A hyperspectral closure study using AIRS radiances and ARM ground observations: implication for sounding validations and reanalysis assessments

Xiuhong Chen, Xianglei Huang[1], Norman G. Loeb[2], Xiquan Dong[3], Baike Xi[3], 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 or retrieval against observations, how good is good enough?
- Premise: if two simultaneous **high-quality** observations exist and they differ by Δ (in radiance or in geophysical space), then
  - If retrieval-obs/reanalysis-obs smaller than Δ, then the retrieval or reanalysis is indistinguishable from obs
  - Otherwise, retrieval/reanalysis has bias.

Inversion/Reanalysis

Obs1

Inversion/Reanalysis

Obs2

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

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
  - Millimeter wave Cloud Radar (MMCR): 30km-by-30km scan for cloud (eliminate ambiguity about satellite clear-sky detection)
  - Raman lidar for T (<0.3K) and q (~0.4%)
  - Surface temperature and surface radiation

CAPABILITIES > INSTRUMENTS

MMCR

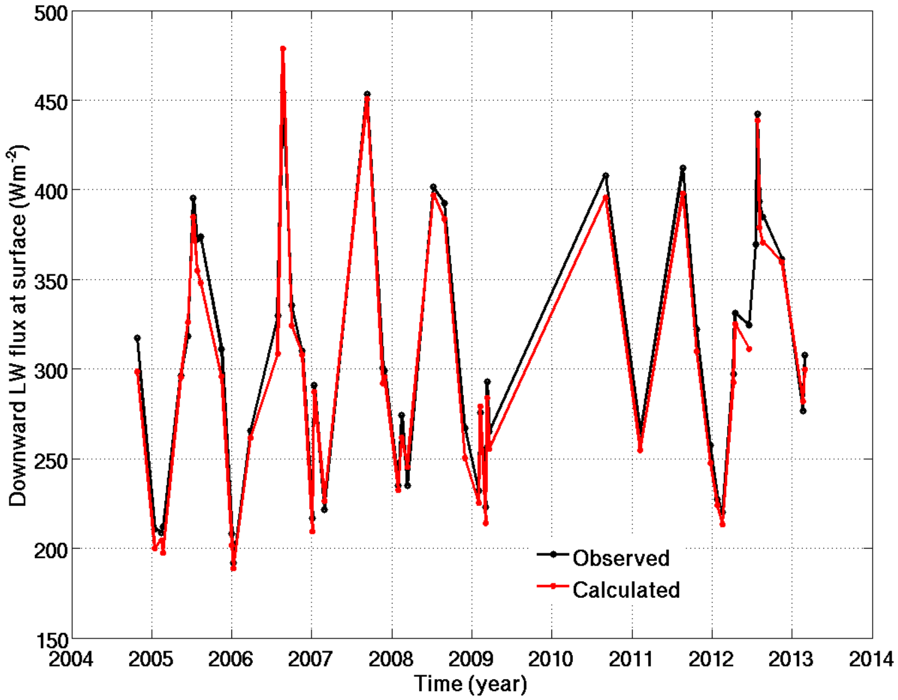
MMCR: MILLIMETER WAVELENGTH CLOUD RADAR

The millimeter wavelength cloud radar (MMCR) systems probe the extent and composition of clouds at millimeter wavelengths. The MMCR is a zenith-pointing radar that operates at a frequency of 35 GHz. The main purpose of this radar is to determine cloud boundaries (e.g., bottoms and tops). This radar will also report radar reflectivity (dBZ) of the atmosphere up to 20 km. The radar has a Doppler capability that allows measurement of cloud constituent vertical velocities.

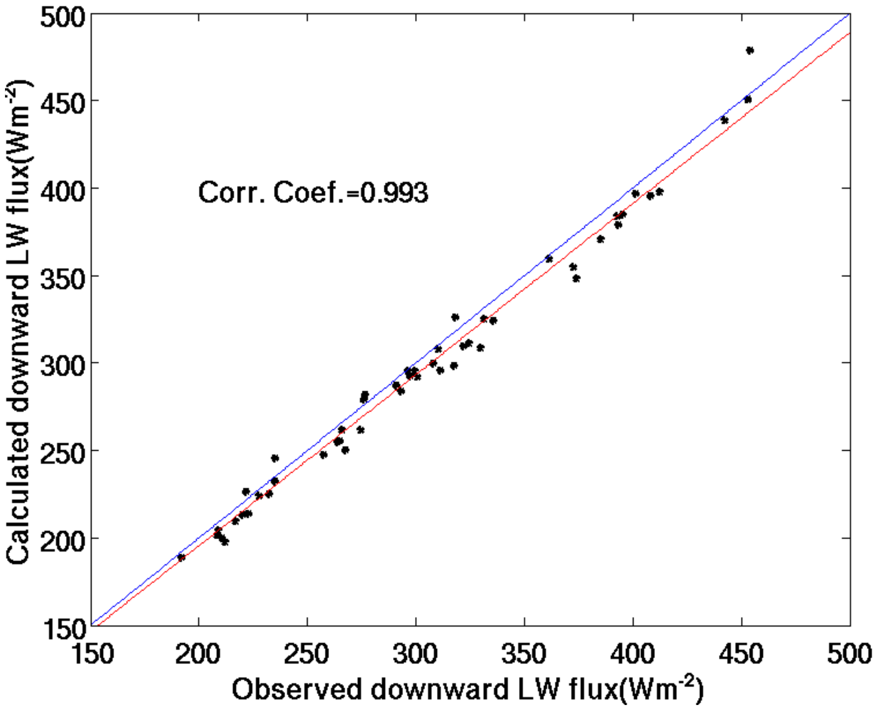
(from ARM facility website)

Downward LW flux at surface calculated using MODTRAN5

Forward modeling is straightforward



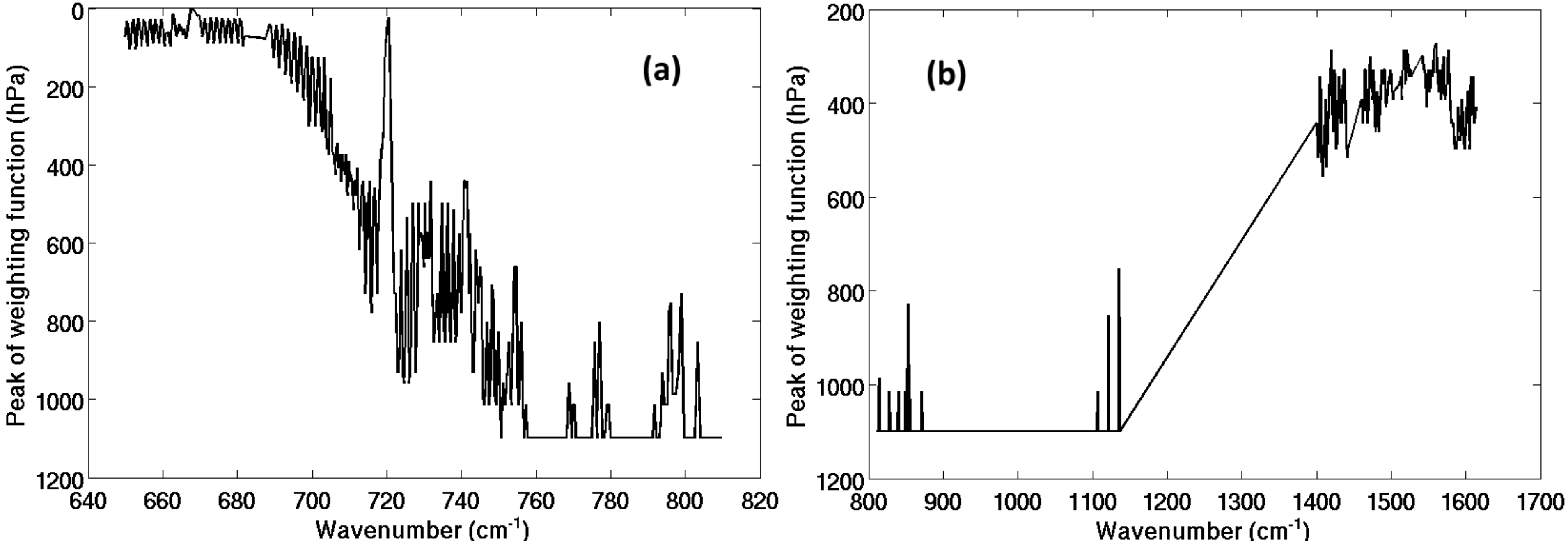
Regression slope:0.9934



Approach

- Using ARM MMCR to identify clear-sky scene (30km-30km) 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 but not by other greenhouse gases (done with LBLRTM/HITRAN/AIRS SRF)
- Group selected channels according to the peaks of their weighting functions
- Make comparisons in radiance space and for each such group

Grouping channels based on the peaks of their W.F. (LBLRTM cal.)



