Overview of Atmospheric Radiative Transfer

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Workshop for Soundings from
High Spectral Resolution observations
SSEC - UWisconsin
May 6-8, 2003

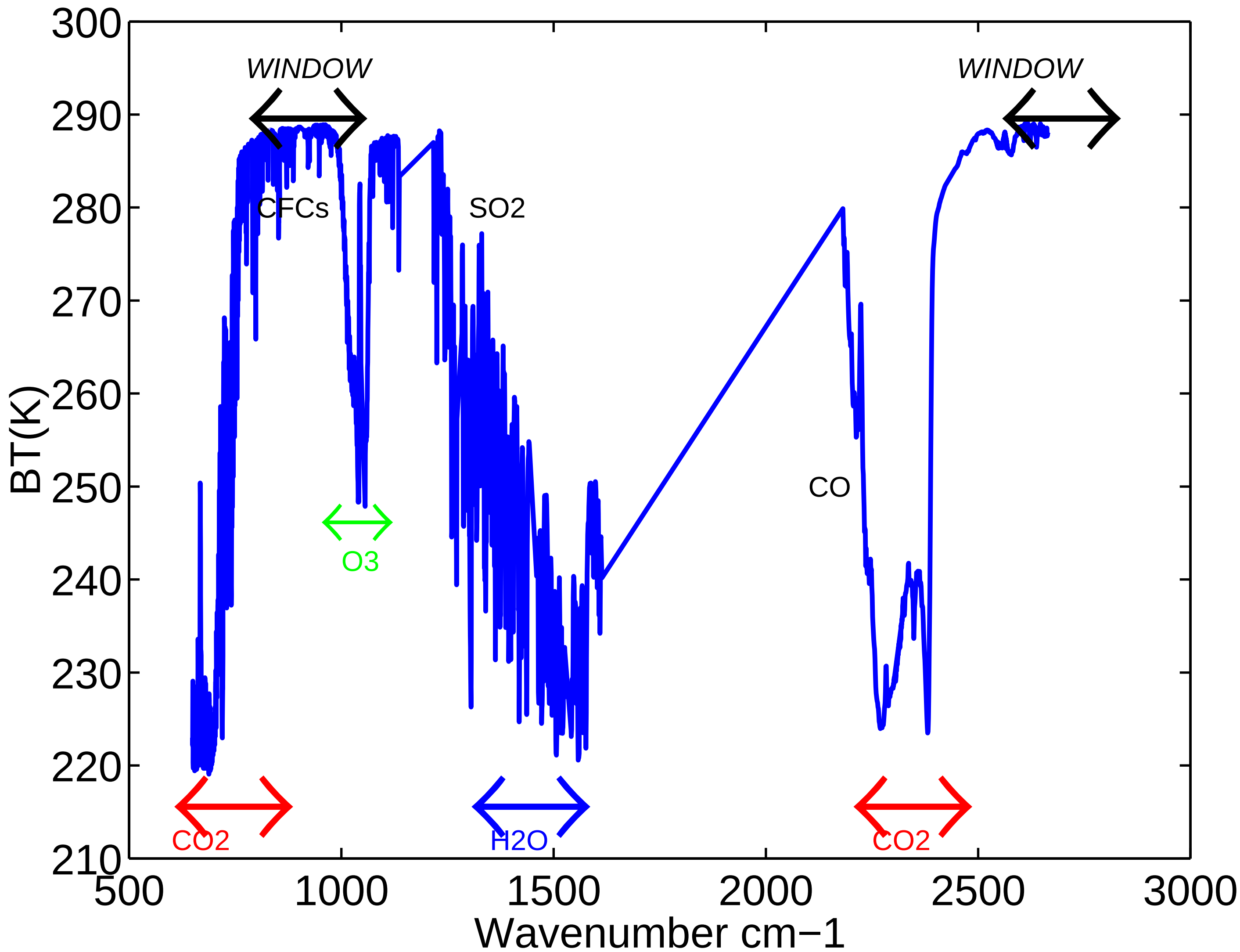
Overview

- Introduction
- Line by line Infrared Spectroscopy
- Radiative transfer : Clear, cloudy, NLTE
- Fast model (spectroscopy + radiative transfer)
- Validating the Fast model (clear sky)
- Sources of unknown bias?
- Cirrus observations
- Duststorm observations
- Volcanic eruption observations
- Conclusions

Introduction

- New generation instruments for remote sensing are high resolution, low noise
- Require accurate forward models for radiative transfer
- Both spectroscopy and radiative transfer algorithm must be accurate
- Complications in IR spectroscopy include water vapor, CO_2 lineshapes deviate from Lorentz in the wings, where temperature/amount retrievals require most accuracy!
- Complications in radiative transfer include scattering effects due to clouds and aerosol, surface emissivity, reflectivity uncertainties
- Instruments download tons of data daily, so need accurate, fast models

Radiance vs Wavenumber : Important Gases, Window Regions



Absorption in atmosphere : Infrared Molecular Spectroscopy

- Custom "line-by-line" code UMBC-LBL
- Line parameters obtained from standard databases, such as HITRAN
- For most gas molecules, use voigt lineshape. Quite fast (unless you have hundreds of lines, such as HNO3)
- CO2 : special case, needs linemixing lineshape
- H2O : special case, needs continuum lineshape

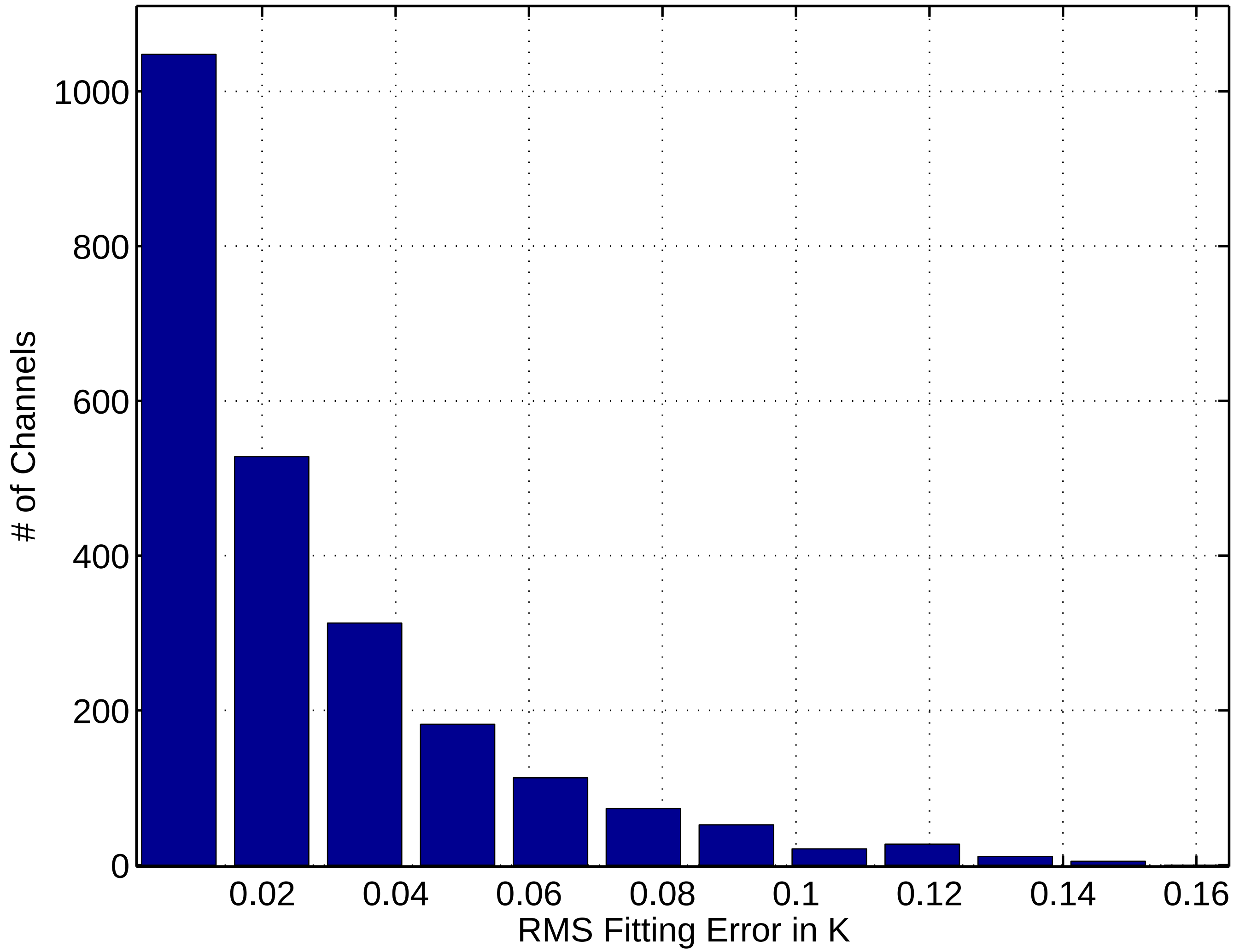
Absorption in atmosphere : Scatterers

- Atmosphere has clouds, aerosols etc
- These particles can strongly absorb and/or scatter radiation
- Modelling their scattering parameters can be straightforward (assume spherical particles, simple size distribution) or painful (irregular particles, multimode size distributions etc)
- Need accurate knowledge of refractive index
- Some literature, or OPAC database, has low resolution info (5 cm-1)
- In the 10-12 um window region the absorption of a cloud strongly affects the TOA radiance. This gives valueable clues to type of particles in cloud, as absorption depends on refractive index
- In the 3.8 um window region scattering of cirrus particles can give clues about crystal habit
- Thin cirrus/ aerosol events seem to make it thru the clear sky filter and could impact the retrieval algorithm

Fast Models

- “line-by-line” codes are accurate, but SLOW
- ‘kCARTA uses compressed look up database of optical depths to compute ’monochromatic LBL” radiances
- SARTA is a Fast Model based on kCARTA
- Fast Model   0.5 secs/profile; kCARTA   10 mins/profile (1 GHz machine)

Histogram of AIRS-RTA fitting errors.



