Comparisons of Brightness Temperatures and Atmospheric Temperature Retrievals between ATMS and COSMIC RO

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Outline

- **Data Selection by a Quality Control (QC) Procedure**
- **Comparison of Brightness Temperatures between ATMS observations and COSMIC RO Simulations**
  - Simulation of ATMS brightness temperatures using ROs as input to Community Radiative Transfer Model (CRTM)
  - Bias characterization of reprocessed ATMS data
- **Comparison of Temperature Retrievals between ATMS and RO**
  - Temperature Retrieval Algorithm from ATMS Observations
  - Temperature differences between ATMS and RO Retrievals
- **Summary and Future Plan**

ATMS Instrument Characteristics

Channel NO.	Frequency (GHz)	NEΔT (K)	Beam Width (deg)	Peak WF (hPa)
1	23.8	0.5	5.2	Surface
2	31.4	0.6	5.2	Surface
3	50.3	0.7	2.2	Surface
4	51.76	0.5	2.2	950
5	52.8	0.5	2.2	850
6	53.596±0.115	0.5	2.2	700
7	54.4	0.5	2.2	400
8	54.94	0.5	2.2	250
9	55.5	0.5	2.2	200
10	57.29	0.75	2.2	100
11	57.29±0.217	1	2.2	50
12	57.29±0.322±0.048	1	2.2	25
13	57.29±0.322±0.022	1.25	2.2	10
14	57.29±0.322±0.010	2.2	2.2	5
15	57.29±0.322±0.0045	3.6	2.2	2
16	88.2	0.3	2.2	Surface
17	165.5	0.6	1.1	Surface
18	183.31±7.0	0.8	1.1	800
19	183.31±4.5	0.8	1.1	700
20	183.31±3.0	0.8	1.1	500
21	183.31±1.8	0.8	1.1	400
22	183.31±1.0	0.9	1.1	300

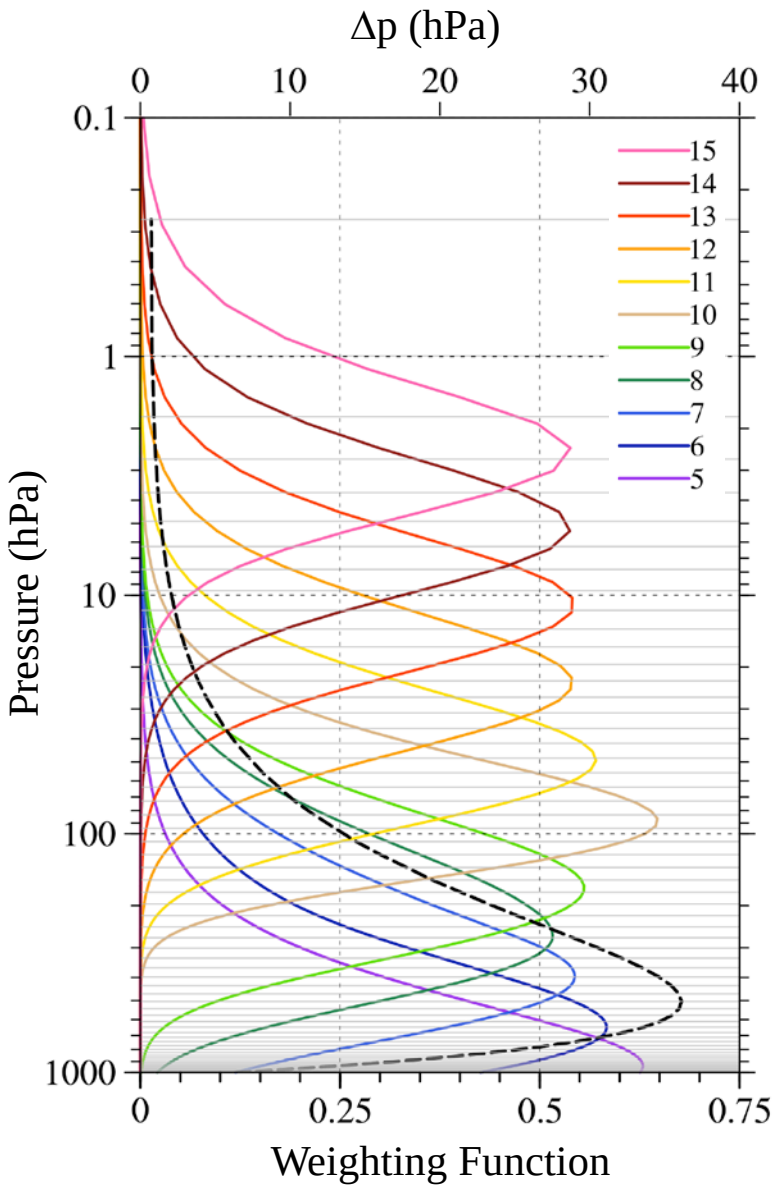
Surface sensitive channels

Temperature sounding channels

Window channels

Humidity sounding channels

ATMS Temperature Sounding Channels



ATMS temperature sounding channels 5-15 are evenly distributed in the vertical direction with their weighting functions peaking from 850 to 2 hPa.

ATMS temperature sounding channels 5-15 are similar to AMSU-A channels 4-14. In other words, we have 19 years of such satellite microwave observations from 1998 till now.

Selection of COSMIC ROs by a Three-Step QC (1/4)

A four steps quality control (QC) procedure for data selection:

Step 1: A Range Check

- RO profiles cover the layer 50-800 hPa
- T (unit: K) and N (unit: N unit) are positive

Step 2: Observation outliers are eliminated

- Observation with a z-score greater than 2.5

Step 3: Simulation outliers are eliminated

- Simulation with a z-score greater than 3.5

Step 4: O-B^{ECMWF} outliers are eliminated

- O-B with a z-score greater than 2.5

Given a sample $\{X_i, i=1, 2, \ldots, n\}$,

Biweight Mean:

$$BM(X_i) = M + \frac{\sum_{i=1}^{n}\left(1-w_i^2\right)^2\left(X_i - M\right)}{\sum_{i=1}^{n}\left(1-w_i^2\right)^2}$$

Biweight STD:

$$BSD(X_i) = \frac{\left(n\sum_{i=1}^{n}\left(1-w_i^2\right)^4\left(X_i - M\right)2\right)^{1/2}}{\left|\sum_{i=1}^{n}\left(1-w_i^2\right)\left(1-5w_i^2\right)\right|}$$

Z-score:

$$Z_i = \frac{X_i - BM(X_i)}{BSD}$$

M — Median

MAD — Median absolute deviation

$w_i = \frac{X_i - M}{7.5 \times MAD}$ — Weighting coefficient

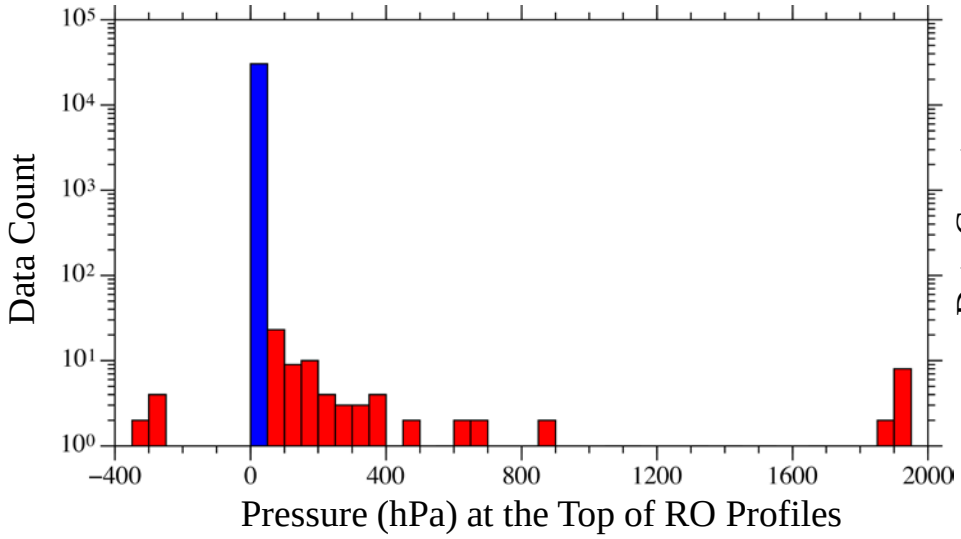
Some details of the above quality control (QC) can be found in the following article:

Zou, X. and Z. Zeng, 2006: A quality control procedure for GPS RO data. *J. Geoph. Res.*, **111**, D02112, doi:10.1029/2005JD005846.

