Atmospheric Radiative Transfer for Hyperspectral Sensors

(Lessons Learned from AIRS)

L.Larrabee Strow

Atmospheric Spectroscopy Laboratory (ASL)
UMBC Physics Department
and the
Joint Center for Earth Systems Technology

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Thanks to: S.E. Hannon, Sergio De Souza-Machado, H.E. Motteler and many others.

Overview

AIRS is a proxy for Hyperspectral Sounders

- Introduction to AIRS
- Generation of the AIRS RTA
- Validation of the AIRS RTA and underlying spectroscopy
- Atmospheric trace gas variability and RTA accuracy
    1. Mineral aerosols (dust)
    2. Non-LTE emission
    3. Trace Gases: CO_2, CH_4, HNO_3, SO_2, CO, N_2O (assume H_2O and O_3 varied in retrieval/assimilation)
- Preparing for CrIS, IASI, and Climate Change observations with hyperspectral sensors
- Will not talk about clouds, downwelling radition, emissivity
- Will not talk about (a) our fast model parameterization (some of which has been adapted into RTTOVS) or (b) our fast scattering RTA

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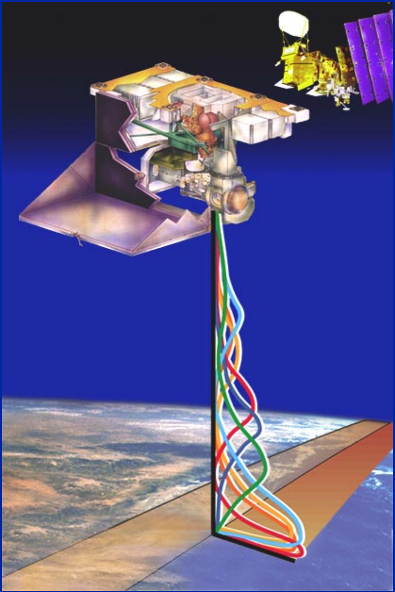
Main Points

- AIRS is extremely accurate and stable
- Highly accurate RTA needed to utilize this accuracy
- Must take into account atmospheric variability in using the RTA (minor gases, non-LTE, aerosols)
- Must consider many details of the instrument SRF (spectral response function)
- Line-by-line algorithms do no yet incorporate new spectroscopy, etc. we have learned during AIRS validation, needed for CrIS and IASI

Atmospheric Infrared Sounder (AIRS)



- ***MISSION:***
  - ***Earth Observing System (EOS)***
  - ***NASA Polar Platform 2 (EOS-PM1)***
- ***SCIENCE OBJECTIVE:***
  - ***Determine global atmospheric temperature and humidity profiles***
- ***TECHNIQUE:***

  Multispectral IR Remote Sensing

– *Vertical Coverage*	*0 - 25 km*
– *Vertical Resolution*	*1 km*
– *Temperature Accuracy*	*1 K*
– *Ground Footprint*	*13 km x 13 km @ Nadir*

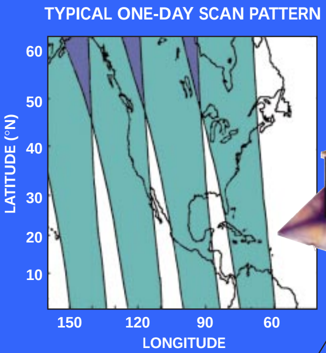
- ***INSTRUMENT:***

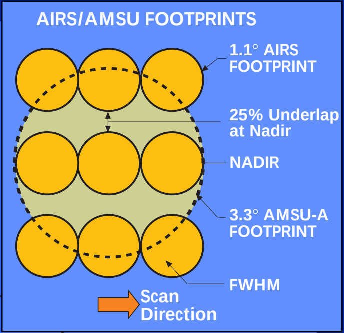
  Array Grating Spectrometer

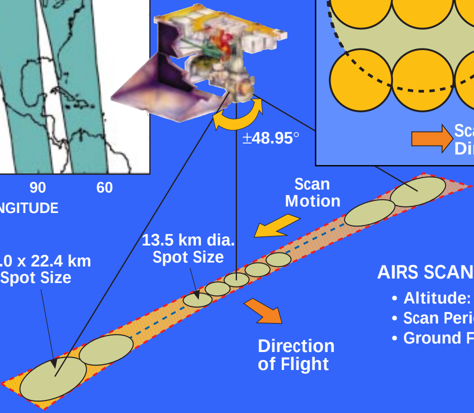
– *IR Spectral Coverage*	*3.74 - 4.61 μm* *6.20 - 8.22 μm* *8.80 - 15.4 μm*
– *IR Spectral Resolution, $\lambda/\Delta\lambda$*	*1200*
– *IR Spectral Samples*	*2378*
– *Sensitivity (NEΔT)*	*0.2K*
– *4 Visible Channels:*	*0.4 - 1.0 μm*
– *Operating Lifetime*	*5 years*

AIRS/AMSU/ HSB Scan Patterns

Matched for Optimum Cloud Clearing





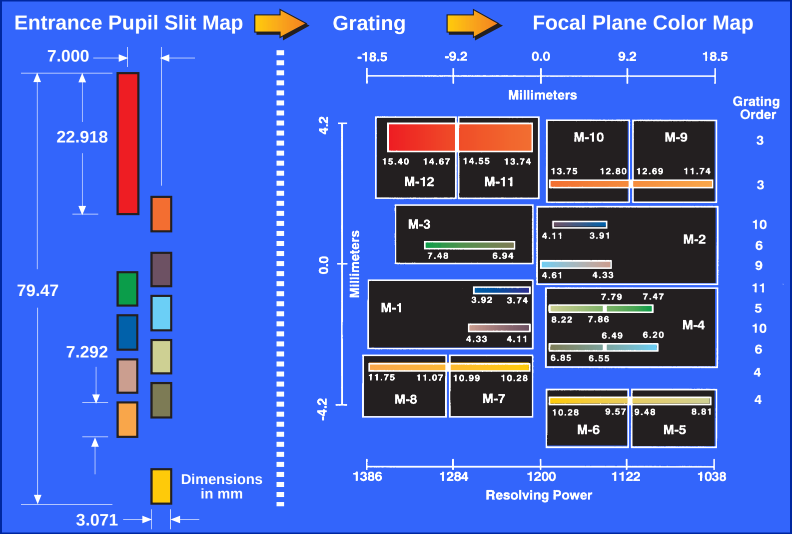


AIRS SCAN GEOMETRY

- Altitude: 705 km
- Scan Period: 2.667 s
- Ground Footprints: 90

System Entrance Pupil/FPA

Color Map Relationship - 13.7 µm PV/PC Transition



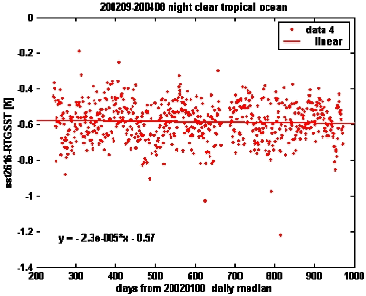
Stability of AIRS Radiometry

- Clear FOVS, ocean only
- Compare observed 2616 cm^{-1} radiance to computed radiance using NOAA RTG-SST product
- RTA-SST tied to bulk SST measured by large network of tropical buoys

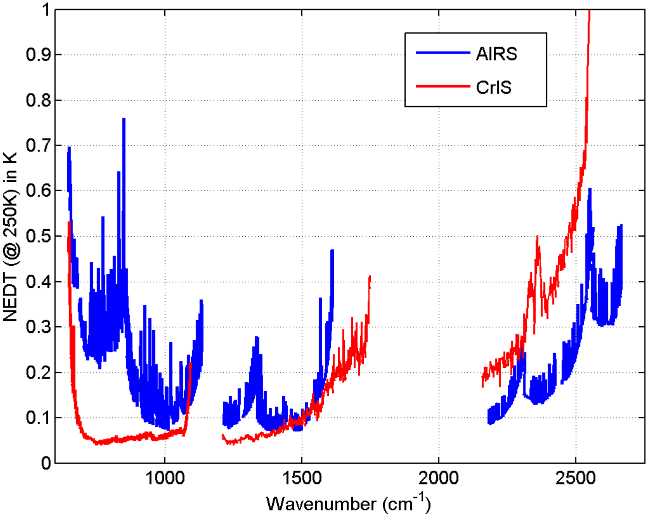
Slope is 0.008 K/year, so no measurable radiometric drift

Offset due to day/night aliasing and evaporative cooling of skin

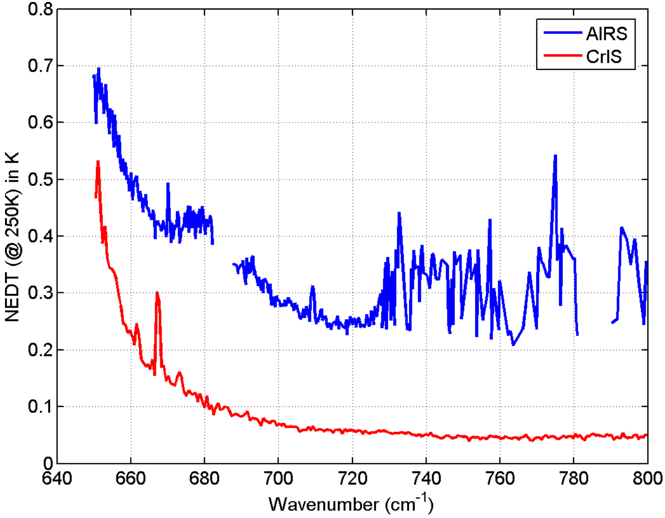
This result is key to using AIRS for climate studies at other frequencies sensitive to air temperature, water abundance, and minor gases.



