Update of 2014 CLARREO Publications

Jacola Roman, R. Knuteson, S. Ackerman, et al. 2014: ***Time-To-Detect Trends in Precipitable Water Vapor with Varying Measurement Error***. J. Climate, accepted, in press for next issue.

Jacola Roman, R. Knuteson, S. Ackerman, et al. 2014: ***Predicted Changes in the Frequency of Extreme Precipitable Water Vapor Events***. J. Climate (Recently submitted)

Jacola Roman, R. Knuteson, S. Ackerman, H. Revercomb, 2014: ***Measurement and Sampling Requirements for Satellite Remote Sensing of Precipitable Water Vapor in a Changing Climate***, EUMETSAT Climate Symposium, 13-17 Oct 2014, Darmstadt, Germany http://www.theclimatesymposium2014.com/

Michelle Feltz, R. Knuteson, S. Ackerman, D. Tobin, and H. Revercomb, 2014, ***A methodology for the validation of temperature profiles from hyperspectral infrared sounders using GPS radio occultation: Experience with AIRS and COSMIC***, J. Geophys. Res. Atmos., 119.

Michelle Feltz, R. Knuteson, S. Ackerman, and H. Revercomb, 2014, ***Application of GPS Radio Occultation to the Assessment of Temperature Profile Retrievals from Microwave and Infrared Sounders***, Atmospheric Measurement Techniques, accepted, *in press*.

Combining IR and GPS RO in the Determination of Stratospheric Temperature Trends: Recent Results on COSMIC and GRAS Biases

Robert Knuteson[1]*, **Michelle Feltz[2]**, Steve Ackerman[3], Hank Revercomb[1] , Dan DeSlover[1], Dave Tobin[1]

[1]Space Science and Engineering Center(SSEC)
[2]University of Wisconsin-AOS Department
[3]Cooperative Institute for Meteorological Satellite Studies(CIMSS)

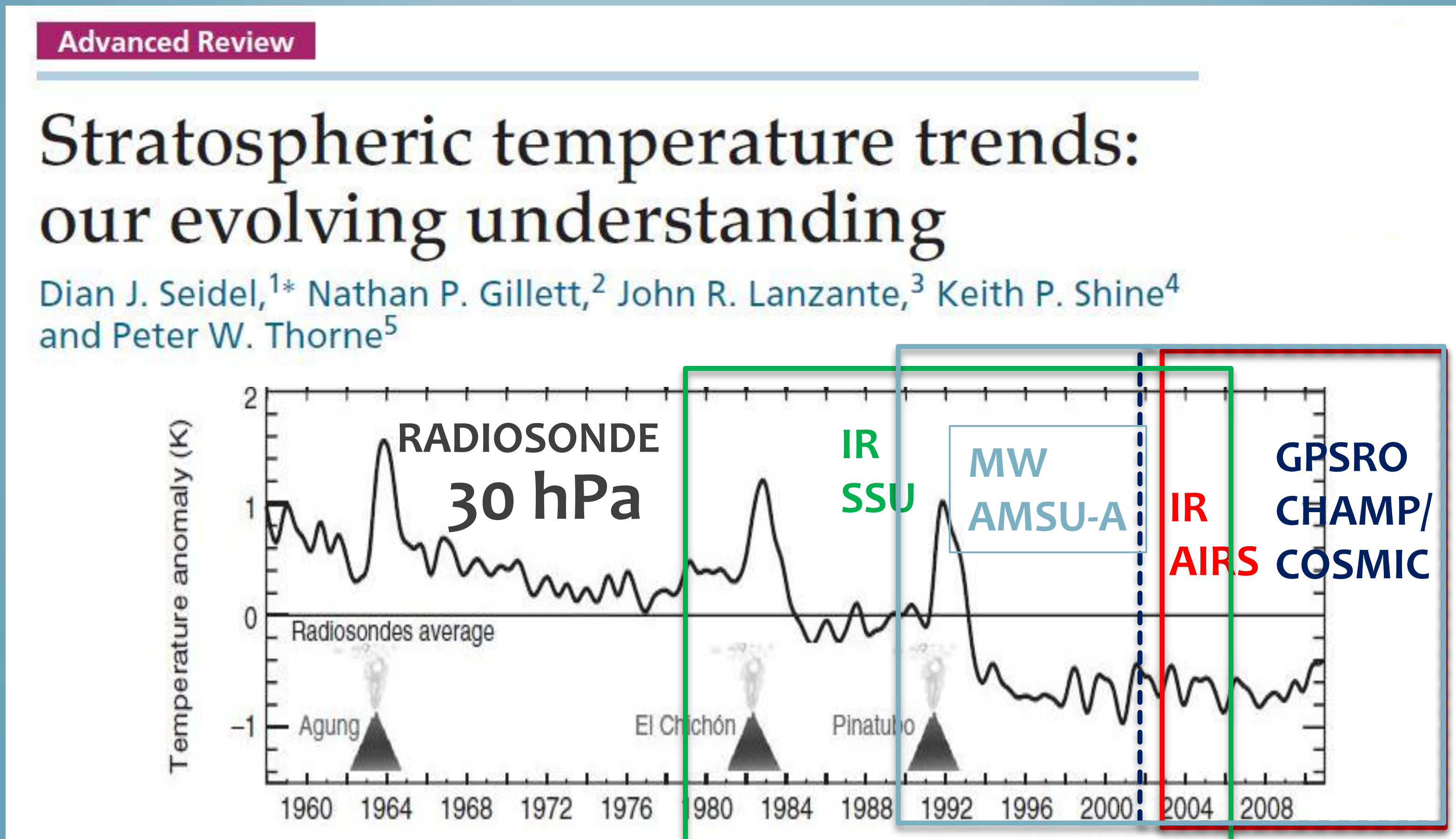
29 Oct 2014

CLARREO SDT Meeting, Hampton, VA

Outline of Talk

- Review what is known about stratospheric temperature TRENDS
- Characteristics of past, current, and future SENSORS
- Science questions of Zonal/Seasonal Patterns in Stratosphere
- Decadal Observed IR B.T. trends (Lower and Upper Stratosphere)
- Assessment of IR using GPS RO (using RO as reference)
- Assessment of GPS RO using IR (using IR as reference)
- Conclusions/Future Work

Lower Stratosphere Historical Radiosonde Temperature Monitoring



WIREs Clim Change **2011 vol 2 pp592–616 DOI: 10.1002/wcc.125**

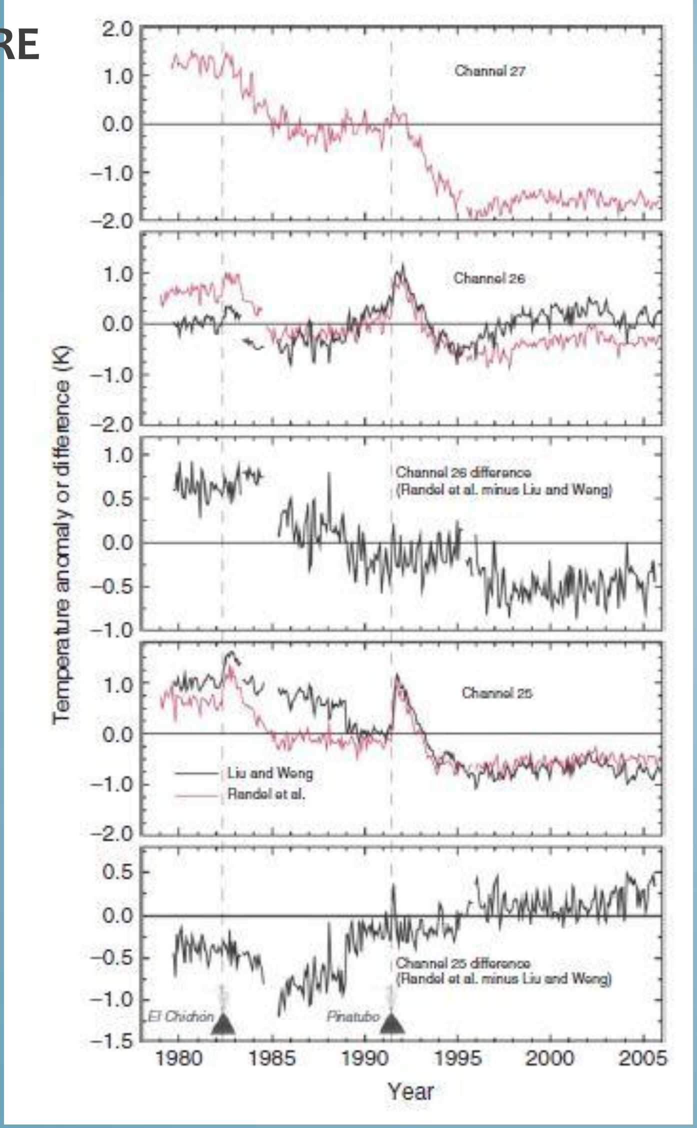
- 50 year radiosonde **Lower Stratosphere** Temperature: cooling 1958-1995 then **constant since 1996**.

STRATOSPHERE

UPPER

MIDDLE

LOWER



HERITAGE SATELLITE SOUNDER

SSU channel 27

SSU channel 26

SSU channel 26
Structural Uncertainty

SSU channel 25

SSU channel 25
Structural Uncertainty

WIREs Clim Change 2011 vol 2 pp592–616 DOI: 10.1002/wcc.125

- 25 year Satellite Stratospheric Sounder Temperature record: cooling 1979-1995 then constant through 2005? Lots of issues!!

Estimating low-frequency variability and trends in atmospheric temperature using ERA-Interim

Quarterly Journal of the Royal Meteorological Society   *Q. J. R. Meteorol. Soc.* 140: 329–353, January 2014

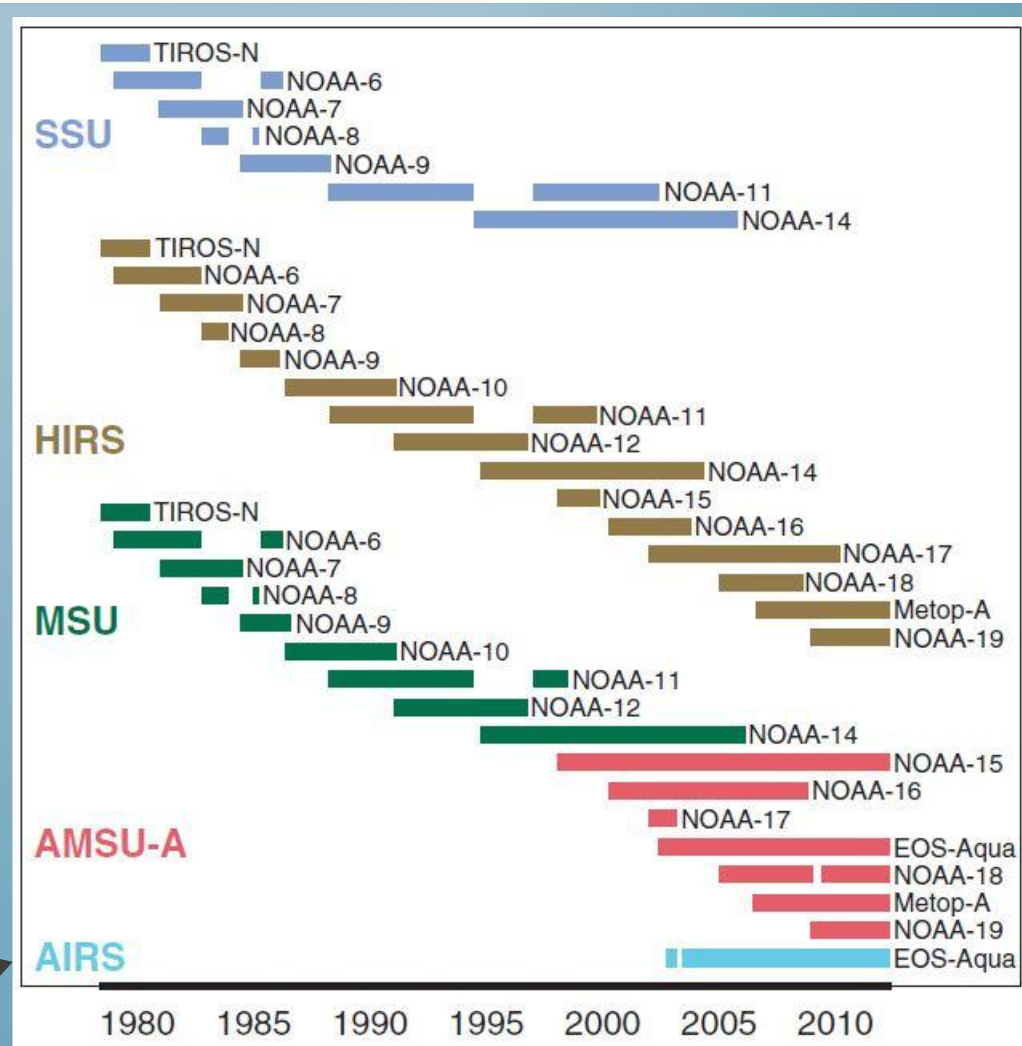
A. J. Simmons,[a*] P. Poli,[a] D. P. Dee,[a] P. Berrisford,[a] H. Hersbach,[a] S. Kobayashi[b] and C. Peubey[a]
[a] *European Centre for Medium-Range Weather Forecasts, Reading, UK*
[b] *Japan Meteorological Agency, Tokyo, Japan*

