USING HYPERSPECTRAL INFRARED RADIANCE GLOBAL DATA SETS TO VALIDATE WEATHER AND CLIMATE ANALYSES

Mitchell D. Goldberg, Lihang Zhou, Xingpin Liu, Zhaohui Cheng, Likun Wang

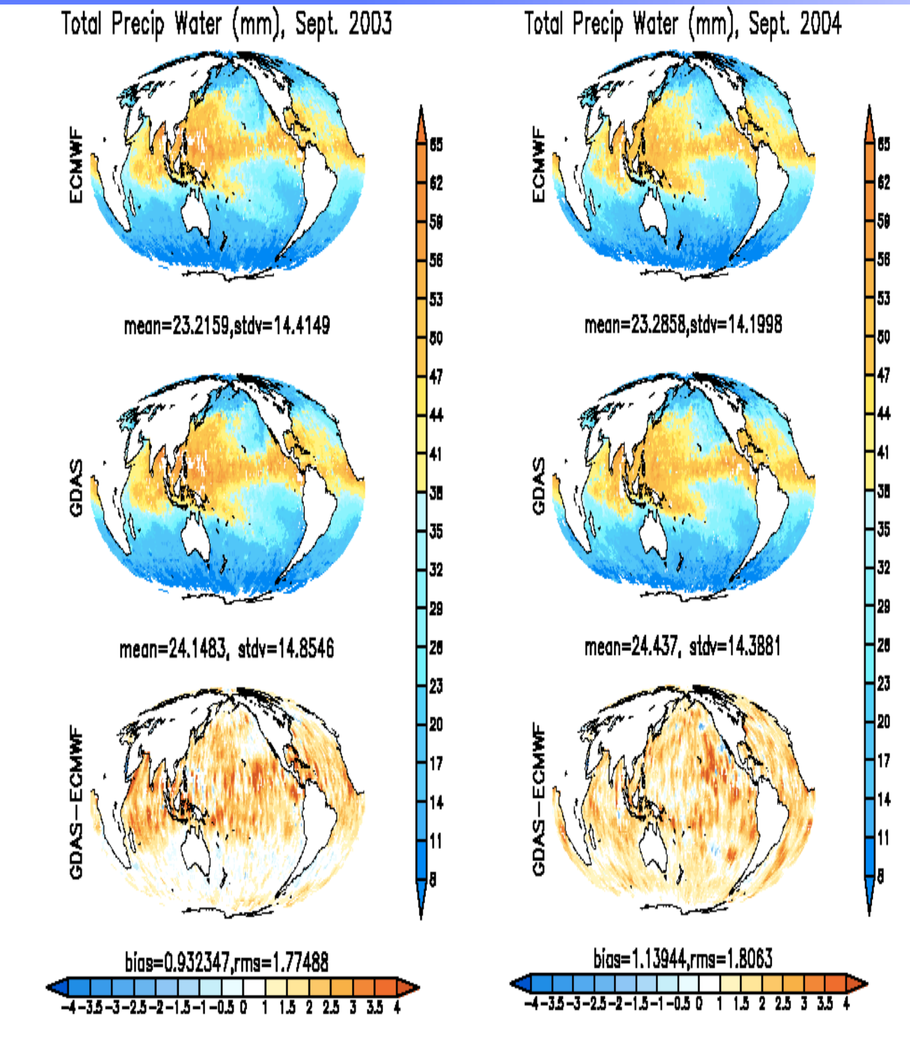
NOAA/NESDIS

Motivation

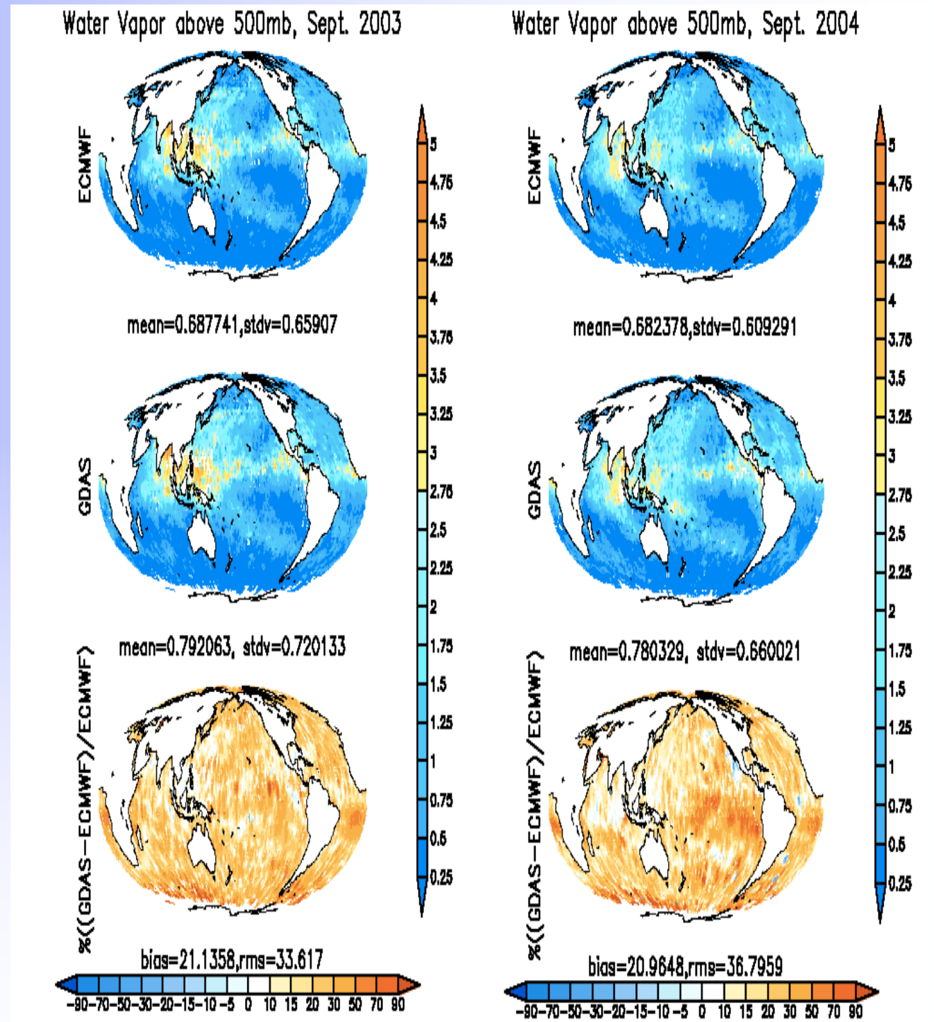
- Many studies comparing AIRS, IASI and aircraft interferometer have demonstrated the accuracy and stability of AIRS and IASI.
- Finally we have a very precise, accurate reference dataset to validate other datasets, such as radiosondes, model analyses, reanalyses, etc.
- Unlike GPS RO, the thermal infrared radiances are influenced by key essential climate variables:
  - CO_2, CH_4, O_3, CO, Clouds, Aerosols, Temperature, Moisture.
- CLARREO mission is design to meet this objective, with onboard SI traceability.
- Climate Reanalyses are gaining recognition for providing climate trends but each are different, why??

National Environmental Satellite, Data, and Information Service

NCEP Water Vapor is consistently higher than ECMWF Wx Analysis



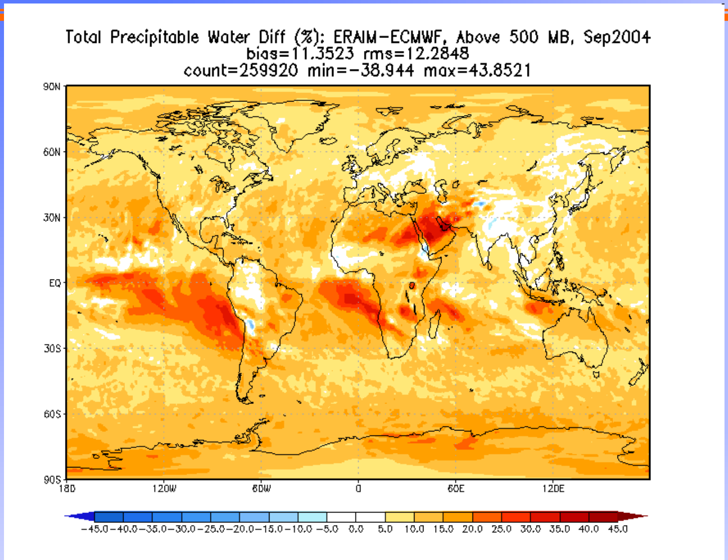
TPW

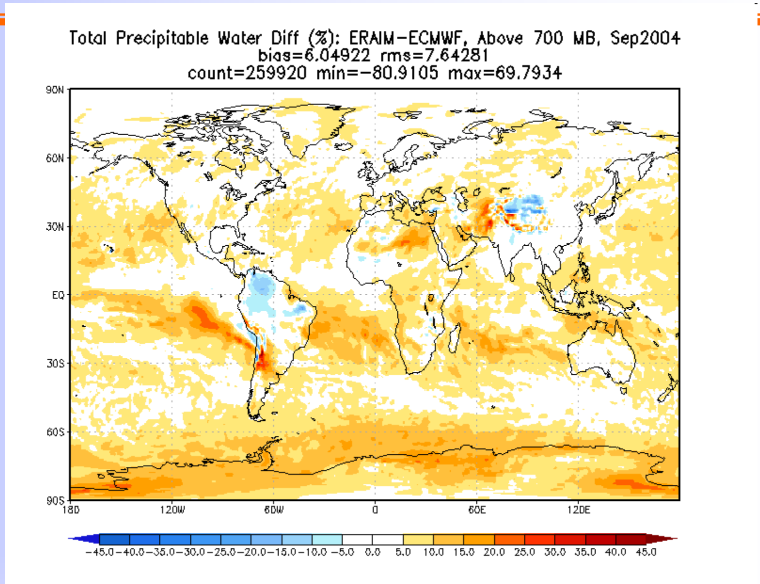


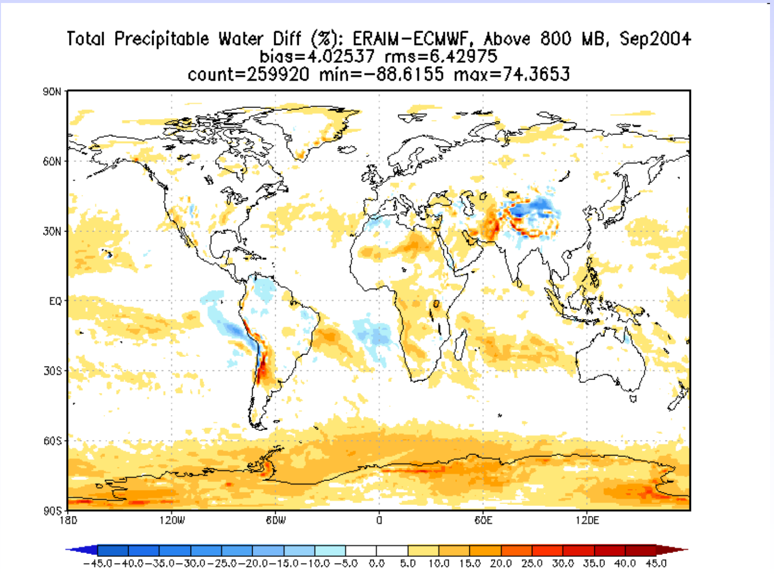
Integrated Water Vapor above 500 mb

National Environmental Satellite, Data, and Information Service

ERA Interim Reanalysis - ECMWF Weather Analysis – September 2004



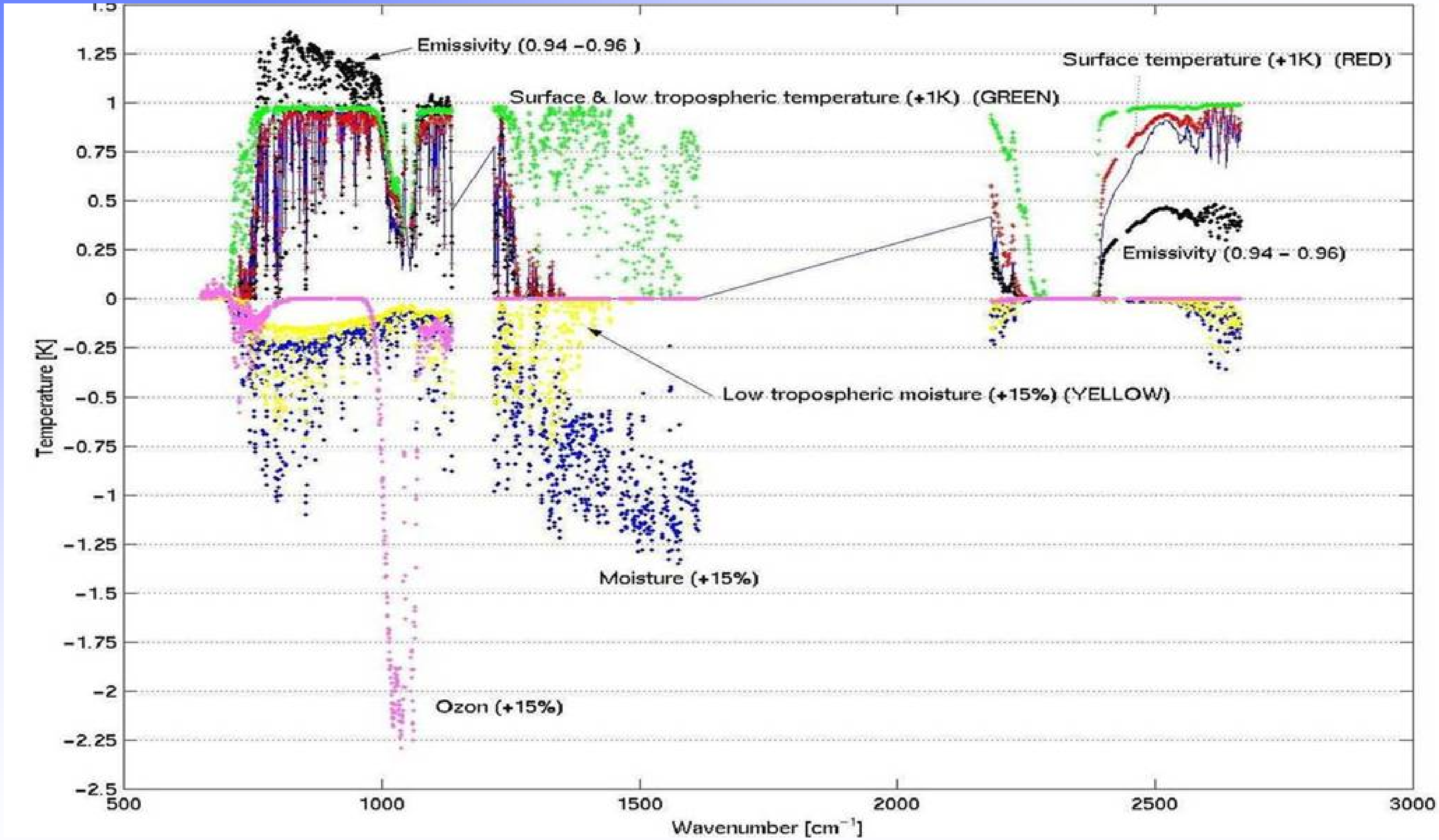




AIRS Spectrally Resolved InfraRed (SRIR) Climate Data Record (CDR)

- Purpose: To describe a new spectrally resolved infrared dataset from AIRS demonstrate its utility to:
  - Validate weather analyses and climate reanalyses to test the realism of the model-derived atmospheric states with very high certainty.
  - Assess changes in model-derived fields due to assimilation of new data or an operational change in processing

AIRS Sensitivity to Atmospheric Change



Approach

- We limb adjust AIRS observations and then average into daily and monthly grids for both ascending and descending orbits. (Spectrally Resolved InfraRed (SRIR) Climate Data Record: 2003 – 2007)

- We create gridded datasets of ECMWF and NCEP analyses and compute brightness temperatures using SARTA (Strow).

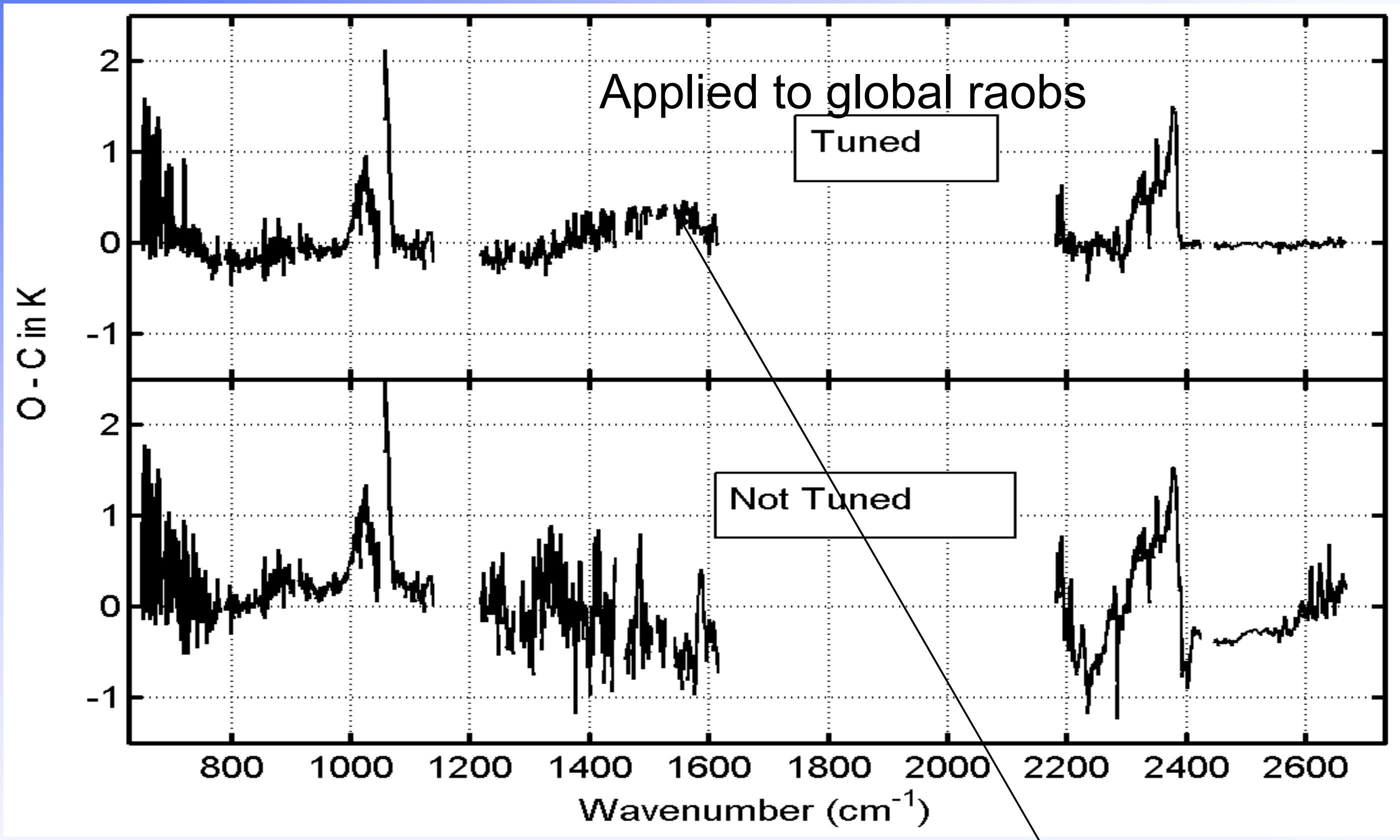
- Compute differences between observations and calculate, and make an assessment of which model is more accurate.

Limiting factors

- How good is the limb adjustment?

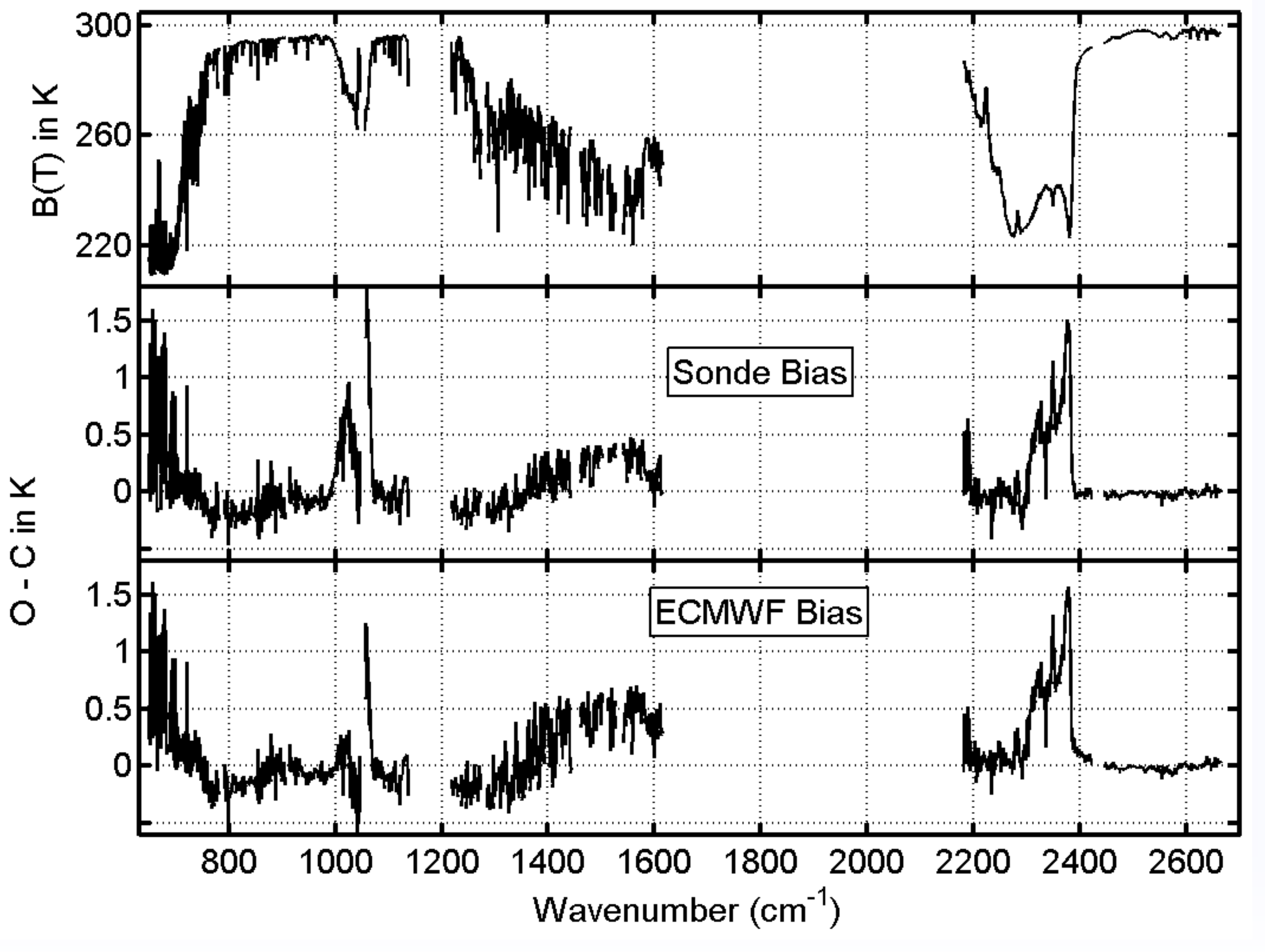
- How good is the radiative transfer model (SARTA)?
  - AIRS is climate quality
  - Spectroscopy is not (quote from Strow)
    - Hence the RTA must be tuned against high quality insitu observations

SARTA is tuned using GRUAN-like radiosondes



Uncertainty of the SARTA is less than 0.5 K

SARTA BIAS with global radiosonde



Steps to derive the SRIR climatology

Steps

- Gridded radiances are converted to Principal Component Scores (PCS) and stored into gridded daily datasets (0.5 long x 2.0 lat).
- PCS are limb adjusted and stored in angle adjusted gridded daily datasets
- Angle adjusted PCS are converted to brightness temperatures and stored in gridded daily datasets.
- Each gridbox for each dataset has a clear flag.
- Compute monthly clear and all-sky gridded datasets of limb adjusted brightness temperatures.