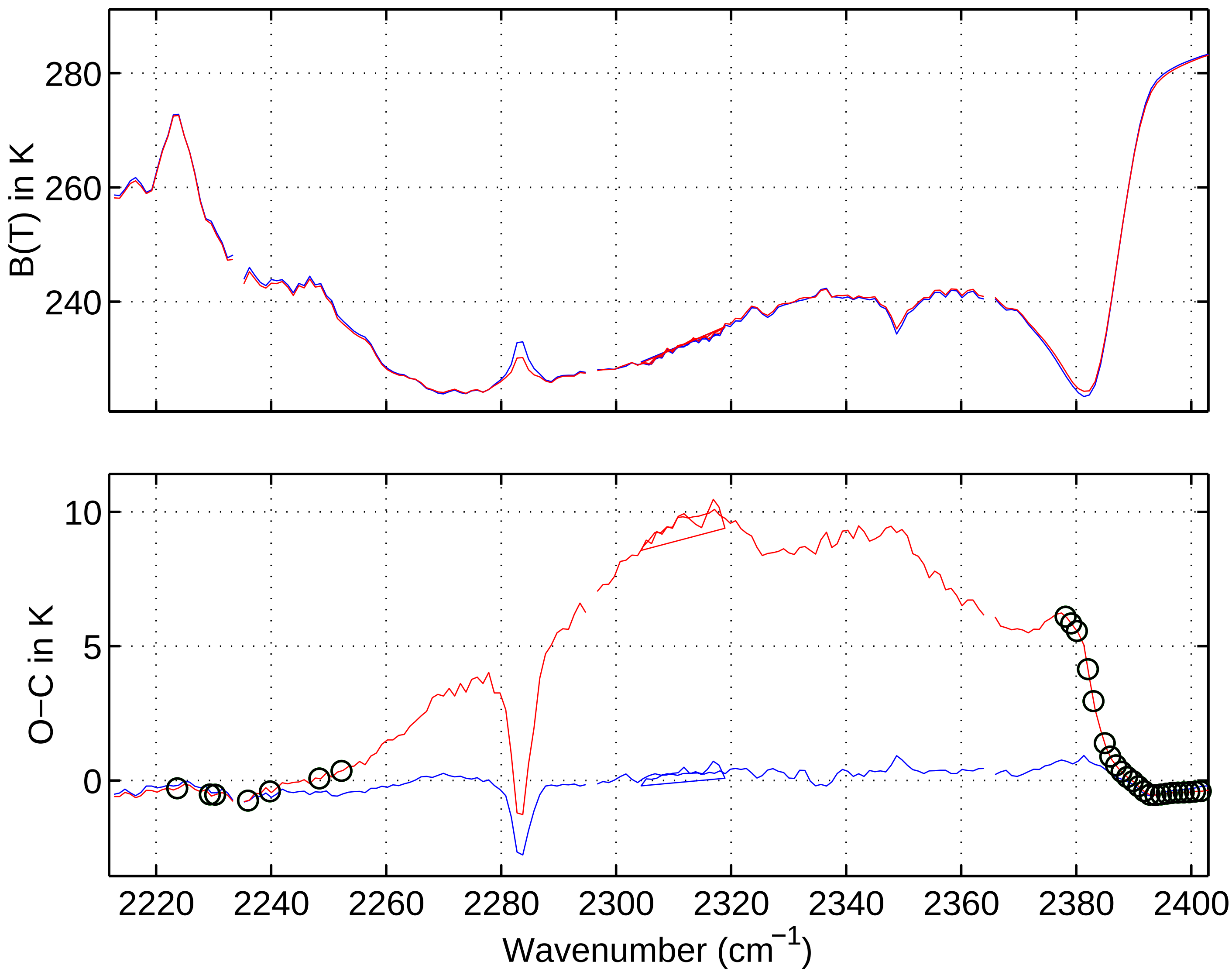
Radiative Transfer

- At steady state, the 1D Schwartzchild Equation says

$$\mu \frac{dI(\nu,\theta)}{k_e dz} = -I(\nu,\theta) + J(\nu)$$

- $\mu = cos(\theta)$, dz is the vertical coordinate
- k_e is the total extinction (due to gases, clouds etc)
- $k_e dz = d\tau$ is the optical depth
- $I(\nu,\theta)$ is the radiance intensity
- J is the source function
- Clear Sky, in LTE : $J = B(\nu, T)$, Easy!
- Clear Sky, in NLTE : $k_e^{'} = r_1 k_e; J = r_2 B(\nu, T)$
- Cloudy Sky, in LTE : integro-differential equation, Hard!

Effect on Non-LTE on AIRS instrument



Solution of Radiative transfer Equation III : Cloudy Sky

- For Cloudy Sky, solution is much more complicated!
- Solution by specialised codes, such as DISORT,RTSPEC,kTWOSTREAM
- Need to worry about scattering parameters : particle size distribution, particle shape, cloud vertical extent
- Depending on complexity of solution, code can be quite slow!
- DISORT well tested, solar beam scattering, multiple streams, slow!
- RTSPEC well tested, two streams, no solar beam, fast!
- kTWOSTREAM tested against above codes, two streams, solar beam scattering, quite fast!
- We wrote kTWOSTREAM so we included it in Fast Model!
- Fast Model   0.75 secs/profile; LBL   15 mins/profile (1 GHz machine)
- Plan to validate $kTwoStream$ with LIDAR Data from Chesapeake Lighthouse (Dr. Ray Hoff) – ice crystal habits (Dr. Anthony Baran will provide scattering parameters for eg aggregates)

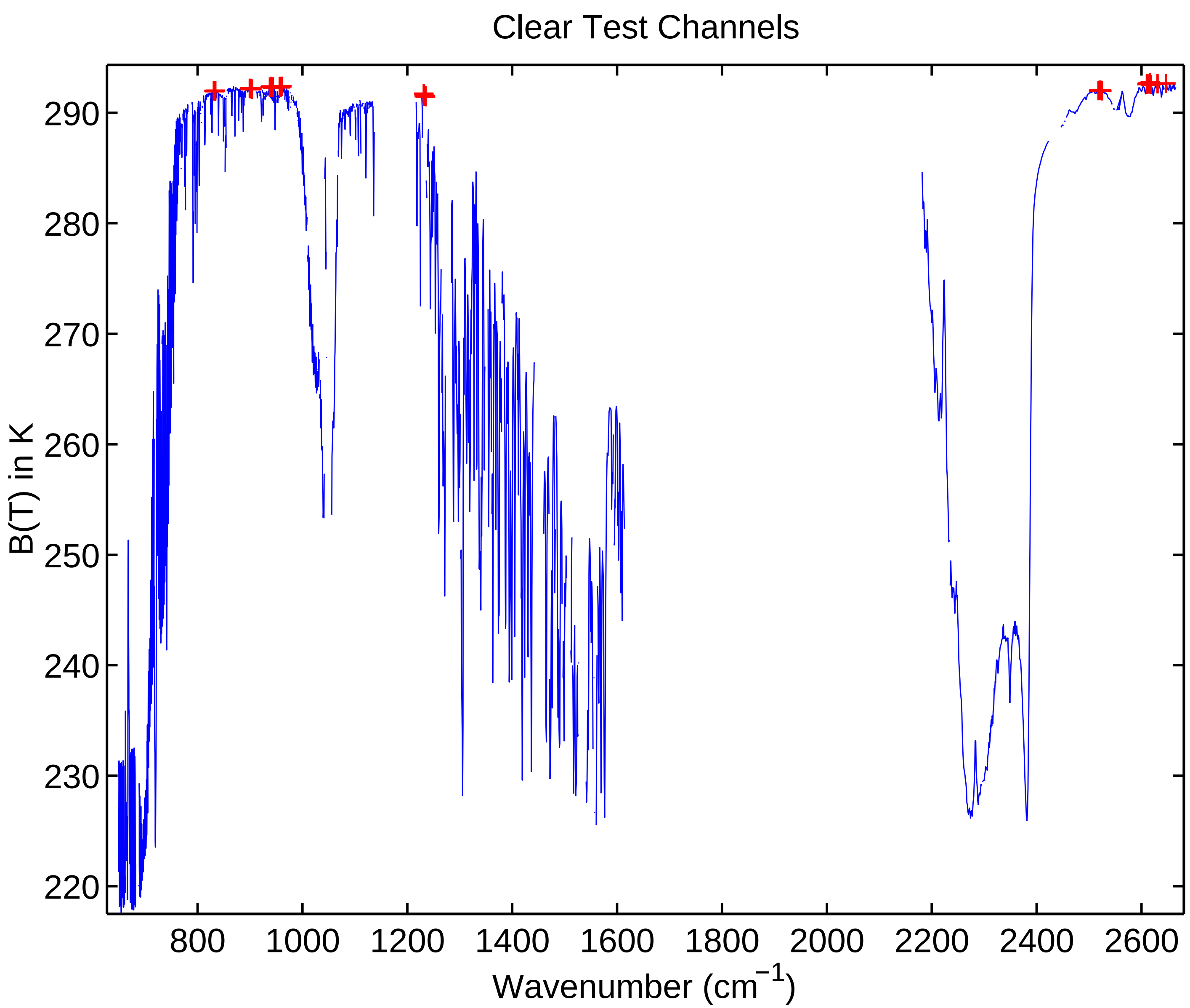
Clear sky : Requirements for small biases

Bias = (mean) obs - (mean) calcs

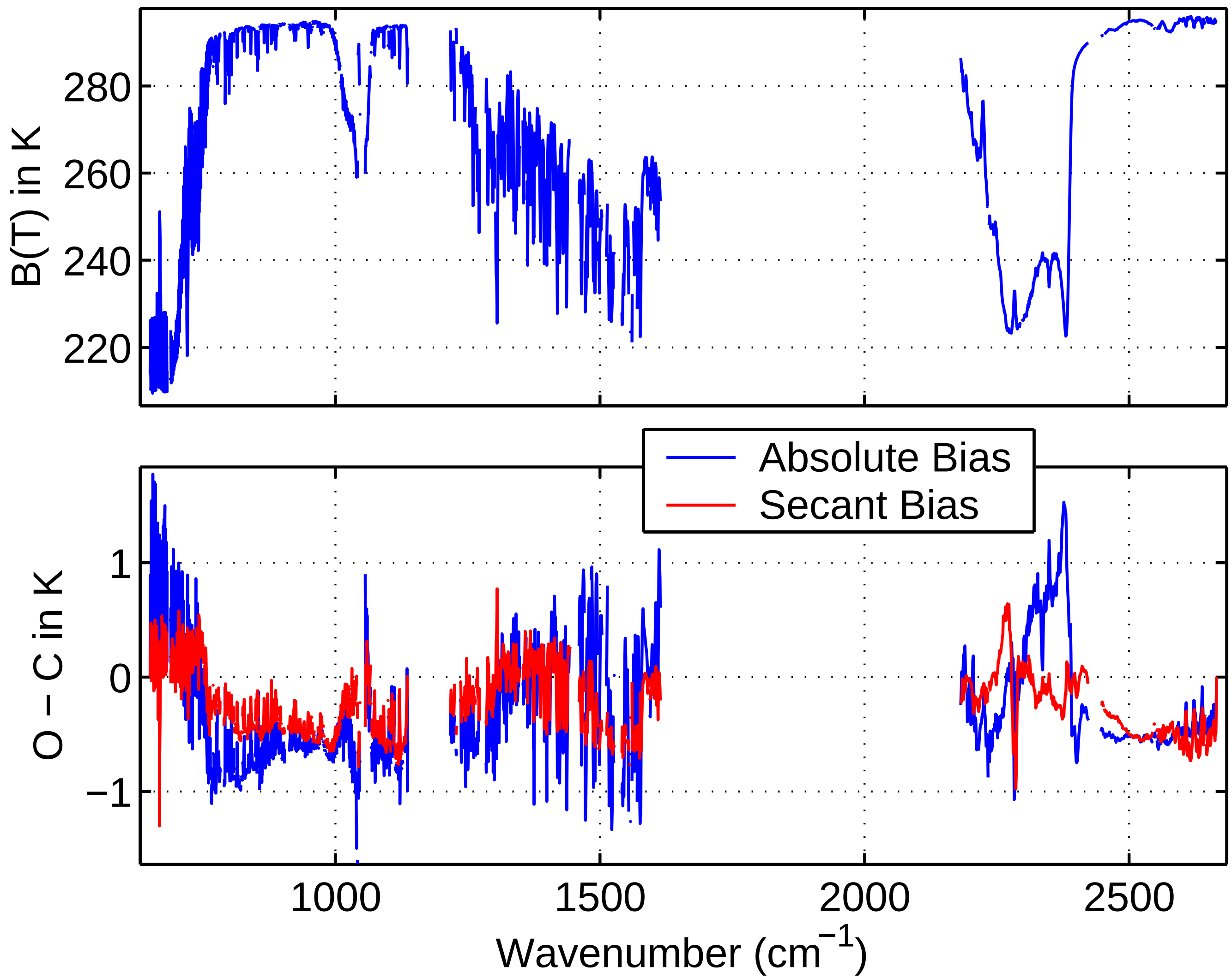
- Spectroscopy for AIRS-RTA is correct
  kCARTA has P/R linemixing for CO2, updated H2O continuum
- SRFs used to simulate the AIRS-RTA radiances are accurate
  SRFs well characterized post-launch
- Profile data fields used for simulations must be statistically accurate
  ECMWF data fields are best global NWP fields
  We are also starting to use ARM-CART radiosondes
- AIRS radiances are radiometrically correct
  Analysis of sea surface radiances by Aumann et al indicate radiometric accuracy of at least 0.5K