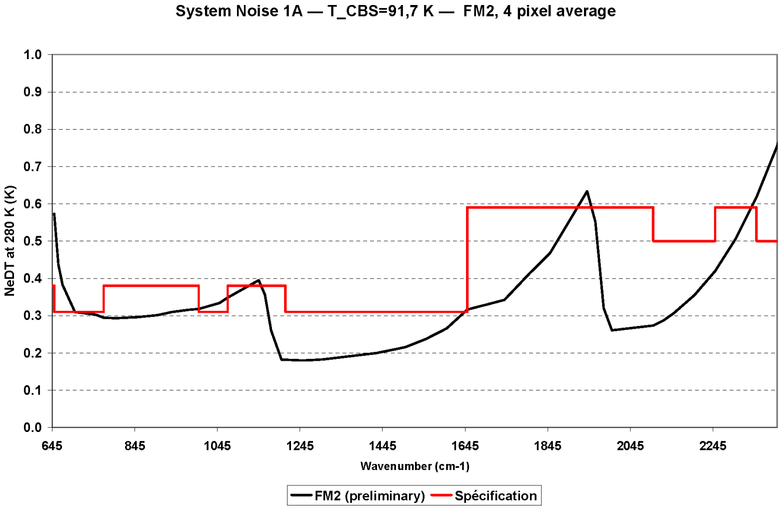
CrIS Noise: More Demanding in LongWave



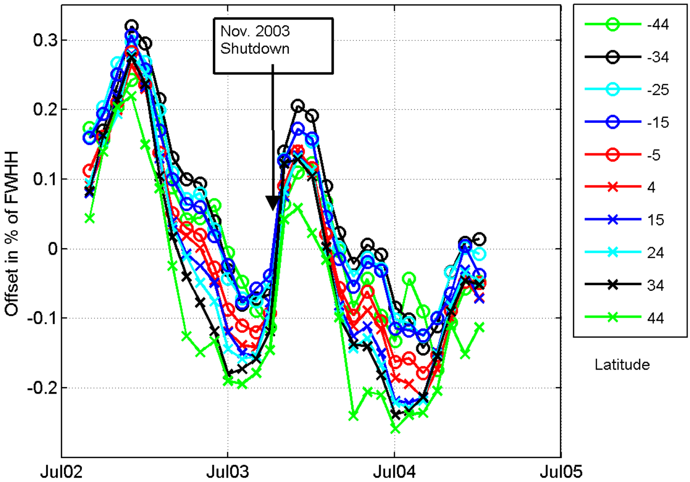
CrIS Noise: More Demanding in LongWave



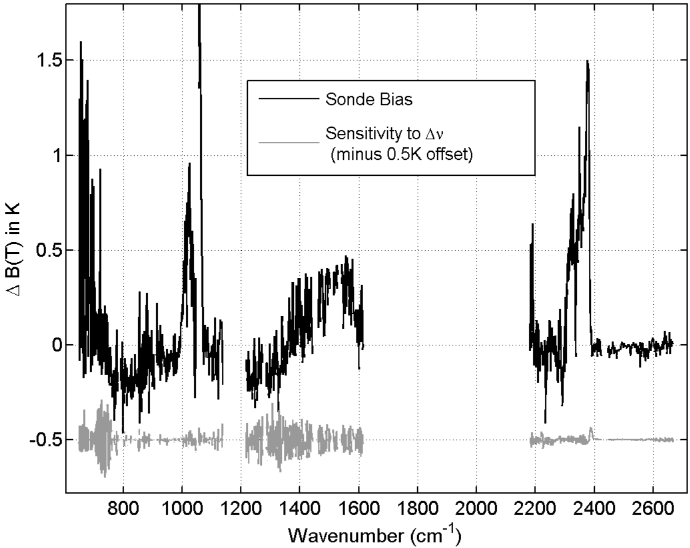
IASI Noise


System Noise 1A — T_CBS=91,7 K — FM2, 4 pixel average
NeDT at 280 K (K)
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
645
845
1045
1245
1445
1645
1845
2045
2245
Wavenumber (cm-1)
FM2 (preliminary)
Spécification

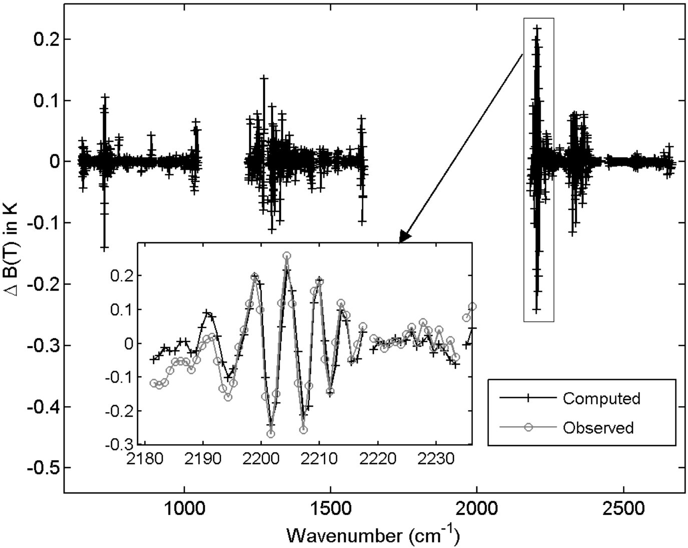
AIRS SRF Center Freqs Shift *Slightly*



SRF Center Freq Shifts in Δ B(T)



SRF Shape (fringes) Introduce Bias: Understood but not totally implemented



A great RTA validation dataset exists

Table: Number sonde launches, LIDAR observations, coincident with AIRS.

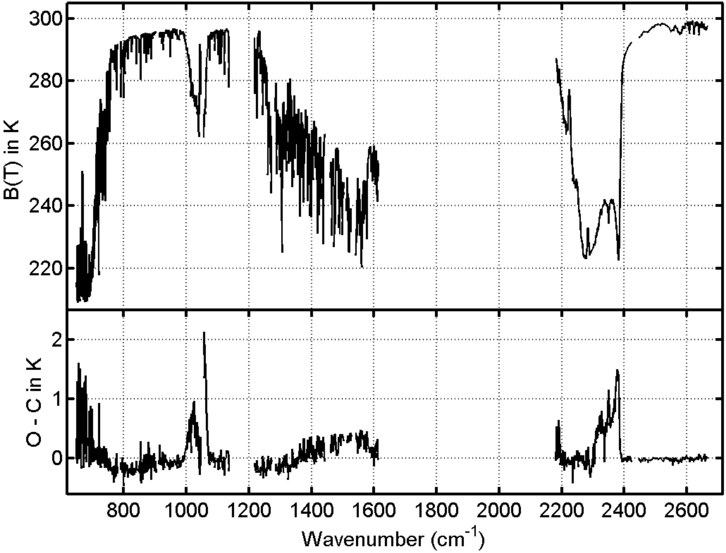
Name	Technique	# of Coincident Sondes
ARM TWP Phase1	RS-90	154
ARM TWP Phase2	RS-90	178
ARM TWP Phase3	RS-90	163
ARM SGP Phase1	RS-90	125
ARM SGP Phase2	RS-90	171
ARM SGP Phase3	RS-90	160
Mcmillan/ABOVE	RS-90	195
Minnett	RS-90	146a
Vömel	FP	29
Whiteman/LIDAR	SRL	23

a. Includes RS-80 sondes not used here.

