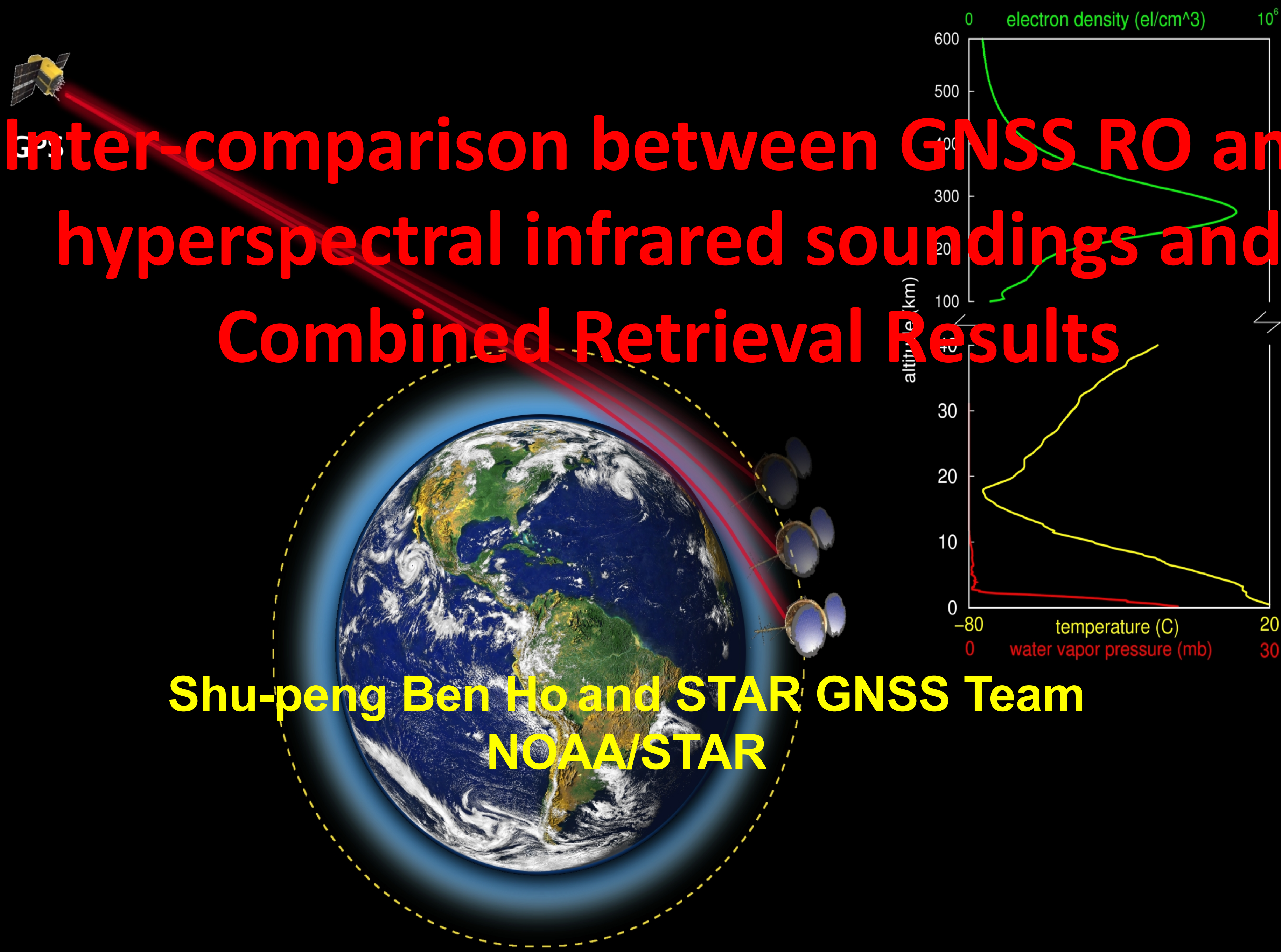
# Inter-comparison between GNSS RO and hyperspectral infrared soundings and Combined Retrieval Results





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

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

## Data Assimilation

Data Assimilation

Non-local Bending Angle (Ray-tracing)

Local Bending Angle (Forward Abel)

Local Refractivity

JCSDA and TMP project

**As JCSDA partners, STAR and NCEP work together closely to perform impact assessment**

## Multi-sensor Validation

Validation

Radiosonde (Dr. Xi Shao from CICS)

Microwave Sounders ATMS, AMSU-A (CICS)

Infrared Sounders CrIS, AIRS, IASI (Dr. Erin Lynch from CICS)

Retrievals (temperature, water vapor)

ECMWF model

**Well established NOAA system NPROVS for sounding validation**

## Integrated Cal/Val System (ICVS) for Monitoring

Performance Monitoring

Operational monitoring

RO measurements

Parameters for all RO data levels

Statistics

Long-term monitoring

(Mr. Xinjia Zhou GST

Dr. Yuxiang He GST

Dr. Ling Liu CICS)

**Well established system for all NOAA satellites expanded to include RO; tested using KOMPSAT5, KOMPSAT5, COSMIC, Metop-A, -B, -C GRAS data data**

## RO Data Processing

Independent Verification

Time delay (L0-L1): Dr. Bin Zhang, Jun Dong from CICS and Yuxiang He from GST)

Excess phase

POD

Bending angle (L1- L2): Dr. Lok Adhikari (CICS)

Impact parameter

Refractivity

Geometric height

Temperature, water vapor, pressure: Dr. Stanislav Kireev (GST)

**Tested & verified using ROPP (EUMETSAT) and KOMPSAT5, COSMIC, Metop-A, -B, -C GRAS data**

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)

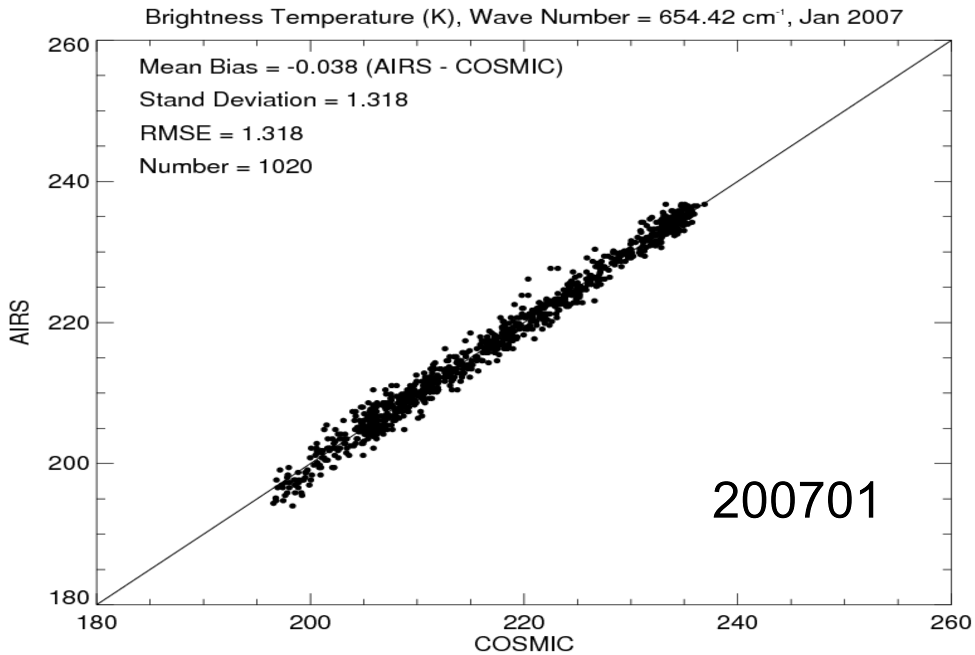
Advanced Technology Microwave Sounder (ATMS),
Cross-track Infrared Sounder (CrIS),
Ozone Mapping Profiler Suite (OMPS),
Radiation Budget Instrument (RBI),
Visible Infrared Imaging Radiometer Suite (VIIRS)

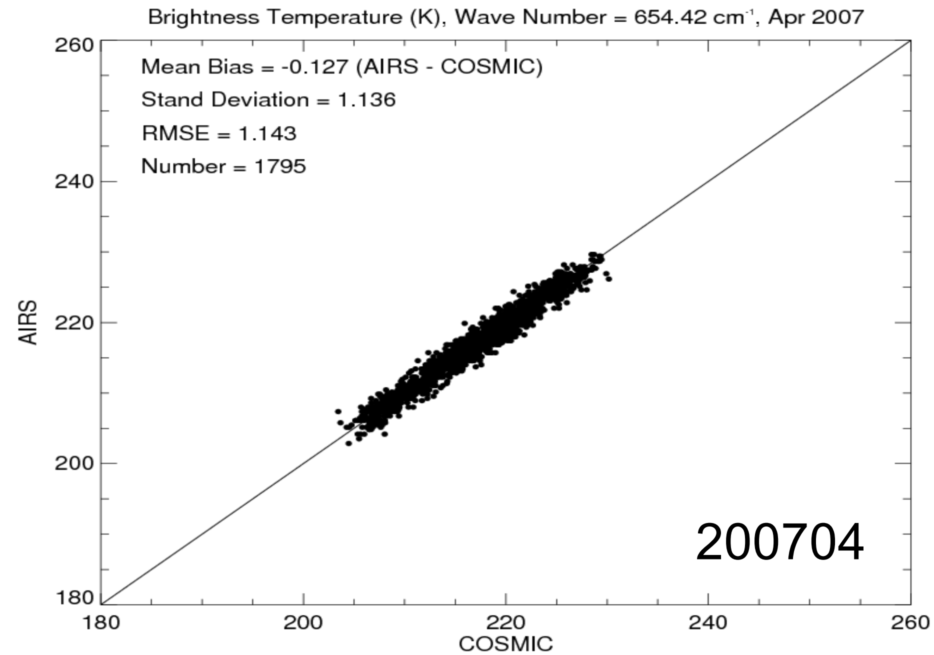
**1. Using RO simulated brightness temperatures to monitoring the quality of measurements from satellite IR sounders**

