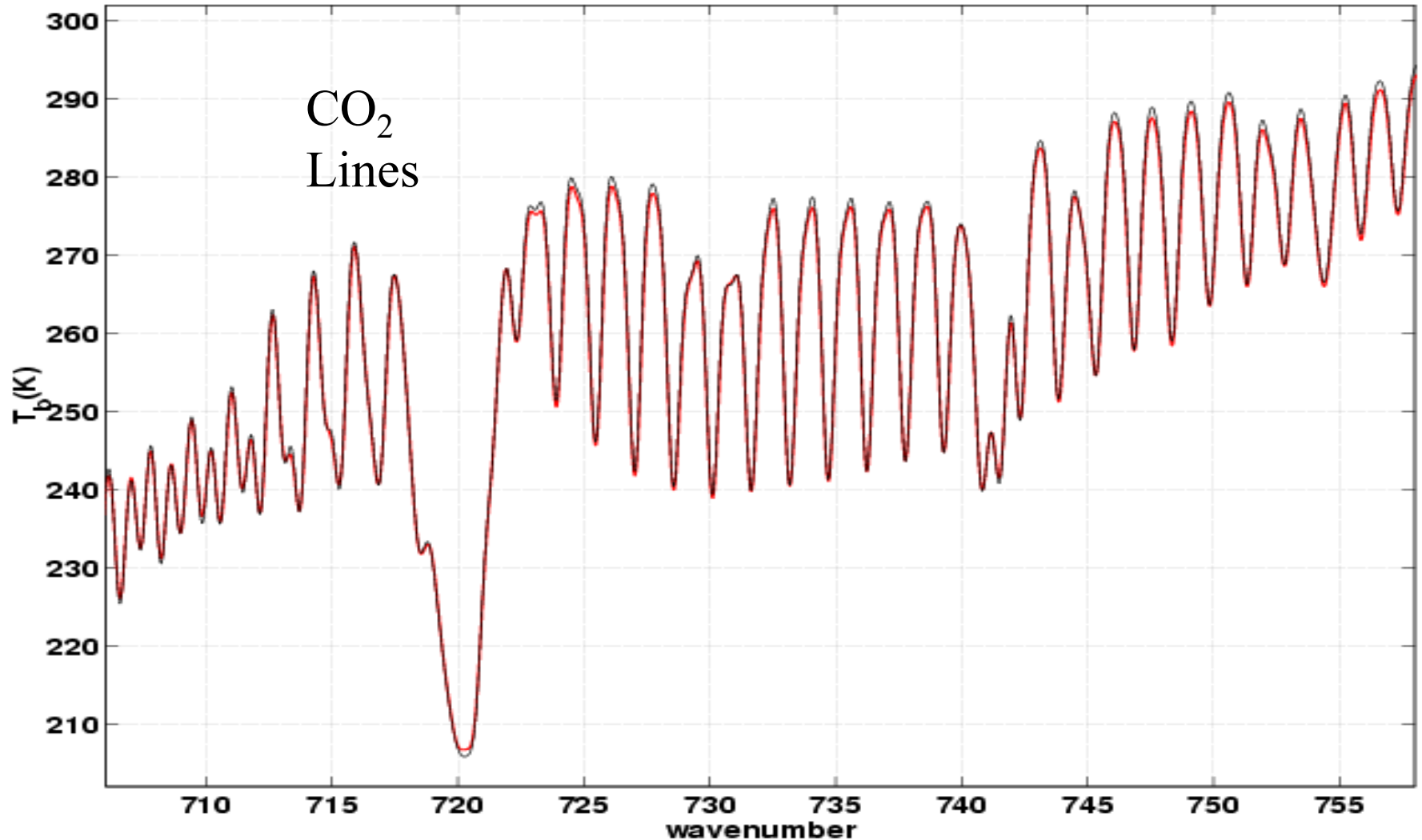


Wavelength

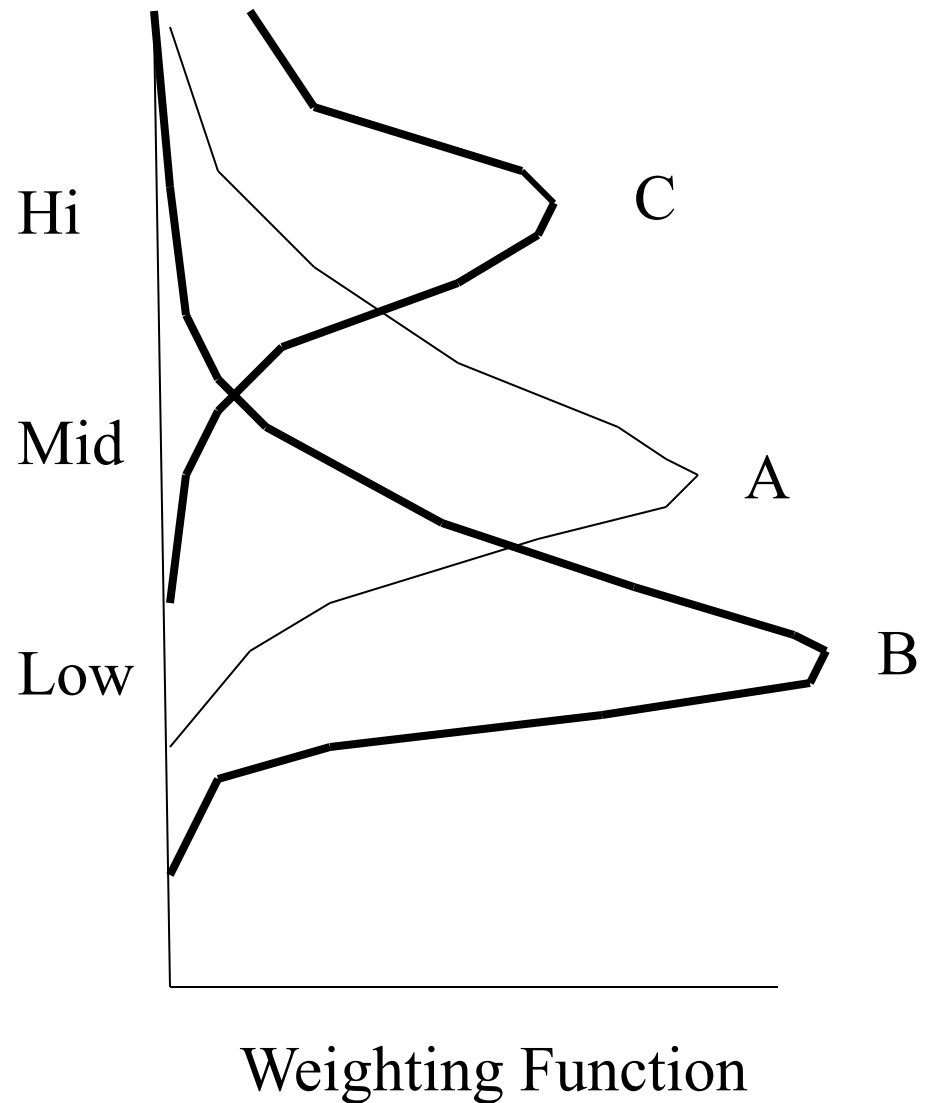
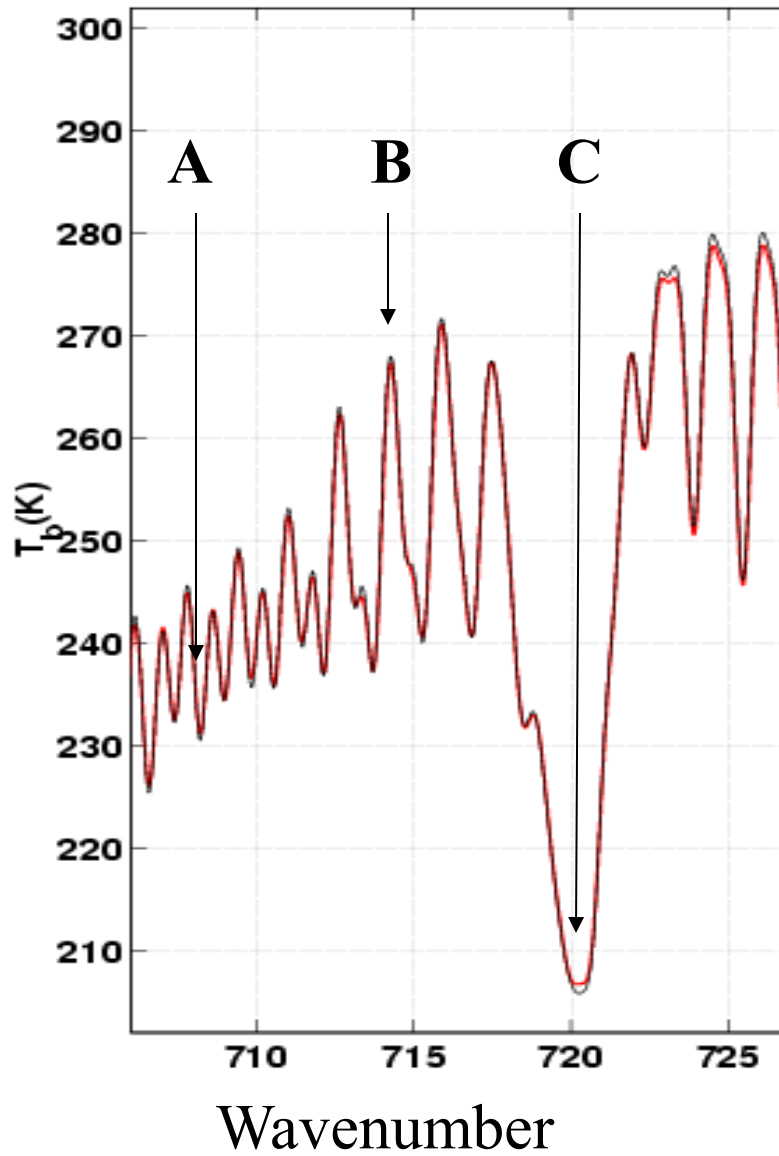


Energy Contribution

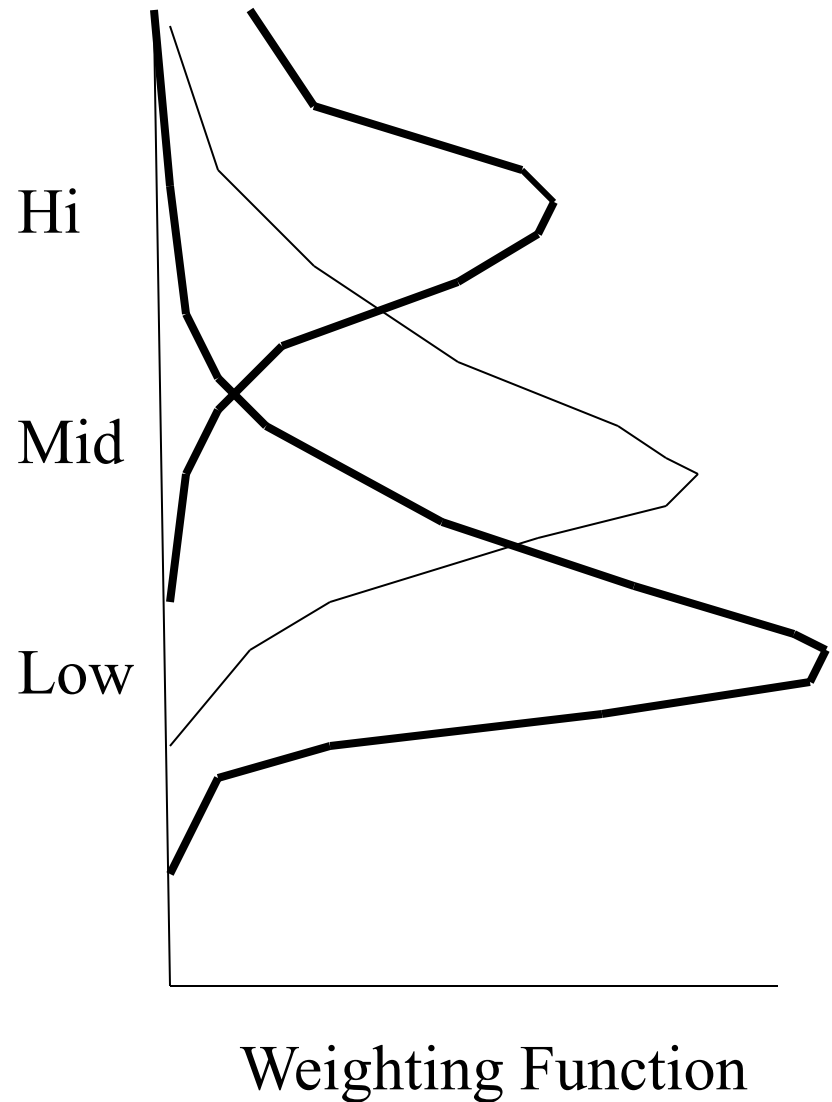
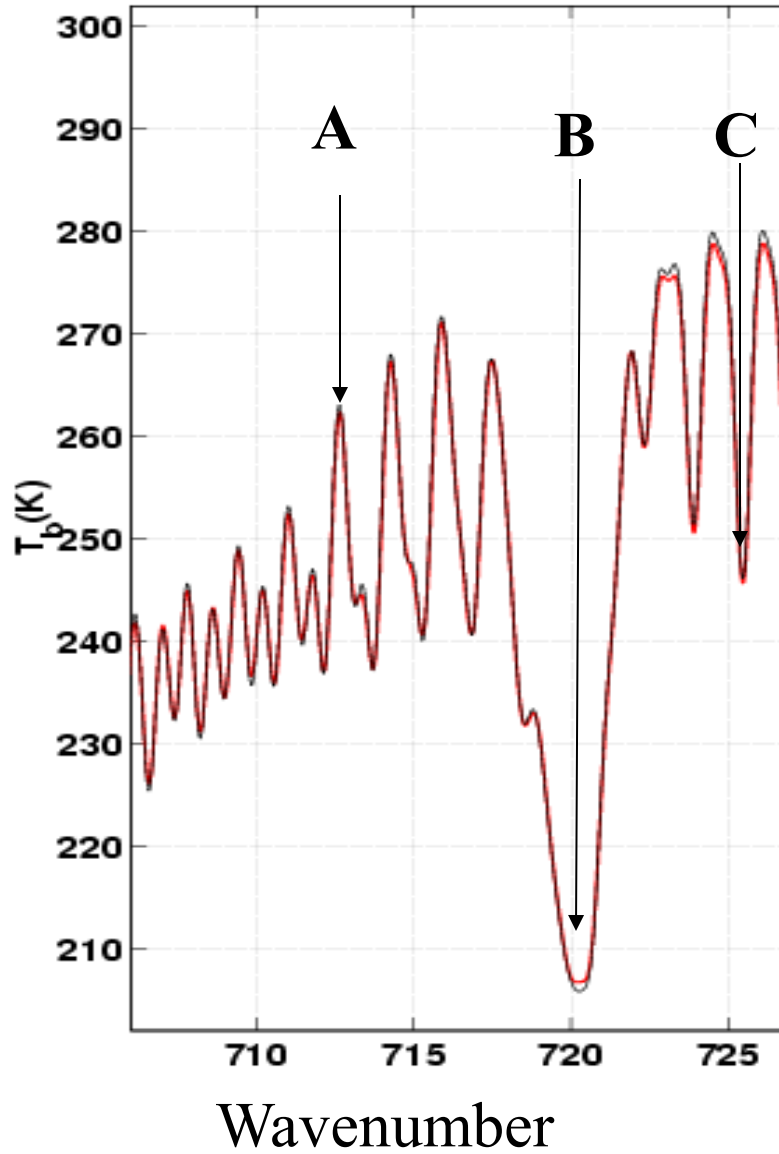
Earth emitted spectrum in CO₂ sensitive 705 to 760 cm⁻¹



Associating relative weighting functions with the CO₂ rotational bands



Associating relative weighting functions with the CO₂ rotational bands

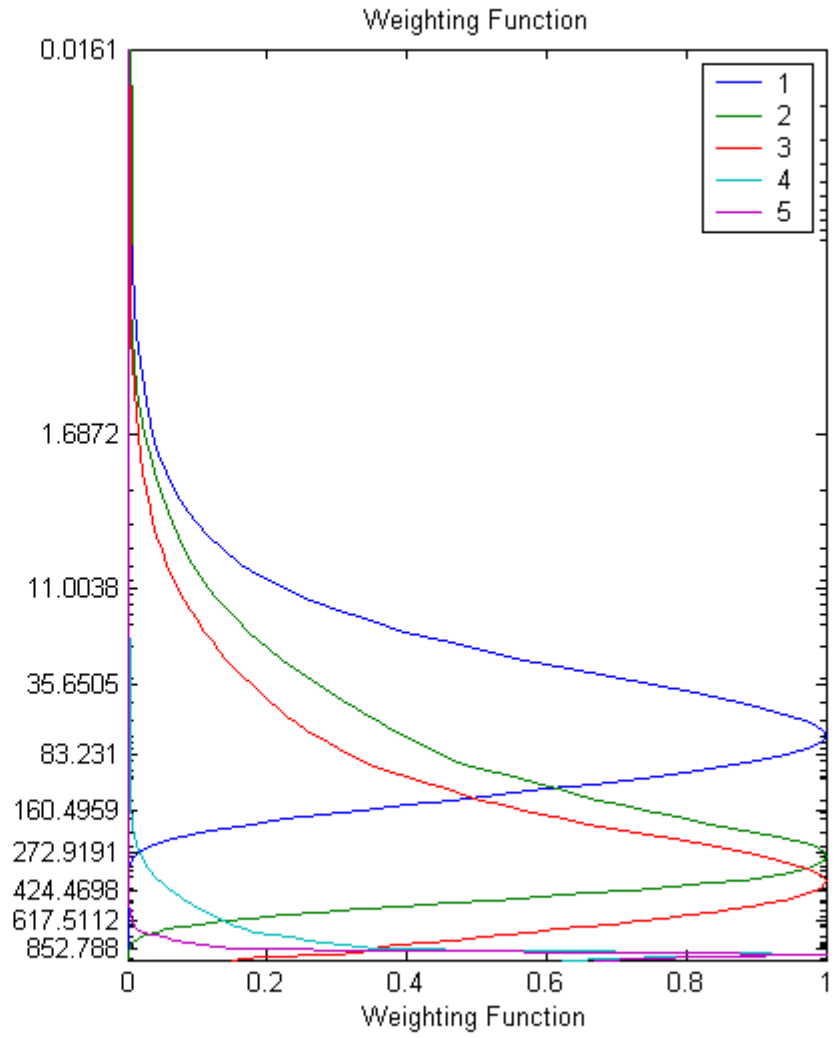
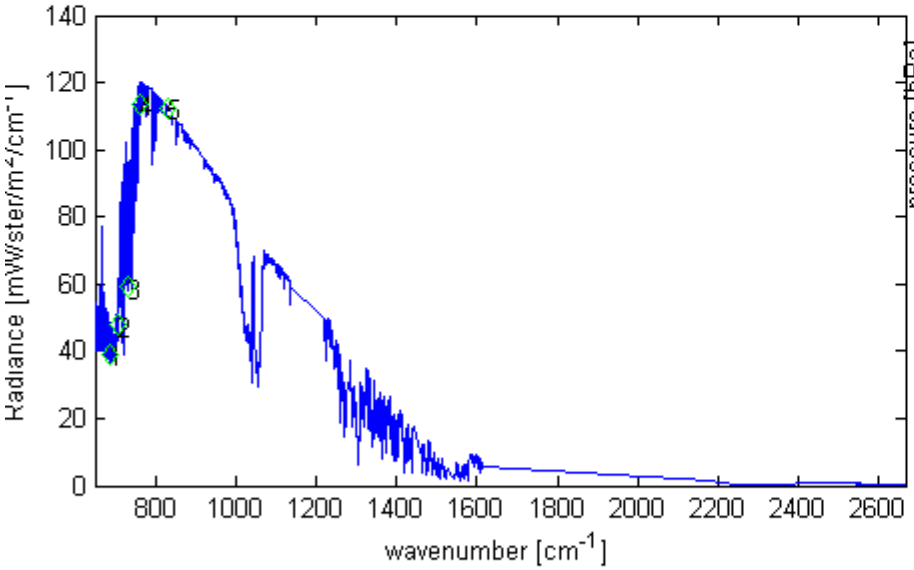


Select

5

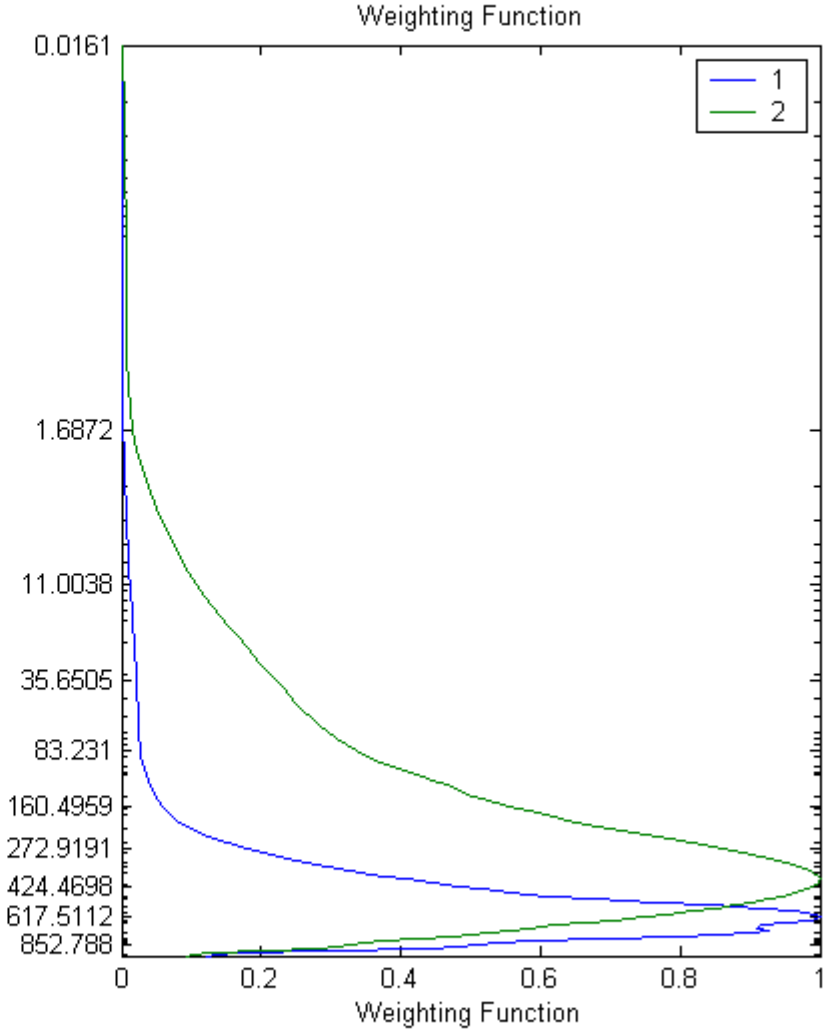
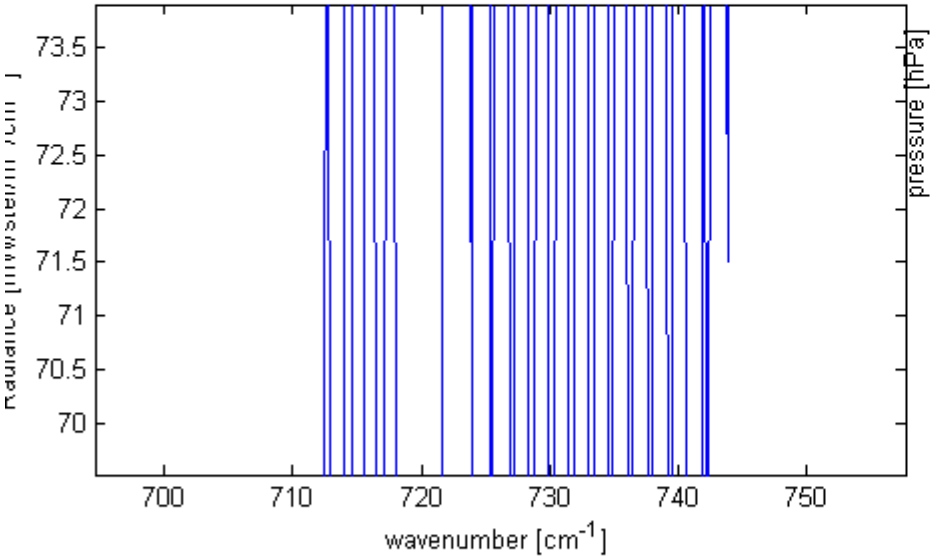
Selected Channel:

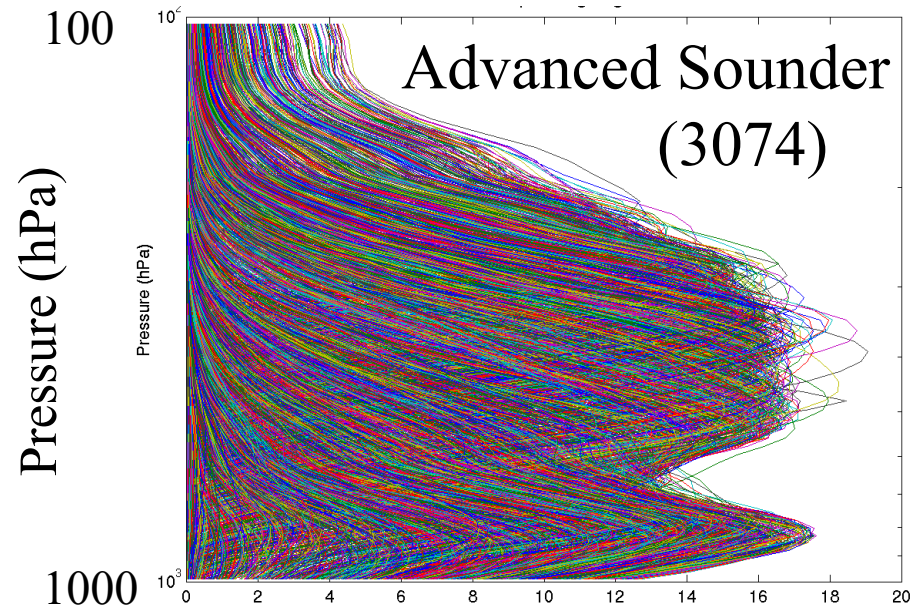
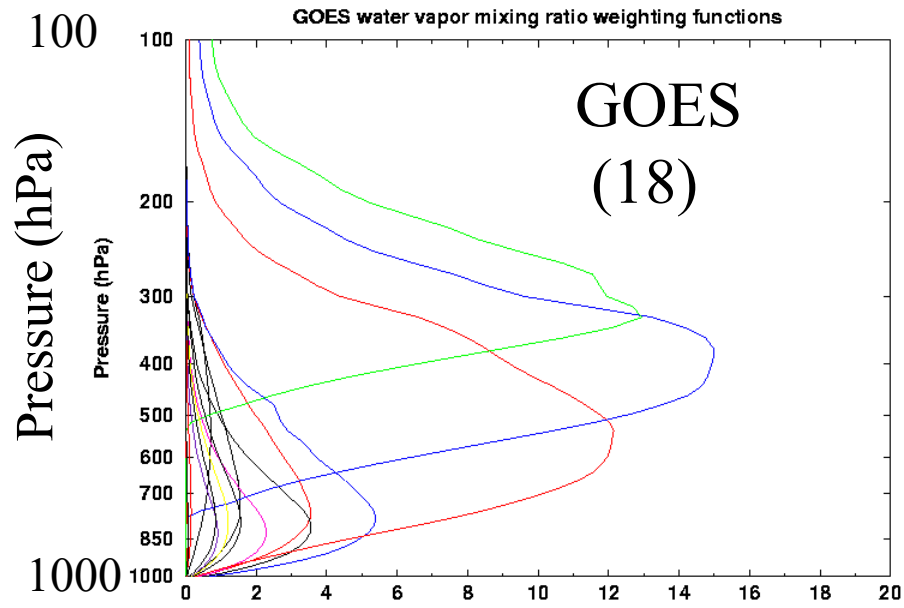
multi



On-line off-line at 735 cm-1

Select Selected Channel: multi





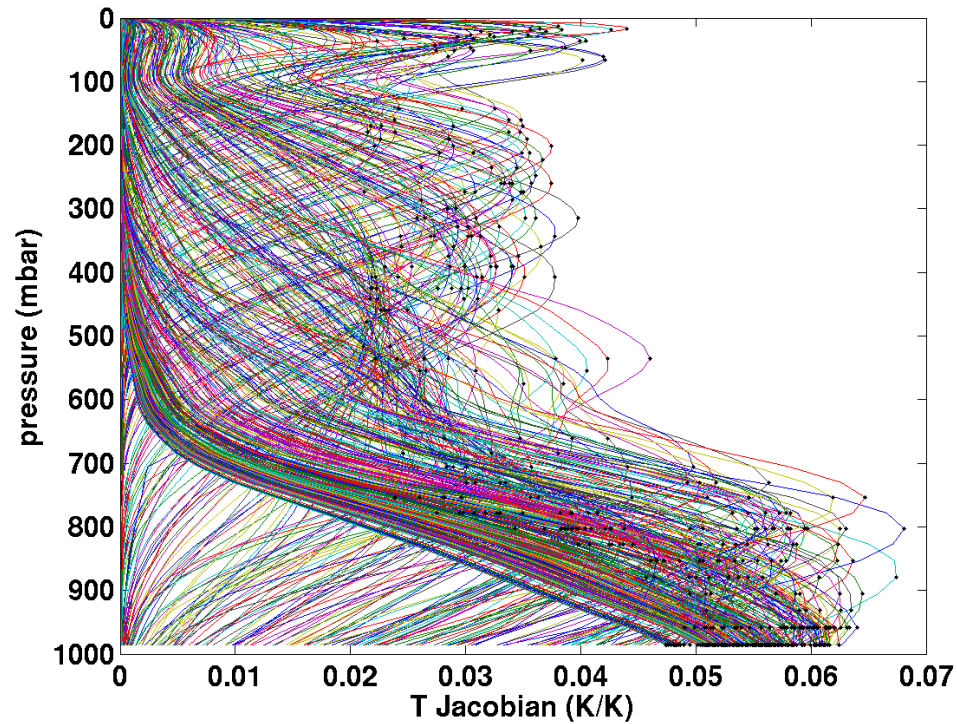
Moisture Weighting Functions

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

AIRS movie



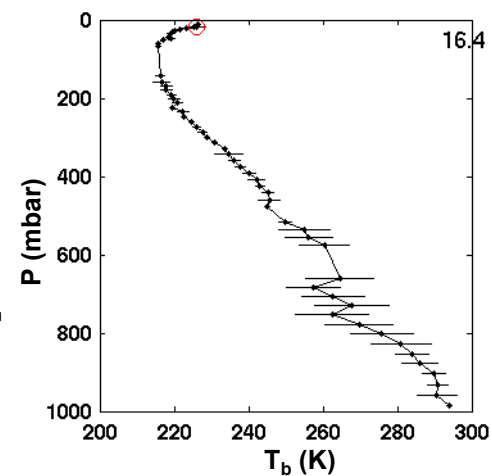
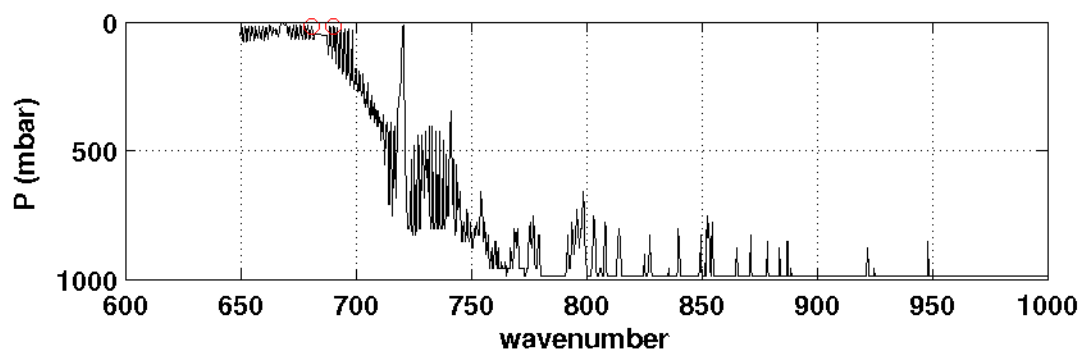
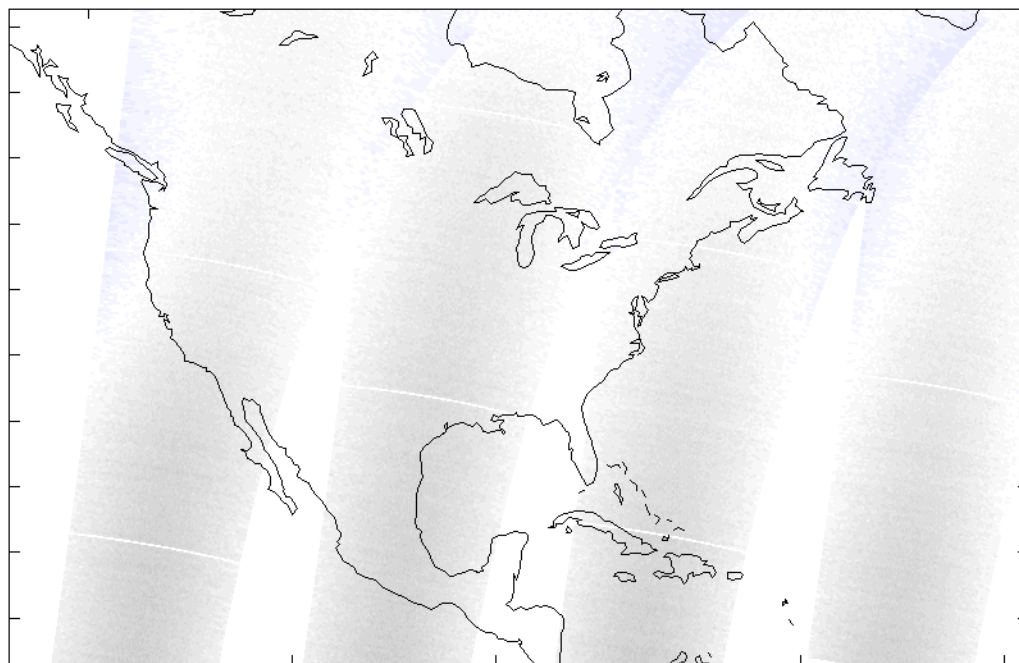
AIRS Clear Sky Temperature Jacobians for US Standard atmosphere, $680 \text{ cm}^{-1} < \nu < 900 \text{ cm}^{-1}$, Bad_Flag = 0



↙ Sort channels by pressure of Jacobian peaks

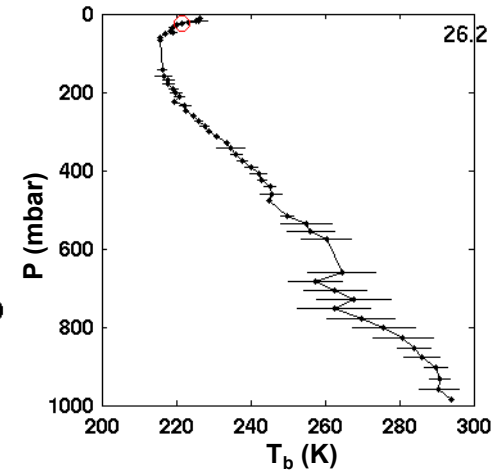
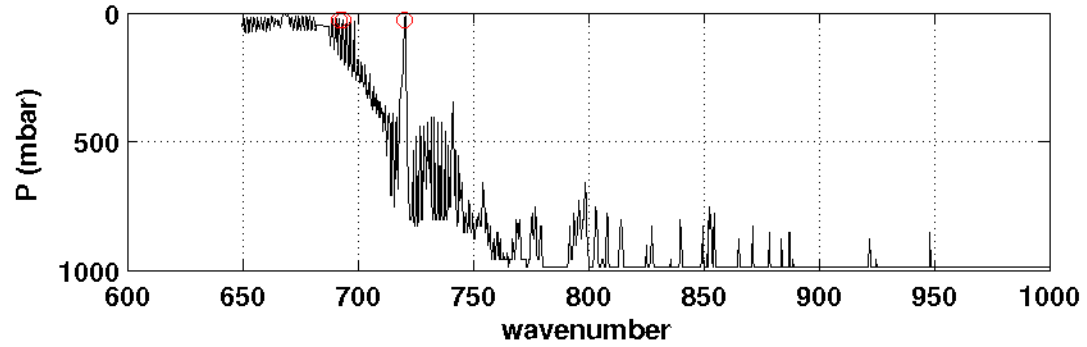
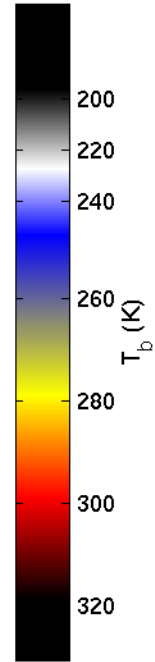
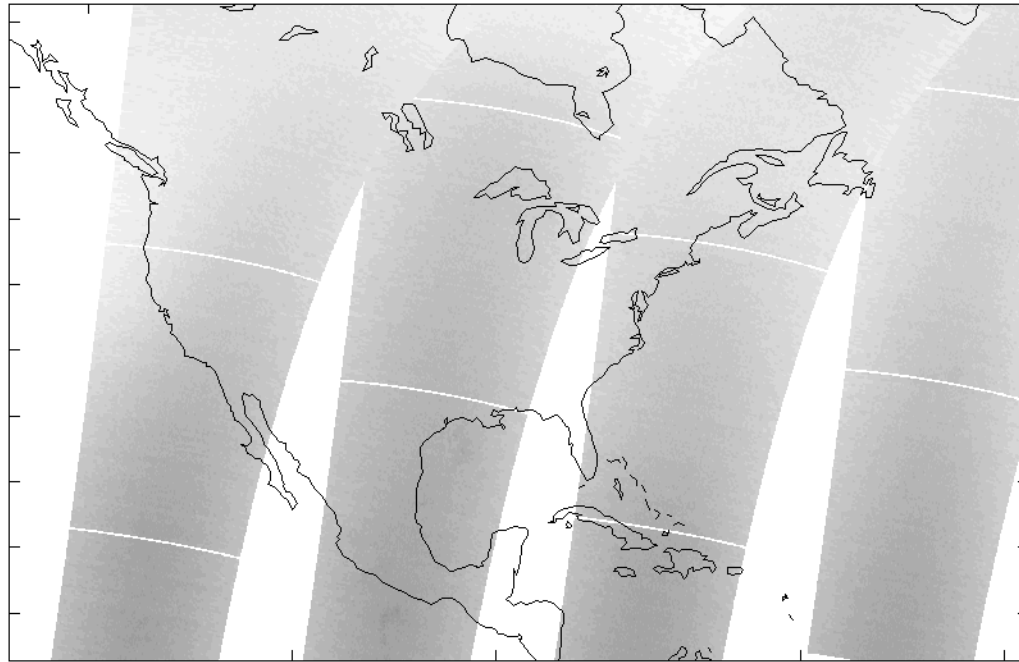
AIRS nighttime granules over CONUS, 6 Sept 2002

16.4 mbar

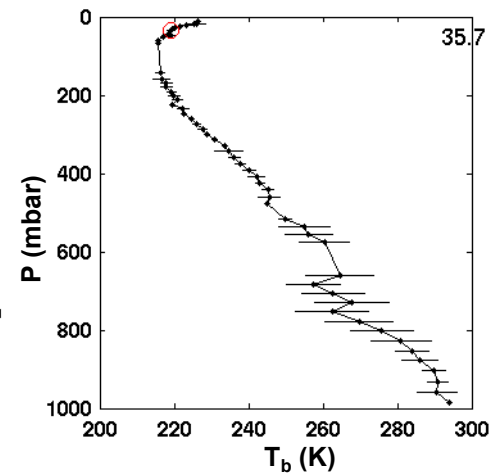
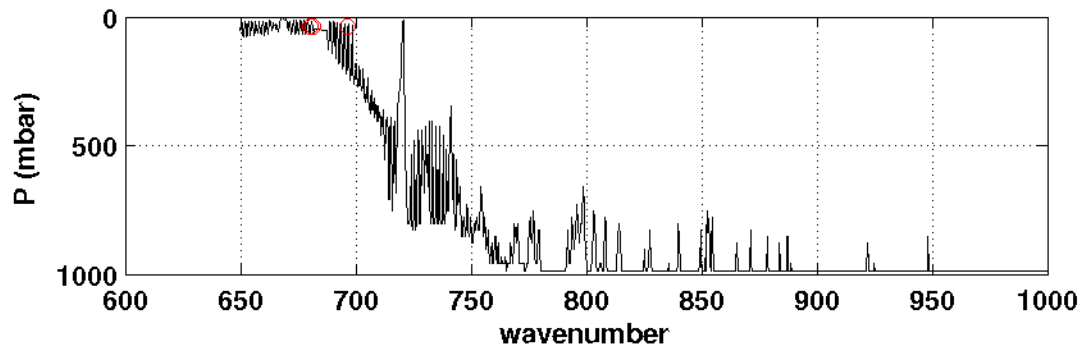
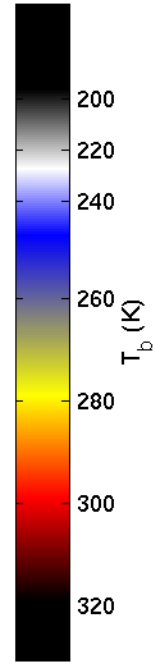
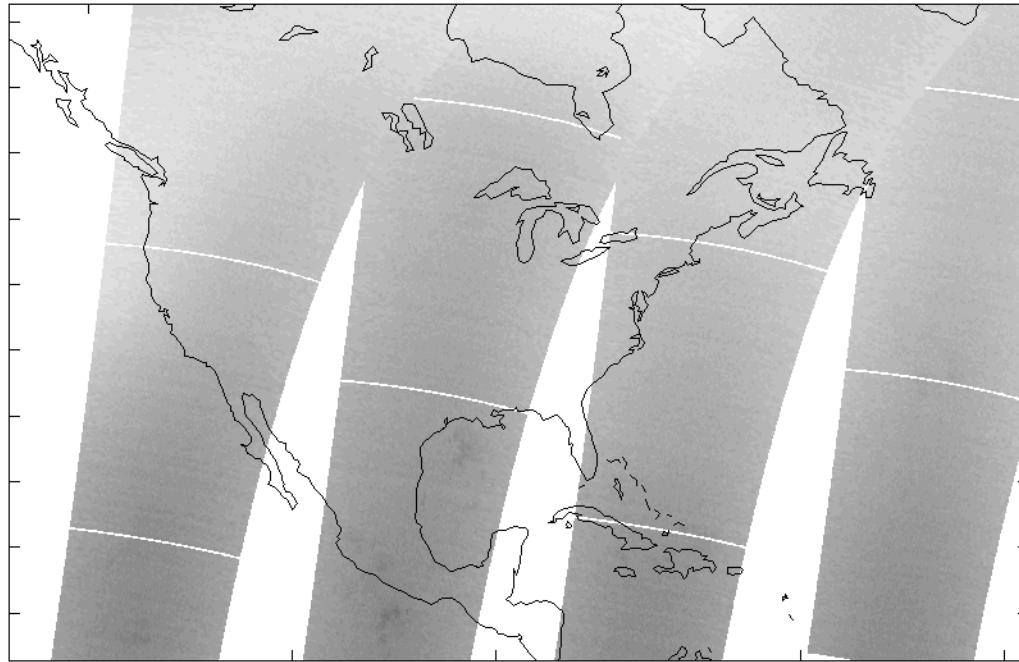


Mouse click or page down to start movie

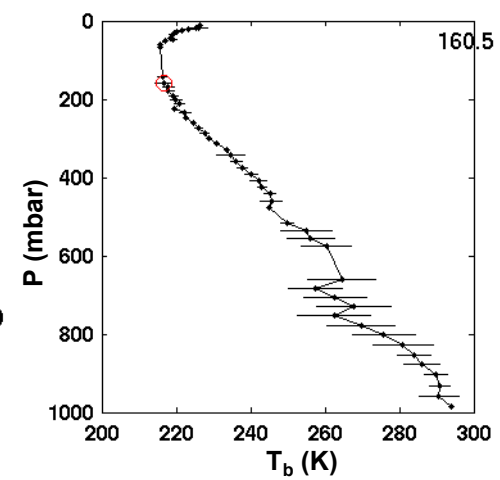
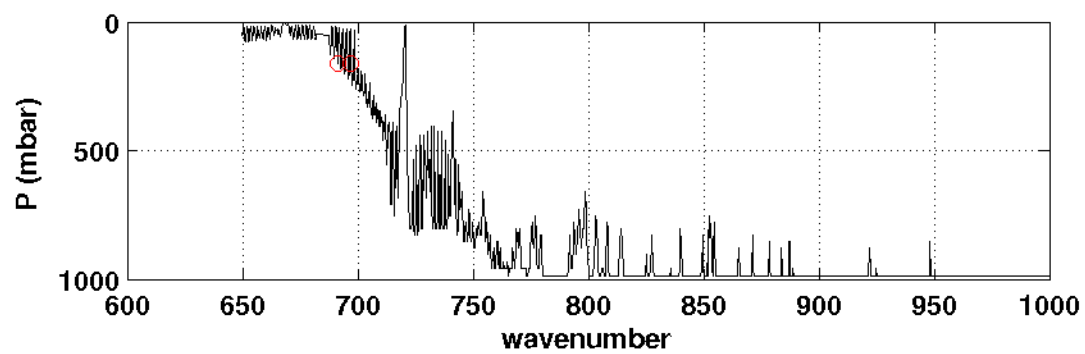
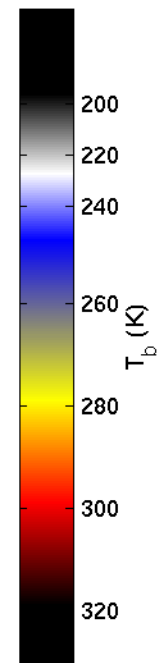
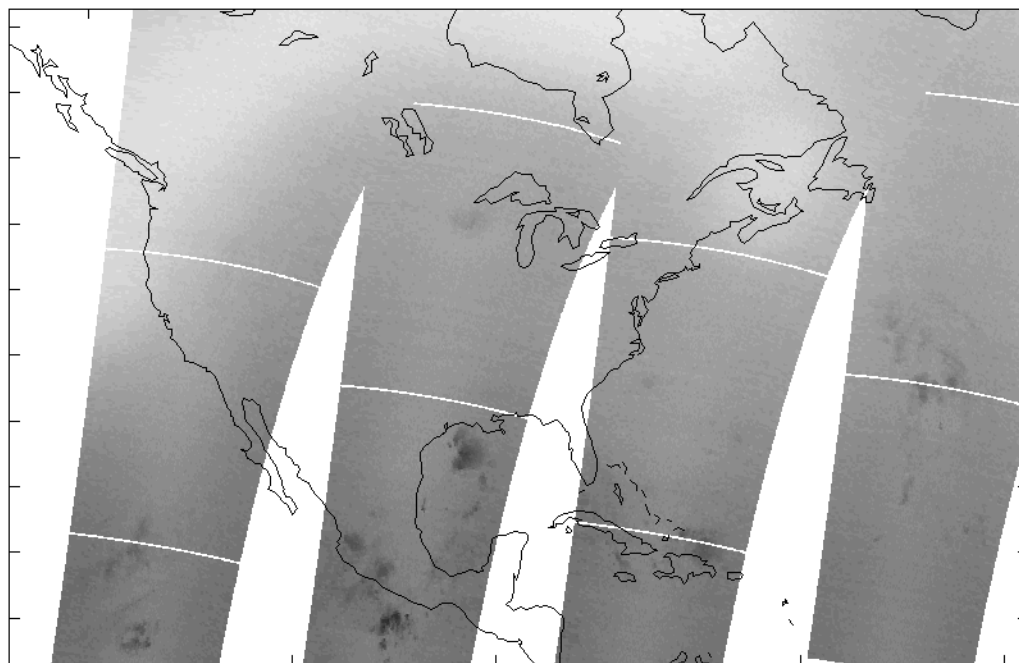
26.2 mbar



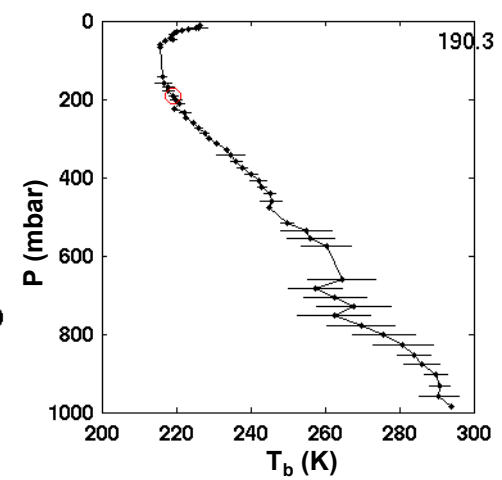
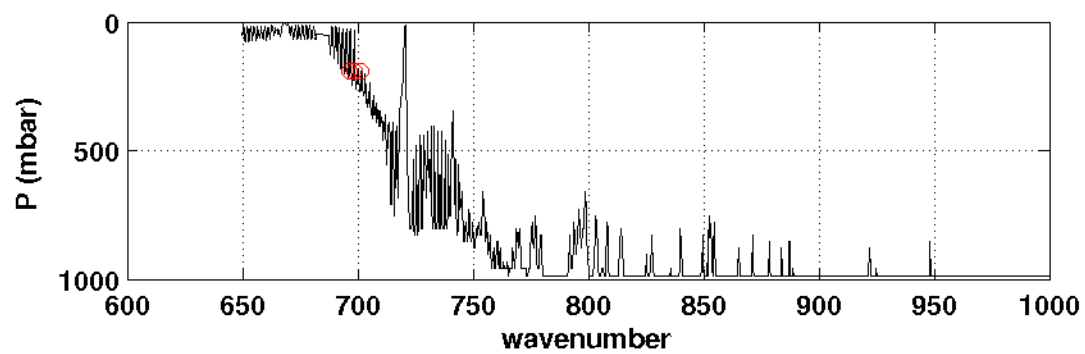
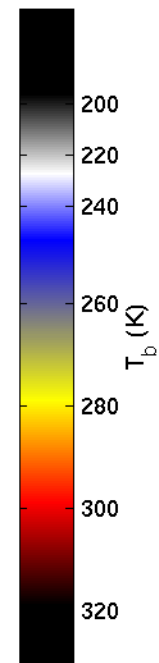
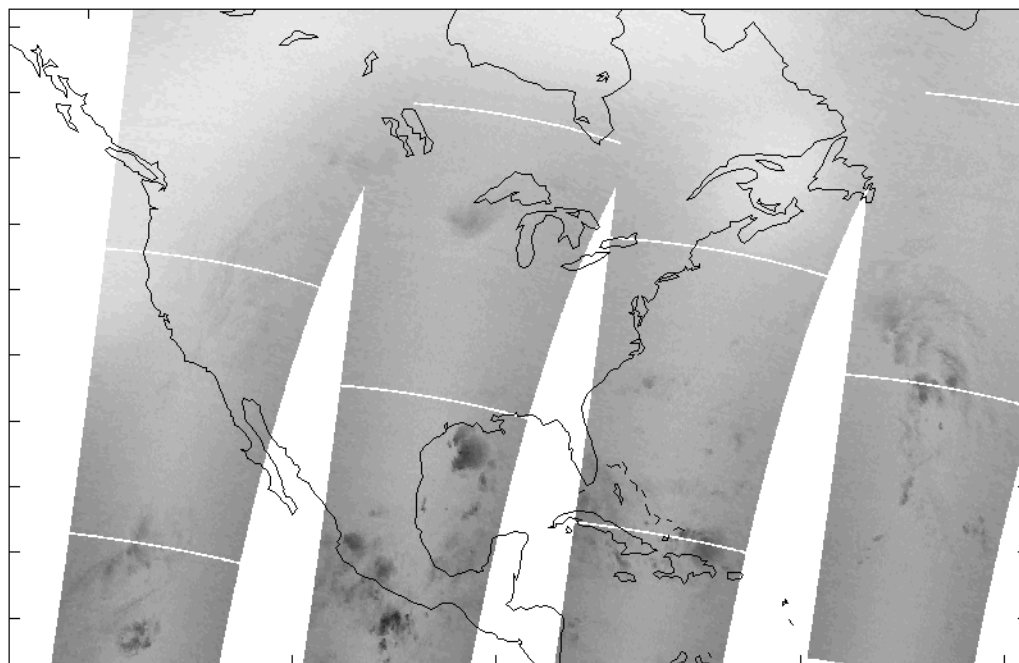
35.7 mbar