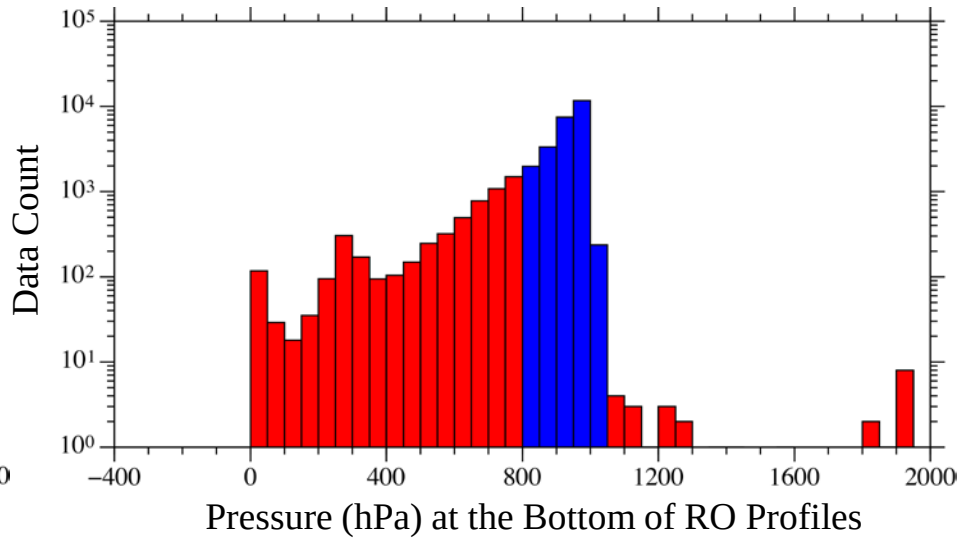
QC Step 1 — Range Check

COSMIC RO Data in January 2012 as an Example

RO Profile Top



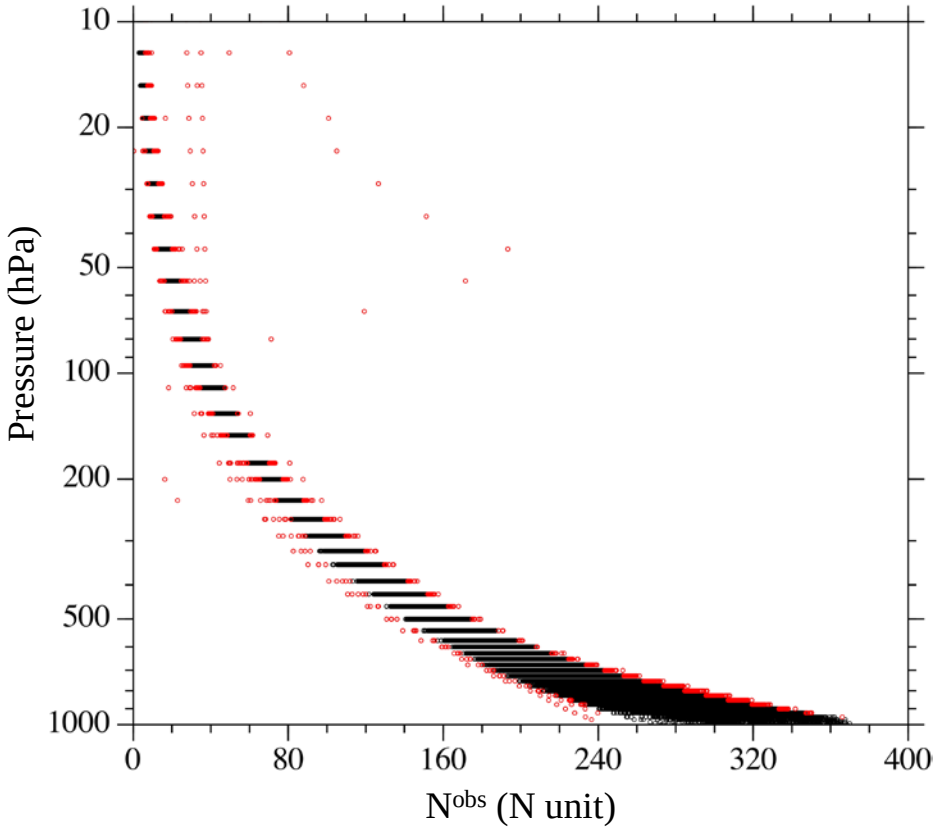
RO Profile Bottom



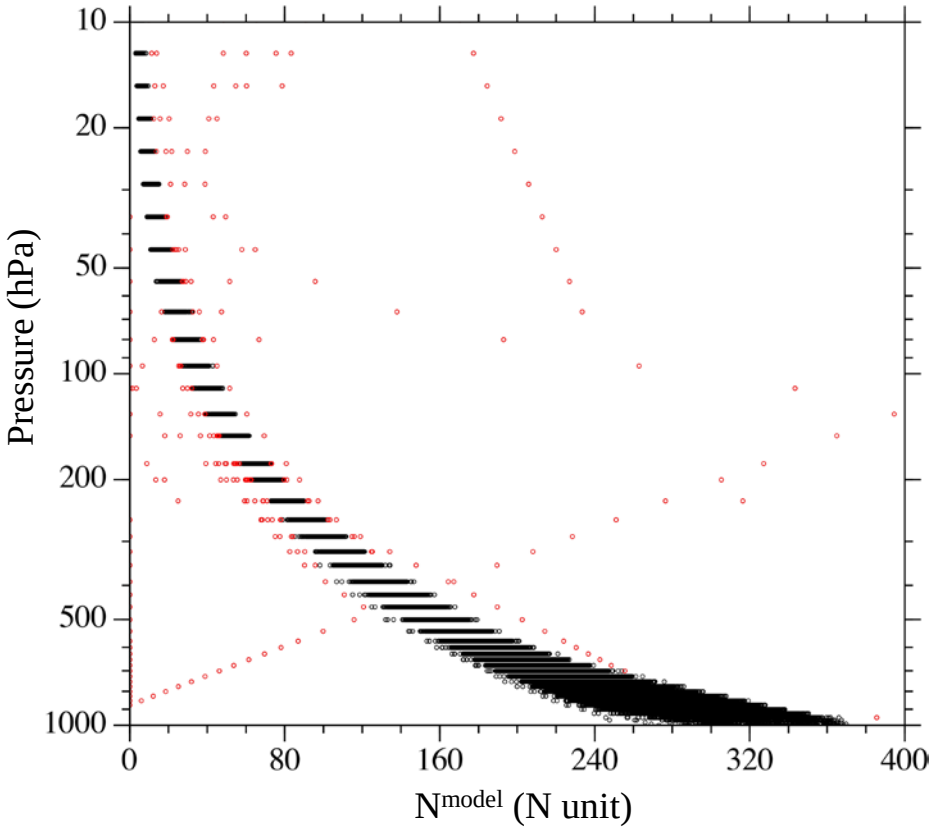
- The top of all selected RO profiles is above 50 hPa
- The bottom of all selected ROs reaches below 800 hPa

QC Steps 2 and 3 — Removing Outliers

QC Step 2 (Observation Outliers)