	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

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

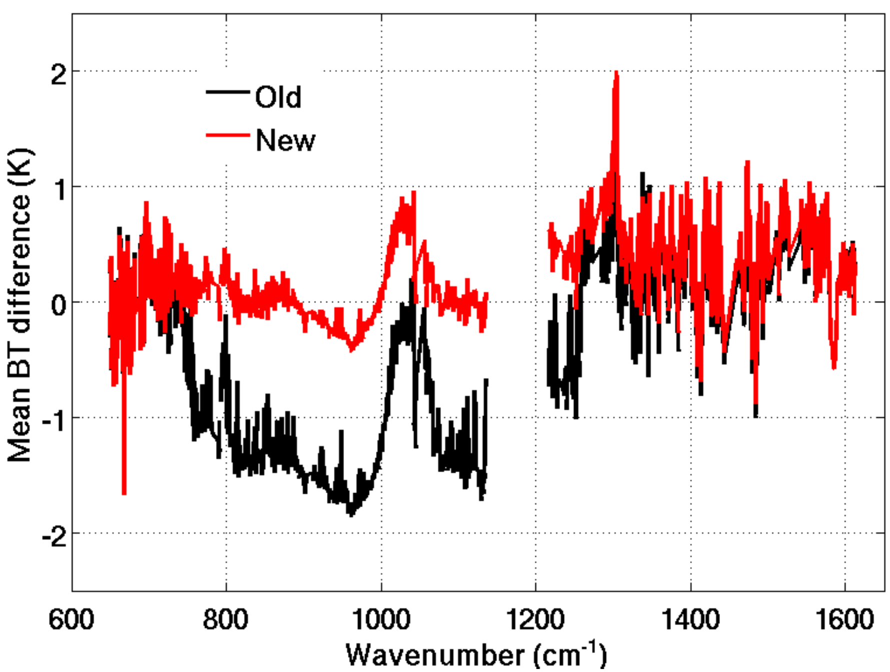
Still using woody savannas emissivity

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

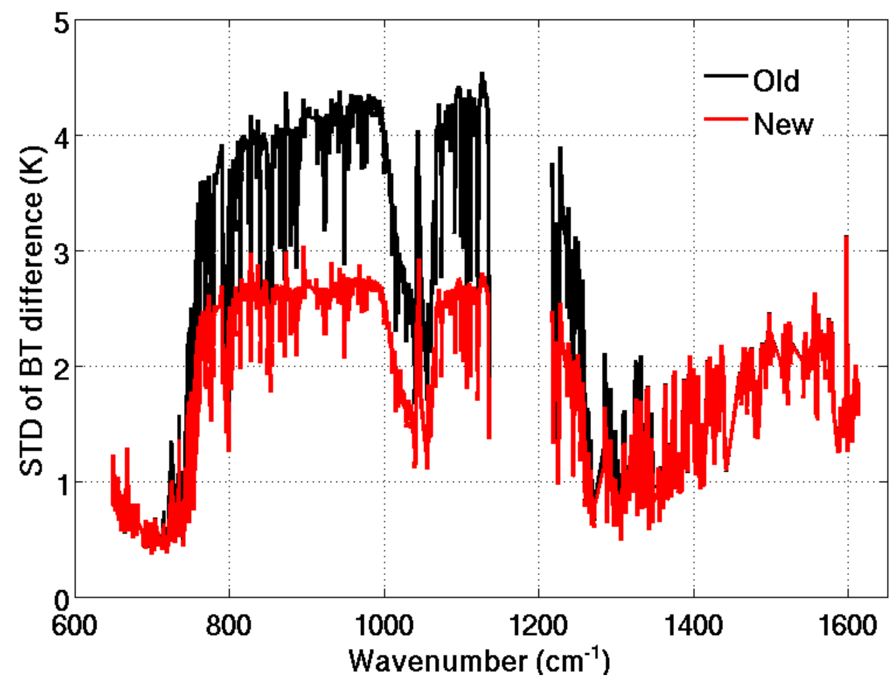
Synthetic – AIRS L1 using ARM SGP data

51 profiles

Mean difference



Standard deviation

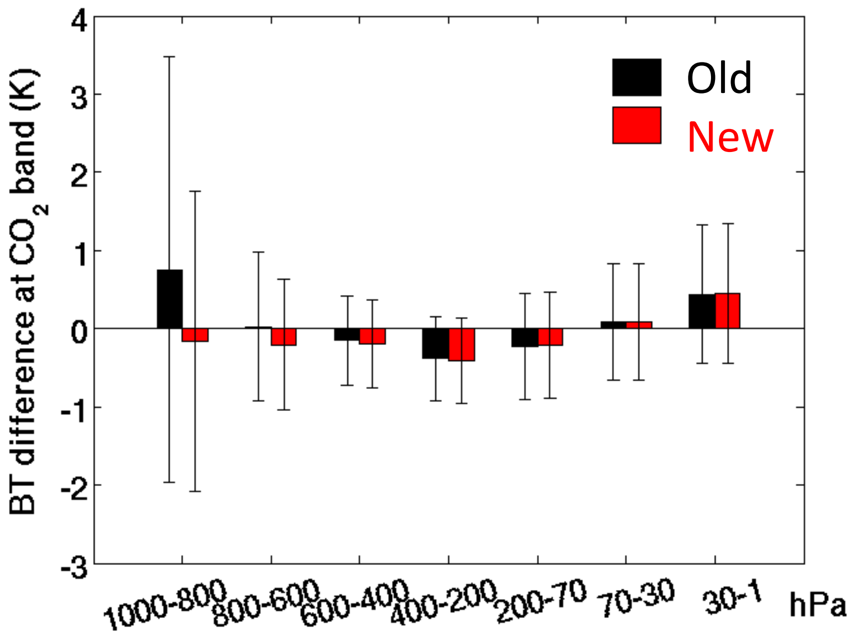


Old: surface temperature directly from ARM

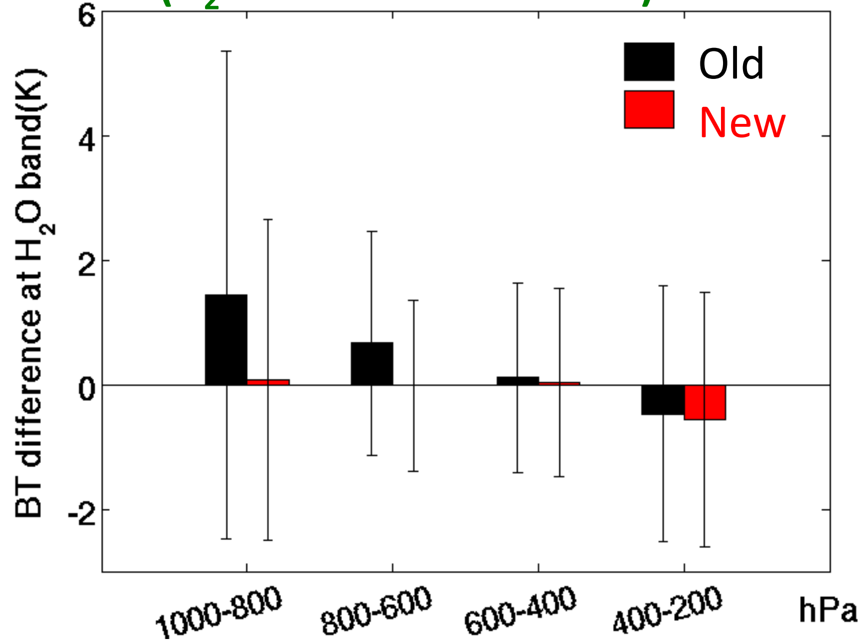
New: surface skin temperature from LW measurements @ARM SGP

