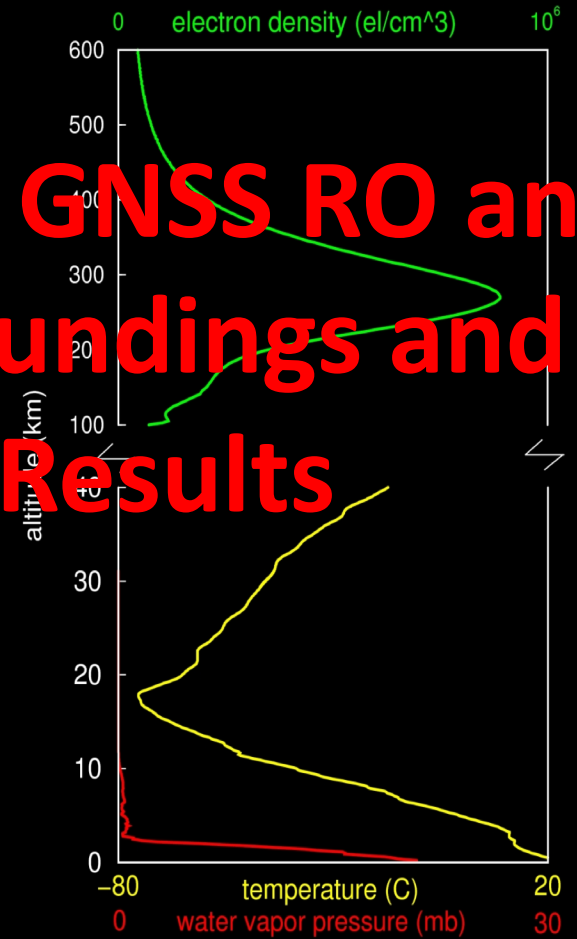


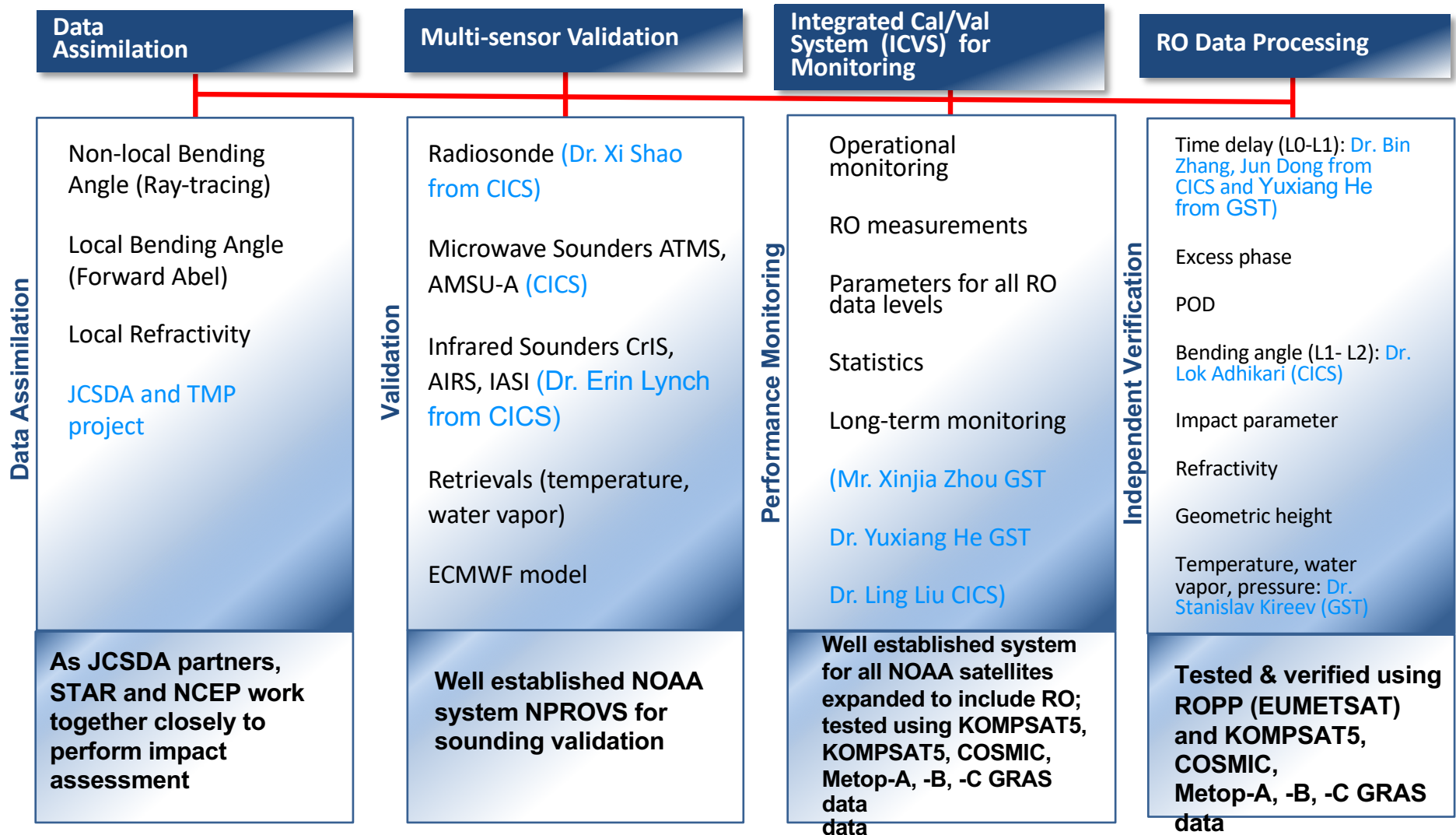


# Inter-comparison between GNSS RO and hyperspectral infrared soundings and Combined Retrieval Results



Shu-peng Ben Ho and STAR GNSS Team  
NOAA/STAR

# NOAA/STAR in-house Expertise to support CWDP/COSMIC-2 Tasks



Four major focus areas of Cal/Val work have been

## **RO missions and JPSS series in NOAA**

**NOAA JPSS series** (Suomi NPP and JPSS-1, the JPSS-2, JPSS-3 and JPSS-4 missions)

Advanced Technology Microwave Sounder (ATMS),

Cross-track Infrared Sounder (CrIS),

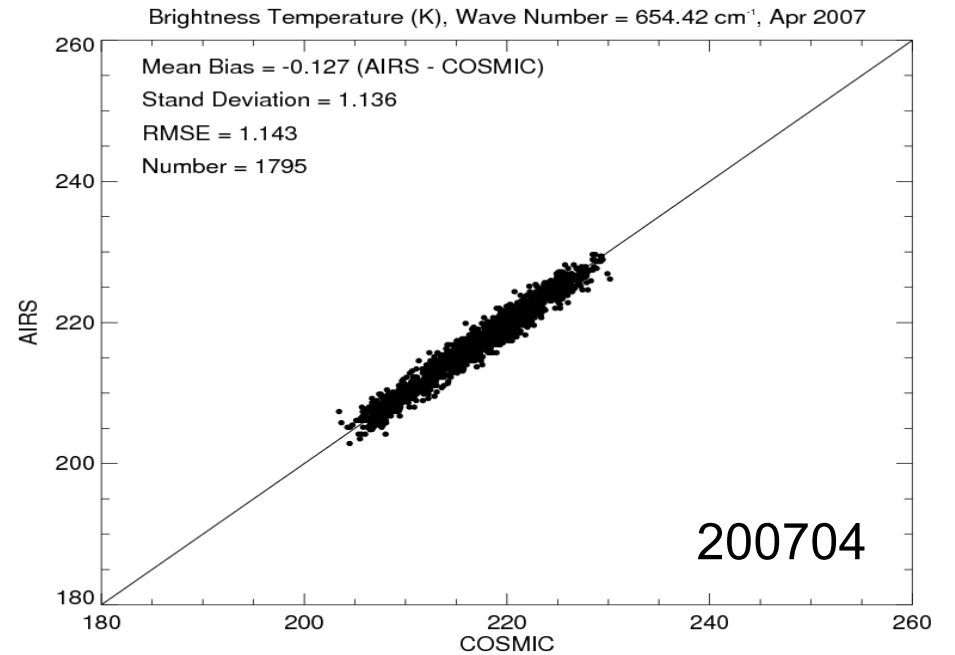
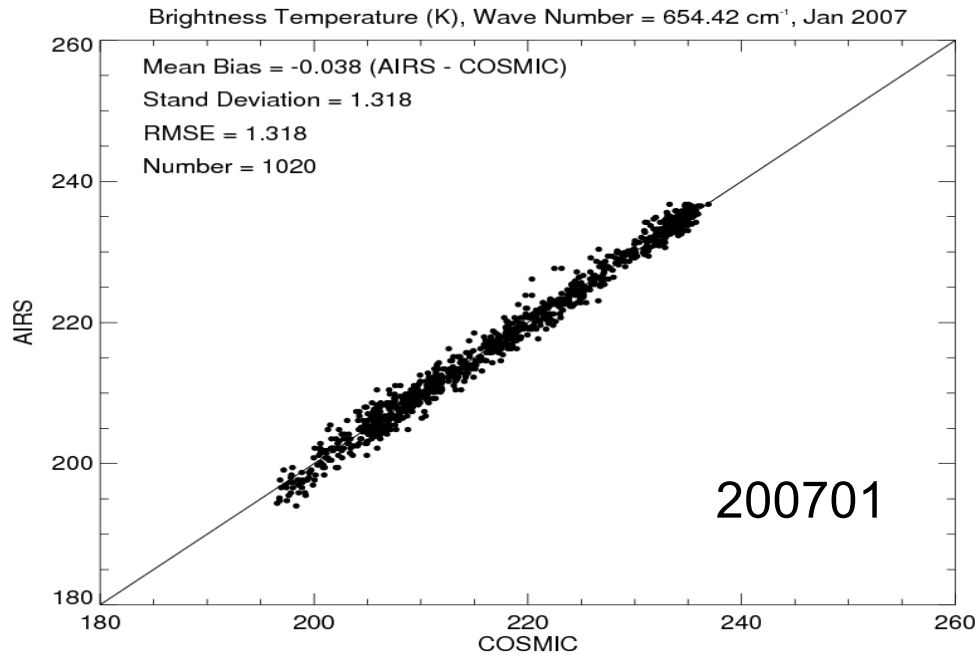
Ozone Mapping Profiler Suite (OMPS),