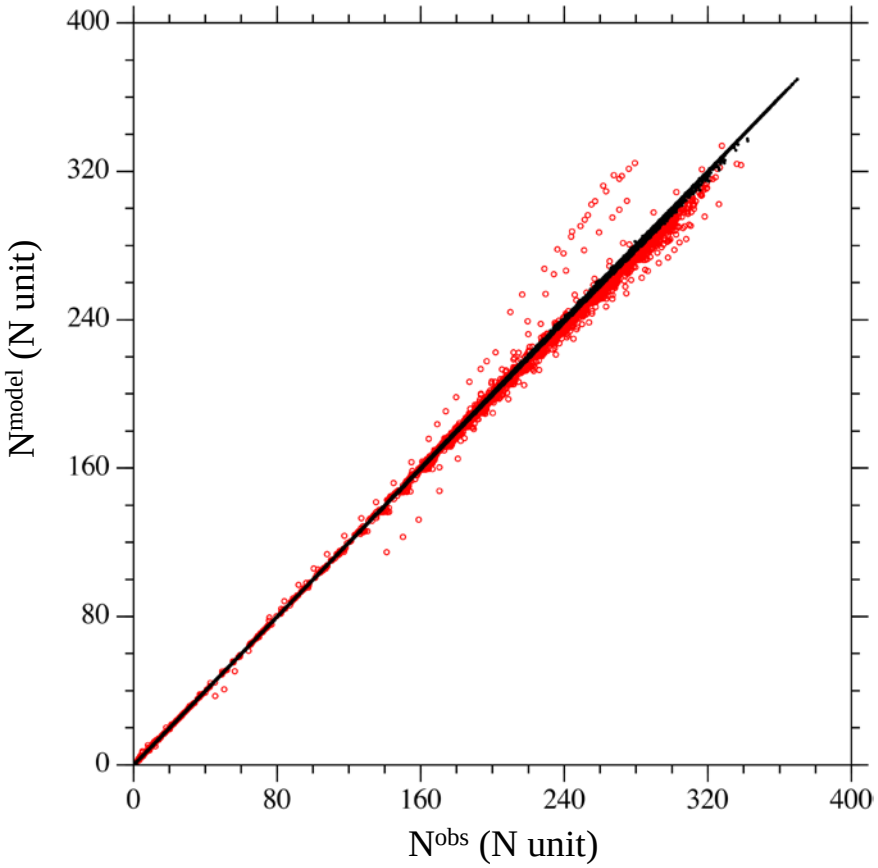


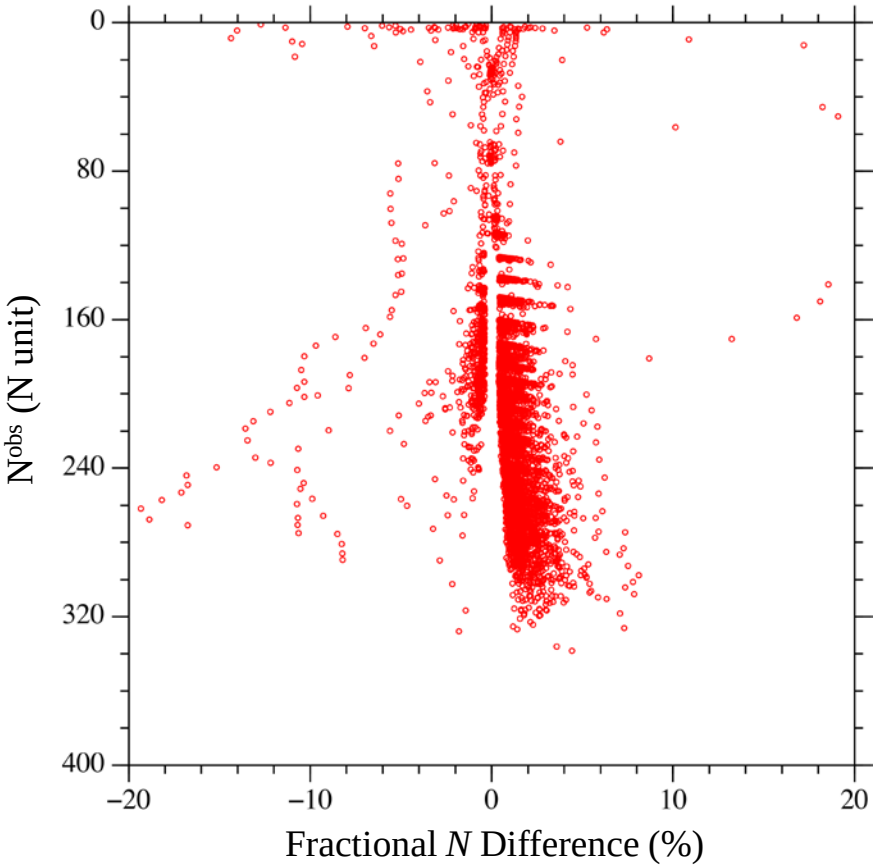
QC Step 3 (Simulation Outliers)



- RO data points that are removed by QC steps 1 and 2 are indicated in red
- Outliers (red) are found in observed (left) and simulated (right) refractivity

QC Step 4 — Removing O-B Outliers

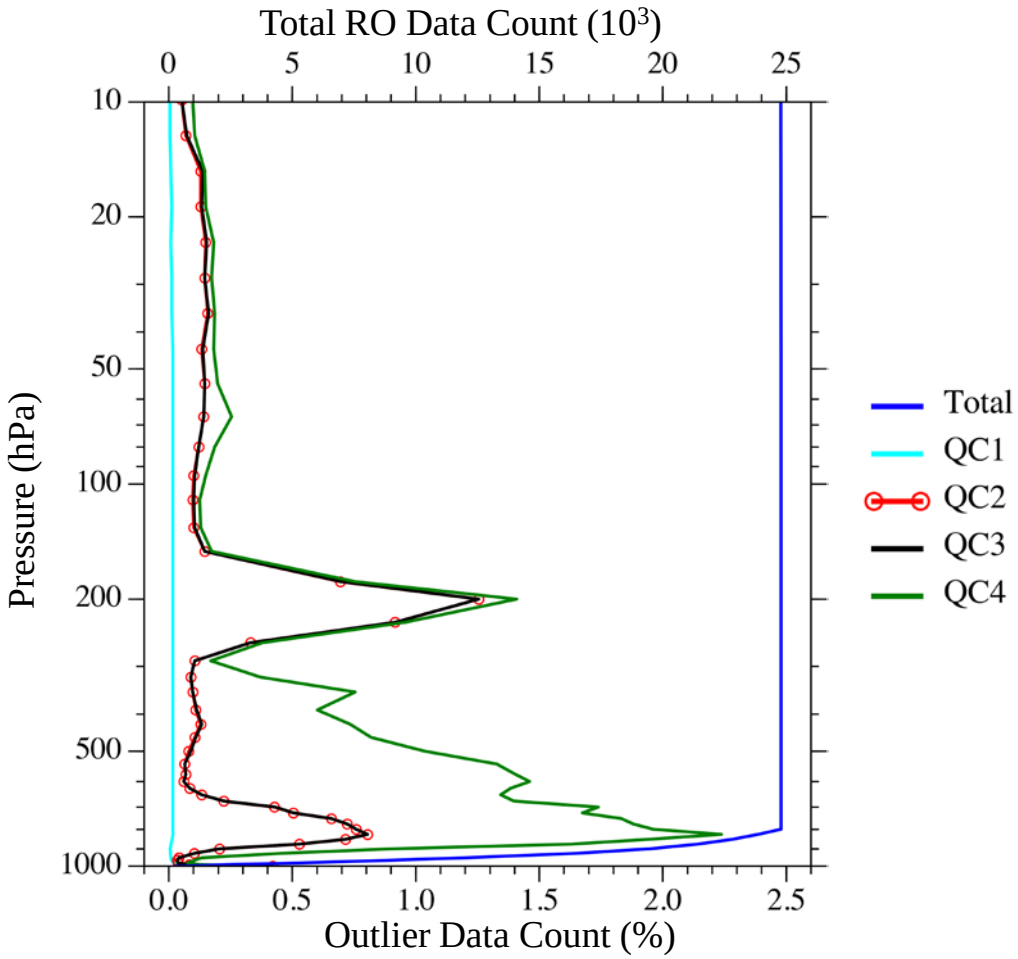




- Some observations deviate greatly from model simulations
- Observations deviate greatly from model simulations are removed

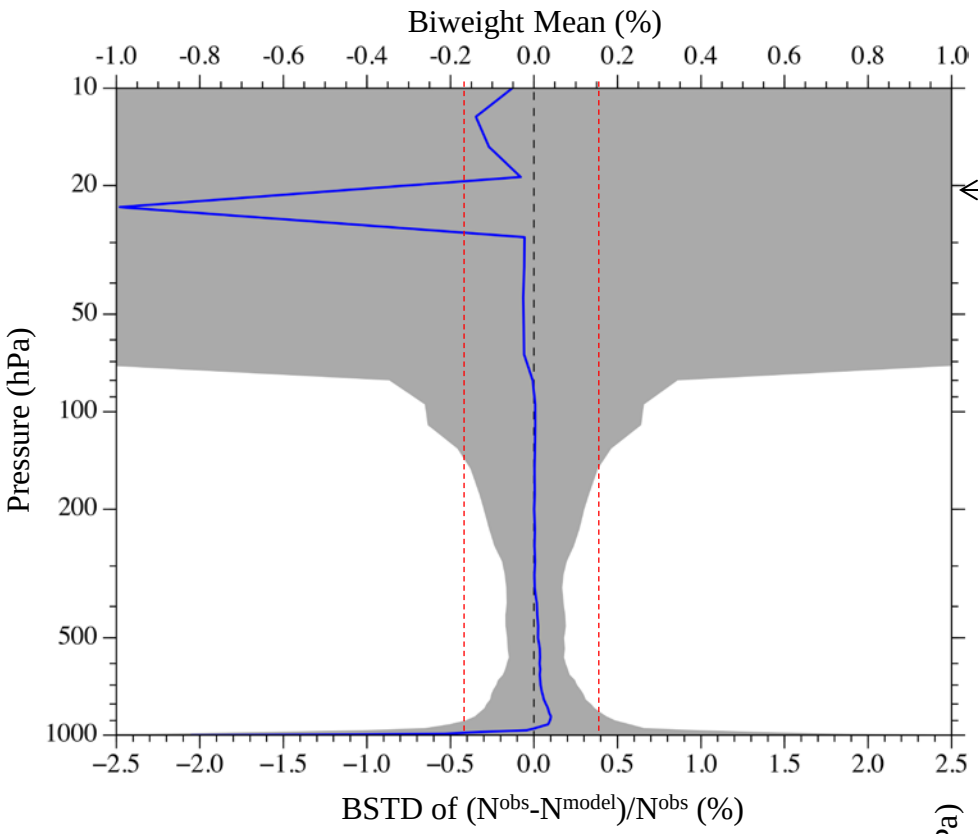
  → Fractional *N* differences larger than 2%