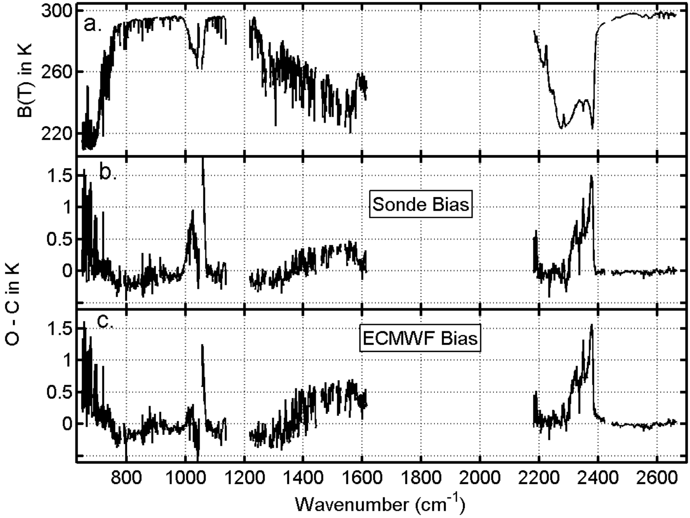
Table: Summary of number of clear observations over ocean at night.

Name	% Clear	# Sonde/Lidar Profiles
ARM TWP	15	38
Mcmillan/ABOVE	7	7
Minnett	25	23

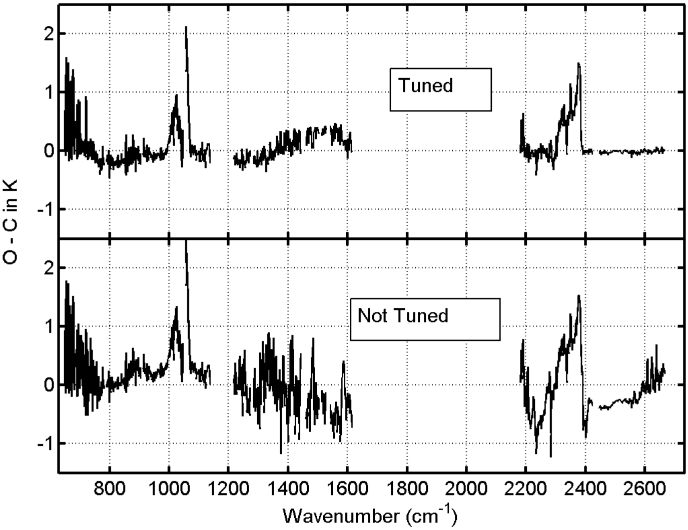
RS-90 Validation Campaign Bias Results



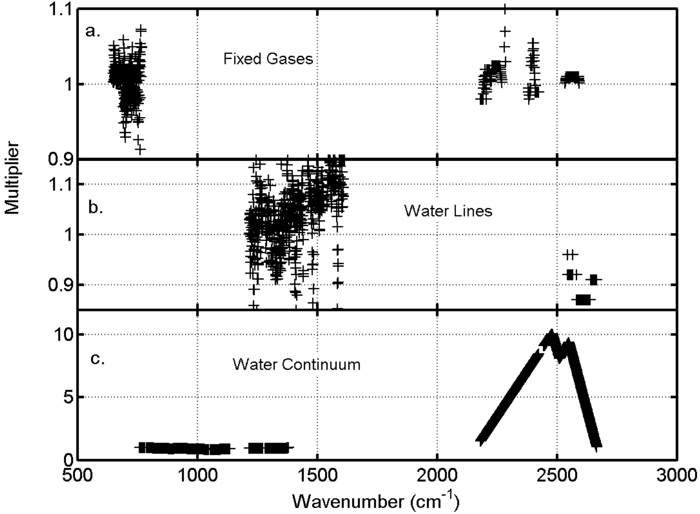
RS-90 vs ECMWF Biases: 24 Month Avg



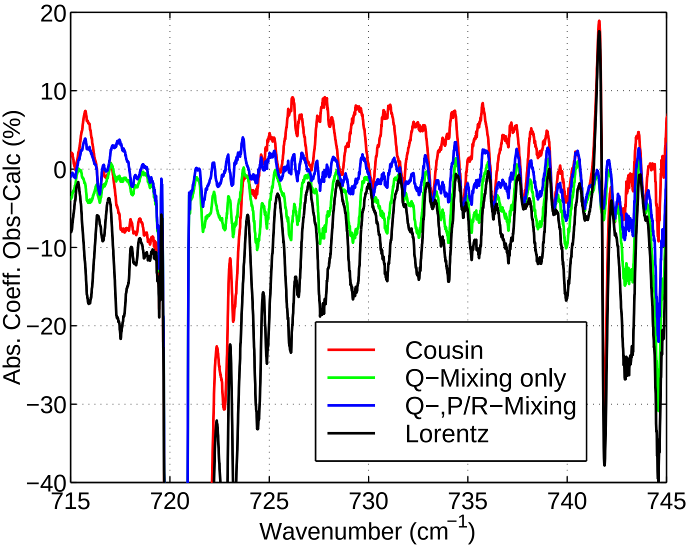
BUT (the bad news): We had to empirically adjust transmittances.



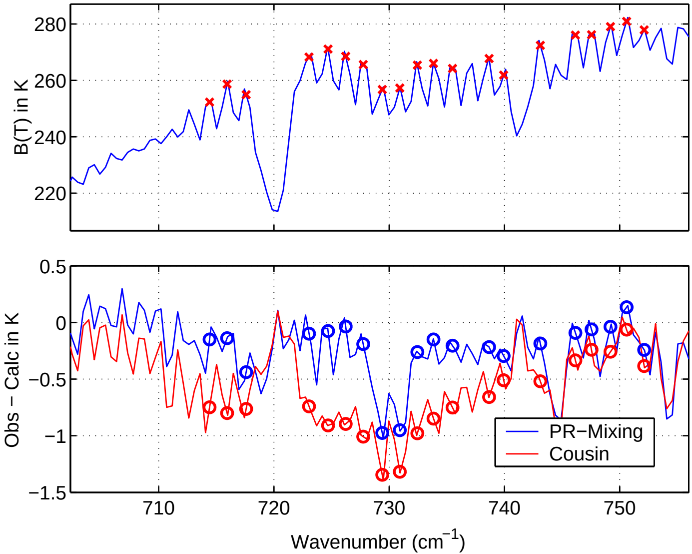
Adjustments in units of optical depths



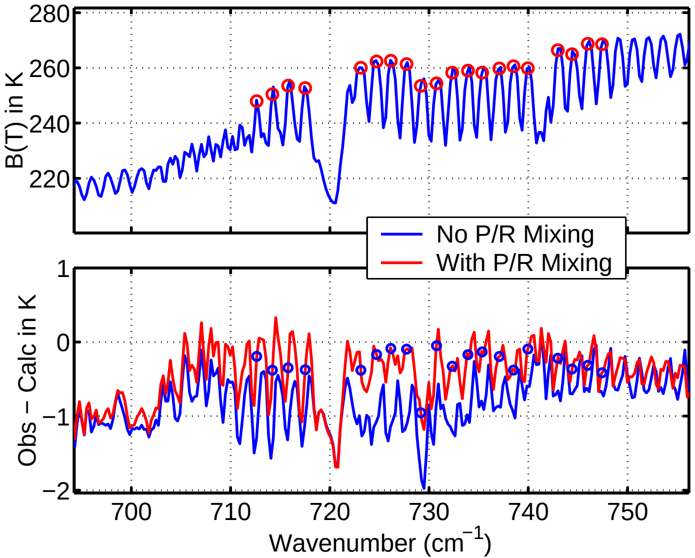
We've got a lot of new things in our LBL: kCARTA



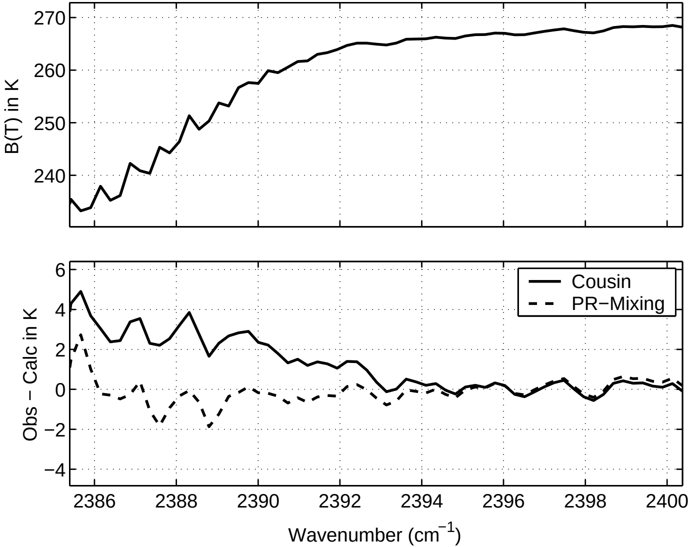
RTA Tested with Aircraft Hyperspectral Obs.: CLAMS