Radiation Budget Instrument (RBI),

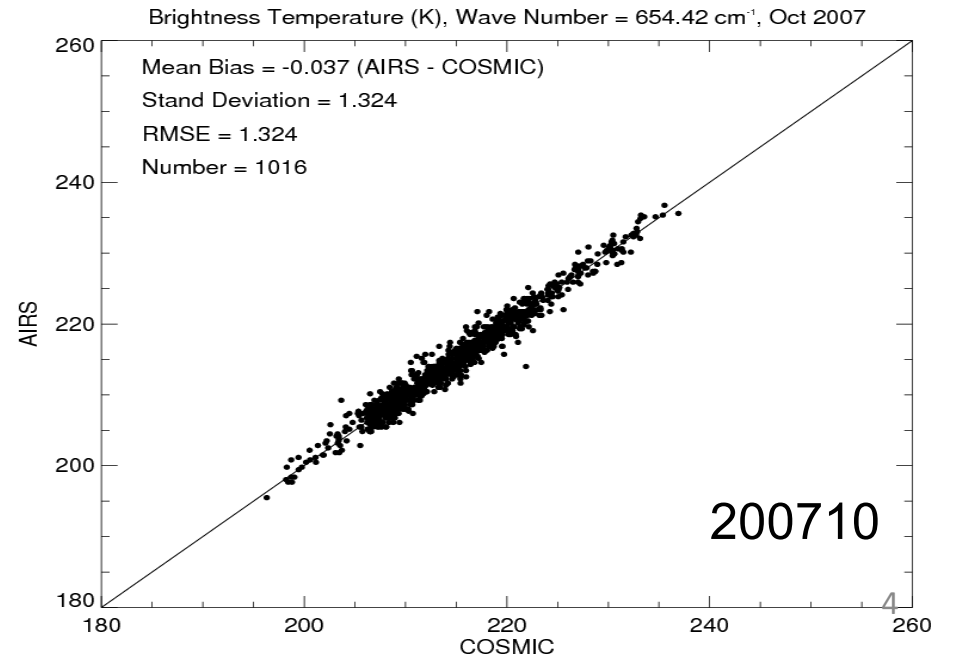
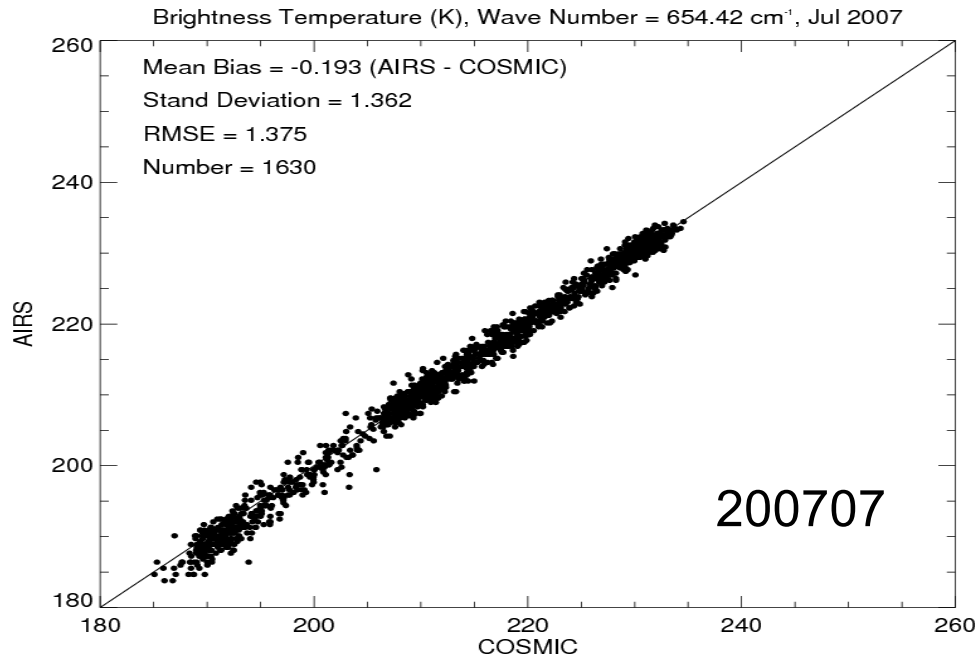
Visible Infrared Imaging Radiometer Suite (VIIRS)

- 1. Using RO simulated brightness temperatures to monitoring the quality of measurements from satellite IR sounders**
- 2. Using RO retrievals to validate the IR retrieval results**
- 3. AIRS + RO combined inversion**