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

Channels sensitive to T (CO_2 band)

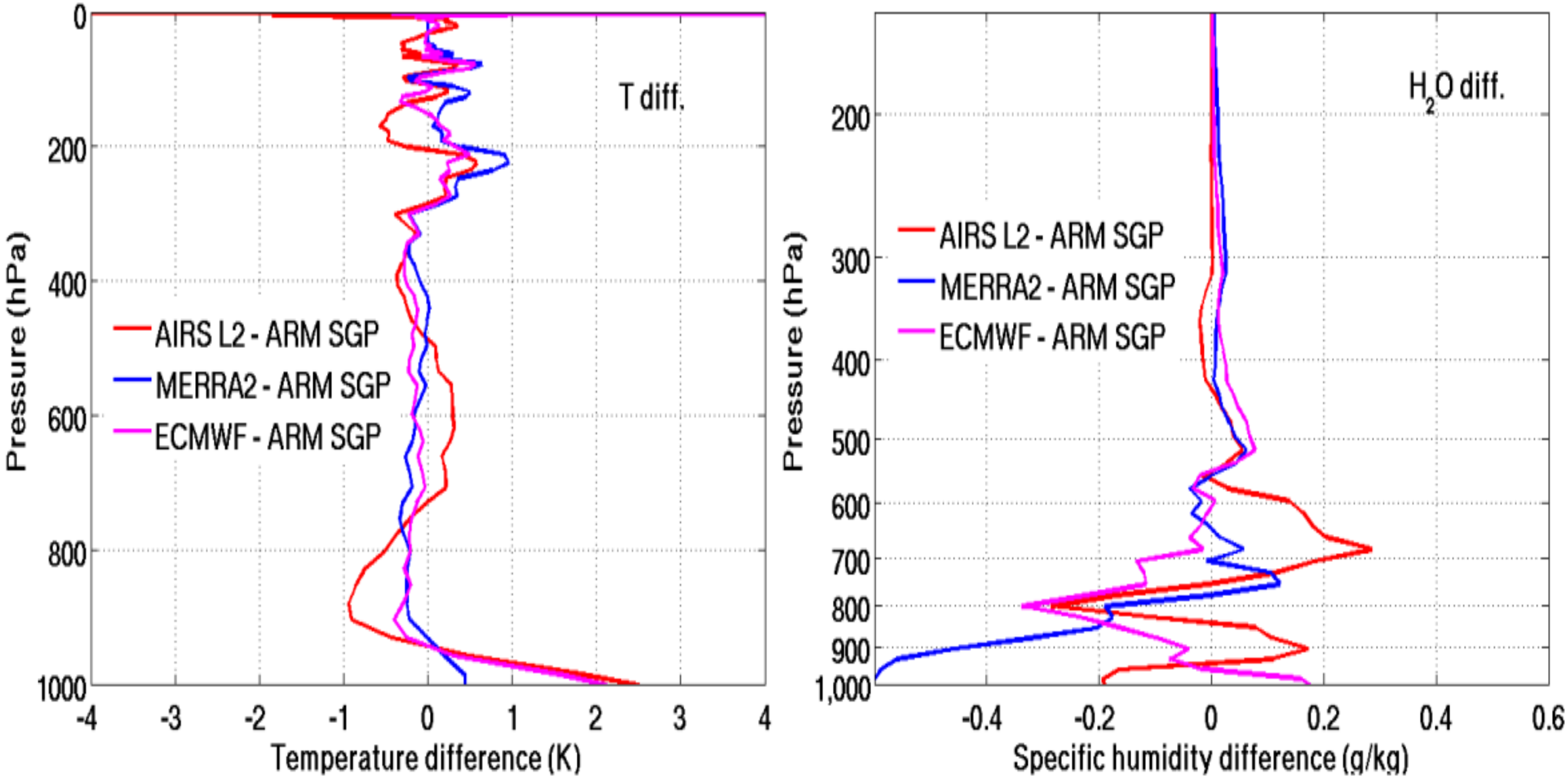


Channels sensitive to T & q (H_2O and window bands)



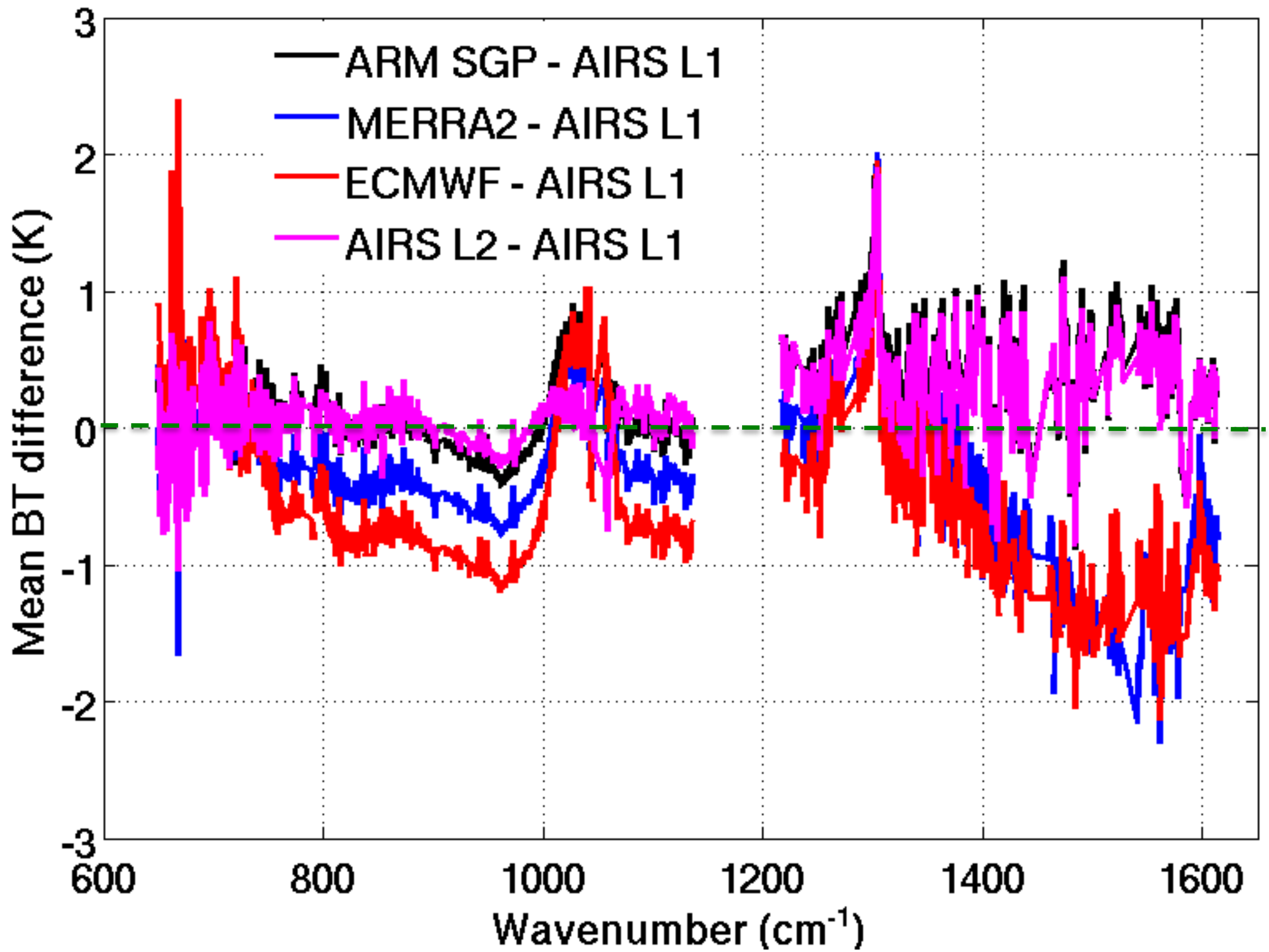
Red bars are the uncertainties bracketed by AIRS L1 and ARM-SGP

