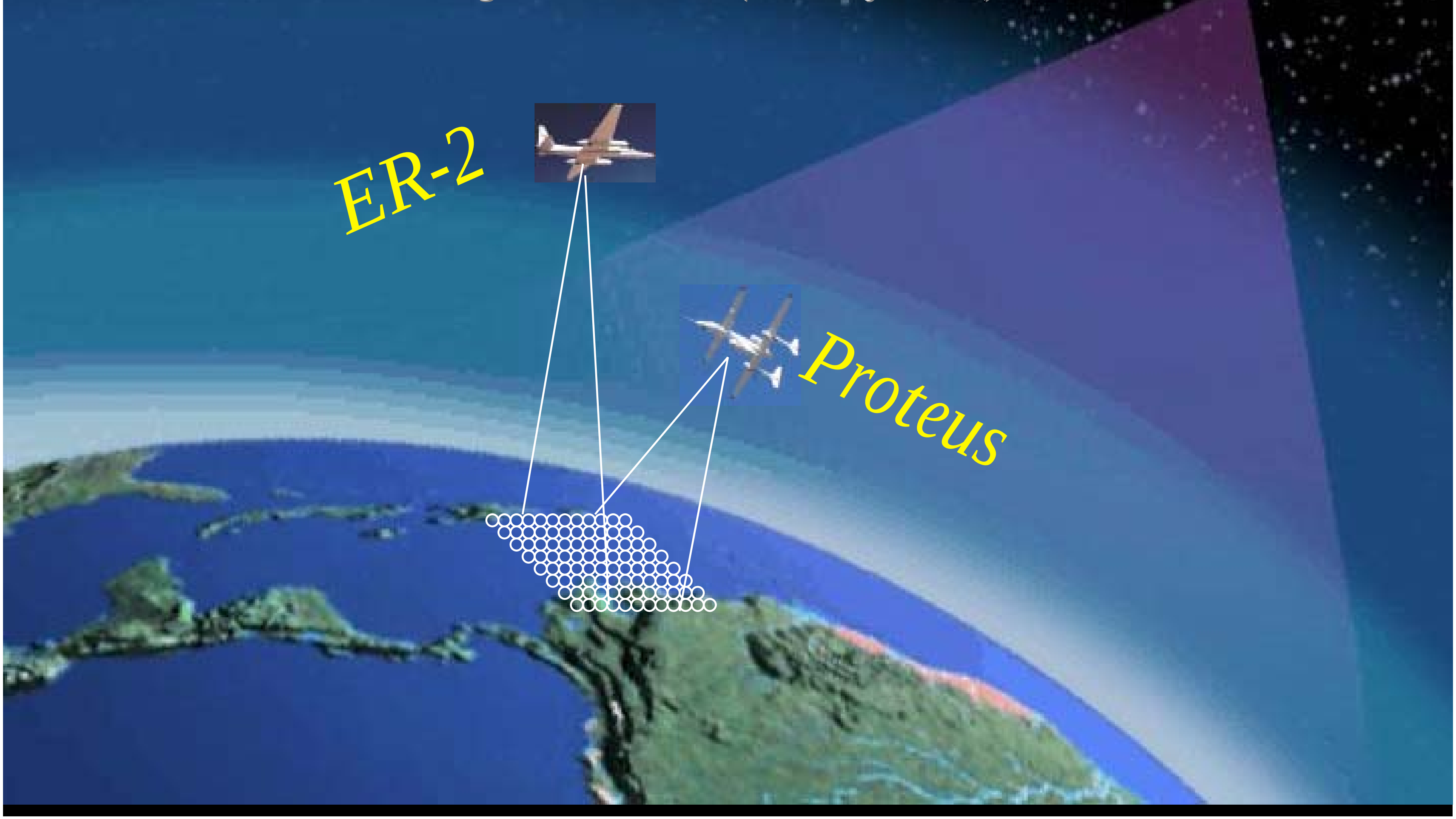
Key Ingredients for Regression Inversion: AIRS Satellite and NAST-I Aircraft Applications

W. L. Smith, D. K. Zhou, P. Antonelli, et. al.,

"Sounding from High Spectral Resolution Infrared Observations"
UW Science Meeting, Madison WI (6-8 May, 2003)



Empirical Orthogonal Function (EOF) NAST-I/AIRS Regression Retrieval

For clear sky and opaque cloud:

$$R = \varepsilon_{s,c} B_{s,c} \tau_{s,c} - \int_{P_{ac}}^{P_{s,c}} B\,d\tau - (1-\varepsilon_{s,c})\,\tau_{s,c} \int_{P_{s,c}}^{0} B\,d\tau^*$$

Radiance EOF Amplitudes

$$C_i = \sum_{j=1}^{nc} R_j E_{ji}$$

$$\left.\begin{matrix} \mathbf{T_s,} \\ \boldsymbol{\varepsilon_s(\nu)}, \\ \mathbf{T(p),} \\ \mathbf{Q(p)} \end{matrix}\right\} = \sum_{i=1}^{n-1} K_{mi} C_i + K_{mn} P_s$$

Retrieval Solution

R = radiance

$\varepsilon_{s,c}$ = surface or cloud emissivity

$B_{s,c}$ = surface or cloud Planck radiance

τ = transmittance between aircraft and atmospheric Pressure level (P)

$\tau_{S,c}$=atmospheric transmittance between aircraft and surface or cloud ($P_{S,c}$)

τ^* = atmospheric transmittance between surface or cloud P and aircraft

P_{ac} = aircraft pressure, P_s = surface pressure

$\Re$ = radiance

E = radiance covariance EOFs

C = radiance EOF amplitudes

T = temperature

Q = H_2O mixing ratio

K = regression coefficients

- **Physical Regression – EOFs and regression training based on calculated radiances**
- **Training should include cloud, sfc. emissivity, skin temp, and solar variability**
- **Null radiance errors assumed for PC specification and regression training**
- **EOF # selected by spatial radiance RMSD (observed minus retrieval) minimization**

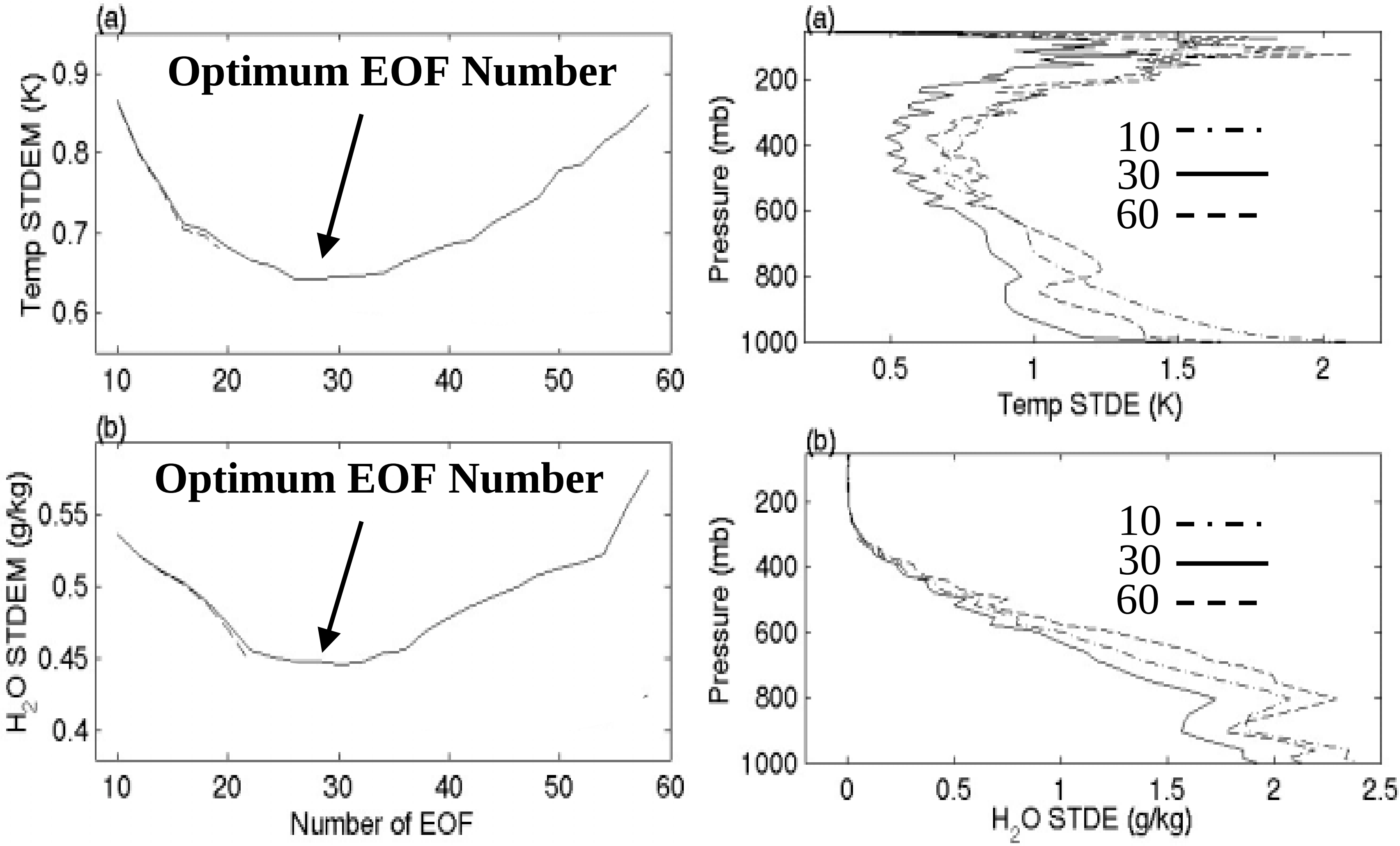
Important Notes on EOF Regression

- **Training:**
  - *Regional (~3000 km), seasonal (~3 month) radiosonde sample*
  - *Trace gases manufactured using statistical regression data sets*
  - *Surface emissivity/reflectivity spectrum provided by random selection from the Salisbury/SEBASS data sets*
  - *Cloud-free and cloud radiance spectra computed for each profile. Cloud profiles modified to be isothermal (@ cloud temperature) and humidity below cloud level diagnosed from radiosonde humidity profile*
  - *Radiance EOFs and retrieval parameter regressions produced from "error-free" synthetic data*
  - *For surface emissivity, 5 amplitudes of EOF representation of Salisbury/SEBASS data set are regressed against radiance*
  - *Predictors are radiance EOF amplitudes and surface pressure*
  - *Predictands are sfc skin temperature, sfc emissivity amplitude, reflected solar intensity amplitude, atmospheric temperature,* H_2O, O_3, *and CO mixing ratio.*

Important Notes on EOF Regression

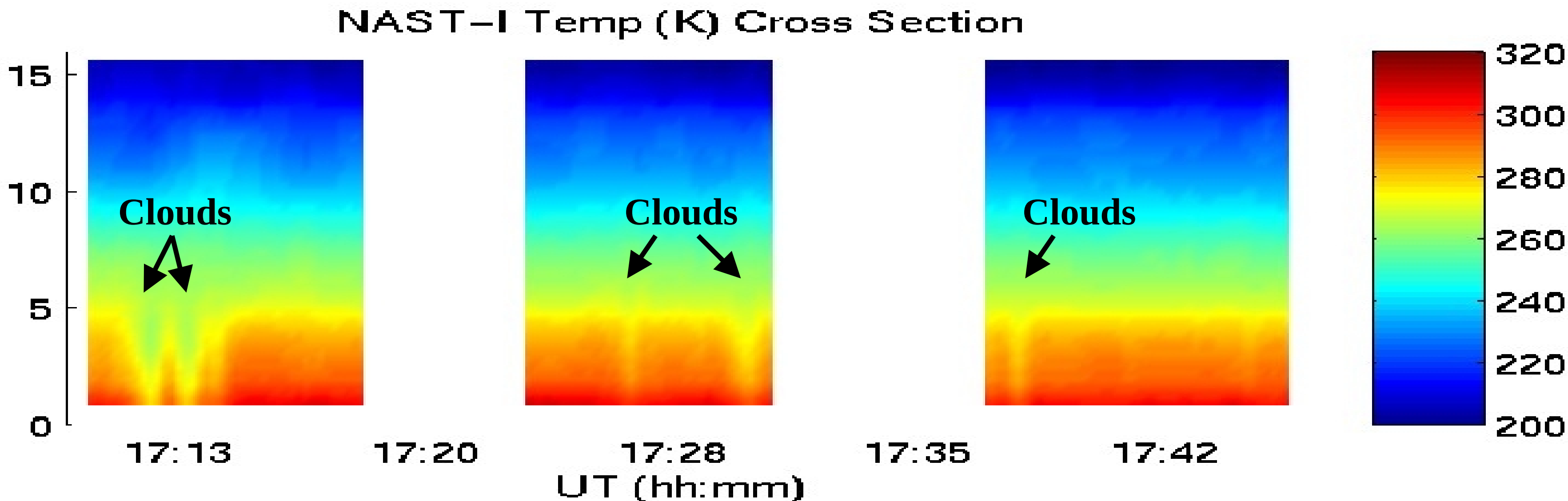
- **Application:**
  - *EOF # selected as that value which minimizes the spatial radiance RMSD (observed minus retrieval) for a representative regional sample of the data set being analyzed*
  - *Surface pressure used in regression estimated from surface height for standard atmospheric conditions*
  - *Surface emissivity spectrum produced using 5 EOF representation and amplitudes predicted radiance spectra*
  - *Cloud height altitude diagnosed from retrieved relative humidity profile and local (i.e., 3 x 3) variance of temperature profile retrievals*
  - *Solar contribution should be accounted for by assuming that the surface reflectivity is proportional to the surface emissivity, given the solar zenith angle and measurement nadir angle as measured variables. Solar contribution is included in the training with a single coefficient (the amplitude of the solar reflectivity spectrum) being retrieved.*

EOF # Selection Example

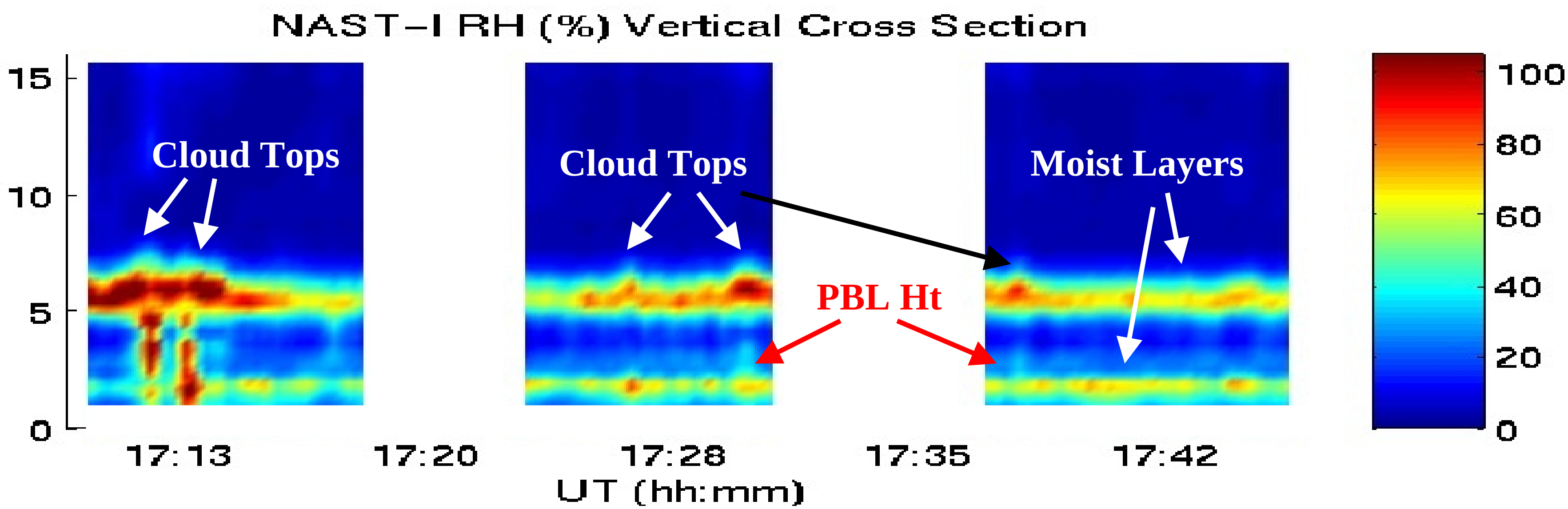


EOF Reduction of 1000's of Spectral Channels of Radiance to 10's of Independent Pieces of Information Improves S/N by an order of magnitude

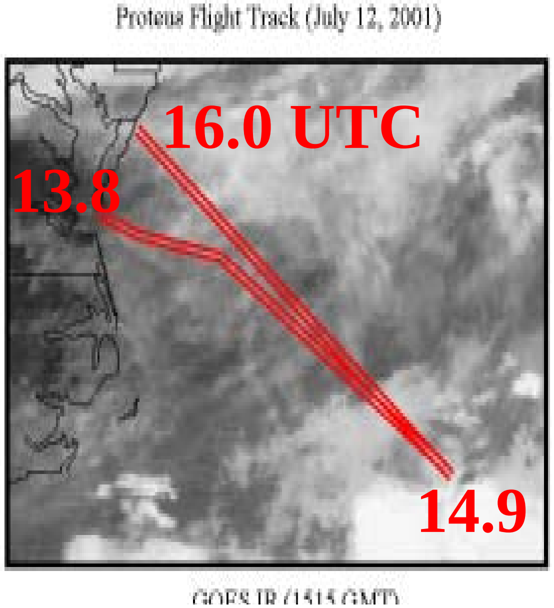
Opaque Cloud Effects on Retrieval

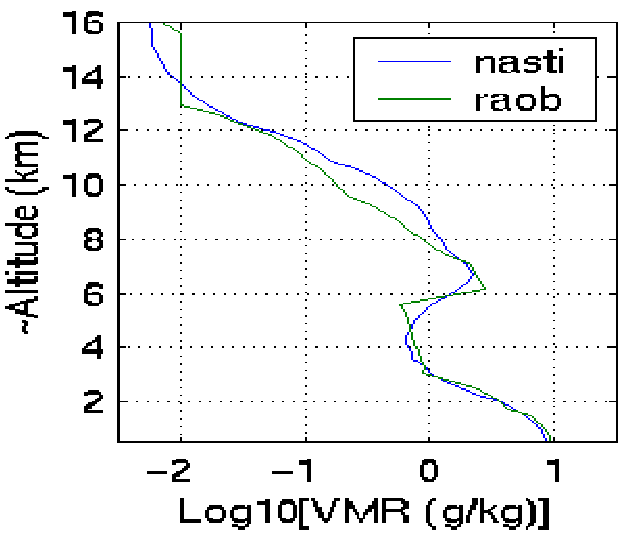


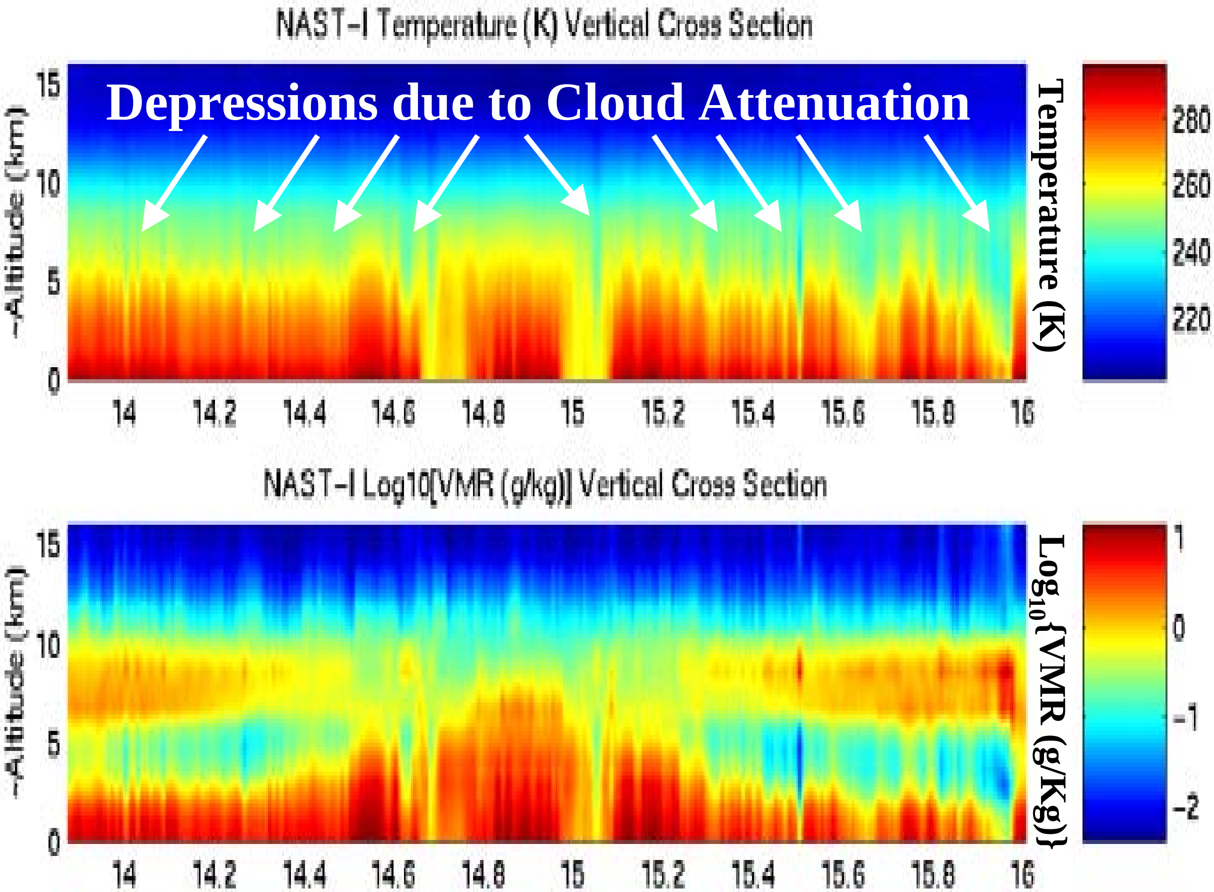
NAST I-HOP June 12, 2002 Over Oklahoma



Cirrus Cloud Effects on Retrieval

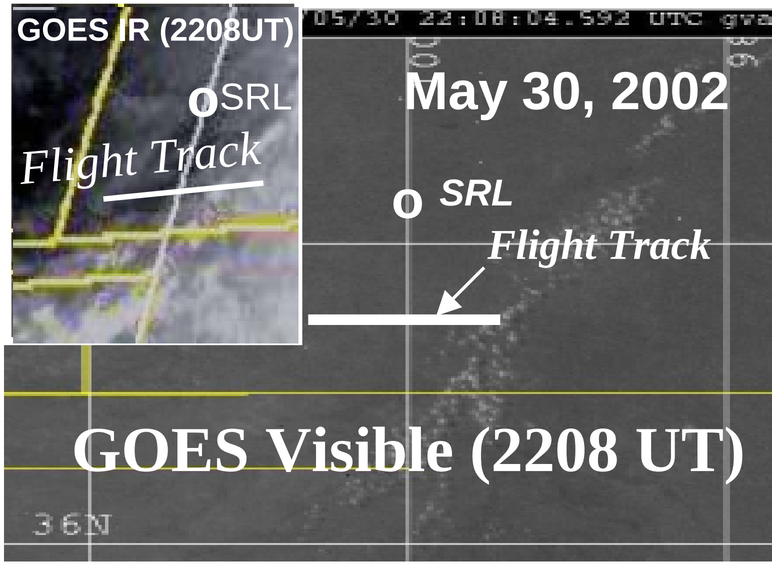


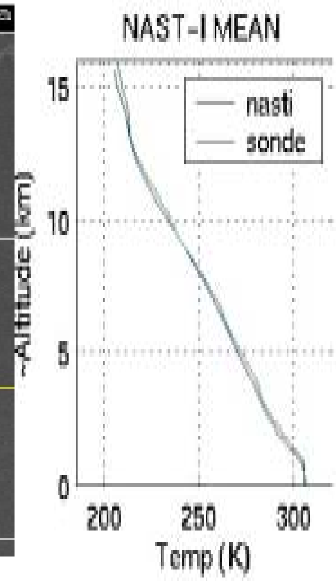


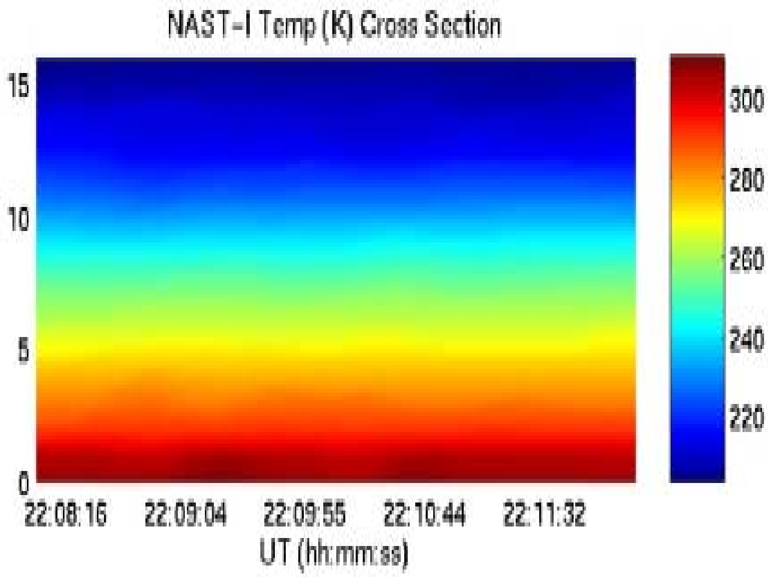


These retrievals, uncorrected for cloud attenuation, demonstrate the ability to sense the spatial structure of moisture below a scattered and semi-transparent cirrus cloud cover