# 1. Comparison of AIRS and RO simulated AIRS brightness temperatures

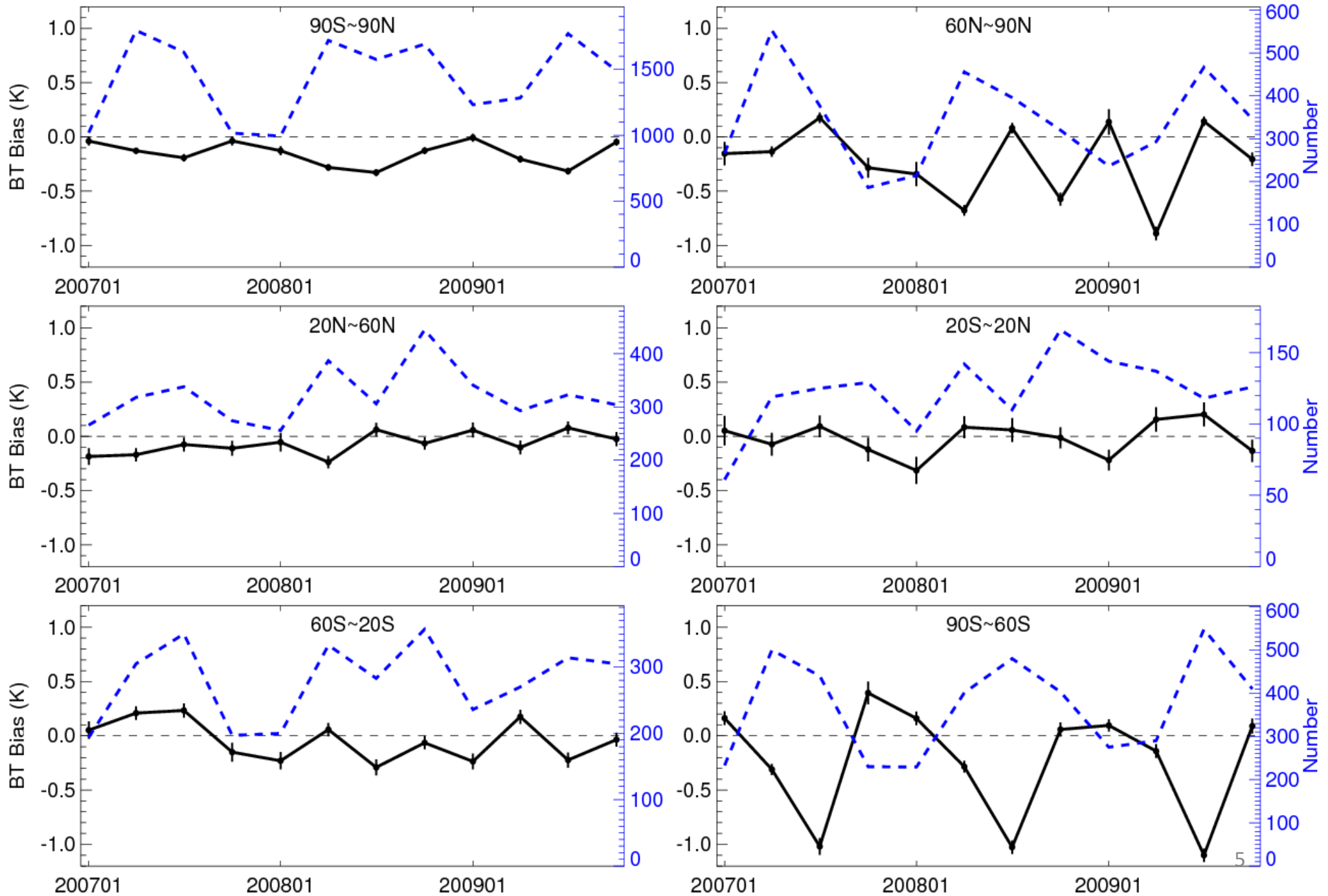


Distance difference = 100km, Time Difference = 30 minutes



# Using RO data to monitoring quality of AIRS Measurements

Brightness Temperature Bias (AIRS-COSMIC), Wave Number = 654.42 cm<sup>-1</sup>

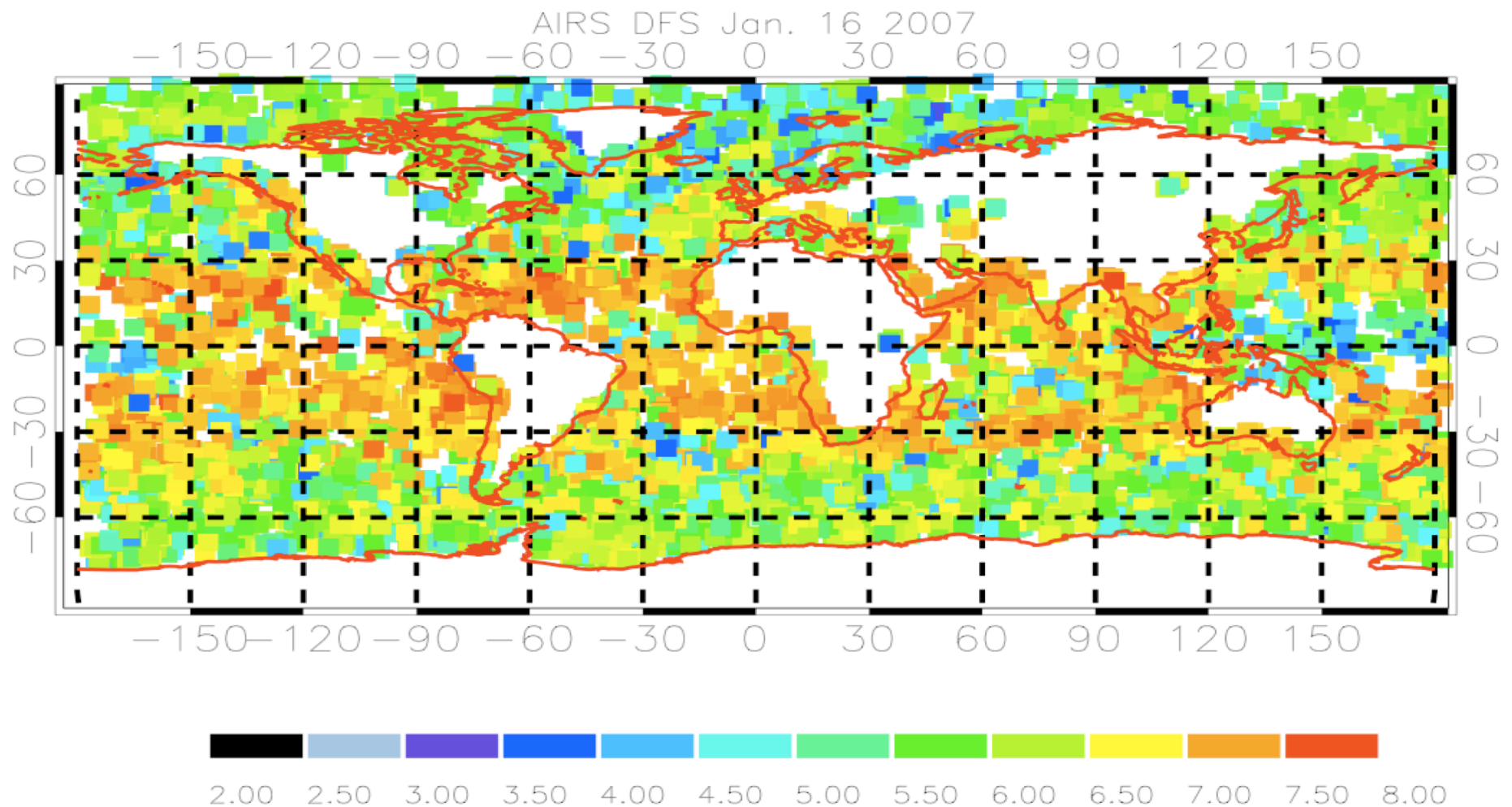


## 2. Using RO data to monitoring AIRS data and retrievals

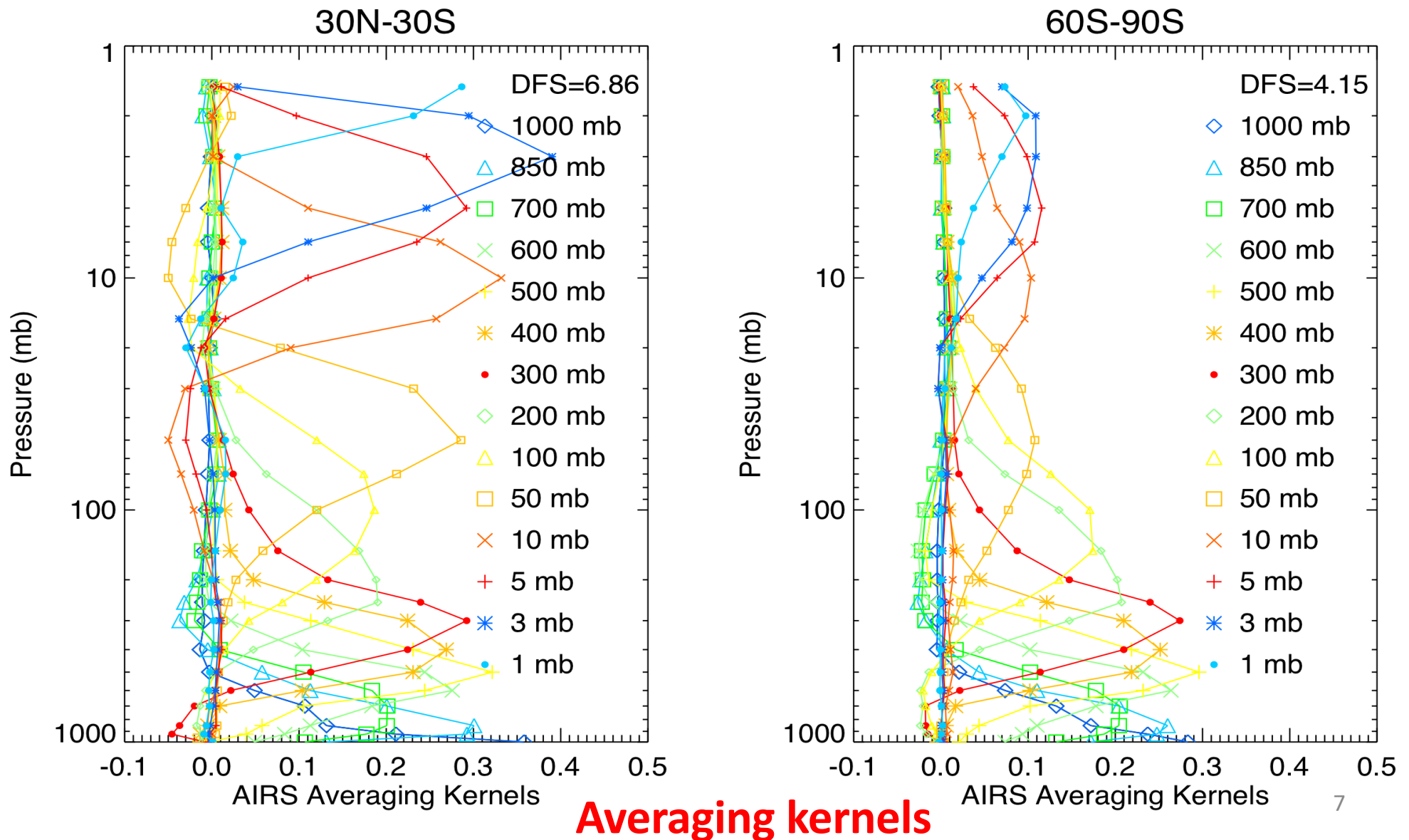
DFS is a function of atmospheric and surface conditions.

So AIRS temperature retrievals depend on the a priori profile and atmospheric/surface conditions, and also the retrieval methods.

$$T_{AIRS}^{Ret} = A_{AIRS} T_{True} + (1 - A_{AIRS}) T_{AIRS}^{Apr}$$



**Approach: Smooth RO temperature to eliminate effects of AIRS priori profiles and vertical resolution mismatch defined by averaging kernels - examine the AIRS temperature**

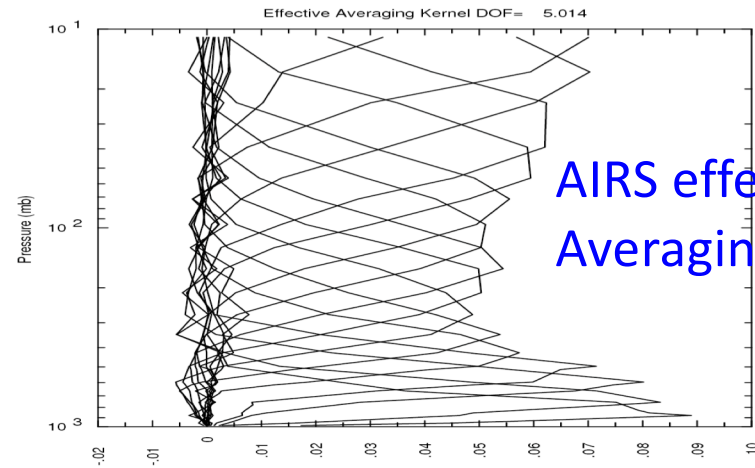
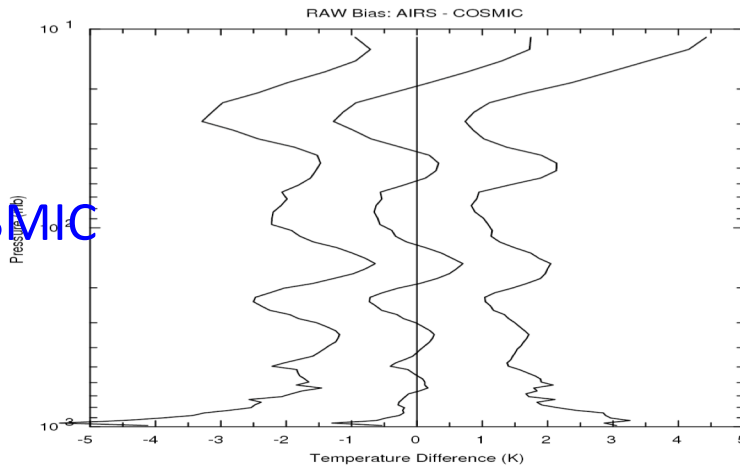


**Results: eliminate effects of AIRS priori profiles and vertical resolution mismatch defined by averaging kernels (Eric Maddy' method)**

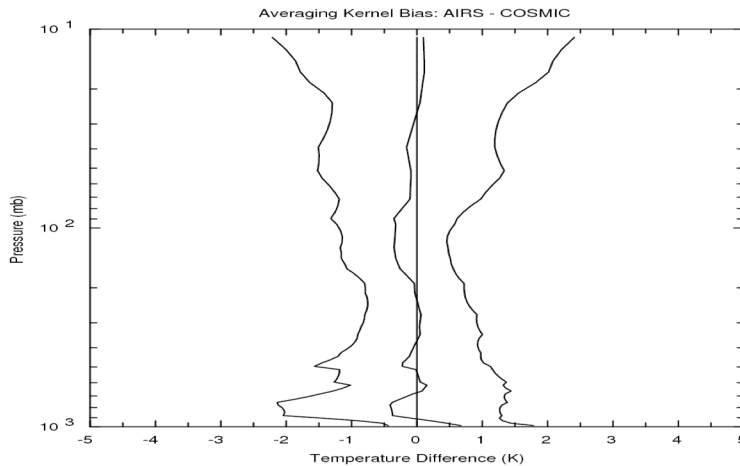
$$T_{AIRS}^{New} = A_{AIRS}^{Effective} T_{COSMIC} + (1 - A_{AIRS}^{Effective}) T_{AIRS}^{Apr}$$