**2. Using RO retrievals to validate the IR retrieval results**

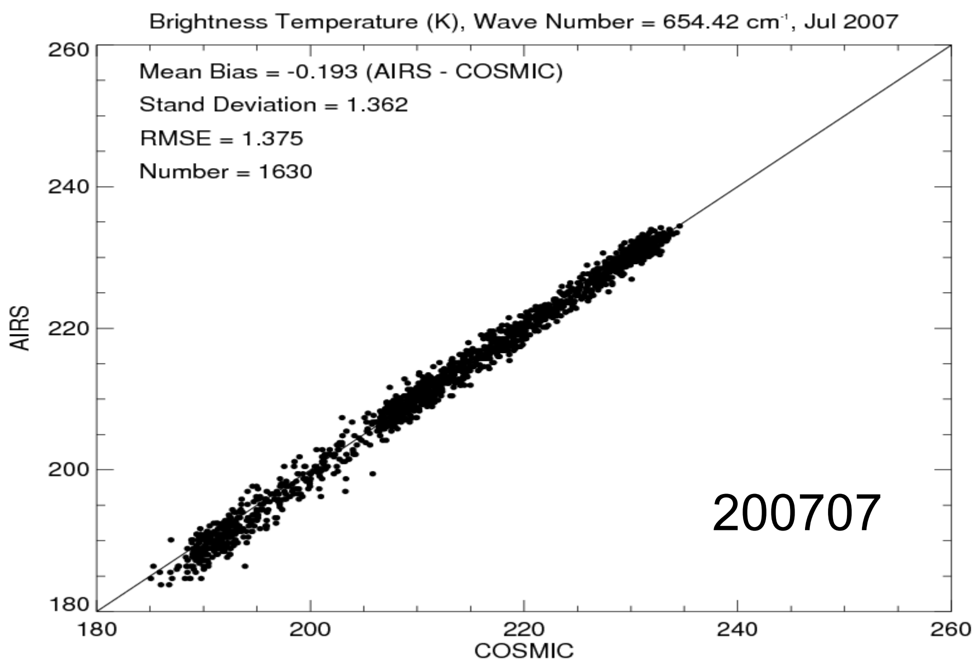
**3. AIRS + RO combined inversion**

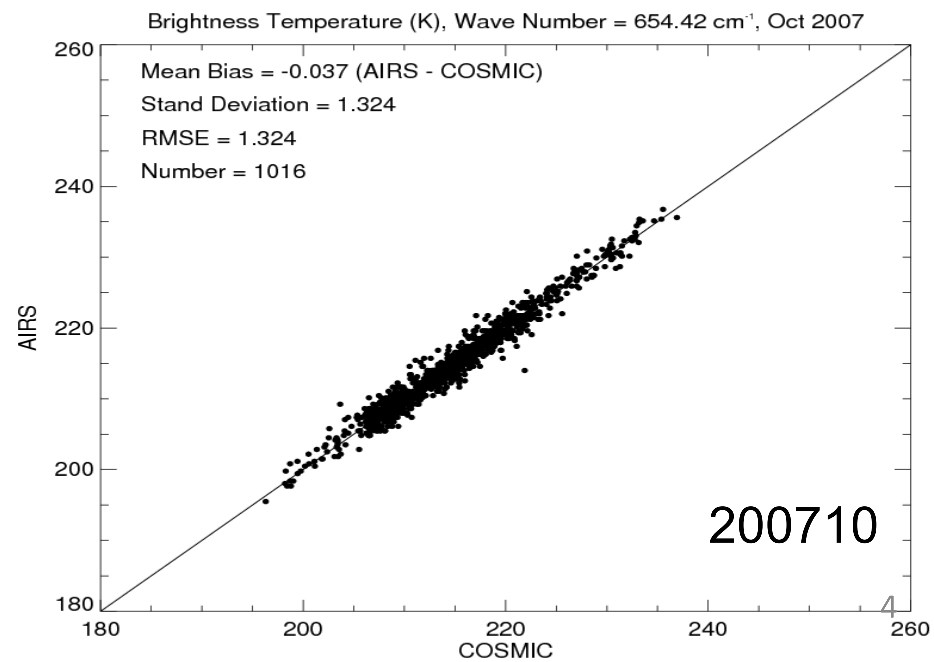
# 1. Comparison of AIRS and RO simulated AIRS brightness temperaetures