Thin Cirrus Effects on Retrieval



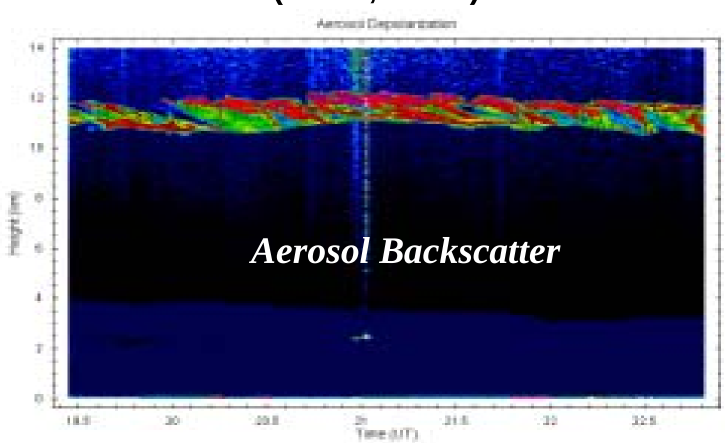


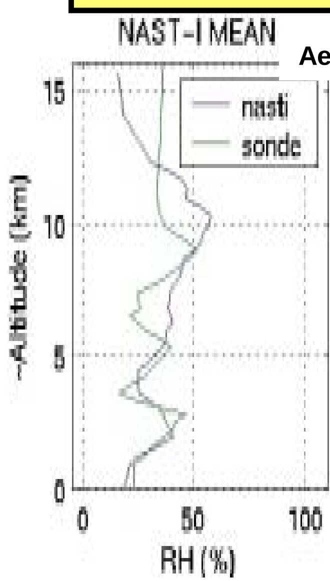


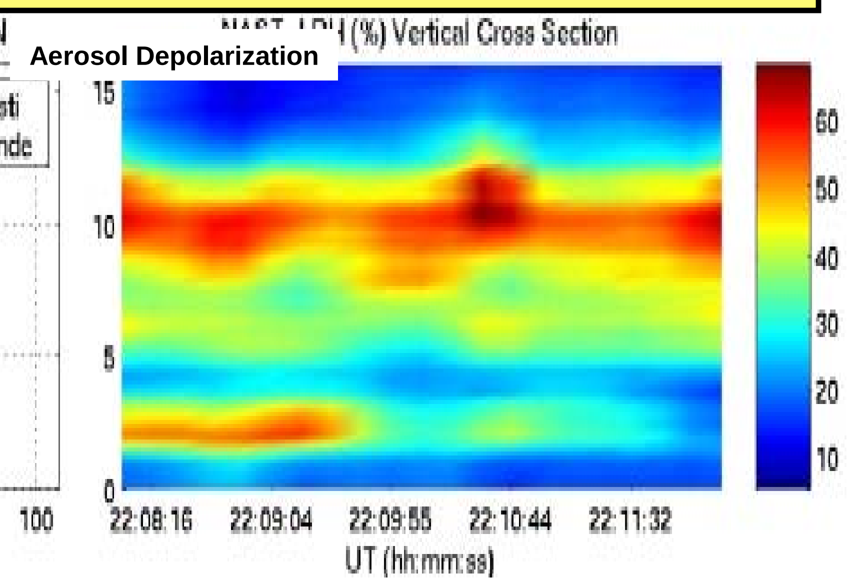
Thin cirrus produces little effect on retrieval

NASA SRL data

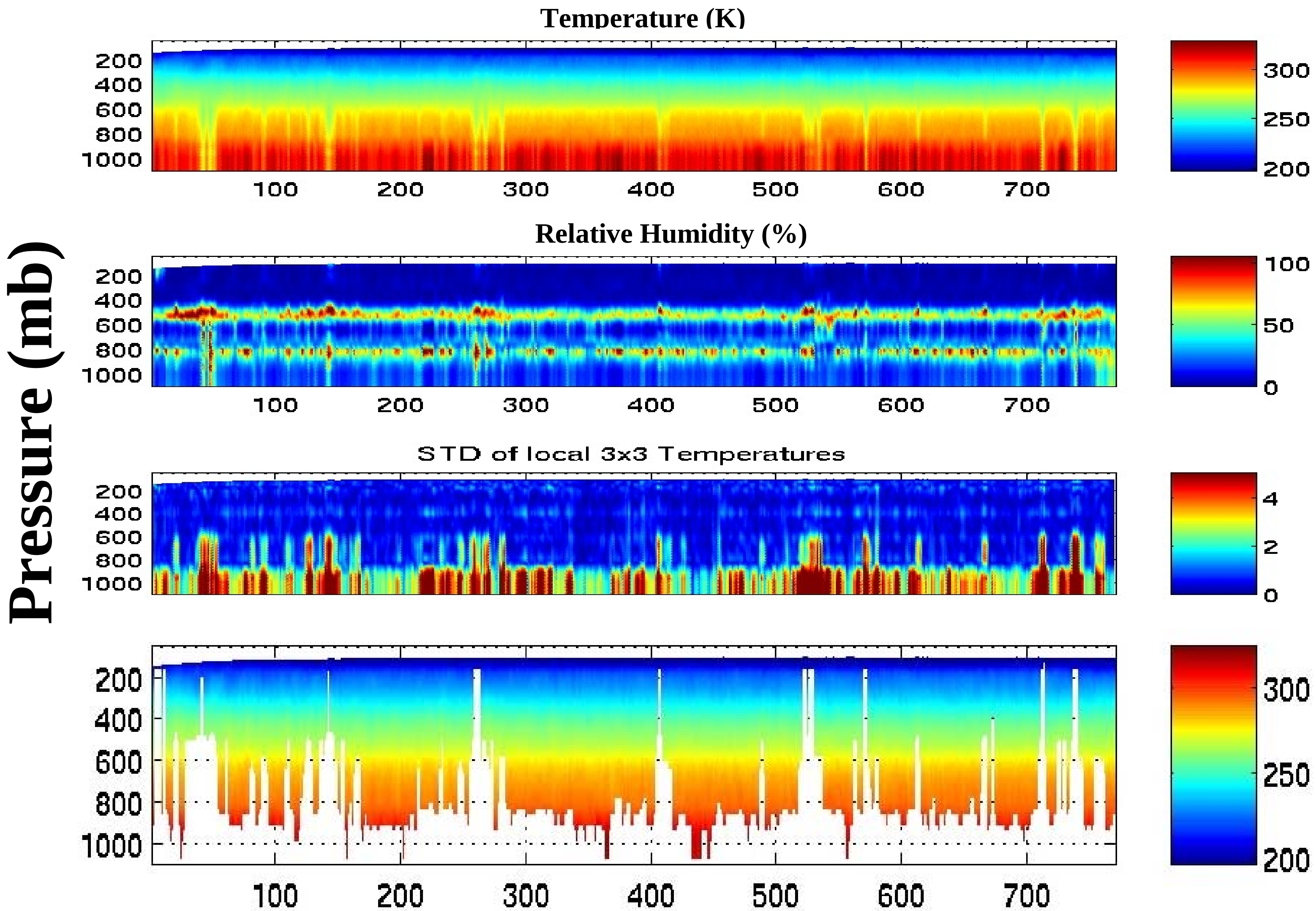
May 30, 2002 (19.5 – 23 UT)
(37.8N, 100W)



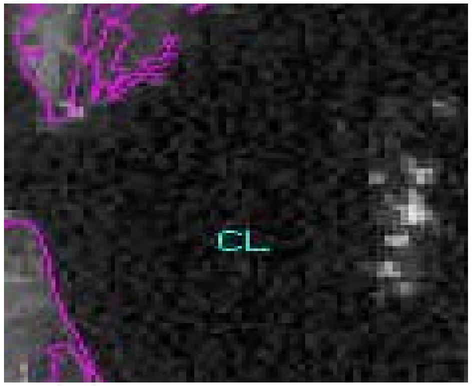


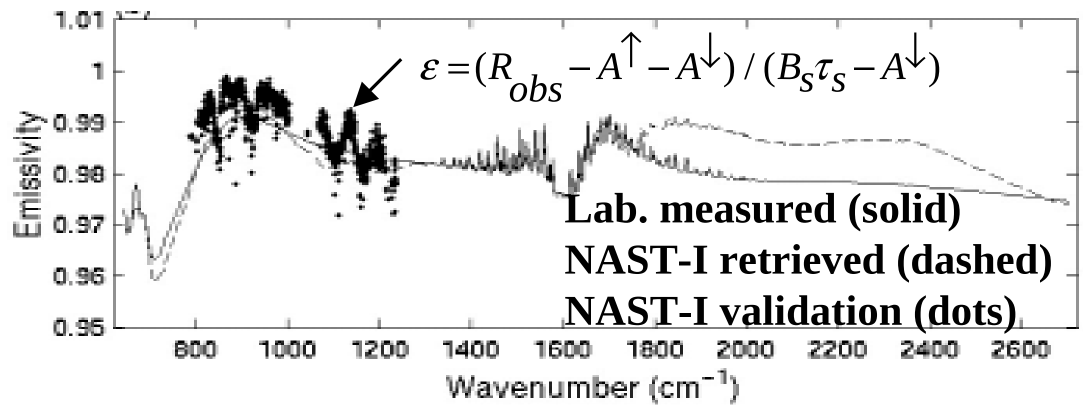


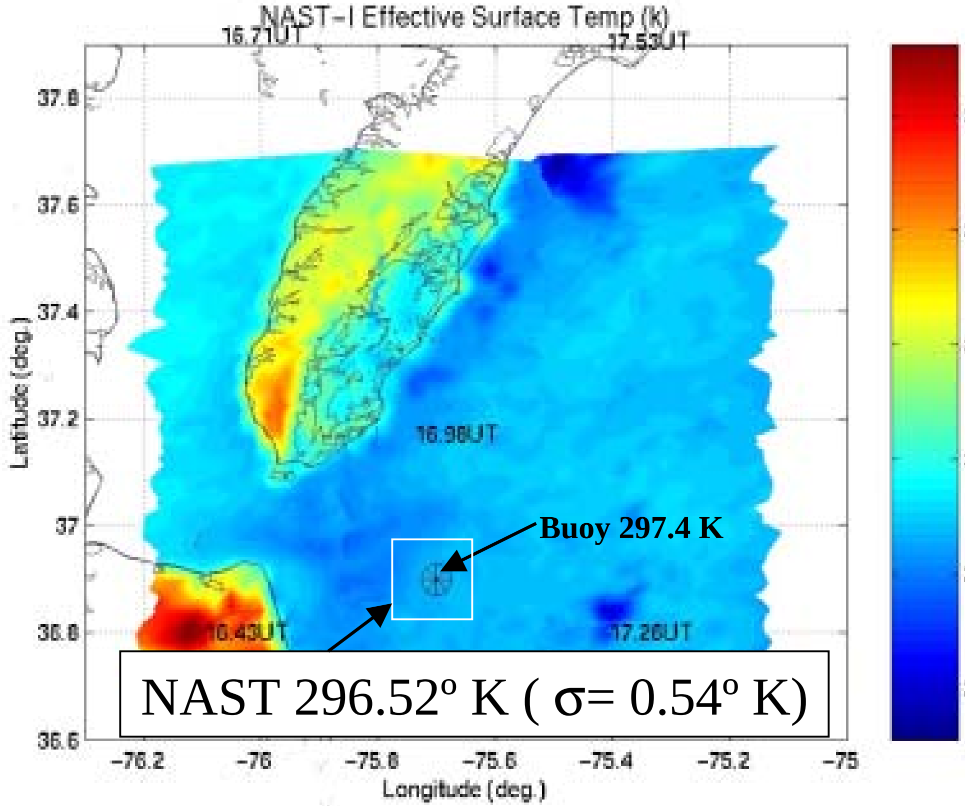
Cloud Height Diagnosis

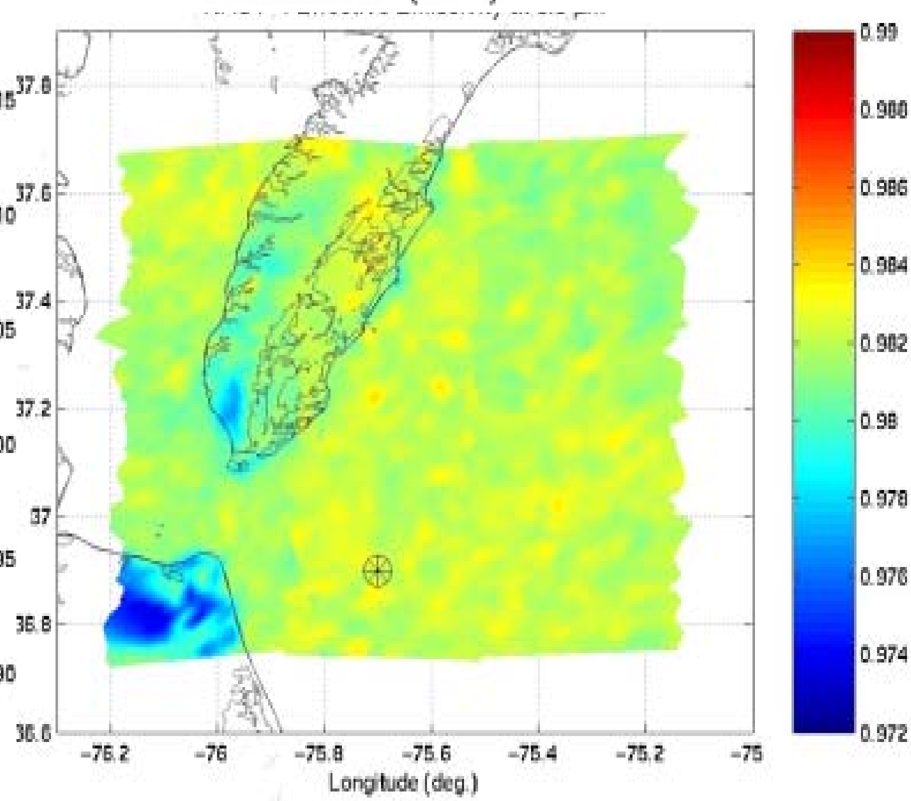


Surface Temperature & Emissivity Retrieval

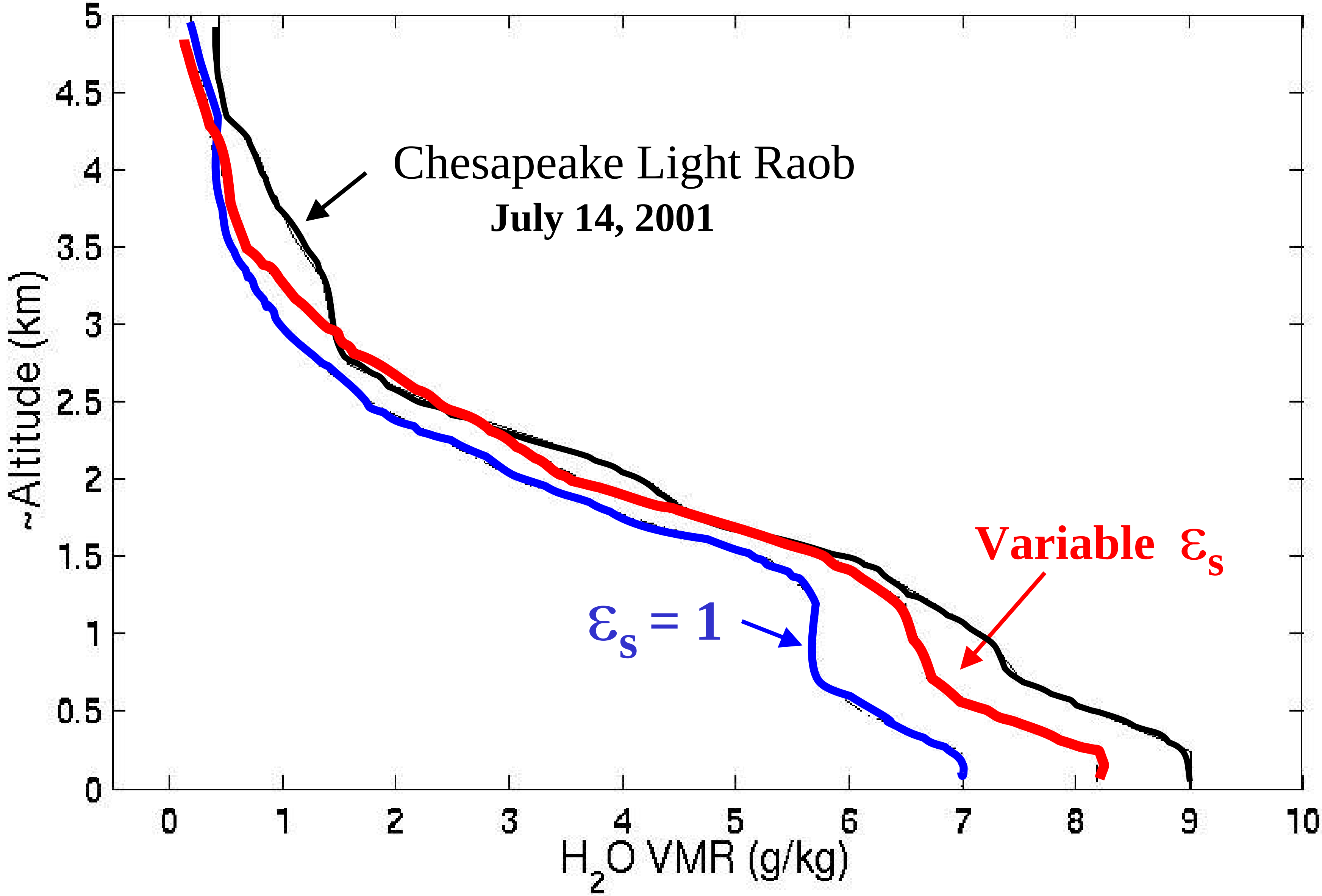








Surface Emissivity Impact on PBL Moisture



AIRS, NAST, "CrIS", and "GIFTS" Retrievals

AIRS (IR Grating Spectrometer)

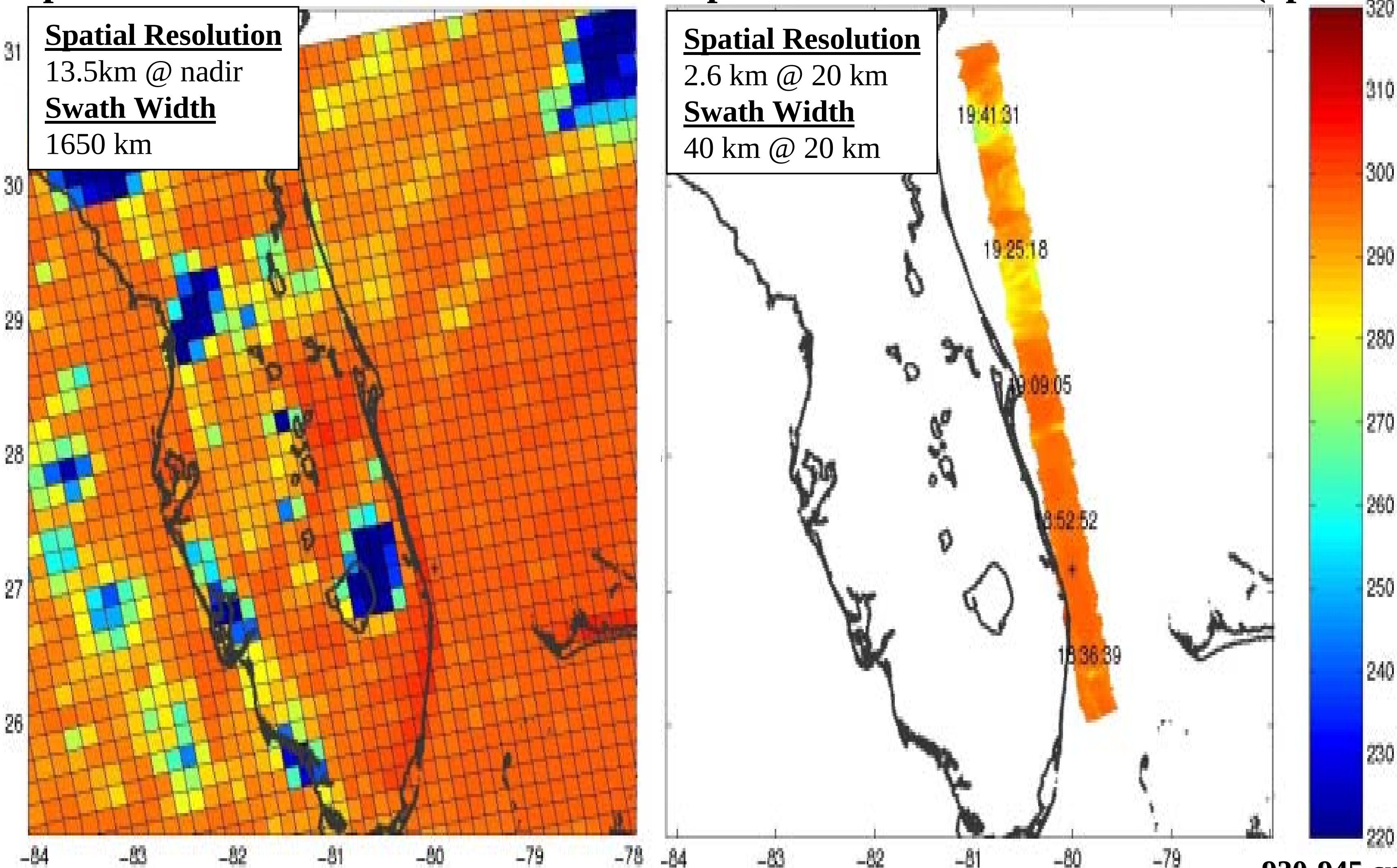
Spectral Range: 3.7 – 15.4 Microns

Spectral Resolution: $\nu/\delta\nu$ = 1200

NAST-I (IR Interferometer)