$$A_{AIRS}^{Effective} = F A_{AIRS} F^*$$

AIRS-COSMIC

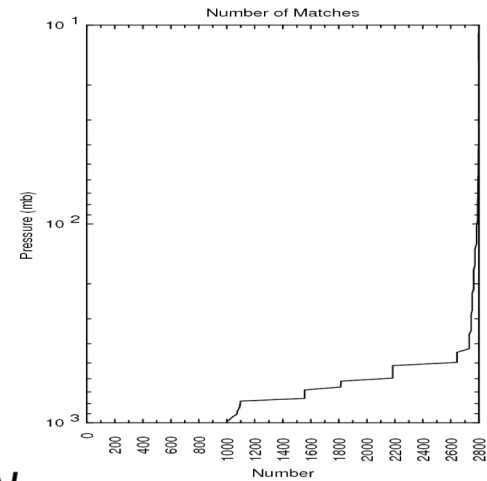


AIRS effective Averaging kernels



Average Dates:  
Begin: 9 / 2006  
End: 11 / 2006

ALL Latitudes  
Land & Ocean  
No Clouds  
Day & Night



AIRS-Smoothed COSMIC

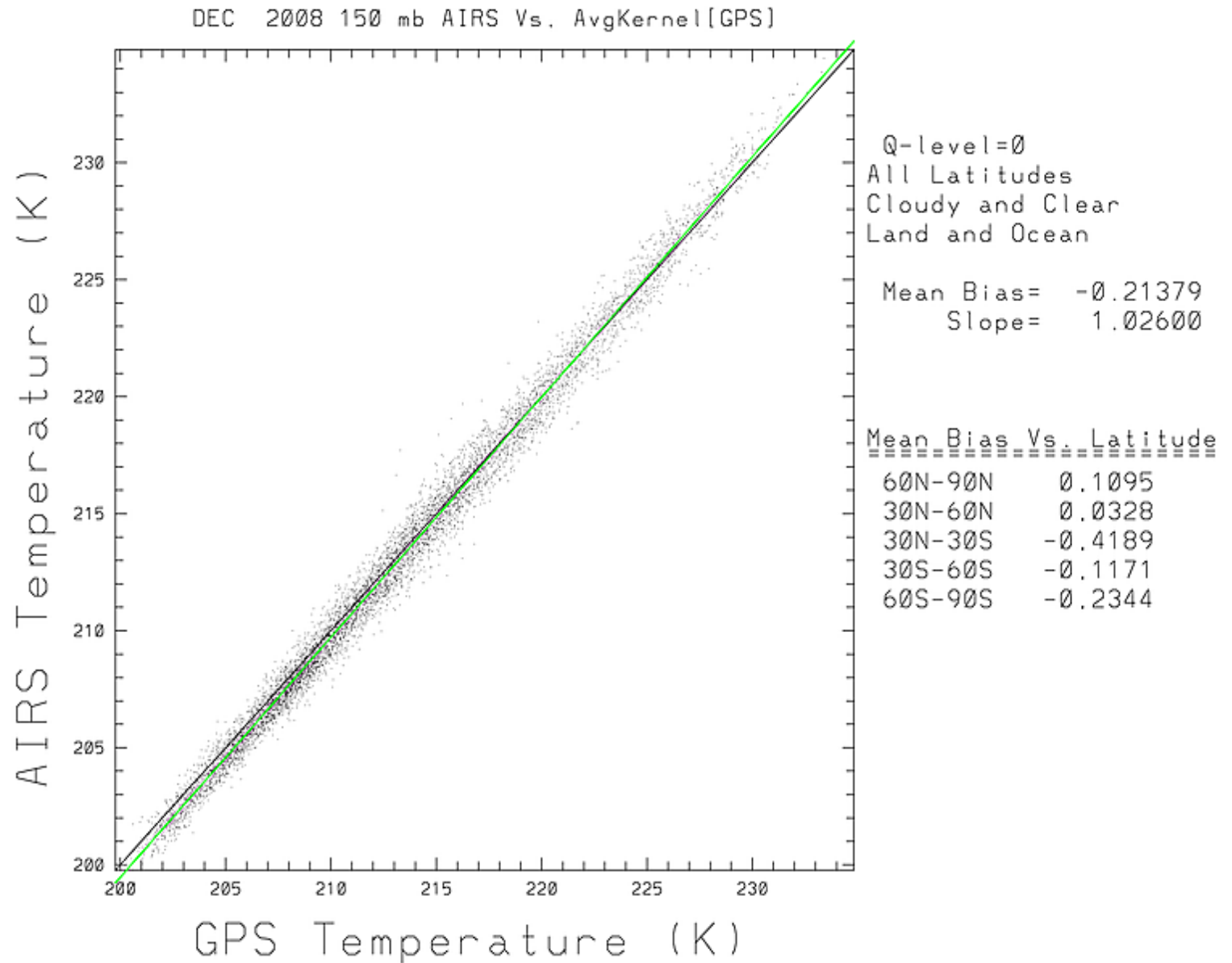
$$\Delta T_{AIRS} = T_{AIRS} - T_{AIRS}^{New}$$



# 150 mb AIRS vs. smoothed COSMIC Temperature (K)

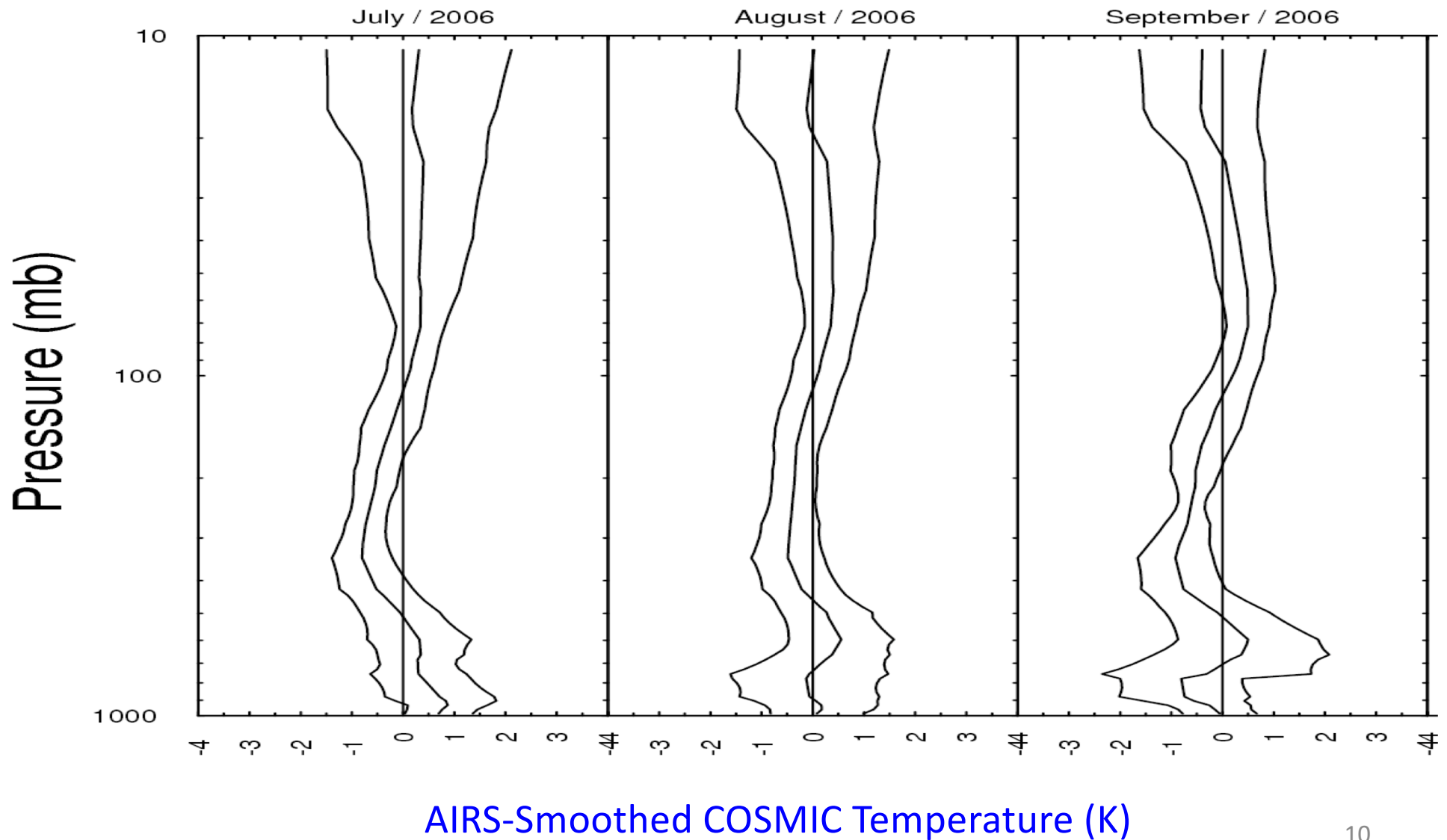
Corr ~ 1.0

We can use the defined slope and offset to calibrate AIRS temperatures



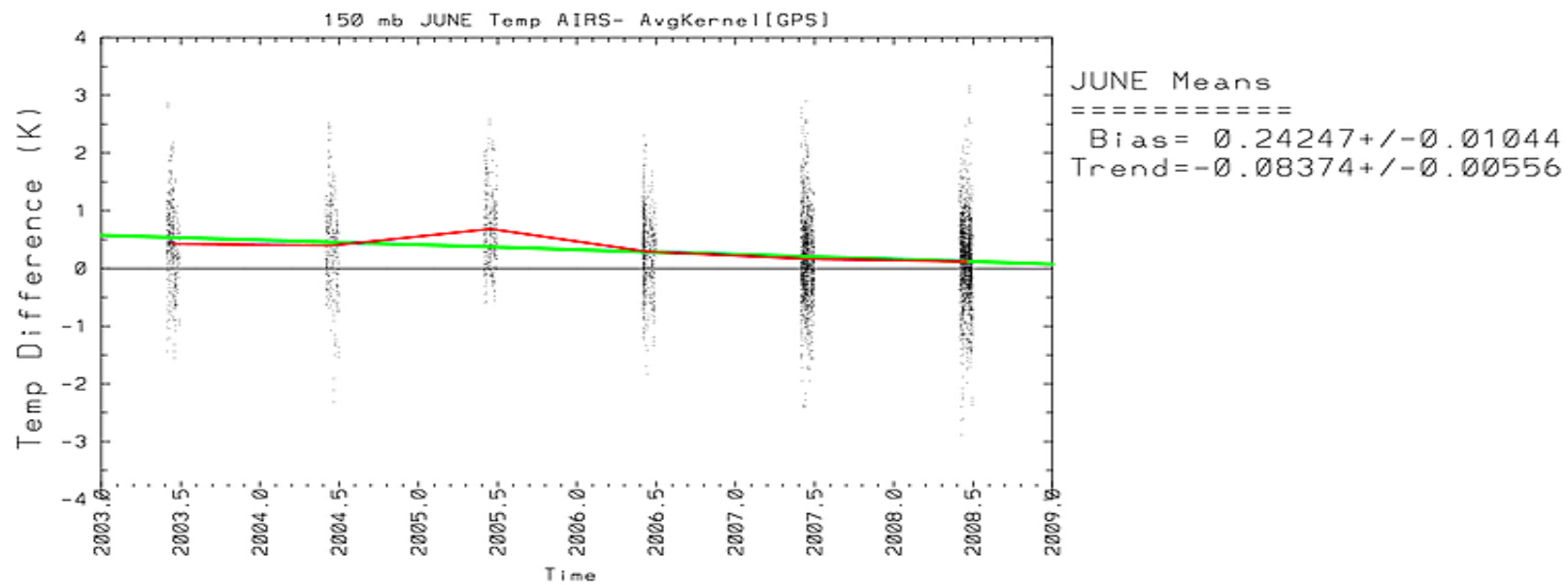
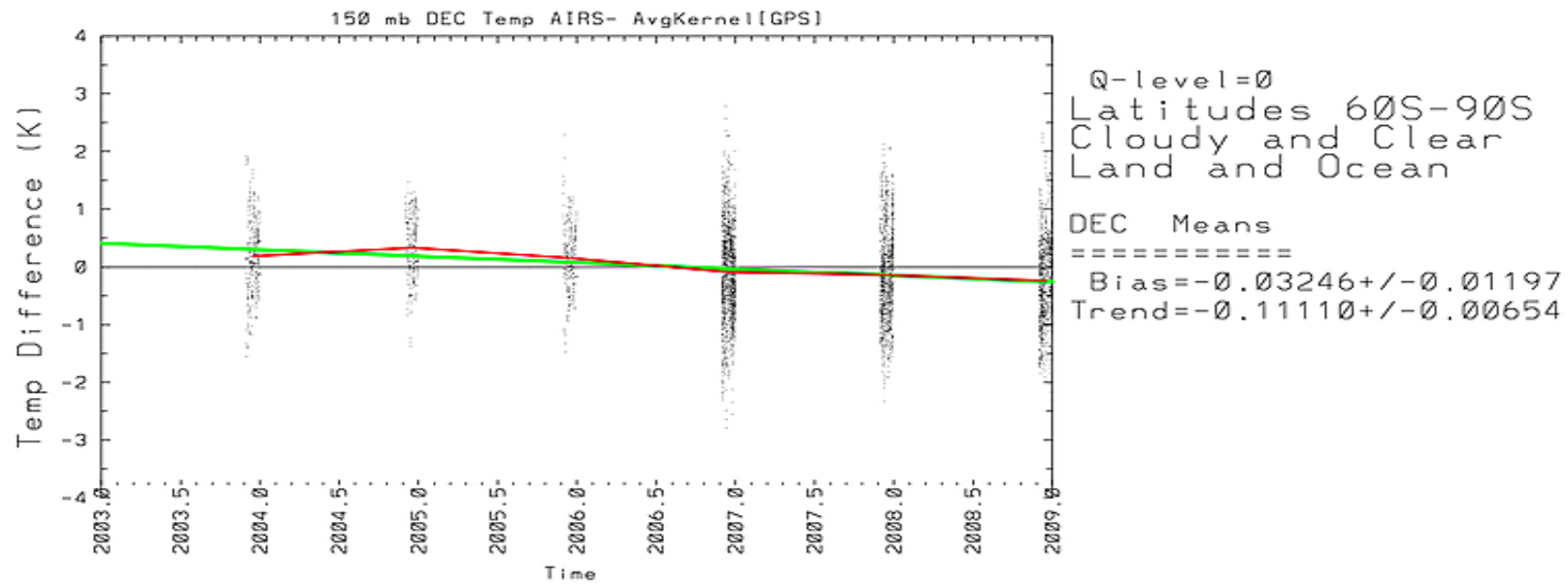
# Biases are dependent on geo-location and and season ?

