A Hyperspectral Closure Study Using AIRS Radiances, ARM SGP Observations, and MERRA2 & ERA-interim Reanalyses: *how good is good enough?*

Xiuhong Chen, Xianglei Huang[1], Norman G. Loeb[2], Xiquan Dong[3], Baike Xi[4], Erica Dolinar[4], Michael Bosilovich[5], Seiji Kato[2], William L. Smith Jr.[2], Paul Stackhouse[2]

[1] The University of Michigan

[2] NASA Langley

[3] University of Arizona

[4] University of North Dakota

[5] NASA GSFC

Outline

- Motivations
- Approach
- Results
- Extrapolation
- Conclusions and discussions

Motivations

- Any observation or measurement has its own uncertainty
- When evaluate reanalysis/model against observations, how good is good enough?
  - For SARB project, how much can the T/q profiles be tweaked?
- Premise: if two simultaneous **high-quality** observations exist and they differ by Δ, then
  - If mod-obs/reanalysis-obs smaller than Δ, then mod is indistinguishable from obs
  - Otherwise, model/reanalysis has a bias.

In this study: T(z) and q(z)

Mod/Reanalysis

Obs1

Mod/Reanalysis

Obs2

AIRS (Atmospheric Infrared Sounder)

Table 1. AIRS Standard Products in Version 5.0

Product	RMS Require-ment	Uncertainty Estimate	Vertical Coverage	Val Status
Radiances (Level 1B)			N/A	
AIRS IR Radiance	3%	<0.2%; 0.1 K at Antarctica	N/A	Val5
AIRS VIS/NIR Radiance	20%	15-20%	N/A	Prov
AMSU Radiance	0.25-1.2 K	1-3 K	N/A	Val3
Standard Geophysical Products			N/A	
Cloud Cleared IR Radiance	1.0 K	Accuracy ~1 K, precision 0.3-8 K	N/A	Val3
Sea Surface Temperature	0.5 K	1.0K	N/A	Val1
Land Surface Temperature	1.0 K	2-3 K	N/A	Prov
Temperature Profile	1 K / km	1-2 K / km in troposphere, 2-3 K / km above	Surface to 1 hPa	Val4
Water Vapor Profile	15% / 2 km	20 % / 2 km lower trop; 20-60% / 2km upper trop	Surface to 200 hP or tropopause.	Val4
Total Precipitable Water	5%	5-20%; 0.1 mm wet bias in Antarctic	N/A	Val5
Fractional Cloud Cover	5%	5-30%, cloud type dependent.	900 to 100 hPa	Val2
Cloud Top Height	0.5 km	0.5-2 km, cloud type dependent.	900 to 100 hPa	Val3
Cloud Top Temperature	1.0 K	1-2 K	900 to 100 hPa	Val1
Total Ozone Column	-	5% tropics; 5-40% poles	N/A	Val3
Ozone Profile	-	20%	200 hPa to 70 HPa	Val4
Carbon Monoxide	-	10-50% at 500mb	800-200 hPa layer	Val3
Methane	-	1.5% monthly in mid-trop. (alt. & lat. dependent)	700-200 hPa layer	Prov
Carbon Dioxide (Research)	< 2 ppm	< 1.45 ppm	500-300 hPa	Beta
Outgoing Longwave Radiation	-	< 5 W/m^2	N/A	Prov

Observations

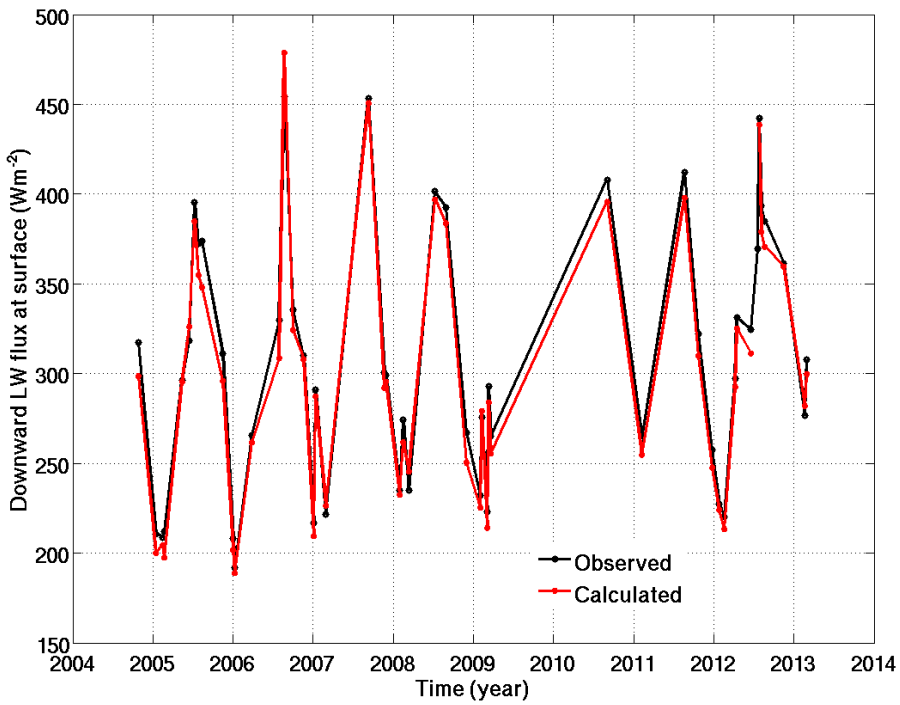
- AIRS L1 spectral radiances and L2 retrievals

	Pros	Cons
L1	Highly accurate (NeBT < 0.3K) and stable (drift <0.03K). Forward modeling is accurate	Clouds, trace gases also contribute
L2	Directly comparable with model/reanalysis	Retrieval uncertainties

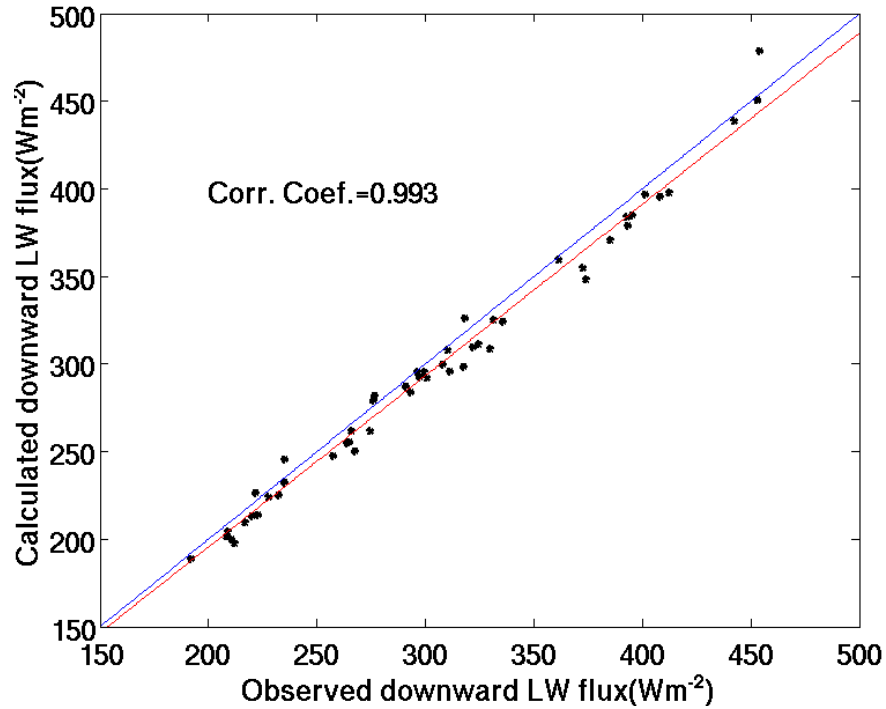
- ARM observations
  - MMCR (30km-by-30km scan)
  - Raman lidar for T (<0.3K) and q (~0.4%)
  - Surface temperature and surface radiation