AIRS Limb Adjustment Methodology:

Step 1) Limb adjust the off-nadir PCS to the nadir PCS.

Use regression to predict the limb adjusted PCS from the first six PCS and the PCS to be limb adjusted

$$\text{Limb-adj PCS}(n,\text{angle}) = \sum_{i=1}^{6} C(i,\text{angle})*PCS(i,\text{angle}) + C(n,\text{angle})*PCS(n,\text{angle})$$

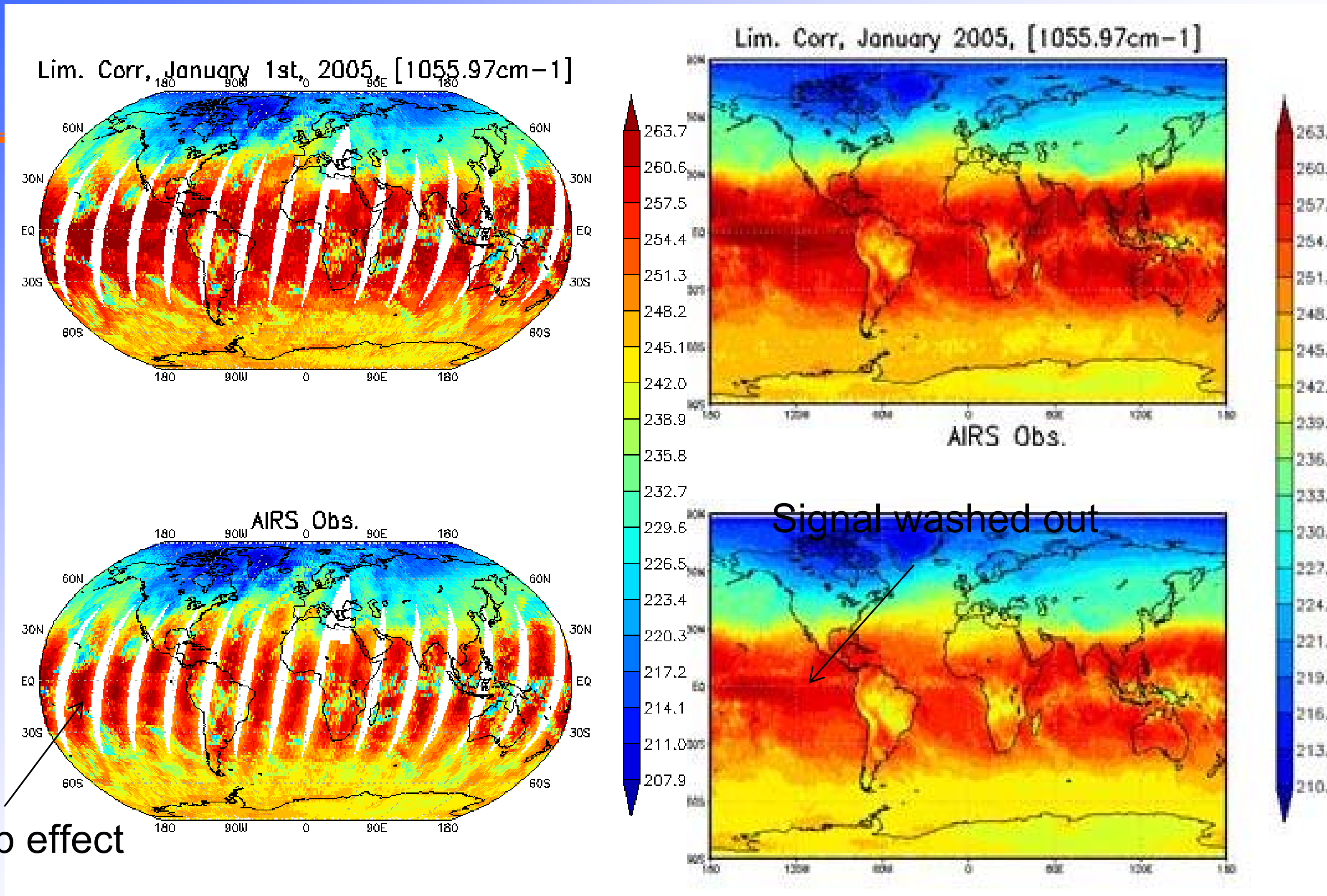
The regression coefficients are generated from six months of data. Averaged PCS as a function of scan angle (90 per scan line) over two degree latitude bands for ocean and non ocean cases.

Step 2) Reconstruct the limb adjusted radiance from the limb-adjusted PCS.

Step 3) Convert the limb adjusted radiances to limb adjusted brightness temperatures

National Environmental Satellite, Data, and Information Service

Example of AIRS limb adjusted data

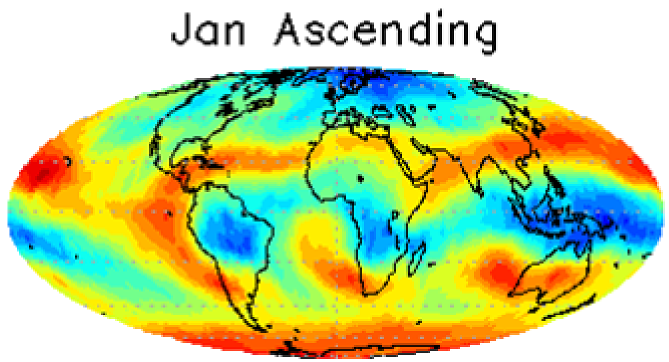


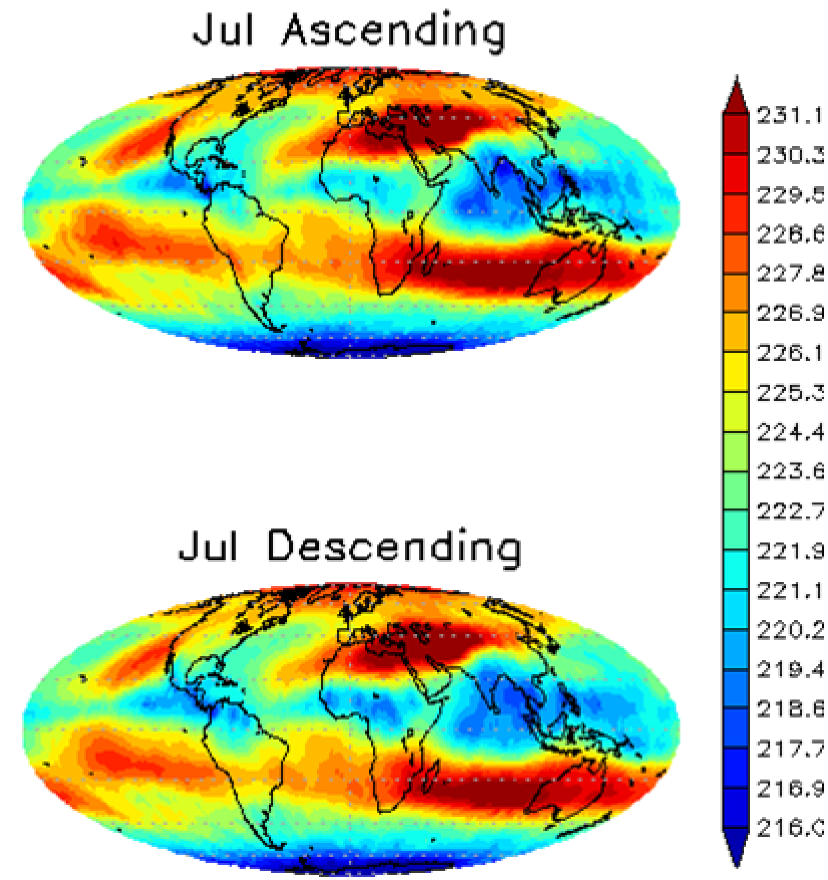
Limb corrected (upper left) and original observed (lower left) AIRS radiance; monthly averaged limb corrected (upper right) and original (lower right) AIRS radiance

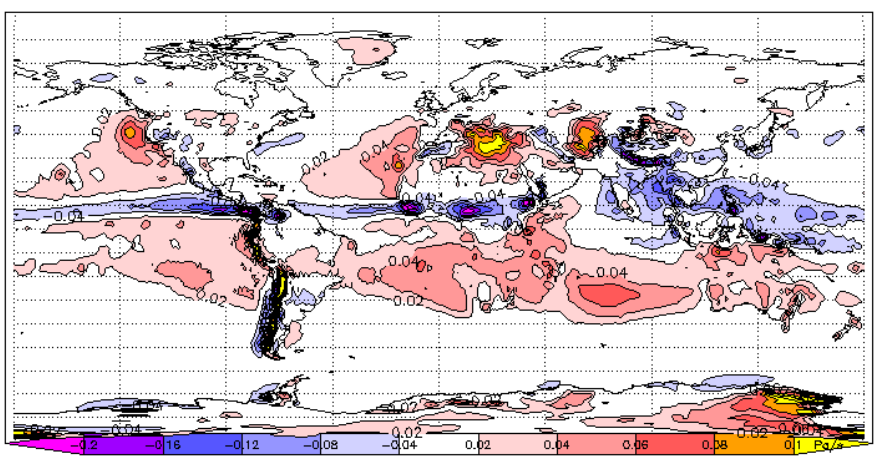
Must limb adjust the data to create meaningful global datasets

1520.87cm−1

2006 Mid – upper tropospheric water vapor channel







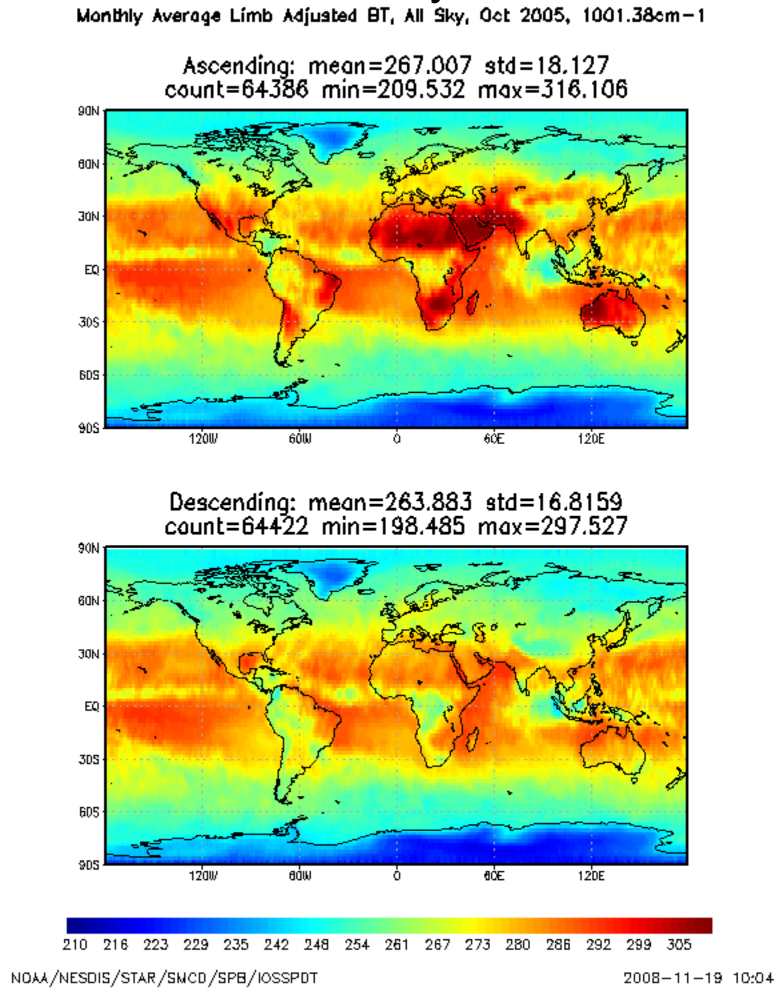
ERA40 July 1979-2001 mean

Warmer brightness temperatures correspond to dryer air and matches areas of descending air from ERA40

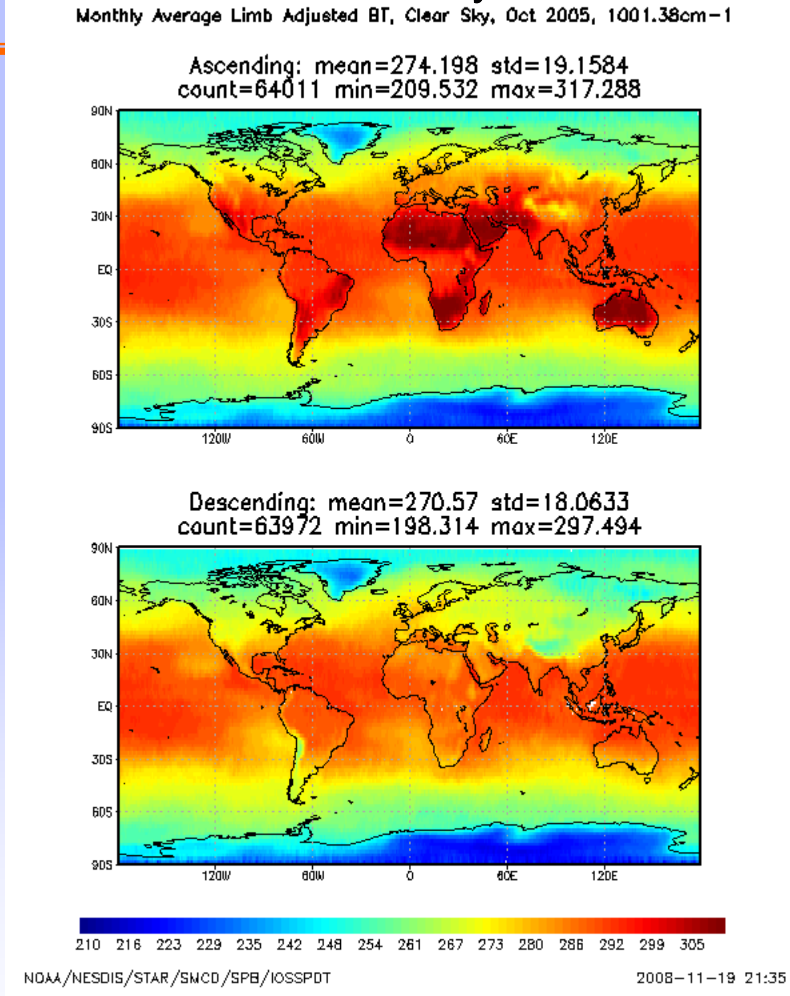
Clear Flag

- Clear test is described in detail in [*Goldberg et al.*, 2003].
- Predict clear AIRS (2390 cm-1) from AMSU
- Compare predicted AIRS (2390 cm-1) with actual AIRS.
- Predict surface temperature from AIRS and compare with NCEP forecast surface temperature.
- Compute variability of AIRS (2390 cm-1) for 3x3 array of AIRS footprints within the AMSU footprint.

All Sky



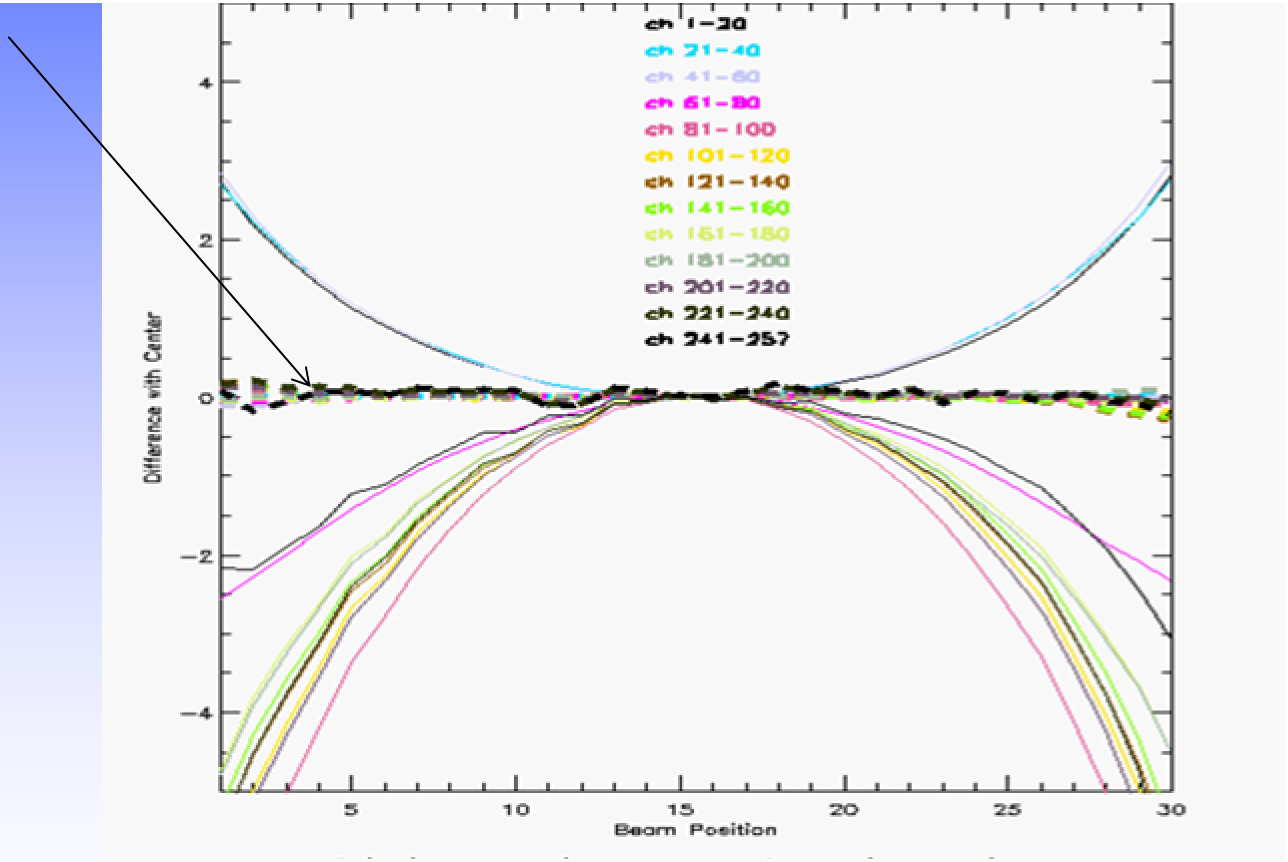
Clear Sky



Validation of the SRIR climatology

Validation of Limb Adjustment

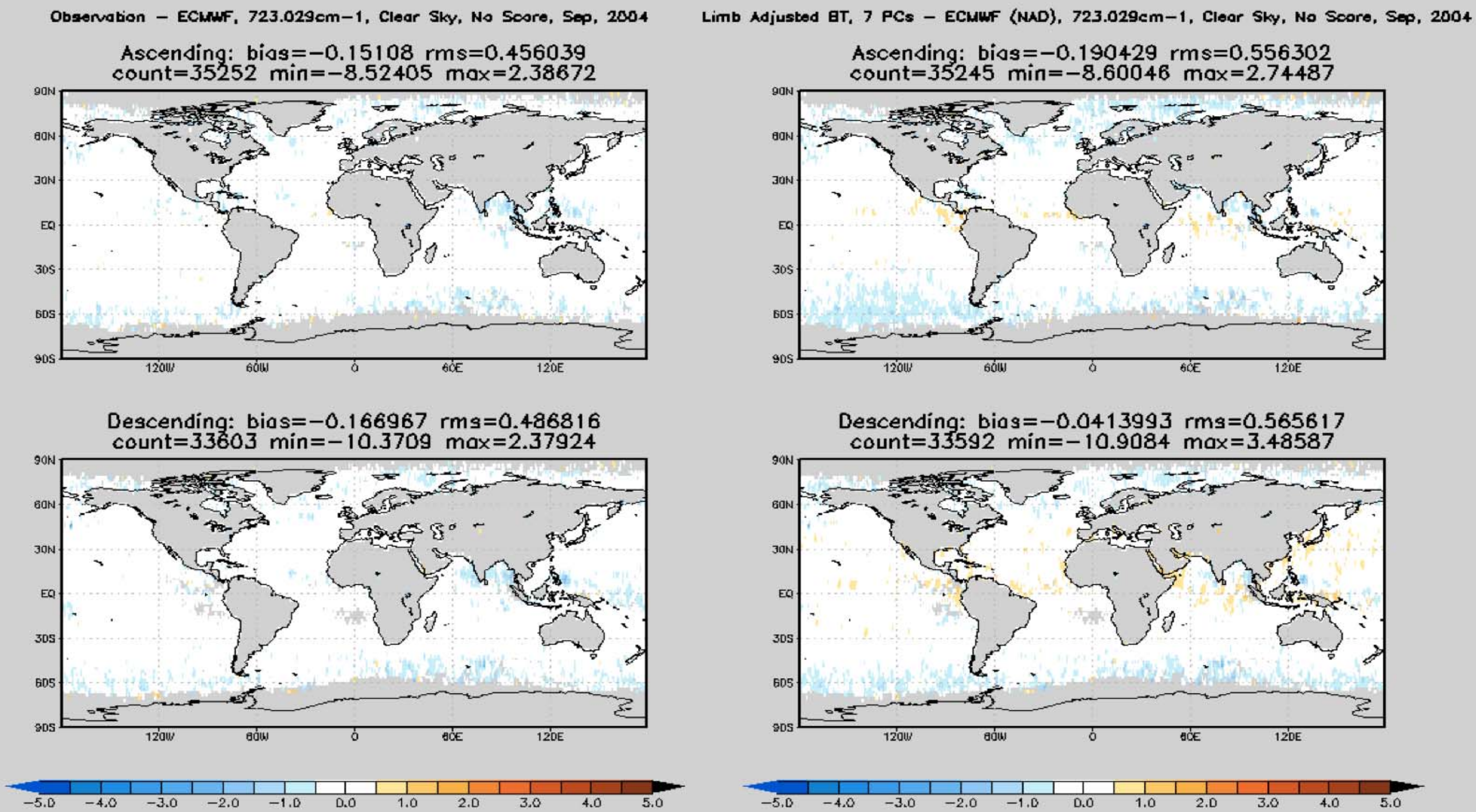
Limb adjustment successfully removes the large scanline dependency