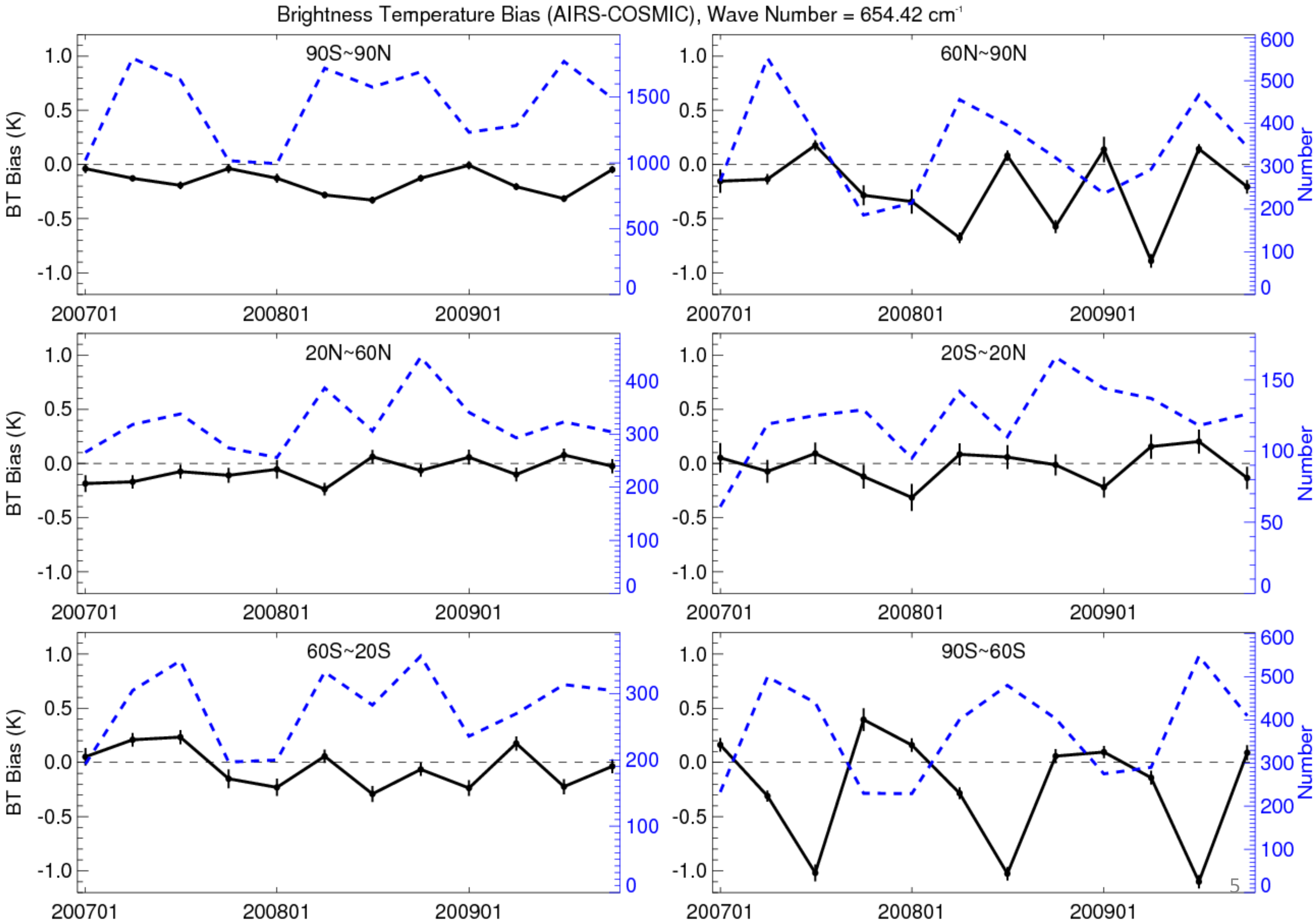




## Distance difference = 100km, Time Difference = 30 minutes



# Using RO data to monitoring quality of AIRS Measurements

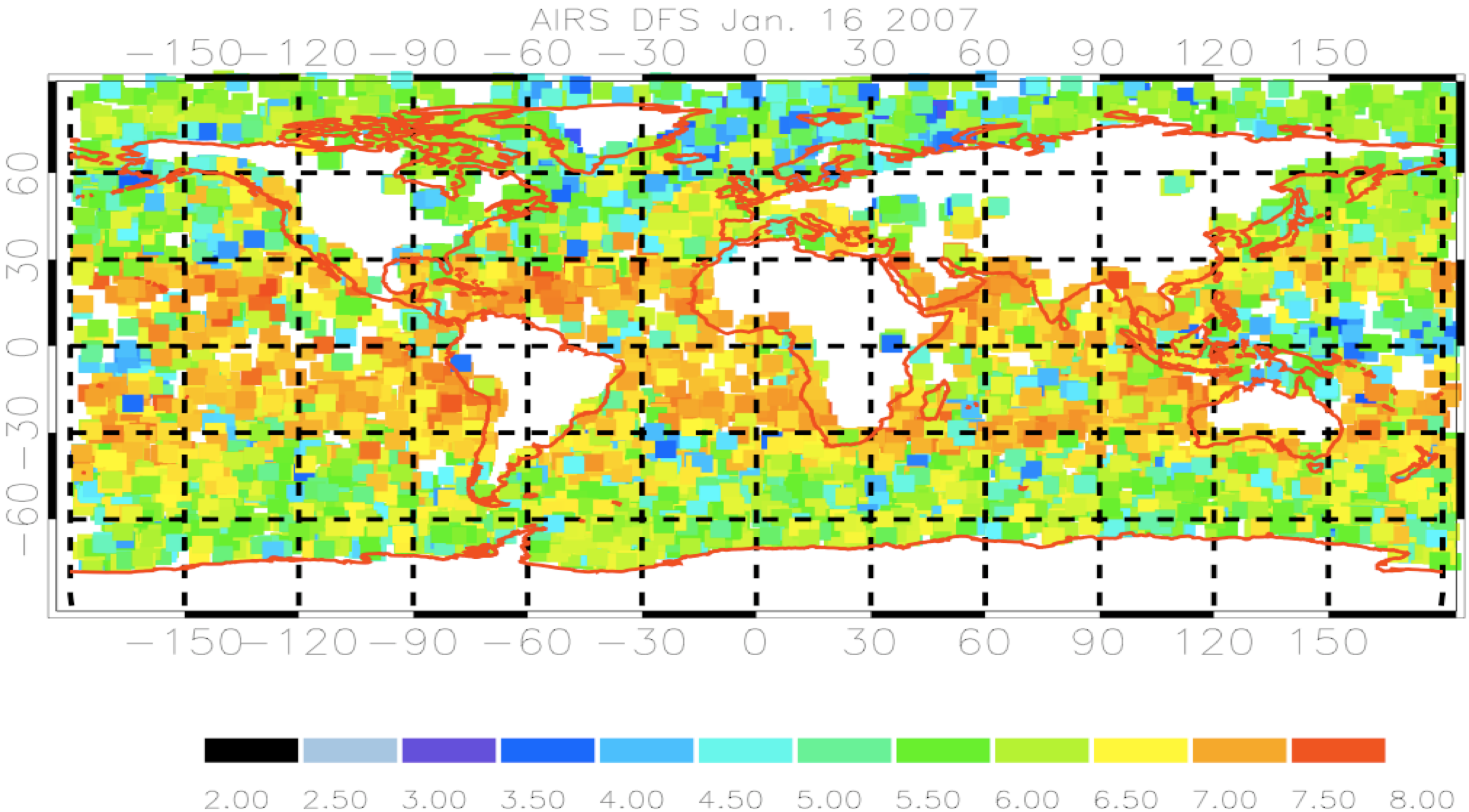


## 2. Using RO data to monitoring AIRS data and retrievals

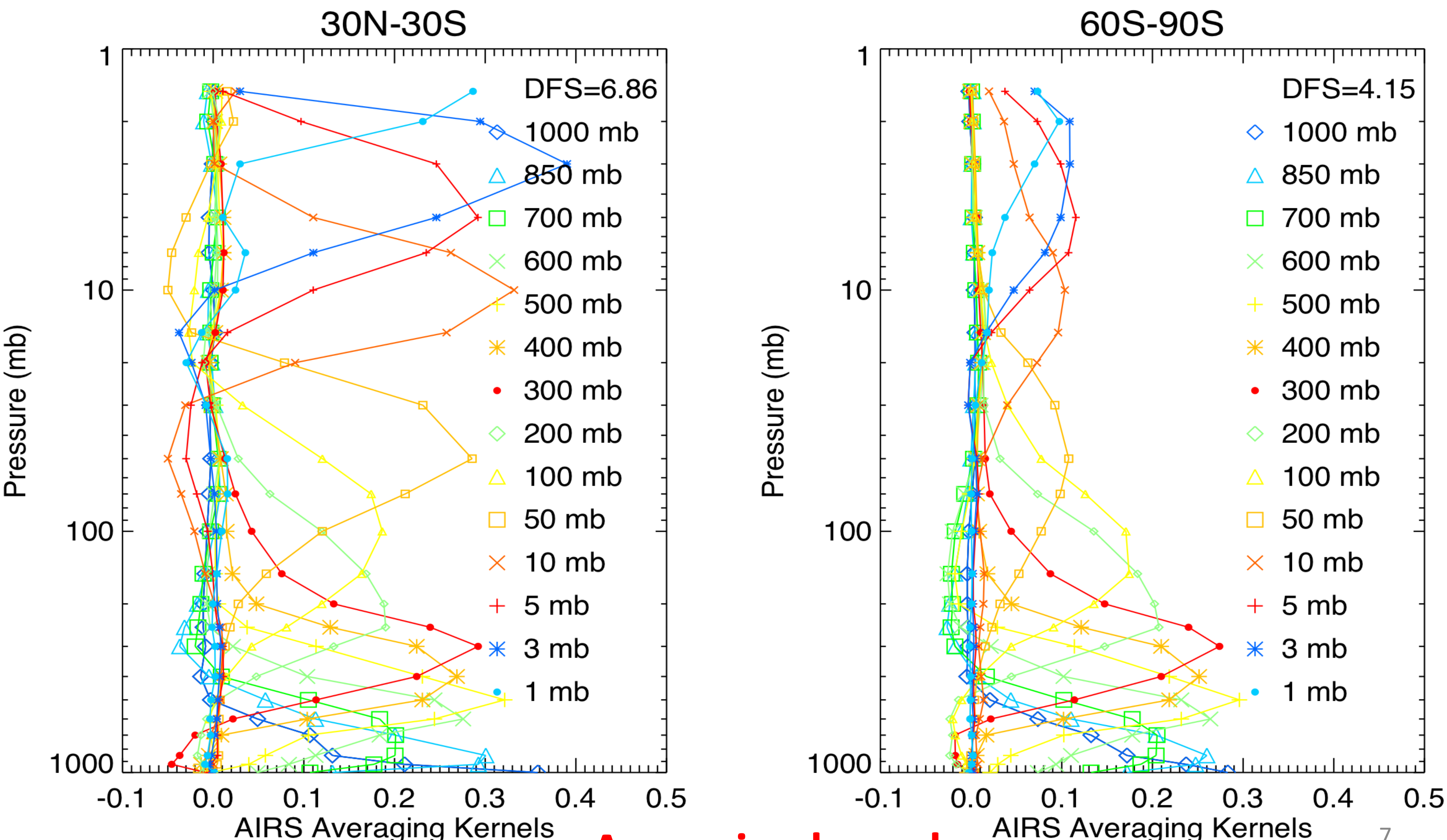
**DFS is a function of atmospheric and surface conditions.**

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

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



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



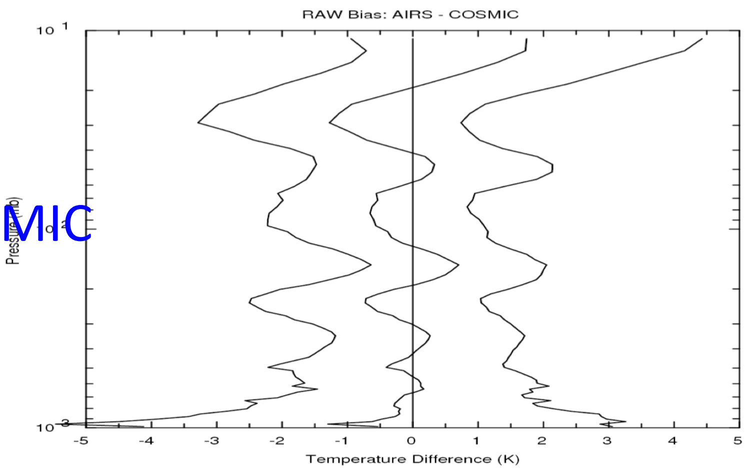

**Averaging kernels**

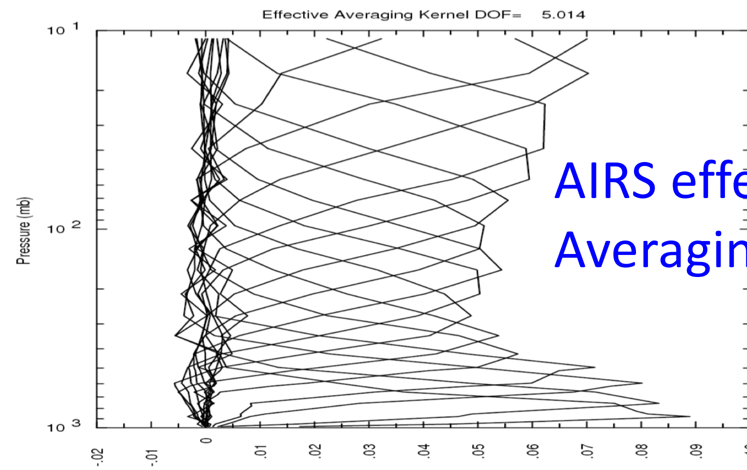
## Results: eliminate effects of AIRS priori profiles and vertical resolution mismatch defined by averaging kernels (Eric Maddy' method)

$$T^{New}_{AIRS} = A^{Effective}_{AIRS} T_{COSMIC} + (I - A^{Effective}_{AIRS}) T^{Apr}_{AIRS}$$