Downward LW flux at surface calculated using MODTRAN5

Forward modeling is straightforward



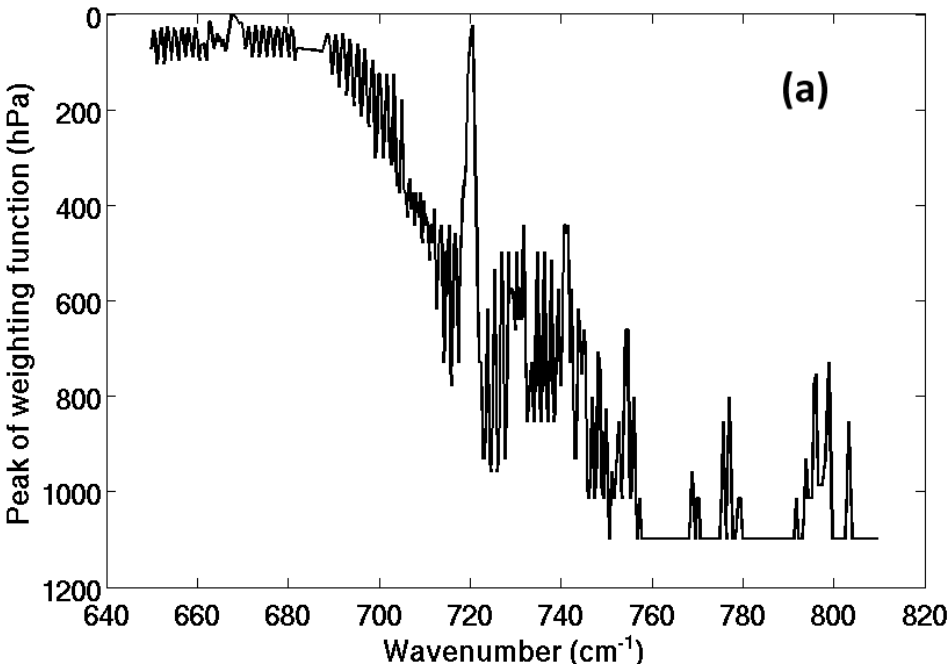
Regression slope:0.9934

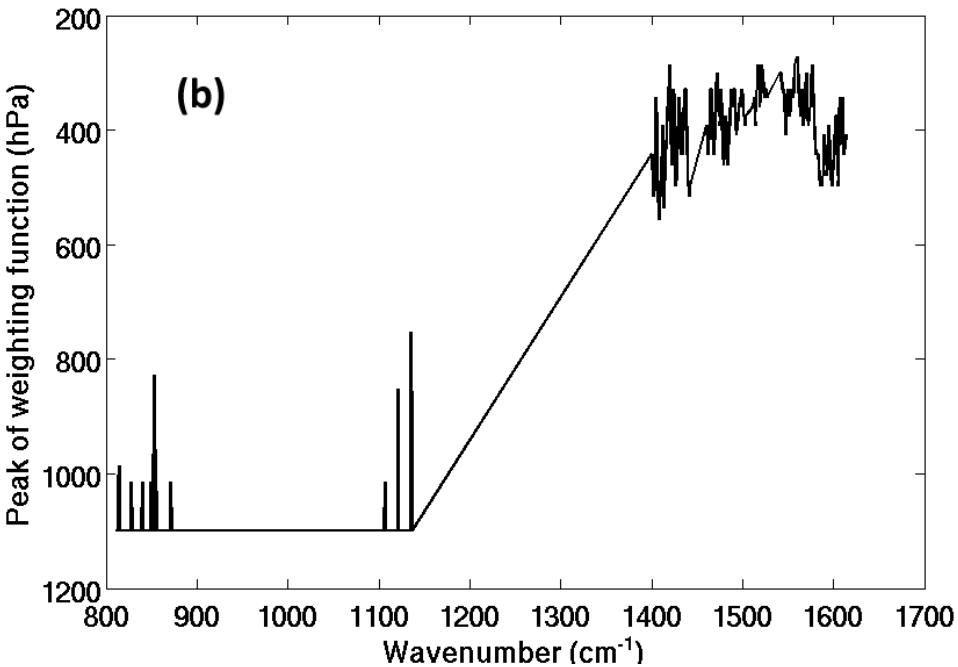


Approach

- Using ARM MMCR to identify clear-sky scene when Aqua passed over (Dolinar et al., 2016, JGR)
  - 51 scenes selected for 2004 to 2013 (19 day; 32 night)
- Fed ARM in-situ obs to PCRTM to generate synthetic AIRS L1 spectrum
- Do the same with the ERA-interim/MERRA-2/ AIRS-L2 profiles
- Single out channels that are affected by only T, q, and CO_2 (done with LBLRTM/HITRAN/AIRS SRF)
- Make comparisons

Grouping channels based on the peaks of their W.F.





	CO_2 band		H_2O band & WN band	
Group	Peak of the W.F. (hPa)	Number of channels	Peak of the W.F. (hPa)	Number of channels
1	1000-800	155	1000-800	442
2	800-600	45	800-600	1
3	600-400	46	600-400	124
4	400-200	33	400-200	136
5	200-70	77		
6	70-30	67		
7	30-1	28		

The **devil** is in the **detail:** surface skin temperature

Old: Calculation using ARM SGP profiles, surface temperature and woody savannas emissivity

New: Calculation using ARM SGP profiles and *surface skin temperature* derived from ARM upward/downward LW fluxes at surface

$$F_{sfc}^{\uparrow} = \int_0^{\infty} \varepsilon_v \pi B(T_s) dv + (1 - \bar{\varepsilon}) F_{sfc}^{\downarrow}$$

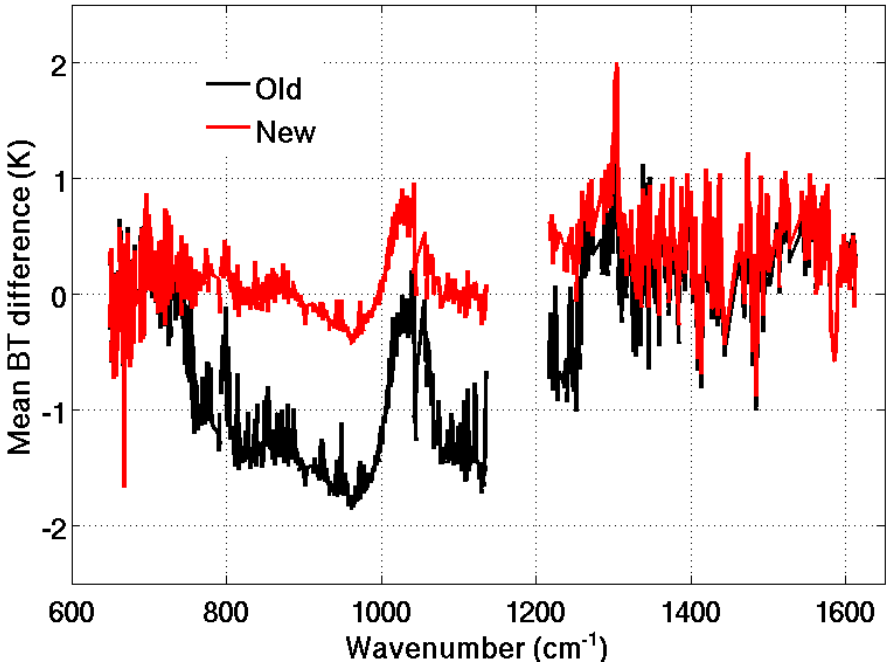
Still using woody savannas emissivity

51 clear-sky cases at ARM SGP site (36.61°N, 97.49°W)