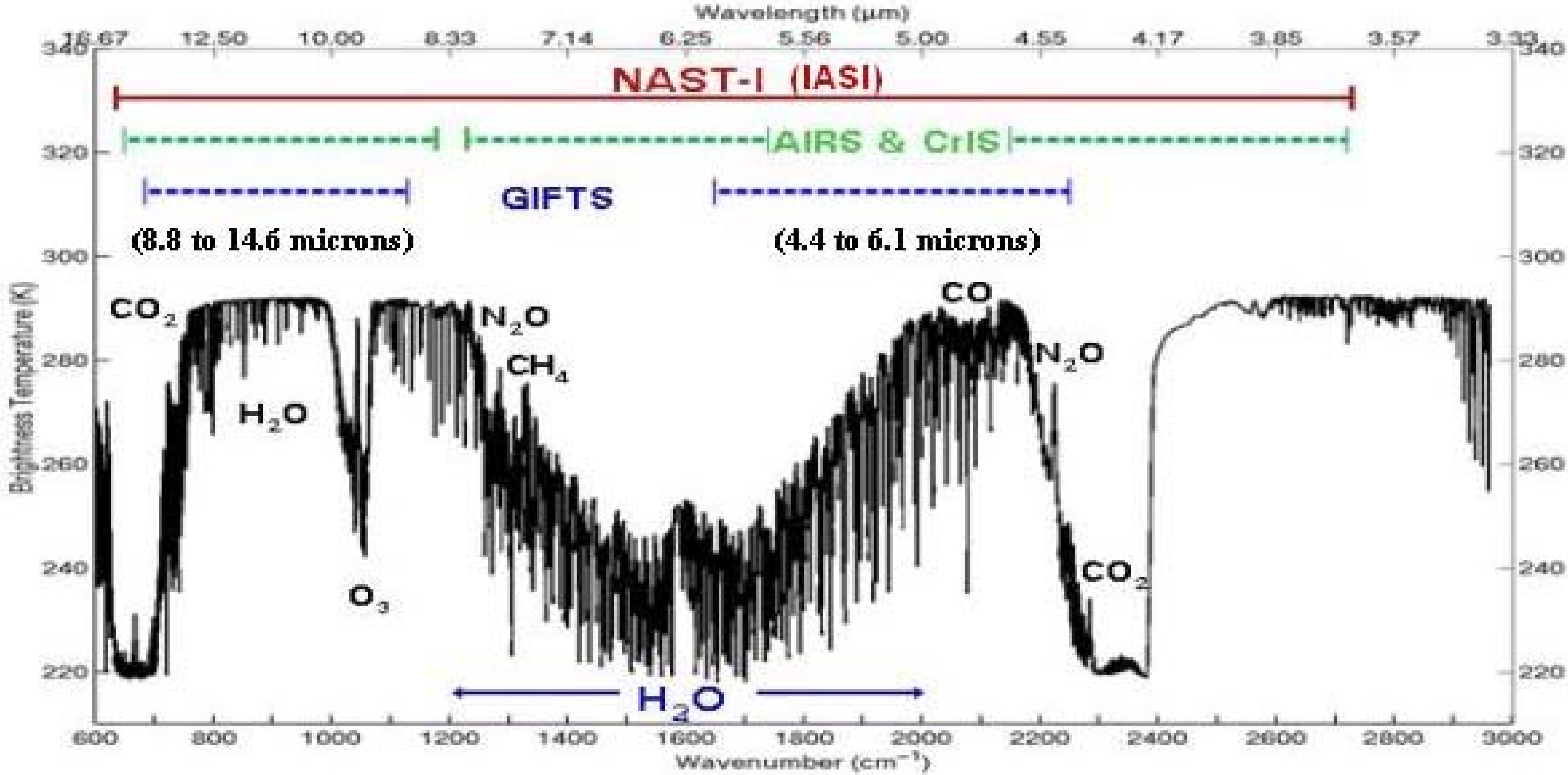
Spectral Range: 3.5 - 16 Microns

Spectral Resolution: $\delta\nu$ = 0.5 cm^{-1} (apodized)

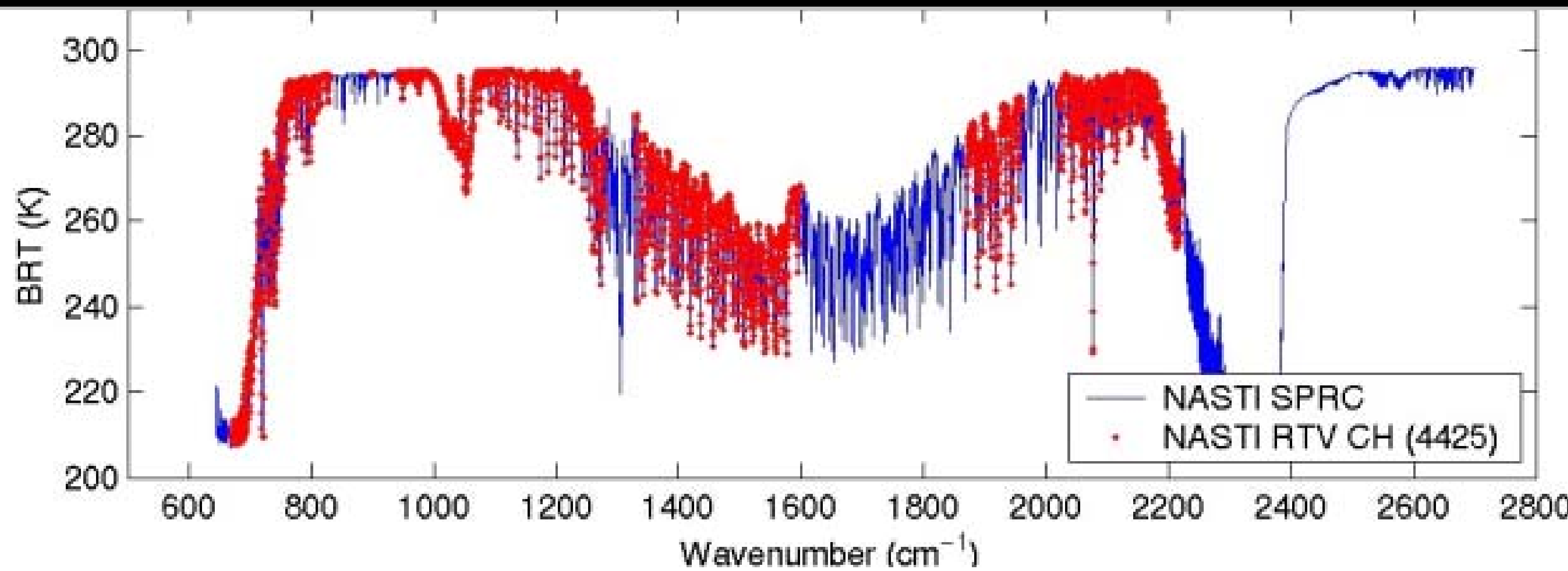


930-945 cm-1

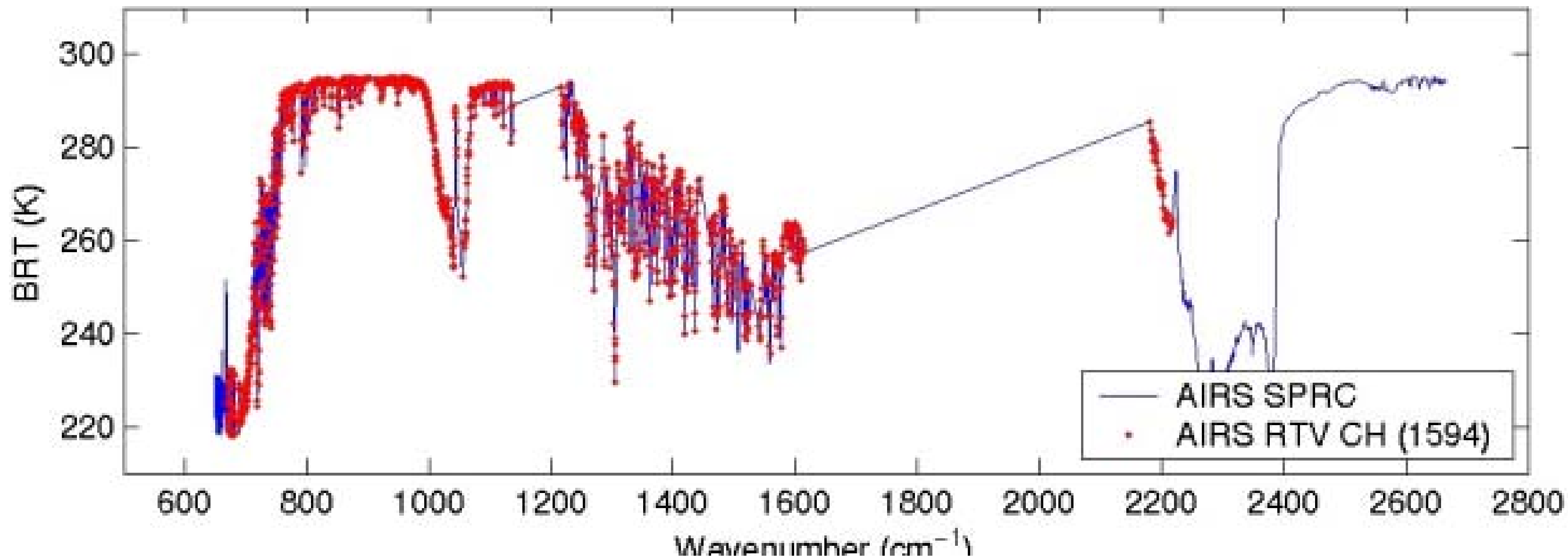
AIRS, NAST, "CrIS", and "GIFTS" Retrievals

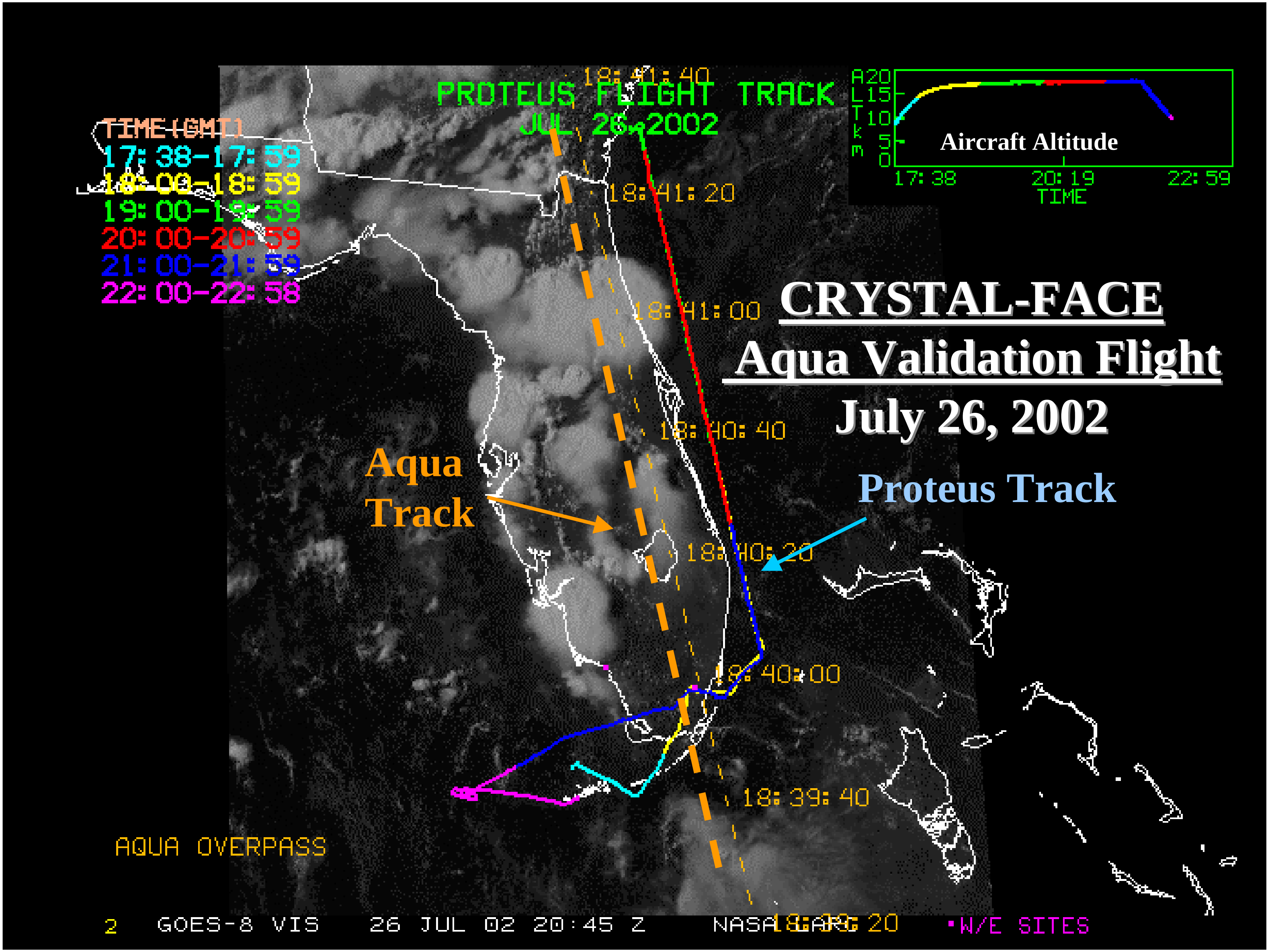


NAST-I and AIRS Spectra and Retrieval Channels

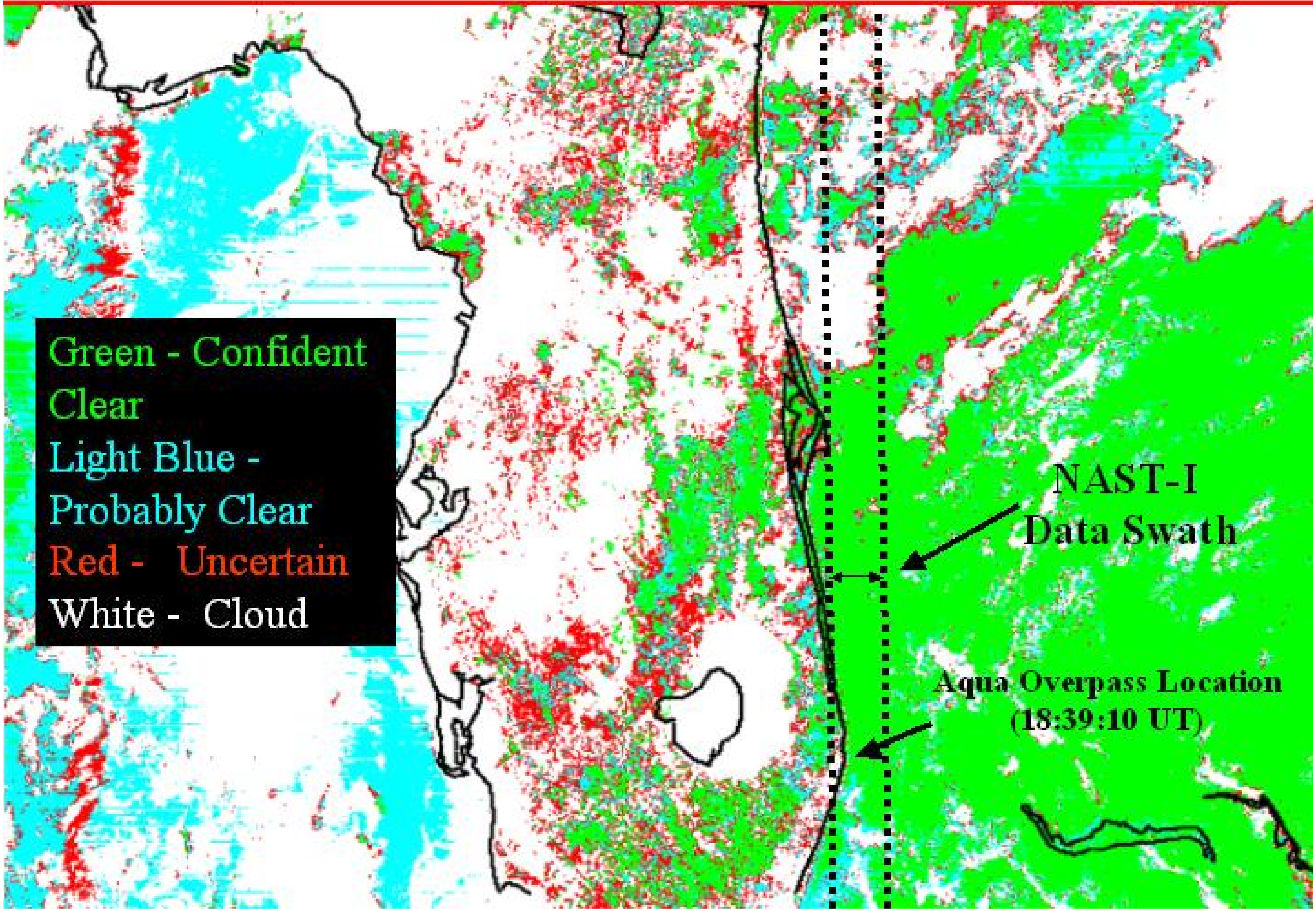


Note: NAST Retrieval Channel NEdN @ AIRS Spatial Resultion < 0.05K



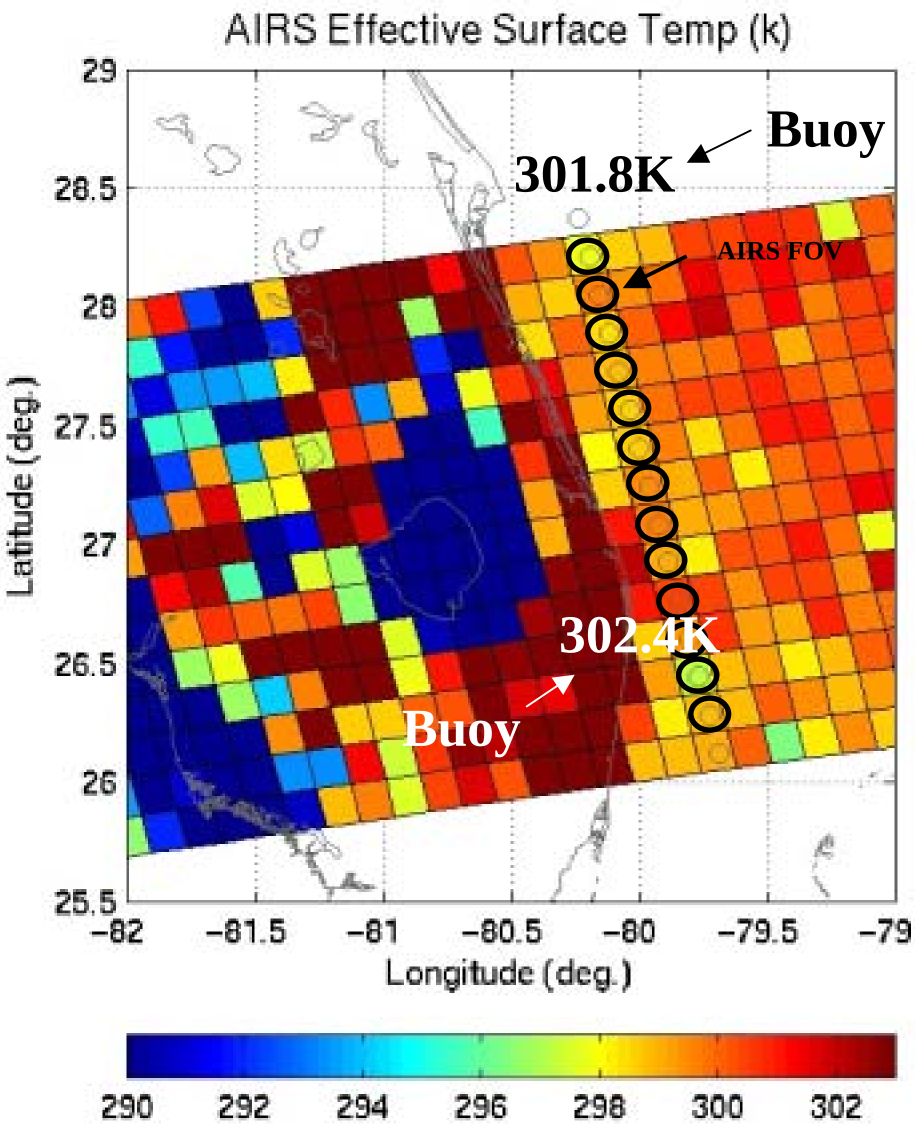

CRYSTAL-FACE
Aqua Validation Flight
July 26, 2002
PROTEUS FLIGHT TRACK
JUL 26,2002
TIME(GMT)
17:38-17:59
18:00-18:59
19:00-19:59
20:00-20:59
21:00-21:59
22:00-22:58
ALT km
20
15
10
5
0
Aircraft Altitude
17:38
20:19
22:59
TIME
18:41:40
18:41:20
18:41:00
18:40:40
18:40:20
18:40:00
18:39:40
18:39:20
Aqua Track
Proteus Track
AQUA OVERPASS
2
GOES-8 VIS
26 JUL 02 20:45 Z
NASA LARC
W/E SITES