July, August and September, 2006, 30N-30S

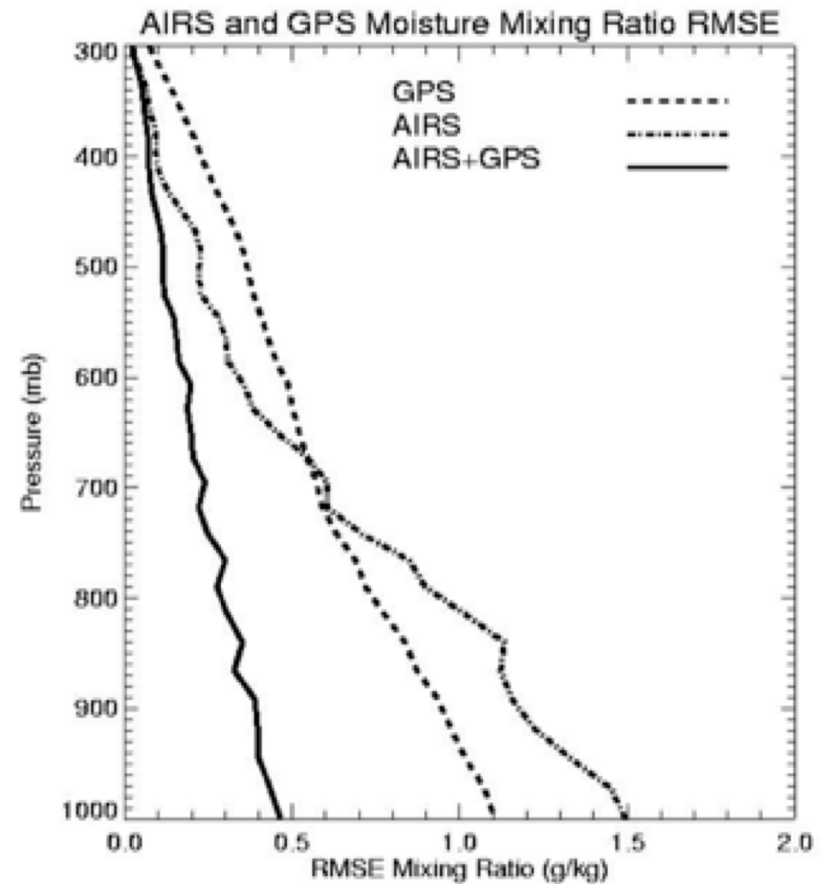
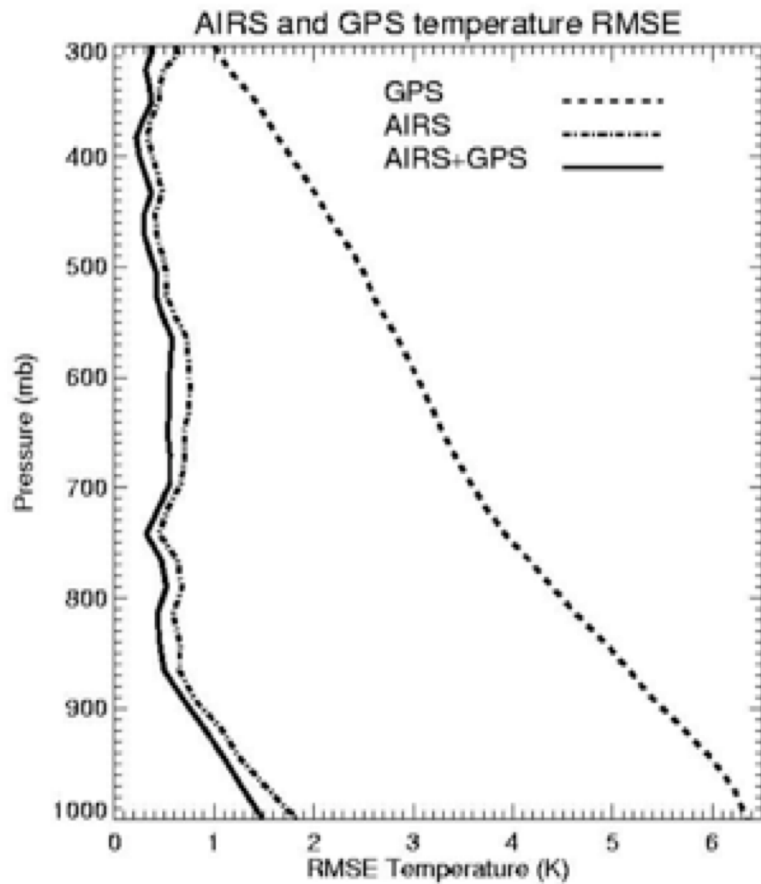


# Biases drift with years ?

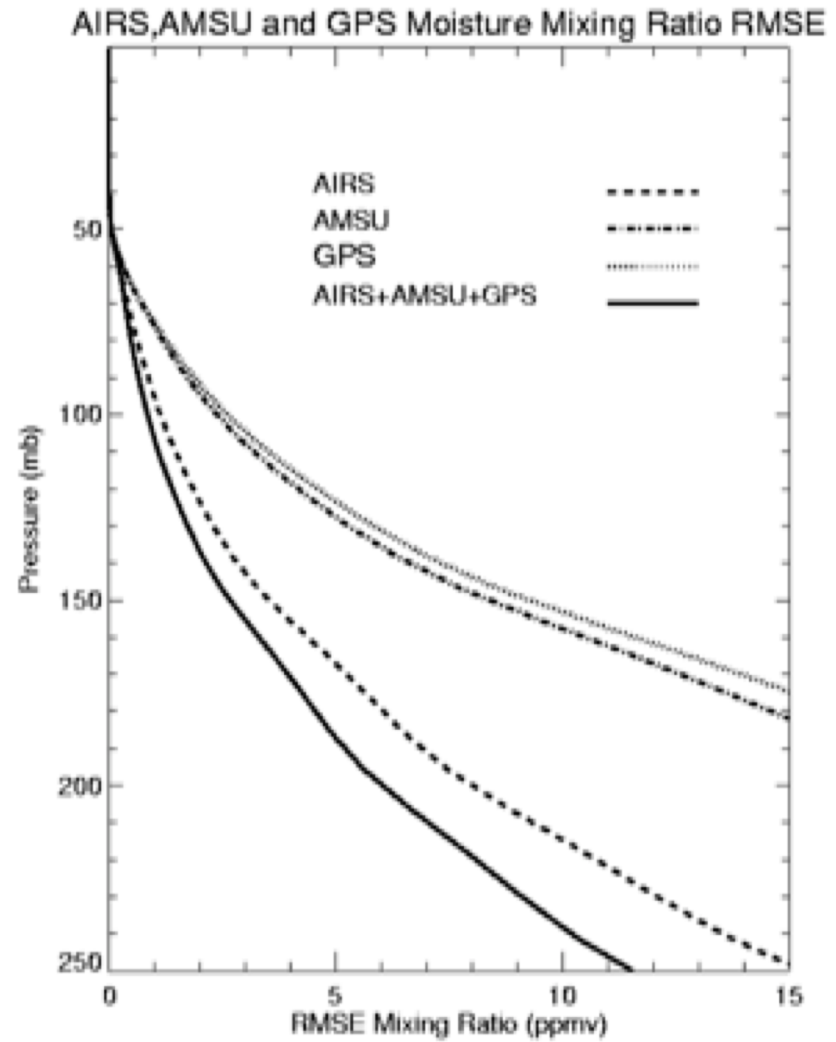
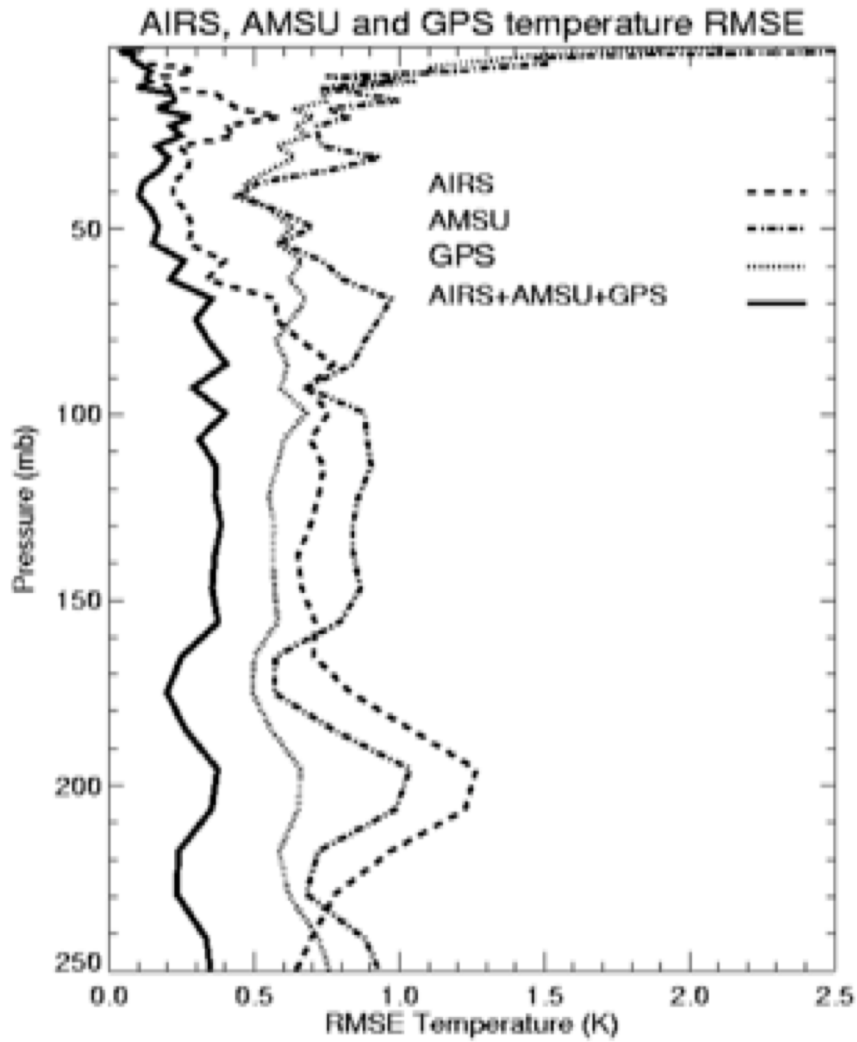
## 60S - 90 S



