What we have learnt from the AIRS experience, and prospects from NPOESS/CrIS

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NOAA/NESDIS

& Chris Barnet, Walter Wolf, Eric Maddy, Lihang Zhou, plus many more

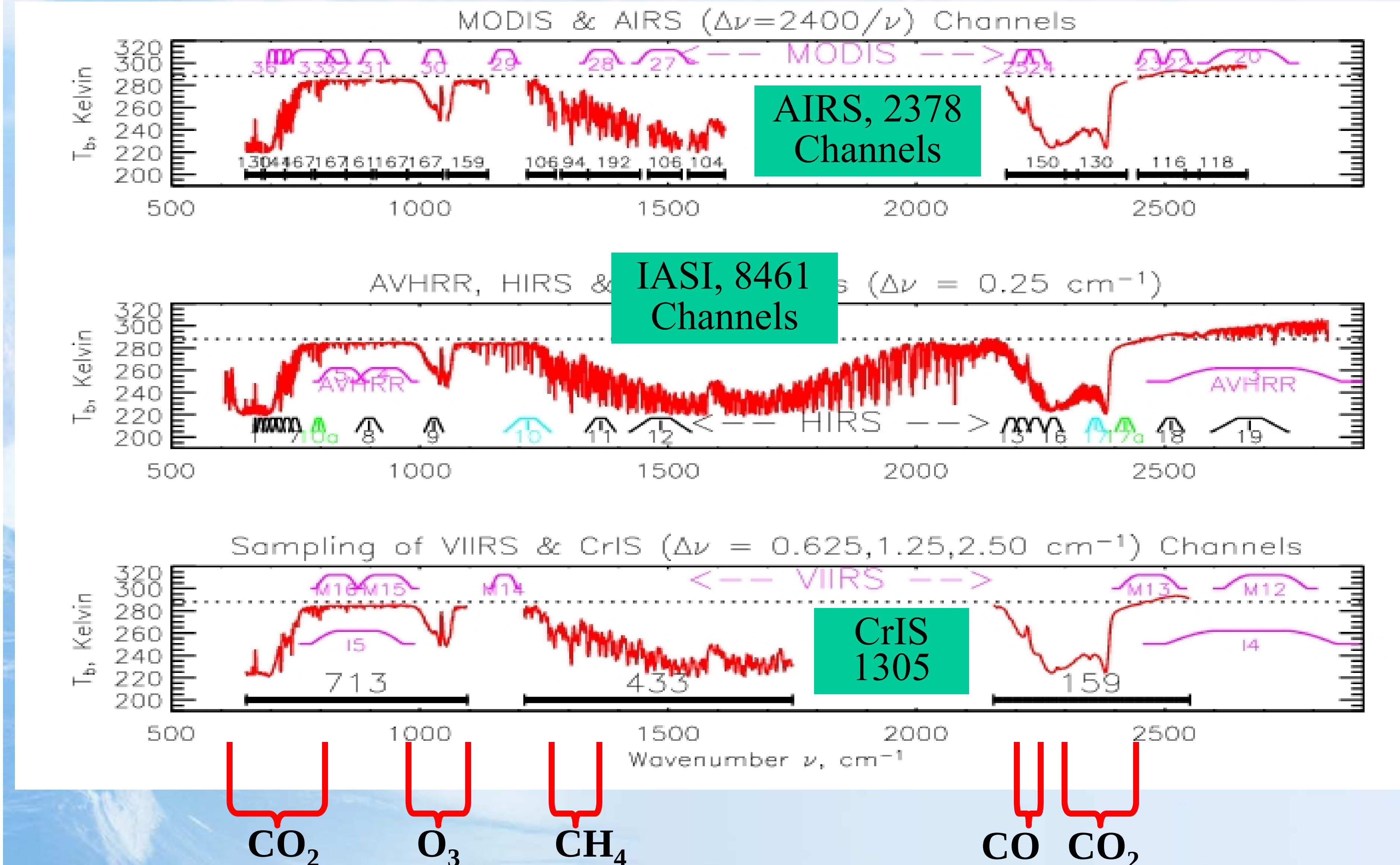
So what have we learned?

- AIRS significantly improves temperature and moisture sounding accuracy
- AIRS instrument is extremely stable and operating very well with an expected 12 year life.
- AIRS can produce trace gases products of ozone, carbon dioxide, methane, carbon monoxide plus more..
- AIRS PCA can be used for data compression and noise filtering, and is particularly important for IASI
- AIRS cloud cleared radiances substantially increases the yield of "clear" observations with retrieval performance nearly as good as AIRS real clear
- AIRS can be used to intercalibrate lower spectral resolution infrared sensors to better characterise spectral response functions

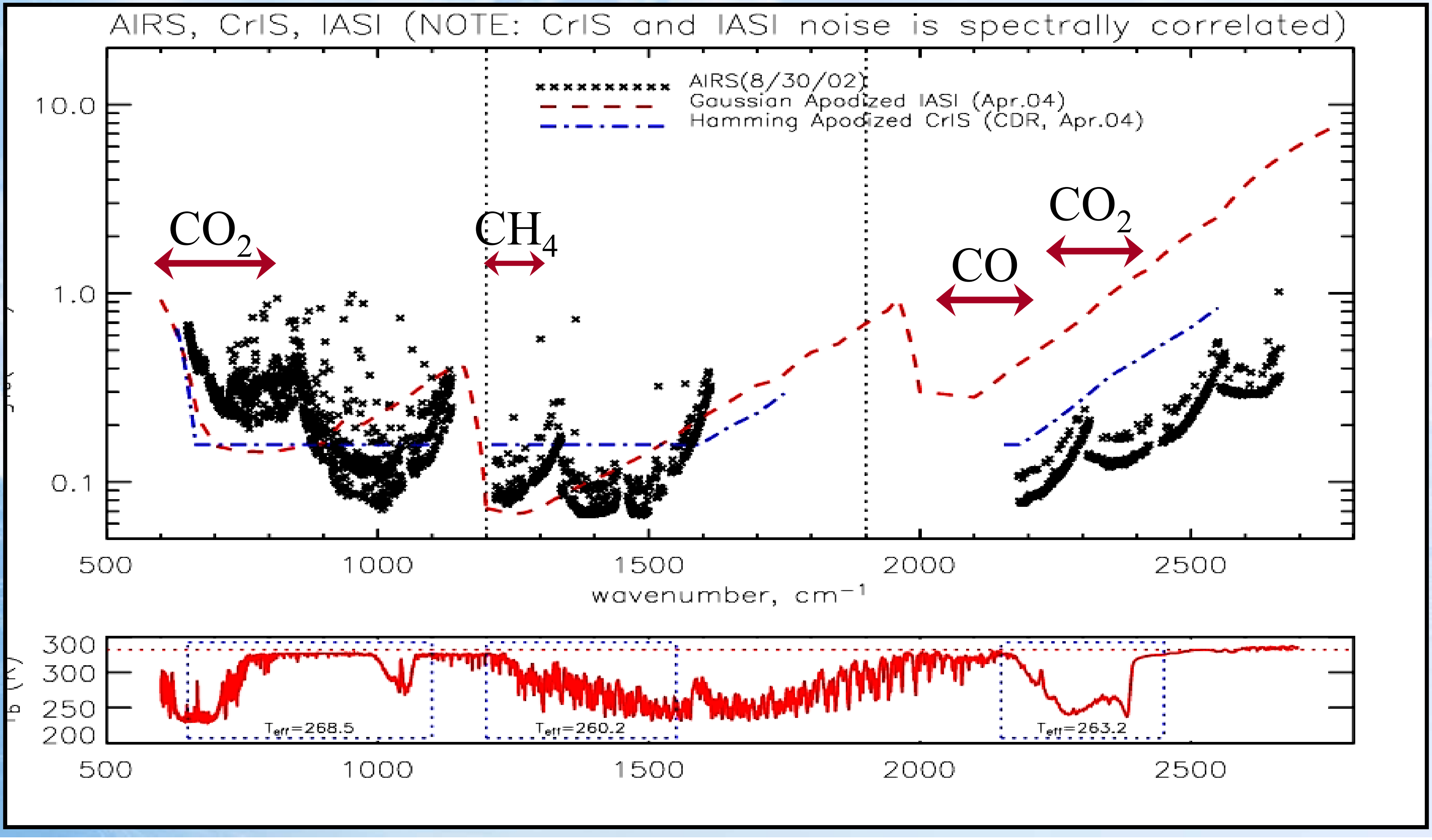
So what have we learned?

- AIRS can be used to validate climate and NWP models: A number of model derived water vapor fields are generally too moist when compared with AIRS
- Comparisons of seasonal variability of water vapor from AIRS with 17 different climate models and found significant differences in the amount of water (H2O) at a given level.
- Retrieval assimilation experiments at NASA GMAO have resulted in larger positive impacts than radiances

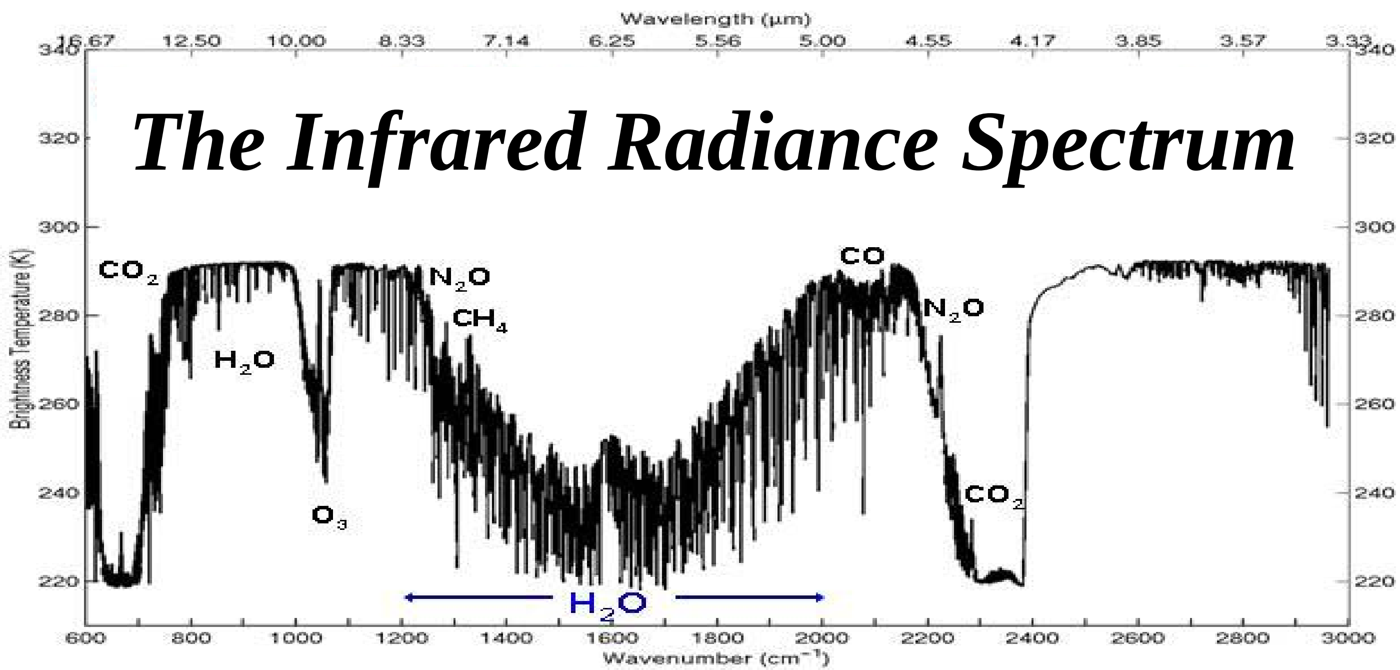
Spectral Coverage of Thermal Sounders (Example BT's for AIRS, IASI, & CrIS)



Instrument Noise, NEΔT at 250 K (Interferometers Noise Is Apodized)



IR Spectrum is a fundamental climate data record



<u>Products:</u>

Water vapor (soundings, fluxes, winds)

Temperature (sounding, stability)

Carbon monoxide concentration (2 Layers) and total CO2 conc.

Methane concentration (total column)

Ozone concentration (4 Layers)

Surface Temperature ,emissivity, land characterization

Clouds (altitude, optical depth, microphysical properties, winds)

Aerosol Concentration and Depth

Why high spectral resolution?

- Improved spectral resolution results in

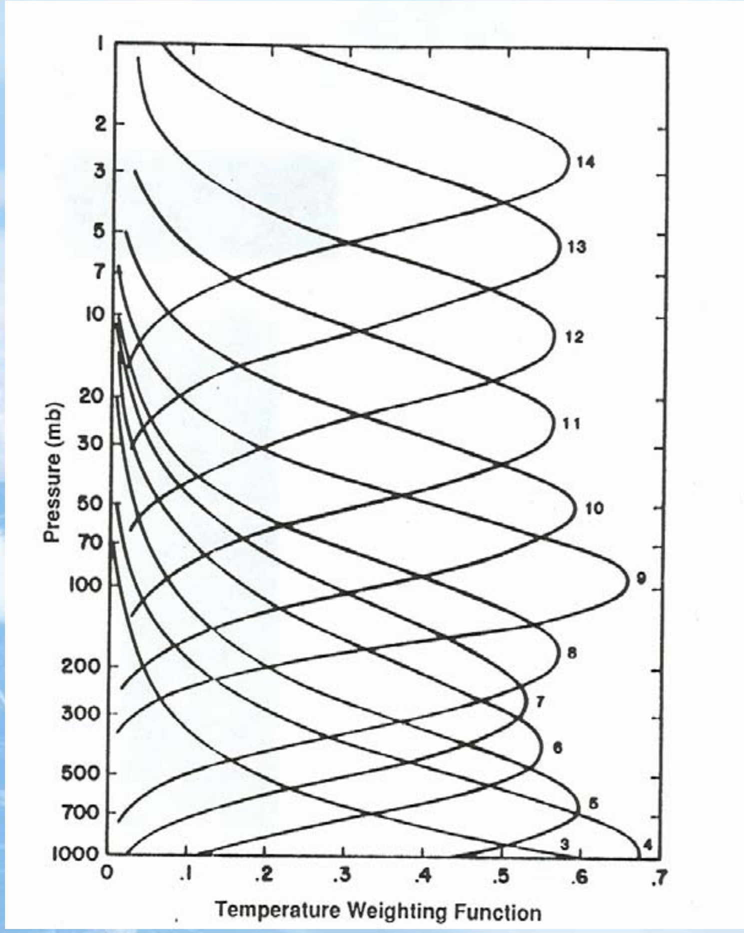
  Sharper weighting functions

  "Clean" channels (e.g. temperature channels not contaminated by water vapor lines)

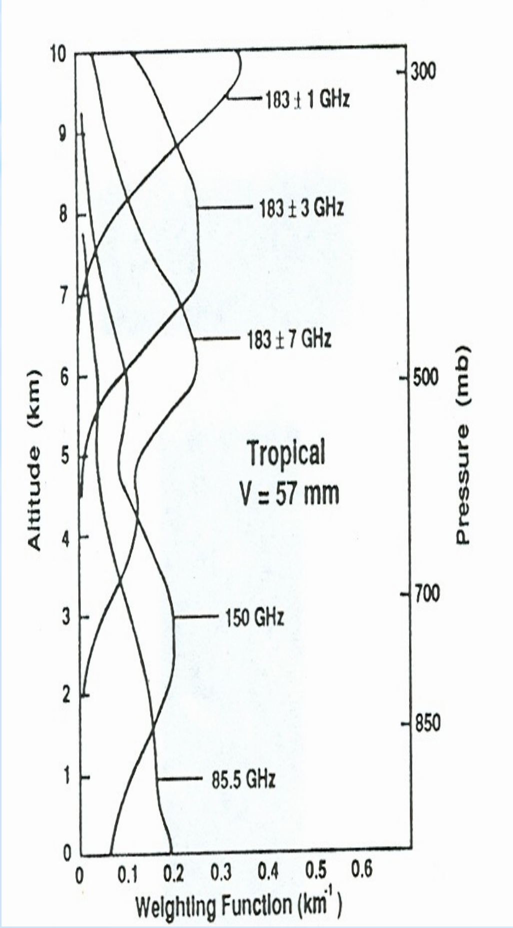
- Many channels with sharper weighting functions combined with low noise improves vertical resolution
- Retrieval accuracy is greatly improved (temperature , moisture , skin temperature and surface emissivity)
- Resolving individual water vapor absorption lines allow detection of temperature inversions
- High spectral resolution allow the retrieval of trace gases
- Validate weather and climate prediction models

AMSU Temperature & Moisture Channel Weighting Functions

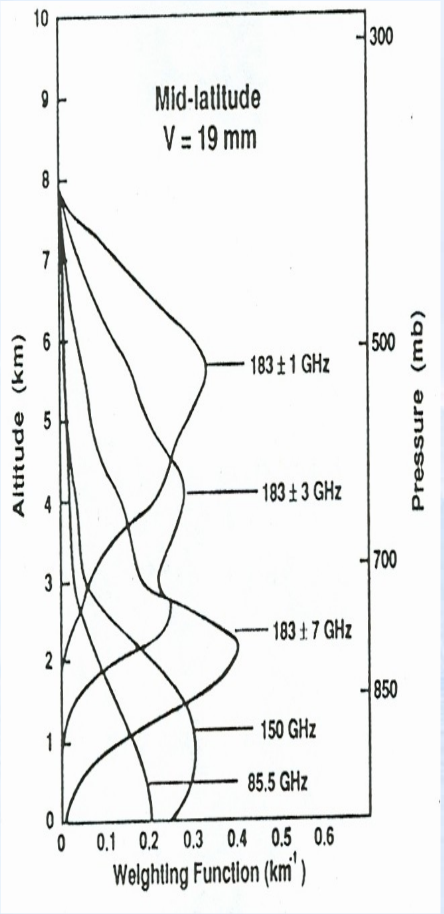
W = dτ/dz



W = dτ/dq tropical



W = dτ/dq mid-lat

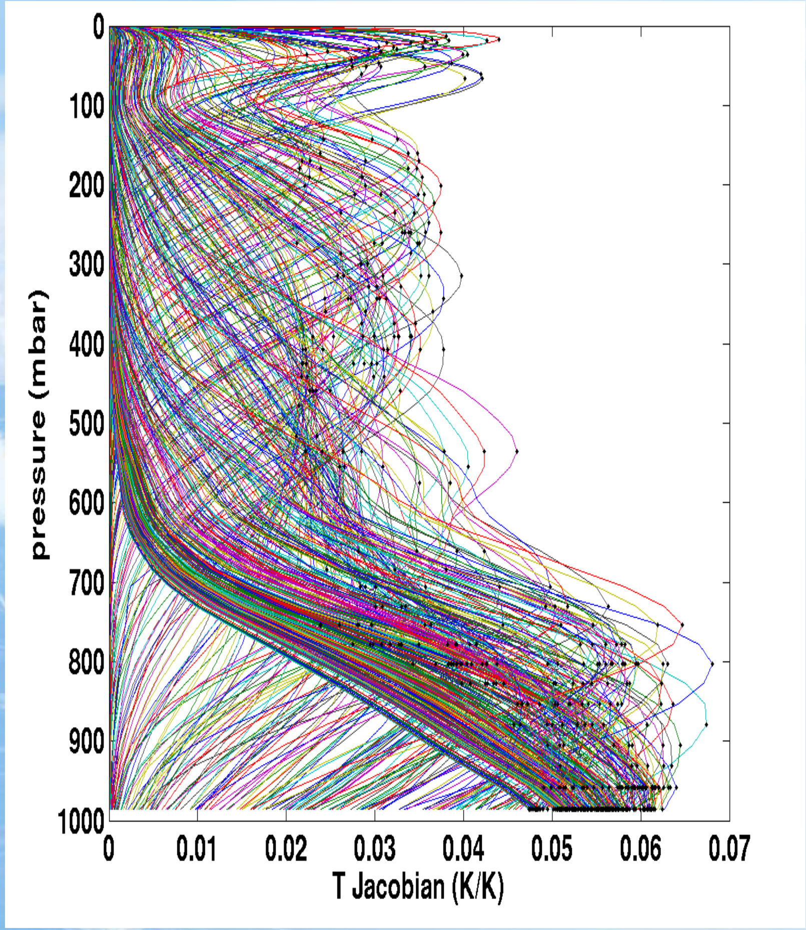


K = $dB_{\upsilon}(t)/dT * d\tau/dz$, Figures from M.A. Janssen 1993 John Wiley & Sons

Example Channel Kernel Functions, $K_{n,j}$ for Temperature and Moisture

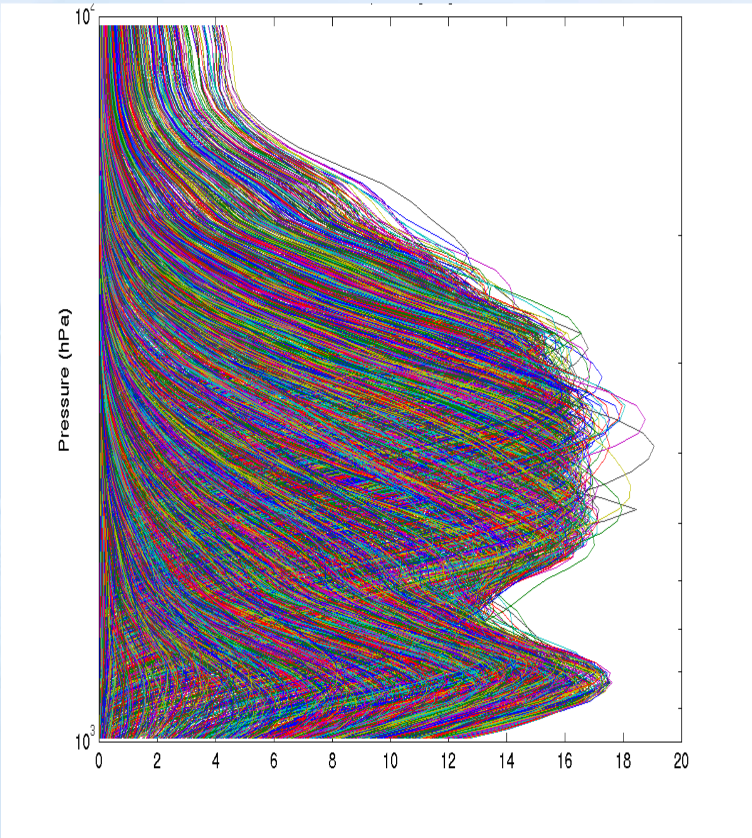
AIRS 15 µm (650-800 cm-1) band

K = dR/dT



AIRS 6.7 µm (1200-1600 cm^{-1}) band

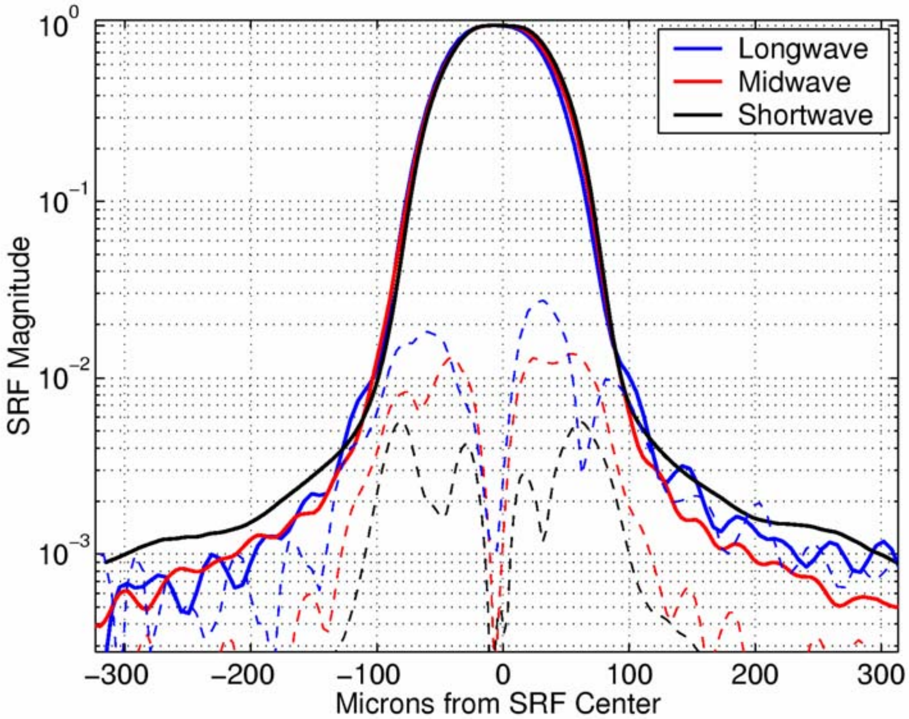
K = dR/dq



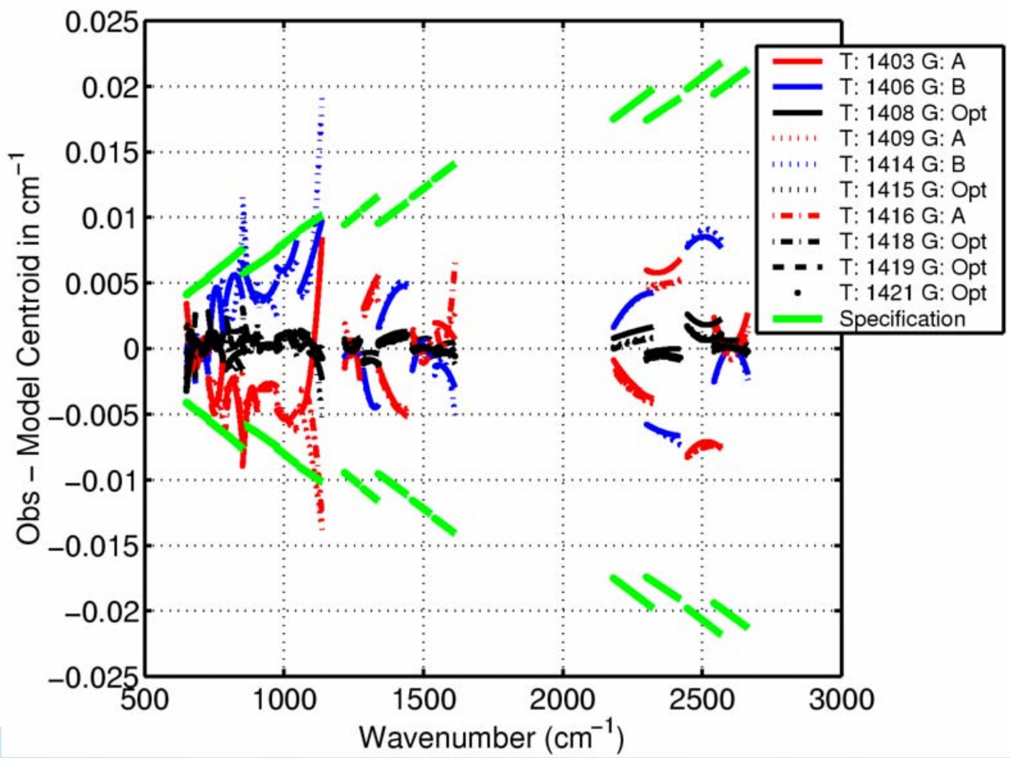
Accuracy, Precision and Stability

PREFLIGHT SPECTRAL CAL SHOWS EXCELLENT SPECTRAL SHAPE AND STABILITY

SRF Shape Well Characterized to <10^{-3}

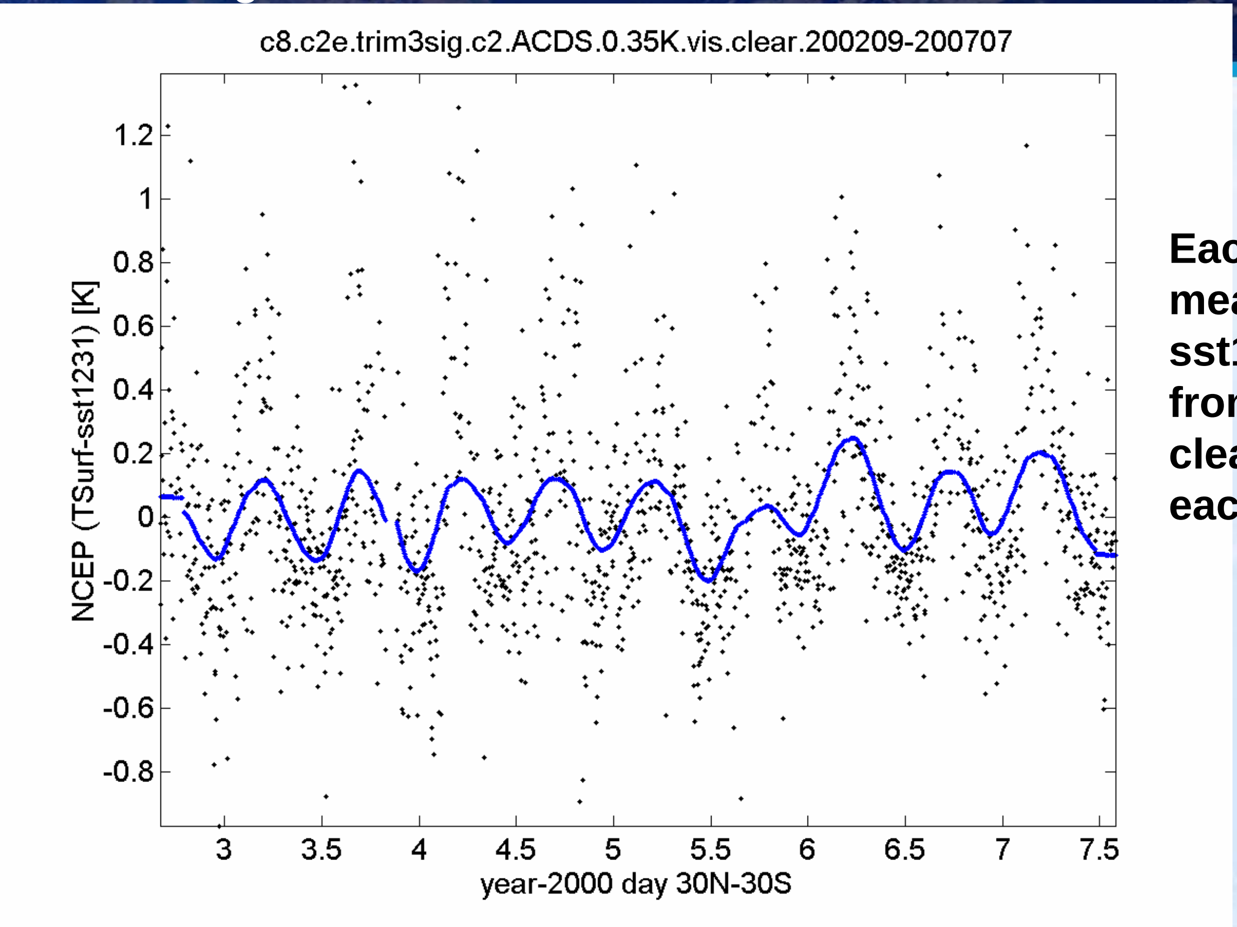


Knowledge of Centroids Within Spec Limits



Temperature Dependence Well Behaved

The vis clear sst1231-TSurf shows that the absolute calibration of AIRS is good at the better than 100 mK level

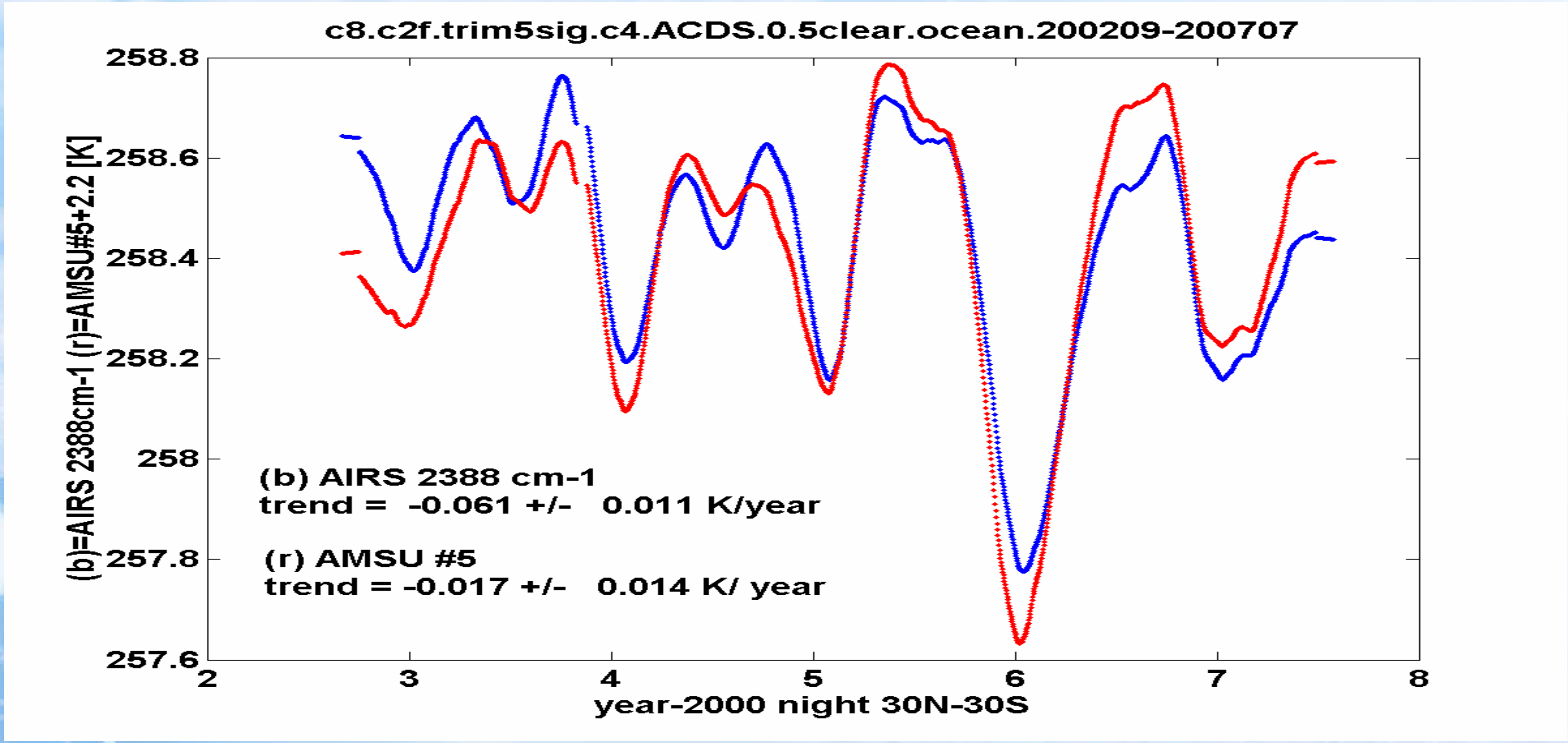


Each dot it the mean of sst1231-TSurf.NCEP from about 3000 clear spectra each day

sst1231-TSurf Trend = + 0.014 +/- 0.005 K/year
mean= -0.047 K

Large positive excursions (sst1231 warmer than TSurf) are due to the fact that the NCEP TSurf known nothing about solar skin heating under extremely clear conditions.

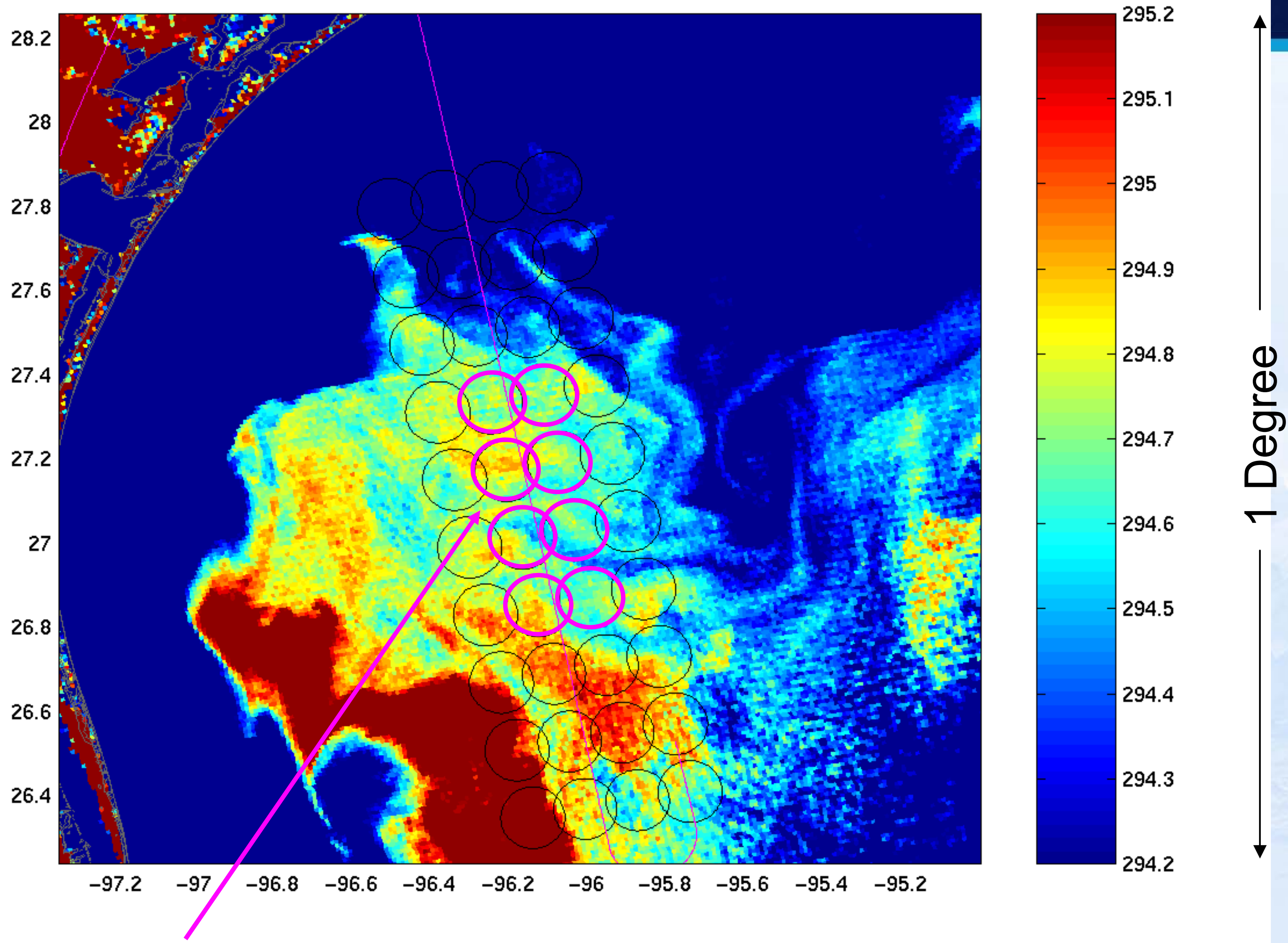
The temperature at 5 km altitude decreases 46 mK/year due to the the increase in co2 at the rate of 1.7 ppmv/year



day trend 2388 = -0.061 +/- 0.014 K/year

AMSU#5 = -0.015 +/- 0.016 K/year

Scanning HIS vs AIRS



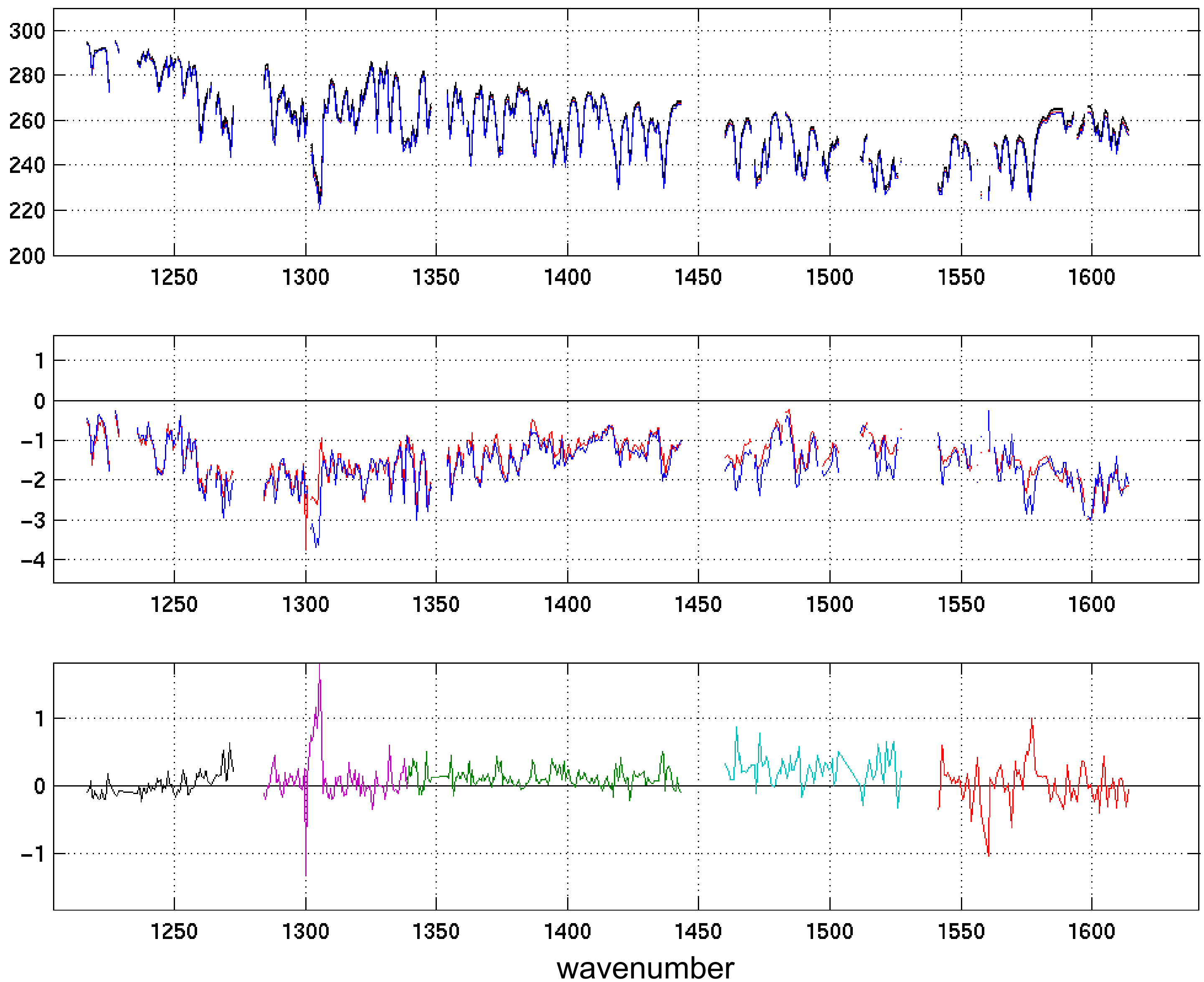
8 AIRS FOVs and SHIS Data w/in them (448 fovs) used in the following comparisons

"comparison 3"

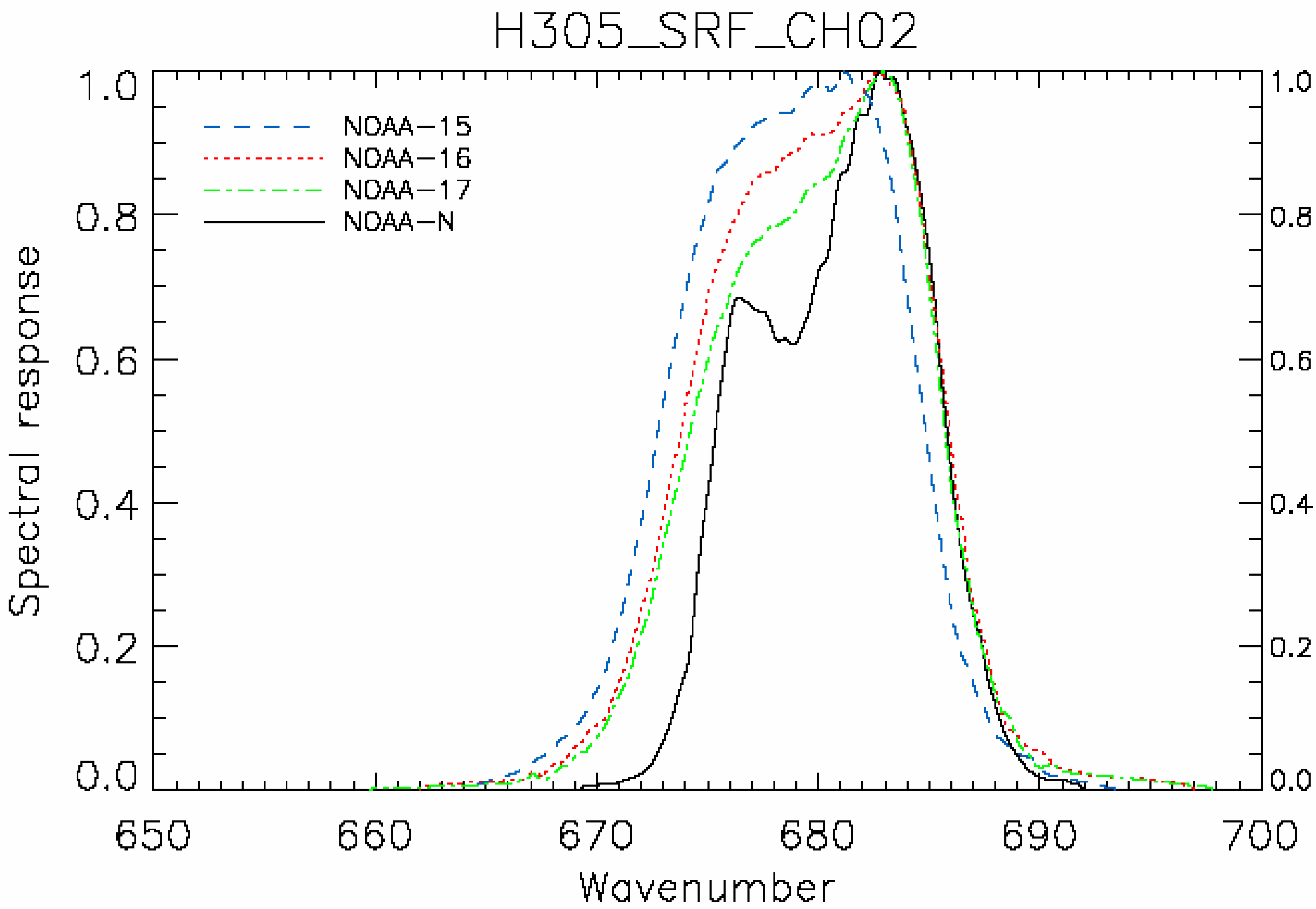
AIRSobs
SHISobs

(AIRSobs-AIRScalc)
(SHISobs-SHIScalc)

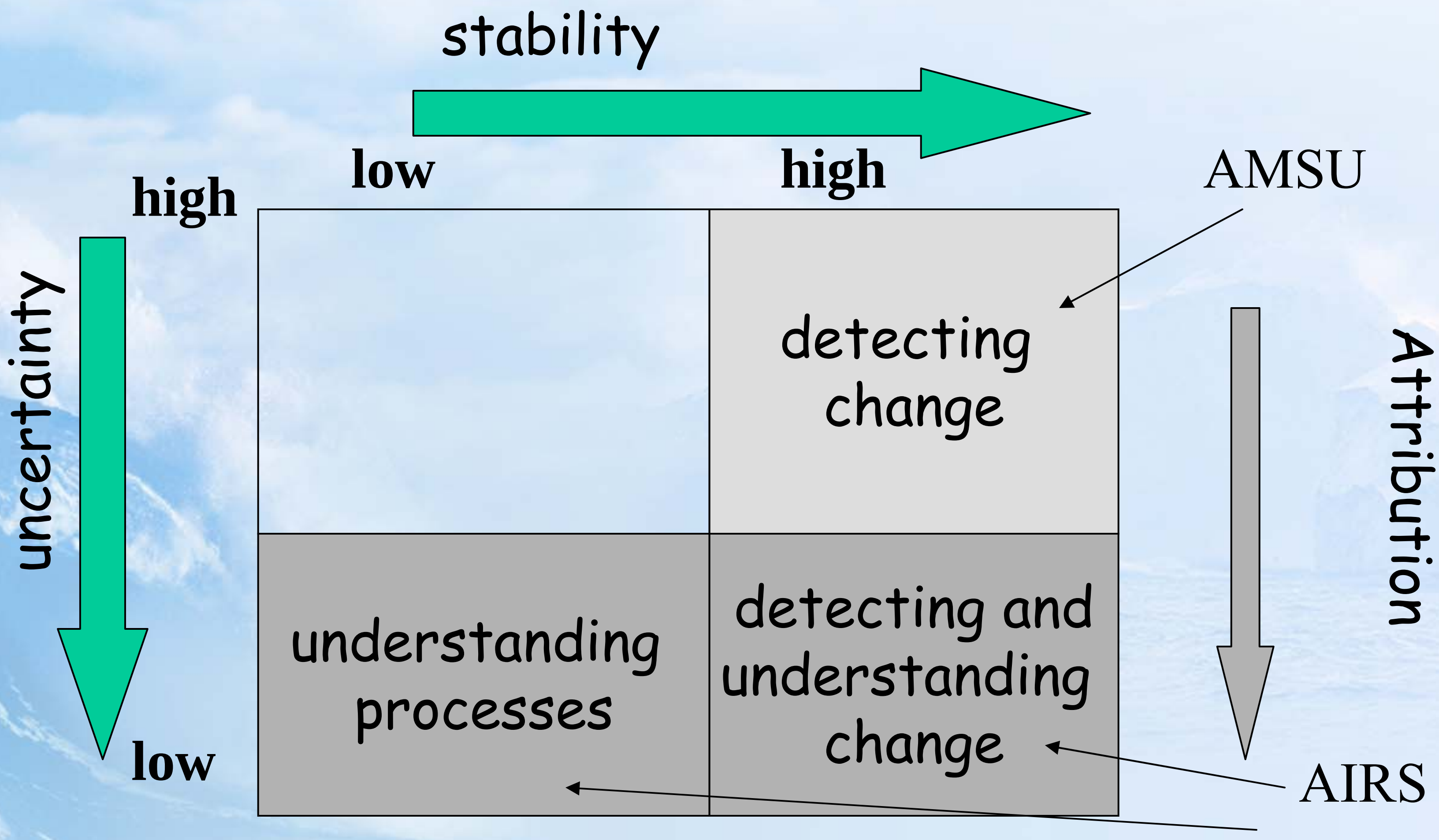
(AIRSobs-AIRScalc)-
(SHISobs-SHIScalc)



HIRS Spectral Response Functions
Channel 2



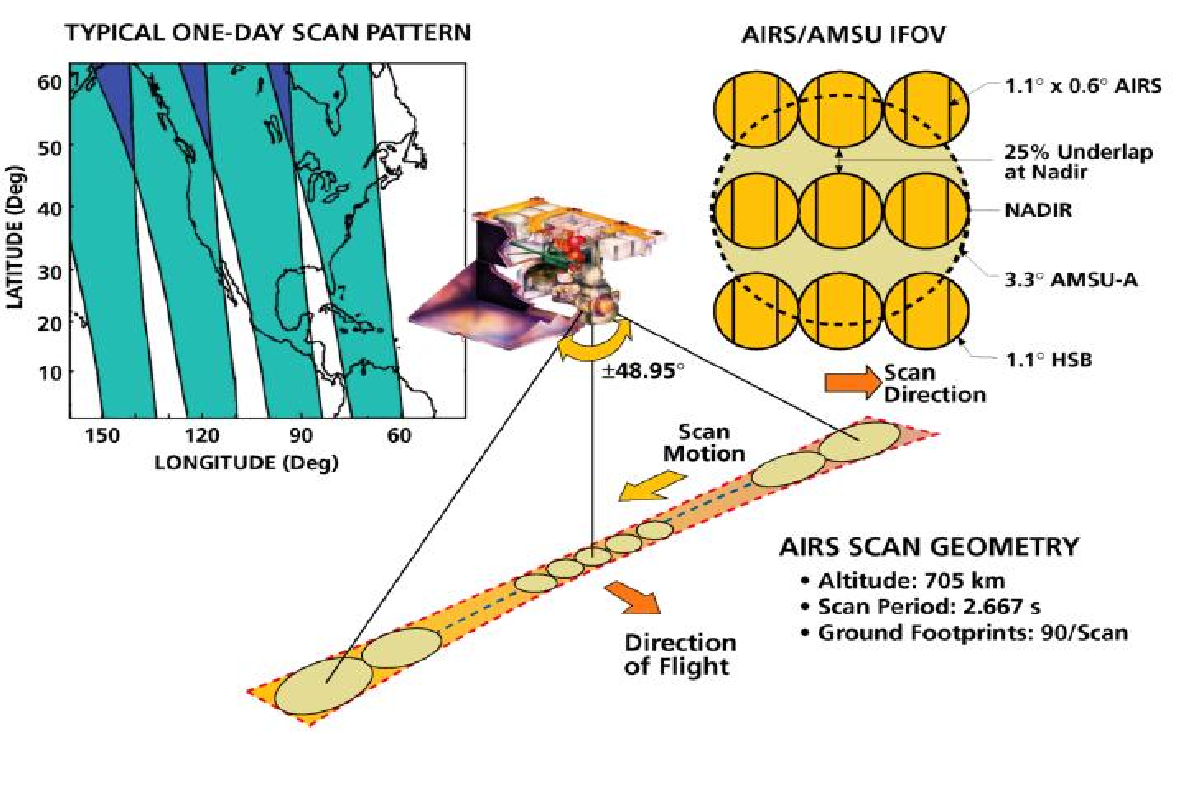
Desired characteristics of an observing system (After G. Stephens, 2003)



Retrieval Methodology

Sounding Strategy in Cloudy Scenes: Co-located Thermal & Microwave (& Imager)

- **Sounding is performed on 50 km a field of regard (FOR).**
- **FOR is currently defined by the size of the microwave sounder footprint.**
- **IASI/AMSU has 4 IR FOV's per FOR**
- **AIRS/AMSU & CrIS/ATMS have 9 IR FOV's per FOR.**
- **ATMS is spatially over-sampled can emulate an AMSU FOV.**



AIRS, IASI, and CrIS all acquire 324,000 FOR's per day

Spatial variability in scenes is used to correct radiance for clouds.