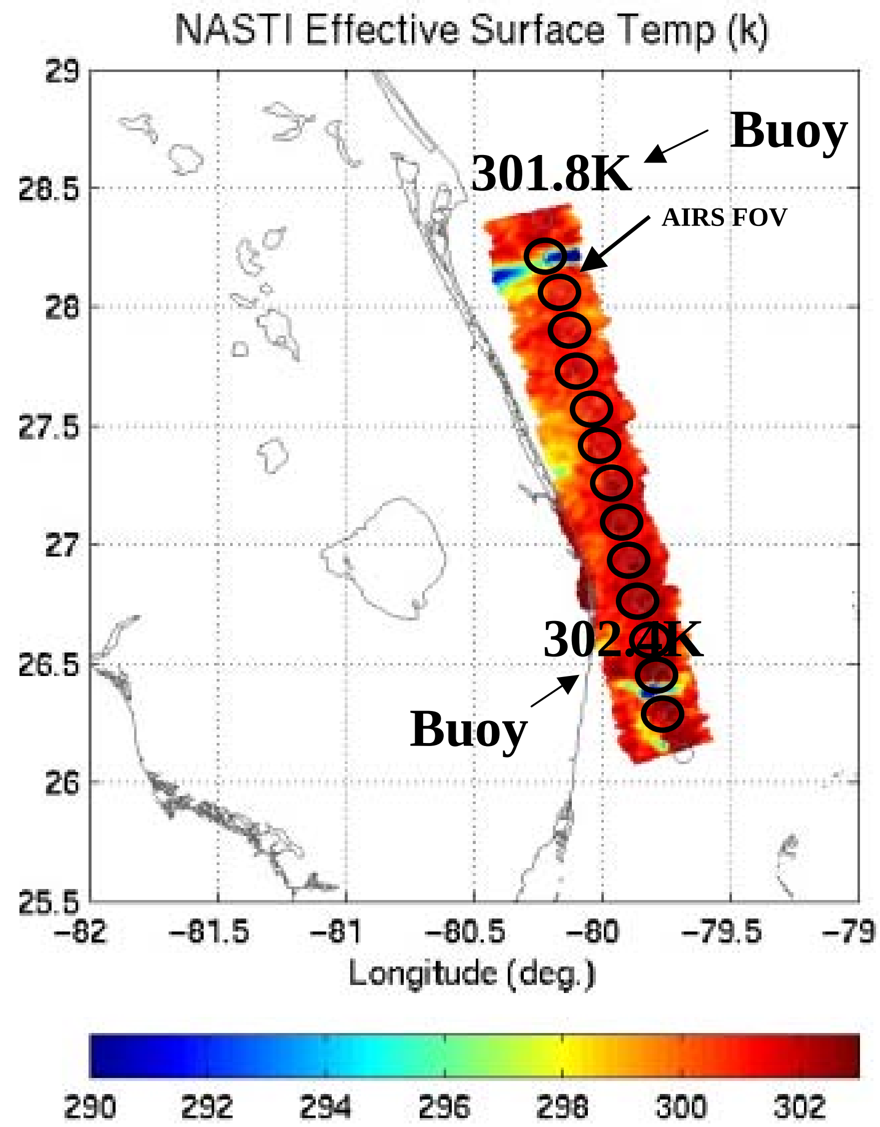
MODIS Cloud Mask - 26 July 2002, 18:40 UTC



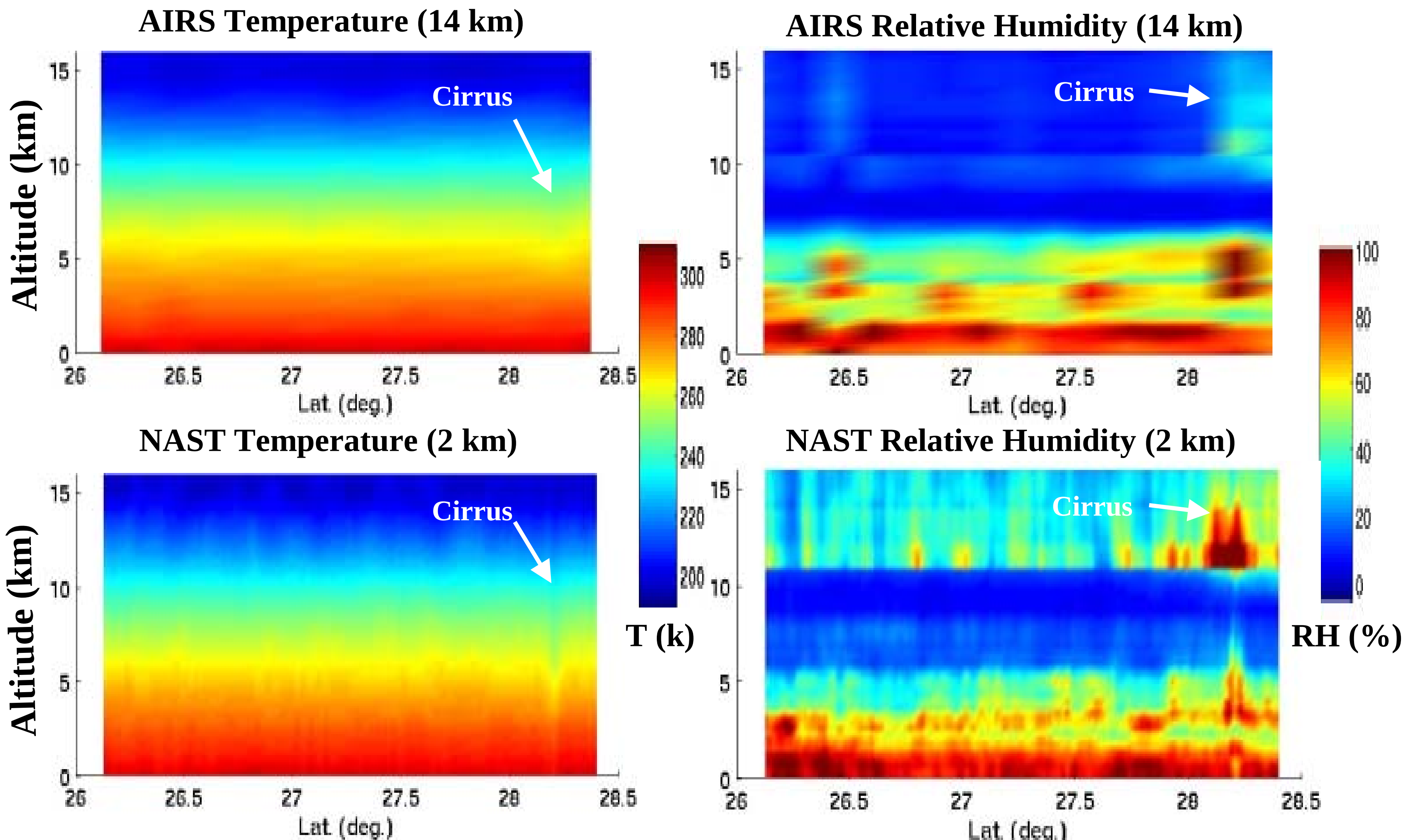
AIRS and NAST-I Retrieved Surface Temperature

(AIRS FOV locations used for NAST-I comparisons shown)



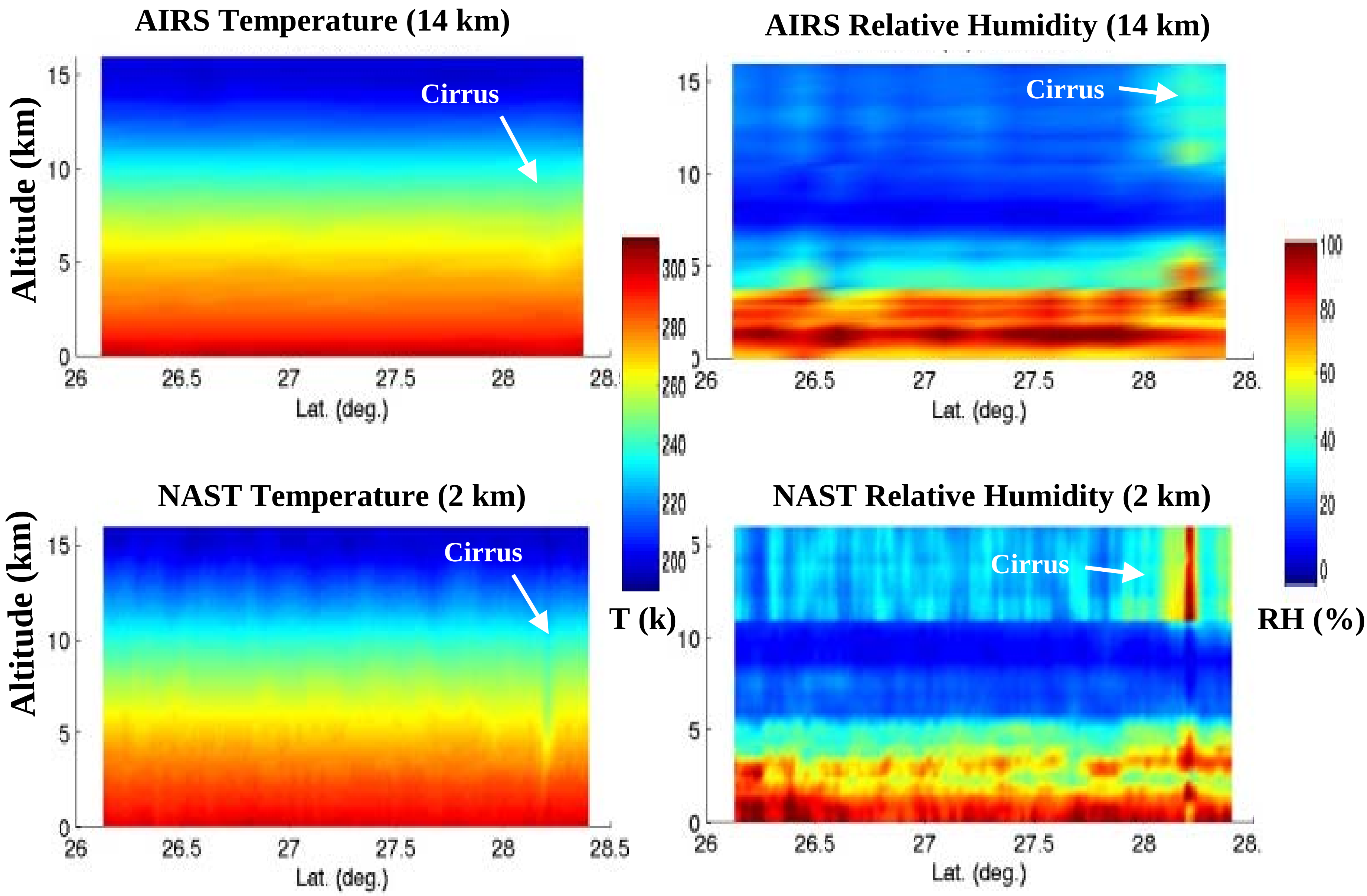


Temperature & Relative Humidity Comparisons

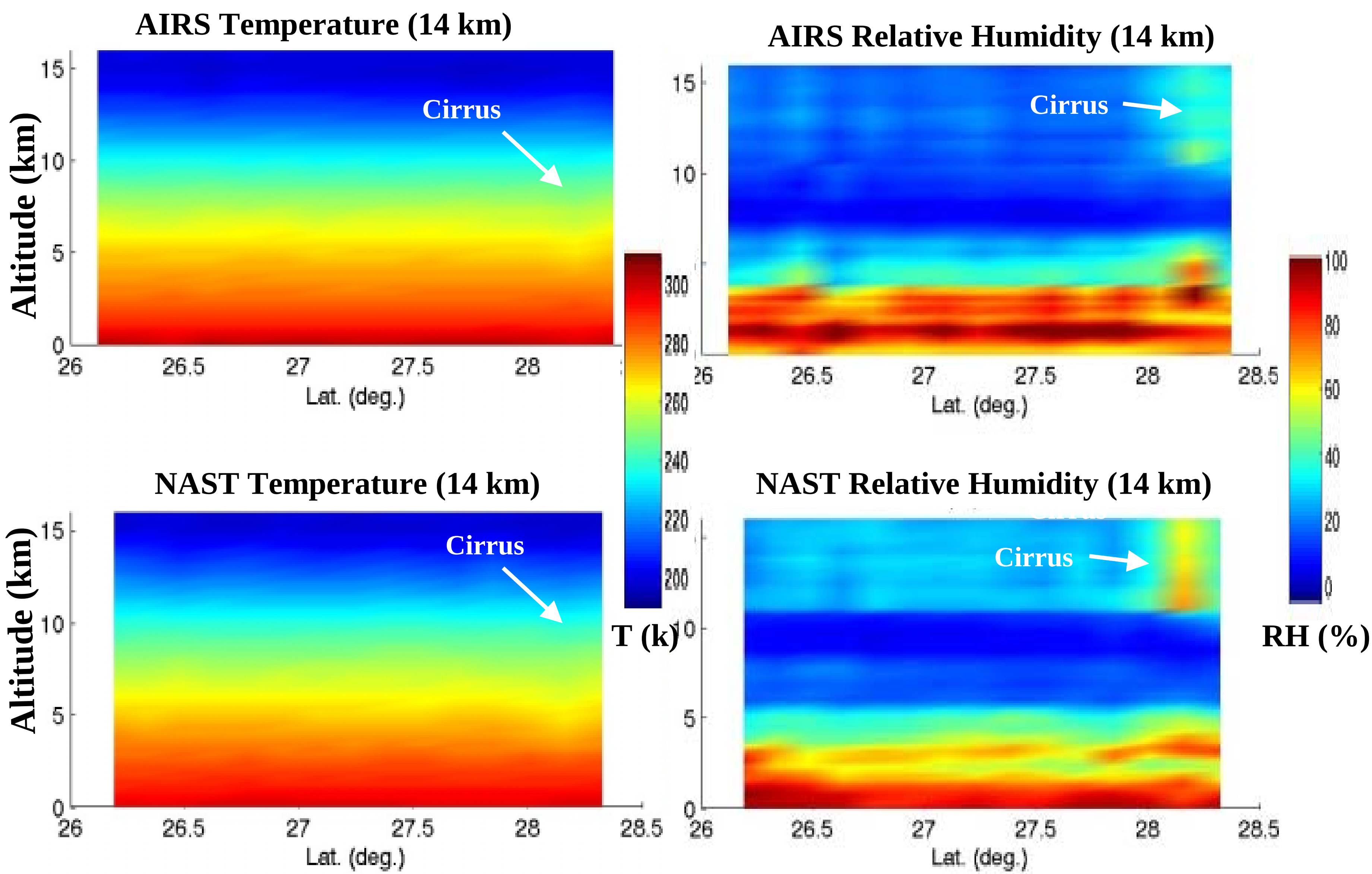


<u>Note</u>: Retrievals based on same algorithm (Physical EOF Regression) but different line-by-line codes (The UMBC kCARTA/SARTA for AIRS and the AER LBLRTM/OSS for NAST). SARTA stands for "Stand Alone AIRS Radiative Transfer Model" and OSS stands for "Optimal Spectral Sampling".

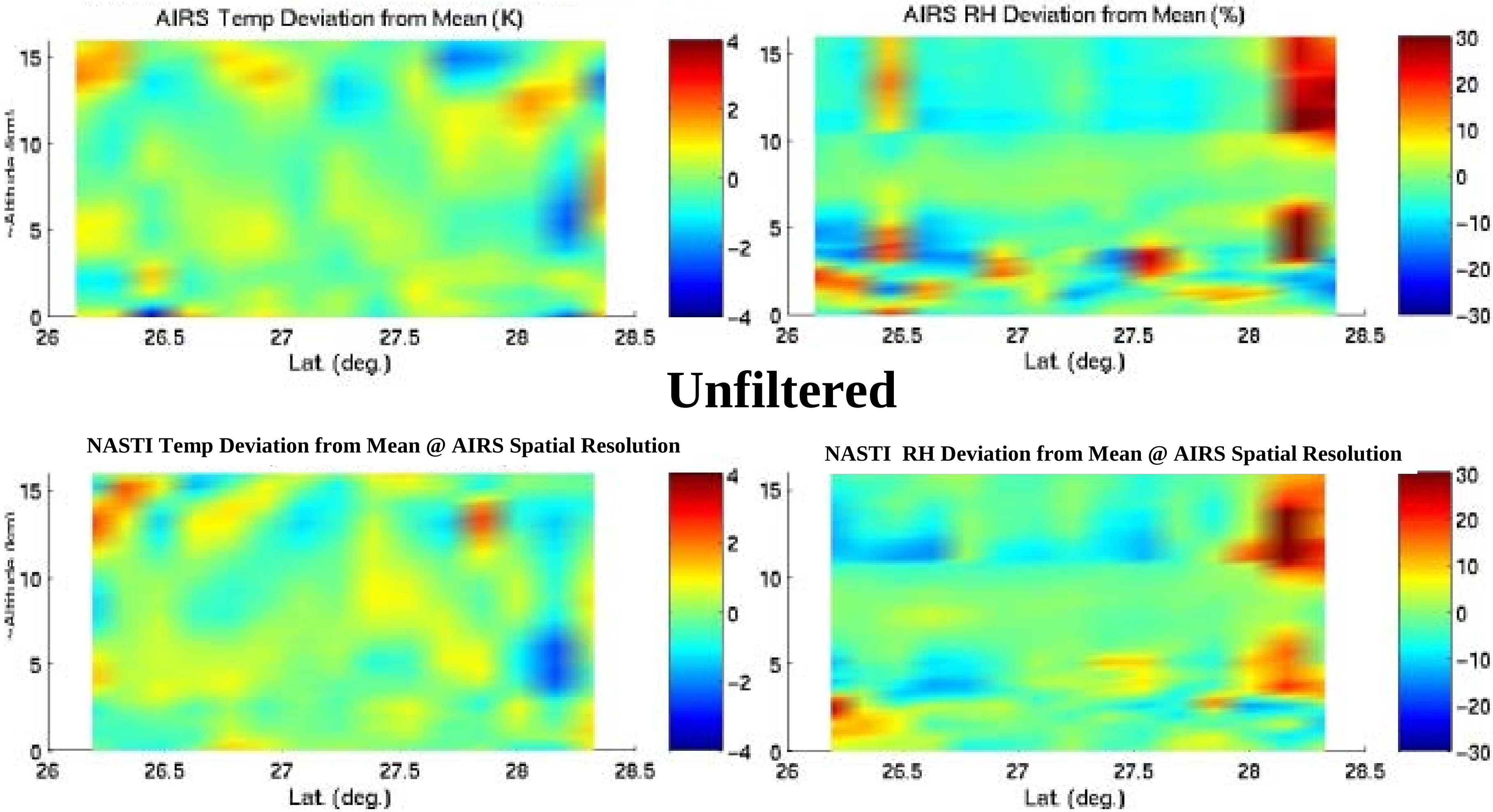
Temperature & Relative Humidity (PC Filtered)



Temperature & Relative Humidity (AIRS Res.)

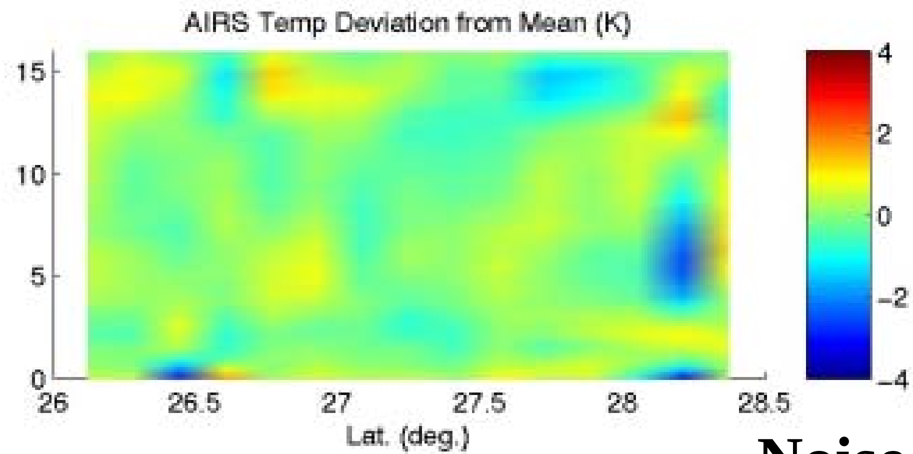


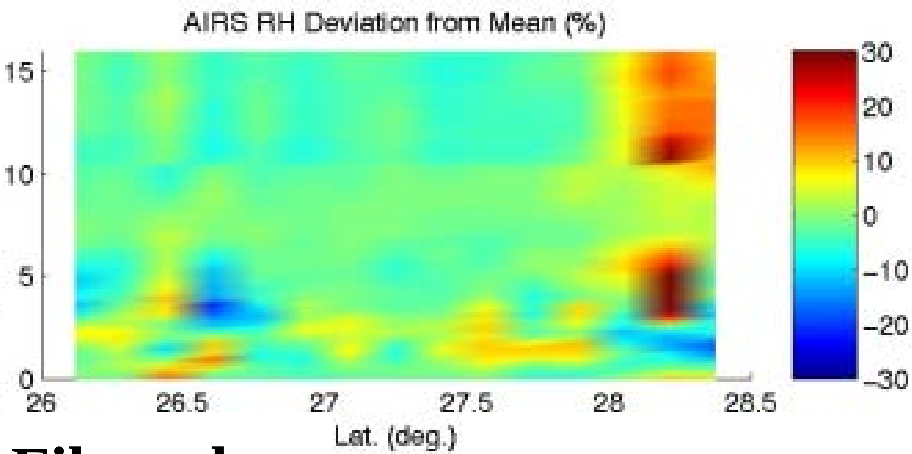
Temperature and Relative Humidity Retrieval Comparisons (Deviation from Mean)



***Note*: Retrievals based on same algorithm (Physical EOF Regression) but different line-by-line codes (The UMBC kCARTA/SARTA for AIRS and the AER LBLRTM/OSS for NAST). SARTA stands for "Stand Alone AIRS Radiative Transfer Model" and OSS stands for "Optimal Spectral Sampling".**

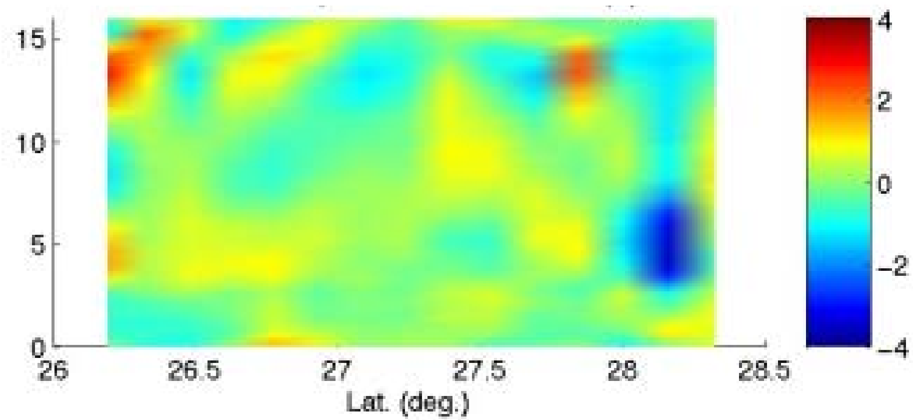
Temperature and Relative Humidity Retrieval Comparisons (Deviation from Mean)