Total Number of RO Data not Selected



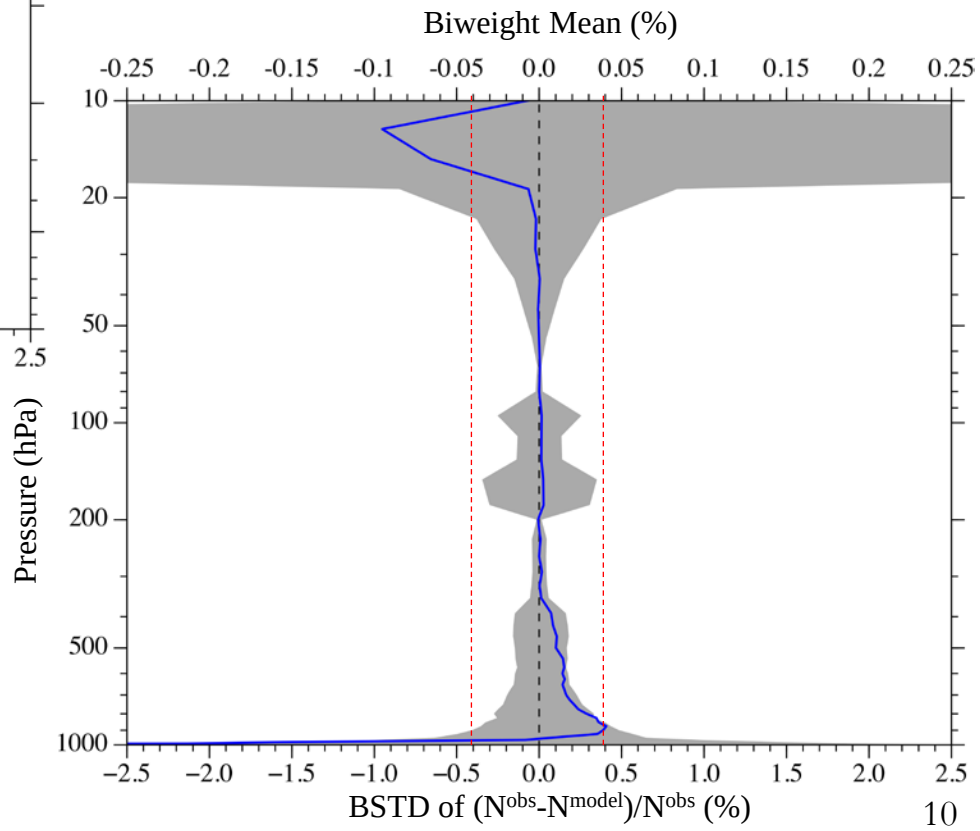
- Very little data are removed by the range check
- Outliers removed by QC steps 3 and 4 are less than 1.3%
- Data removed due to large O-B deviations are less than 2.2%
- More data are removed near 200 hPa and below 700 hPa

Impact of Data Selection QC Steps 1 and 2



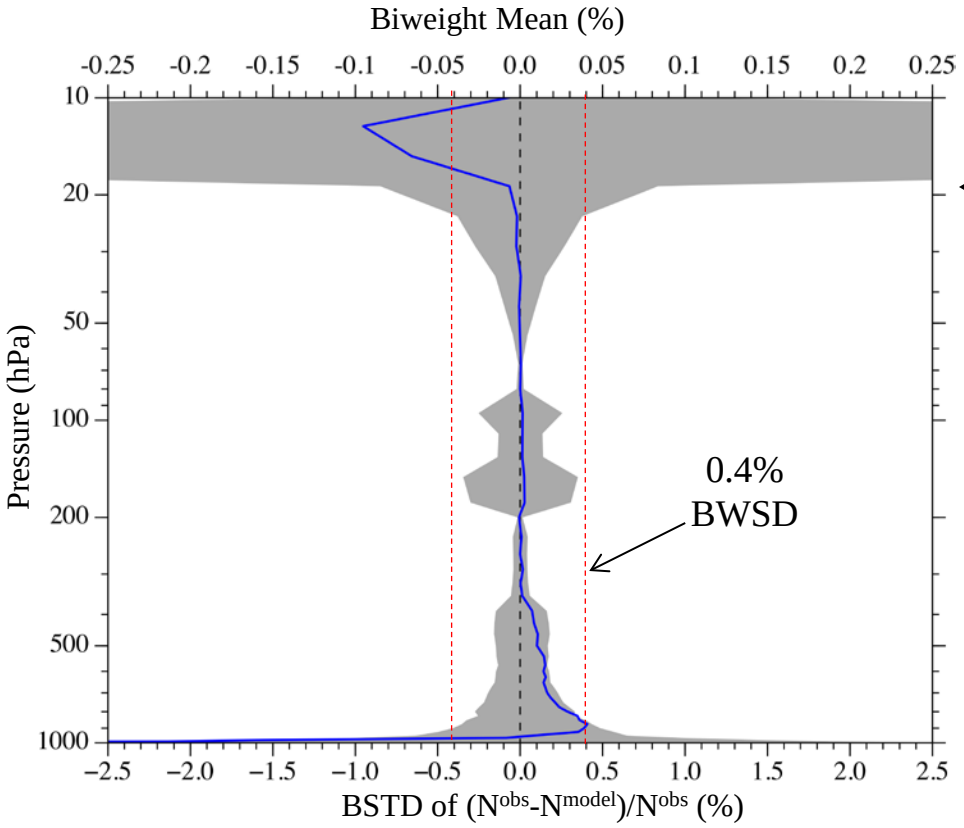
After QC step 1

After QC steps 1 and 2



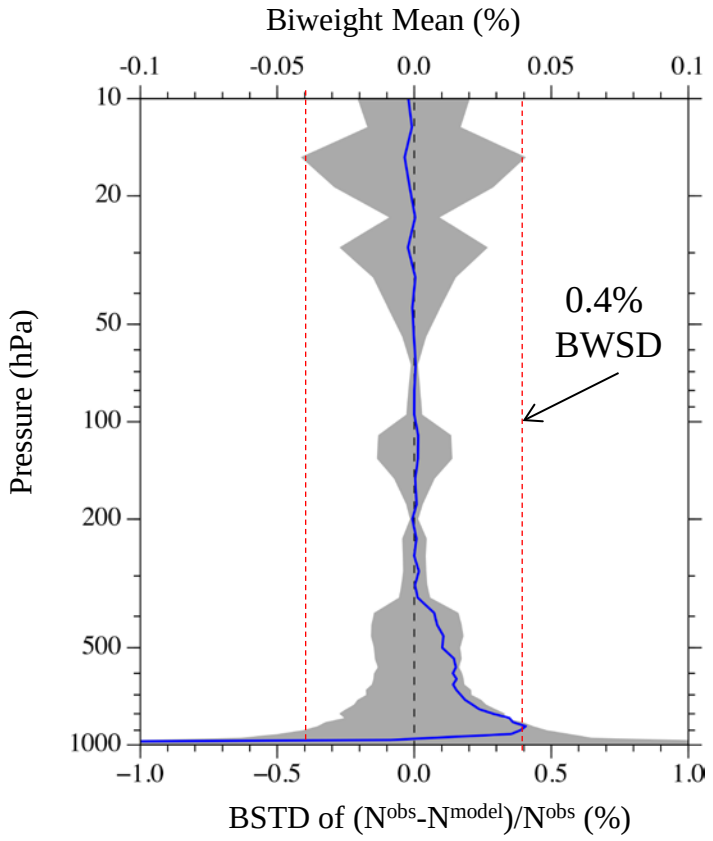
- Large negative bias (~ -1 N unit) appeared between 20-30 hPa
- The fractional N bias is reduced by more than an order of magnitude after removing observation outliers, which is less than 1.5% of the total data points