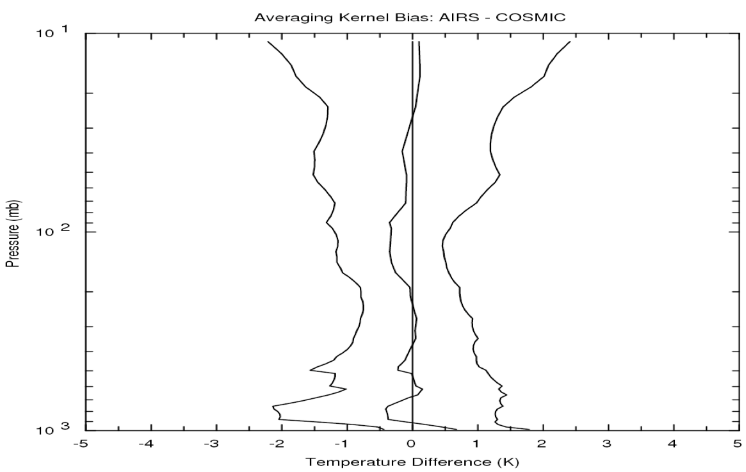
$$A^{Effective}_{AIRS} = F A_{AIRS} F^*$$

AIRS-COSMIC



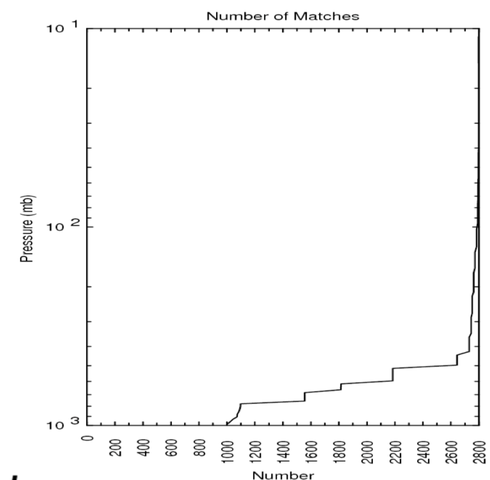




AIRS effective Averaging kernels




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

ALL Latitudes
Land & Ocean
No Clouds
Day & Night



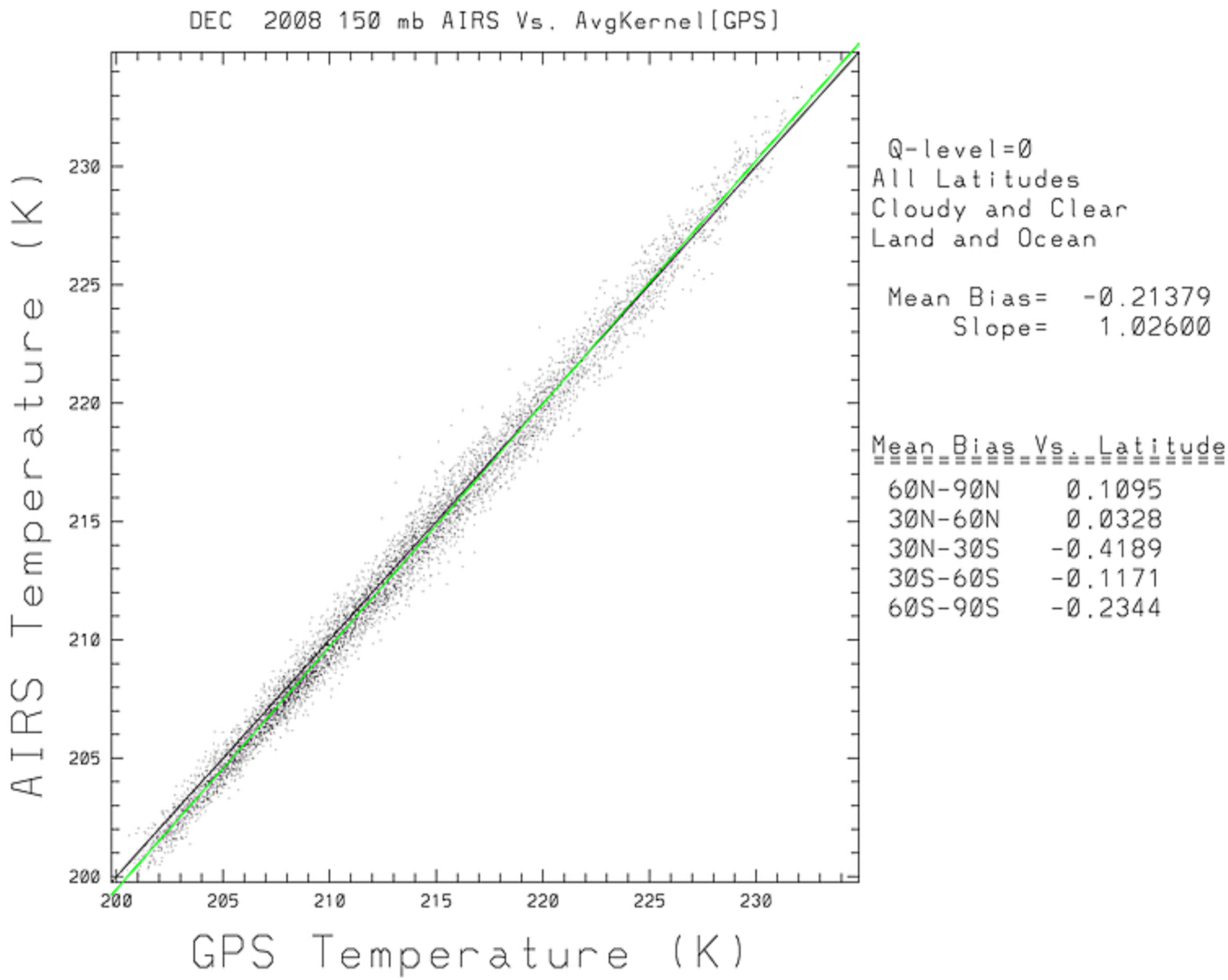

AIRS-Smoothed COSMIC

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