- Assumptions, $R_j = (1-\alpha_j)R_{clr} + \alpha_j R_{cld}$
  - Only variability in AIRS pixels is cloud amount, α_j
    - Reject scenes with excessive surface & moisture variability (in the infrared).
  - Within FOR (9 AIRS scenes) there is variability of cloud amount
    - Reject scenes with uniform cloud amount
- We use the microwave radiances and 9 sets of cloudy infrared radiances to determine a set of 4 parameters and quality indicators to derive 1 set of cloud cleared infrared radiances.
- Roughly 70% of any given day satisfies these assumptions.

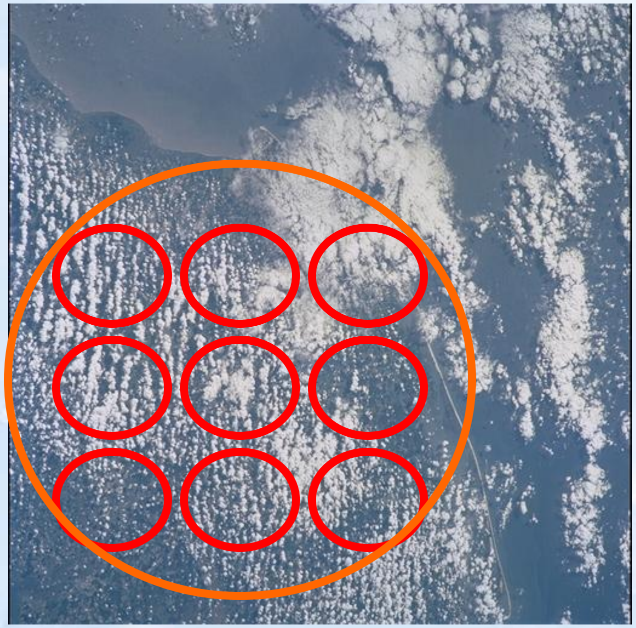


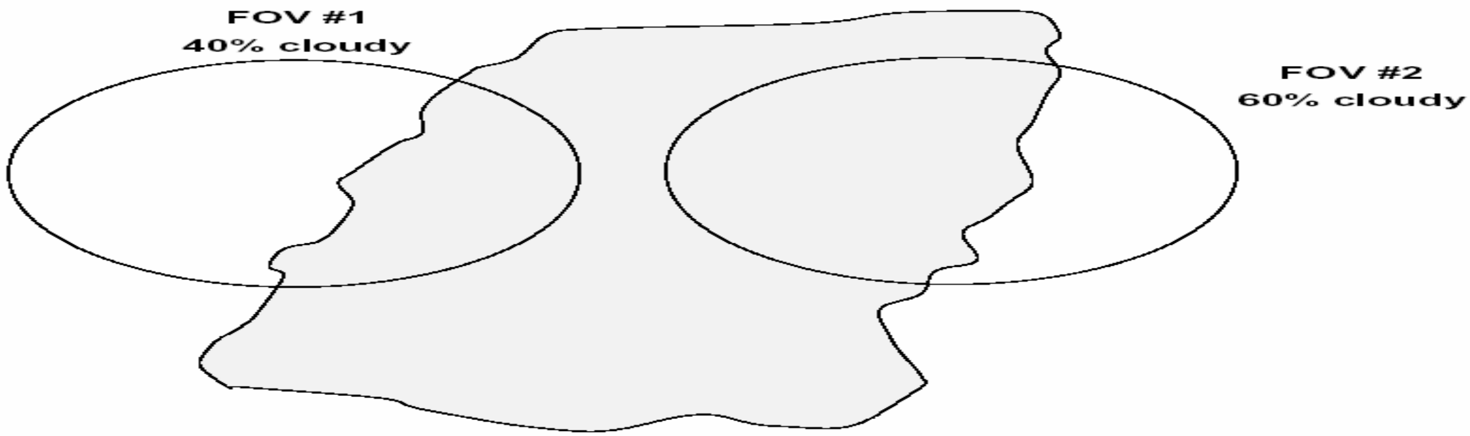
Image Courtesy of Earth Sciences and Image Analysis Laboratory, NASA Johnson Space Center (http://eol.jsc.nasa.gov). STS104-724-50 on right (July 20, 2001). Delaware bay is at top and Ocean City is right-center part of the images.

Cloud Clearing

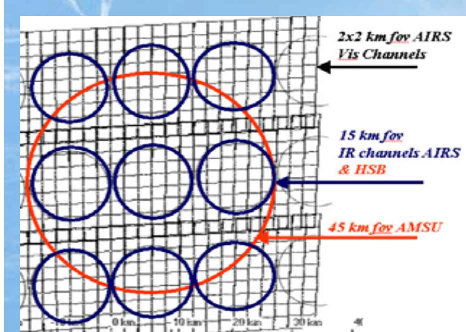
$$R1 = (1-a1)*Rclear + a1*Rcloud$$

$$R2 = (1-a2)*Rclear + a2*Rcloud$$

Assume Scene Is Identical in FOV's except Fraction of Cloud



Two AIRS field of views (FOV's) are illustrated showing that each FOV has some fraction of clear radiance and some fraction of cloudy radiance. We define the ensemble of FOV's as the retrieval field of regard (FOR).



$$Rclear(i) = R1(i) + \eta *[R1(i)-R2(i)]$$

$$\eta = a1/(a2-a1)$$

$$\eta = (R_{clear\text{-}est} - R1)/(R1-R2)$$

Spatial variability in scenes is used to correct radiance for clouds.

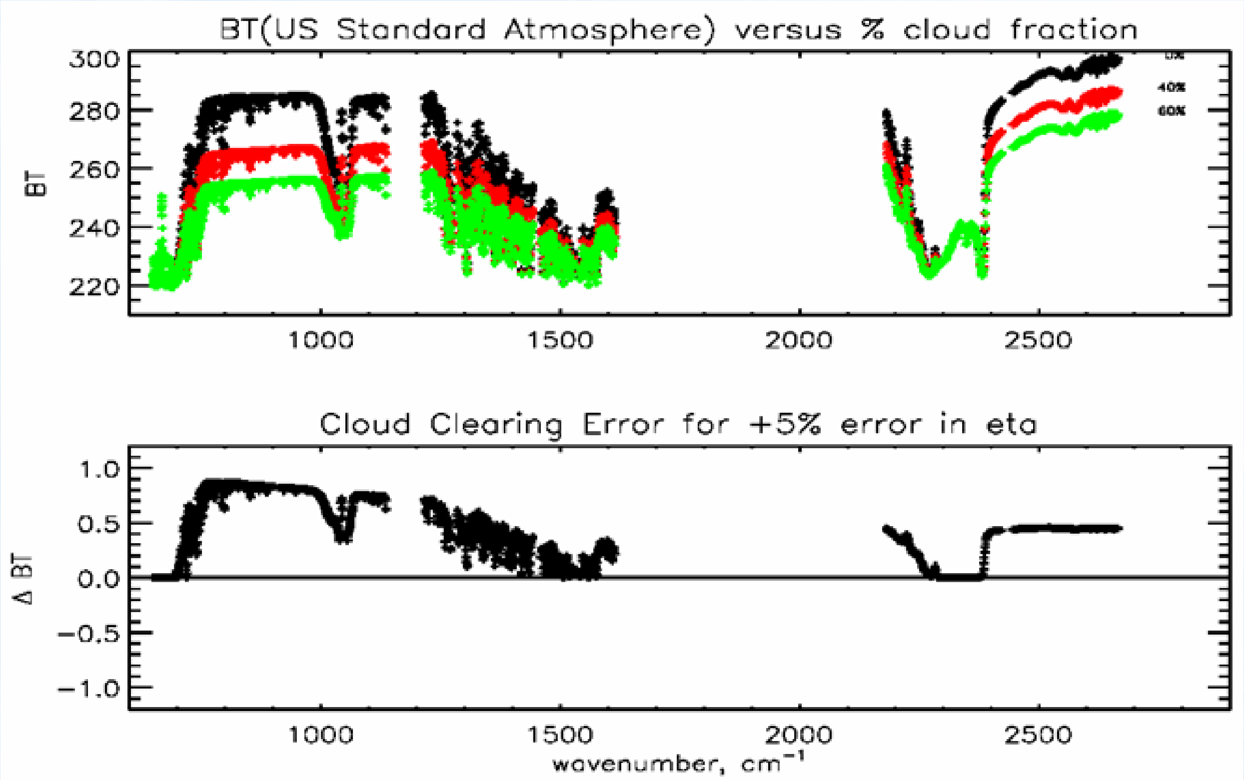
- We use a sub-set (≈ 50 chl's) of computed radiances from the microwave state as a clear estimate, $R_n = R_n(X)$ and 9 sets of cloudy infrared radiances, $R_{n,j}$ to determine a set of 4 parameters, η_j.

$$\hat{R}_n = \langle R_{n,j} \rangle_j + (\langle R_{n,j} \rangle_j - R_{n,j}) \cdot \eta_j$$

- Solve this equation with a constraint that $\eta_j \leq 4$ degrees of freedom (cloud types) per FOR
- A small number of parameters, η_j, can remove cloud contamination from thousands of channels.
  - Does not require a model of clouds and is not sensitive to cloud spectral structure (this is contained in radiances, $R_{n,j}$)
  - Complex cloud systems (multiple level of different cloud types).

Example of AIRS Cloudy Spectra

Example AIRS spectra at right for a scene with α=0% clouds (black), α=40% clouds (red) and α=60% clouds (green).

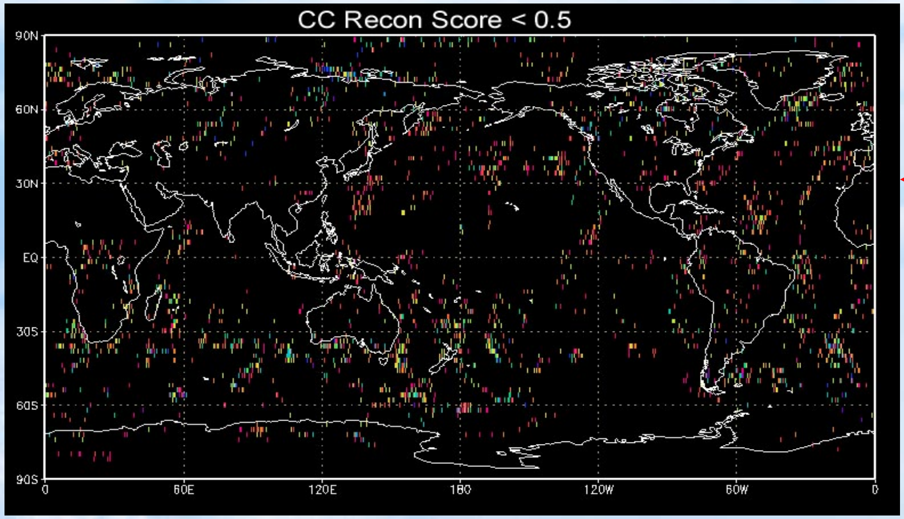


Can use any channels (*i.e.*, avoid window regions, water regions) to determine extrapolation parameters, η_j

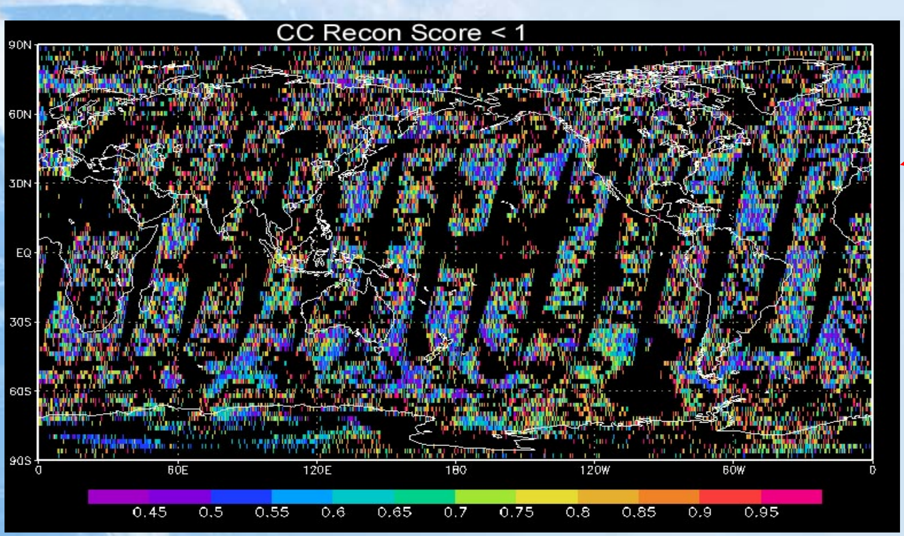
Note that cloud clearing produces a spectrally correlated error

In this 2 FOV example, the cloud clearing parameters, η_j, is equal to $\frac{1}{2}\langle\alpha\rangle/(\alpha_j-\langle\alpha\rangle)$

Cloud Clearing Dramatically Increases the Yield of Products

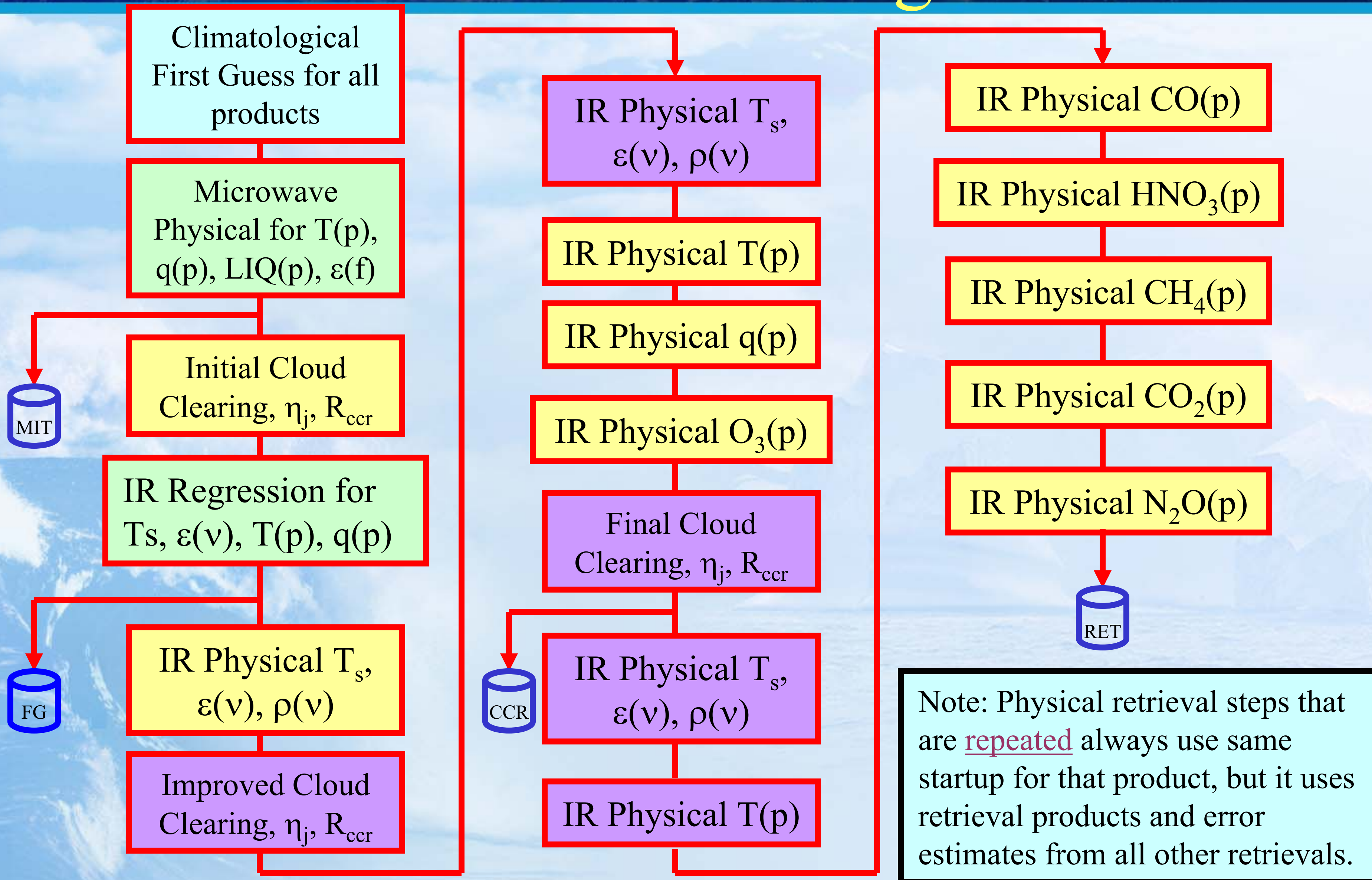


- ***AIRS experience:***
  - **Typically, less than 5% of AIRS FOV's (13.5 km) are clear.**
  - **Typically, less than 2% of AIRS retrieval field of regard's (50 km) are clear.**



- **Cloud Clearing can increase yield to 50-80%.**
- **Cloud Clearing reduces radiance product size by 1:9 for AIRS and 1:4 for IASI.**

Simplified Flow Diagram of AIRS Science Team Algorithm



1DVAR versus AIRS Science Team Method

1DVAR	AIRS Science Team Approach
Solve all parameters simultaneously	Solve each state variable (*e.g.*, T(p)), separately.
Error covariance includes only instrument model.	Error covariance is computed for all *relevant* state variables that are held fixed in a given step. Retrieval error covariance is propagated between steps.
Each parameter is derived from all channels used (*e.g.*, can derive T(p) from CO2, H2O, O3, CO, … lines).	Each parameter is derived from the best channels for that parameter (*e.g.*, derive T(p) from CO2 lines, q(p) from H2O lines, etc.)
A-priori must be rather close to solution, since state variable interactions can de-stabilize the solution.	*A-priori* can be simple, since this method is very stable.
Regularization must include *a-priori* statistics to allow mathematics to separate the variables and stabilize the solution.	Regularization can be reduced (smoothing terms) and does not require *a-priori* statistics for most geophysical regimes.
This method has large state matrices (all parameters) and covariance matrices (all channels used). Inversion of these large matrices is computationally expensive.	State matrices are small (largest is 25 T(p) parameters) and covariance matrices of the channels subsets are quite small. Very fast algorithm. Encourages using more channels.
Has never been done simultaneously with clouds, emissivity(ν), SW reflectivity, surface T, T(p), q(p), O3(p), CO(p), CH4(p), CO2(p), HNO3(p), N2O(p) – if any of these are constant, then it is no longer simultaneous.	*In-situ* validation and satellite inter-comparisons indicate that this method is robust and stable. There are still spectroscopy and algorithm improvements to work out.

AIRS/AMSU Products for a ≈50 km footprint (varies w/ view angle), 324,000 footprints/day

- Cloud Cleared Radiance
- Temperature, 1K/ 1km
- Moisture, 5%
- Ozone, 5%
- Land/Sea Surface Temperature
- Surface Spectral Emissivity
- Surface Reflectivity
- Cloud Liquid Water (AMSU product)
- Cloud Fraction/height (per 15 km footprint).
- Carbon Monoxide, 15%
- Carbon Dioxide, 1%
- Methane, 1%
- Cirrus Cloud Optical Depth and Particle Size

Trace Gas Product Potential from Operational Thermal Sounders

gas	Range (cm^{-1})	Precision	d.o.f.	Interfering Gases
H2O	**1200-1600**	**15%**	**4-6**	**T(p)**
O_3	**1025-1050**	**10%**	**1.25**	**H2O,emissivity**
CO	**2080-2200**	**15%**	**≈ 1**	**H2O,N2O**
CH_4	**1250-1370**	**1.5%**	**≈ 1**	**H2O,HNO3,N2O**
CO_2	**680-795 2375-2395**	**0.5% ?**	**≈ 1**	**H2O,O3**
Volcanic SO_2	**1340-1380**	**1000%**	**< 1**	**H2O,HNO3**
HNO_3	**860-920 1320-1330**	**50% ??**	**1.25**	**emissivity H2O,CH4,N2O**
N_2O	**1250-1315 2180-2250 2520-2600**	**5% ??**	**≈1**	**H2O H2O,CO**
$CFCl_3$ (F11)	**830-860**	**20%**	**-**	**emissivity**
CF_2Cl (F12)	**900-940**	**20%**	**-**	**emissivity**
CCl_4	**790-805**	**50%**	**-**	**emissivity**

Product Available @ NASA DAAC (H2O, O_3, CO, CH_4)

Research Product Available at NOAA NESDIS (CO_2, Volcanic SO_2, HNO_3, N_2O)

Held Fixed ($CFCl_3$, CF_2Cl, CCl_4)

Haskins, R.D. and L.D. Kaplan 1993

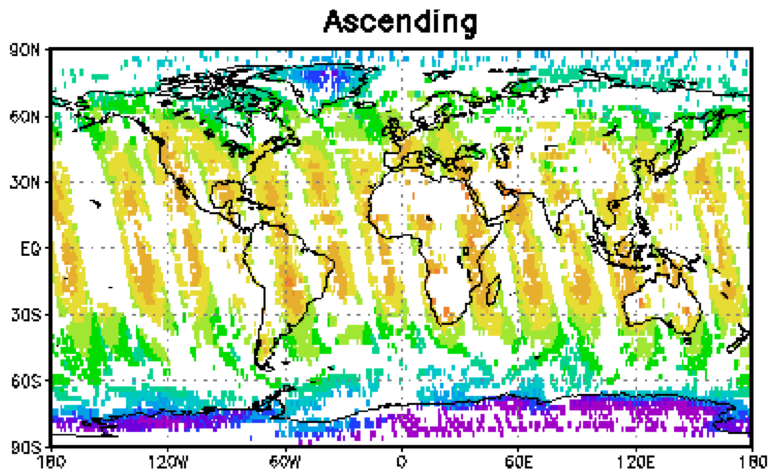
NESDIS Products

- Same AIRS science algorithms and products for IASI/AMSU/MHS and CrIS/ATMS
- Use MODIS, AVHRR, and VIIRS for improved cloud detection and cloud clearing qc for AIRS, IASI and CrIS, respectively

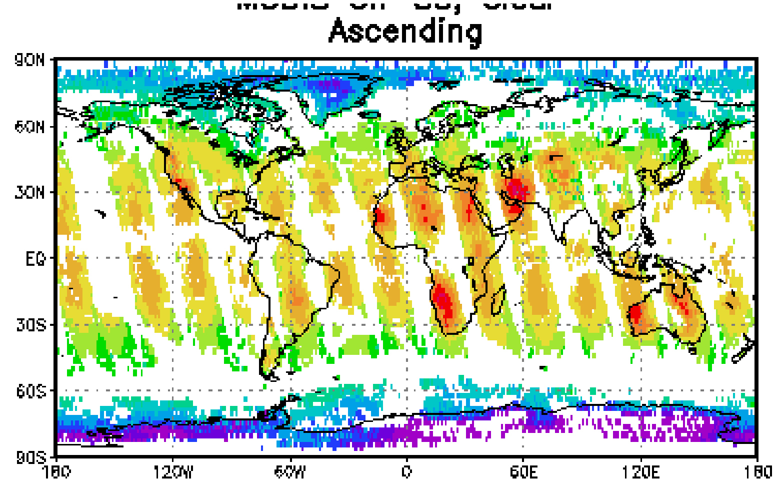
Using MODIS to QC AIRS Cloud-Cleared Radiances

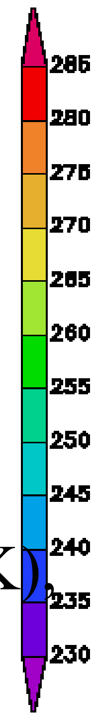
MODIS and AIRS Data Fusion

Cloud-Cleared AIRS spectrally convolved to MODIS



Clear MODIS spatially convolved to AIRS



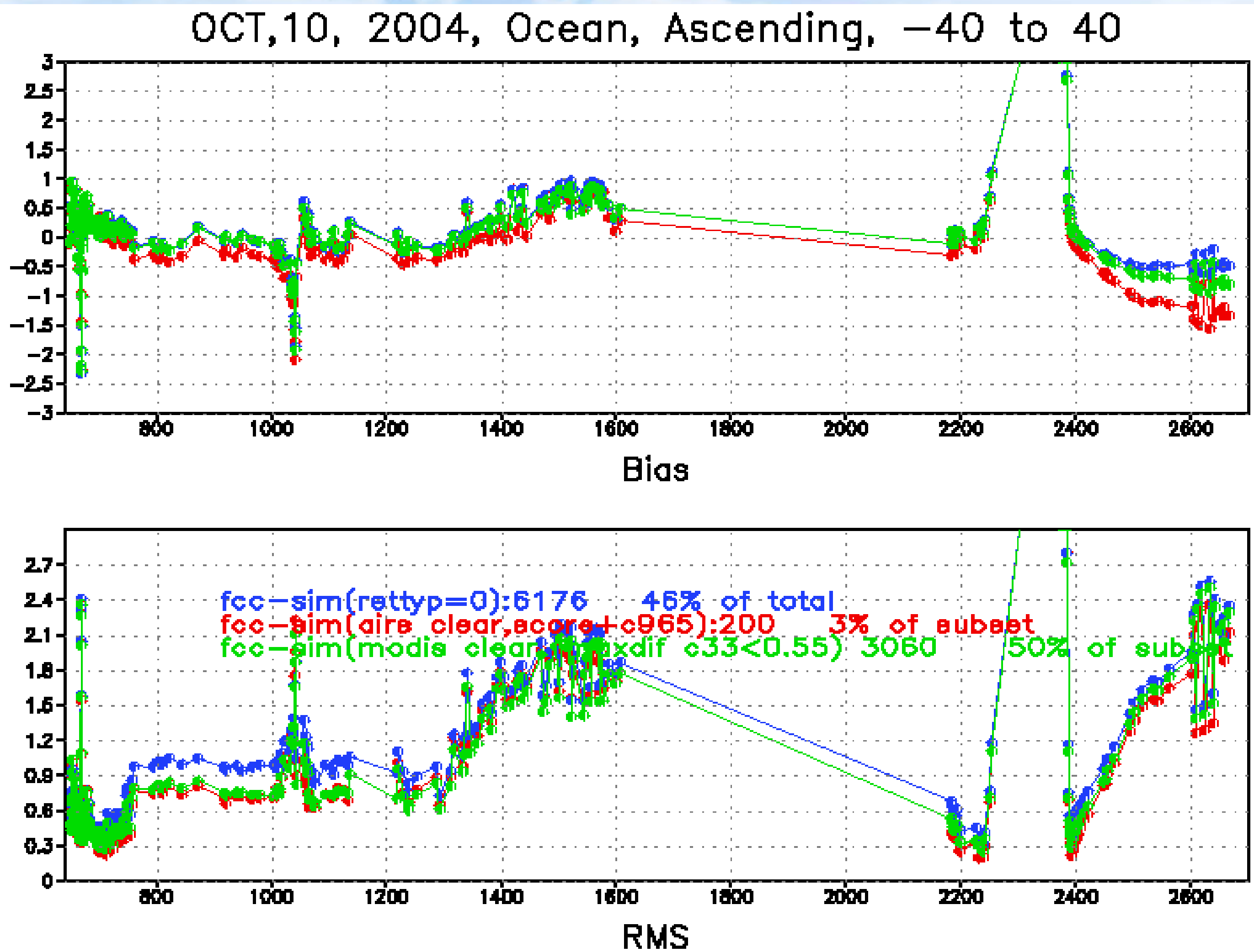


CHANNEL 33

If the clear MODIS agrees with cloud-cleared AIRS (within 0.5 K), then the AIRS cloud cleared radiances are noted as very high confident cloud cleared.

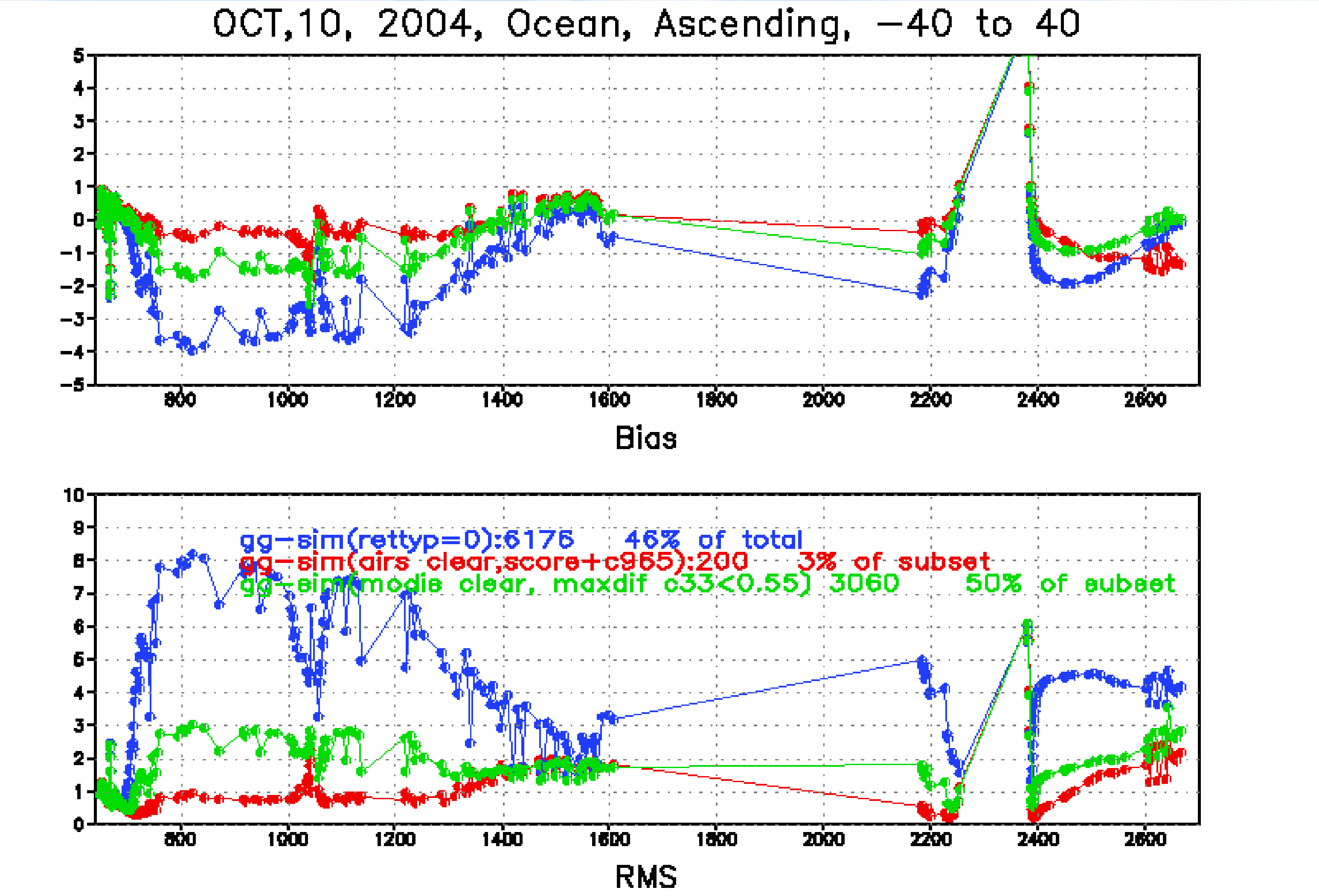
Currently using MODIS to quality control AIRS Cloud-Cleared Radiances

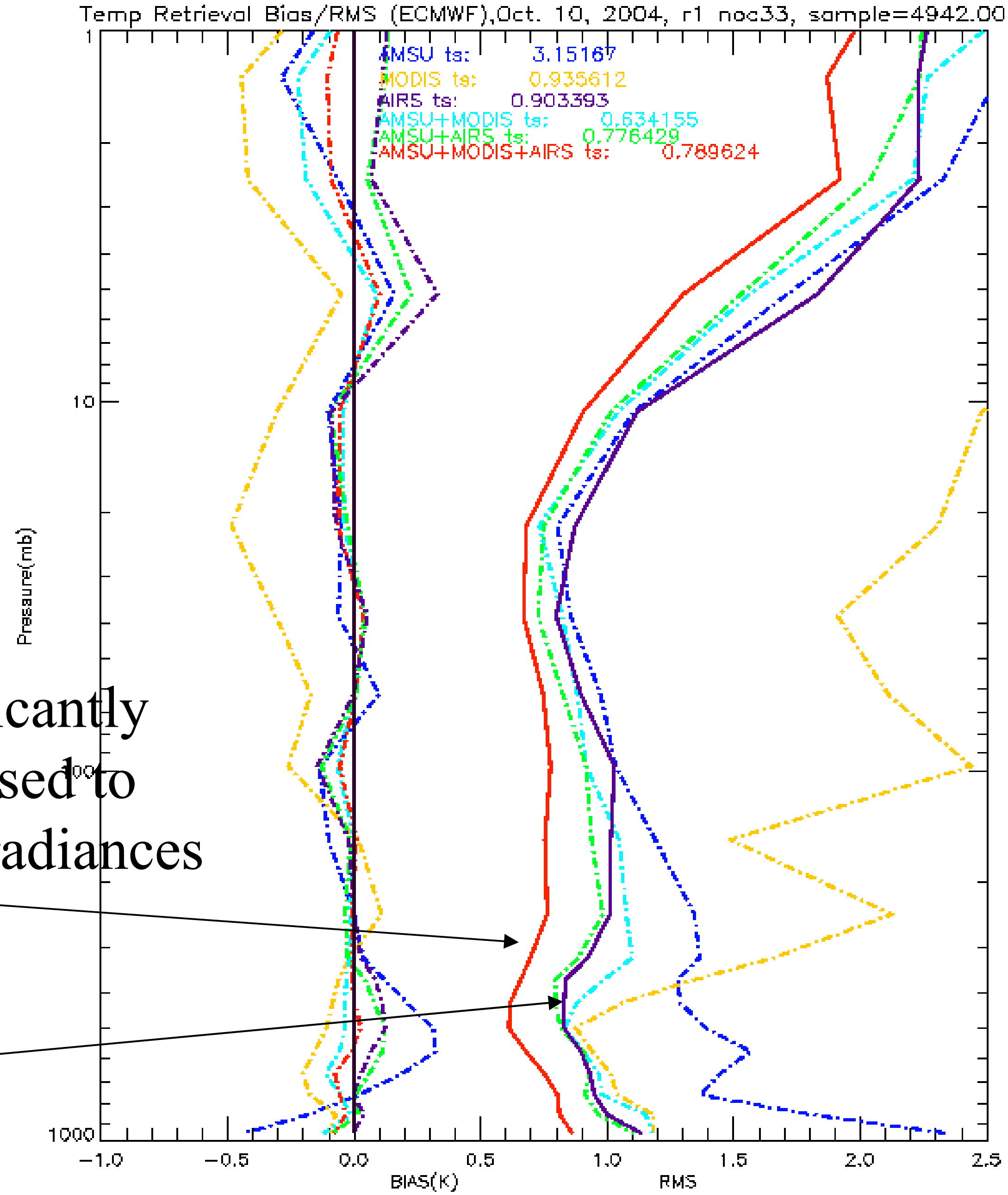
Cloud-clear minus clear simulated (ECMWF)



Consequence of not cloud-clearing

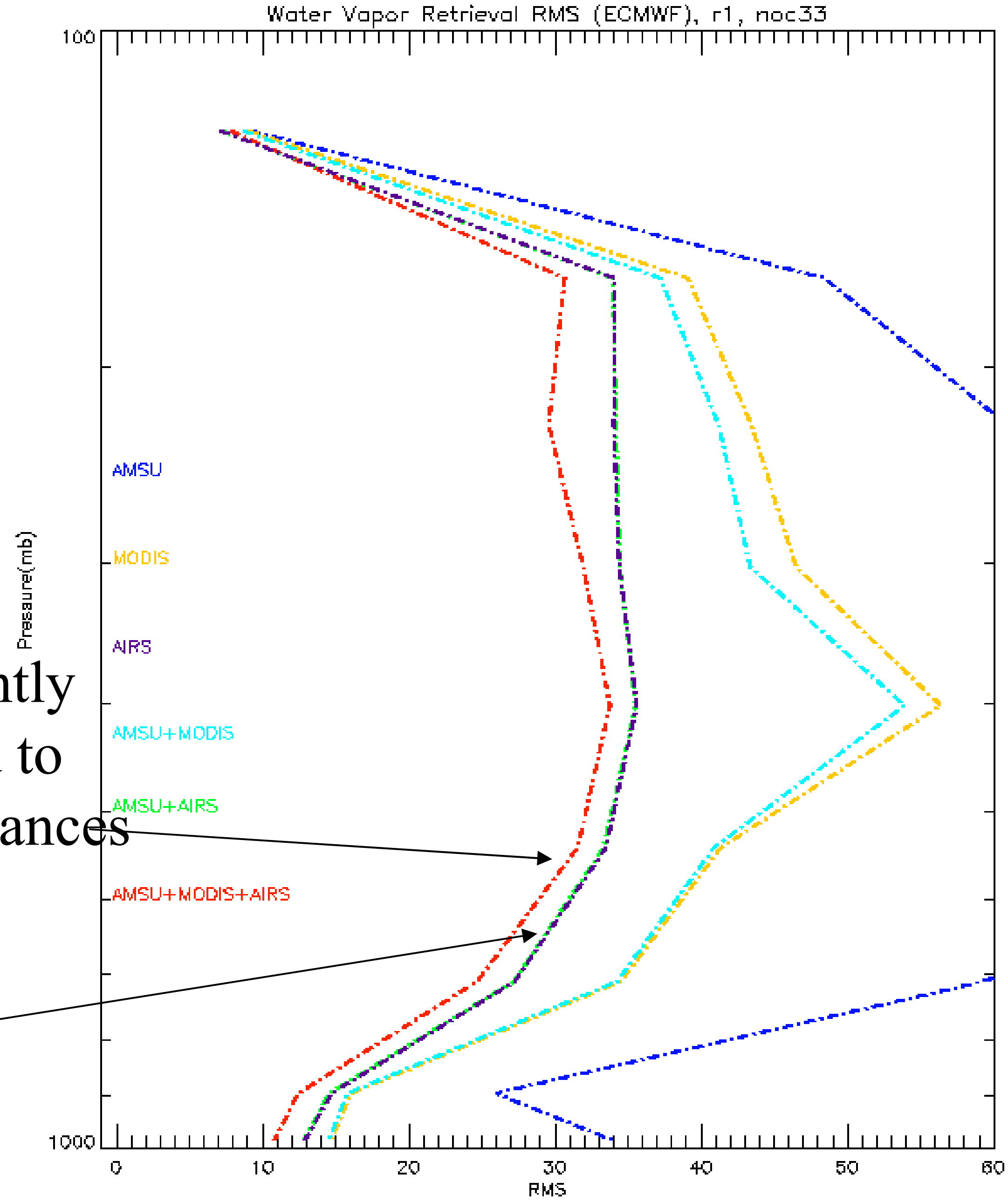
All-sky minus clear simulated (ECMWF)





Retrieval errors are significantly reduced after MODIS is used to QC AIRS cloud-cleared radiances

W/O QC



Retrieval errors are significantly reduced after MODIS is used to QC AIRS cloud-cleared radiances

W/O QC

Validation and Monitoring of Core Products

JOURNAL OF GEOPHYSICAL RESEARCH, VOL. 111, D09S15, doi:10.1029/2005JD006116, 2006

Validation of Atmospheric Infrared Sounder temperature and water vapor retrievals with matched radiosonde measurements and forecasts

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Eric Maddy,[3] Walter Wolf,[3] Lihang Zhou,[3] and Xingpin Liu[3]

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[1] An evaluation of the temperature and moisture profile retrievals from the Atmospheric Infrared Sounder (AIRS) data is performed using more than 2 years of collocated data sets. The Aqua-AIRS retrievals, global radiosonde (RAOB) measurements, forecast data from the National Center for Environmental Prediction Global Forecasting System

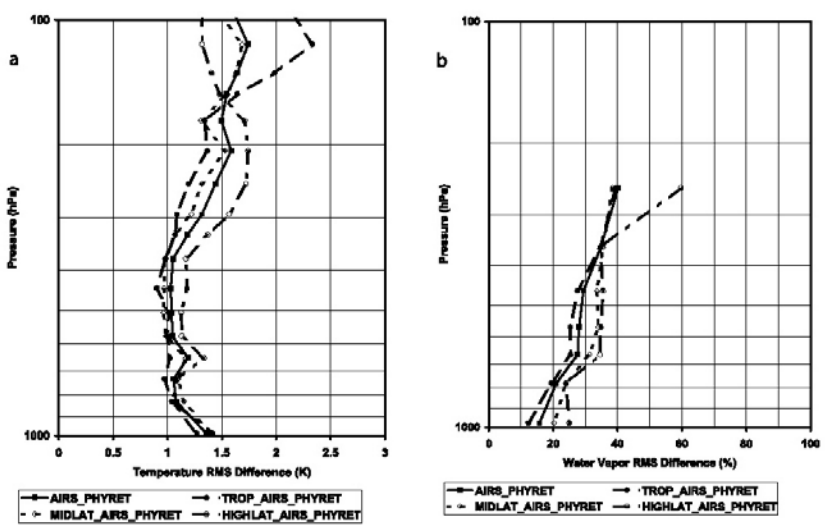
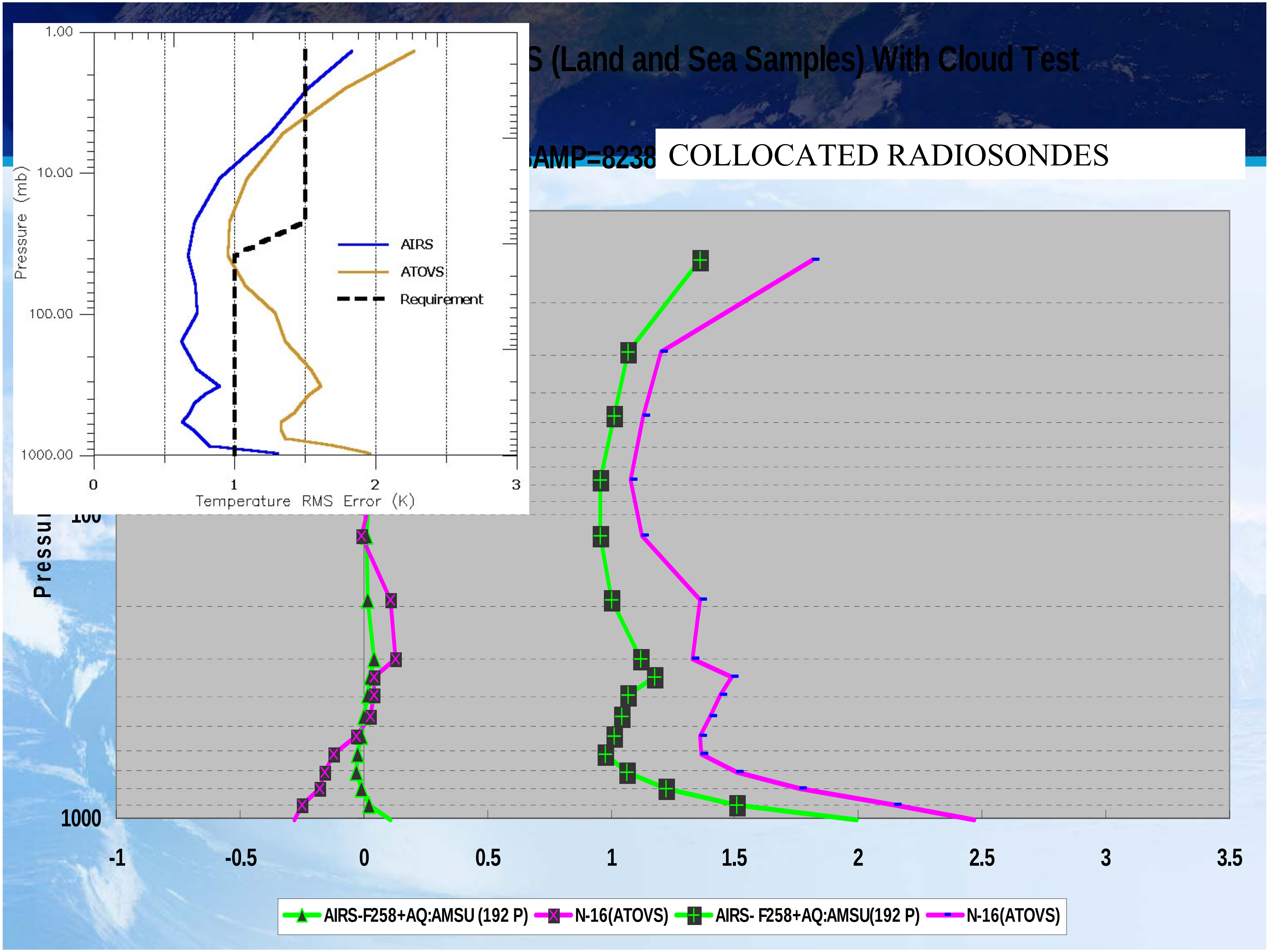
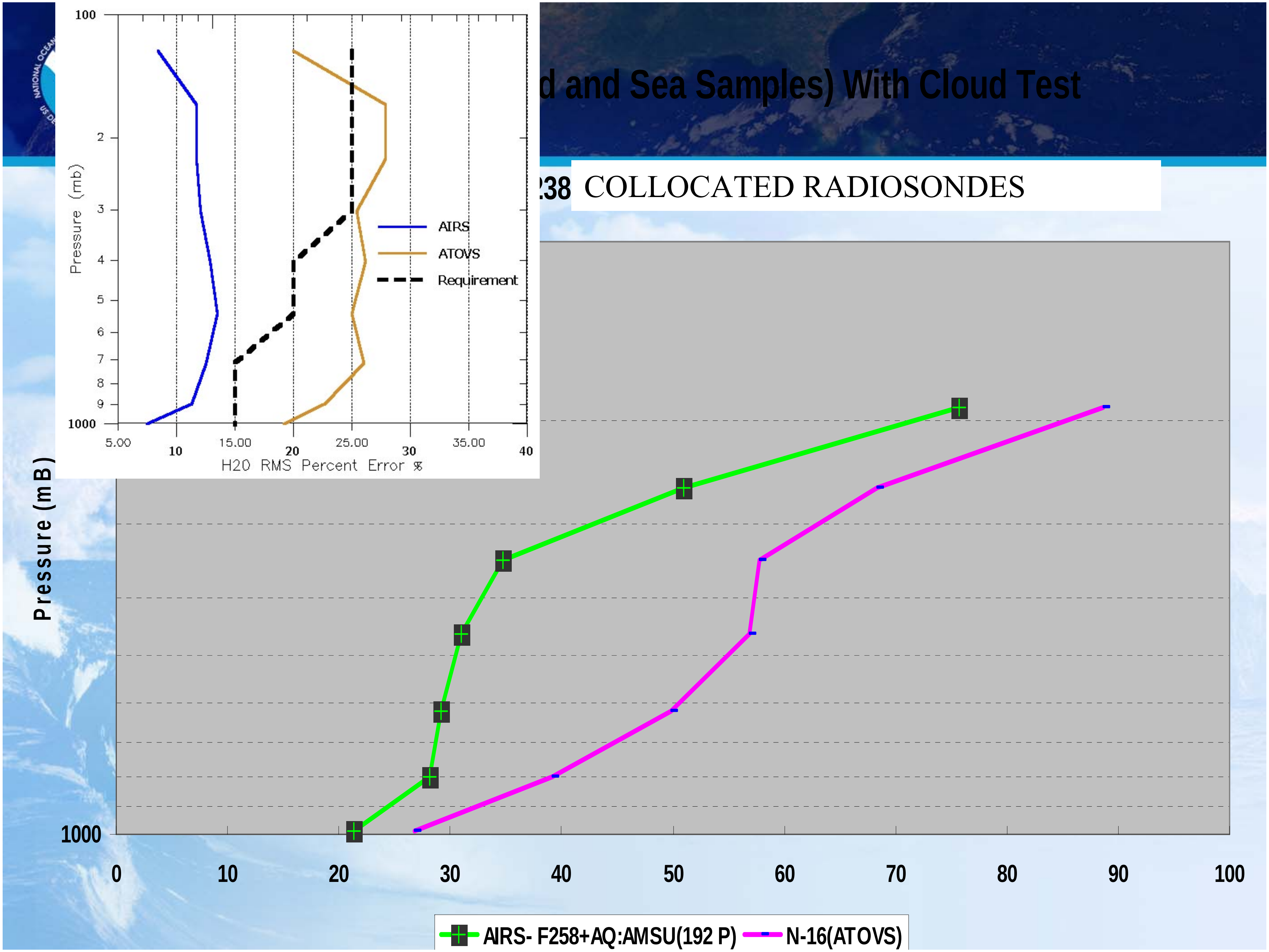


Figure 10. (a) Same as in Figure 9a but for the "sea" category. (b) Same as in Figure 9b but for the "sea" category.