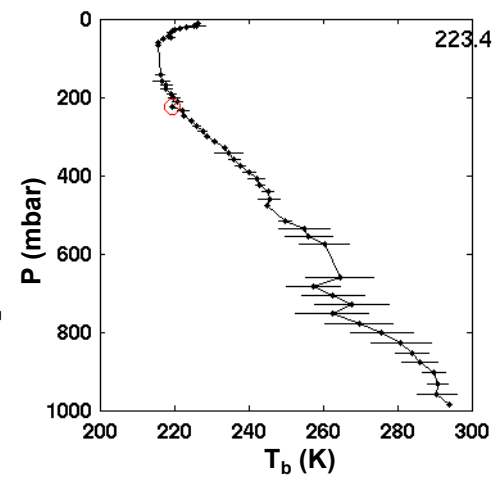
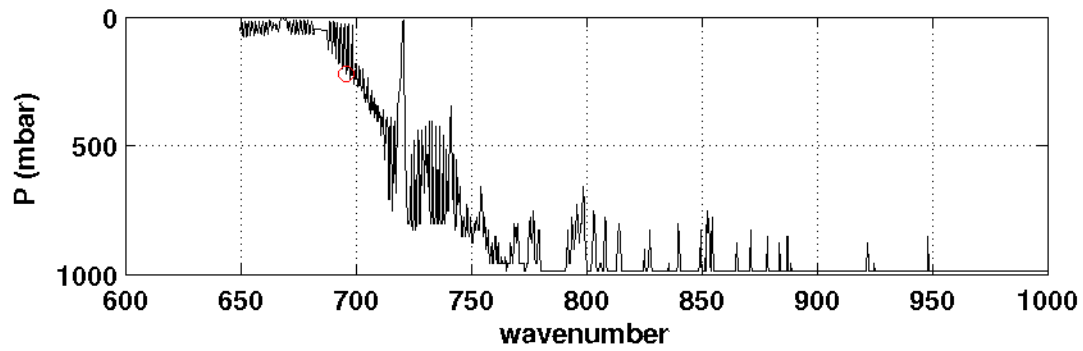
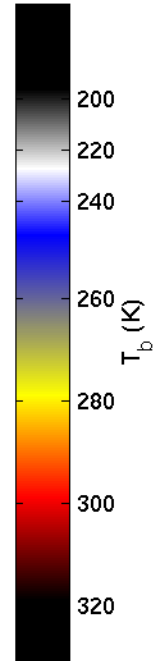
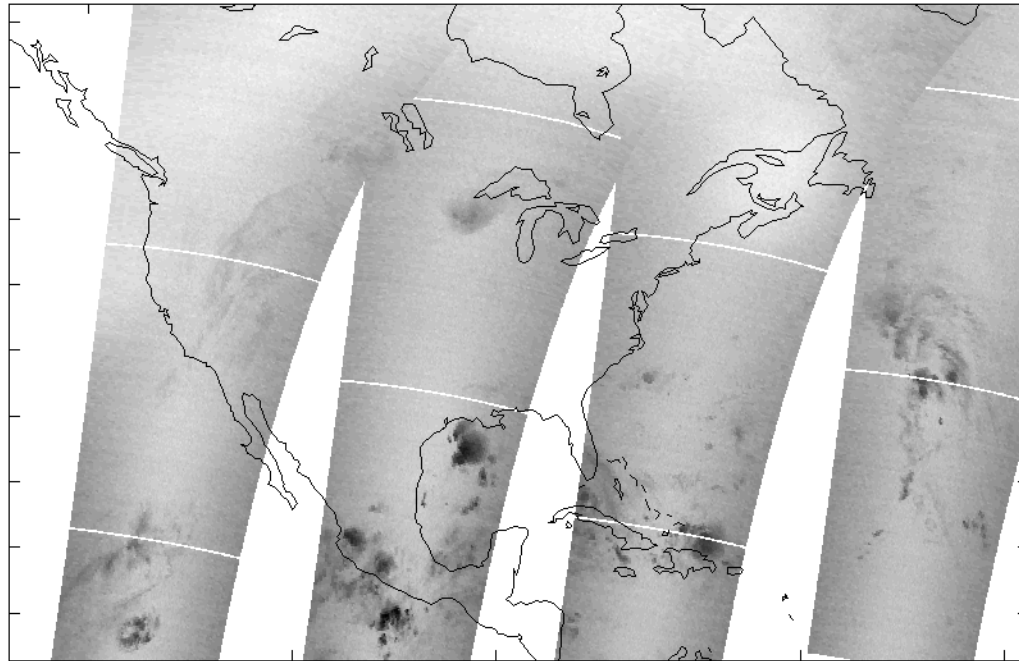
160.5 mbar



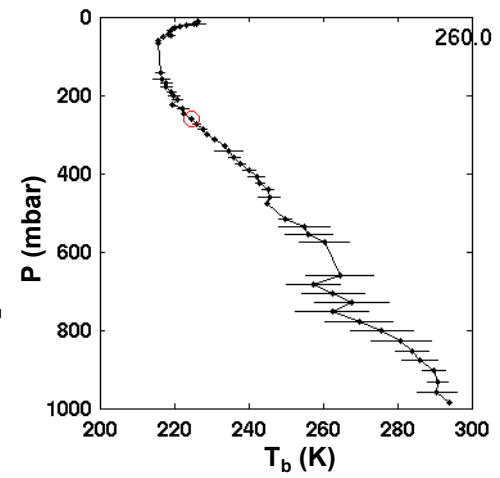
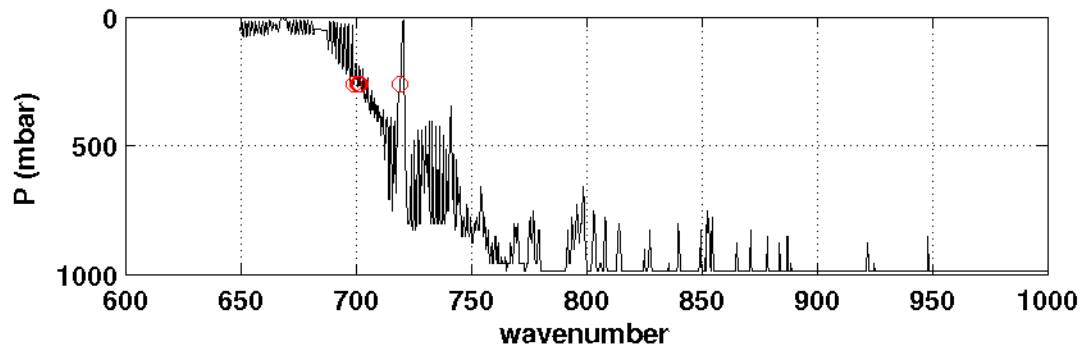
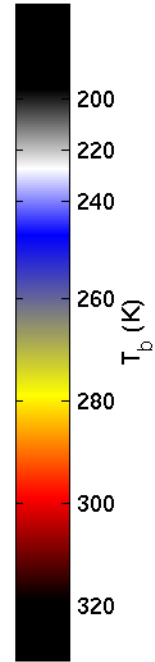
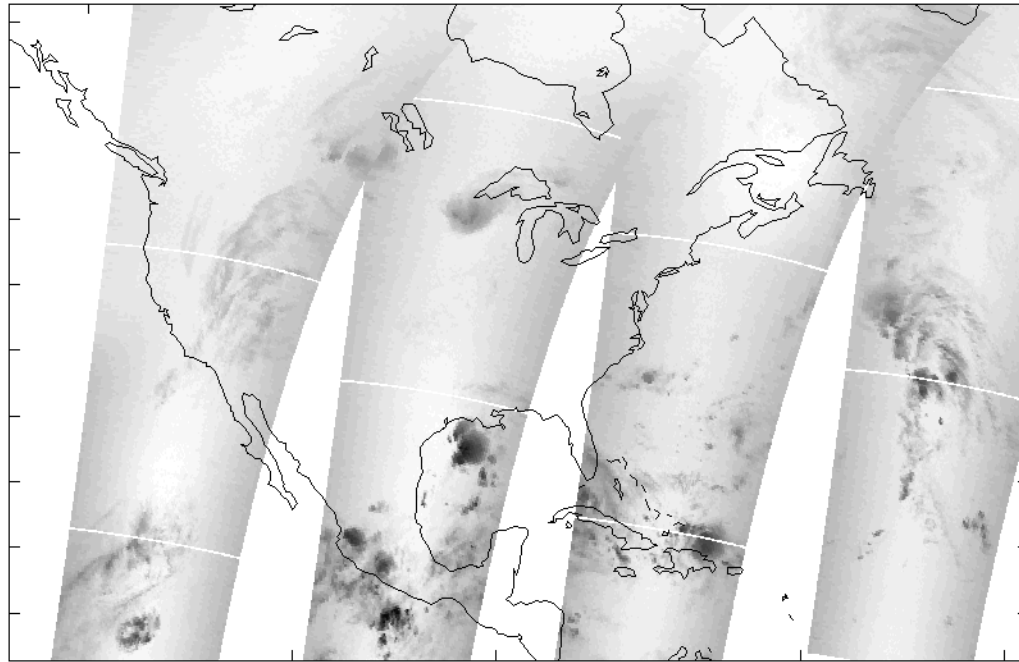
190.3 mbar



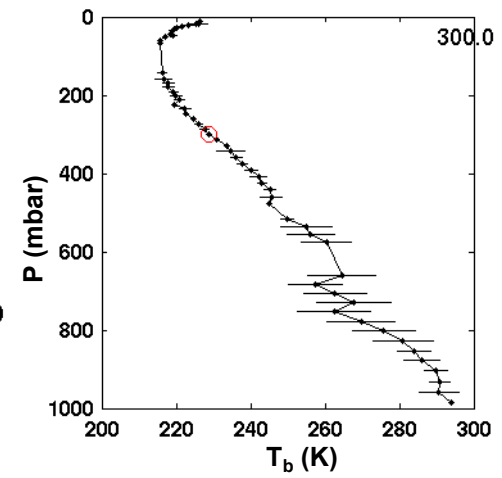
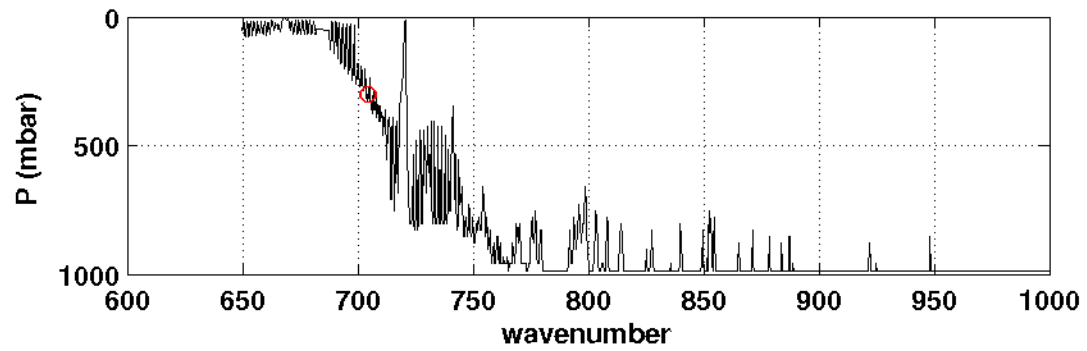
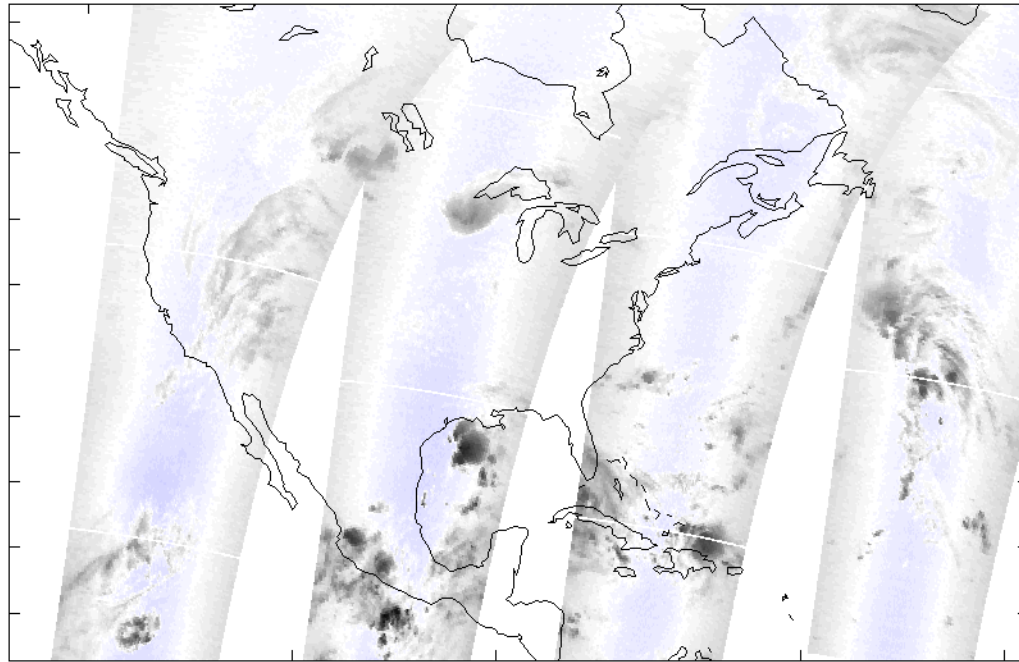
223.4 mbar



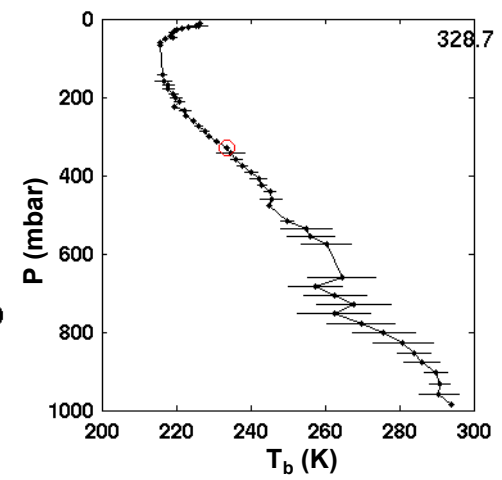
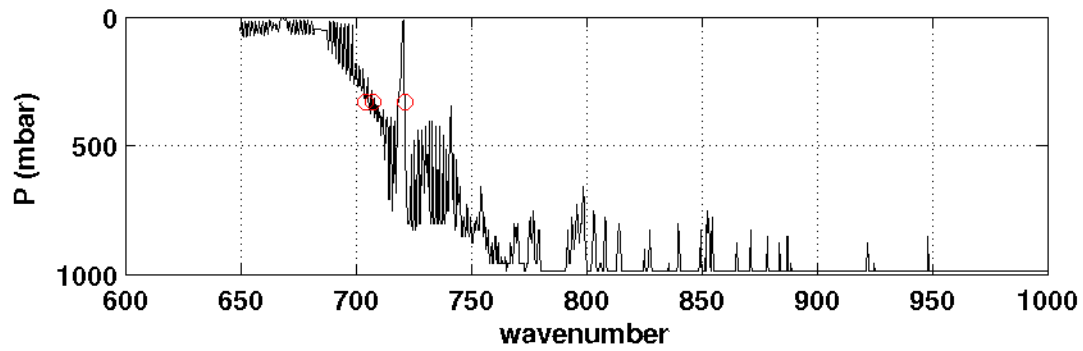
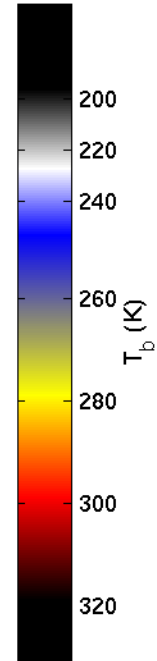
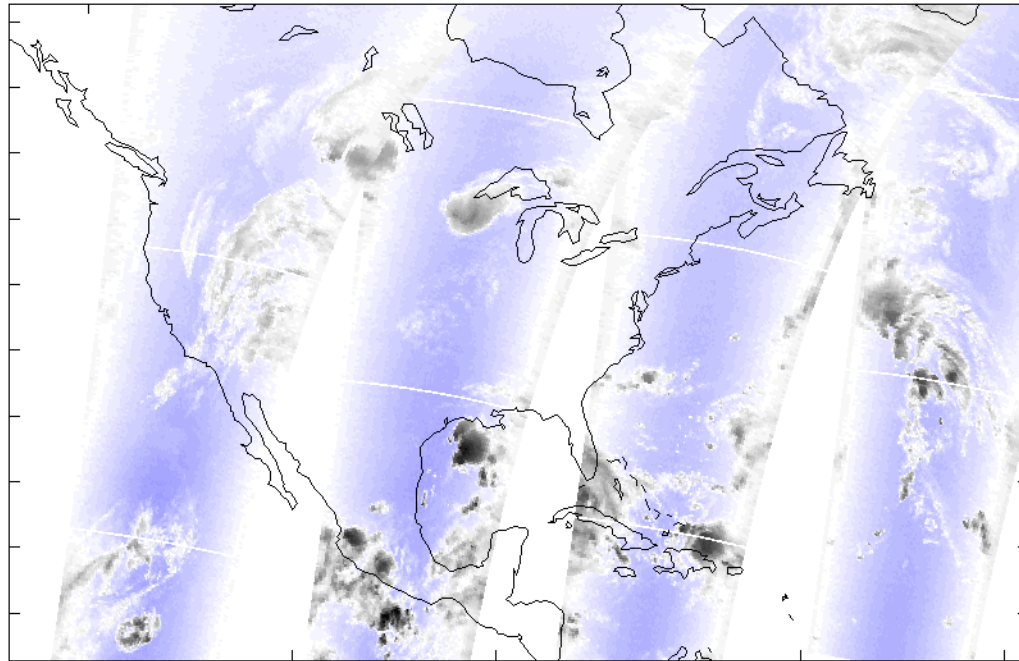
260.0 mbar



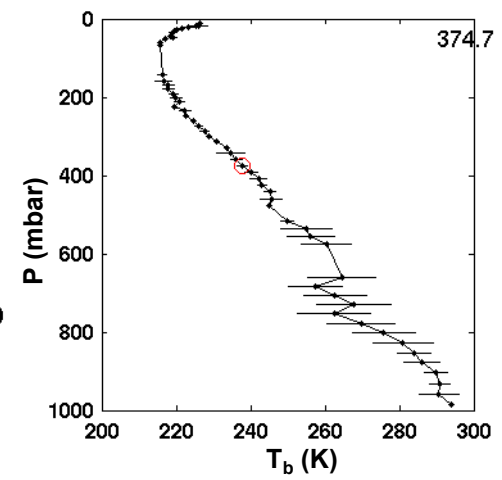
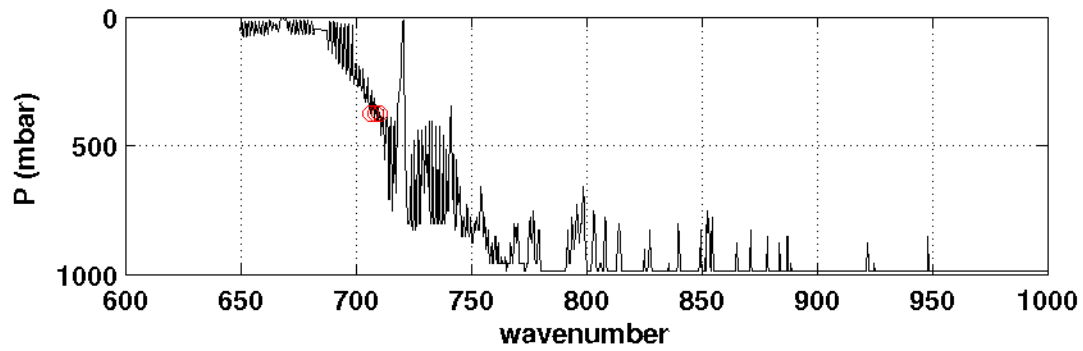
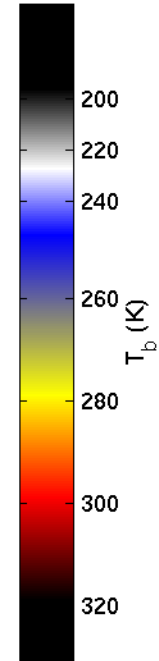
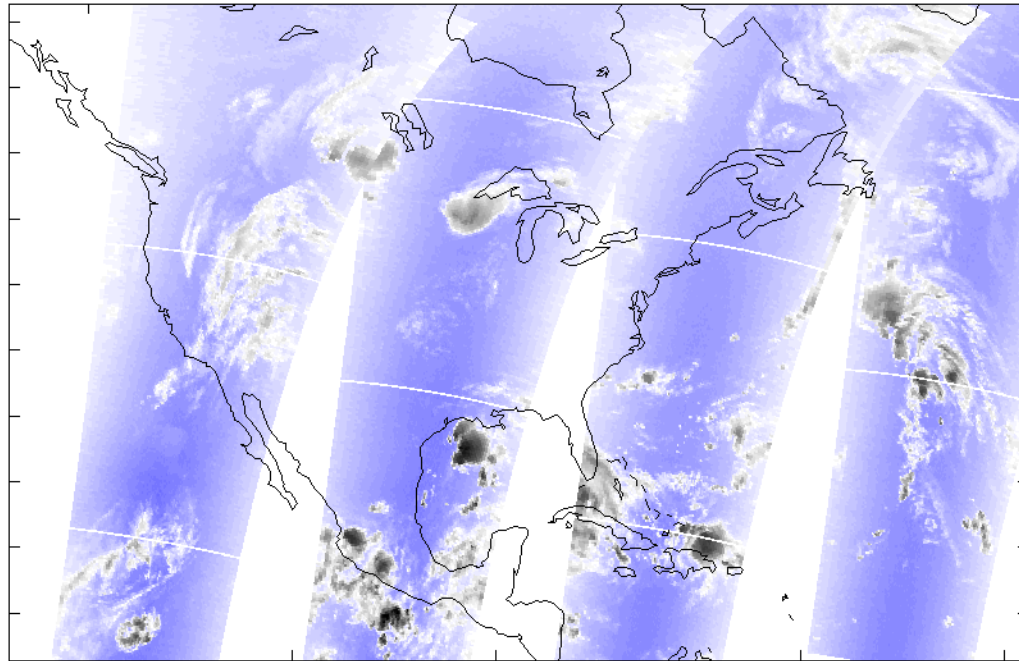
300.0 mbar



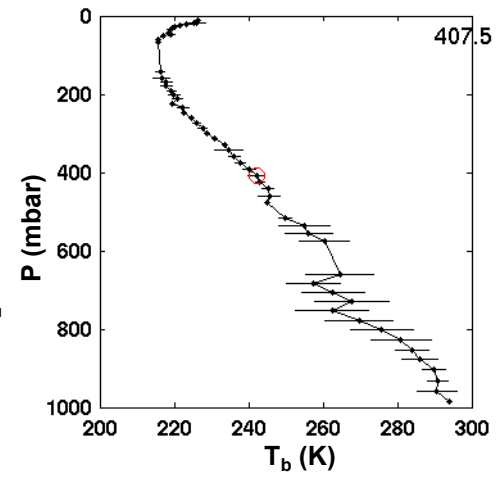
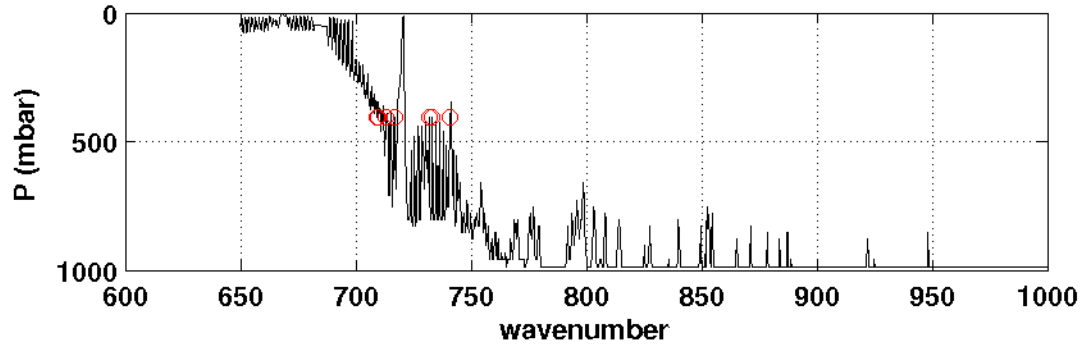
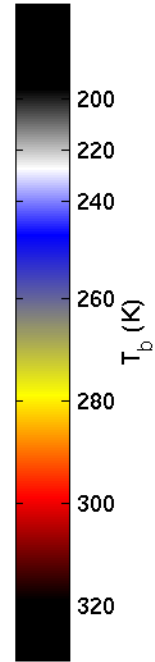
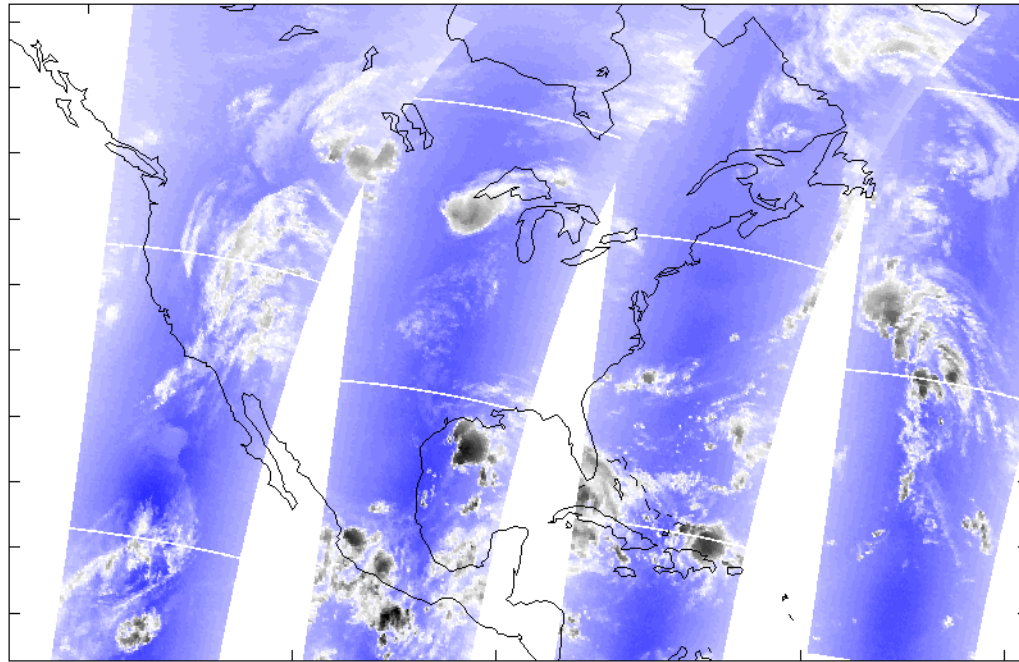
328.7 mbar



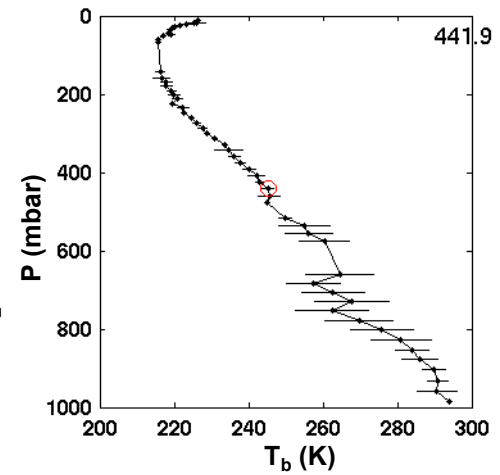
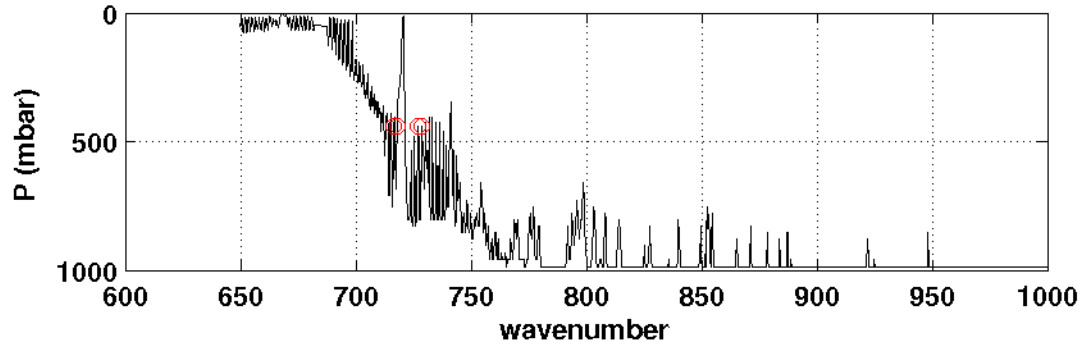
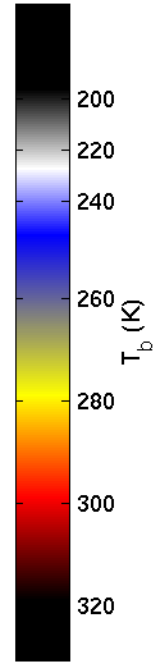
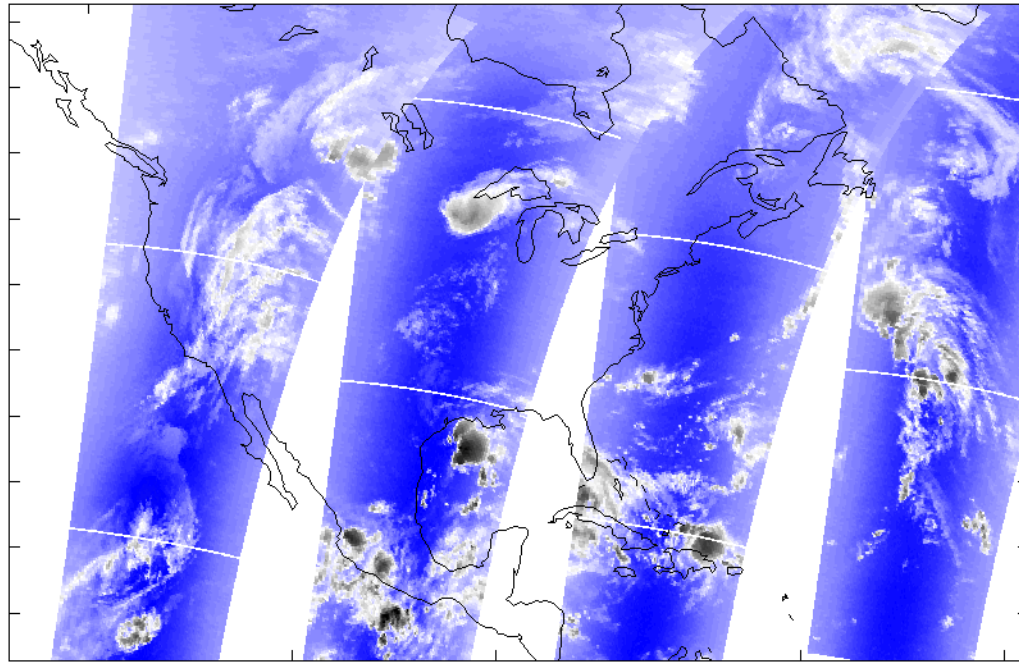
374.7 mbar



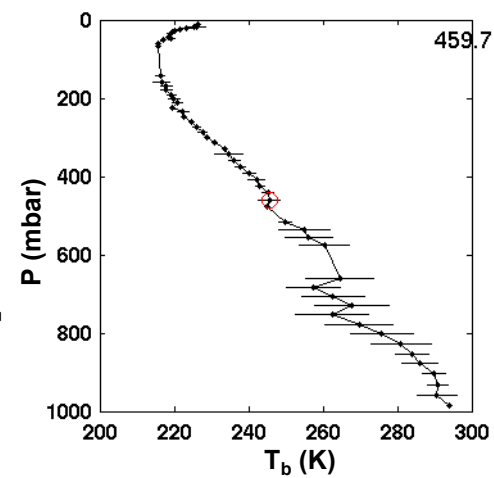
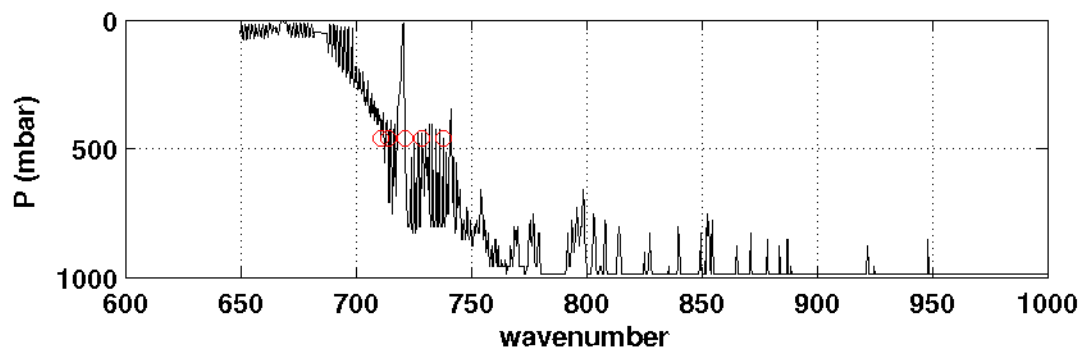
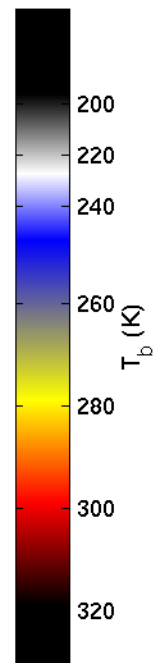
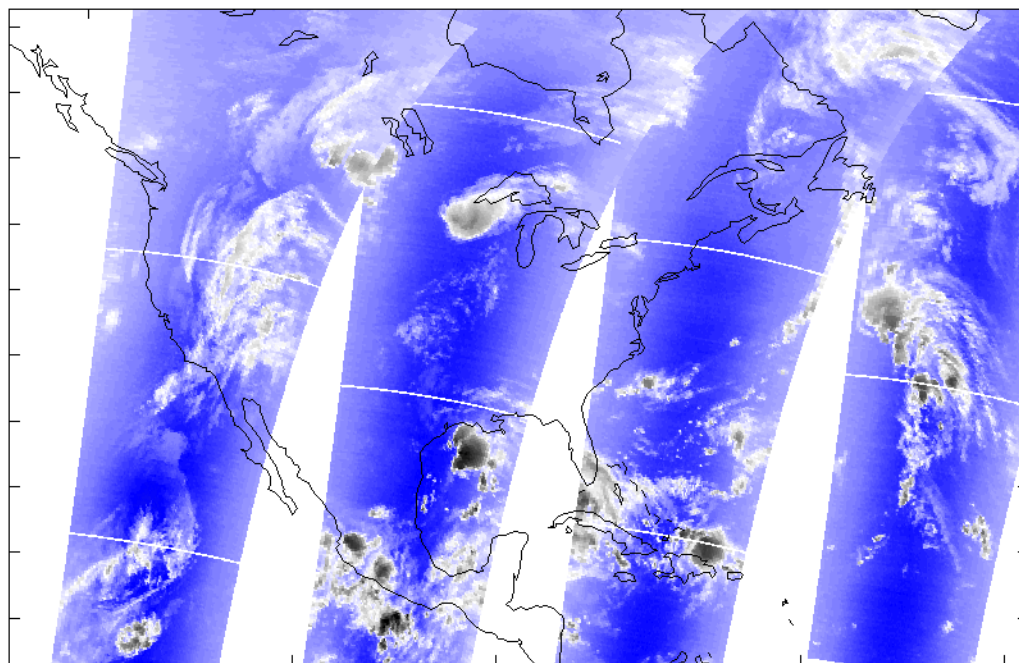
407.5 mbar



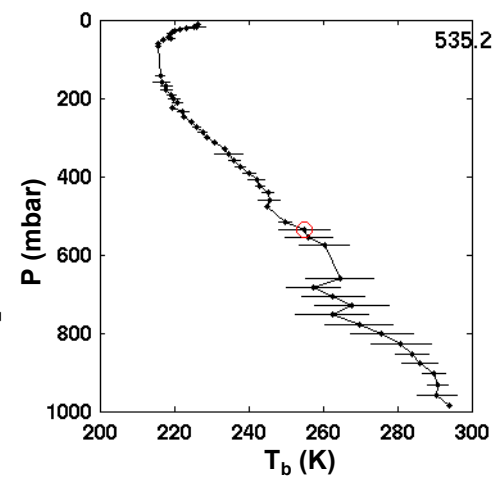
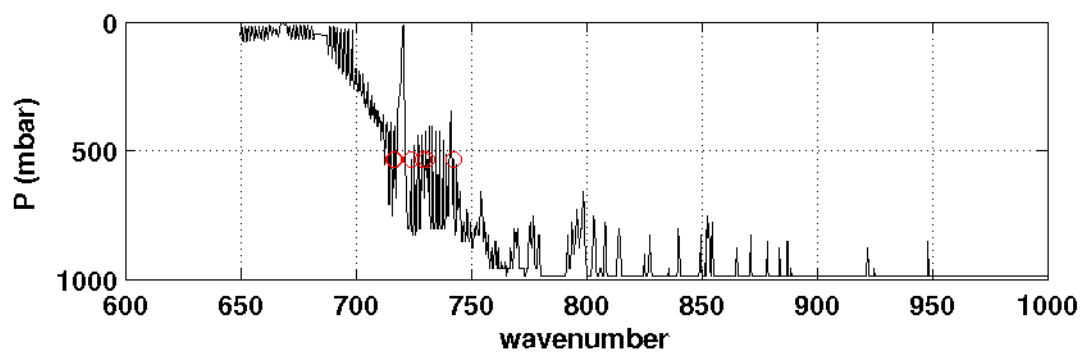
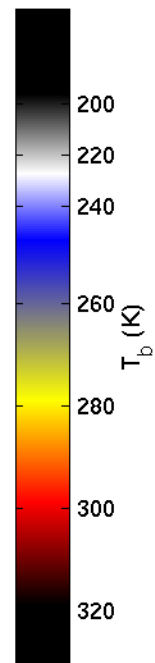
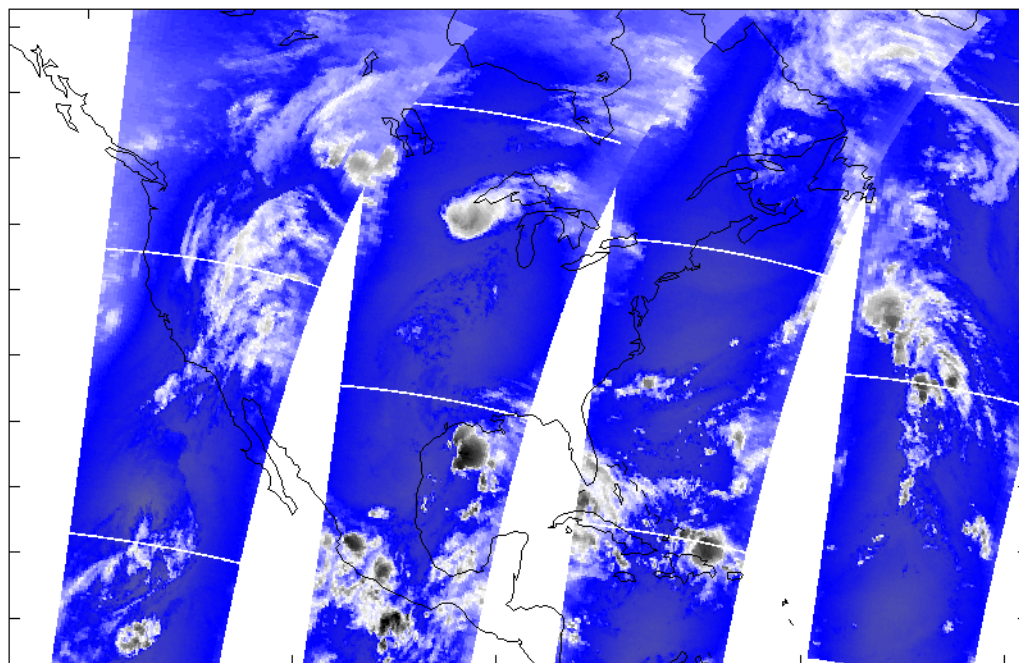
441.9 mbar



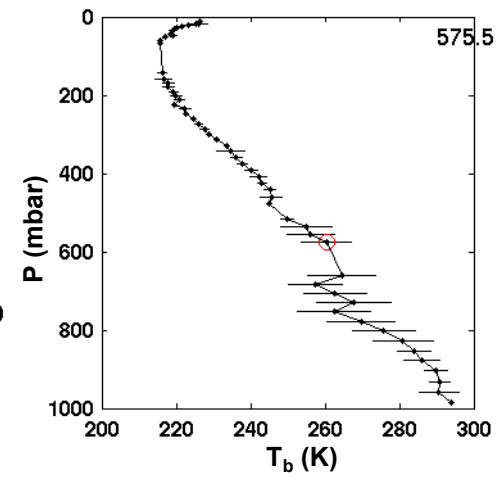
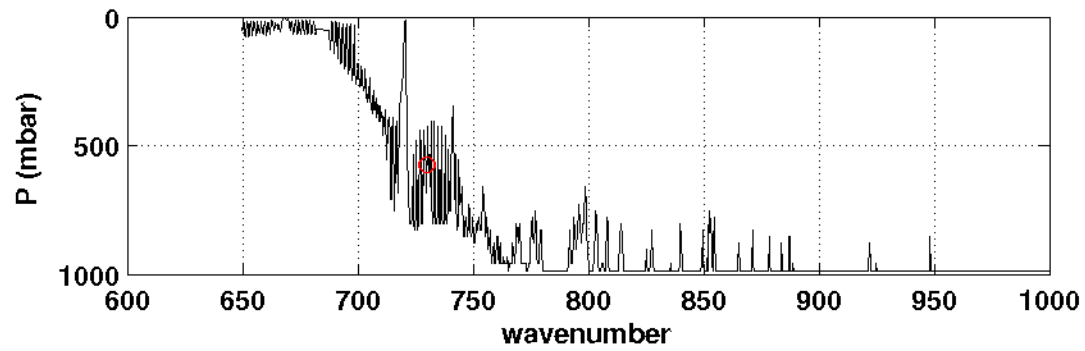
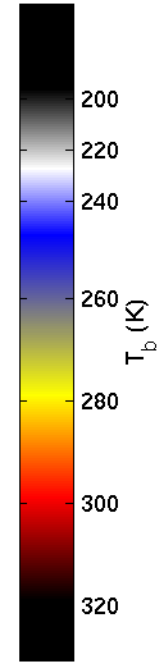
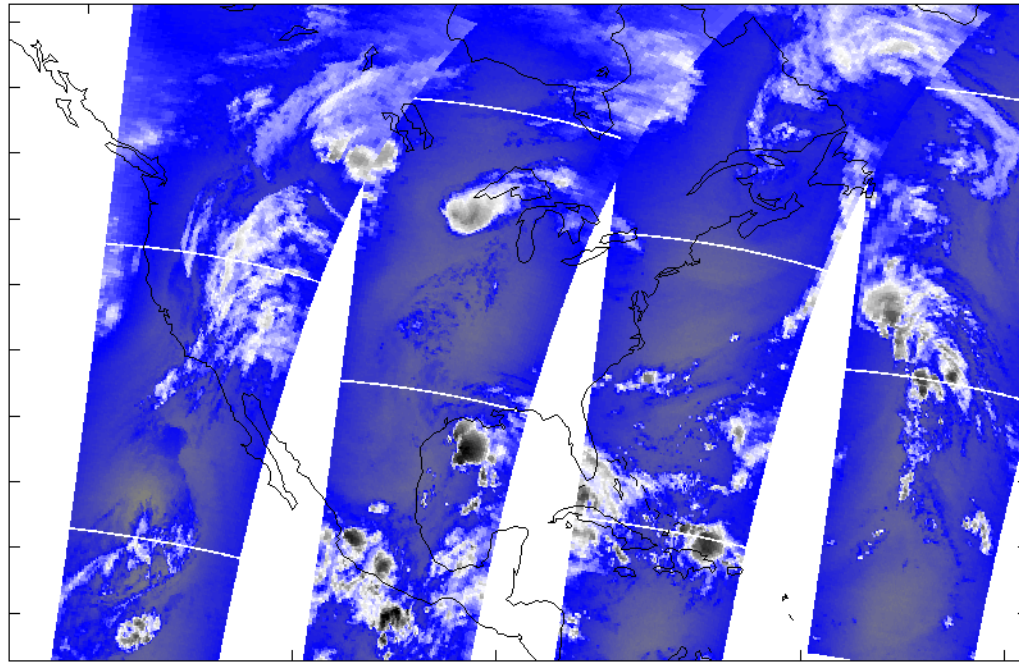
459.7 mbar



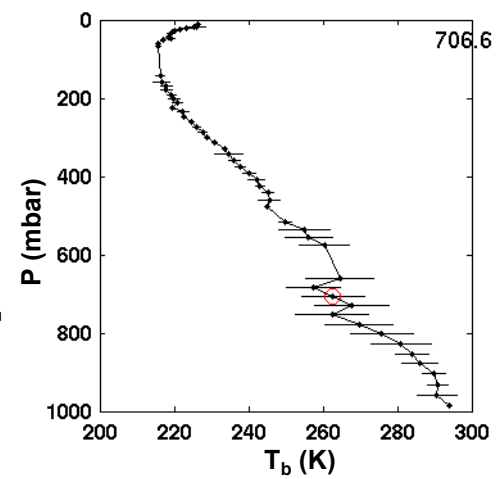
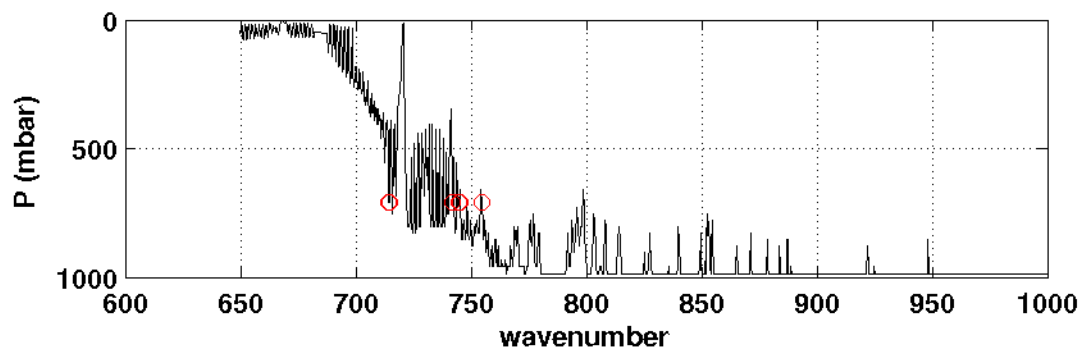
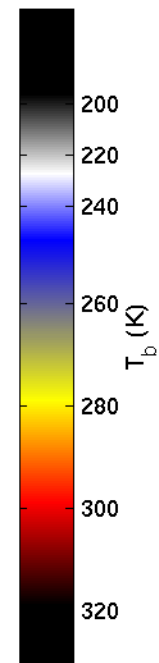
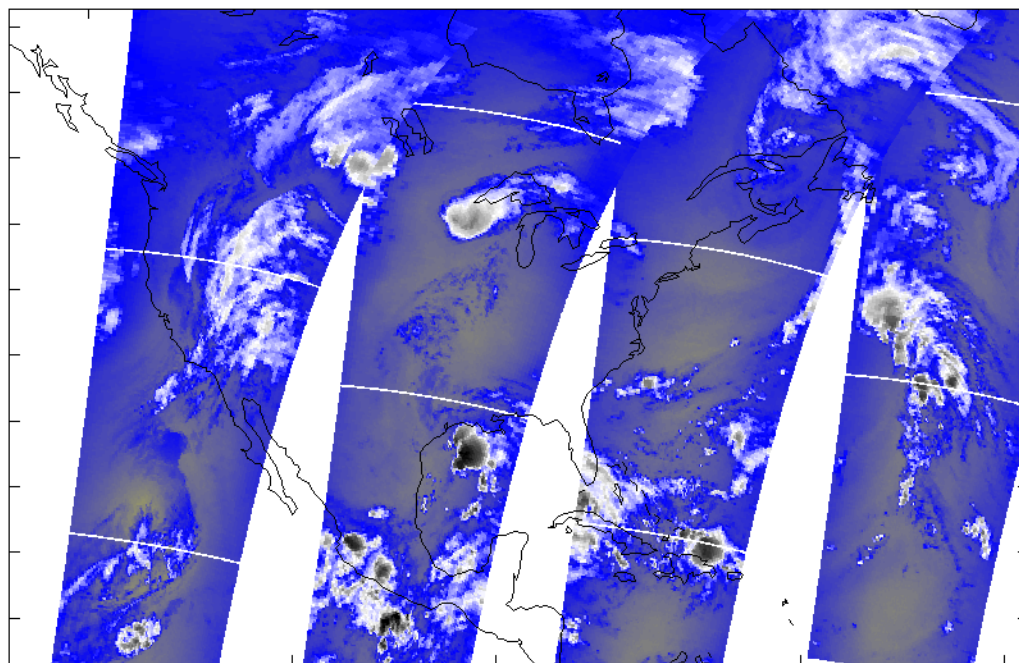
535.2 mbar



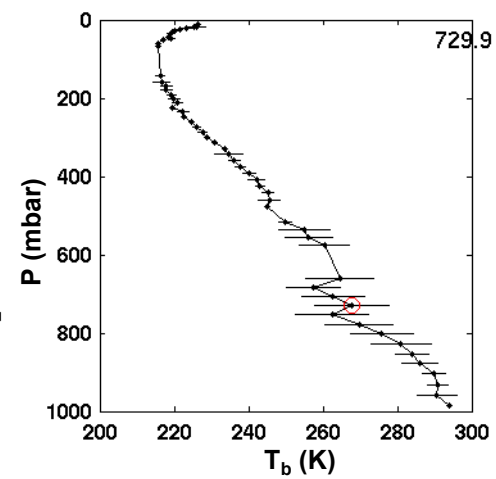
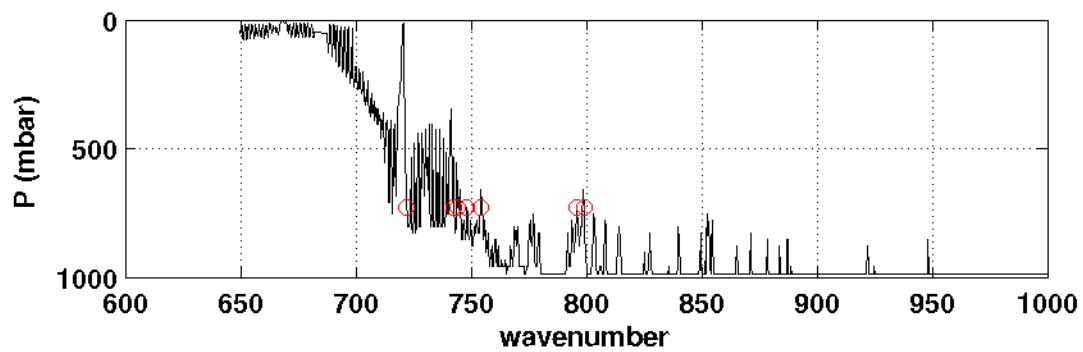
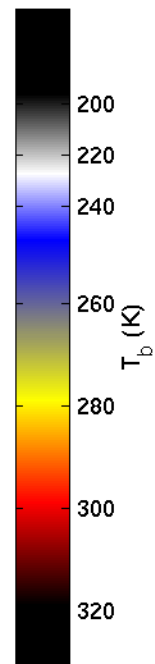
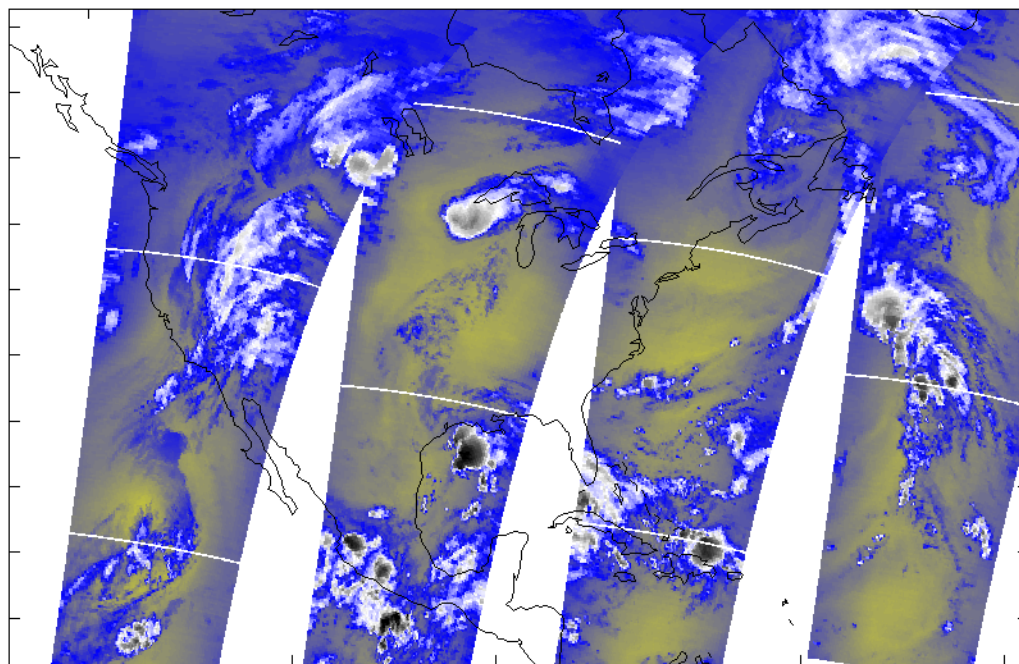
575.5 mbar