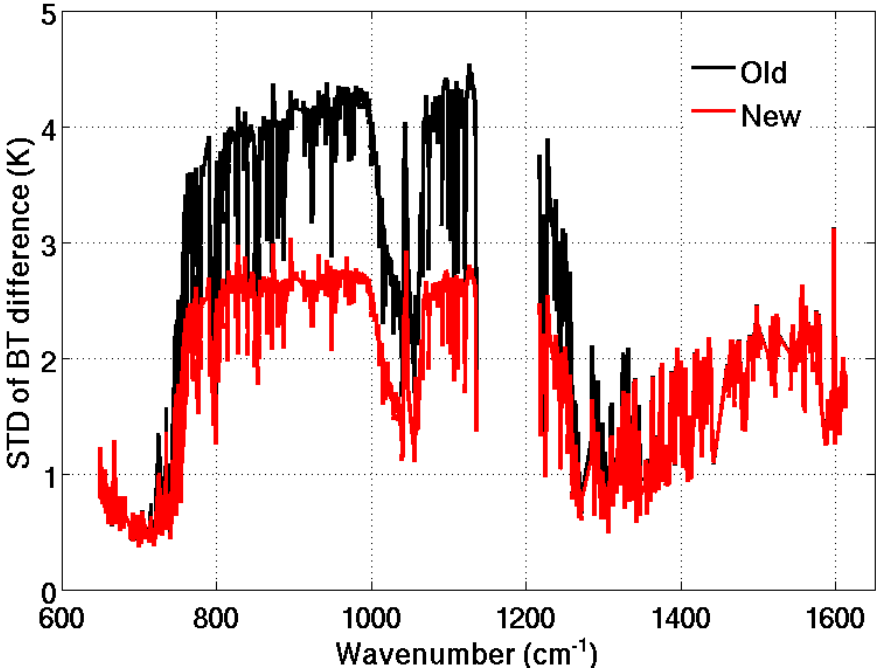
Synthetic – AIRS L1 using ARM SGP data

51 profiles

Mean difference



Standard deviation

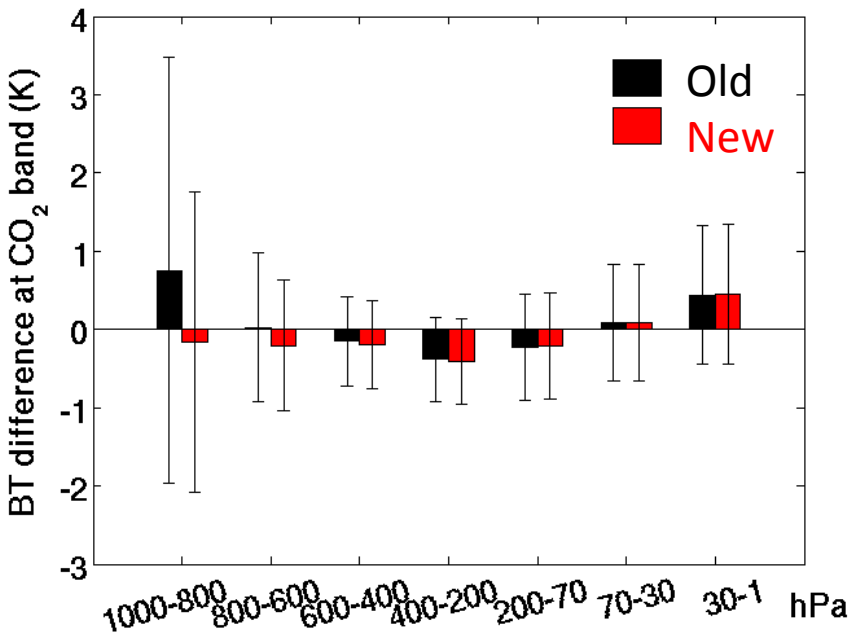


Old: surface temperature directly from ARM

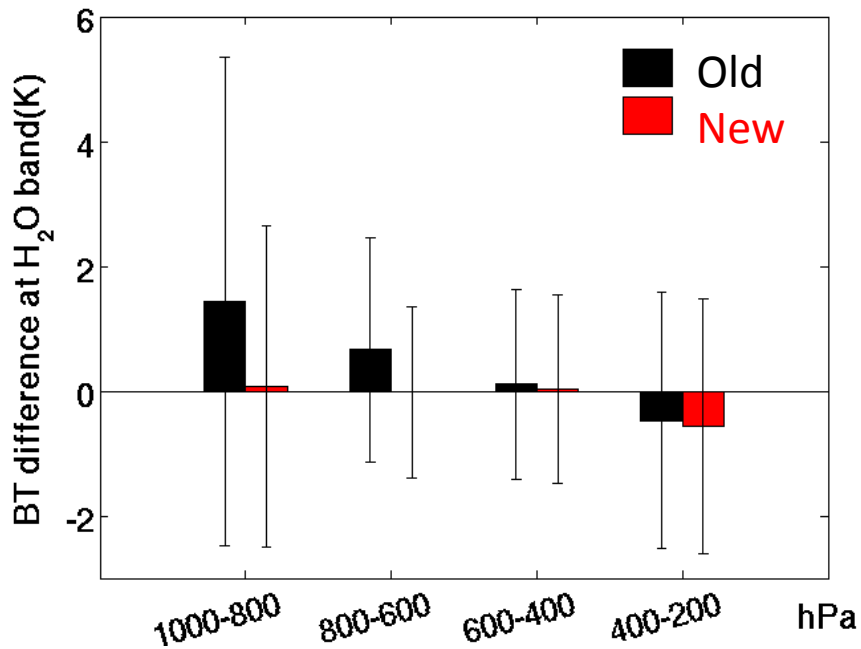
New: surface skin temperature from LW measurements @ARM SGP

AIRS L1 – Synthetic using ARM SGP data: Channels grouped w.r.t. peaks of weighting functions