Deviations of averaged original (colored curves) for groups of channels and limb adjusted (heavy dashed curve) brightness temperatures from nadir as a function of beam position

SRIR validation by comparing measured vs simulated brightness temperatures against ECMWF with and without limb adjustment

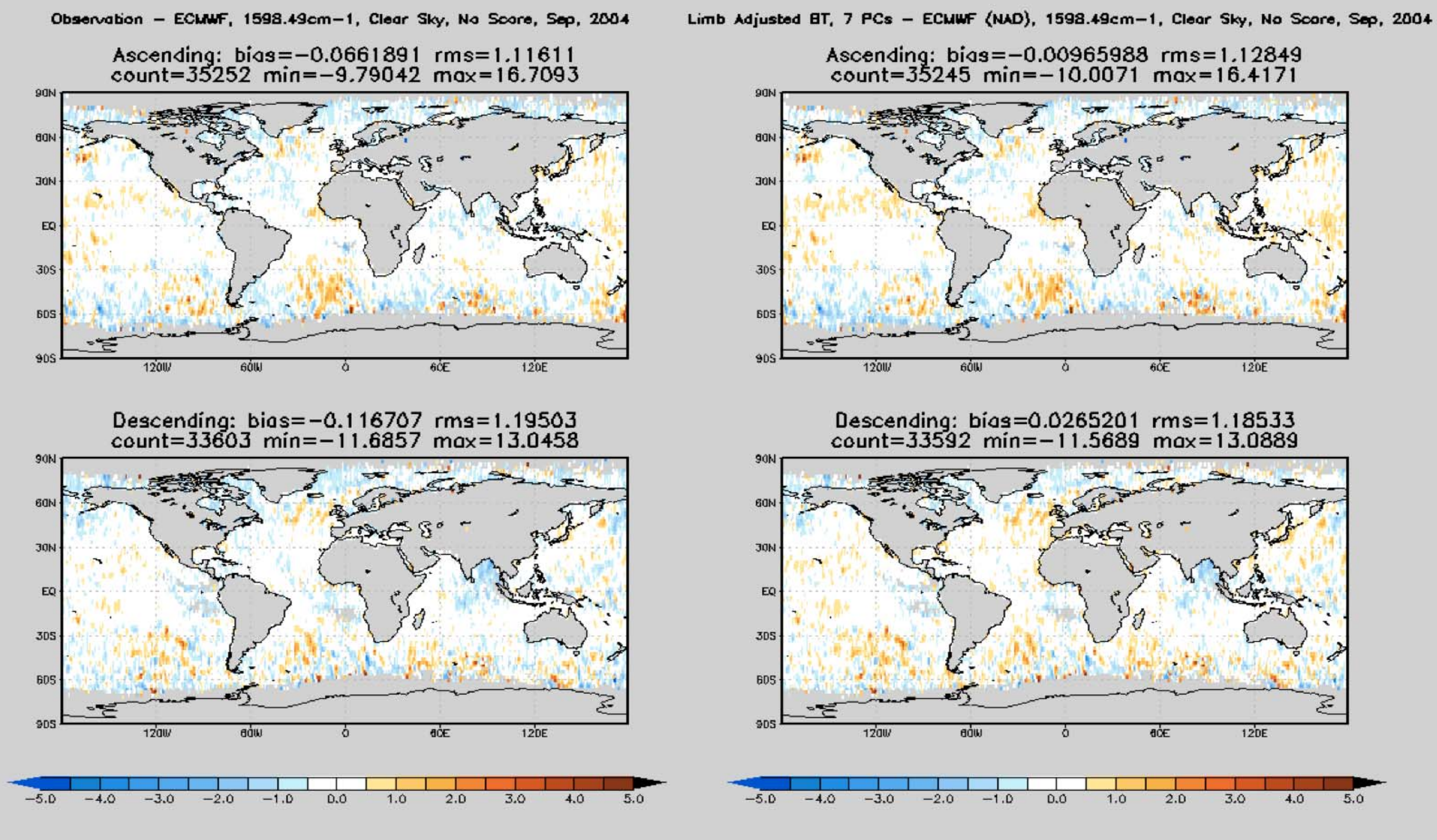
Original - EC(sim, f(angle)) Limb adjusted – EC(sim, f(nadir))



Bias and standard deviation nearly the same, channel peaks near 700 mb

SRIR validation by comparing measured vs simulated brightness temperatures against ECMWF with and without limb adjustment

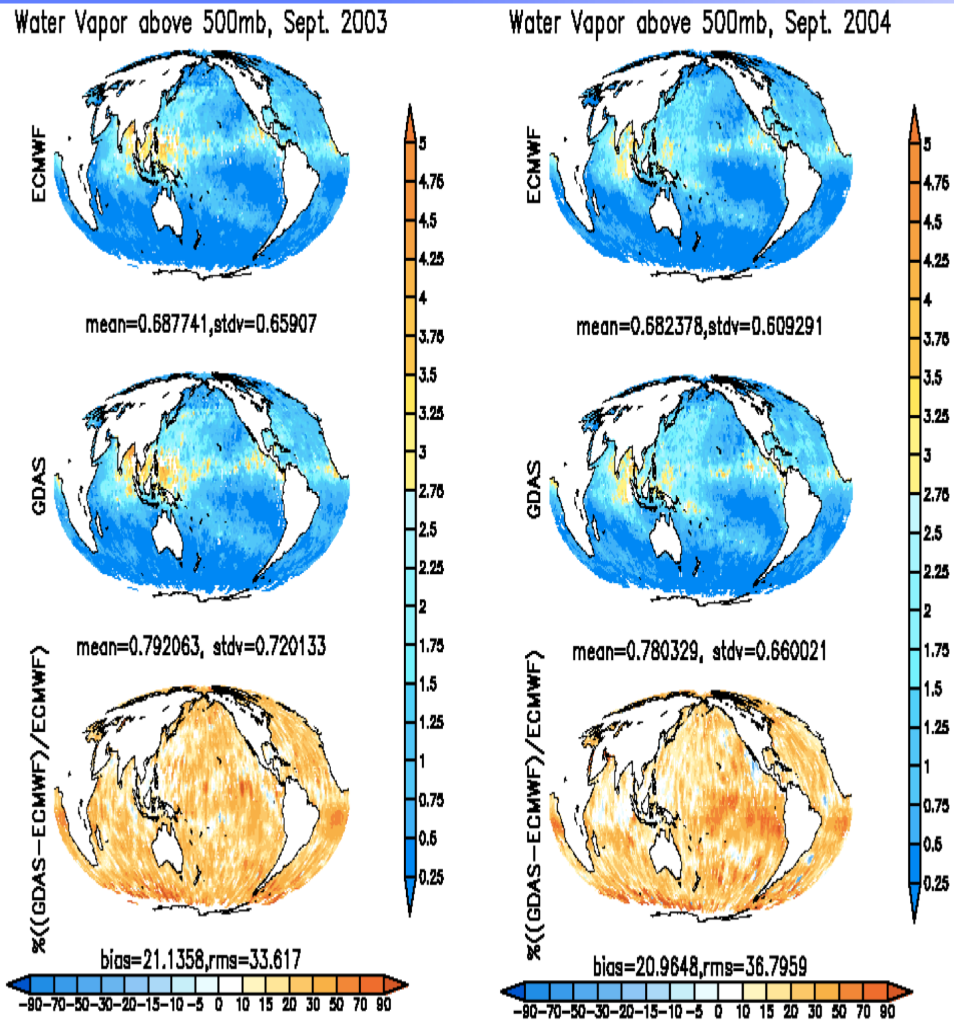
Original - EC(sim, f(angle))   Limb adjusted – EC(sim, f(nadir))

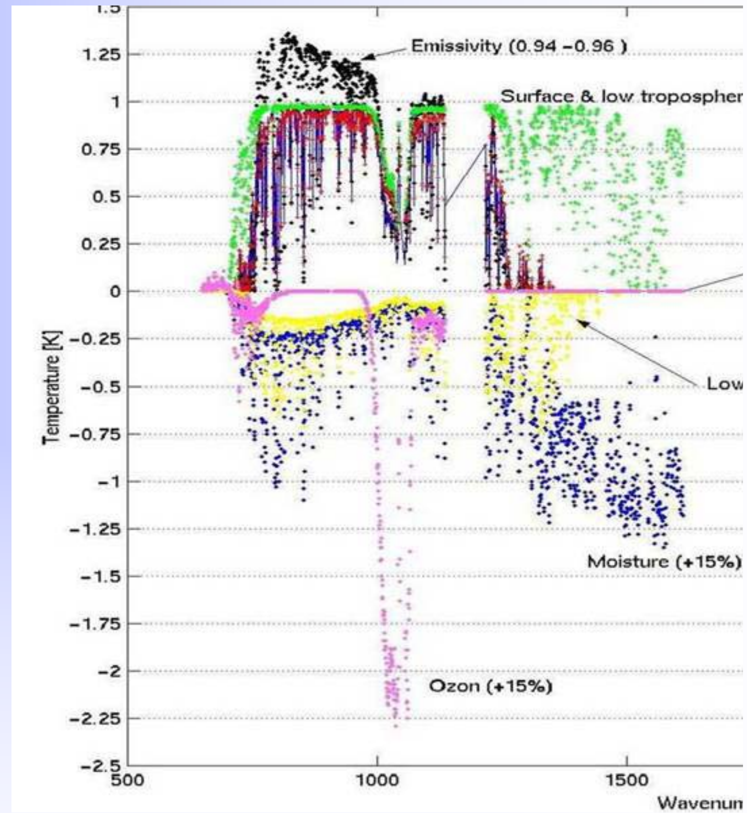


Bias and standard deviation nearly the same, water vapor channel peaking near 500 mb (for mean profile)

National Environmental Satellite, Data, and Information Service

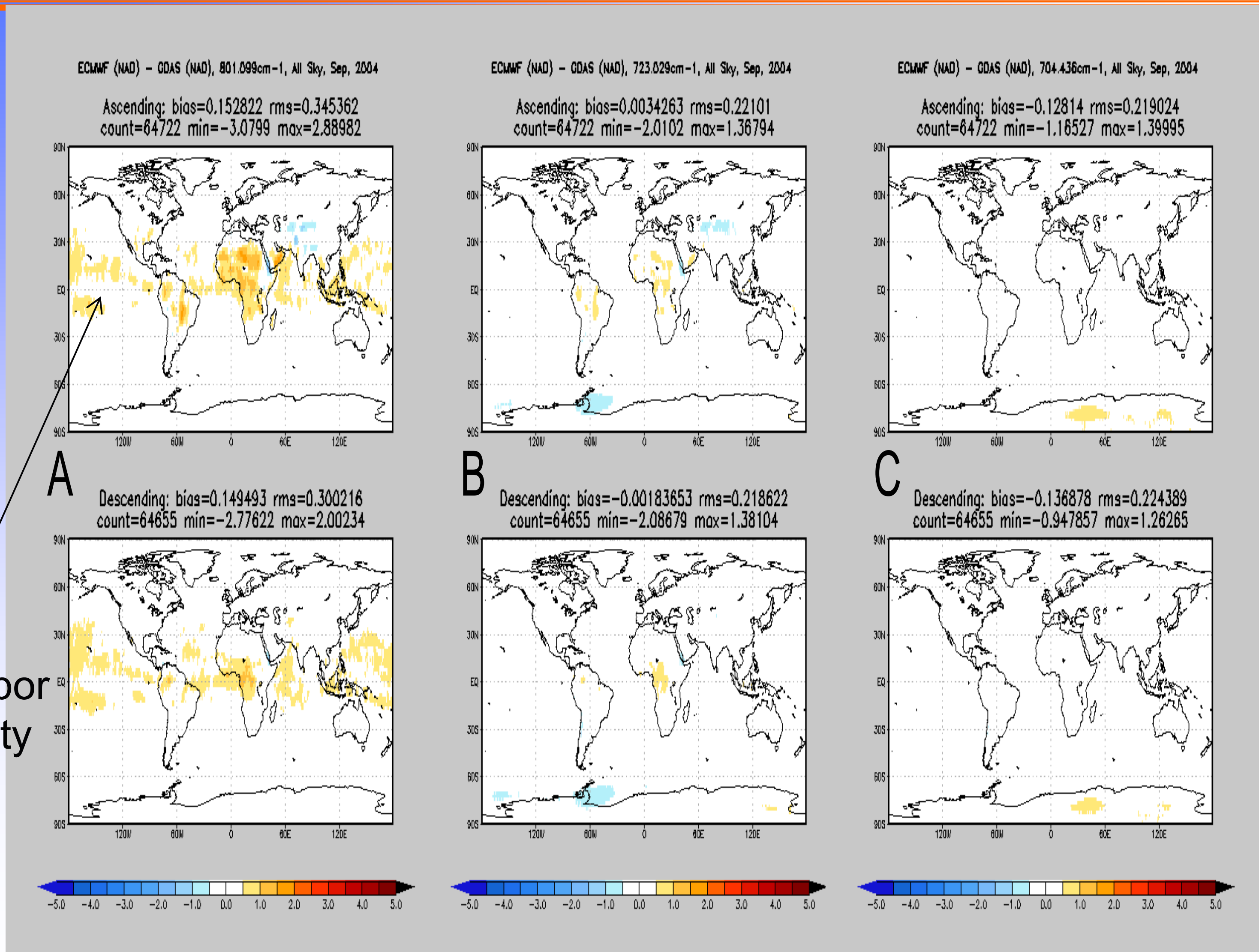
Validation of model fields using AIRS clear-sky SRIR climatology





20% ~ 1.6 K

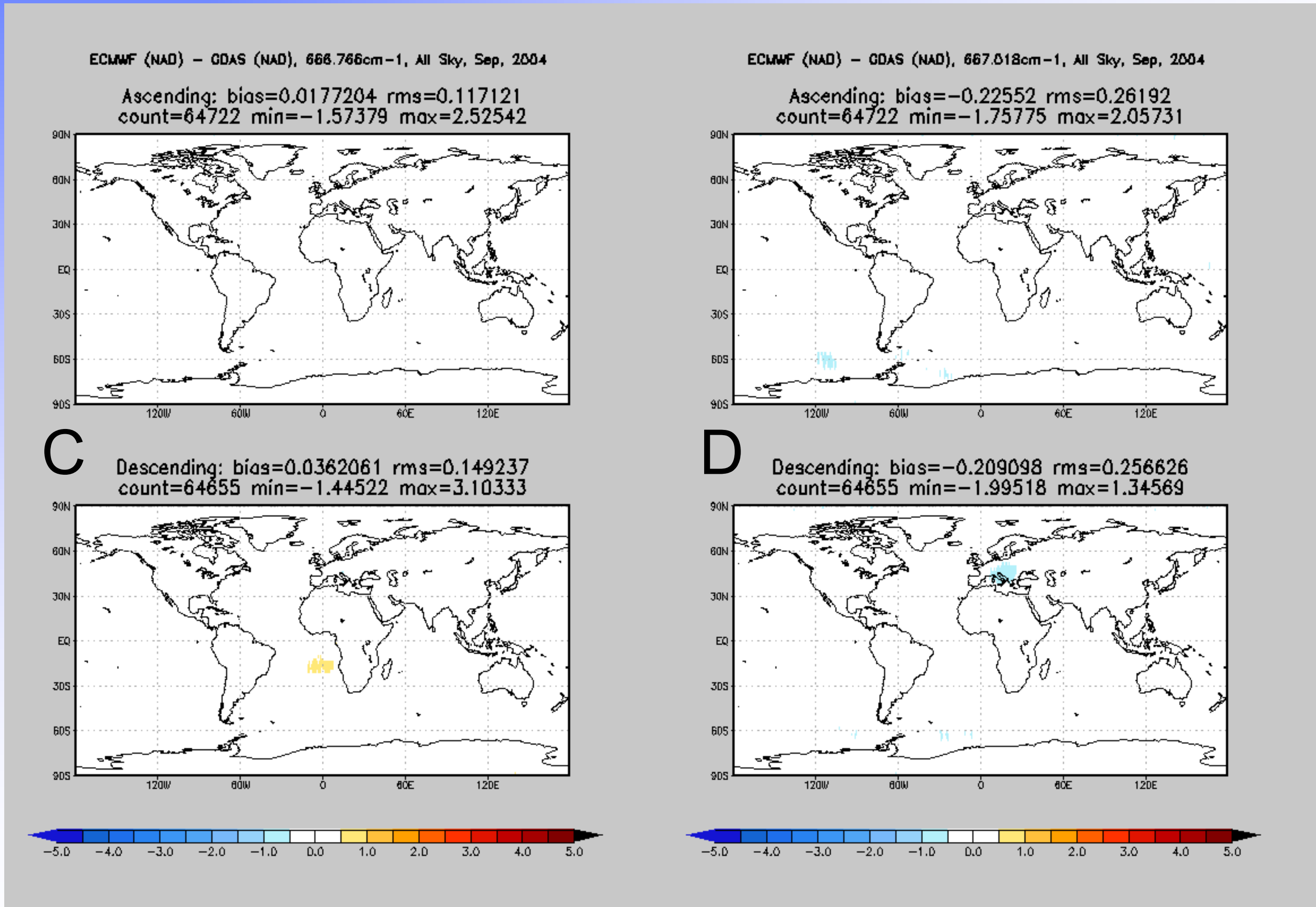
ECMWF minus GDAS simulated brightness temperatures for A: 801.09 cm^{-1} (850 mb), B: 723.029 cm^{-1} (700 mb), and C: 704.436 cm^{-1} (350 mb)



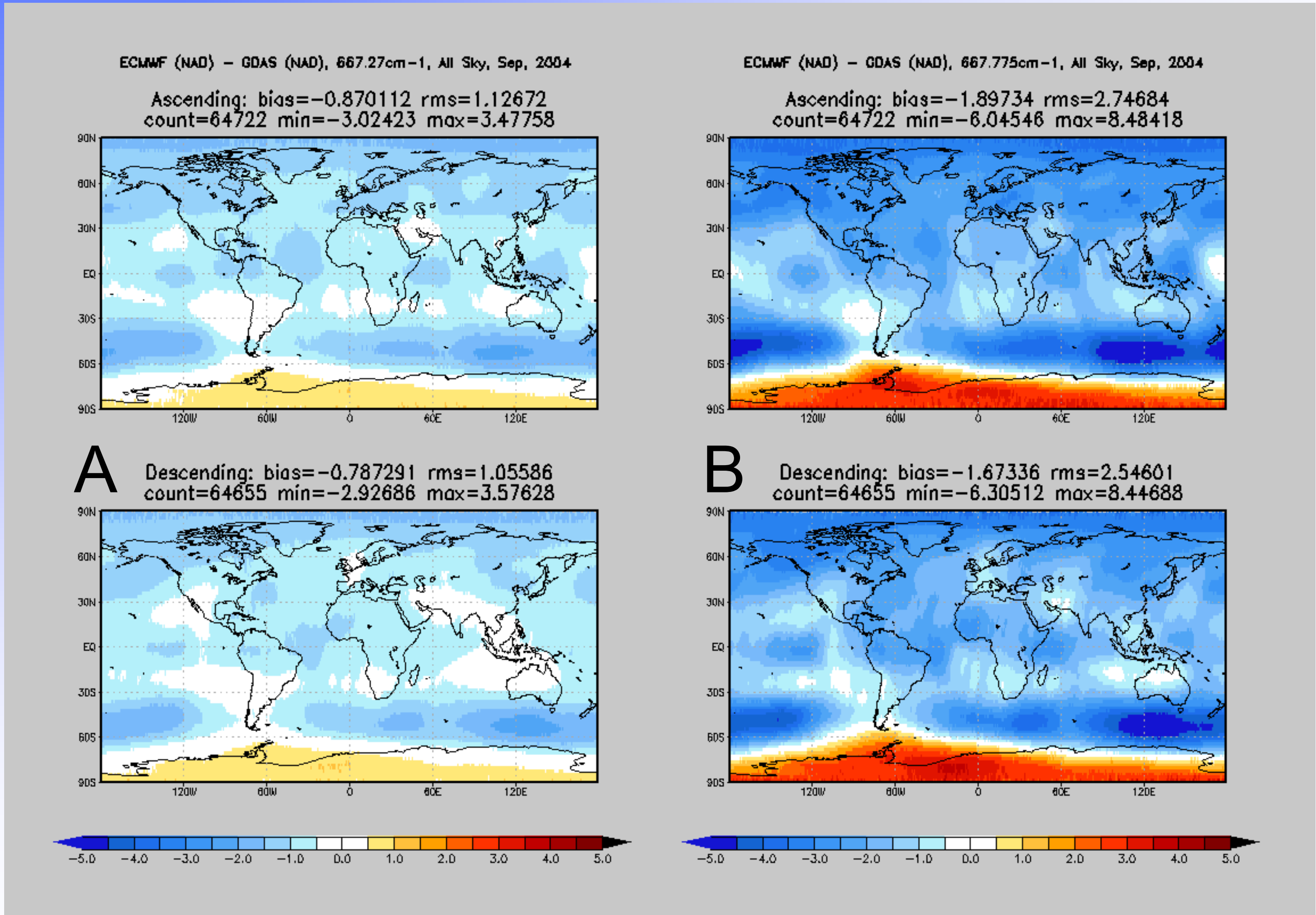
Water vapor sensitivity

Temperature channel differences are very small

ECMWF minus GDAS simulated brightness temperatures for C: 666.766 cm^{-1} (40 mb), and D: 667.018 cm^{-1} (25 mb)