Stratospheric Sounding Unit

Tropospheric Sounding

Stratospheric Sounding AMSU-A

Trop. & Lower Strat. AIRS



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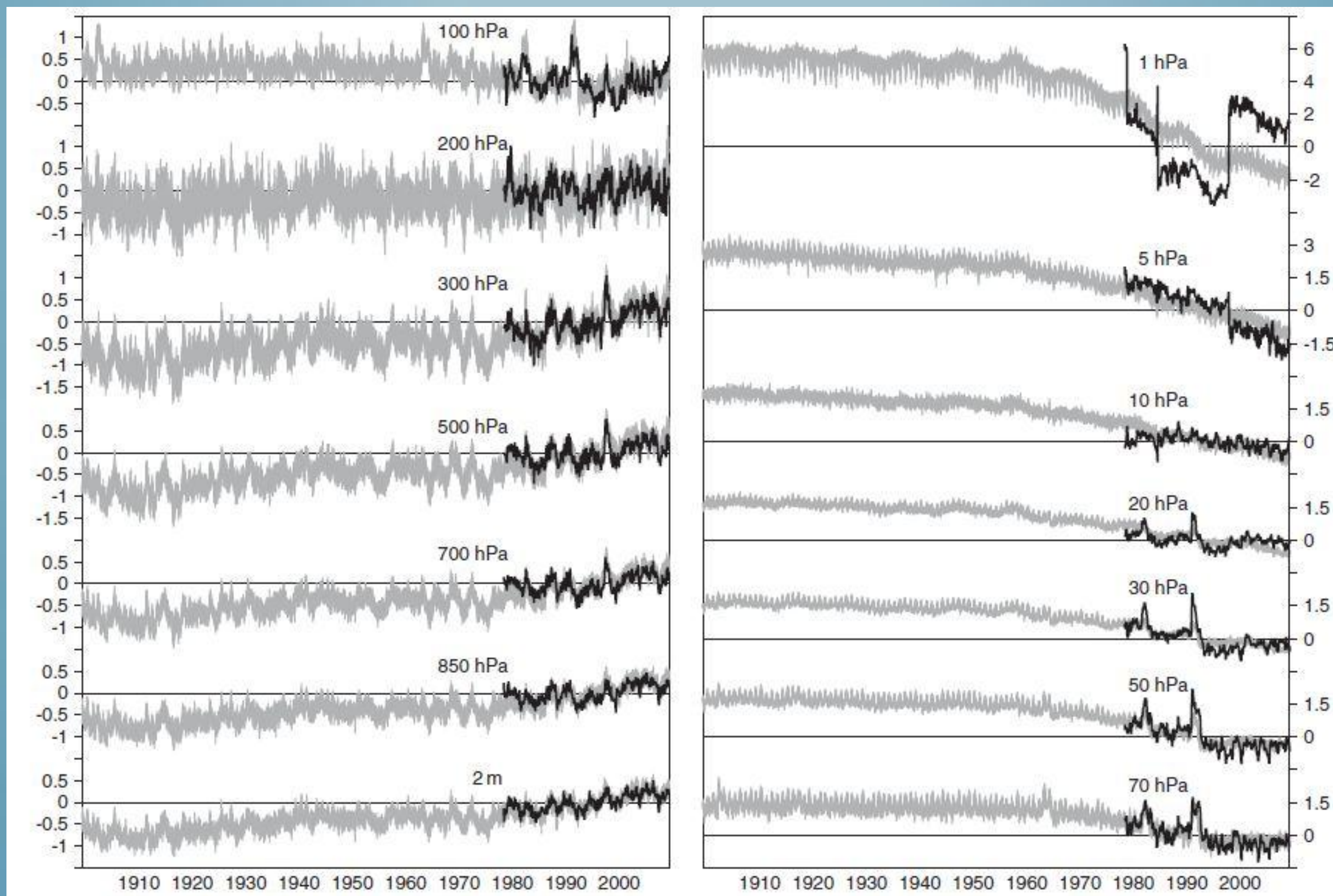
[b]Japan Meteorological Agency, Tokyo, Japan

100 hPa
200 hPa
300 hPa
500 hPa
700 hPa
800 hPa
2 meter



1 hPa
5 hPa
10 hPa
20 hPa
30 hPa
50 hPa
70 hPa

Figure 21. Anomalies in monthly and globally averaged temperatures (K) from ERA-Interim (black) and from ten model runs (grey) for 1900–2009 with prescribed distributions of SST (varying from run to run), sea-ice and trace constituents, at the indicated tropospheric and stratospheric levels: (a) 2 m and 850–100 hPa, (b) 70–1 hPa. Anomalies are calculated relative to 1980–2009, and for each model run the anomaly is relative to the ensemble mean.

Estimating low-frequency variability and trends in atmospheric temperature using ERA-Interim

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1 hPa

5 hPa

10 hPa

20 hPa

30 hPa

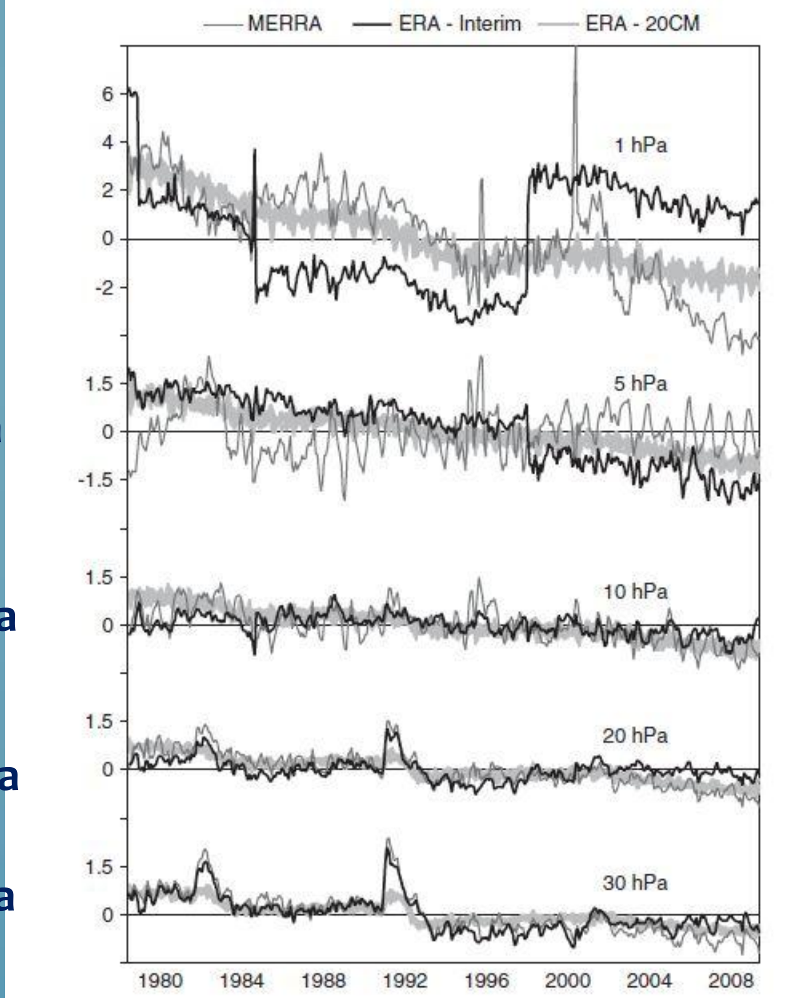


Figure 22. As Figure 21, adding the MERRA anomalies (thinner lines, darker grey) but showing only the uppermost five highest levels and the period 1979–2009.

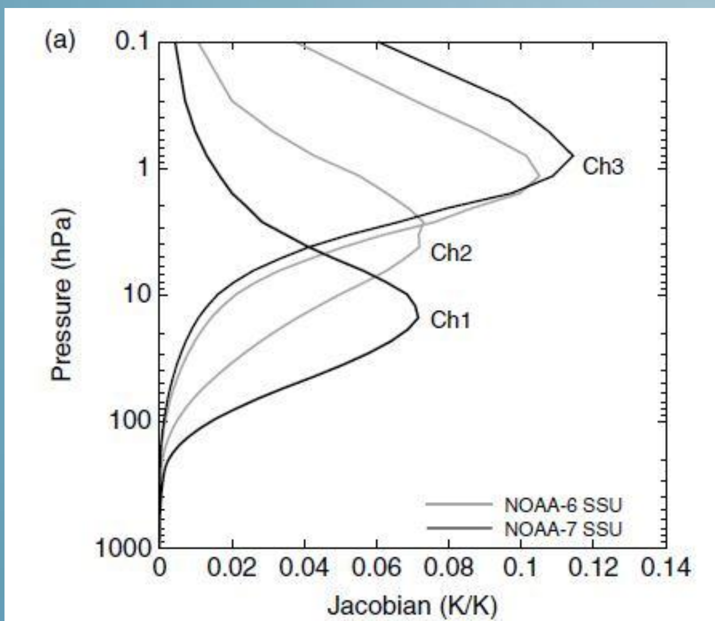
ERA discontinuity due to transition from SSU to AMSU-A

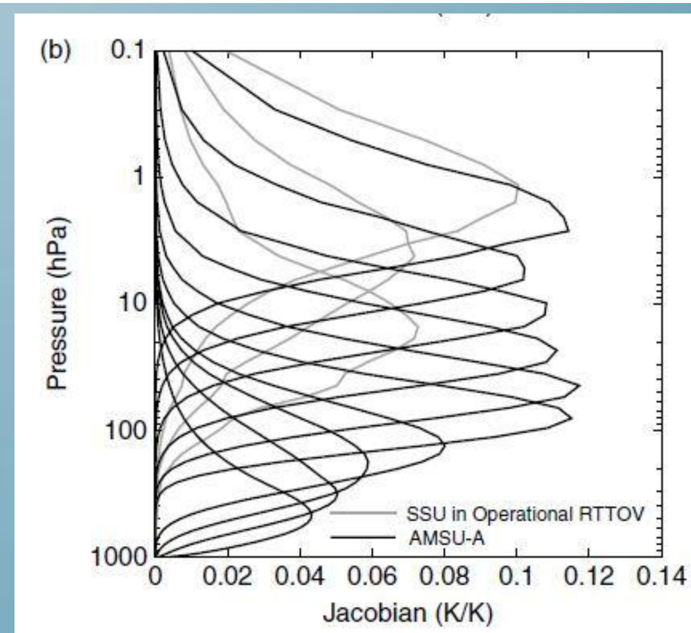
"There is thus good consistency between the height-resolved upper-stratospheric cooling extracted from SSU and AMSU-A data by ERA-Interim and the corresponding cooling simulated by ERA-20CM due to prescribed changes in carbon dioxide and ozone."

QUARTERLY JOURNAL OF THE ROYAL METEOROLOGICAL SOCIETY
Q. J. R. Meteorol. Soc. **135**: 2086–2099 (2009)
Published online 20 October 2009 in Wiley InterScience
(www.interscience.wiley.com) DOI: 10.1002/qj.514

Toward a consistent reanalysis of the upper stratosphere based on radiance measurements from SSU and AMSU-A

Shinya Kobayashi,[a,b] Marco Matricardi,[a]* Dick Dee[a] and Sakari Uppala[a]
[a]*European Centre for Medium-Range Weather Forecasts, Reading, UK*
[b]*Japan Meteorological Agency, Tokyo, Japan*





SSU Stratospheric Sounding Channels
CO_2 leaked from gas cell on some SSU units causing peak of Jacobian to rise over time!

AMSU-A Microwave Channels
Currently used for strat. Monitoring.
But what is the calibration accuracy??