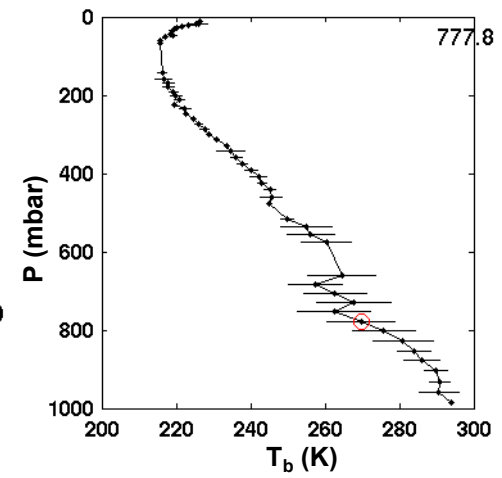
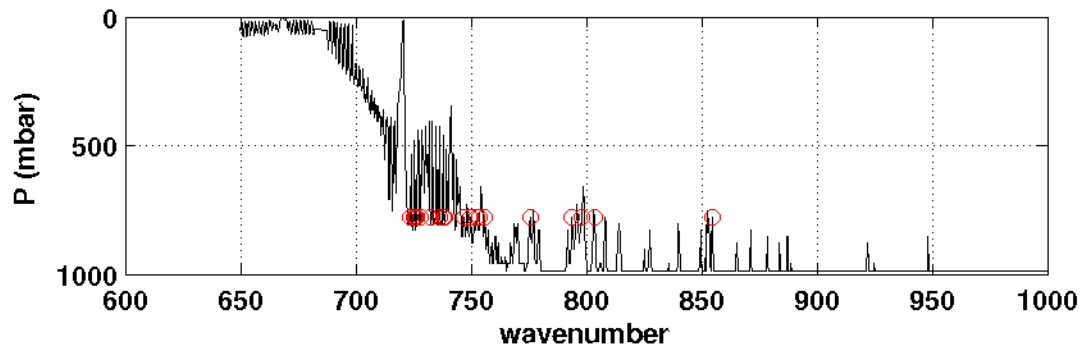
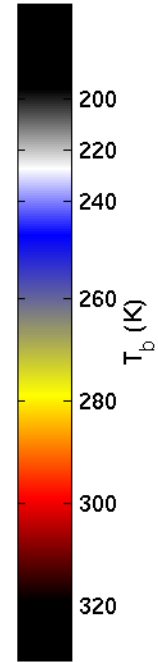
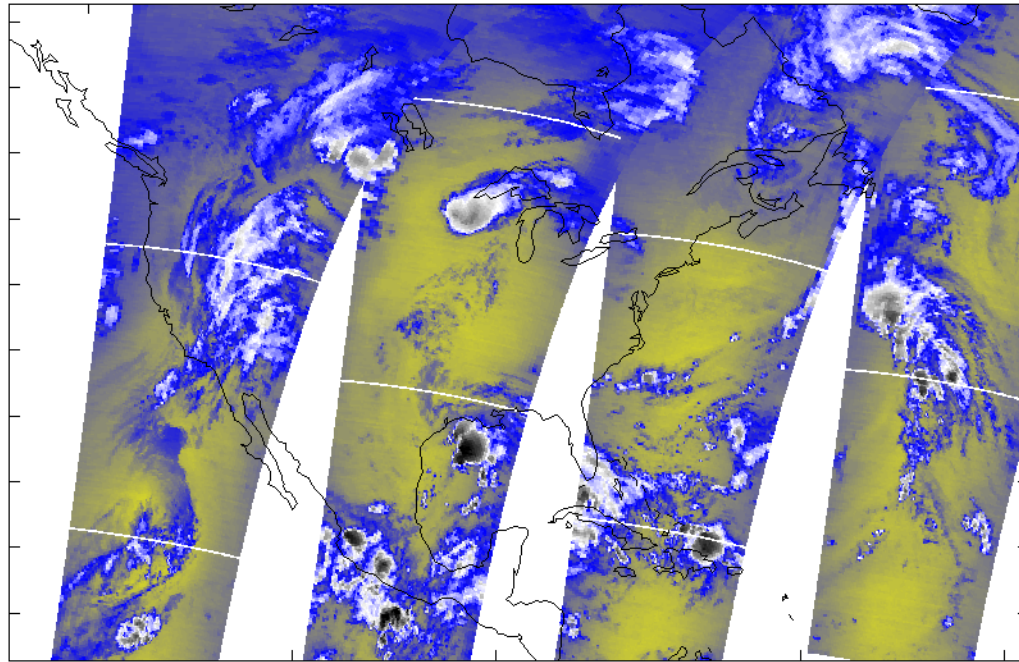
706.6 mbar



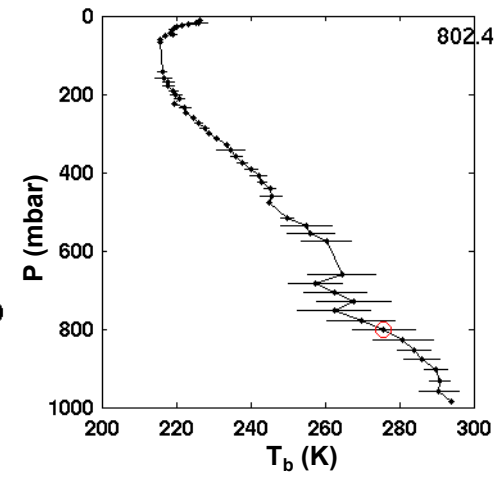
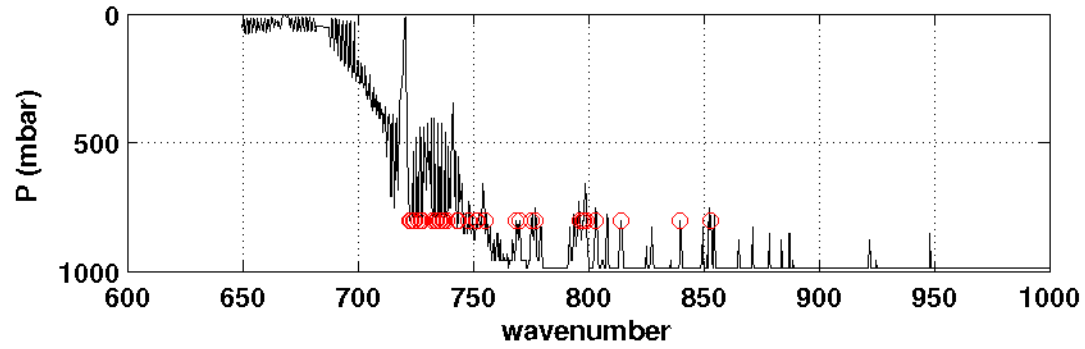
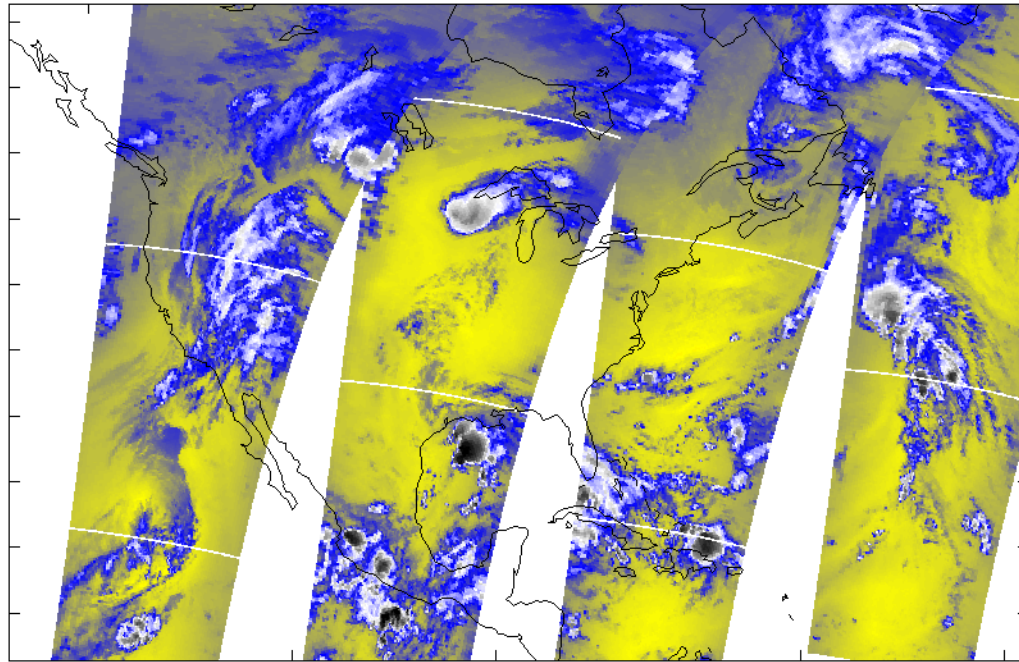
729.9 mbar



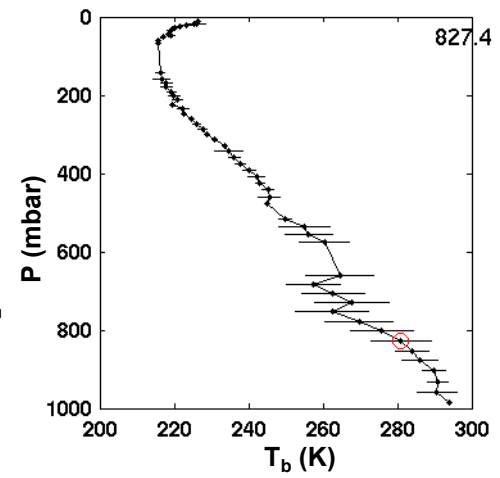
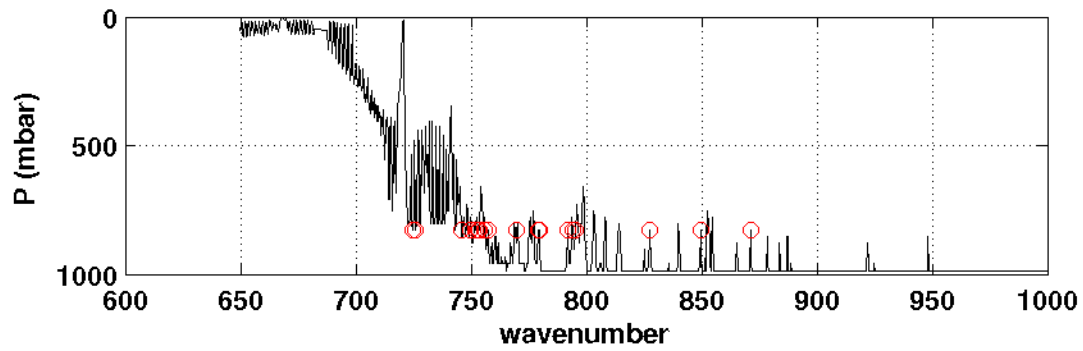
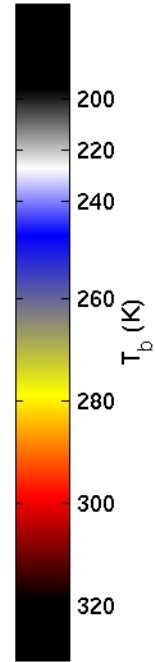
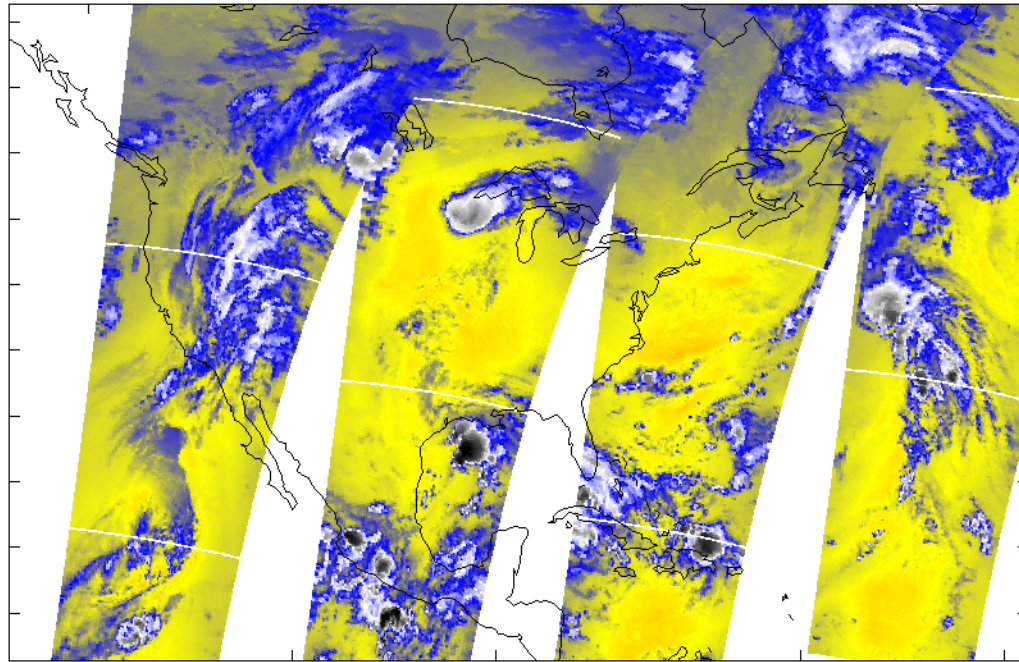
777.8 mbar



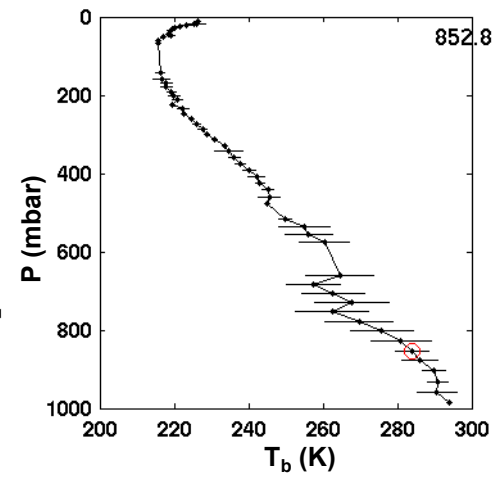
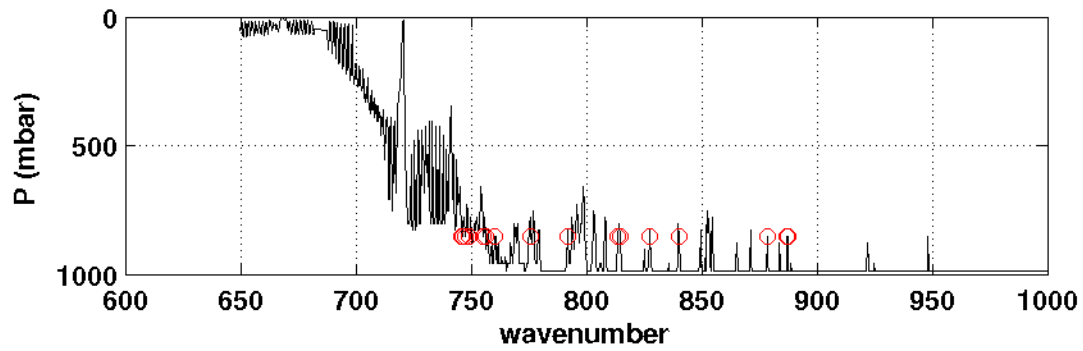
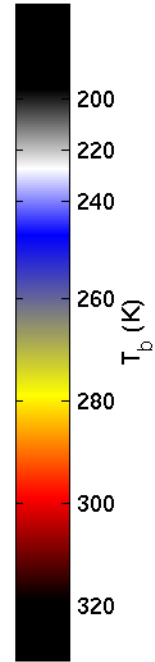
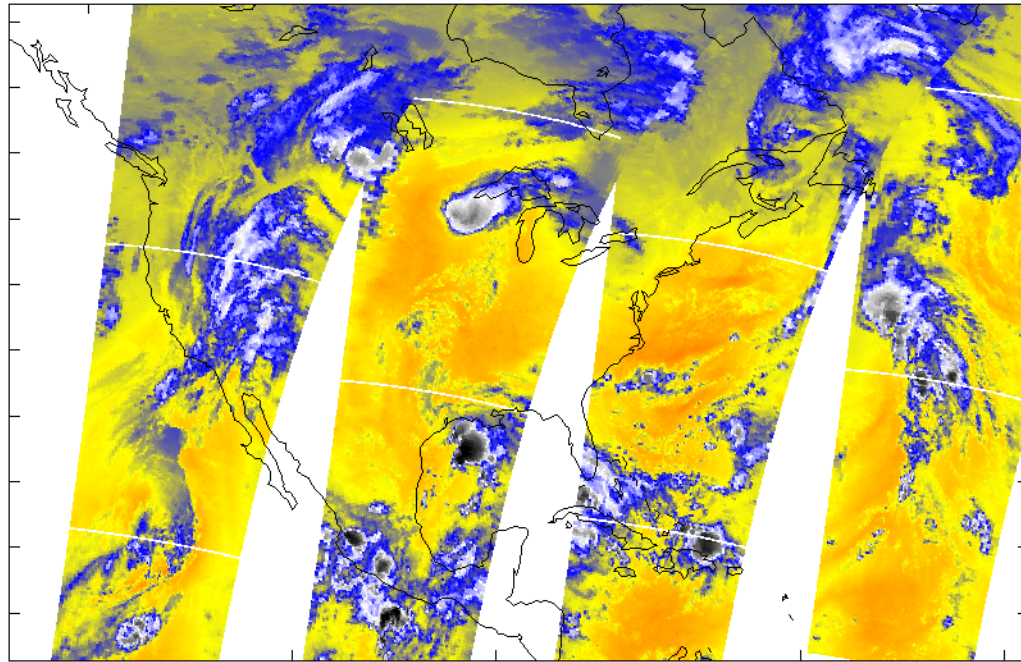
802.4 mbar



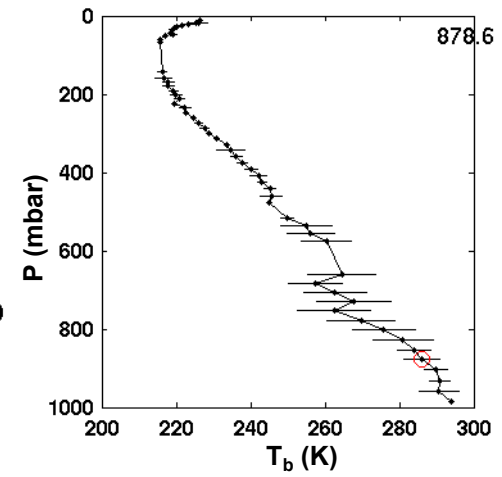
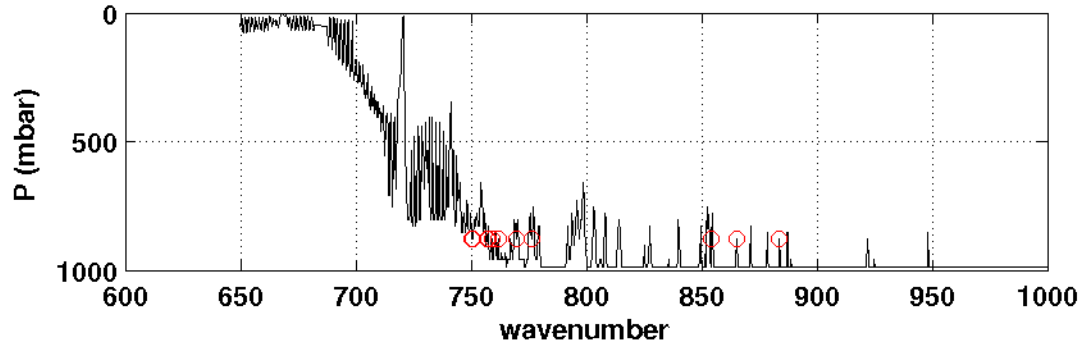
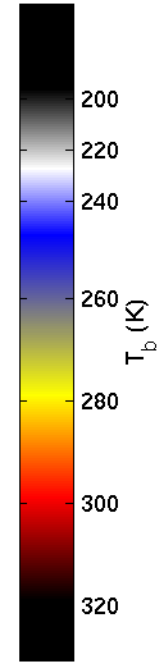
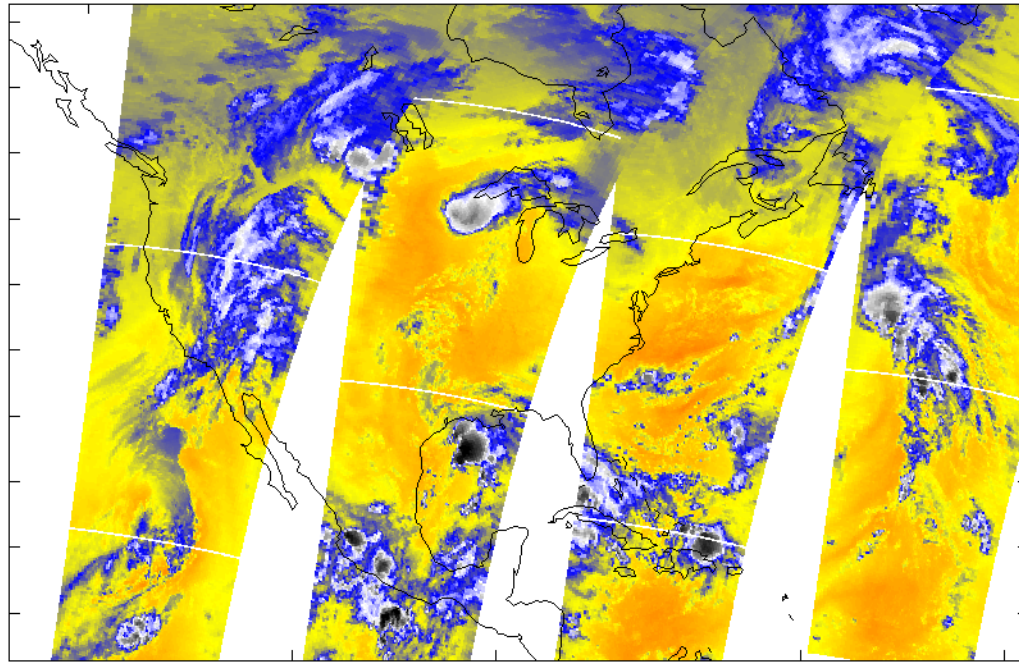
827.4 mbar



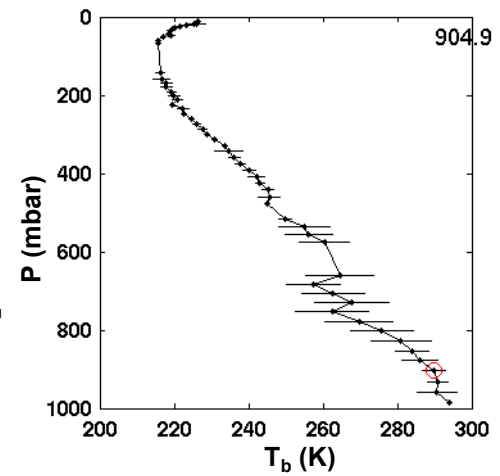
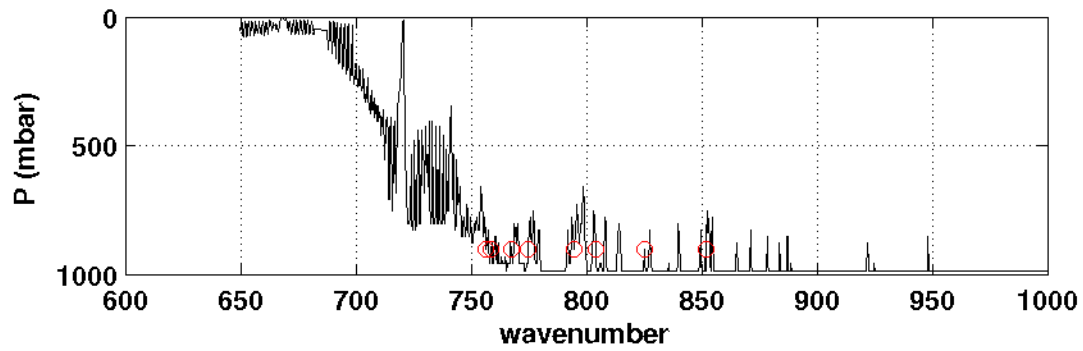
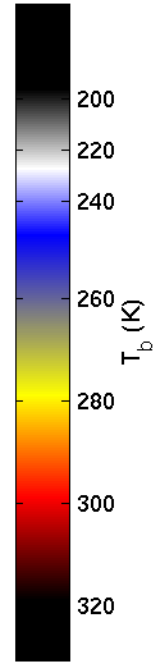
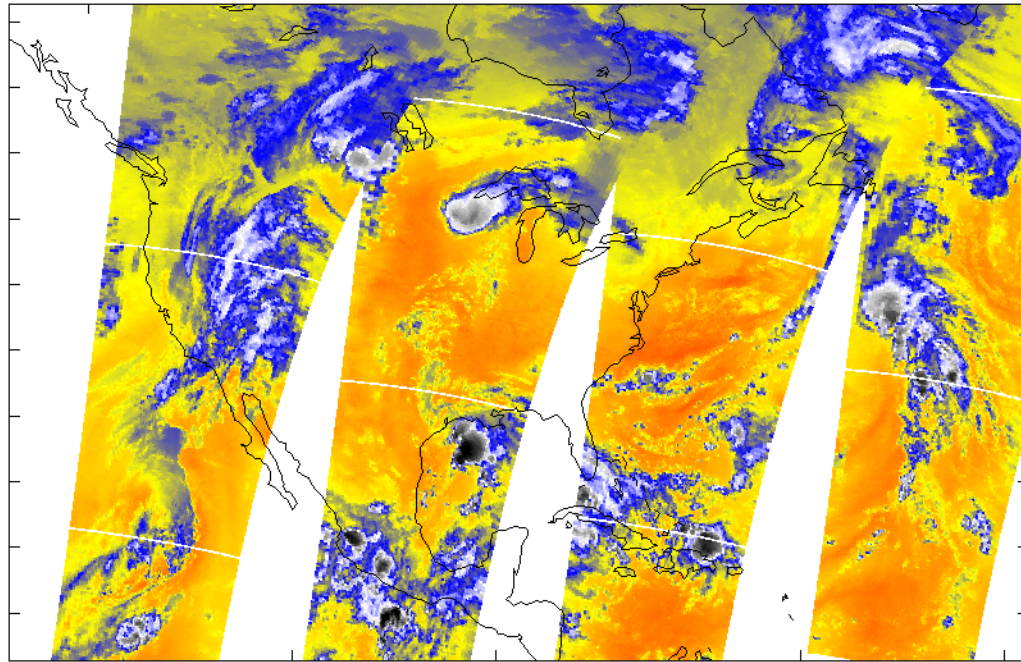
852.8 mbar



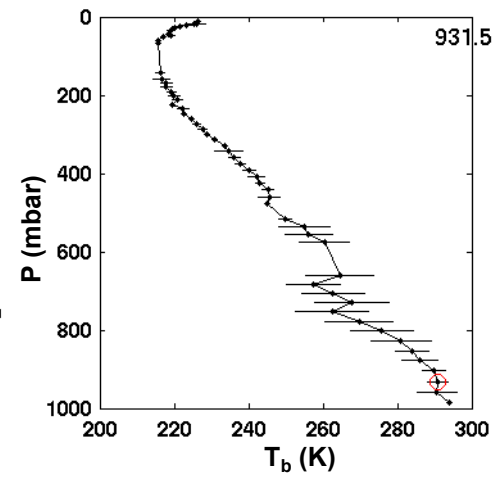
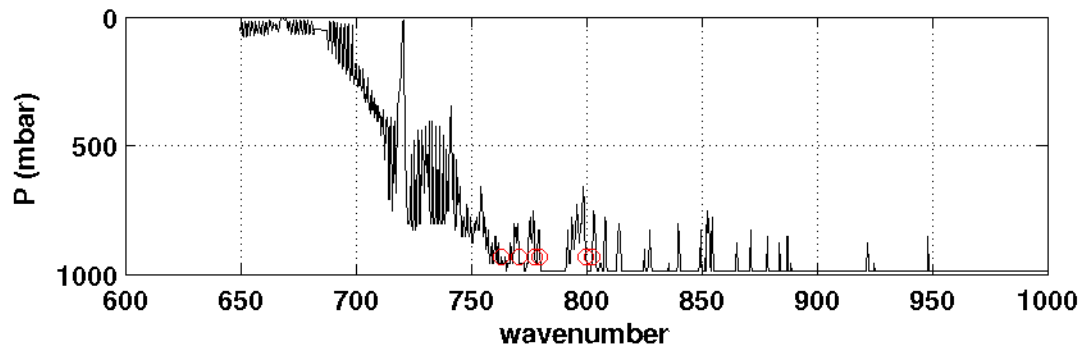
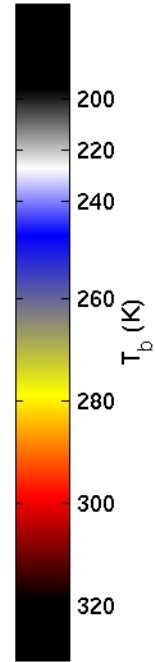
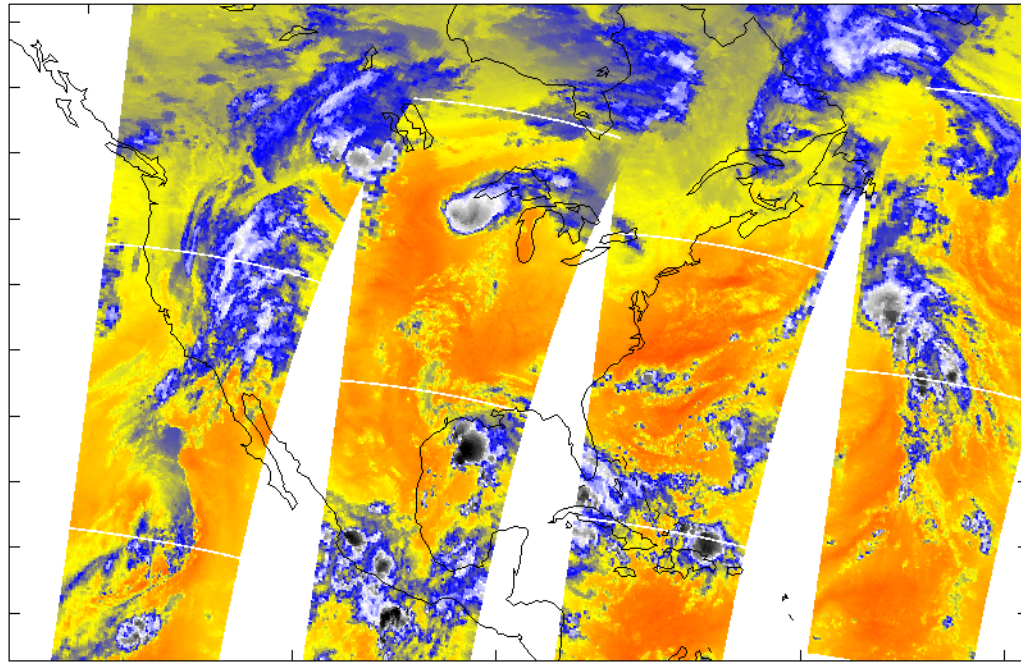
878.6 mbar



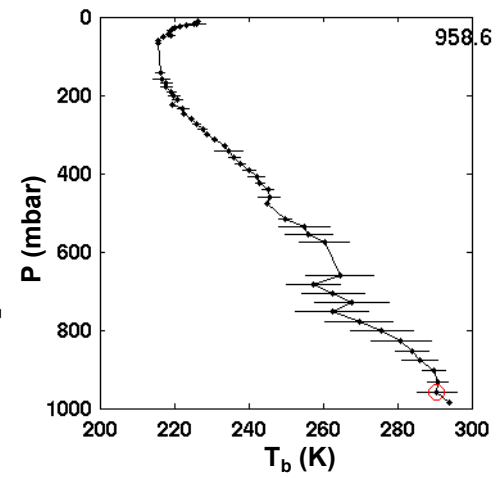
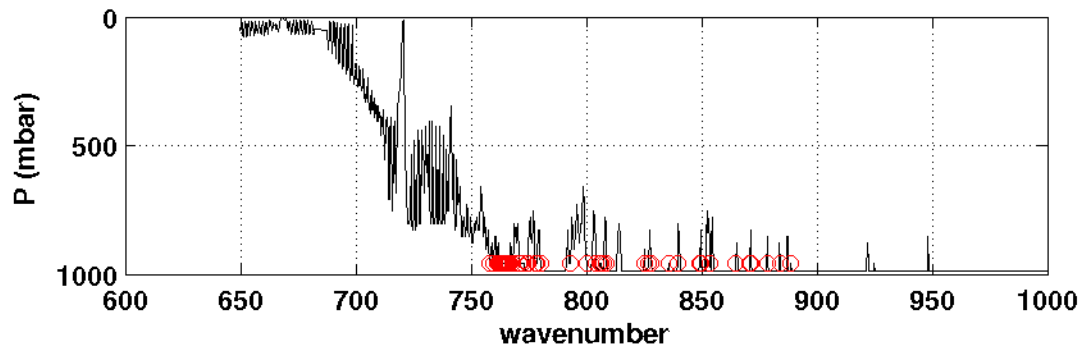
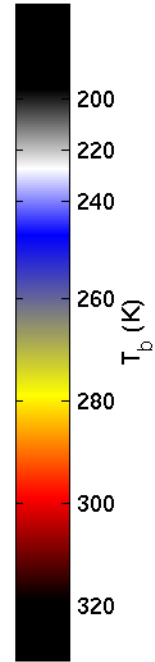
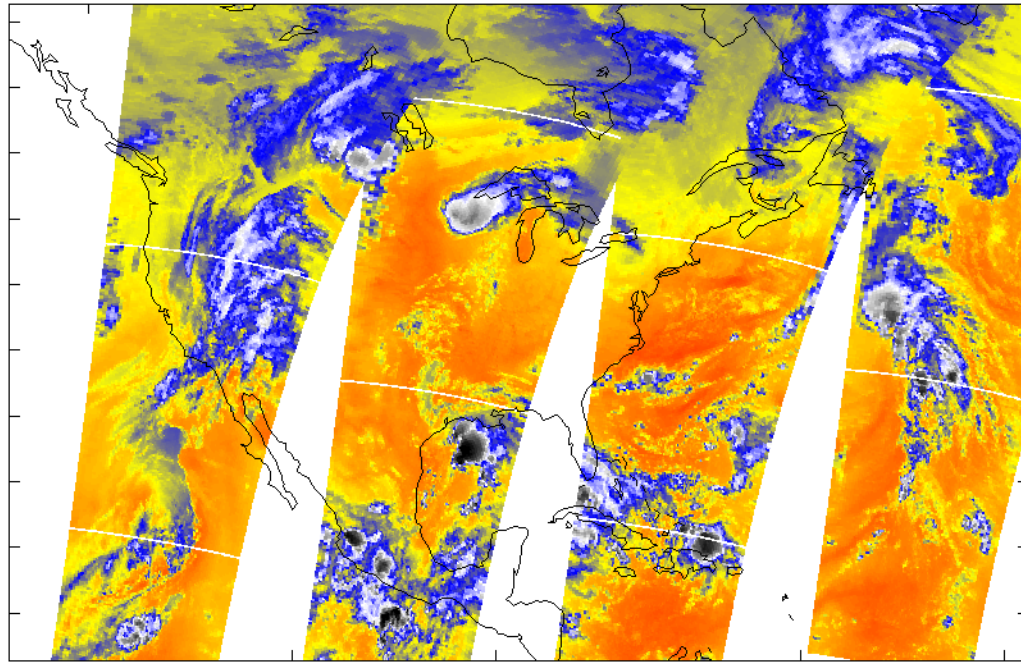
904.9 mbar



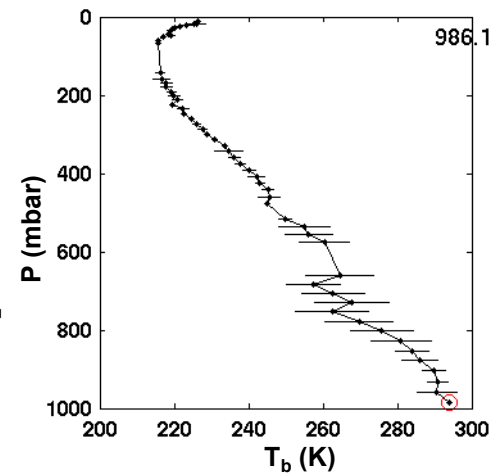
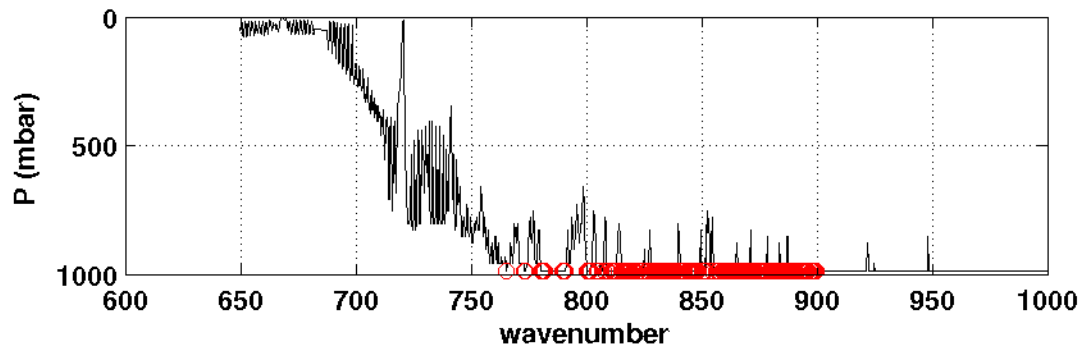
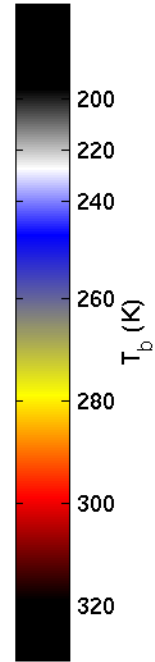
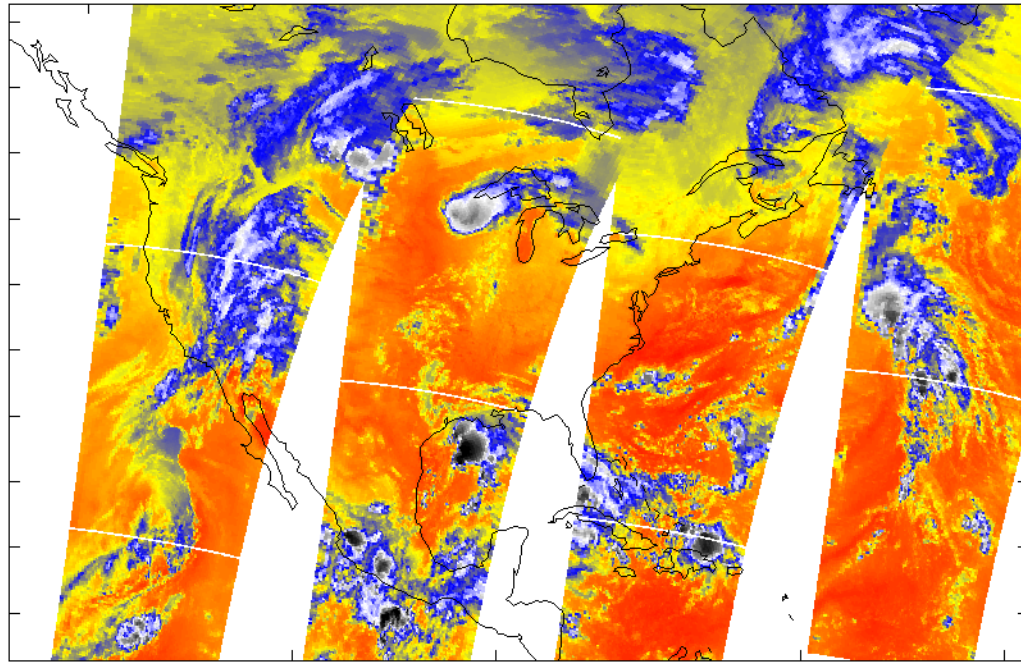
931.5 mbar



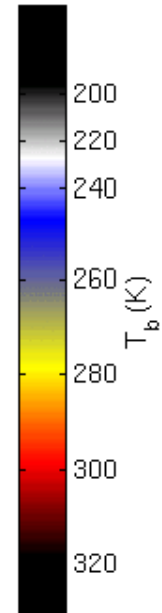
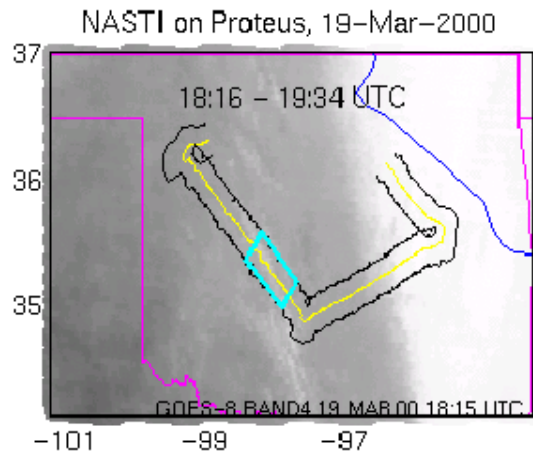
958.6 mbar



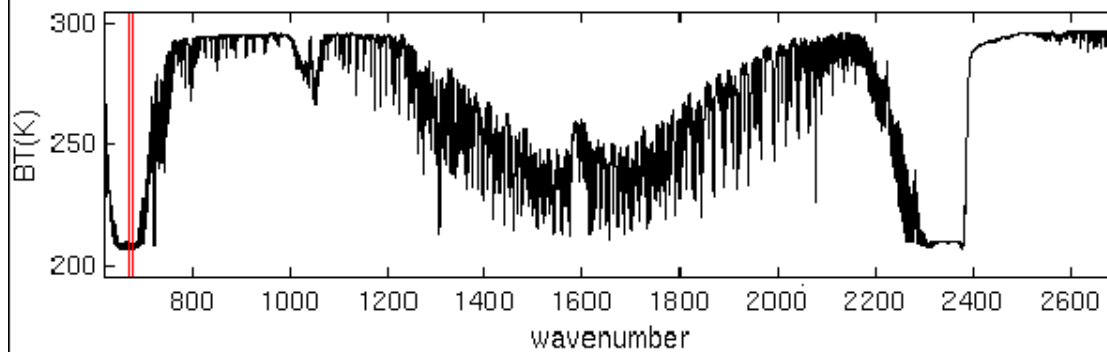
986.1 mbar



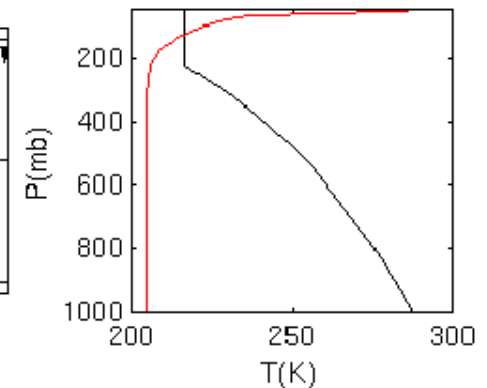
670-680 cm^{-1}



nominal clear sky calculation at NASTI resolution



Std T profile and normalized mean weighting function

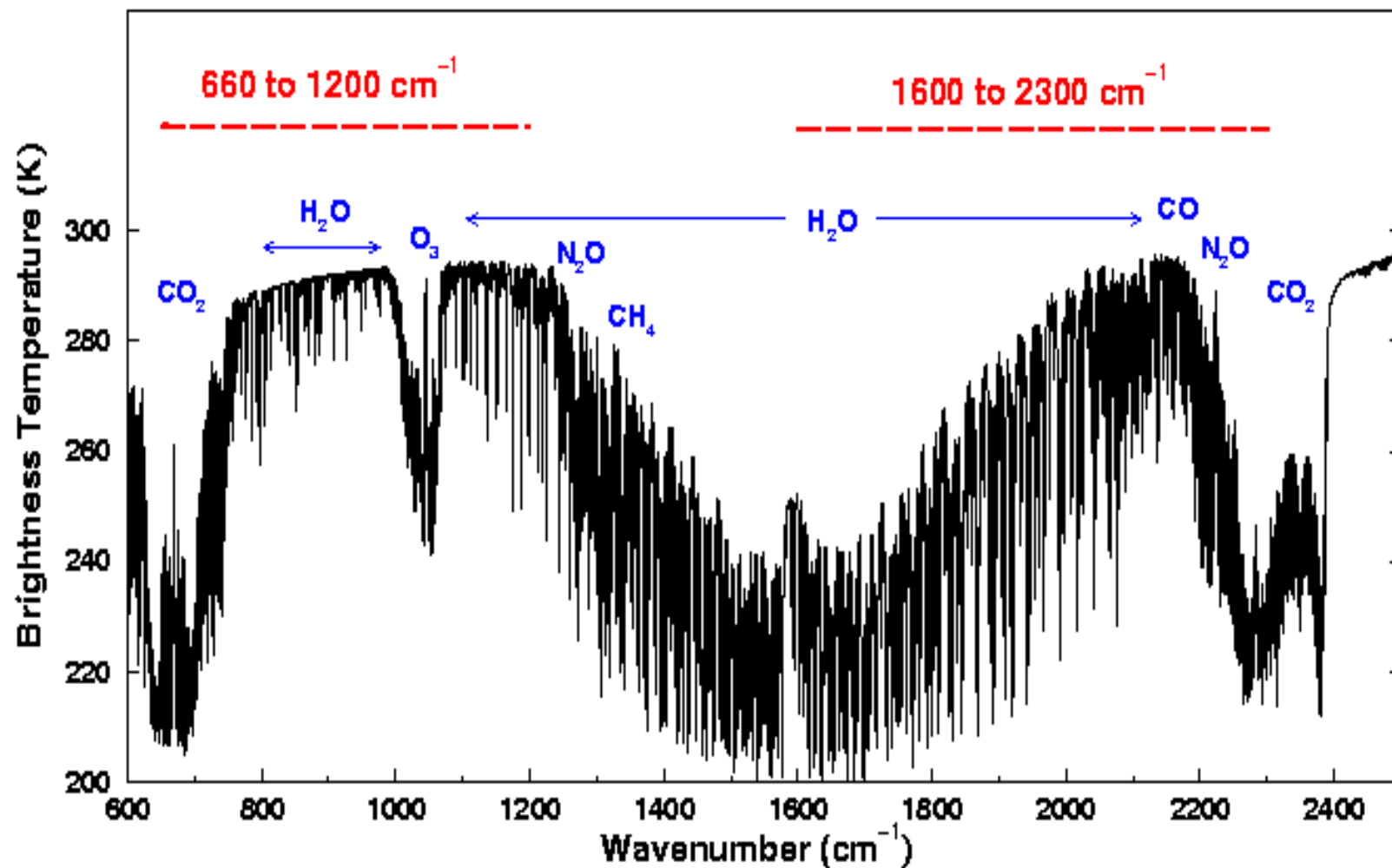


AIRS data and Level 2 Products are being processed at the GSFC DAAC and now available to the public!

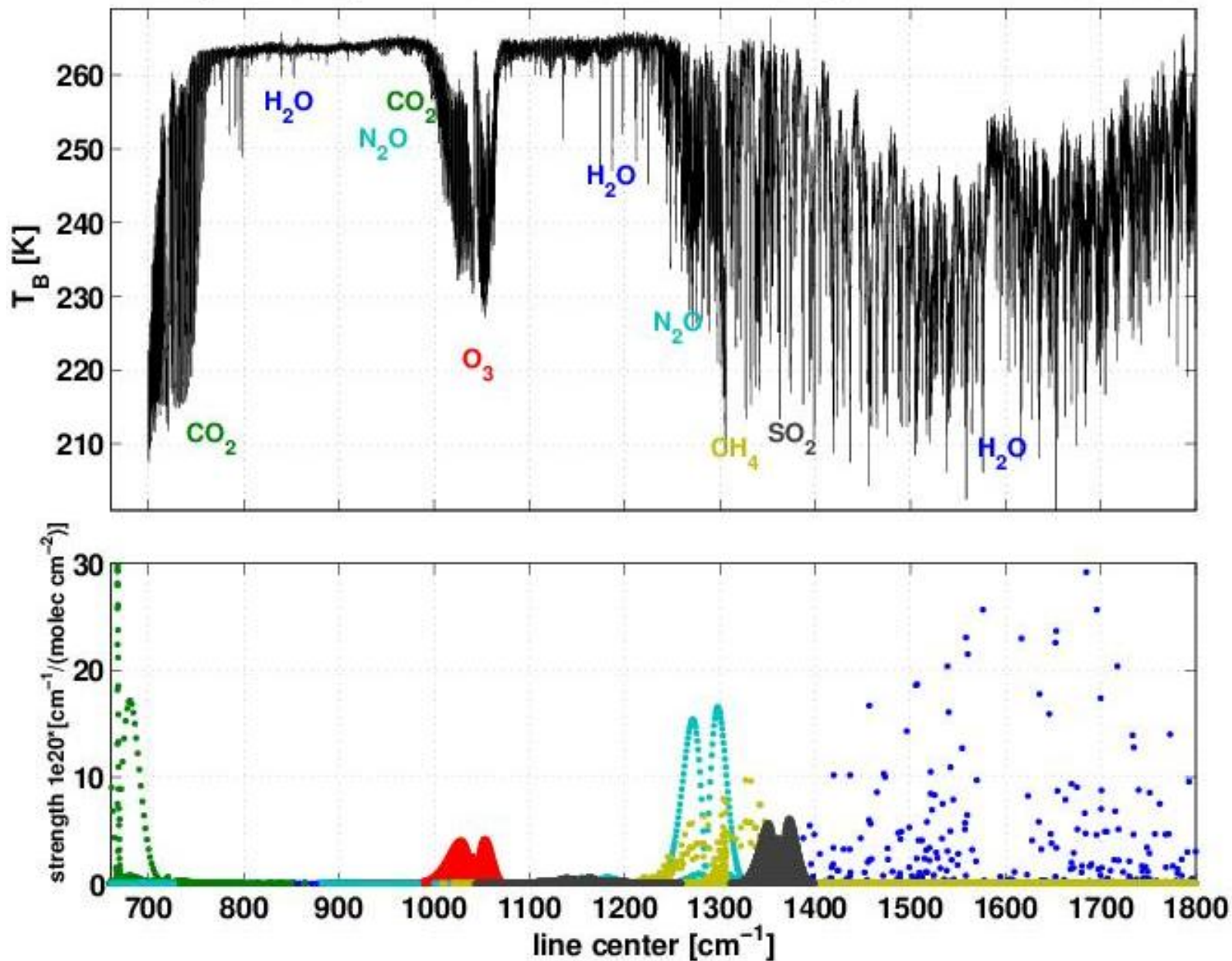
The NASA GSFC Data Active Archive Center at

<http://daac.gsfc.nasa.gov/>

offers a menu driven selection of archived calibrated navigated radiances as well as derived products such as temperature and moisture soundings and total column concentrations of water vapor and ozone.