- Validation of products versus operational sonde networks
  - Temperature
  - Humidity
  - Ozone
- Monitoring of radiance products.
- Validation and Evaluation core product effects on Trace Gas Products



S (Land and Sea Samples) With Cloud Test
AMP=8238
COLLOCATED RADIOSONDES
Pressure (mb)
1.00
10.00
100.00
1000.00
0
1
2
3
Temperature RMS Error (K)
AIRS
ATOVS
Requirement
100
1000
-1
-0.5
0
0.5
1
1.5
2
2.5
3
3.5
AIRS-F258+AQ:AMSU (192 P)
N-16(ATOVS)
AIRS- F258+AQ:AMSU(192 P)
N-16(ATOVS)



d and Sea Samples) With Cloud Test
238 COLLOCATED RADIOSONDES
Pressure (mb)
H20 RMS Percent Error %
AIRS
ATOVS
Requirement
Pressure (mB)
1000
0 10 20 30 40 50 60 70 80 90 100
AIRS- F258+AQ:AMSU(192 P)
N-16(ATOVS)

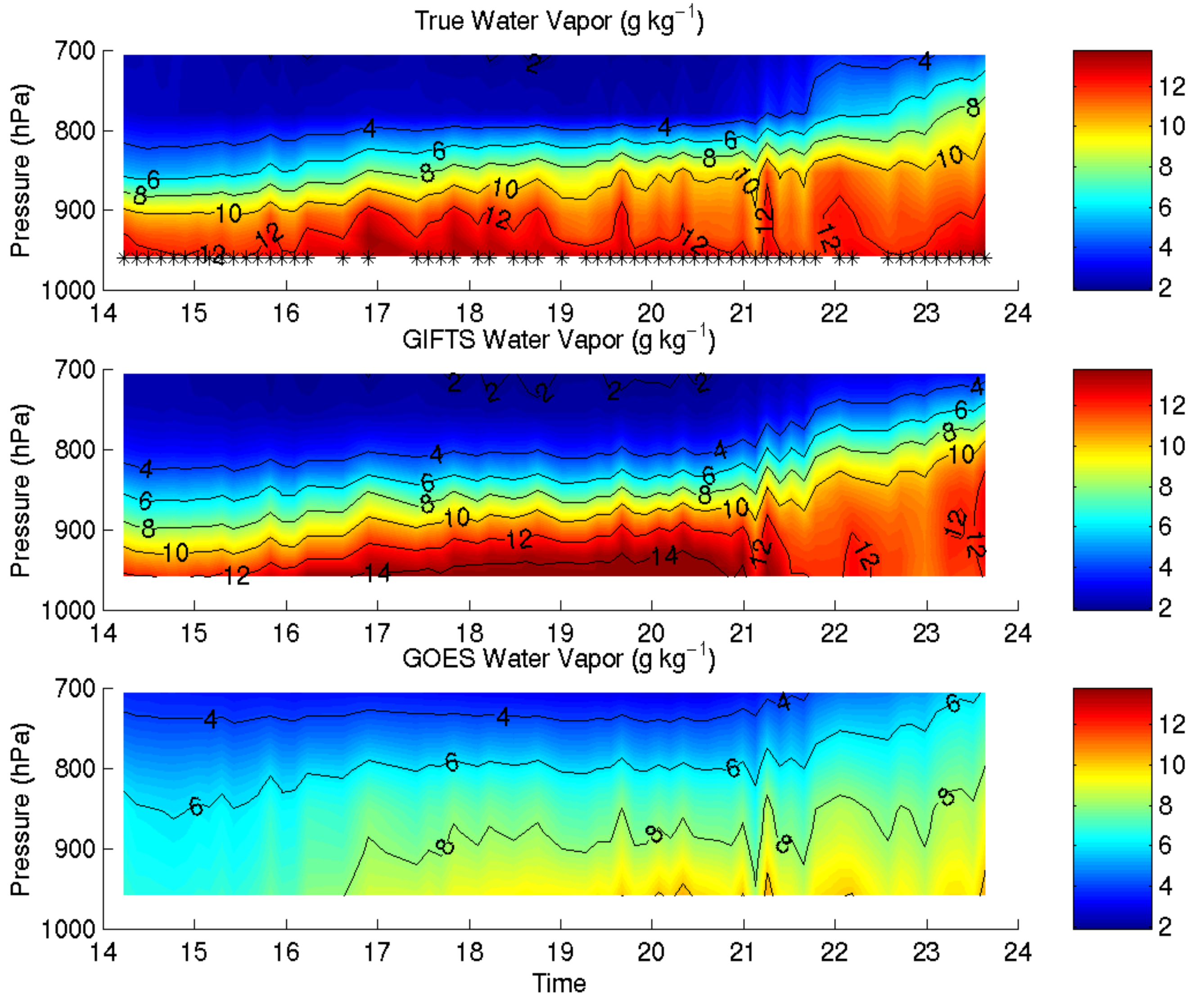
Time series of low-level vertical moisture structure during 9 hours prior to Oklahoma/Kansas tornadoes on 3 May 1999

Truth>

Geo-I>

Note Geo-I retains strong vertical gradients for monitoring convective instability

Current GOES>



Geo-I traces moisture peaks and gradients with greatly reduced errors

3 May 1999 – Oklahoma/Kansas tornado outbreak
GIFTS/GOES Retrieved-Moisture (g/kg) Errors

Truth>

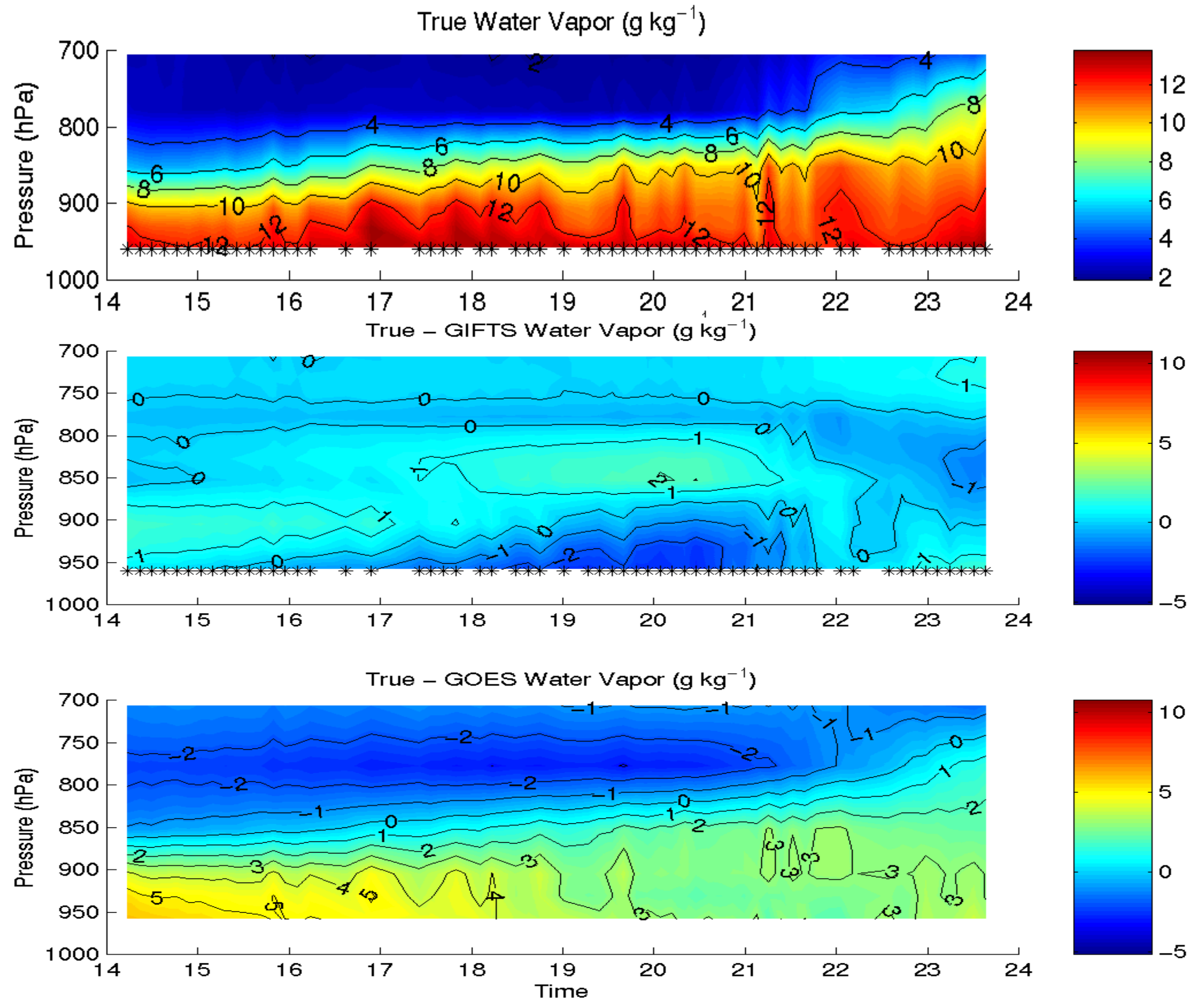
Geo-I Errors>

Standard Dev. = 0.9 g/kg

Note Geo-I reduces errors and captures low-level moisture peaks and vertical gradients

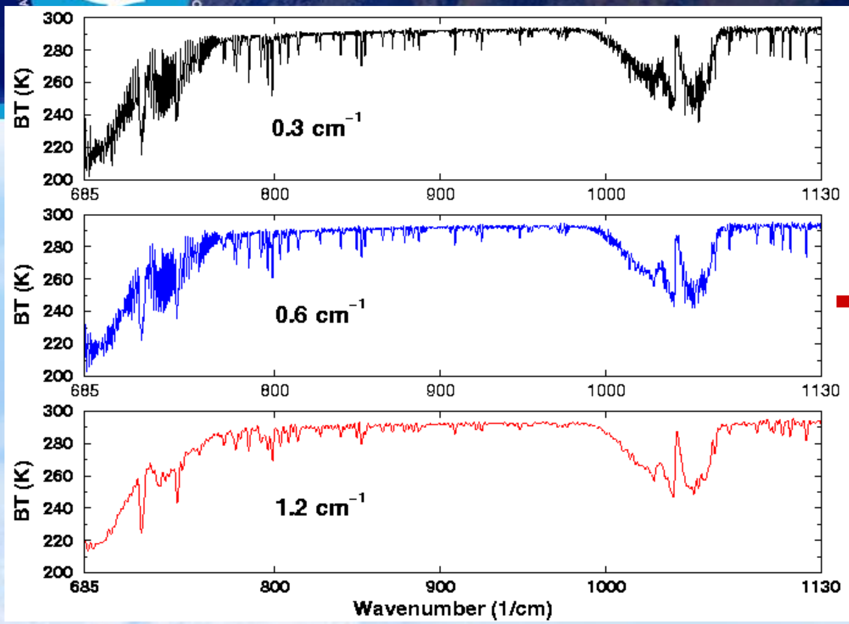
GOES Errors>

Standard Dev. = 2.4 g/kg

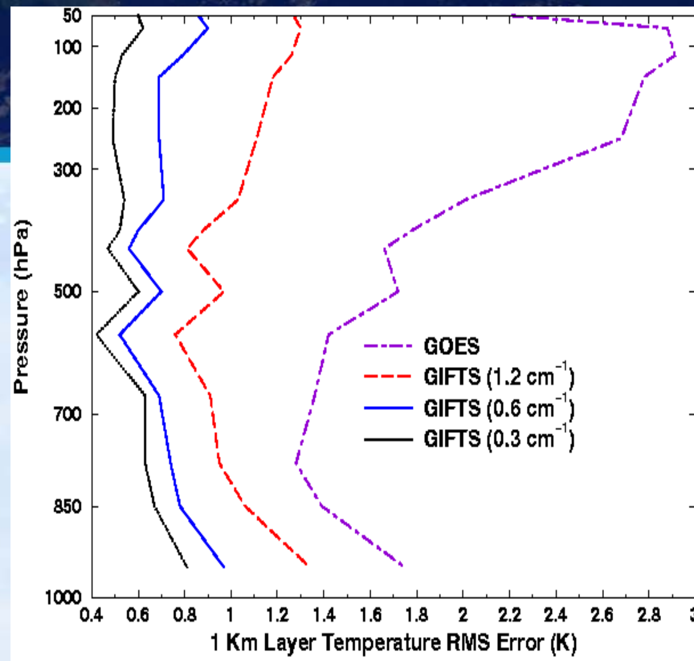


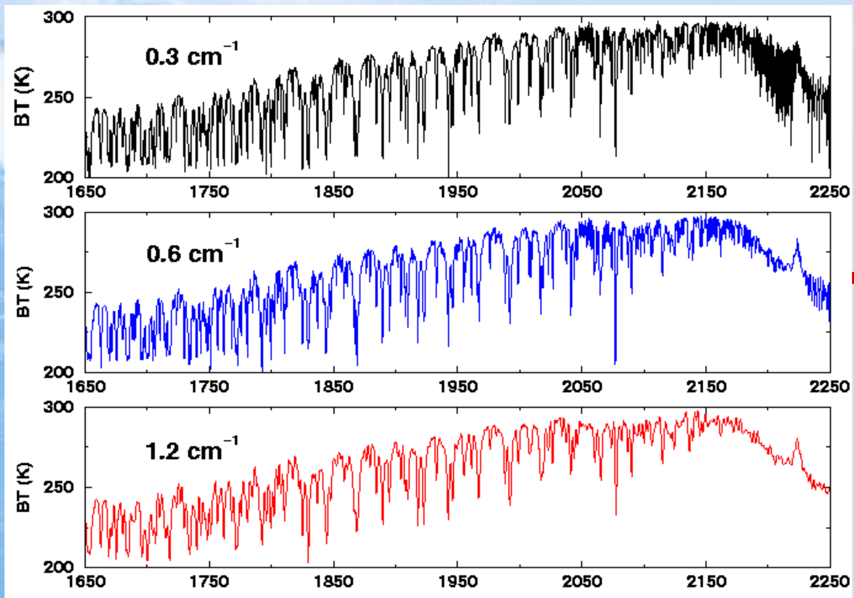
Geo-I correctly captures important vertical moisture variations

Spectral resolution (0.3, 0.6, 1.2 cm**-1) impact on T/q retrieval

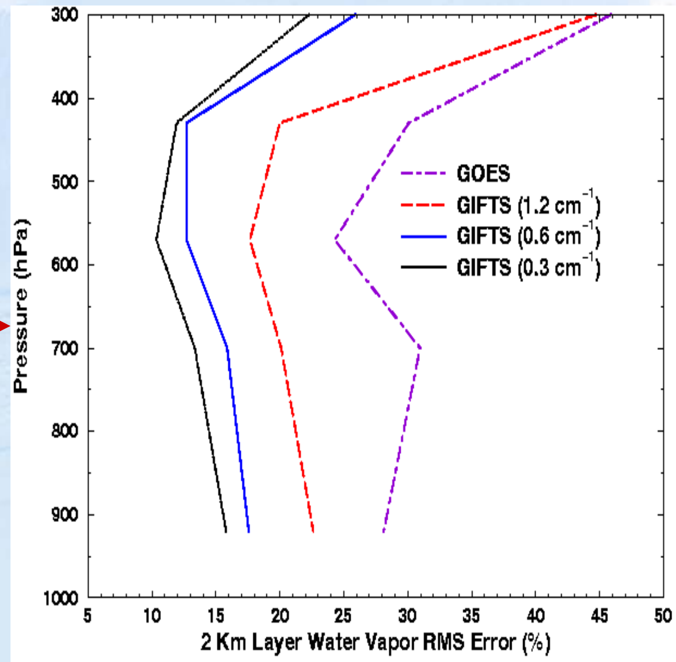


LW

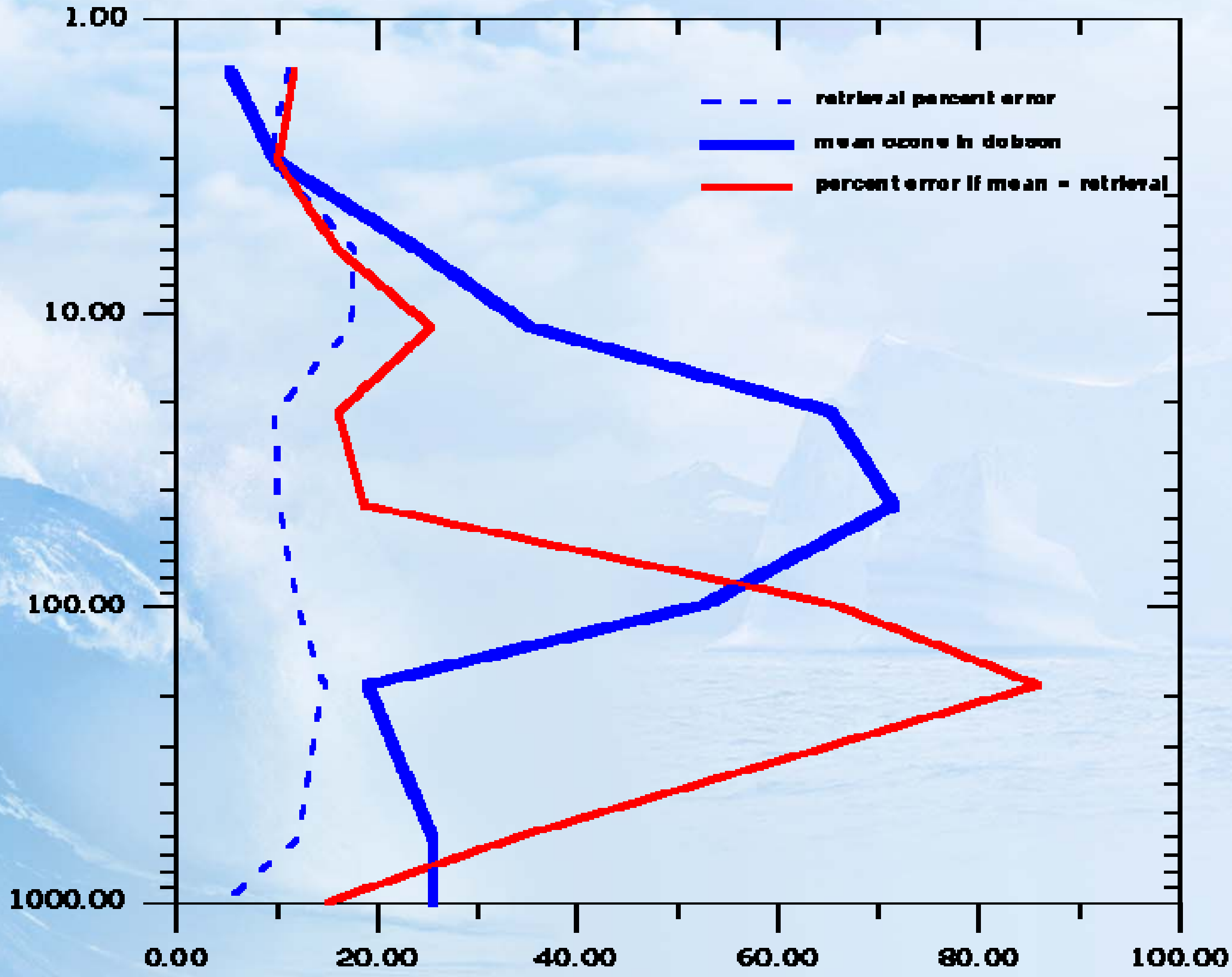




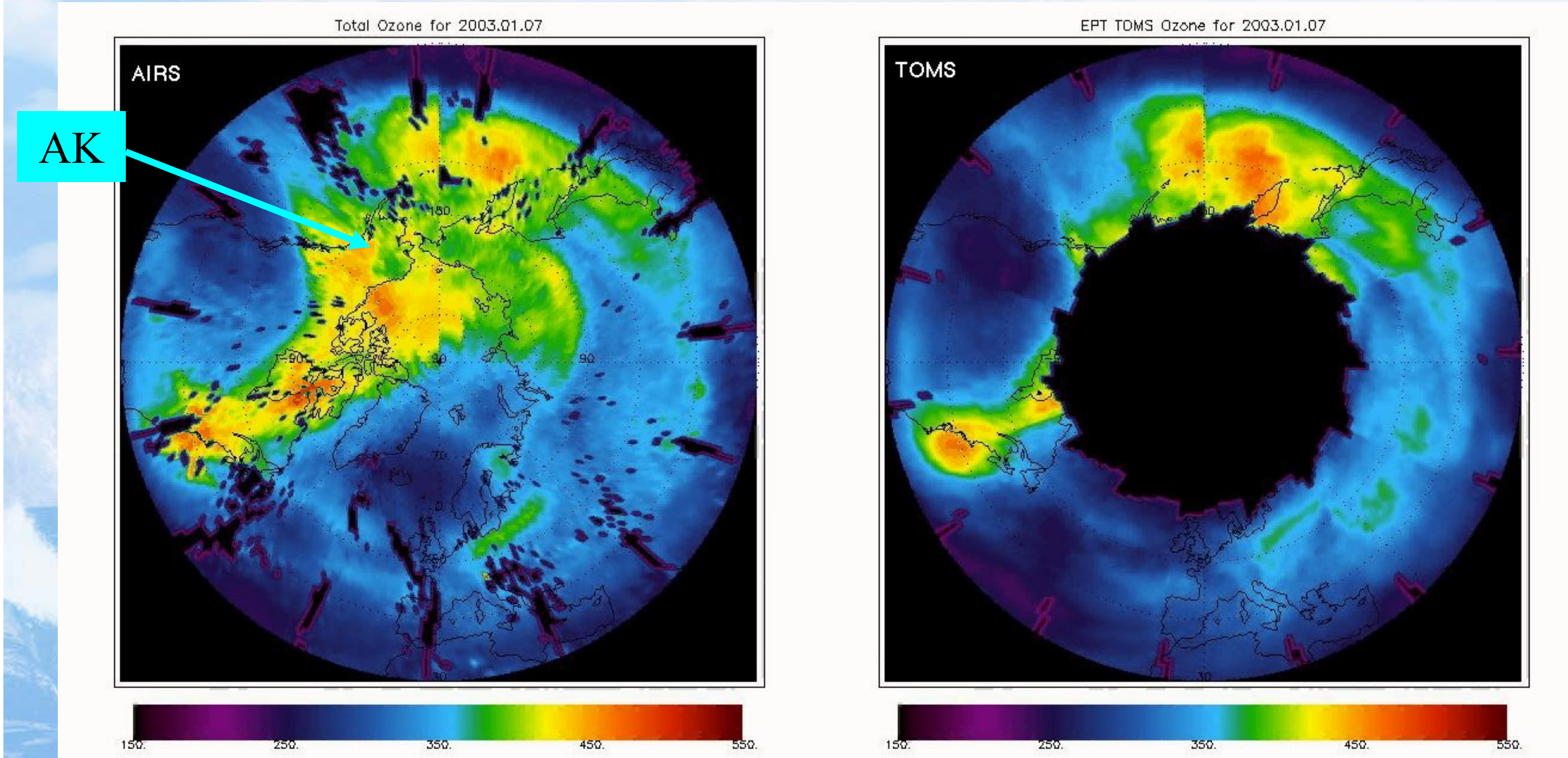
SMW



Assessment of Ozone Retrieval Capability



AIRS and TOMS Northern Polar Night
Mike Newchurch (UAH), Bill Irion (JPL)



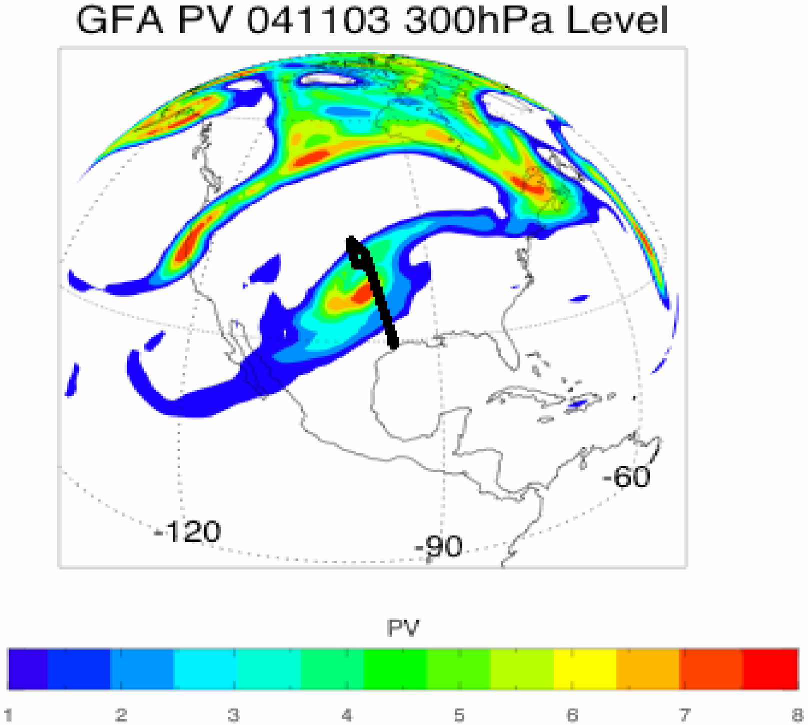
Note: TOMS Ozone derived only when Sun is above horizon

Stratospheric-Tropospheric Analysis of Regional Transport (START) Experiment

- Laura Pan is PI of START Ozone team
- Nov. 21 to Dec. 23, 2005, 48 flight hours using NCAR's new Gulfstream V "HAIPER" aircraft.
- Ozone measured with NCAR's UV-abs spectrometer

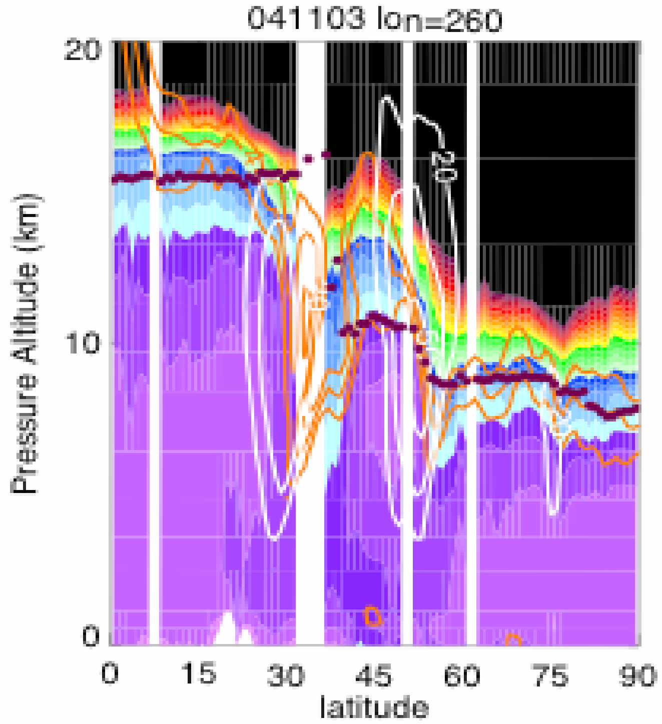
- NOAA NESDIS supported this experiment with real time AIRS L1b & L2 products, including ozone and carbon monoxide.
- Jennifer Wei is the NOAA/NESDIS liason to START team.
  - 3 stratospheric fold events were measured during this campaign
  - analysis is in process.

This is the day the Aura Validation Experiment (AVE) mission sampled a tropopause fold near Houston



Black Line is Flight Track

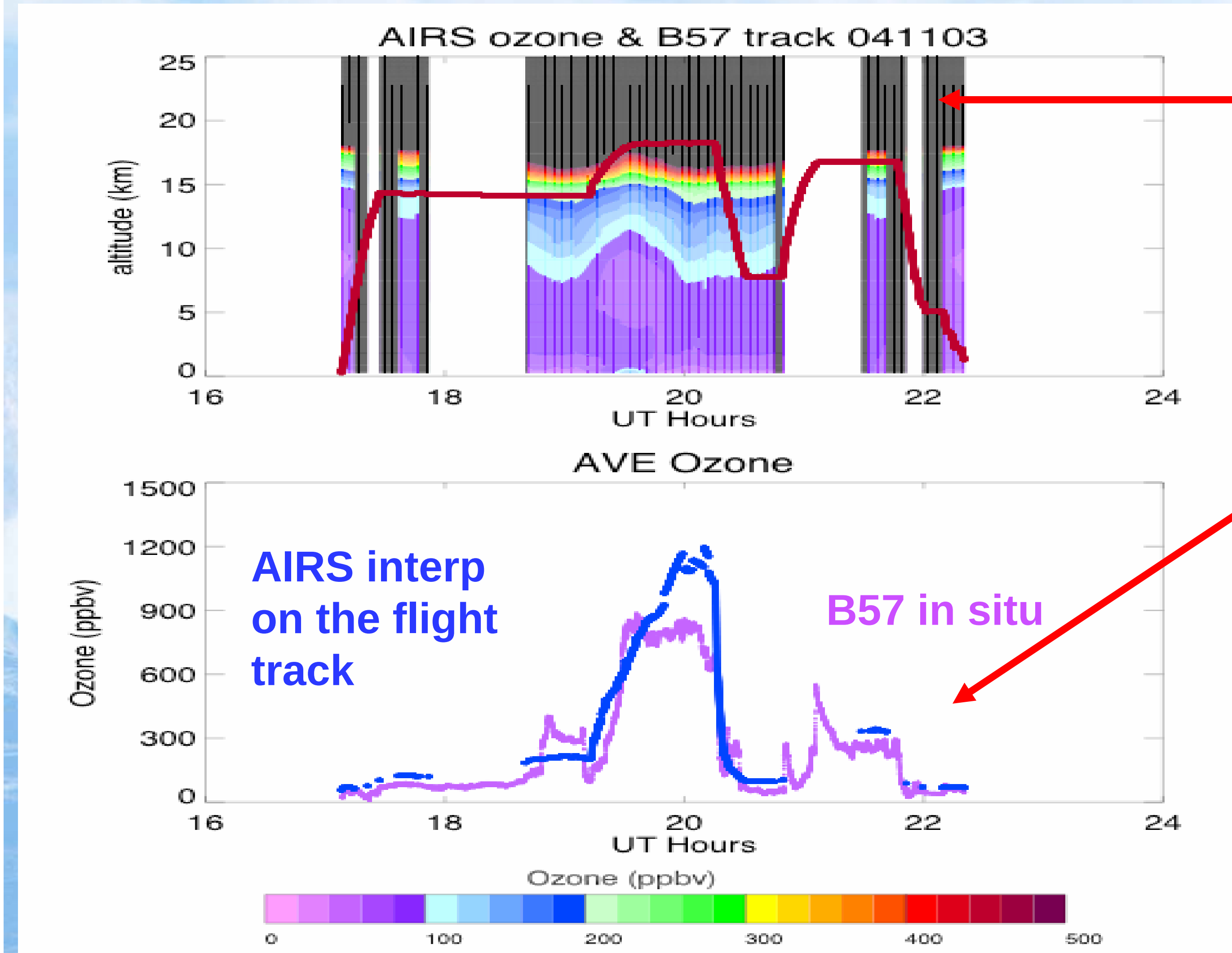
AIRS Cross-section



Potential Vorticity (PV) is an important quantity for O3 dynamics

Laura Pan, NCAR/ACD

Example of Laura Pan's in-situ comparisons in dynamic regions (AVE campaign)

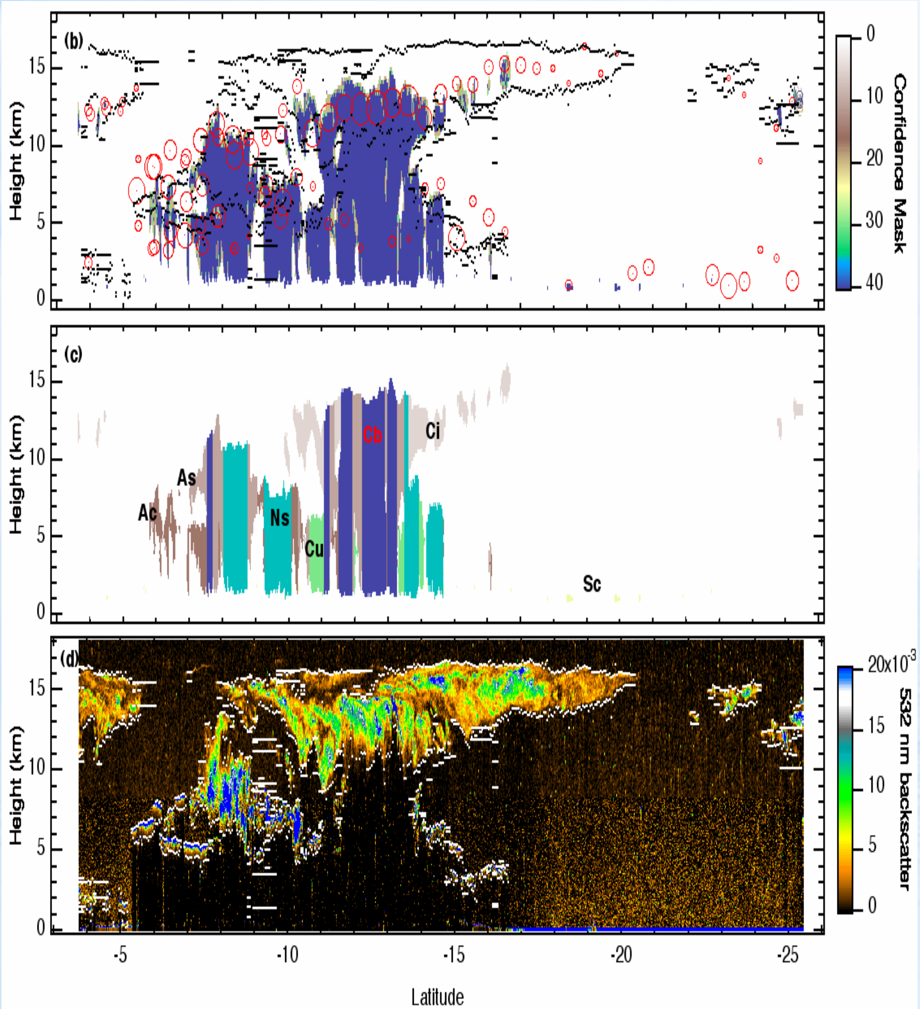


ignore the black columns - missing data

"Good agreement between AIRS and in situ between 50-500 ppb"

Calipso/AIRS Intercomparisons

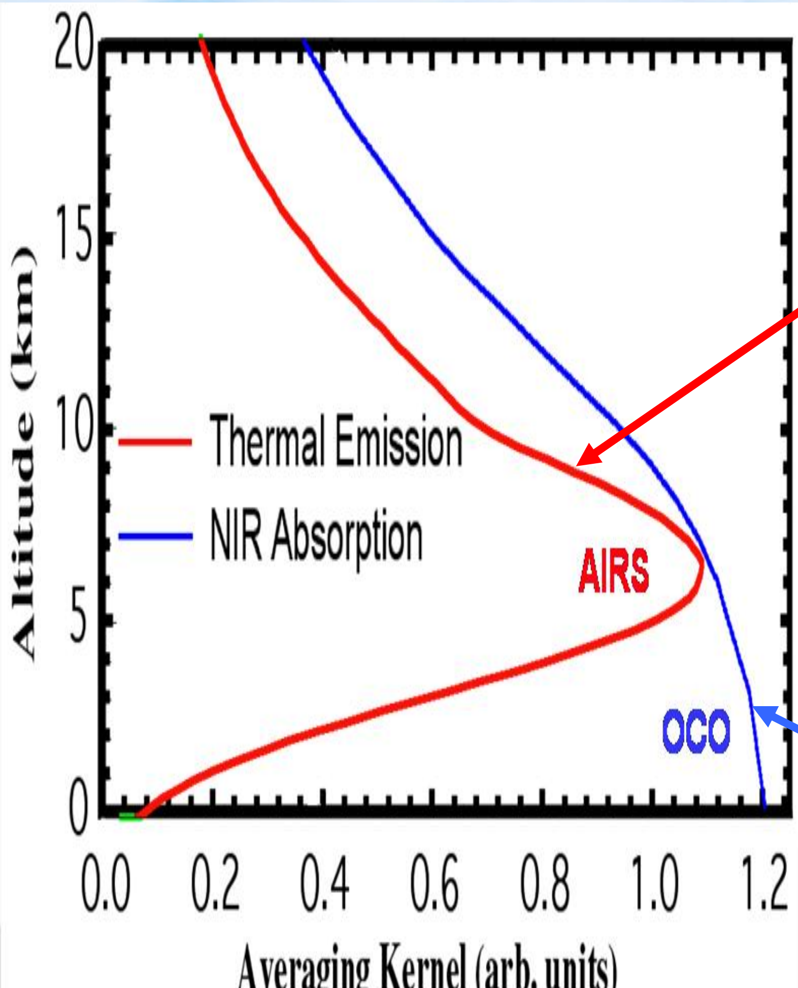
- Kahn et al. 2007 are comparing AIRS products (red circles) with cloud products derived from the recently launched Calipso & CloudSat
- Calipso/CALIOP is a 1064 nm & 532 nm LIDAR (0.3 km footprint, 30 m vertical resoluton).
- CloudSat is a microwave RADAR. 94 GHz (1.4 x 2.5 km product with 0.48 km vertical resolution).



Retrieval of Atmospheric Trace Gases Requires Unprecedented Instrument Specifications

- **Need Large Spectral Coverage (multiple bands) & High Sampling**
  - Increases the number of unique pieces of information
    - Ability to remove cloud and aerosol effects.
    - Allow simultaneous retrievals of T(p), q(p), O_3(p).
- **Need High Spectral Resolution & Spectral Purity**
  - Ability to isolate spectral features → vertical resolution
  - Ability to minimize sensitivity to interference signals..
- **Need Excellent Instrument Noise & Instrument Stability**
  - Low NEΔT is required.
  - Minimal systematic effects (scan angle polarization, day/night orbital effects, etc.)

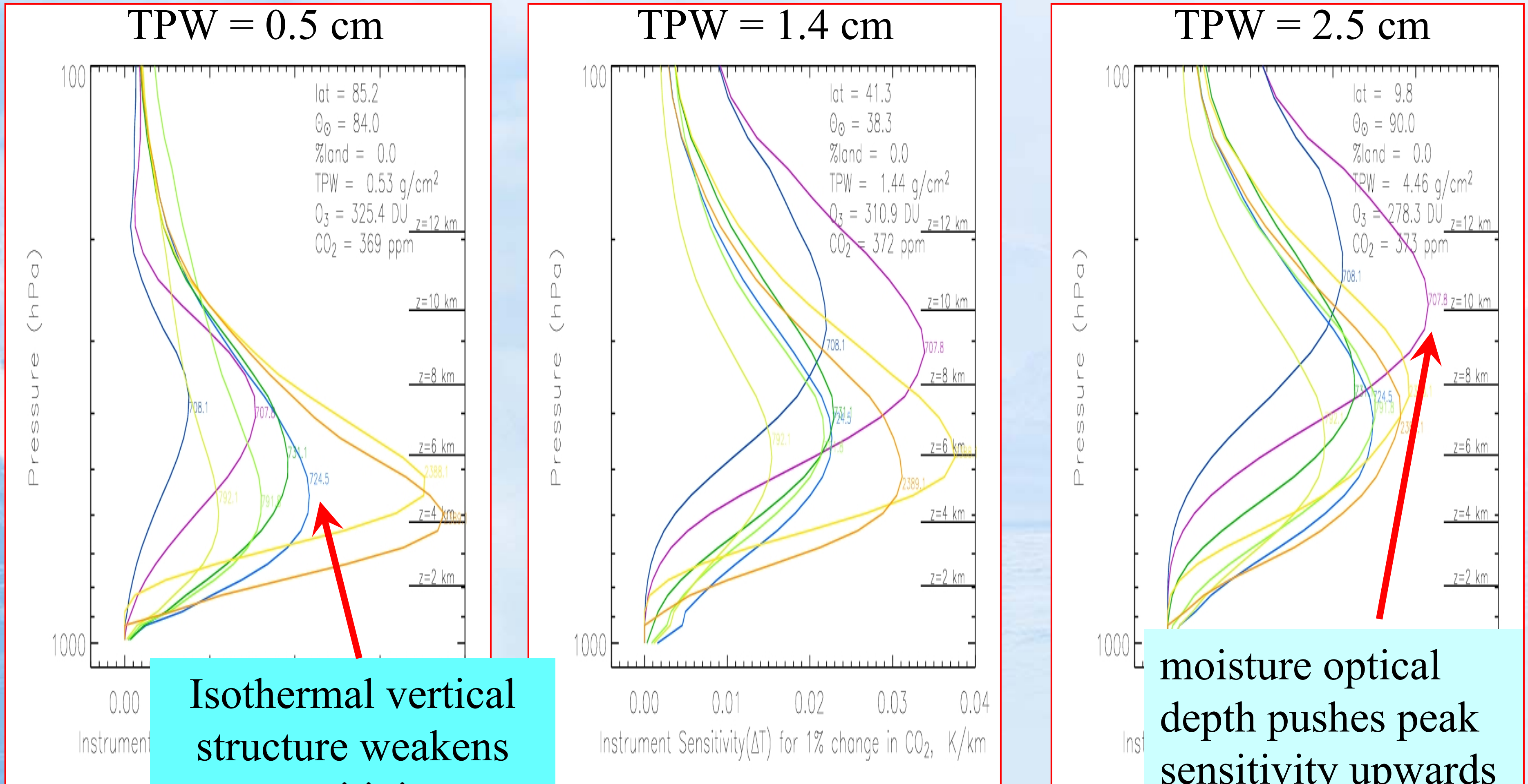
Deriving sources and sinks require knowledge of vertical averaging



- Thermal instruments measure mid-tropospheric column
  - Peak of vertical weighting is a function of T profile and water profile
  - Age of air is on the order of weeks or months.
  - Significant horizontal and vertical displacements of CO_2 from the sources.
- Passive solar instruments (like OCO) & laser approaches measure a total column average.
  - Mixture of surface and near-surface atmospheric contribution
  - Age of air varies vertically.

LW Thermal CO_2 Kernel Functions are also Sensitive to H_2O, T(p), & O_3(p).