Impact of Data Selection QC Steps 1, 2 and 3



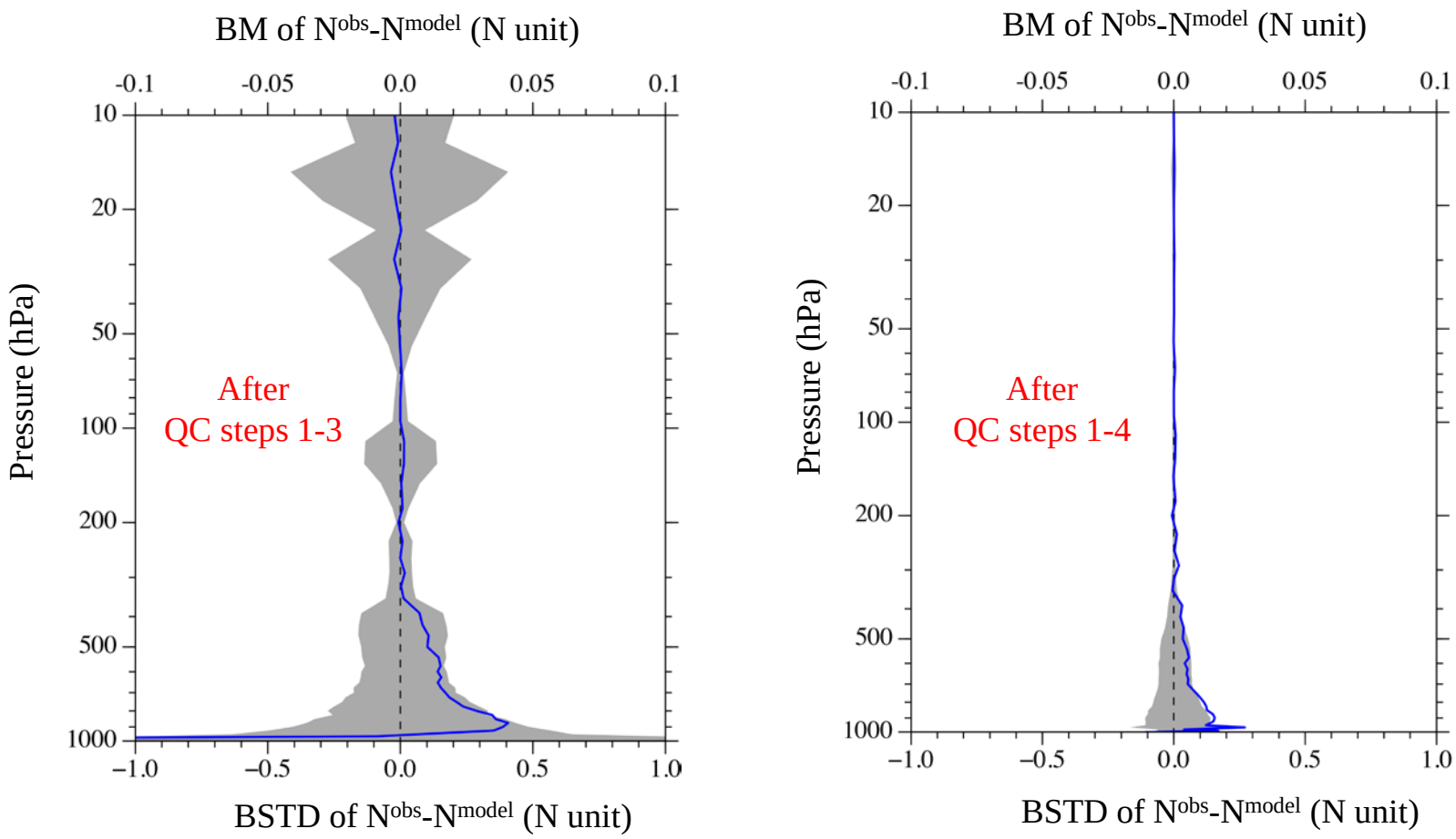
After QC steps 1 and 2

After QC steps 1, 2 and 3



- The bias is smaller than 0.1% throughout the vertical range 1000-10 hPa after QC 1 and 2
- Biweight standard deviations are still large above 20 hPa even after removing observation outliers
- Removing model outliers significantly reduced both the biweight bias and standard deviations

Impact of Data Selection QC Steps 3 and 4



- The BM is quite small but BSTD is still relatively large after QC steps 1-3
- Although only a small percentage of RO data is eliminated, the mean and standard deviations are significantly reduced after QC steps 1-4

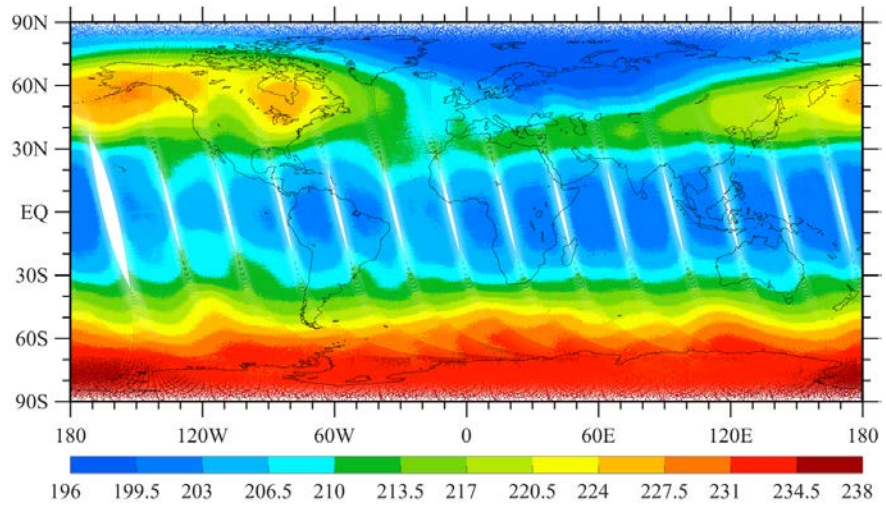
The S-NPP Life-Cycle Reprocessed ATMS Data

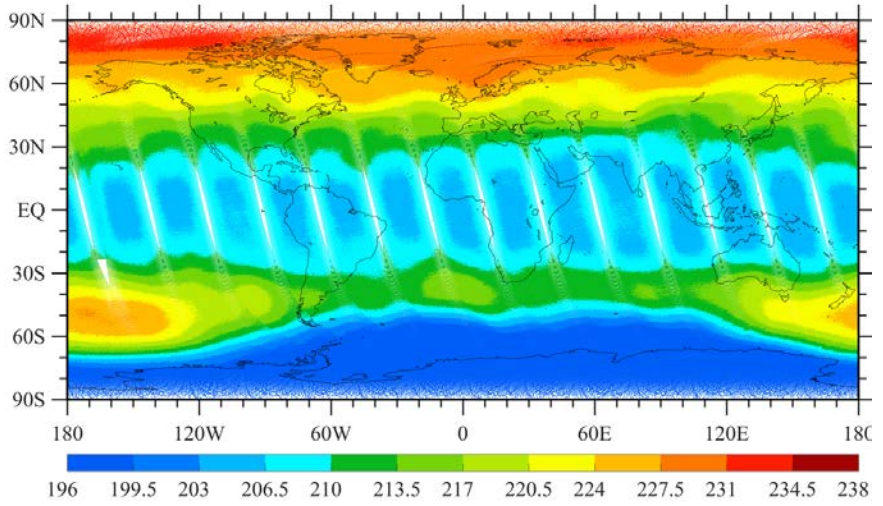
- The ATMS SDR data was operationally generated may have different error characteristics due to constant updates of the cal/val algorithms
- The reprocessed ATMS SDR data are generated with the same and most advanced cal/val algorithms throughout the S-NPP life cycle to remove calibration induced inconsistency
- The ATMS reprocessing involved the following updates:
    - Antenna reflector emission correction
    - Lunar intrusion detection and correction
    - Non-linearity coefficients correction
    - Full radiance processing
    - Striping noise mitigation
    - Resampling of channels 1-2 from 5.2^{o} to 2.2^{o} beam width

A Need for Reprocessing ATMS Data — It's done!