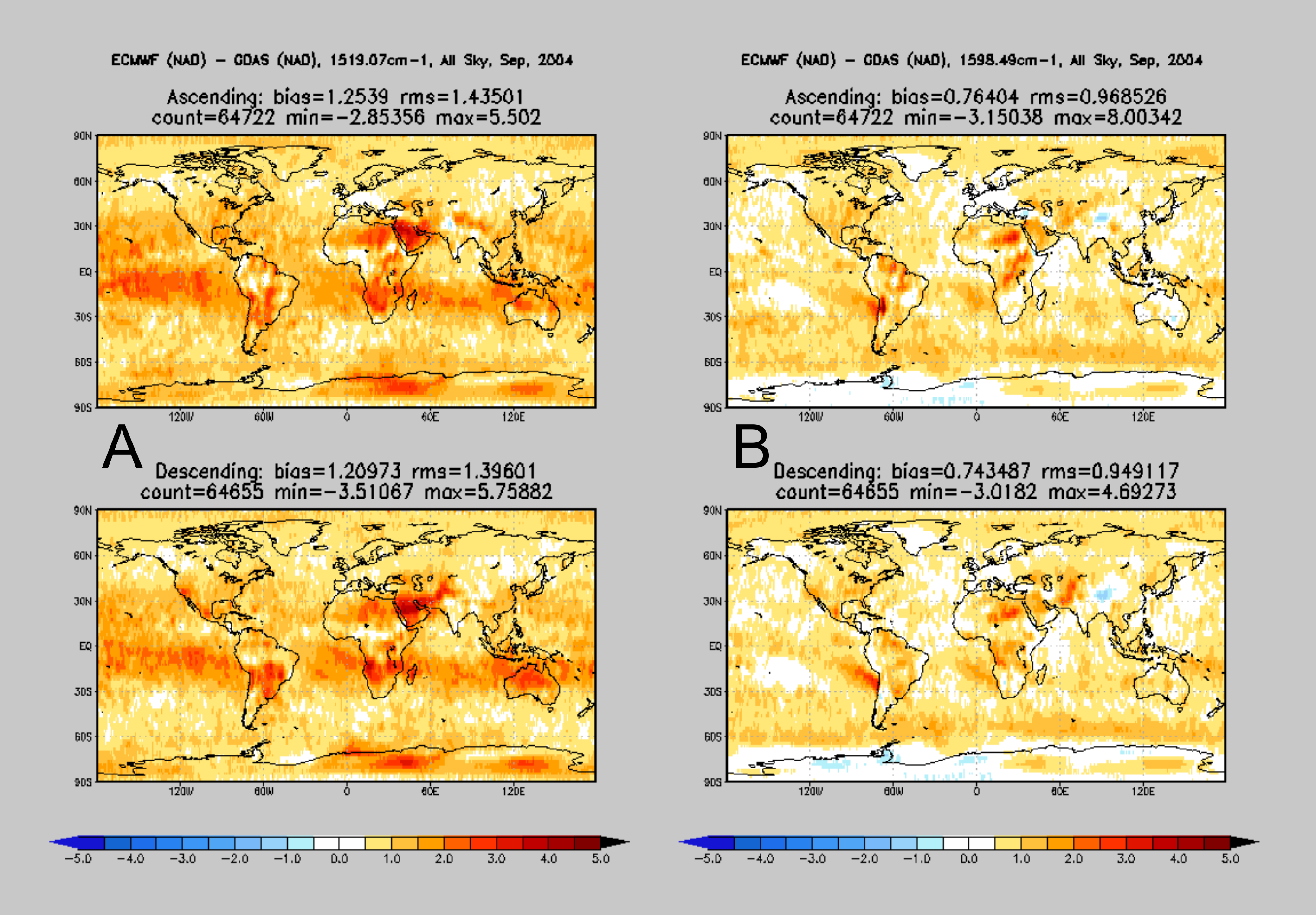


ECMWF minus GDAS simulated brightness temperatures for A: 667.27 cm-1 (15 mb) and B: 667.775 cm-1 (1.5 mb)



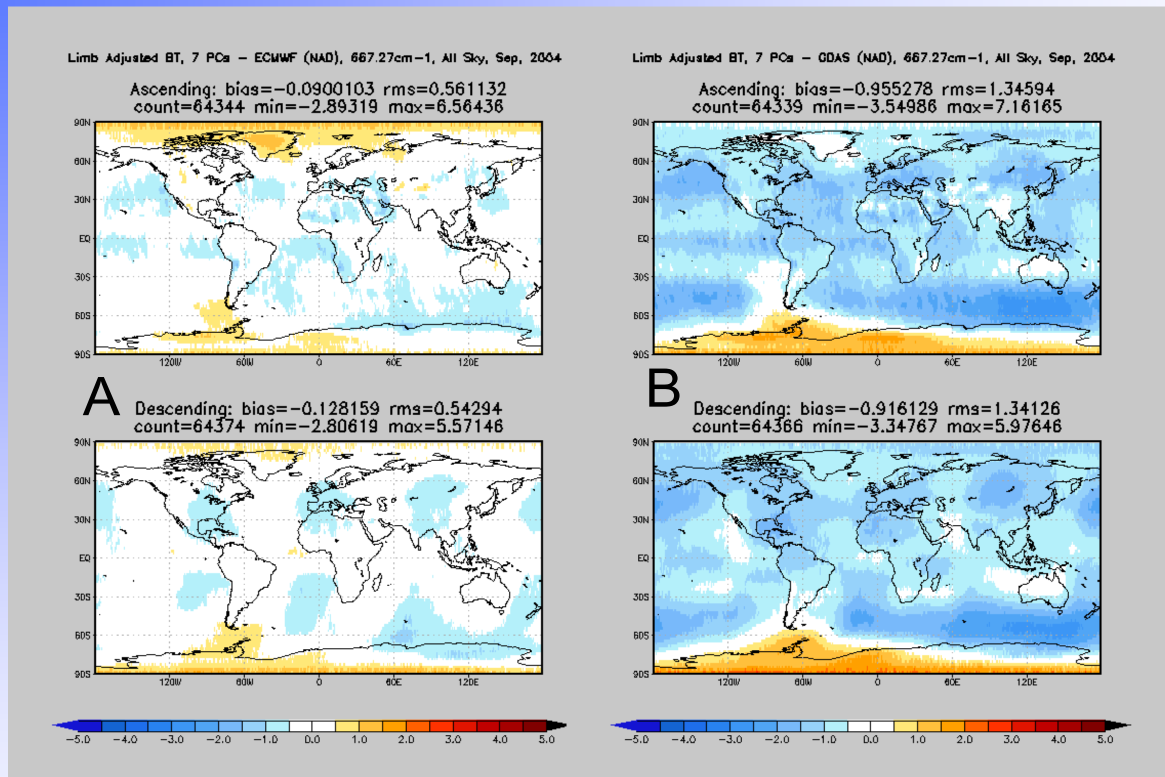
Finally we see large differences at 15 and 1.5 mb

ECMWF minus GDAS simulated brightness temperatures for A: 1519.07 cm^{-1} (315 mb) and B: 1598.45 cm^{-1} (490 mb)



And large differences in water vapor

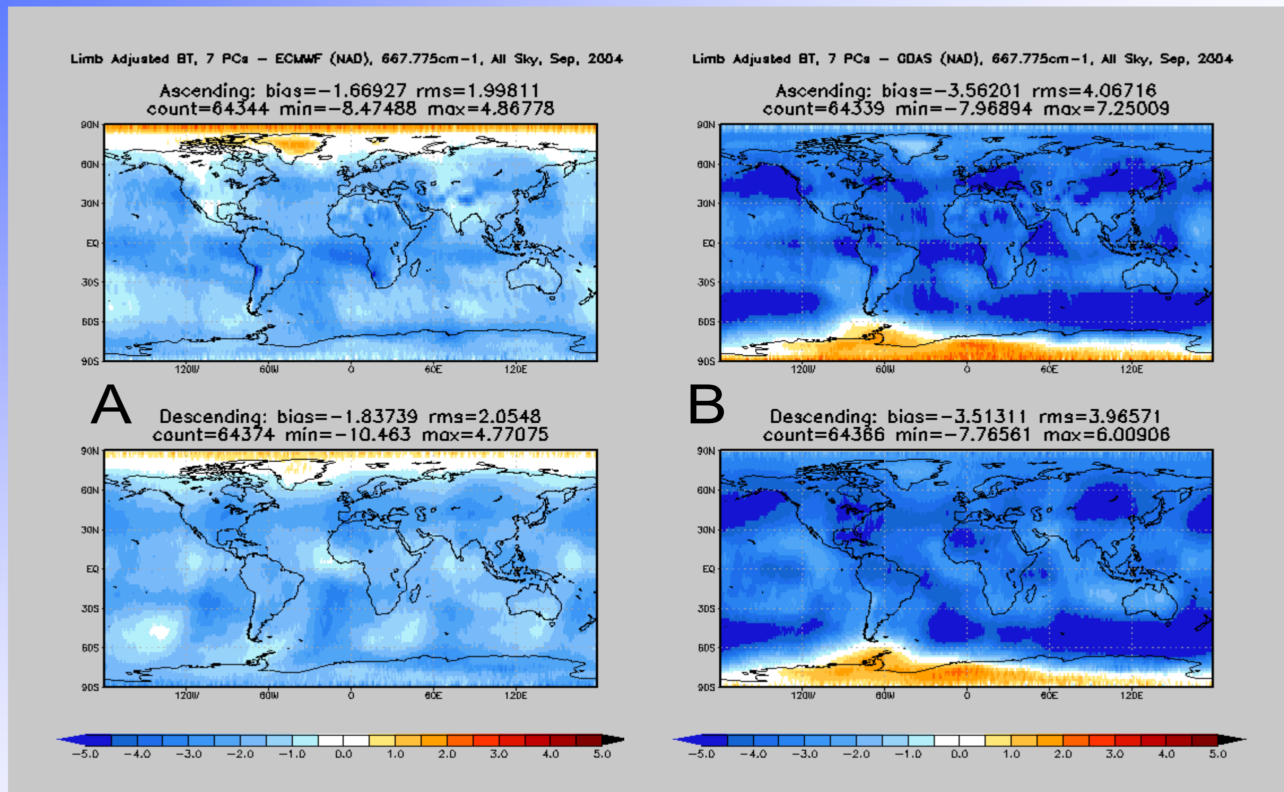
ECMWF more accurate at ~15 mb



Difference between limb adjusted AIRS and simulated ECMWF brightness temperatures (A) and with NCEP (B) for 667.27 cm^{-1} (15 mb)

ECMWF agrees with the AIRS SRIR Climate Data Record , The difference with ECMWF is nearly zero

ECMWF more accurate at ~ 1.5 mb

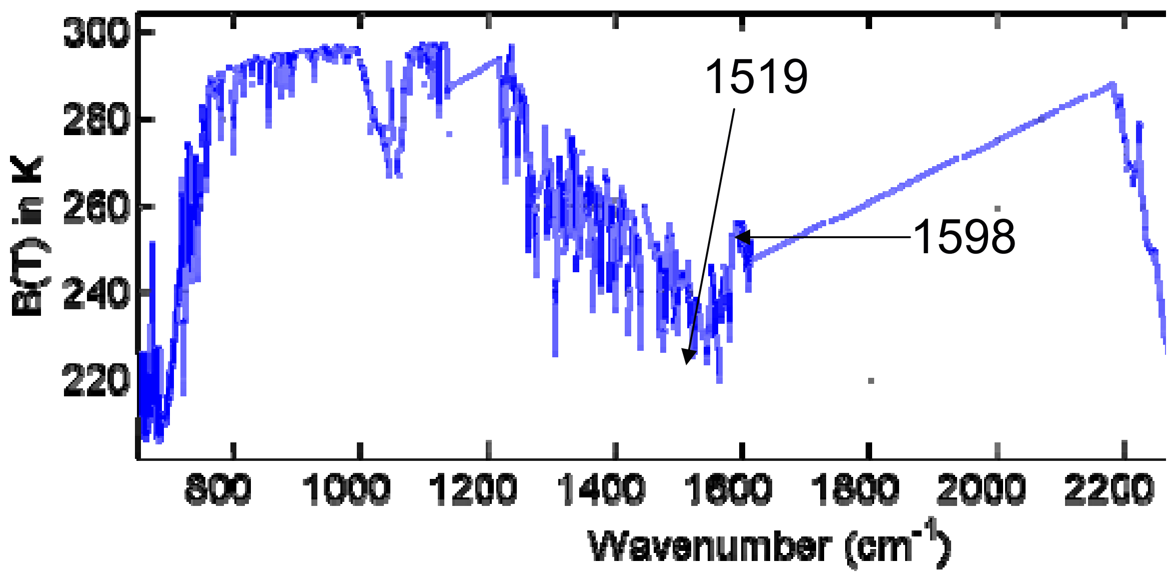


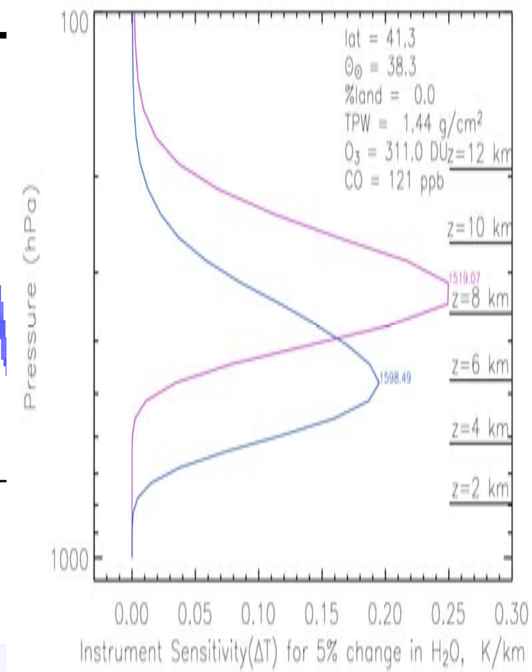
Difference between limb adjusted AIRS and simulated ECMWF brightness temperatures (A) and with NCEP (B) for 667.775 cm^{-1} (1.5 mb)

ECMWF agrees better with the AIRS SRIR Climate Data Record , Both model analysis need to improve

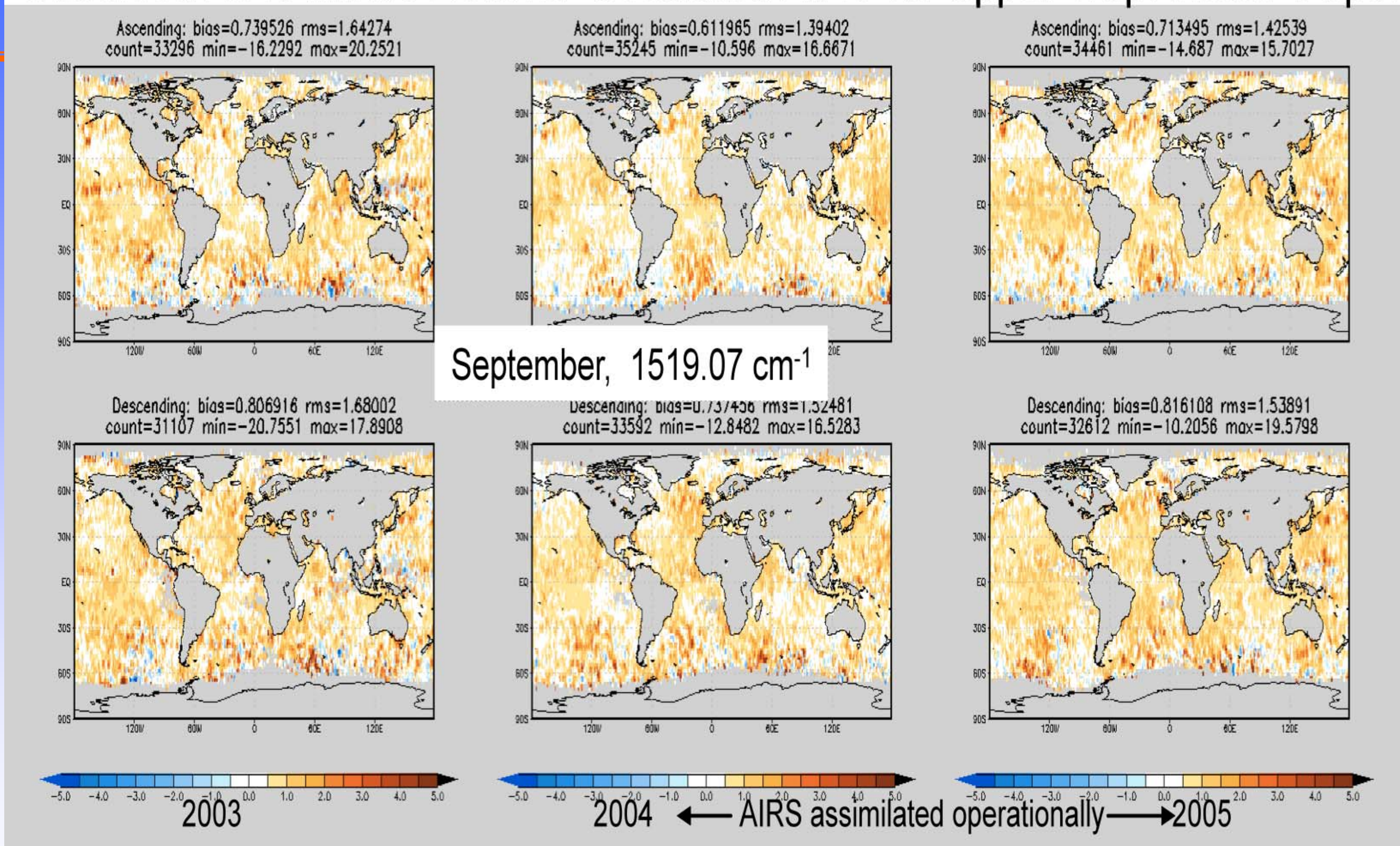
National Environmental Satellite, Data, and Information Service

Which water vapor field more accurate?
We selected an upper tropospheric water vapor channel (1519 cm-1) and a mid tropospheric water vapor channel (1598 cm-1)