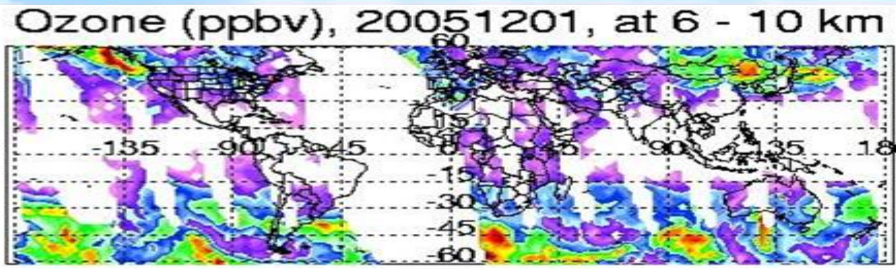
Polar | Mid-Latitude | Tropical

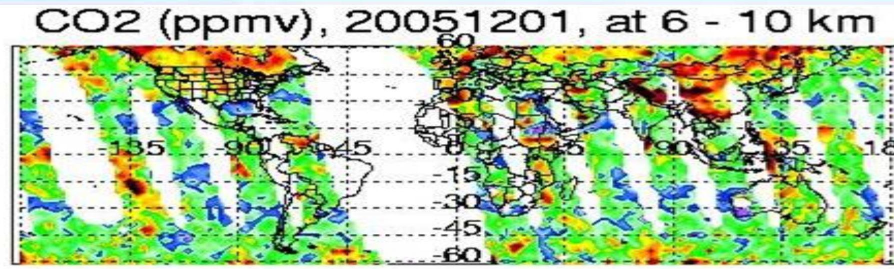


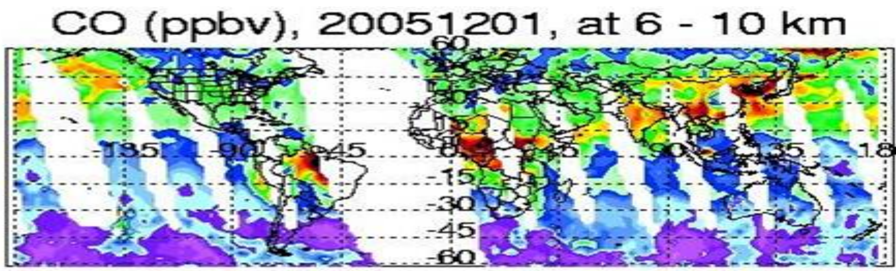
Isothermal vertical structure weakens sensitivity

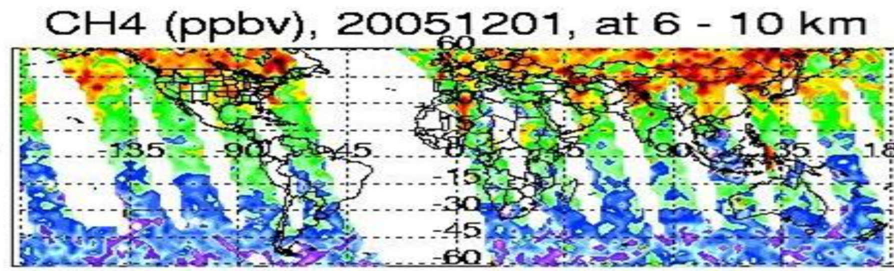
moisture optical depth pushes peak sensitivity upwards

Example of Trace Gas Product Suite (Ascending Orbit, 1:30pm, Single Day)

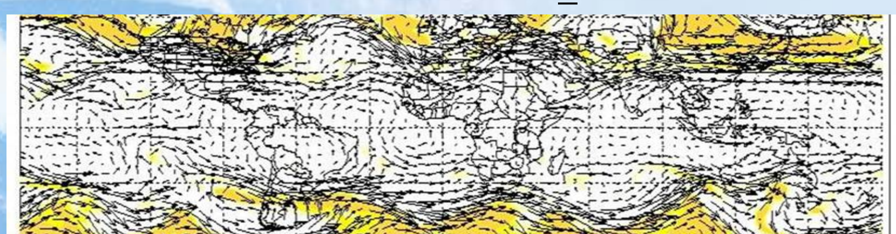


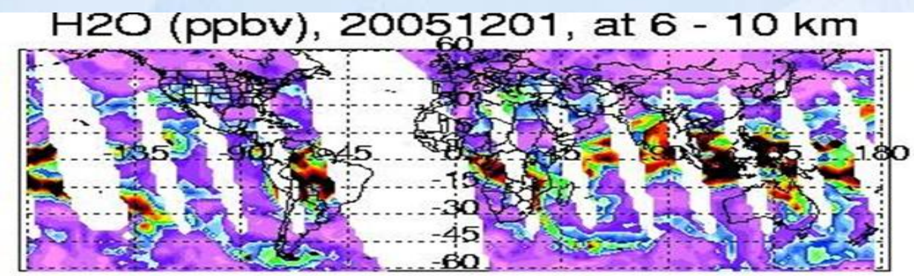


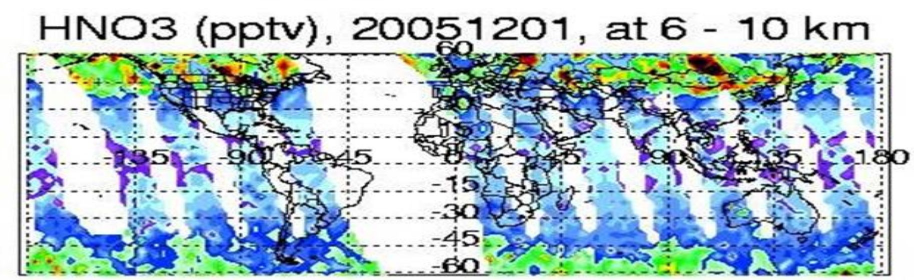




NCEP PV/Wind 20051201_18 at 300 hPa

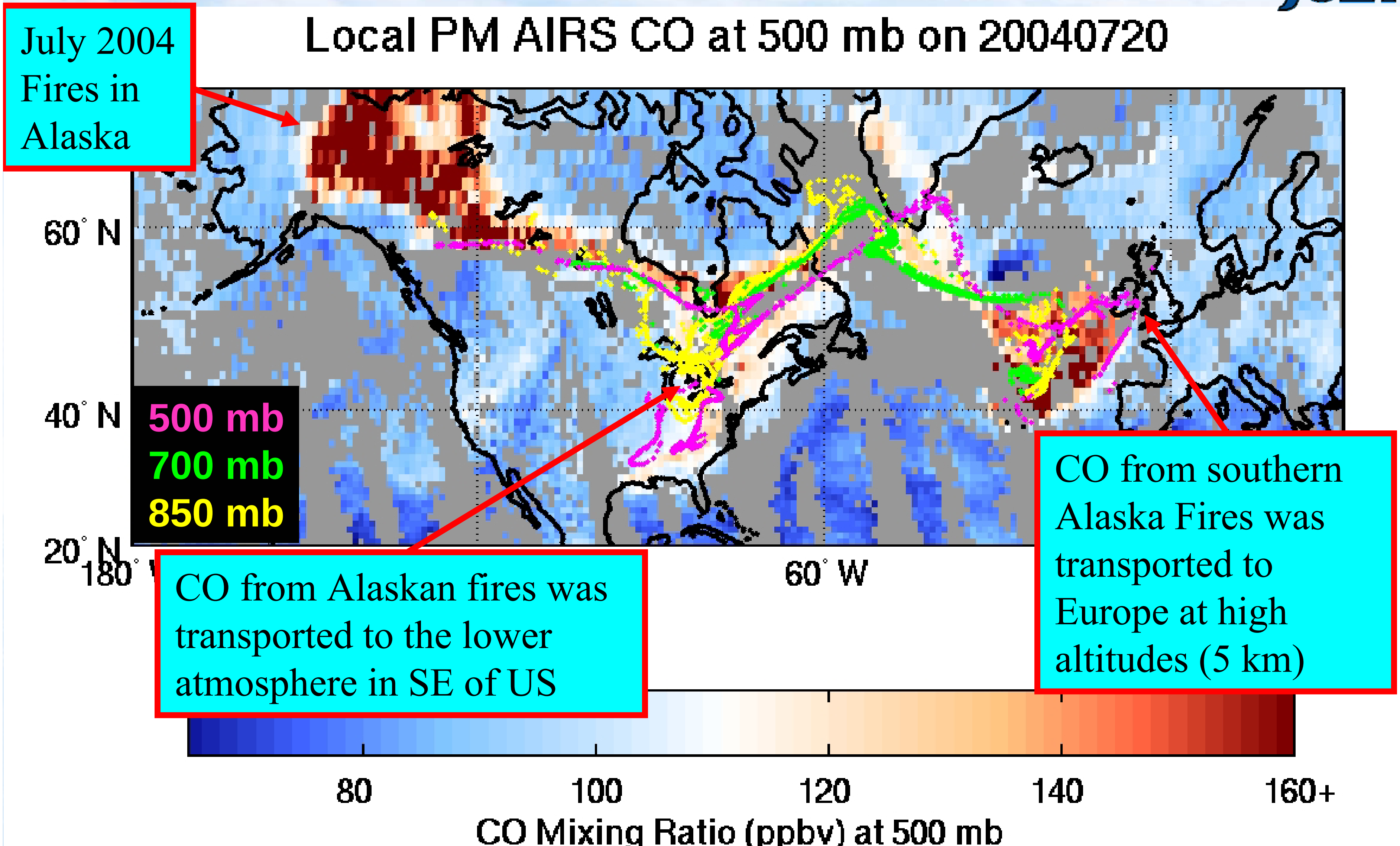




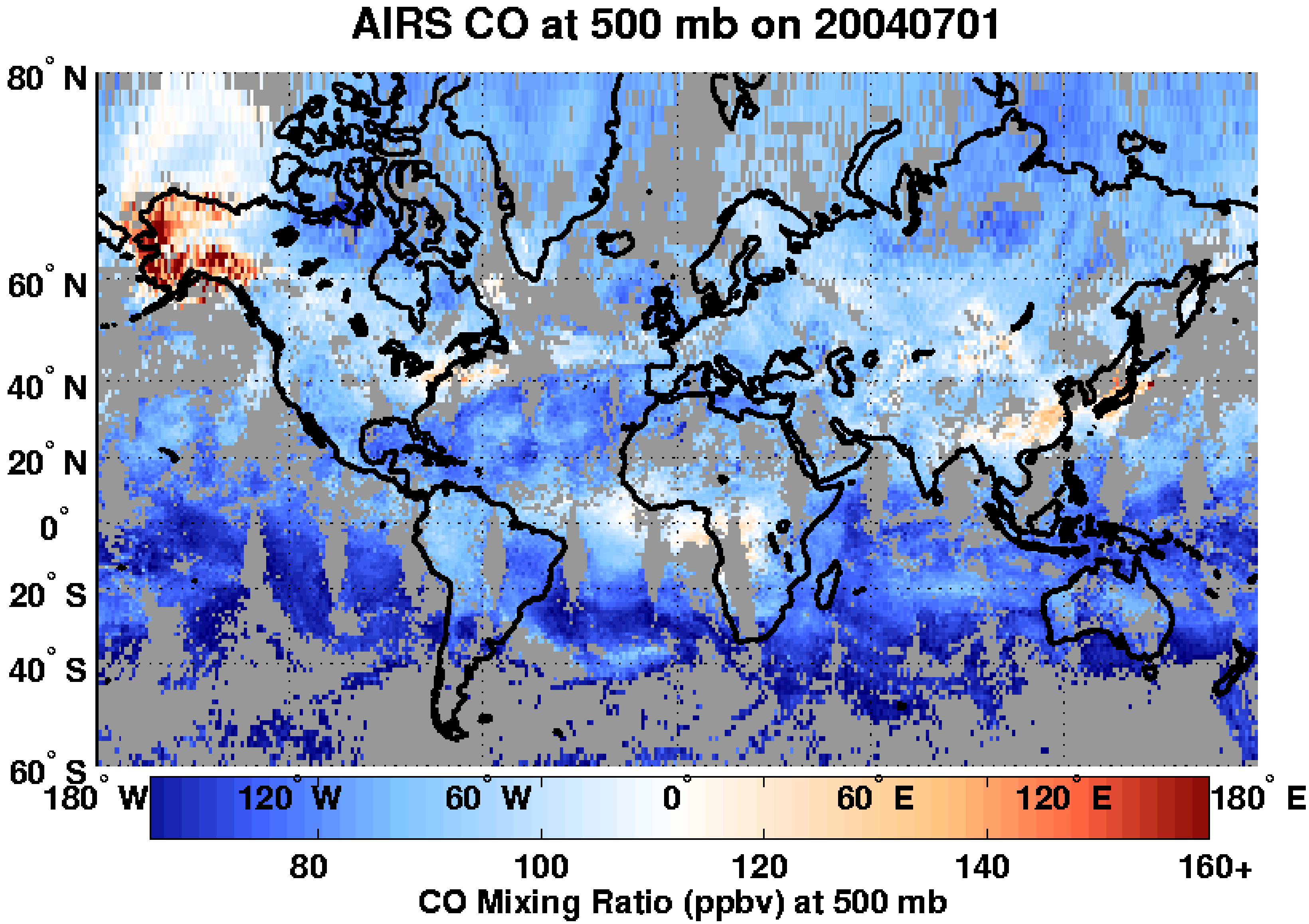


Stratospheric air masses (colored yellow in NCEP PV figure, where PVU ≥ 2) can be seen in AIRS upper tropospheric O_3, CO, and HNO_3 in the figures above. The H_2O figure is scaled to show tropical convective features.

Example of AIRS CO Product and Use of Trajectory Models



July 2004 AIRS Daily Global CO

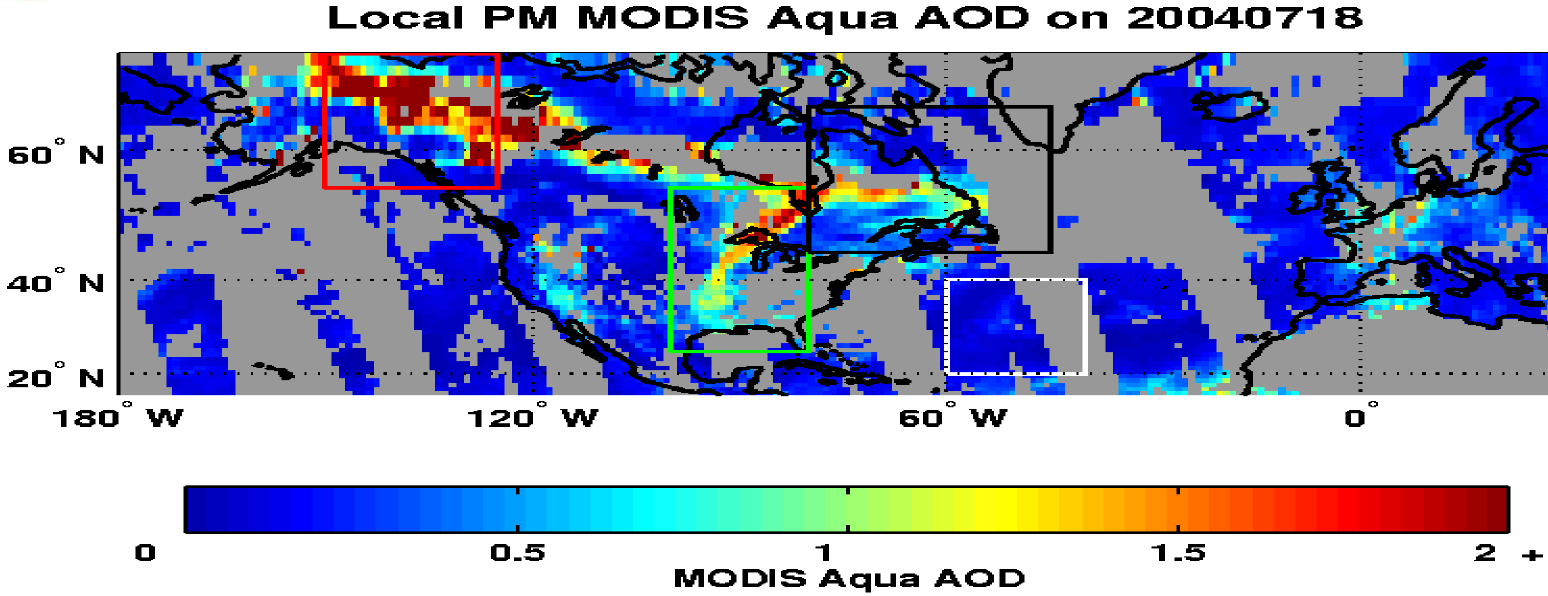


UMBC

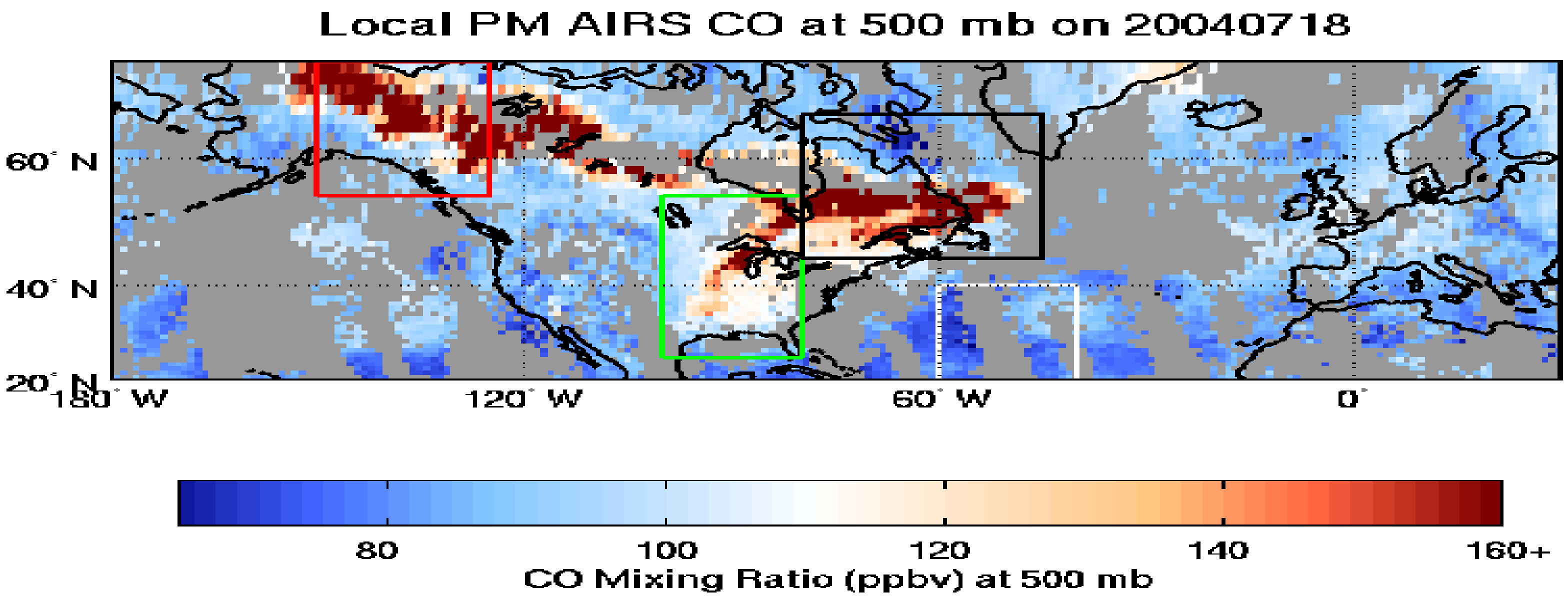
JCET

UMBC

JCET

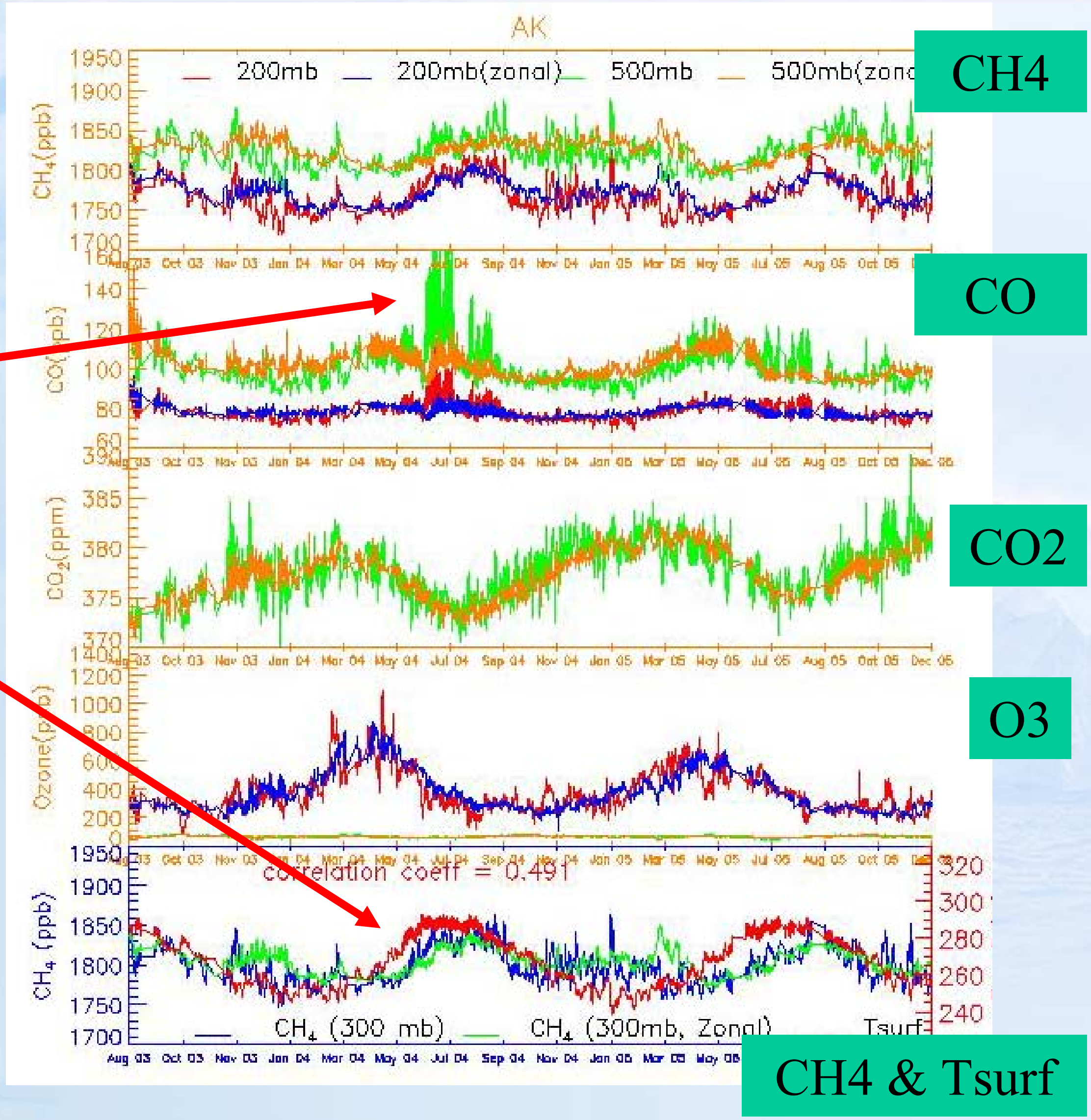


From Wallace McMillan, UMBC

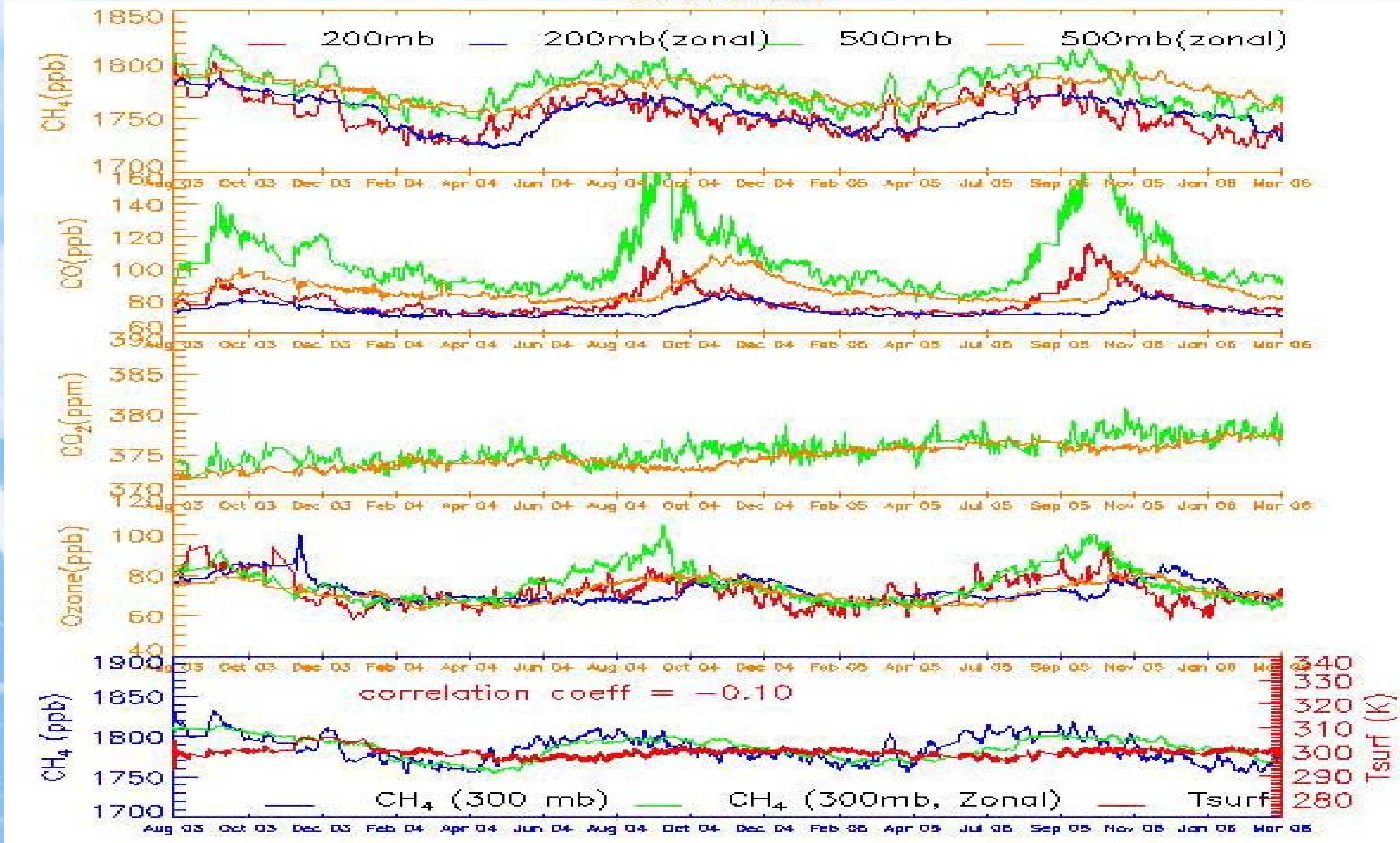


AIRS measures multiple gases (and temperature, moisture and cloud products) simultaneously

- 29 month time-series of AIRS trace gas products: Alaska & Canada Zone (60 ≤ lat ≤ 70 & -165 ≤ lon ≤ -90)
- July 2004 Alaskan fires are evident in CO signal (panel 2)
- Seasonal methane may be correlated to surface temperature (wetlands emission?)
- We have begun to investigate correlations that should exist between species (e.g., O_3, CO, CH_4 interaction)

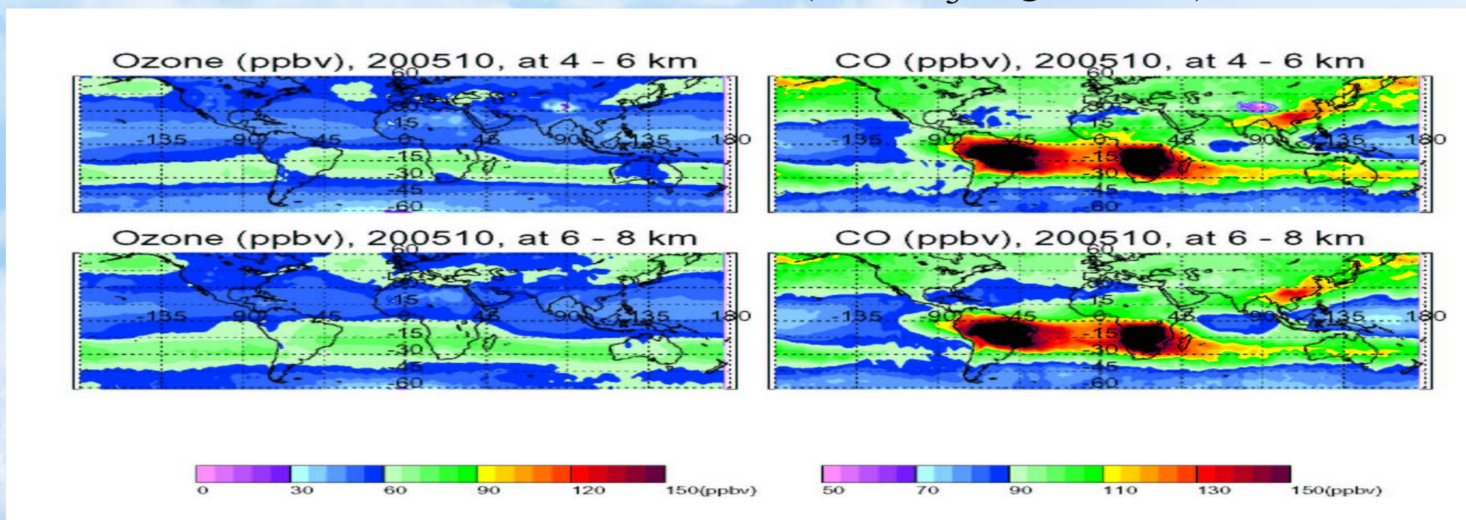


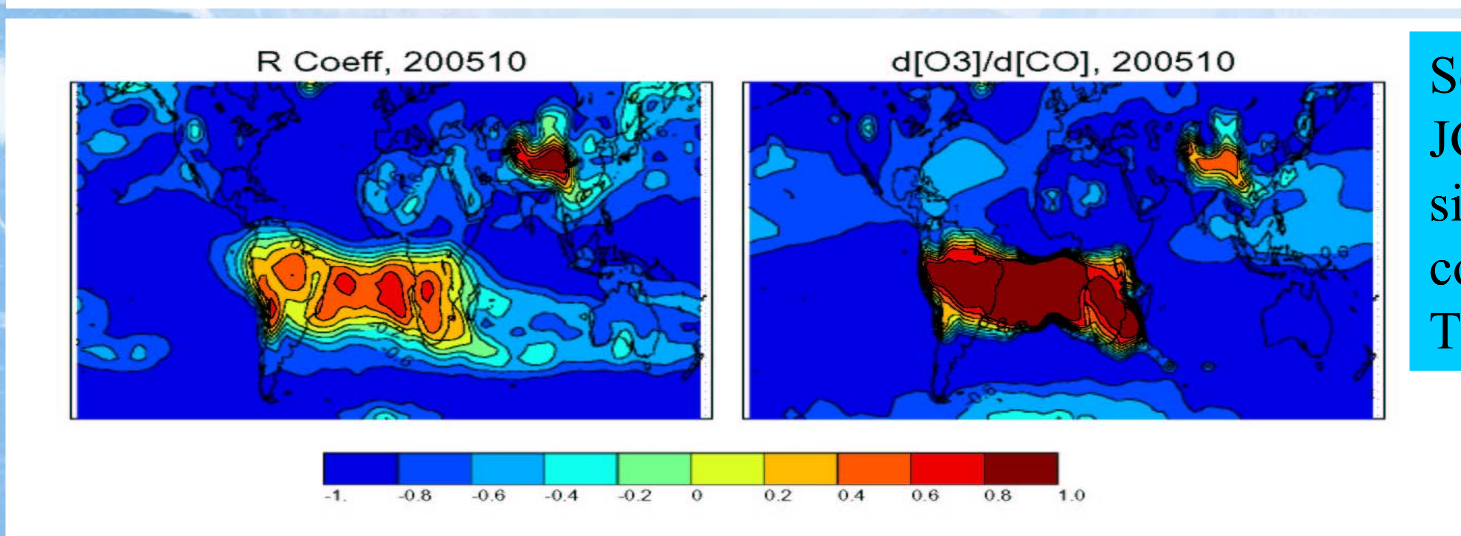
29 month time-series of AIRS products
South America Zone (-25 ≤ lat ≤ EQ , -70 ≤ lon ≤ -40)



AIRS operational products confirm tropospheric ozone production from biomass burning as seen by TES

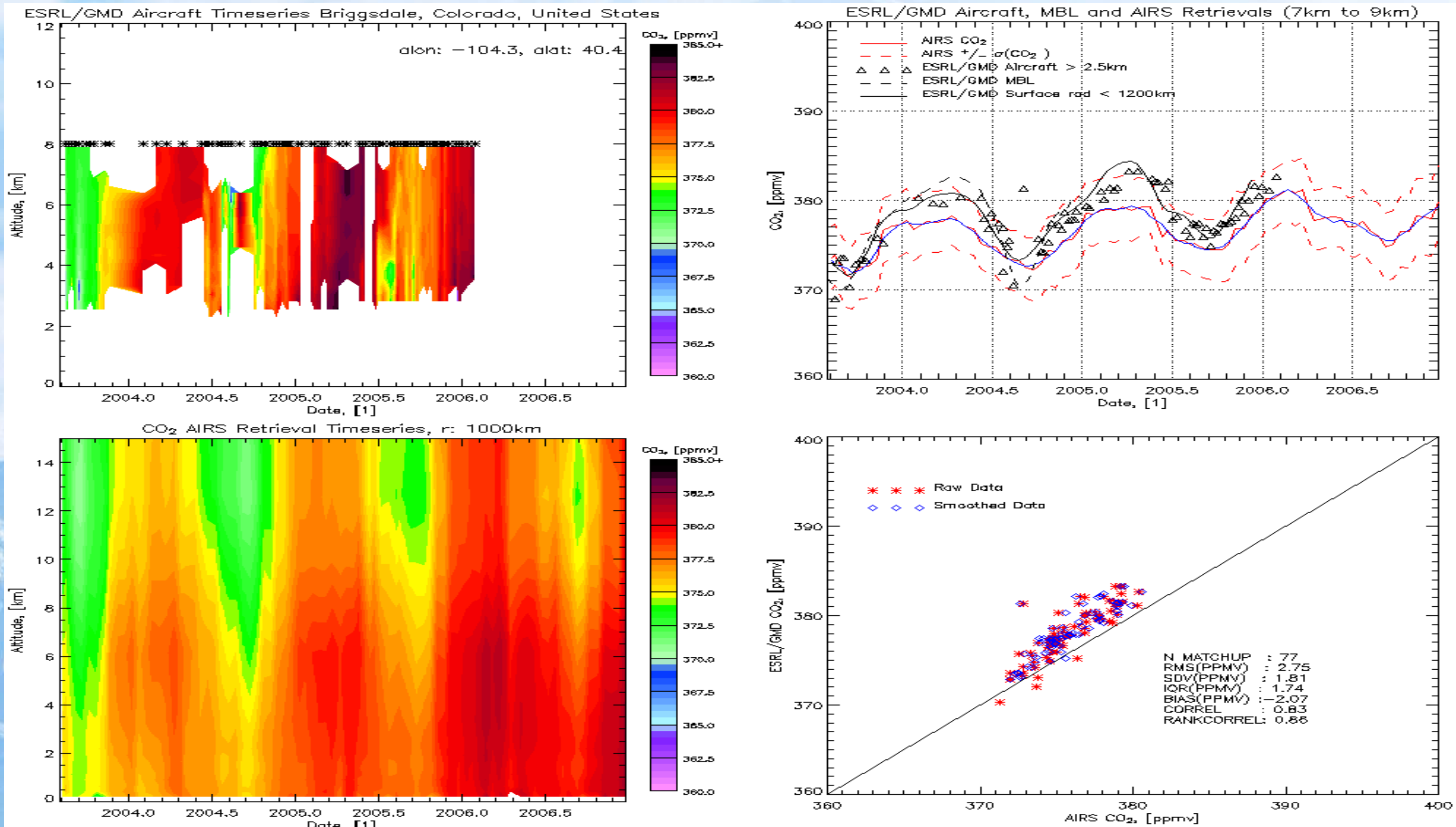
Version 5.0 (w/o O_3 regression)





See Zhang et .al JGR 2007 for similar comparison using TES

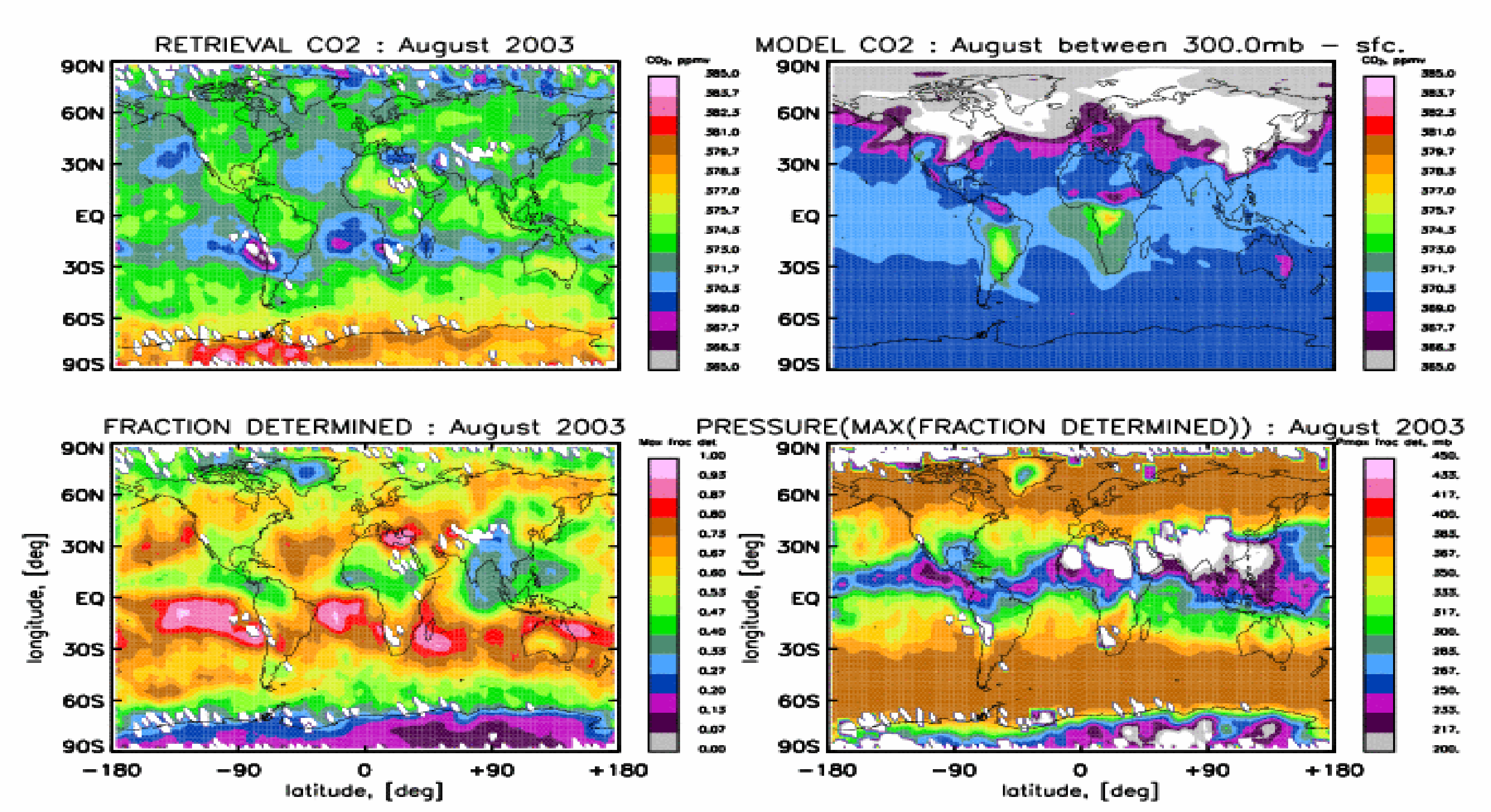
Comparison of NOAA CO_2 product with *in-situ* aircraft at Carr, CO



29 Months of AIRS CO_2 Product

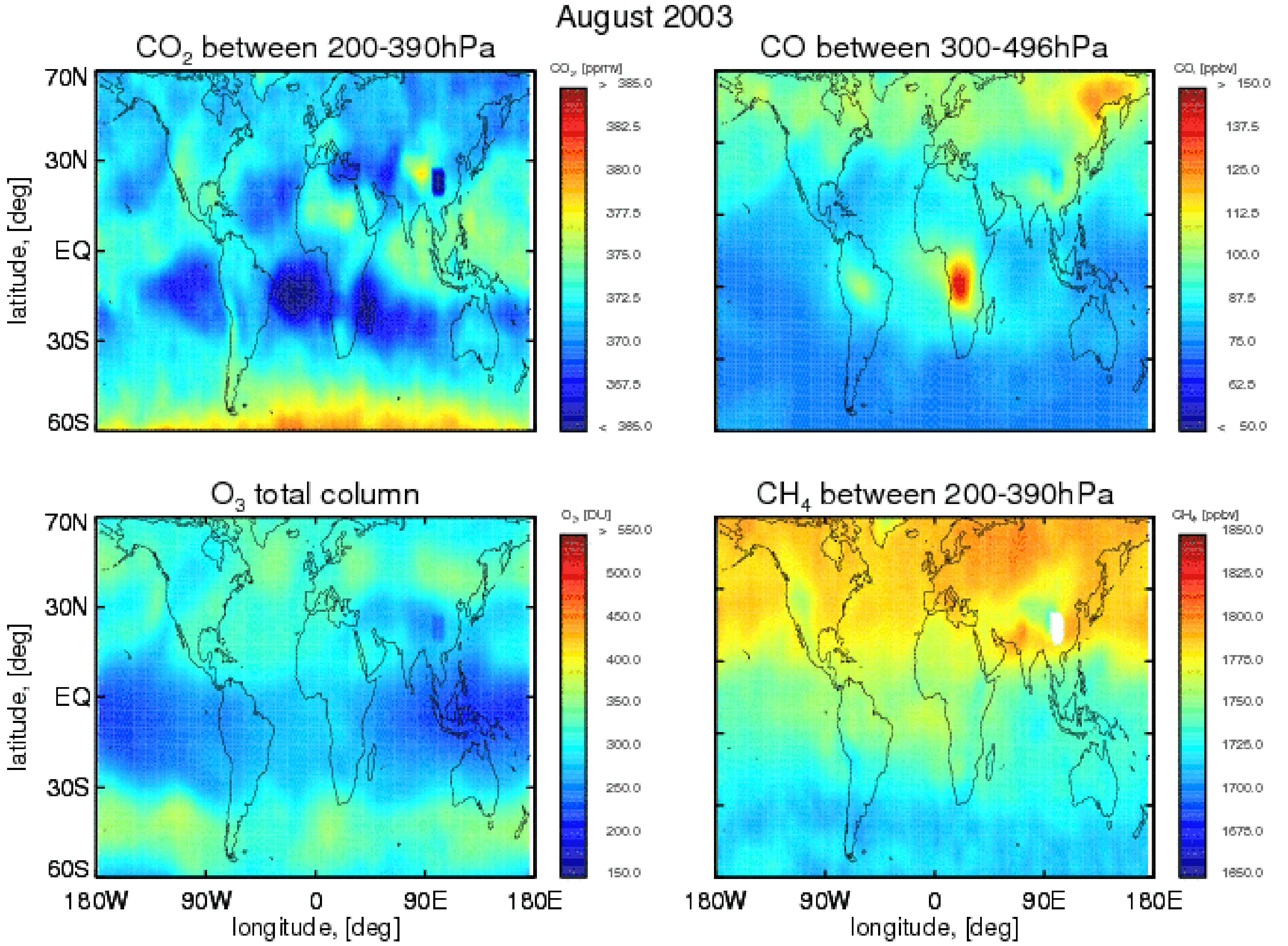
AIRS mid-trop measurement column

CO_2 Model Kawa (GSFC)



Fraction Determined from AIRS Radiances

Averaging Function Peak Pressure

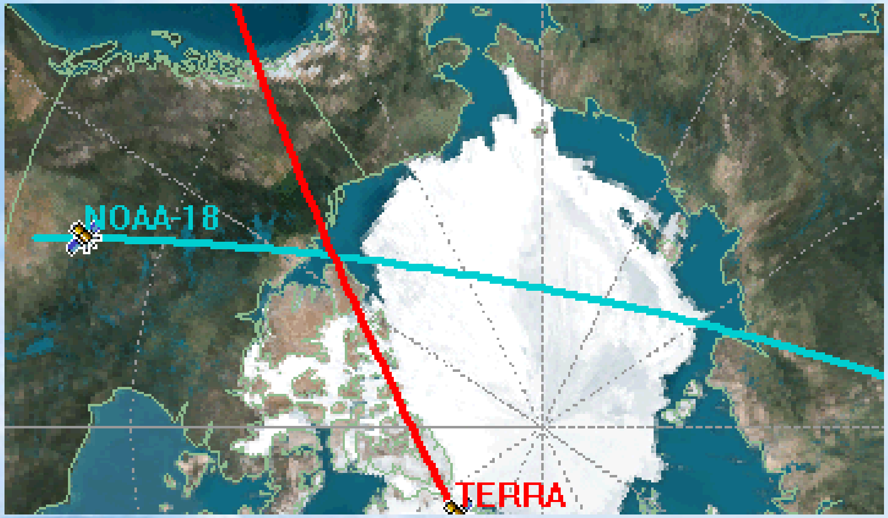


August 2003
CO2 between 200-390hPa
CO between 300-496hPa
O3 total column
CH4 between 200-390hPa
70N
30N
EQ
30S
60S
latitude, [deg]
180W
90W
0
90E
180E
longitude, [deg]

Intercalibration using AIRS and IASI

Simultaneous Nadir Overpass (SNO) Method
-a core component in the Integrated Cal/Val System

POES intercalibration



•Unique capabilities developed at NESDIS

•Has been applied to microwave, vis/nir, and infrared radiometers for on-orbit performance trending and climate calibration support

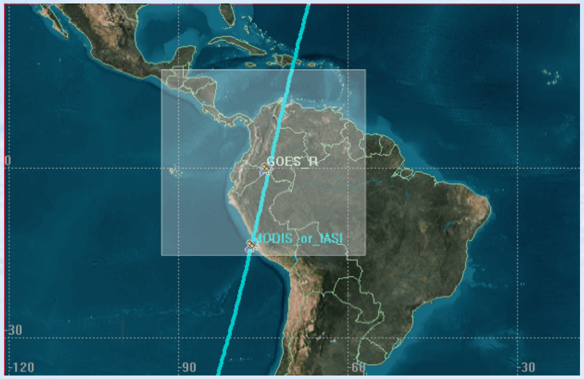
•Capabilities of 0.1 K for sounders and 1% for vis/nir have been demonstrated in pilot studies

•Method has been adopted by other agencies

• Useful for remote sensing scientists, climatologists, as well as calibration and instrument scientists

•Support new initiatives (GEOSS and GSICS)

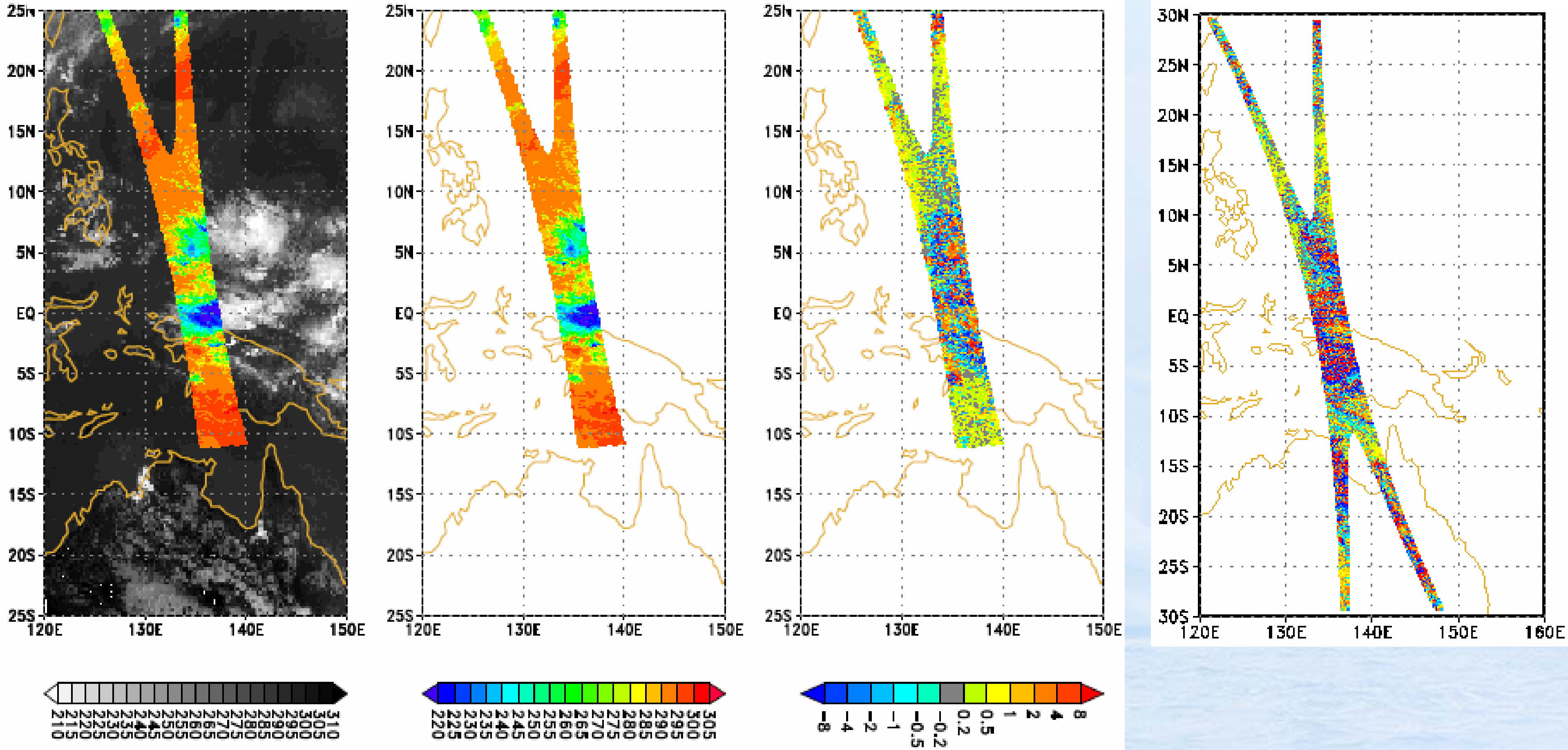
• Significant progress are expected in GOES/POES intercal in the near future



GOES vs. POES

Real Data Comparison (JMA)

MTSAT-1R IR2 | AIRS virtual ch | MTSAT – AIRS | MTSAT – NOAA18 AVHRR ch 5



04:42 UTC, 2 Nov 2006

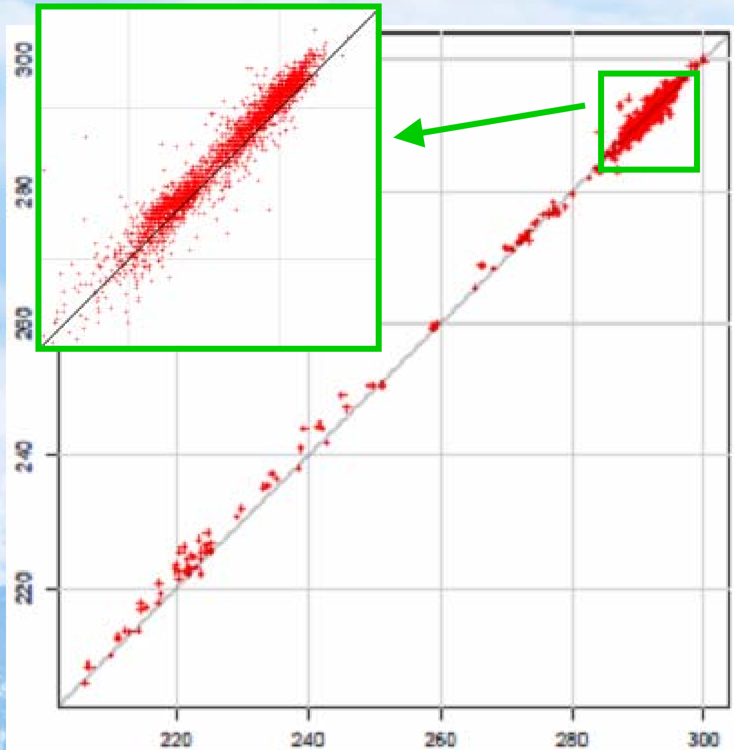
04:42 UTC, 3 Nov 2006

Real Data Comparison (statistics)

MTSAT-1R IR2 vs. AIRS virtual ch

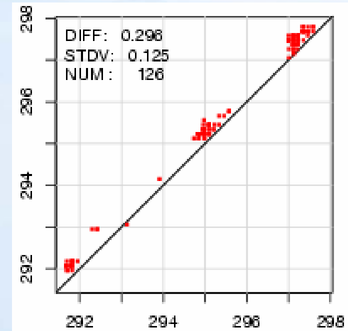
MTSAT-1R vs. NOAA-18/AVHRR ch 5

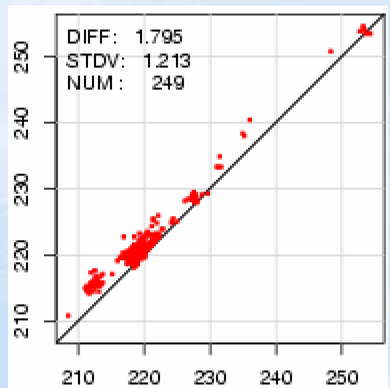
MTSAT-1R IR2



AIRS virtual ch.