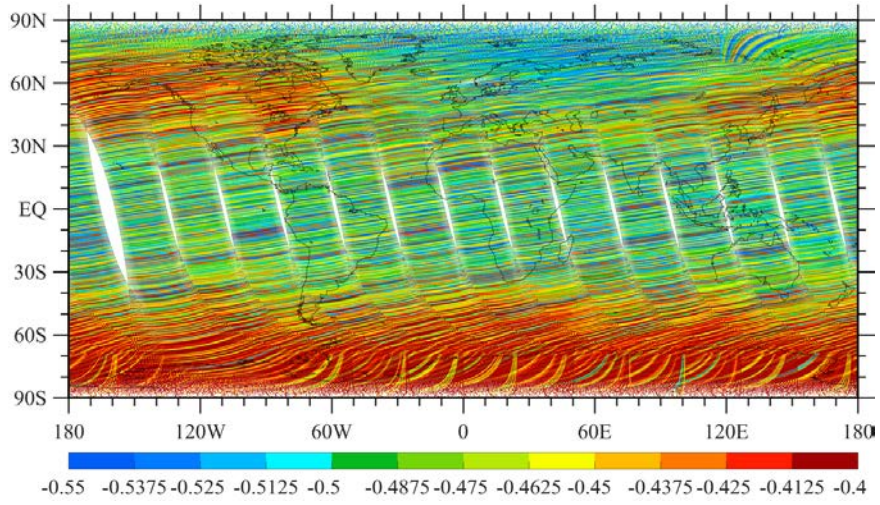
January 2, 2012 **August 1, 2016**

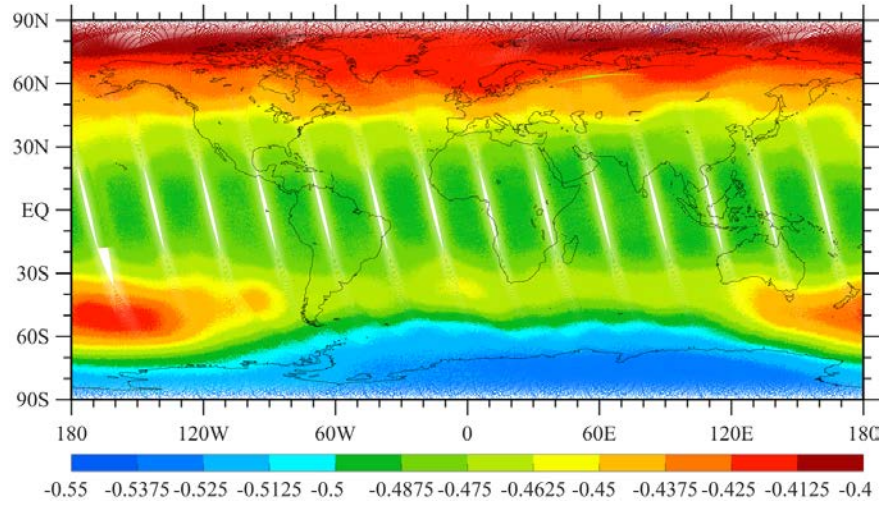
T_b of channel 10 from the operational (CLASS)





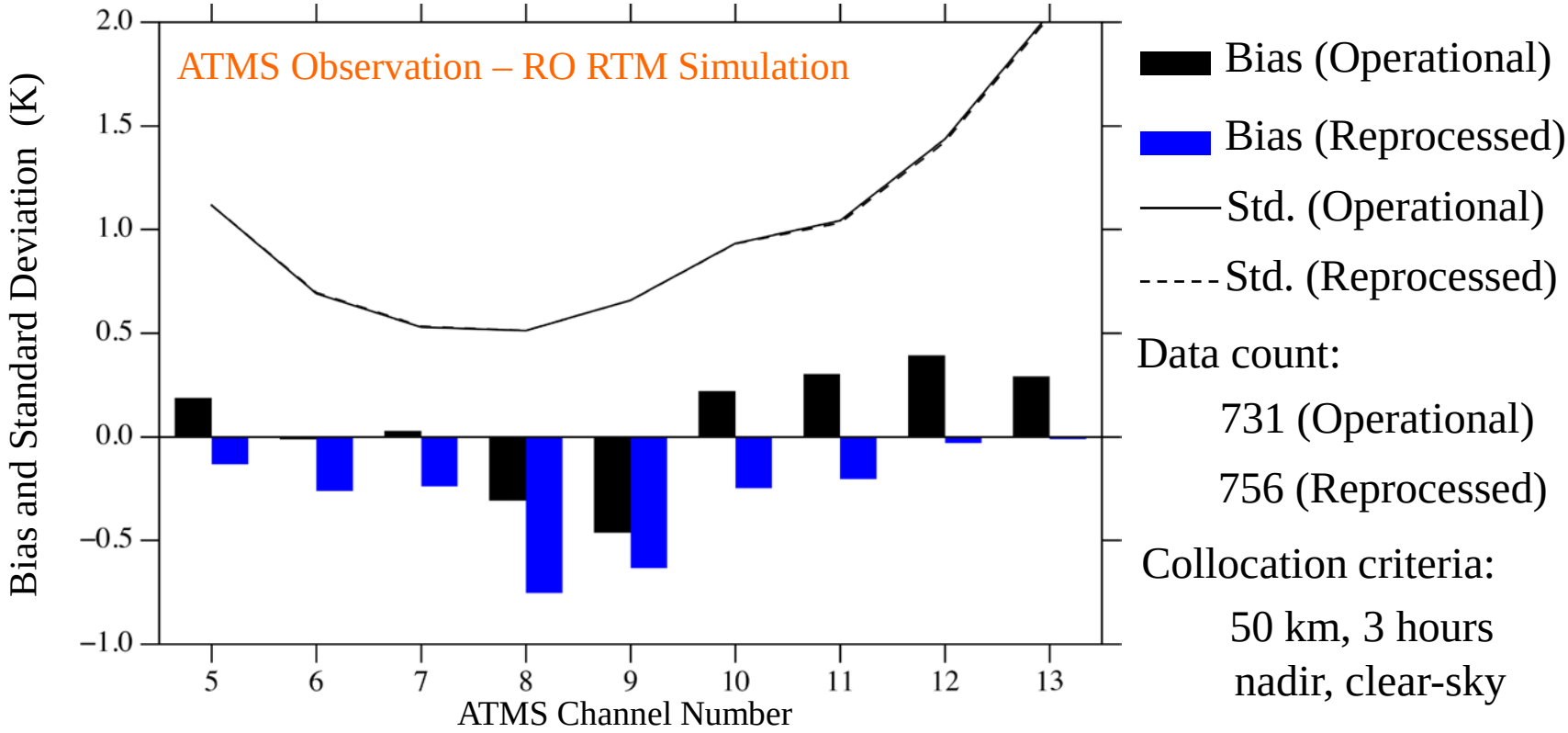
ΔT_b of channel 10 (reprocessed minus operational)





Bias Estimate of ATMS Brightness Temperatures

Post-Launch Calibration of ATMS Biases by COSMIC RO Data in 2012



- Biases of ATMS channels 5-13 are consistently negative, which is physically consistent with what we expect from theory for nadir data over ocean, i.e., antenna physical temperature

$$T_a^{obs} = T_b^{RTM} + \varepsilon_v (T_r - T_b^{RTM}),\ T_a^{obs} = T_b^{RTM} + \varepsilon_v (T_r - T_b^{RTM}),\ T_r \approx 283K > T_b^{RTM} \text{ over ocean}$$

- The bias differences before and after reprocessing is due to a nonlinearity coefficient error in generating operational data

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  - Simulation of ATMS brightness temperatures using ROs as input to Community Radiative Transfer Model (CRTM)
  - Bias characterization of 5-year reprocessed ATMS data
- **Comparison of Temperature Retrievals between ATMS and RO**
  - Temperature Retrieval Algorithm from ATMS Observations
  - Temperature differences between ATMS and RO Retrievals
- **Summary and Future Plan**

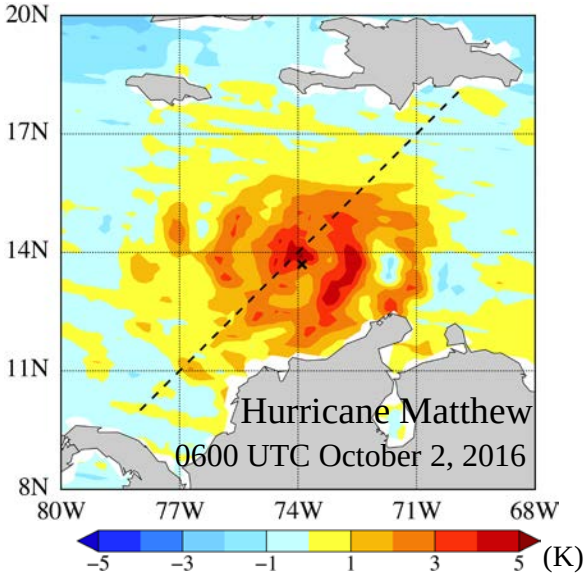
ATMS Temperature Retrieval Algorithm

The regression equation (Tian and Zou, 2016, JGR)