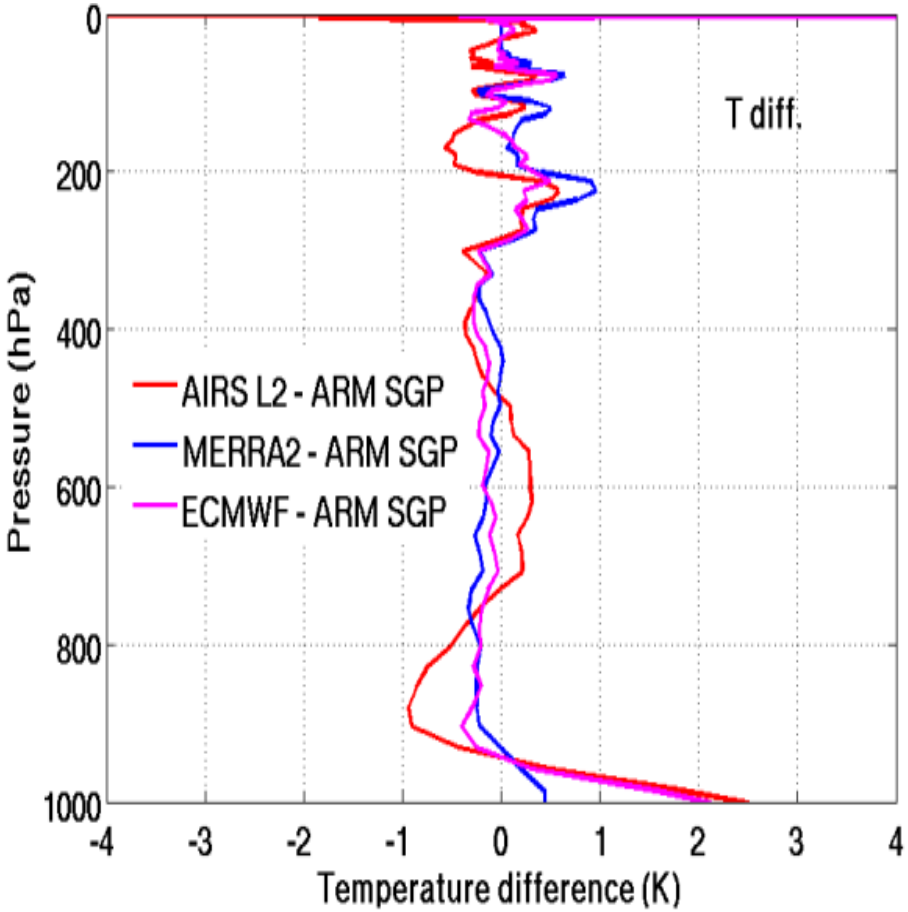
Sensitive to T

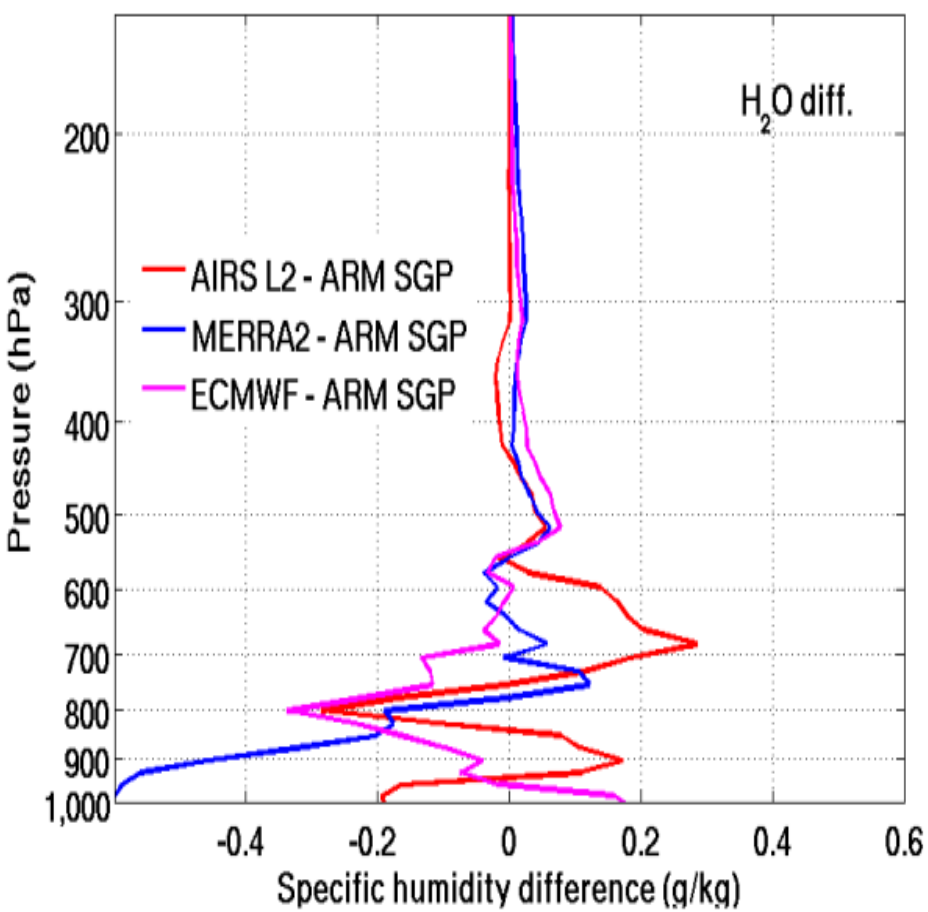


Sensitive to T & q



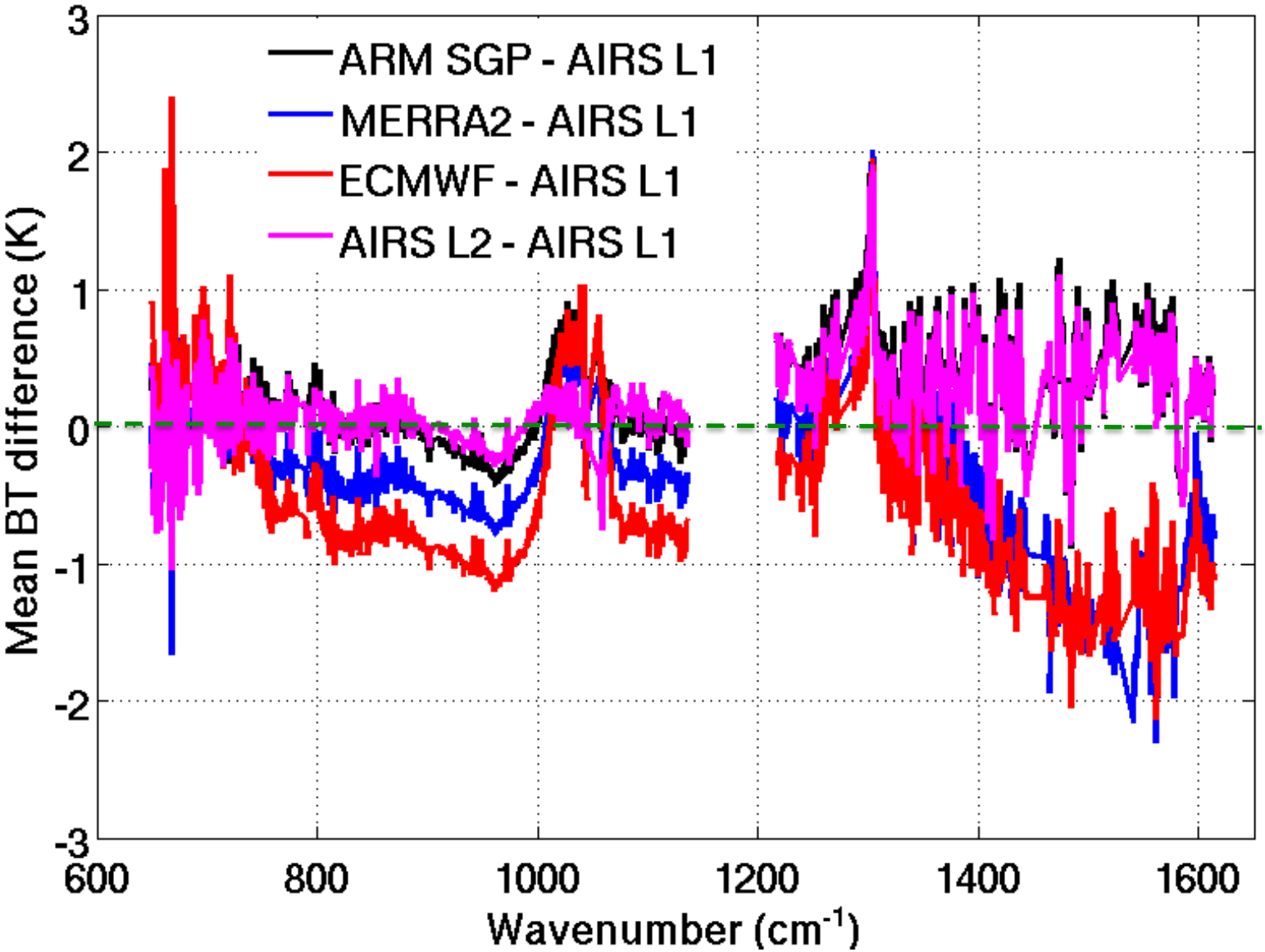
Direct T & q comparisons





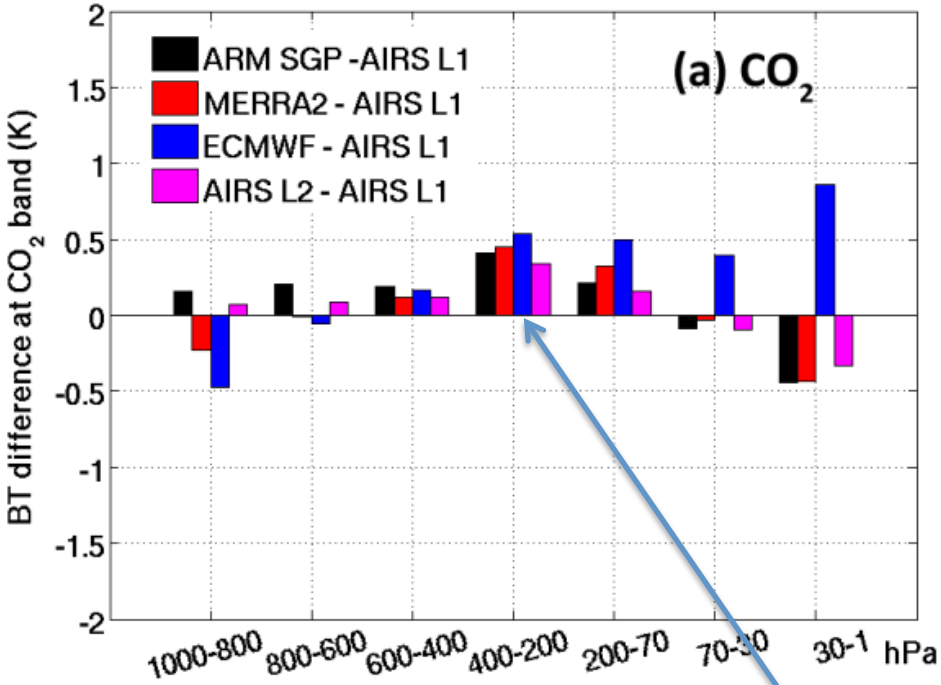
Results

Synthetic mean spectrum – AIRS mean spectrum

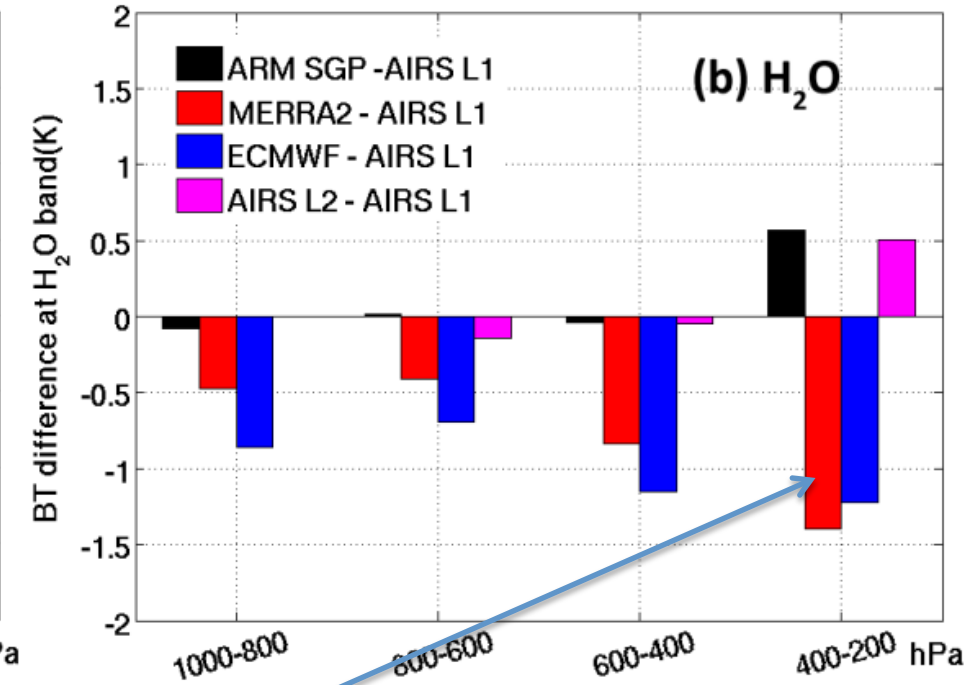


BT Difference in grouped channels

Sensitive to T

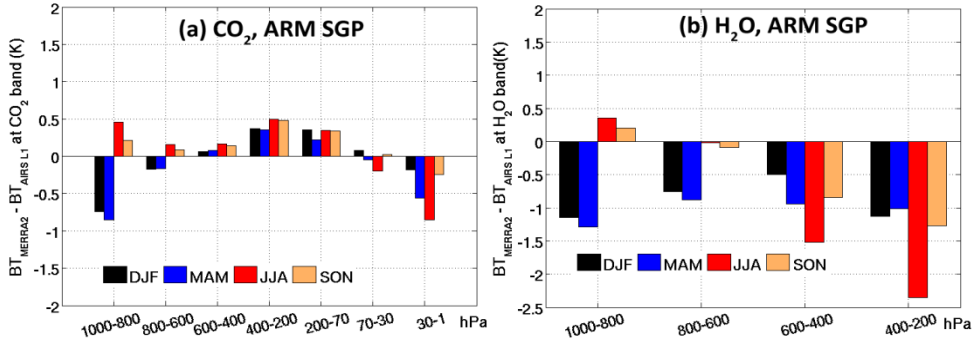


Sensitive to T & q



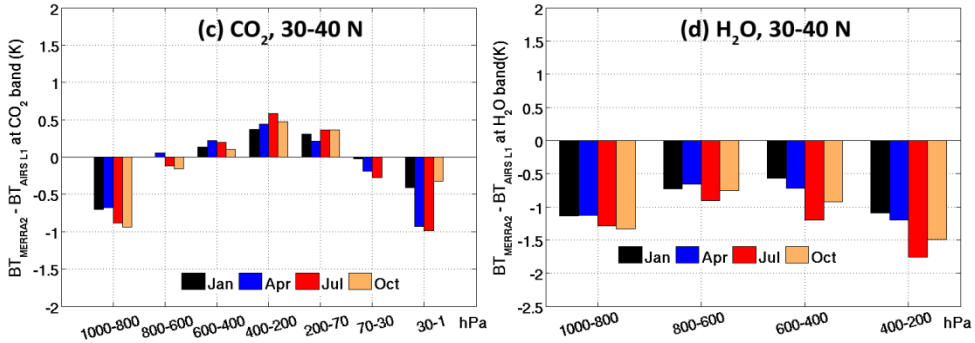
1. Reanalyses wet bias in mid-upper troposphere
2. AIRS L2 agrees with ARM SGP and AIRS L1 in all groups except 800-600hPa H_2O
3. Similar results when compositing the difference w.r.t. season or w.r.t. TCWV
4. Difference in the 1000-800 hPa groups: additional factor for ARM – AIRS L1

Extending the comparison



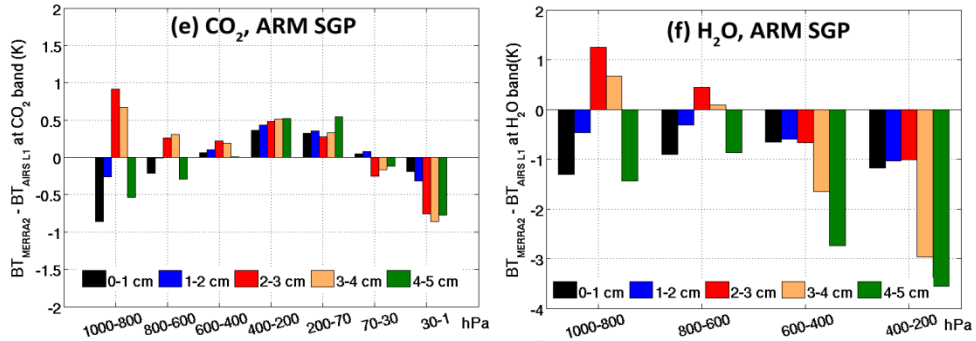
MERRA2 – AIRS L1 at ARM-SGP site

Clear-sky; 51 cases in total

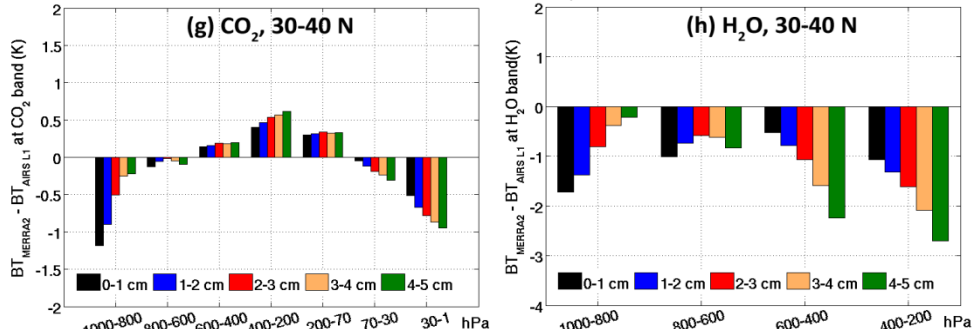


MERRA2 – AIRS L1 in 30°-40°N

Clear-sky, 187, 053 cases in total



MERRA2 – AIRS L1 at ARM-SGP site



MERRA2 – AIRS L1 in 30°-40°N

Conclusion and discussion