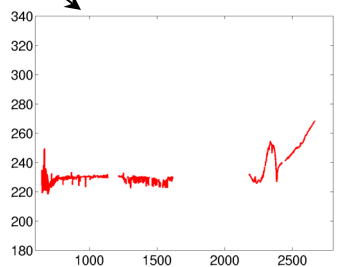
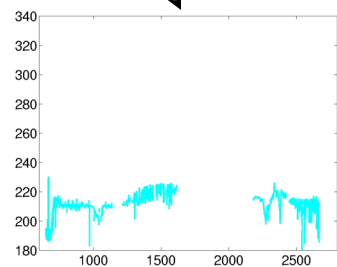
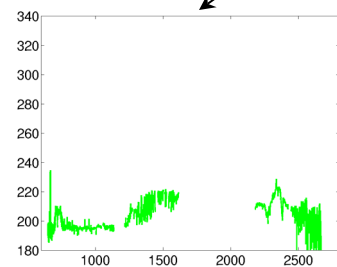
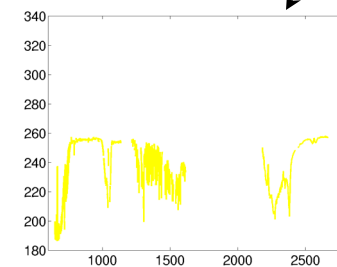
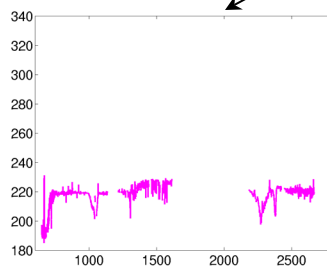
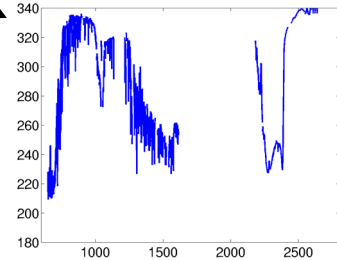
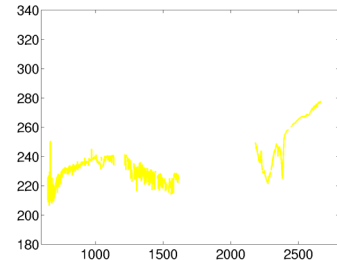
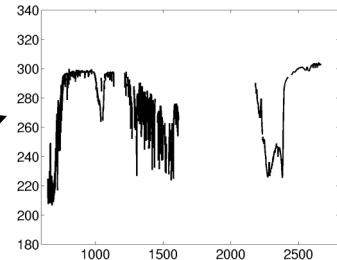
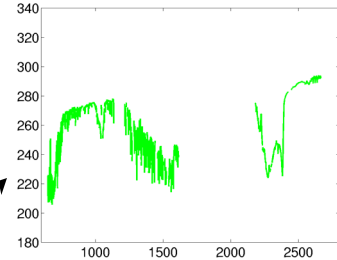
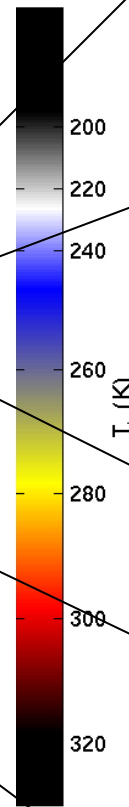
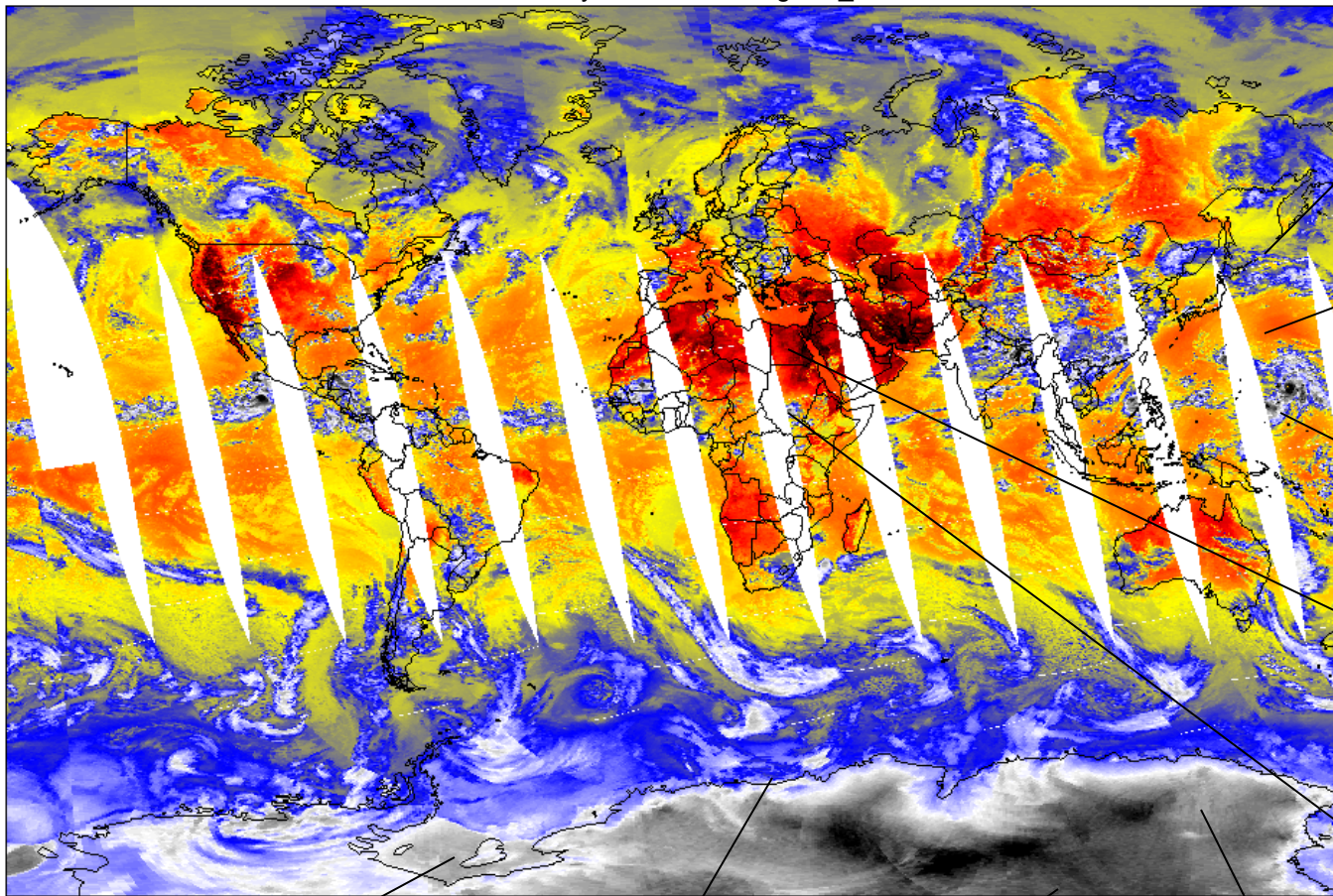


IMG spectrum (WINCE, 970128 over Nebraska) and HITRAN database

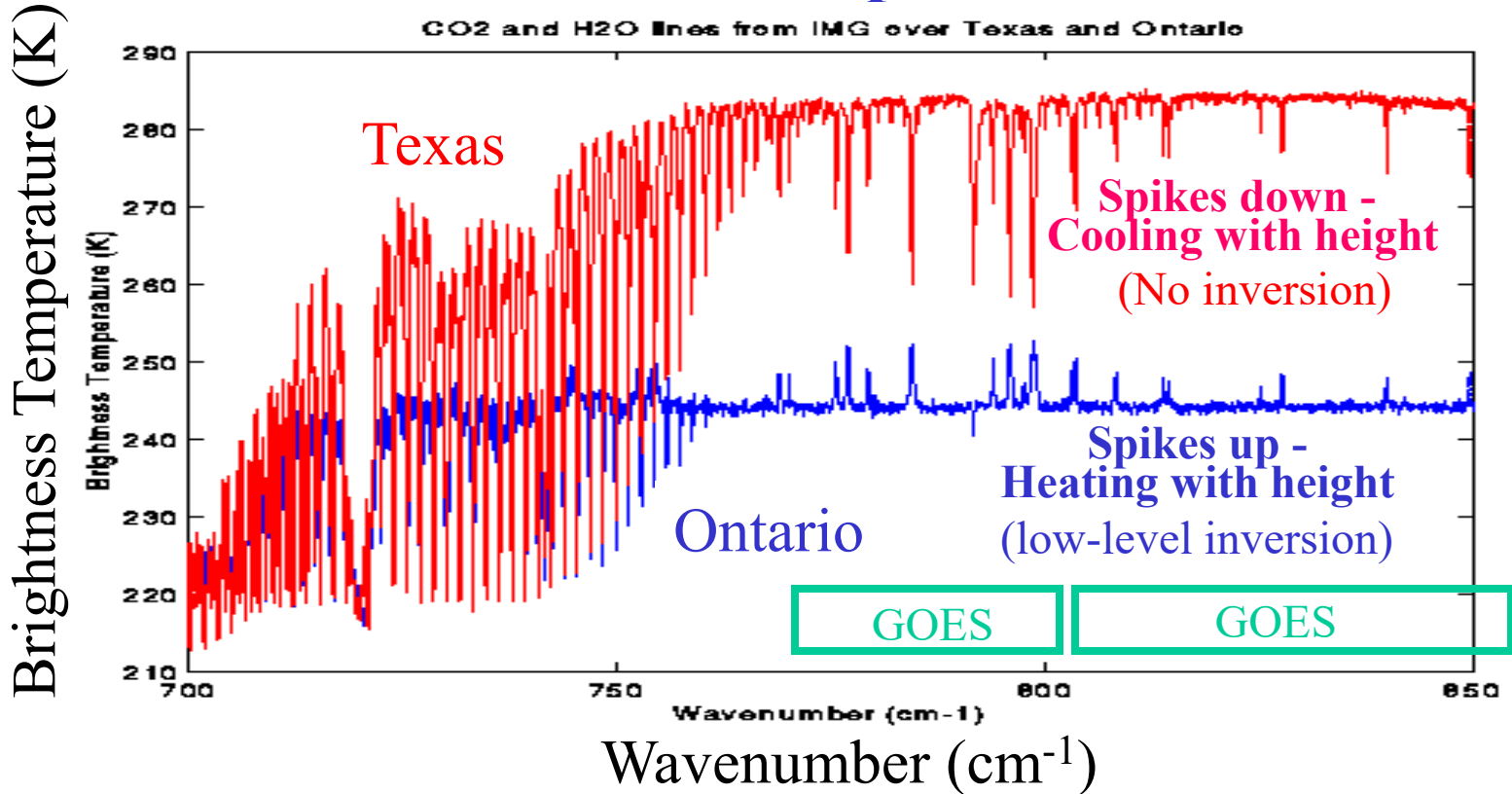


AIRS Spectra from around the Globe

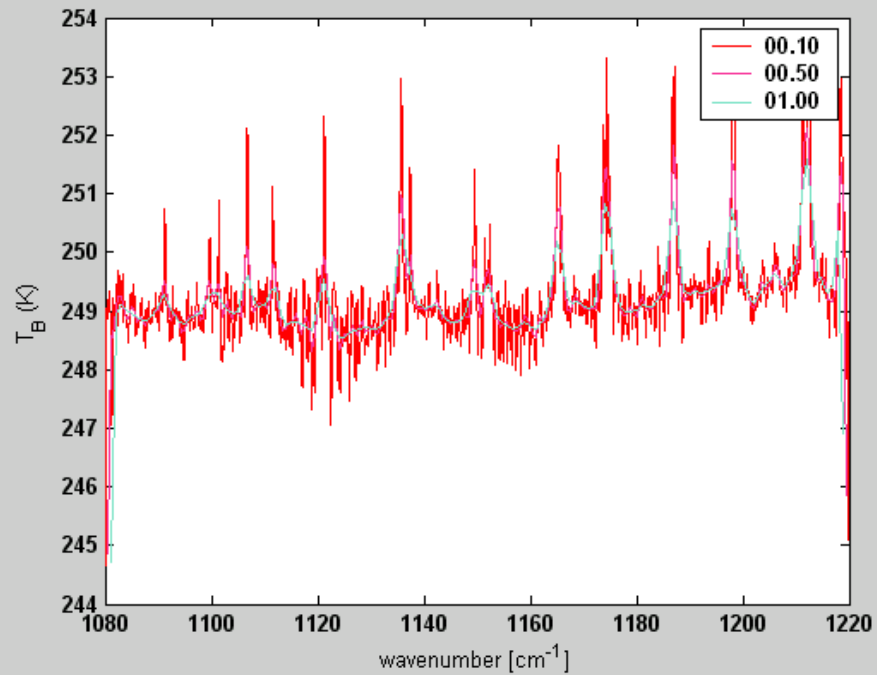
20-July-2002 Ascending LW_Window



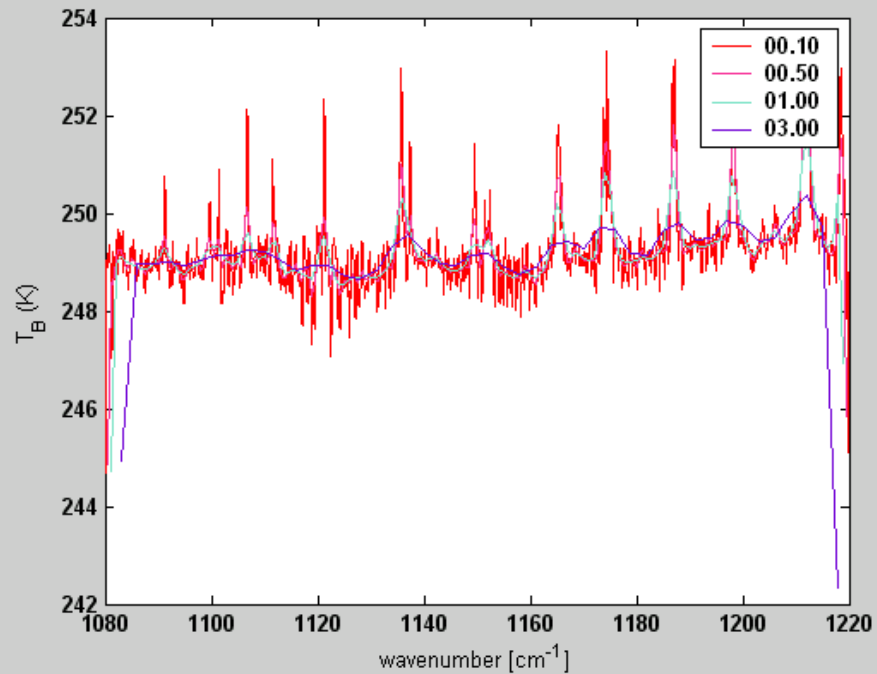
Resolving absorption features in atmospheric windows enables detection of temperature inversions



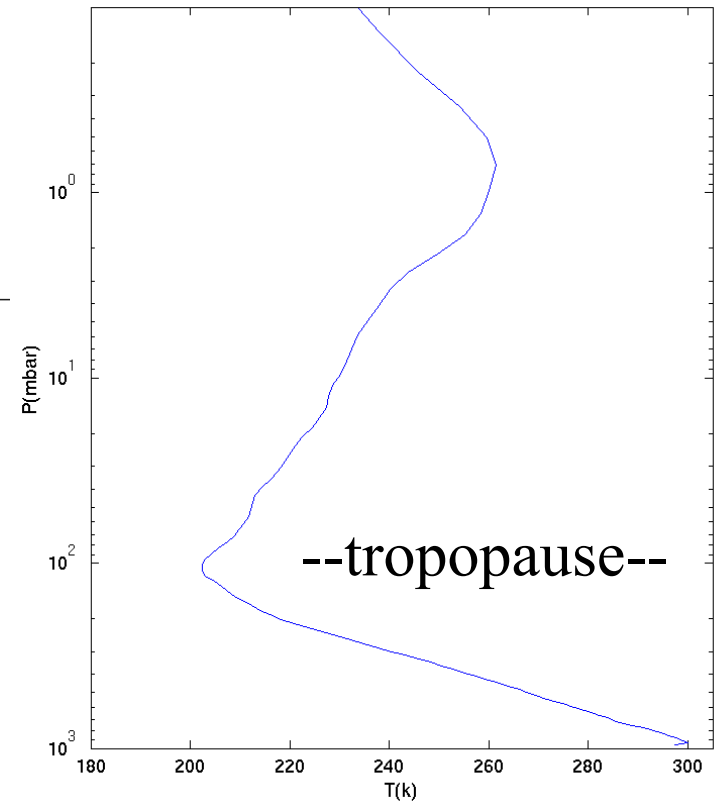
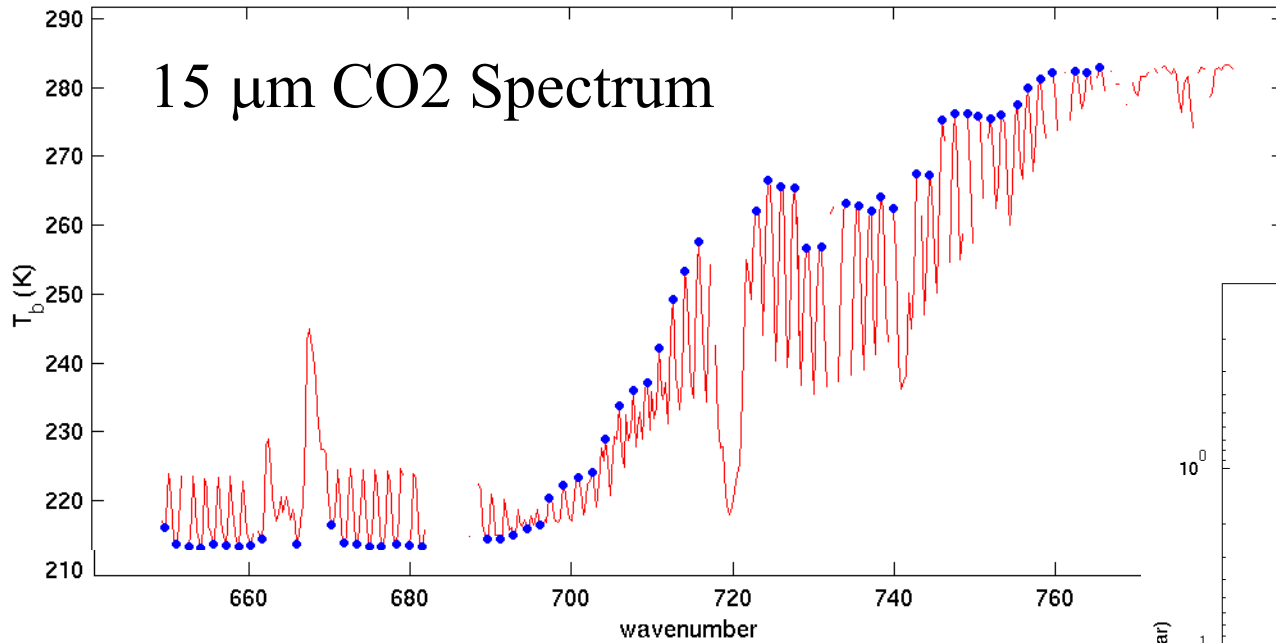
Detection of inversions is critical for severe weather forecasting. Combined with improved low-level moisture depiction, key ingredients for night-time severe storm development can be monitored.



Ability to detect inversions
disappears with
broadband observations
($> 3 \text{ cm}^{-1}$)



Twisted Ribbon formed by CO₂ spectrum: Tropopause inversion causes On-line & off-line patterns to cross

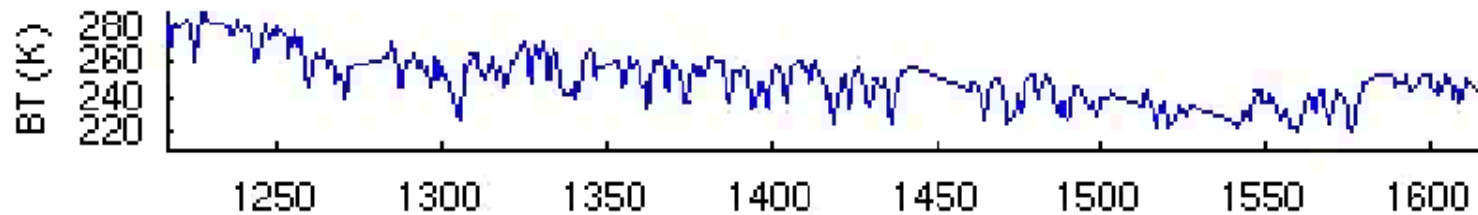
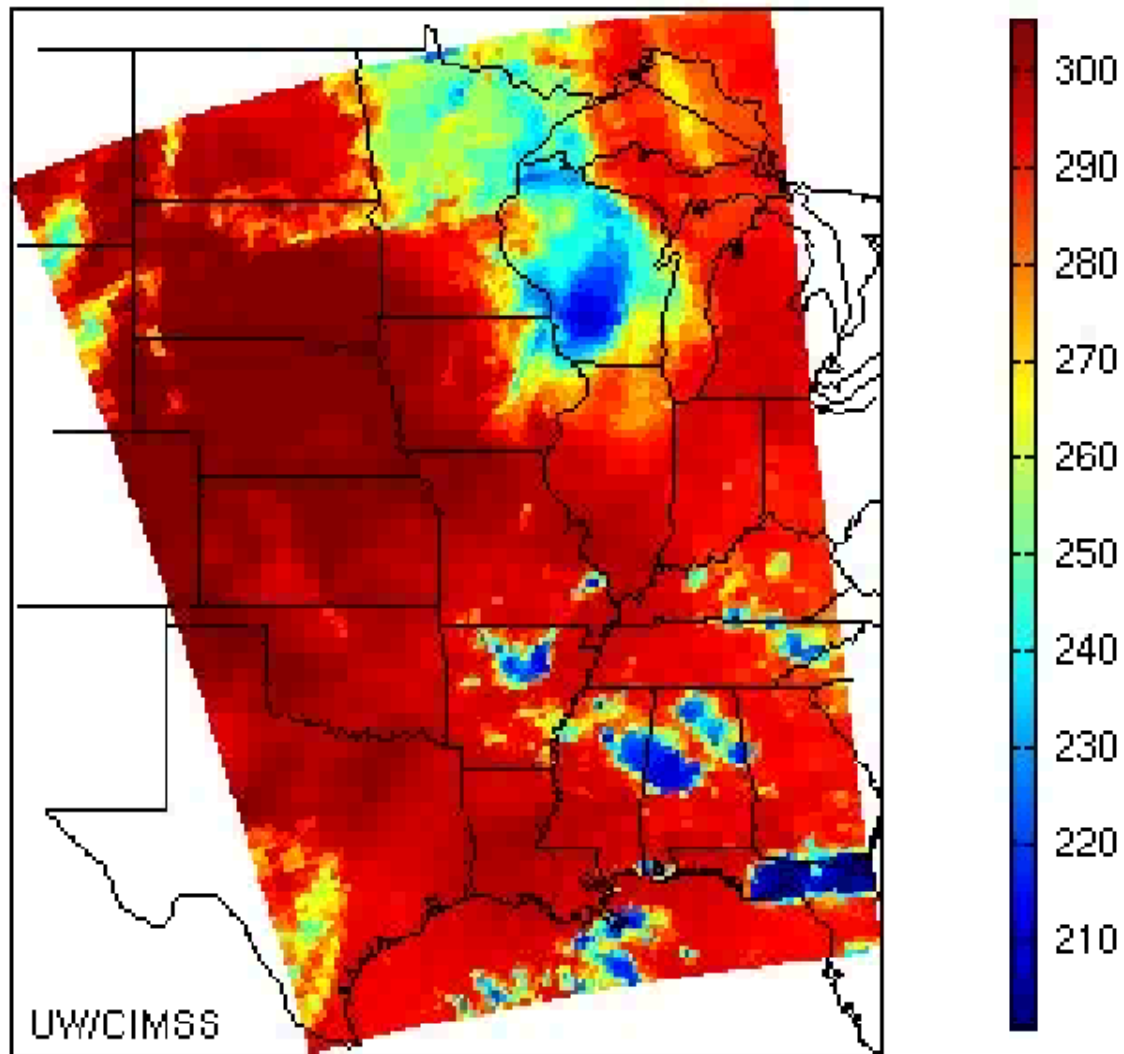


Blue between-line T_b
warmer for tropospheric channels,
colder for stratospheric channels

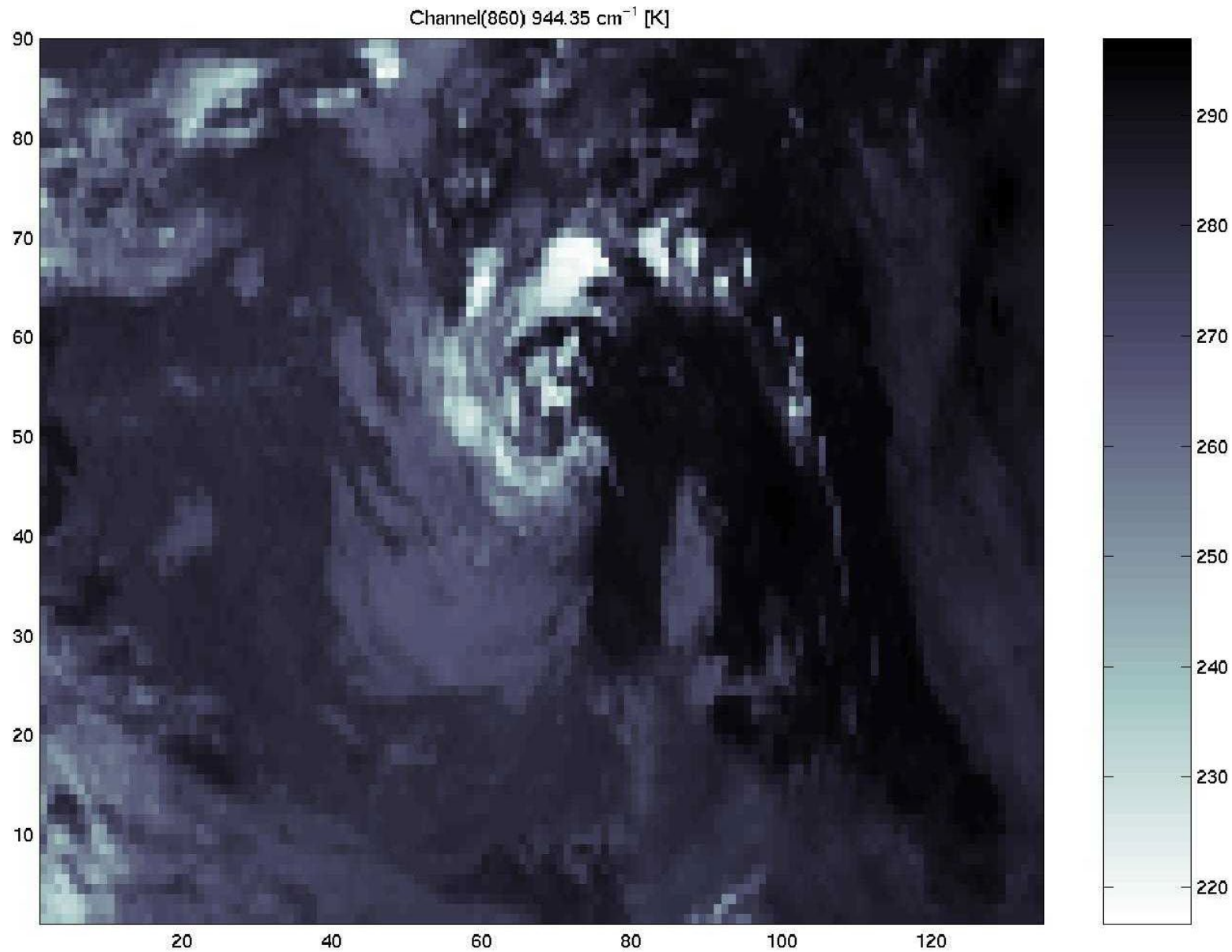
Signature not available at low resolution

Channel 1106 (1216.71 cm^{-1}) 8.22 μm

AIRS
obs in
H₂O
band

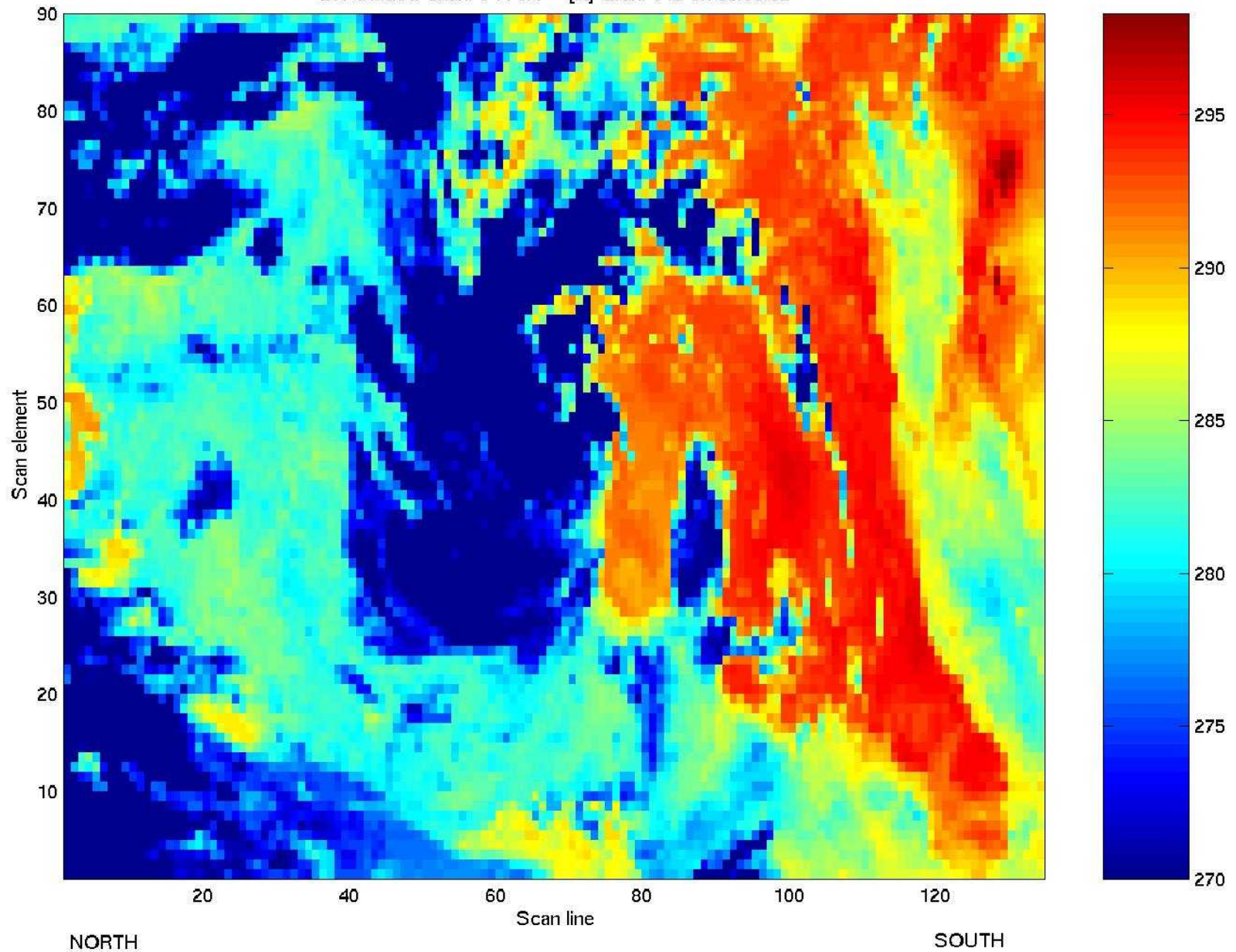


Spatial distribution of 944.1 [1/cm] measurements [K]



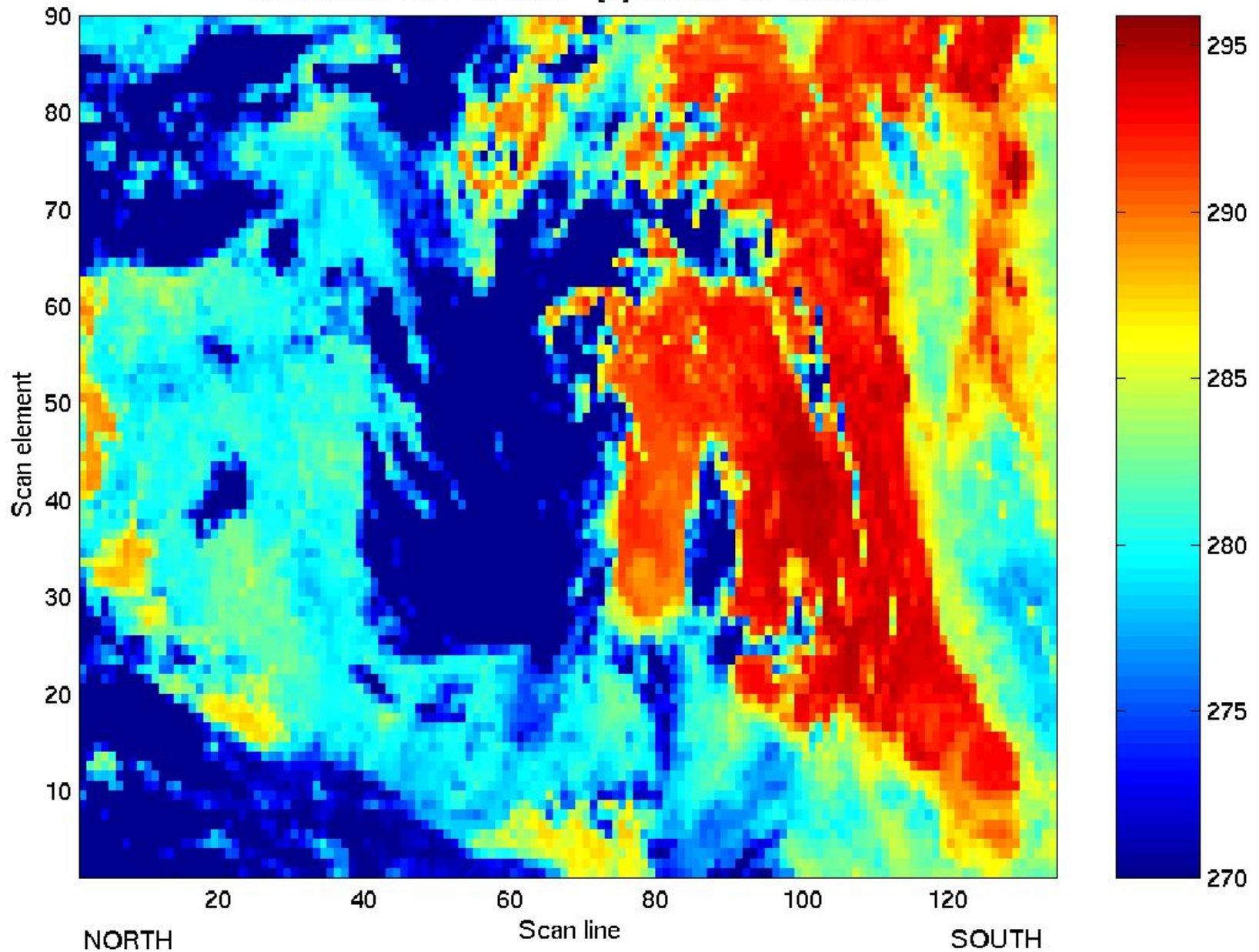
Spatial distribution of 944.1 [1/cm] measurements [K]

LW window chan. 944 cm^{-1} [K] Gran. 016 on 09.06.02

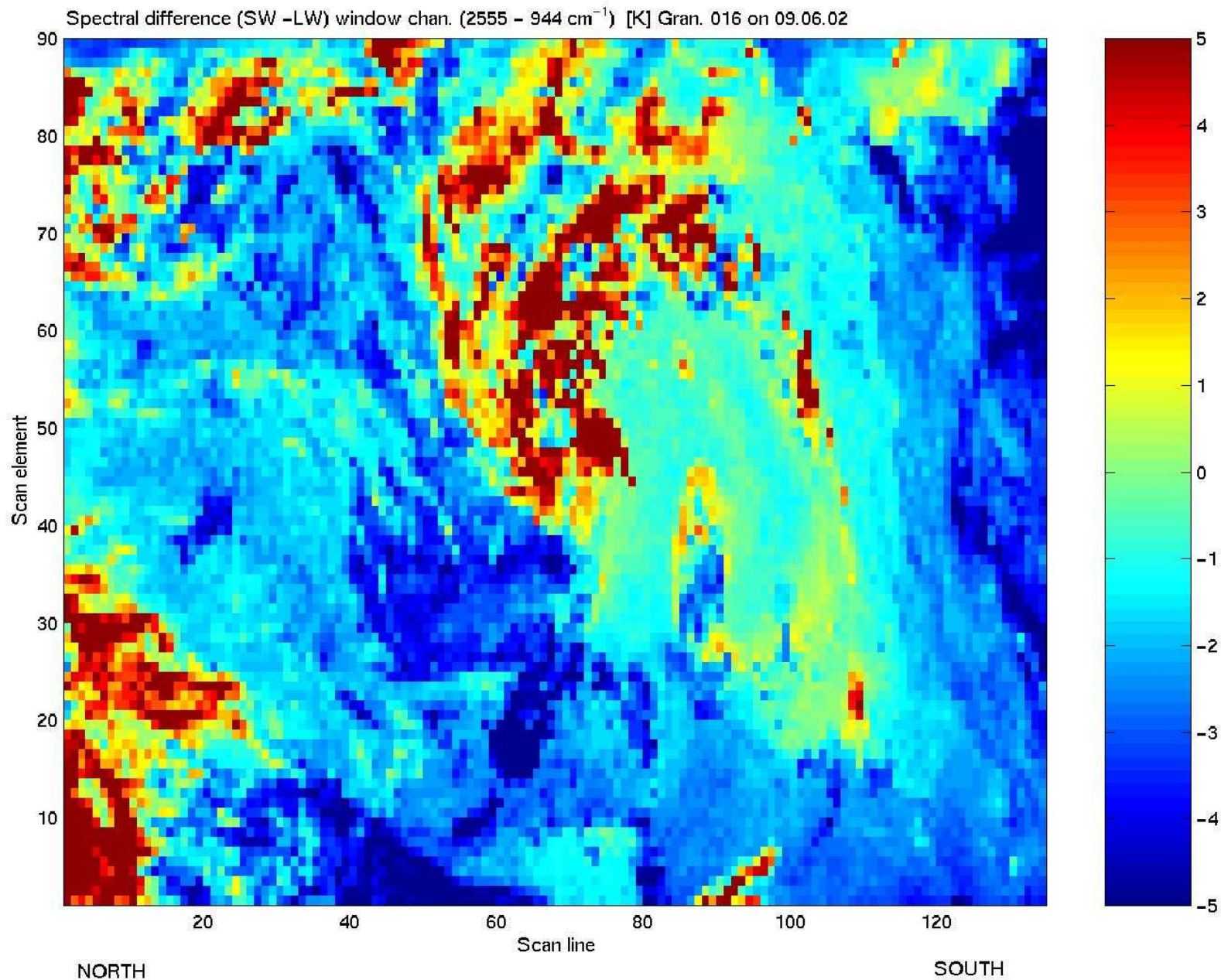


Spatial distribution of 2555 [1/cm] measurements [K]

SW window chan. 2555 cm^{-1} [K] Gran. 016 on 09.06.02

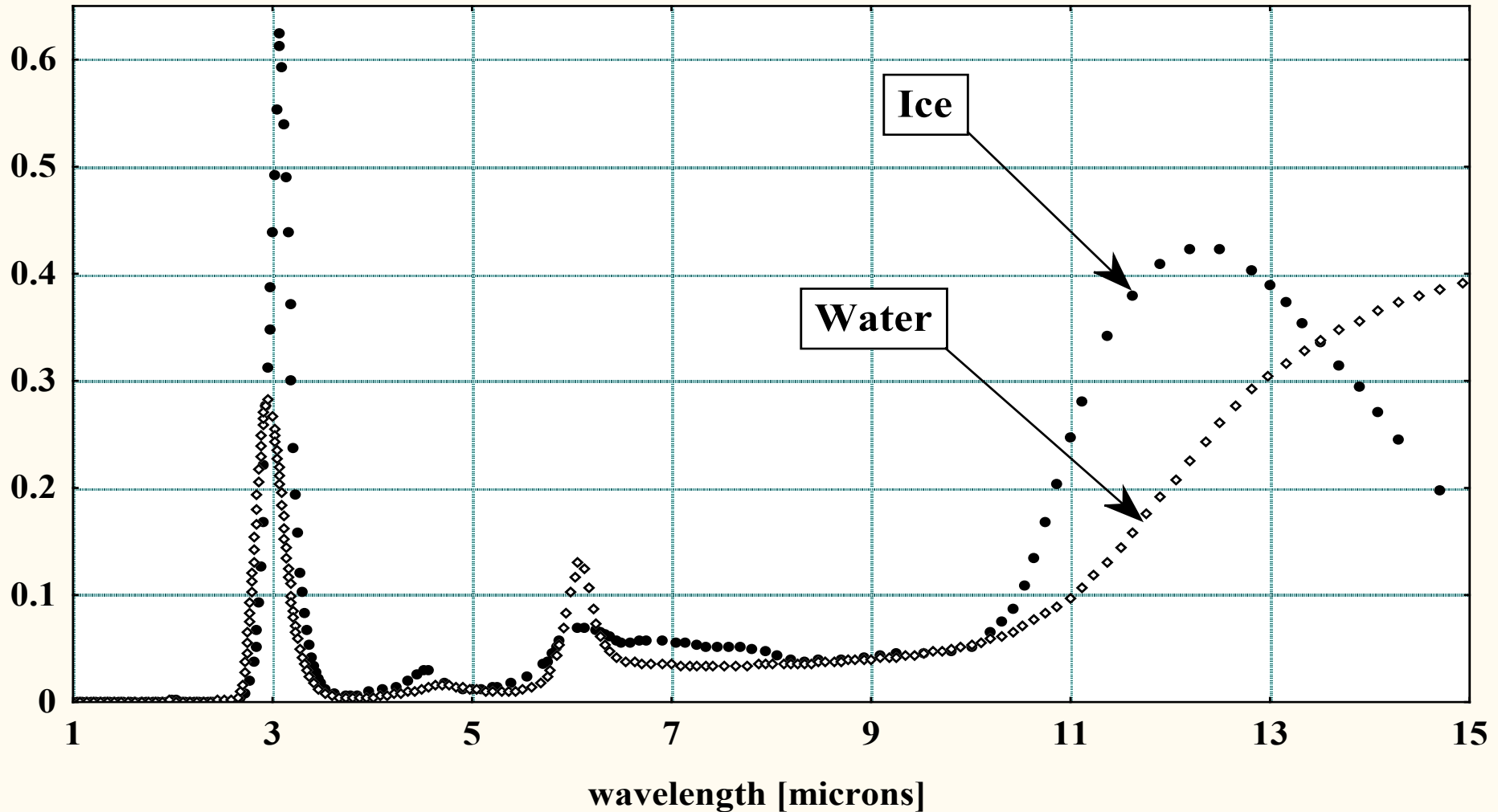


Spatial distribution of 2555 – 944.1 [1/cm] measurements [K]

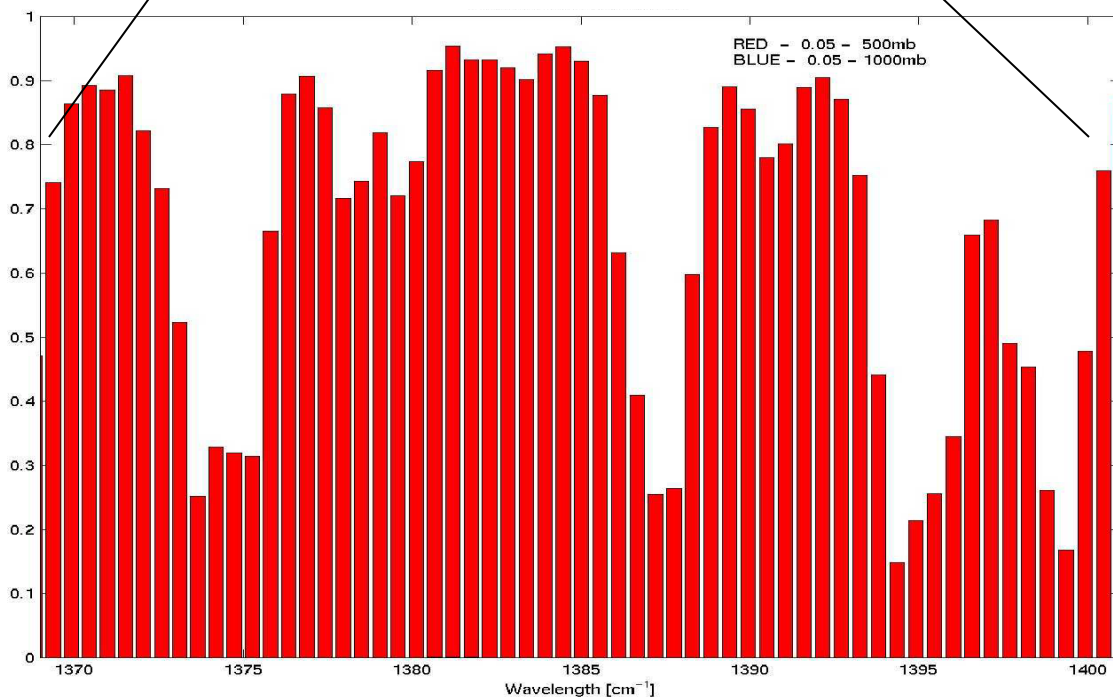
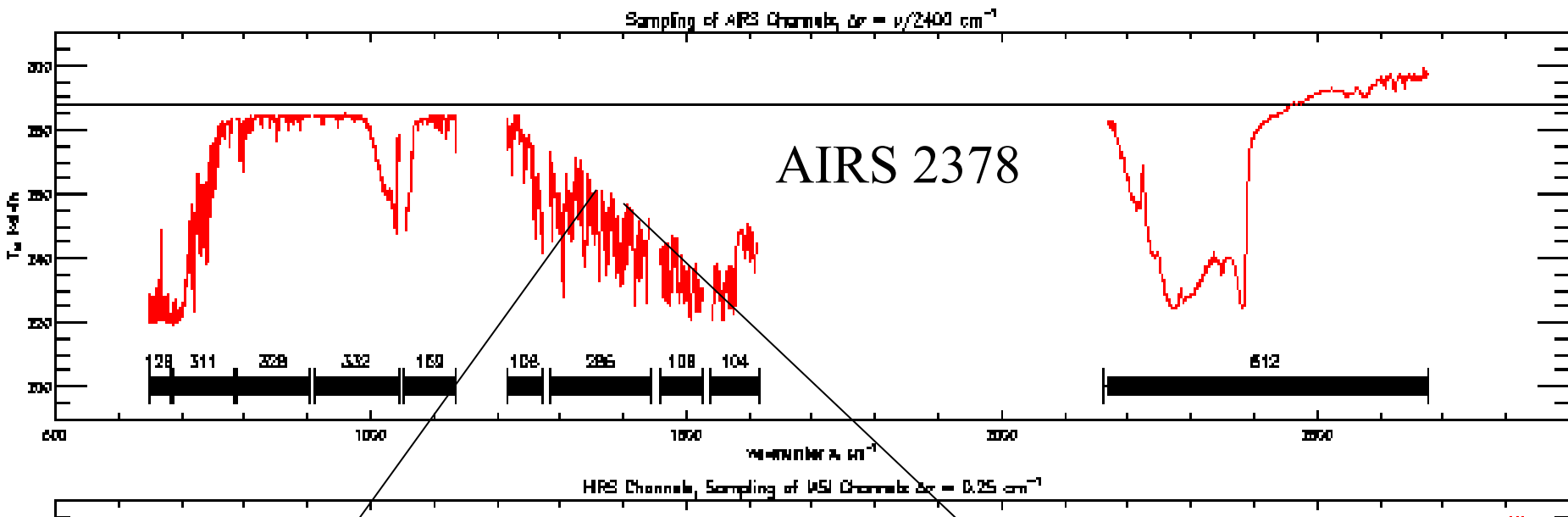


Optical properties of cloud particles: imaginary part of refractive index

Imaginary part of refractive index

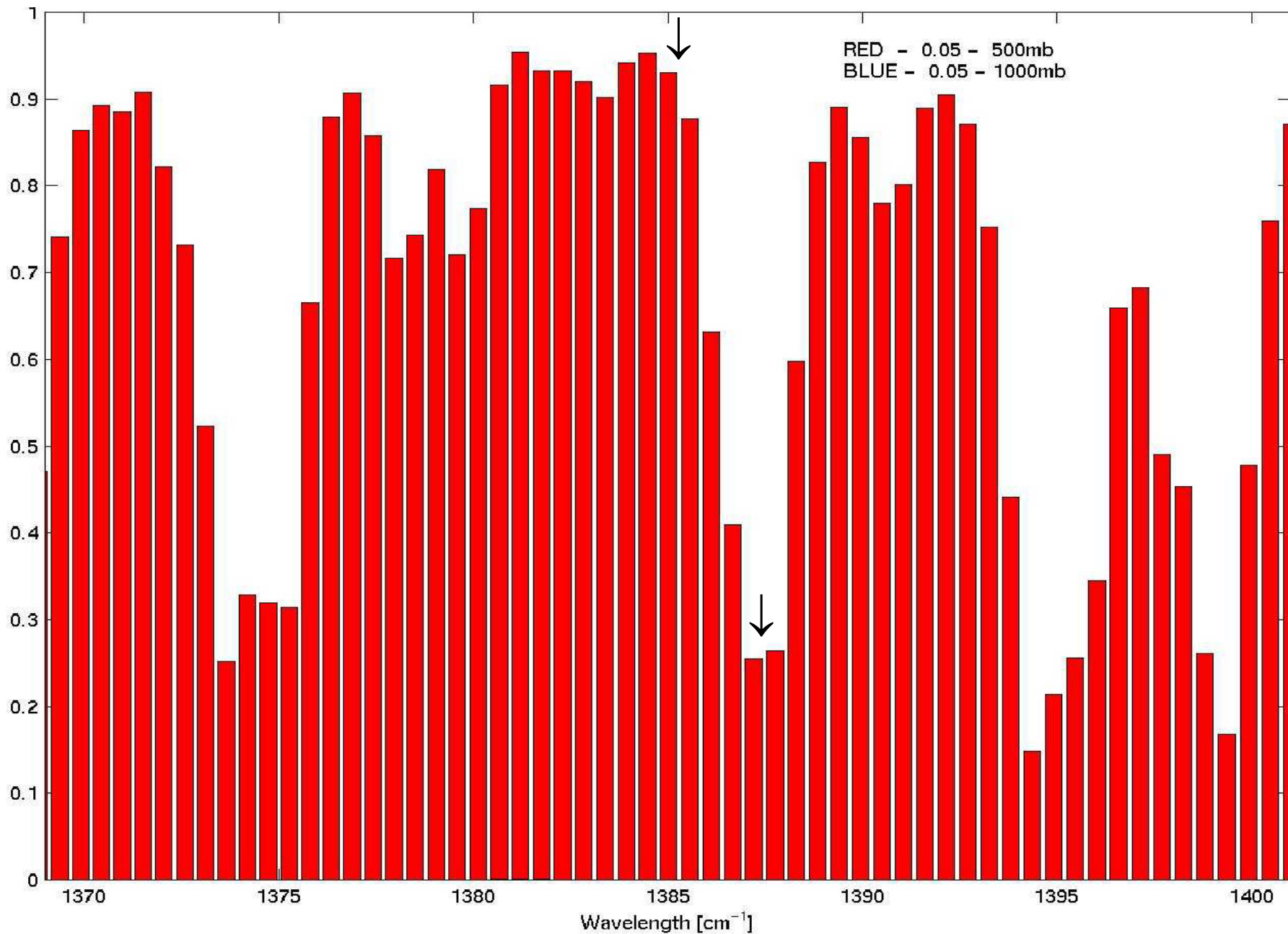


SW & LW channel differences are used for cloud identification
{4 μm - 11 μm }, {4.13 μm - 12.6 μm }, and {4.53 μm - 13.4 μm }

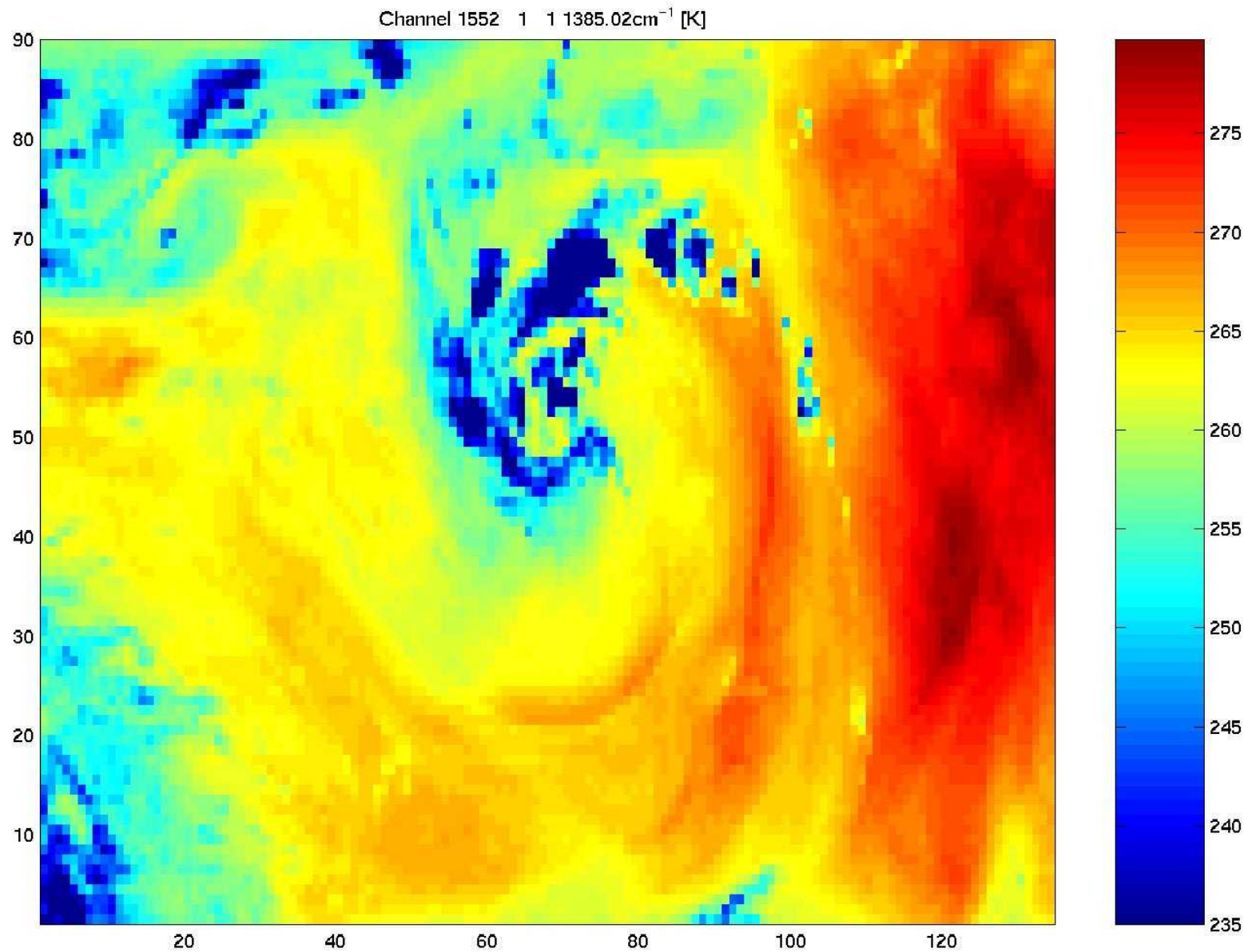


Transmittance
within H₂O
absorption
band

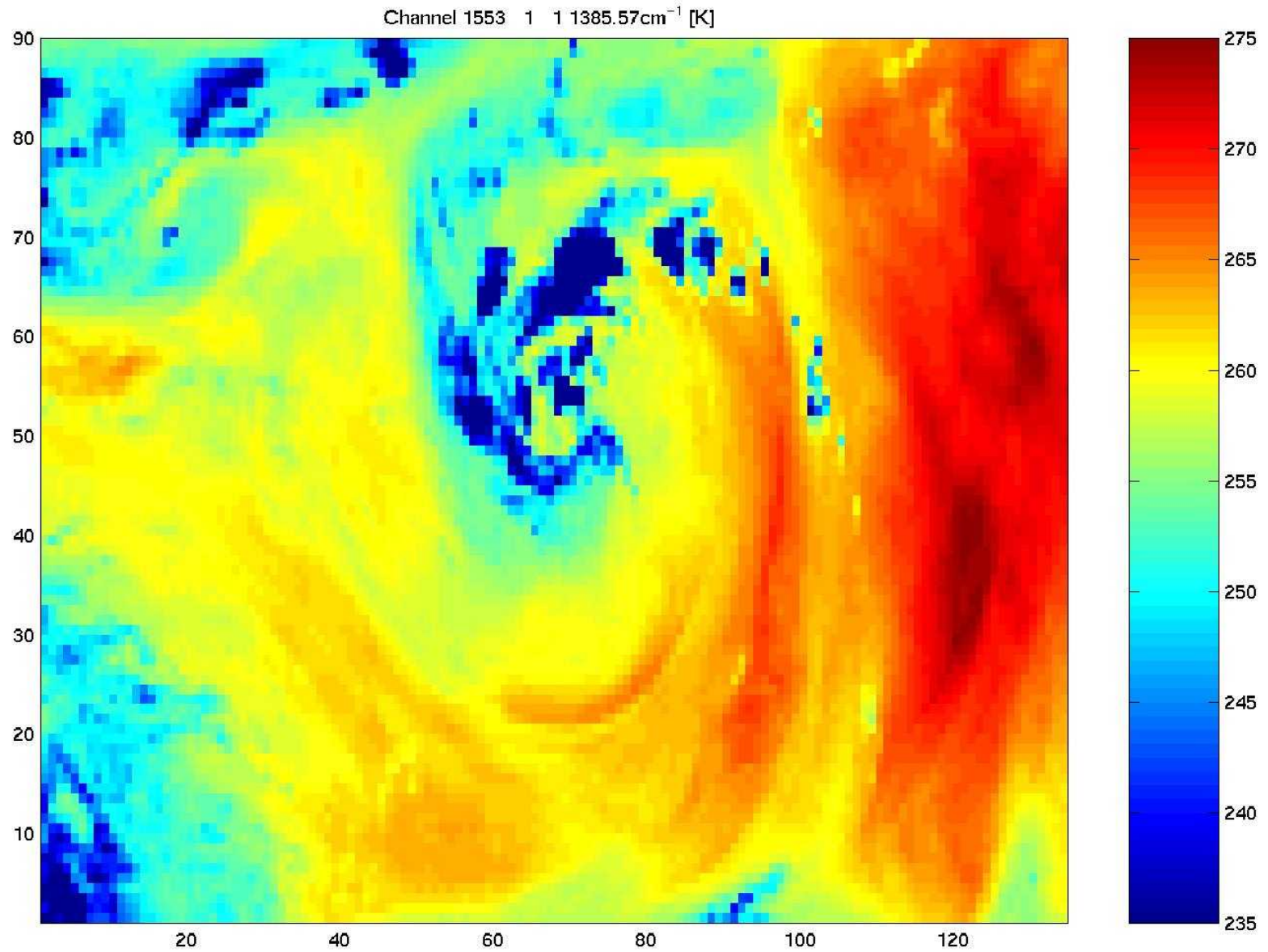
Atmospheric transmittance in H2O sensitive region of spectrum