Direct T & q comparisons

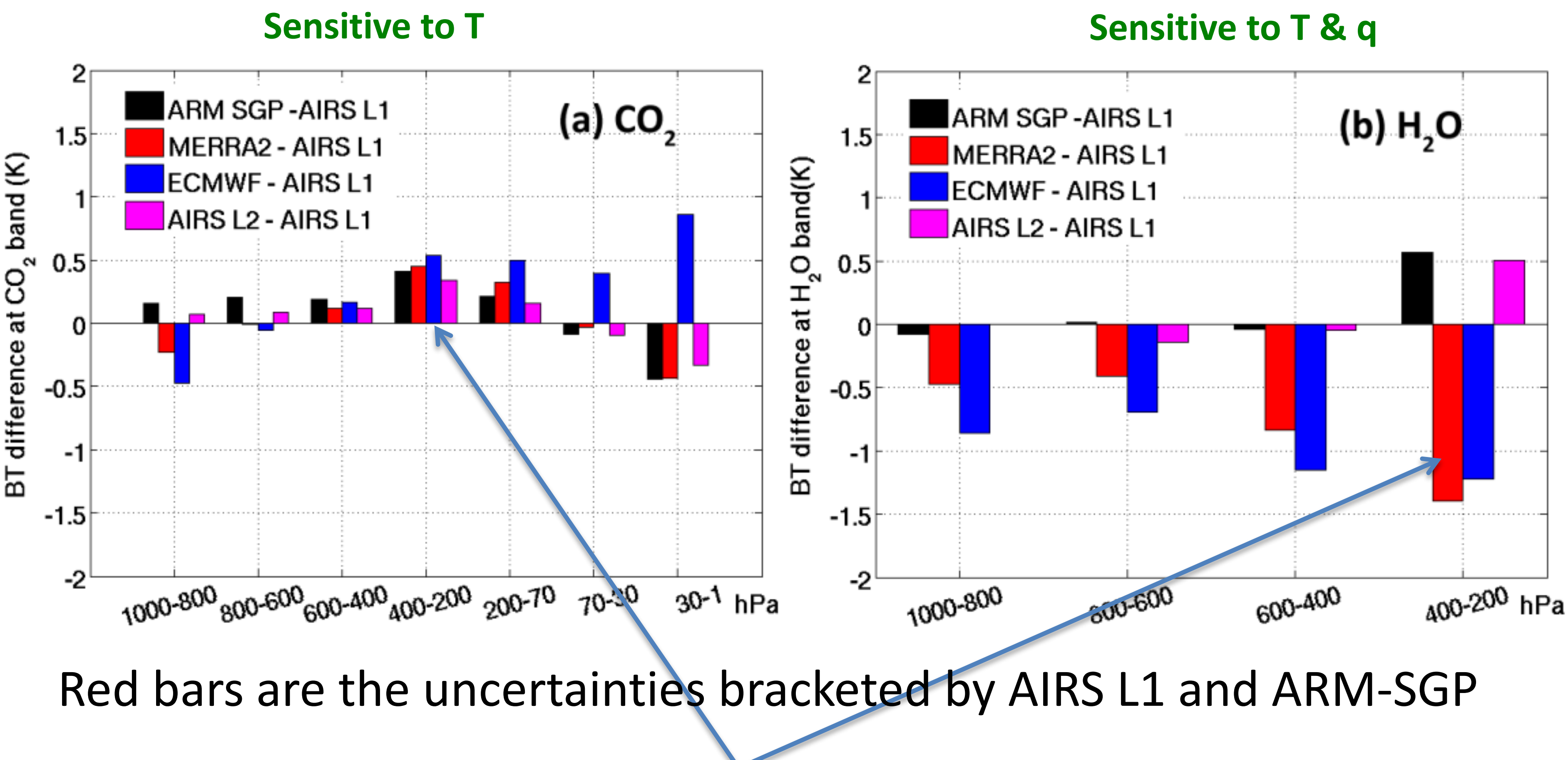


Results

Synthetic mean spectrum – AIRS mean spectrum



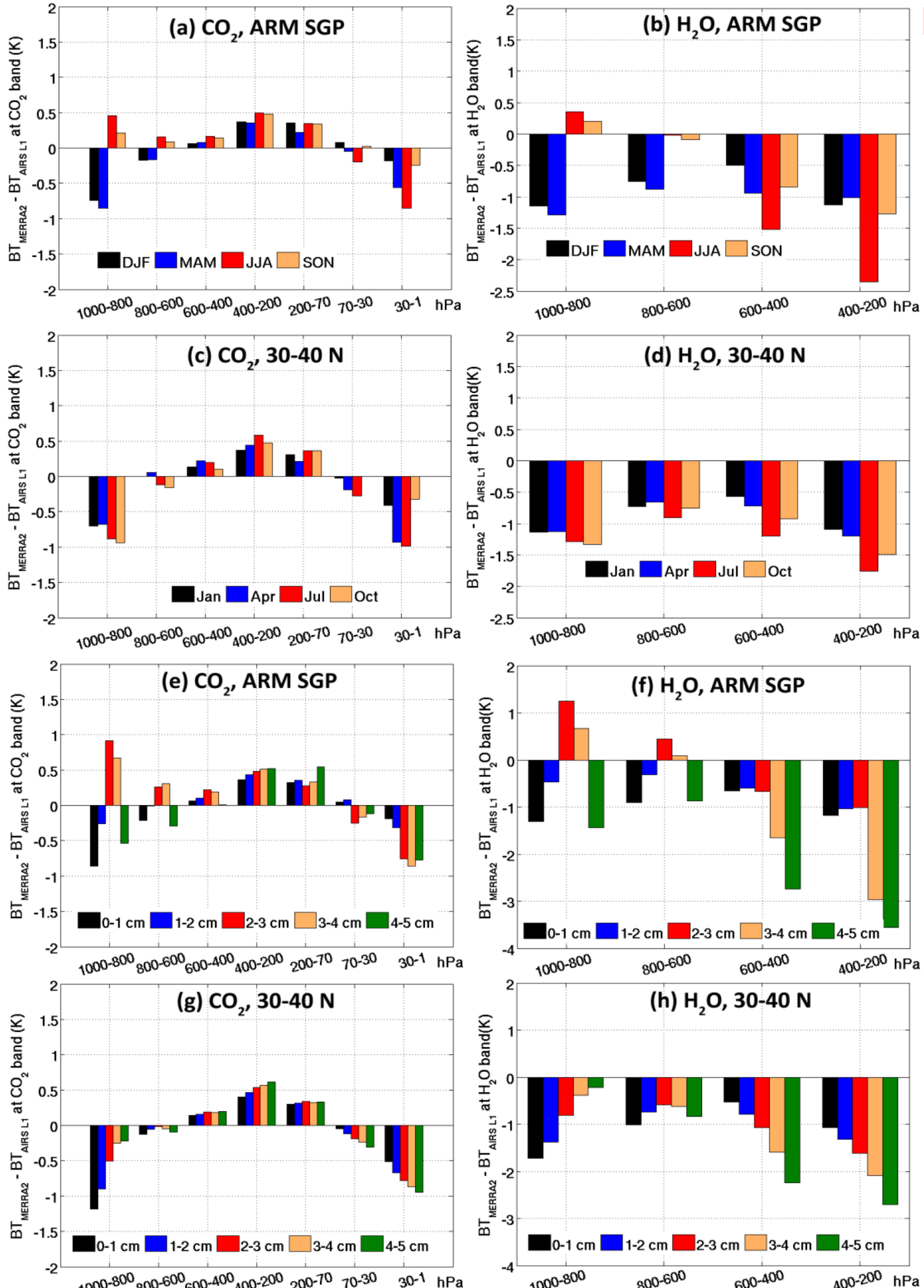
BT Difference in grouped channels



Red bars are the uncertainties bracketed by AIRS L1 and ARM-SGP

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

- In radiance space: AIRS L1 and synthetic ARM-SGP clear-sky radiances agree well, with 0.5K in BT for all groups.
- AIRS L2 retrievals perform well, bracketed within L1 and ARM-SGP
- Both ERA-interim and MERRA show wet bias in 600-200 hPa, for ARM-SGP site and for the entire latitude band.
- 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)