Stratospheric Temperature Jacobians: dR/dT

Heritage Stratospheric Sounders: SSU & MSU (1979-2005)

----- InfraRed ----

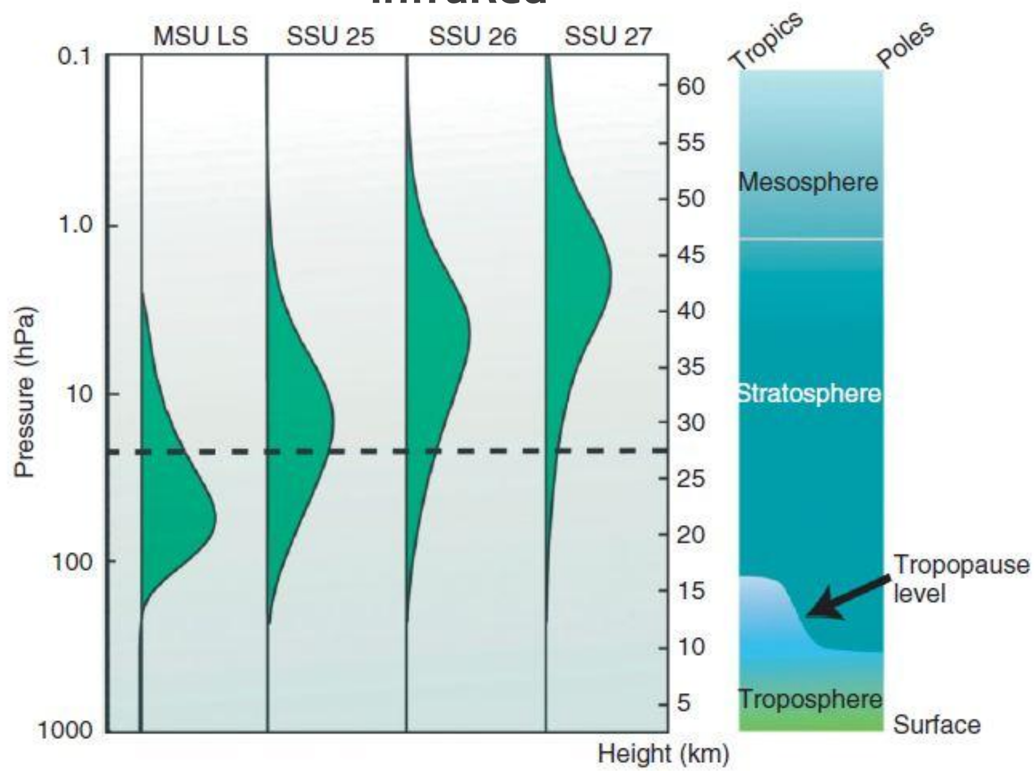
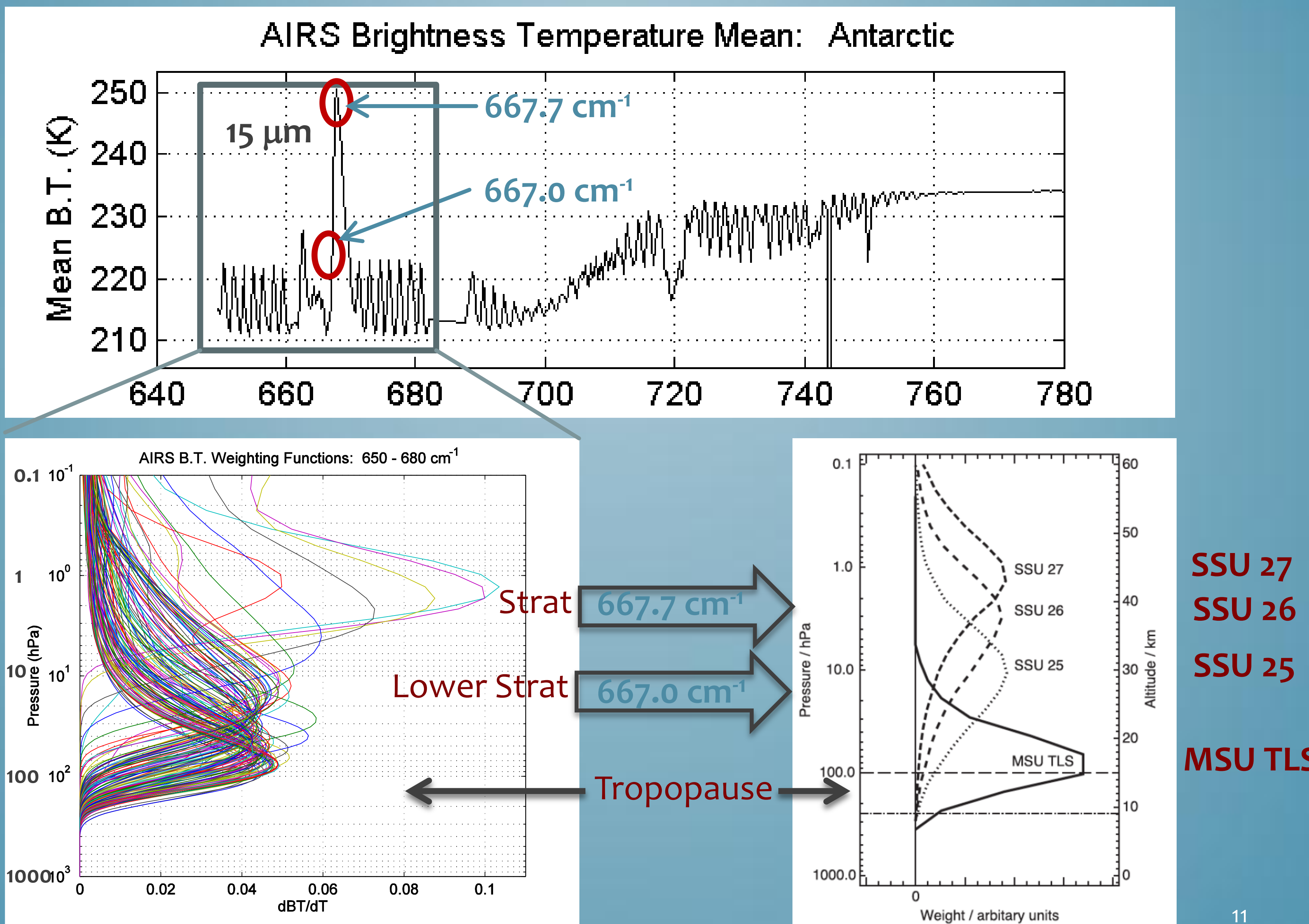


FIGURE 2 | Vertical sampling of satellite and radiosonde observations of stratospheric temperature. *Left*: vertical weighting functions for satellite Microwave Sounding Unit (MSU) and Stratospheric Sounding Unit (SSU) stratospheric temperature observations as a function of pressure (left axis) and height (right axis). The dashed line at about 27 km (30 hPa) indicates the typical maximum height of historical global radiosondes data coverage (Figure 1). *Right*: schematic of atmospheric vertical structure and its latitudinal variation. (Modified from Climate Change Science Program Synthesis and Assessment Product 1.1[4])

WIREs Clim Change 2011 vol 2 pp592–616 DOI: 10.1002/wcc.125

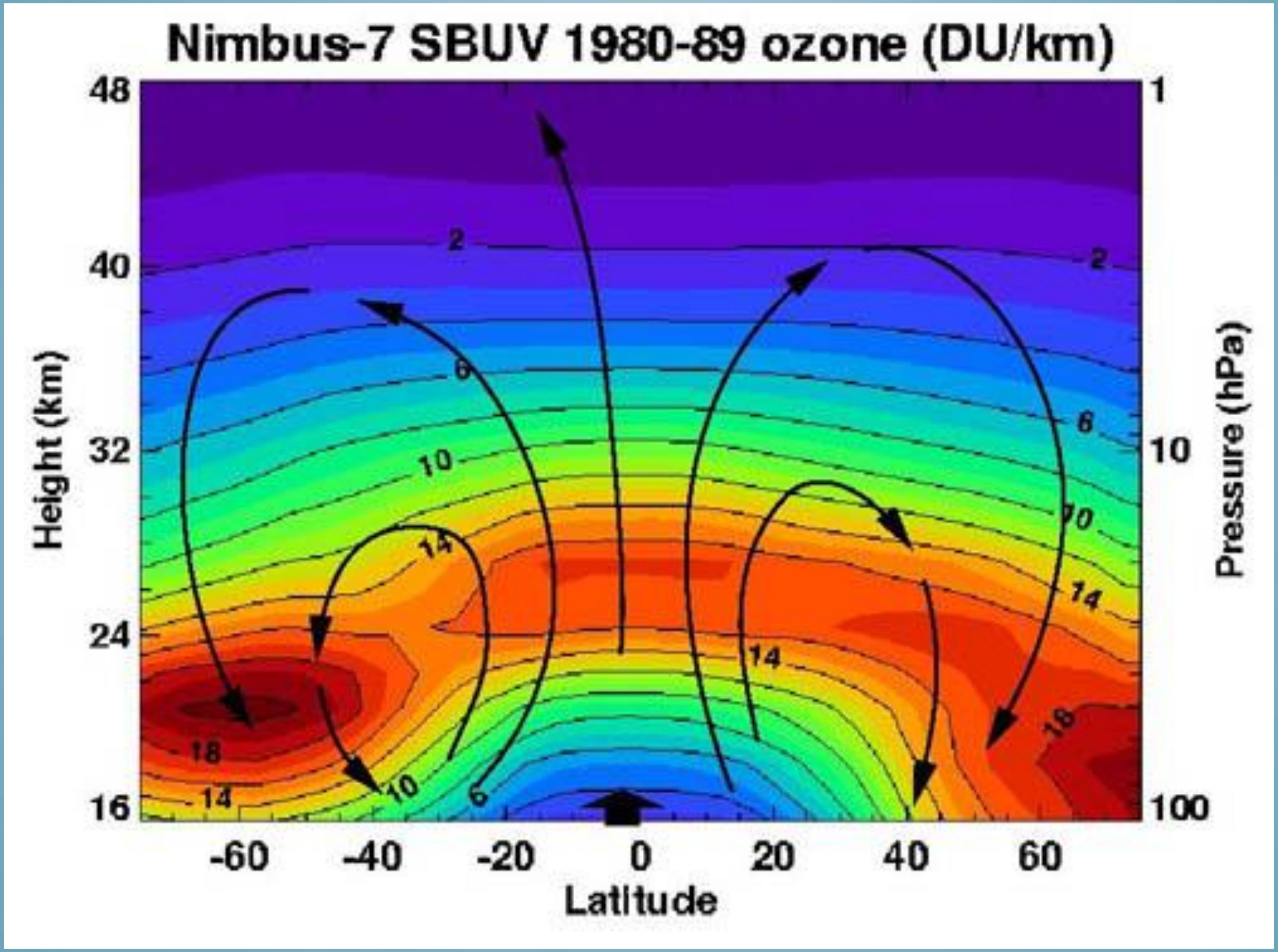
- **Can we use hyperspectral IR to provide a new and better reference for stratospheric trends into the future? Yes!**

Hyperspectral IR Sounder: Stratospheric Jacobians



Sensitivity of weighting functions suggest AIRS, IASI, CrIS could continue this record.

HEATING OF THE STRATOSPHERE



Absorption of UV radiation from the sun by the ozone layer in the tropics provides a source of heating which elevates stratospheric temperatures and creates a tropopause largely separating the tropospheric and stratospheric dynamics. The distribution of ozone is largely explained by the Brewer-Dobson model.