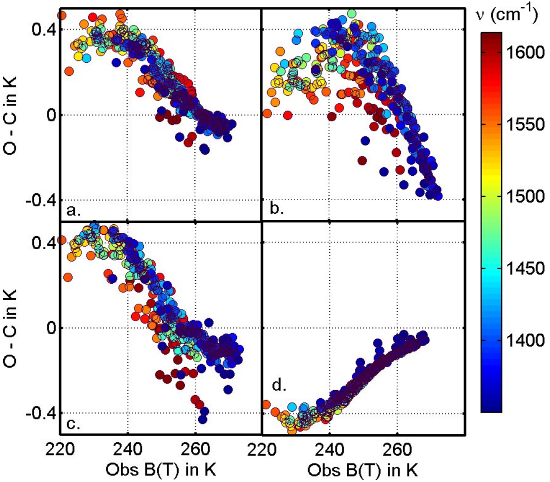
Over different campaigns: WINTEX



And at 4 as well as 15 microns: WINTEX

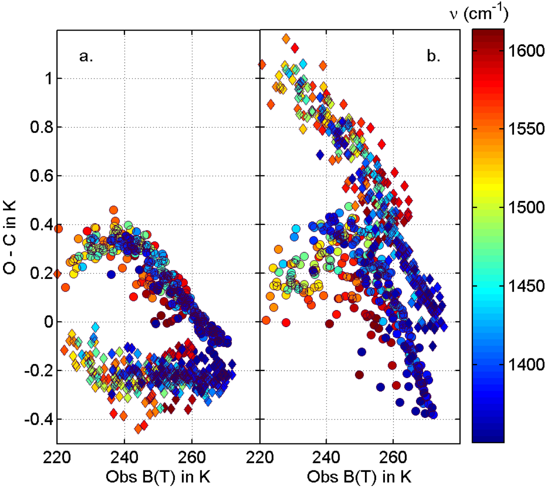


Water spectroscopy still an issue



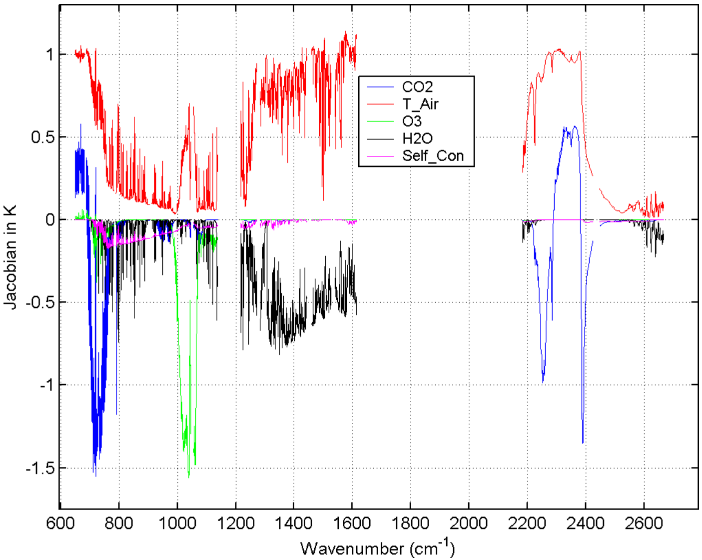
Mean nighttime biases for a. all RS-90 sondes, b. Vömel's (NOAA/CMDL) frost-point hygrometers, and c. Raman lidar water profile measurements. Graph d. is a suggested sonde correction we are evaluating.

Day/Night RS-90 and Frost-Point Differences

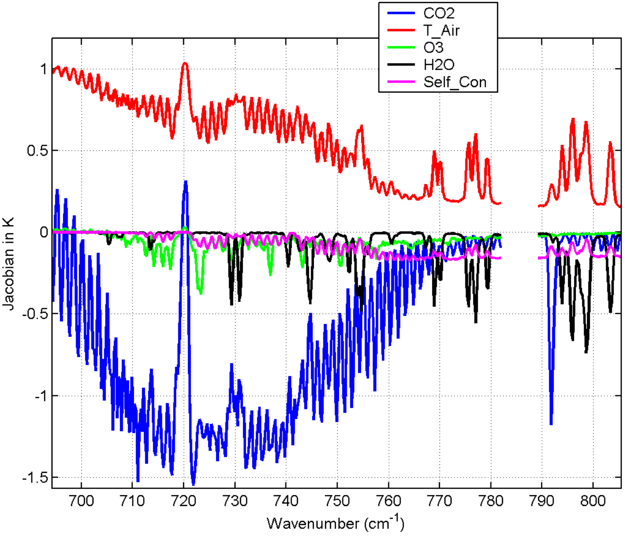


Mean night vs day biases for a. all RS-90 sondes, b. Vömel's (NOAA/CMDL) frost-point hygrometers

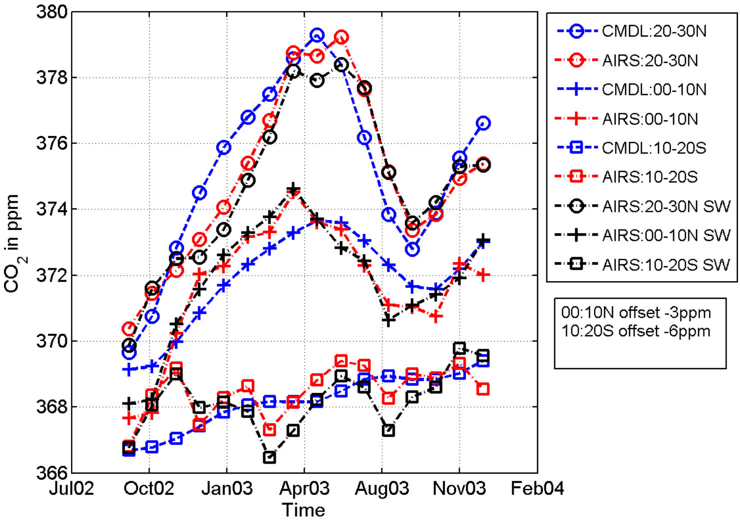
Minor Gas Sensitivities



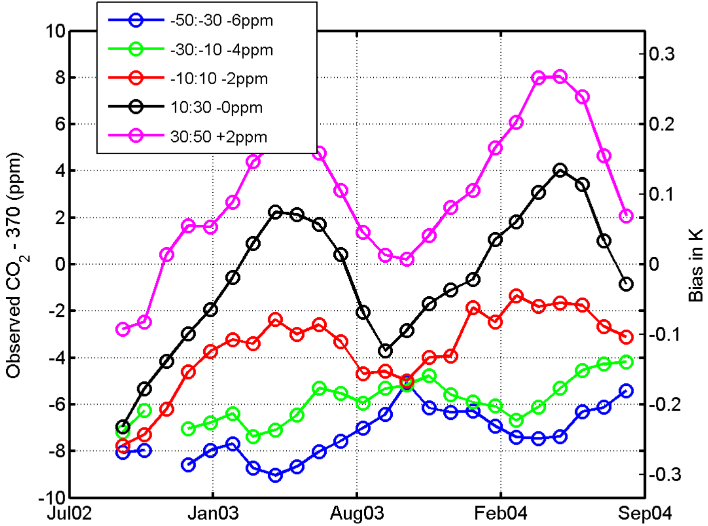
Minor Gas Sensitivities: Zoom



We have to pay attention to CO_2: ECMWF for T(z)



And it's global variation



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CO_2 Important to Track for Weather and Climate