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

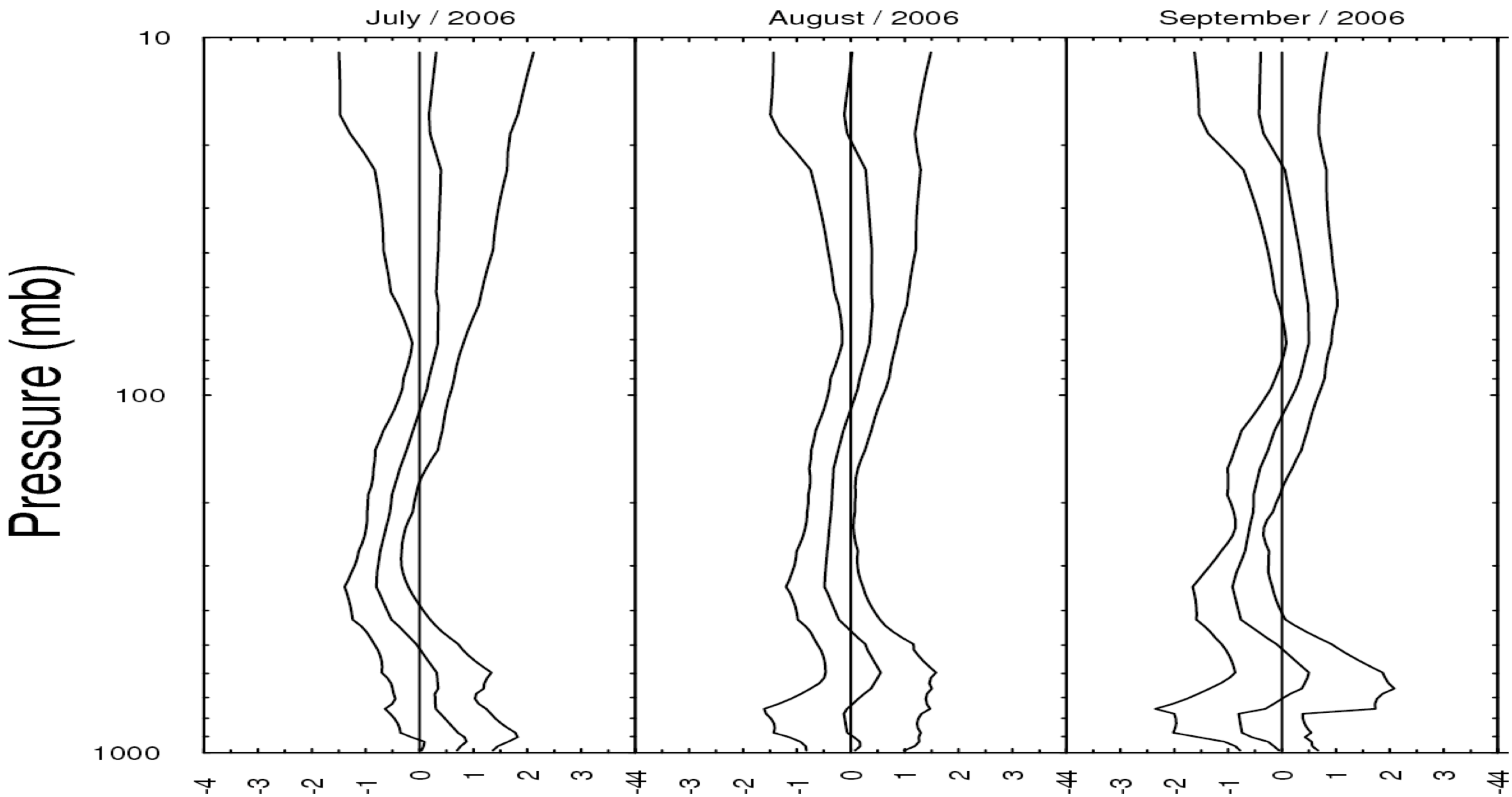
Corr ~ 1.0

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



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

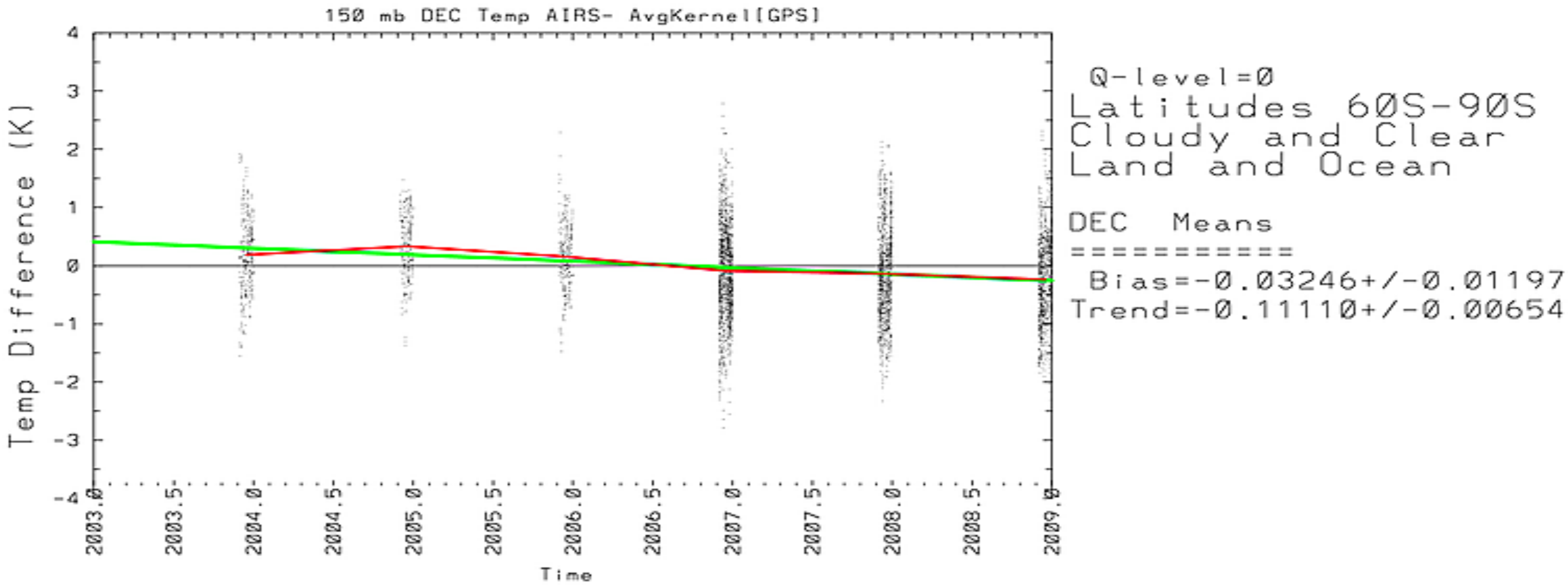
July, August and September, 2006, 30N-30S

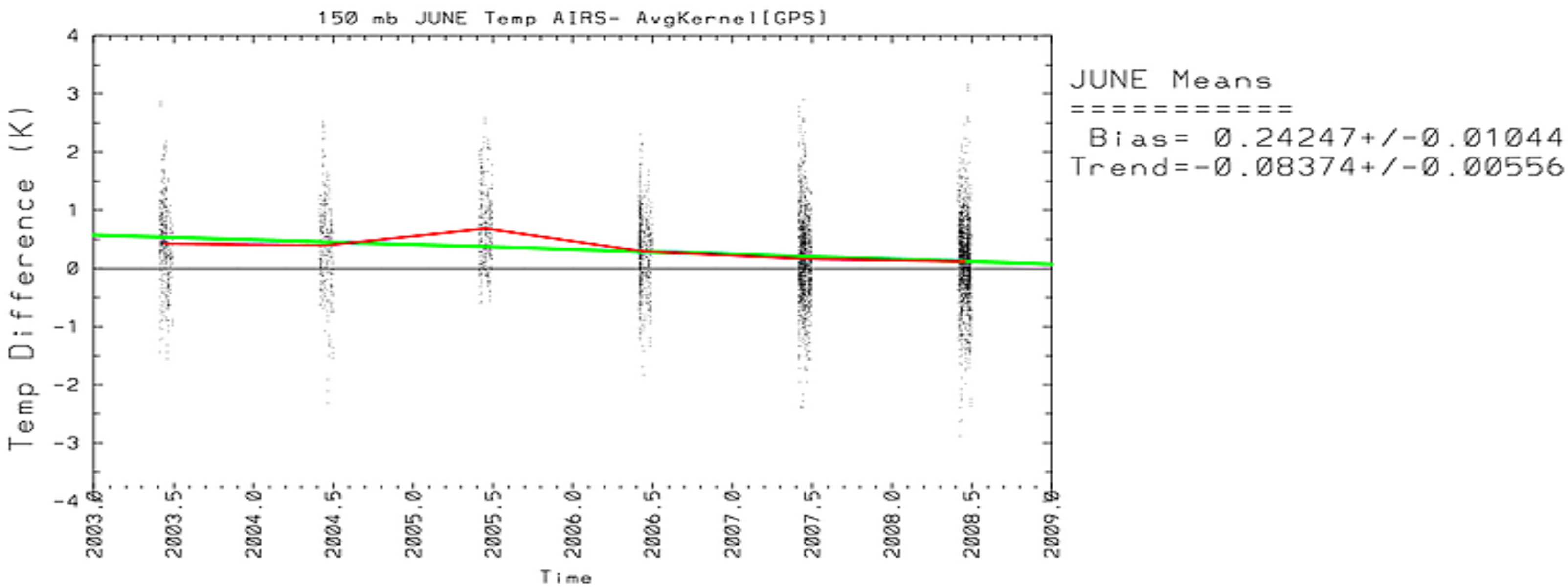



AIRS-Smoothed COSMIC Temperature (K)