SSU & MSU Climatology (1979-2005)

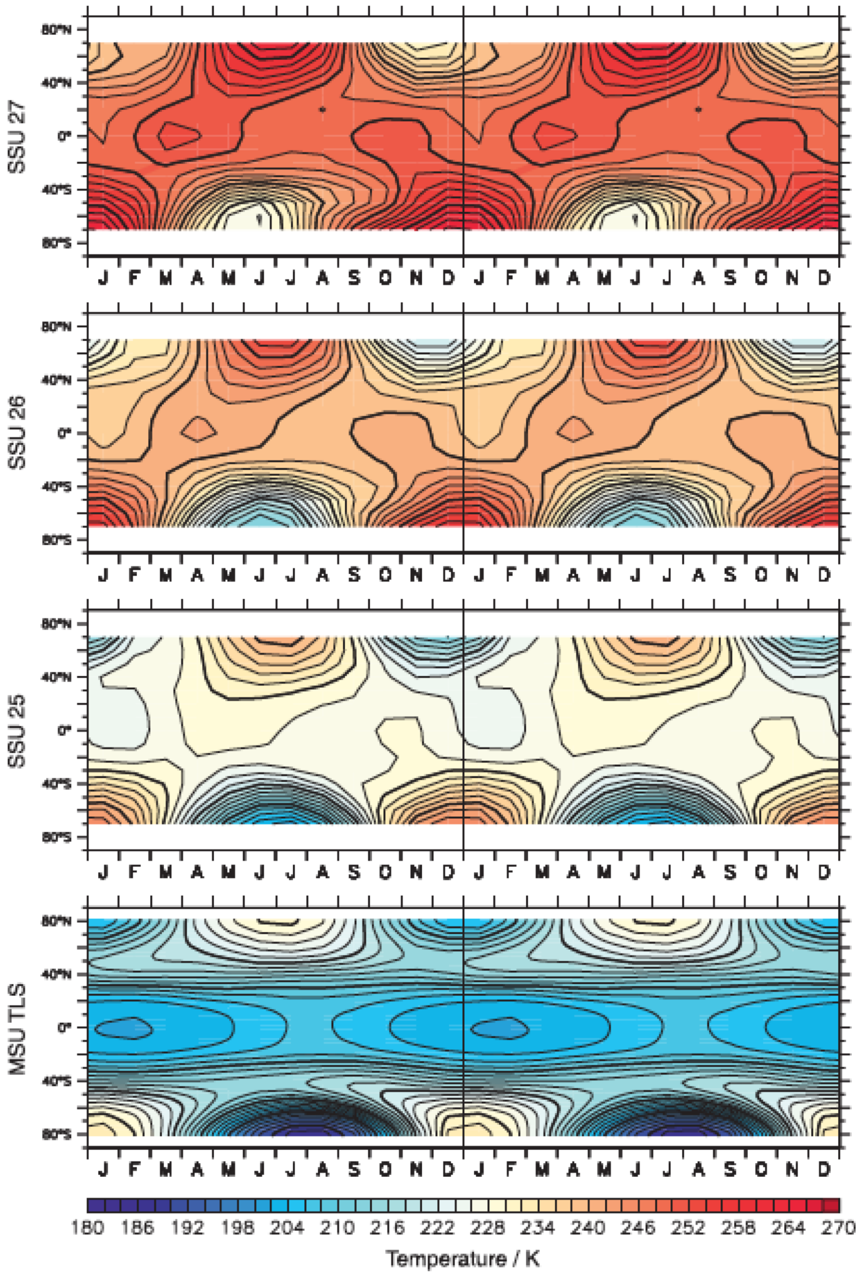
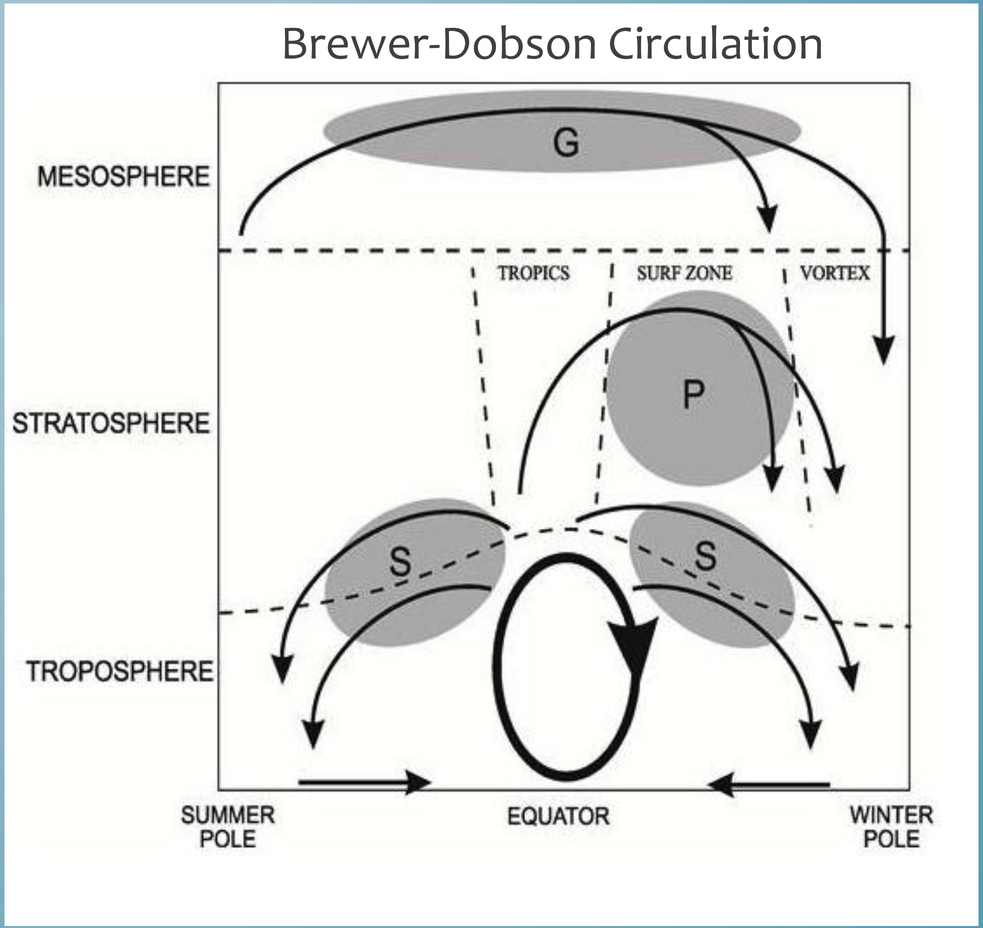


FIG. 2. Latitude–month climatological annual cycle of temperature for (bottom to top) the MSU-TLS and SSU-25, -26, and -27 data. The contour interval is 2 K, with every 10 K highlighted by thicker lines. Two complete cycles are shown.

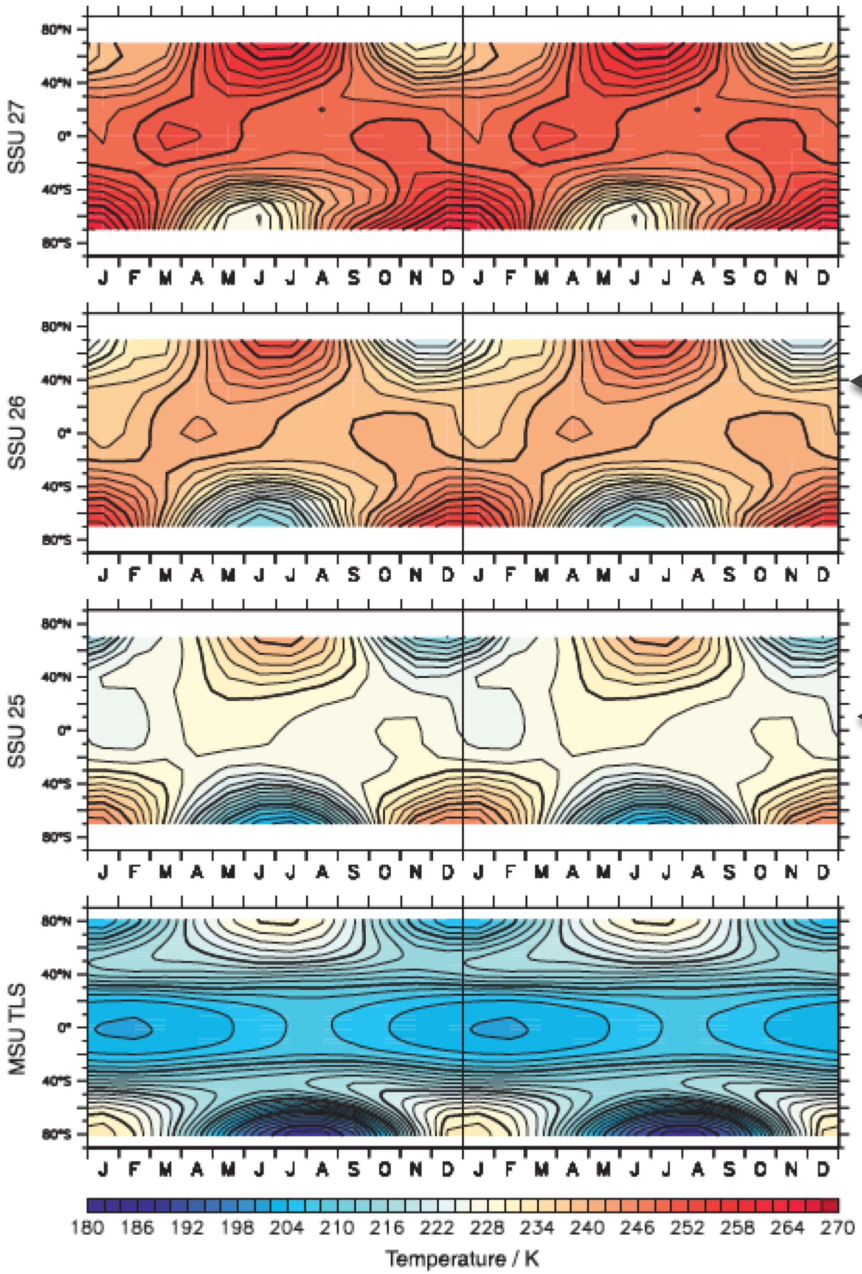
The Latitude Dependence of Stratospheric Temperature exhibits a Seasonal Variation that is explained by the Brewer-Dobson Circulation model.



But the SSU record ended in 2005!
Can hyperspectral IR continue this climatology?

From Young et al., 2011, J. Climate.

SSU & MSU Climatology (1979-2005)

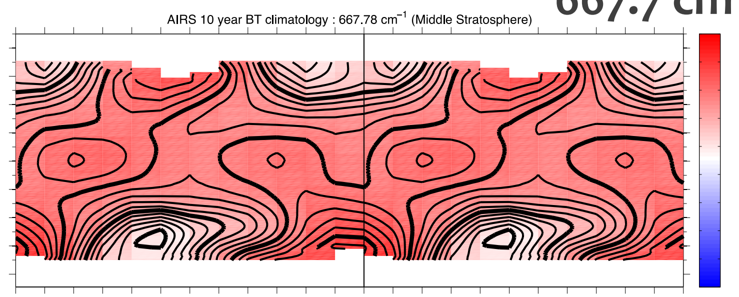


From Young et al., 2011, J. Climate.

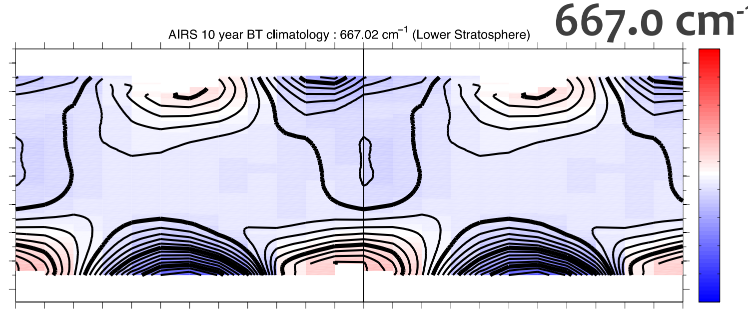
AIRS IR 10-year Climatology (2003-2012)

CIMSS has produced a 10 year radiance climatology from NASA AIRS radiance data.