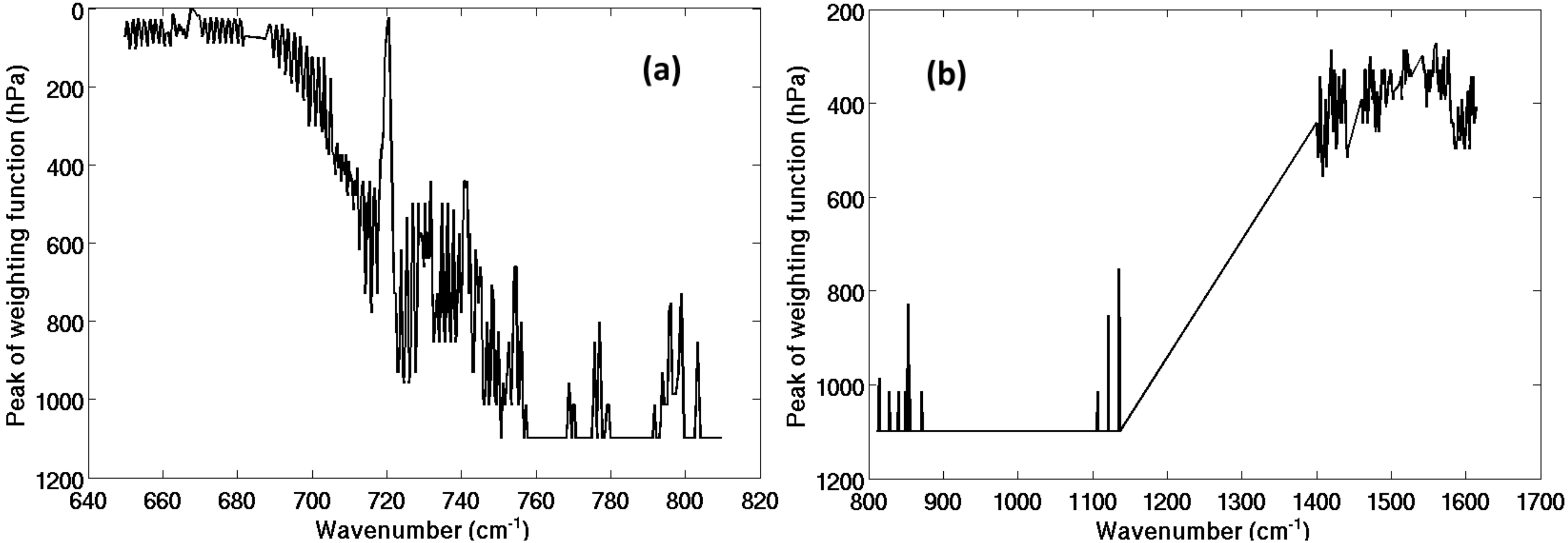
  3-hourly MERRA-2 data on a horizontal grid of 0.5° latitude by 0.625° longitude with 42 vertical levels up to 0.1 hPa
- ECMWF ERA-Interim (T, q, o3)

  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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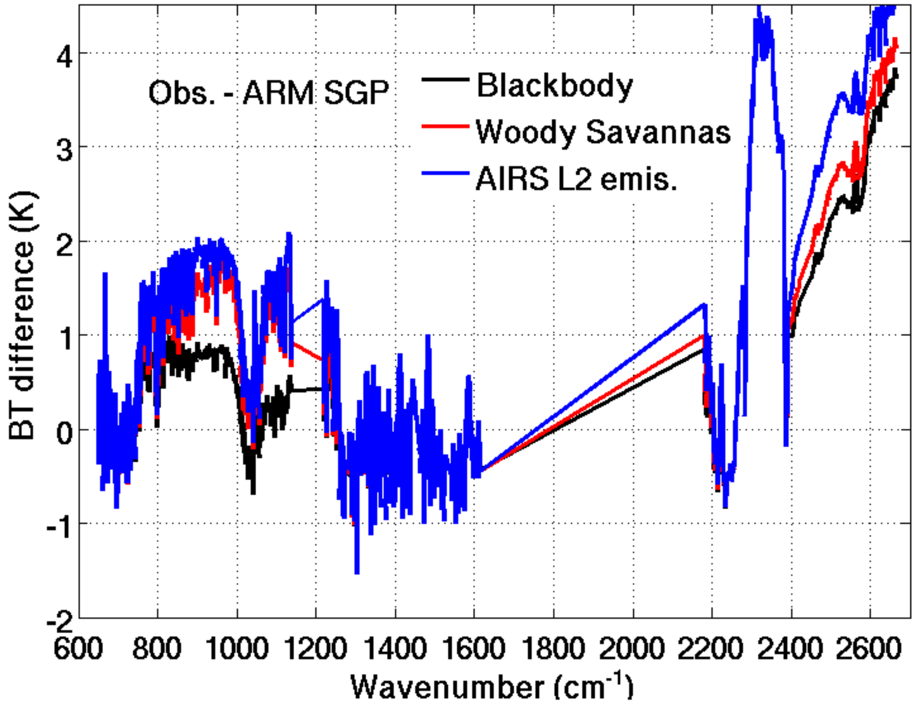
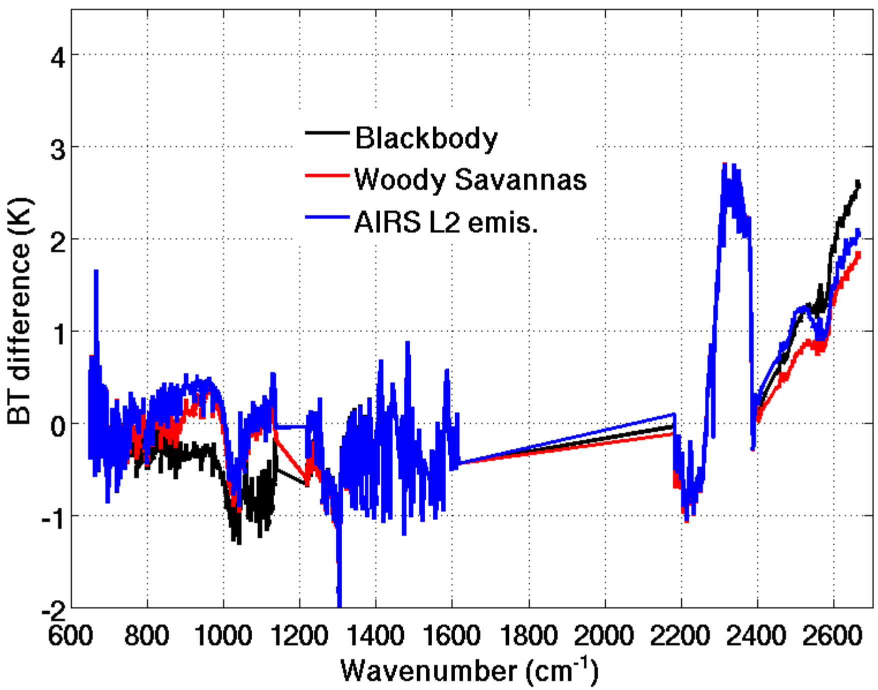
Obs. – ARM SGP