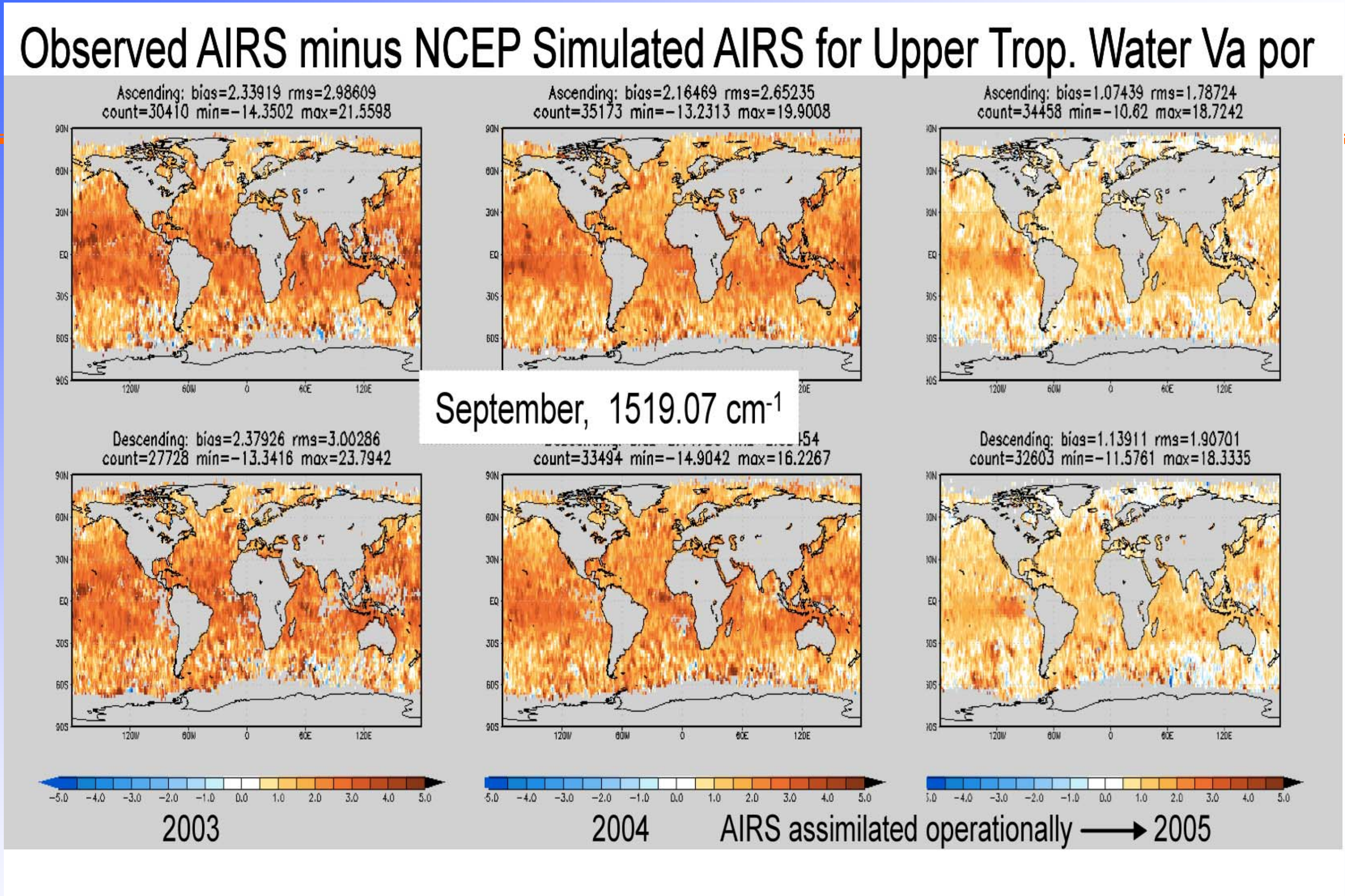


Observed AIRS minus ECMWF Simulated AIRS for Upper Trop. Water Vapor



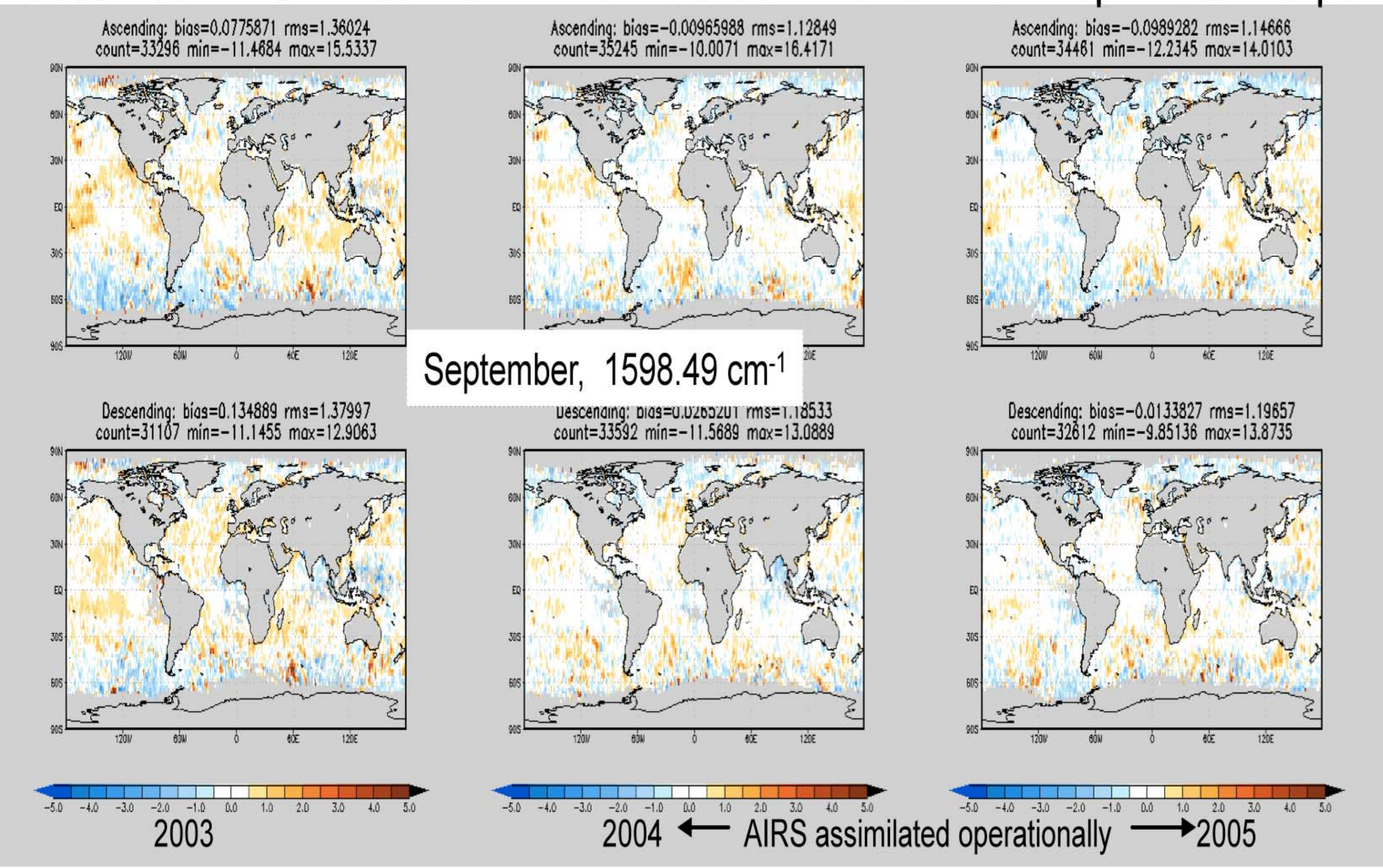
ECMWF bias is about 0.7 K, and seems to be consistent for 2003 – 2005

Note 2004 ECMWF assimilated AIRS

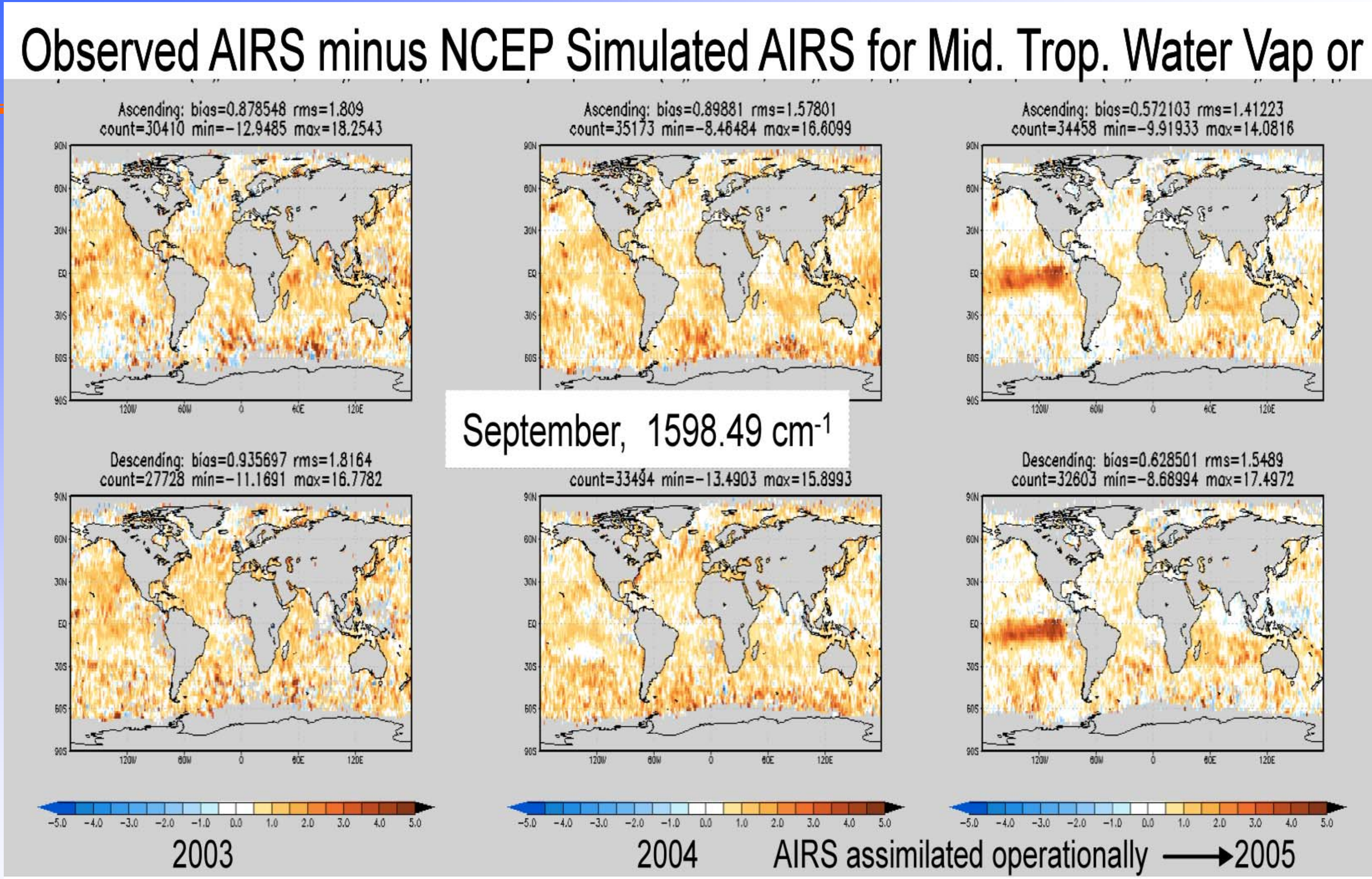


NCEP bias is 3 times larger but reduces by half after AIRS is assimilated.

Observed AIRS minus ECMWF Simulated AIRS for Mid. Trop. Water Va por



ECMWF bias is nearly zero !!!



NCEP bias is relatively much larger, reduces after AIRS is assimilated, but large bias over equatorial eastern Pacific

ECMWF water vapor fields are more accurate

- But ………

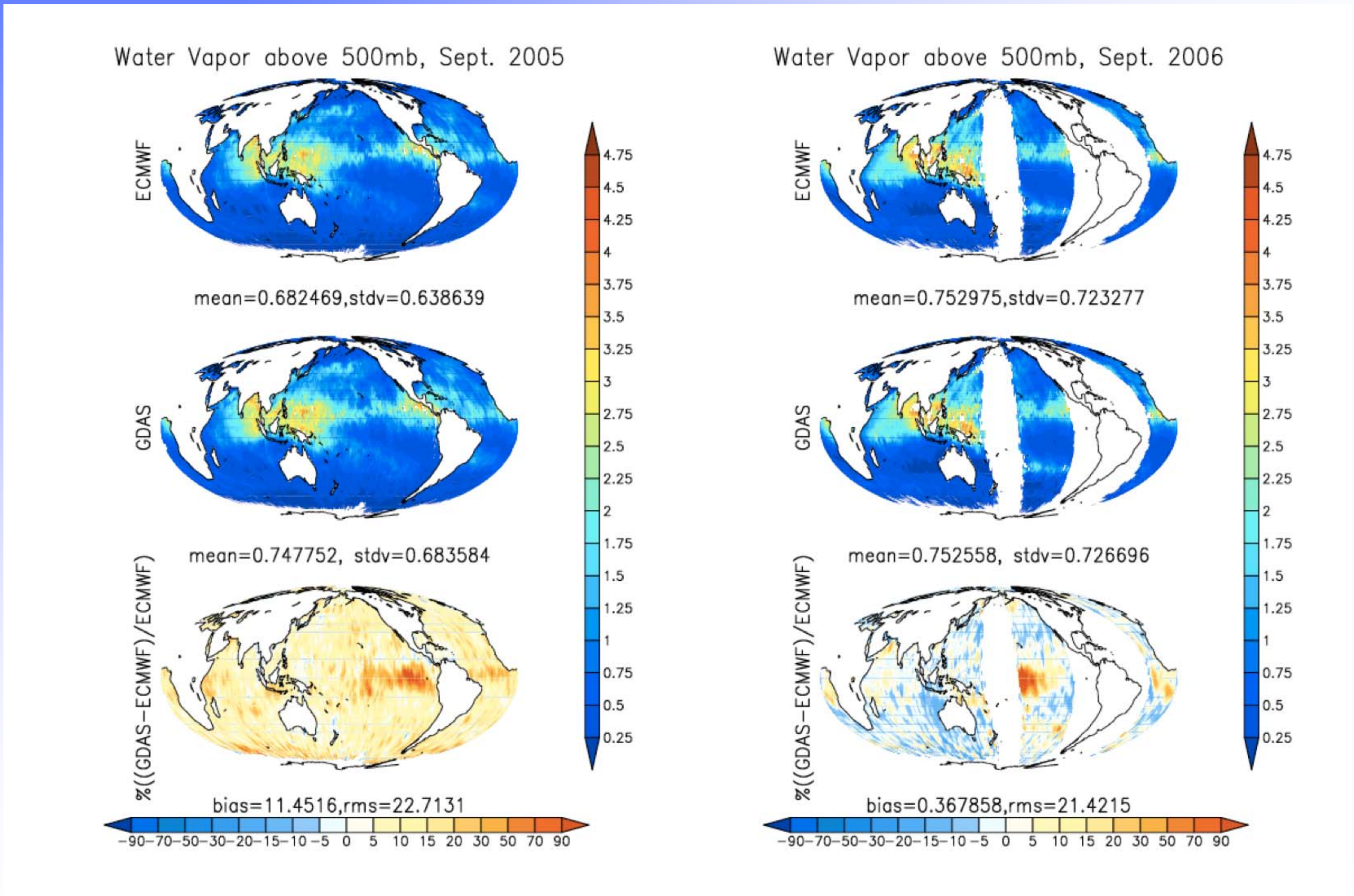
- Operational change in ECMWF in Sept. 2006 caused an increase in the bias.

- NCEP above 500 mb TPW in 2003 and 2004 was 20% higher, then in 2005 just 11% higher because NCEP assimilated AIRS, and in 2006 the difference is close to 0% because of a change in the ECMWF water vapor field.

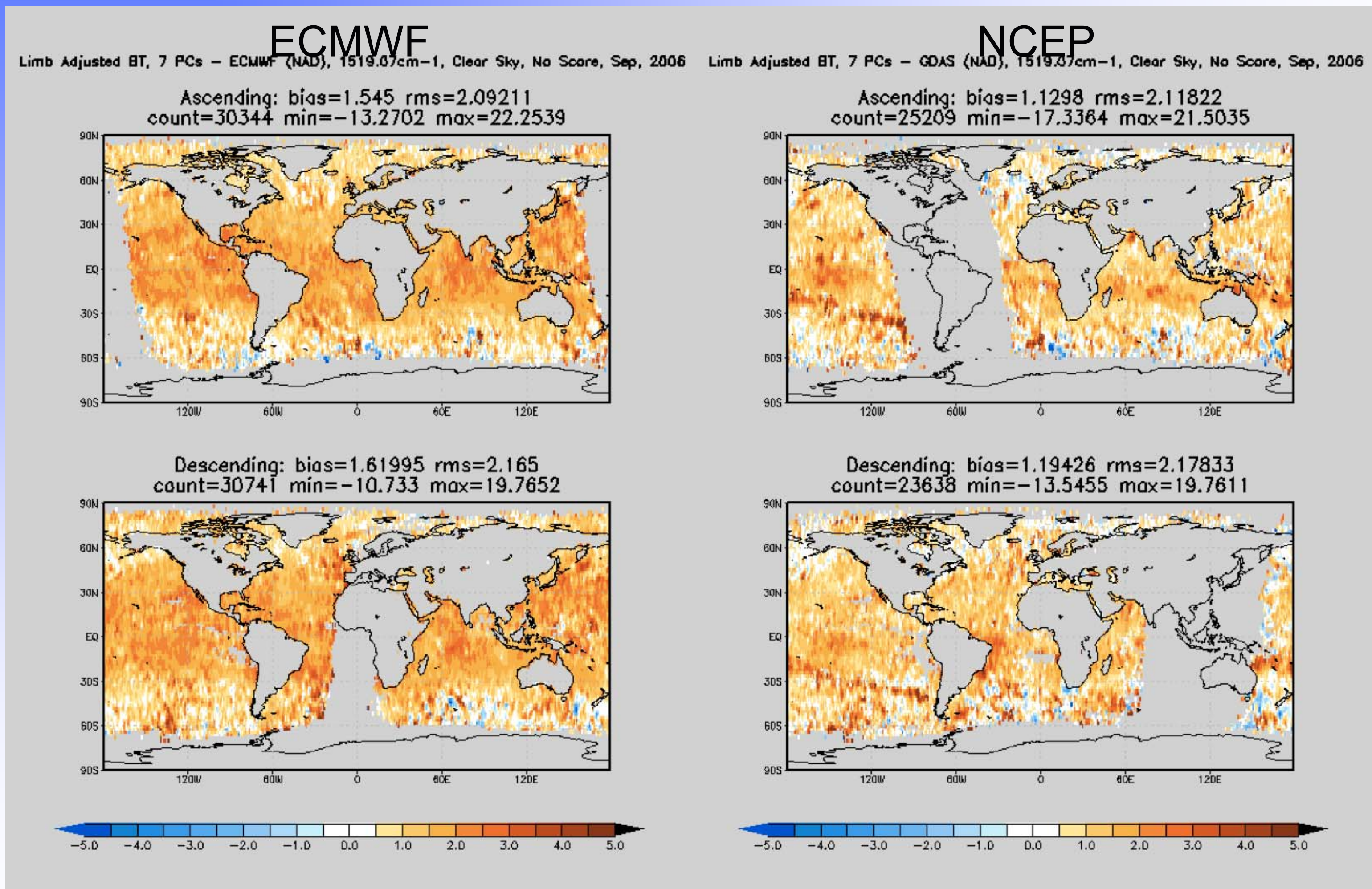
Sept. 2006 Changes

- 12 September 2006 Introduction of Cycle 31r1. This version includes the following changes:
- Revisions to the cloud scheme, including treatment of ice supersaturation and new numerics
- Implicit computation of convective transports
- Introduction of turbulent orographic form drag scheme and revision to sub-grid scale orographic drag scheme
- Gust fix for orography and stochastic physics
- Reduction of ocean surface relative humidity from 100% to 98% (due to salinity effects)
- Revised assimilation of rain-affected radiances
- **Variational bias correction of satellite radiances**
- Thinning of low level AMDAR data (mainly affects Japanese AMDAR network

Note ECMWF TPW above 500 mb in 2006 is now similar with NCEP

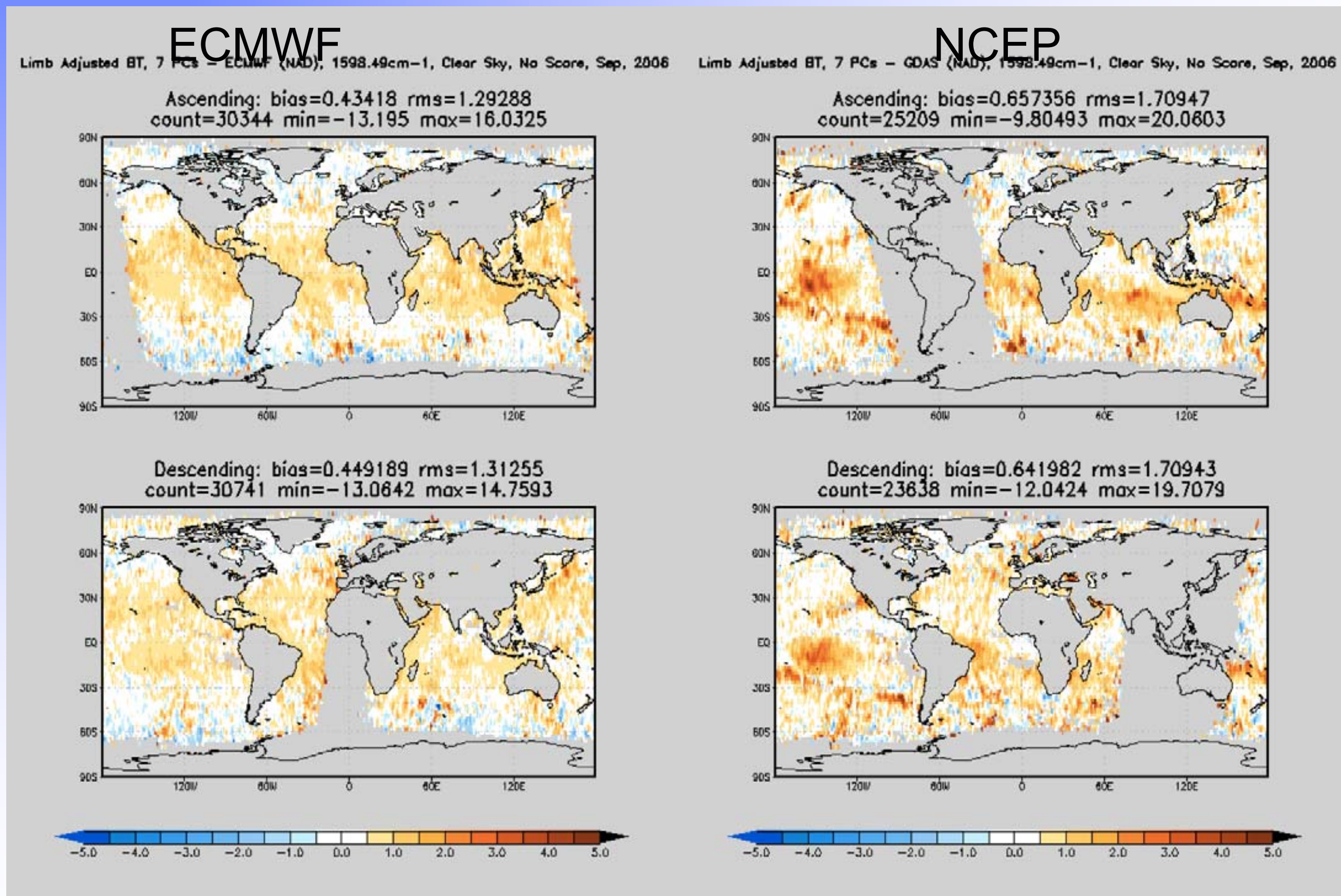


Upper Tropospheric Water Vapor Channel - 2006



ECMWF bias is now larger than NCEP!!! (increased by ~0.8 K)