Hyperspectral RTA

L. Strow

Overview

Introduction to AIRS

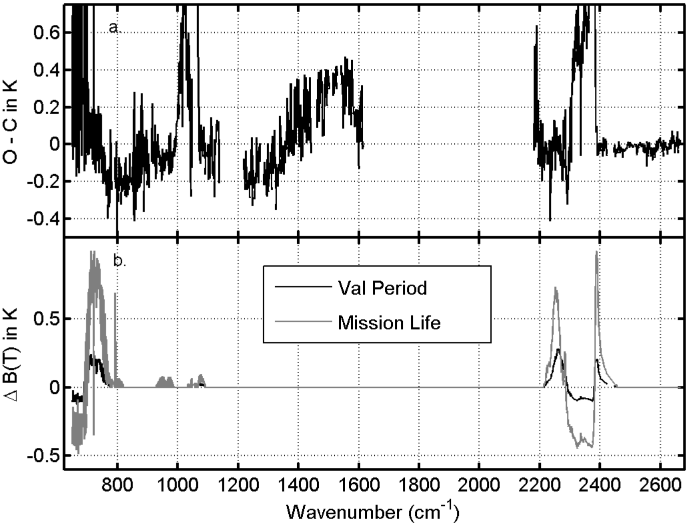
AIRS RTA Validation

Minor Gases

Non-LTE Emission

Dust

SARTA vs kCARTA



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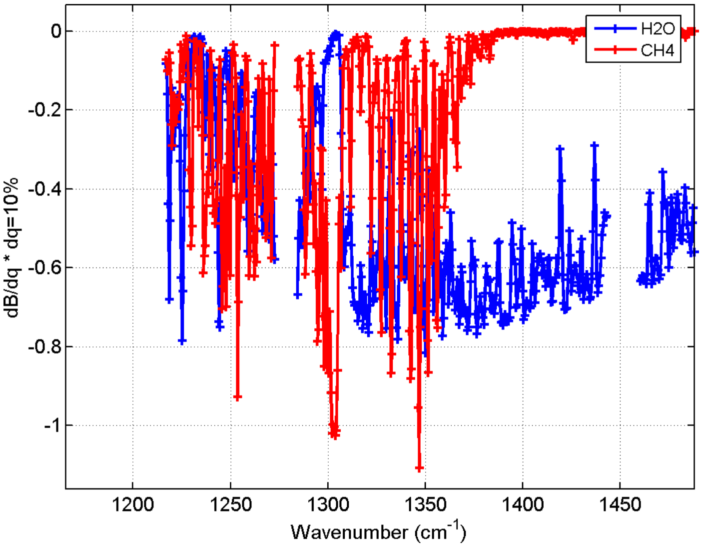
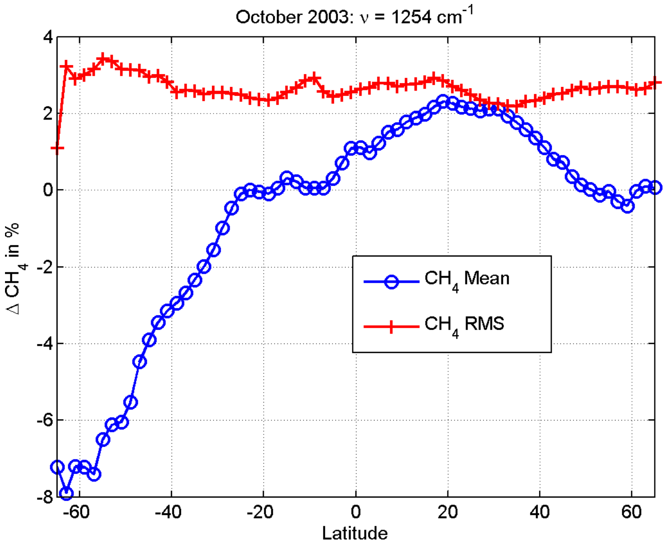
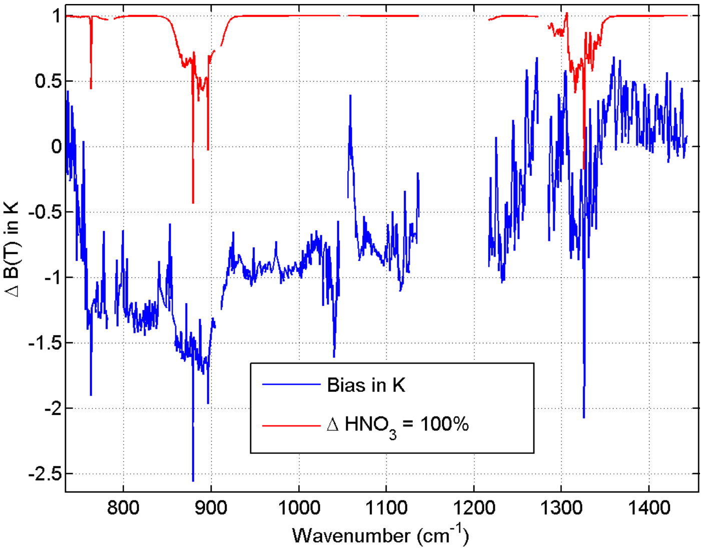
CH_4 Interferes with H_2O



CH_4


October 2003: ν = 1254 cm-1
Δ CH4 in %
Latitude
CH4 Mean
CH4 RMS
4
2
0
-2
-4
-6
-8
-60
-40
-20
0
20
40
60

HNO_3


1
0.5
0
-0.5
-1
-1.5
-2
-2.5
Δ B(T) in K
800
900
1000
1100
1200
1300
1400
Wavenumber (cm^{-1})
Bias in K
Δ HNO_3 = 100%

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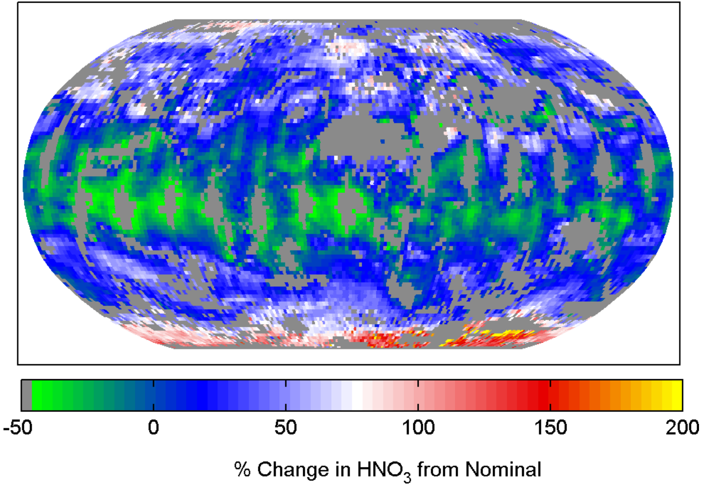
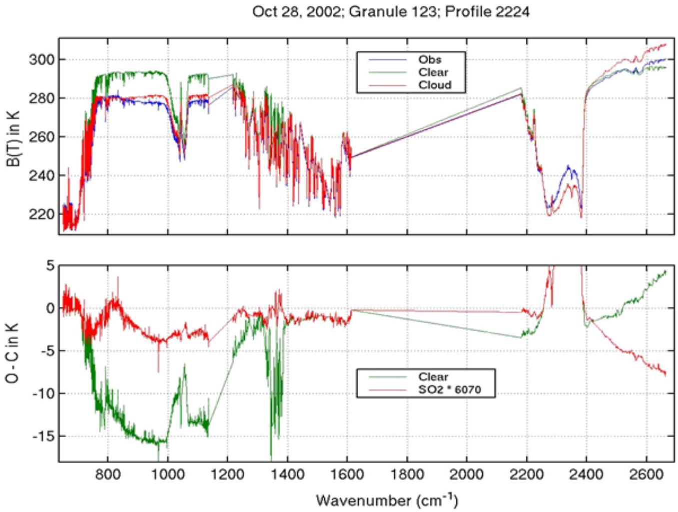
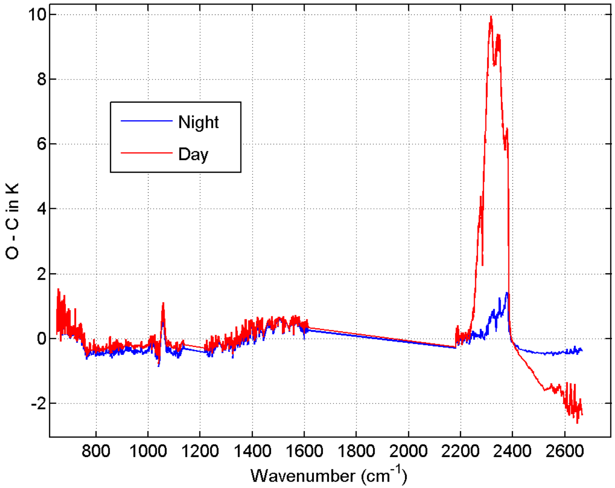
HNO_3 Global