Before

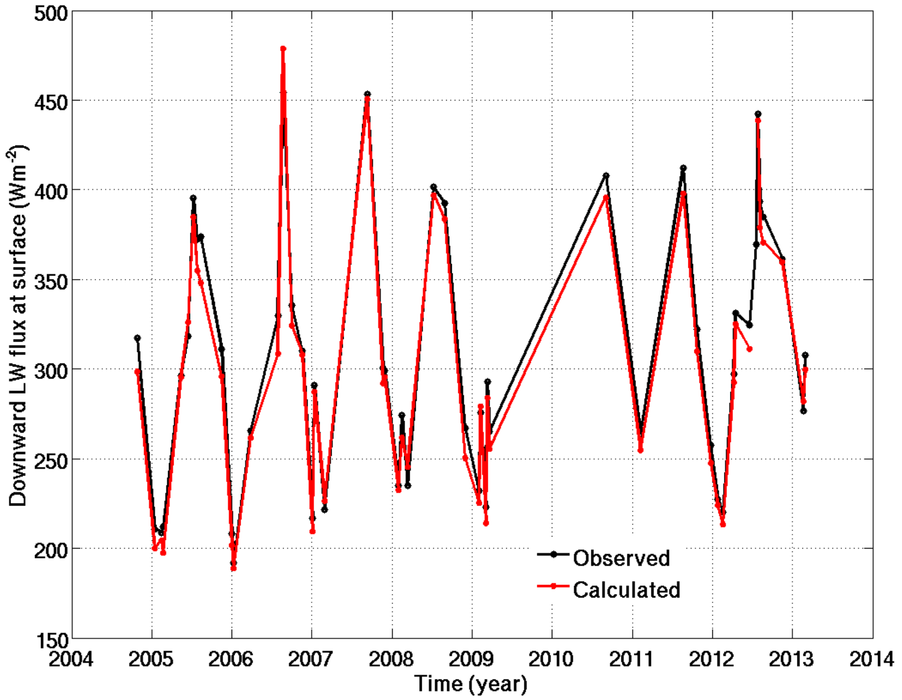


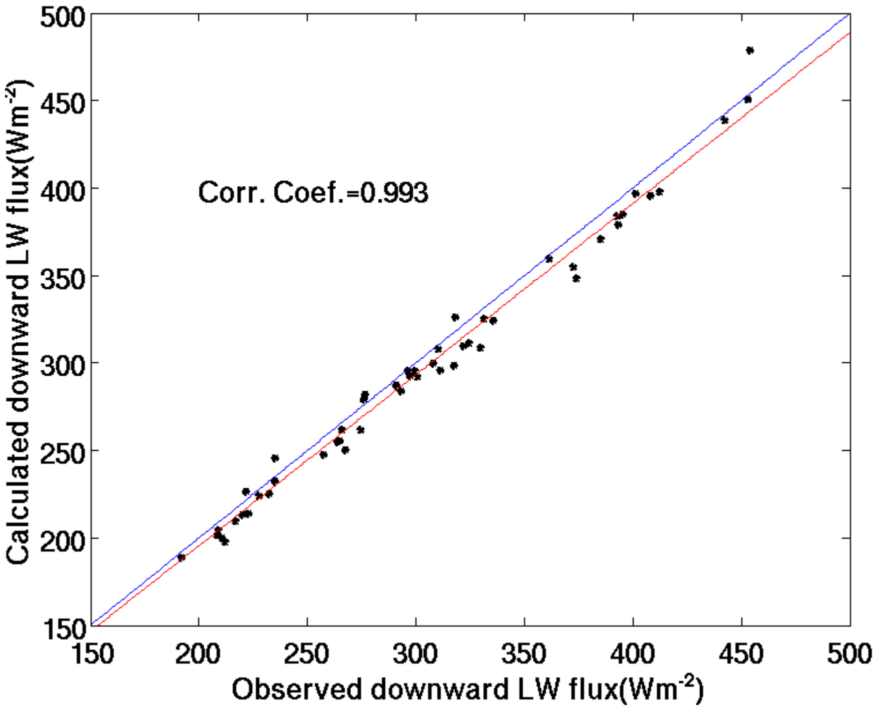
After

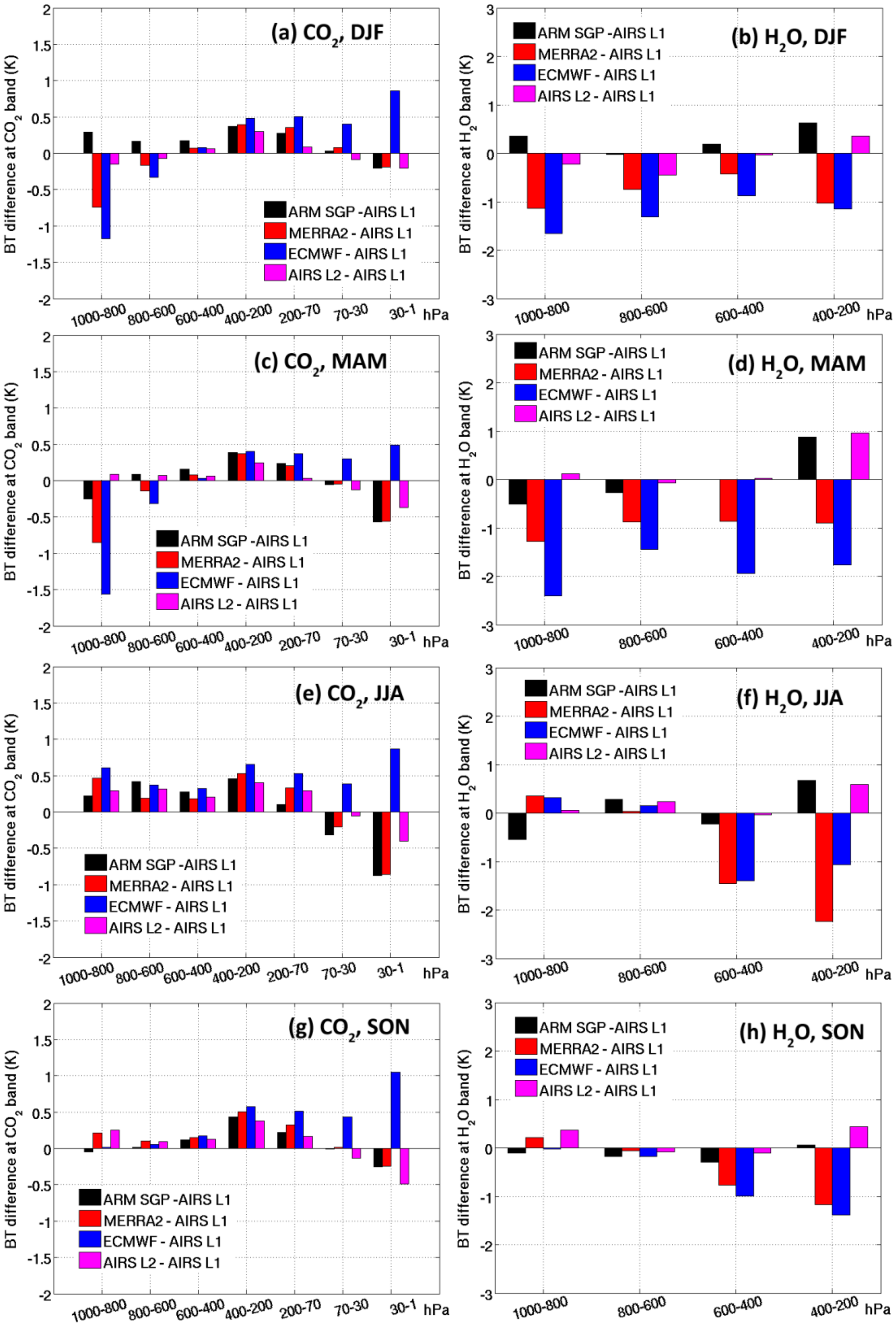


Why blackbody surface has the smallest difference of Obs.-ARM?
Surface thermal inhomogeneity?