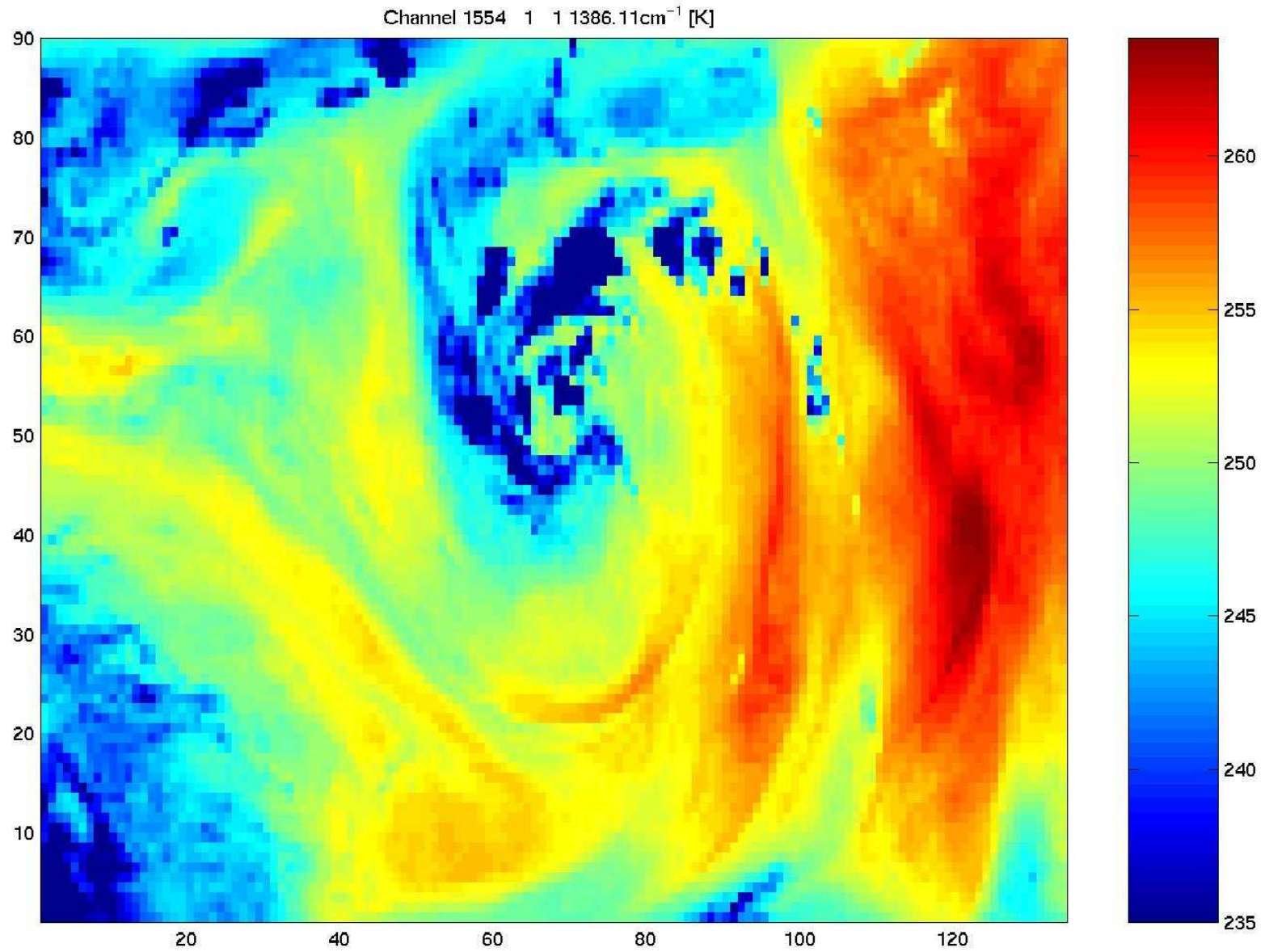
Spatial distribution of Ch 1552 at 1385.02 [1/cm] measurements [K]



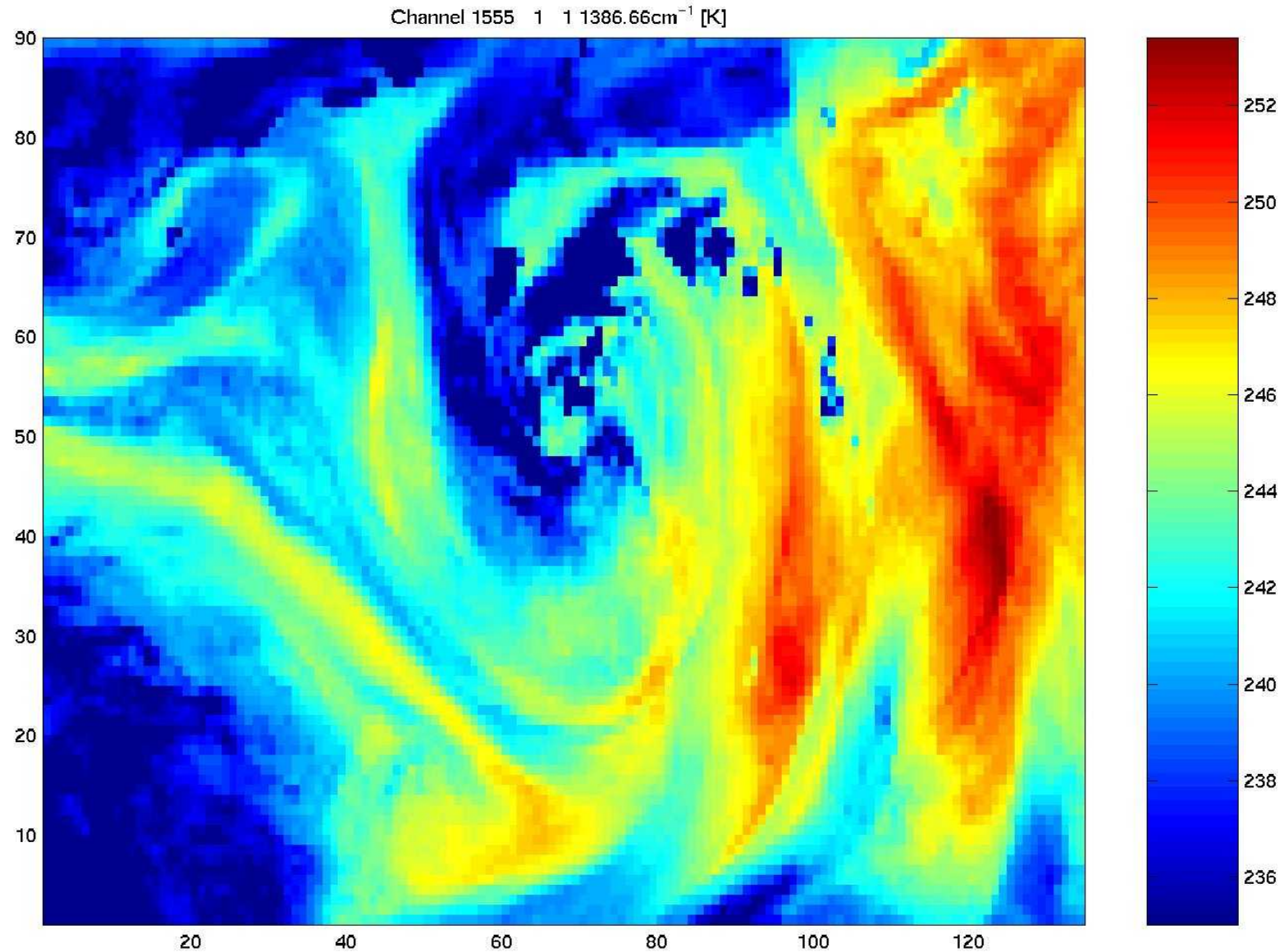
Spatial distribution of Ch 1553 at 1385.57 [1/cm] measurements [K]



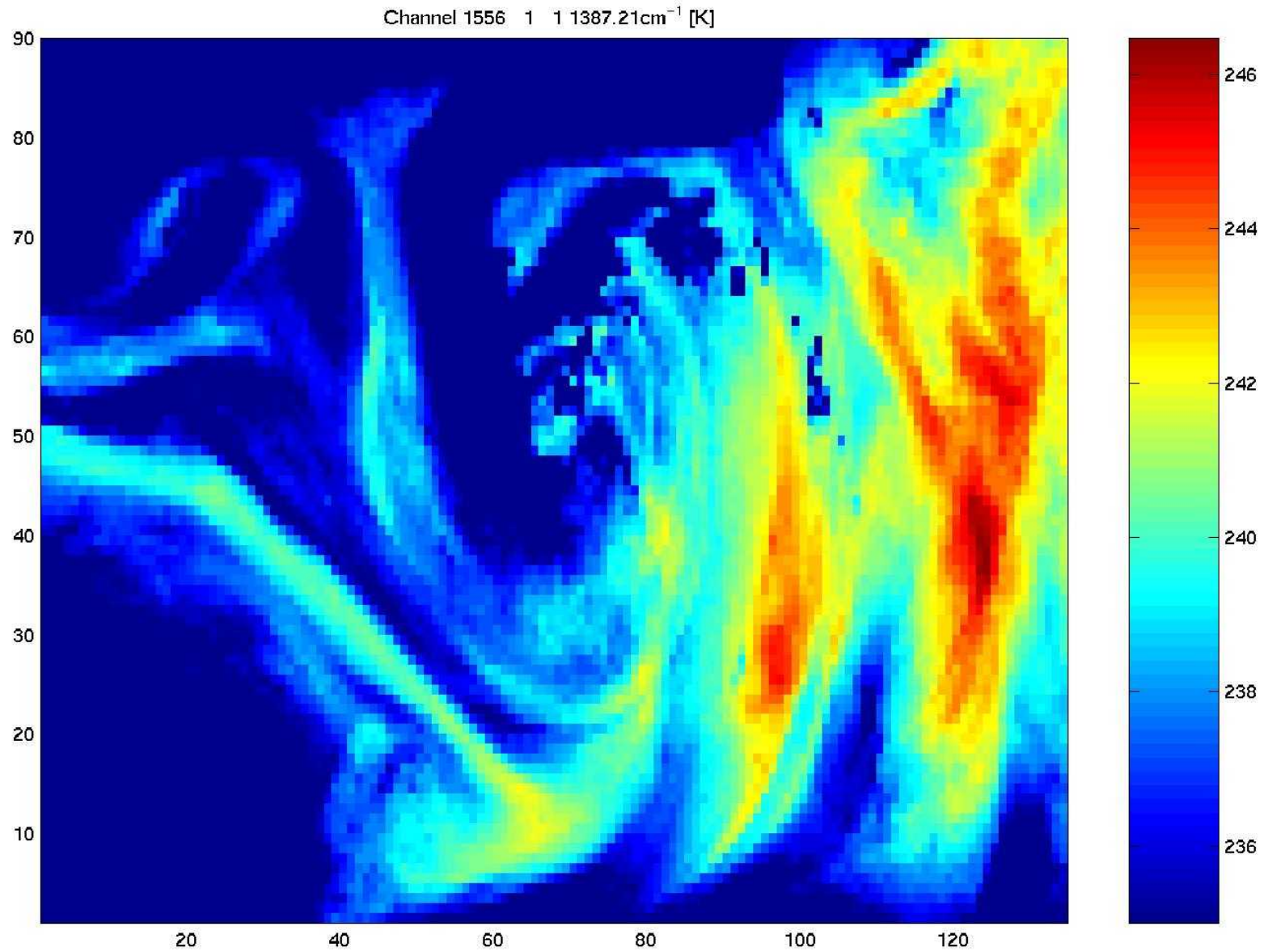
Spatial distribution of Ch 1554 at 1386.11 [1/cm] measurements [K]



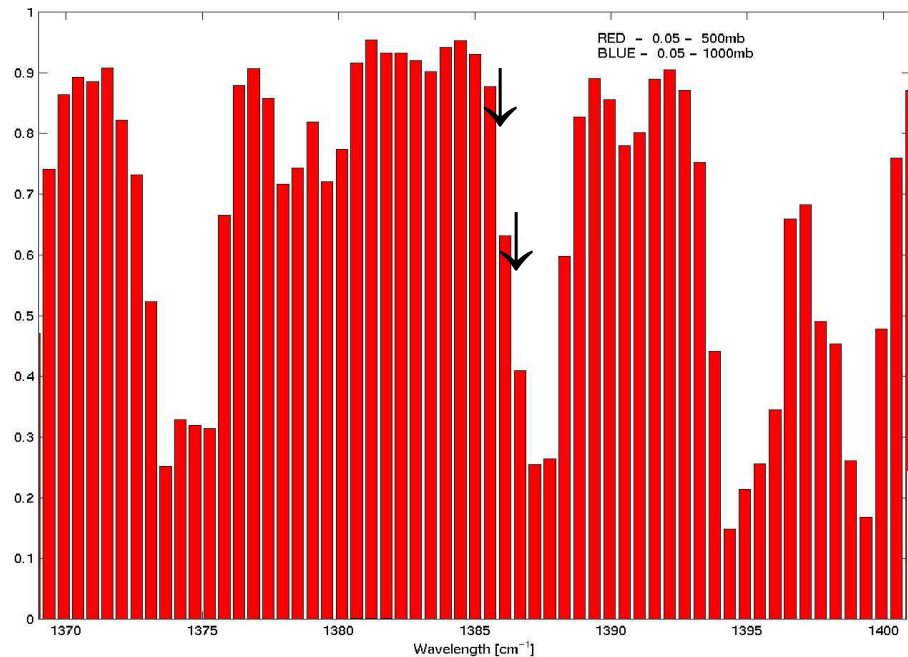
Spatial distribution of Ch 1555 at 1386.66 [1/cm] measurements [K]



Spatial distribution of Ch 1556 at 1387.21 [1/cm] measurements [K]



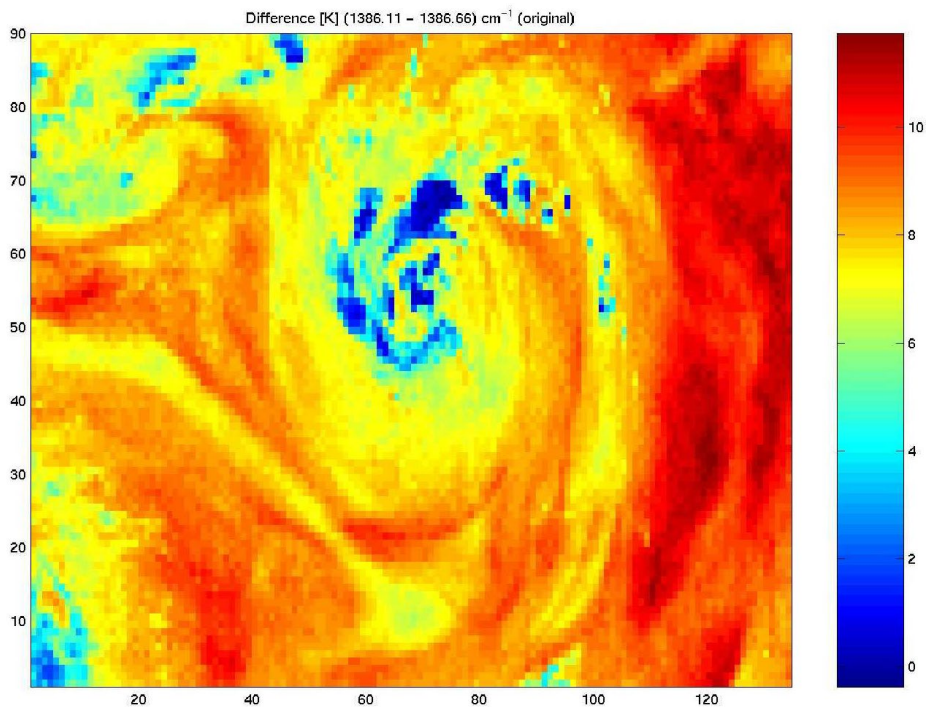
Atmospheric transmittance in H₂O sensitive region of spectrum

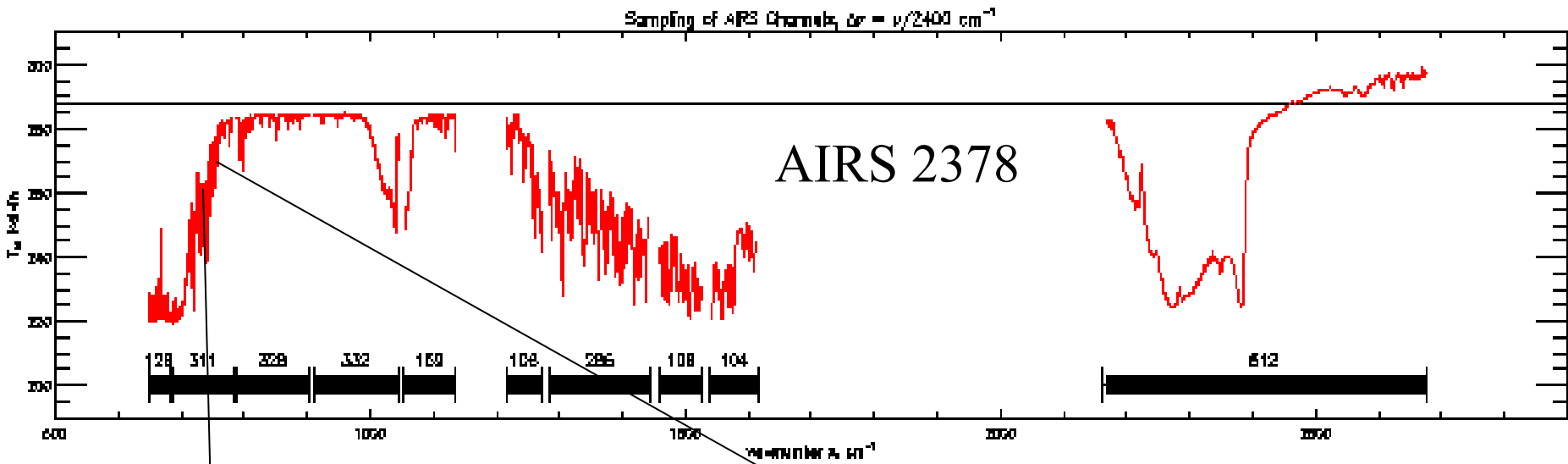


**Spectral change of 0.5 cm^{-1}
causes BT changes > 10 C**

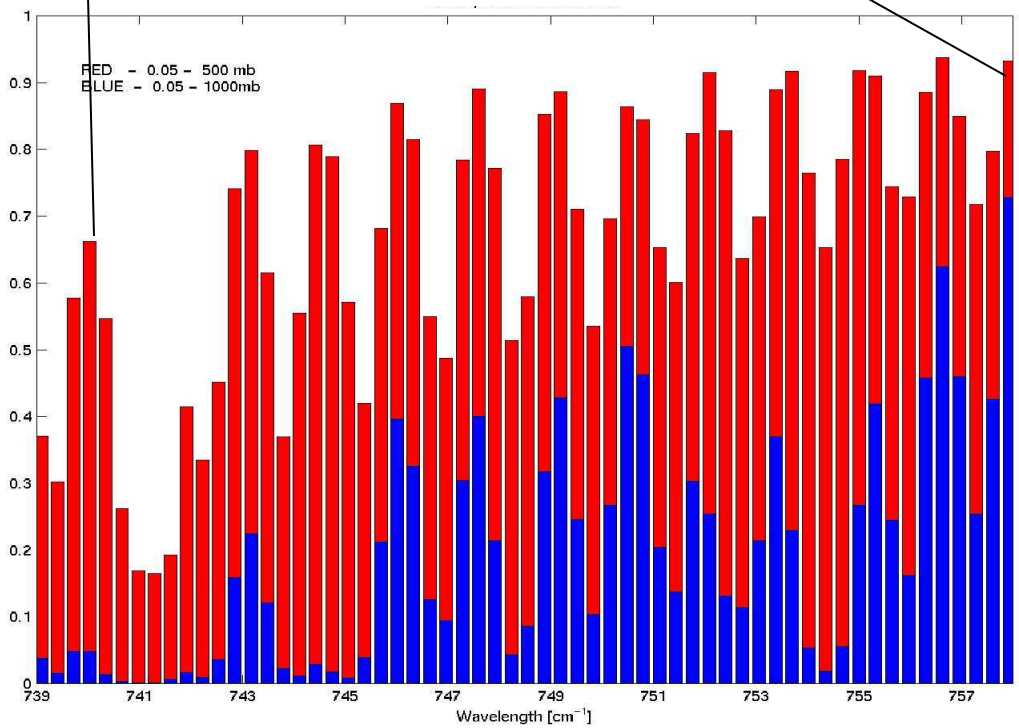
Studying spectral sensitivity with AIRS Data

AIRS BT[1386.11] – BT[1386.66]



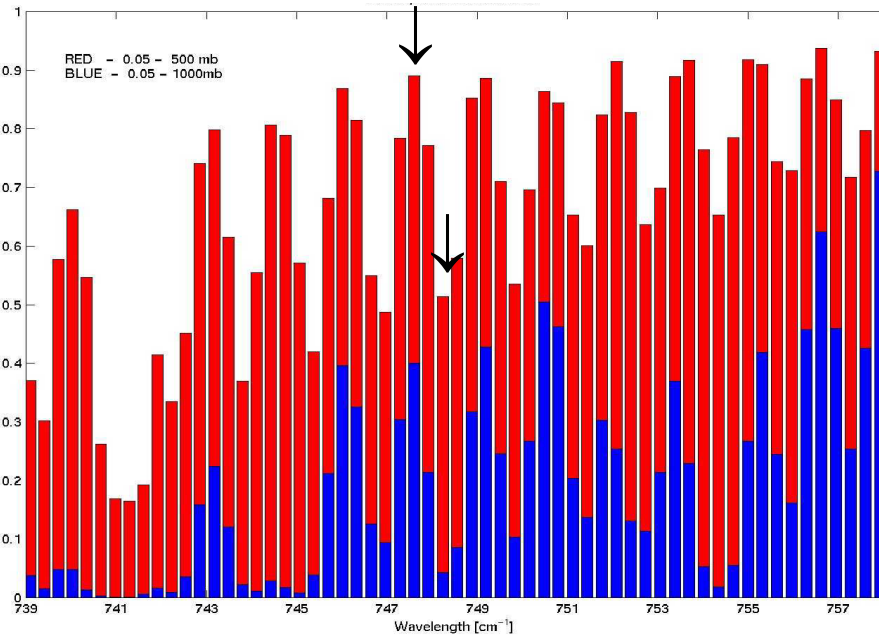


HRS Channels, Sampling of HSI Channels $\Delta\nu = 0.25 \text{ cm}^{-1}$



Transmittance
within CO₂
absorption
band

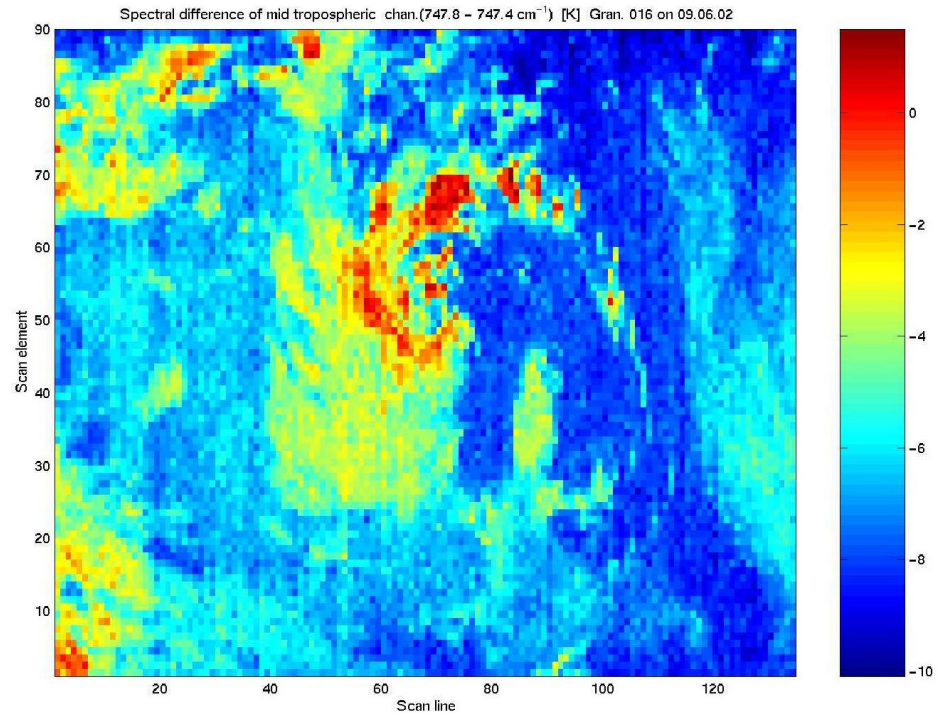
Atmospheric transmittance in CO2 sensitive region of spectrum



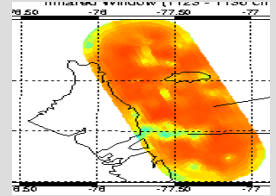
Spectral change of 0.4 cm⁻¹ causes BT changes > 8 C

Studying spectral sensitivity with AIRS Data

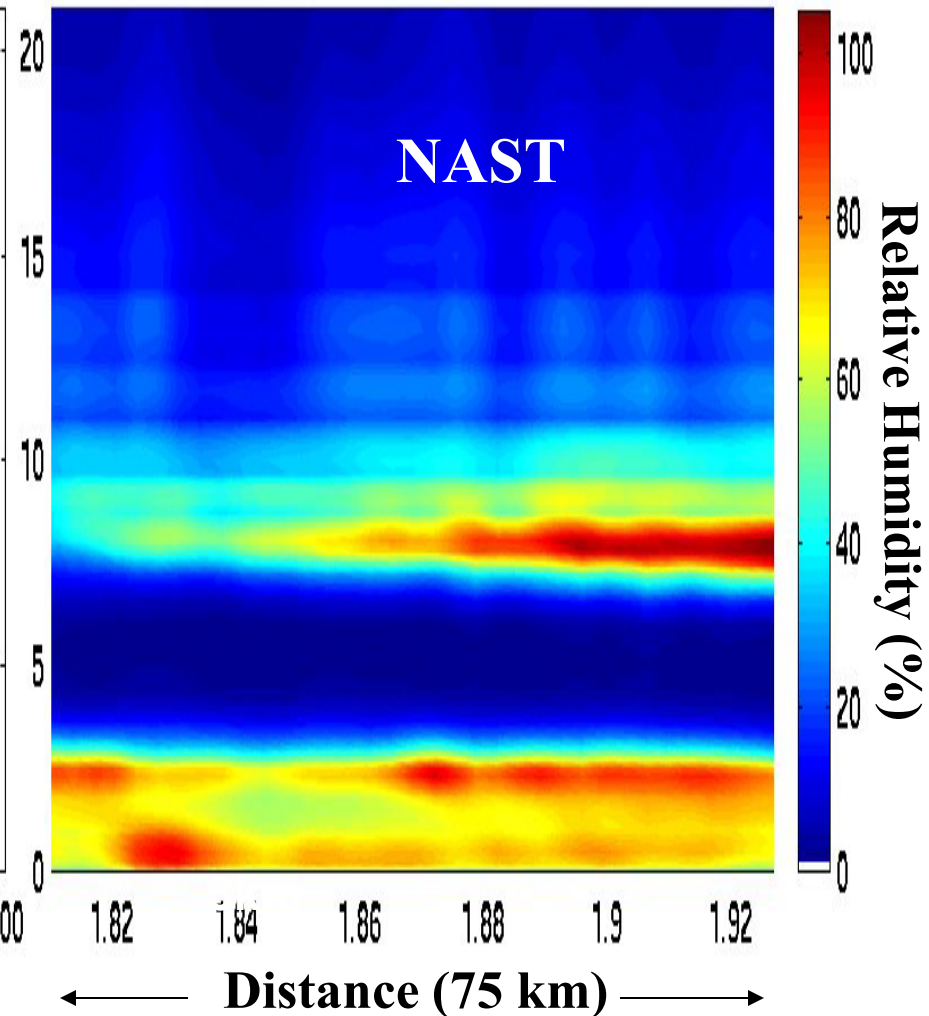
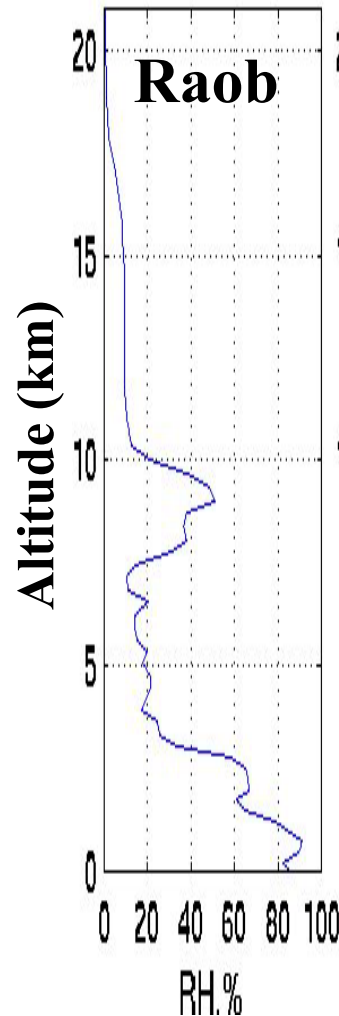
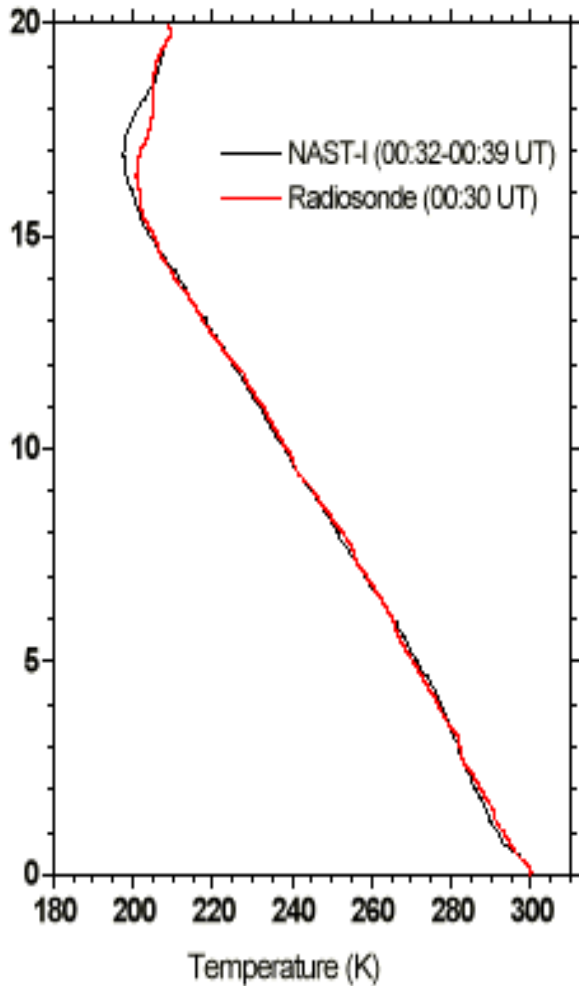
AIRS BT[747.8] – BT[747.4]



Radiosonde Validation



Andros Is. Bahamas, Sept 12, 1998



Spectral Signatures seen with AIRS

Lectures in Krakow
May 2006

Paul Menzel
NOAA/NESDIS/ORA

AIRS data from 28 Aug 2005

The screenshot displays a Windows desktop environment with the following elements:

- Taskbar:** Shows the Start button, taskbar buttons for "ET EGOS input to...", "c:\ run HYDRA", "Microsoft Power...", "Hydra (Version: ...)", "Multi-Channel Vie...", and system tray icons for volume, network, and time (10:36 AM).
- Desktop Icons:** Mozilla Firefox, VZAccess Manager, Mozilla Thunderbird, and Shortcut to IEXPLORE.
- Hydra (Version: v1.6b2) Window:** Features a menu bar (File, Load, Tools, Settings, Start) and a toolbar with navigation icons. The main display area shows a map of Europe with a grayscale satellite-style image overlaid on a rectangular region.
- Multi-Channel Viewer Window:** Contains a "Tools Settings" menu and a plot titled "Clear Sky Spectra".
 - Plot:** The y-axis is labeled "brightnessTemp" with values 180 and 320. The x-axis is labeled "wavenumber" with values 1000 and 2500. A green vertical line is positioned at approximately 2446.20 on the x-axis.
 - Wavenumber Input:** A text box below the plot contains "wavenumber 2446.20 cm⁻¹".
 - Map:** A zoomed-in view of the map from the Hydra window, showing two specific data points: a yellow dot labeled "230.65" and a green dot labeled "327.09".
 - Instrument:** A label at the bottom of the window reads "Instrument: AIRS".

AIRS data from 28 Aug 2005

The image displays a Windows desktop environment with several open applications. The desktop background is a landscape with a blue sky and green grass. The taskbar at the bottom shows the Start button and several open programs: ET EGOS input to..., run HYDRA, Microsoft Power..., Hydra (Version: ...), Multi-Channel Vie..., 80% battery, and system tray icons including a clock showing 10:40 AM.

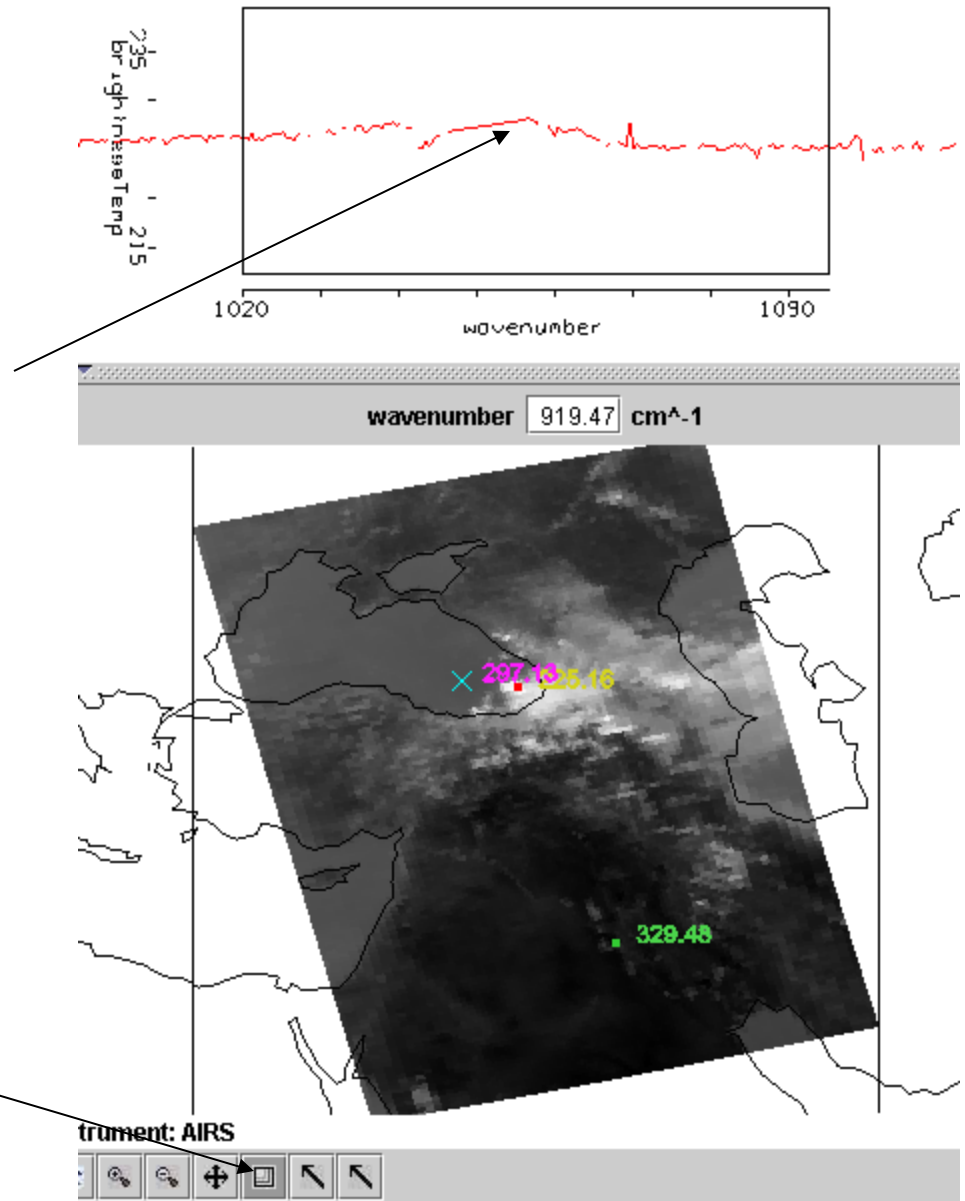
The primary application in the foreground is **Hydra (Version: v1.6b2)**. It features a menu bar with **File**, **Load**, **Tools**, **Settings**, and **Start**. Below the menu is a toolbar with icons for home, search, zoom, and other functions. The main display area shows a map of Europe with a large, tilted satellite image of a cloud field overlaid on it.

Another application window, **Multi-Channel Viewer**, is open on the right side of the screen. It has a menu bar with **Tools** and **Settings**. The main window title is **Clear Sky vs Opaque High Cloud Spectra**. It contains a spectral plot with the following characteristics:

- Y-axis:** labeled "brightness Temp", with values 180 and 220.
- X-axis:** labeled "wavenumber", with values 1000 and 2500.
- Traces:** Two spectral traces are shown, one in black and one in red. The black trace shows significant absorption features, while the red trace is relatively flat.
- Zoomed View:** Below the main plot, a zoomed-in view of a specific wavenumber is shown. The wavenumber is **2446.20 cm⁻¹**. Three data points are marked on this zoomed view:
 - A cyan 'x' at **294.25**
 - A red square at **236.65**
 - A green square at **327.09**
- Instrument:** The text **Instrument: AIRS** is displayed at the bottom of the zoomed view.

The Multi-Channel Viewer also has a toolbar at the bottom with icons for home, search, zoom, and other functions.

Zoom in
on spectra from cloudy fov
to see warming with height
above tropopause
in O3 absorption band

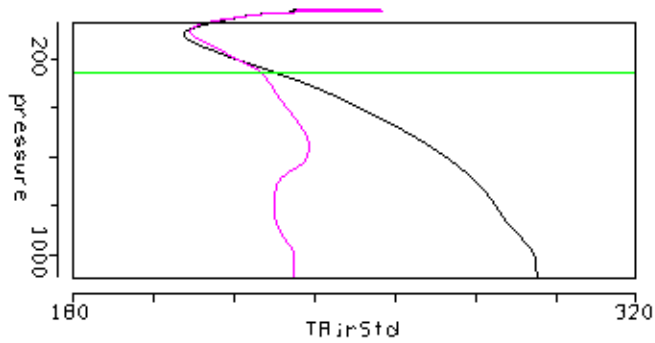


Zoom toolbar

High cloud at 250 hPa

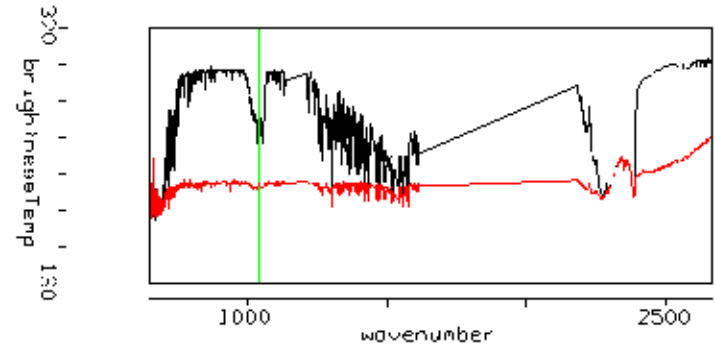
Hydra AIRS Level 2 Products

Variables Levels Settings Tools

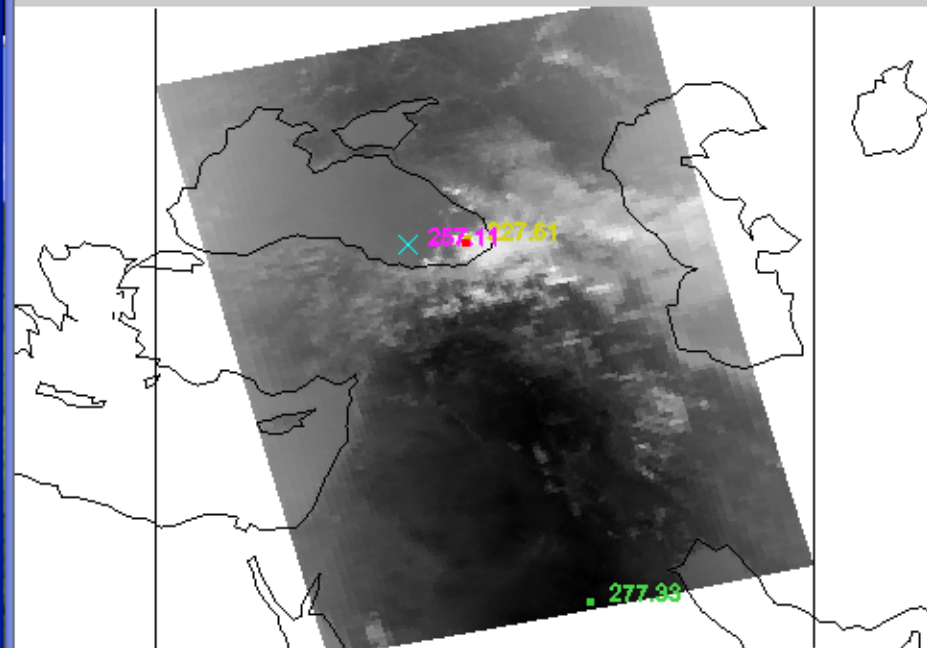
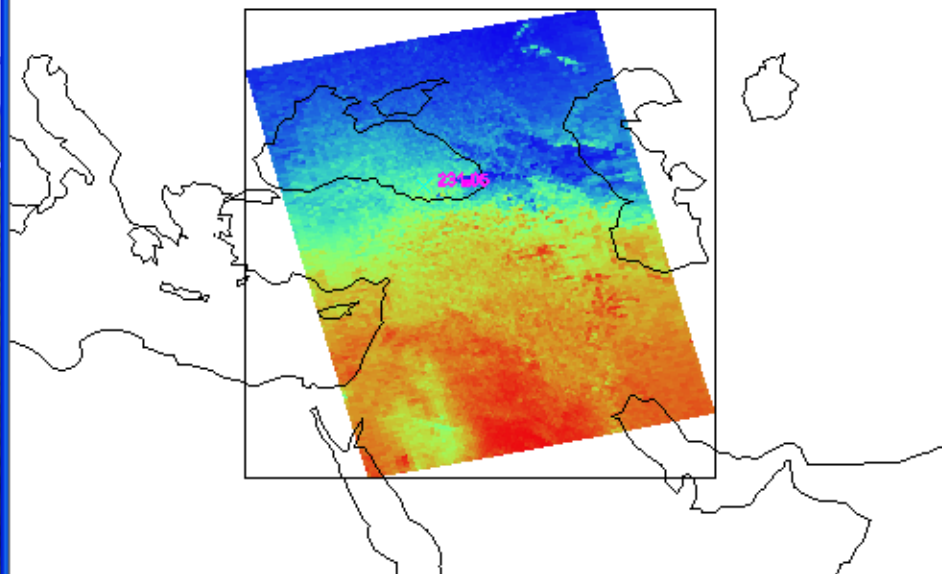


Multi-Channel Viewer

Tools Settings



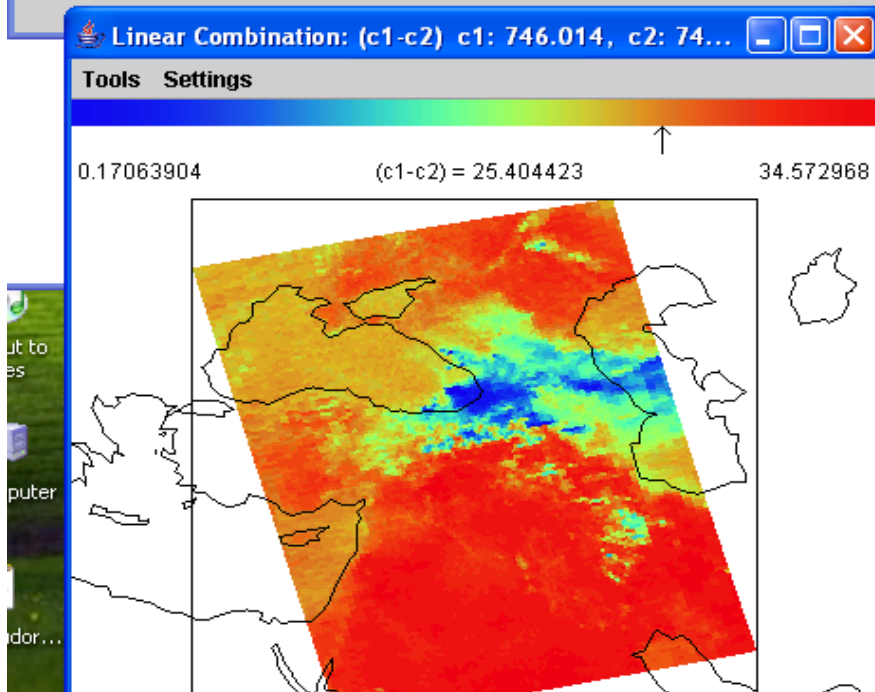
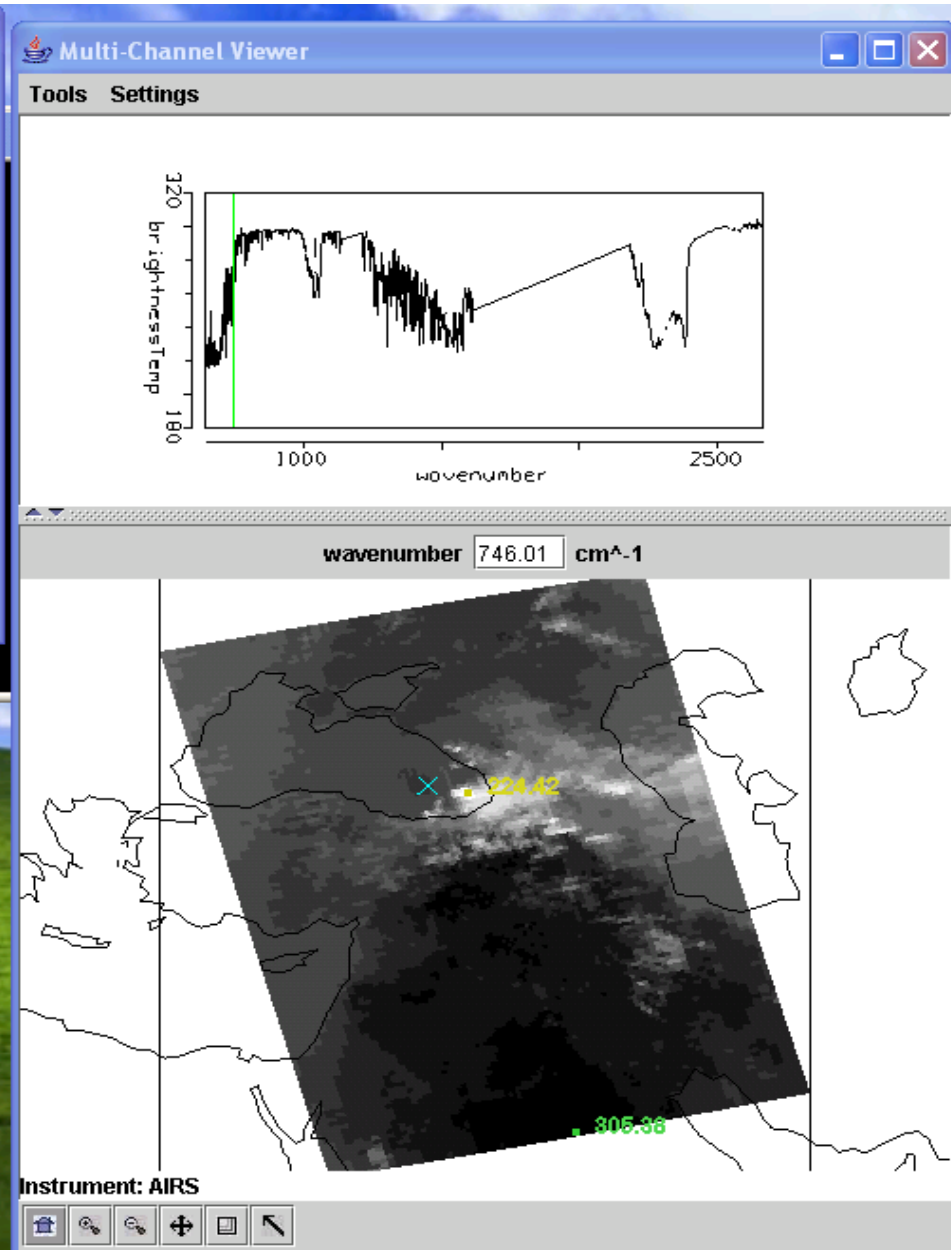
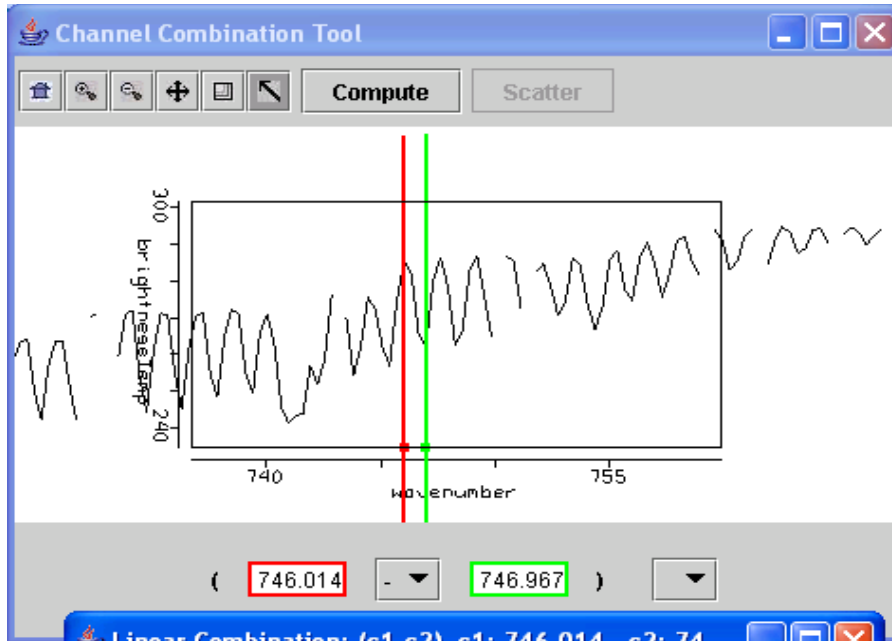
wavenumber 1040.61 cm⁻¹



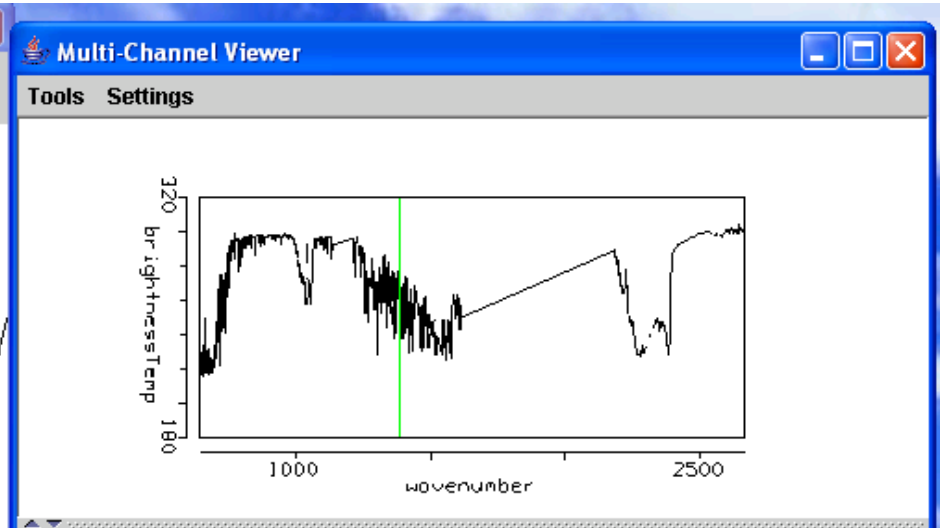
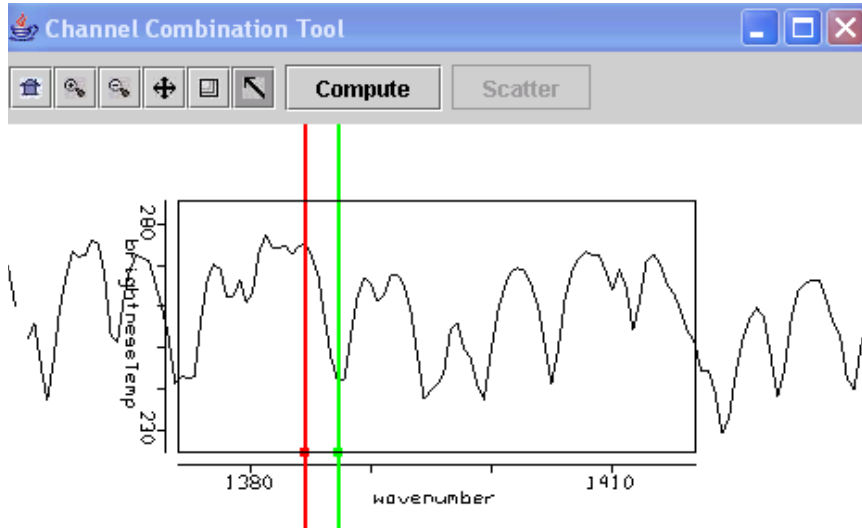
Instrument: AIRS



Offline-Online in LW CO2



Offline-Online in H2O



(1384.476 - 1387.200)

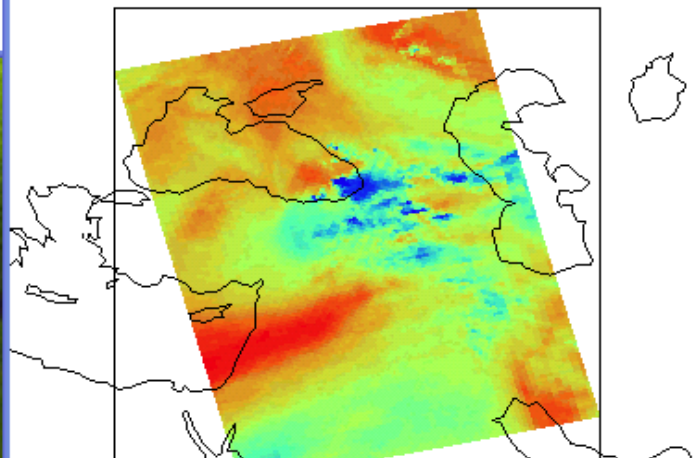
Linear Combination: (c1-c2) c1:1384.476...