667.7 cm^{-1}



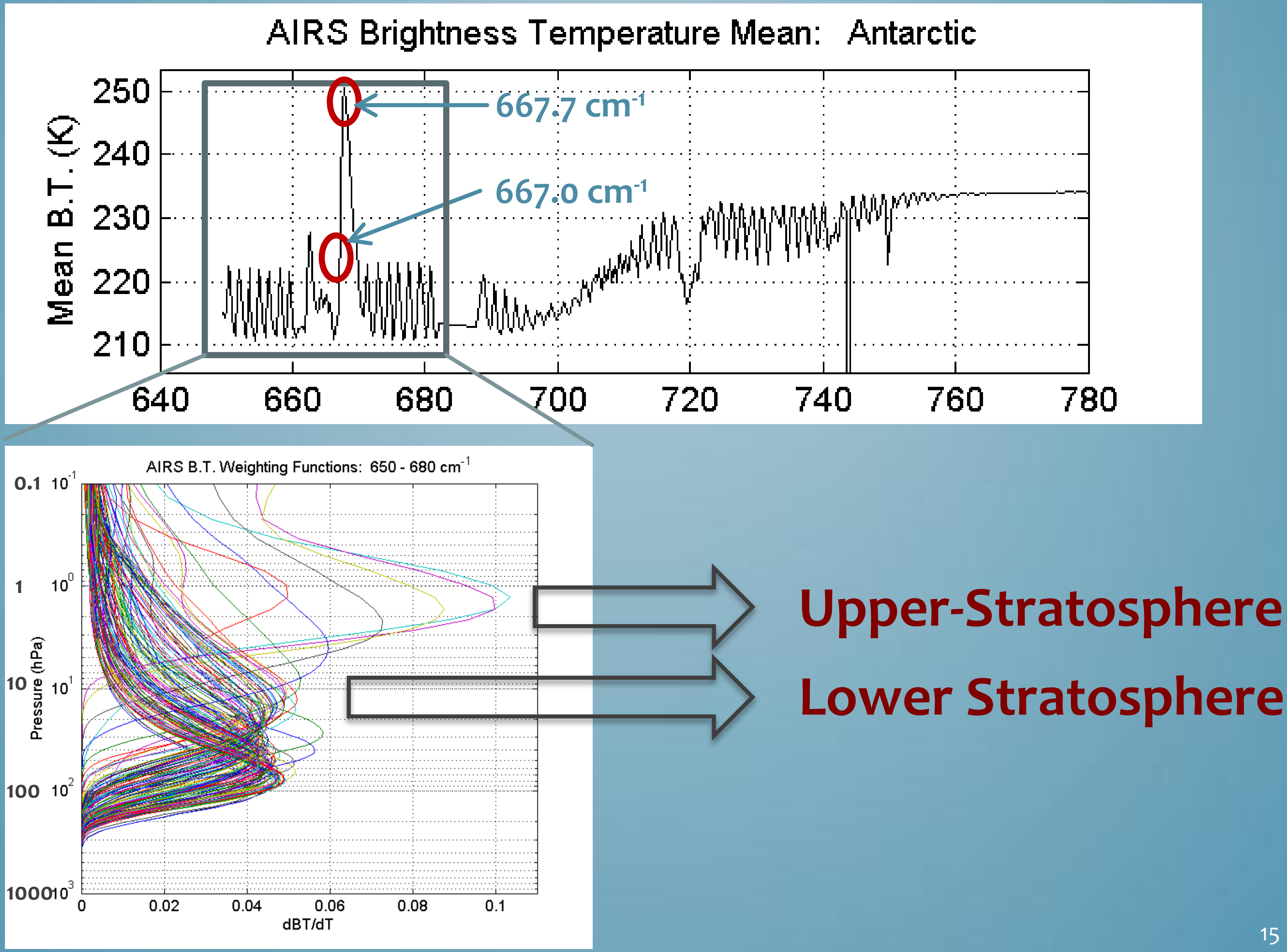
667.0 cm^{-1}



Contour lines show the same patterns in AIRS. Please note the color scale could not be matched.

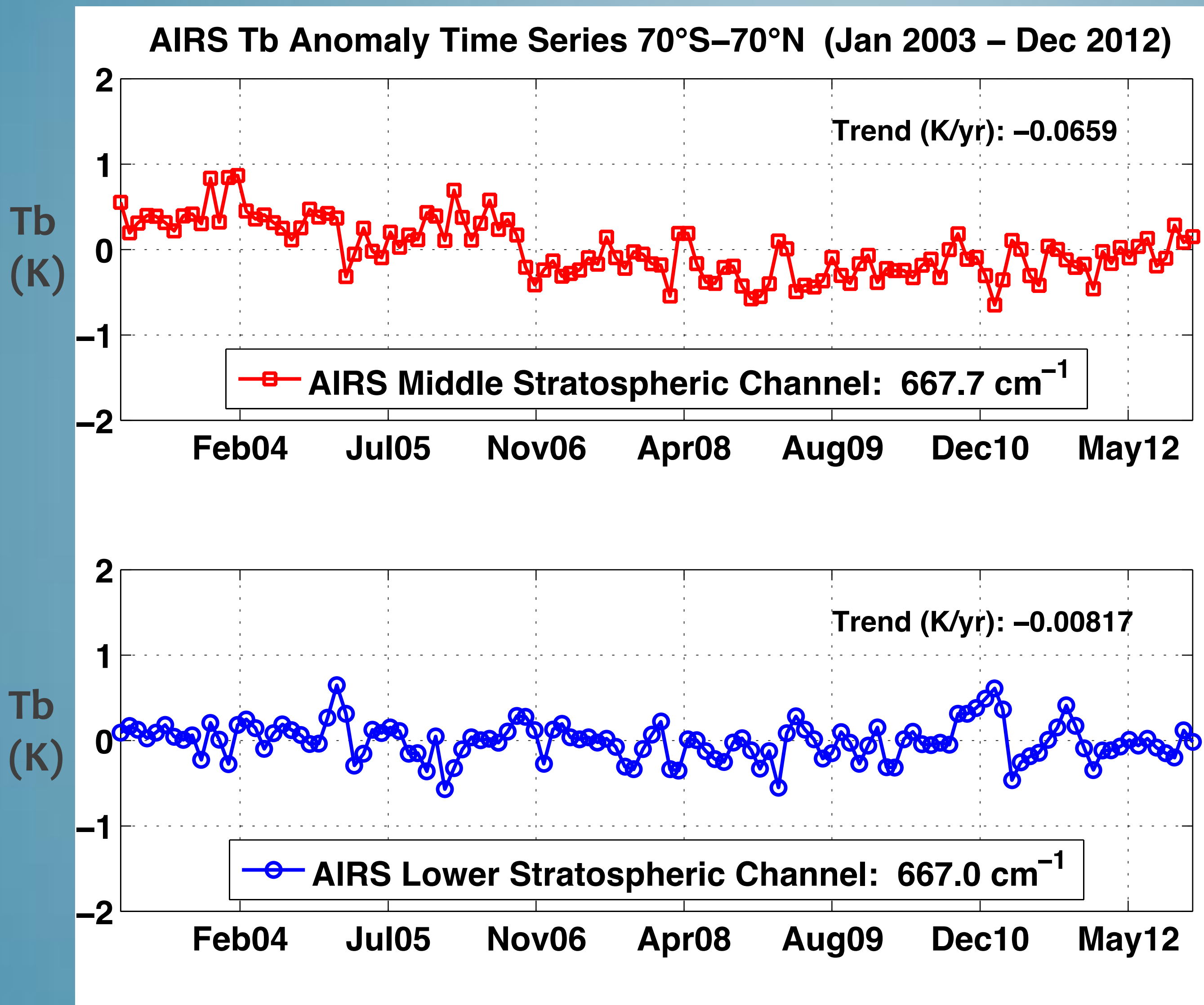
This result confirms the assertion that the hyperspectral infrared can be used to continue the record of stratospheric monitoring from SSU in support of climate studies.

Hyperspectral IR Sounder: Stratospheric Wgt Fcns



Sensitivity of weighting functions suggest AIRS, IASI, CrIS could continue this record.

AIRS 10 YEAR DECADAL TB TRENDS: 2003-2012



Upper Stratosphere
AIRS decadal TB trend is about 0.6K/decade. Consistent with GCM predictions for 100 year temperature trends due to CO_2 Doubling.

Lower Stratosphere
AIRS decadal TB trend is nearly zero. Consistent with radiosonde data.

Predicted stratospheric cooling ~0.5 K / decade

How can we Verify AIRS BT trends?

<u>Approach (Completed):</u>

1) Develop a time/space matchup method between IR and GPS RO that greatly reduces sampling error (Feltz et al. (2014) JGR, accepted)

2) Apply matchup methodology to compare L2 derived products from both IR and GPS RO (Feltz et al. (2014) AMT, accepted)

[Result caused a "stir" in the RO community regarding GPS RO systematic errors.]

How can we Verify AIRS BT trends?

Approach (in progress):

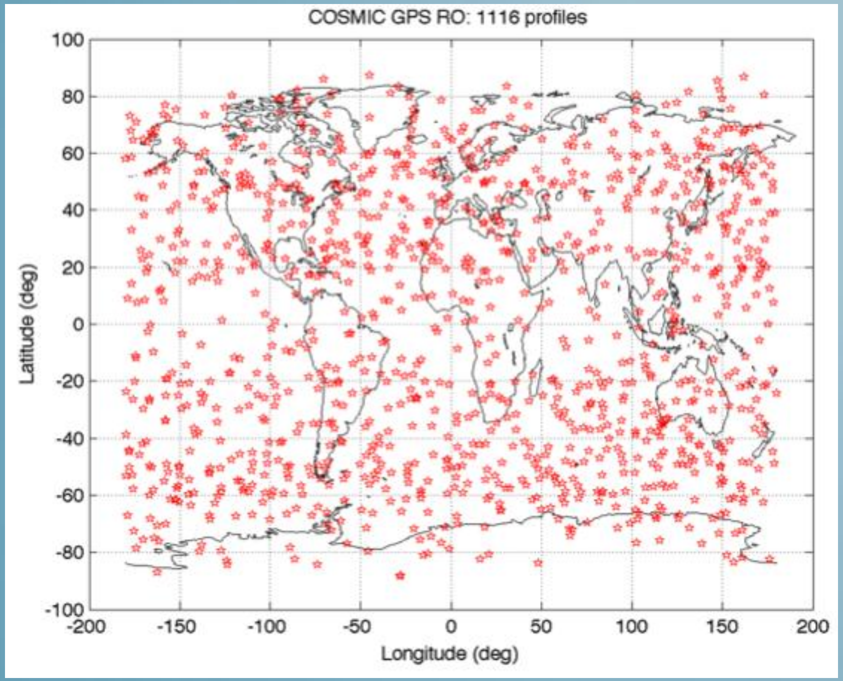
3) Perform radiative transfer model calculations to convert GPS RO temperature retrievals into brightness temperature for comparison to AIRS observations.

4) Perform an detailed uncertainty analysis of the IR and GPS RO in units of brightness temperature.

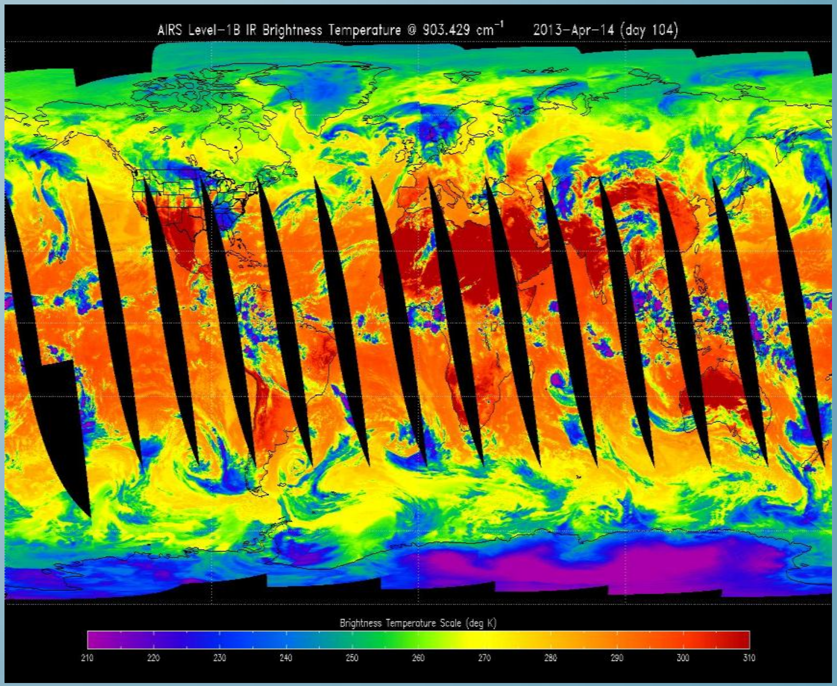
Steps 1-4 comprise the Master's Thesis of Michelle Feltz at UW-Madison.