Clear Sky : Comparing AIRS observations to SARTA simulations

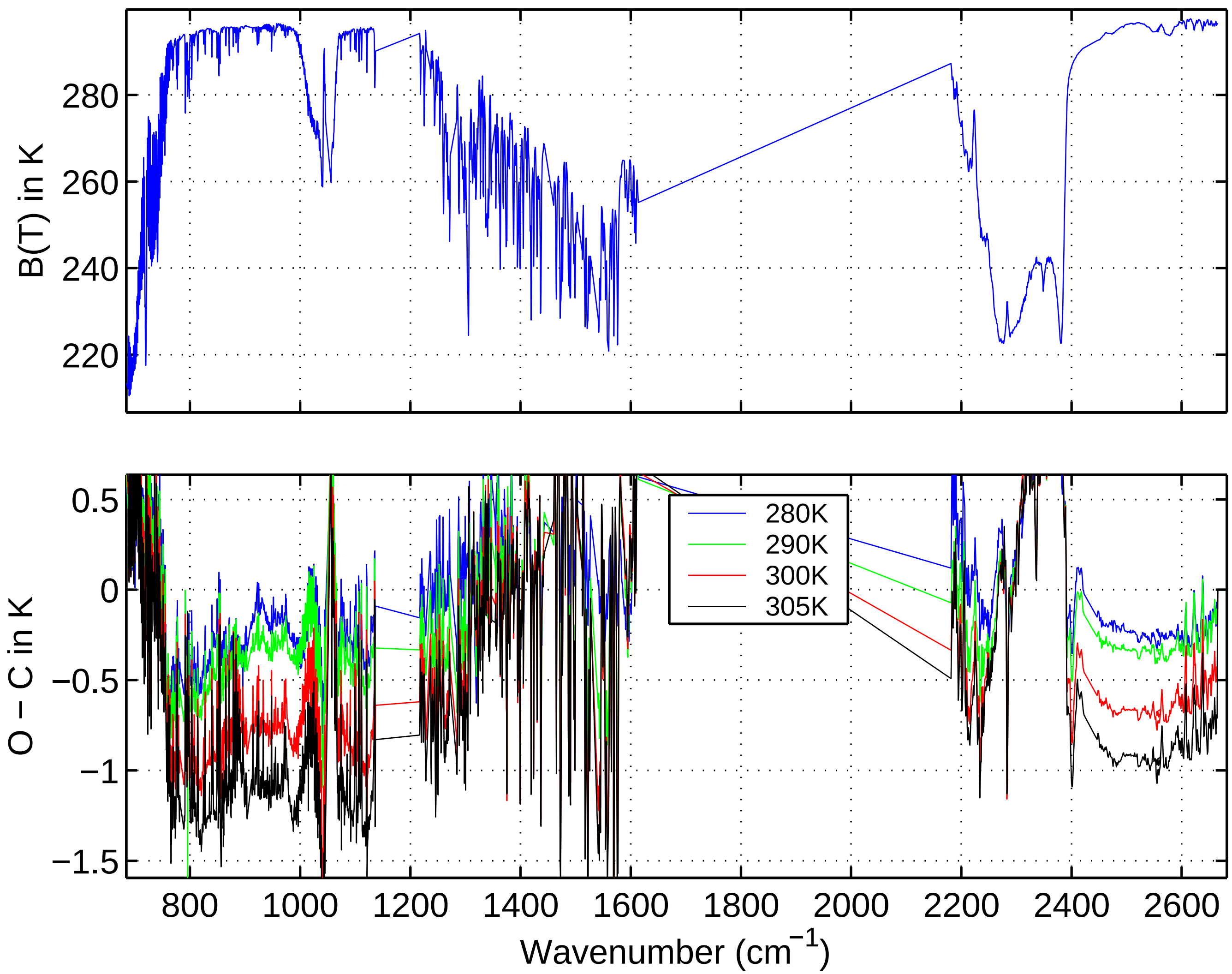
- AIRS-RTA developed for Clear Sky
- 1) Select nitetime views over ocean (sea surface emissivity well characterised)
- 2) Restrict latitudes to ± 60 degrees, use all scan angles
- 3) find FOVS where adjacent BTs are within 0.25 K of center FOV.
  Test done in window channels of 10, 3.8 micron region.
  Test channels used = [900,961],[2611,2616] cm^{-1}
  Throws partly coudy, highly variable water vapor scenes away
- 4) SST from channels in 10, 3.8 microns identical withn about 0.4 K
  Test lessens dependancy on AIRS radiometric calibration
- 5) ECMWF model temperatures, observed SST agree within 4K.
  Test discriminates against low cloud decks
- These tests “throw” away lots of data, yet we typically analyse about 400 FOVs per granule!!


Clear Test Channels
B(T) in K
290
280
270
260
250
240
230
220
800
1000
1200
1400
1600
1800
2000
2200
2400
2600
Wavenumber (cm^{-1})

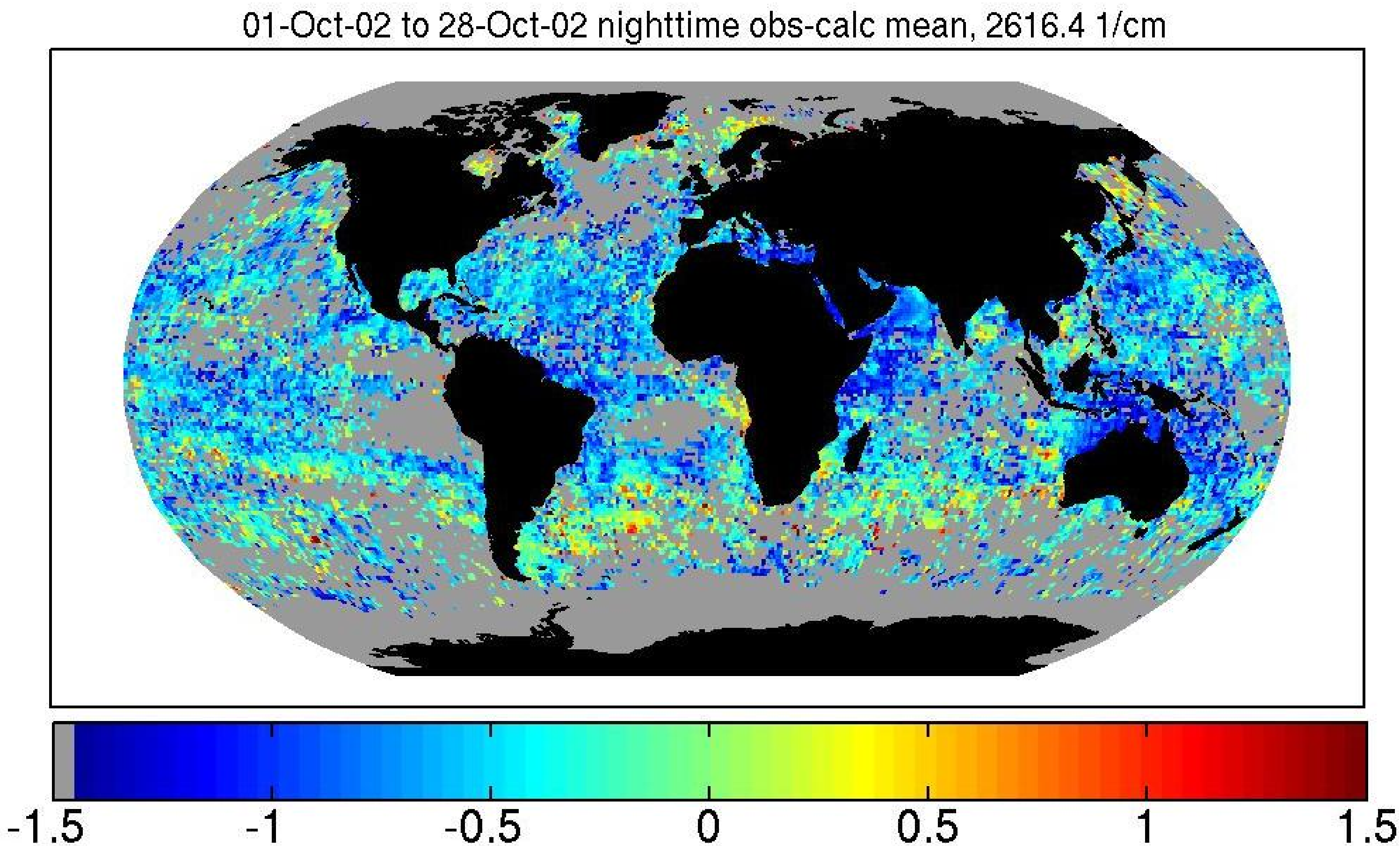
AIRS brightness temperature biases for clear, ocean, night scenes for October 2002 with ECMWF model fields



Mean monthly bias between AIRS and ECMWF computed brightness temperatures as a function of SST.