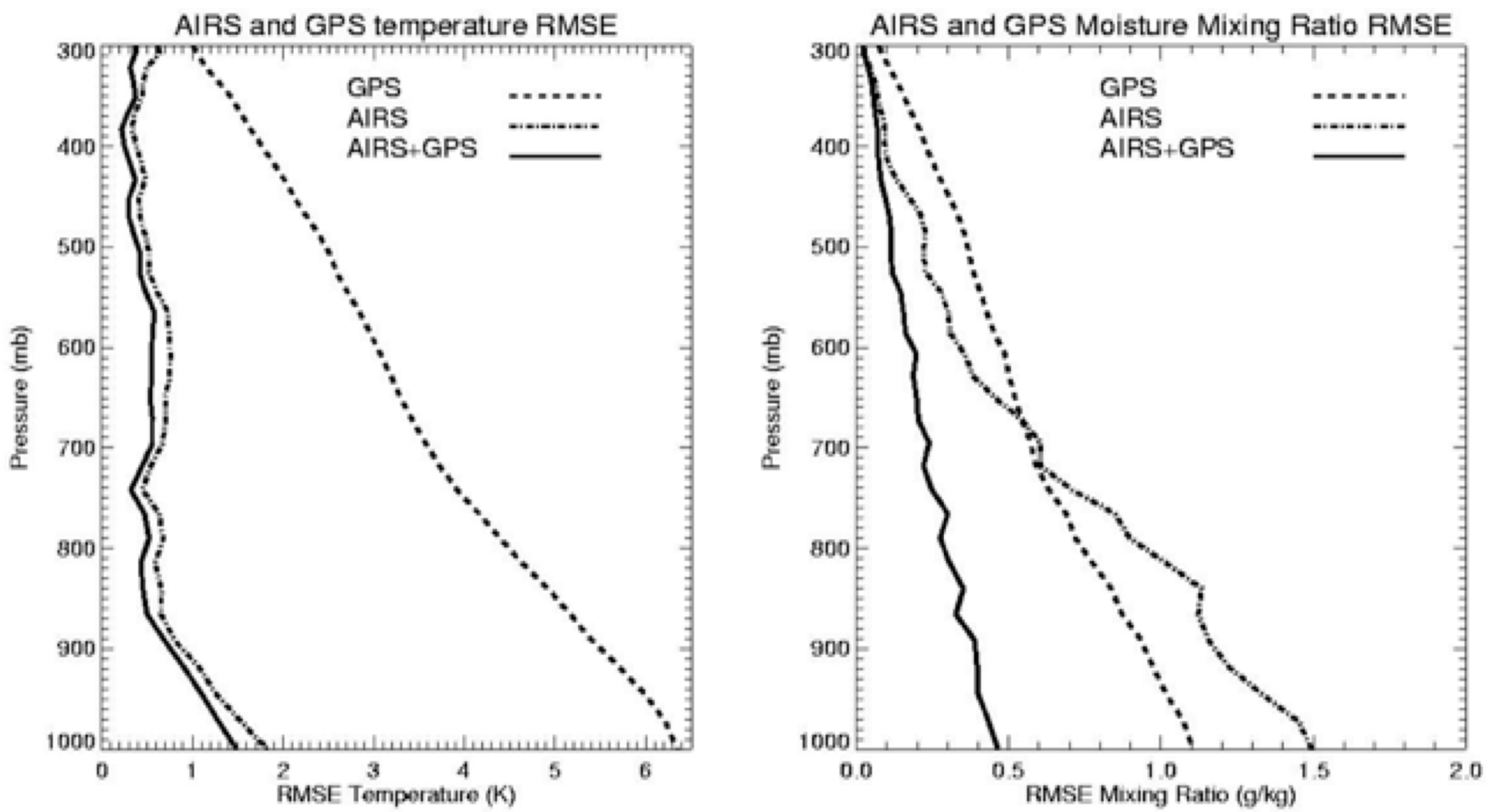
# Biases drift with years ?

## 60S - 90 S

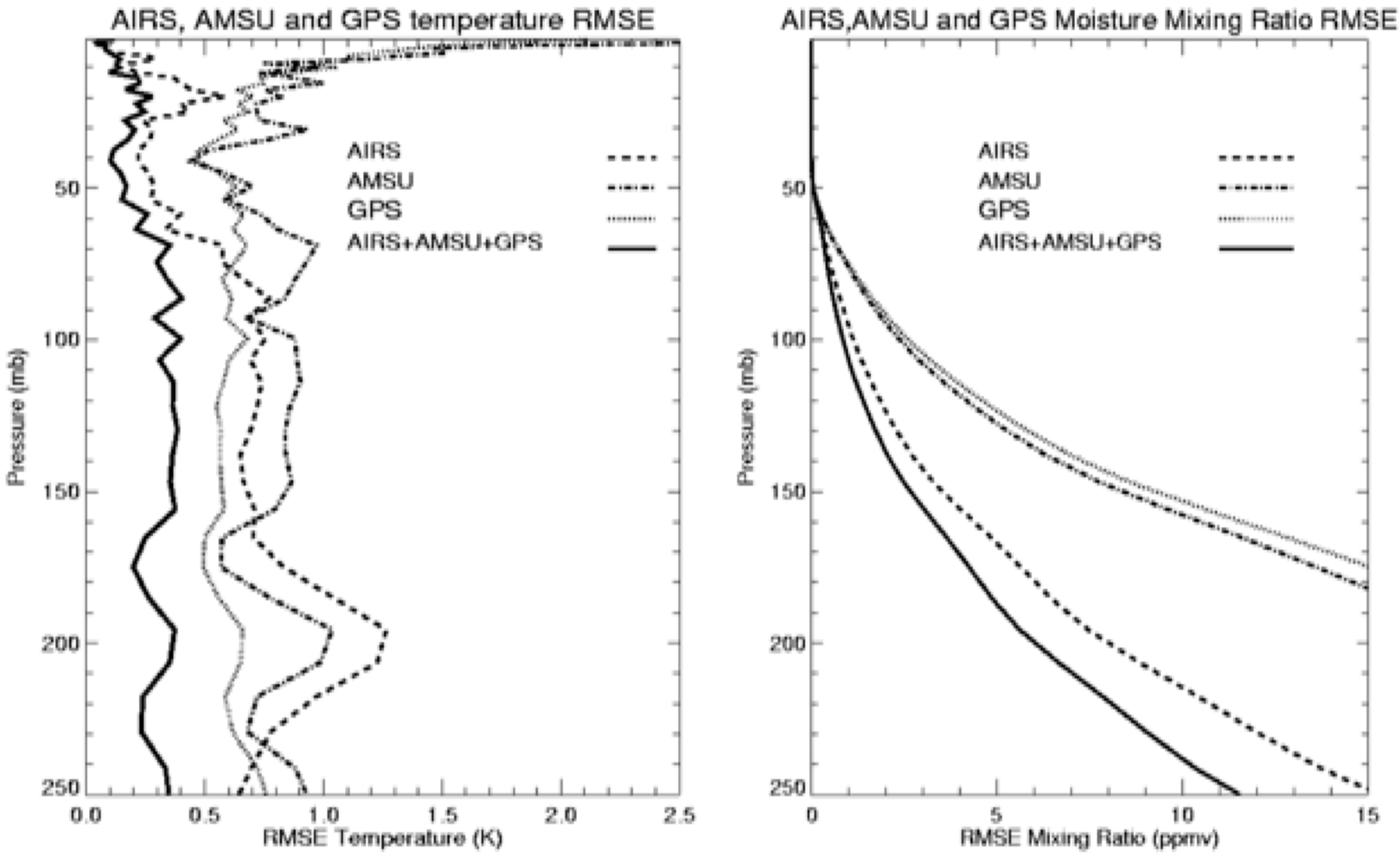


## 3. Improving AIRS Temperature and Moisture Retrievals in Lower Troposphere, and Upper Troposphere and Lower Stratosphere using GPS RO data




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**

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

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

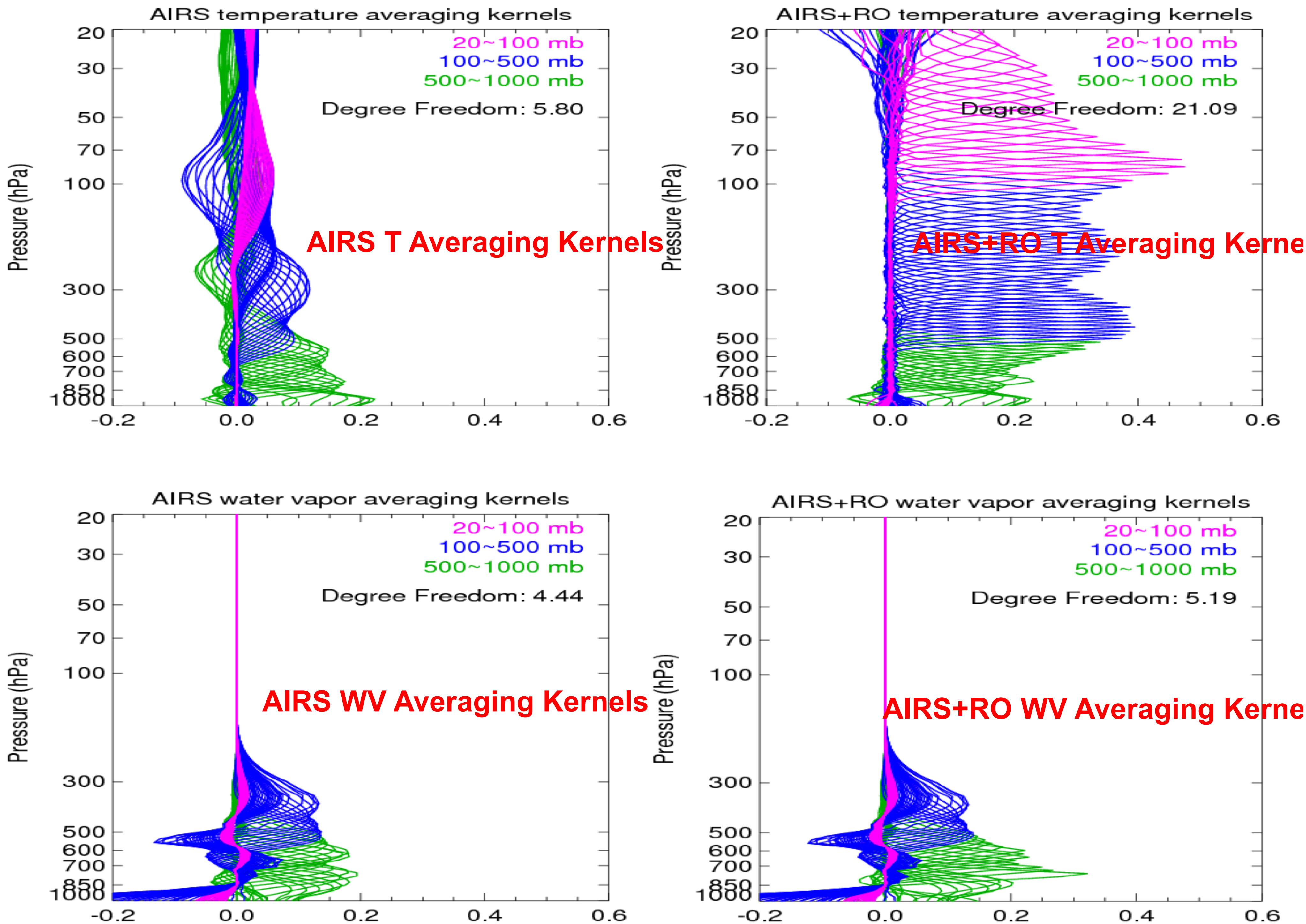
**Data :** Aqua/AIRS data: we used AIRS V6 L1 data and COSMIC2013 for this work.