- AIRS and ARM-SGP clear-sky radiances agree well with 0.5K in BT.
- Both ERA-interim and MERRA show wet bias in 600-200 hPa, for ARM-SGP site and beyond.
- Additional constrain on how much tweaks can be done to UTH in SARB algorithm.
- Using two observations to bracket observational uncertainties:
  - Other ARM sites (TWP and NSA)
  - Overcast and broken clouds

Thank You!

Atmospheric input profiles and radiative transfer forward model

- ARM SGP sounding profiles (T, q; o3 is from MERRA-2)

  1-minute time resolution, 266 levels from surface to ~20 km

- AIRS version 6 level2 standard products (AIRS + AMSU; T, q, o3)

  Horizontal resolution: ~45 km at nadir; Water vapor mixing ratio: 15 levels from surface to 50 hPa, and temperature and traces gases: 28 levels from surface to 0.1 hPa

- MERRA-2 (T, q, o3)

  3-hourly MERRA-2 data on a horizontal grid of 0.5° latitude by 0.625° longitude with 42 vertical levels up to 0.1 hPa

- ECMWF ERA-Interim (T, q, o3)

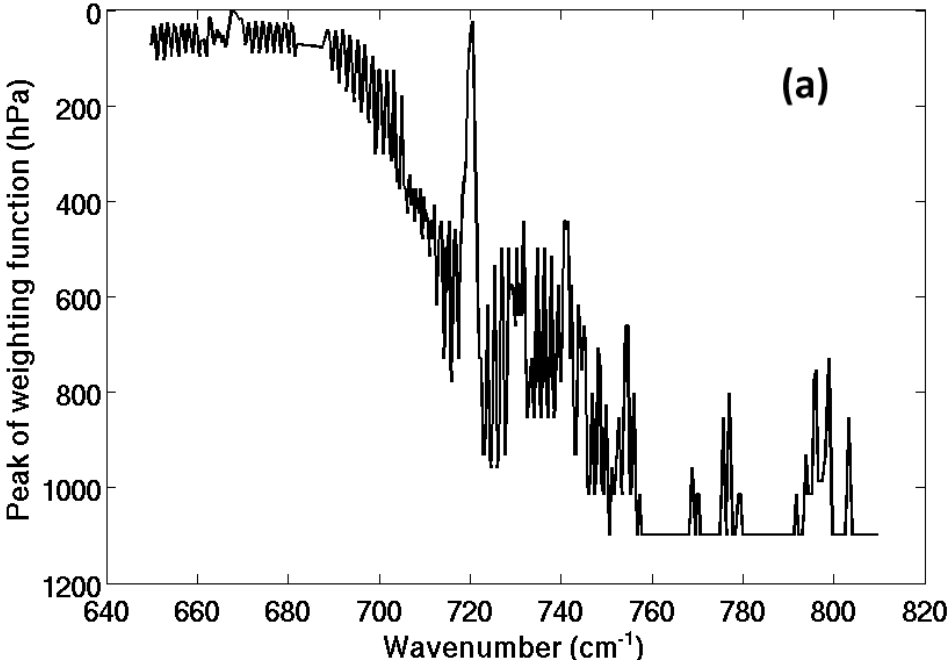
  6-hourly ECMWF ERA-Interim data on the 0.75° by 0.75° horizontal resolutions and 37 vertical levels from surface to 1 hPa