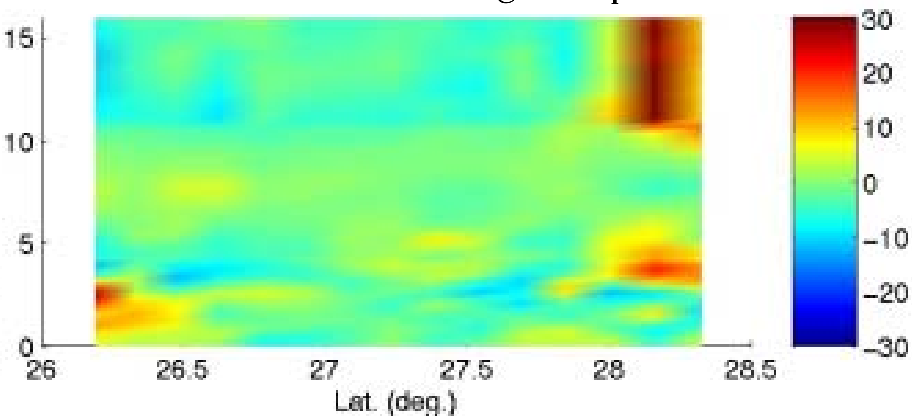


Noise Filtered

NASTI Temp Deviation from Mean @ AIRS Spatial Resolution

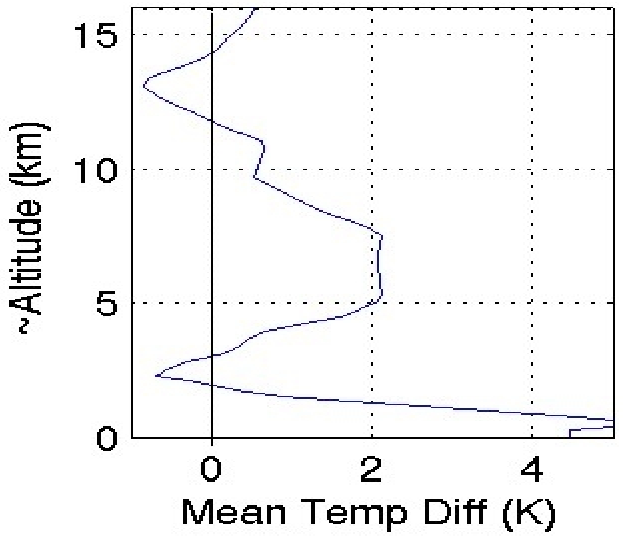


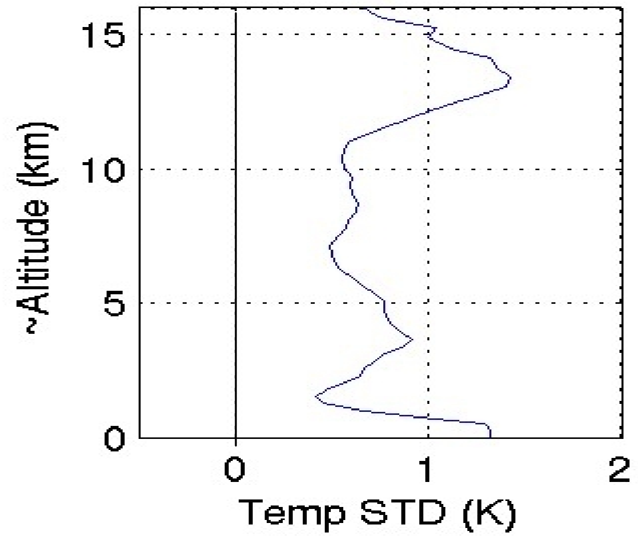
NASTI RH Deviation from Mean @ AIRS Spatial Resolution



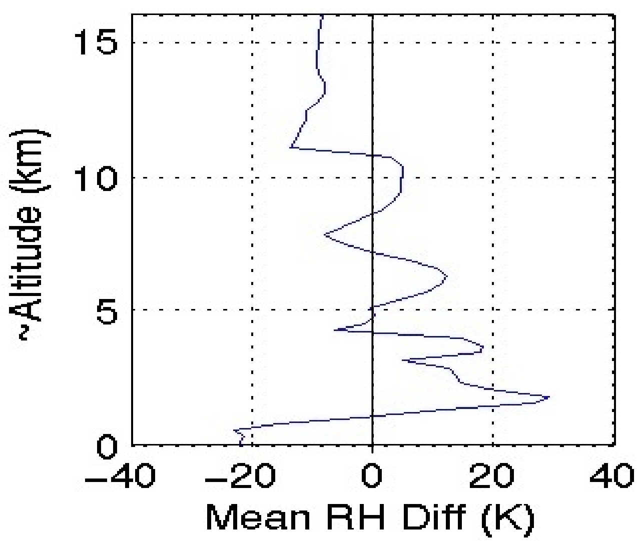
PC filter removes noise but does not change the vertical resolution

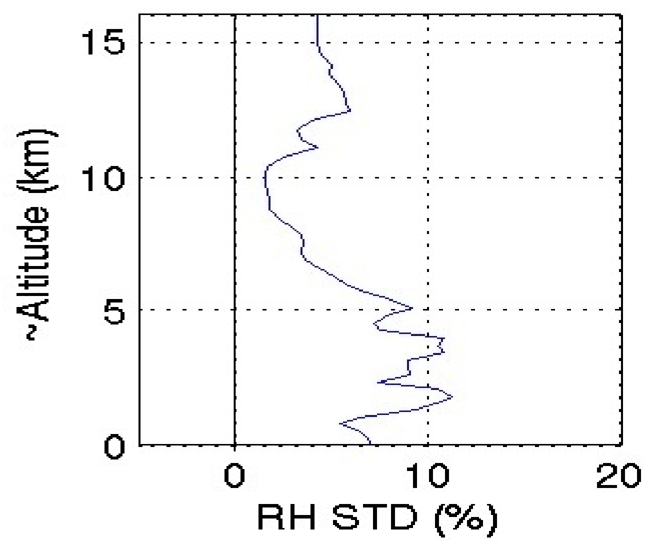
Difference: AIRS – NAST-I



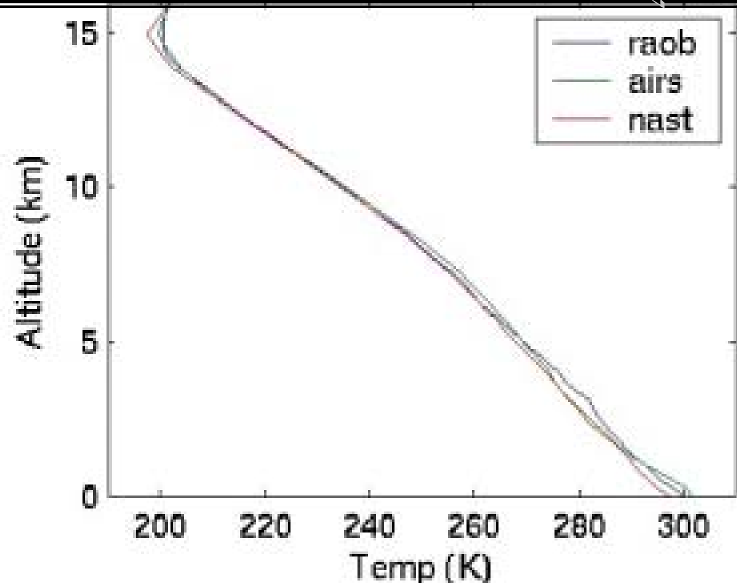


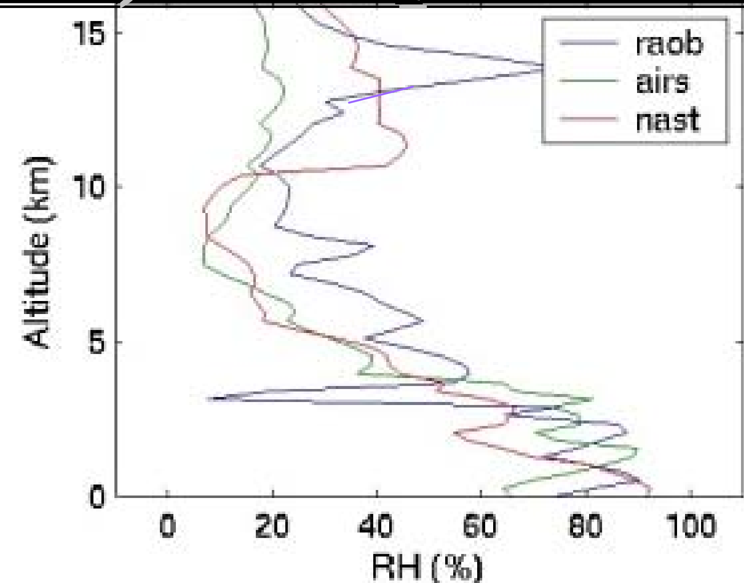
Differences Consistent with Current Retrieval and Forward Model Accuracy Expectation



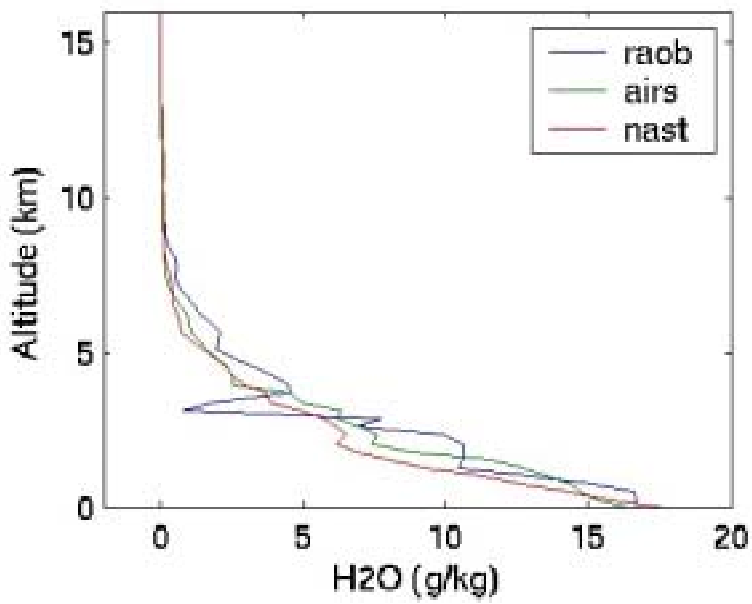


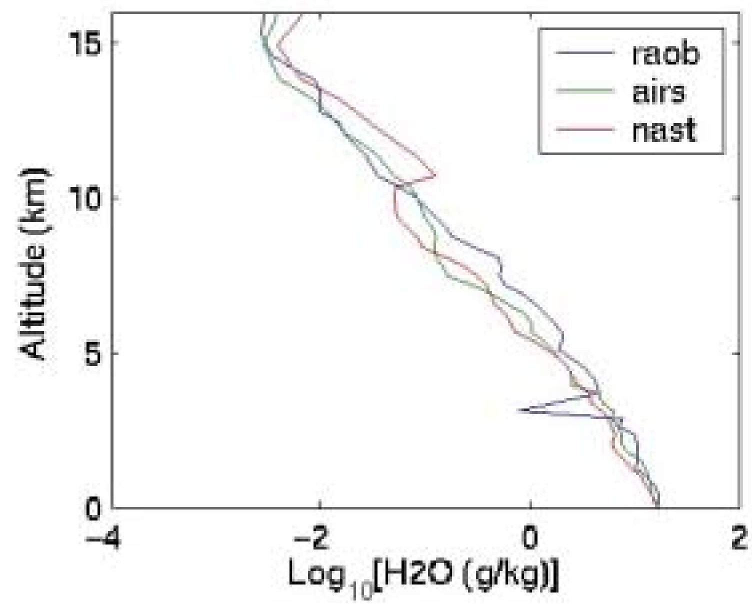
Radiosonde (Miami) Comparisons



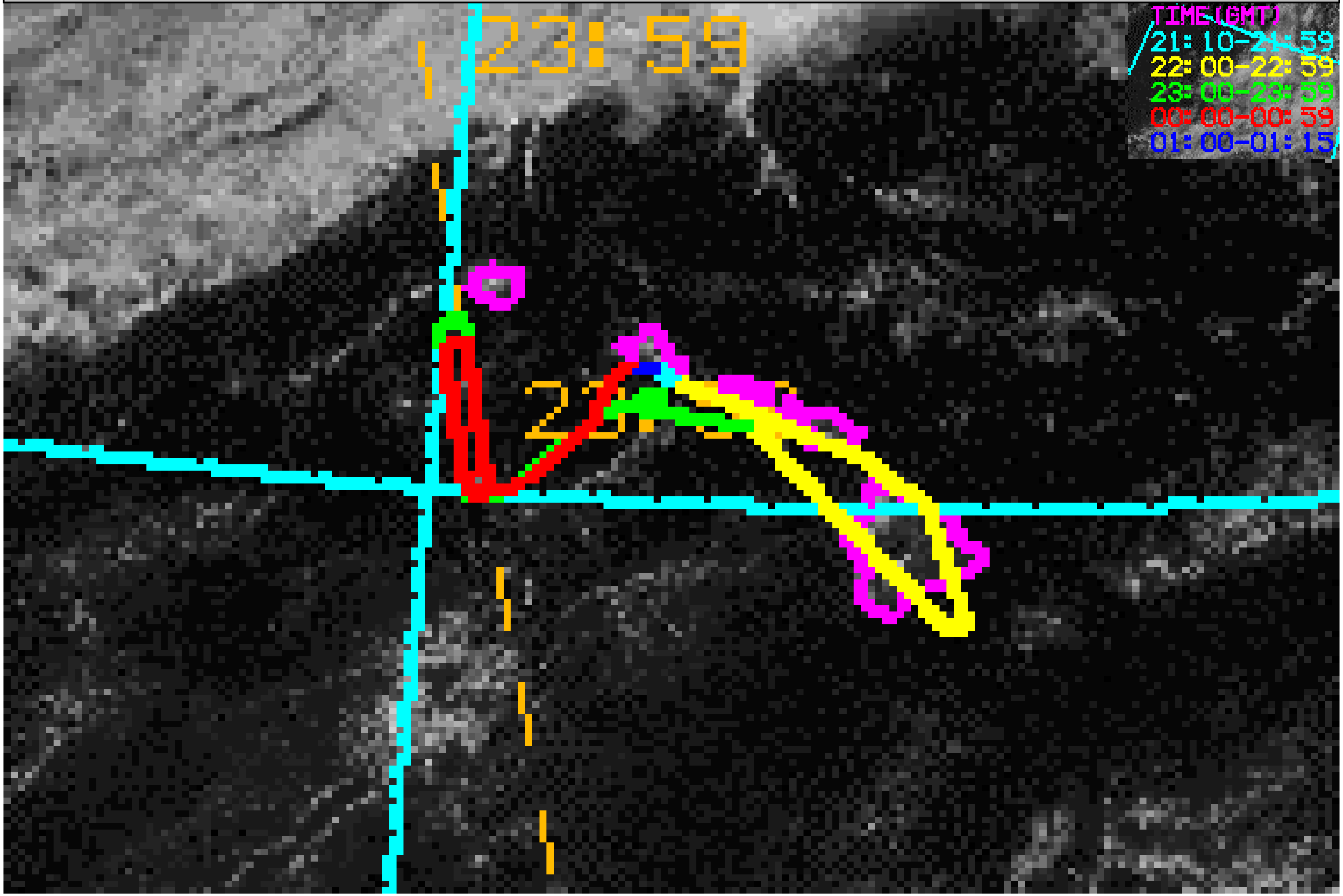


Note: Radiosonde is ~160 km South of AIRS & NAST-I Soundings

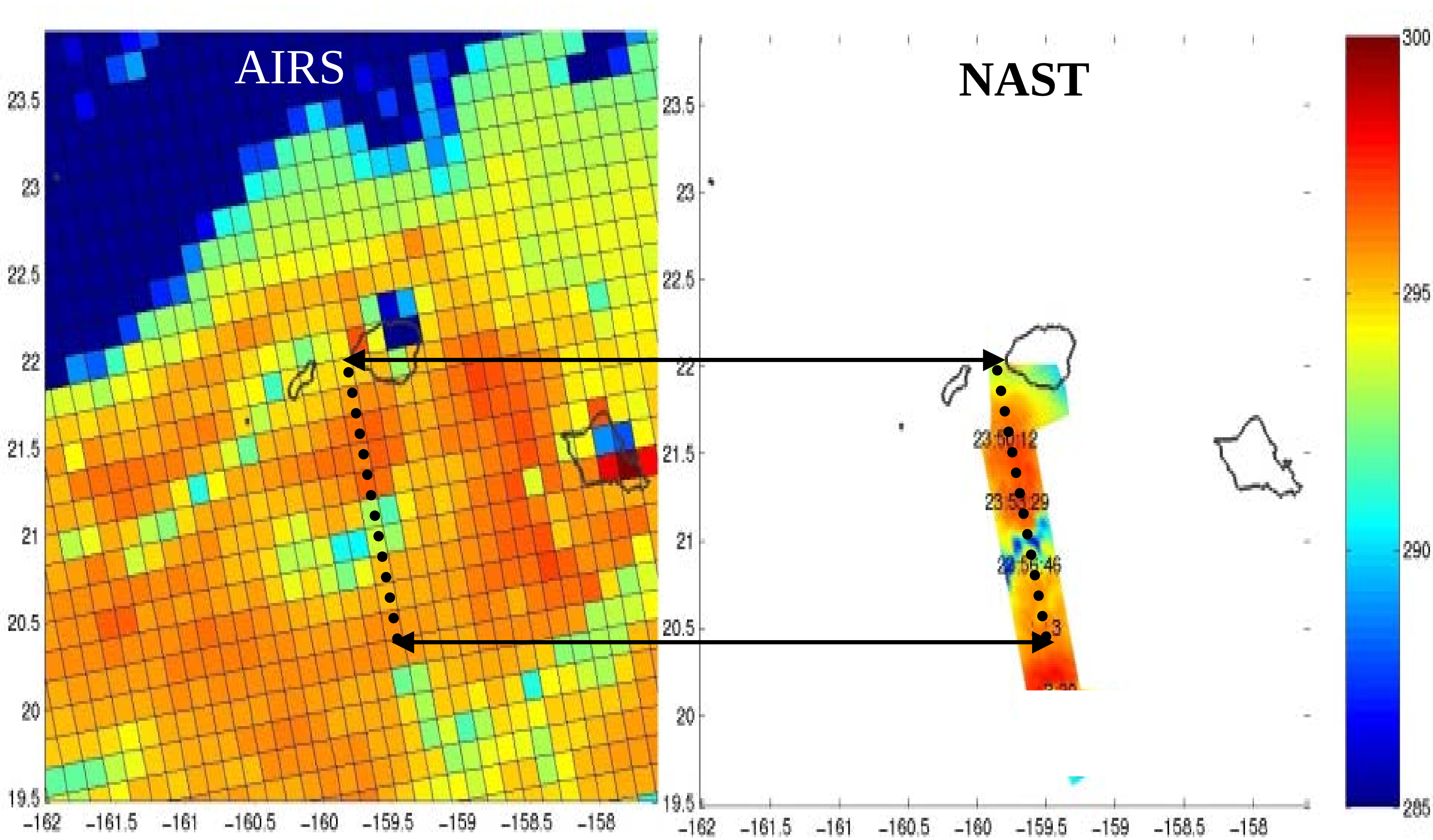




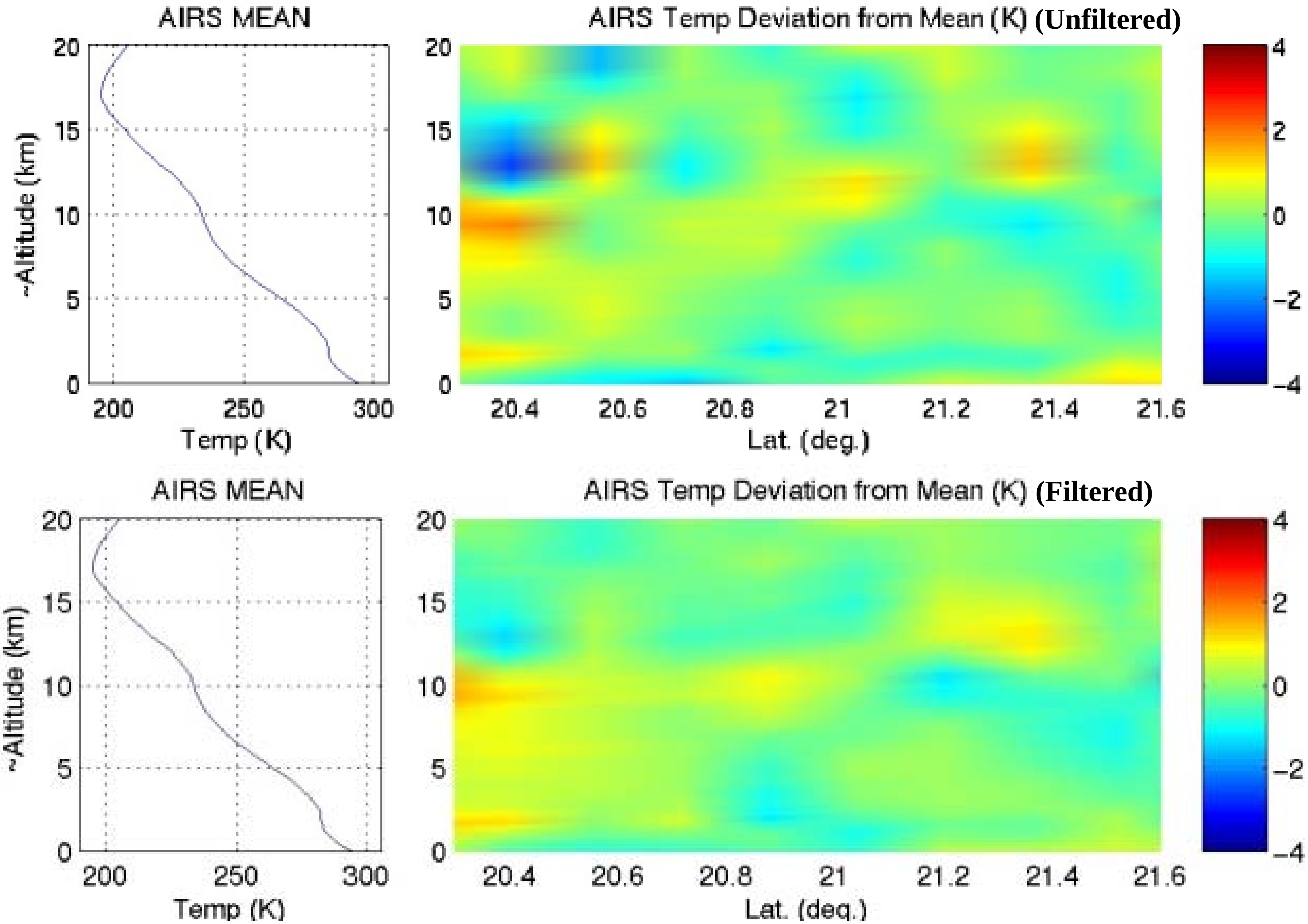
Aqua Overpass Flight (March 3, 2003)



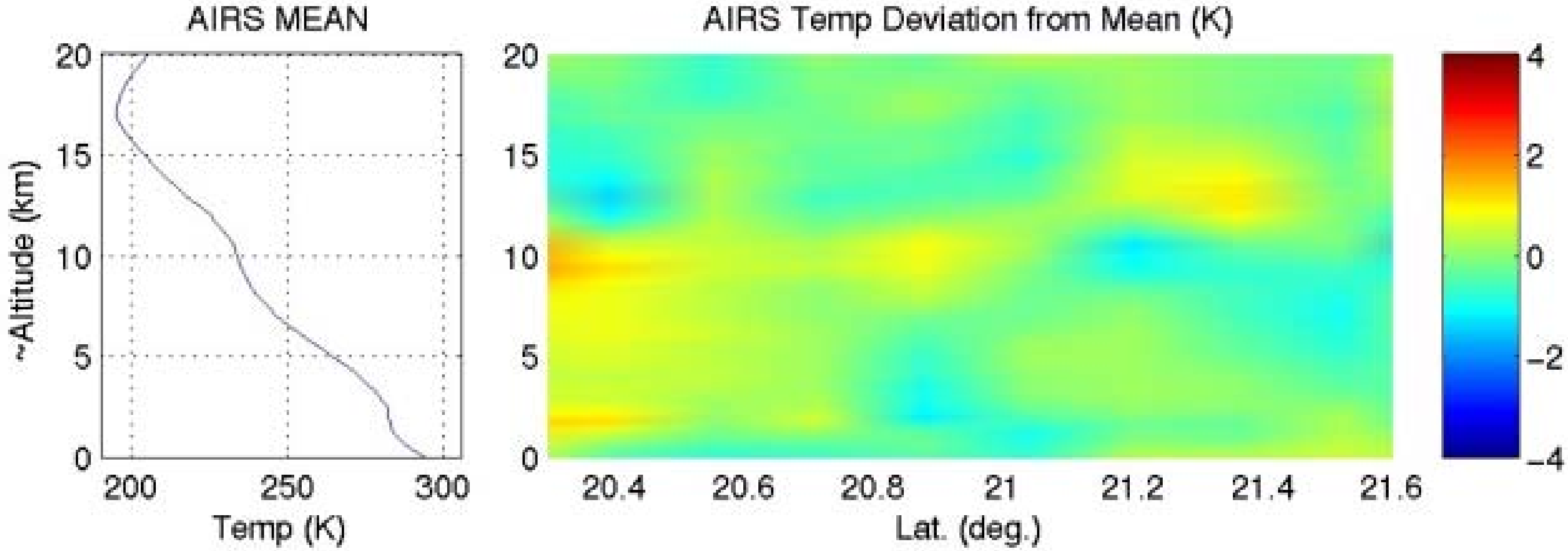
AIRS and NAST Date Used for Intercomparison