### 3. Improving AIRS Temperature and Moisture Retrievals in Lower Troposphere, and Upper Troposphere and Lower Stratosphere using GPS RO data



From surface to 300 hPa



From 250 hPa to above

## Approaches :

- a. 1D var AIRS retrieval (Thanks for C-Y Liu from NCU and Jun Li from SSEC WISC)
- b. 1D var RO retrieval
- c. 1D Var RO+AIRS (RO-AIRS) retrieval

$$J(X) = \{Y - F(X)\}^T E^{-1} \{Y - F(X)\} + \gamma (X - X_0)^T C^{-1} (X - X_0),$$

$$X_{n+1} = X_0 + (K_n^T E^{-1} K_n + \gamma C^{-1})^{-1} K_n^T C^{-1} \{\delta Y_n + K_n (X_n - X_0)\}.$$

**Data :** Aqua/AIRS data: we used AIRS V6 L1 data and COSMIC2013 for this work.

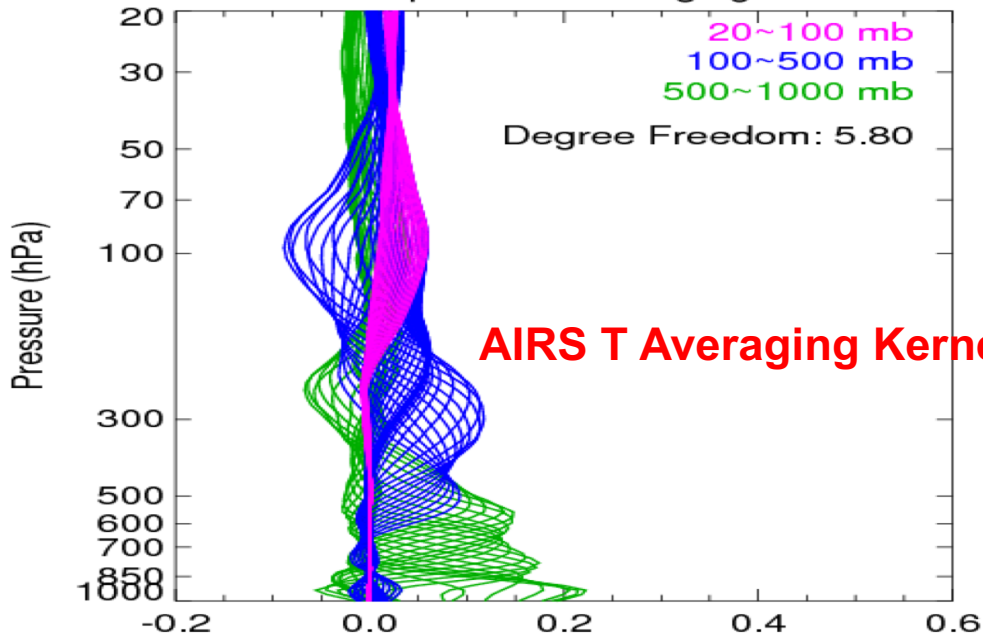
**Collocation :** COSMIC data from 200801-12 with < 200 km and < 3 hrs of AIRS data will be used to perform the RO + AIRS physical retrievals.

### Forward model:

**AIRS:** the updated fast and accurate AIRS transmittance model (Standard Alone AIRS-Radiance Transfer Algorithm package – SARTA) is served as AIRS forward operator.

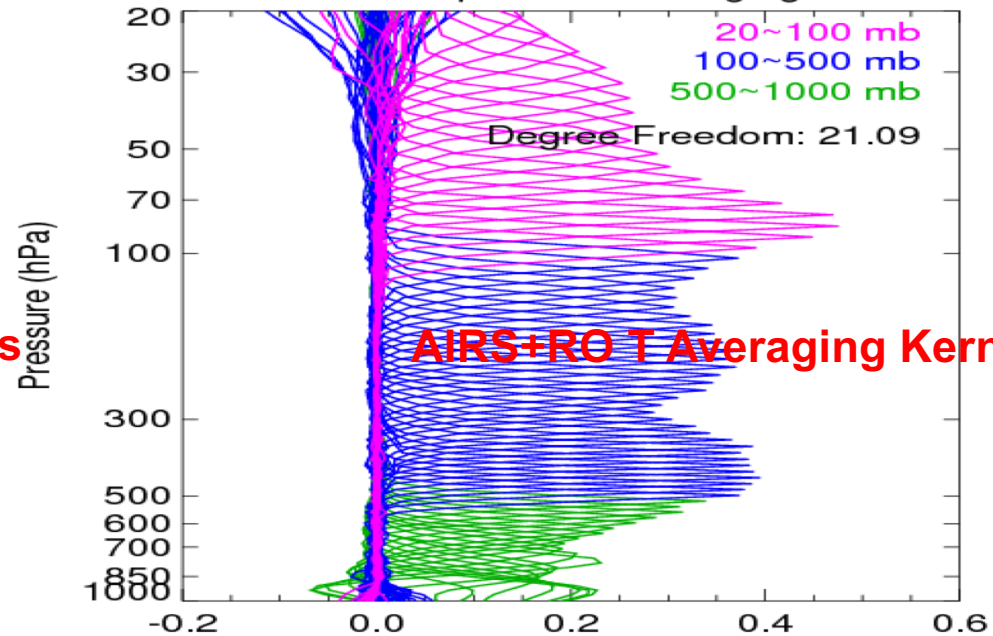
**RO Refractivity forward model:** 
$$N = 77.6 \frac{P}{T} + 3.73 \times 10^5 \frac{P_w}{T^2}$$