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

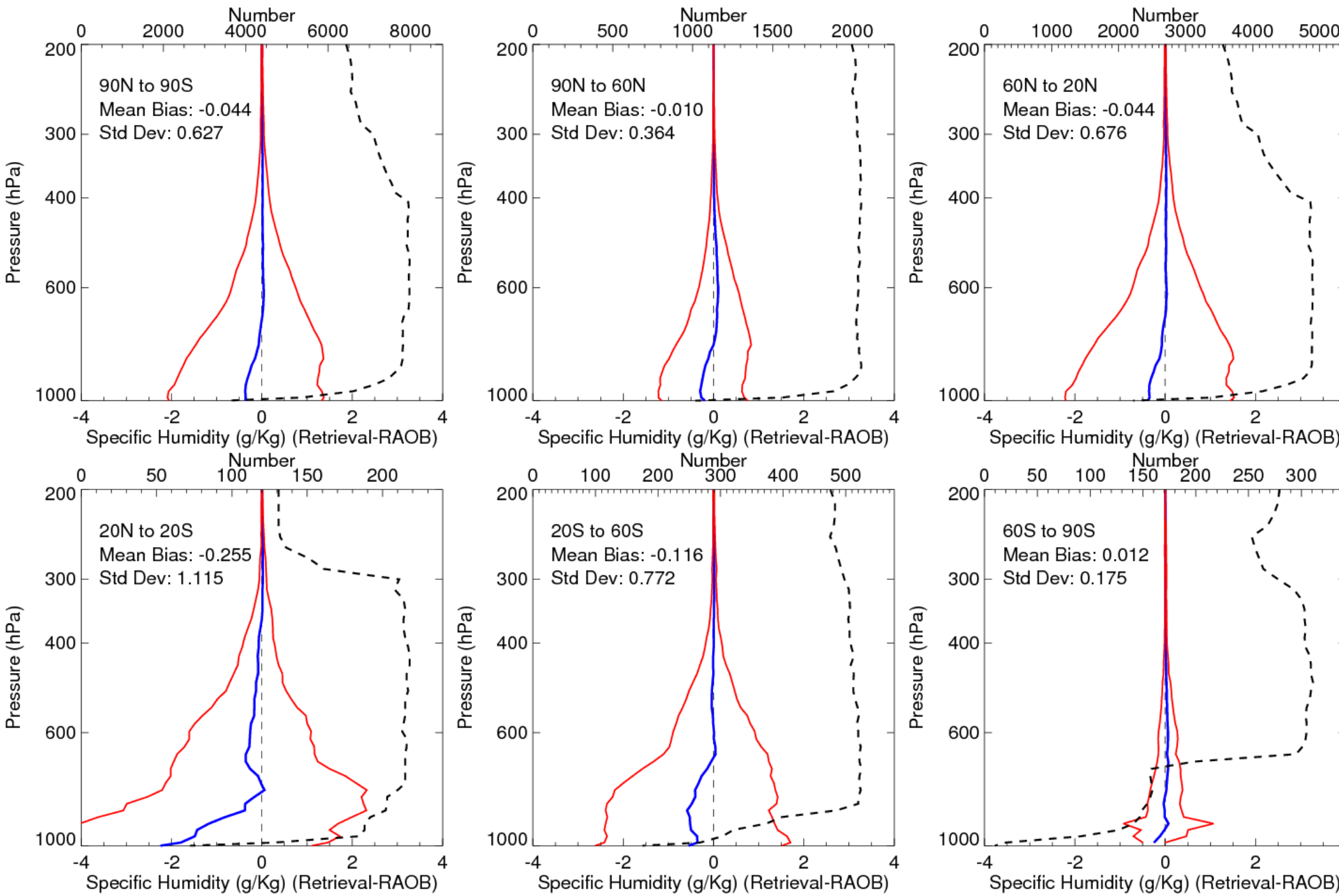
**Forward model:**

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

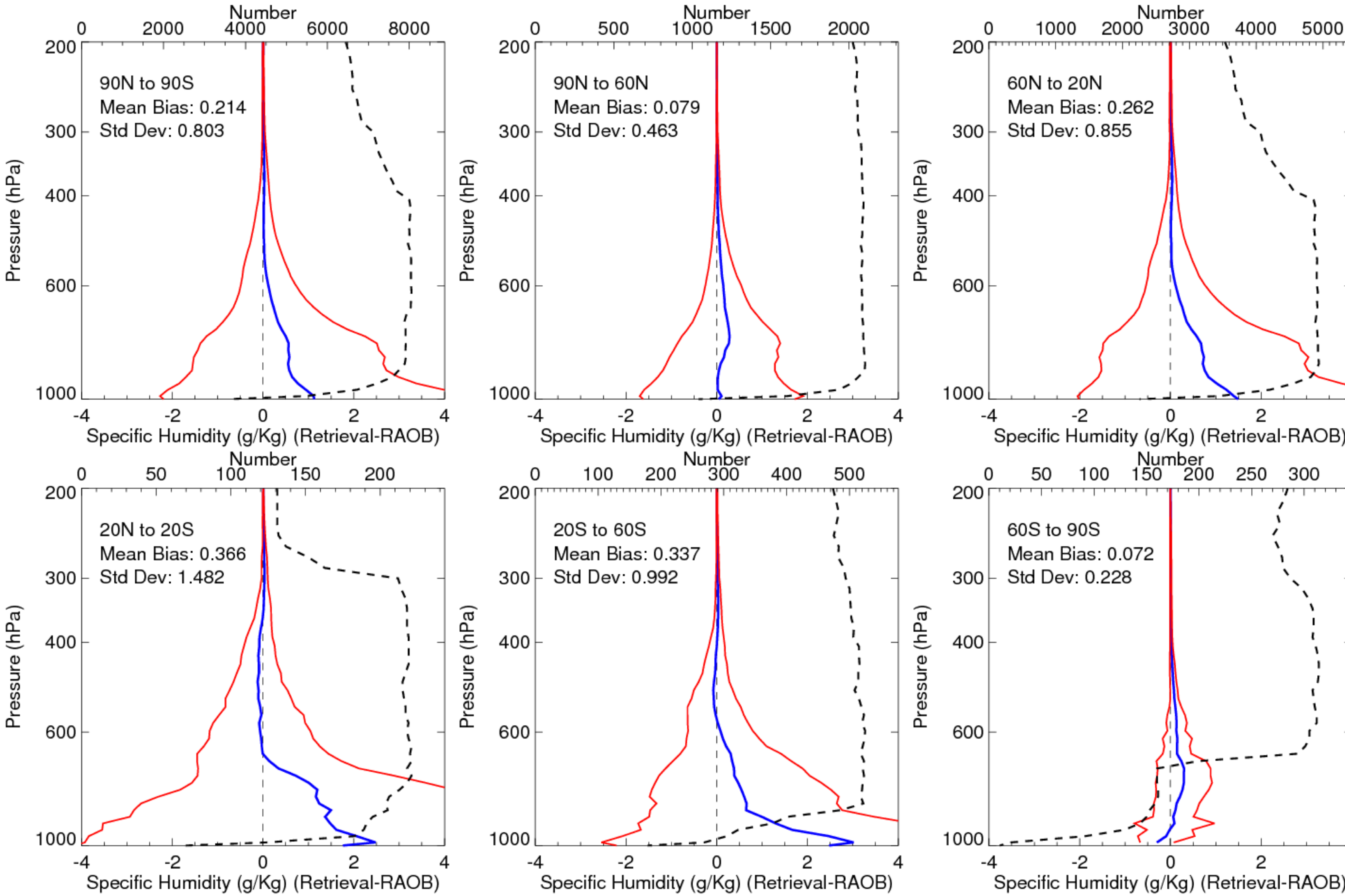
**RO Refractivity forward model:** $N = 77.6\frac{P}{T} + 3.73\times10^5\frac{P_W}{T^2}$