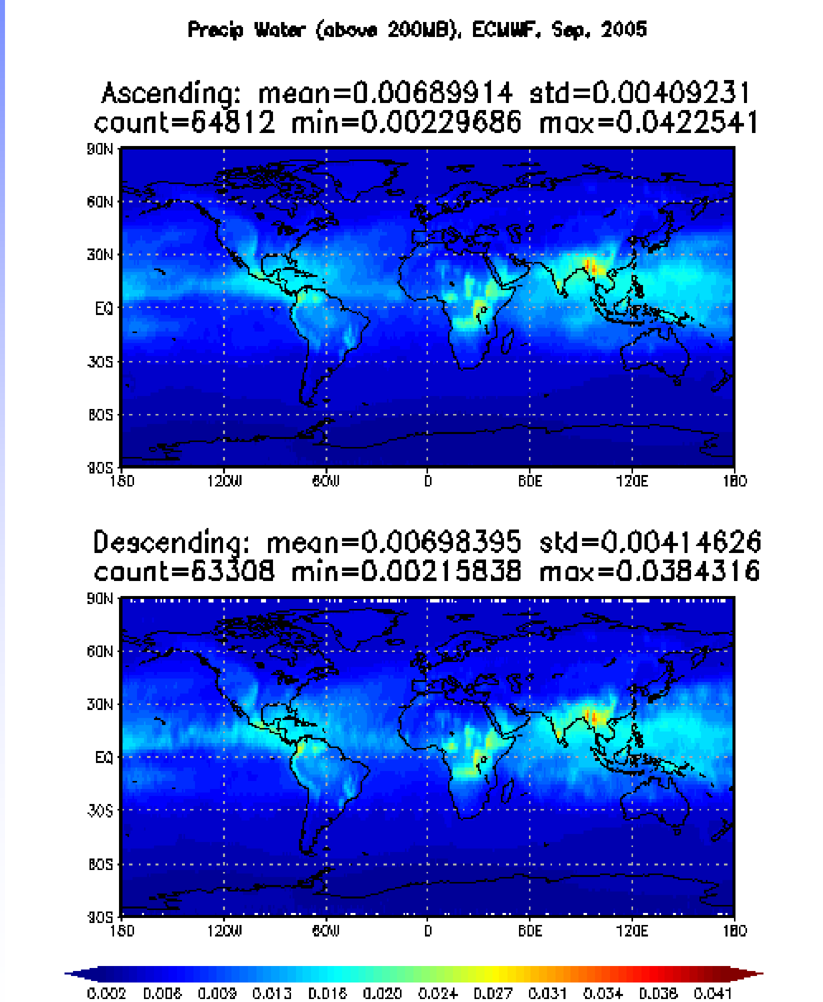
Mid Tropospheric Water Vapor Channel - 2006

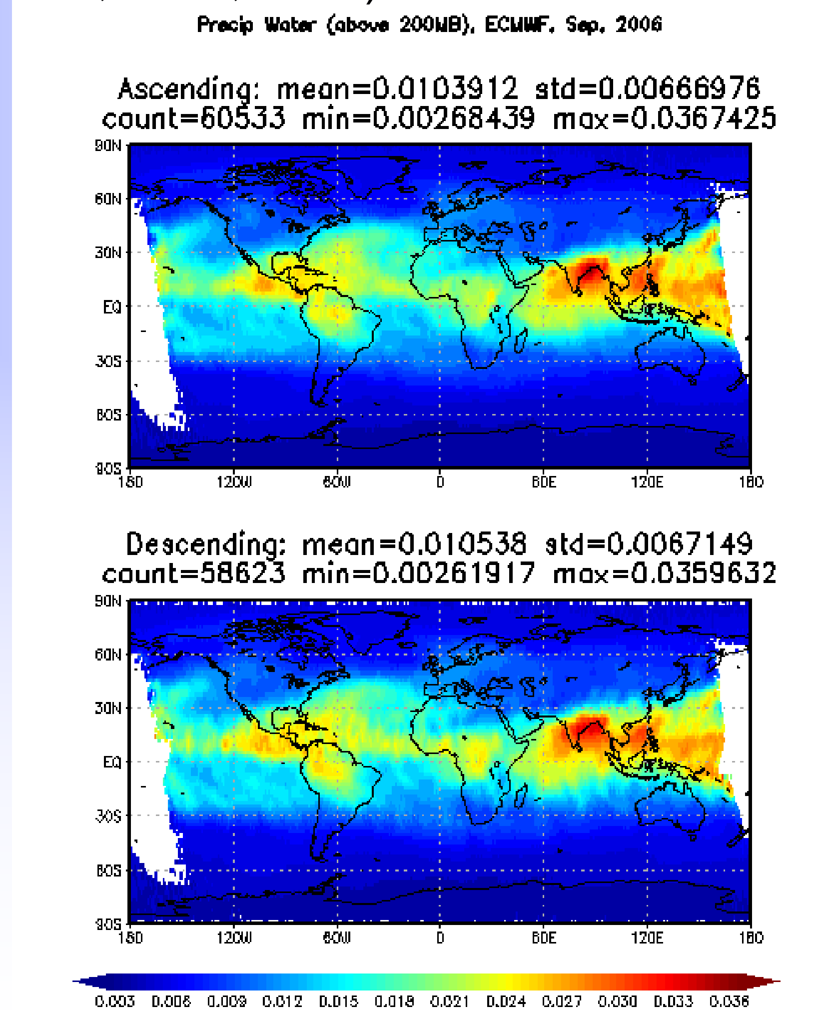


ECMWF bias is nearing NCEP

So what is the cause??

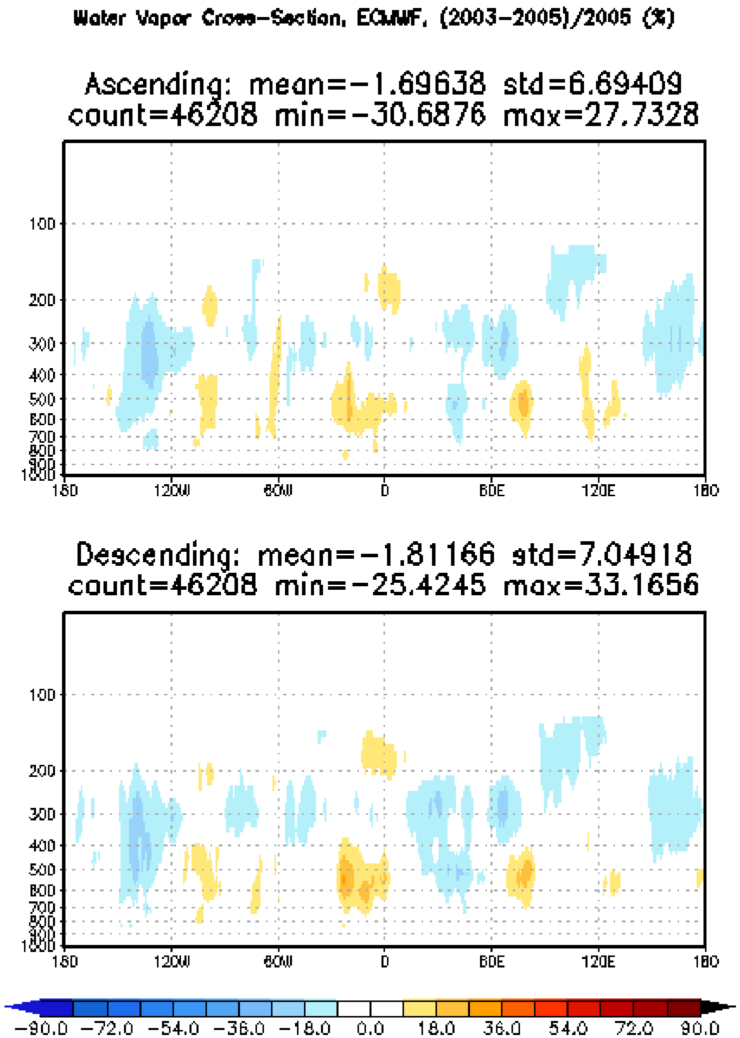
We found the water vapor (TPW) above 200 mb is nearly twice as large
(this is consistent for 2006, 2007, 2008)



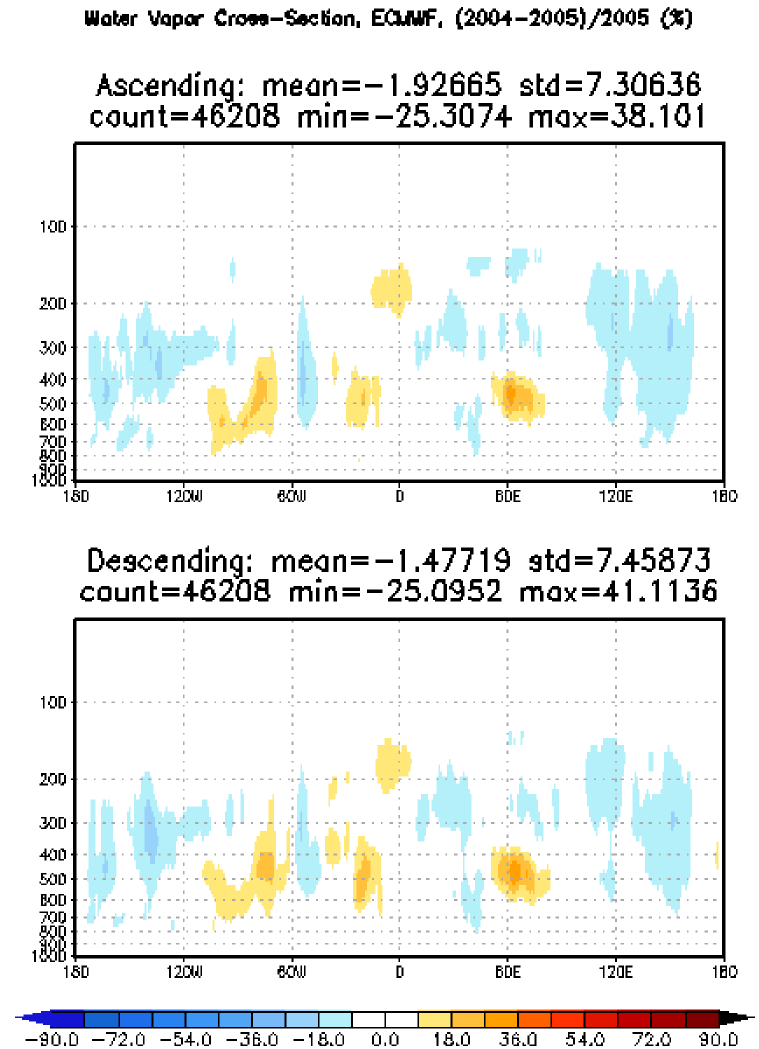


Compare Annual Difference (%) of ECMWF using 2005 as Base Year

Very small year to year differences (2003 – 2005, 2004 – 2005)



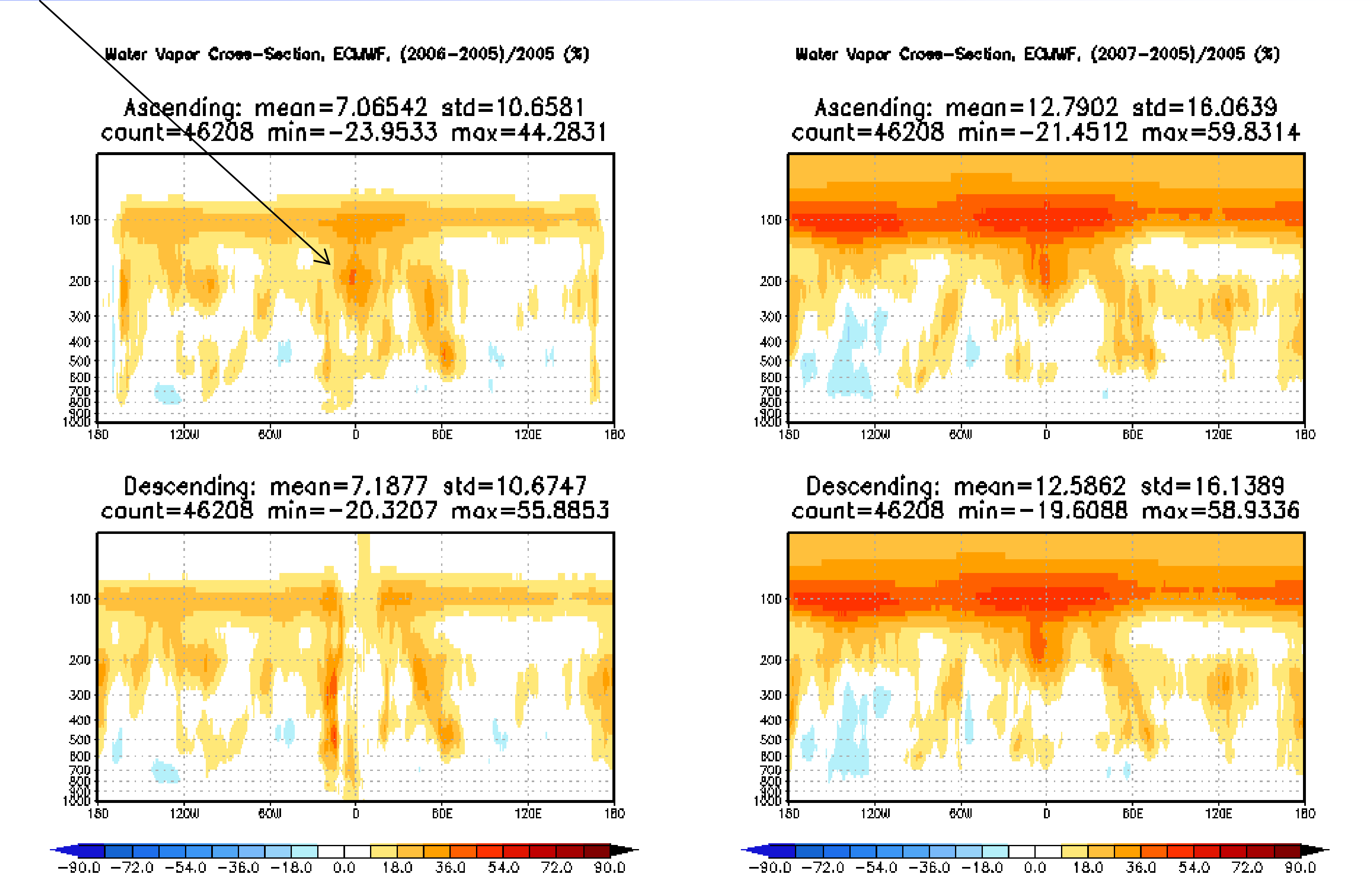
2003



2004

Compare Annual Difference (%) of ECMWF using 2005 as Base Year

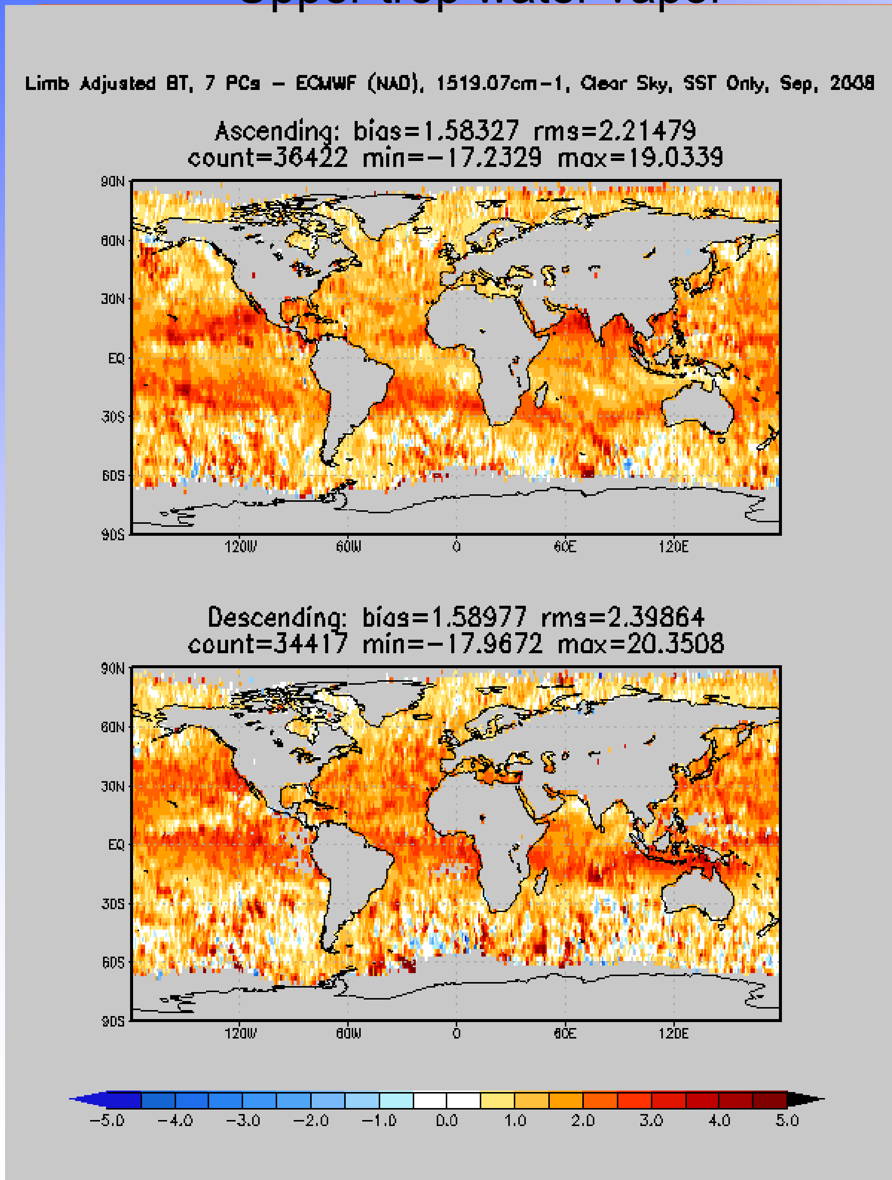
More water from previous years, difference with 2005 is now much larger



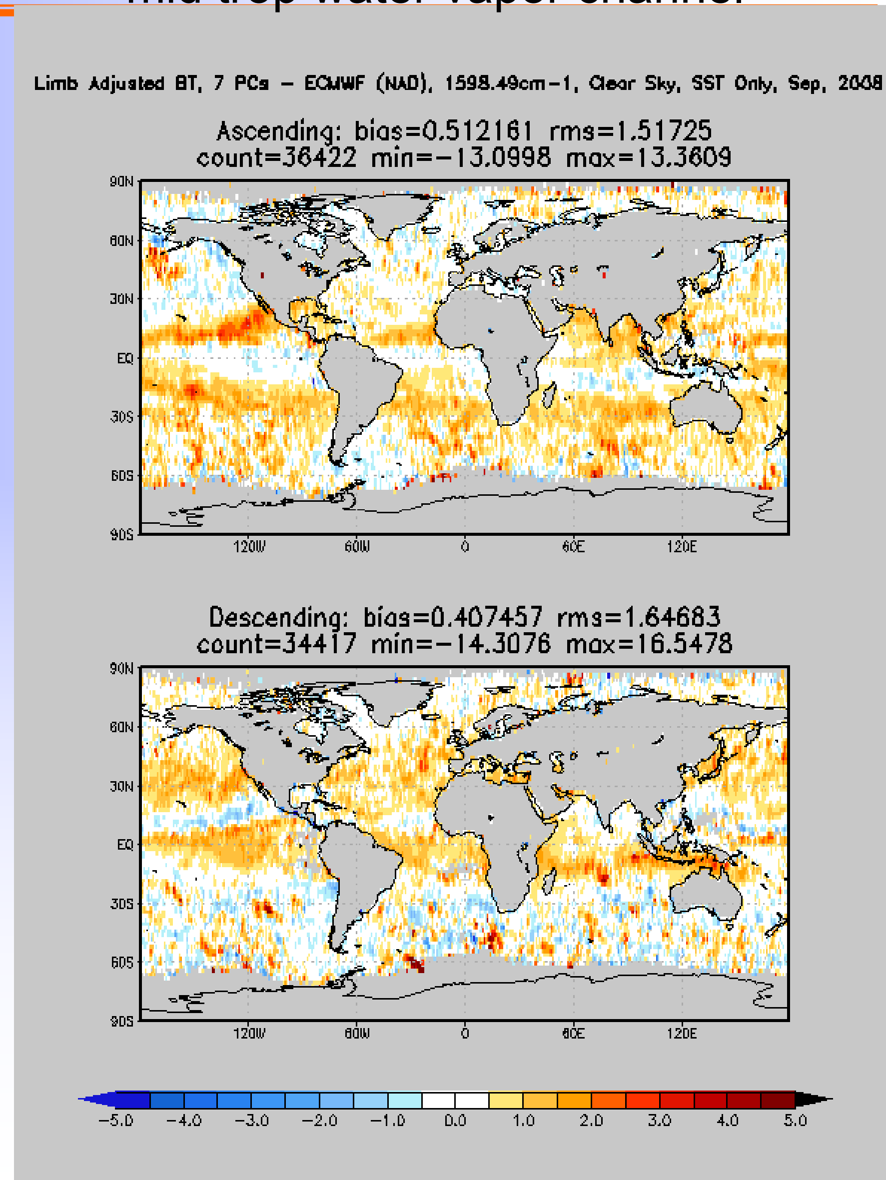
2006 2007 (2008 ~ 2007)

September 2008 AIRS – EC bias remains consistent with 2006

Upper trop water vapor



mid trop water vapor channel



How about Reanalyses??