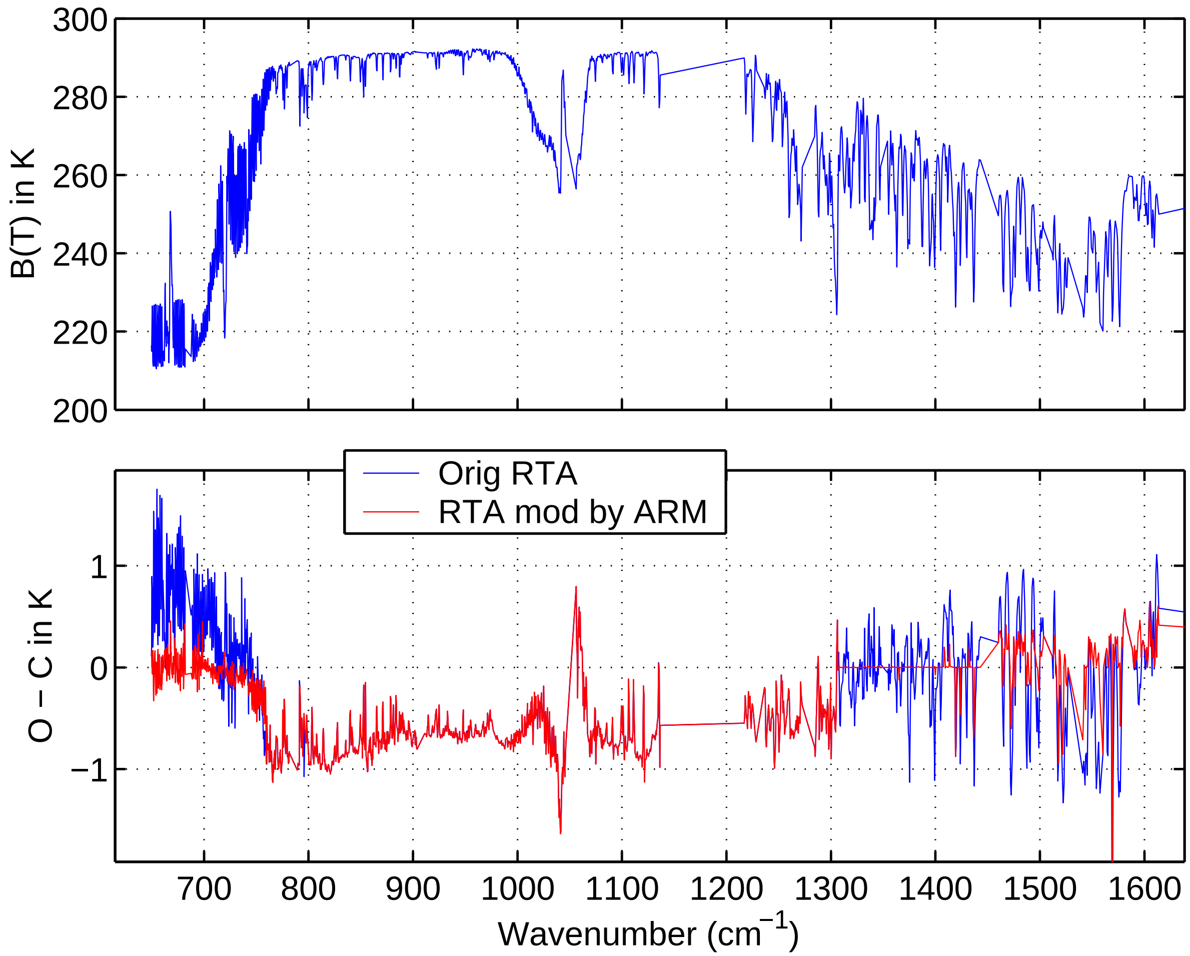
Scatter plot of bias at 2616 cm-1



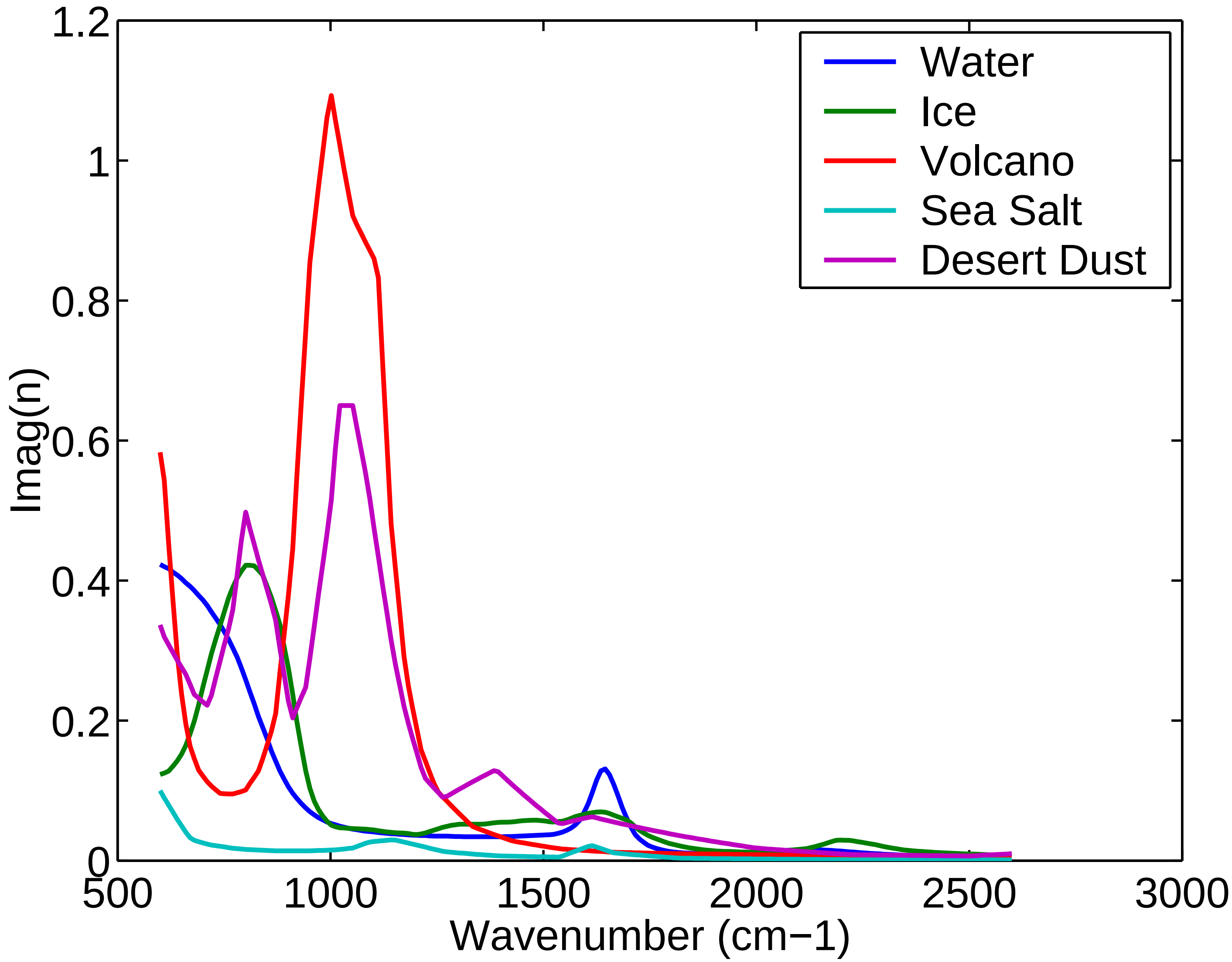
Oct 2002 bias vs Validated bias

Top plot : Mean spectra

Bot plot : Validated data, adjusting continuum coeffs, fixed gas predictors



Scattering particles in Atmosphere : Refractive Index



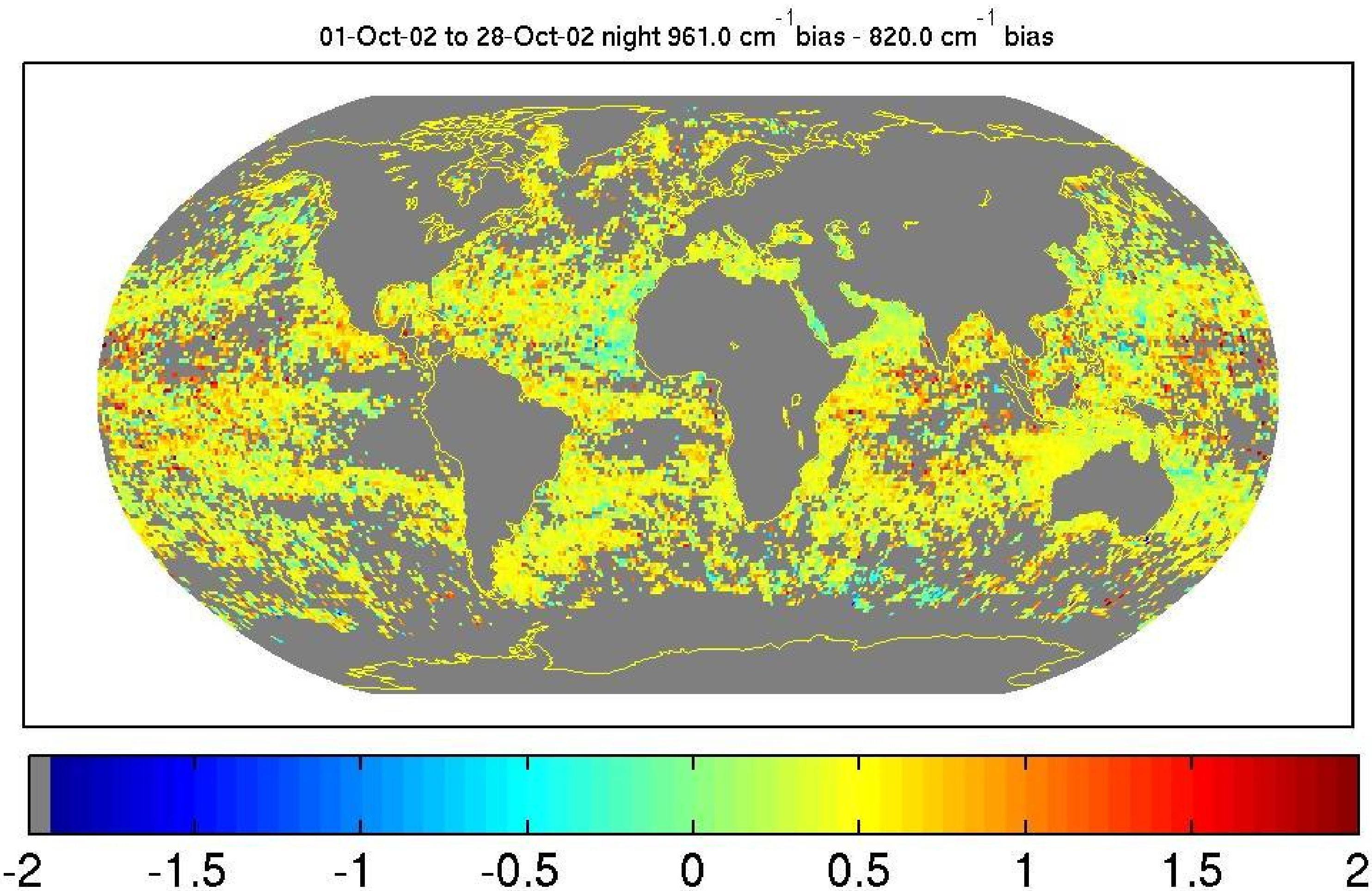
Detecting Cirrus Clouds with AIRS

- Refractive index of ice means that typically, BT(980) $\geq$ BT(820)
- Crystal habit information can be recovered from analysing the 10-12, and 8 um windows *and* 3.8 um windows as well
- Have detected and analysed cirrus clouds using scattering parameters for spheres and aggregates (Dr. Anthony Baran)

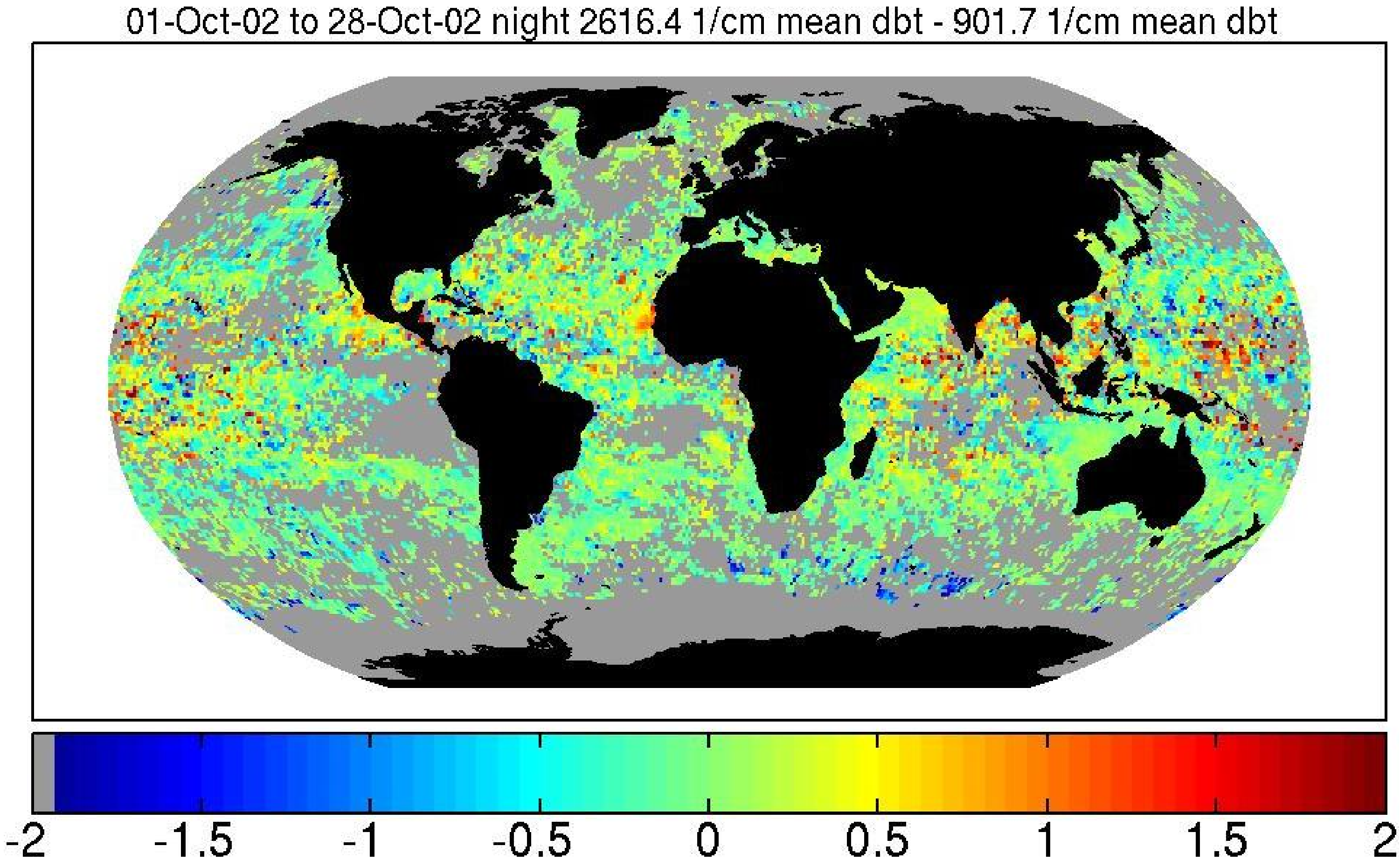
Detecting Cirrus Clouds with AIRS (contd)