Clear sky comparison

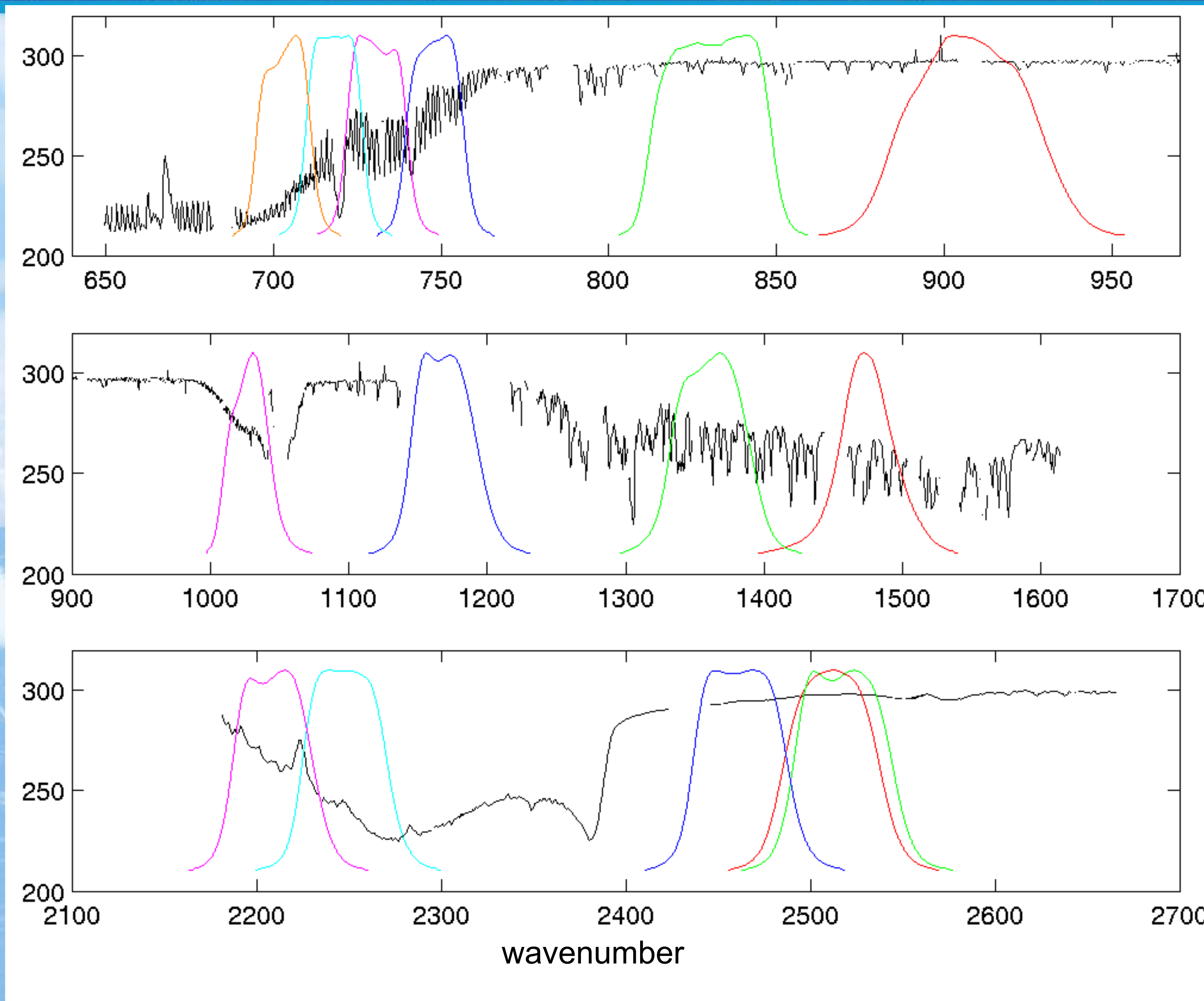




Smooth cloud Top comp.

```
MEAN: +0.324 K (MTSAT-AIRS)
STDV:  0.551 K
CORR:  0.998
NUM :  3113
```

AIRS spectrum and Aqua MODIS Band Spectral Response Functions (Tobin)



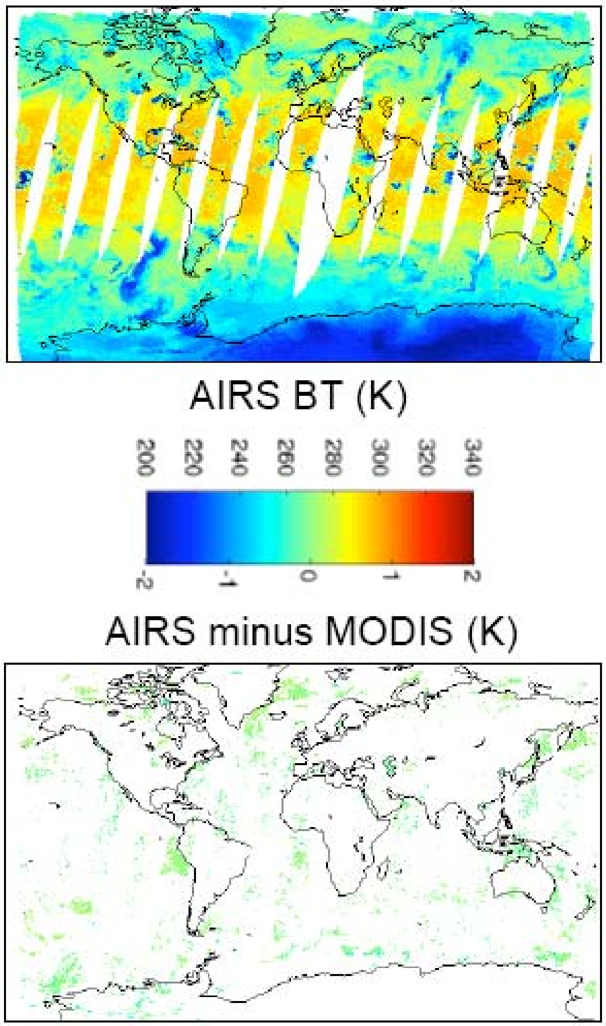
MODIS Band / wavelength(μm)

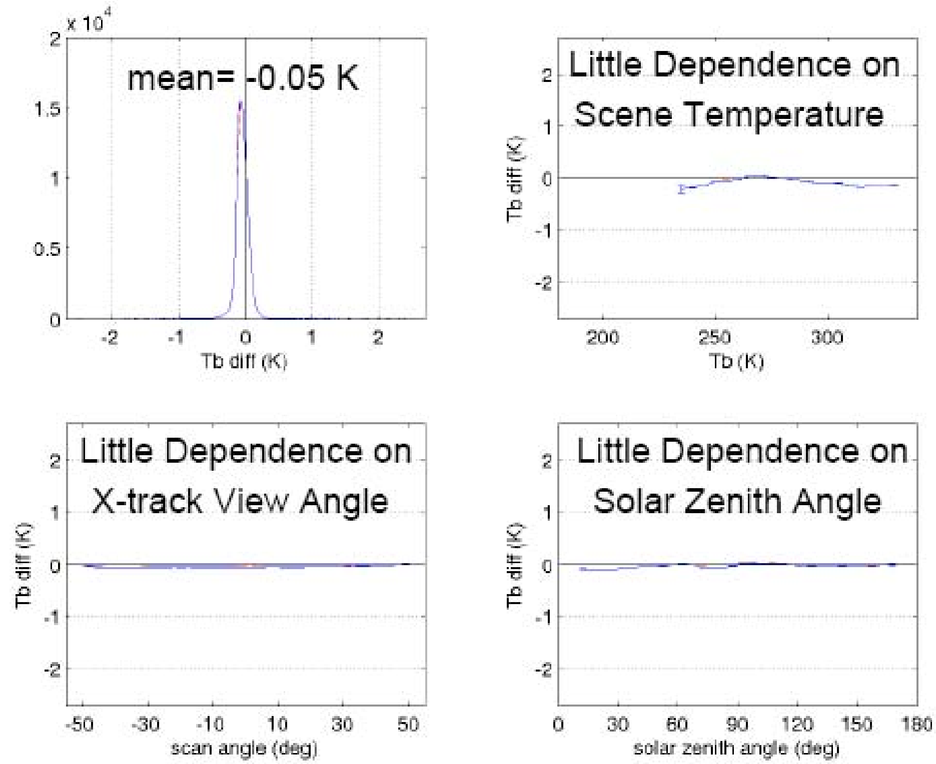
36 / 14.2
35 / 13.9
34 / 13.7
33 / 13.4
32 / 12.0
31 / 11.0

30 / 11.0
29 / 9.7
28 / 7.3
27 / 6.8

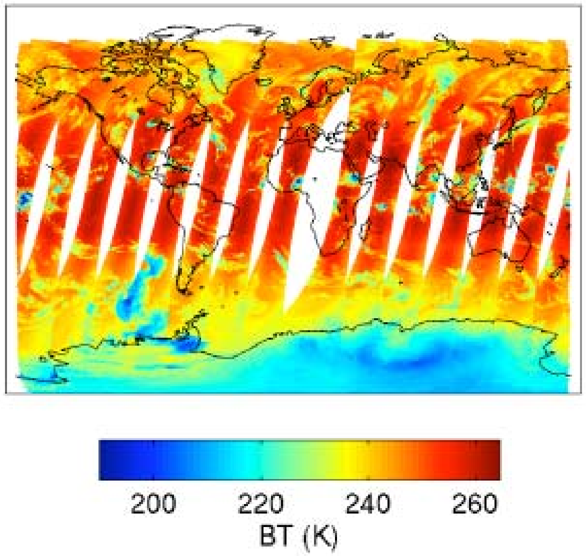
25 / 4.5
24 / 4.4
23 / 4.1
22 / 4.0
21 / 4.0

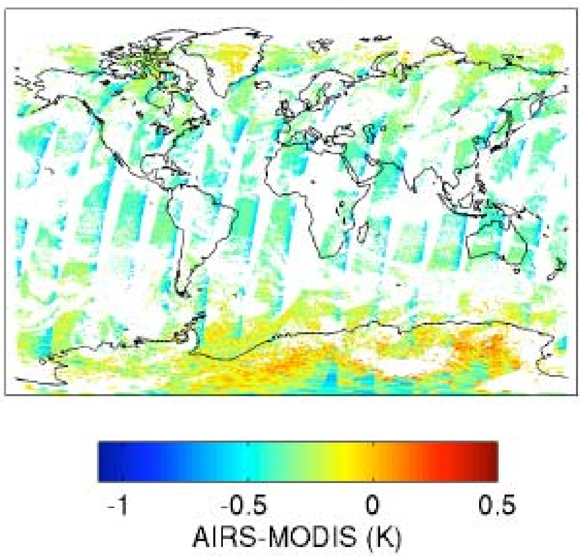
Example comparisons for band 22 (4.0 μm) on 6 Sept 2002.

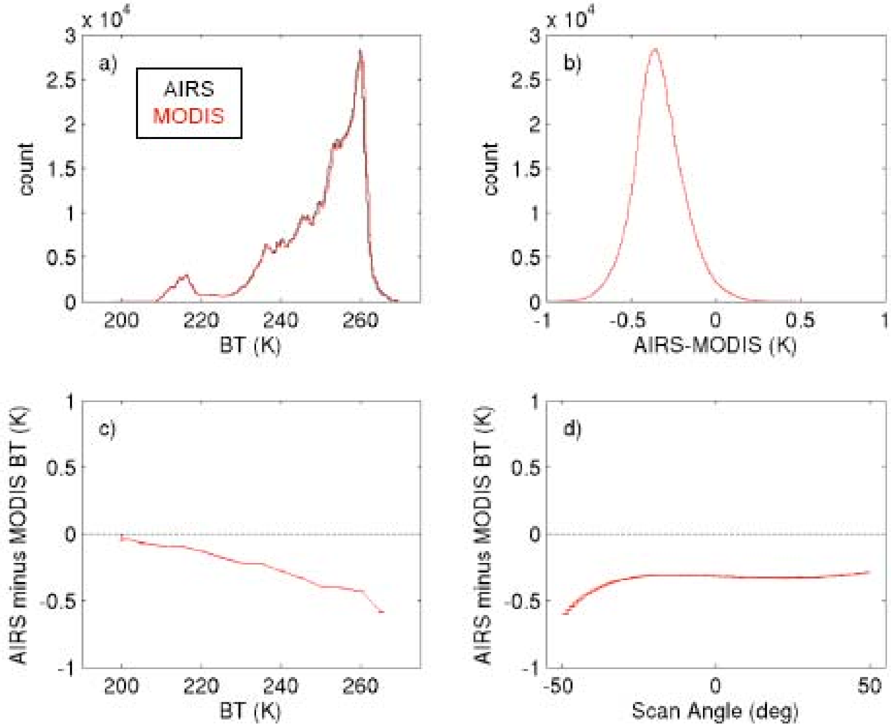




Example comparisons for band 34 (13.7 μm) on 6 Sept 2002.

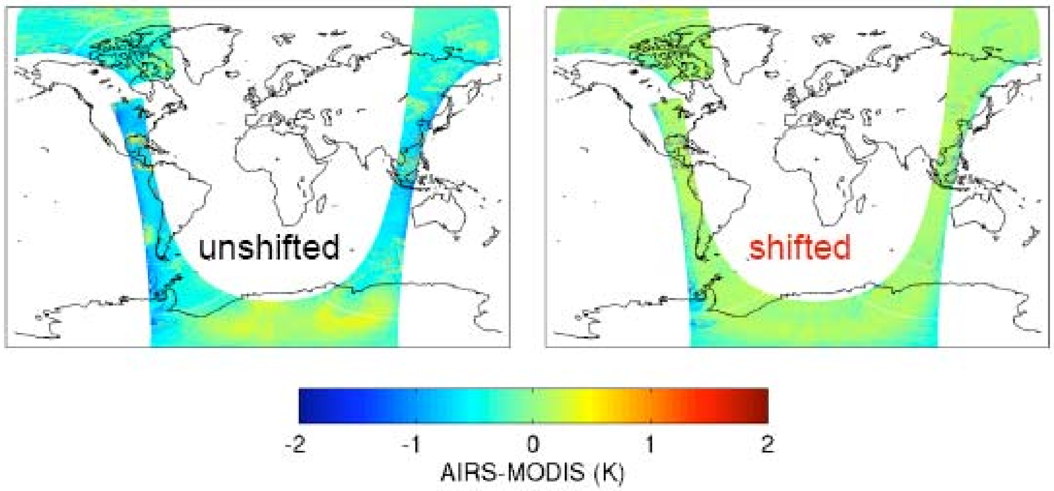




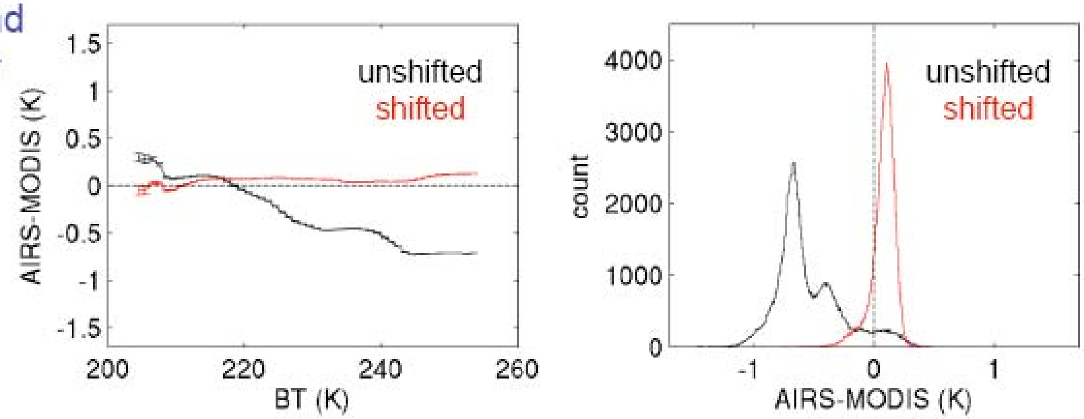


Band 35 (13.9 μm)

brightness temperature differences for one orbit of data on 6 Sept 2002 using (1) the nominal MODIS SRF and (2) the MODIS SRF shifted by +0.8 cm^{-1}.

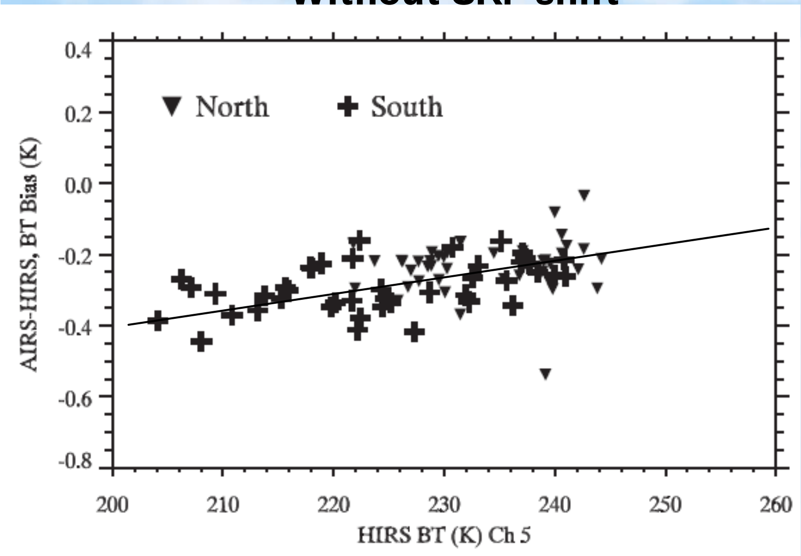


MODIS SRF out-of-band response also currently being investigated.

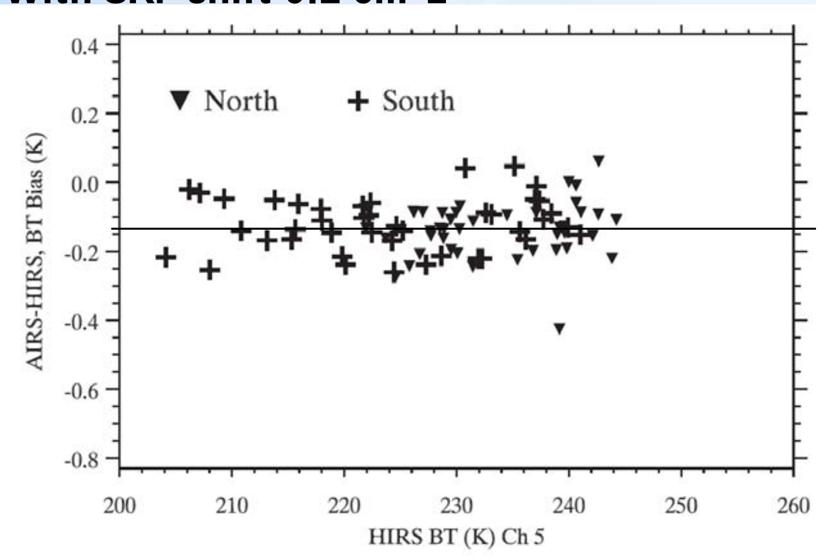


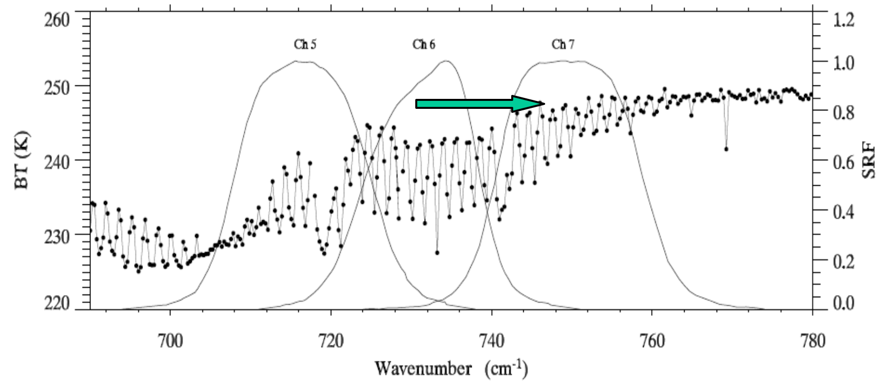
SRF Shift for HIRS Channel 6

Without SRF shift



With SRF shift 0.2 cm-1





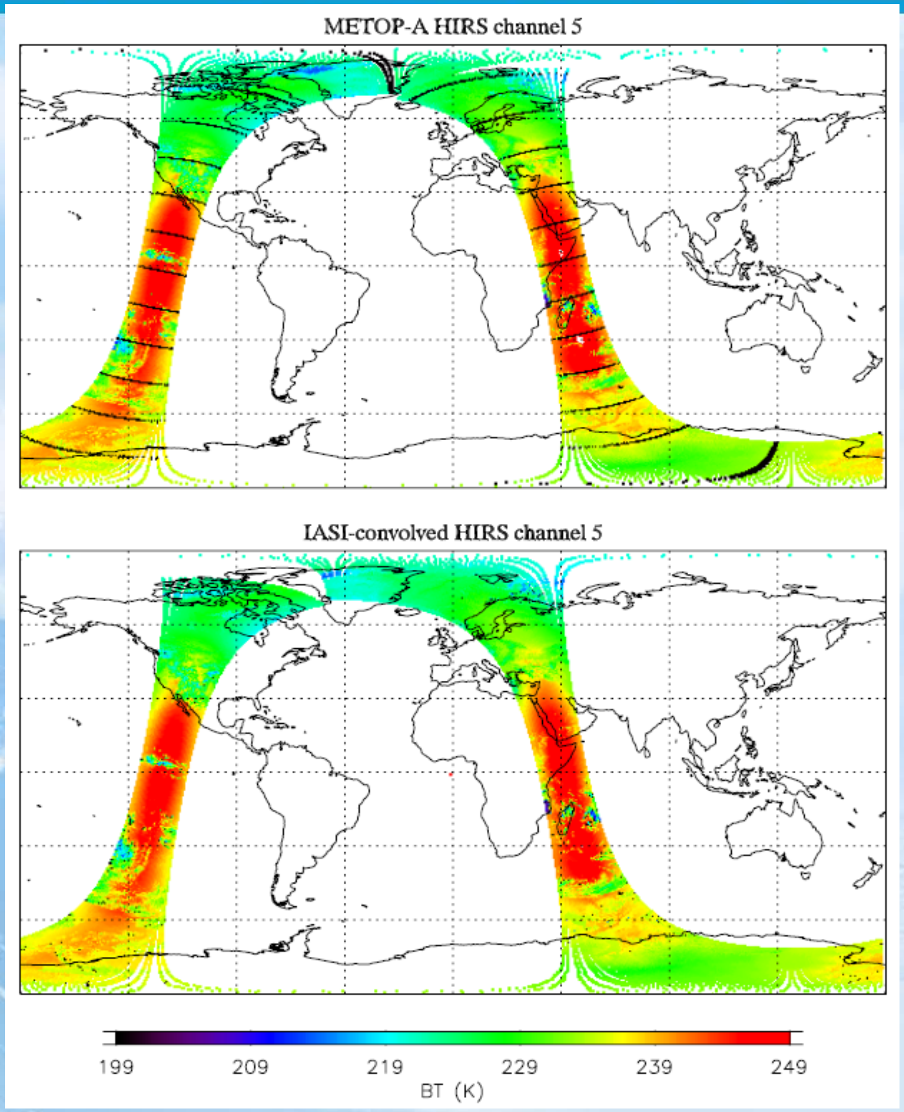
Since the HIRS sounding channels are located at the slope region of the atmospheric spectra, a small shift of the SRF can cause biases in observed radiances.

Details can be referred to Wang et al. (manuscript for JTECH, 2006)

IASI-convolved HIRS vs. HIRS Ch 5

HIRS

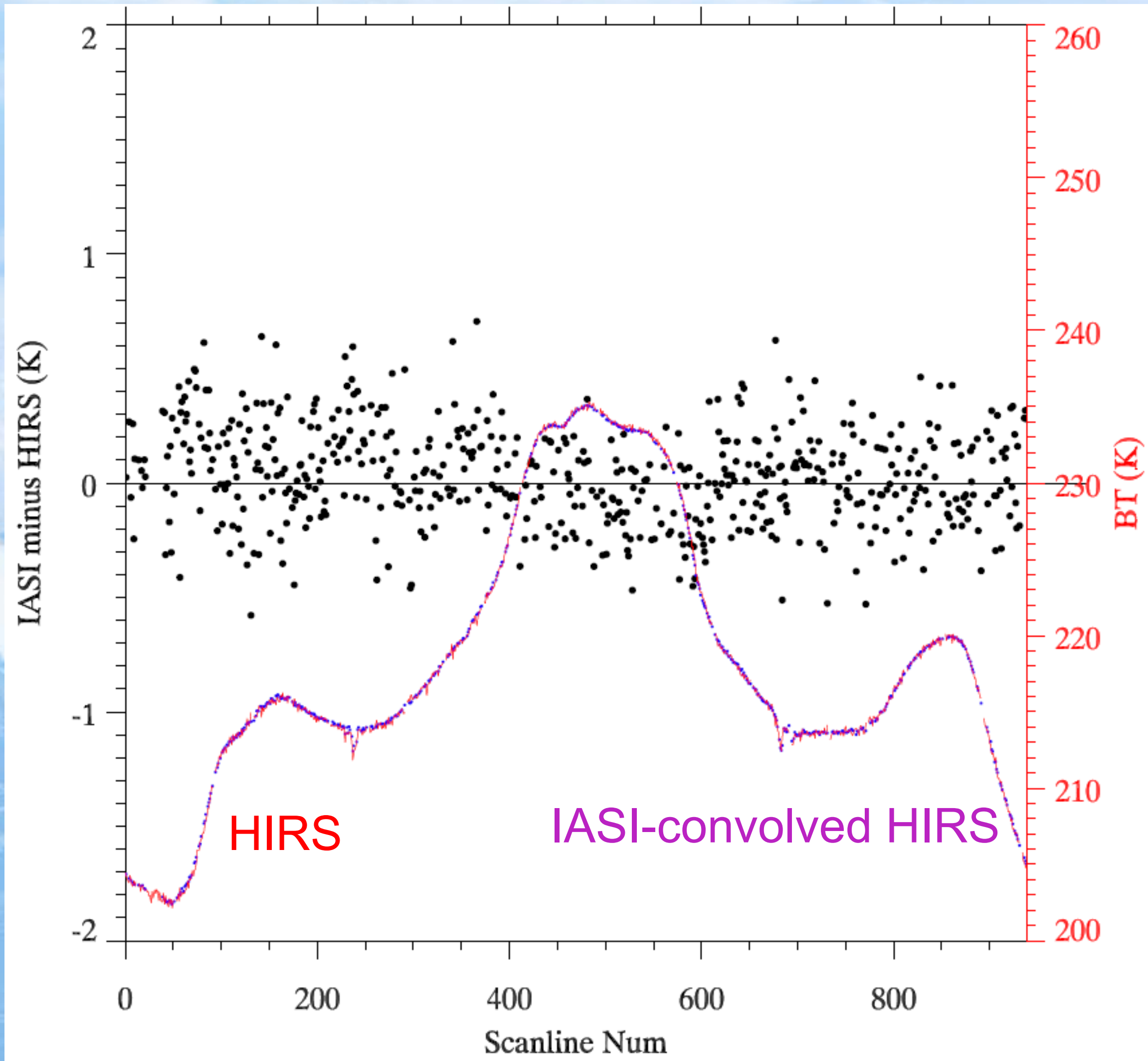
IASI

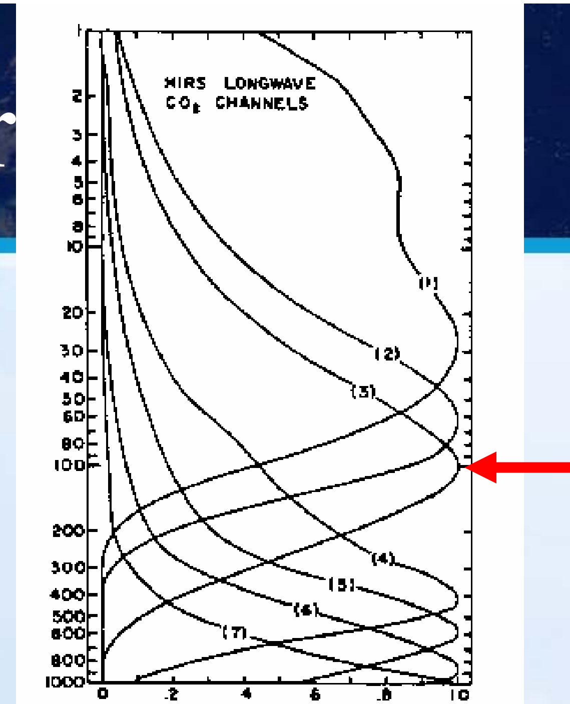


Brightness distribution patterns agree each other well.

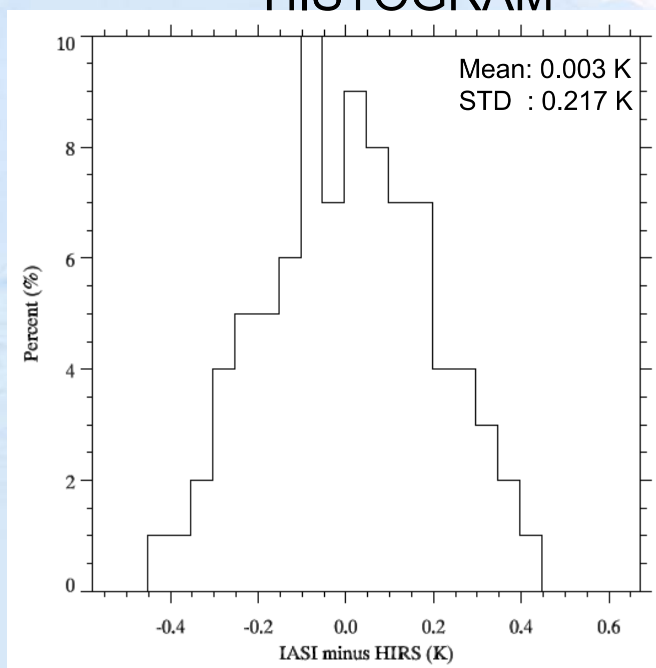
But we need the pixel-by-pixel comparison results!

Channel 3 at nadir

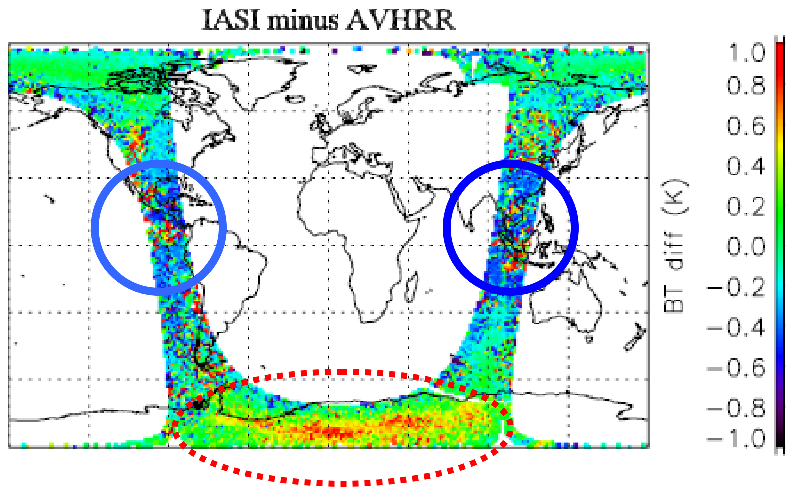


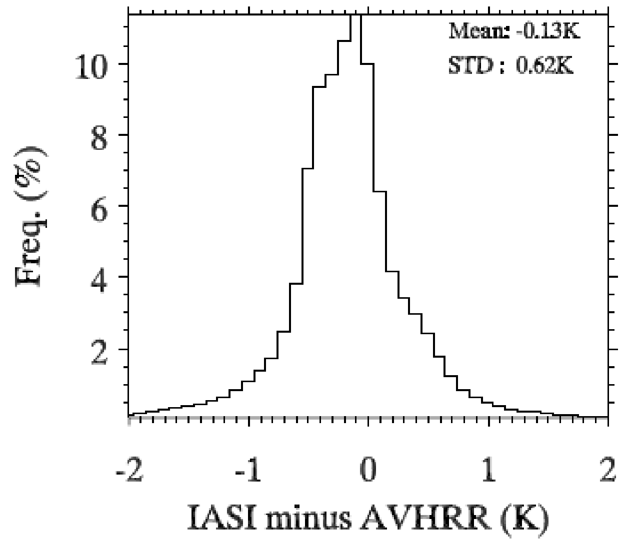


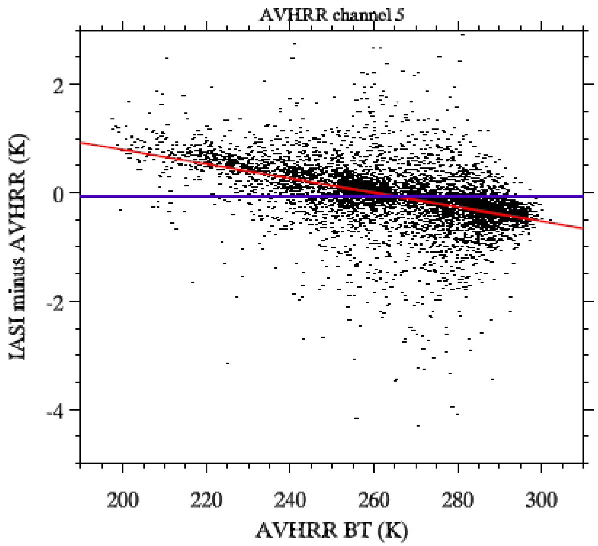
HISTOGRAM



Difference between IASI and AVHRR



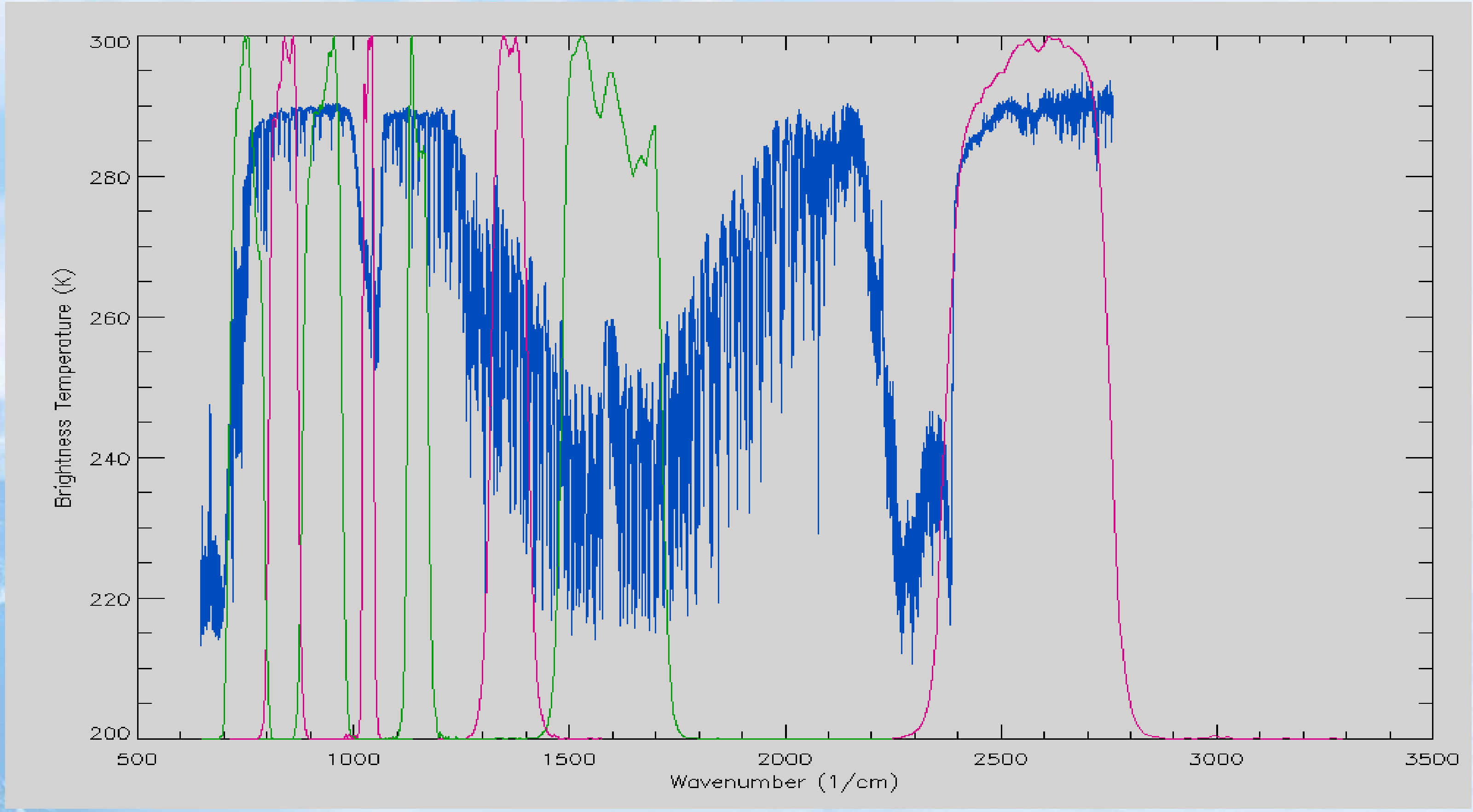




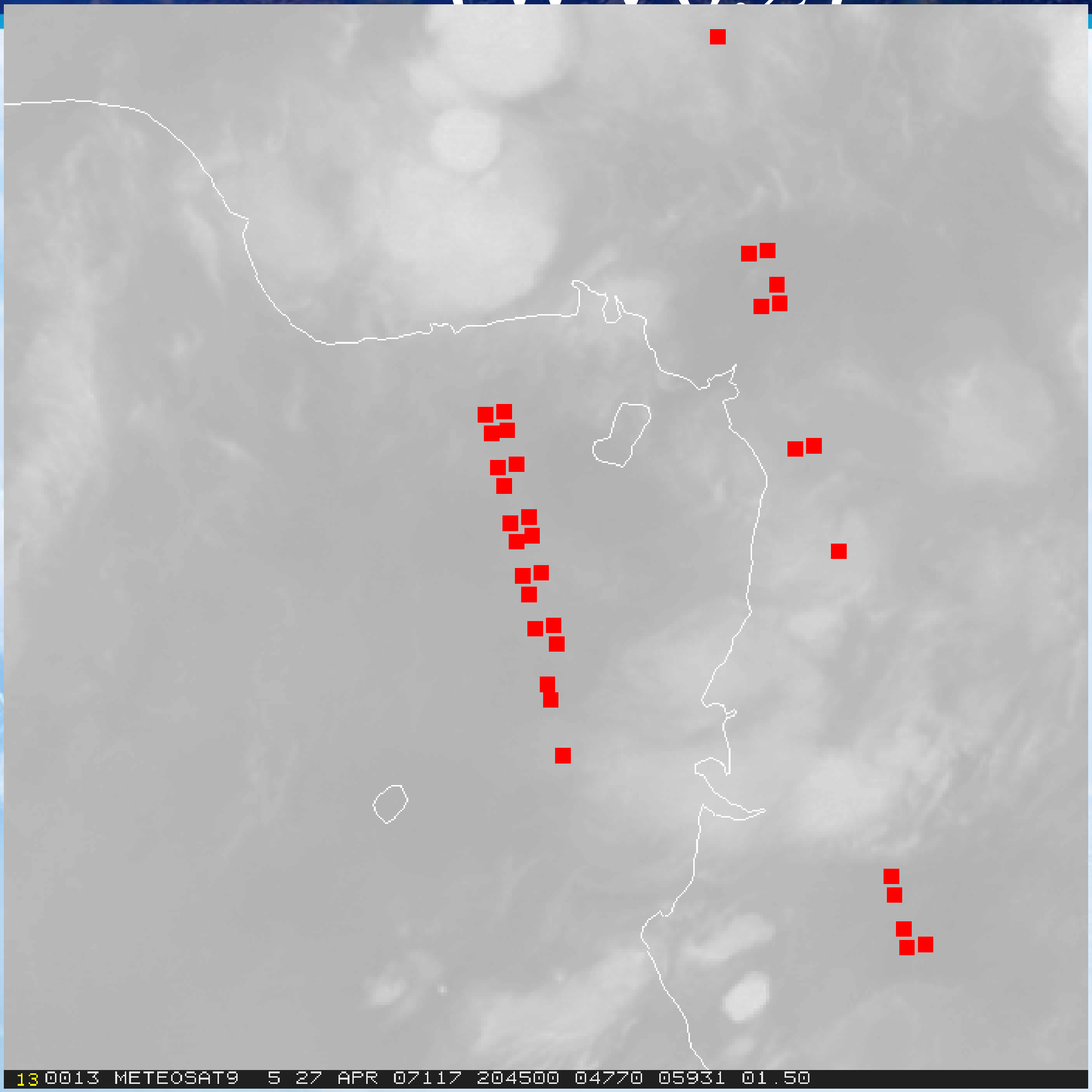
Statistically, the temperature observed from AVHRR channels 4 and 5 is slightly warmer than IASI.

The bias distribution has spatial patterns, which is related to scene termperature

IASI Spectrum – MSG Filter



"Homogeneous" Targets (WV6.2)



Meteosat-8

and

Meteosat-9

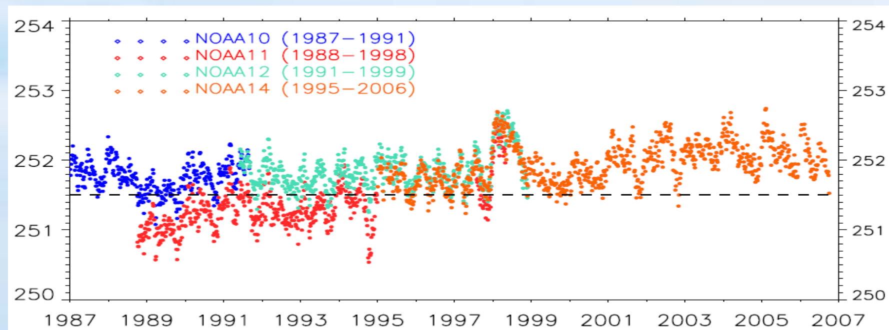
Results for 27 April 2007

Channel	ΔT IASI – Meteosat-8*	ΔT IASI – Meteosat-9 *
IR3.9	-0.17	-0.20
WV6.2	-0.24	-0.40
WV7.3	-0.51	-0.14
IR8.7	0.15	0.15
IR9.7	0.17	0.20
IR10.8	0.16	0.07
IR12.0	0.19	0.08
IR13.4	0.44	1.7

Comparison Between Pre-launch and SNO calibrations - MSU

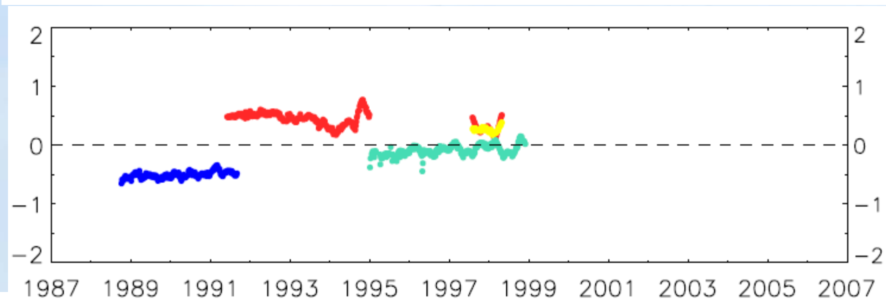
Important for reanalyses!!

Time series for pre-launch calibration



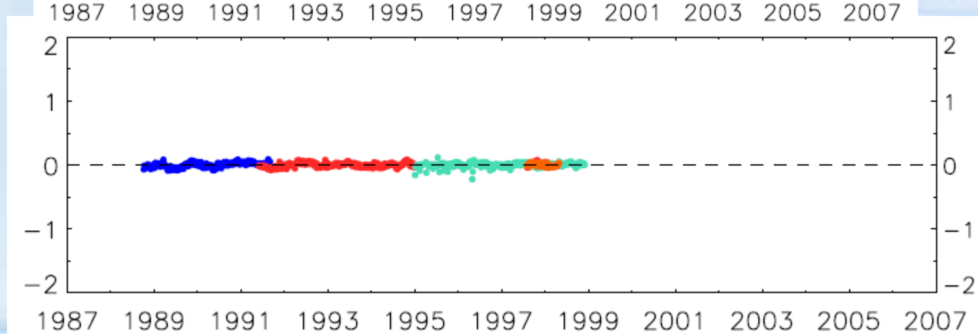
Time series differences for pre-launch calibration

Std=0.1K



Inter-satellite differences after SNO calibration

std=0.04K



Generation of AIRS Radiance Dataset for Climate Studies

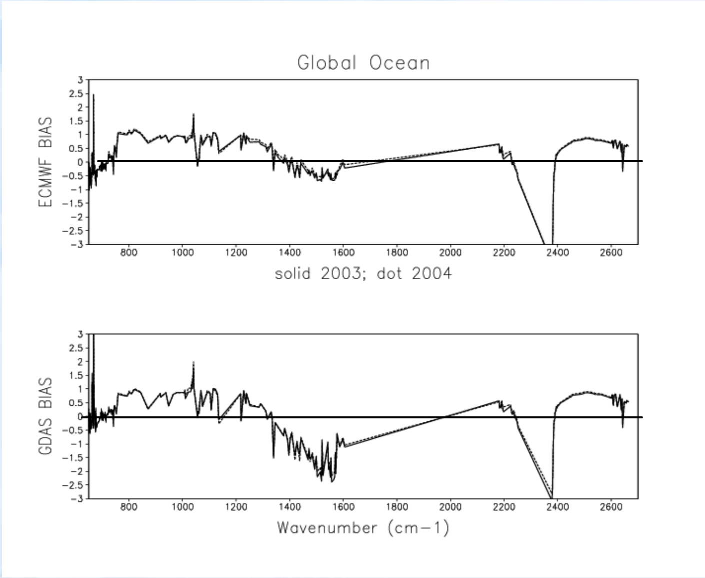
Background

- AIRS radiances are climate quality
- Key climate forcing, feedback and response variables are imbedded in AIRS
- Generate monthly maps of nadir angle adjusted AIRS radiances from our gridded datasets (single AIRS fov per 0.5 lon x 2.0 lat) for climate change detection and attribution and model validation

Applications of Mapped Spectrally Resolved Radiances

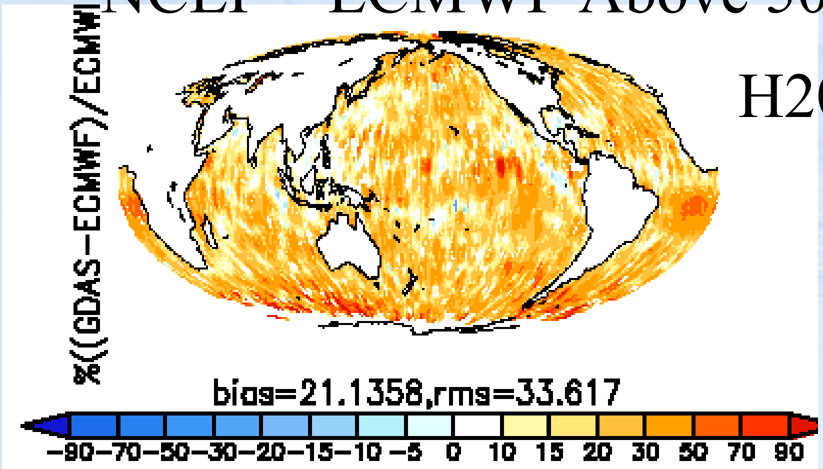
- Compare radiances with simulated radiances from model analyses

- Compare different years to see how the outgoing infrared radiances have changed.