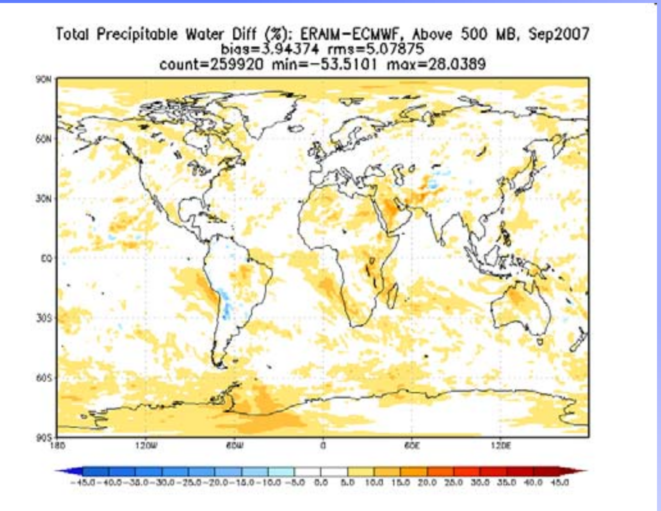
New Generation of Reanalyzes

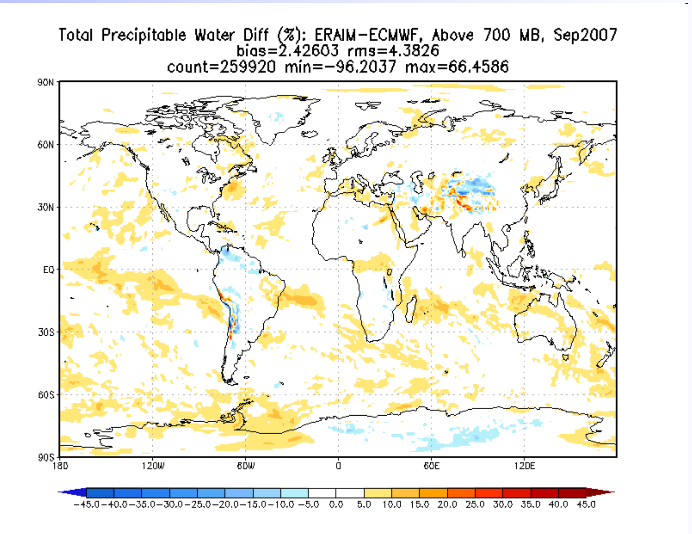
	MERRA	ERA Interim	JRA-25	CFSR
Producer	NASA	ECMWF	JMA	NCEP
Time Period	1979-now	1989-now	1979-now	1979 to 2009
Data Assimilation	Incremental Analysis Updates (IAU)	4D-Var	3D-Var	3D-Var
Vertical Resolution	42	37	23	64
Model Top (hPa)	0.1	1.0	0.4	0.26
Horizontal Resolution	0.66*0.5	1.5*1.5	1.25*1.25	0.5*0.5
Data Format	HDF	netCDF	GRIB	?

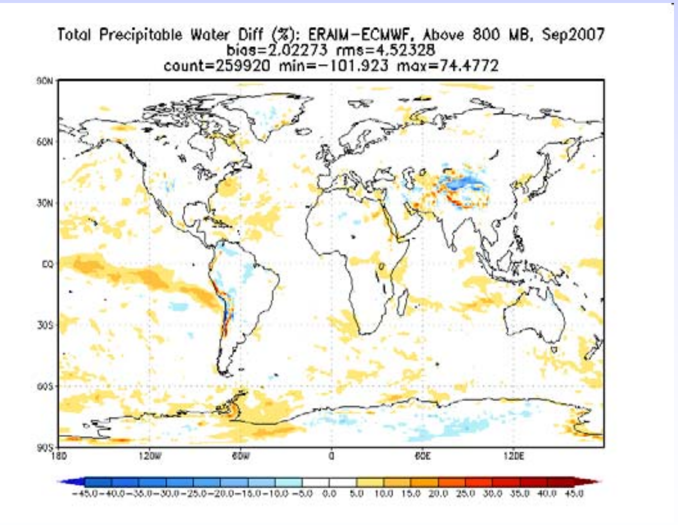
Conservative Error Budget for Water Vapor Channels

- RTA ~ 0.5 K ~ 5%
- Interpolation to RTA levels ~ 5%
- RMSE ~ 7%
- Cannot determine which water vapor field is more accurate if differences are within 7%

ERA Interim Reanalysis - ECMWF Weather Analysis Sept. 2007

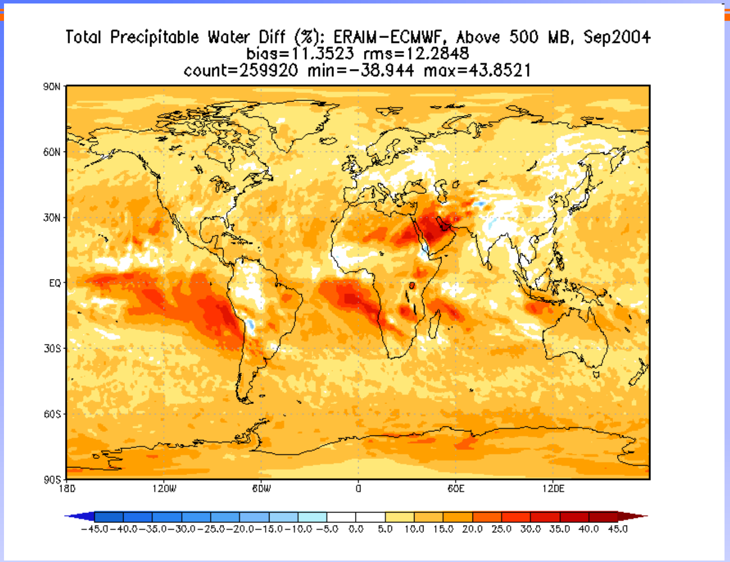


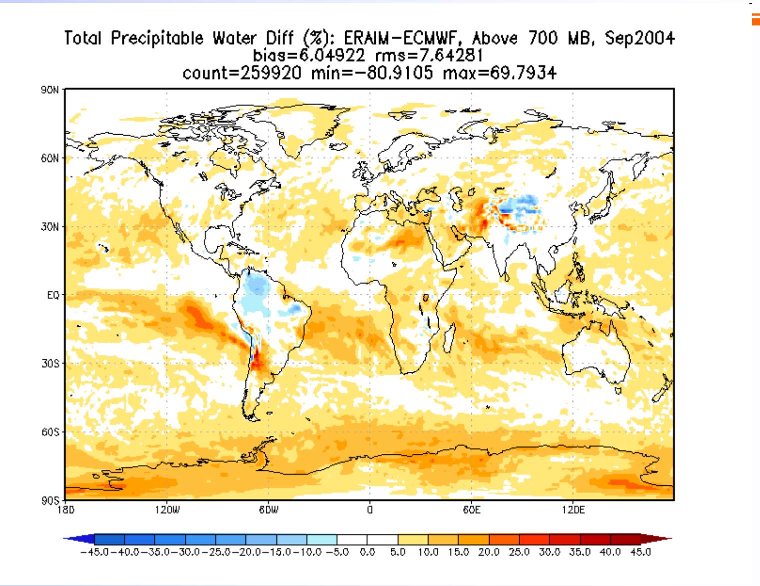


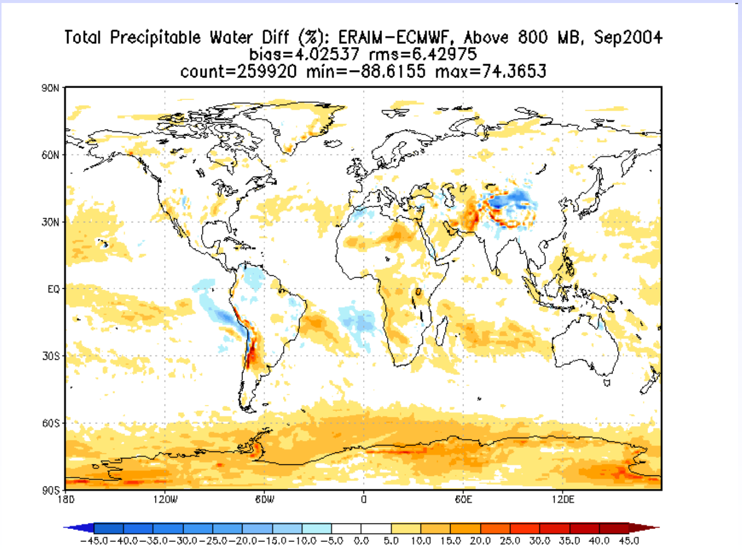


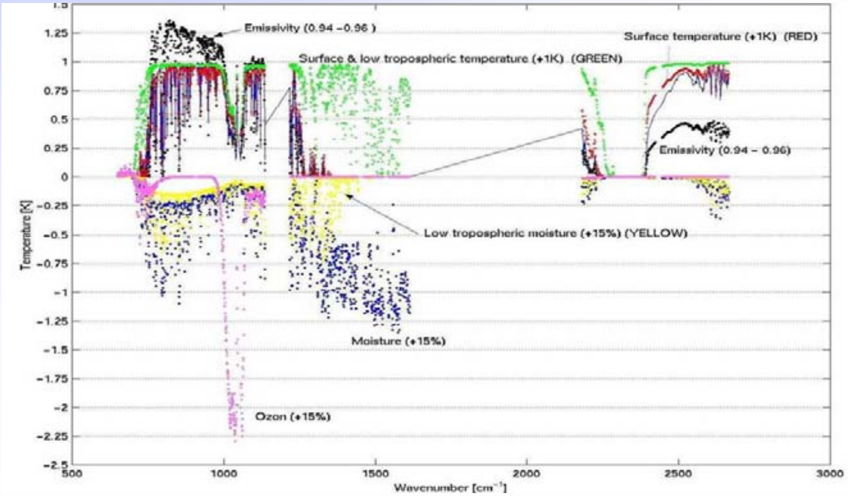
ECMWF 2003 – 2005 can be used to validate reanalyses

ERA Interim Reanalysis - ECMWF Weather Analysis Sept. 2004

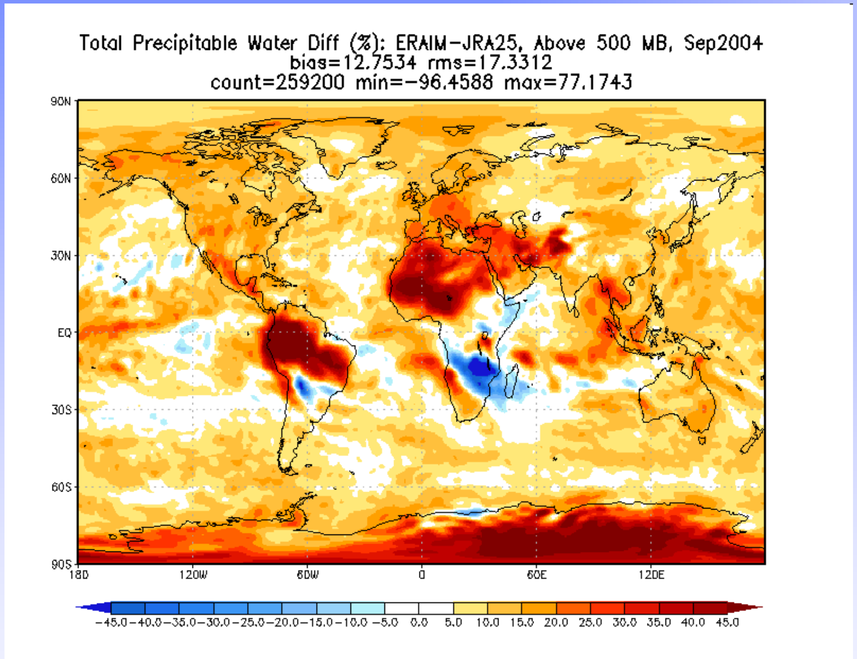




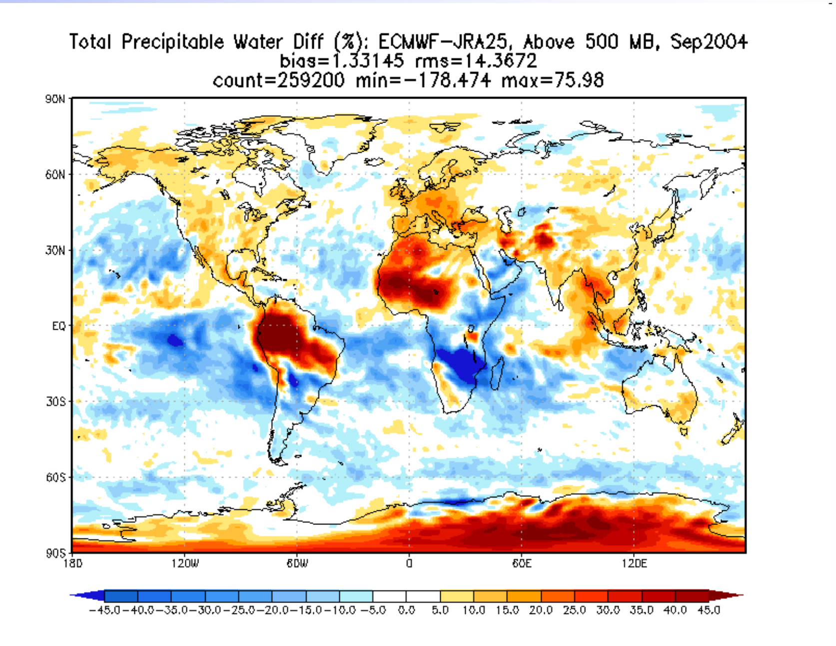




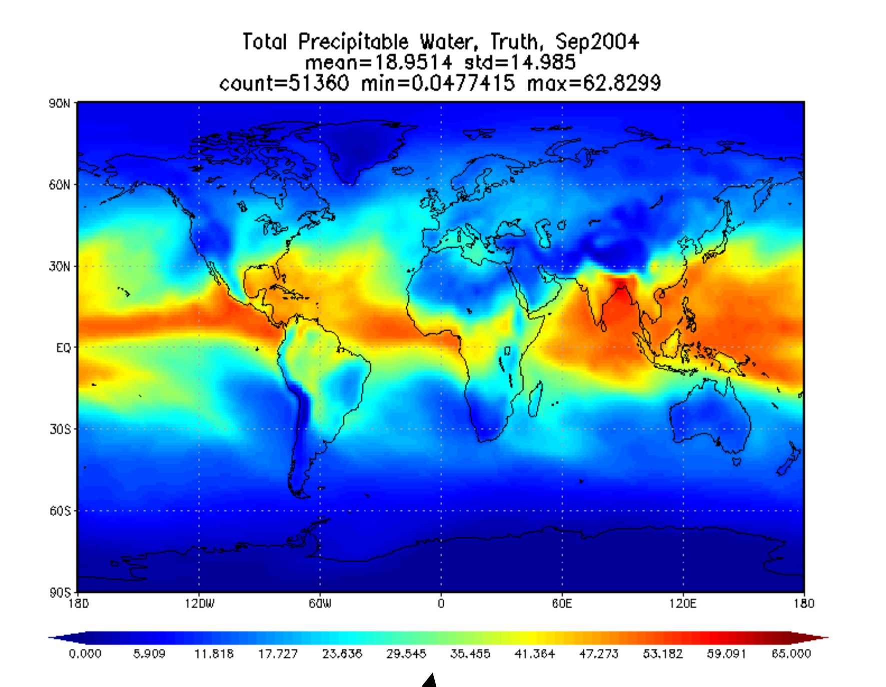
JRA25 vs ECMWF and ERA Interim (above 500 mb)

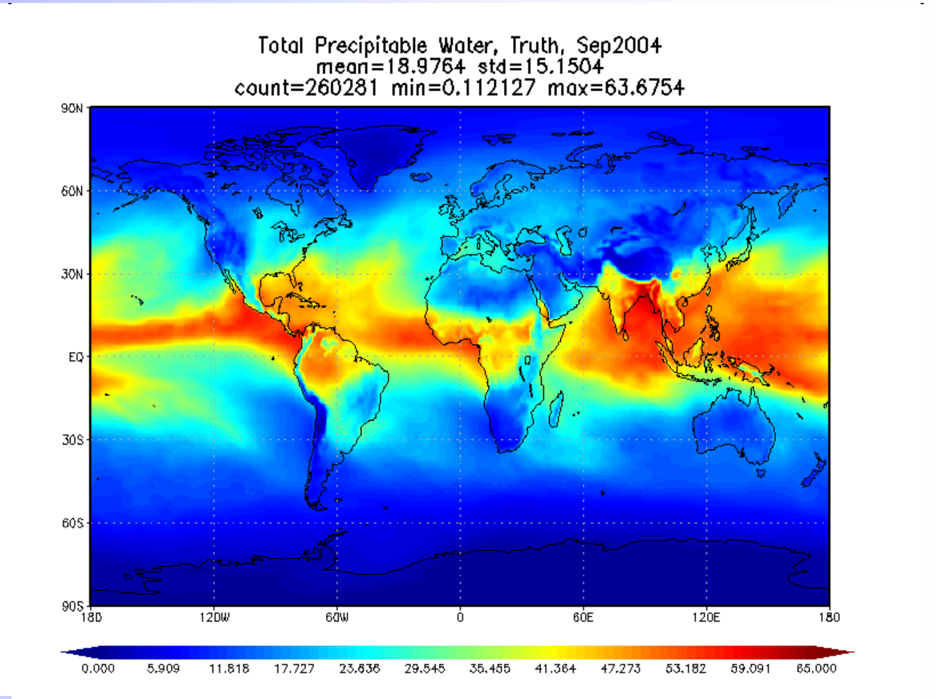


ERAIM - JRA25

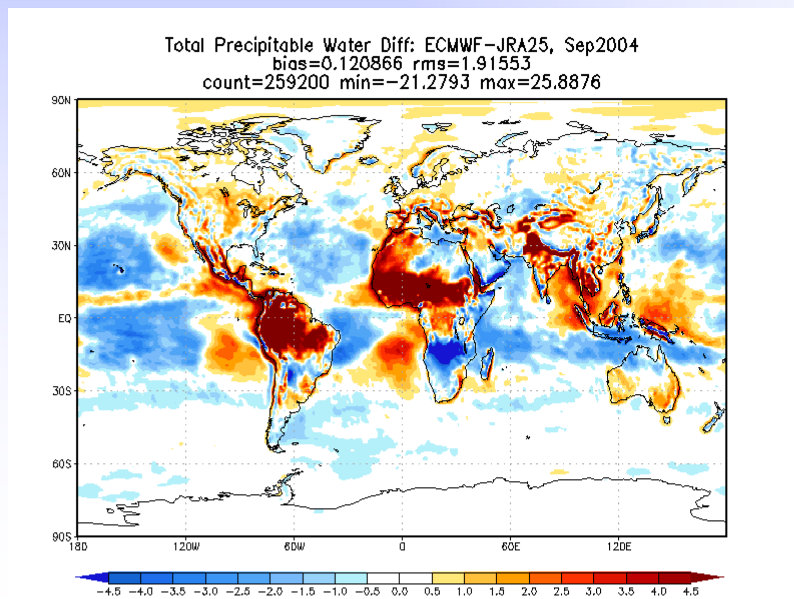


ECMWF - JRA25





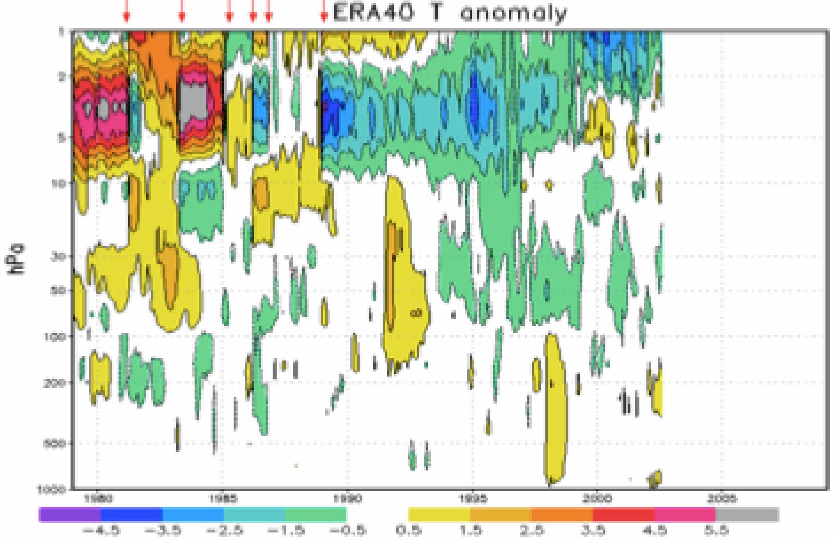
TPW Comparison of ECMWF vs JRA25



ERA40 / CFSR /MERRA

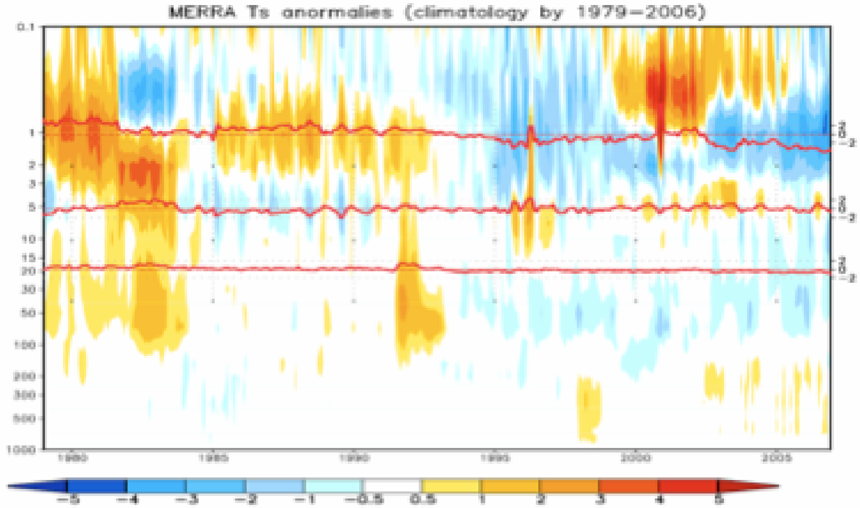
Changes in satellite data used

ERA-40

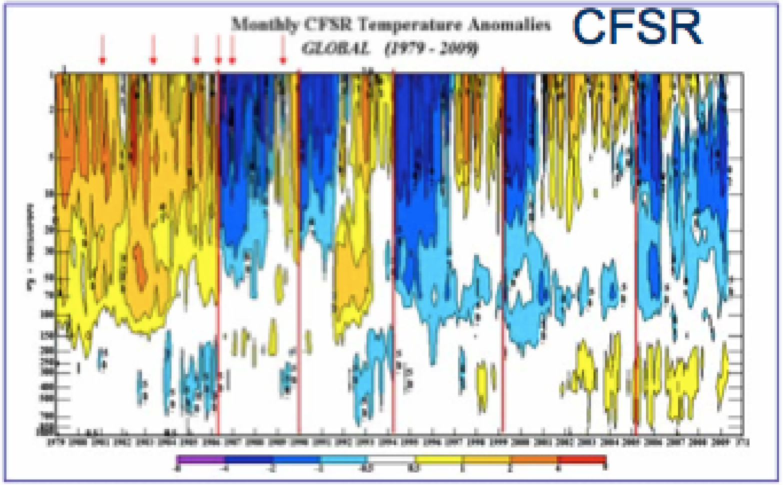


No apparent changes in satellite data used, BUT Big inter-stream jumps!