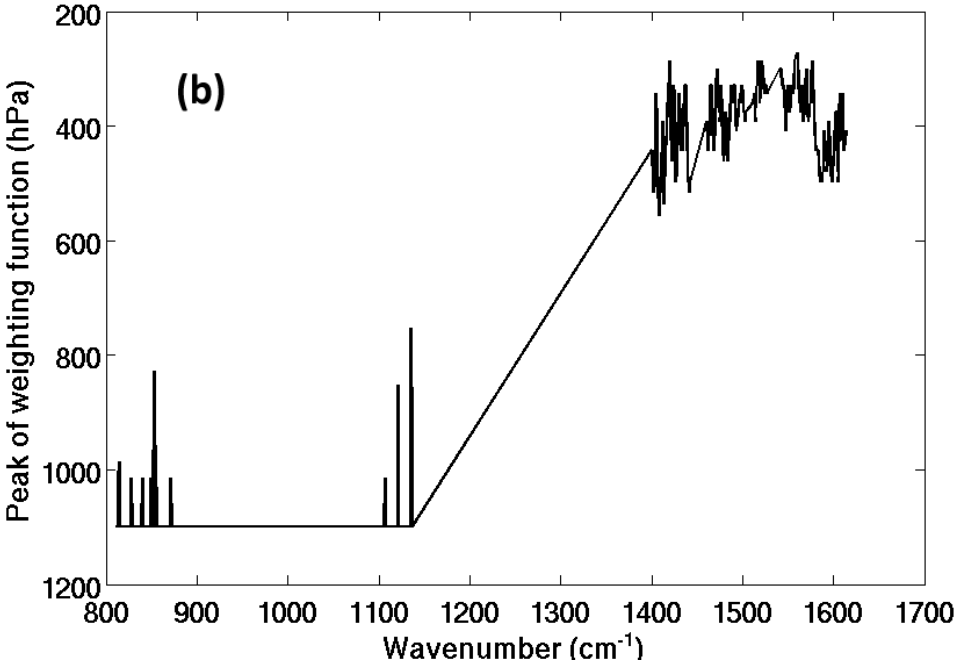
- PCRTM-based satellite simulator (Chen et al., 2013)

  Profiles are linearly interpolated onto AIRS trajectories;
  Surface emissivity is from IGBP woody savannas
  (This is not the forward model used in AIRS L2 retrievals)

CO_2 band:650-810 cm^{-1}

Wave vapor and window bands excluding CO_2, O_3, CH_4 and N_2O: 810-990, 1093-1205 and 1400-1612 cm^{-1}.





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5	200-70	77		
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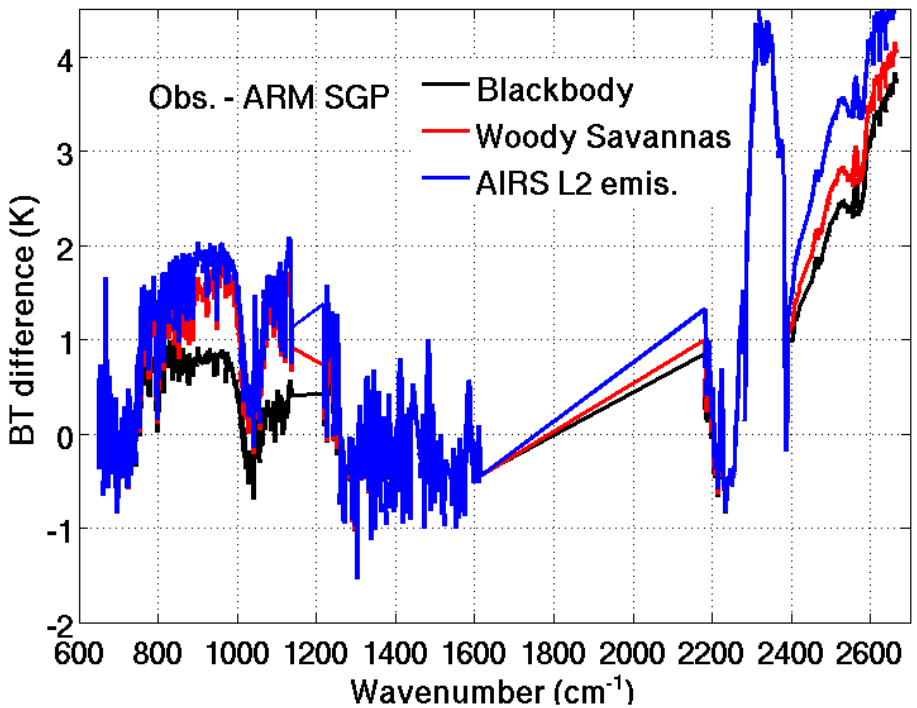
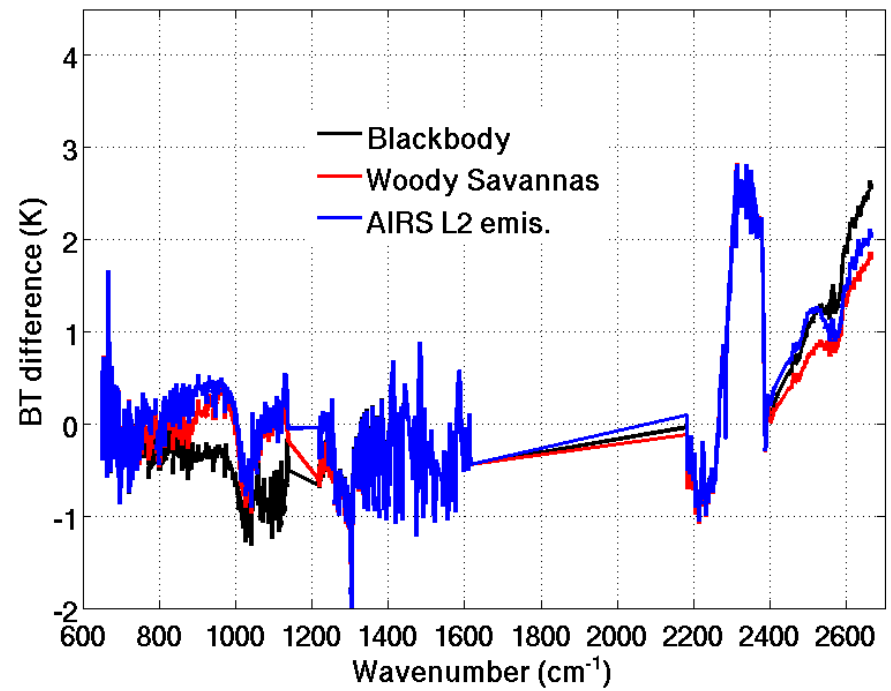
Obs. – ARM SGP