Tools Settings

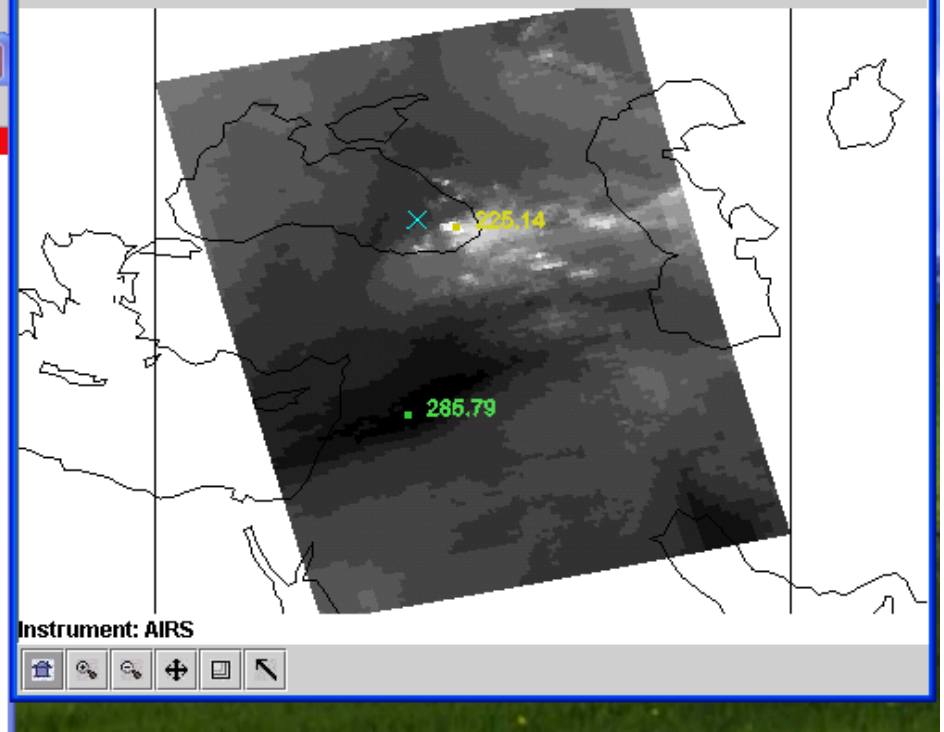
0.95150757

(c1-c2) = 21.7416

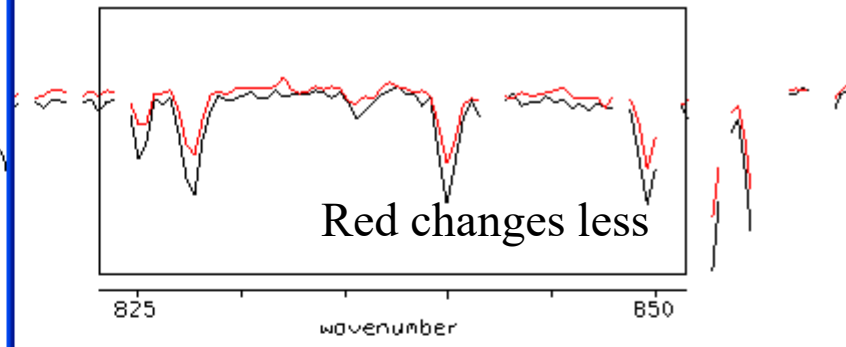
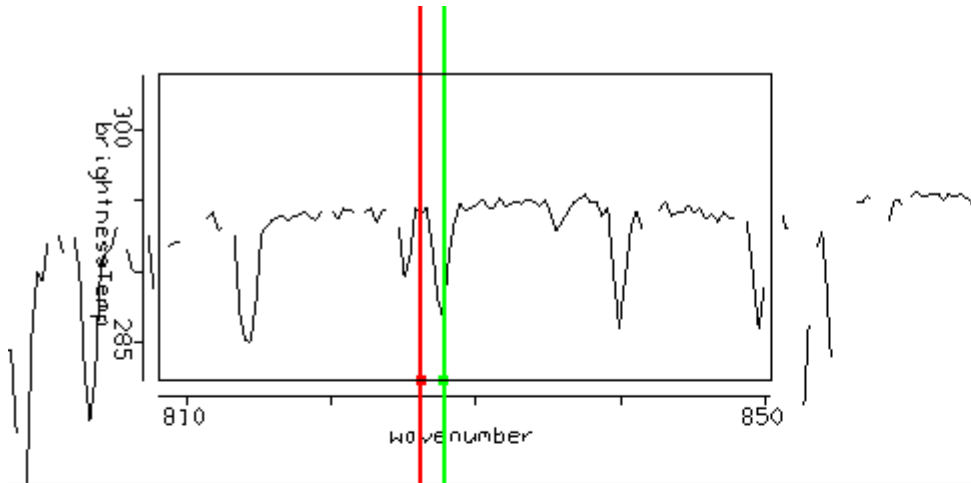
42.531693



wavenumber 1385.02 cm⁻¹



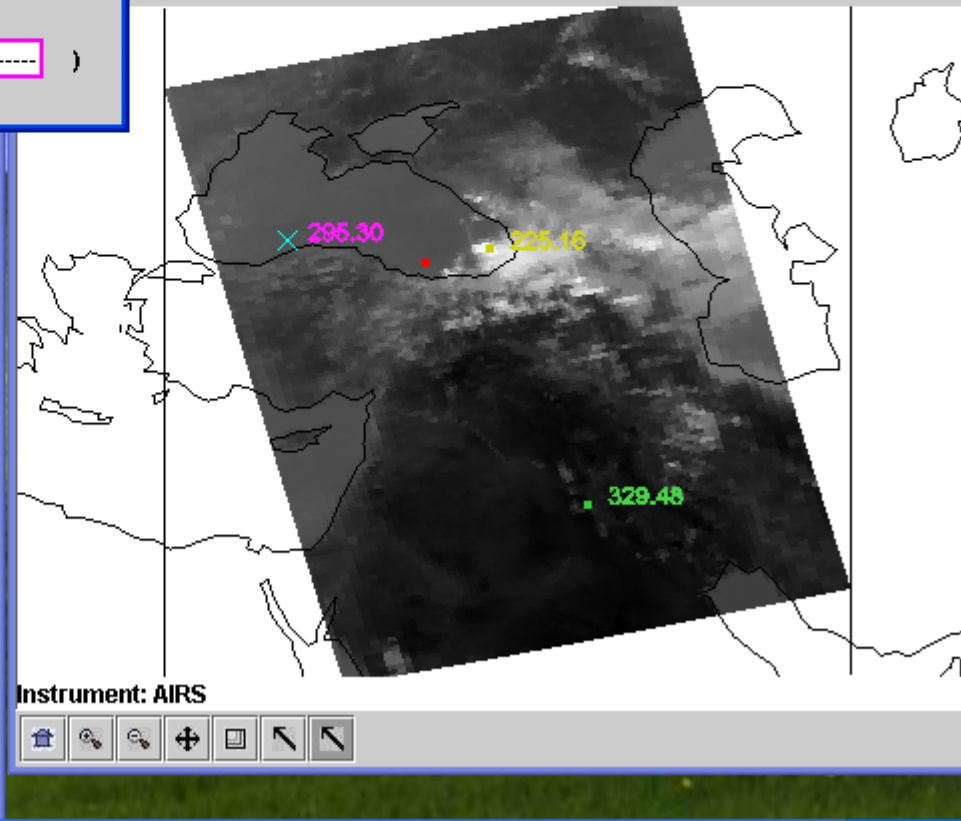
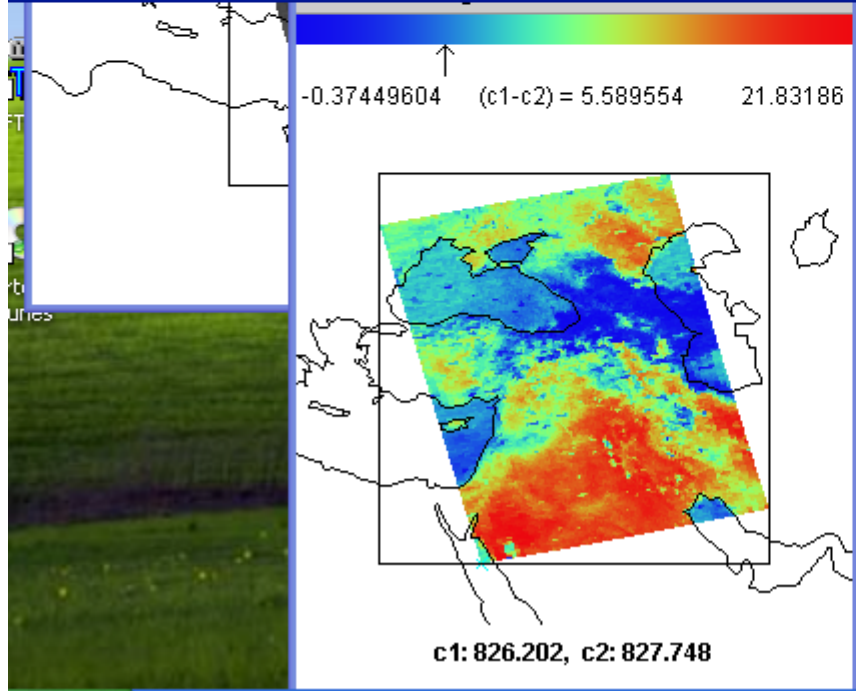
Offline-Online in LW IRW showing low level moisture



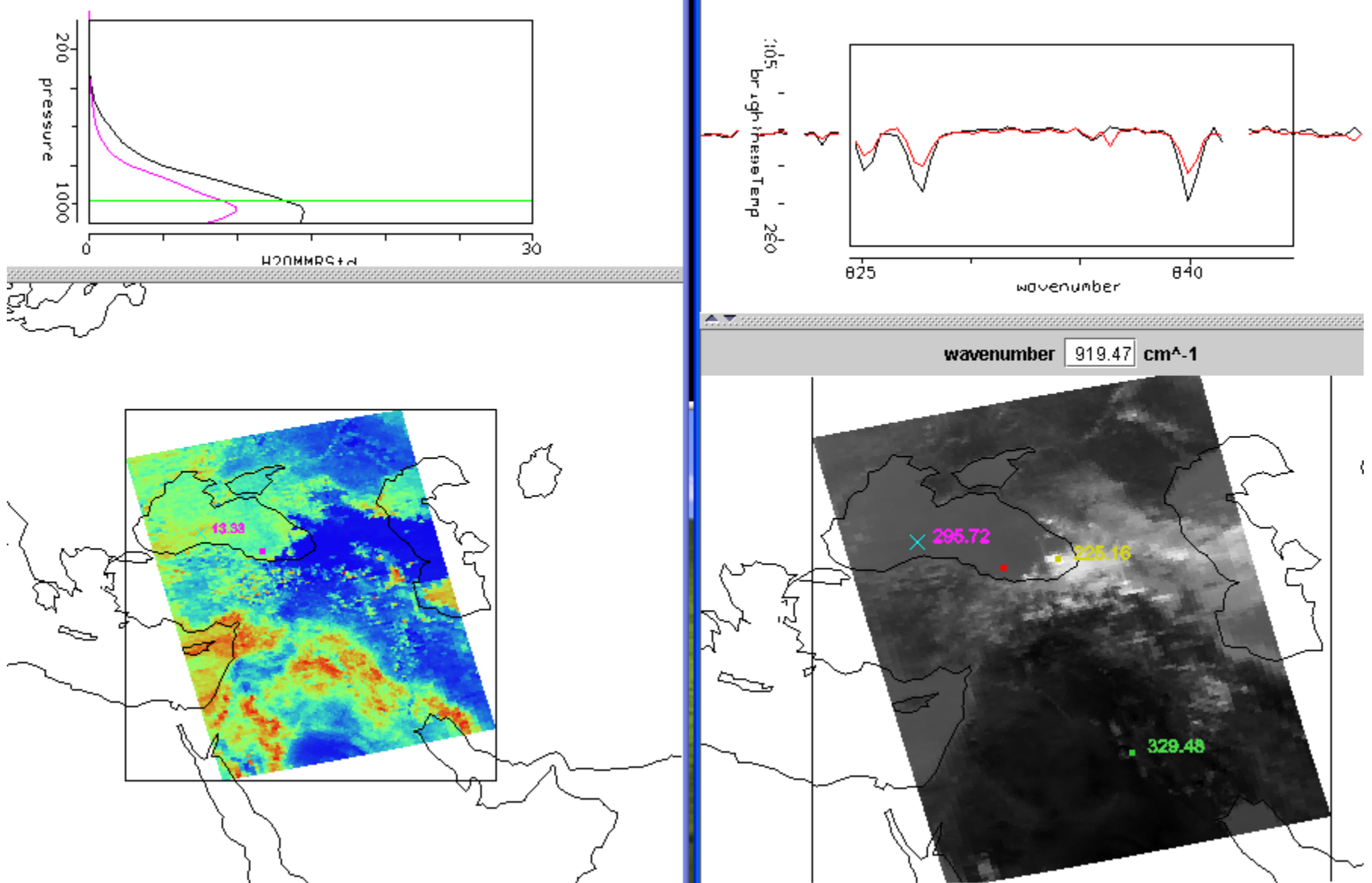
826.202 - 827.748

Control panel with dropdown menus and line style selectors (dashed blue and dashed pink).

wavenumber 919.47 cm⁻¹

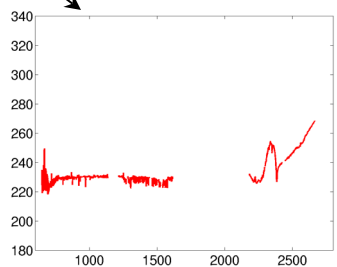
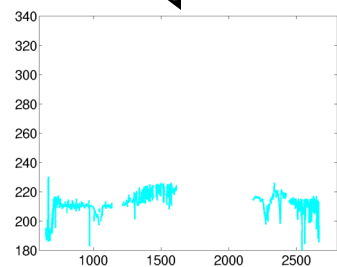
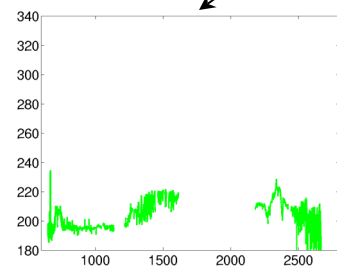
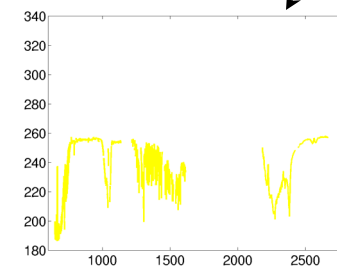
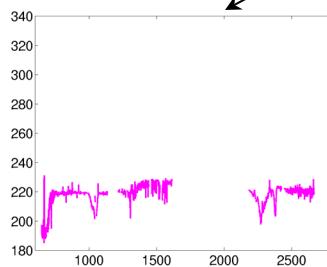
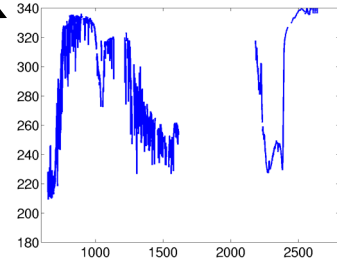
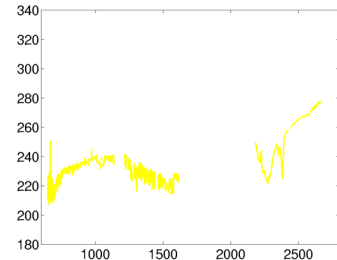
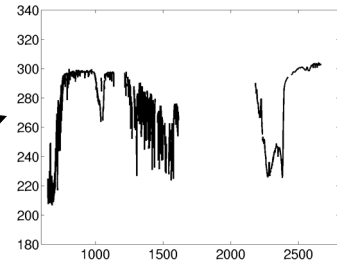
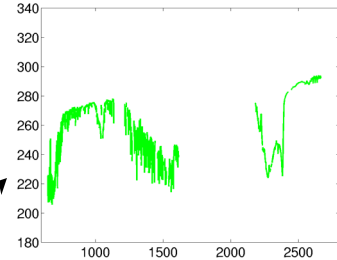
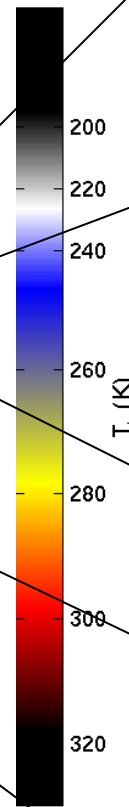
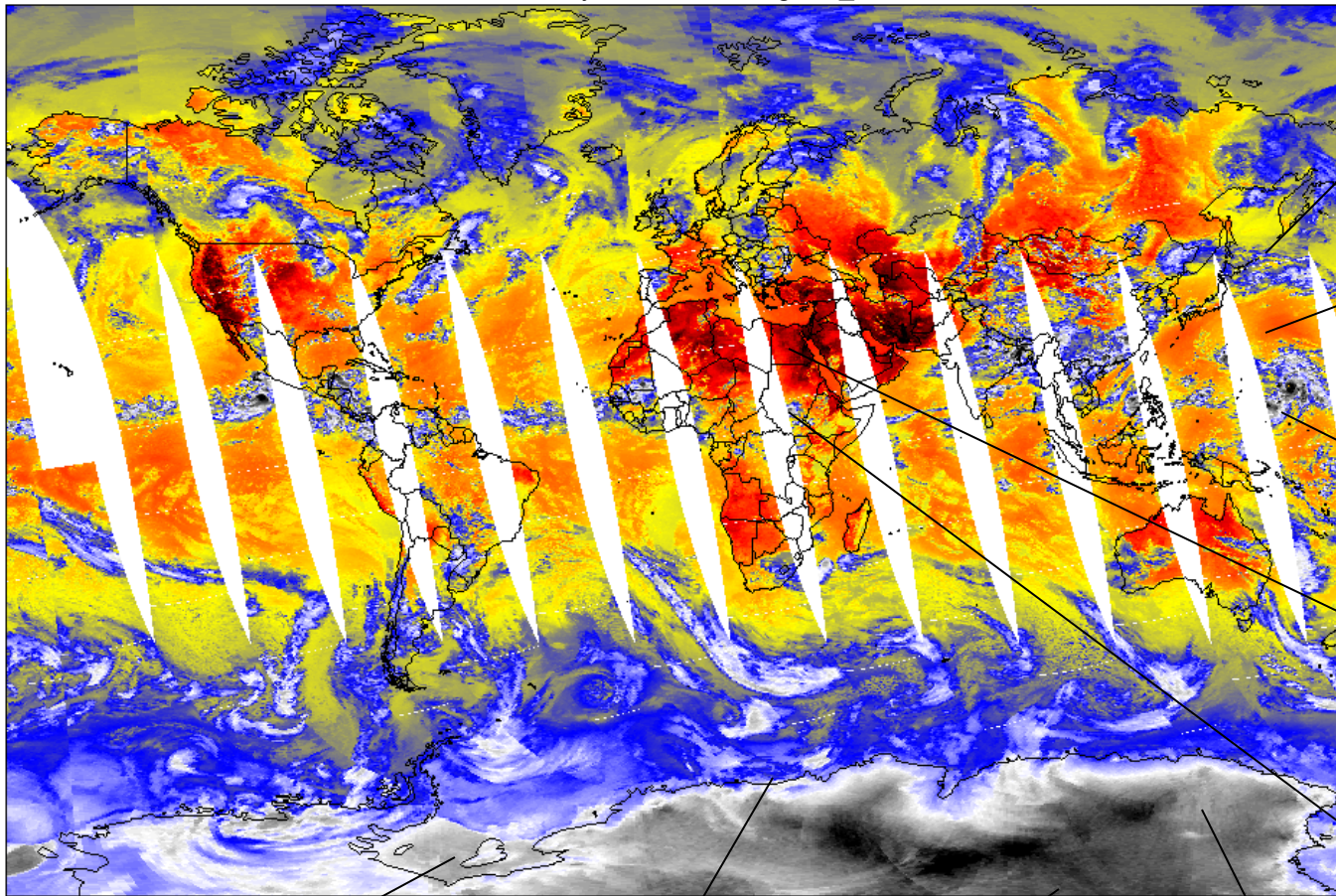


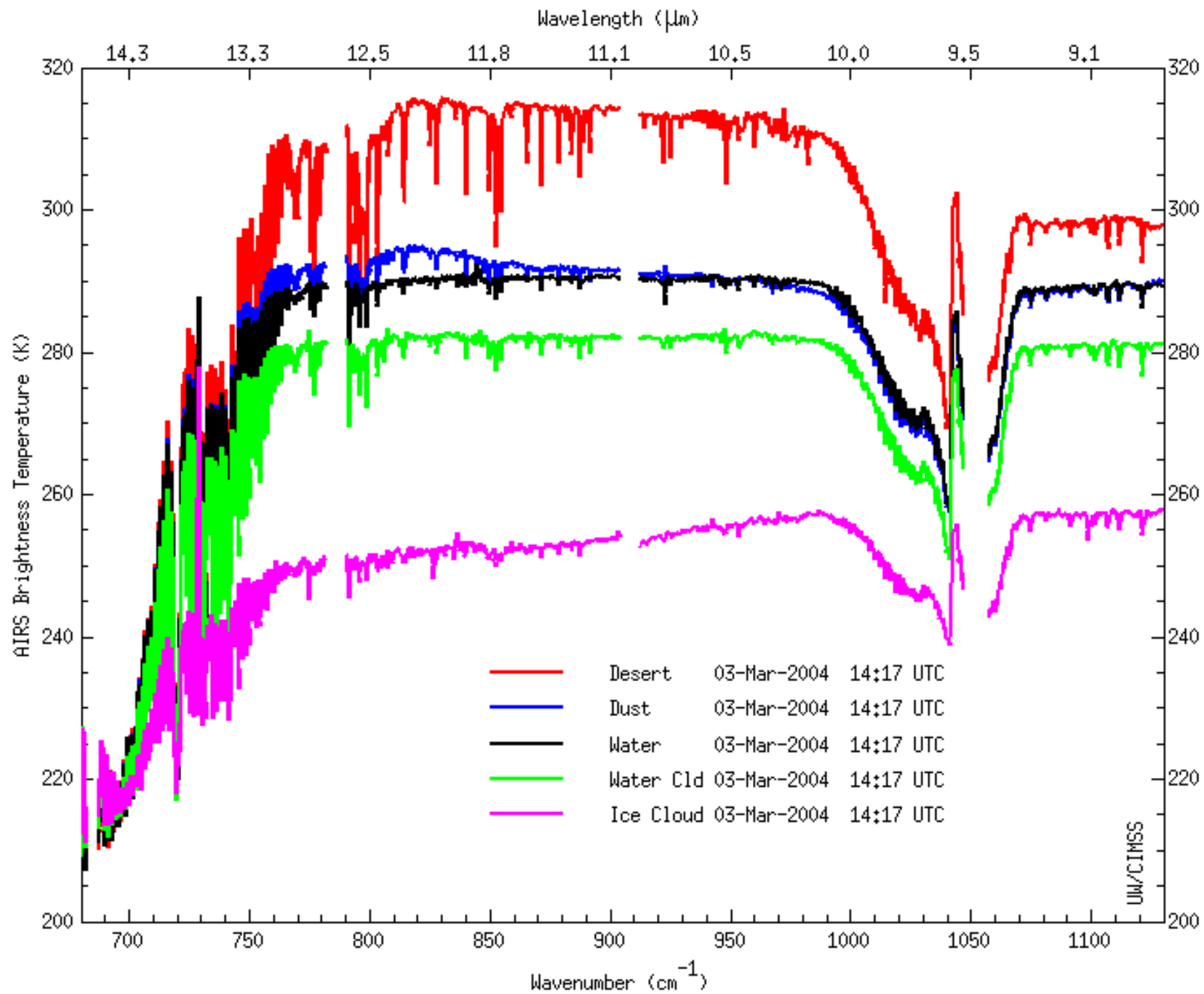
Moisture Profiles (left) confirm west Black Sea (black) is more moist



AIRS Spectra from around the Globe

20-July-2002 Ascending LW_Window

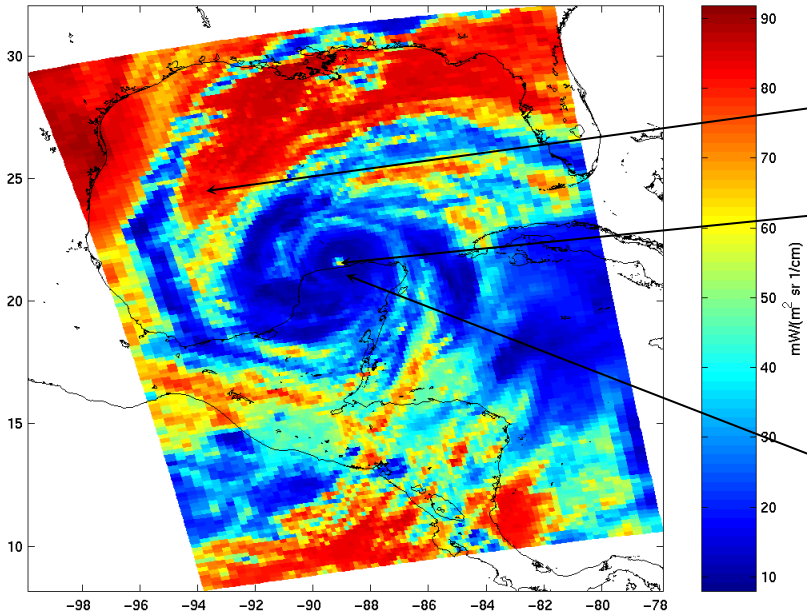




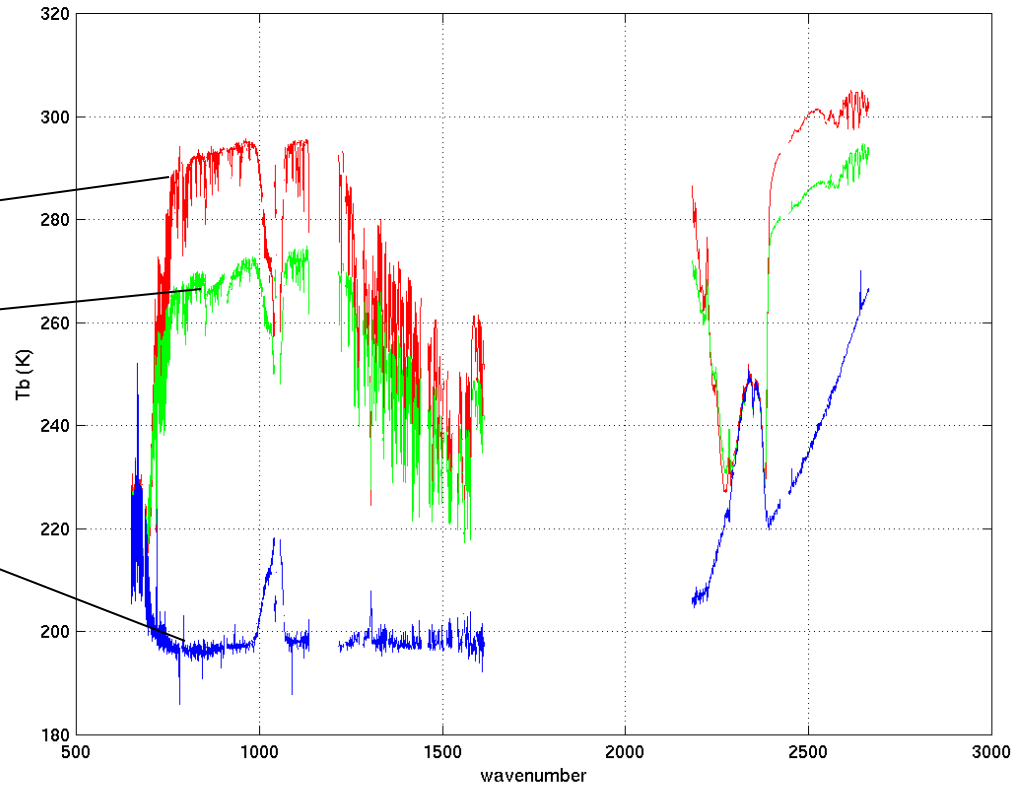
Brightness Temperature Spectra reveal changes in atmosphere from eye to boundary of Tropical Cyclone

~999 1/cm radiances

AIRS.2002.09.22.192.L1B.AIRS_Rad.v2.6.7.3.A02266171833



Brightness temperature spectra



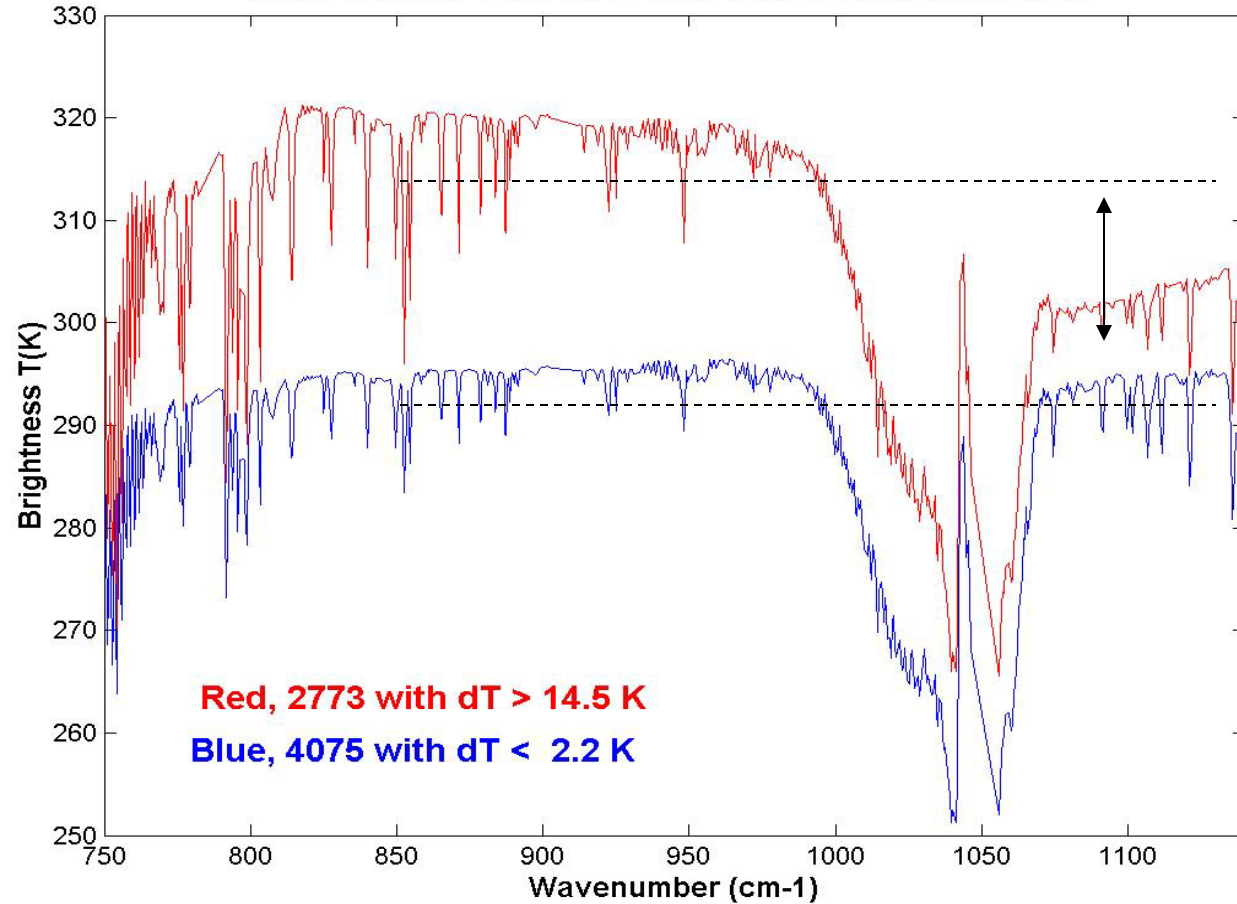
AIRS observations of tropical storm Isadore
on 22 Sept 2002 @ ~19:12-19:18 UTC

Inferring surface properties with AIRS high spectral resolution data

Barren region detection if $T_{1086} < T_{981}$

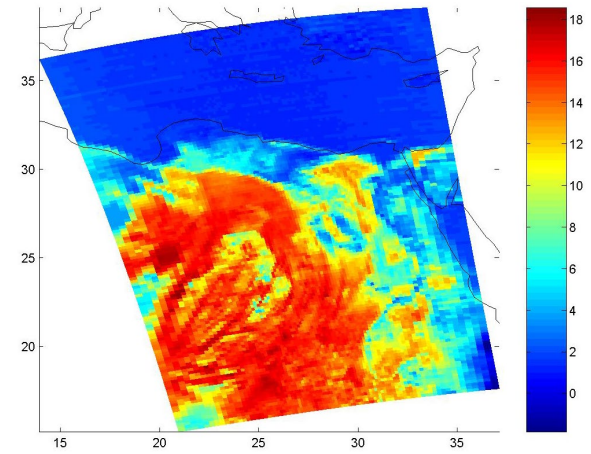
Barren vs Water/Vegetated

Means with 981-1086 cm⁻¹ Large (red) & Small (blue), g115

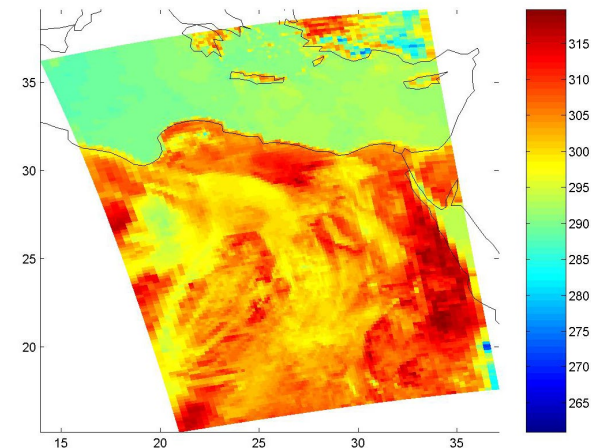


AIRS data from 14 June 2002

$T(981 \text{ cm}^{-1}) - T(1086 \text{ cm}^{-1})$



$T(1086 \text{ cm}^{-1})$

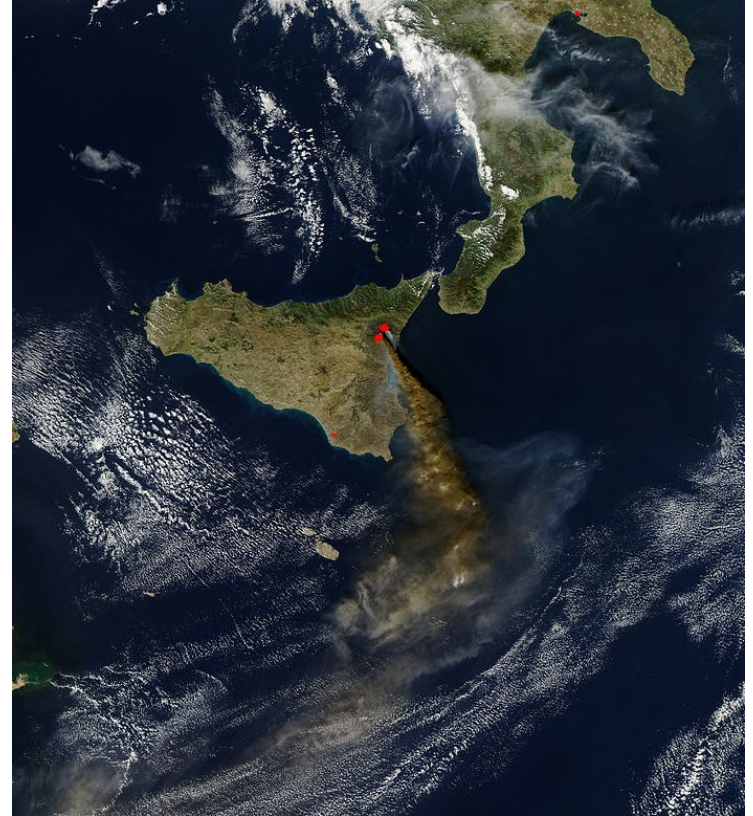


from Tobin et al.

Mt Etna eruption

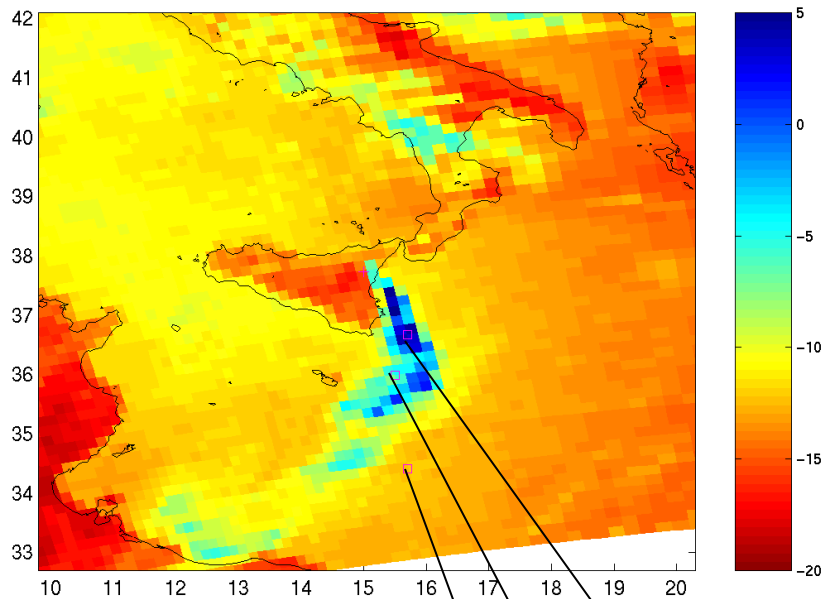


28 October 2002
ISS photo

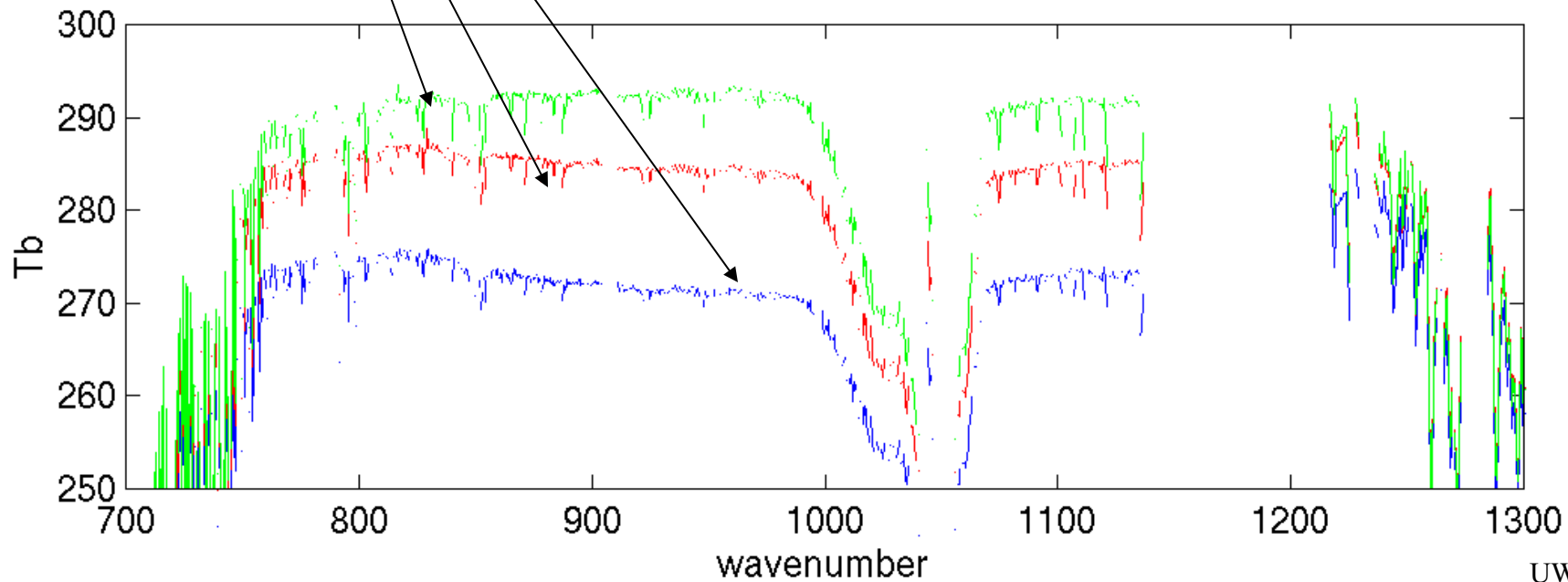
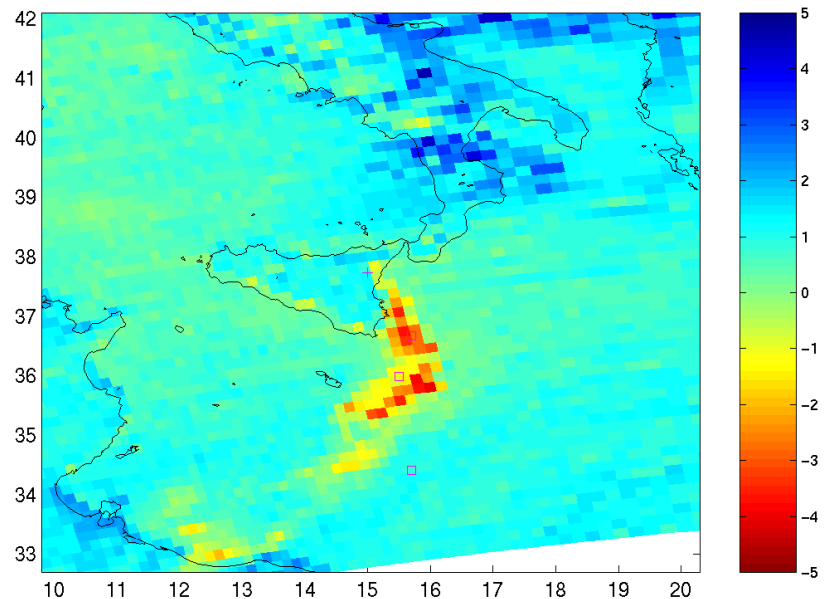


28 October 2002
MODIS Aqua

AIRS.2002.10.28.123.L1B.AIRS_Rad.v2.6.10.3.A02302200913
~1252 1/cm Tb - ~913 1/cm Tb



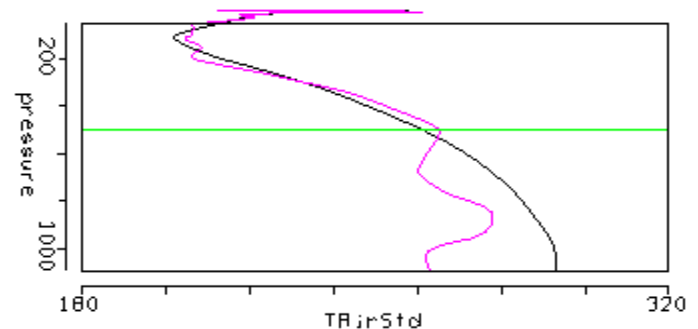
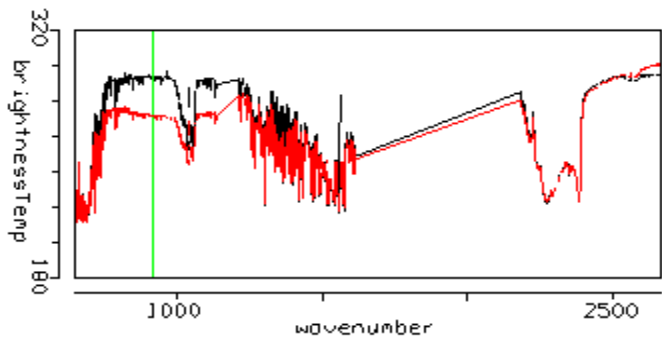
AIRS.2002.10.28.123.L1B.AIRS_Rad.v2.6.10.3.A02302200913
~913 1/cm Tb - ~837 1/cm Tb



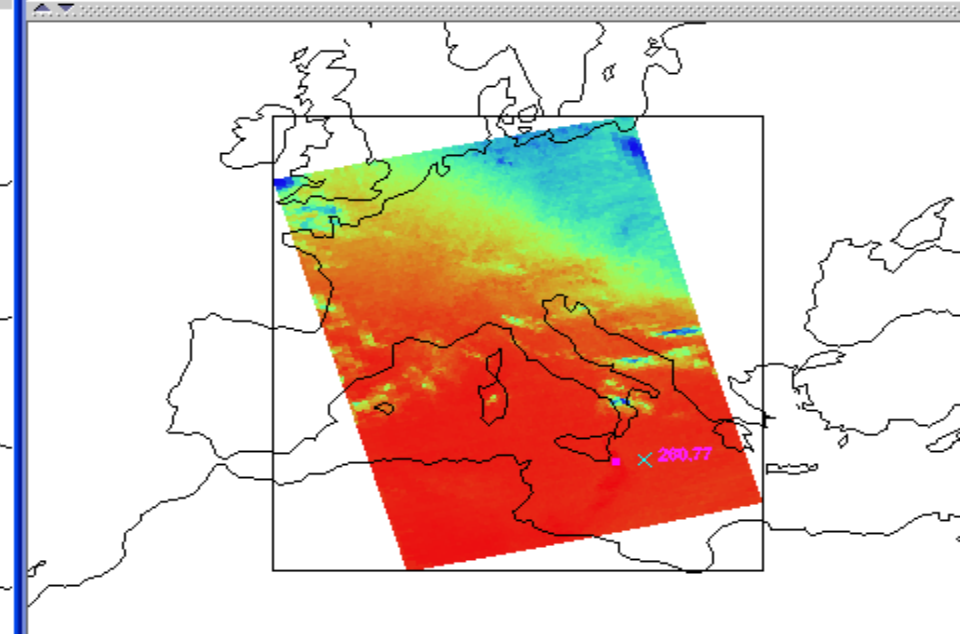
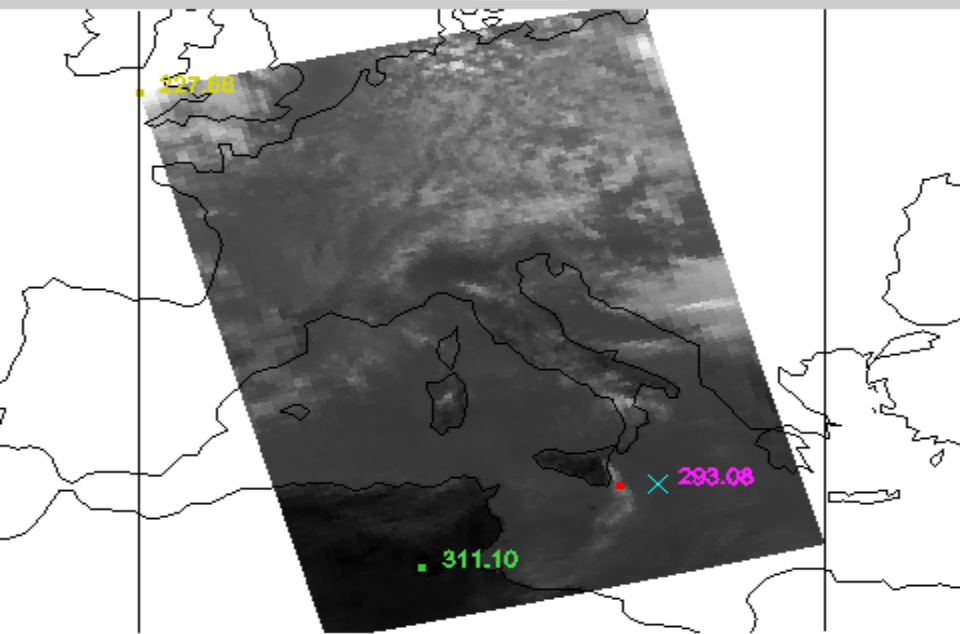
Mt Etna Ash cloud at 500 hPa

Multi-Channel Viewer
Tools Settings

Hydra AIRS Level 2 Products
Variables Levels Settings Tools



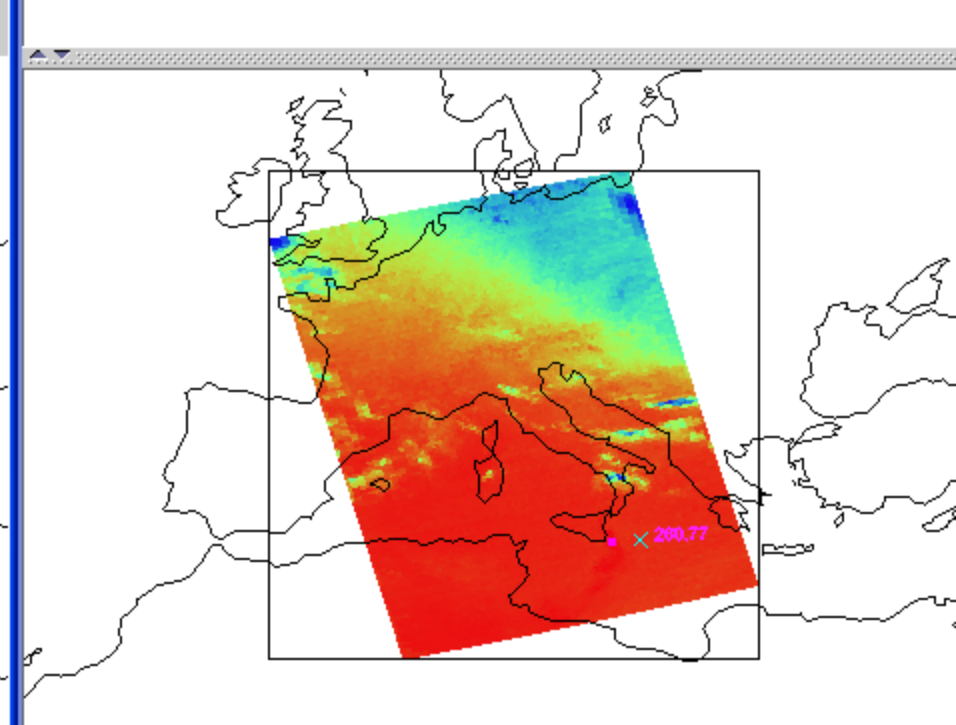
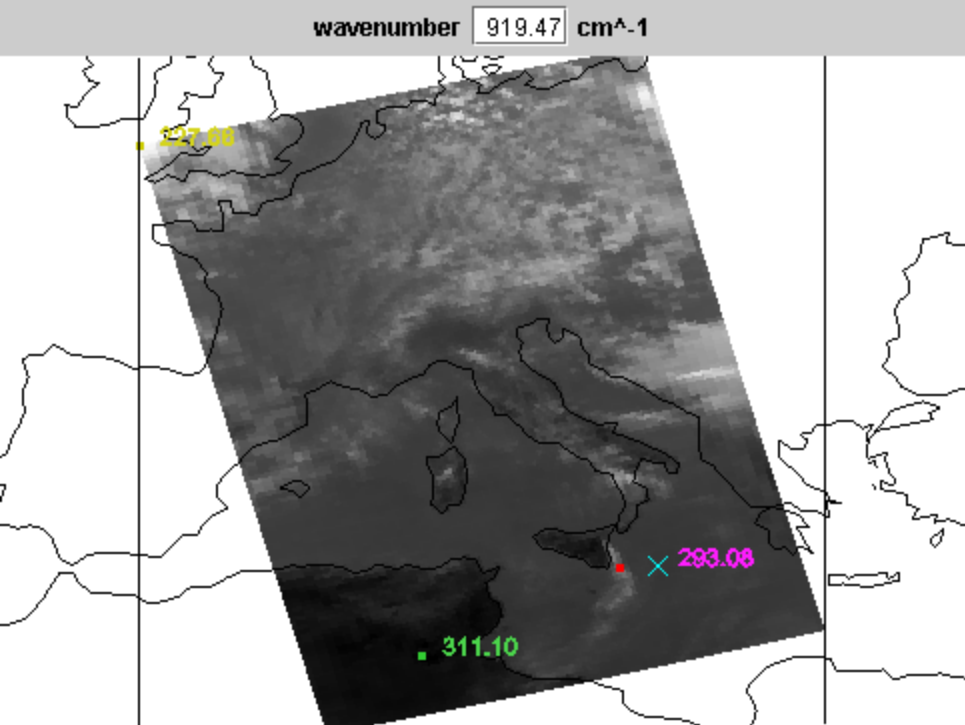
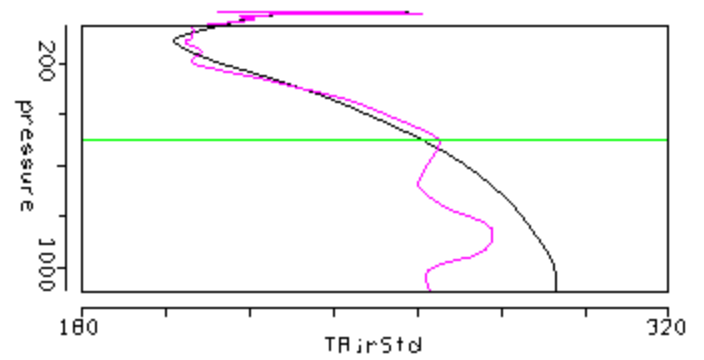
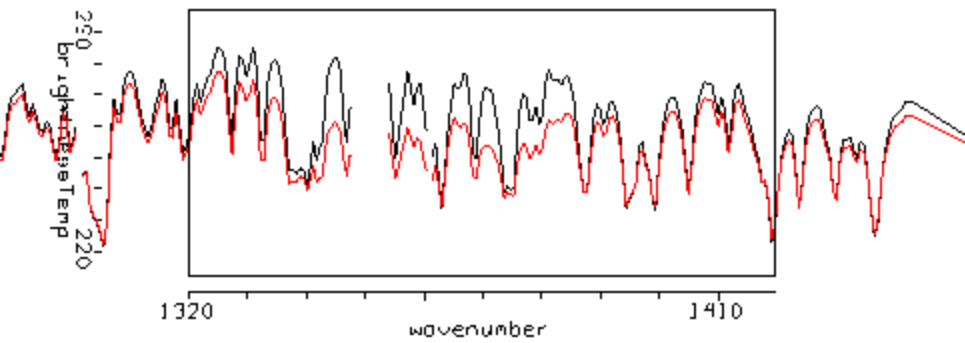
wavenumber 919.47 cm⁻¹