The UW IR/GPSRO Combined Dataset

COSMIC GPS RO



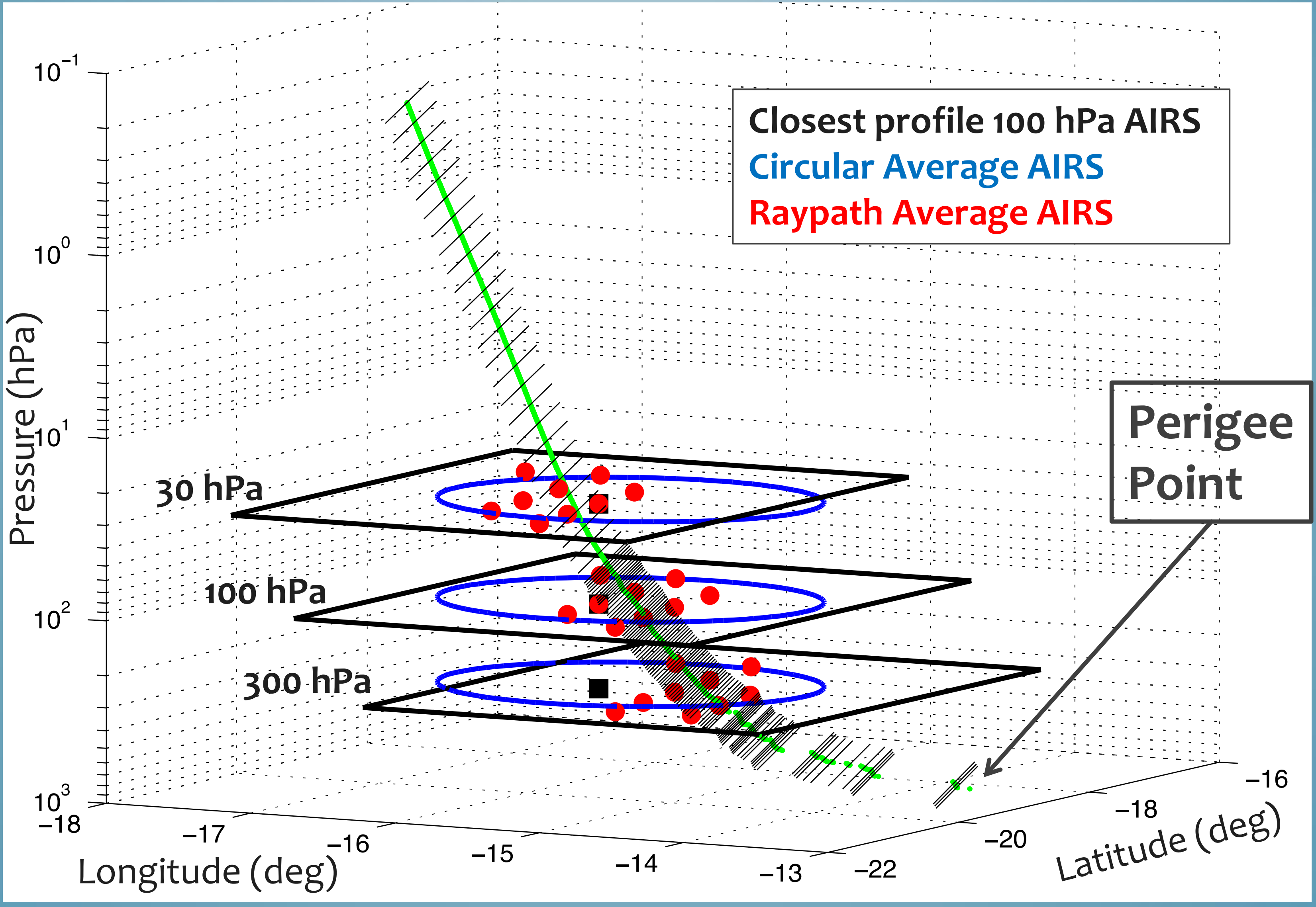
AIRS IR Sounder



COSMIC-I: ~ 1,000 vertical Temperature profiles per day

IR Sounder: ~ 324,000 vertical Temperature profiles per day

GPS RO Profile intersection with IR retrieval fields



See Michele Feltz poster for details on matchup methodology.
Feltz et al. (2014), JGR Atmospheres, in press.

Evaluation of IR using GPS RO

<u>Products to Evaluate:</u>

Aqua/AIRS NASA Science Team Retrieval v6

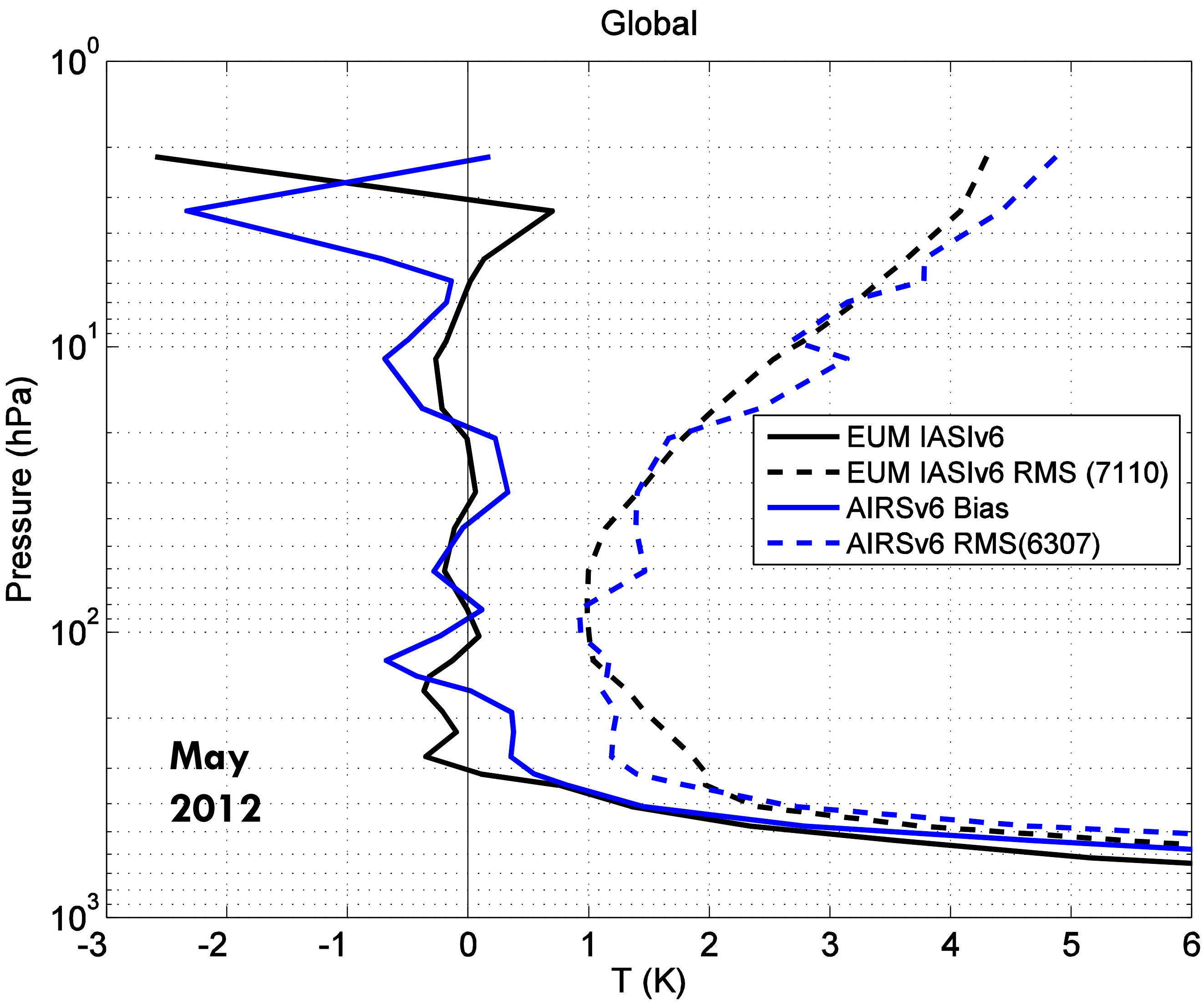
MetOp-A/IASI EUMETSAT Retrieval v6

<u>Reference Dataset:</u>

FormoSat/COSMIC

UCAR Dry Temperature (Version 2012)

(AIRS – COSMIC) & (IASI – COSMIC)

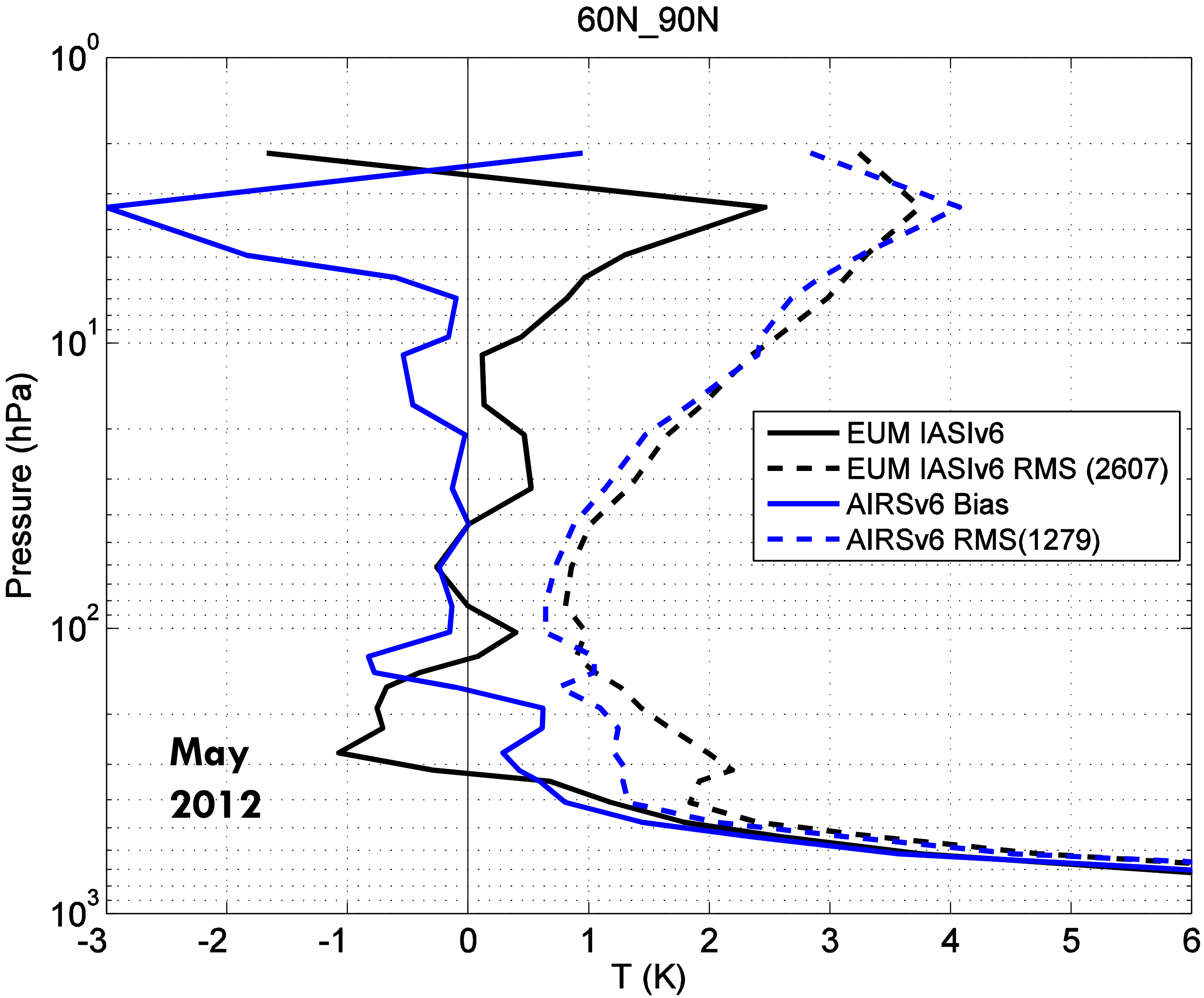


Can COSMIC dry temperatures be used as a reference for IR/MW Sounders?

The area weighted global average difference profiles look good!

Bias is 0.5 or less for pressures from 200 hPa up to 5 hPa.

(AIRS – COSMIC) & (IASI – COSMIC)

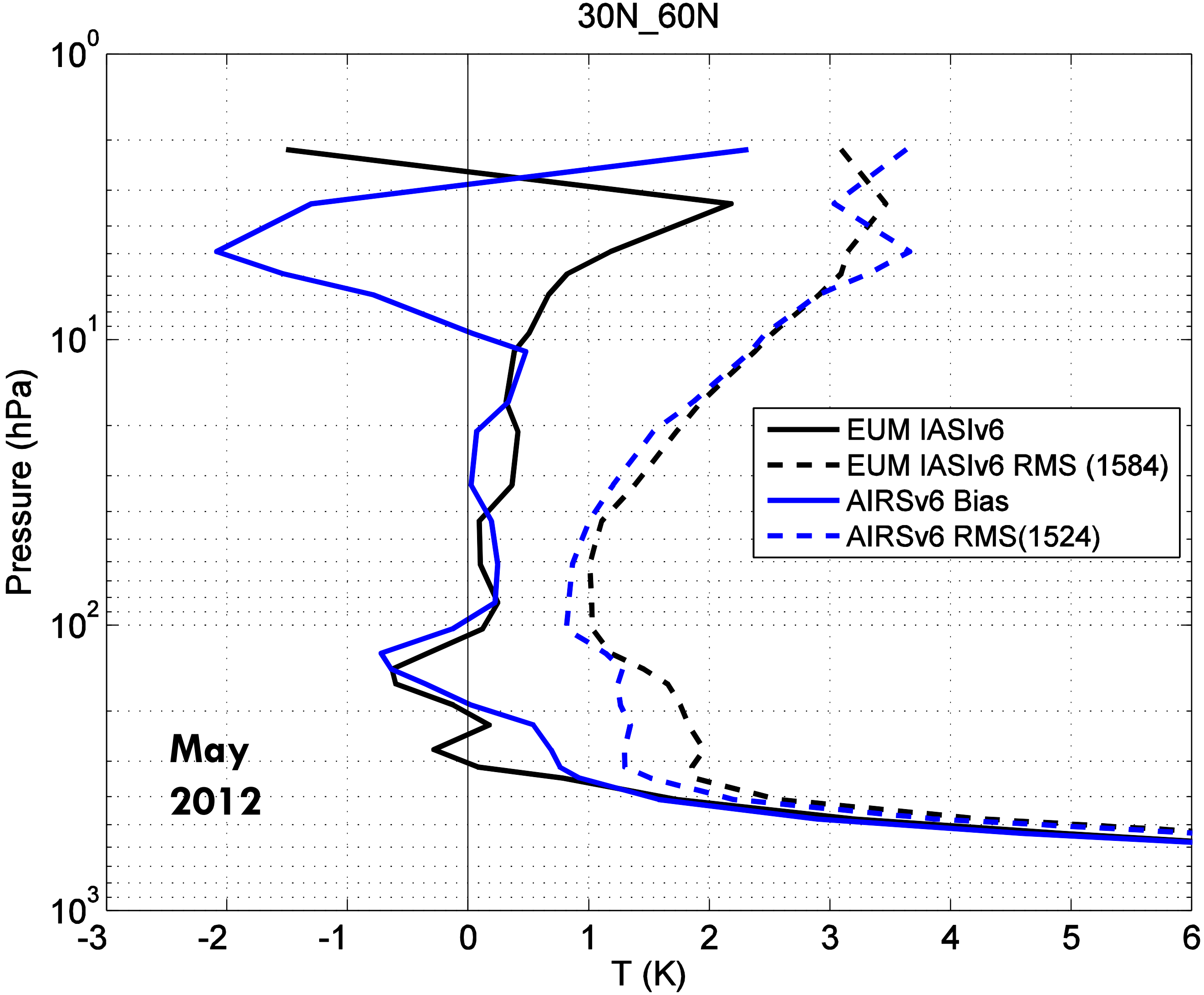


Can COSMIC dry temperatures be used as a reference for IR/MW Sounders?