Before

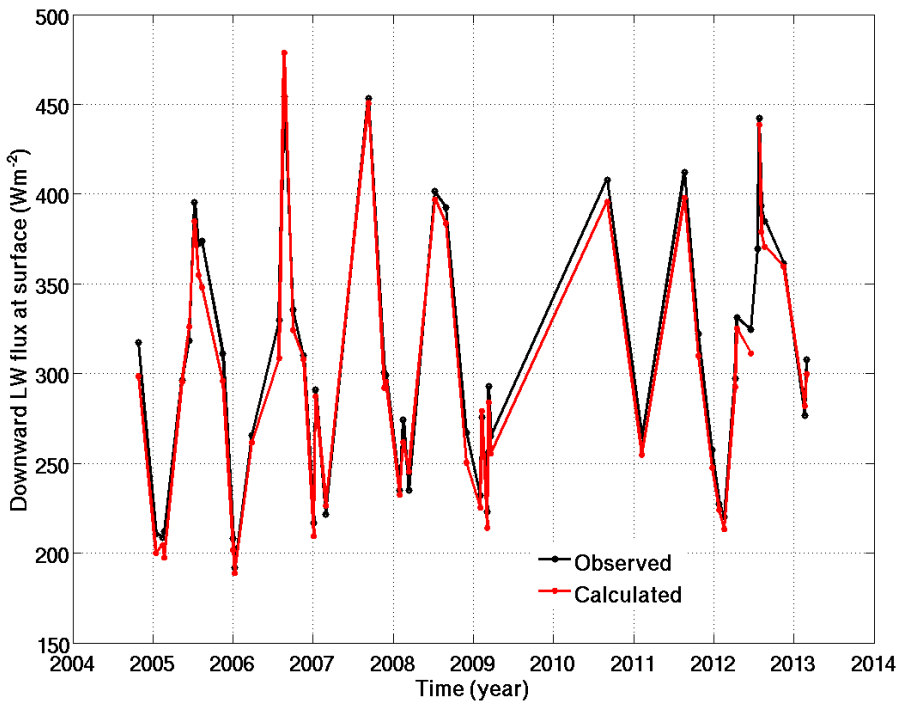


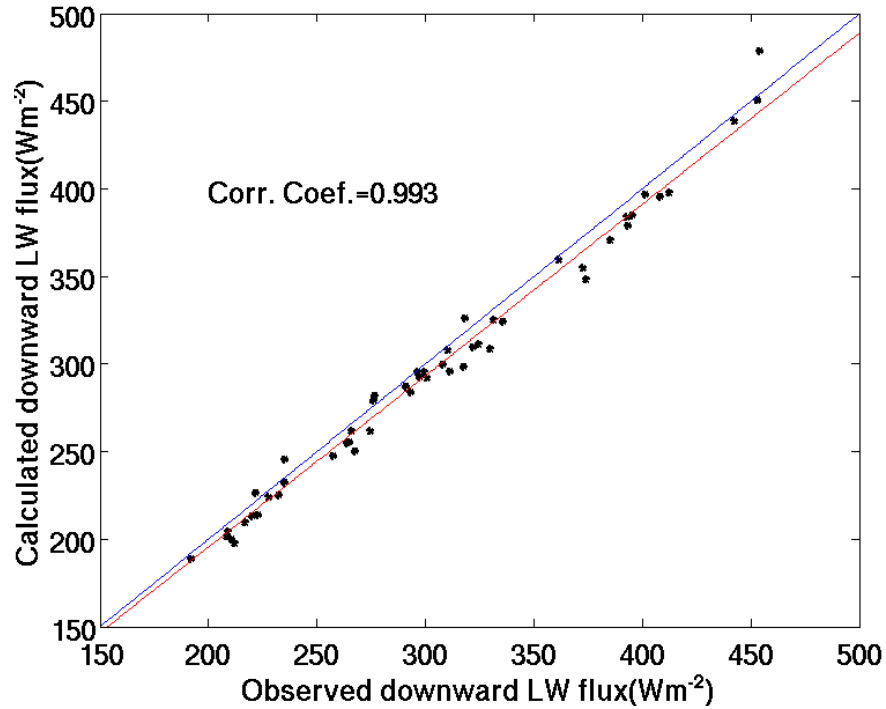
After

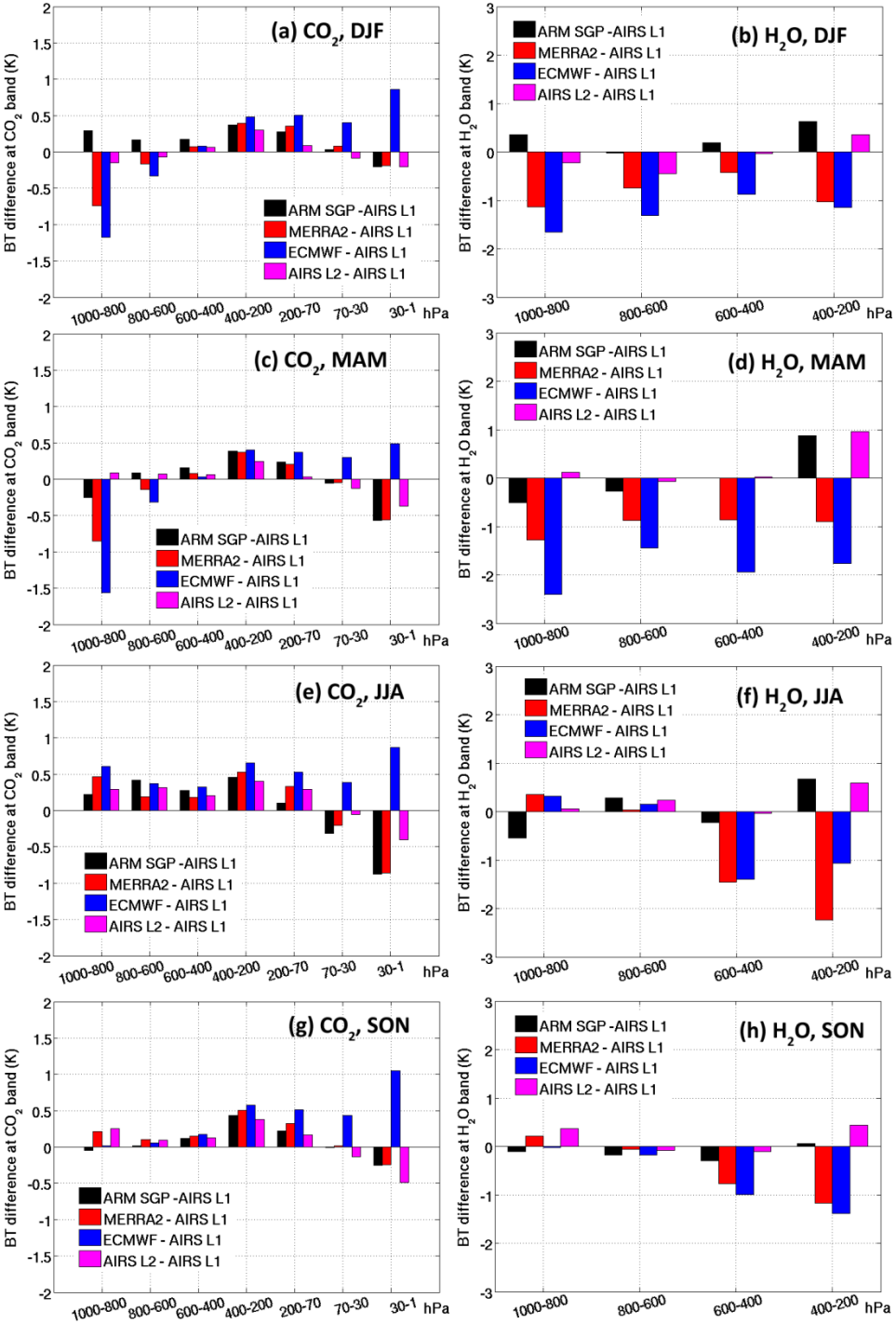


Why blackbody surface has the smallest difference of Obs.-ARM?
Surface thermal inhomogeneity?

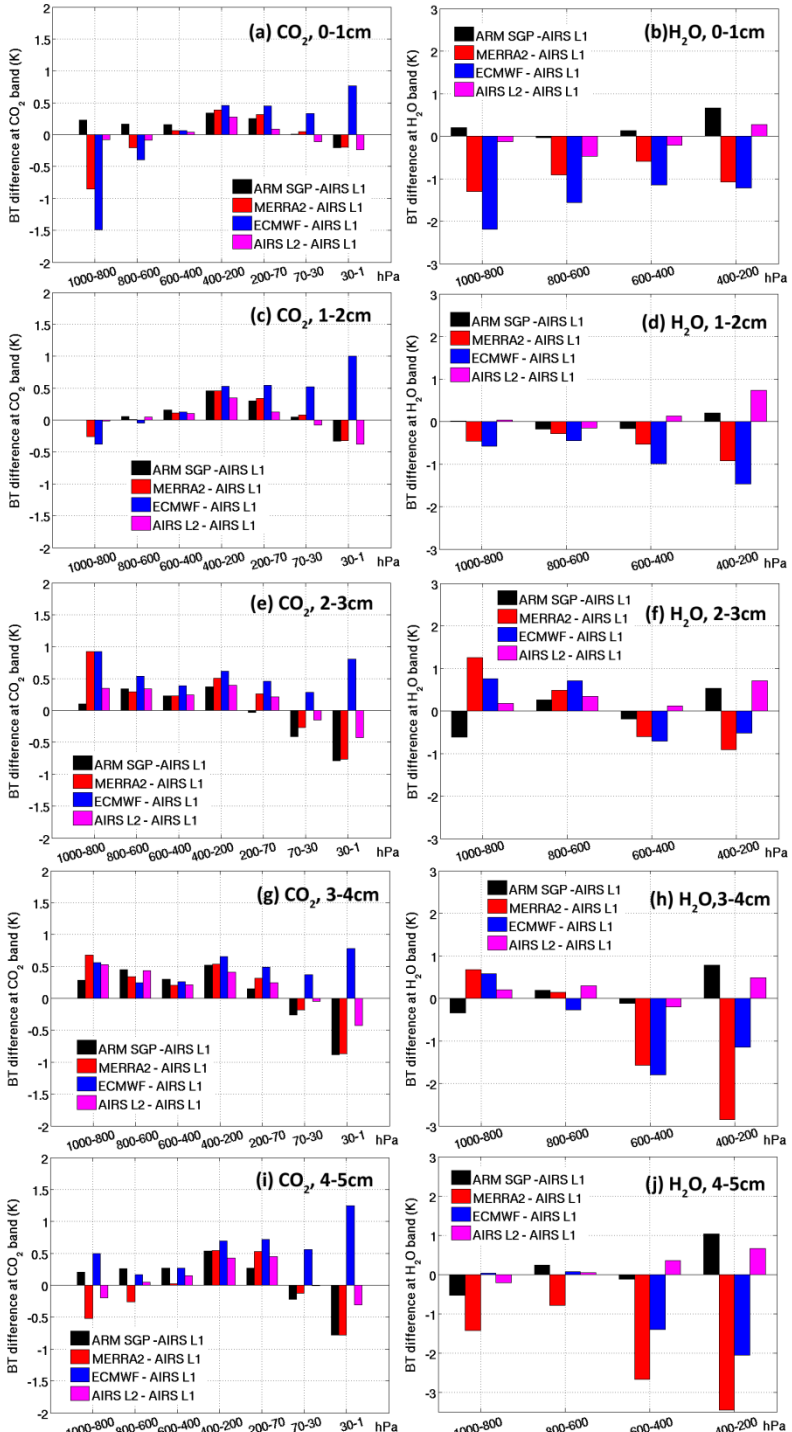
Downward LW flux at surface calculated using MODTRAN5