Instrument: AIRS

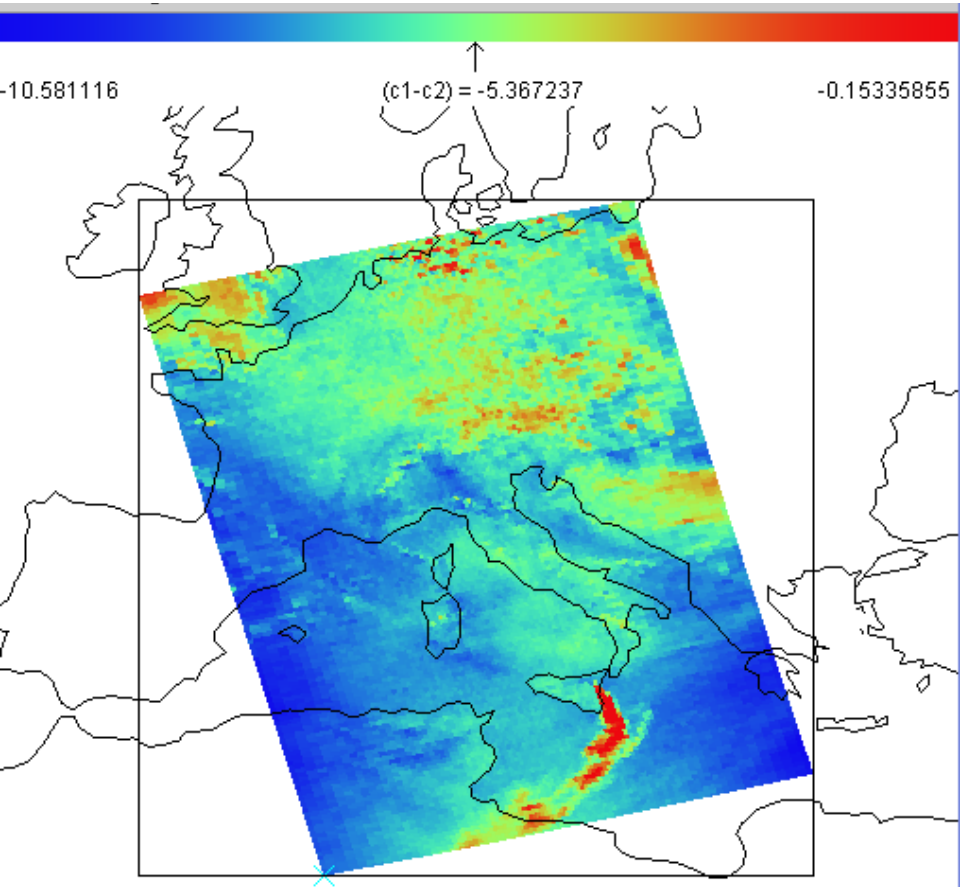
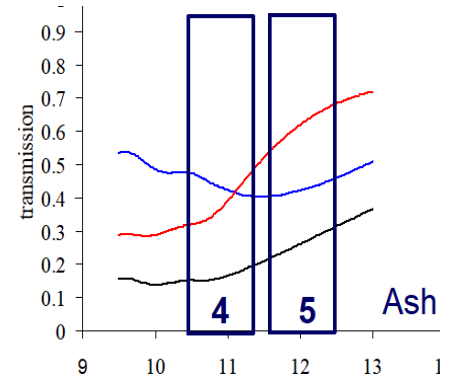
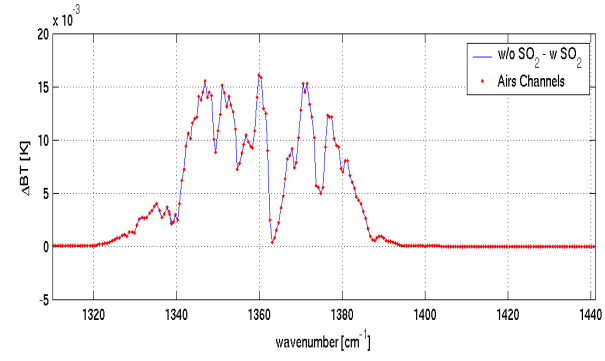


Ash cloud and clear sky spectra

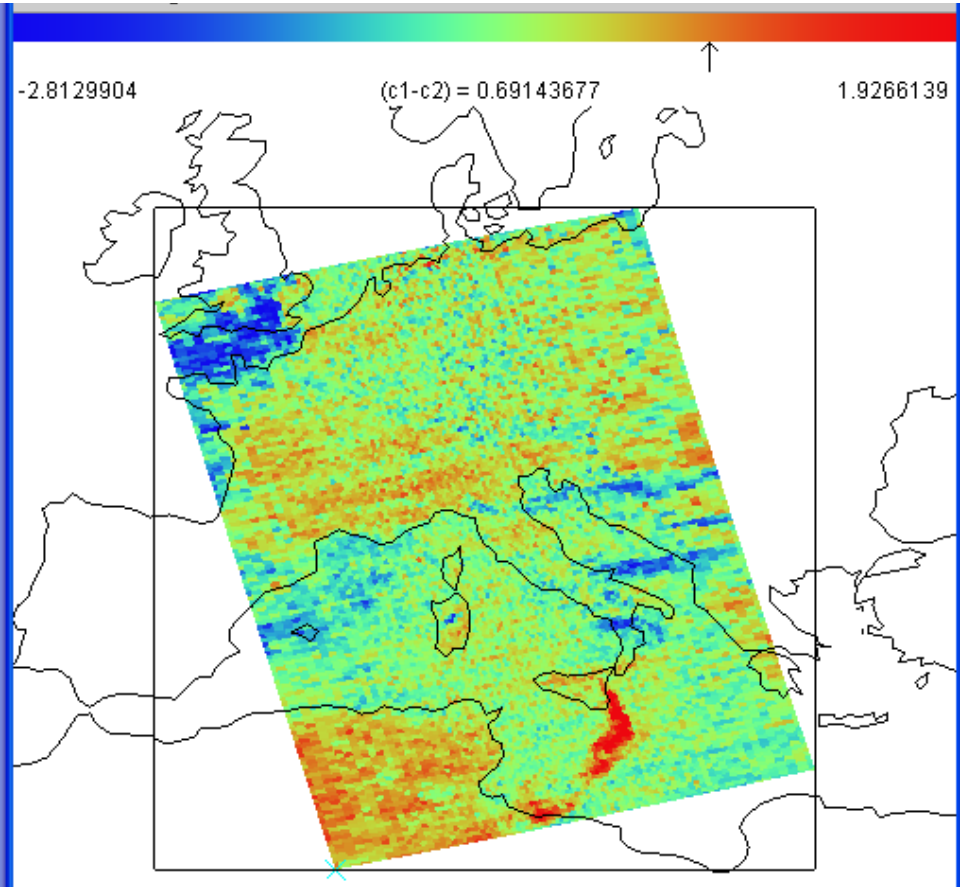


Mt Etna volcanic plume

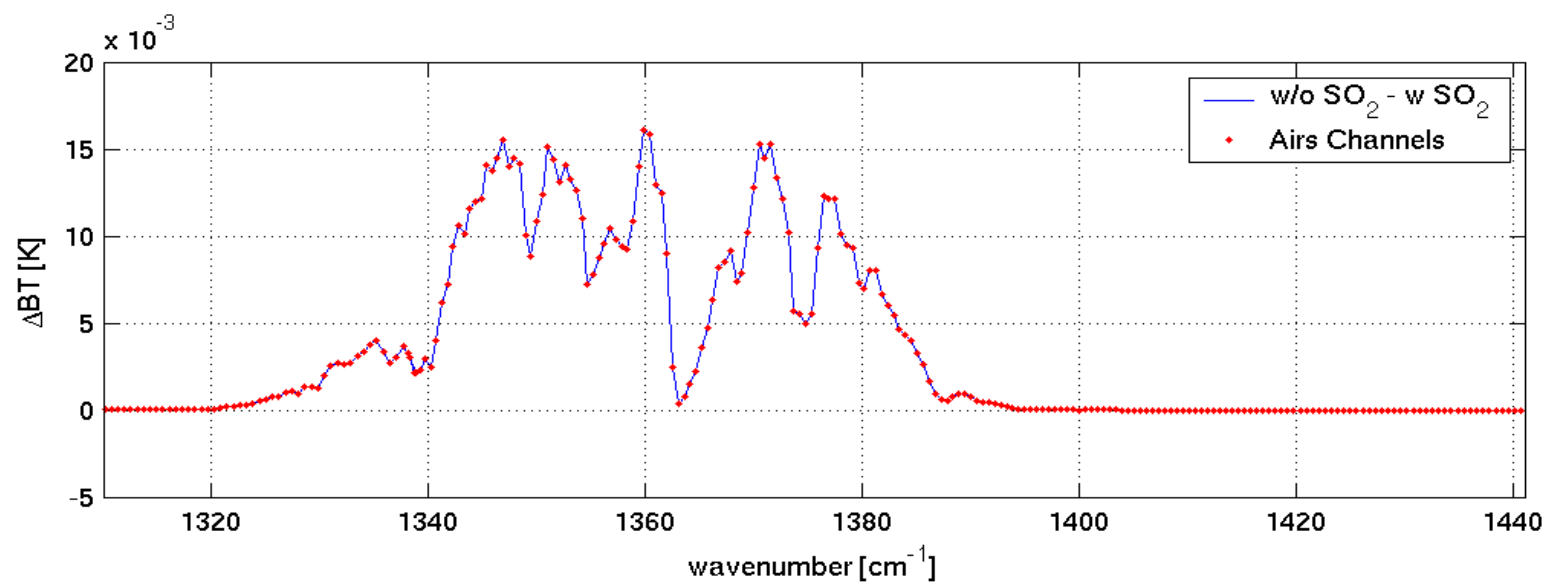
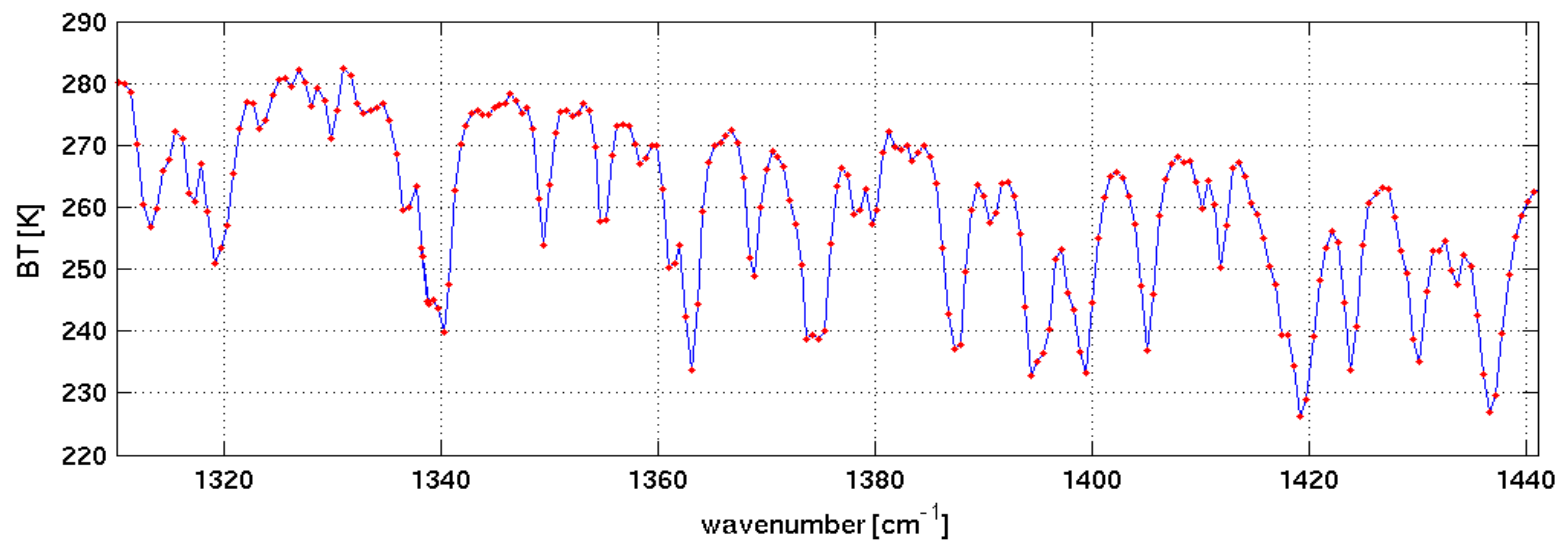
SO₂ (left) from 1284-1345
Ash (right) from 832-900



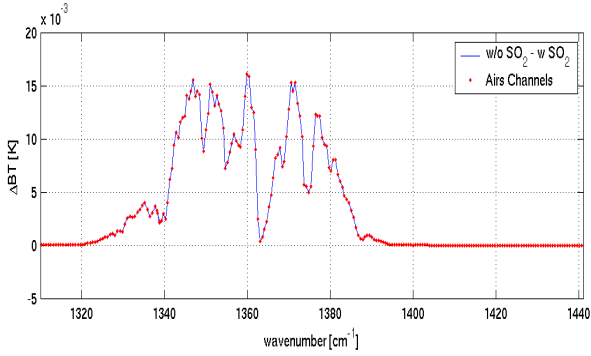
c1:1284.348, c2:1344.799



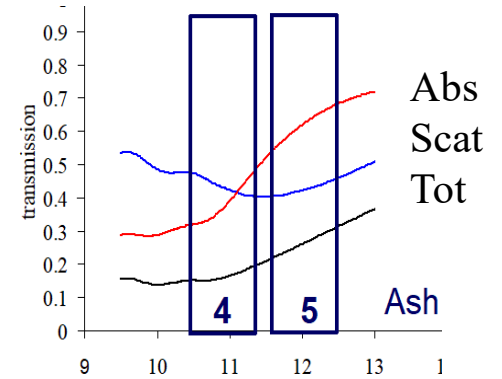
c1: 832.810, c2: 899.965



Anatahan Volcano viewed with AIRS

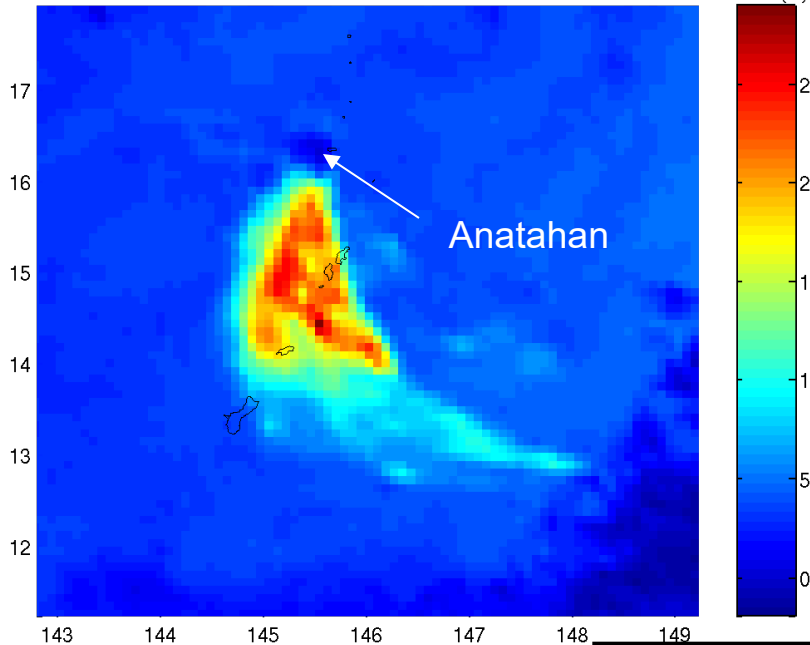


SO₂ signal
1284-1345 cm⁻¹

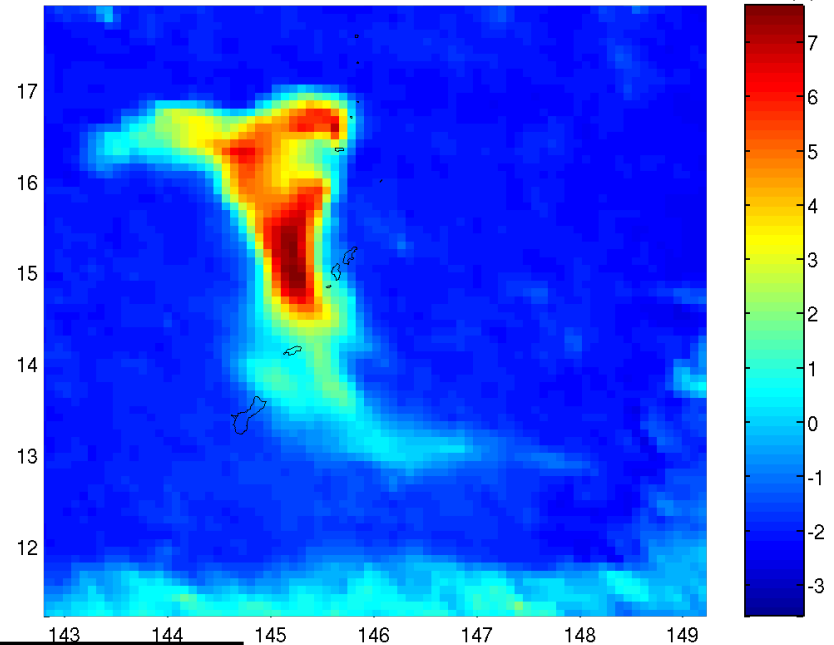


Ash signal
1228-995 cm⁻¹

Anatahan, Mariana Is - 10 May 2003 - gran 159 - 1285.4-1345.3 cm-1



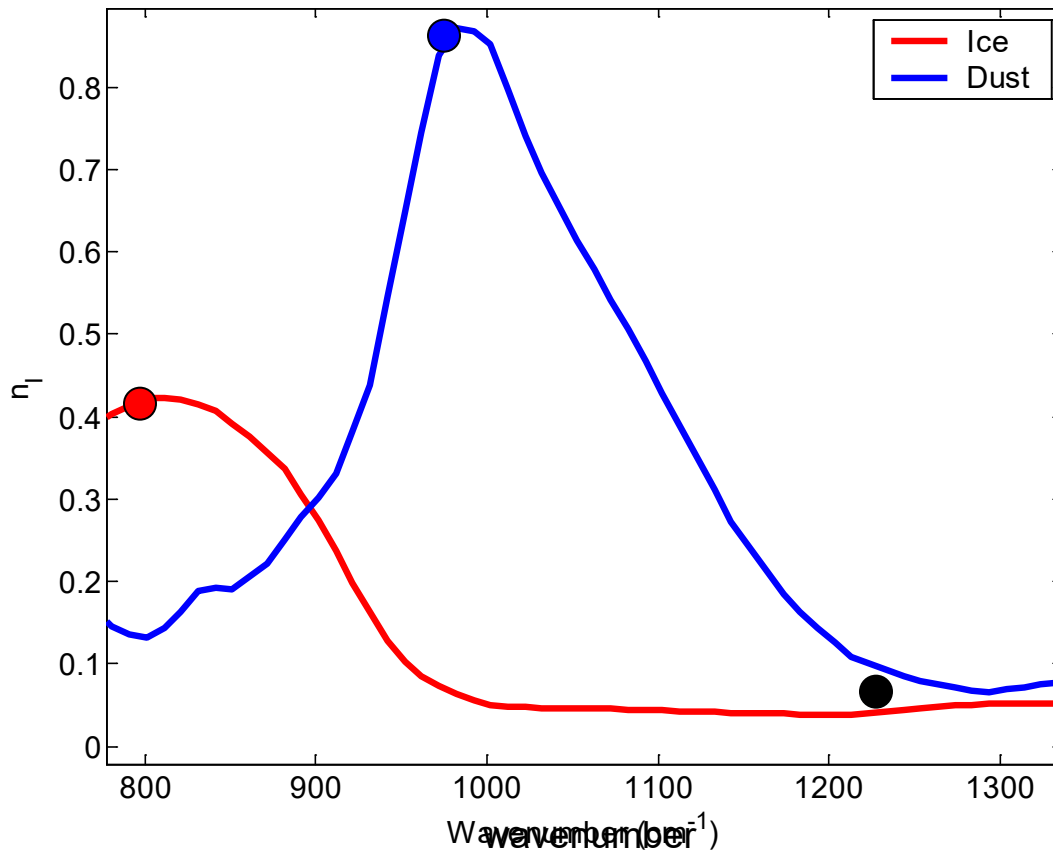
Anatahan, Mariana Is - 10 May 2003 - gran 159 - 1228-980 cm-1



10 May 2003 (1554 UT)

Dust and Cirrus Signals

Imaginary Index of Refraction of Ice and Dust



- Both ice and silicate absorption small in 1200 cm⁻¹ window

- In the 800-1000 cm⁻¹ atmospheric window:

Silicate index increases

Ice index decreases

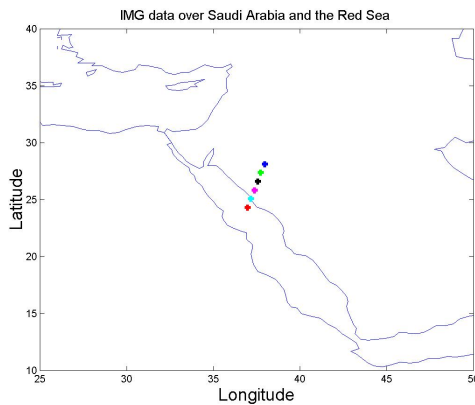
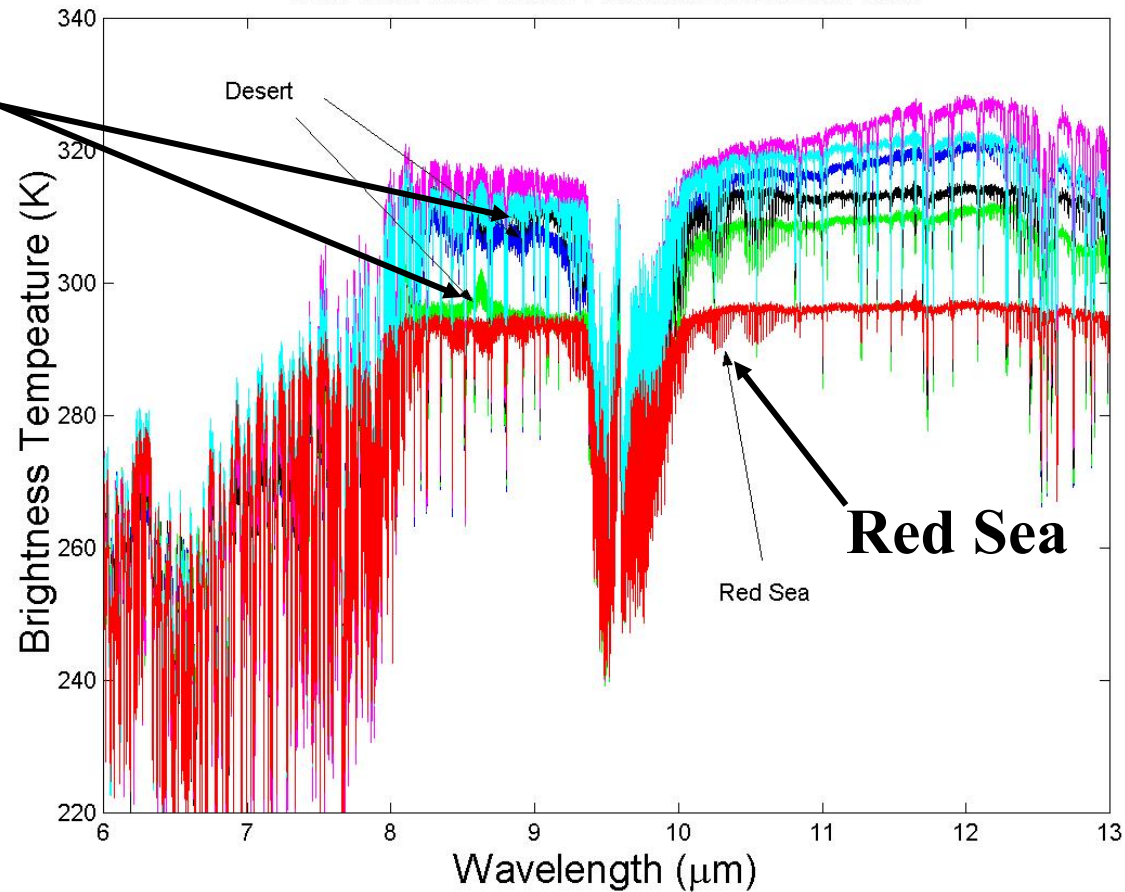
with wavenumber

Volz, F.E. : Infrared optical constant of ammonium sulphate, Sahara Dust, volcanic pumice and flash, Appl Opt 12 564-658 (1973)

Hyperspectral Dust Observations

IMG data over Saudi Arabia and the Red Sea

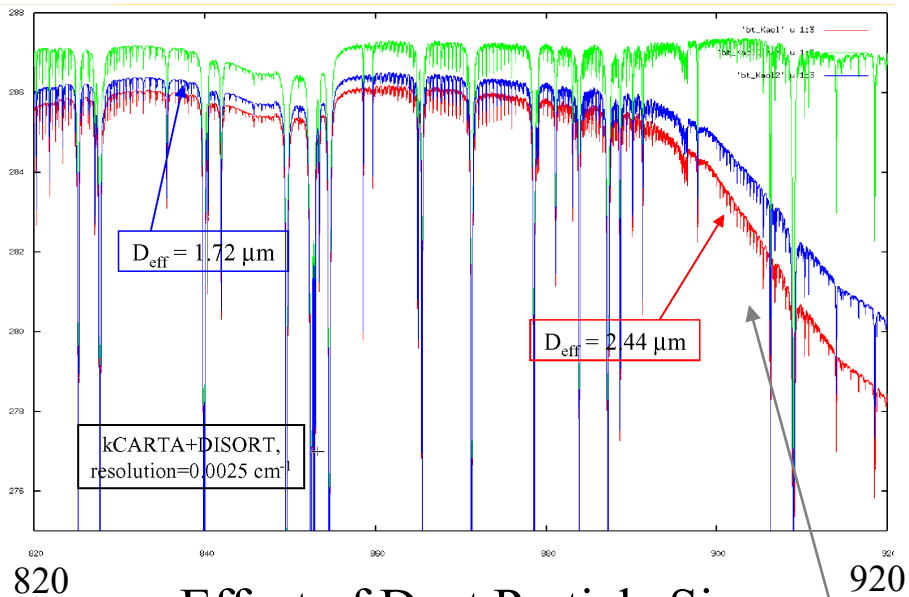
Desert



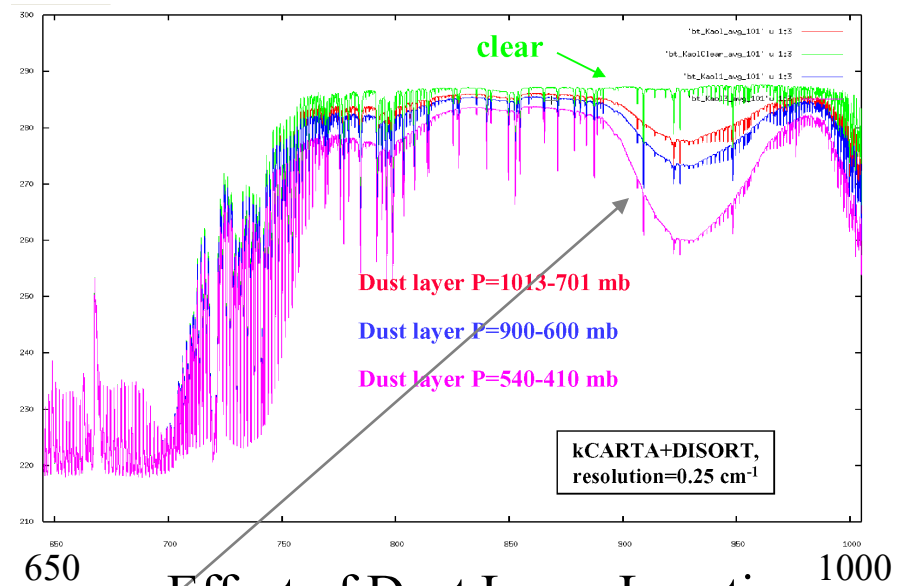
Hyperspectral Dust/Aerosol Modeling

Negative Slope 880 to 920 cm^{-1} – The Dust Signature

Green – Clear Spectrum



Effect of Dust Particle Sizes

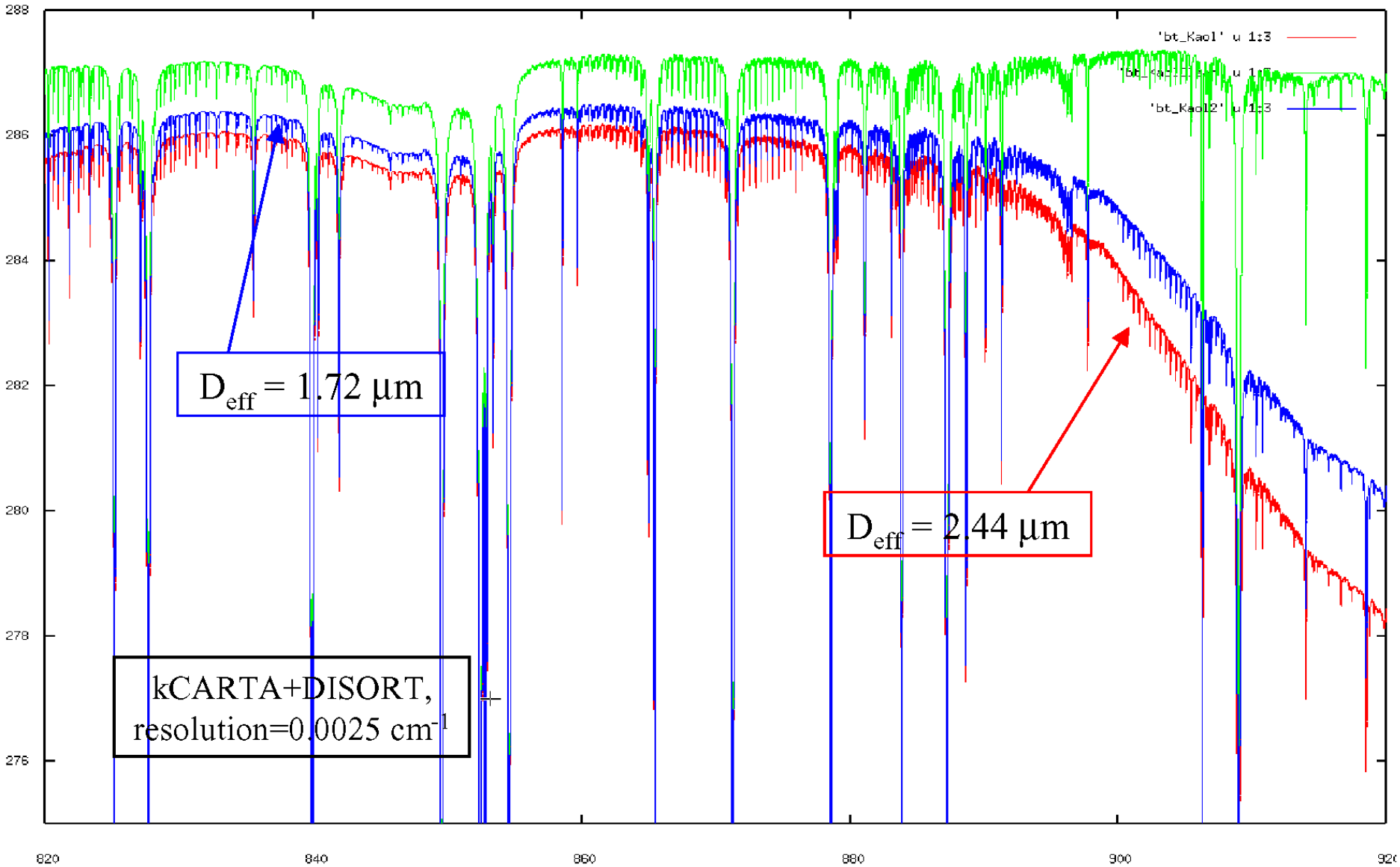


Effect of Dust Layer Location

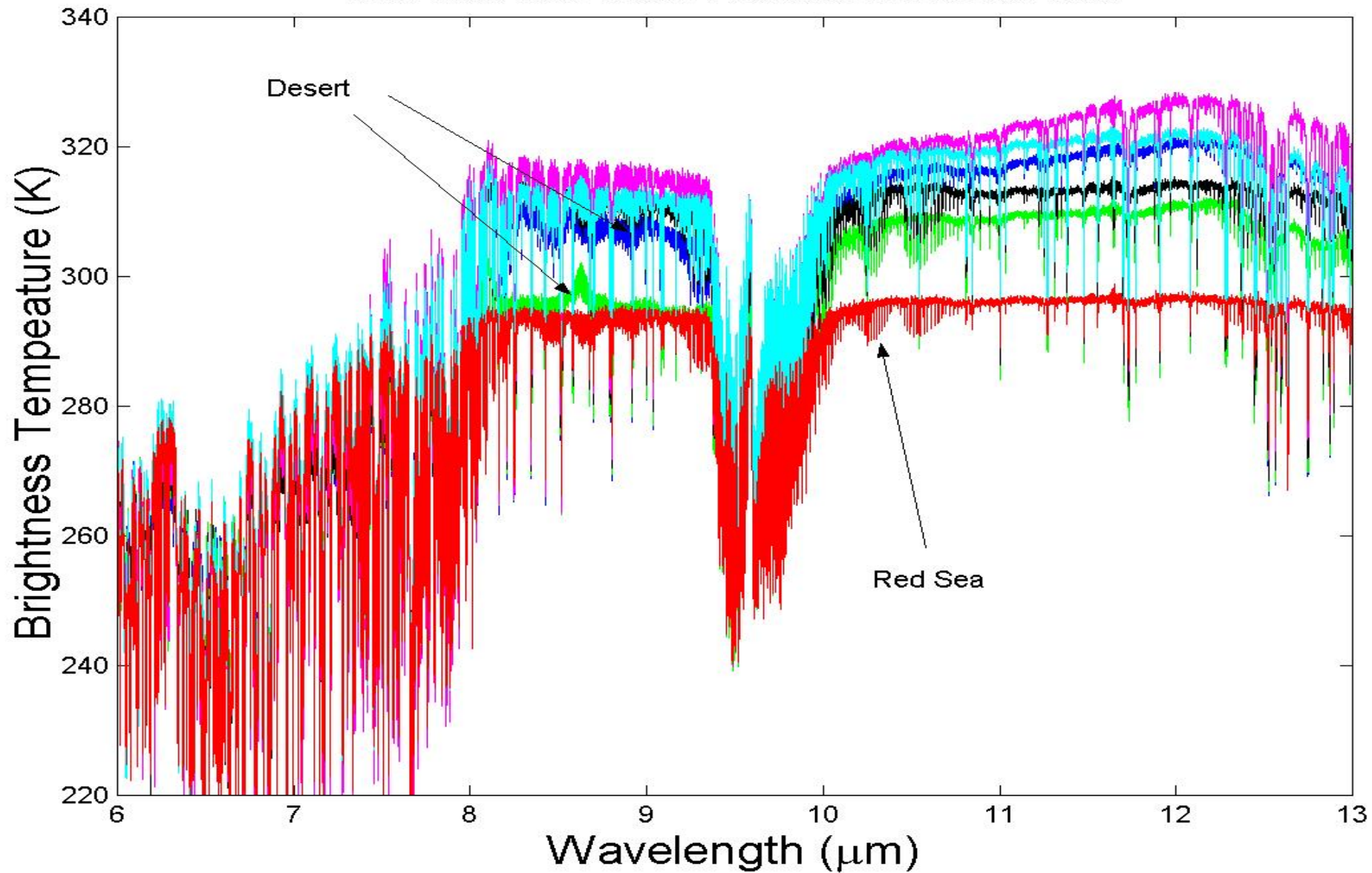
Negative slope

kCARTA+DISORT, spectral resolution = 0.0025 cm^{-1}

Sokolik, Univ Colo, 2002

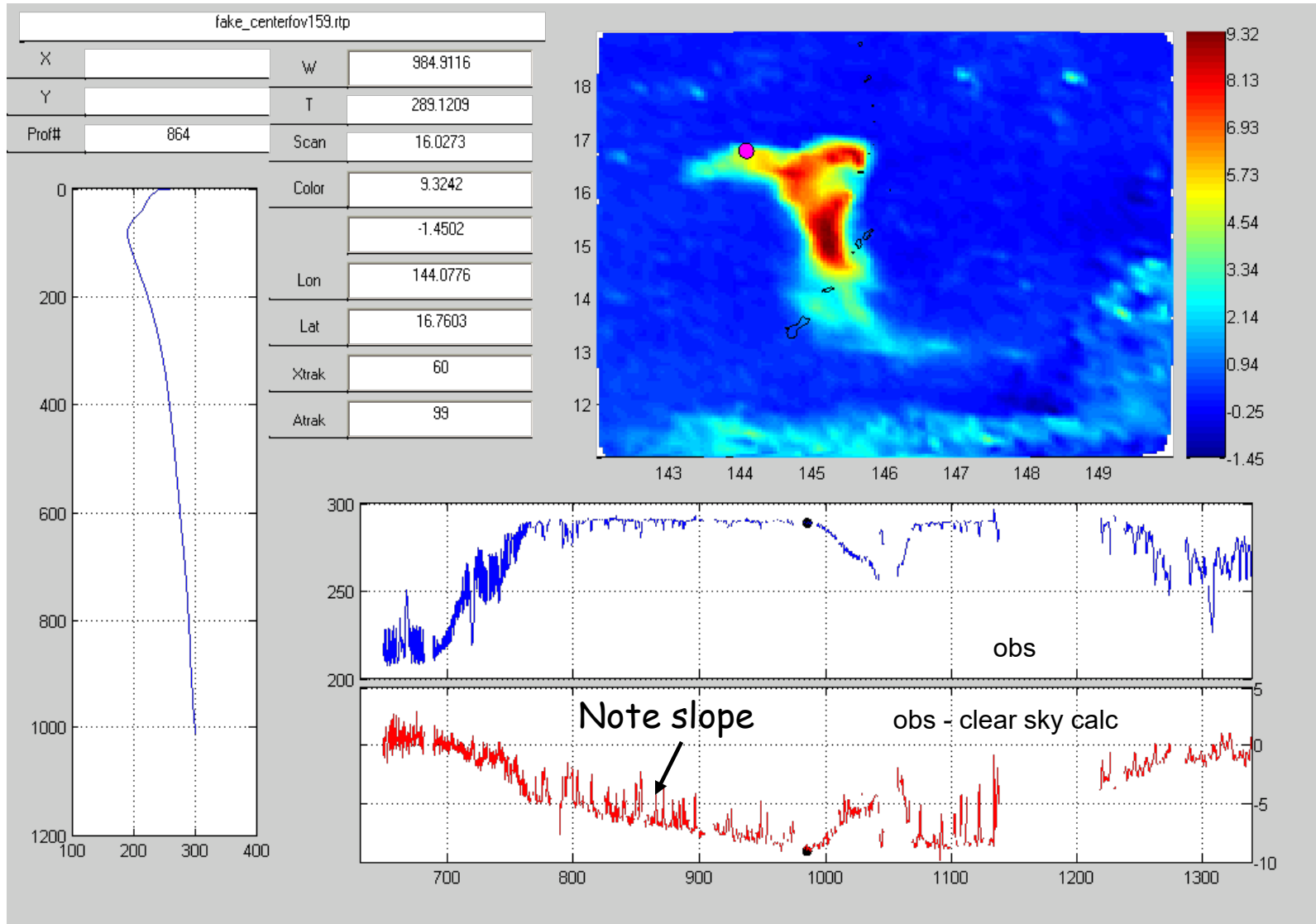


IMG data over Saudi Arabia and the Red Sea



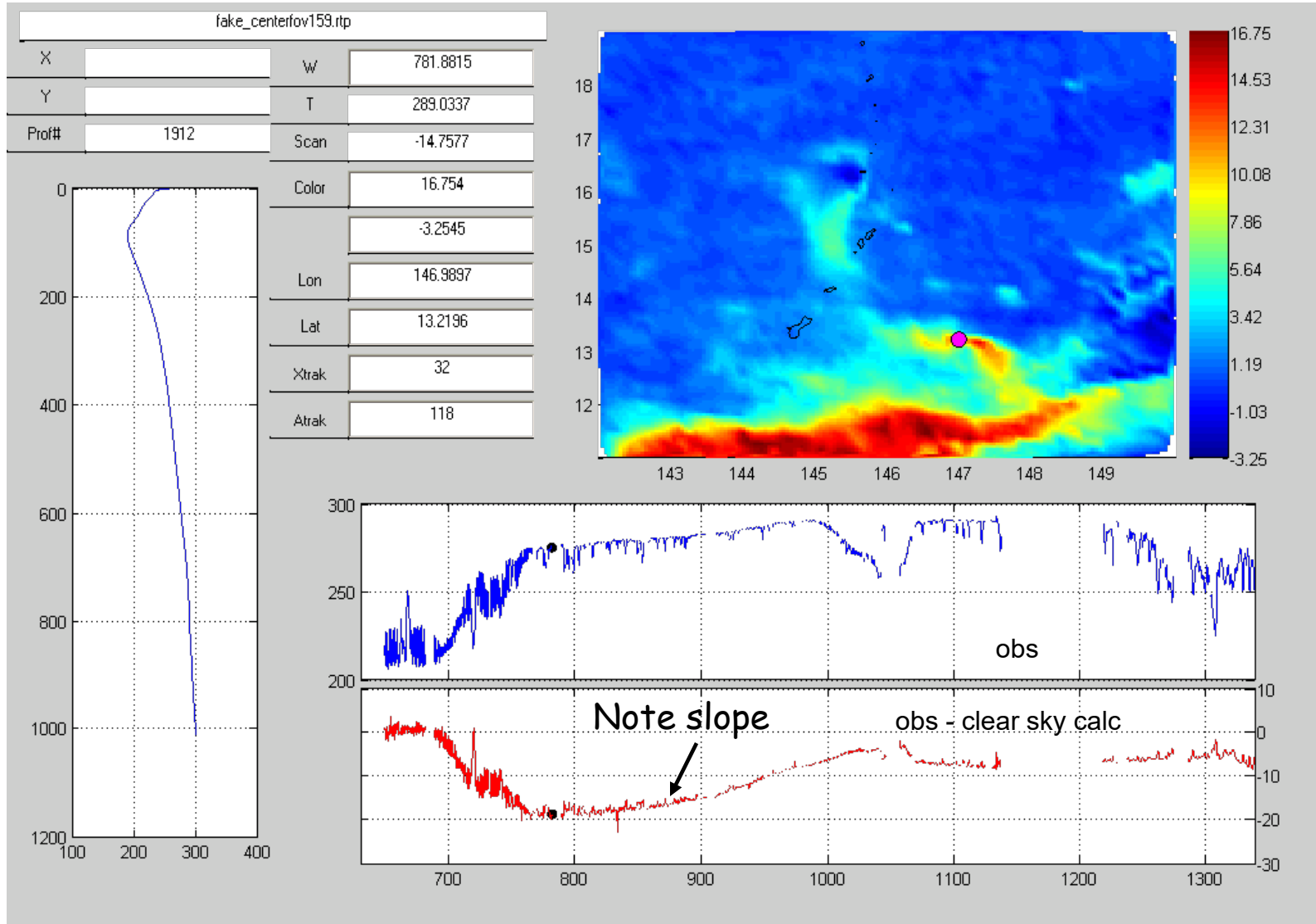
Silicate (ash cloud) signal at Anatahan, Mariana Is

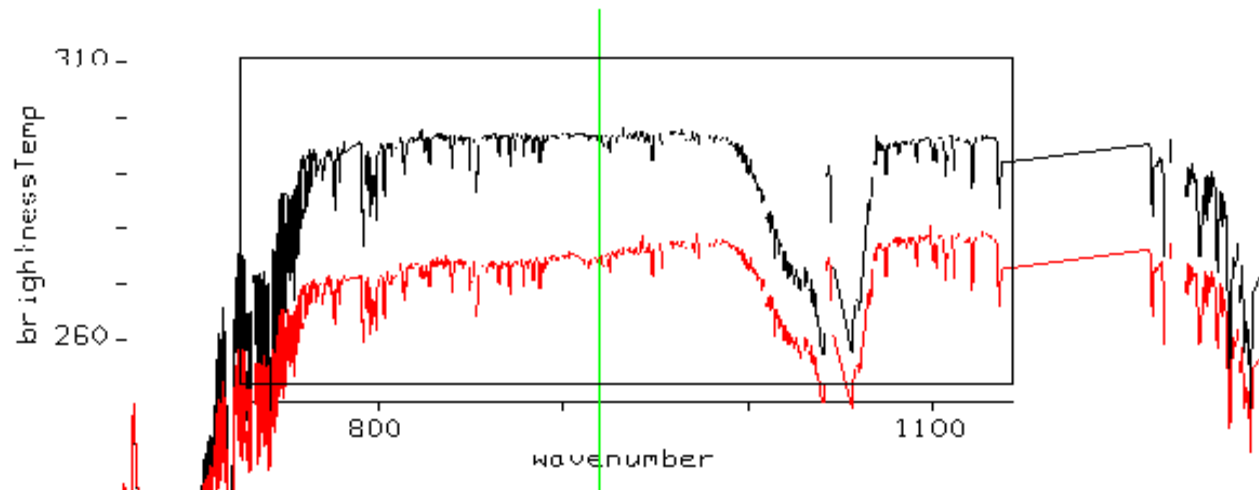
Image is ECMWF bias difference of $1227\text{ cm}^{-1} - 984\text{ cm}^{-1}$ (double difference)



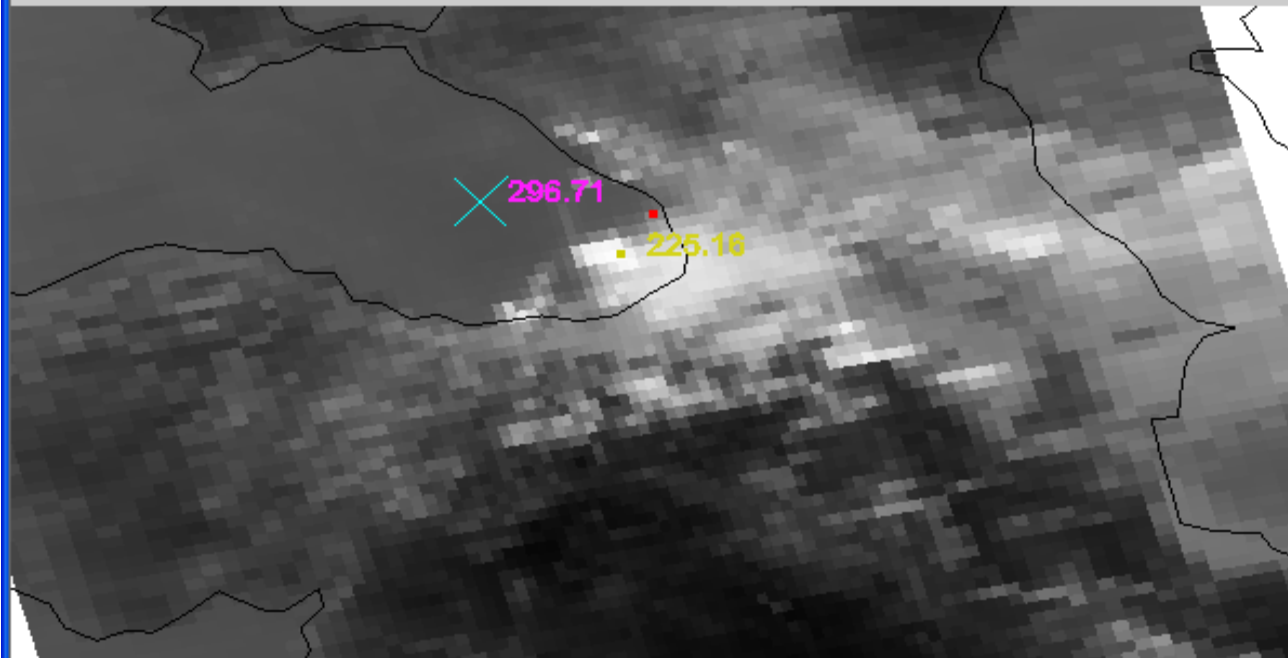
Cirrus signal at Anatahan

Image is ECMWF T_b bias difference of $1227\text{ cm}^{-1} - 781\text{ cm}^{-1}$ (double difference)





wavenumber 919.47 cm⁻¹



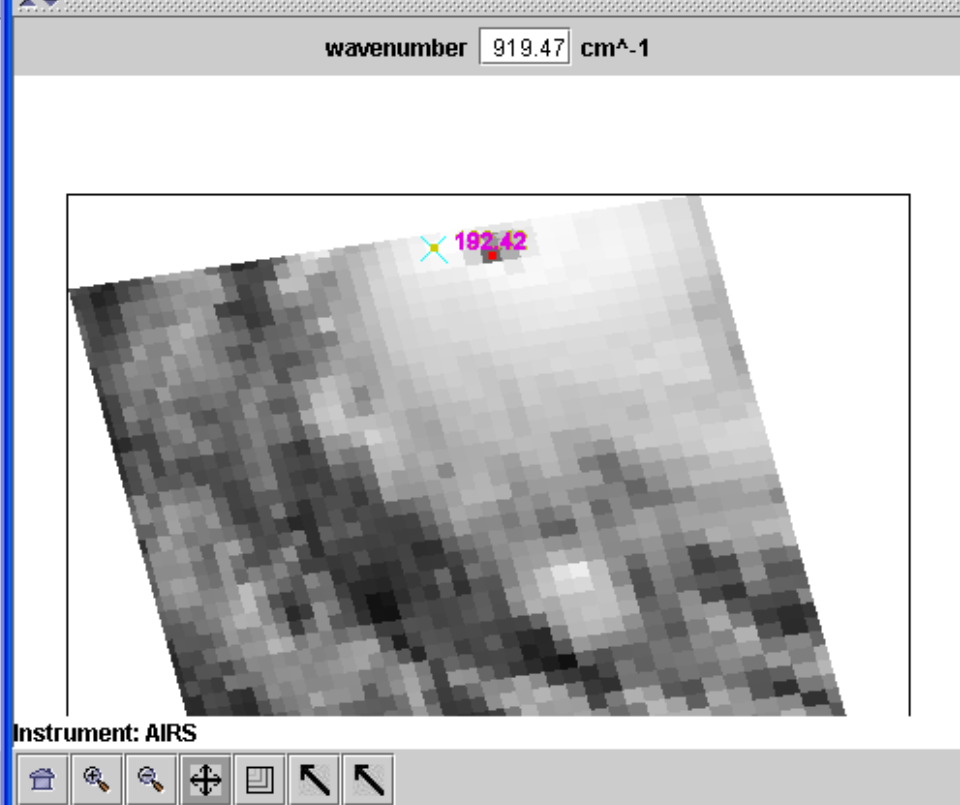
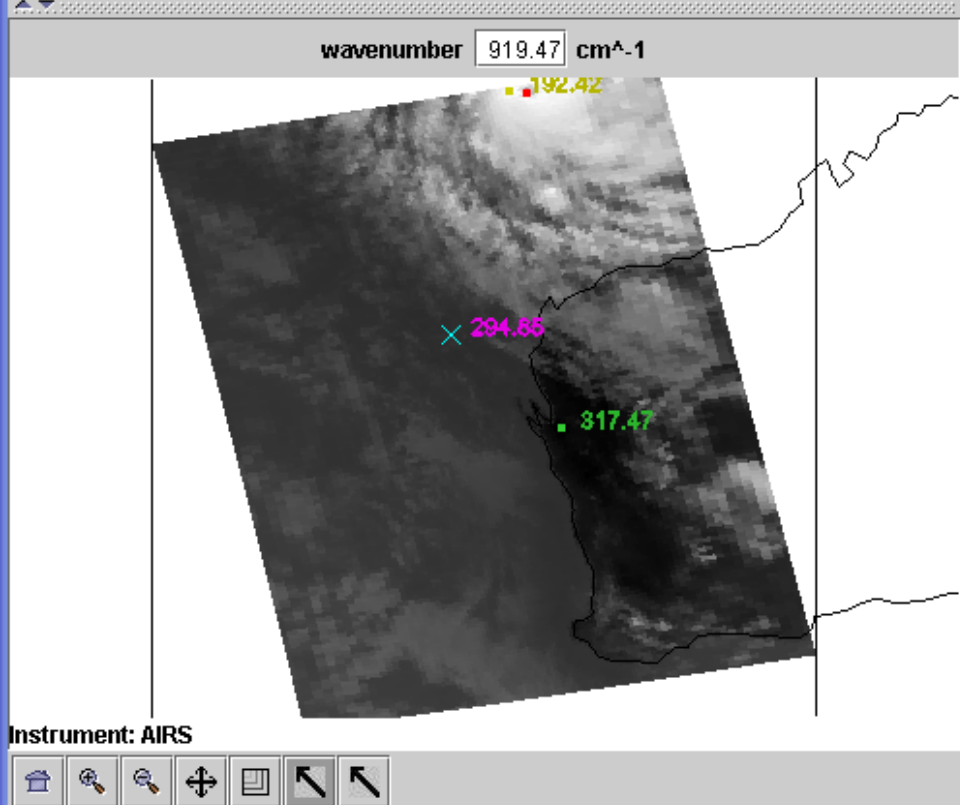
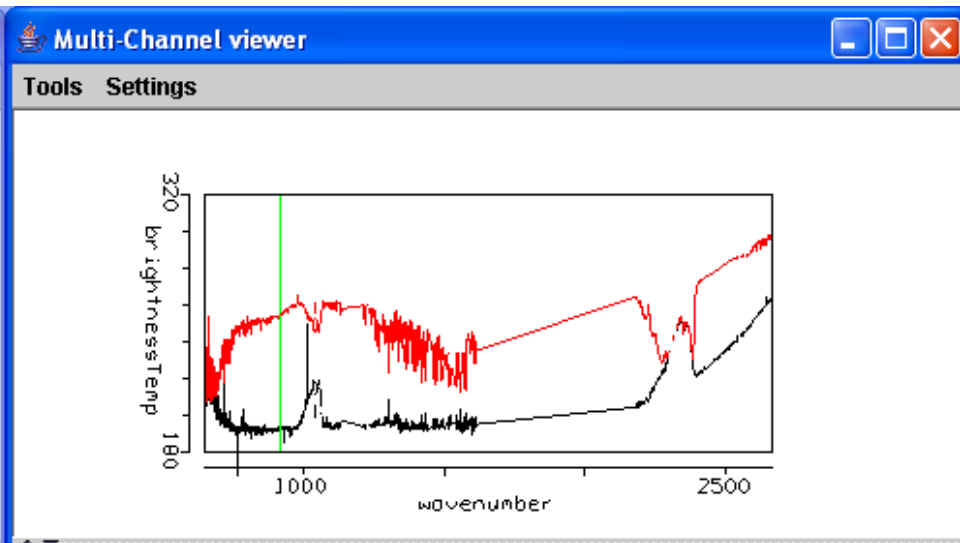
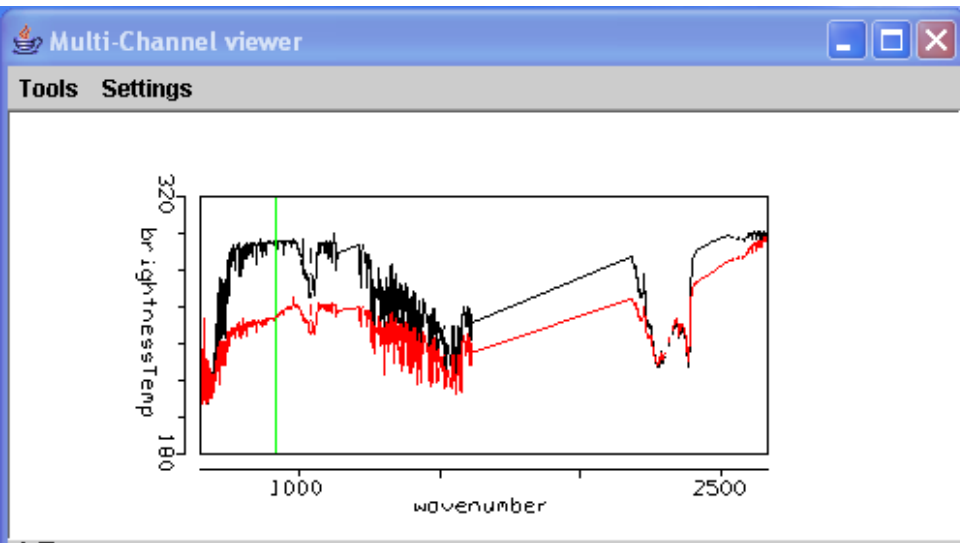
Instrument: AIRS