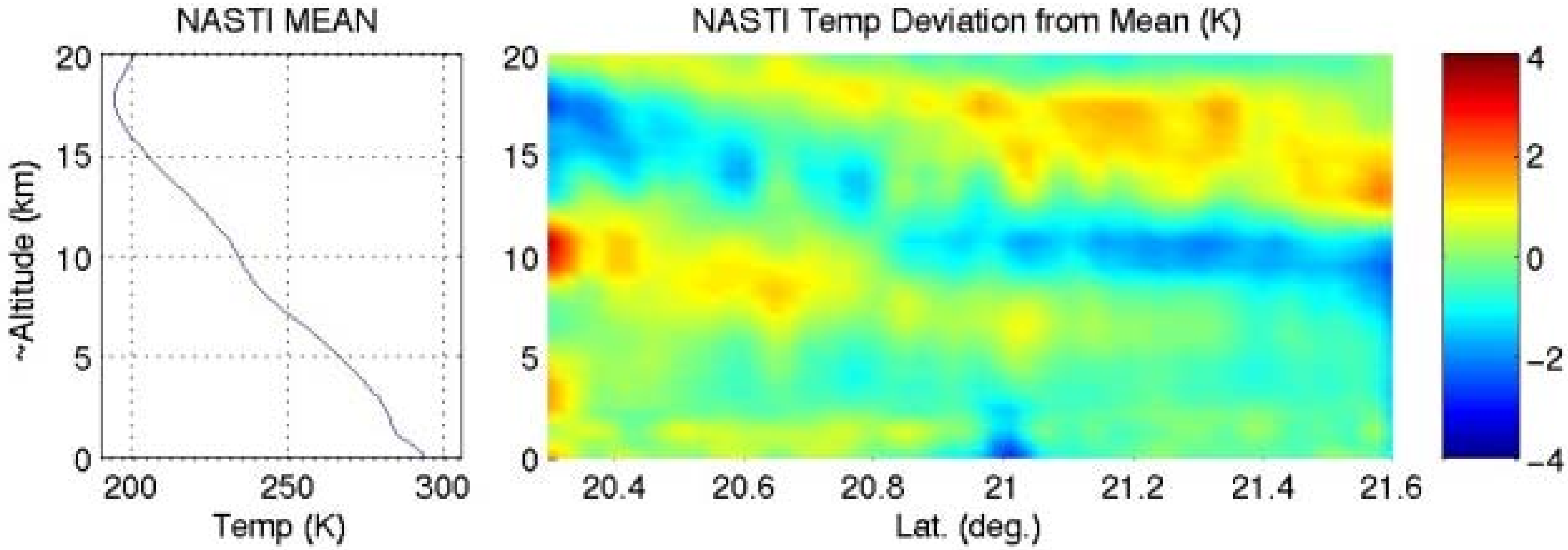
Retrieval Comparisons (PC Noise Filtering)



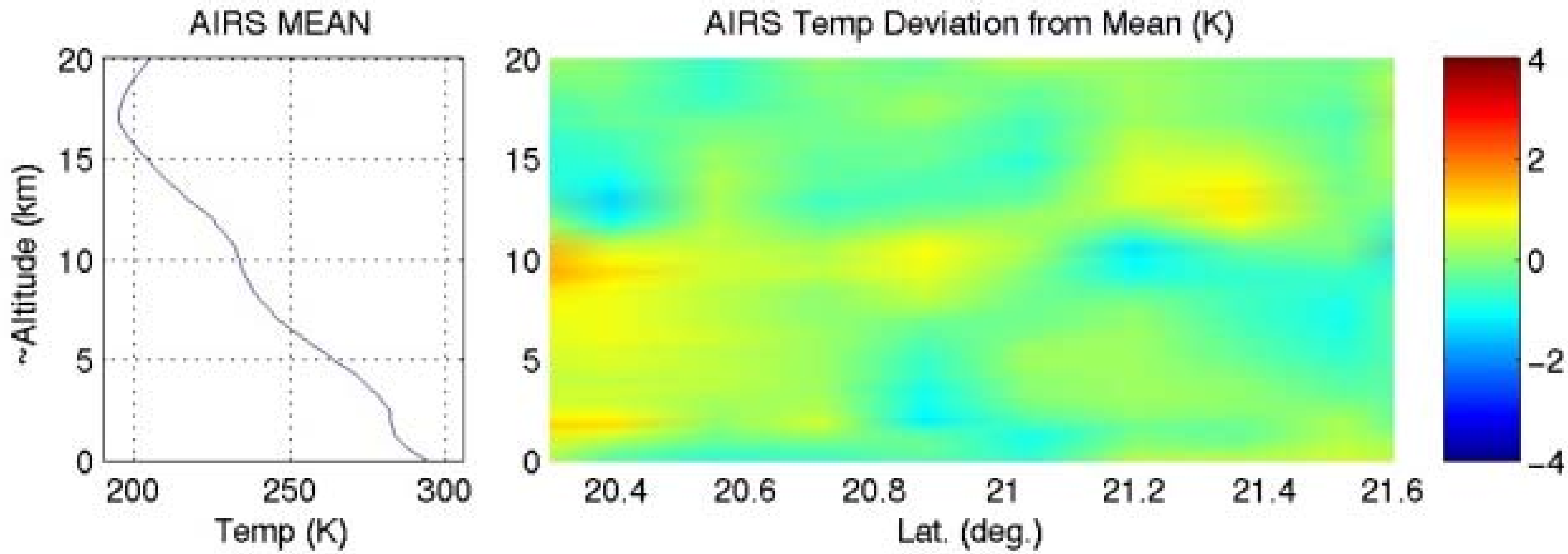
Retrieval Comparisons (Full NAST Resolution)



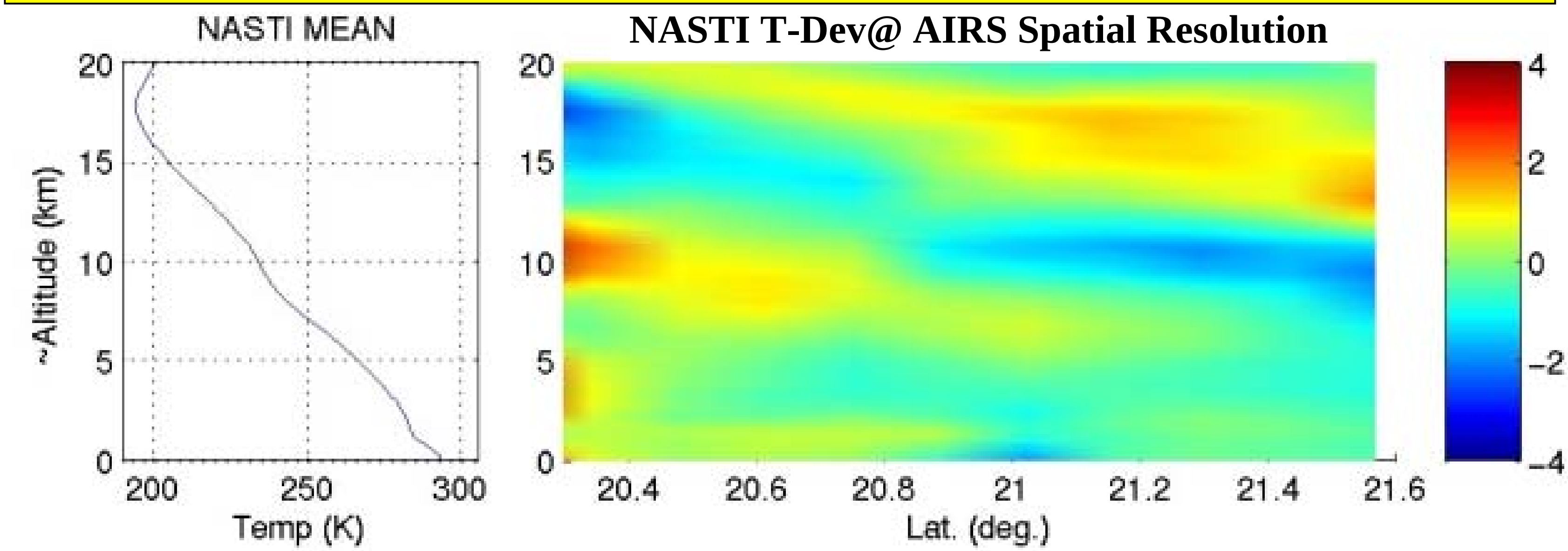
NAST Vertical Resolution Appears To Be Higher Than AIRS Resolution. Why ???



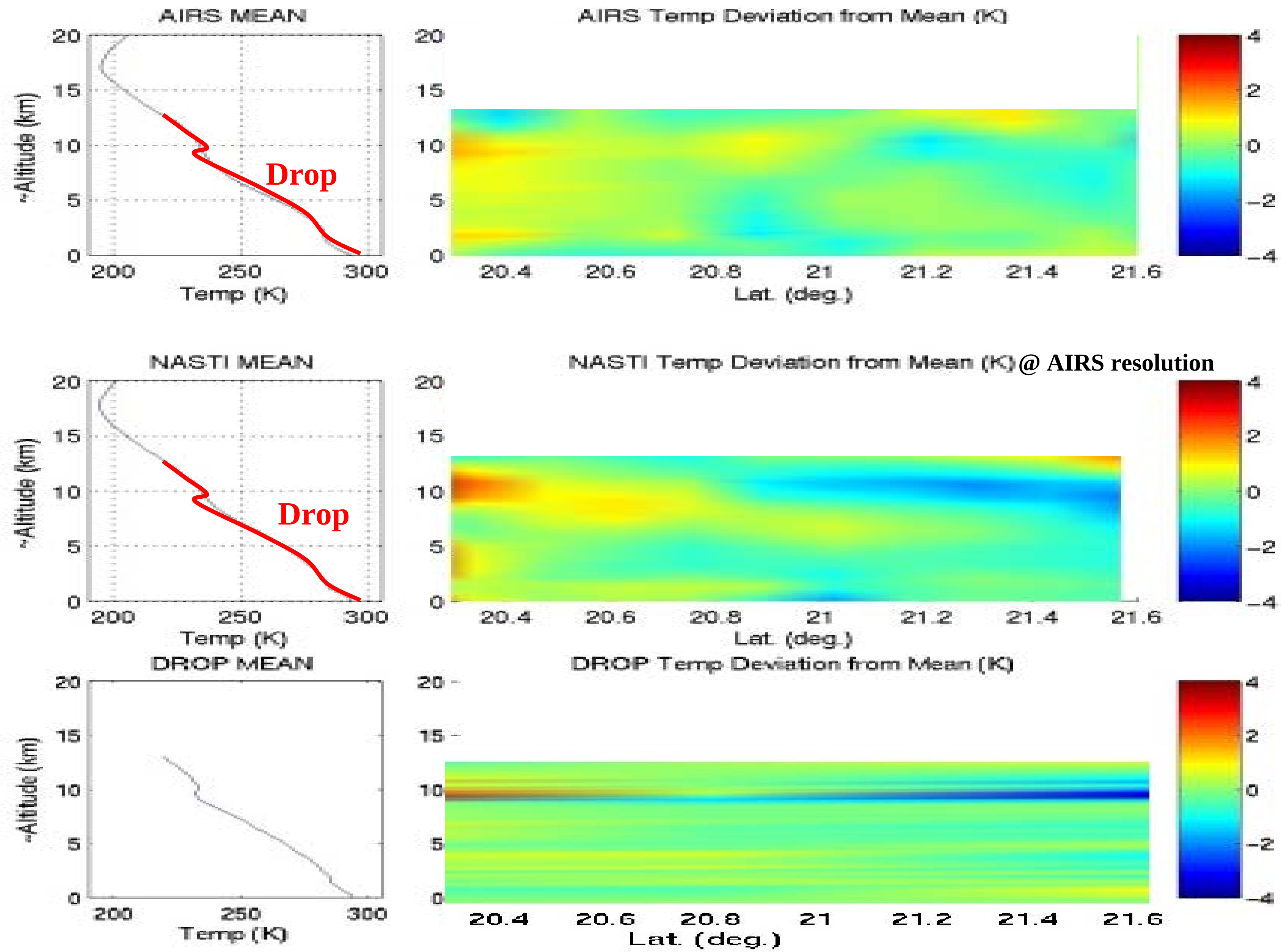
Retrieval Comparisons (NAST at AIRS Resolution)



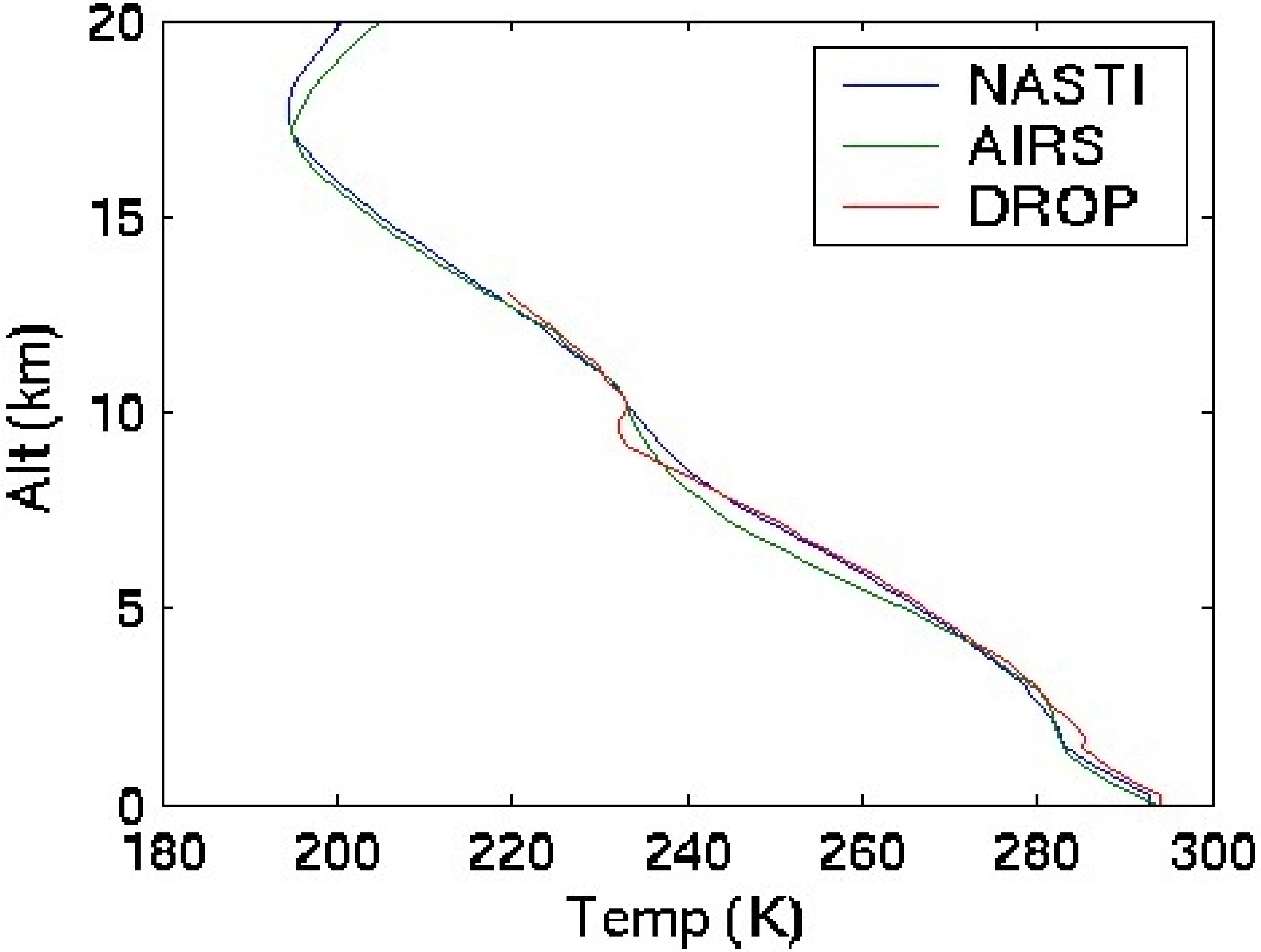
AIRS resolution appears to be higher than AIRS resolution. Noise Difference??



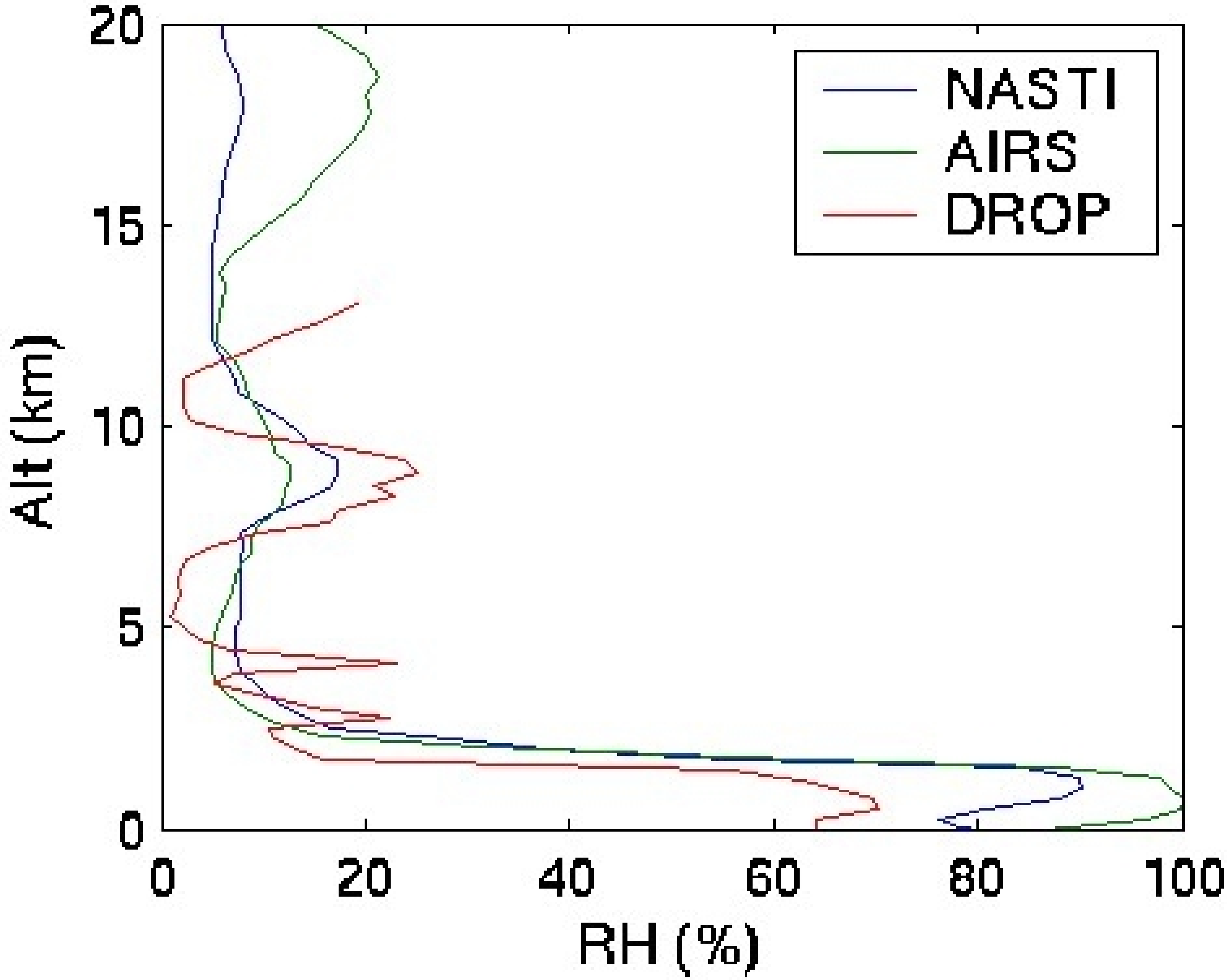
Comparisons With Dropsonde Cross-section