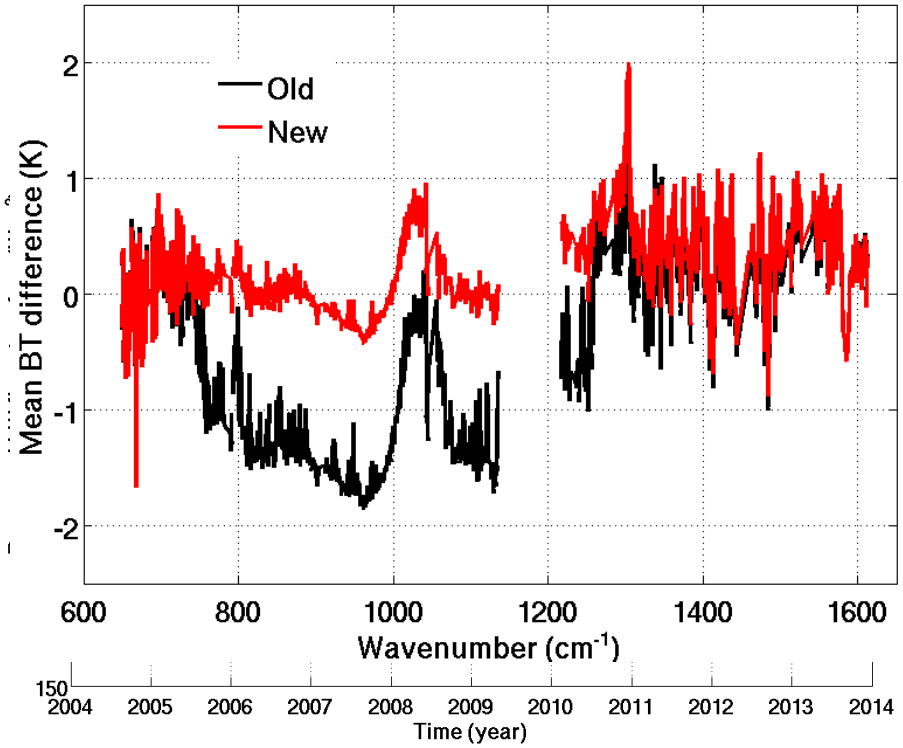


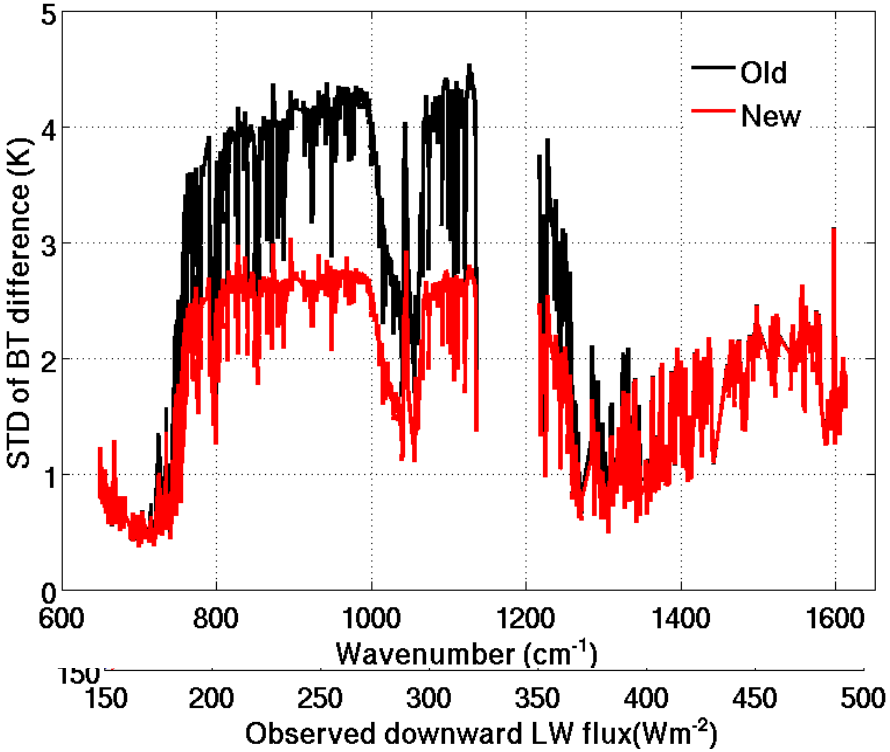
WRT to season



WRT to total column water vapor

Retrieval might be easy. But clear-sky forward modeling is.



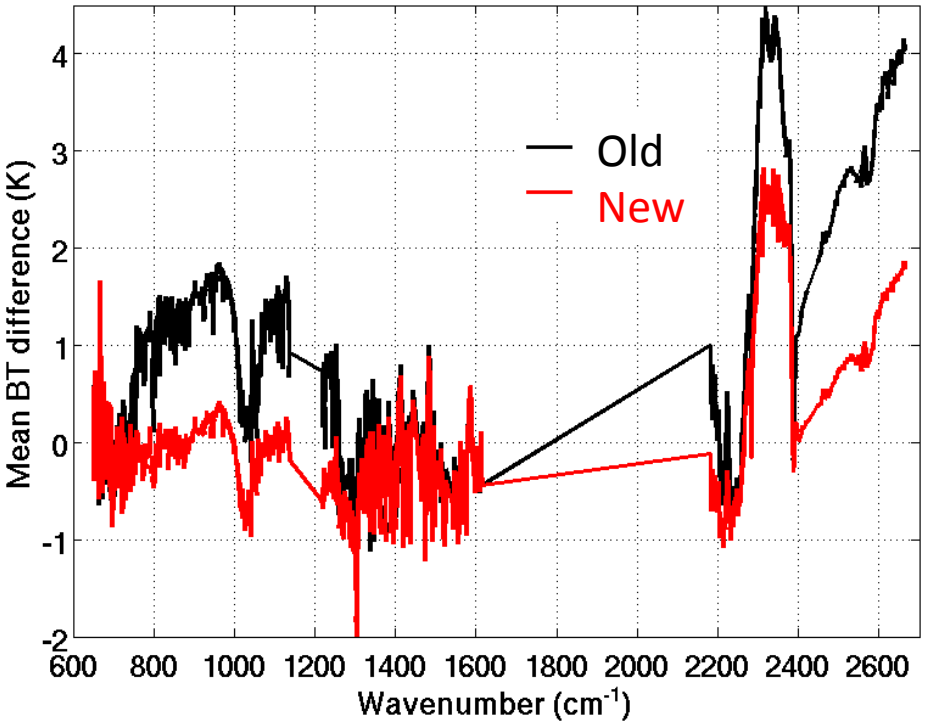


Downward LW flux at surface (obs vs. calculation)

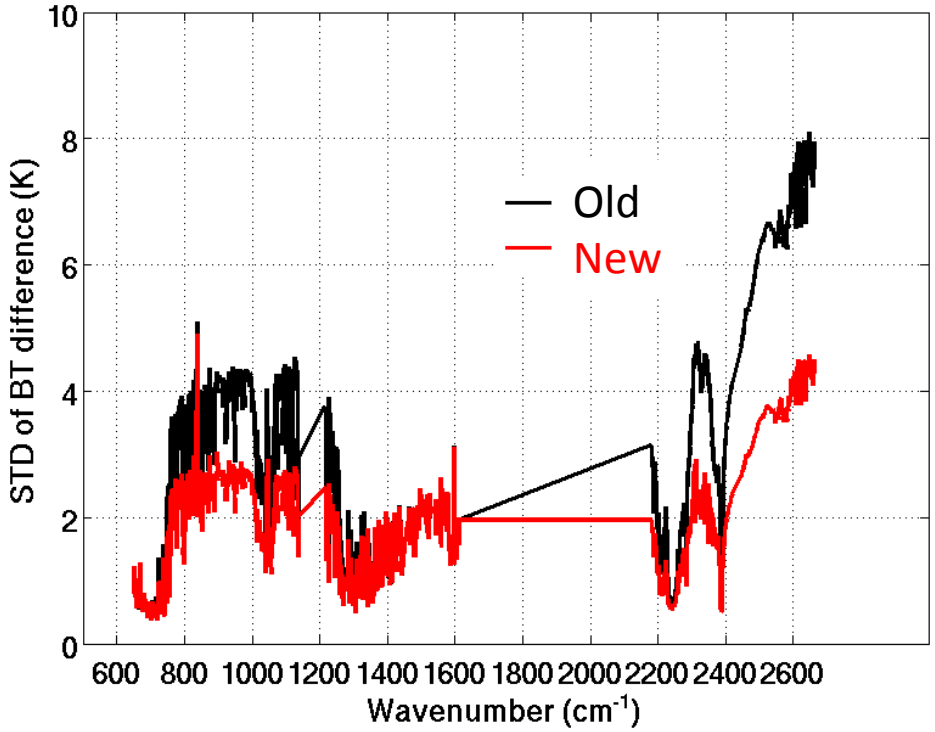
AIRS L1 – Synthetic using ARM SGP data

51 profiles

Mean difference



Standard deviation



Old: surface temperature directly from ARM

New: surface skin temperature from LW measurements @ARM SGP