Lat = 42.604 Lon = 41.110

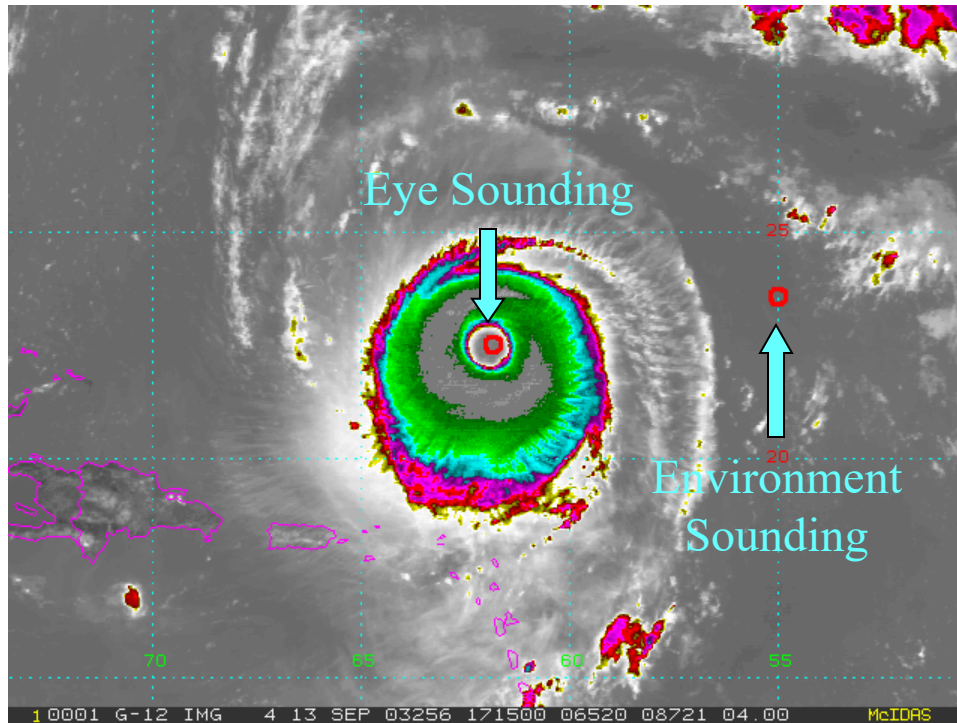


Cirrus VS Clear Sky Spectra

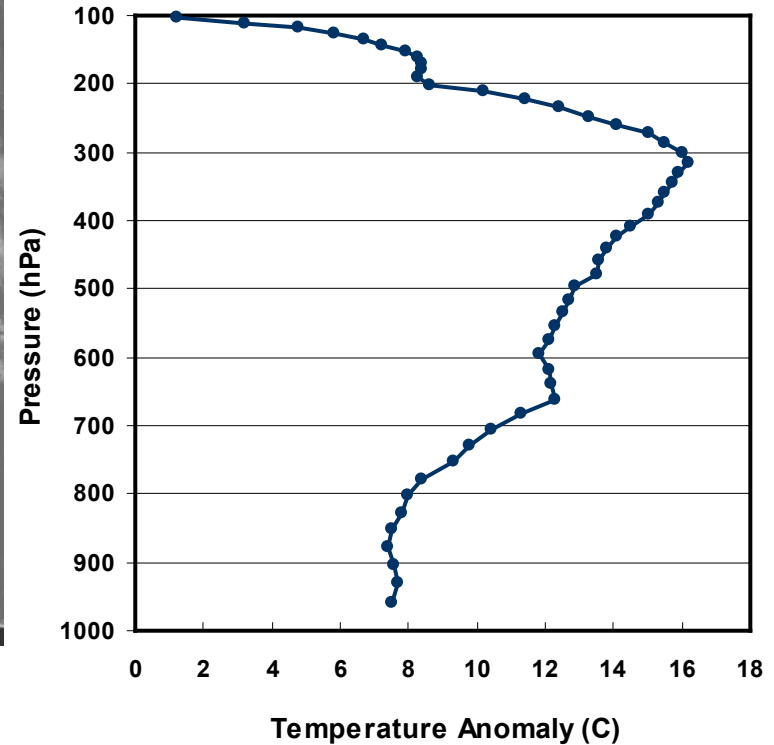
Investigating the Eye of a Tropical Cyclone with AIRS



Isabel Eye Sounding from AIRS



Eye - Environment Temperature



Integrate Hydrostatic Equation Downward from 100 hPa to Surface

Environment Sounding: $P_s = 1012$ hPa

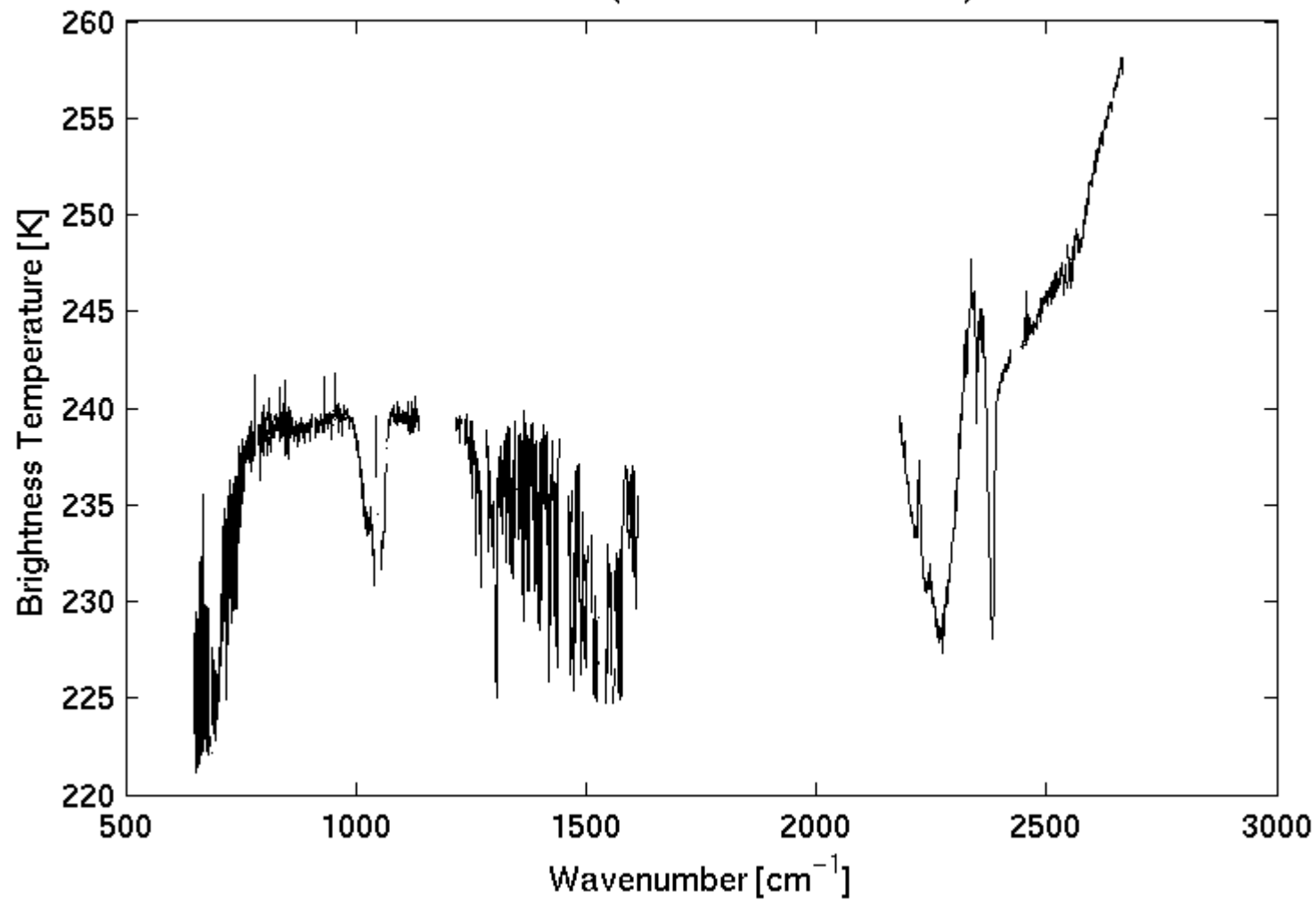
Eye Sounding: $P_s = 936$ hPa

Aircraft Recon: $P_s = 933$ hPa

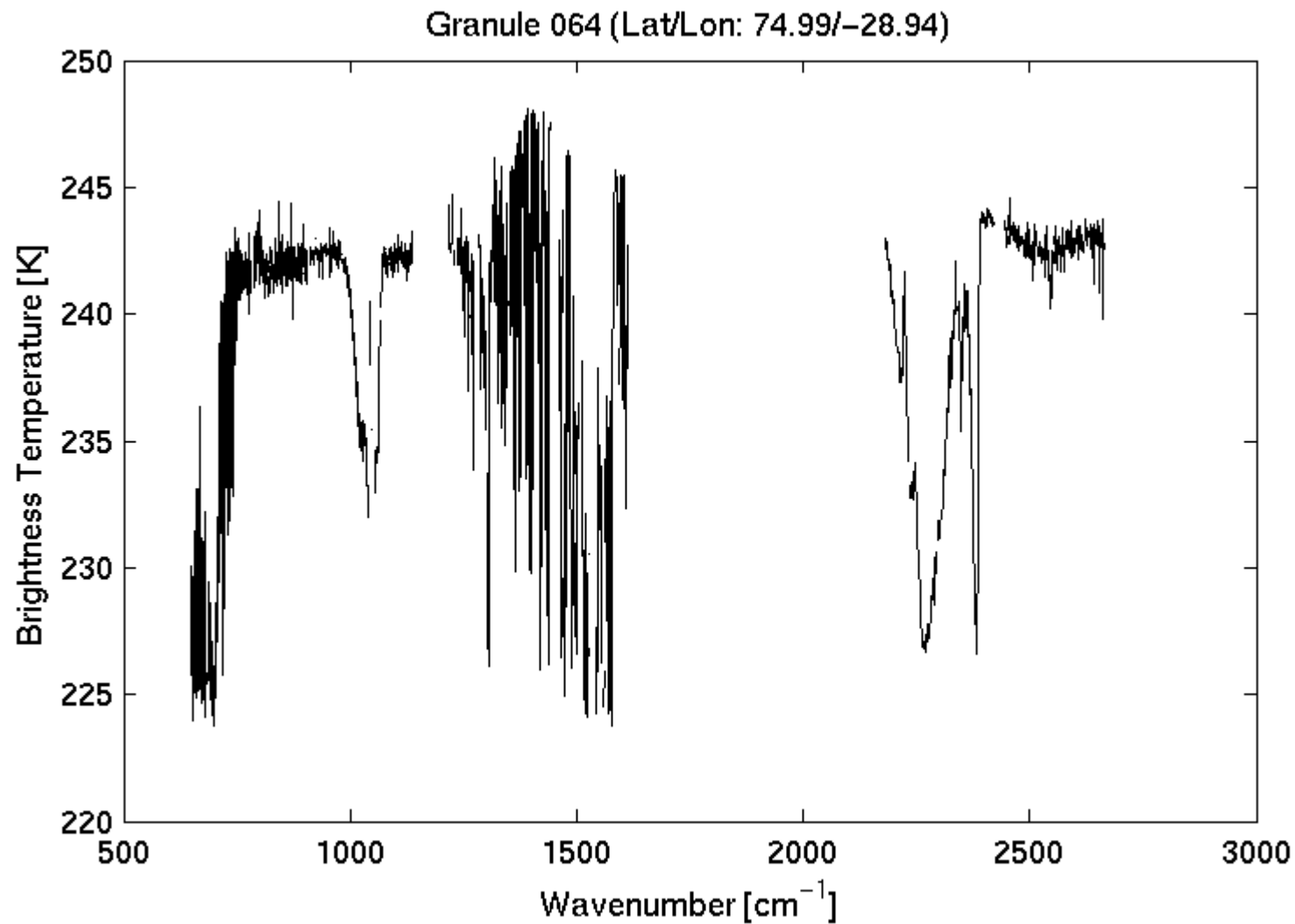
DeMaria, CIRA, 2004

Example Spectra

Granule 227 (Lat/Lon: 66.83/-148.12)

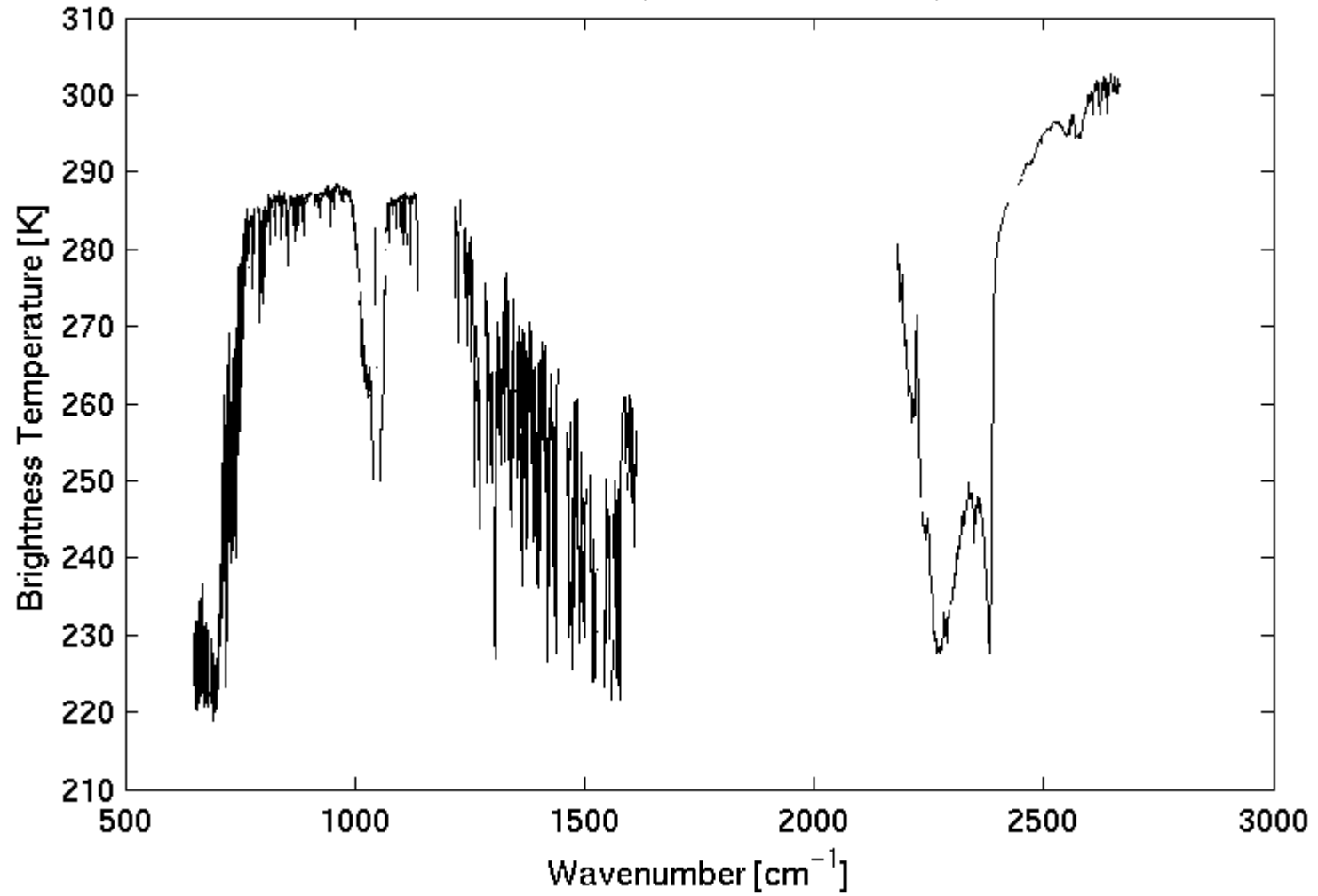


Day or night?



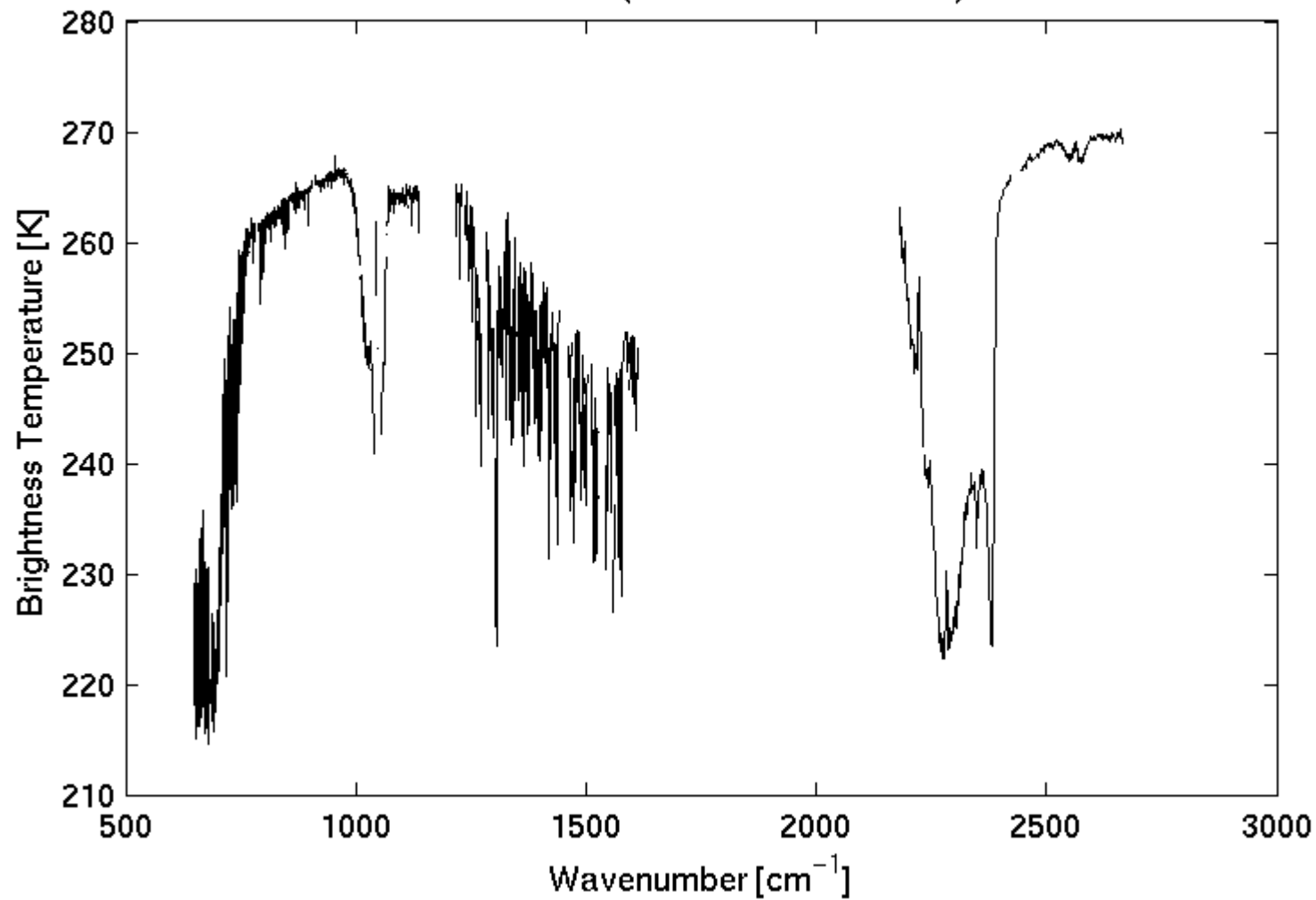
Day, night, desert, or ice/snow?

Granule 127 (Lat/Lon: 48.63/1.69)



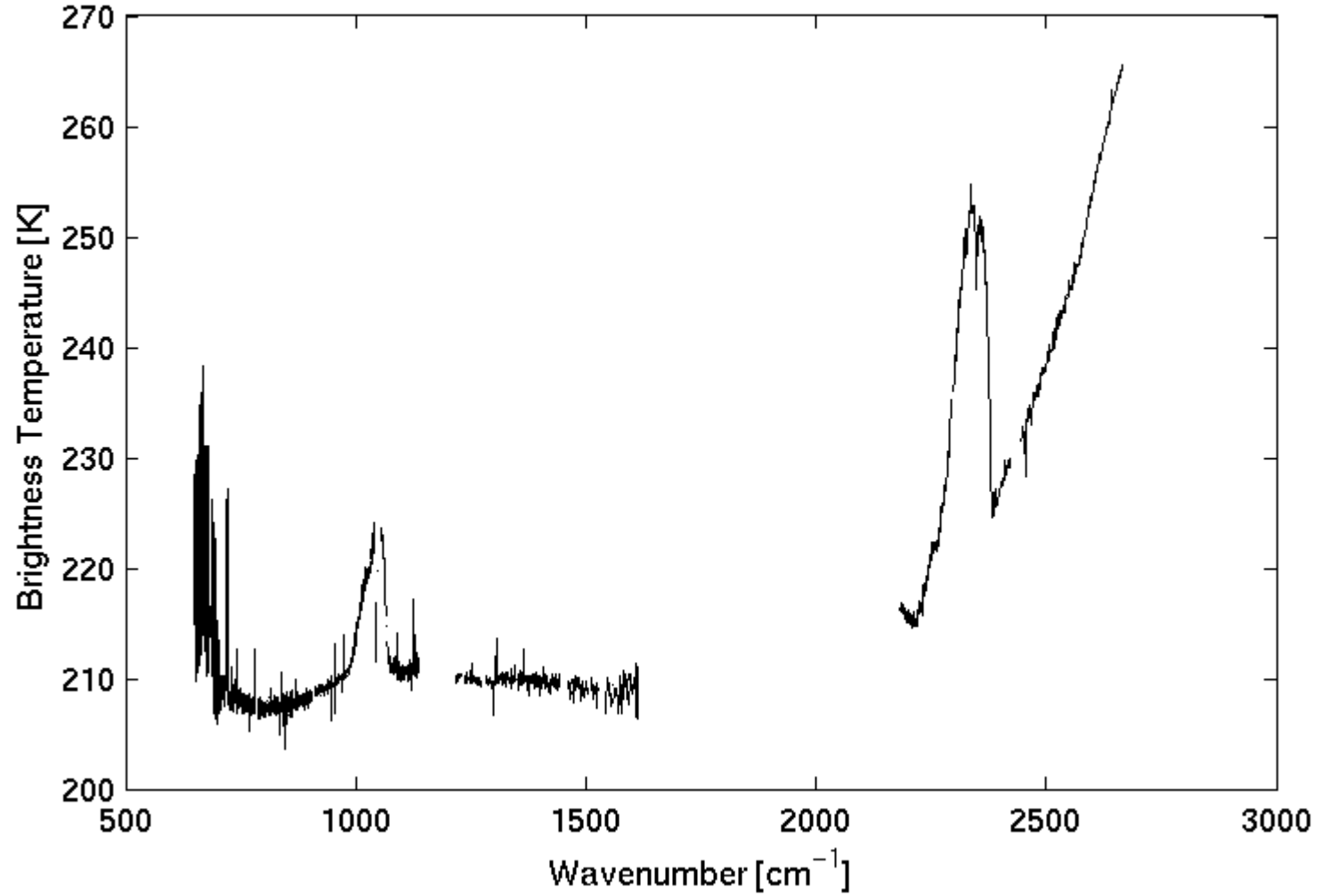
Day or night?

Granule 197 (Lat/Lon: 44.09/102.60)

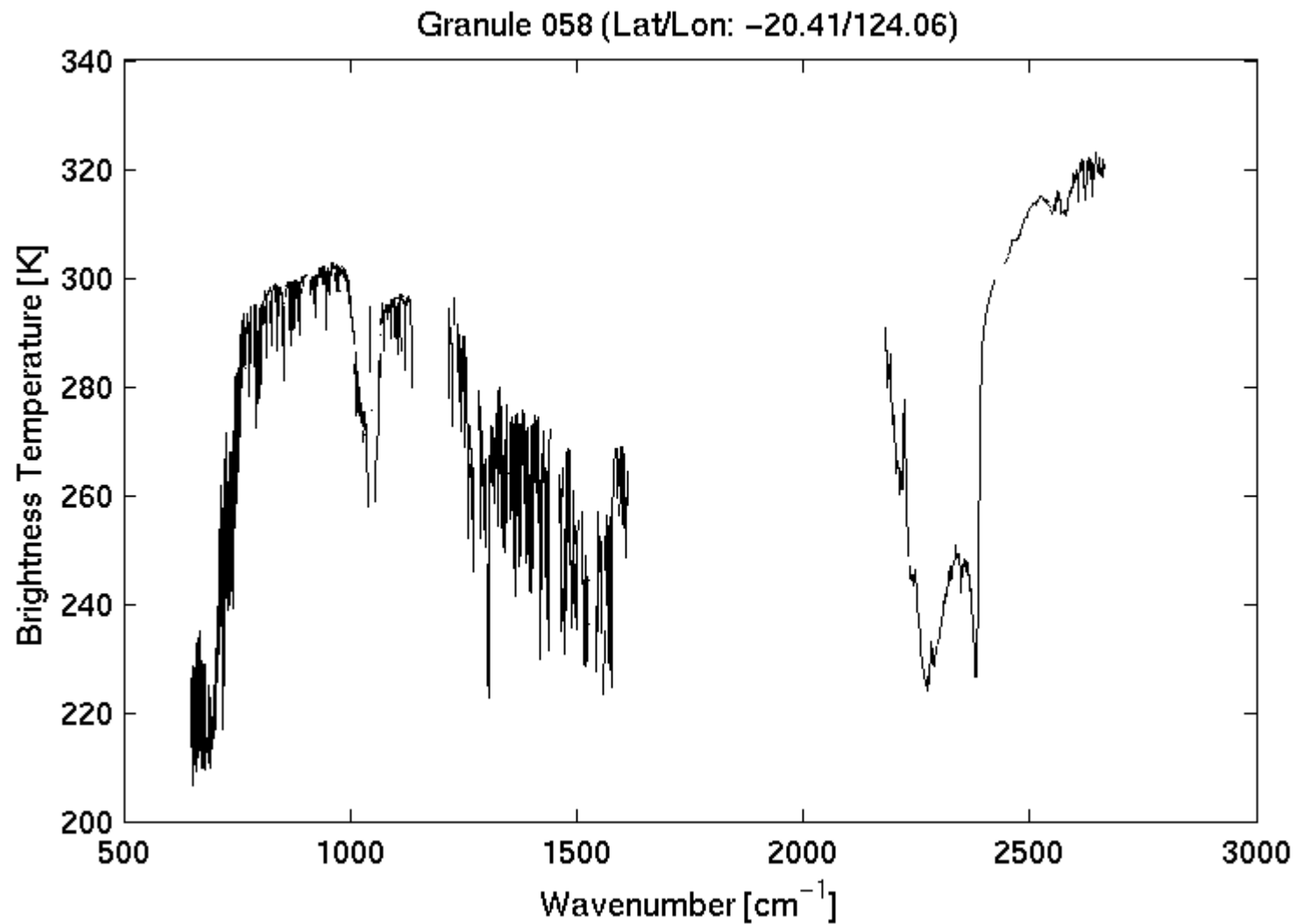


Land or ocean?

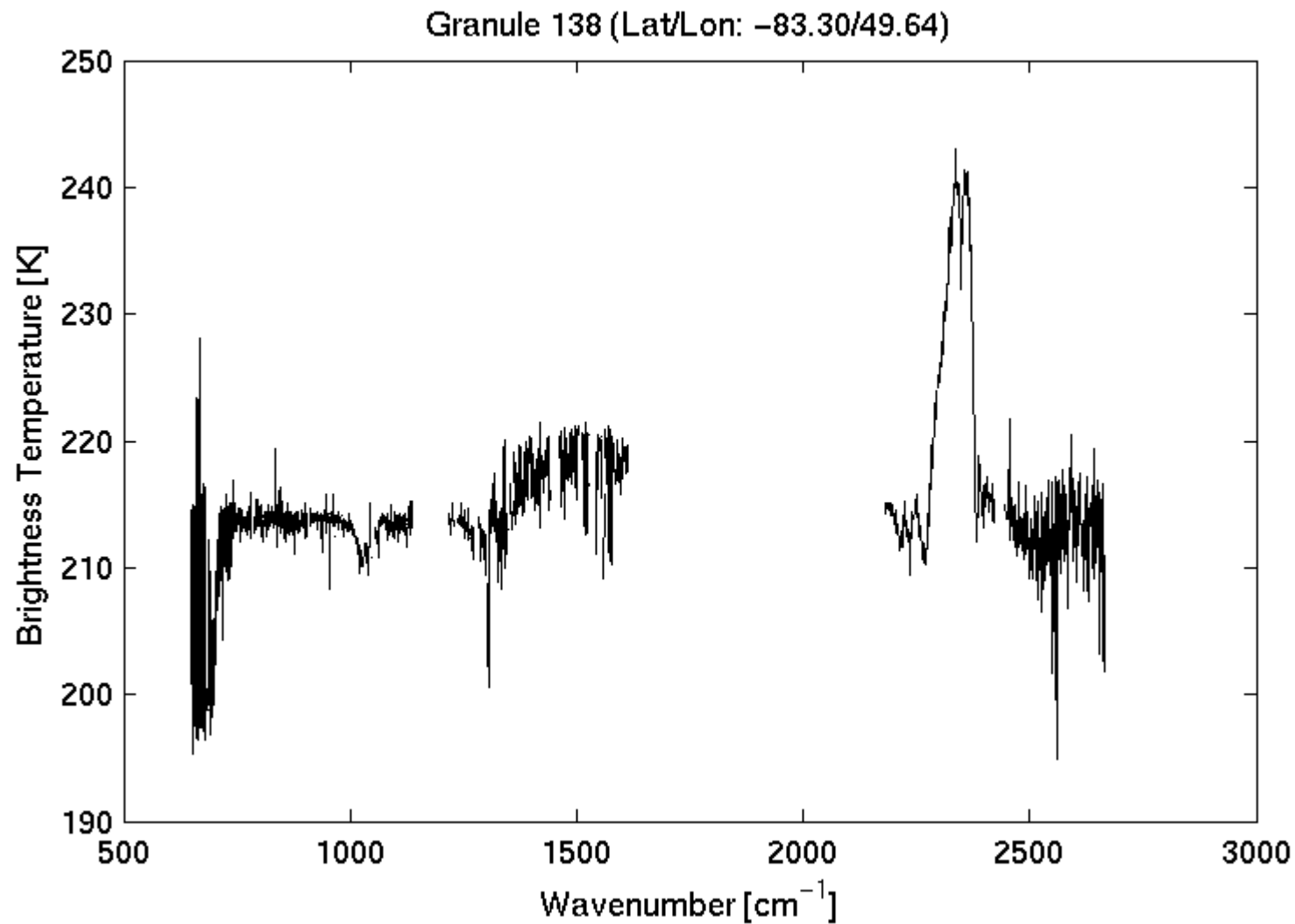
Granule 043 (Lat/Lon: 9.36/144.51)



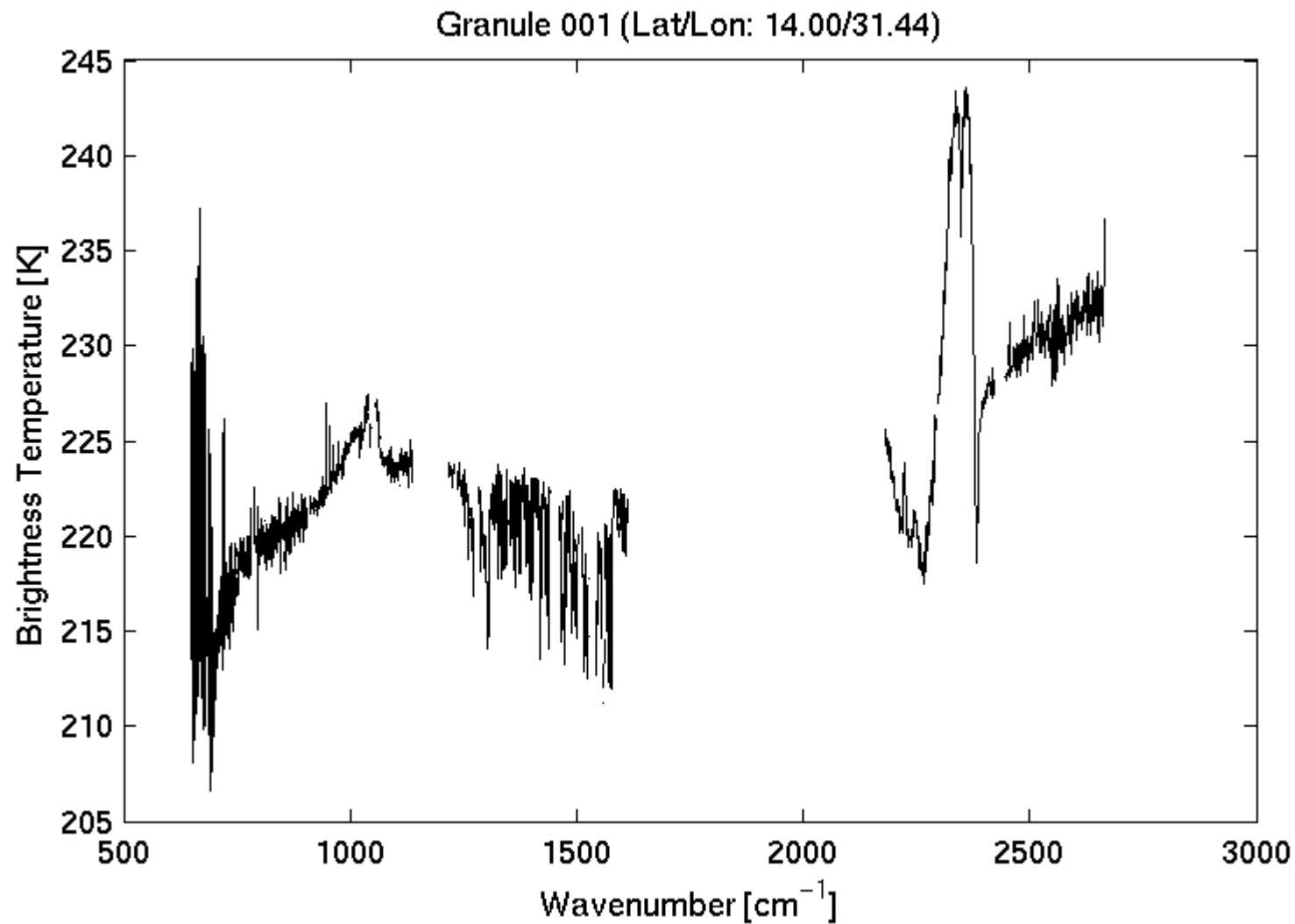
Desert, ocean, or cloudy?



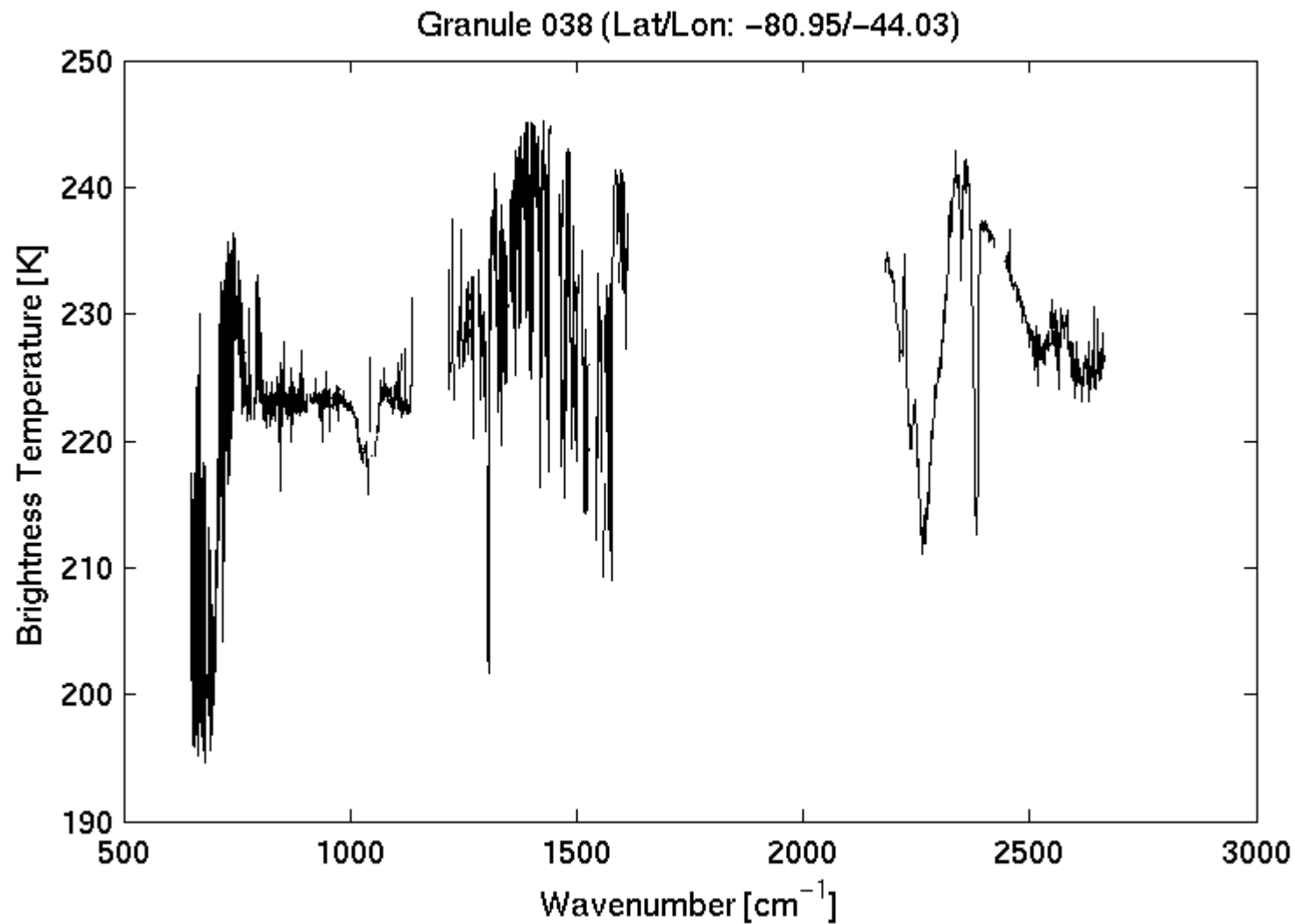
Day, night, desert, or ocean?



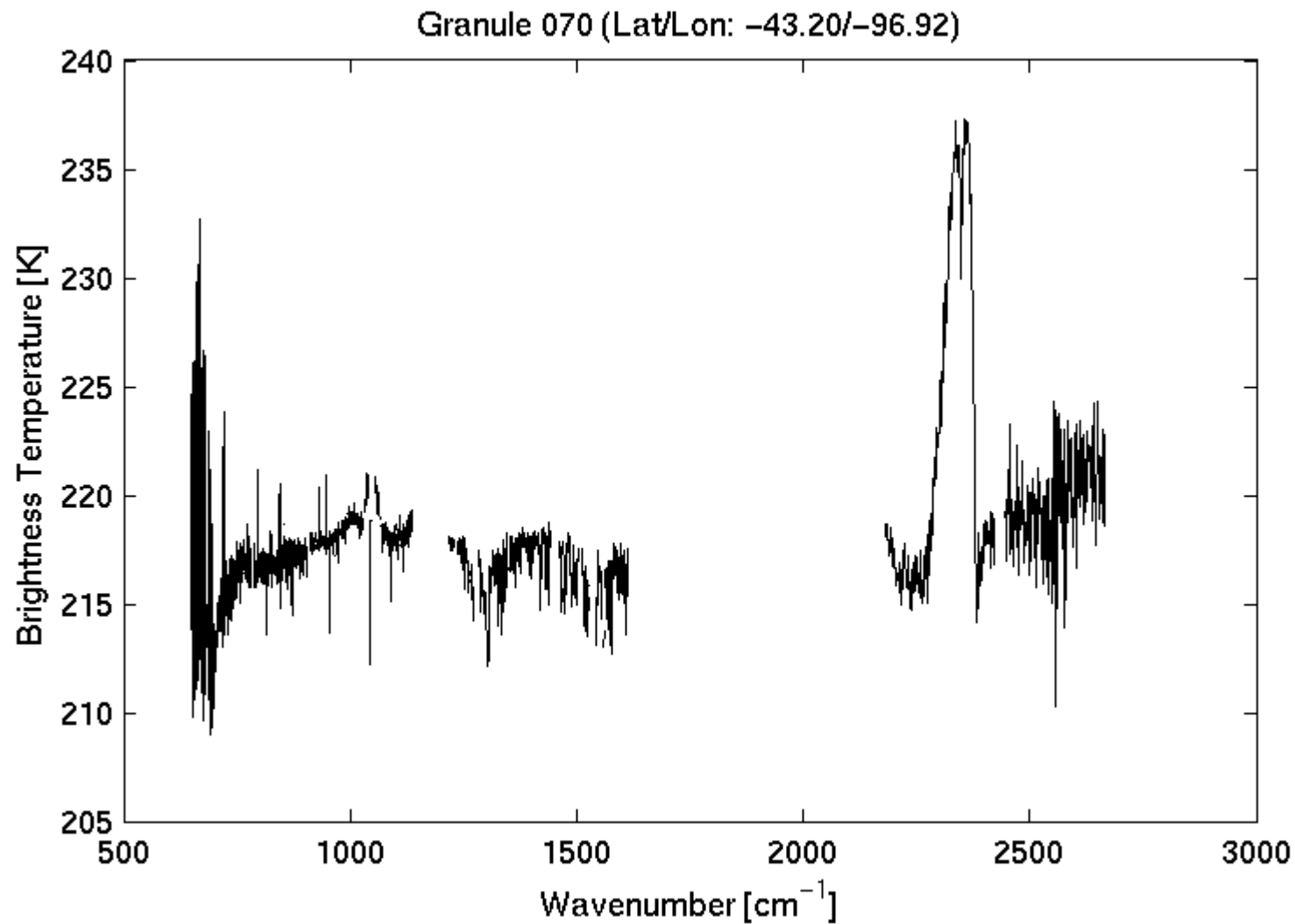
Ocean, cloudy, snow/ice, or desert?



Day, night, desert, or cloudy?

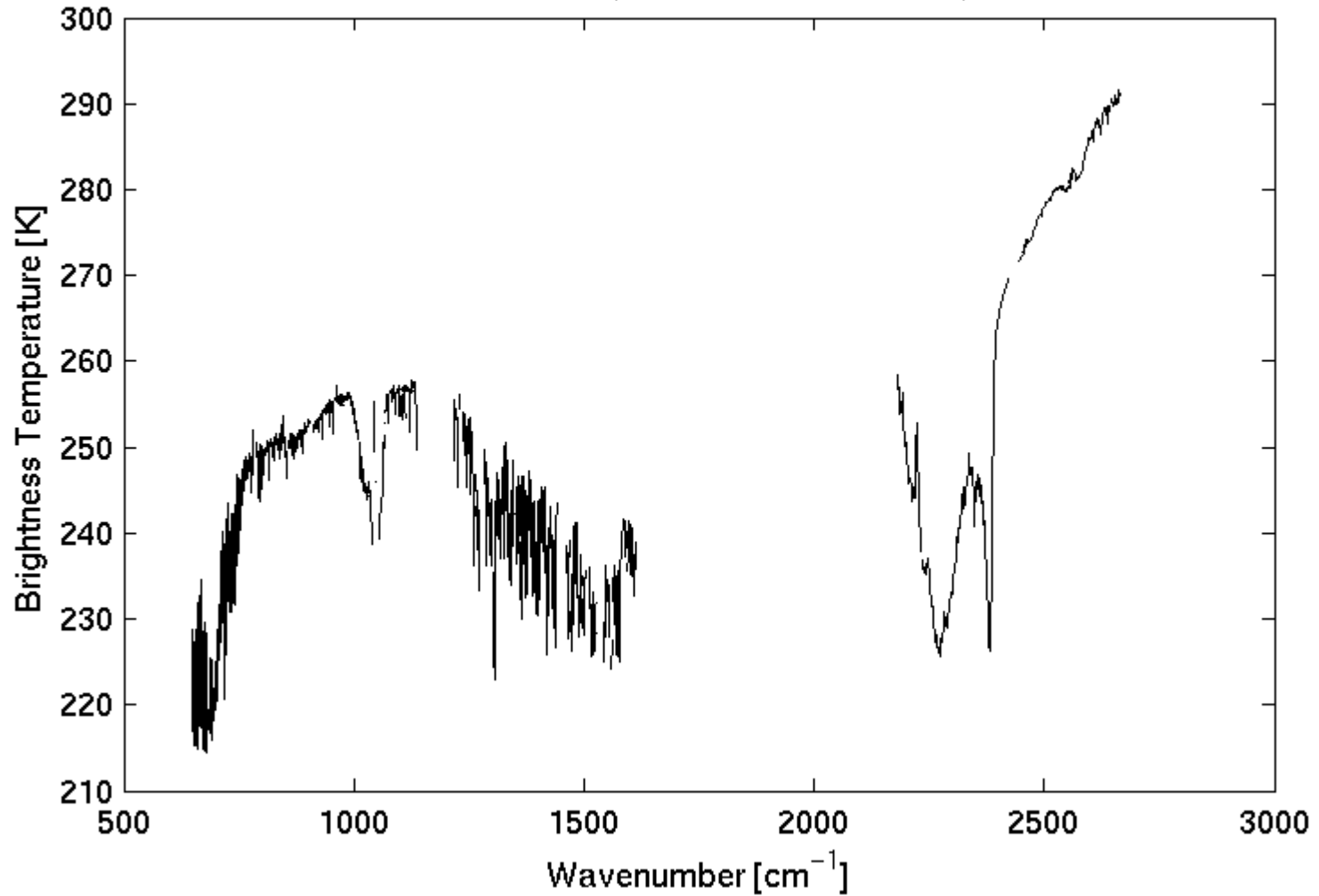


Cloudy, desert, or ocean?

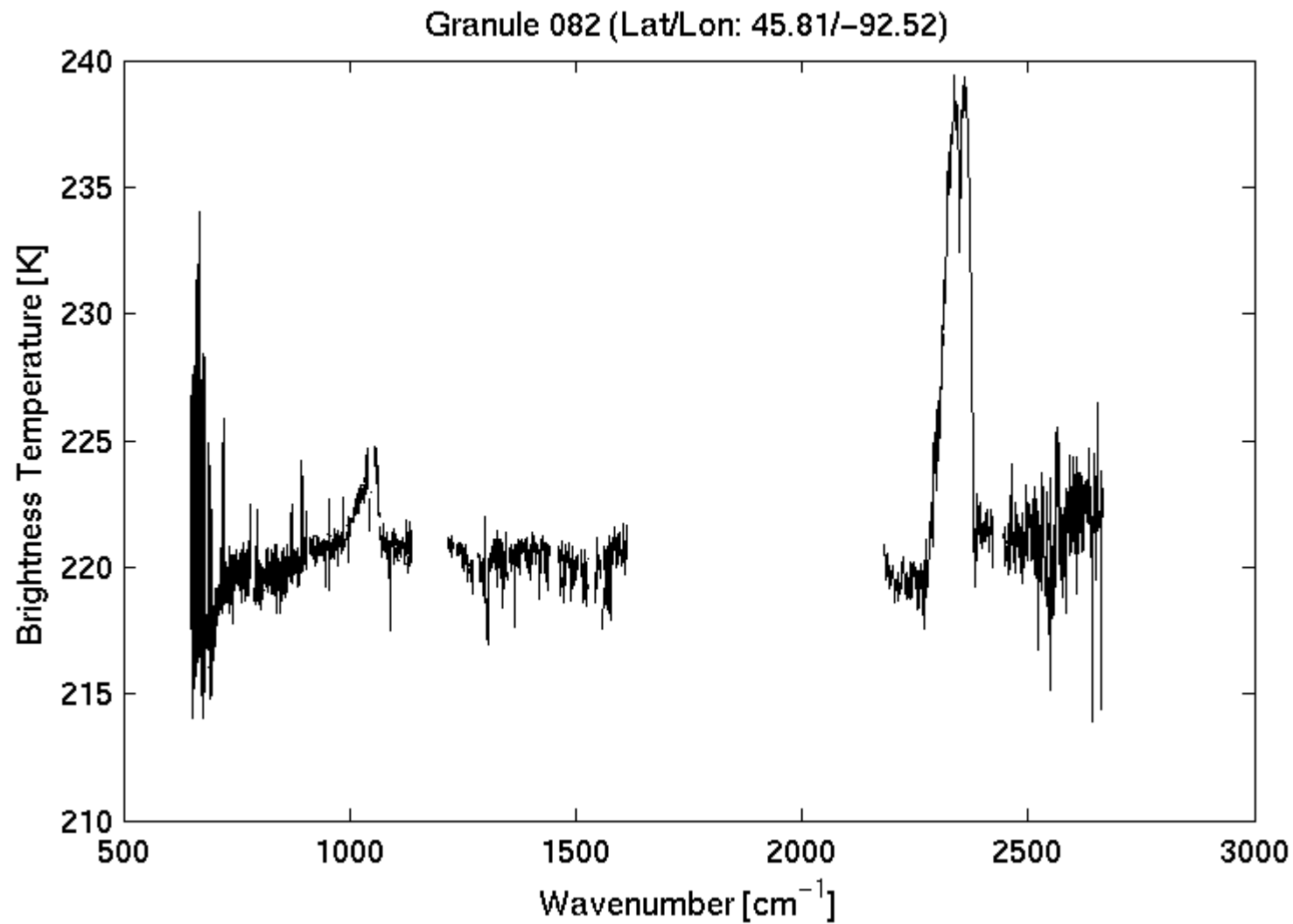


Land, desert, ice/snow, or ocean?

Granule 209 (Lat/Lon: 34.94/-119.14)



Day, night, desert, or cloudy?



Day, night, ocean, or cloudy?