- Currently assume $cfrac = 1$, do CO_2- slicing for cloud top pressure (C. Barnet will do this work for us!!!)
- Assume only ONE cloud in FOV
- Use ECMWF fields for water vapor, temperature, ozone, surface params
- Use about 200 channels, spaced in the 10-12, 8 and 3.8 um windows
- Do a least squares fit using $SARTA\_CLOUDY$
- Ice aggregates (Dr. Anthony Baran) fits AIRS spectra in 10-12 um and 3.8 um windows, better than ice spheres.
- Currently working on a nonlinear retrieval algorithm (seems to work for large cirrus signatures, problems with small signatures)

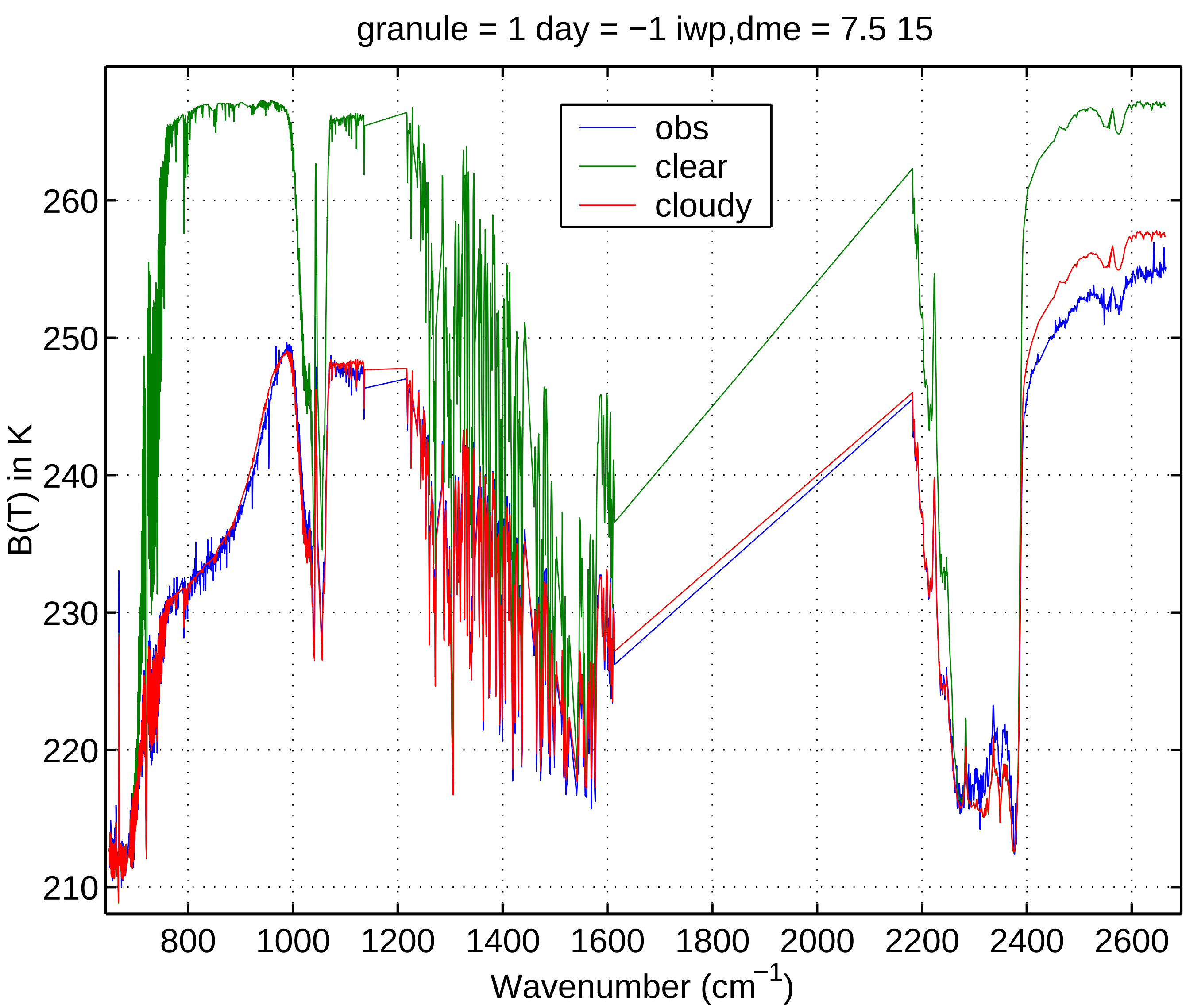
Average monthly difference between the 961 and 820 cm^{-1} channel biases



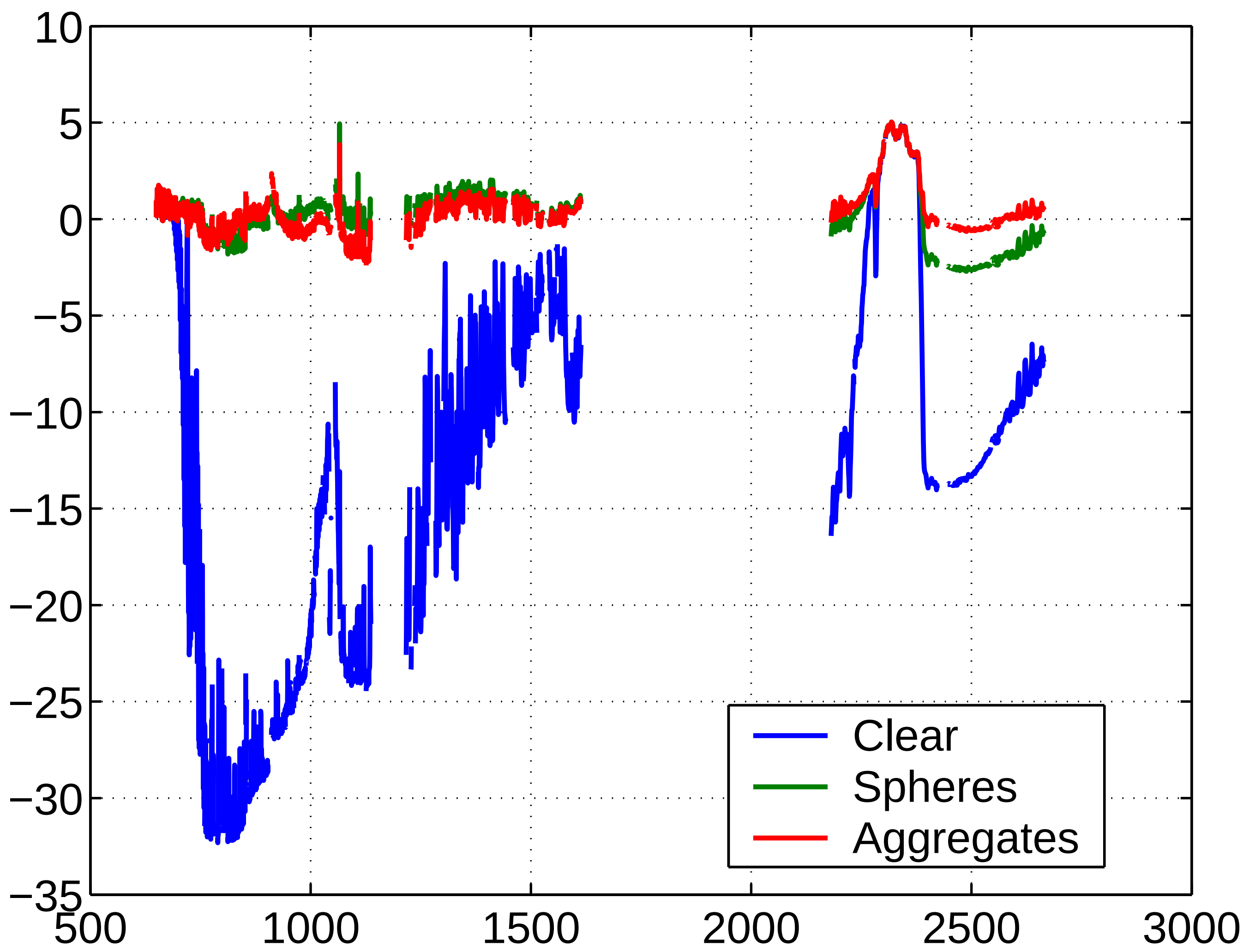
Water vapor under control : Mean monthly bias between AIRS observed brightness temperatures and those computed from ECMWF model fields for the 2616 cm^{-1} channel.