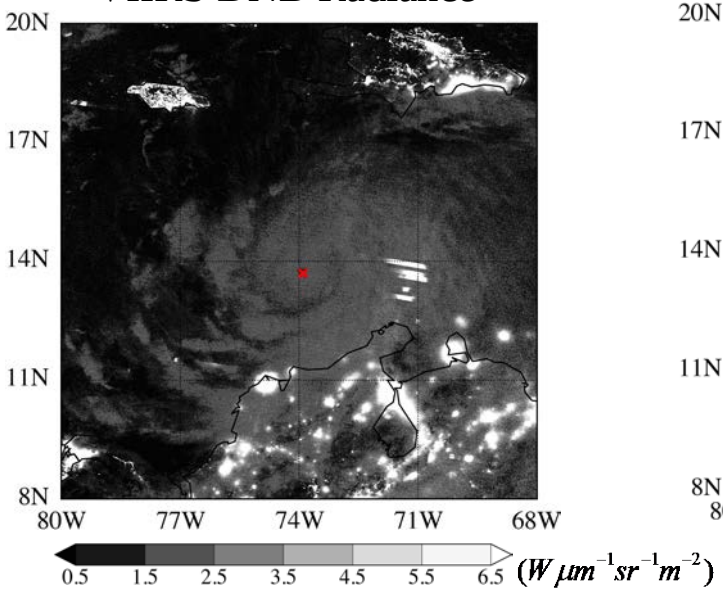
$$T_\theta(p_j) = C_0(p_j,\theta) + \sum_{i=1}^{n_j} C_i(p_j,\theta)\, T_{b,\theta}^{ATMS}(\nu_i)$$

- $T_\theta(p)$ – atmospheric temperatures
- $C_i(p, \theta)$ – regression coefficients trained with GFS temperatures
- $T_{b,\theta}(\nu_i)$ – ATMS-observed brightness temperatures at channels 5-15
- ν_i and θ – Frequency of the i^{th} channel and the local zenith angle

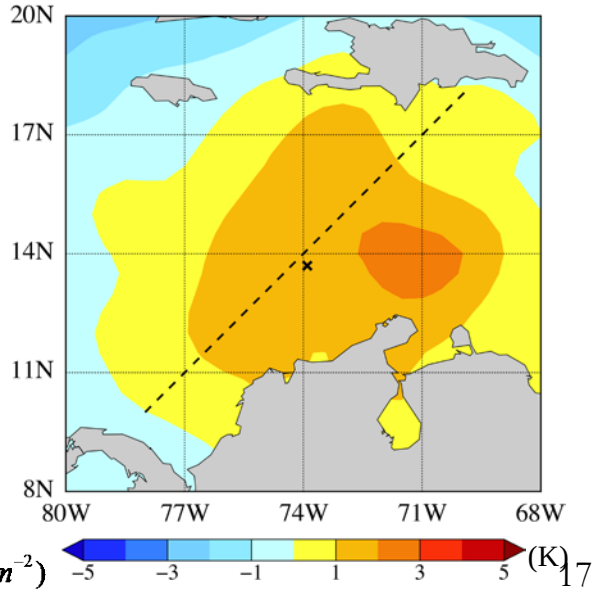
Warm core at 300 hPa



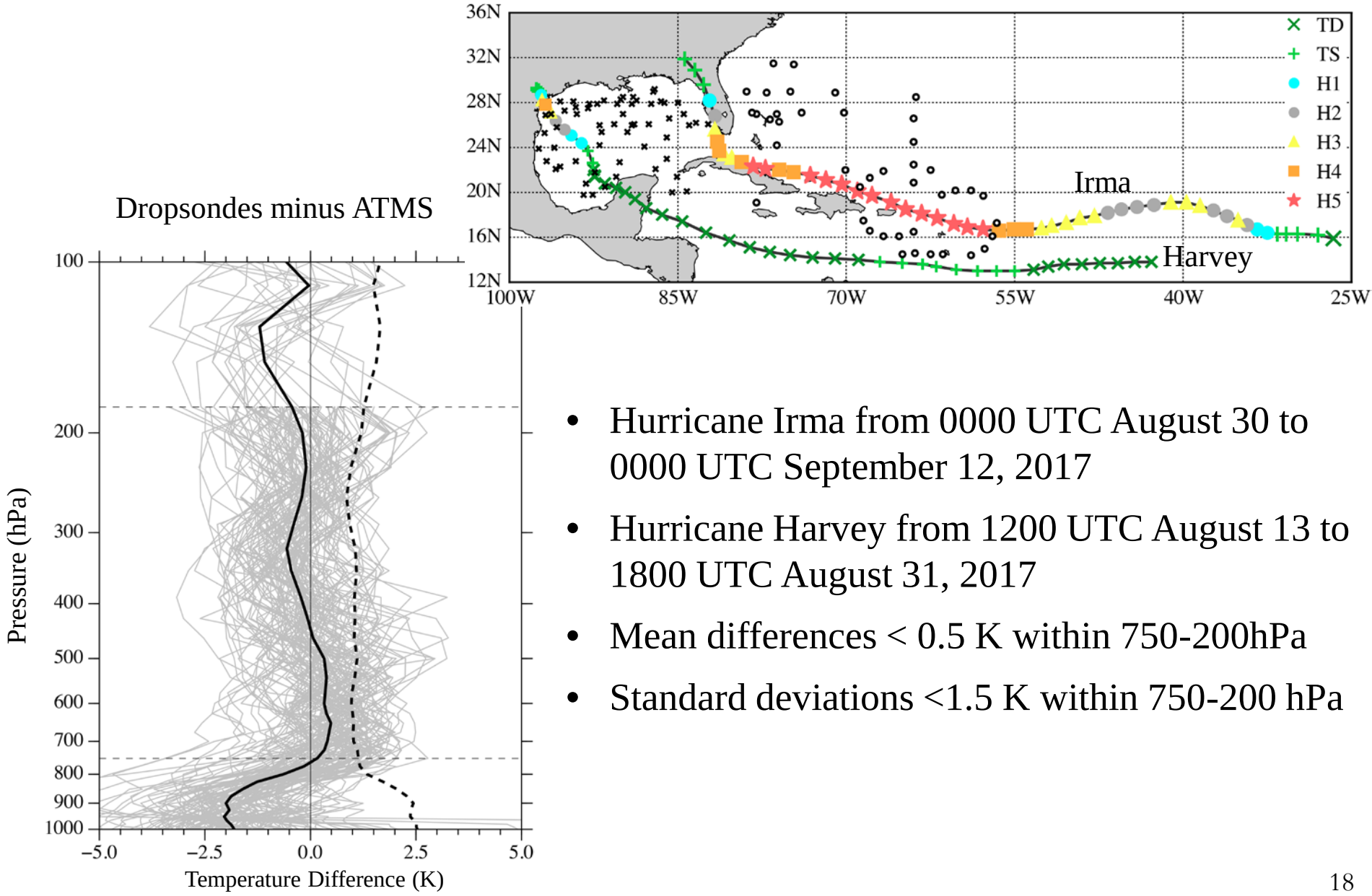
VIIRS DNB Radiance



ECMWF ERA-Interim

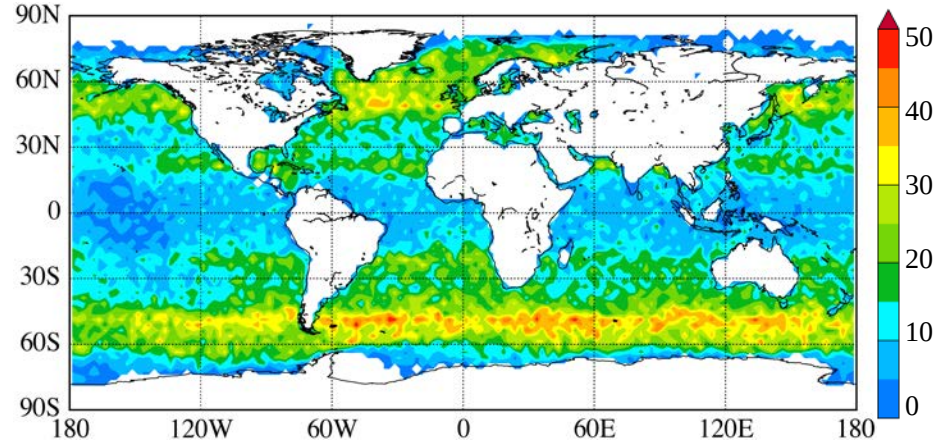


Comparison of between ATMS Temperature Retrievals and Dropsondes Collected during Irma and Harvey