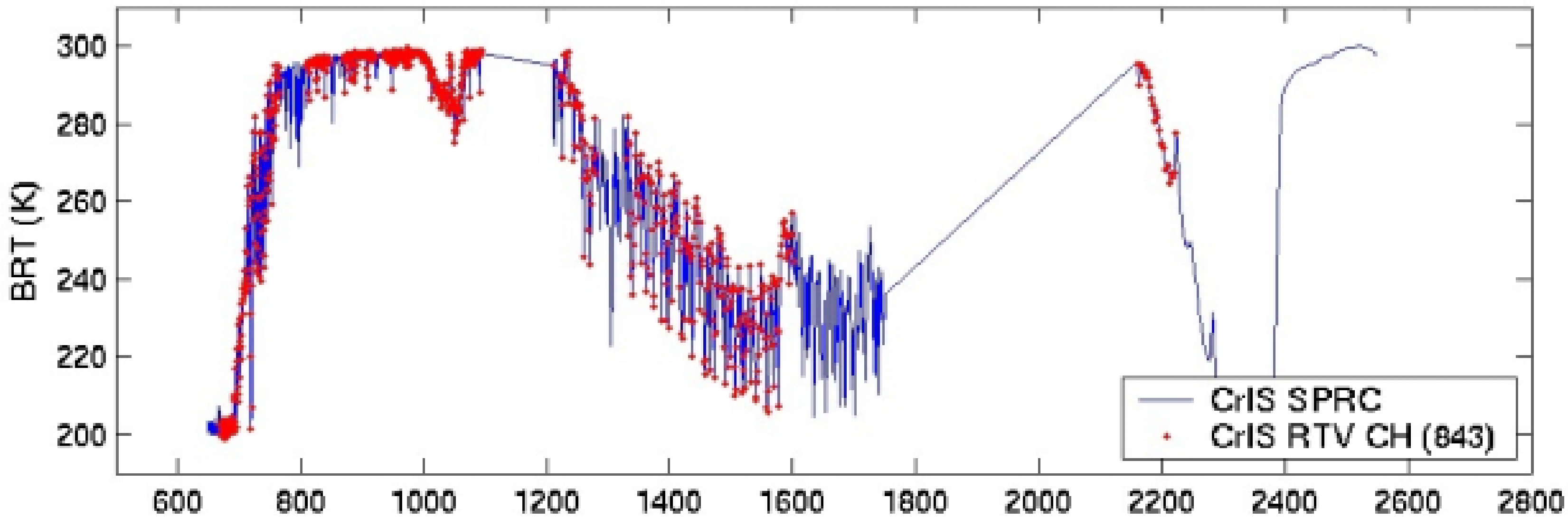
Retrieval Comparisons With Dropsonde



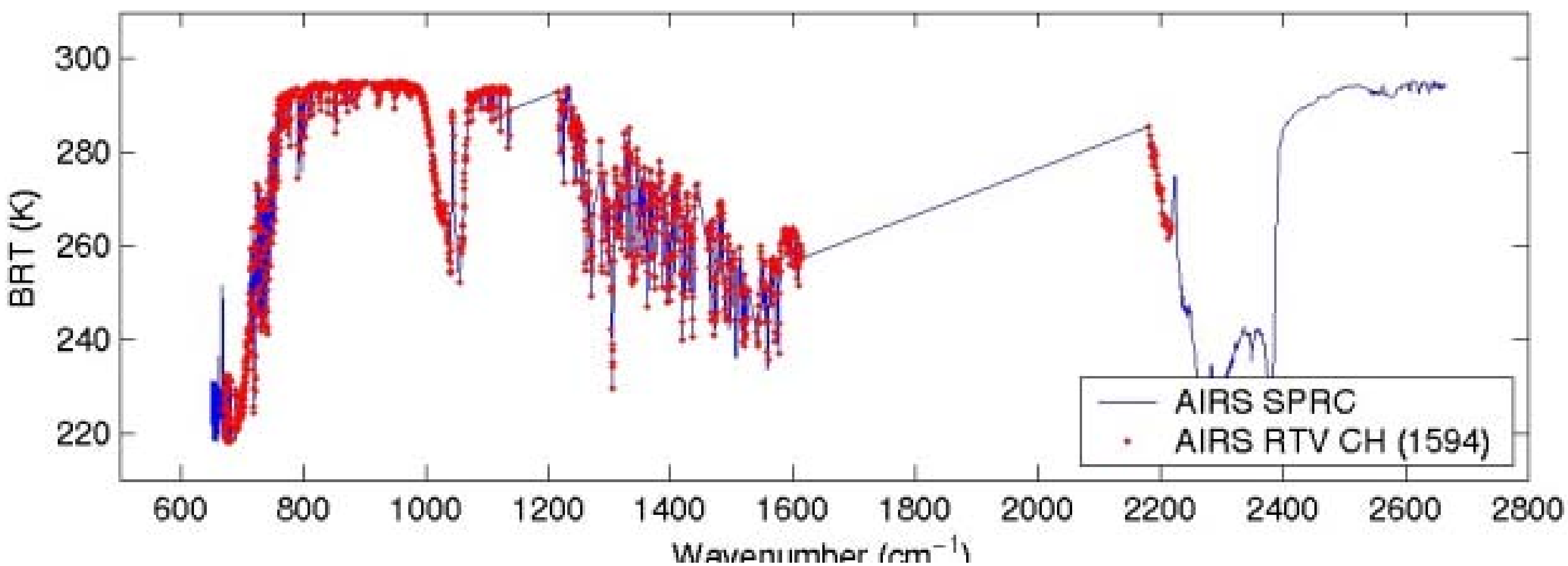
Retrieval Comparisons With Dropsonde



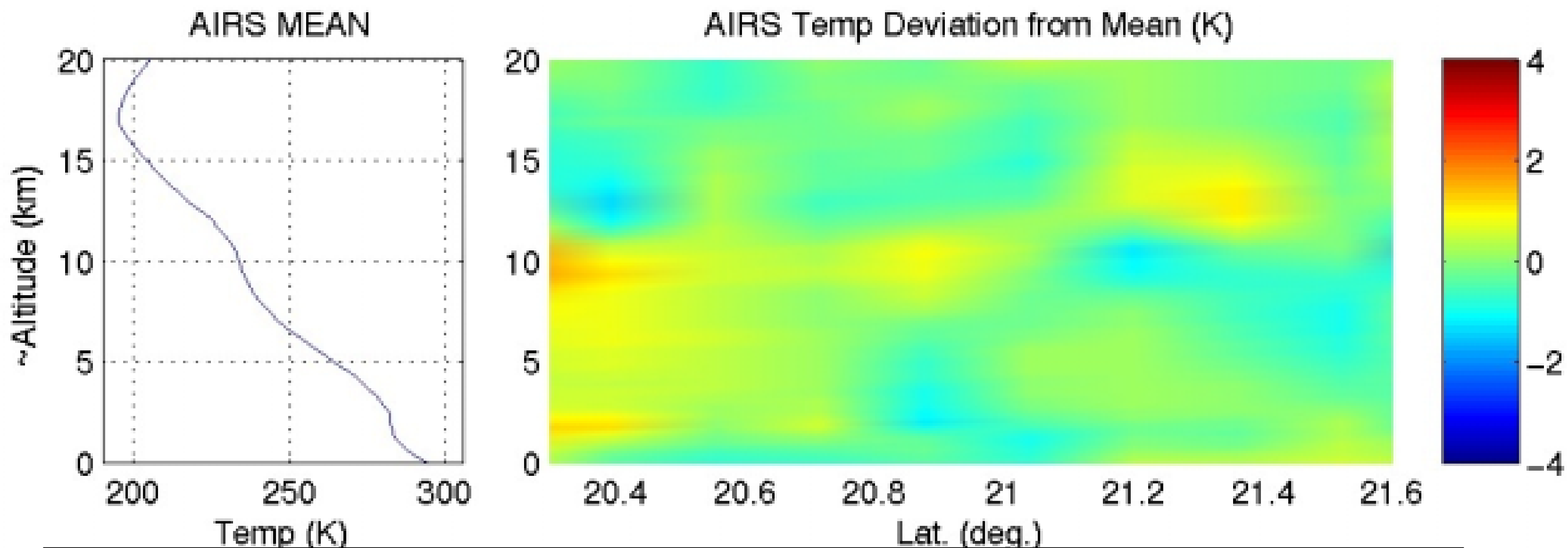
CrIS and AIRS Spectra and Retrieval Channels



CrIS and AIRS Spectral Resolution Comparable.

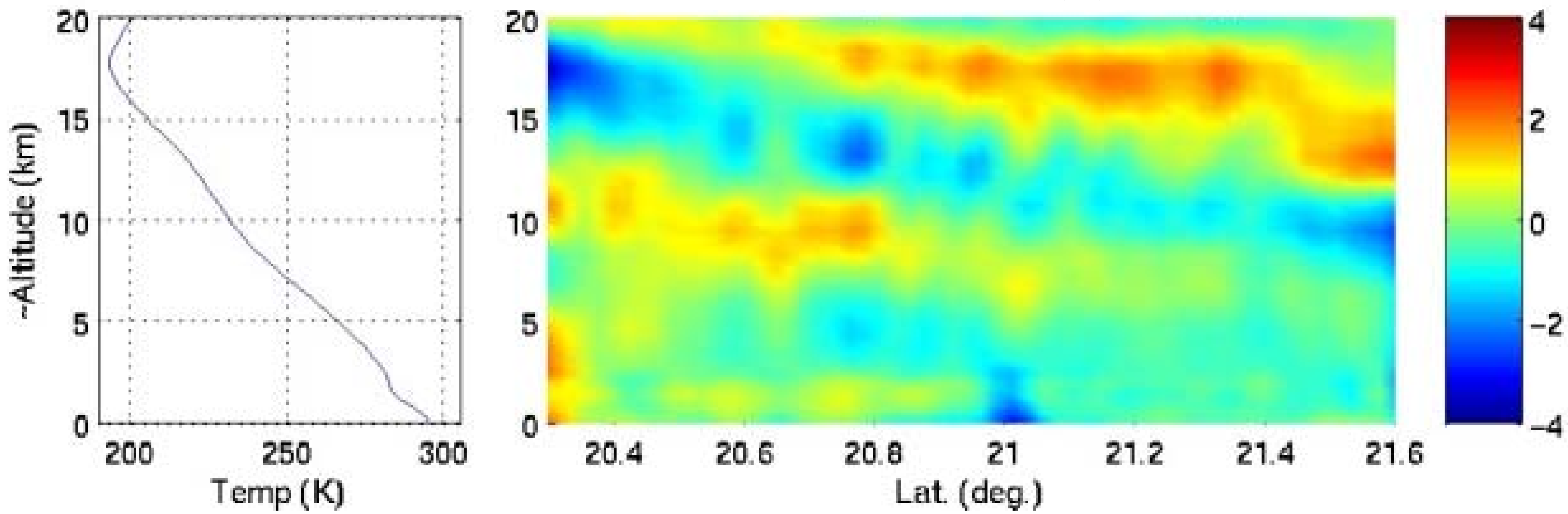


Retrieval Comparisons (Deviation from Mean)

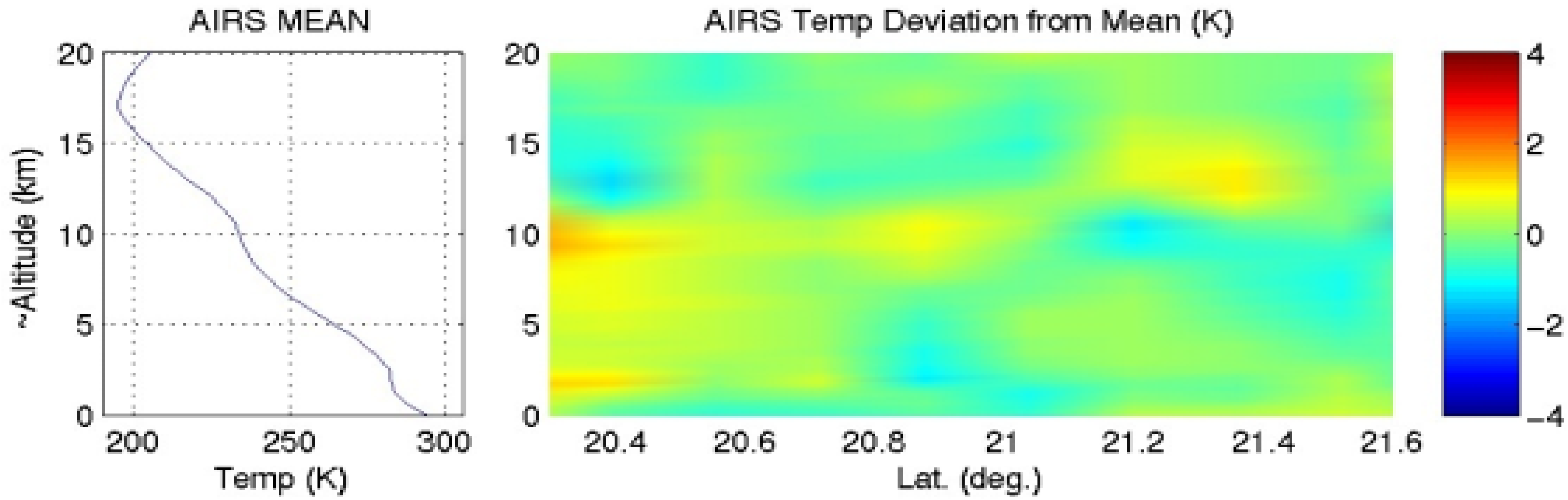


Significant difference in spatial structure of temperature structure

CrIS Mean **CrIS Deviation from Mean (K)@ NAST Resolution**

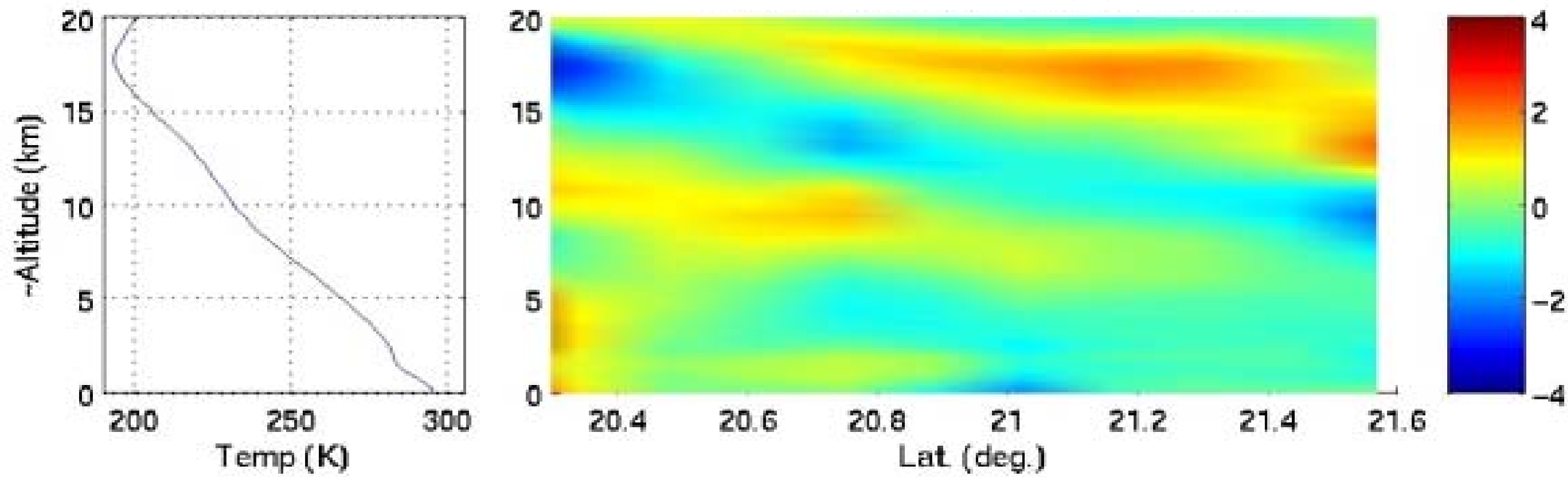


Retrieval Comparisons (Deviation from Mean)

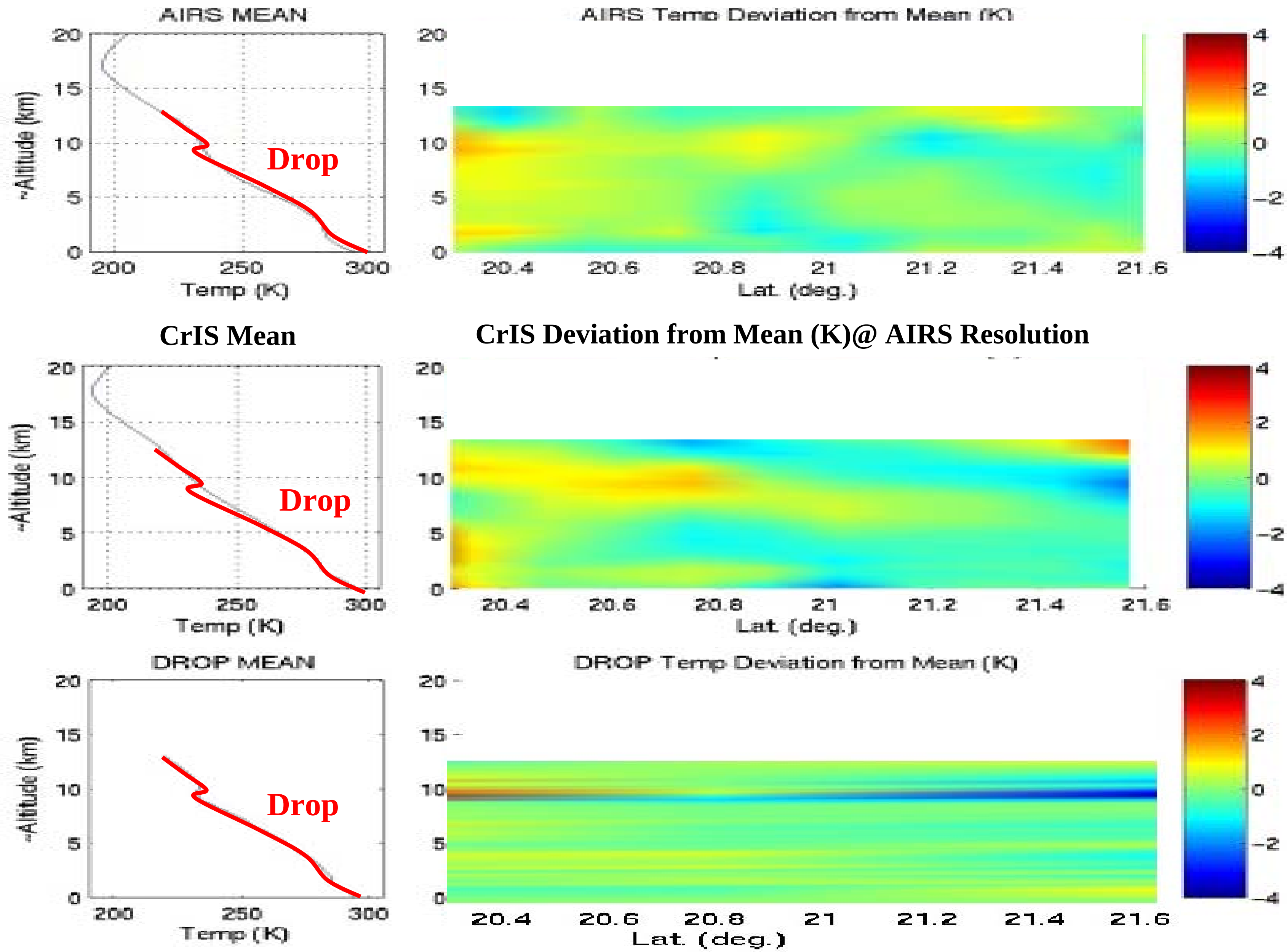


The factor of ten noise reduction from averaging of NAST to AIRS spectral and spatial resolution had little impact on vertical resolution indicating that full resolution NAST is already at a very low noise level. Why??

CrIS Mean **CrIS Deviation from Mean (K)@ AIRS Resolution**

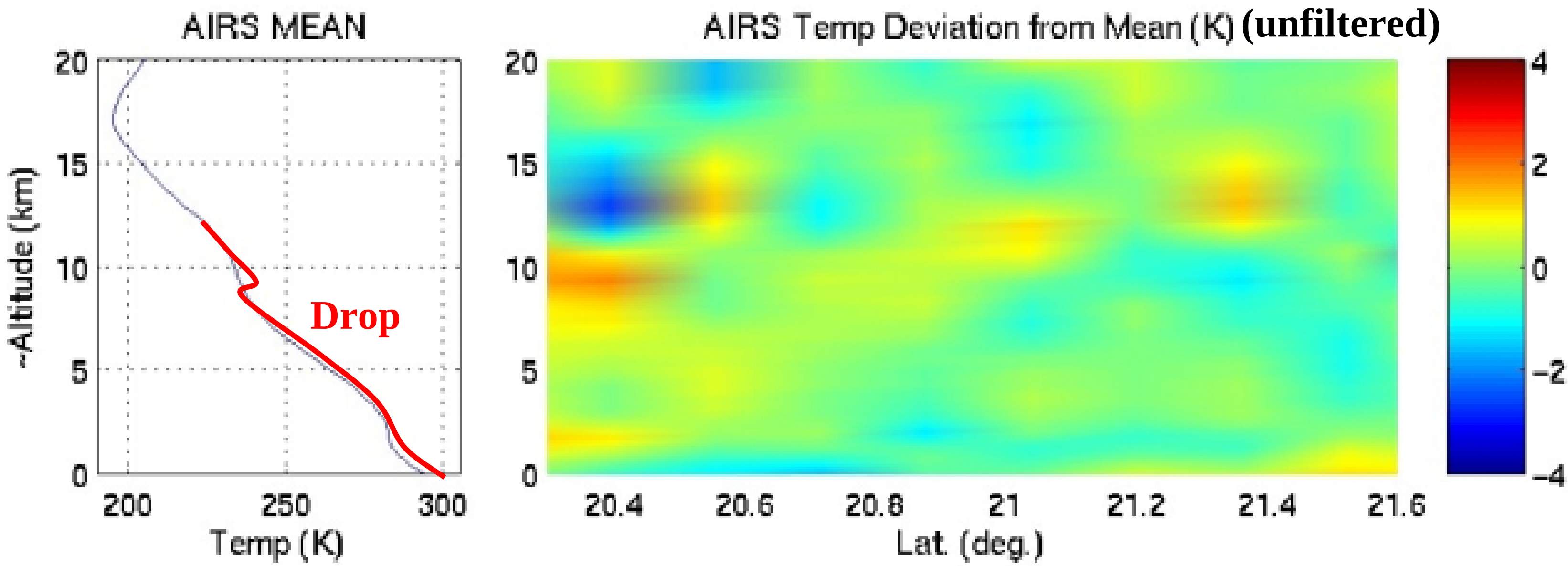


Retrieval Comparisons With Dropsonde

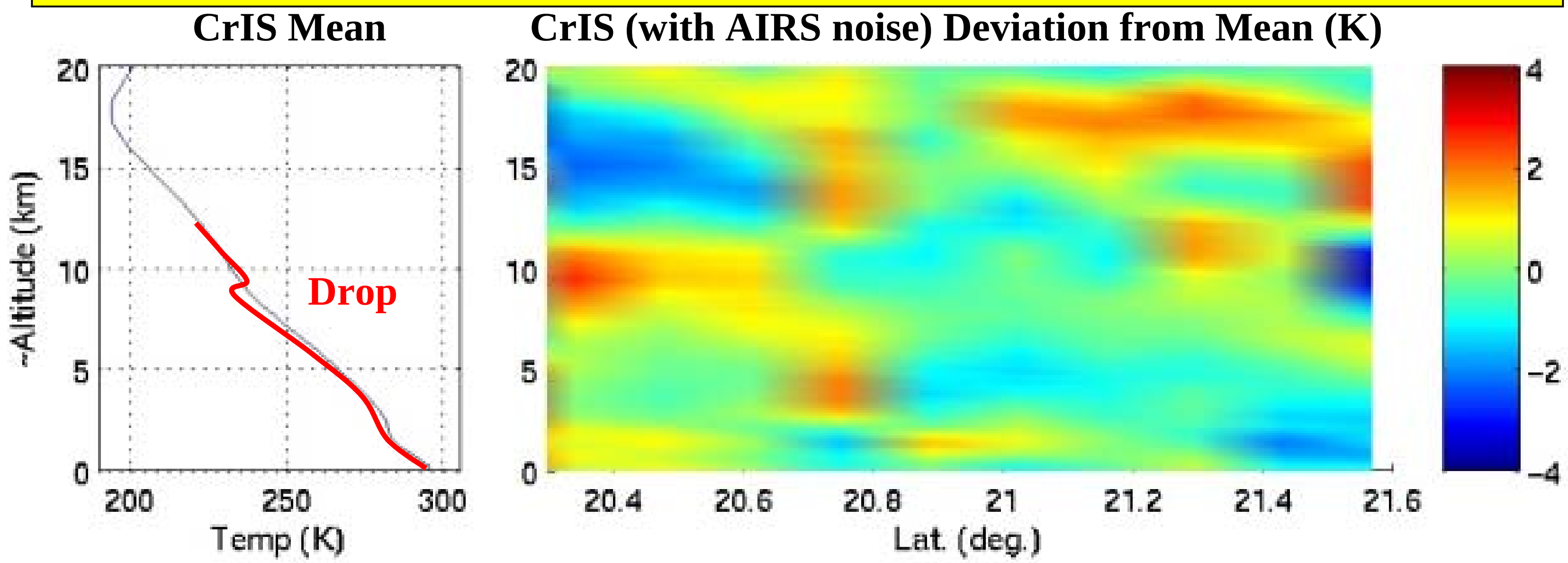


CrIS With AIRS Level Measurement Noise

(i.e., 0.6 K @650cm^{-1} to 0.2 @750 cm^{-1} to 2650 cm^{-1} @ 250K)