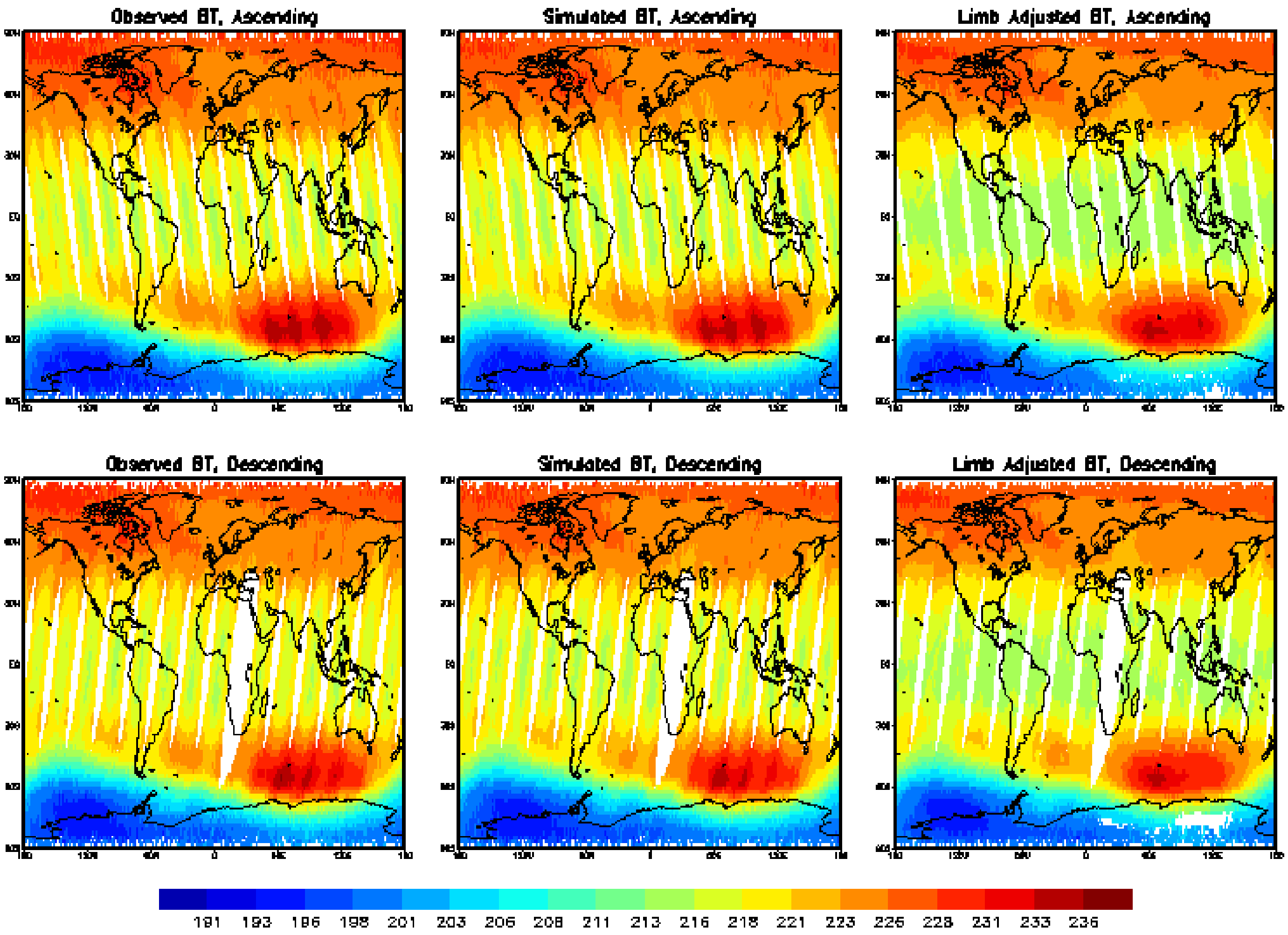


NCEP – ECMWF Above 500 mb

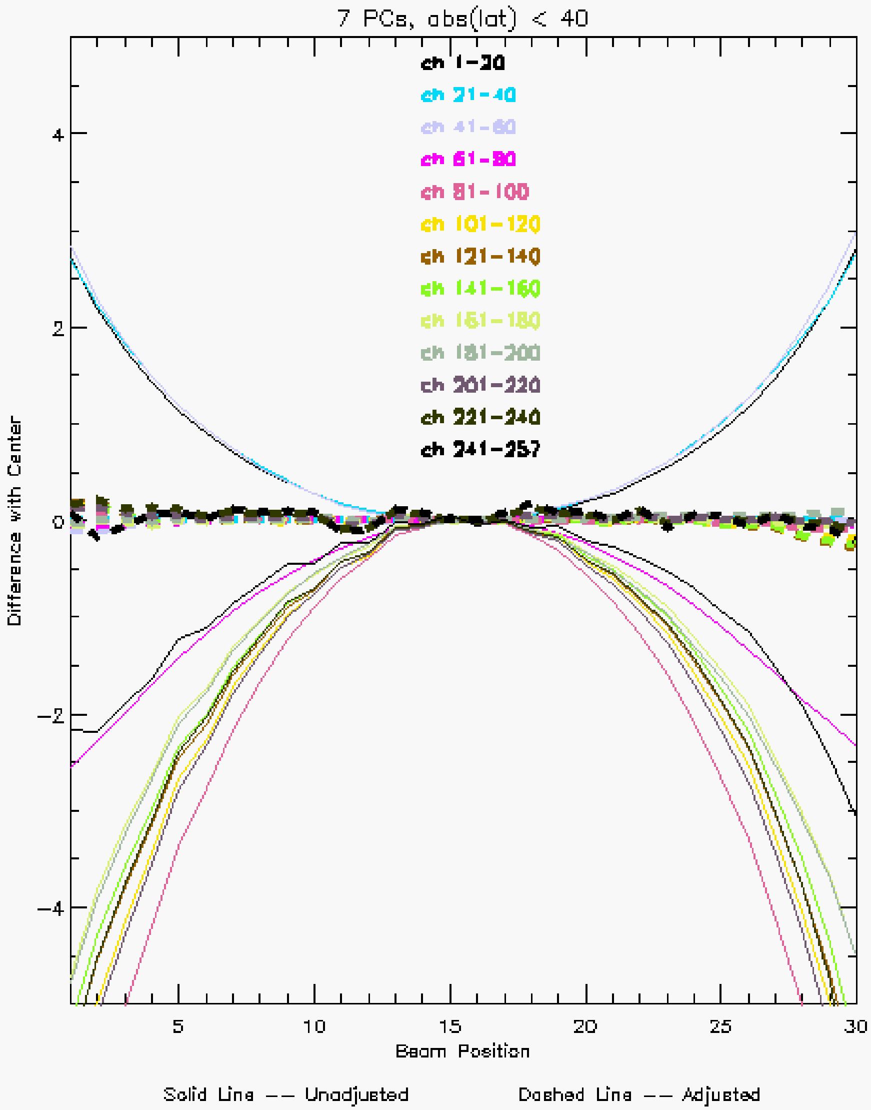
H20

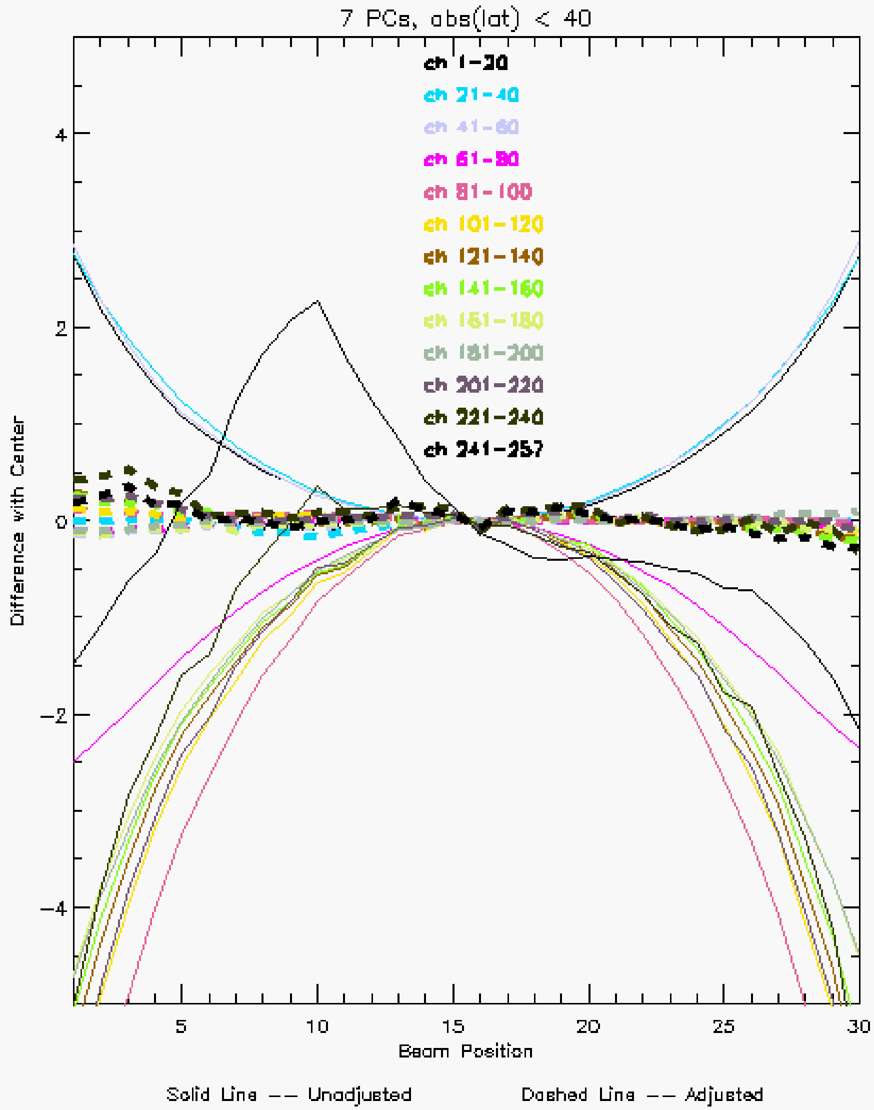


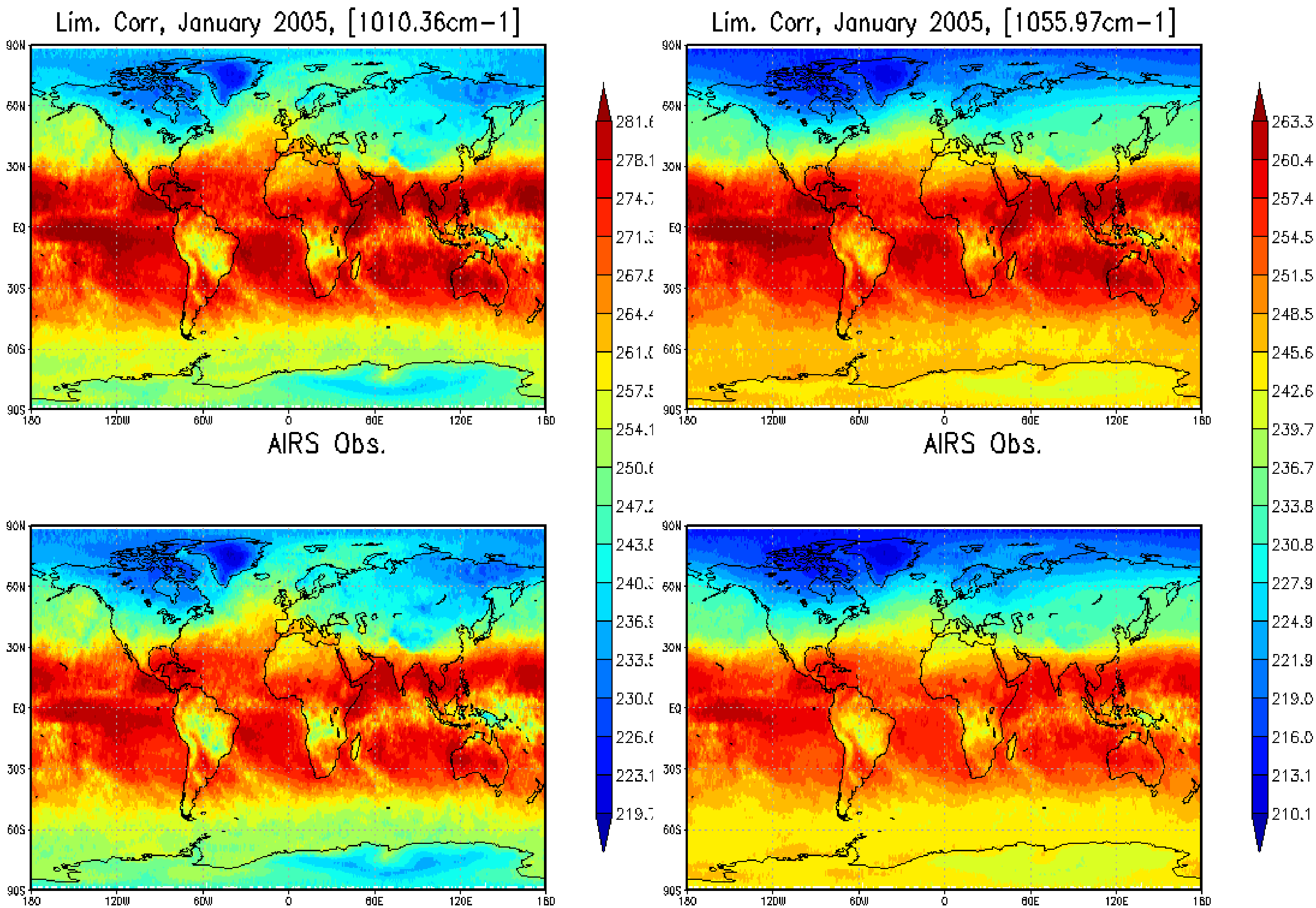
Observed, Simulated vs Limb Adjusted BT, 666.766cm-1, 7 PCs, 2004/09/01



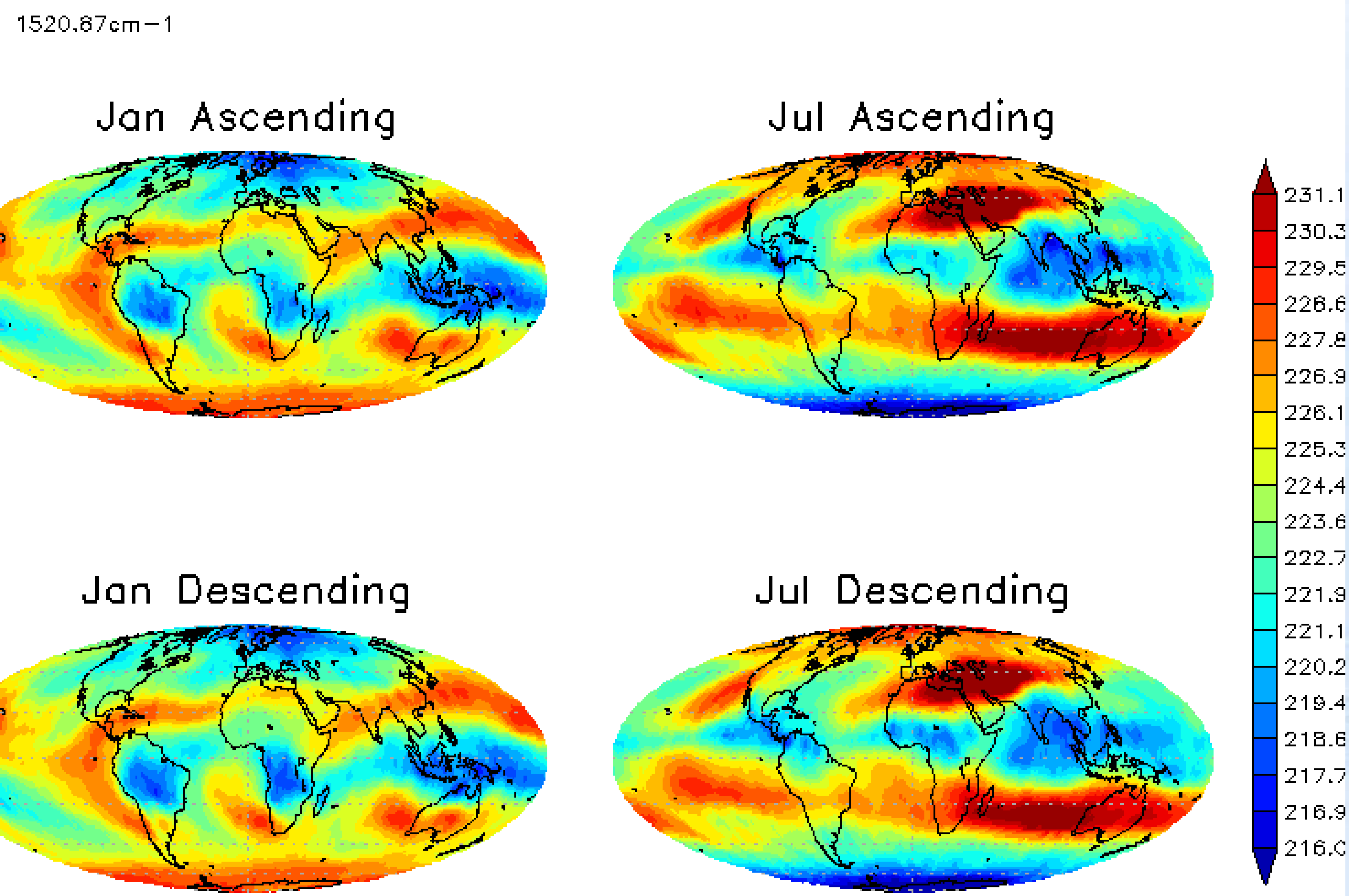
Limb adjust using PCA

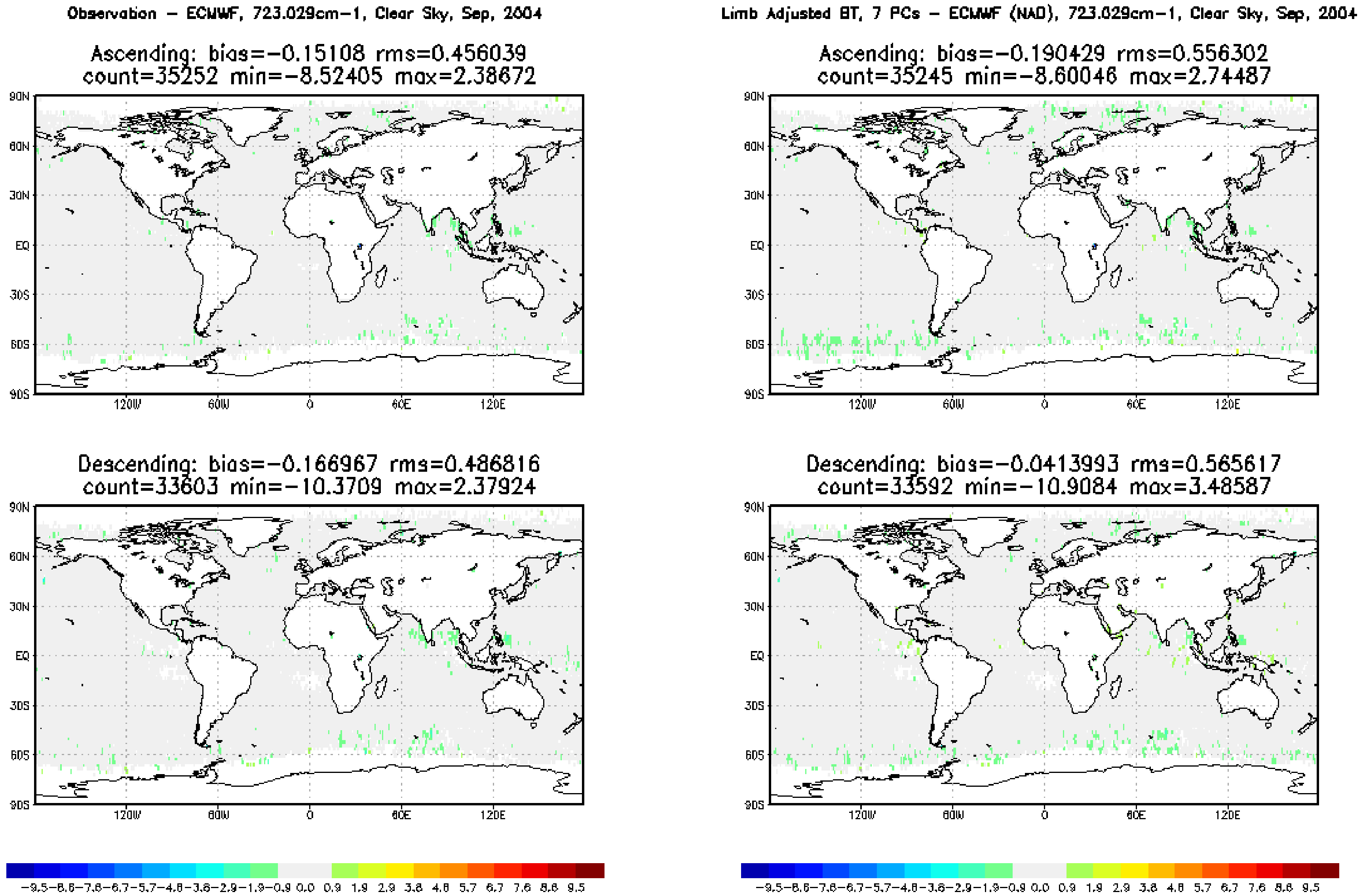




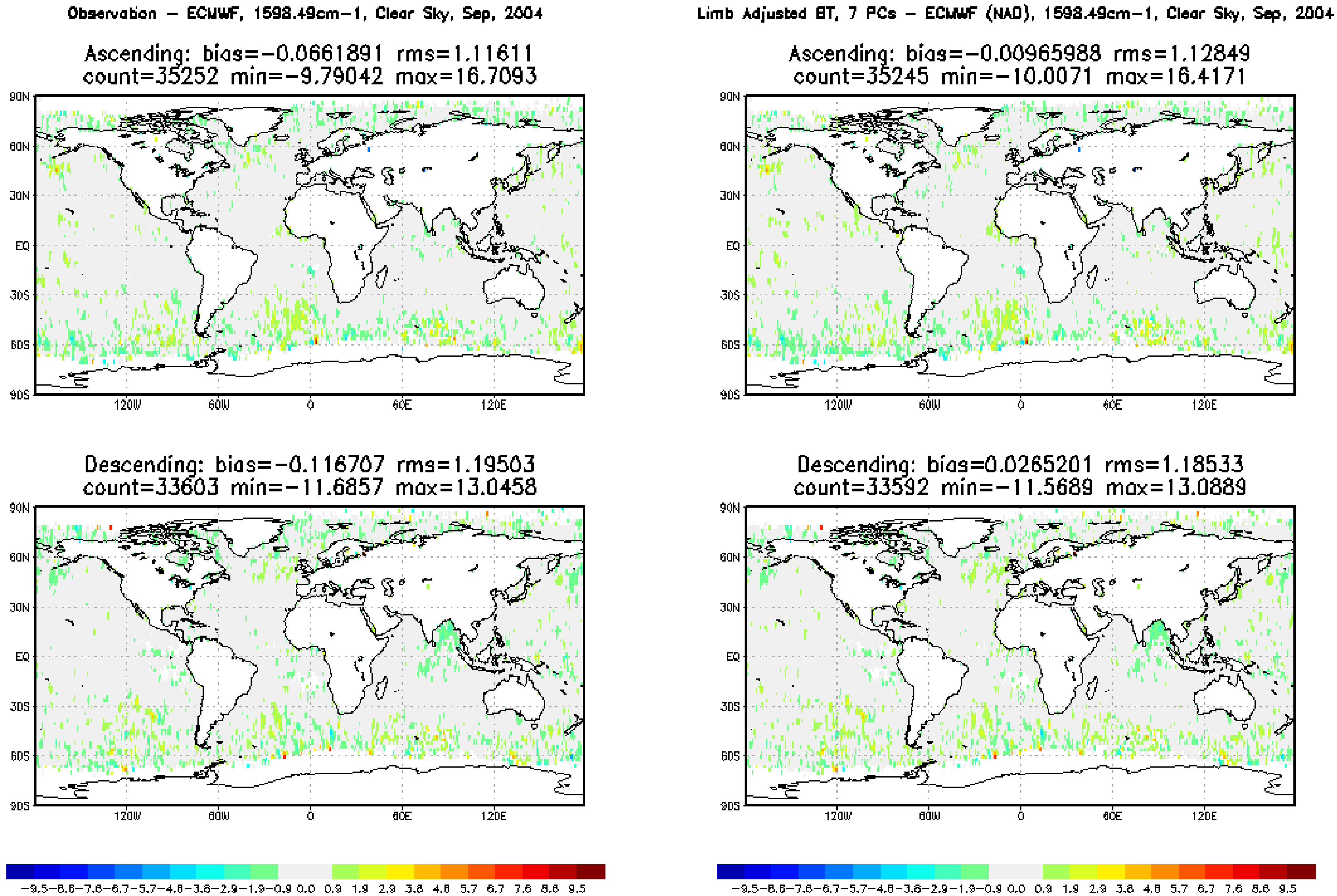

Lim. Corr, January 2005, [1010.36cm-1]
Lim. Corr, January 2005, [1055.97cm-1]
AIRS Obs.
AIRS Obs.
90N
60N
30N
EQ
30S
60S
90S
180
120W
60W
0
60E
120E
180
263.3
260.4
257.4
254.5
251.5
248.5
245.6
242.6
239.7
236.7
233.8
230.8
227.9
224.9
221.9
219.0
216.0
213.1
210.1

Water – Upper Troposphere



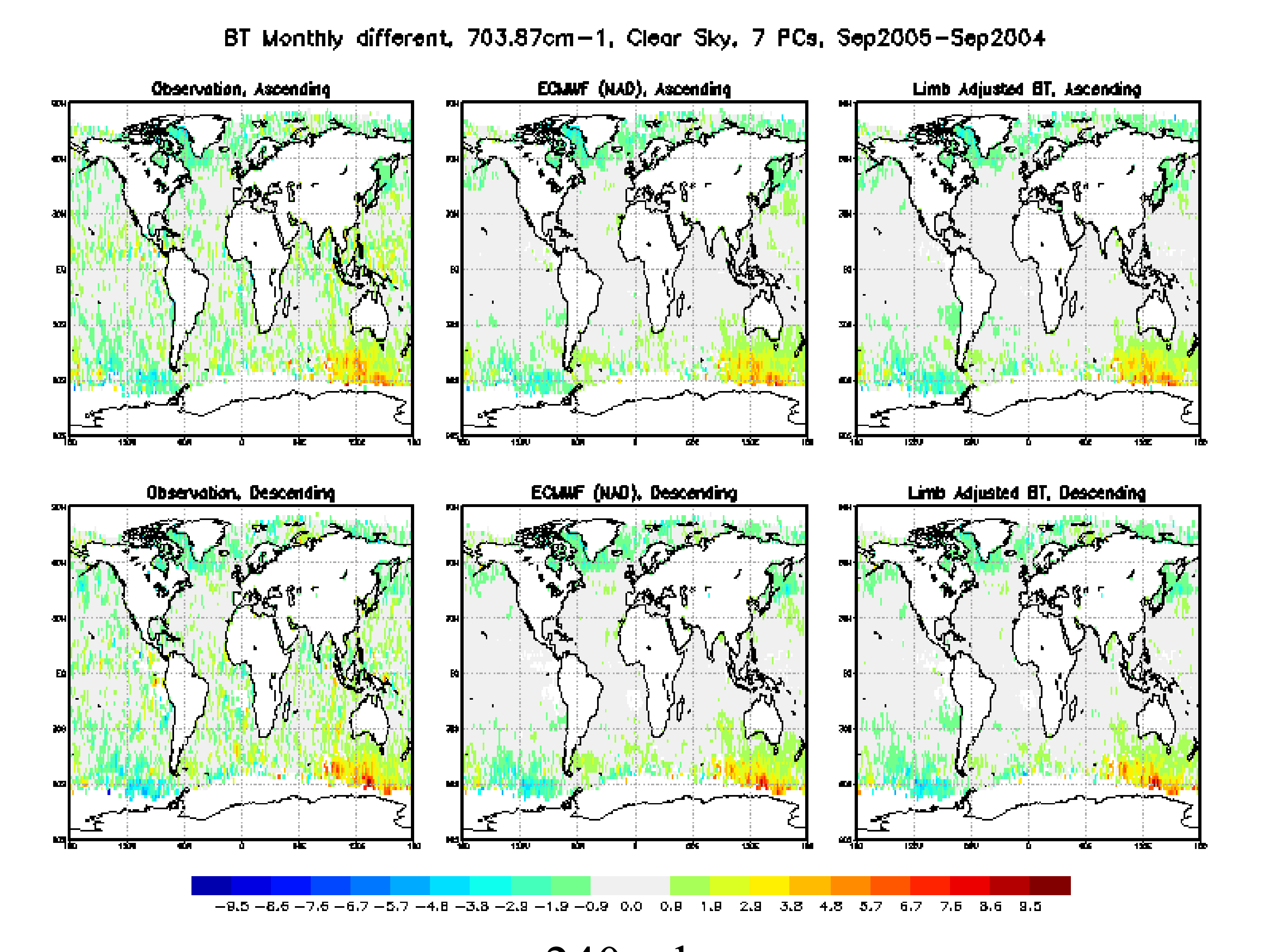

Observation – ECMWF, 723.029cm-1, Clear Sky, Sep, 2004
Ascending: bias=-0.15108 rms=0.456039
count=35252 min=-8.52405 max=2.38672
Descending: bias=-0.166967 rms=0.486816
count=33603 min=-10.3709 max=2.37924
Limb Adjusted BT, 7 PCs – ECMWF (NAD), 723.029cm-1, Clear Sky, Sep, 2004
Ascending: bias=-0.190429 rms=0.556302
count=35245 min=-8.60046 max=2.74487
Descending: bias=-0.0413993 rms=0.565617
count=33592 min=-10.9084 max=3.48587
90N 60N 30N EQ 30S 60S 90S
120W 60W 0 60E 120E
-9.5 -8.6 -7.6 -6.7 -5.7 -4.8 -3.8 -2.9 -1.9 -0.9 0.0 0.9 1.9 2.9 3.8 4.8 5.7 6.7 7.6 8.6 9.5

585 mb

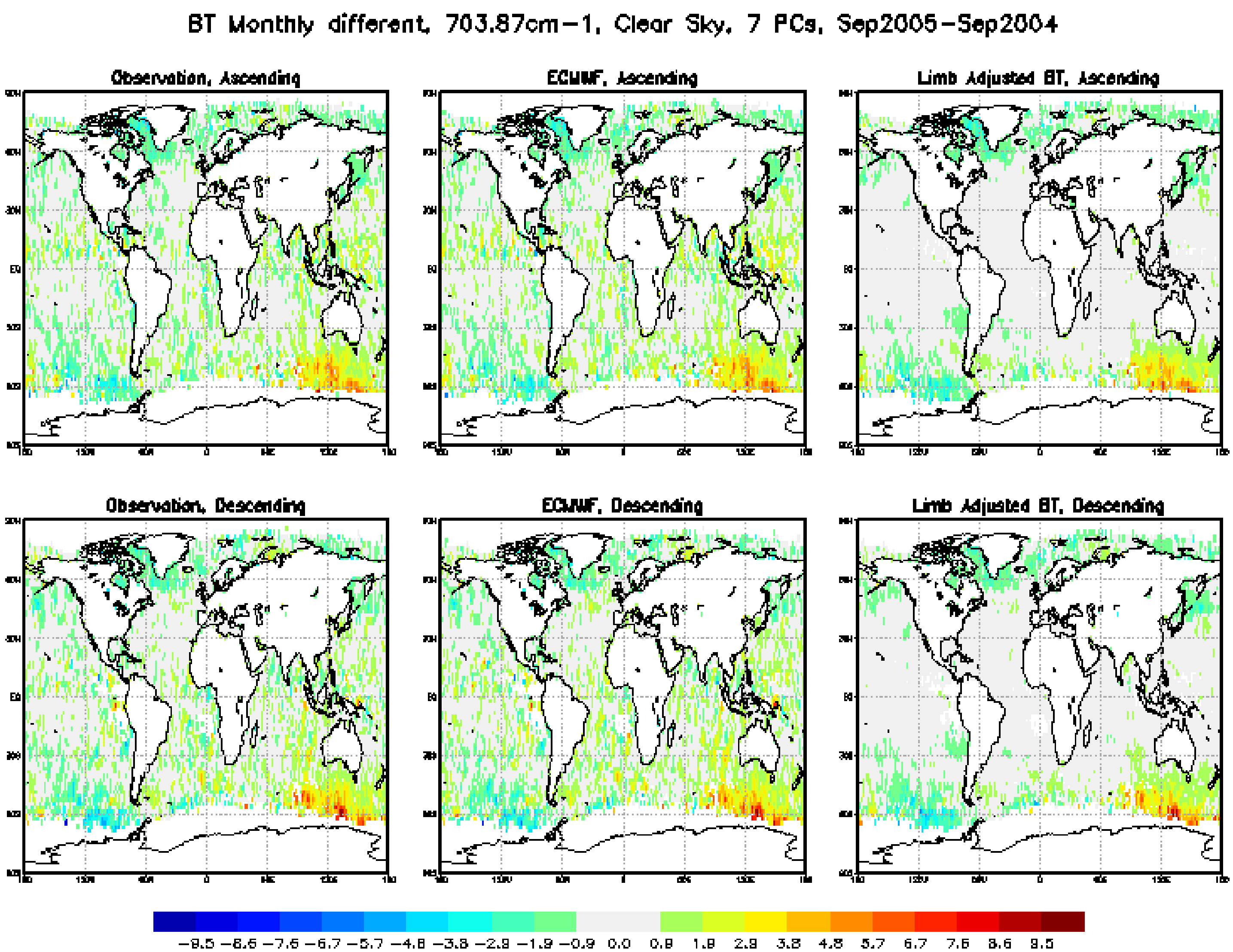

Observation – ECMWF, 1598.49cm−1, Clear Sky, Sep, 2004
Ascending: bias=−0.0661891 rms=1.11611
count=35252 min=−9.79042 max=16.7093
Descending: bias=−0.116707 rms=1.19503
count=33603 min=−11.6857 max=13.0458
Limb Adjusted BT, 7 PCs – ECMWF (NAD), 1598.49cm−1, Clear Sky, Sep, 2004
Ascending: bias=−0.00965988 rms=1.12849
count=35245 min=−10.0071 max=16.4171
Descending: bias=0.0265201 rms=1.18533
count=33592 min=−11.5689 max=13.0889
90N
60N
30N
EQ
30S
60S
90S
120W
60W
0
60E
120E
−9.5 −8.6 −7.6 −6.7 −5.7 −4.8 −3.8 −2.9 −1.9 −0.9 0.0 0.9 1.9 2.9 3.8 4.8 5.7 6.7 7.6 8.6 9.5

520 mb

Limb adjustment is important for averaging



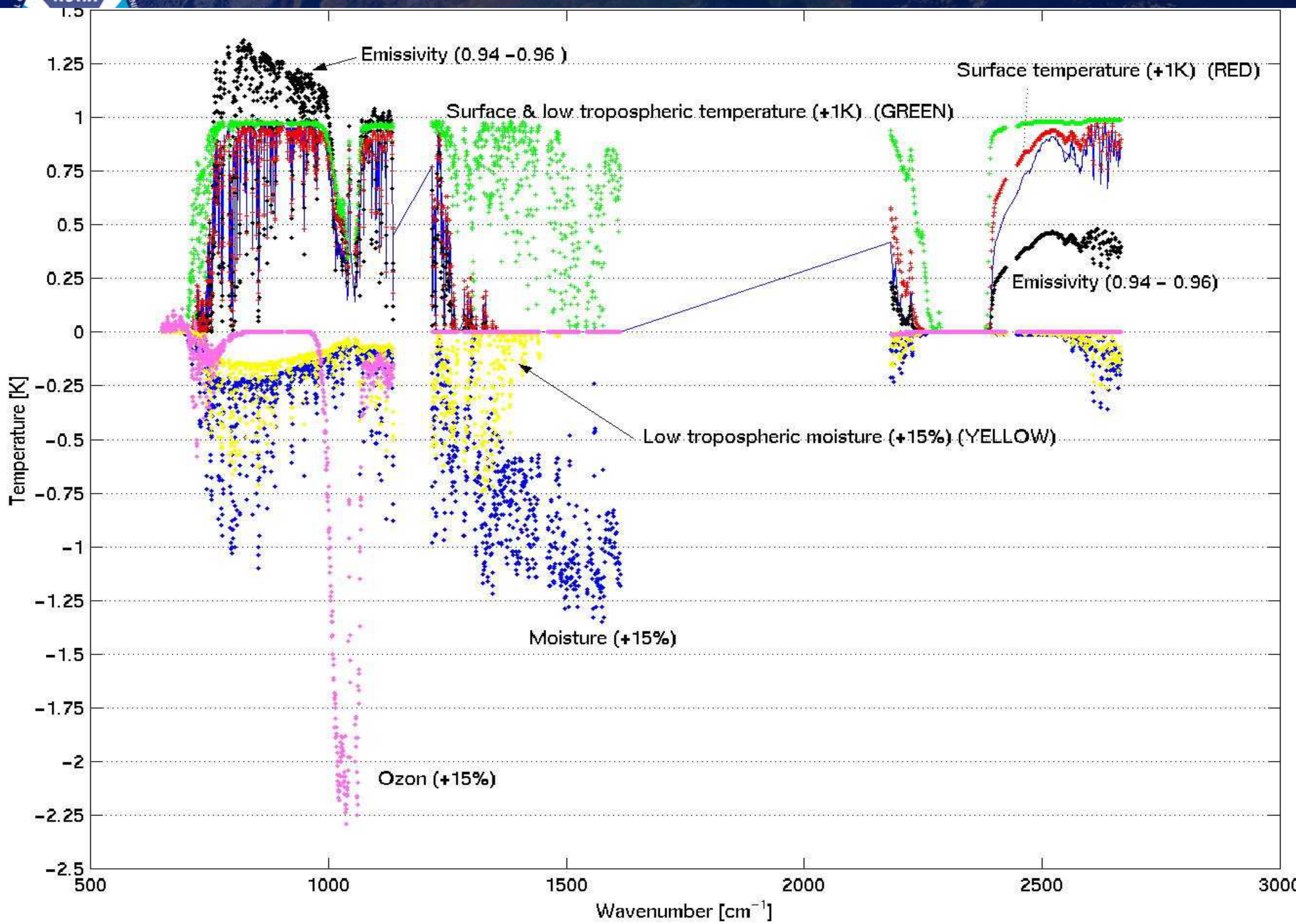
240 mb

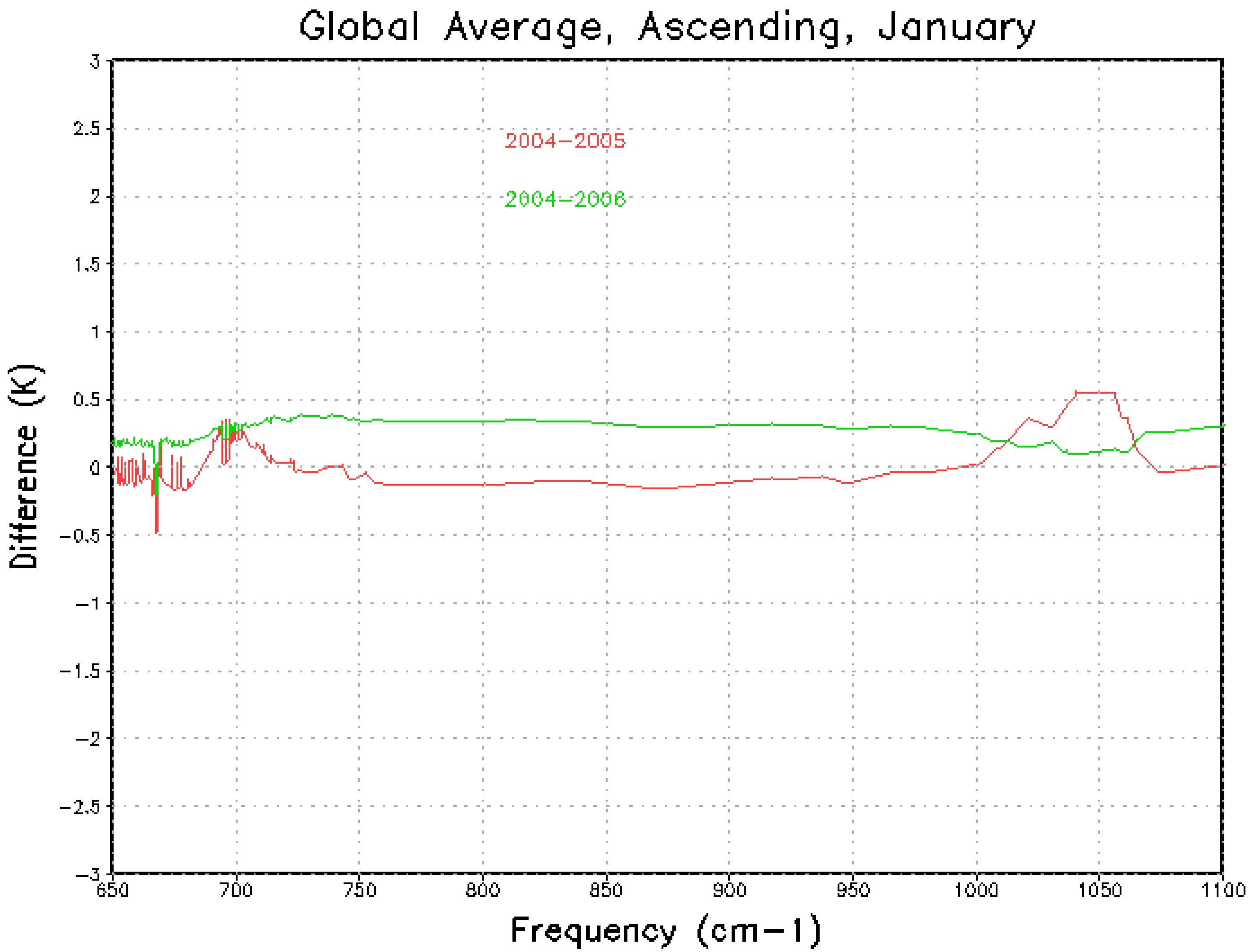


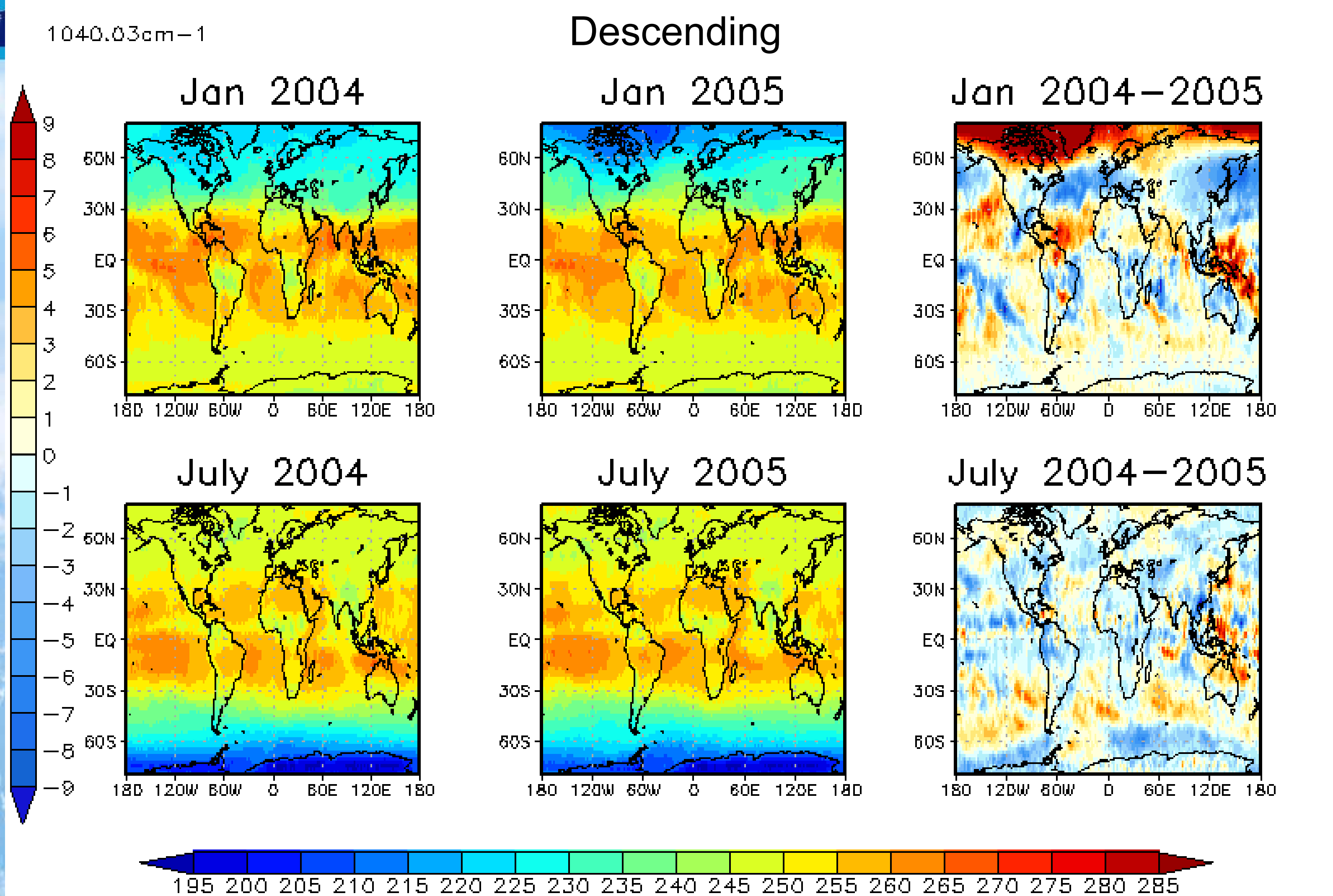
BT Monthly different, 703.87cm−1, Clear Sky, 7 PCs, Sep2005−Sep2004
Observation, Ascending
ECMWF, Ascending
Limb Adjusted BT, Ascending
Observation, Descending
ECMWF, Descending
Limb Adjusted BT, Descending
−9.5 −8.6 −7.6 −6.7 −5.7 −4.8 −3.8 −2.9 −1.9 −0.9 0.0 0.9 1.9 2.9 3.8 4.8 5.7 6.7 7.6 8.6 9.5

240 mb

AIRS radiance changes (in deg K) to atm & sfc changes

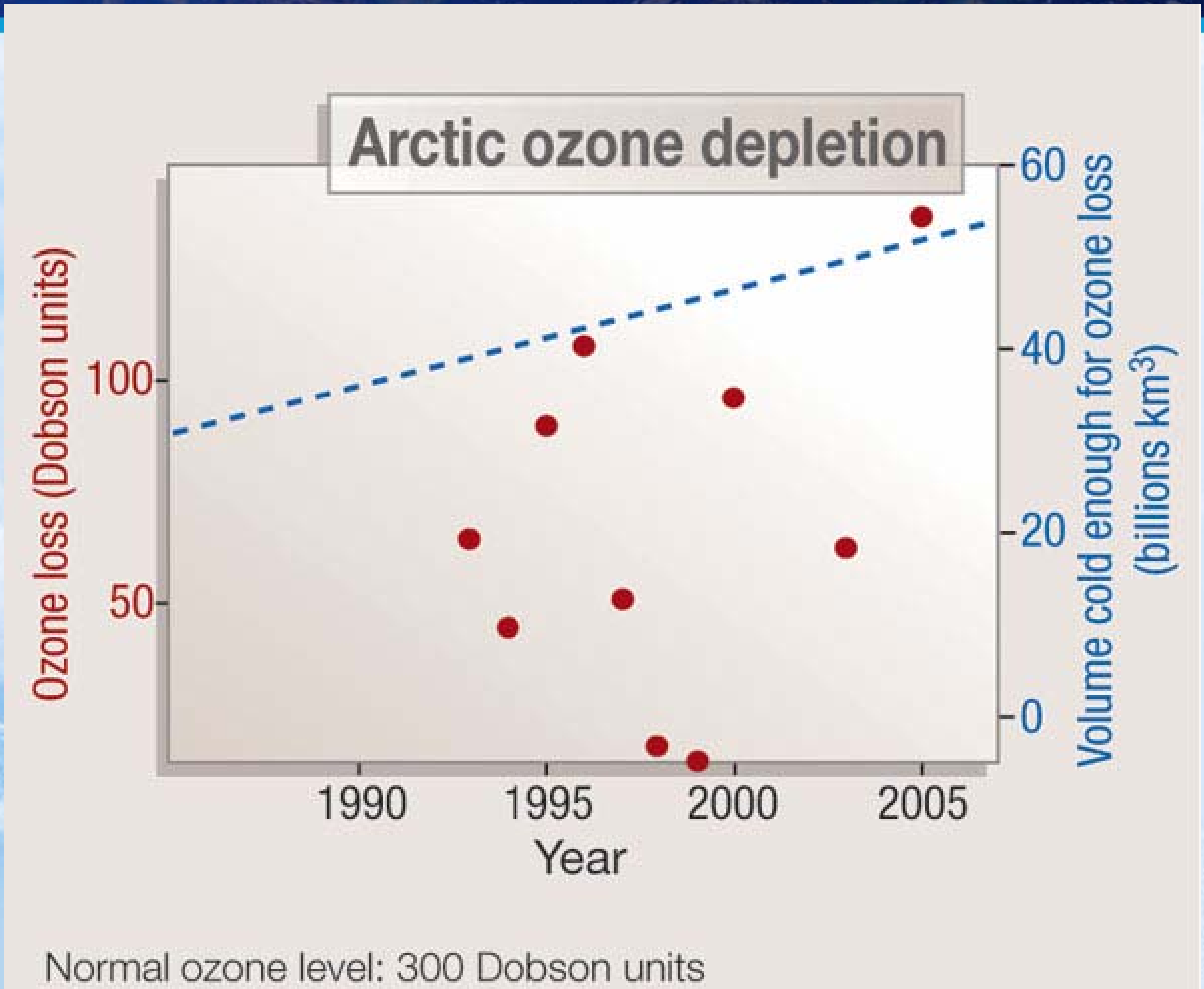



Global Average, Ascending, January
2004-2005
2004-2006
Difference (K)
Frequency (cm-1)
3
2.5
2
1.5
1
0.5
0
-0.5
-1
-1.5
-2
-2.5
-3
650
700
750
800
850
900
950
1000
1050
1100



1040.03cm−1
Descending
Jan 2004
Jan 2005
Jan 2004−2005
July 2004
July 2005
July 2004−2005
60N
30N
EQ
30S
60S
180 120W 60W 0 60E 120E 180
9 8 7 6 5 4 3 2 1 0 −1 −2 −3 −4 −5 −6 −7 −8 −9
195 200 205 210 215 220 225 230 235 240 245 250 255 260 265 270 275 280 285

Ozone Loss

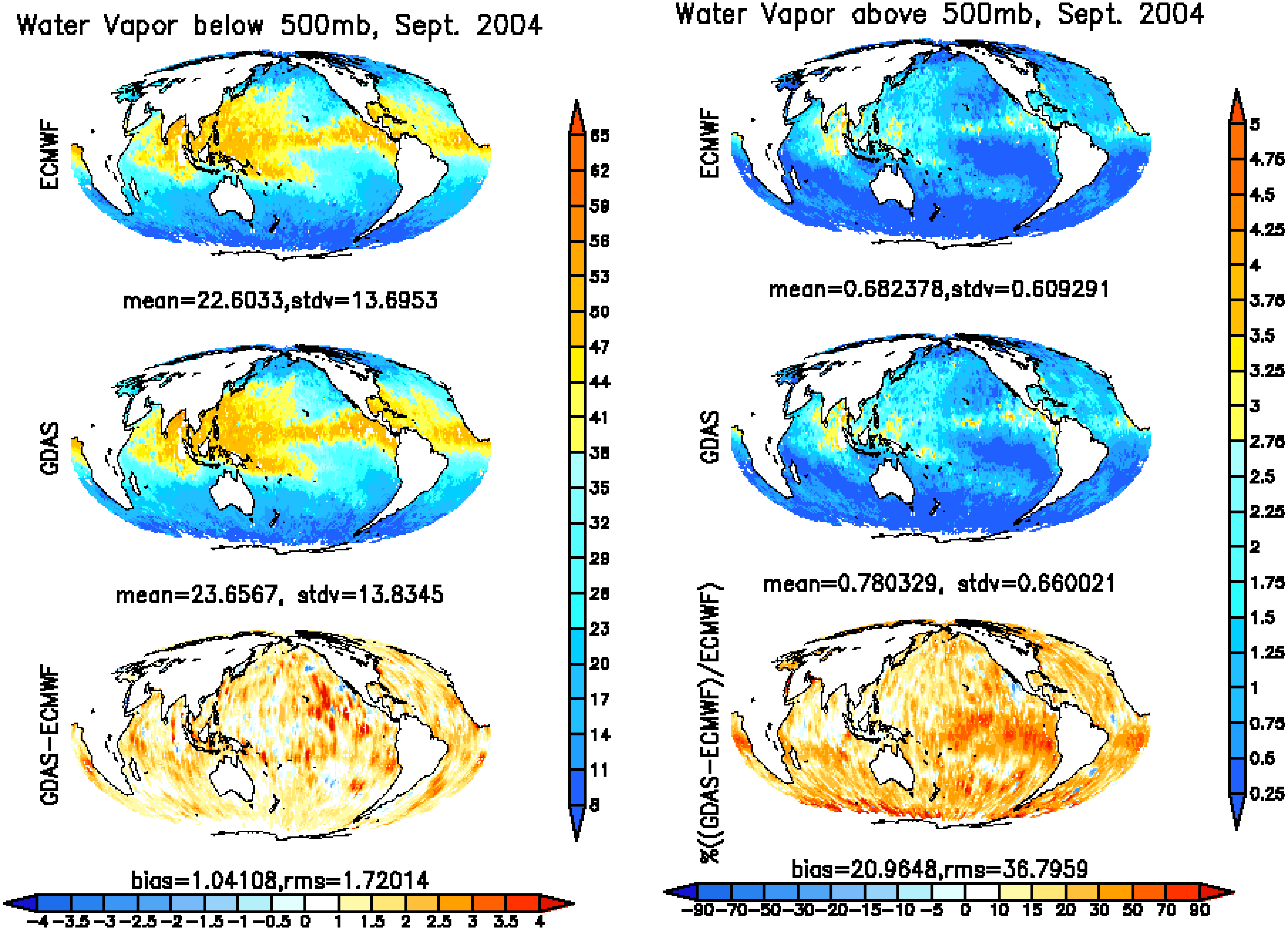


Arctic trends scrutinized as chilly winter destroys ozone

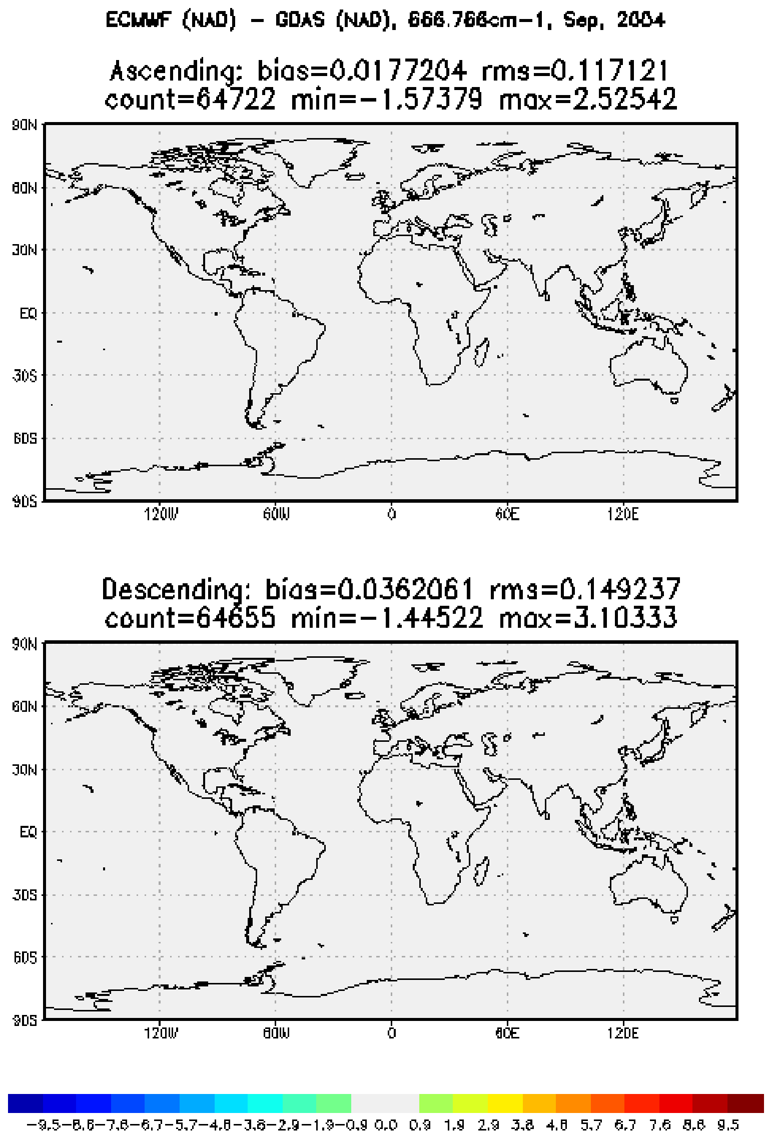
Is climate change to blame for looming northern hole?