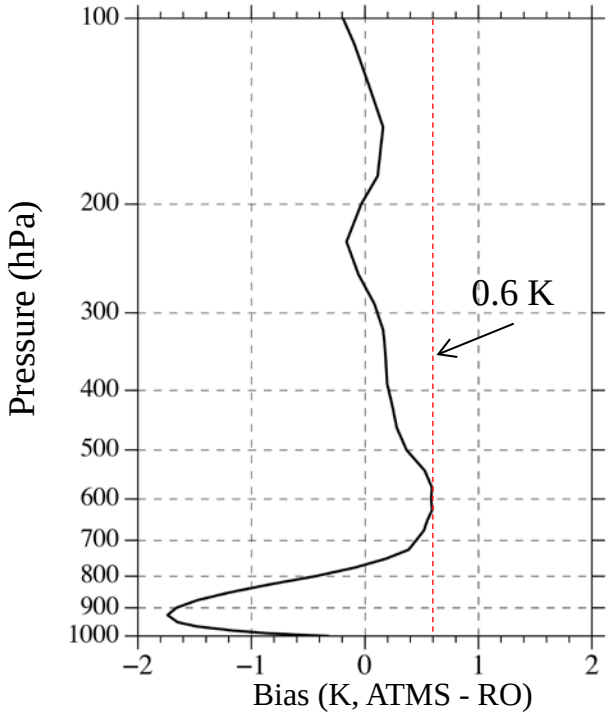


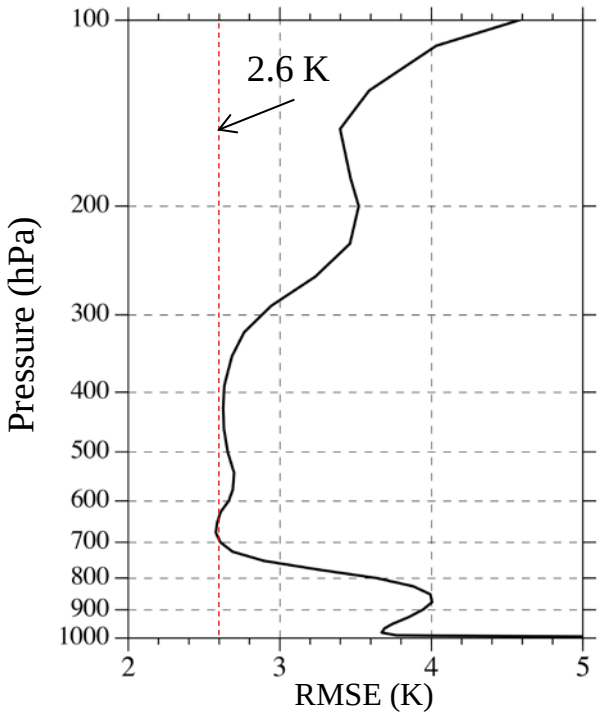
- Hurricane Irma from 0000 UTC August 30 to 0000 UTC September 12, 2017
- Hurricane Harvey from 1200 UTC August 13 to 1800 UTC August 31, 2017
- Mean differences < 0.5 K within 750-200hPa
- Standard deviations <1.5 K within 750-200 hPa

Comparison of Temperature Retrievals between COSMIC RO and ATMS



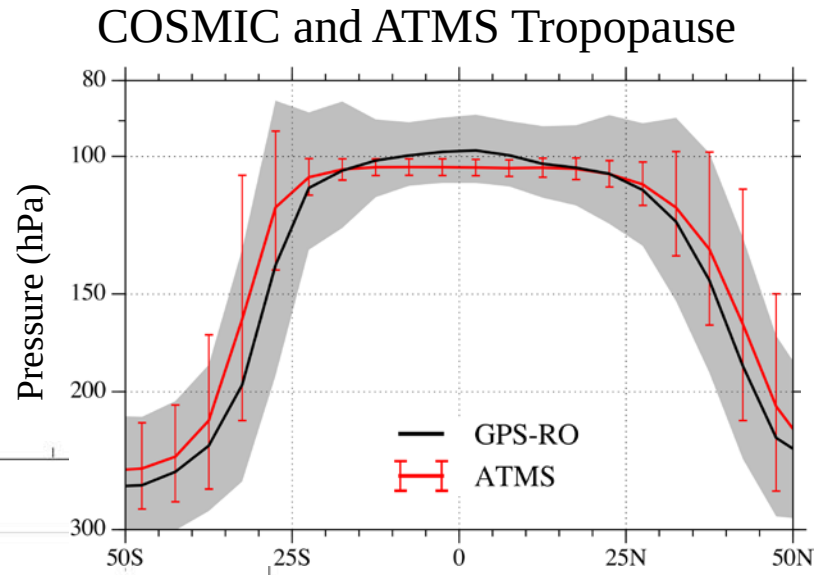
Collocated data count within 2.5ºx2.5º boxes, 2014-2016, collocation criteria: 2 h, 100 km

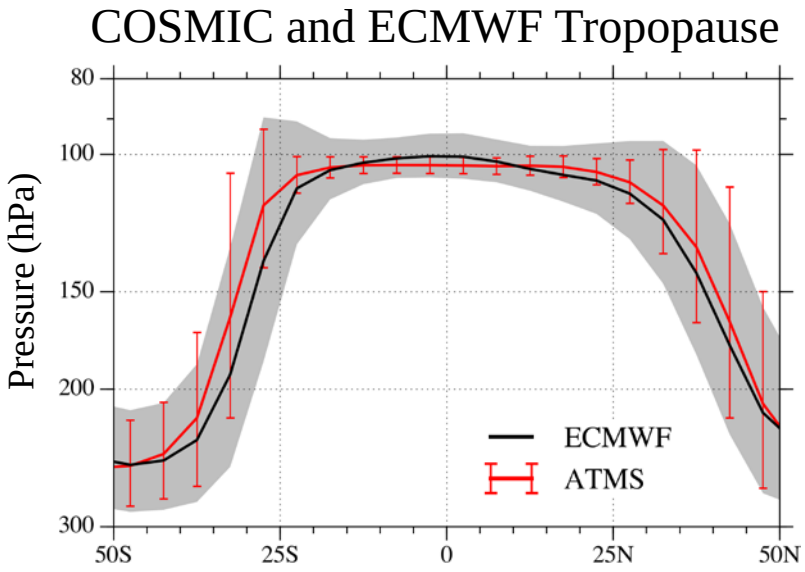




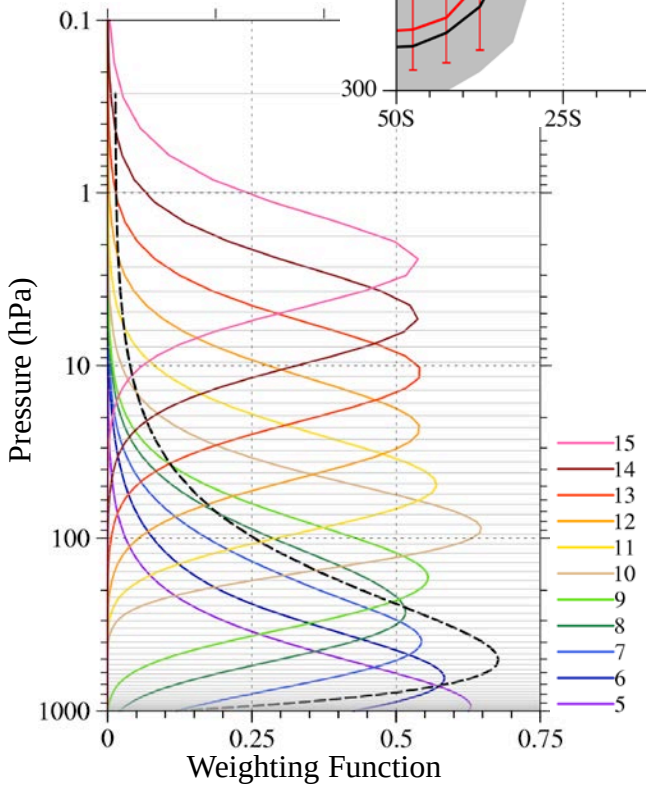
ATMS temperature retrievals compares favorably with COSMIC RO temperature retrievals above 750 hPa.

ATMS Temperature Retrievals Resolve Tropopause Quite Well Compared with COSMIC RO





All Data in September and October in 2016



Although a single channel's weighting function is broad, an nearly homogeneously overlapping distribution of weighting functions of ATMS channels 5-15 allowed a relatively high vertical resolution of atmospheric temperature to be retrieved to capture the tropopause structure!

Summary

- A quality control (QC) procedure was developed for selecting appropriate RO data for post-launch calibration of ATMS temperature sounding channels
- Biases estimated by the differences between ATMS observations and RO simulation of brightness temperatures are physically sound only for reprocessed but not for operational ATMS data in 2012
- An ATMS temperature retrieval algorithm that was originally developed for hurricane warm cores is made applicable globally to produce global atmospheric temperature
- The latitudinal variation of the tropopause height derived from ATMS temperature retrievals compared favorably with that derived from COSMIC ROs, suggesting a reasonably high vertical resolution of the ATMS temperature retrievals achievable by an overlapping nature of the weighting functions of different ATMS sounding channels

Future Plan

- Development and testing of a 2D non-local ray-tracing and a 1D local forward Abel transform bending angle observation operators
  - Development of observation operators (completed)
  - Comparison between COSMIC observations and 1D/2D simulation to draw some useful conclusions
  - Transition of the local and non-local operators to JCSDA
- Development and refinement of a physically based RO quality control procedure applicable to RO data assimilation in operational systems
- Verification against not only microwave sounders and their retrievals reported in this study, but also to infrared sounders to contribute to COSMIC-2 Cal/Val