Comment:

Arctic in May 2012 shows a slight positive bias for IASI-COSMIC above 100 hPa, while AIRS-COSMIC is slightly negative.

(AIRS – COSMIC) & (IASI – COSMIC)

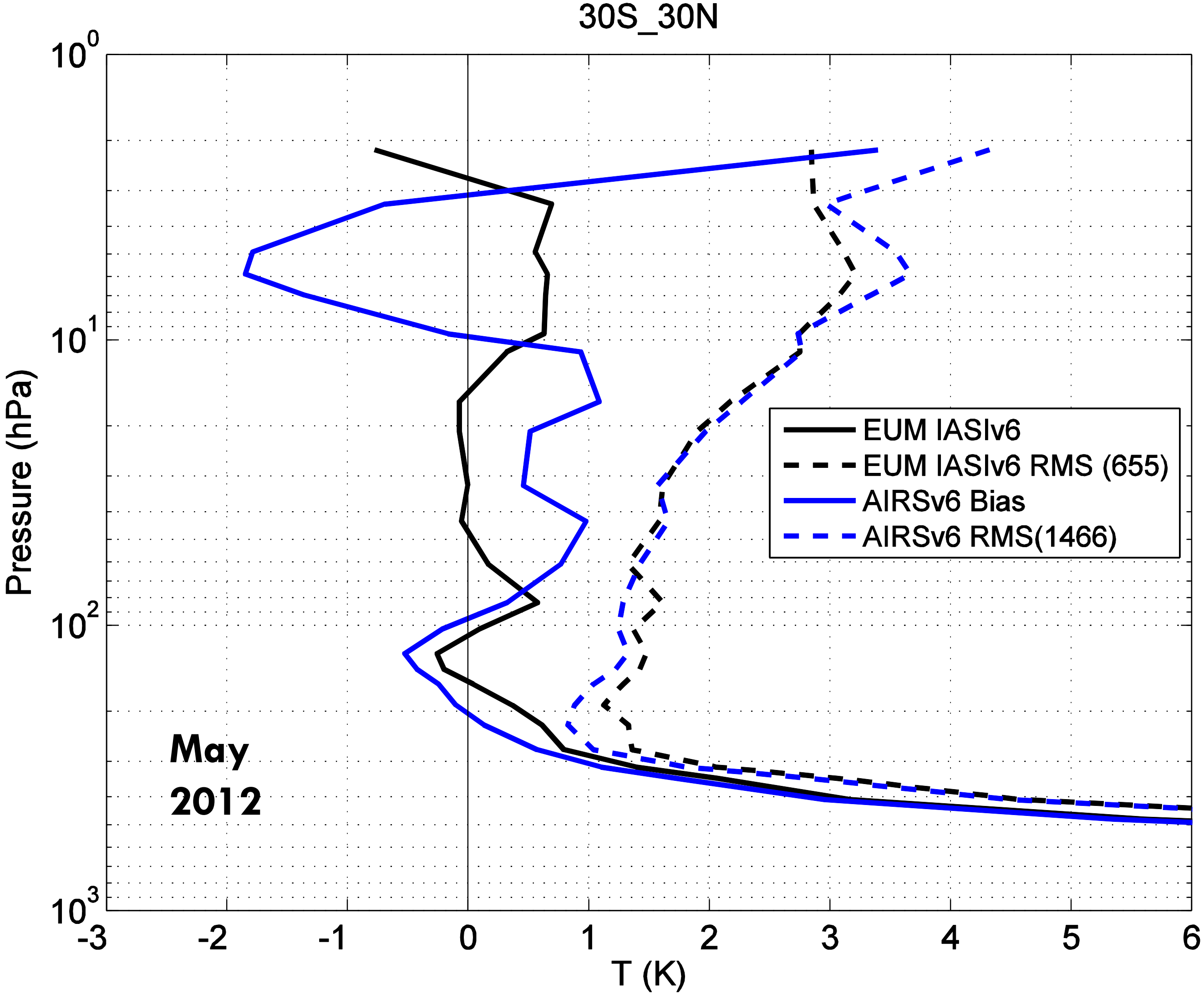


Can COSMIC dry temperatures be used as a reference for IR/MW Sounders?

Comment:

NH Mid-Lat in May 2012 shows a slight positive bias for IASI-COSMIC above 100 hPa, while AIRS-COSMIC is also slightly positive up to 10 hPa then turns negative.

(AIRS – COSMIC) & (IASI – COSMIC)

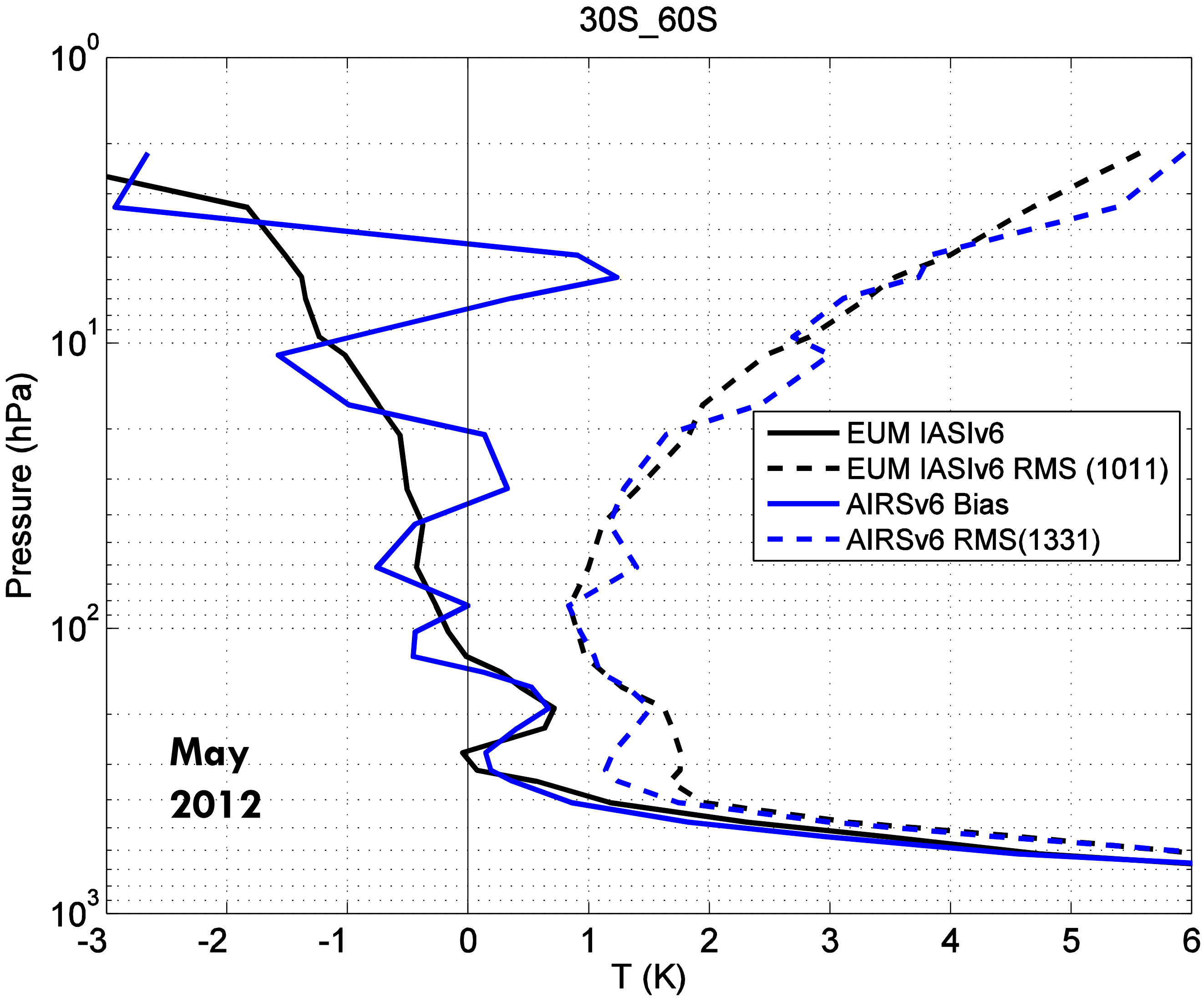


Can COSMIC dry temperatures be used as a reference for IR/MW Sounders?

Comment:

Tropics in May 2012 shows a < 0.5K bias for IASI-COSMIC above 100 hPa, while AIRS-COSMIC is both positive and negative.

(AIRS – COSMIC) & (IASI – COSMIC)

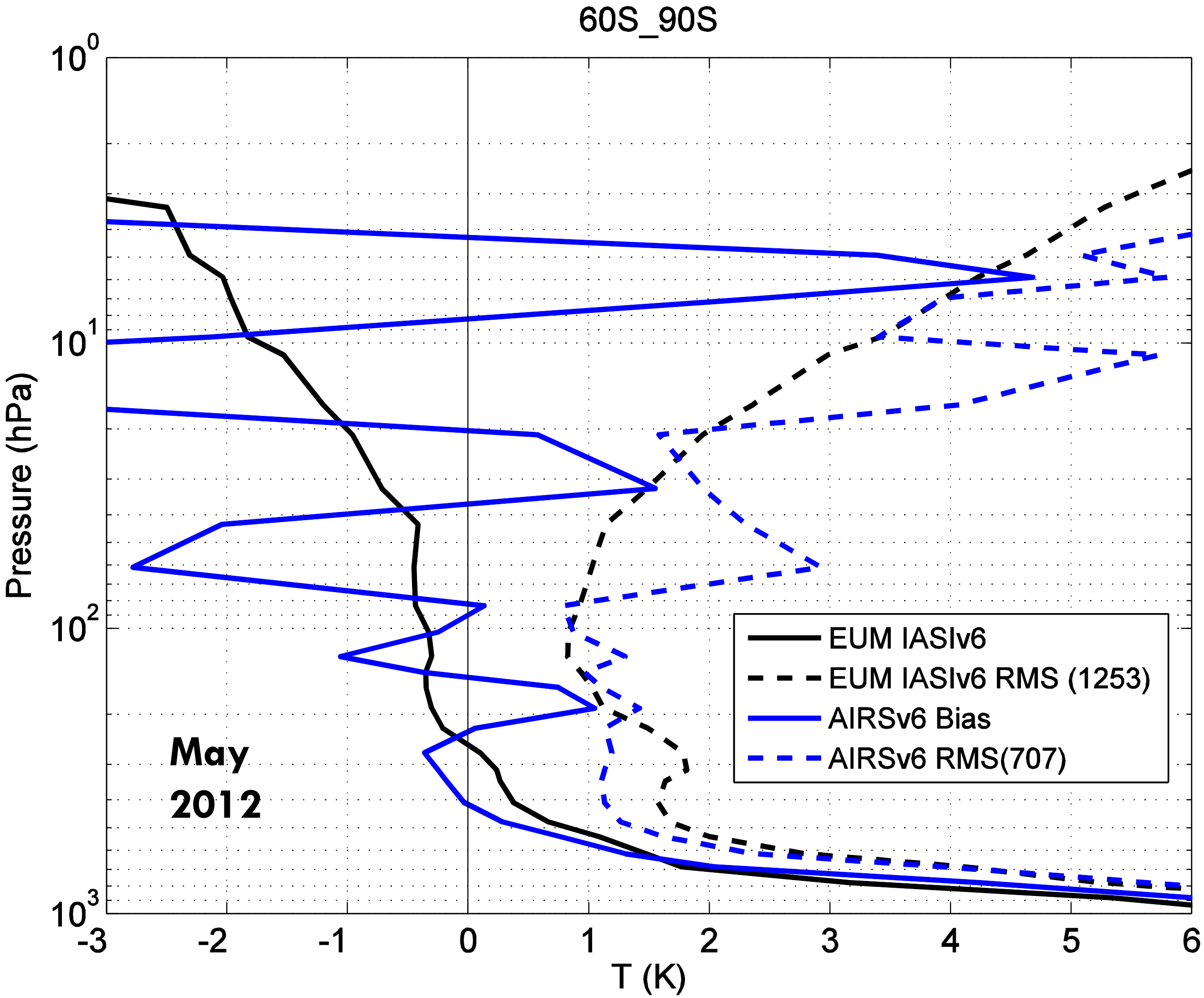


Can COSMIC dry temperatures be used as a reference for IR/MW Sounders?