AIRS temperature averaging kernels
20~100 mb
100~500 mb
500~1000 mb
Degree Freedom: 5.80
AIRS T Averaging Kernels
AIRS+RO temperature averaging kernels
20~100 mb
100~500 mb
500~1000 mb
Degree Freedom: 21.09
AIRS+RO T Averaging Kerne
AIRS water vapor averaging kernels
20~100 mb
100~500 mb
500~1000 mb
Degree Freedom: 4.44
AIRS WV Averaging Kernels
AIRS+RO water vapor averaging kernels
20~100 mb
100~500 mb
500~1000 mb
Degree Freedom: 5.19
AIRS+RO WV Averaging Kerne
Pressure (hPa)
20
30
50
70
100
300
500
600
700
850
1000
-0.2
0.0
0.2
0.4
0.6

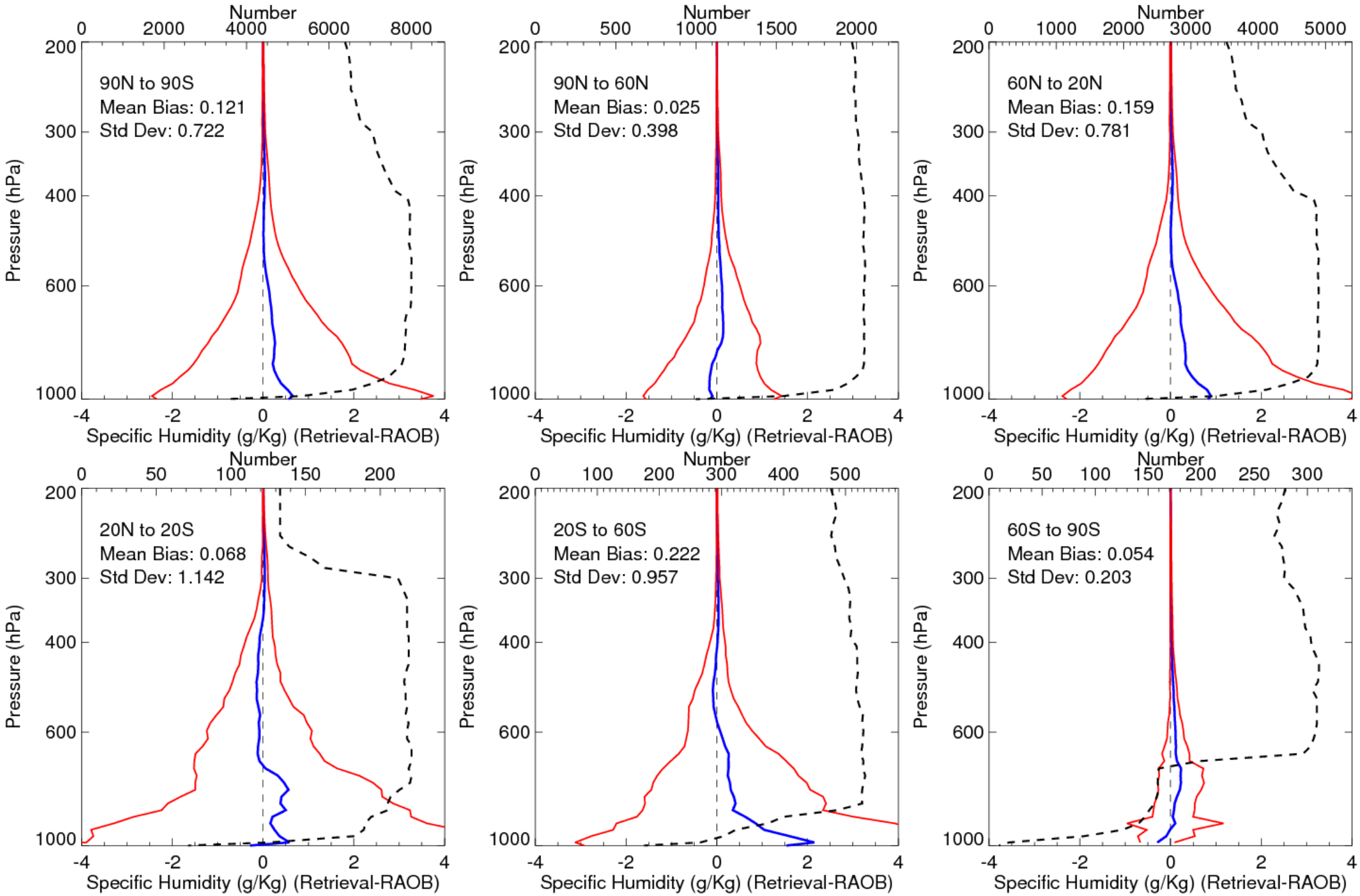
# Results
# RO WV - collocated RAOB WV

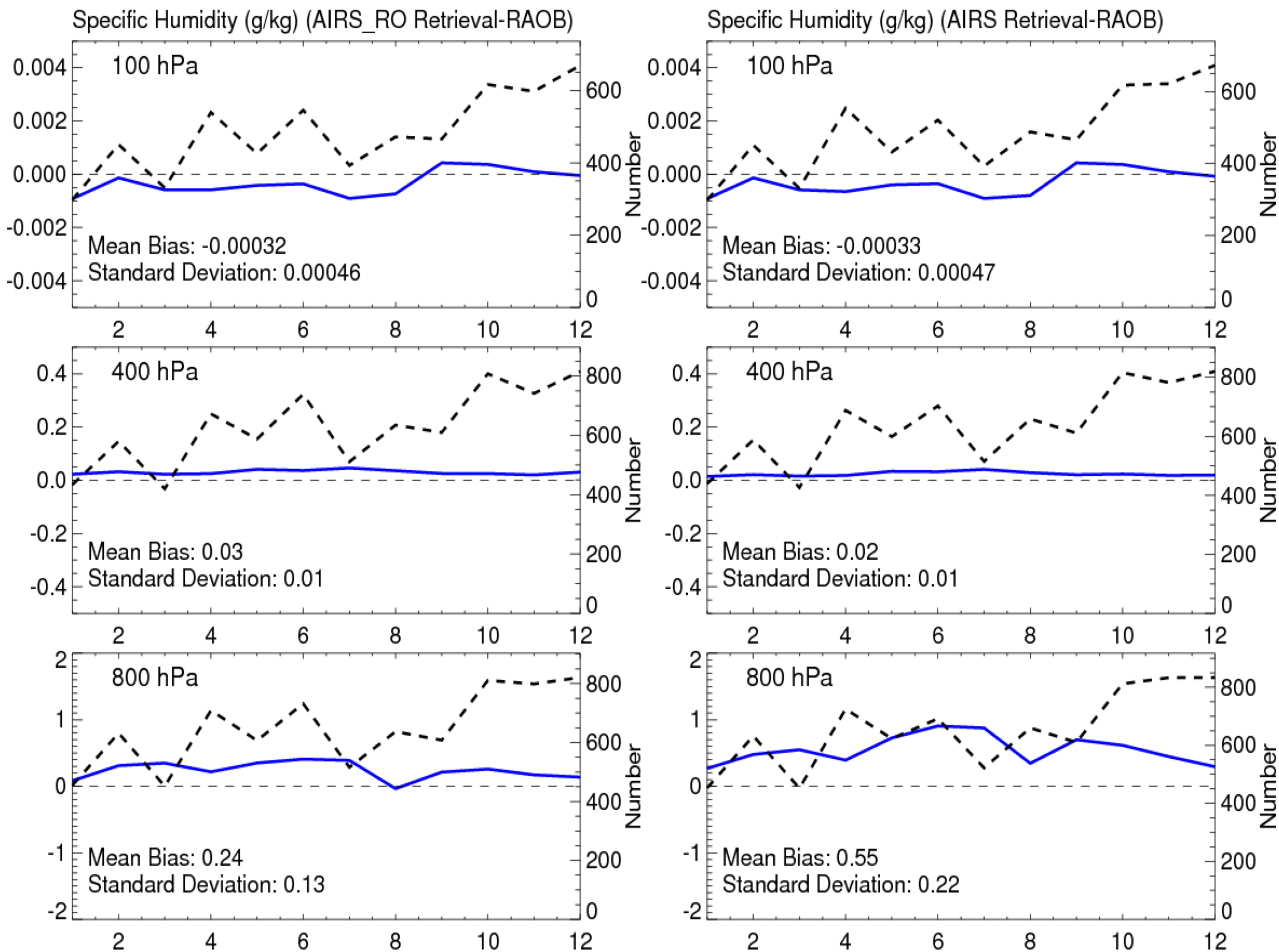


# Results
# AIRS WV - collocated RAOB WV



# Results
# RO + AIRS WV - collocated RAOB WV




Specific Humidity (g/kg) (AIRS_RO Retrieval-RAOB)
100 hPa
Mean Bias: -0.00032
Standard Deviation: 0.00046
400 hPa
Mean Bias: 0.03
Standard Deviation: 0.01
800 hPa
Mean Bias: 0.24
Standard Deviation: 0.13
Specific Humidity (g/kg) (AIRS Retrieval-RAOB)
100 hPa
Mean Bias: -0.00033
Standard Deviation: 0.00047
400 hPa
Mean Bias: 0.02
Standard Deviation: 0.01
800 hPa
Mean Bias: 0.55
Standard Deviation: 0.22
Number

# 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.