AIRS temperature averaging kernels



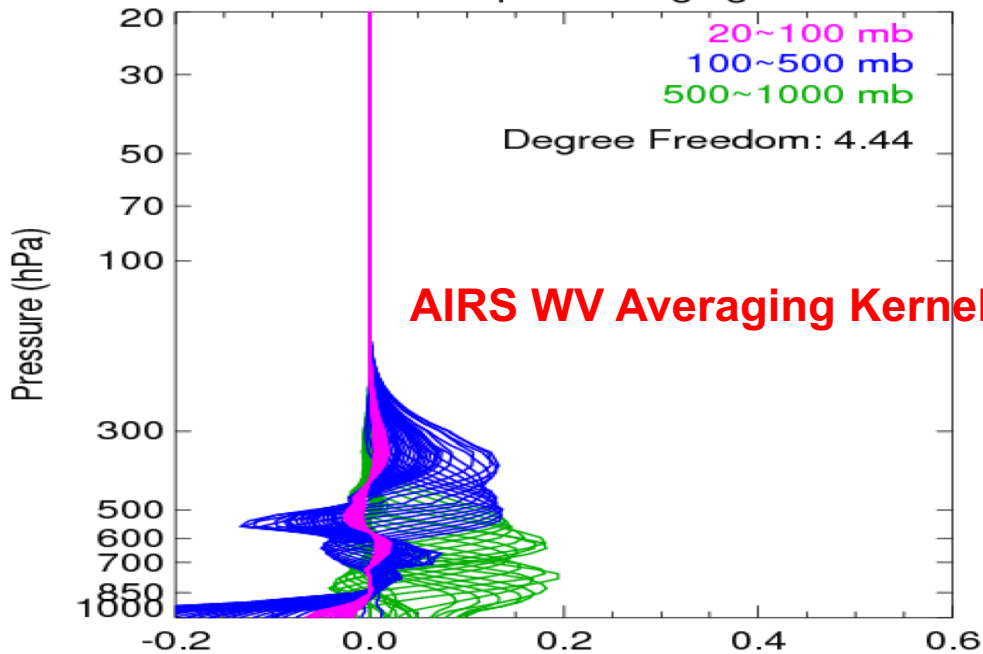
AIRS T Averaging Kernels

AIRS+RO temperature averaging kernels



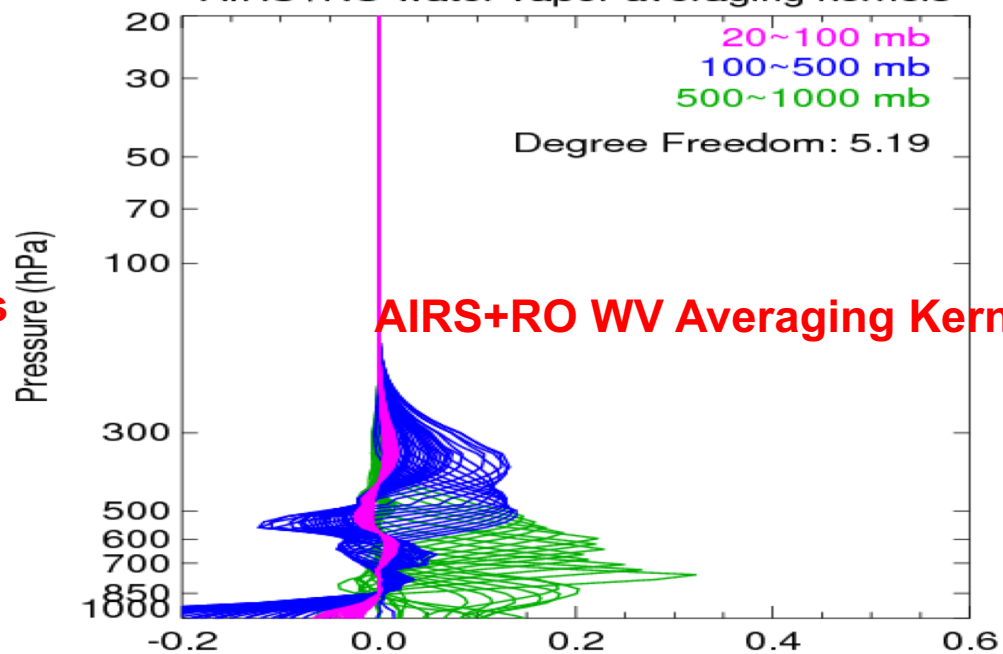
AIRS+RO T Averaging Kerne

AIRS water vapor averaging kernels



AIRS WV Averaging Kernels

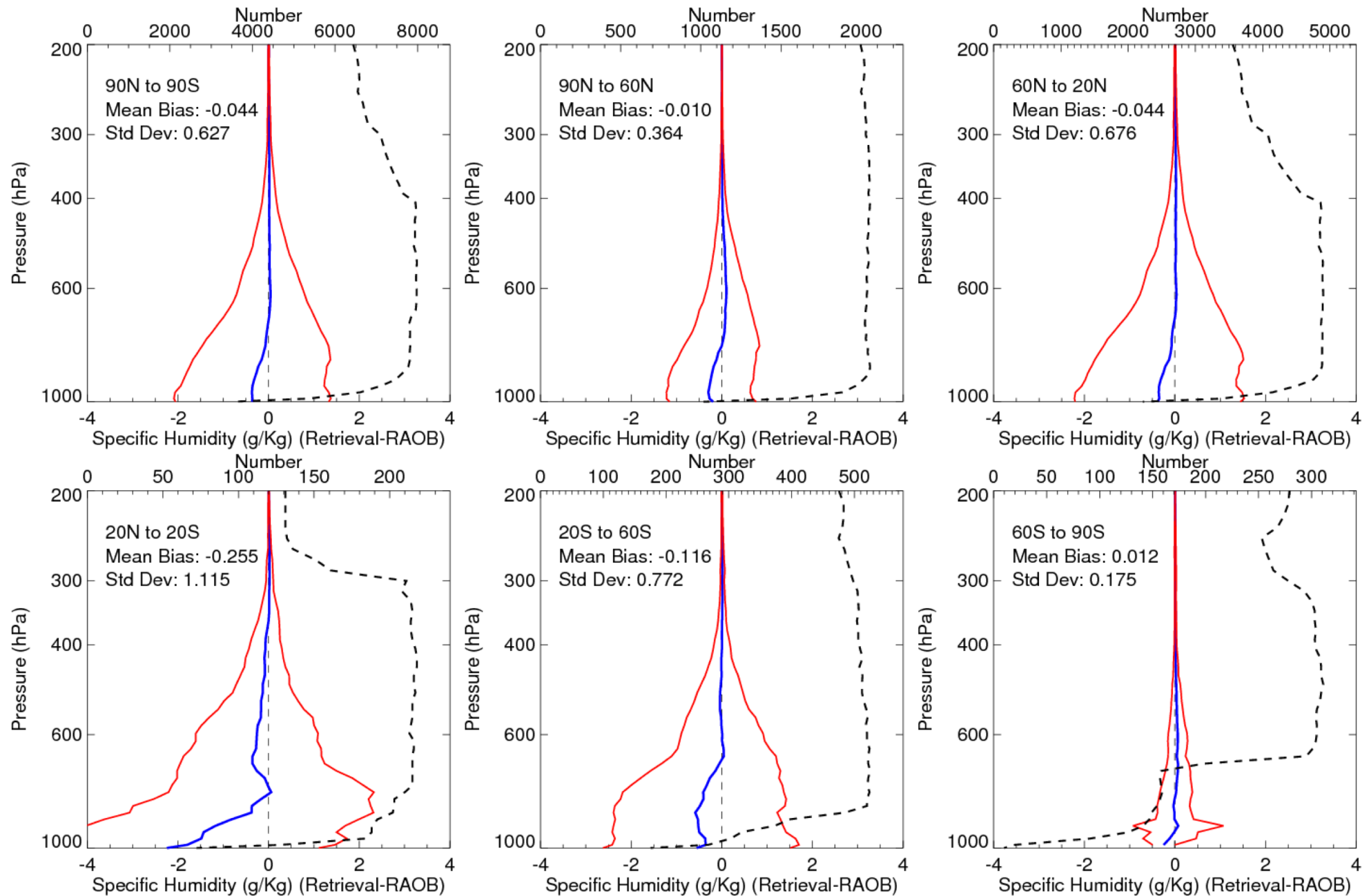
AIRS+RO water vapor averaging kernels



AIRS+RO WV Averaging Kerne

# Results

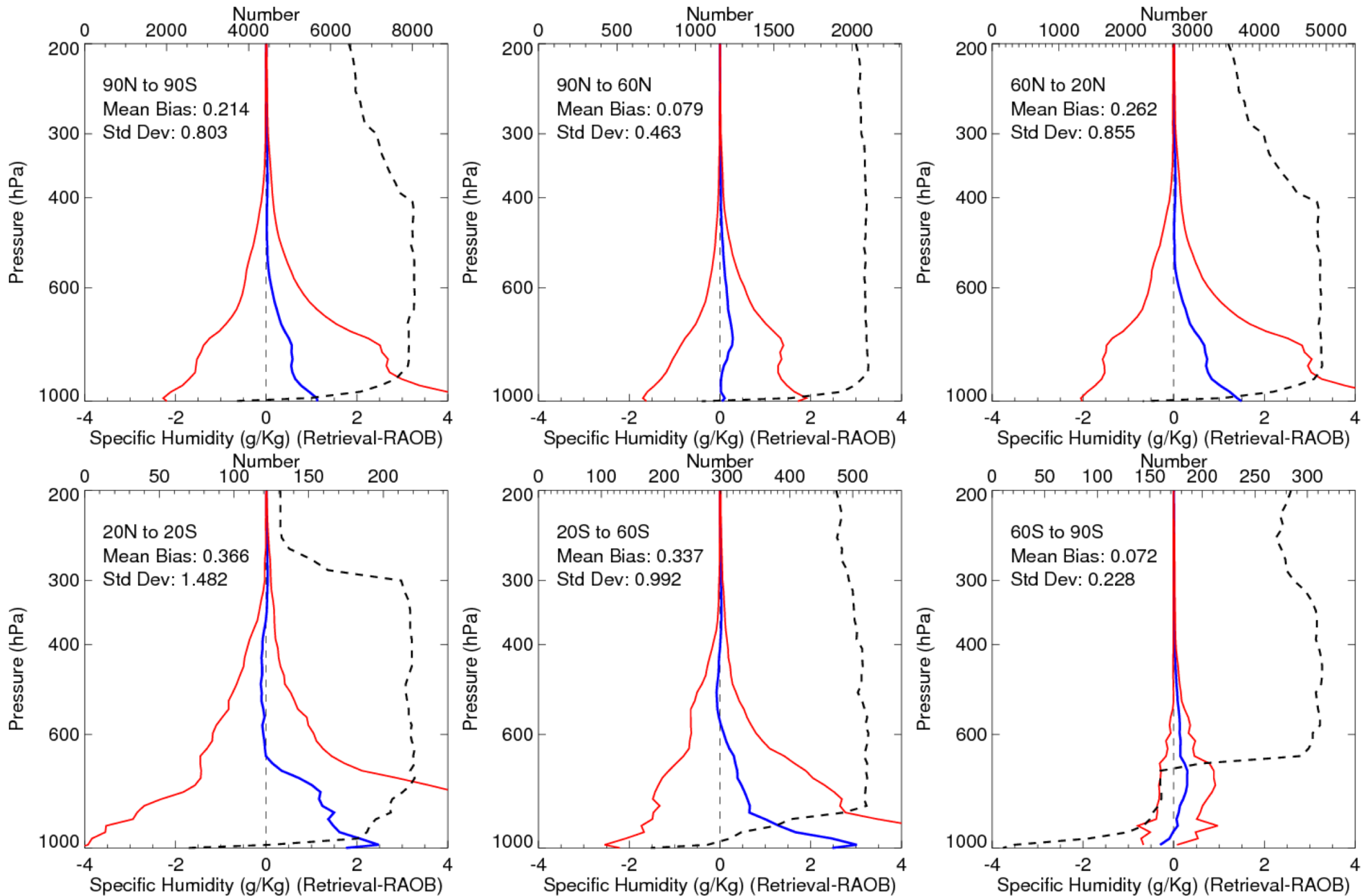
## RO WV - collocated RAOB WV





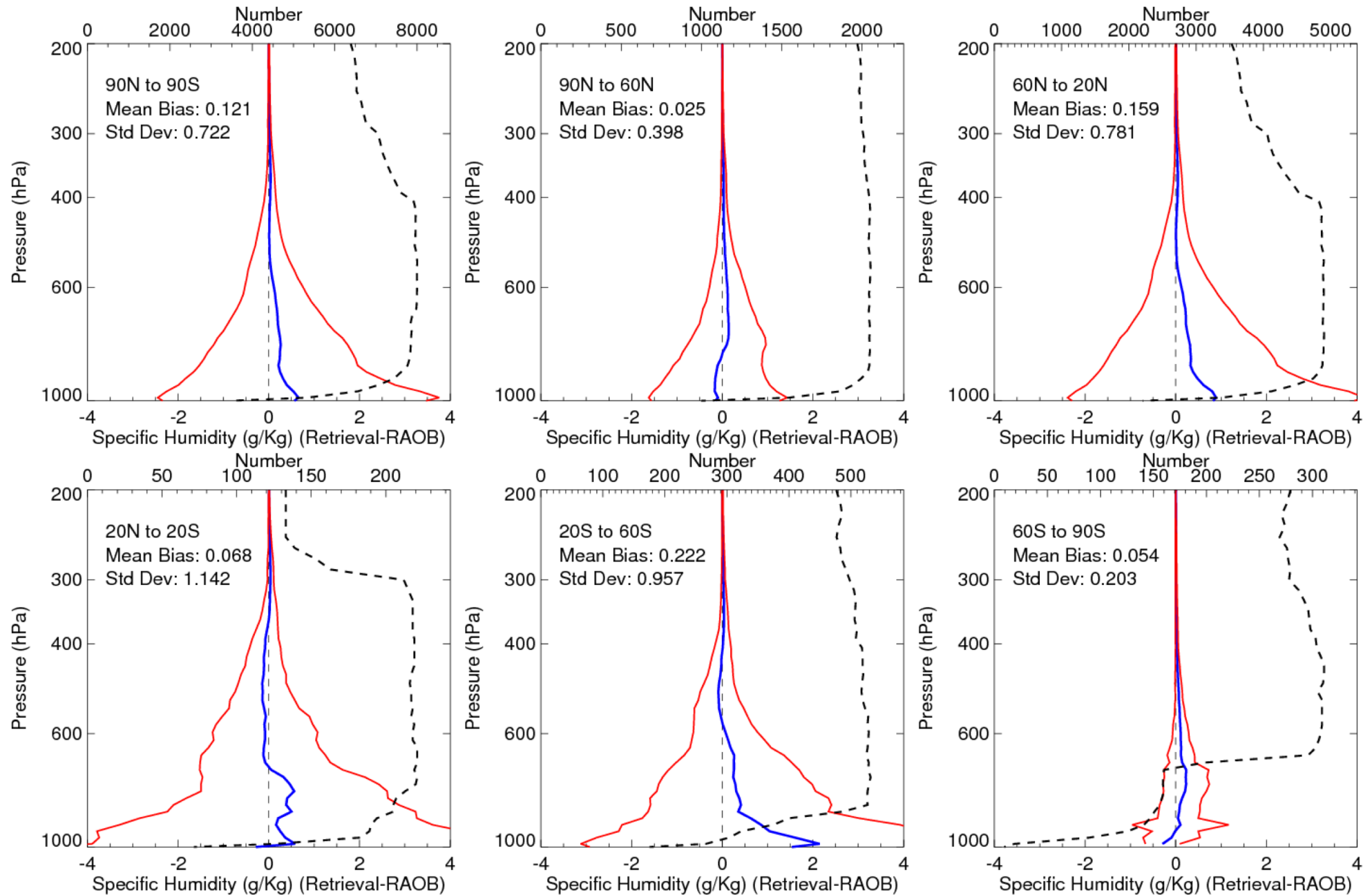
# Results

## AIRS WV - collocated RAOB WV

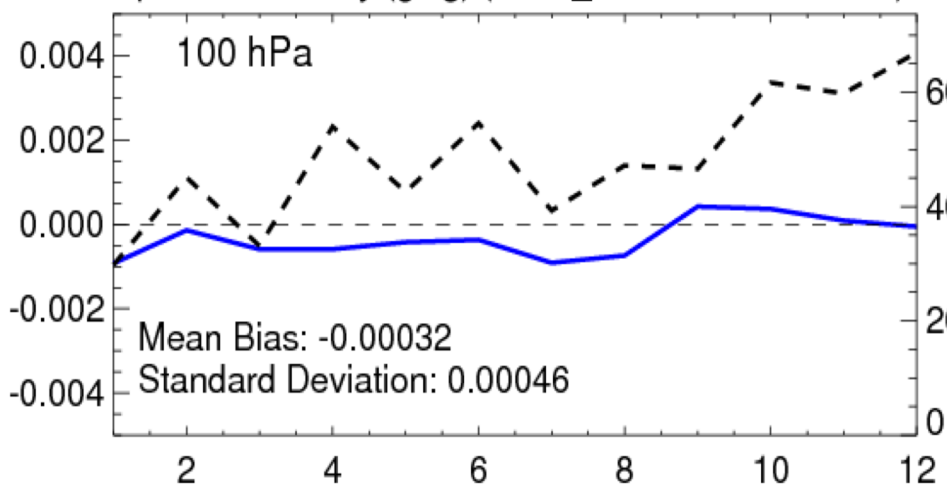


# Results

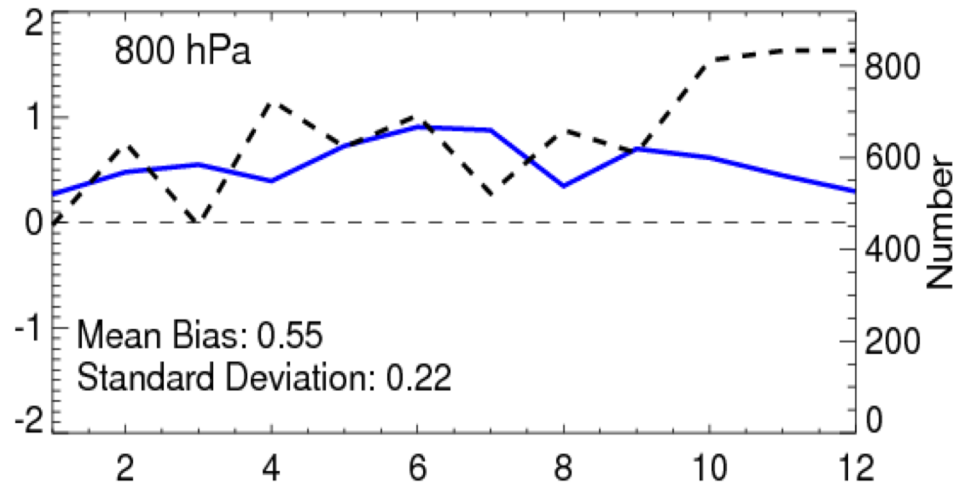
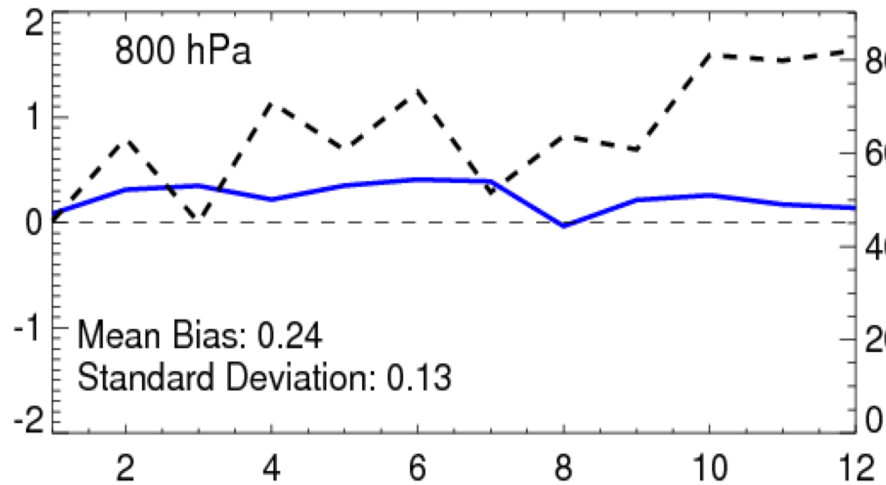
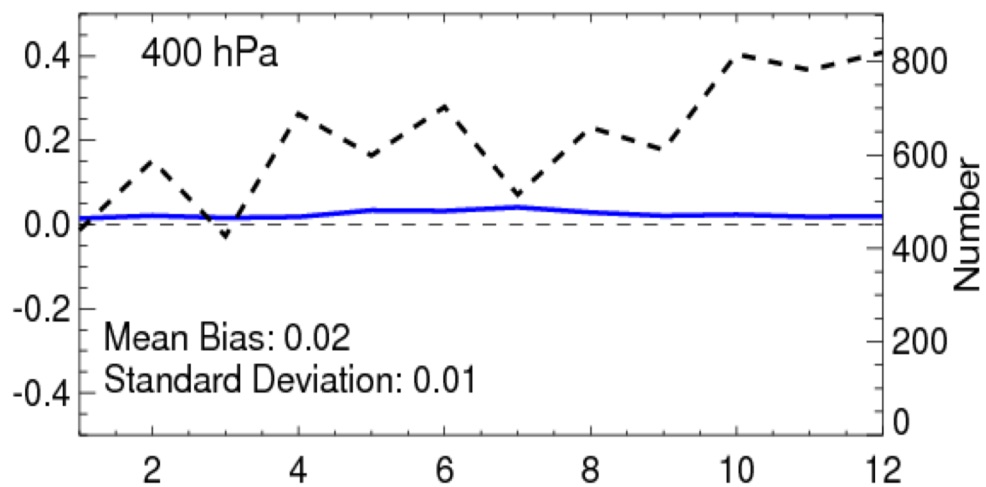
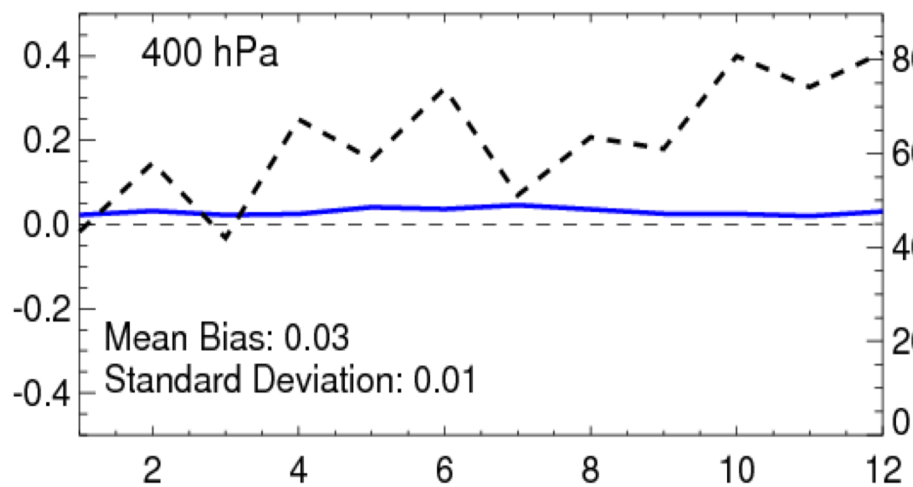
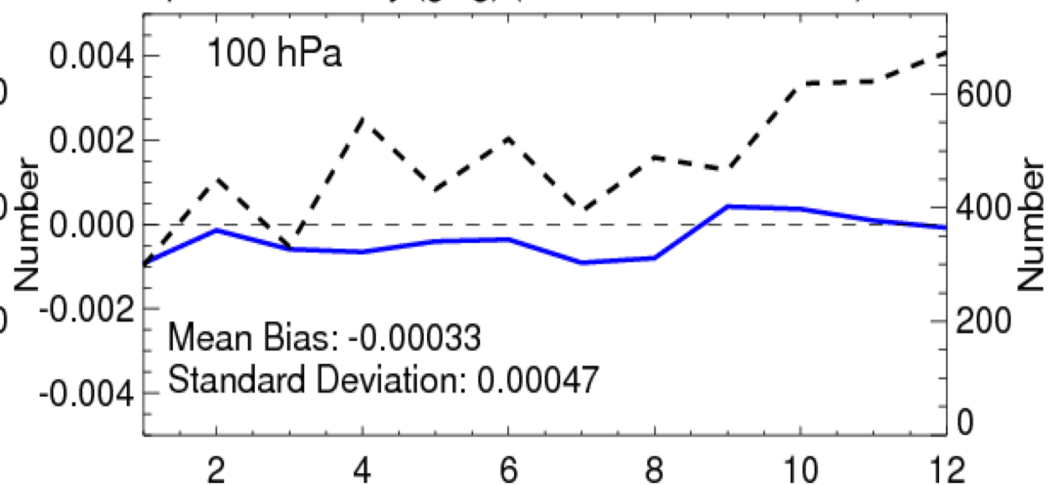
## RO + AIRS WV - collocated RAOB WV



Specific Humidity (g/kg) (AIRS\_RO Retrieval-RAOB)



Specific Humidity (g/kg) (AIRS Retrieval-RAOB)



# Conclusions

- It works
- More validation in lower troposphere, mid-troposphere, and UT/LS is still needed.
- It is demonstrated that the combined AIRS and RO observations act to constrain the individual solutions, the significantly improved water vapor RMSE is found in both the middle and lower troposphere. The RMSEs of water vapor mixing ratio for AIRS and GPS RO are improved from 1.5 g/kg and 1.0 g/kg at surface, respectively, and to 0.5 g/kg for the GPS RO combined AIRS retrievals. Since GPS refractivity is less sensitive to temperature in the troposphere, only small temperature RMSE improvements are found.
- In this future, we will apply AIRS and COSMIC data from 2006 to 2016 to the derived physical inversion algorithm and validate the retrieval results against in situ data.