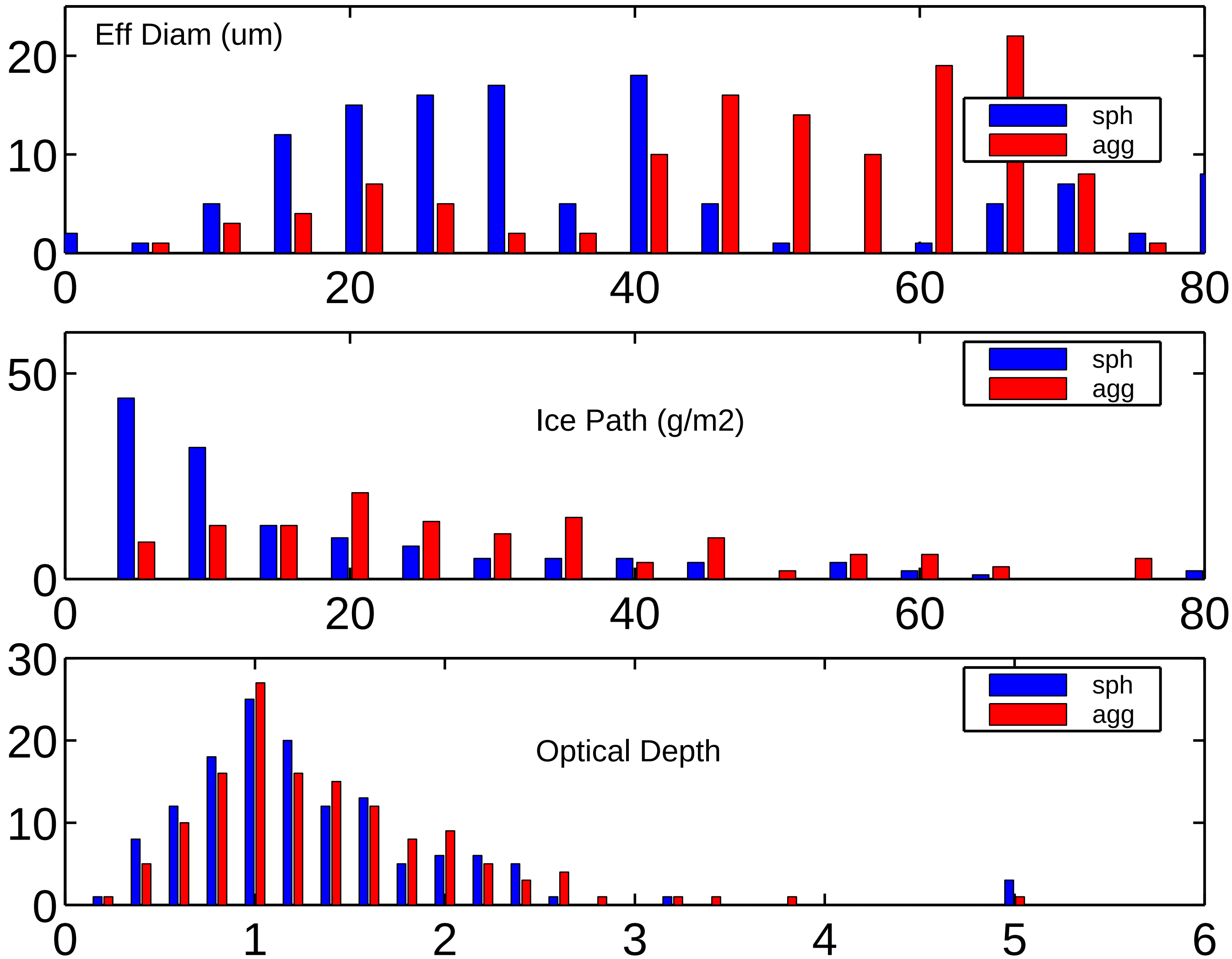
Cirrus Spectral Signature



Mean Cloud forcing (daytime) : Aggregates versus Spheres



Distribution of IWP, DME : Aggregates versus Spheres

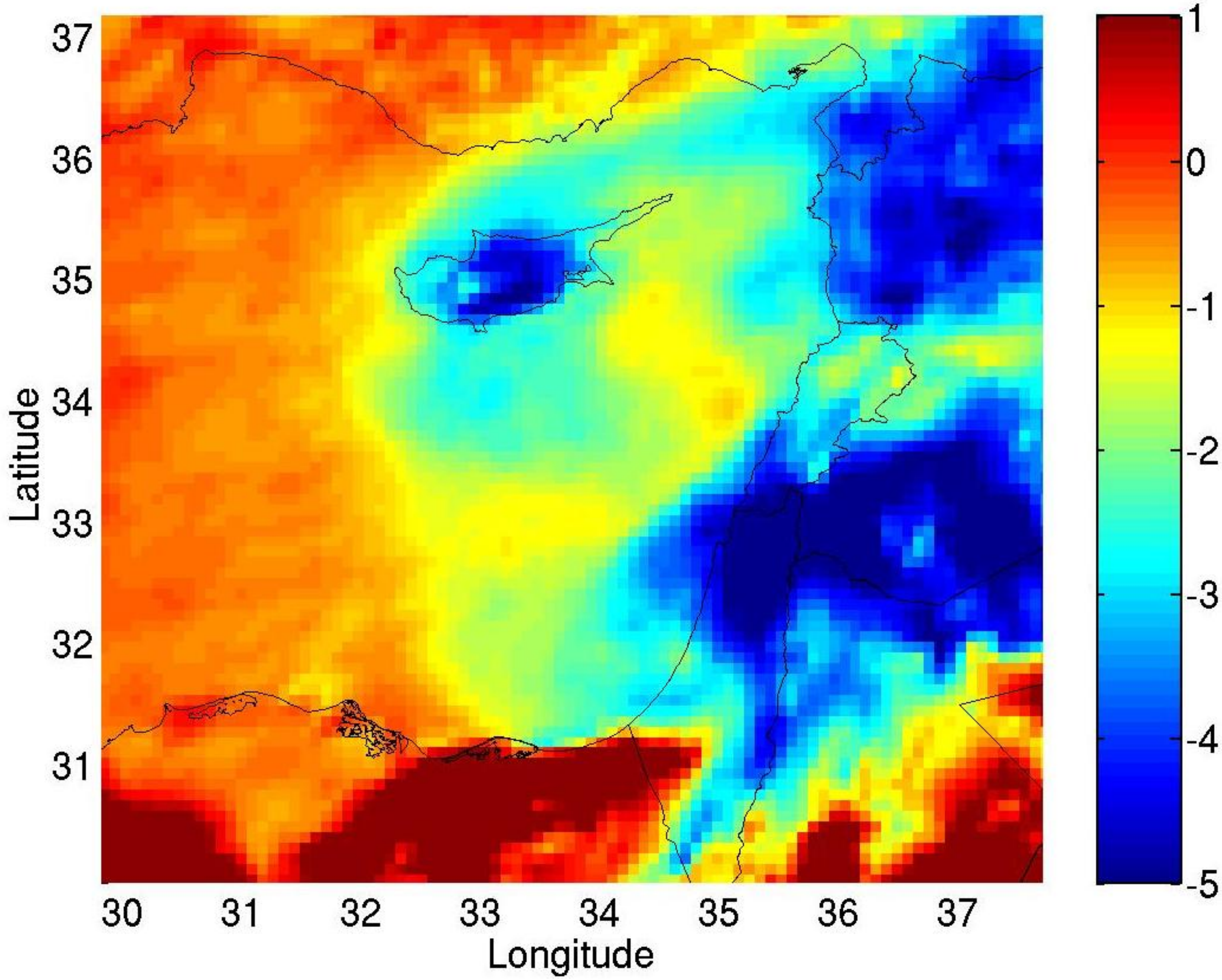


Detecting aerosols with AIRS

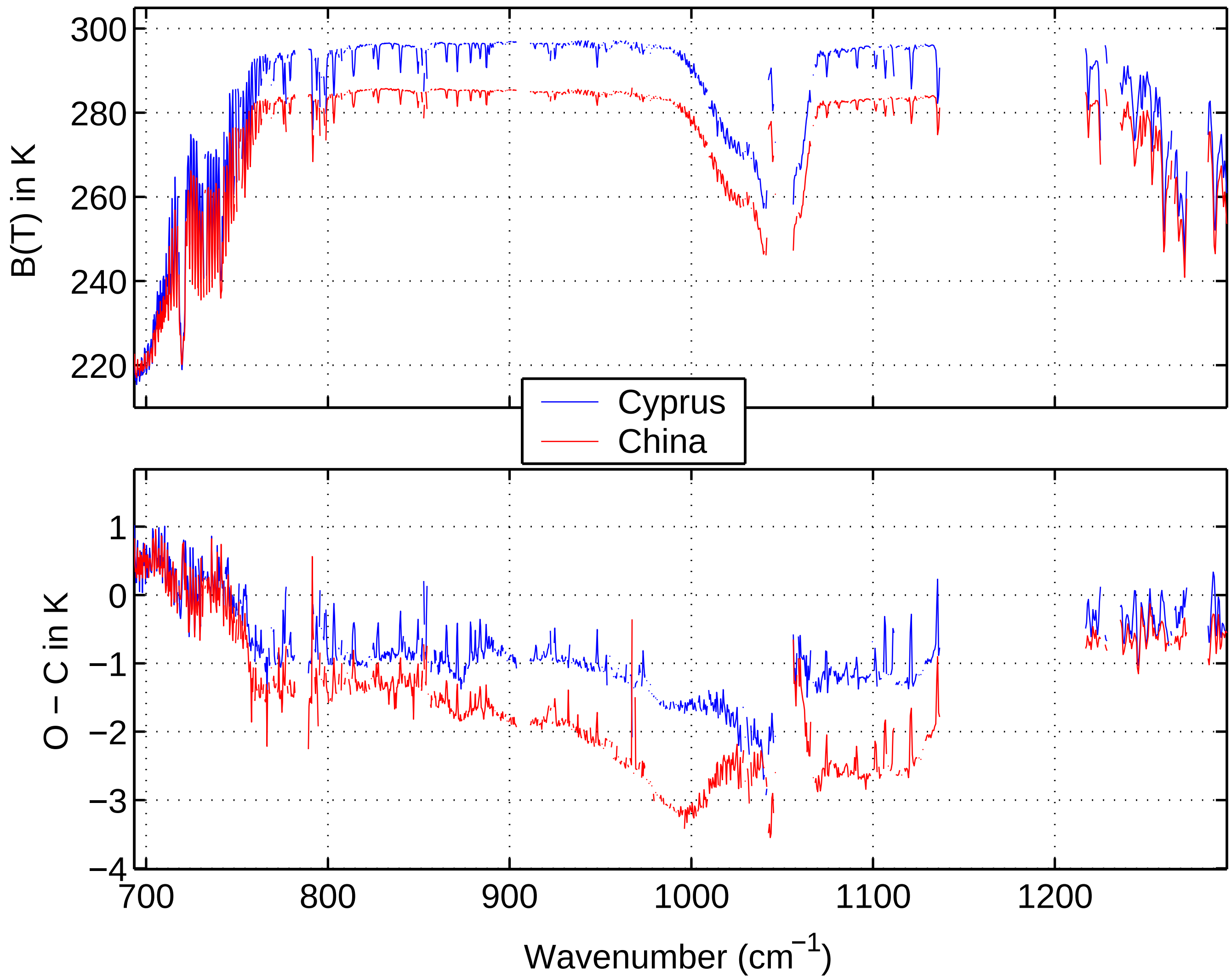
- Refractive index of silicates means that typically, BT(980) $\leq$ BT(820)
- Uncertainty in refractive index
- Have detected and analysed various desert storms with sand blown over water : Atlantic (W.Africa Sahara), Eastern Mediterranean, Gobi Desert dust to China Sea
- Assume only ONE cloud in FOV
- Use ECMWF fields for water vapor, temperature, ozone, surface params
- Use about 100 channels, spaced in the 10-12, 8 um windows

MODIS image for October 19, 2002 over E. Mediterranean

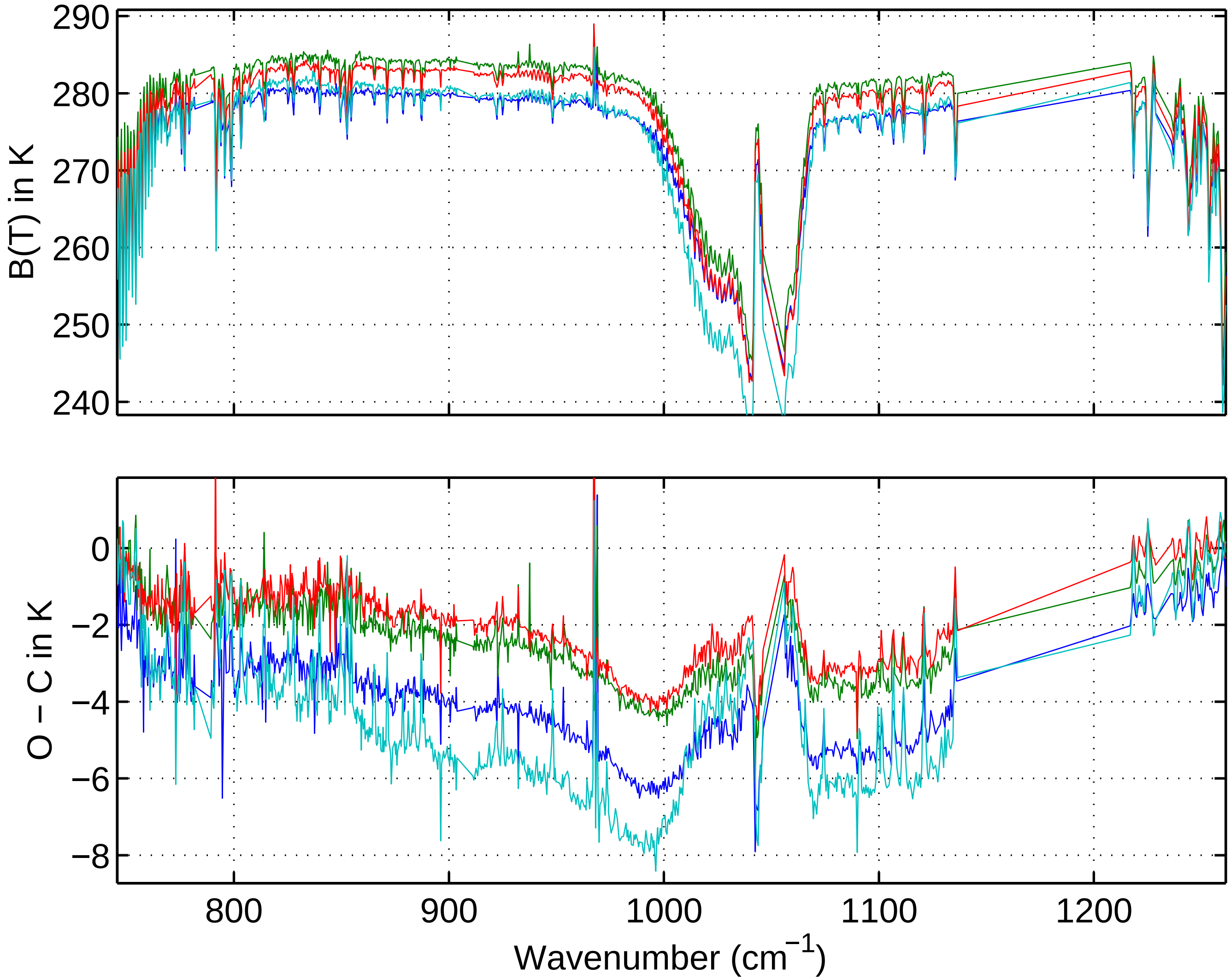
Using AIRS to detect dust : 960 - 1216 cm-1 BT diffs