Downward LW flux at surface calculated using MODTRAN5

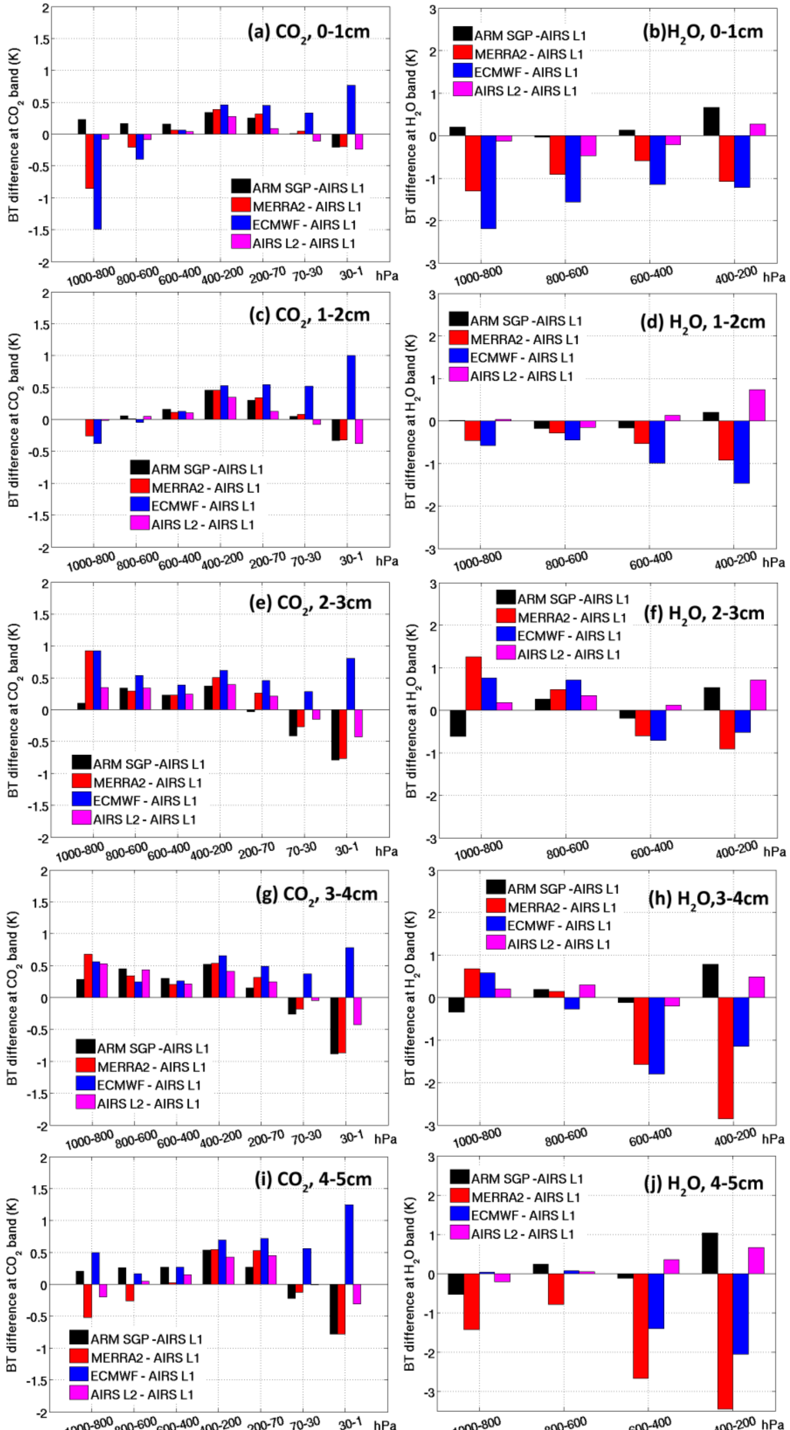




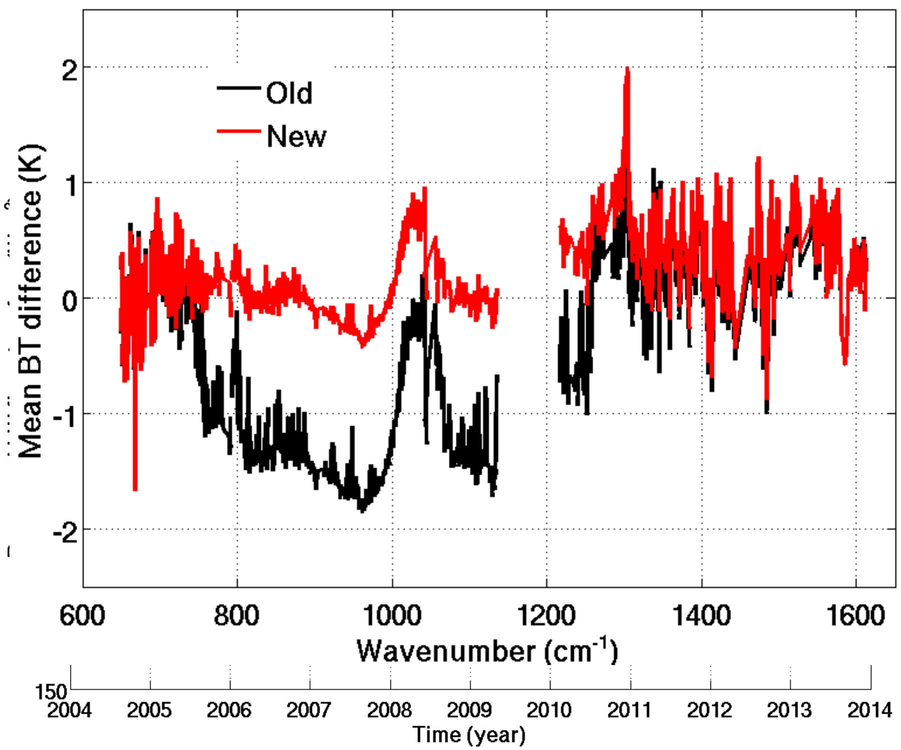


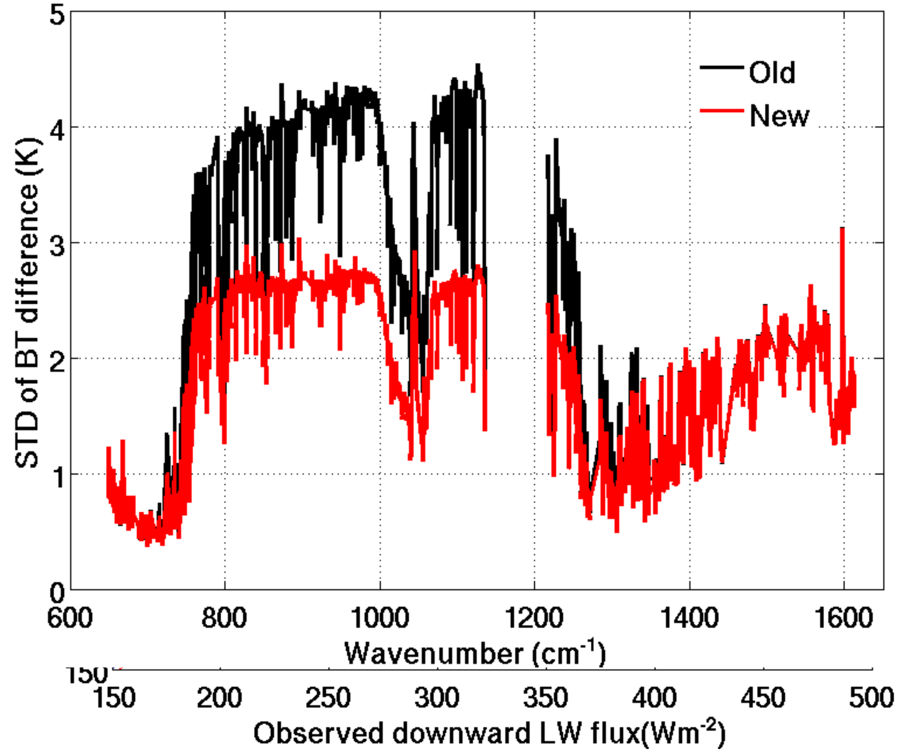
WRT to season

WRT to total column water vapor



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

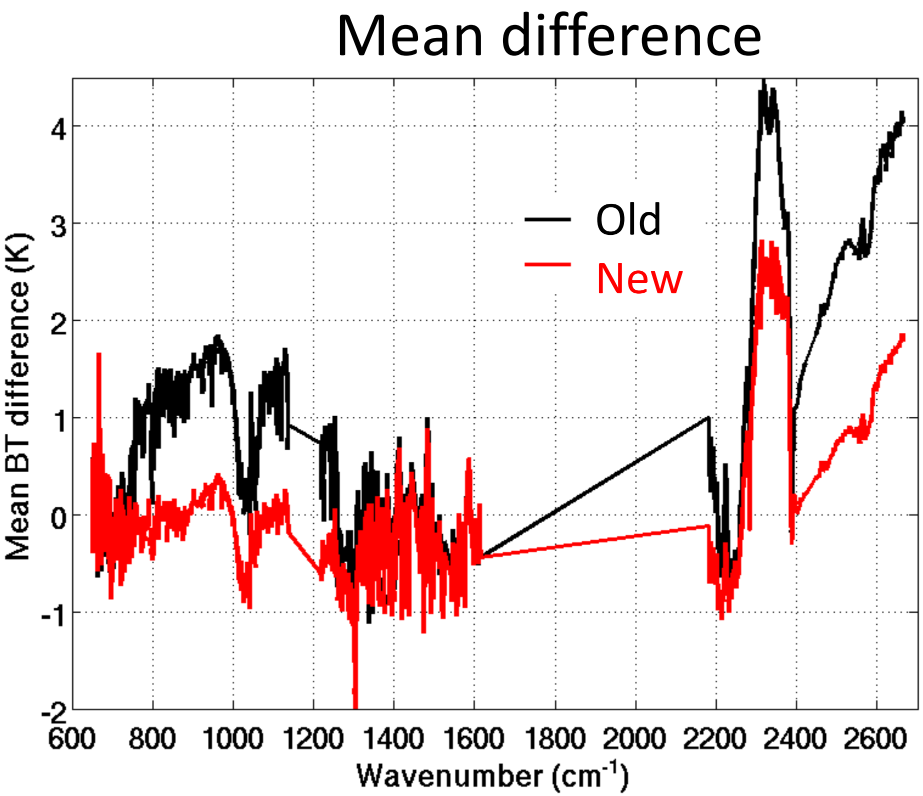


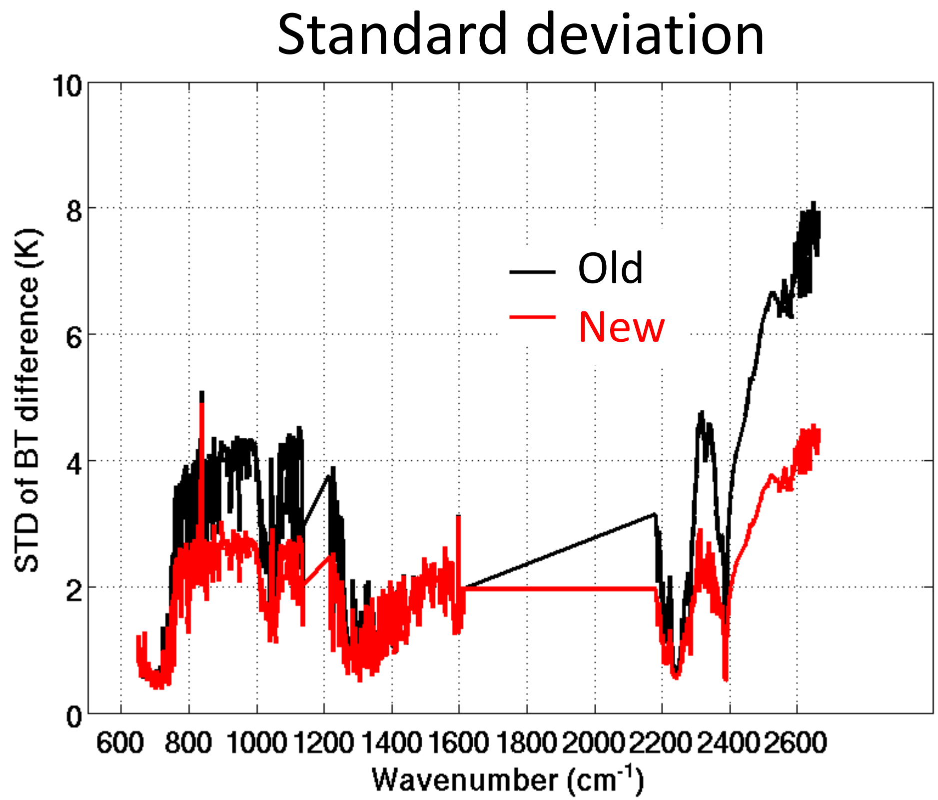


Downward LW flux at surface (obs vs. calculation)