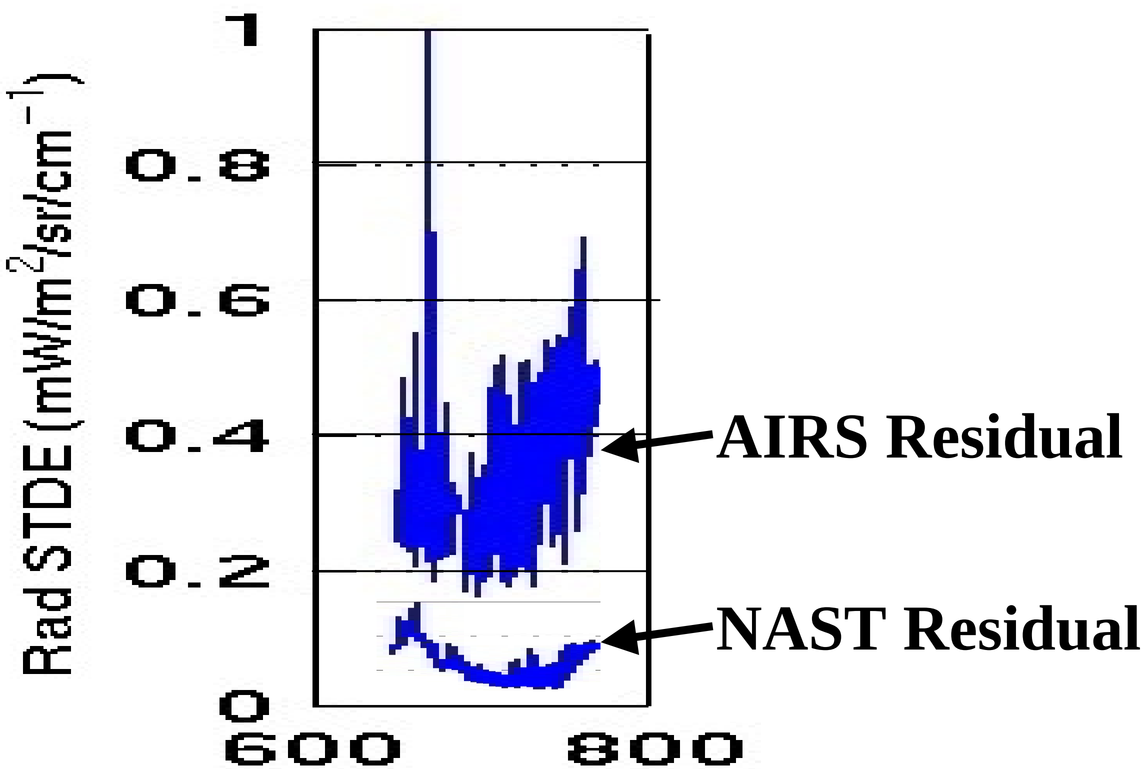


Adding AIRS noise to spatially averaged CrIS produces AIRS retrieval characteristics



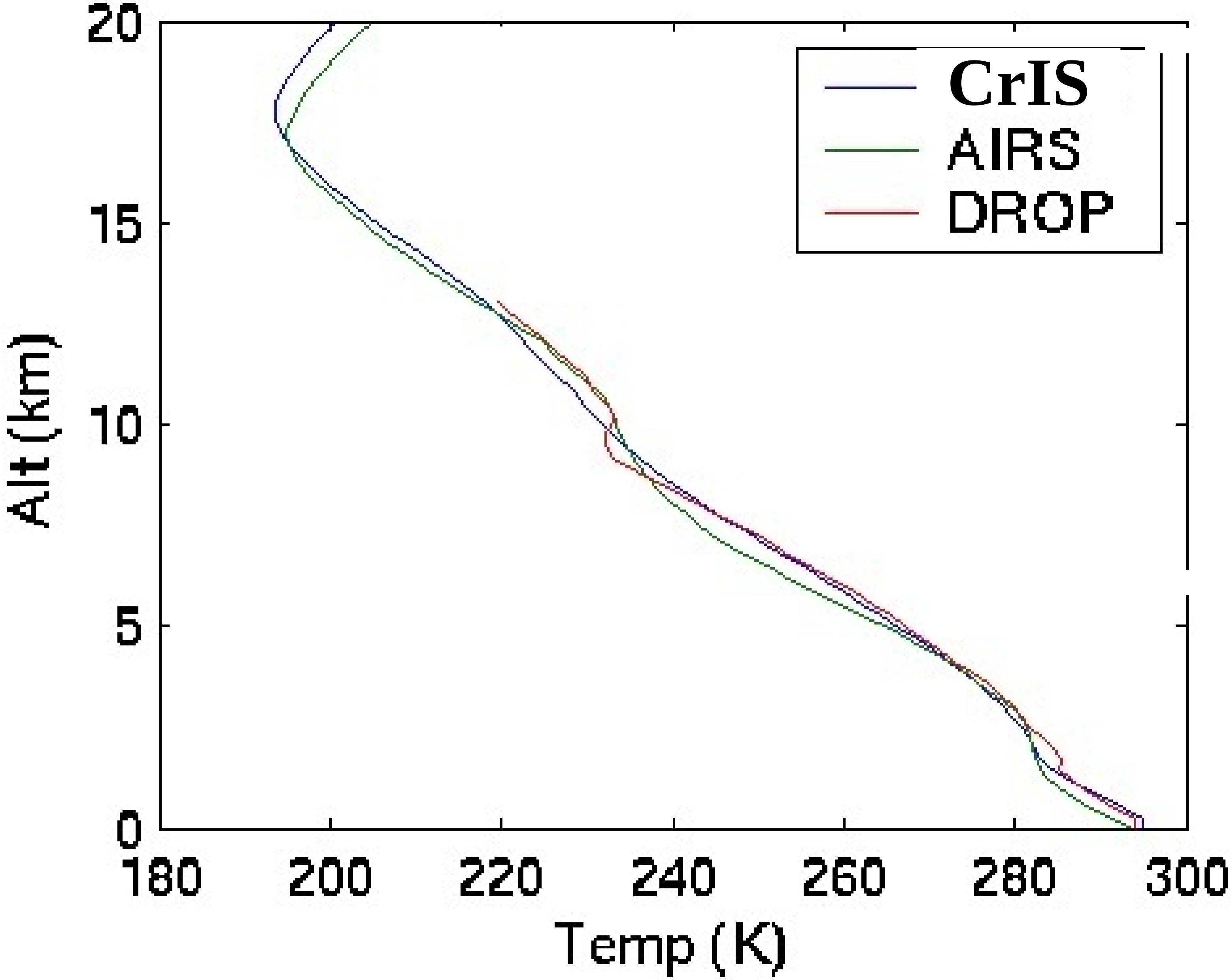
Retrieval Estimate of Noise (030303)

Standard Deviation Between Retrieval Calculated and Observed Radiance

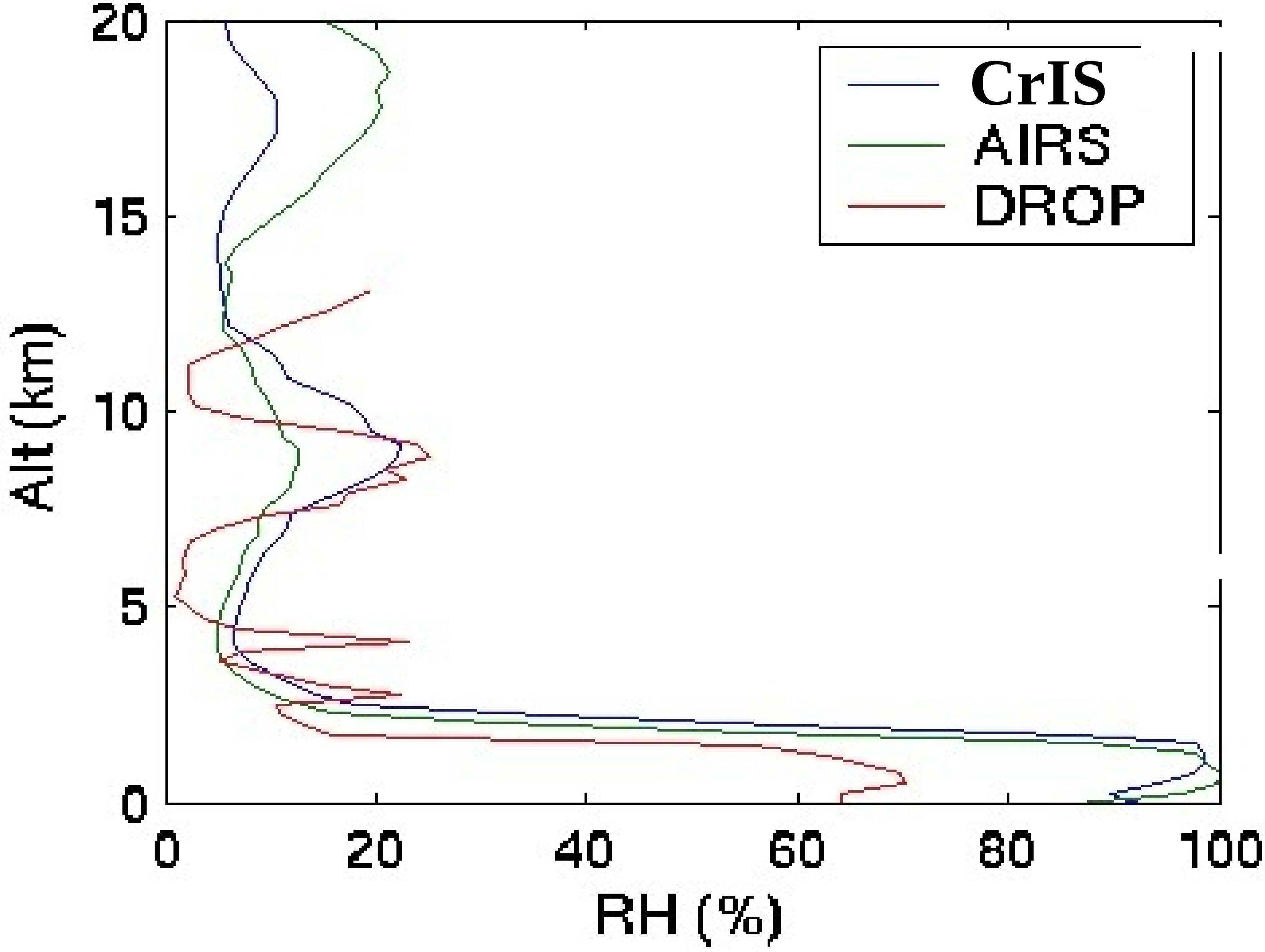


Note that in 650-750 cm^{-1} temperature profiling spectral region the apparent NAST noise level appears to be much smaller than the AIRS noise level, as shown as a residual in the retrievals

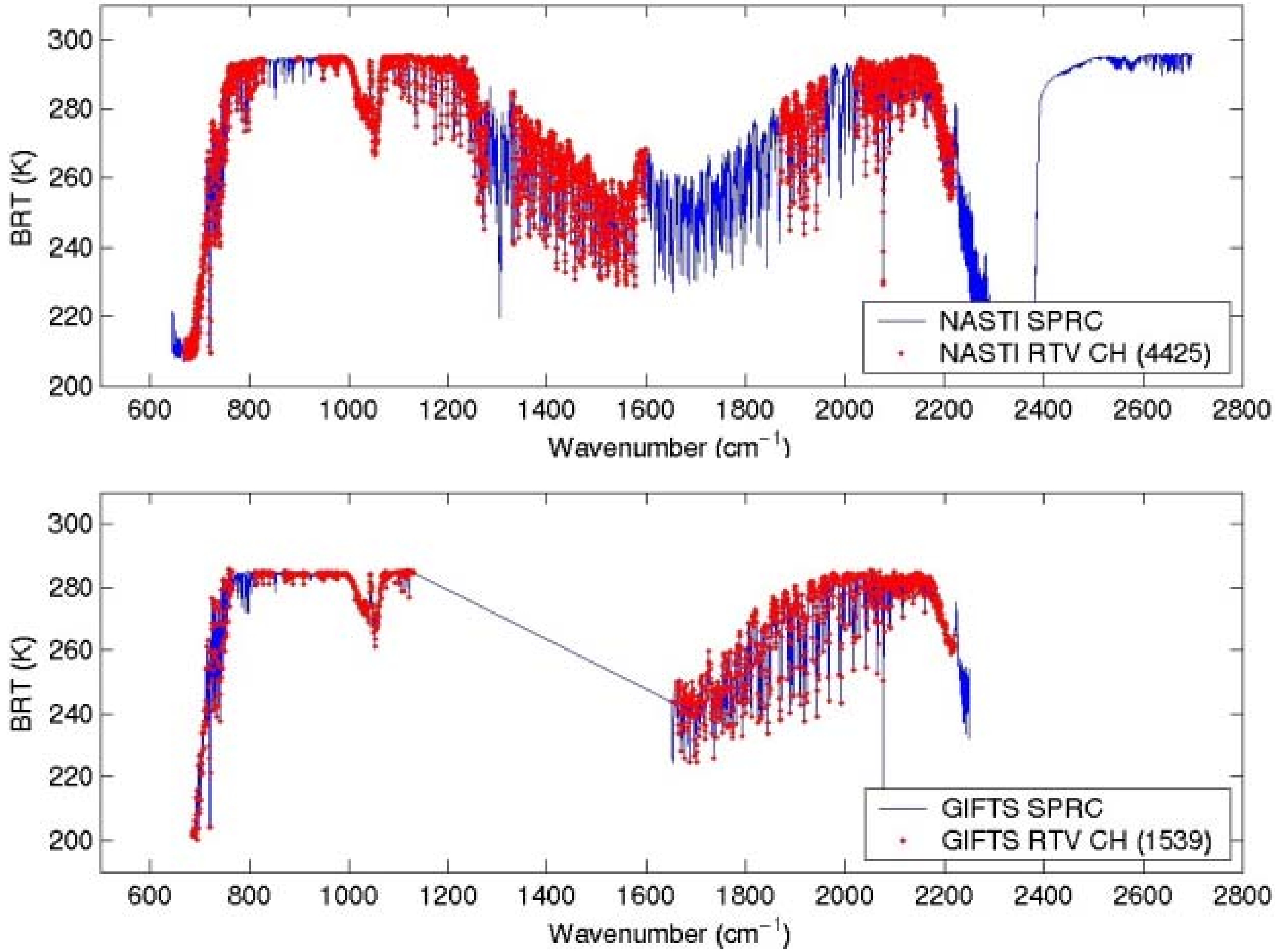
Retrieval Comparisons With Dropsonde



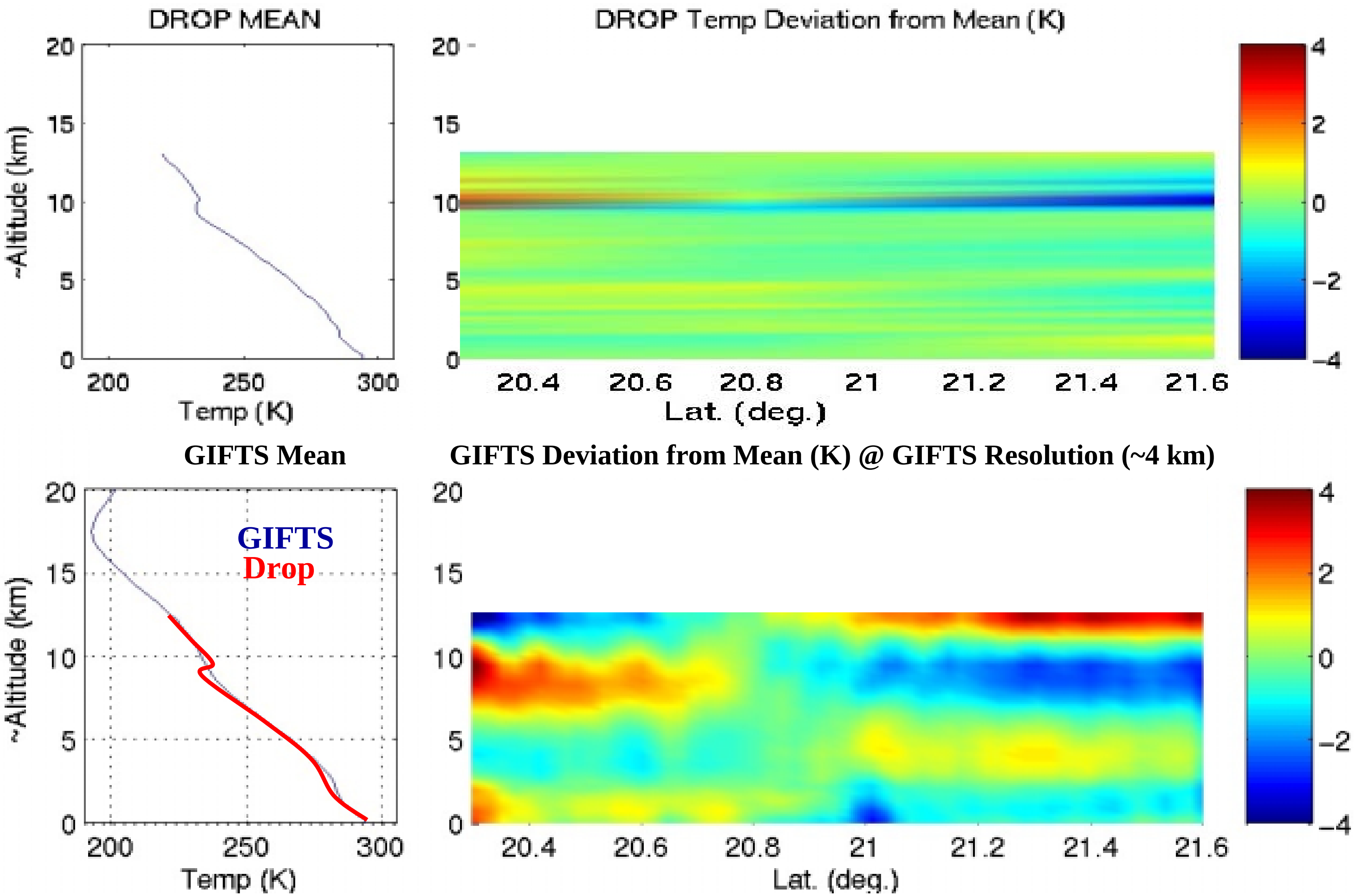
Retrieval Comparisons With Dropsonde



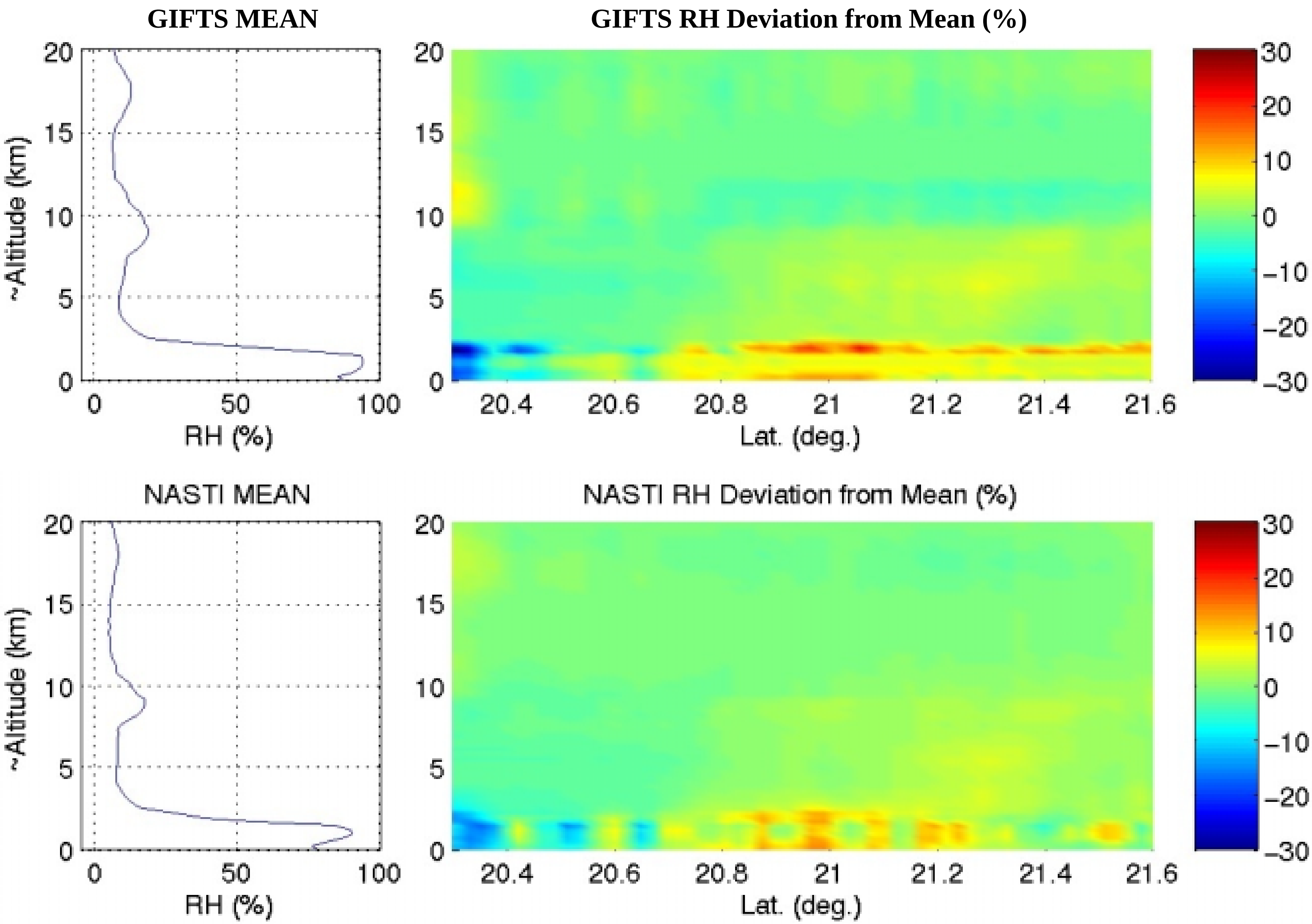
NAST and GIFTS Spectra and Retrieval Channels



Retrieval Comparisons With Dropsonde



GIFTS Sounding Capability



Summary

- **EOF Regression provides high vertical resolution soundings from high resolution radiance spectra**
- **The vertical resolutions of NAST and derived CrIS and GIFTS retrievals appear to be comparable. NAST appears to have a very low spectrally random noise level, on the scale of the absorption line spacing, since little change in vertical resolution results from spectral and spatial averaging of the data.**
- **Adding AIRS level random noise to CrIS (simulated from NAST) radiance spectra produces a vertical resolution of the retrieved profiles similar to that displayed by AIRS retrievals**
- **The high vertical resolution of the NAST appears to be due to small spectrally random noise, on the scale of the absorption line spacing, as shown by the small spatial standard deviation of the retrieval calculated radiance residuals.**

Future Priority*: *Simulate cloud radiances more properly in the training data set and train the algorithm to retrieve the true profile below a semi-transparent and/or a broken cloud cover.