Quirin Schiermeier, Nature, 5/5/05

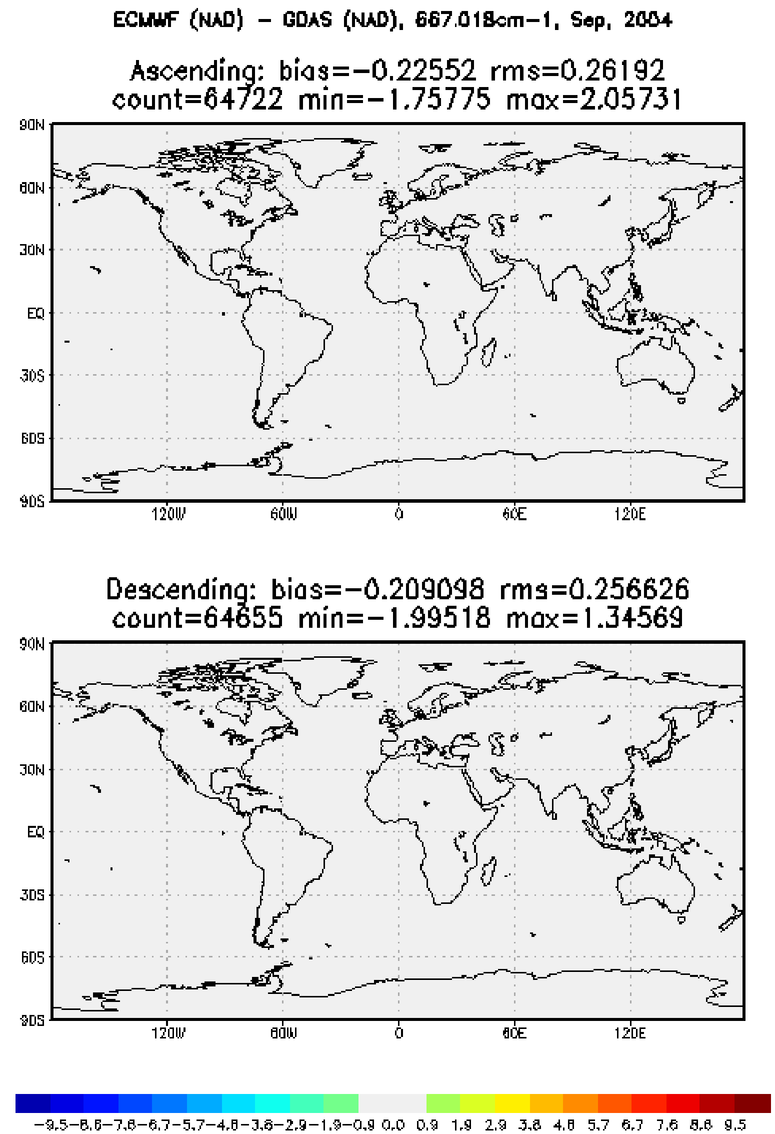
Validating Models


Water Vapor below 500mb, Sept. 2004
ECMWF
mean=22.6033,stdv=13.6953
GDAS
mean=23.6567, stdv=13.8345
GDAS−ECMWF
bias=1.04108,rms=1.72014
−4 −3.5 −3 −2.5 −2 −1.5 −1 −0.5 0 1 1.5 2 2.5 3 3.5 4
65 62 59 56 53 50 47 44 41 38 35 32 29 26 23 20 17 14 11 8
Water Vapor above 500mb, Sept. 2004
ECMWF
mean=0.682378,stdv=0.609291
GDAS
mean=0.780329, stdv=0.660021
%((GDAS−ECMWF)/ECMWF)
bias=20.9648,rms=36.7959
−90 −70 −50 −30 −20 −15 −10 −5 0 10 15 20 30 50 70 90
5 4.75 4.5 4.25 4 3.75 3.5 3.25 3 2.75 2.5 2.25 2 1.75 1.5 1.25 1 0.75 0.5 0.25

ECMWF and NCEP are nearly identical for temperature

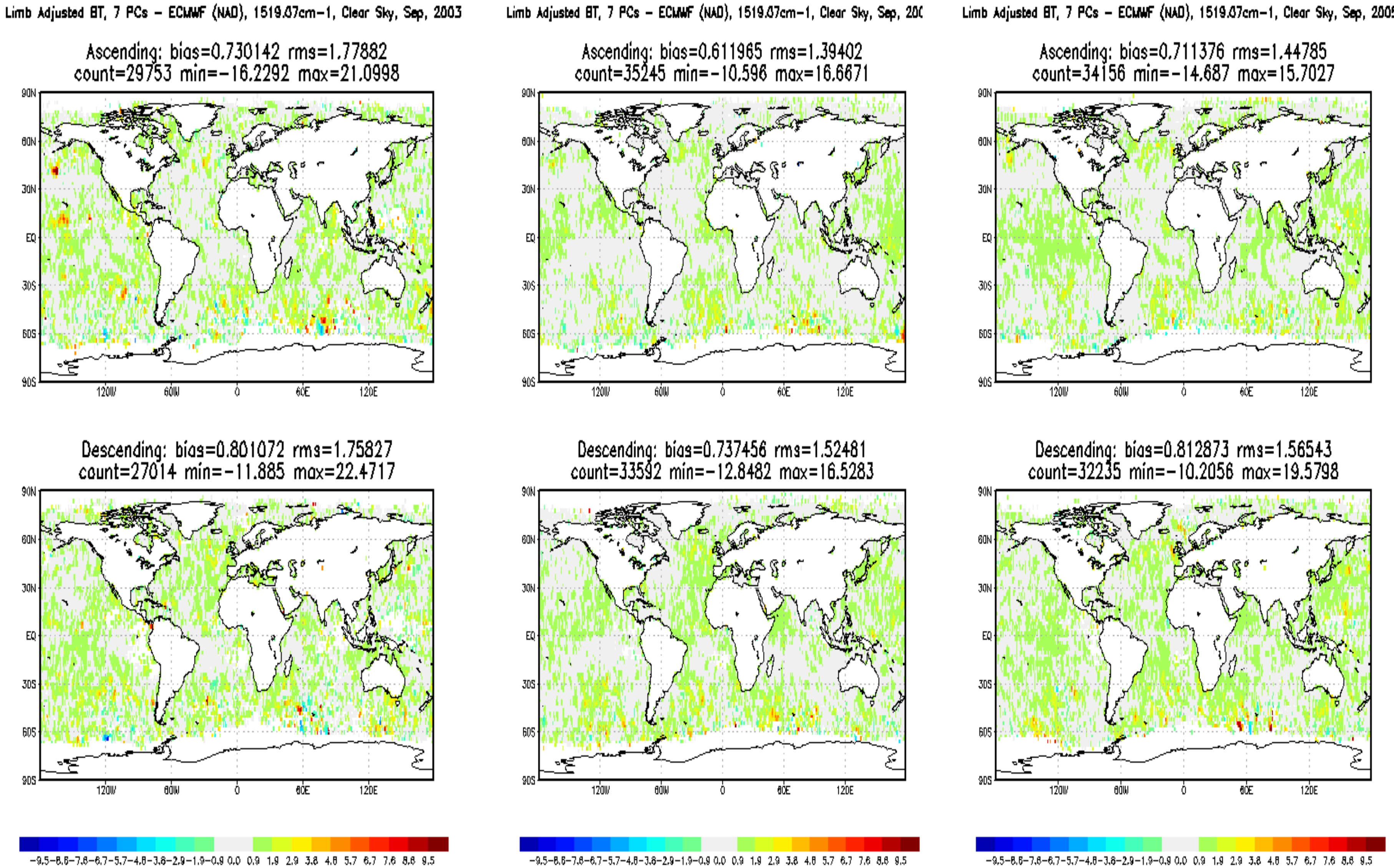


35 mb



26 mb

Observed AIRS minus ECMWF Simulated AIRS for Upper Trop. Water Vapor



2003

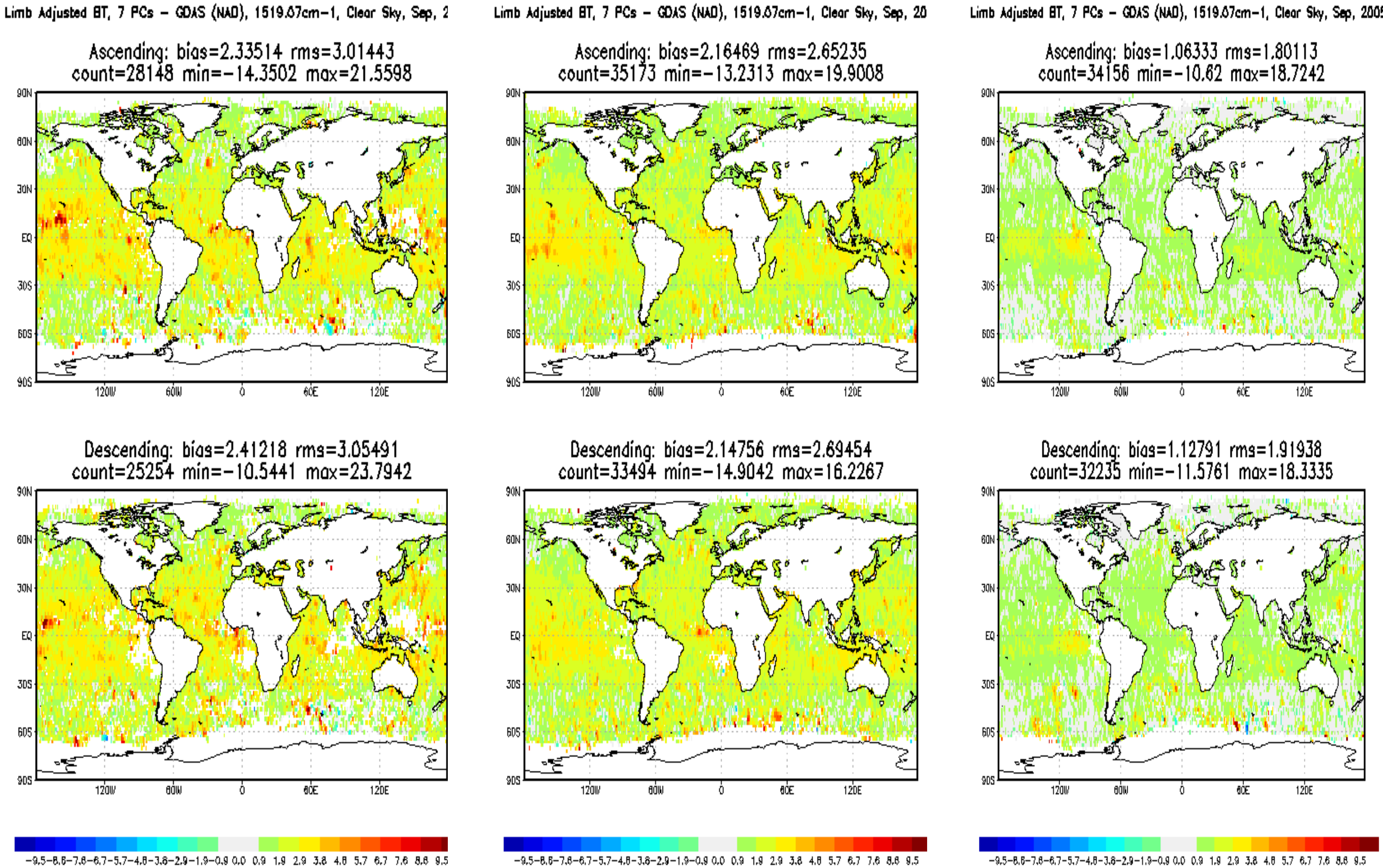
270 mb

2004

2005

AIRS assimilated operationally

Observed AIRS minus NCEP Simulated AIRS for Upper Trop. Water Vapor



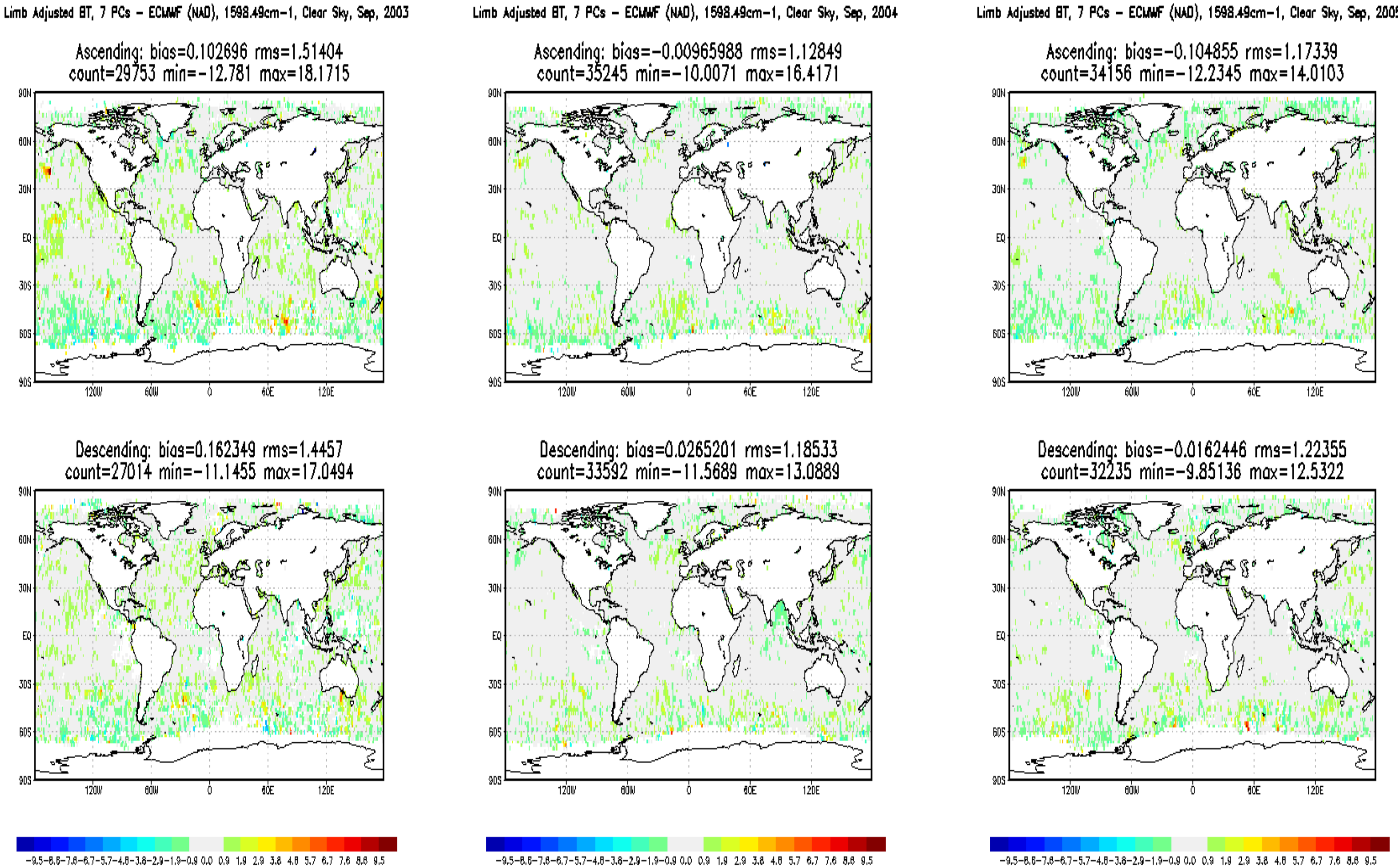
2003

2004

270 mb

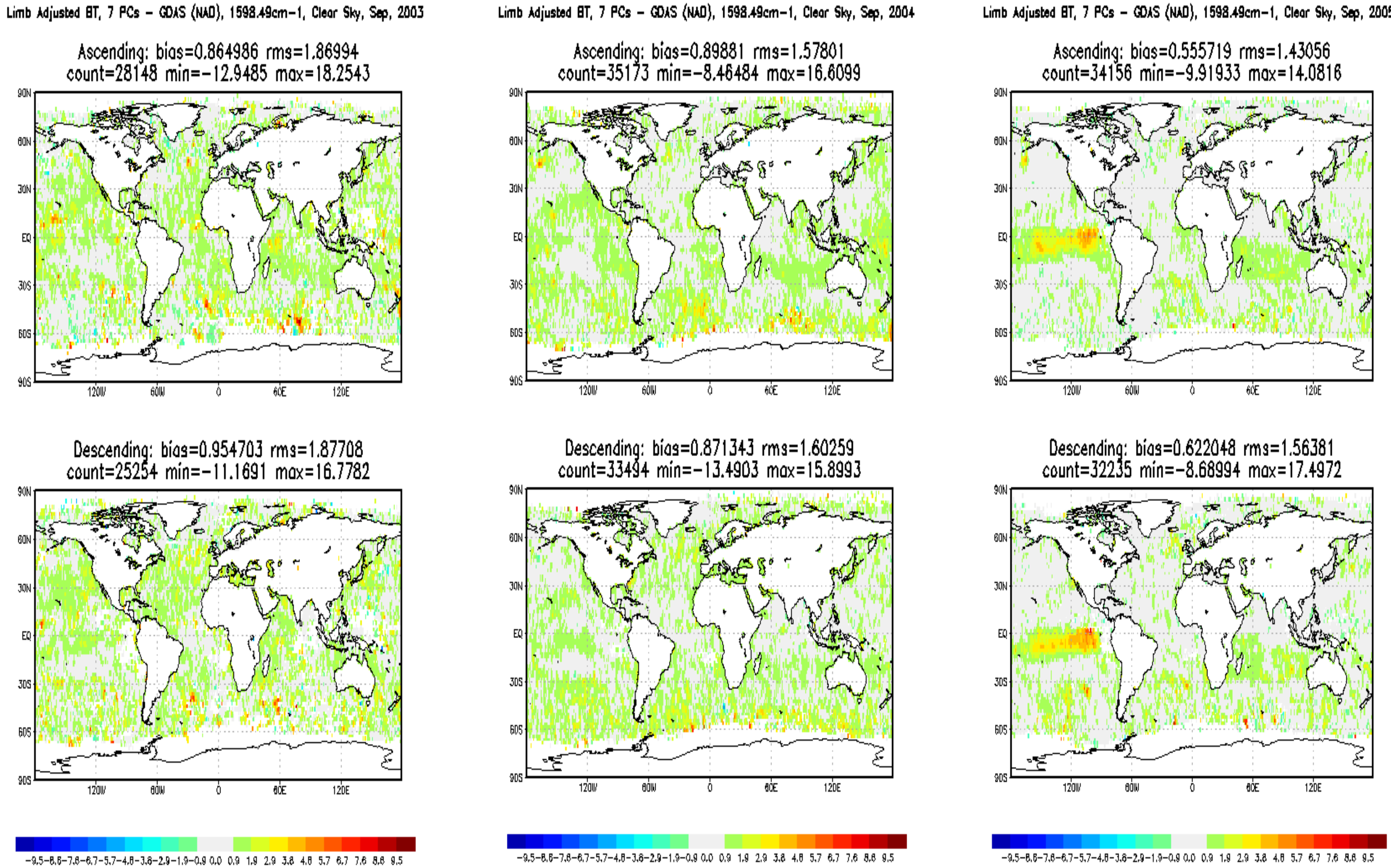
2005

AIRS assimilated operationally



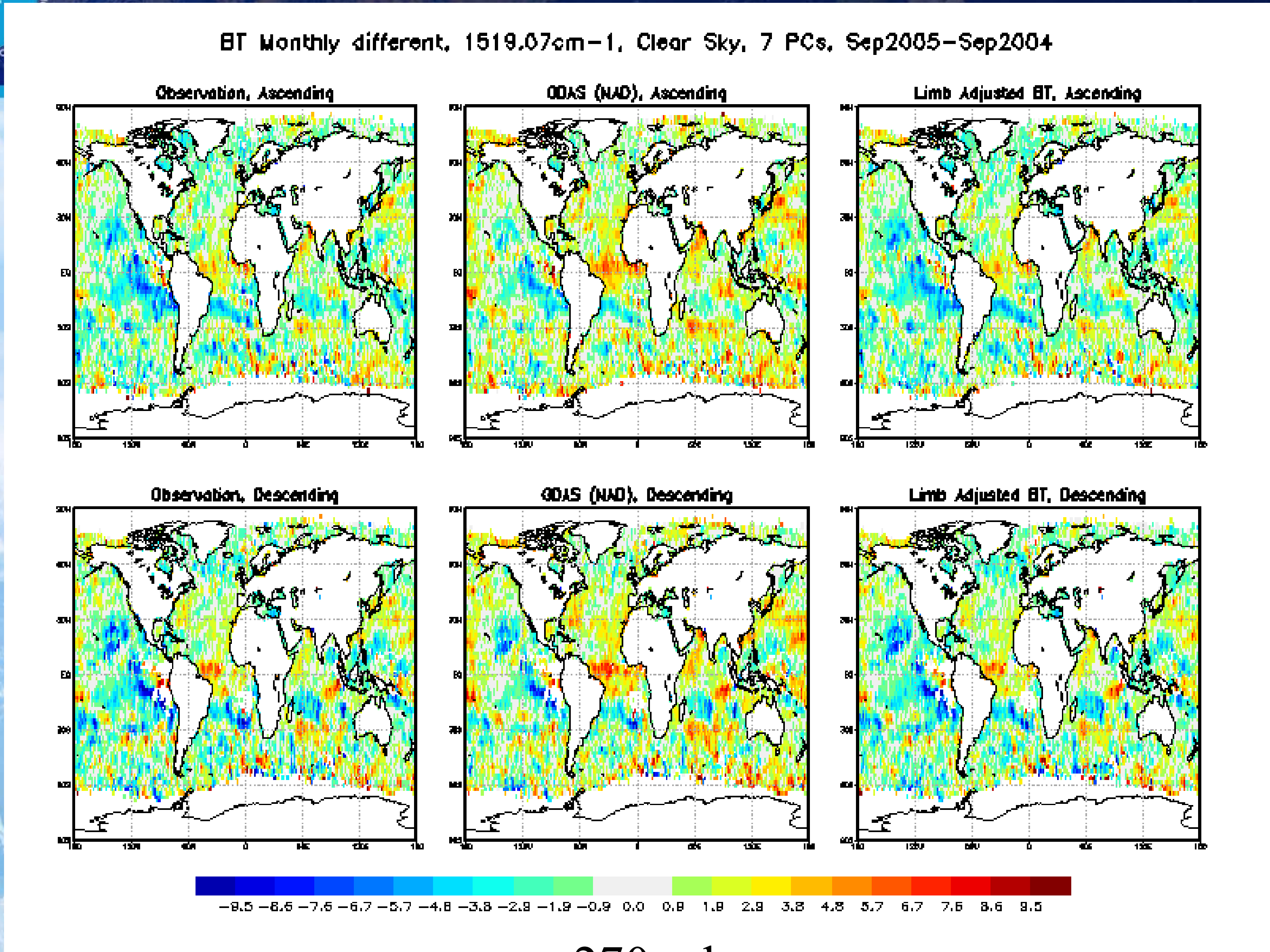
520 mb 2004 2005

AIRS assimilated operationally

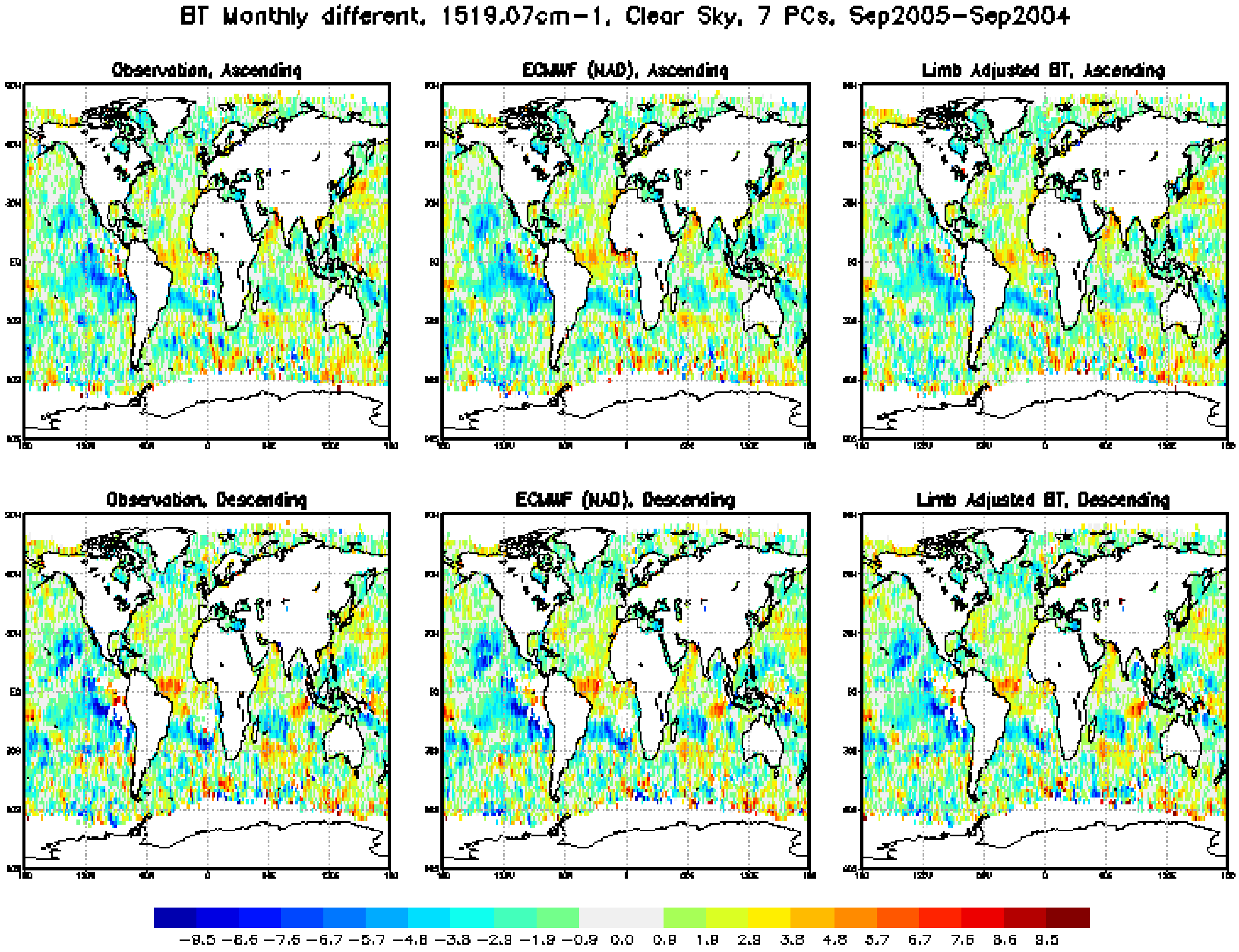


520 mb

AIRS assimilated operationally


BT Monthly different, 1519.07cm-1, Clear Sky, 7 PCs, Sep2005-Sep2004
Observation, Ascending
ODAS (NAD), Ascending
Limb Adjusted BT, Ascending
Observation, Descending
GDAS (NAD), Descending
Limb Adjusted BT, Descending
-9.5 -8.6 -7.6 -6.7 -5.7 -4.8 -3.8 -2.9 -1.9 -0.9 0.0 0.9 1.9 2.9 3.8 4.8 5.7 6.7 7.6 8.6 9.5

270 mb

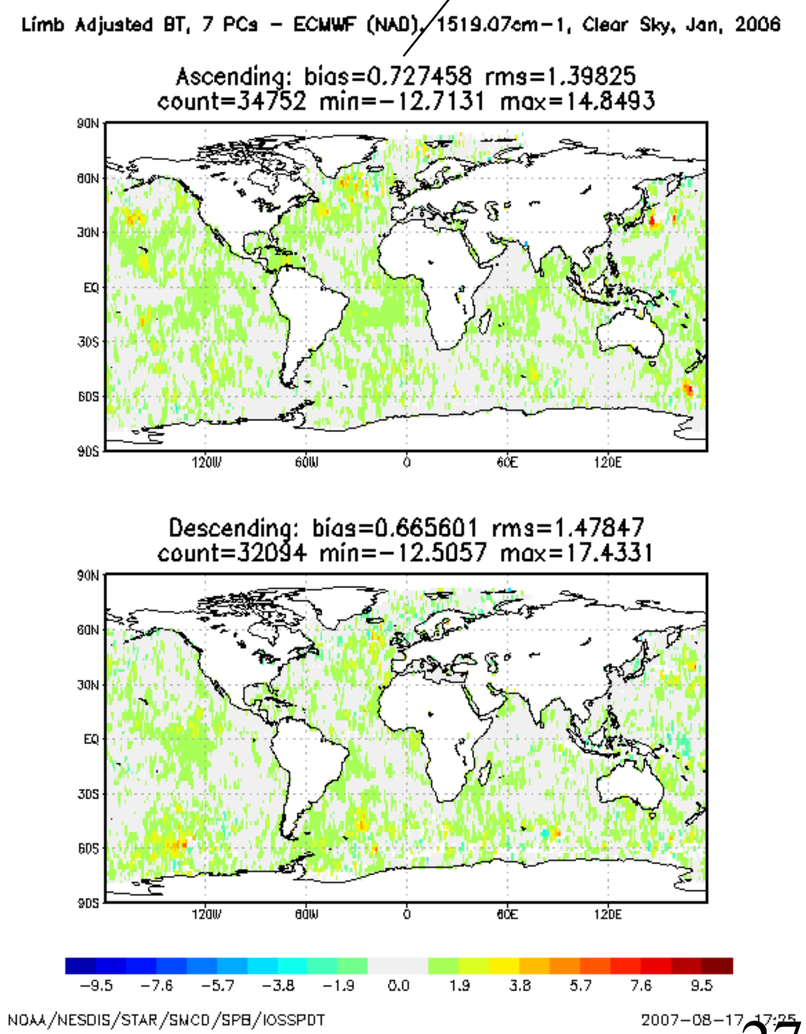

BT Monthly different, 1519.07cm-1, Clear Sky, 7 PCs, Sep2005-Sep2004
Observation, Ascending
ECMWF (NAD), Ascending
Limb Adjusted BT, Ascending
Observation, Descending
ECMWF (NAD), Descending
Limb Adjusted BT, Descending
-9.5 -8.6 -7.6 -6.7 -5.7 -4.8 -3.8 -2.9 -1.9 -0.9 0.0 0.9 1.9 2.9 3.8 4.8 5.7 6.7 7.6 8.6 9.5

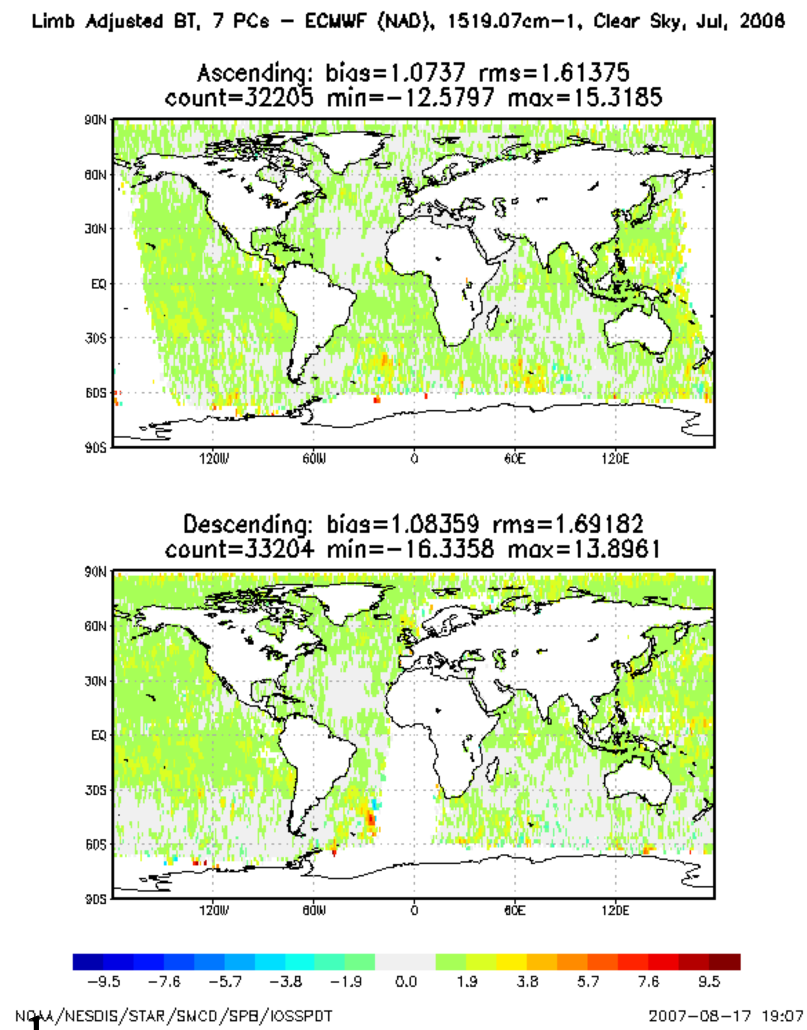
270 mb

However …….

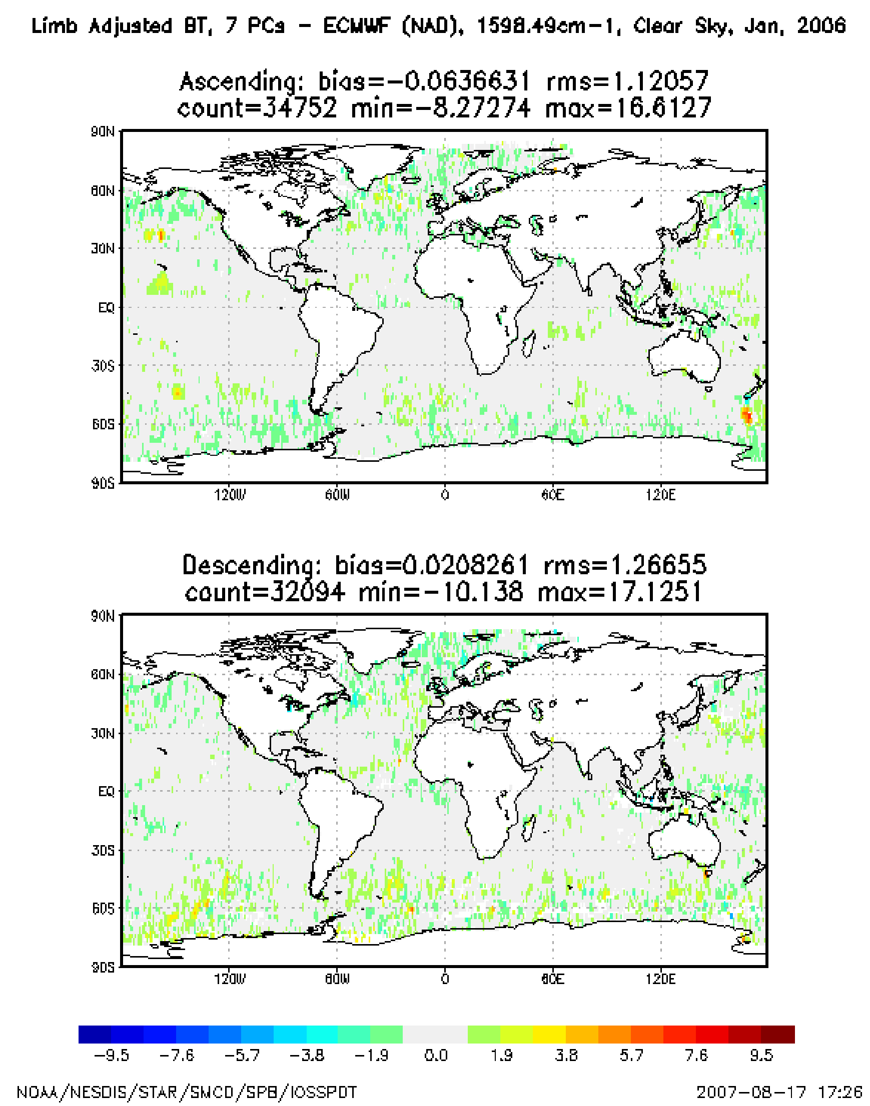
Larger bias in ECMWF water vapor fields after May 2006 model upgrade…

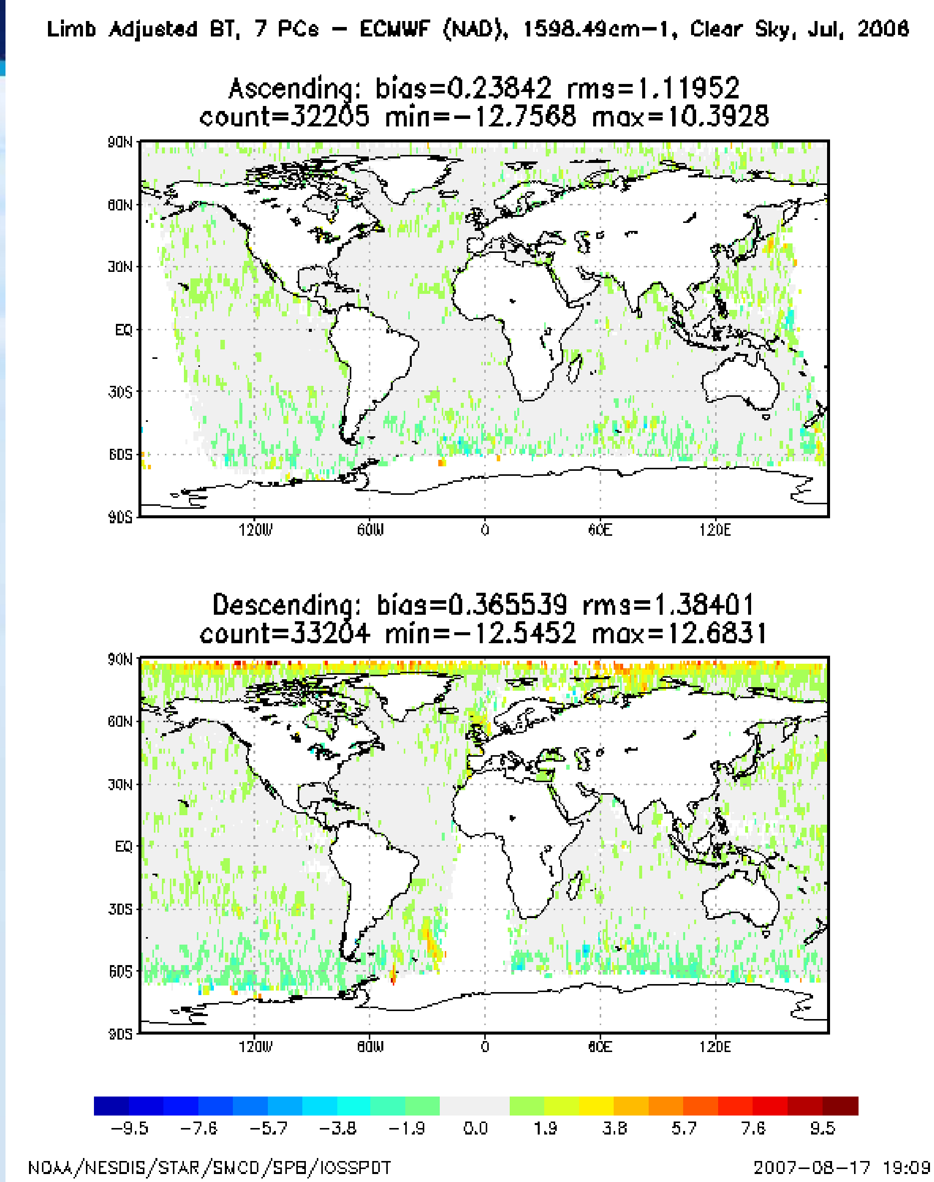
Consistent with Sept 03,04,05





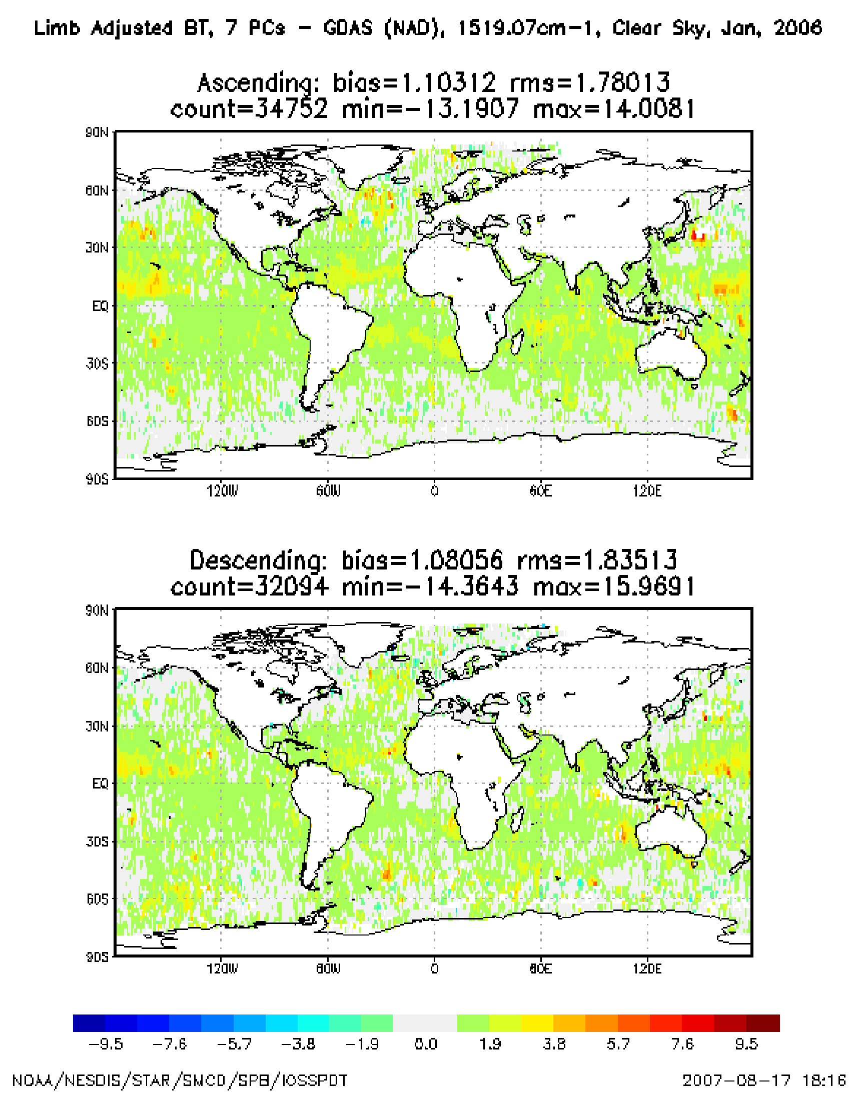
270 mb


Limb Adjusted BT, 7 PCs - ECMWF (NAD), 1598.49cm-1, Clear Sky, Jan, 2006
Ascending: bias=-0.0636631 rms=1.12057
count=34752 min=-8.27274 max=16.6127
Descending: bias=0.0208261 rms=1.26655
count=32094 min=-10.138 max=17.1251
90N 60N 30N EQ 30S 60S 90S
120W 60W 0 60E 120E
-9.5 -7.6 -5.7 -3.8 -1.9 0.0 1.9 3.8 5.7 7.6 9.5
NOAA/NESDIS/STAR/SMCD/SPB/IOSSPDT
2007-08-17 17:26

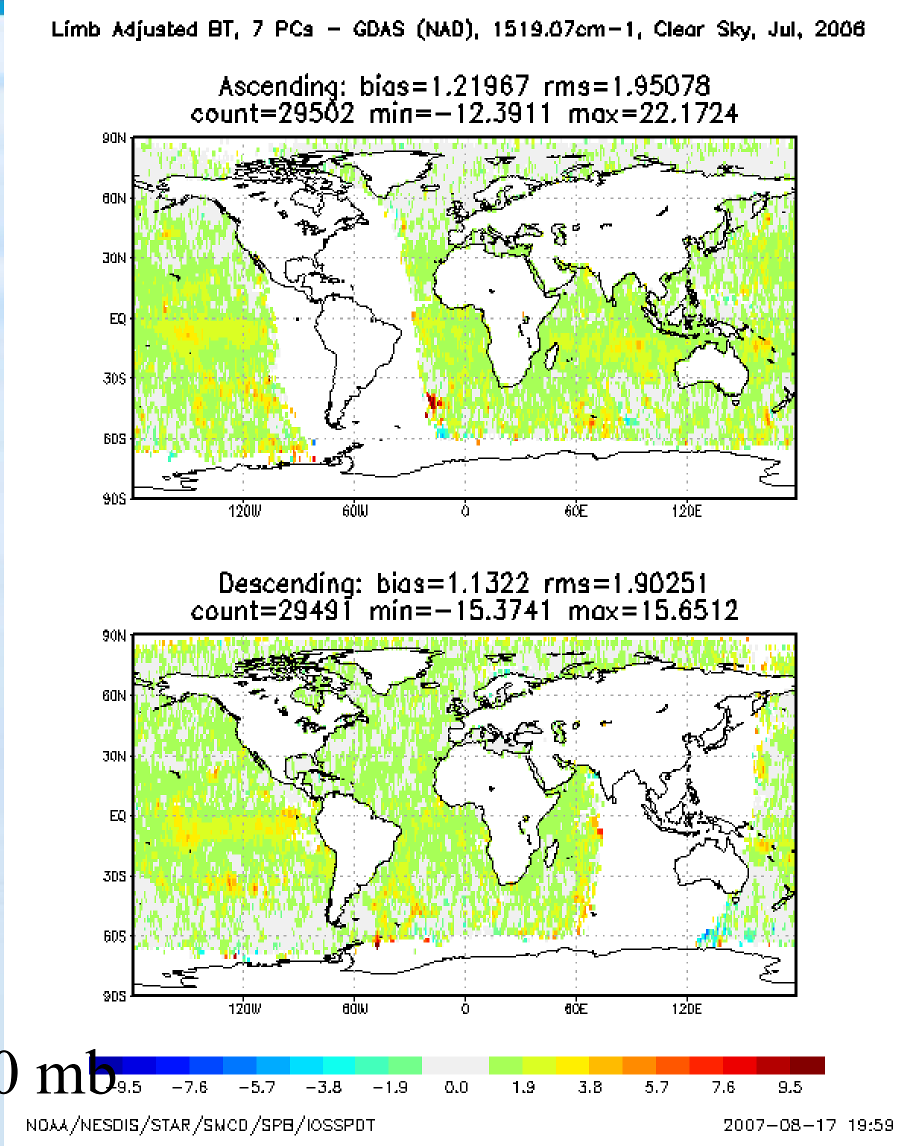

Limb Adjusted BT, 7 PCs - ECMWF (NAD), 1598.49cm-1, Clear Sky, Jul, 2006
Ascending: bias=0.23842 rms=1.11952
count=32205 min=-12.7568 max=10.3928
Descending: bias=0.365539 rms=1.38401
count=33204 min=-12.5452 max=12.6831
90N 60N 30N EQ 30S 60S 90S
120W 60W 0 60E 120E
-9.5 -7.6 -5.7 -3.8 -1.9 0.0 1.9 3.8 5.7 7.6 9.5
NOAA/NESDIS/STAR/SMCD/SPB/IOSSPDT
2007-08-17 19:09