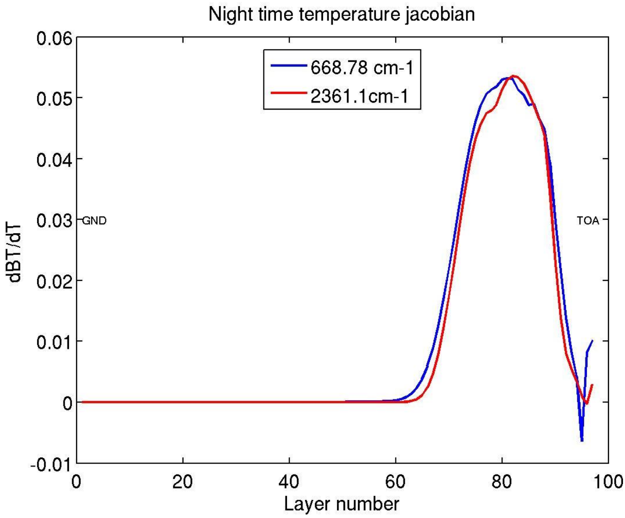
Volcanic SO_2 and Ash are seen



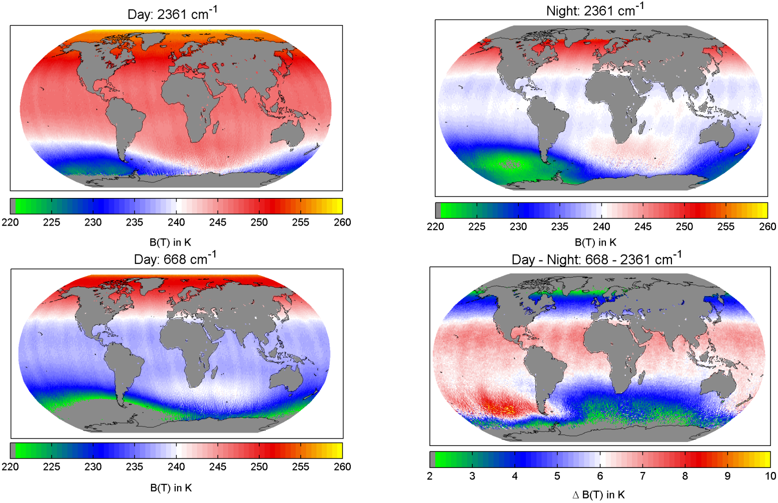
Non-LTE Overview



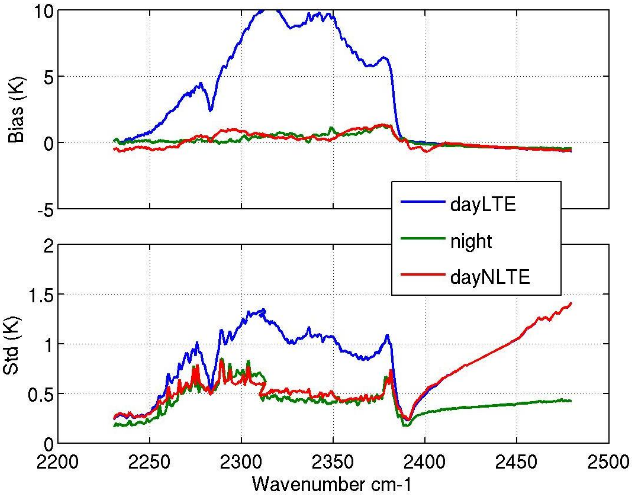
668 vs 2361 cm^{-1} Jacobians



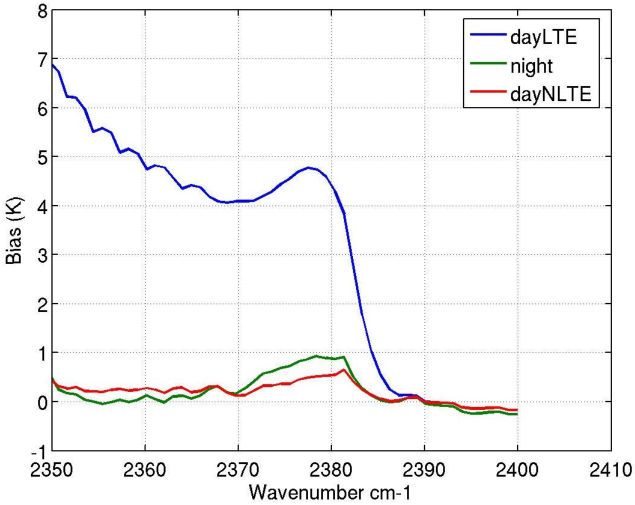
Global Behavior of Non-LTE (July 1-15)



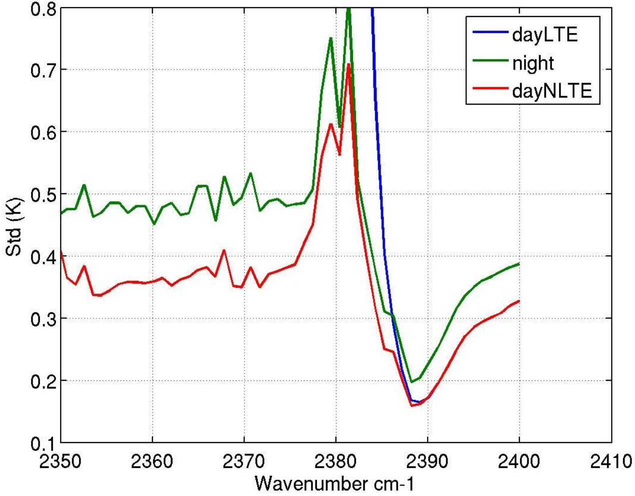
Performance on non-LTE RTA



Performance on non-LTE RTA: Zoom



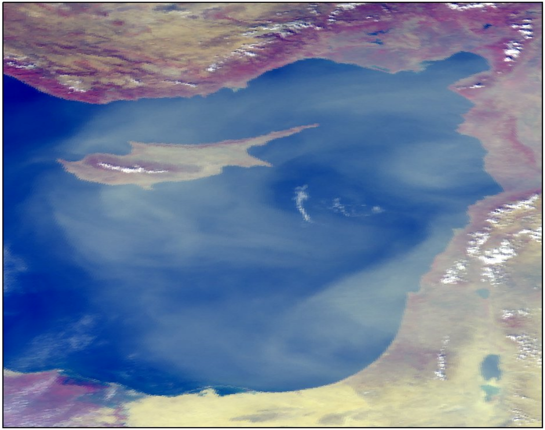
Performance on non-LTE RTA: Zoom of Std. Dev.



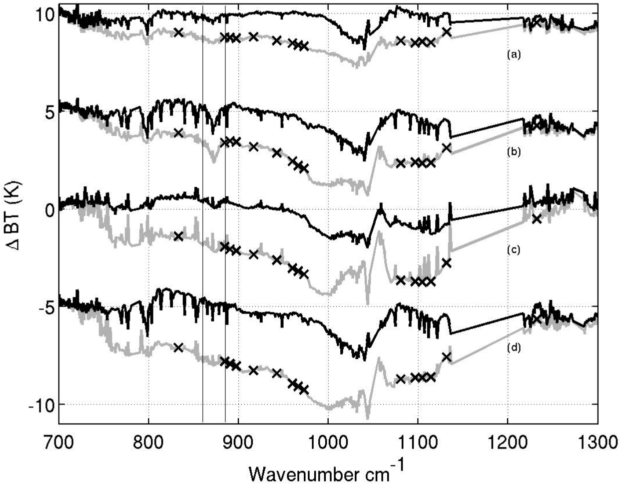
Dust Observations with AIRS

- We have observed many dust outbreaks, with quantitative analysis over oceans using SARTA-scattering
- Submitted to GRL (comparisons to MODIS)
- Some differences in spectral structure (index of refraction)
- Observed volcanic ash clouds
- Hyperspectral IR see dust througout tropical Atlantic in summer: *Important to include in assimilation/retrieval for hurricane applications?*
- Developing a dust flag for next AIRS processing cycle. Hopefully future reprocessing will include dust optical depth. More work needed on how to handle dust vertical structure.