MERRA



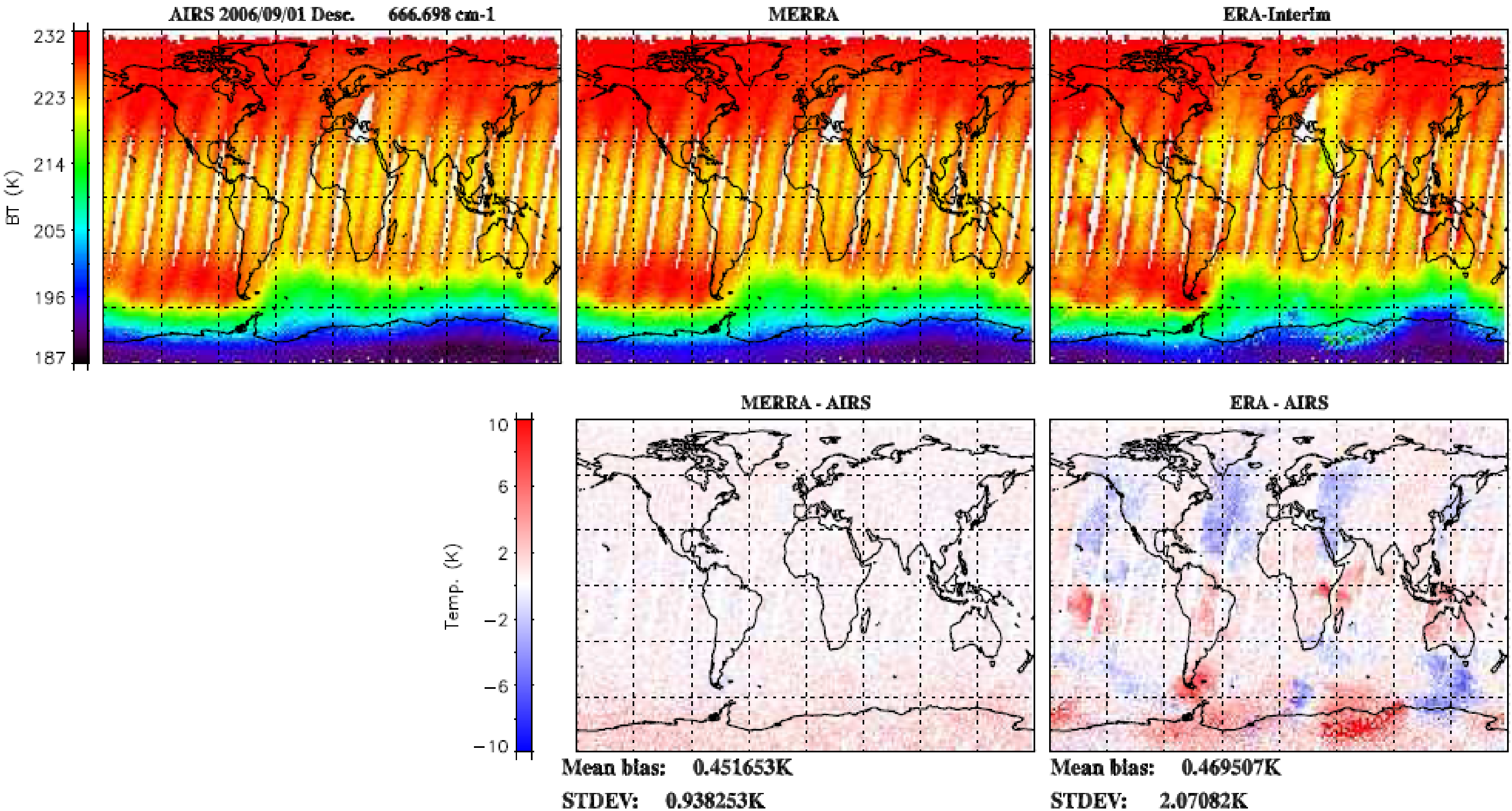
CFSR



NO big jumps between satellites and streams in MERRA

Courtesy of Craig Long

Stratospheric temperature: 666.7 cm-1 channel (1.5 hPa)

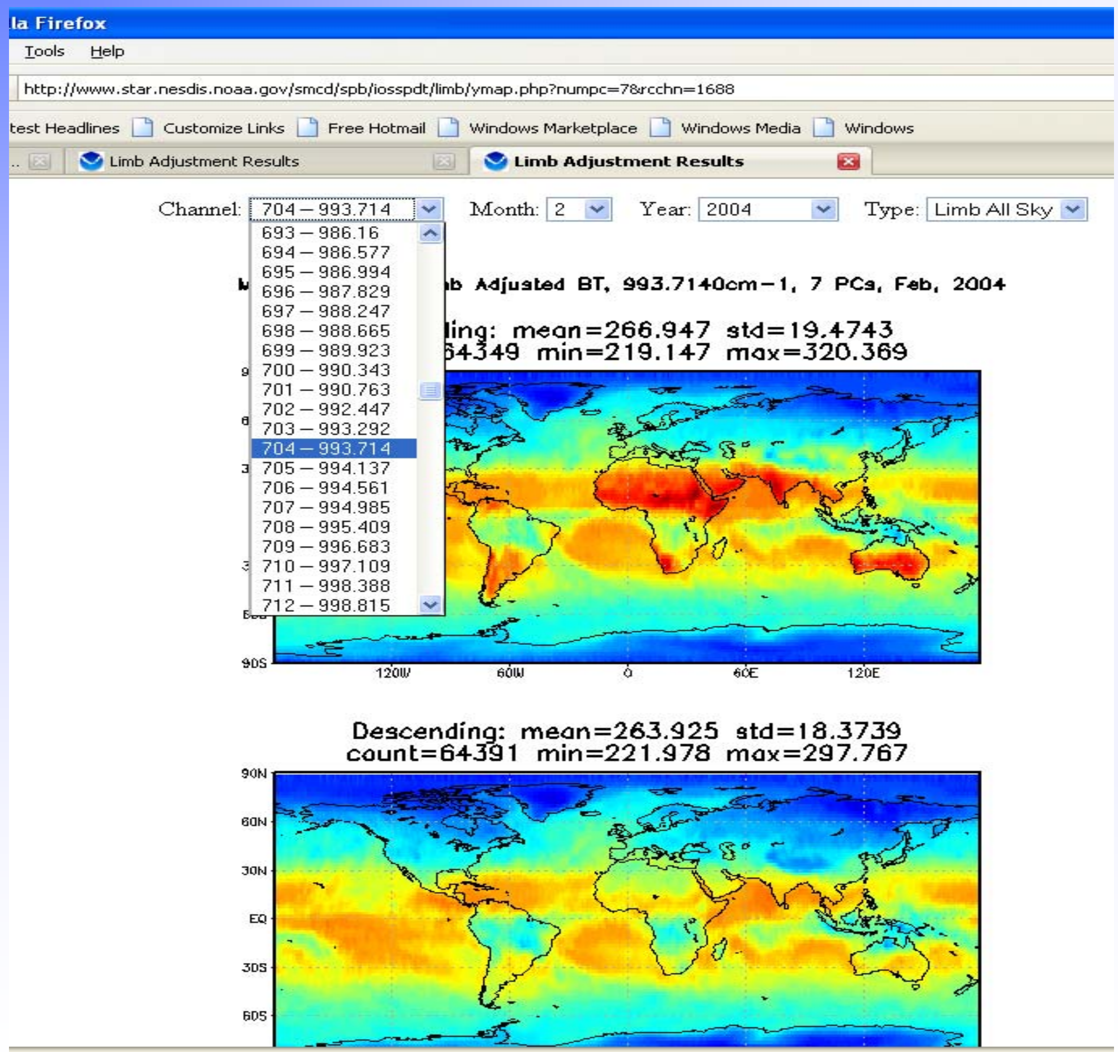


Summary

- Developed a SRIR radiance CDR
- The CDR consists of monthly brightness temperatures for all AIRS channels
  - Ascending (day), clear sky
  - Ascending, all sky
  - Descending (night), clear sky
  - Descending, all sky datasets
- Will extend into the future, and also use IASI and CrIS

Summary

Datasets have been generated for 5 years data from January 2003:



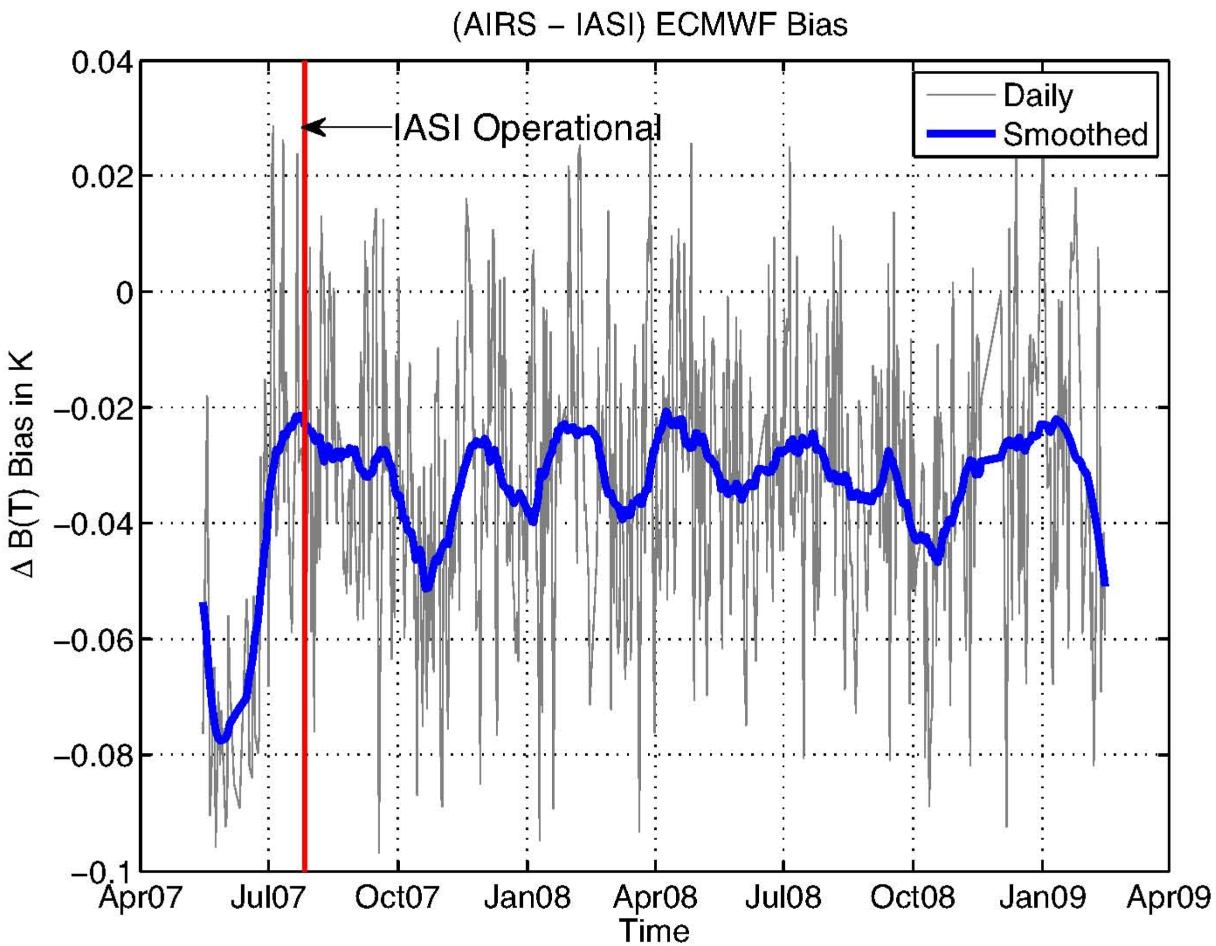
Summary

- Demonstrated two very important applications:
  - Determine the accuracy of model analyses (ECMWF is more accurate 2003-2005, the so-called "Golden Years")
  - Demonstrate the use of the SRIR to monitor the accuracy of models as a function of time (Observed a degradation of ECMWF vs AIRS bias after ECWMF operational changes in September 2006)

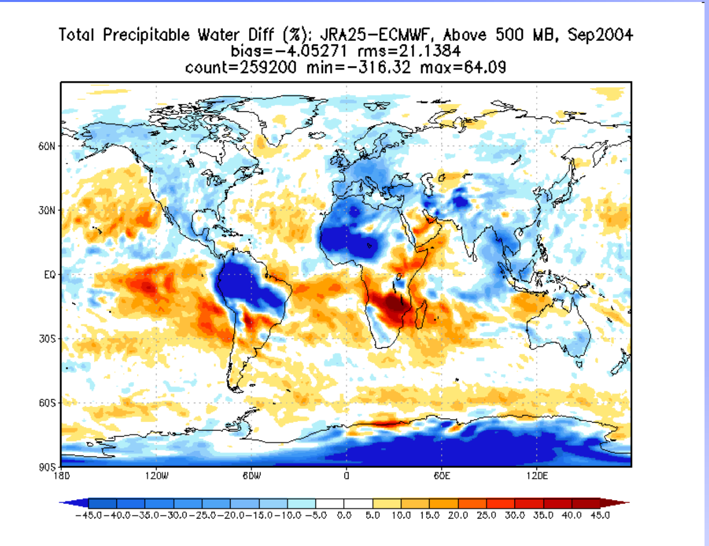
Backup

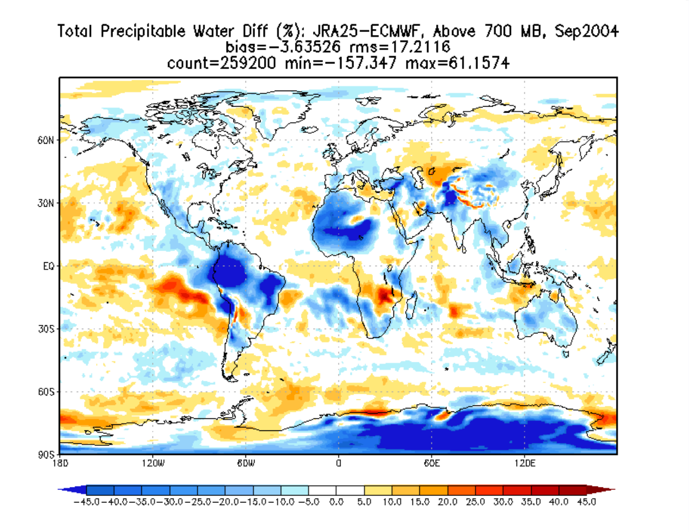
AIRS versus IASI Stability

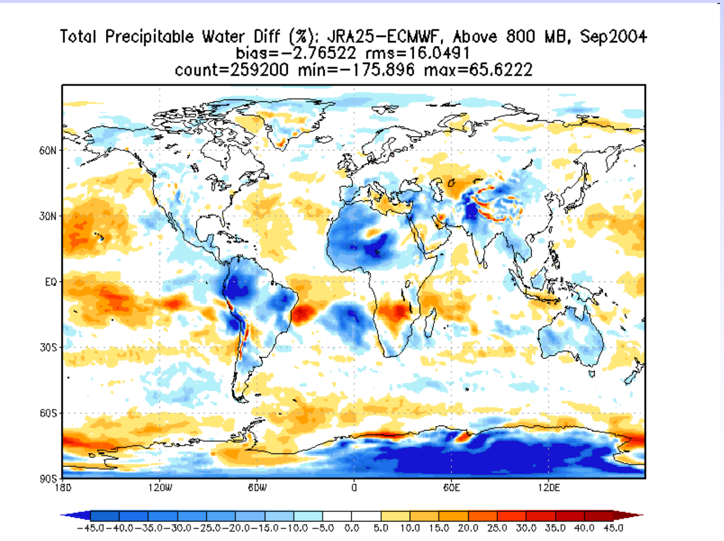
-0.0019K/year ± 0.008K/year (corrected for lag-1 correlation of 0.45)

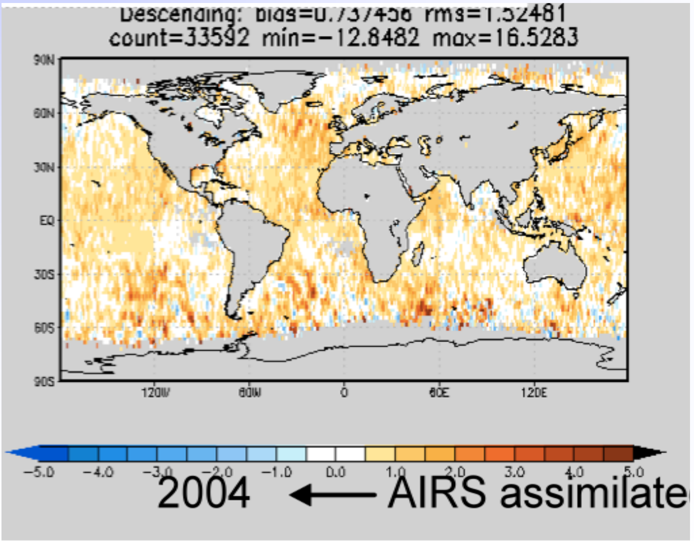


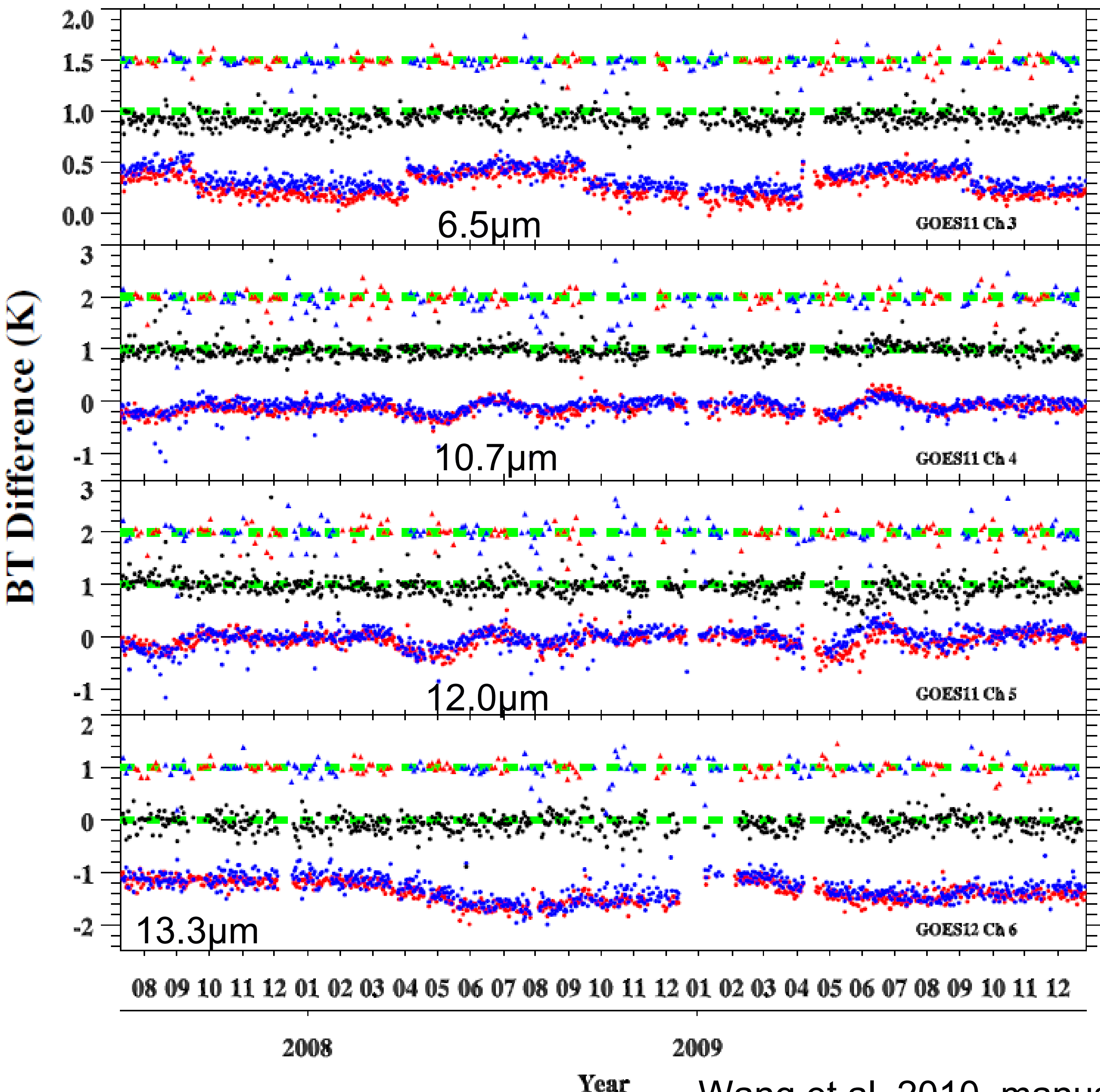
JRA 25 Reanalysis - ECMWF Weather Analysis Sept. 2007











IASI-AIRS

Zero line

SNO North

SNO South

Double Difference

GOES-AIRS

GOES-IASI

Wang et al. 2010, manuscript for GRL

Statistical results

		GOES-11 Ch3	GOES-11 Ch4	GOES-11 Ch5	GOES-12 Ch6
Central Wavelength (µm)		6.7	10.7	12.0	13.3
Double Differences	Sample number	694	688	691	626
	Mean (K)	-0.0707	-0.0262	-0.041	-0.0751
	95% confidence level (K)	0.0052	0.0116	0.0135	0.0124
SNOs	Sample number	228 *	228	228	228
	Mean (K)	-0.011	-0.0624	-0.010	-0.0124
	95% confidence level (K)	0.0091	0.0300	0.0295	0.0211