520 mb

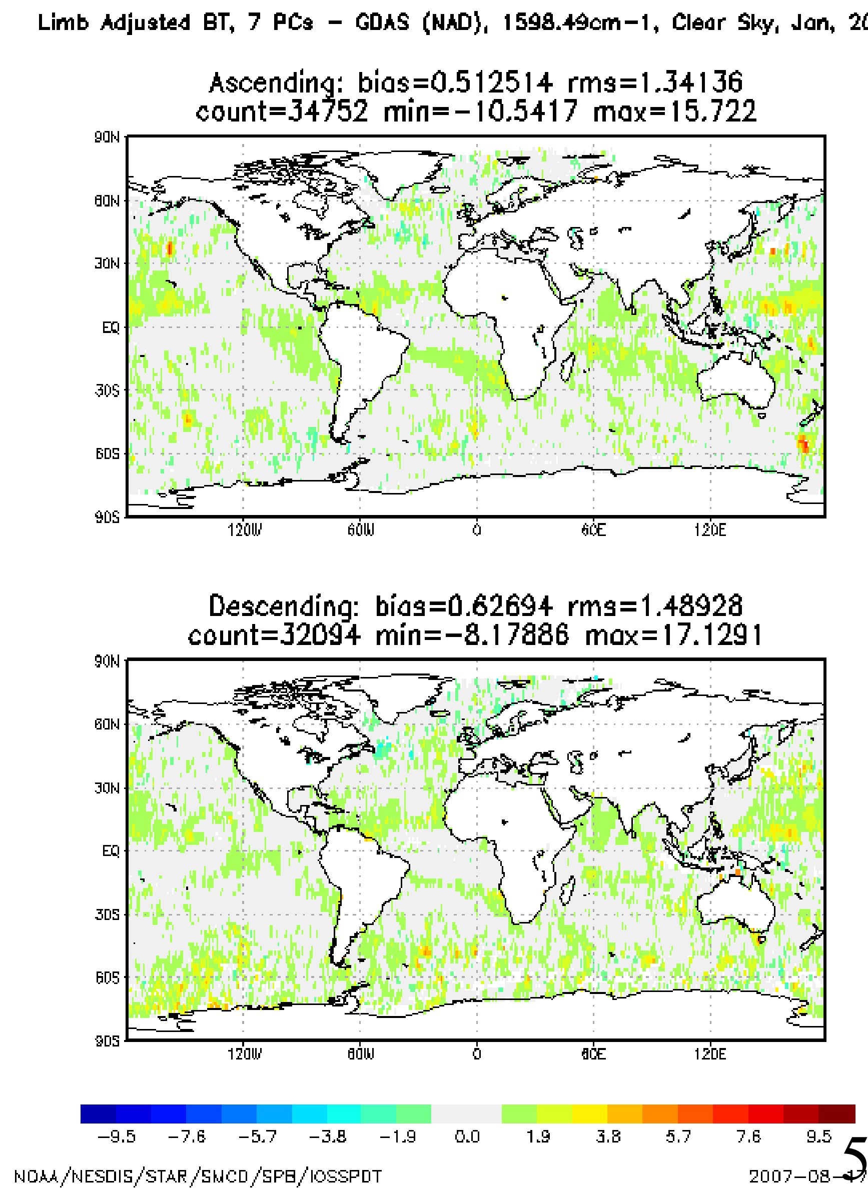
GDAS consistent with Sept 05

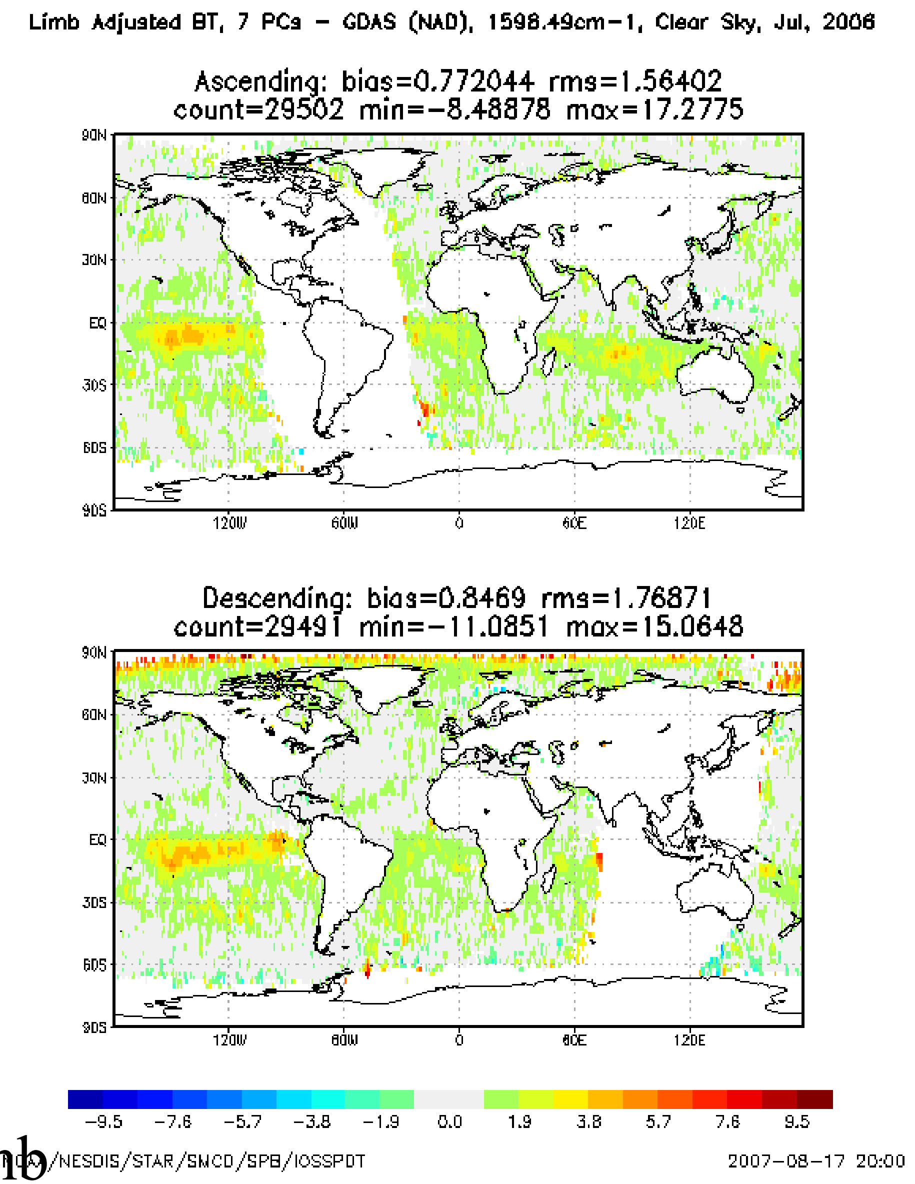


270 mb



GDAD consistent with Sept 05





520 mb

Principal Component Analysis is used for

- Data compression

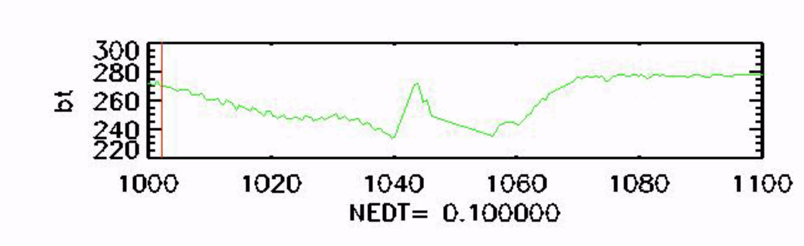
- Reconstructed radiances (noise filtered radiances)

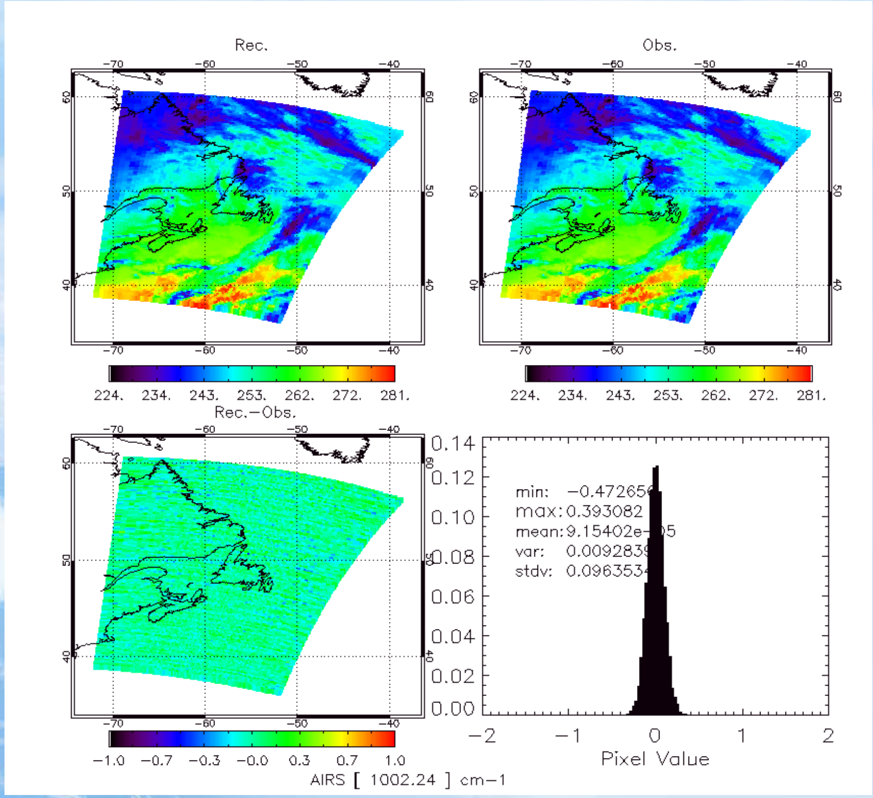
- Case-dependent (dynamic) noise estimation

- Quality control

- Regression retrieval

Data Compression





- 40 PCs for granule dependent EOFs
- 100 PCs for global independent EOFs

- The residuals are at noise levels and can be compressed and stored in a separate file for lossless compression

- Most people will not want the residuals.

- The picture to the left can be also used as a form of metadata to convince the user that the lossy compression is OK.

- Users can decide whether they want the residual file

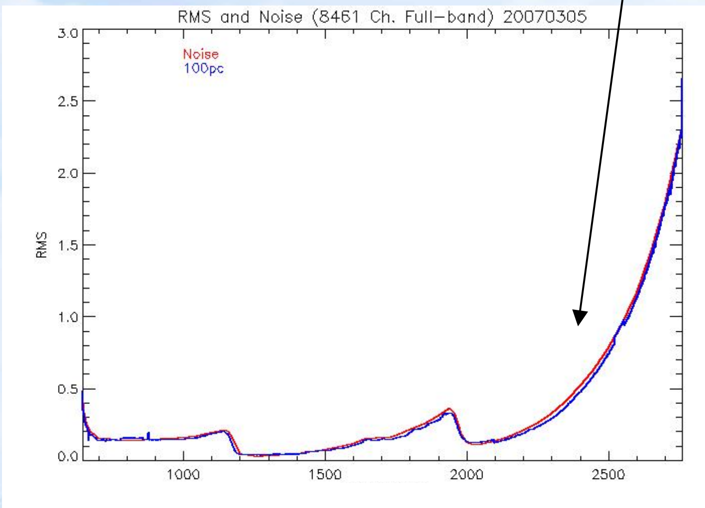
Eigenvector Analysis for Noise Reduction

- Eigenvector analysis allows correlated data to be represented by a relatively small set of functions.

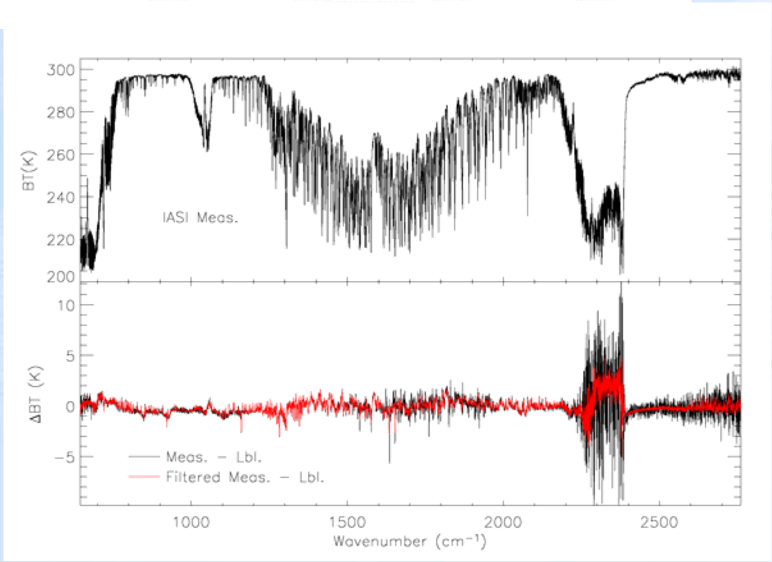
- 8461 channels can easily be represented by a 100 unique coefficients couples with 100 static structure functions (100 x 8461)

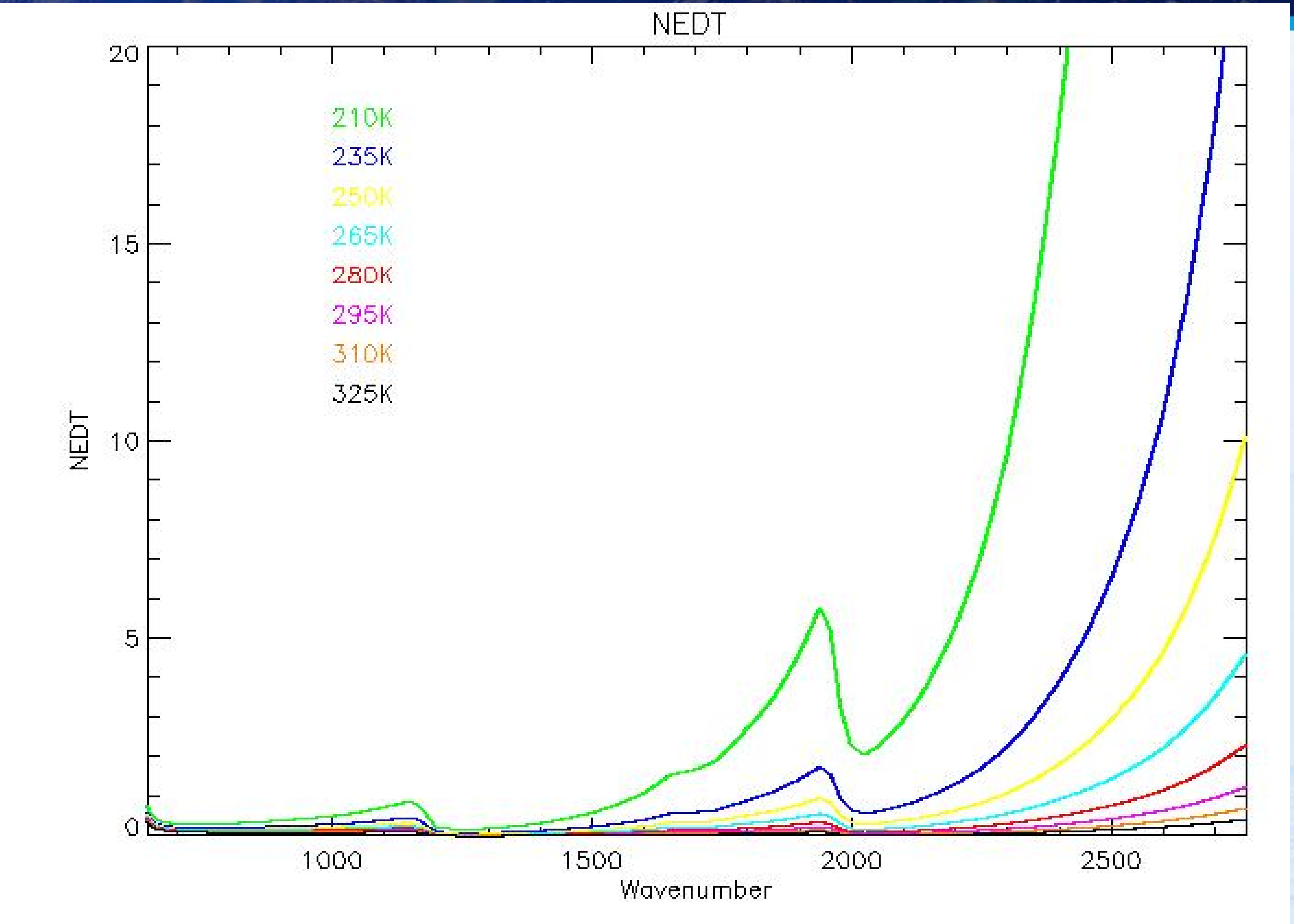
- Benefits: Noise filtering and data compression. Distribute and archive 100 coefficients instead of 8461 channels (lossy compression) We can now use shortwave IR window channels for applications (LW vs SW cloud tests)

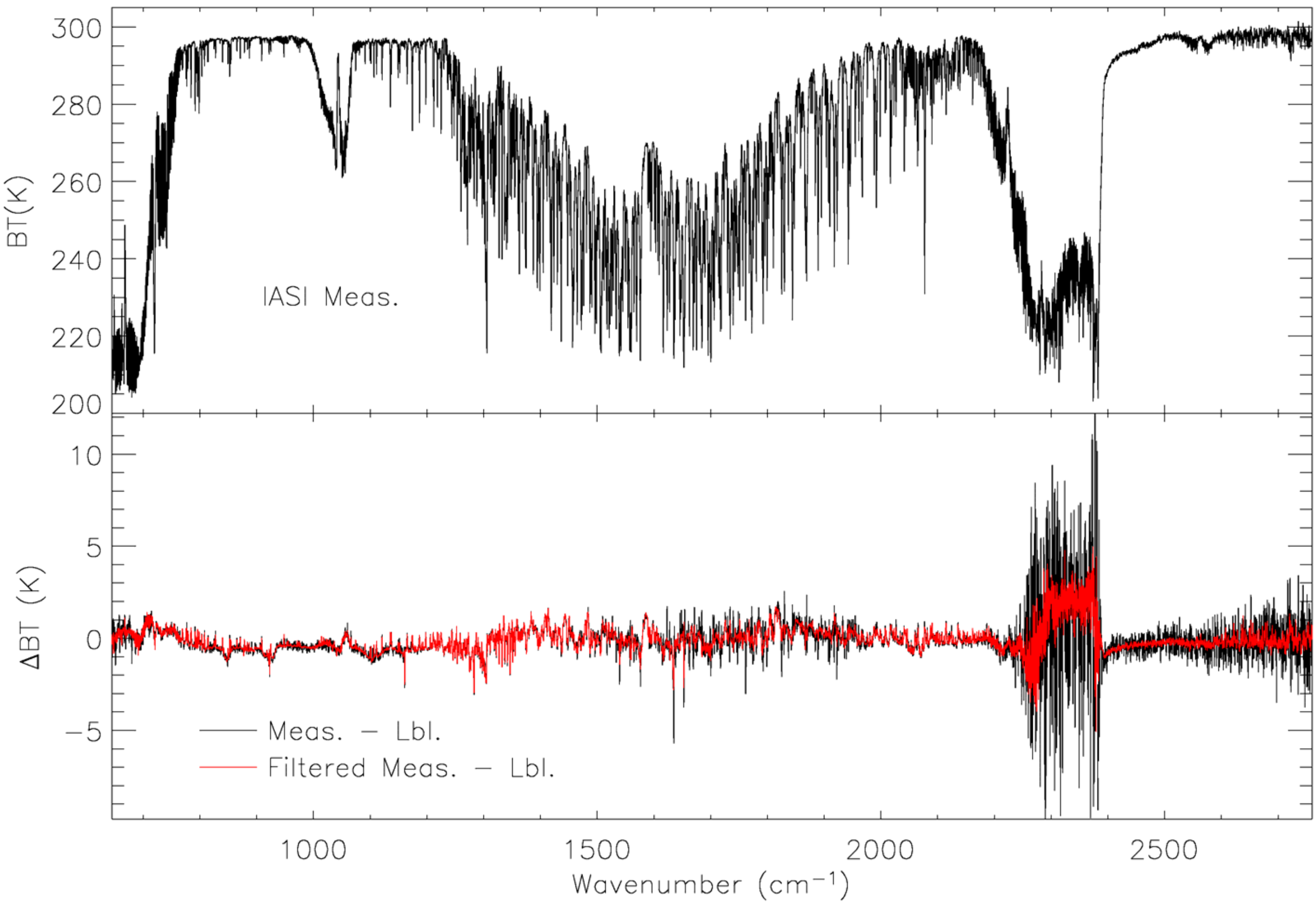
Independent assessment of noise from root mean Square difference between measured and reconstructed noise. The reconstructed radiances are noise filtered, therefore the rms matches the instrument noise



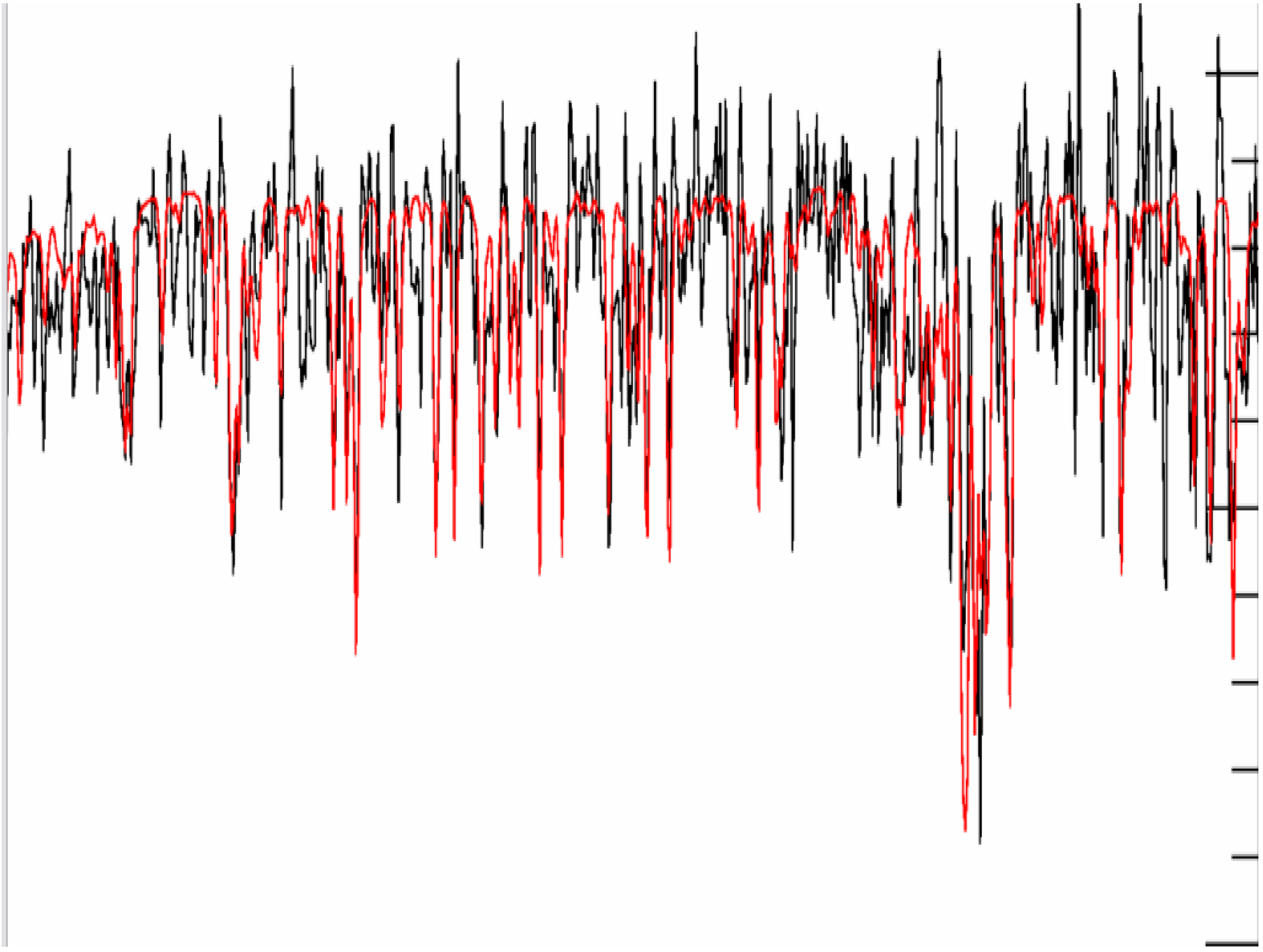
280 K

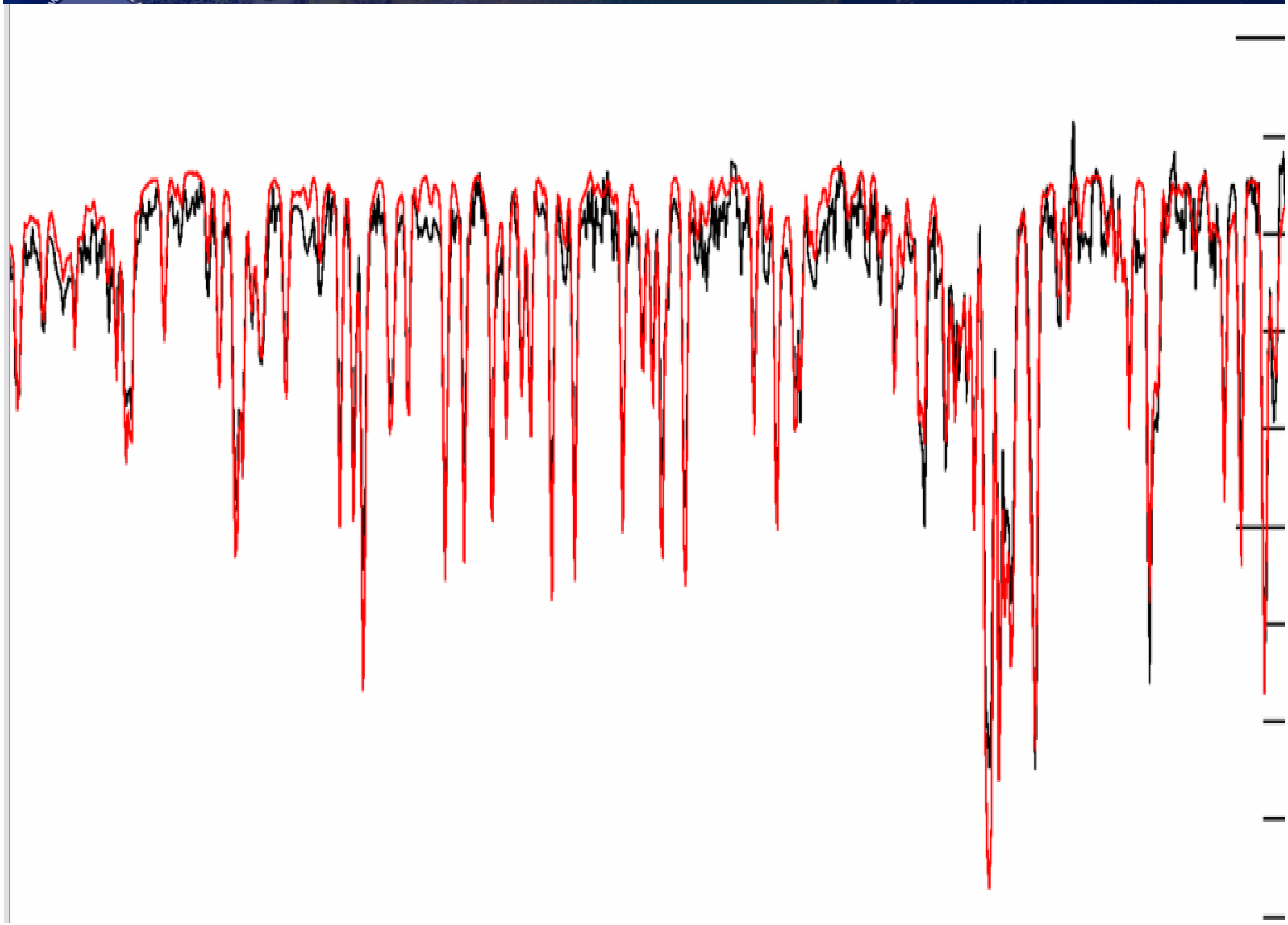



NEDT
210K
235K
250K
265K
280K
295K
310K
325K
NEDT
0
5
10
15
20
1000
1500
2000
2500
Wavenumber



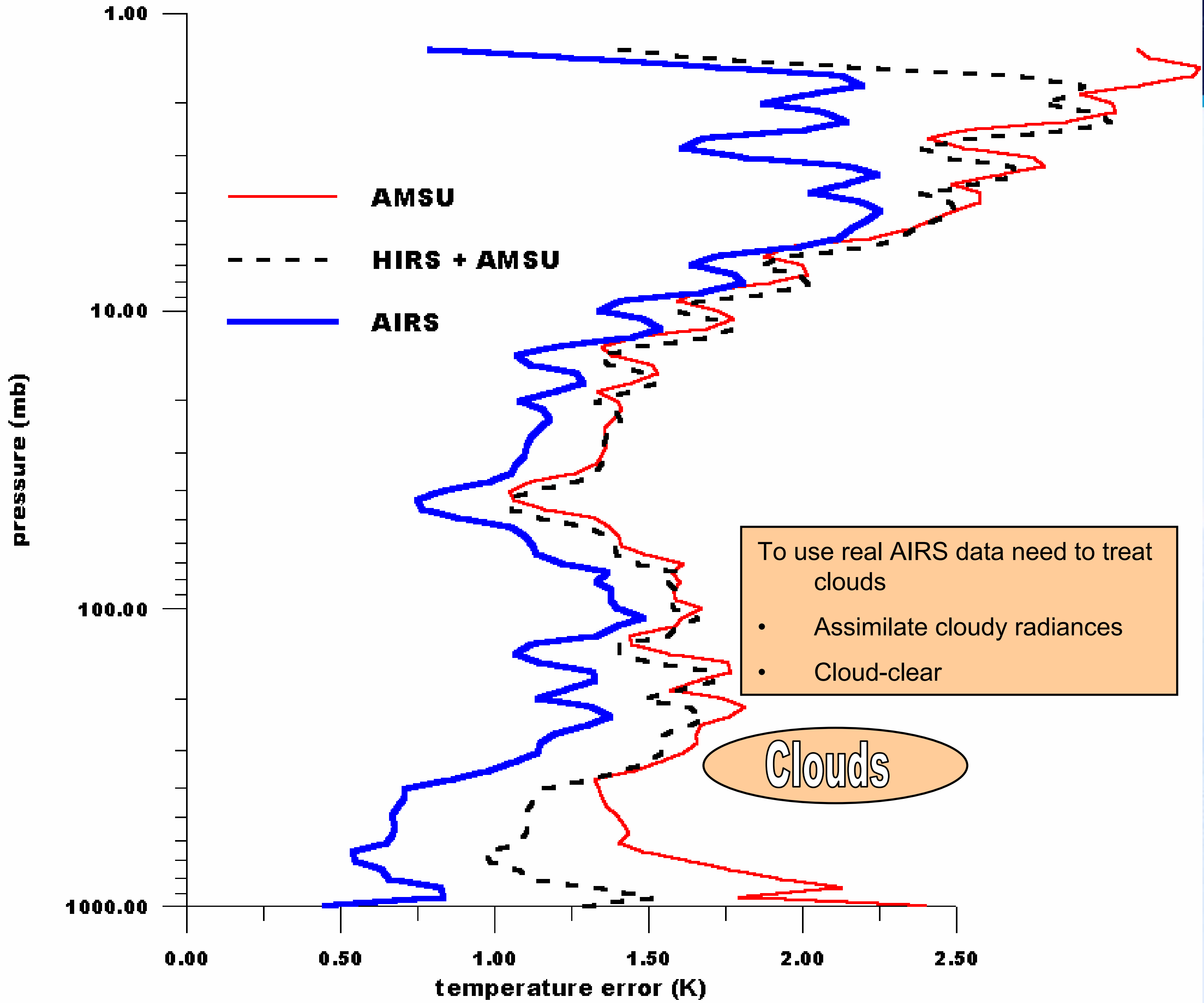
300
280
260
240
220
200
BT(K)
IASI Meas.
10
5
0
−5
ΔBT (K)
Meas. − Lbl.
Filtered Meas. − Lbl.
1000
1500
2000
2500
Wavenumber (cm⁻¹)





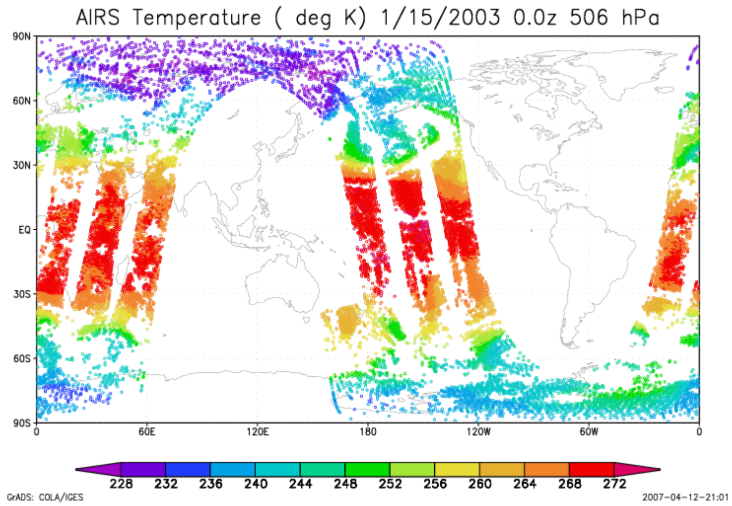
AIRS Retrieval vs Radiance Assimilation

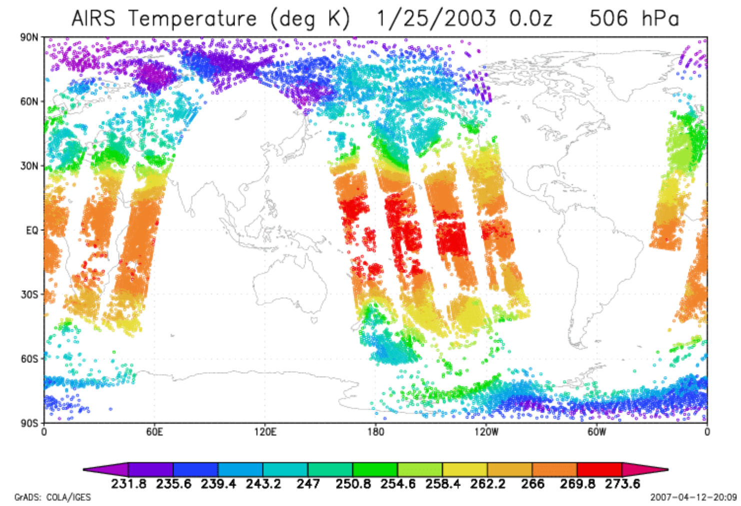
Temperature errors as a function of sounder instrumentation

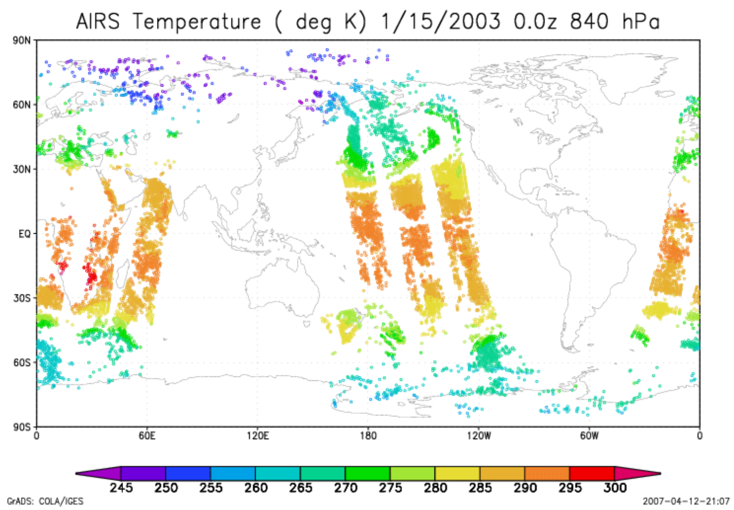


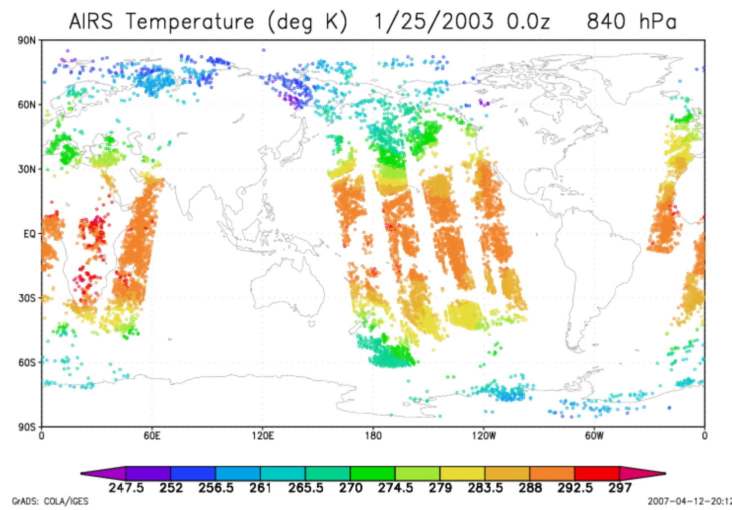
To use real AIRS data need to treat clouds

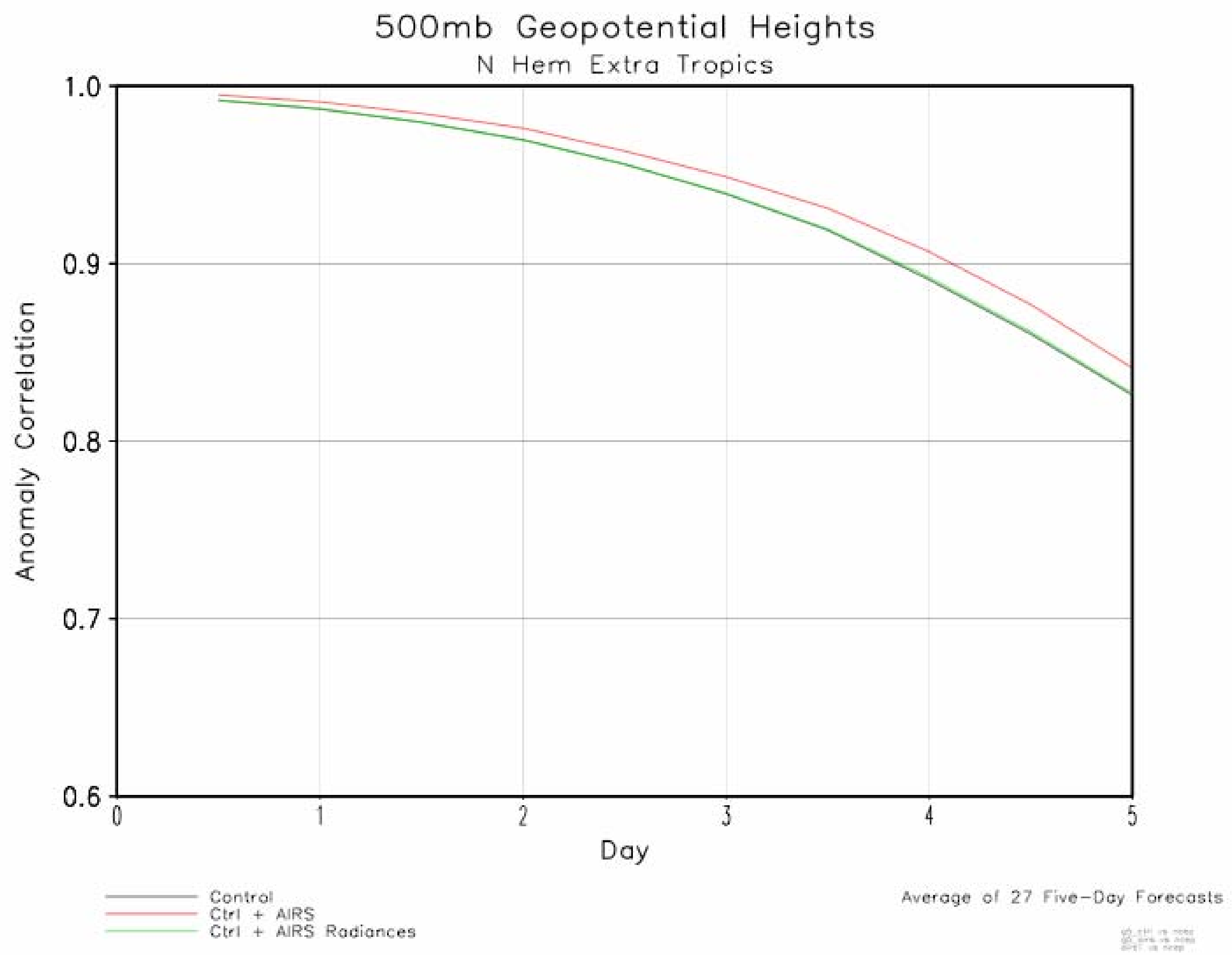
- Assimilate cloudy radiances
- Cloud-clear


AIRS Temperature (deg K) 1/15/2003 0.0z 506 hPa
90N
60N
30N
EQ
30S
60S
90S
0
60E
120E
180
120W
60W
0
228 232 236 240 244 248 252 256 260 264 268 272
GrADS: COLA/IGES
2007-04-12-21:01

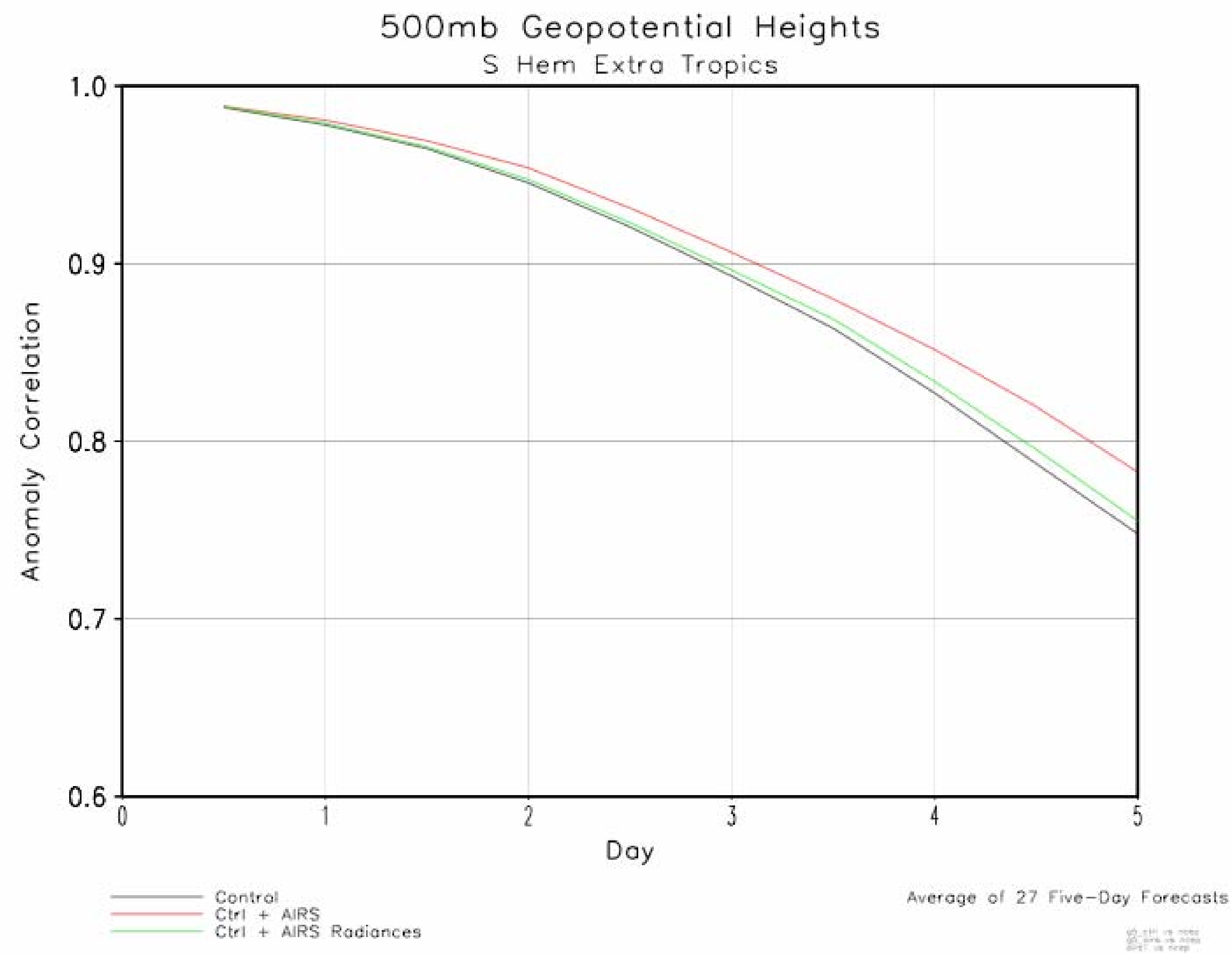

AIRS Temperature (deg K) 1/25/2003 0.0z 506 hPa
90N
60N
30N
EQ
30S
60S
90S
0
60E
120E
180
120W
60W
0
231.8 235.6 239.4 243.2 247 250.8 254.6 258.4 262.2 266 269.8 273.6
GrADS: COLA/IGES
2007-04-12-20:09


AIRS Temperature (deg K) 1/15/2003 0.0z 840 hPa
90N
60N
30N
EQ
30S
60S
90S
0
60E
120E
180
120W
60W
0
245 250 255 260 265 270 275 280 285 290 295 300
GrADS: COLA/IGES
2007-04-12-21:07


AIRS Temperature (deg K) 1/25/2003 0.0z 840 hPa
90N
60N
30N
EQ
30S
60S
90S
0
60E
120E
180
120W
60W
0
247.5 252 256.5 261 265.5 270 274.5 279 283.5 288 292.5 297
GrADS: COLA/IGES
2007-04-12-20:12



500mb Geopotential Heights
N Hem Extra Tropics
Anomaly Correlation
1.0
0.9
0.8
0.7
0.6
0
1
2
3
4
5
Day
Control
Ctrl + AIRS
Ctrl + AIRS Radiances
Average of 27 Five-Day Forecasts



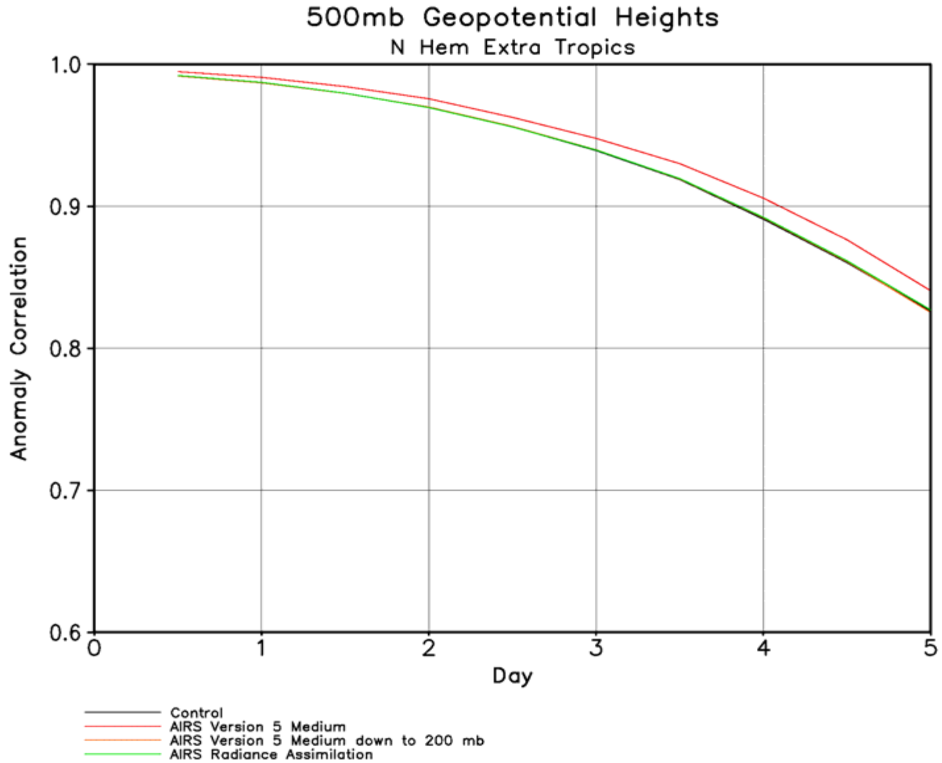
500mb Geopotential Heights
S Hem Extra Tropics
Anomaly Correlation
1.0
0.9
0.8
0.7
0.6
0
1
2
3
4
5
Day
Control
Ctrl + AIRS
Ctrl + AIRS Radiances
Average of 27 Five-Day Forecasts

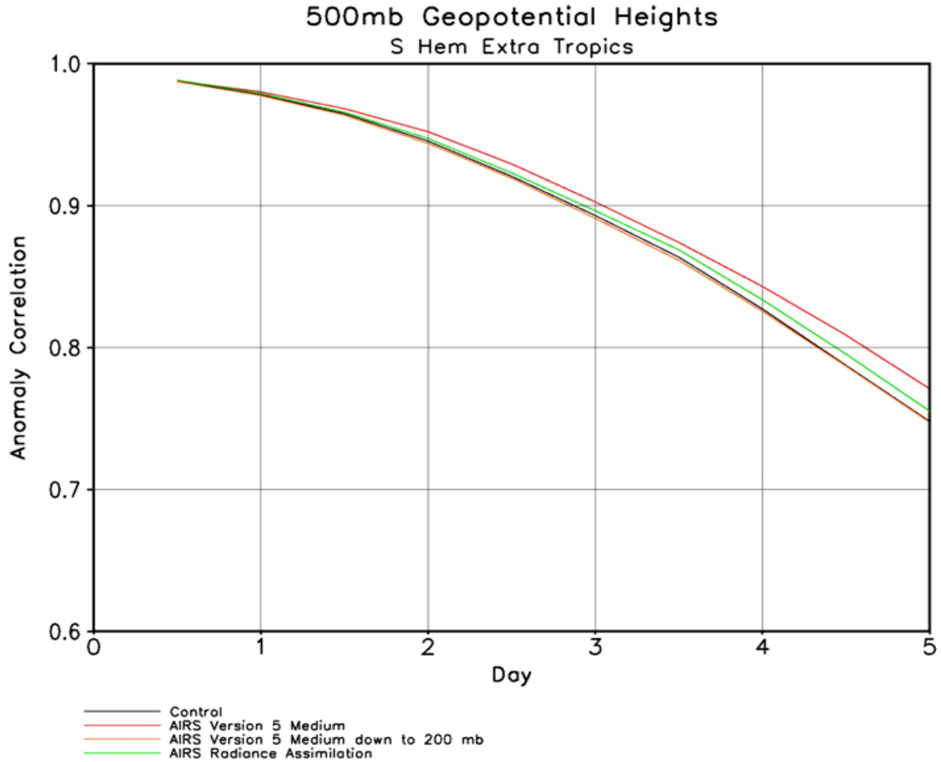
Experiment 2: Test of The Importance of Assimilation of Tropospheric Temperatures

Motivation

Tony McNally at ECMWF stated that most of the impact of AIRS radiances on ECMWF analysis comes from 15μm stratospheric sounding channels-claims only stratospheric information is important

Experiment - Use AIRS retrievals from top to 200 mb vs all levels


500mb Geopotential Heights
N Hem Extra Tropics
Anomaly Correlation
Day
Control
AIRS Version 5 Medium
AIRS Version 5 Medium down to 200 mb
AIRS Radiance Assimilation


500mb Geopotential Heights
S Hem Extra Tropics
Anomaly Correlation
Day
Control
AIRS Version 5 Medium
AIRS Version 5 Medium down to 200 mb
AIRS Radiance Assimilation

Summary

- We have learned quite a bit!!
- AIRS is a very accurate and stable instrument
- Providing very accurate soundings
- Providing the first-ever operational trace gas products
- Used for validation climate and NWP models
- Positive impact in NWP
- Other applications – aerosols, dust, volcanic ash/SO2
- Retrievals impacts are very promising!!!