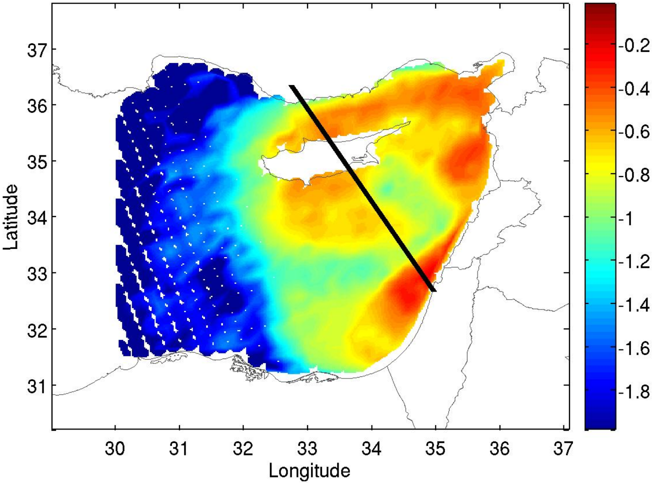
Mediterranean Dust Storm



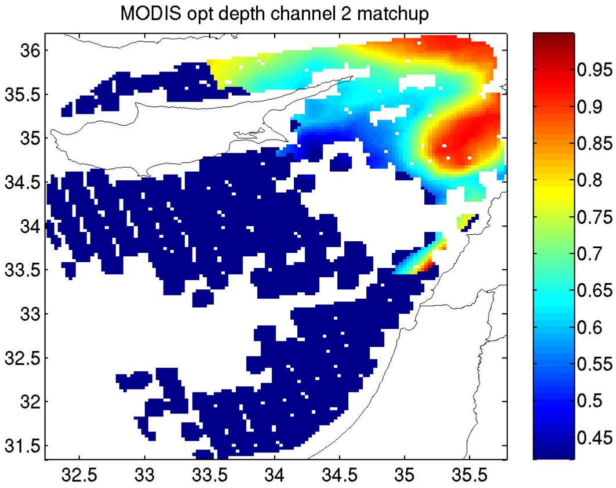
Spectral Effects of Dust



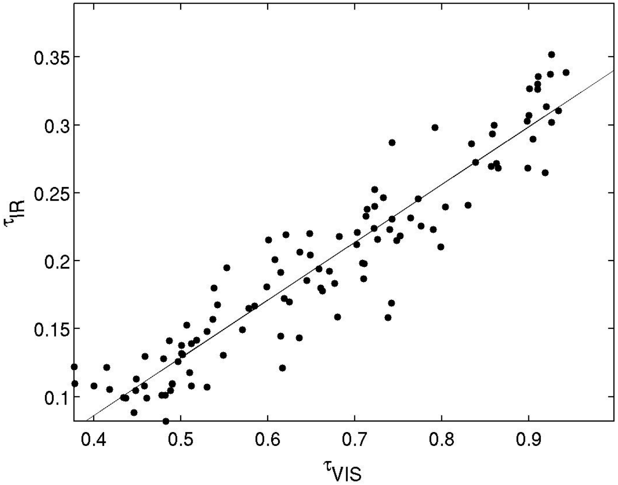
Derived Optical Depths at 900 cm^{-1}: Scattering SARTA