Gobi, Cyprus Dust spectra : MILD cases that passed clear sky test



Gobi Dust spectra : SEVERE cases that failed clear sky test

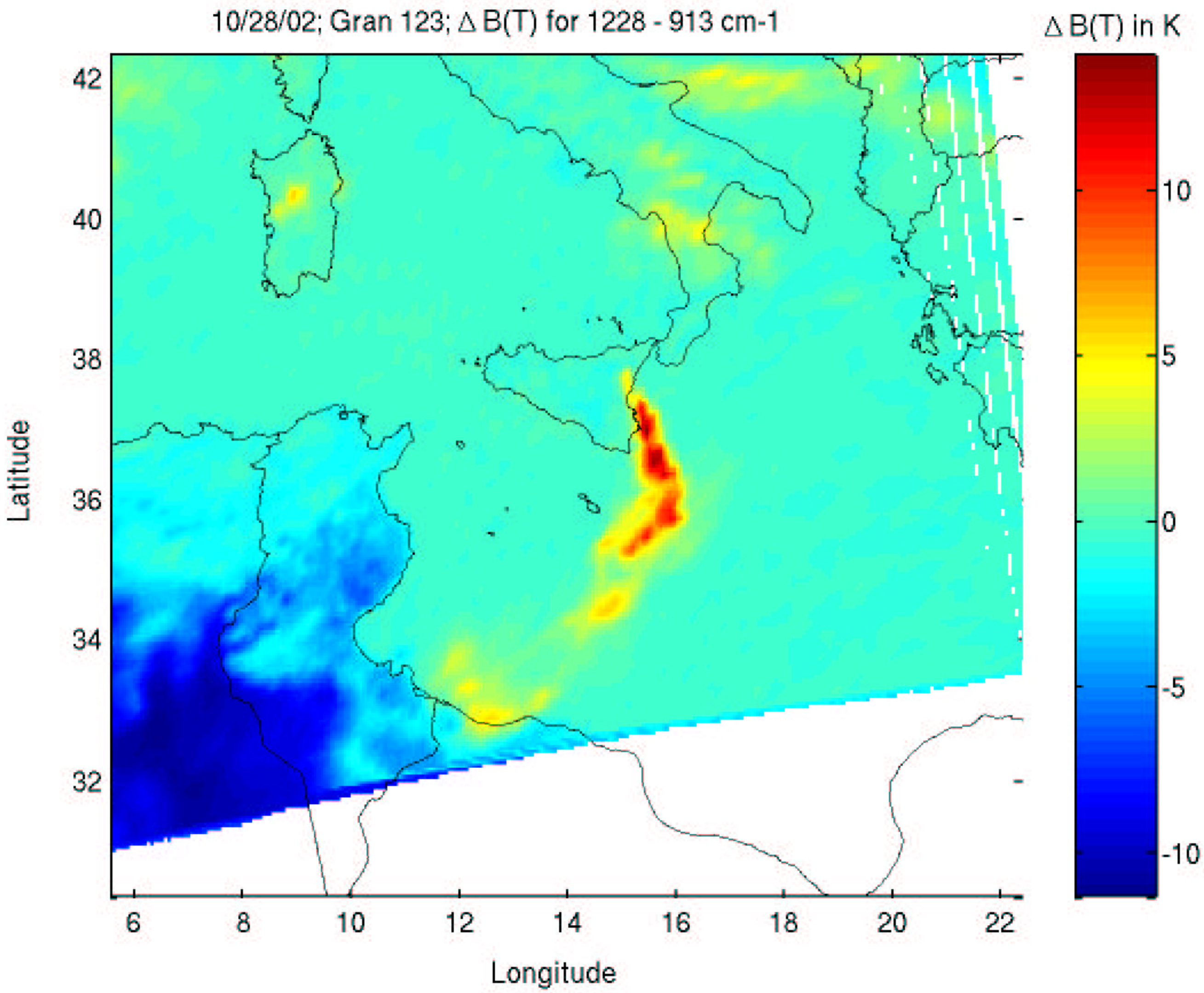


Detecting volcanic eruptions with AIRS

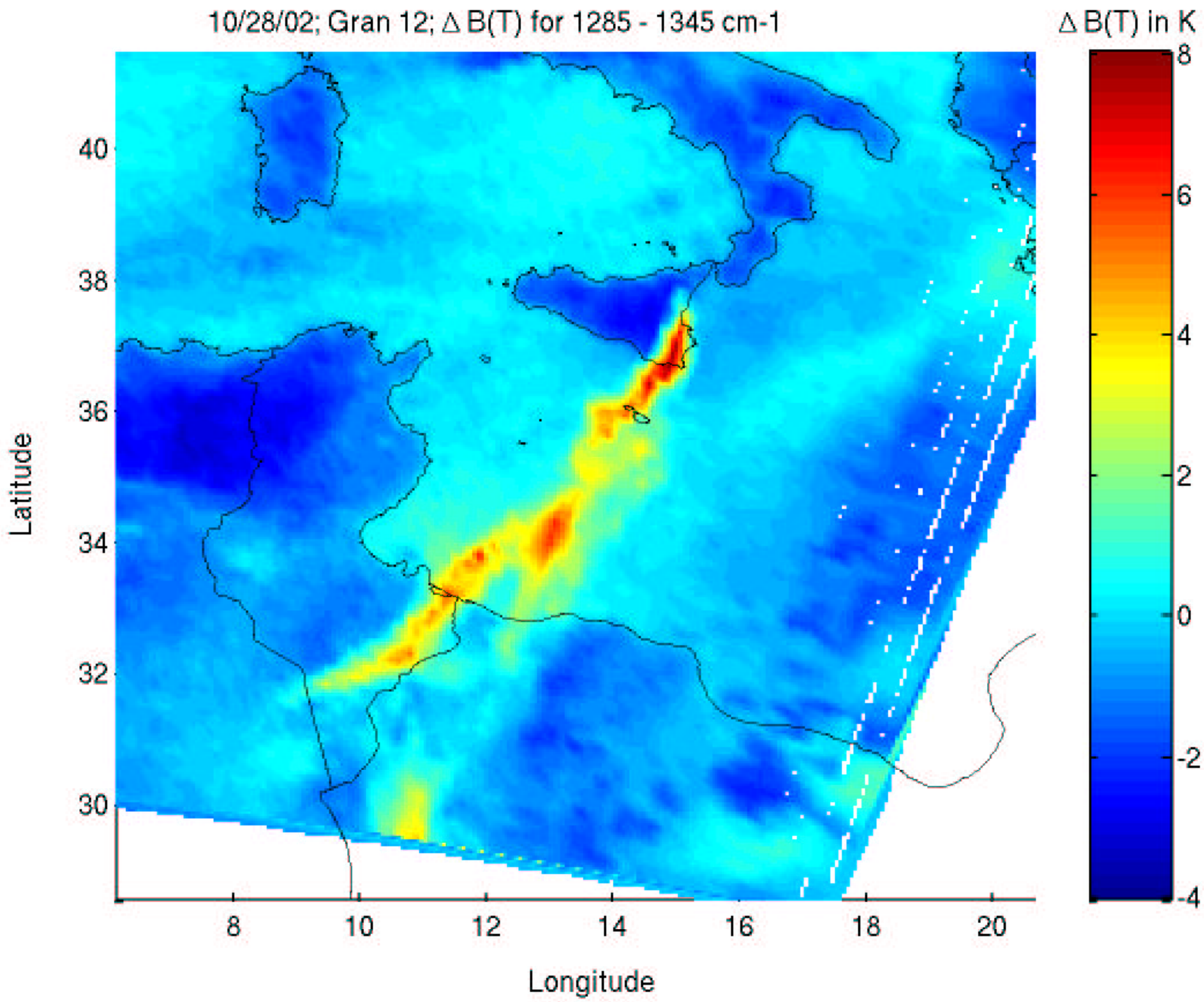
- Mt. Etna erupted in late October, observed by many satellite sensors
- AIRS has sensitivity to SO_2, inside the strong water band.
- AIRS can detect eruption plume in the window region.
- Assumed plume was composed of basalt.
- Andesite and SO_2 signatures well separated in wavelength
- Made preliminary estimates of SO_2 column, plume particle size, and plume particle density, assuming plume is about 8 km high