AIRS L1 – Synthetic using ARM SGP data

51 profiles





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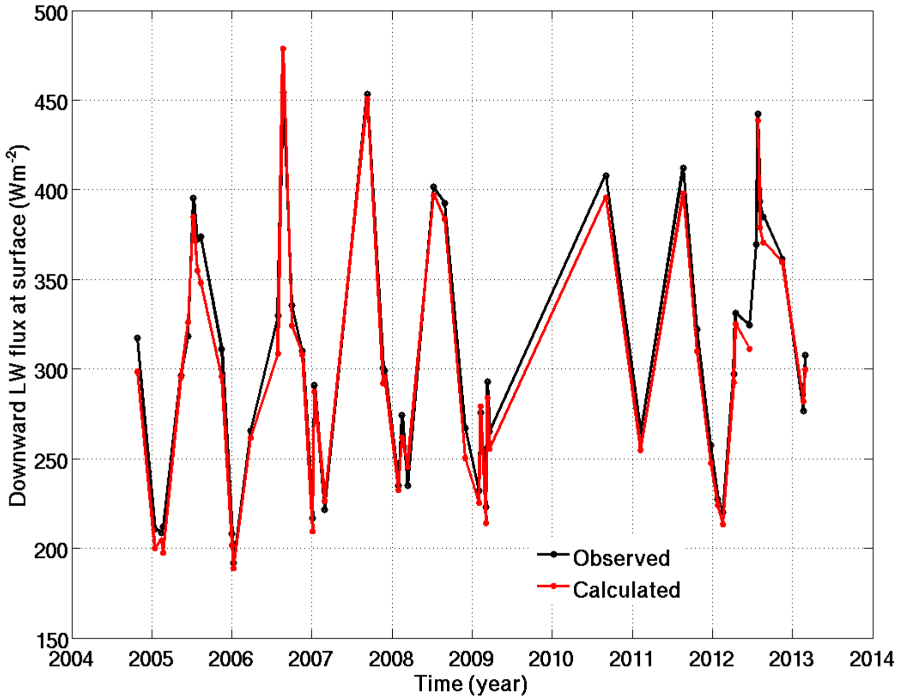

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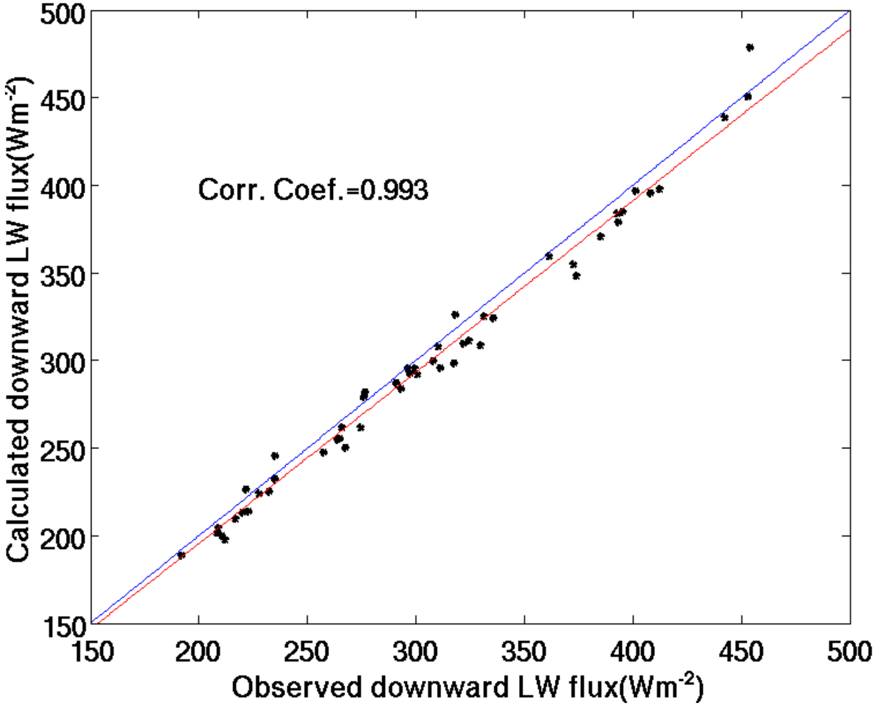

AIRS (Atmospheric Infrared Sounder)

Table 1. AIRS Standard Products in Version 5.0

Product	RMS Requirement	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