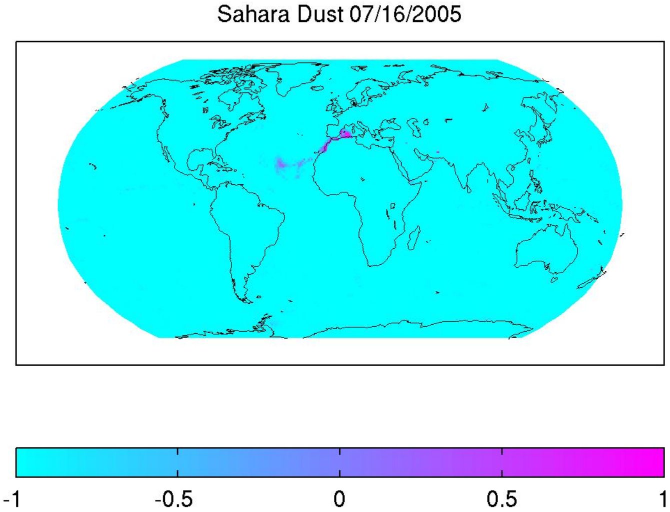
MODIS Observations



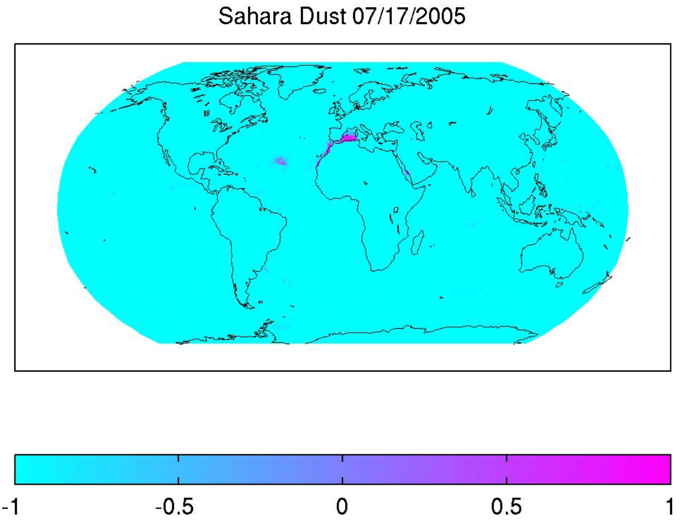
MODIS vs AIRS-derived Optical Depths



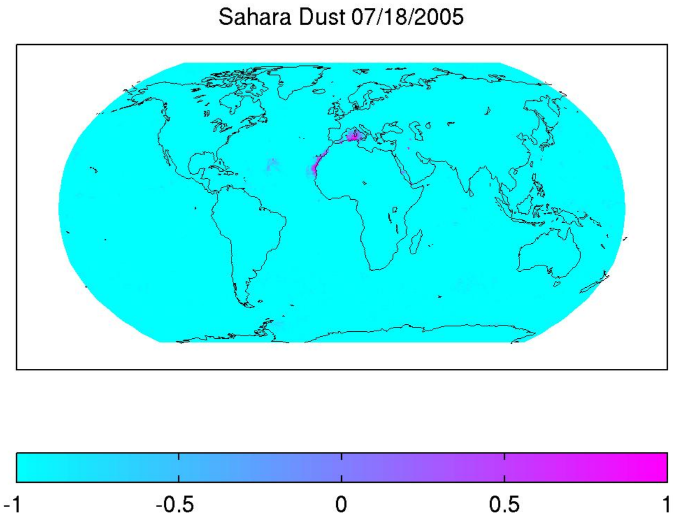
Day 1: Dust Flag



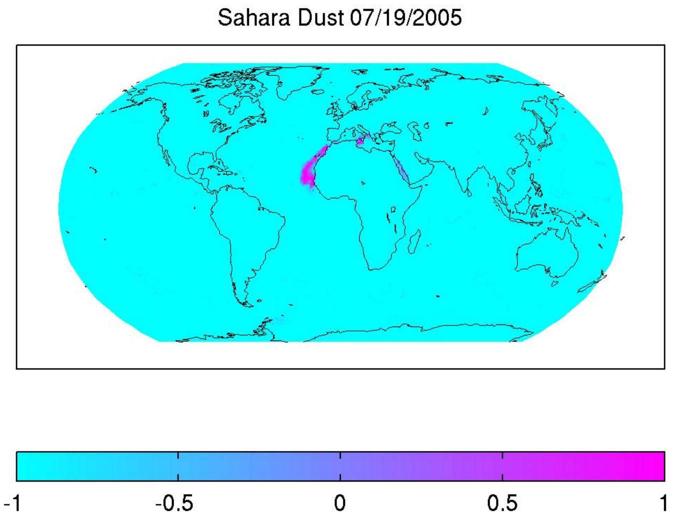
Day 2: Dust Flag



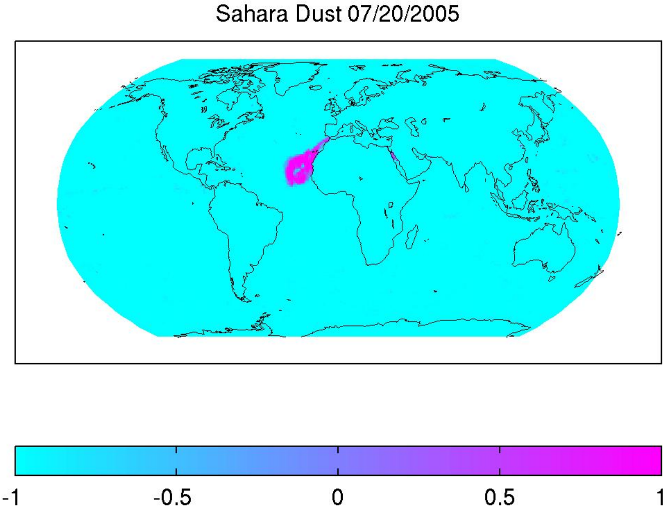
Day 3: Dust Flag



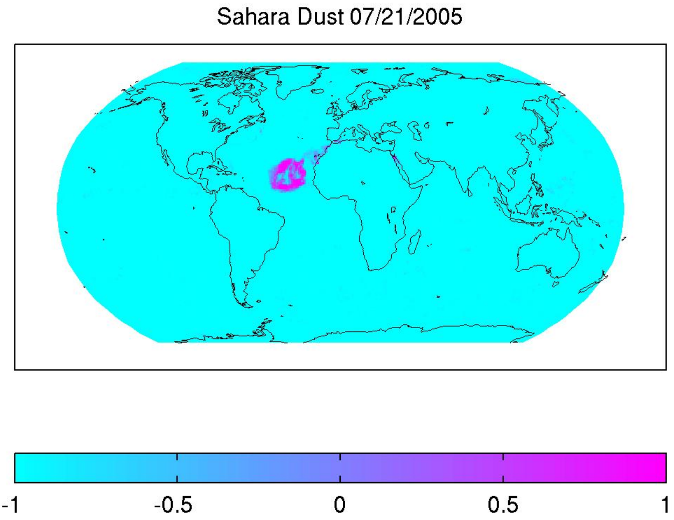
Day 4: Dust Flag



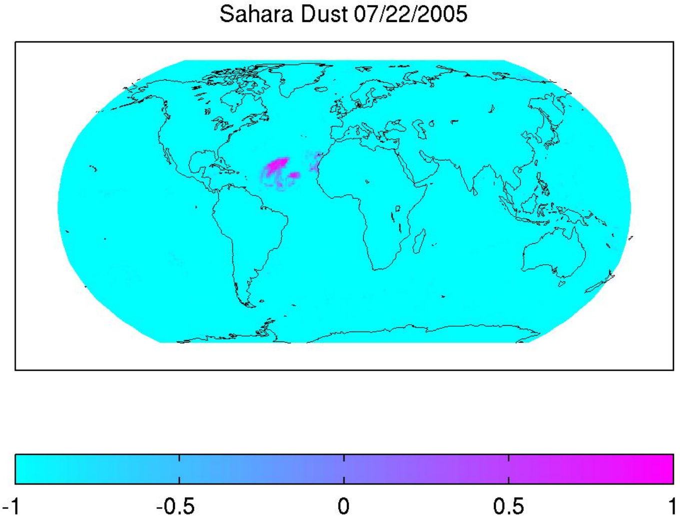
Day 5: Dust Flag



Day 6: Dust Flag

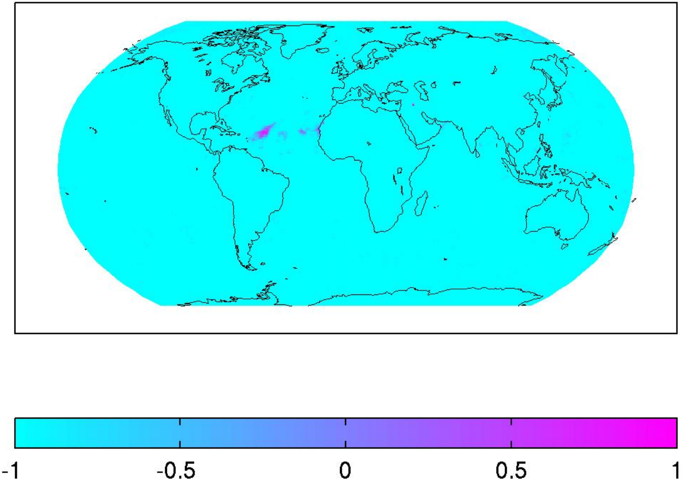


Day 7: Dust Flag

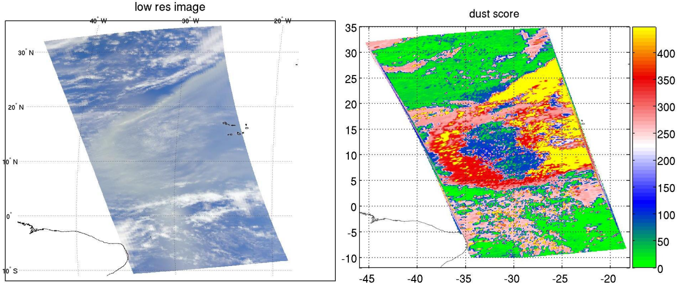


Day 8: Dust Flag

Sahara Dust 07/23/2005



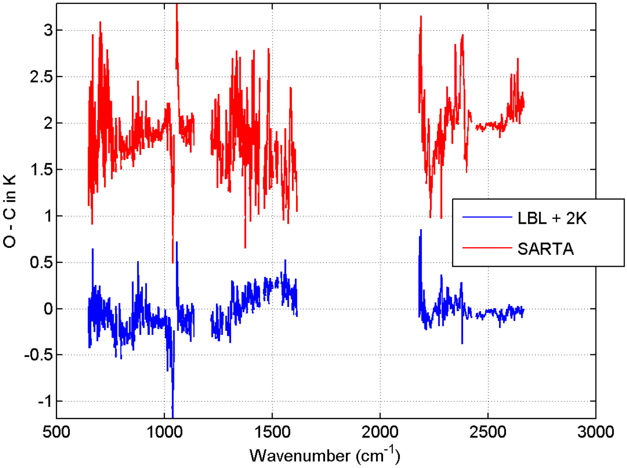
AEROSE Dust Study



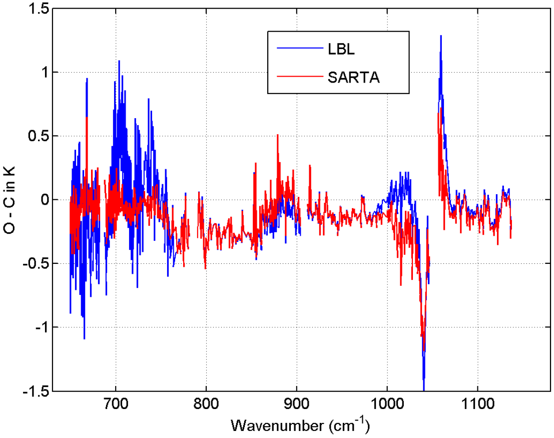
SARTA vs kCARTA

- AIRS validation improvements are only in SARTA, since they were derived from AIRS validation data and applied to the AIRS fast RTA channel transmittances
- kCARTA, our line-by-line algorithm, does not have these improvements.
- We need to either:
  1. Improve the basic molecular spectroscopy using the AIRS validation data (CO_2 and H_2O lineshapes, etc.), OR
  2. Figure out how to put channel-averaged corrections into the line-by-line.

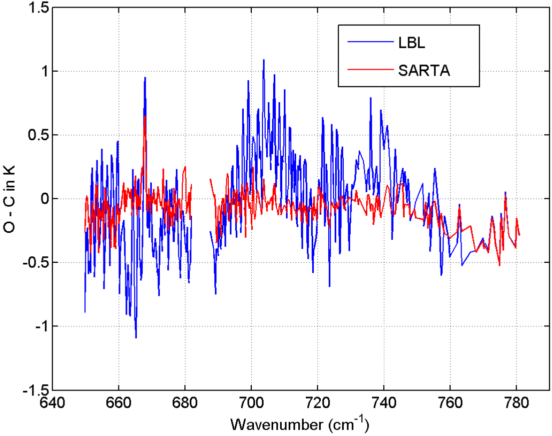
AIRS RTA (SARTA) vs Line-by-line (kCARTA), Retrieved Upper AIR T(z)



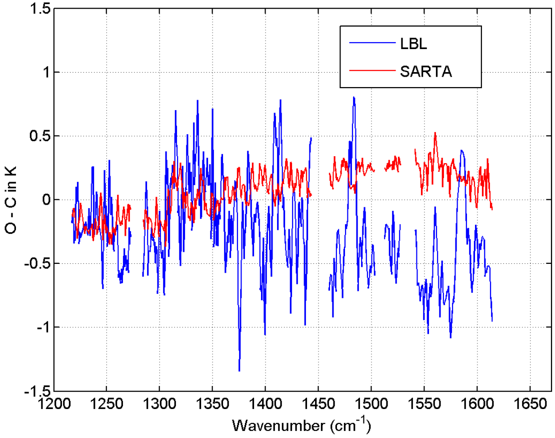
AIRS RTA (SARTA) vs Line-by-line (kCARTA): Zoom



AIRS RTA (SARTA) vs Line-by-line (kCARTA): Zoom



AIRS RTA (SARTA) vs Line-by-line (kCARTA): Zoom



AIRS RTA (SARTA) vs Line-by-line (kCARTA): Zoom