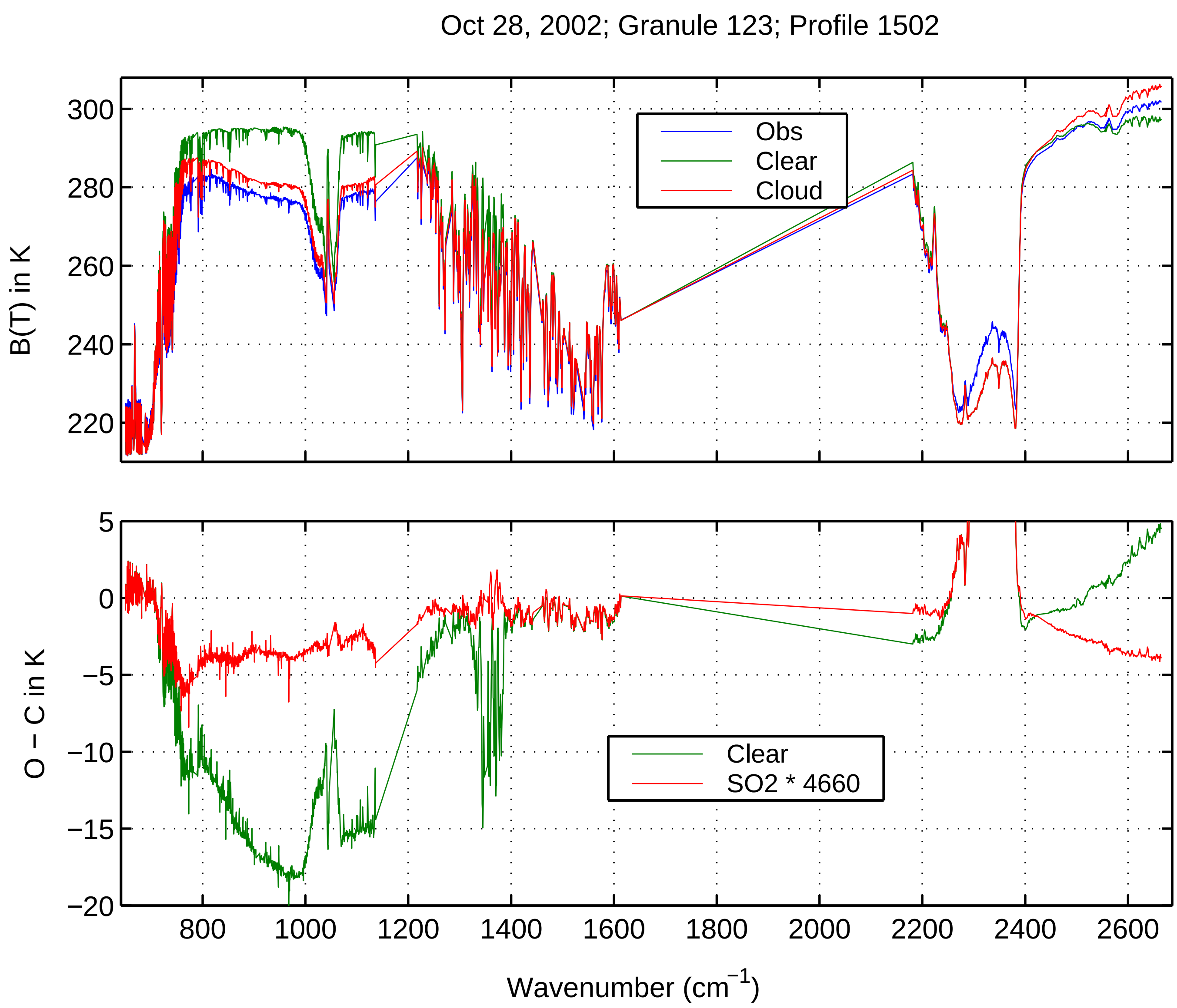
MODIS Image of Plume

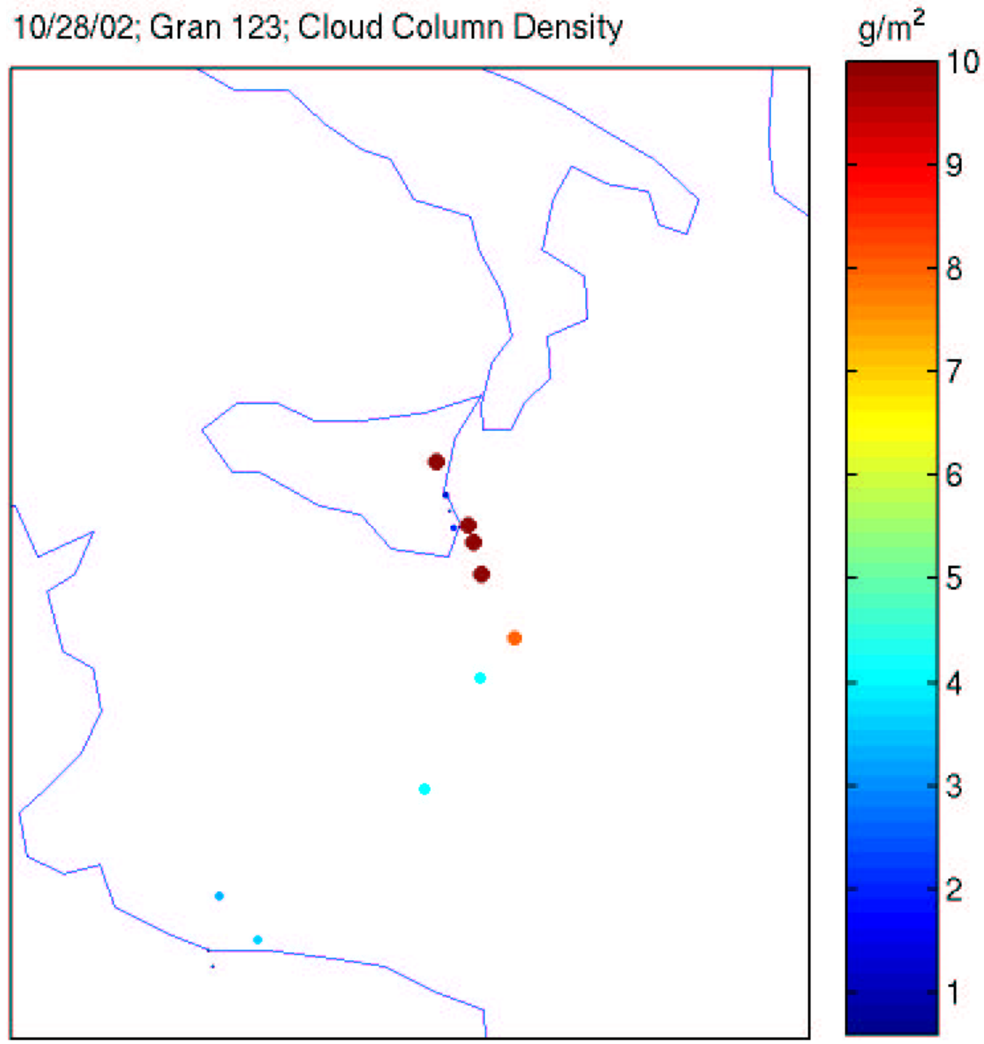
Aerosol Plume

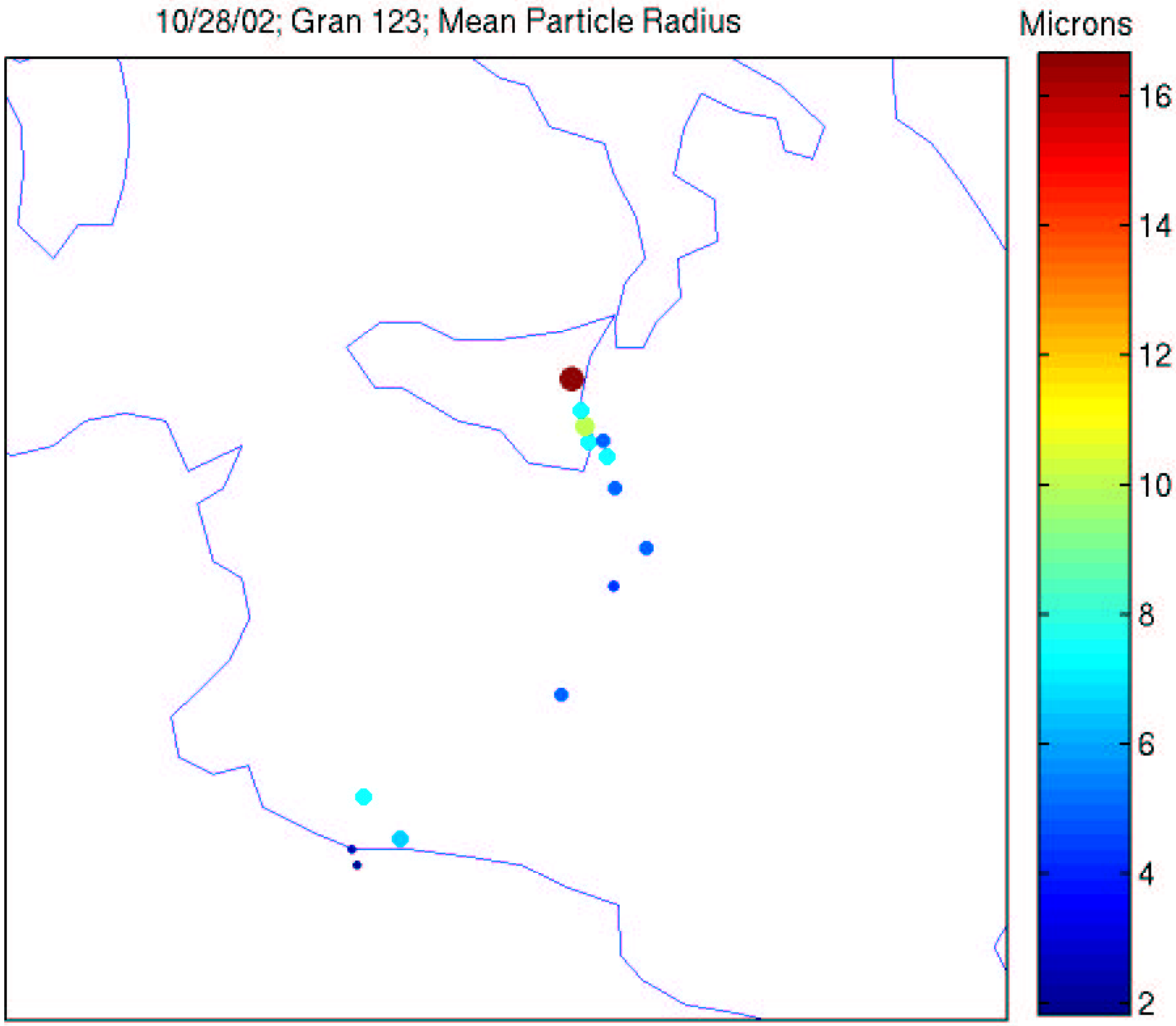


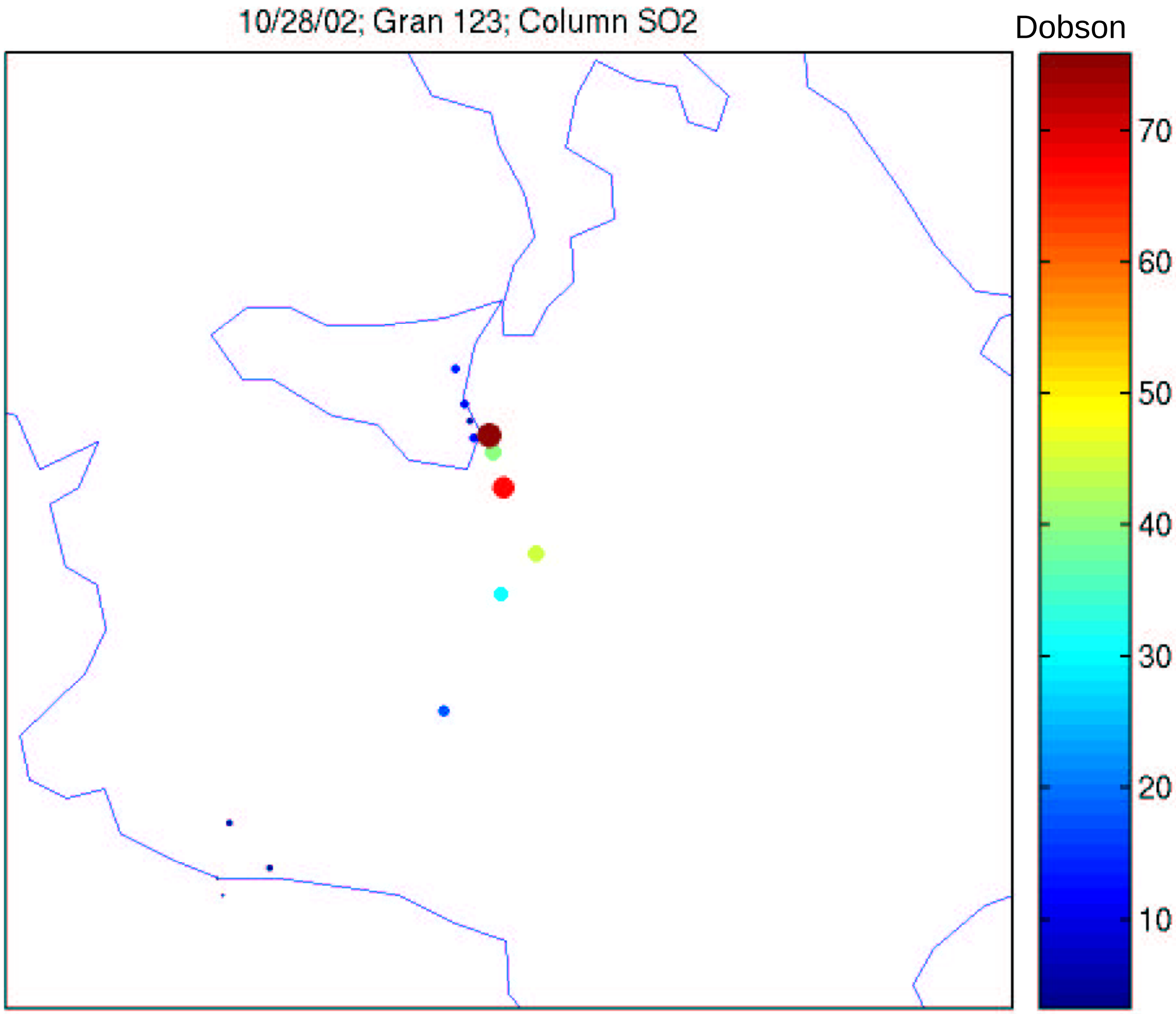
SO_2 Plume


10/28/02; Gran 12; Δ B(T) for 1285 - 1345 cm-1
Δ B(T) in K
Latitude
Longitude
40
38
36
34
32
30
8
10
12
14
16
18
20
8
6
4
2
0
-2
-4


Oct 28, 2002; Granule 123; Profile 1502
B(T) in K
300
280
260
240
220
Obs
Clear
Cloud
O − C in K
5
0
−5
−10
−15
−20
Clear
SO2 * 4660
800
1000
1200
1400
1600
1800
2000
2200
2400
2600
Wavenumber (cm^{-1})


10/28/02; Gran 123; Cloud Column Density
g/m2
10
9
8
7
6
5
4
3
2
1


10/28/02; Gran 123; Mean Particle Radius
Microns
16
14
12
10
8
6
4
2


10/28/02; Gran 123; Column SO2
Dobson
70
60
50
40
30
20
10

Conclusion

- Infrared Spectroscopy
- Radiative Transfer : Clear and Cloudy
- Observations using the AIRS instrument
- Clear sky RTA is in good shape
- Is the Clear Sky Filter letting in thin cirrus effects?
- Cloudy sky RTA seems to be working quite well too!