Comment:

SH Mid-Lat in May 2012 shows a strong negative bias for IASI-COSMIC above 100 hPa, and AIRS-COSMIC also has a strong negative bias increasing with height plus an anomalous oscillation.

(AIRS – COSMIC) & (IASI – COSMIC)



Can COSMIC dry temperatures be used as a reference for IR/MW Sounders?

Comment:

Antarctic in May 2012 shows a strong negative bias for IASI-COSMIC above 100 hPa, and AIRS-COSMIC also has a strong negative bias increasing with height plus an anomalous oscillation.

Evaluation of GPS RO using IR

Products to Evaluate:

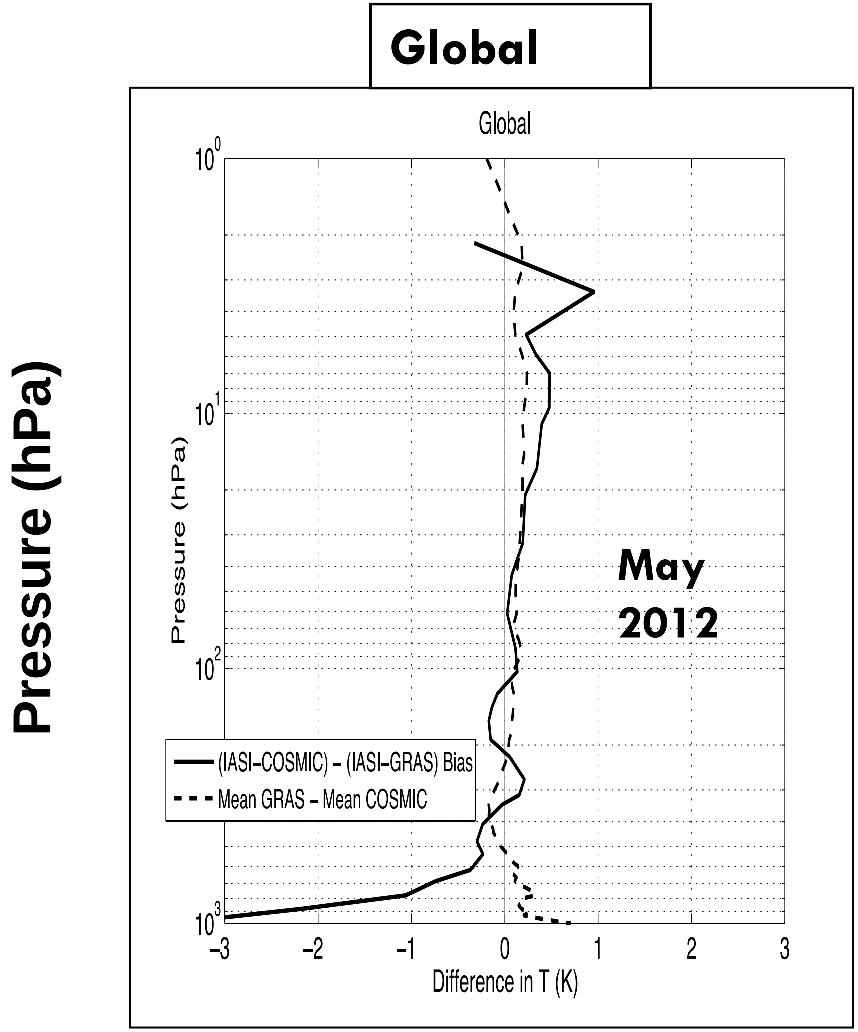
FormoSat/COSMIC	**(six satellites)**
UCAR Dry Temperature	**(Version 2012)**
MetOp-A/GRAS	**(one satellite)**
UCAR Dry Temperature	**(Version 2012)**

Reference Dataset:

MetOp-A/IASI NOAA Retrieval v5

(IASI has better matchup statistics with GRAS, same platform)

(IASI – COSMIC) – (IASI – GRAS)



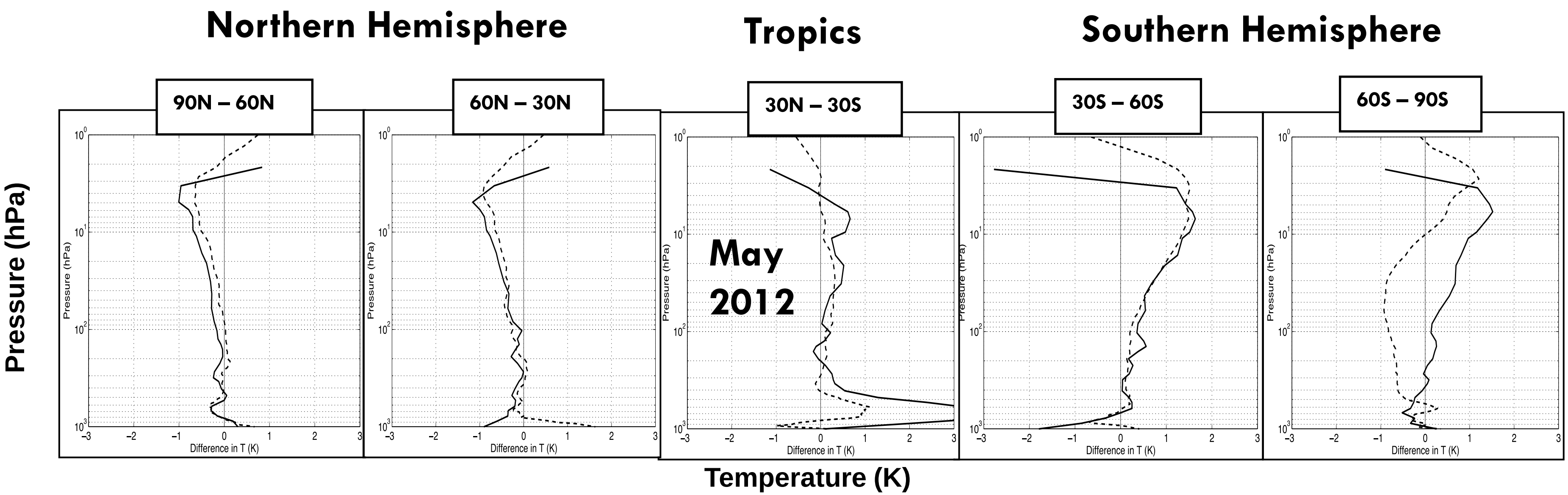
Can either COSMIC or GRAS dry temperatures be used as an equivalent reference?

The area weighted global average DOUBLE DIFFERENCE profiles look good!

Deviations are 0.5 or less for pressures from 200 hPa up to 5 hPa.

The solid lines are the double difference wrt IASI using the IR/GPSRO Level 2 time/space coincident matchup set. The dashed lines are the zone mean difference GRAS minus COSMIC for comparison.

(IASI – COSMIC) – (IASI – GRAS)



NH COSMIC > GRAS   COSMIC ≈ GRAS   SH GRAS > COSMIC

While it was recognized in the RO community that there were systematic differences among the different GPS RO processing centers (UCAR, Wegner, ROM-SAF, ECMWF), it came as a surprise that there would be a bias between COSMIC and GRAS when processed with the same processing software, in this case the UCAR processing code.

This result has lead UCAR to change the code in reprocessing of COSMIC and GRAS data to improve the consistency of the UCAR products but not necessarily improve the accuracy.

Comparison of IR and GPS RO in BT Units (Work in Progress)

Products to Evaluate:

FormoSat/COSMIC L2 Dry Temperature

MetOp-A/GRAS L2 Dry Temperature

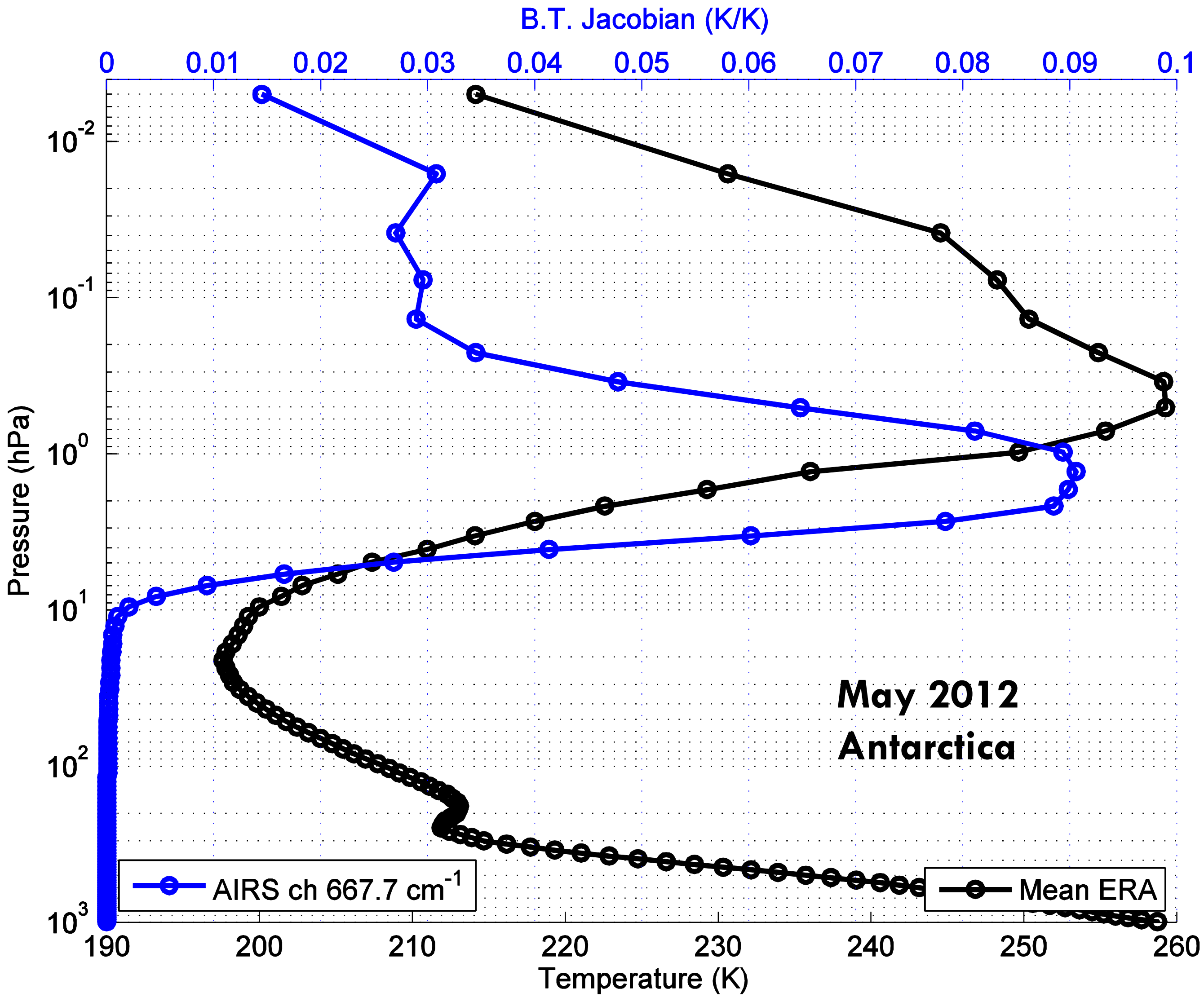
Reference Dataset:

Aqua/AIRS L1B Radiances (NASA v5)

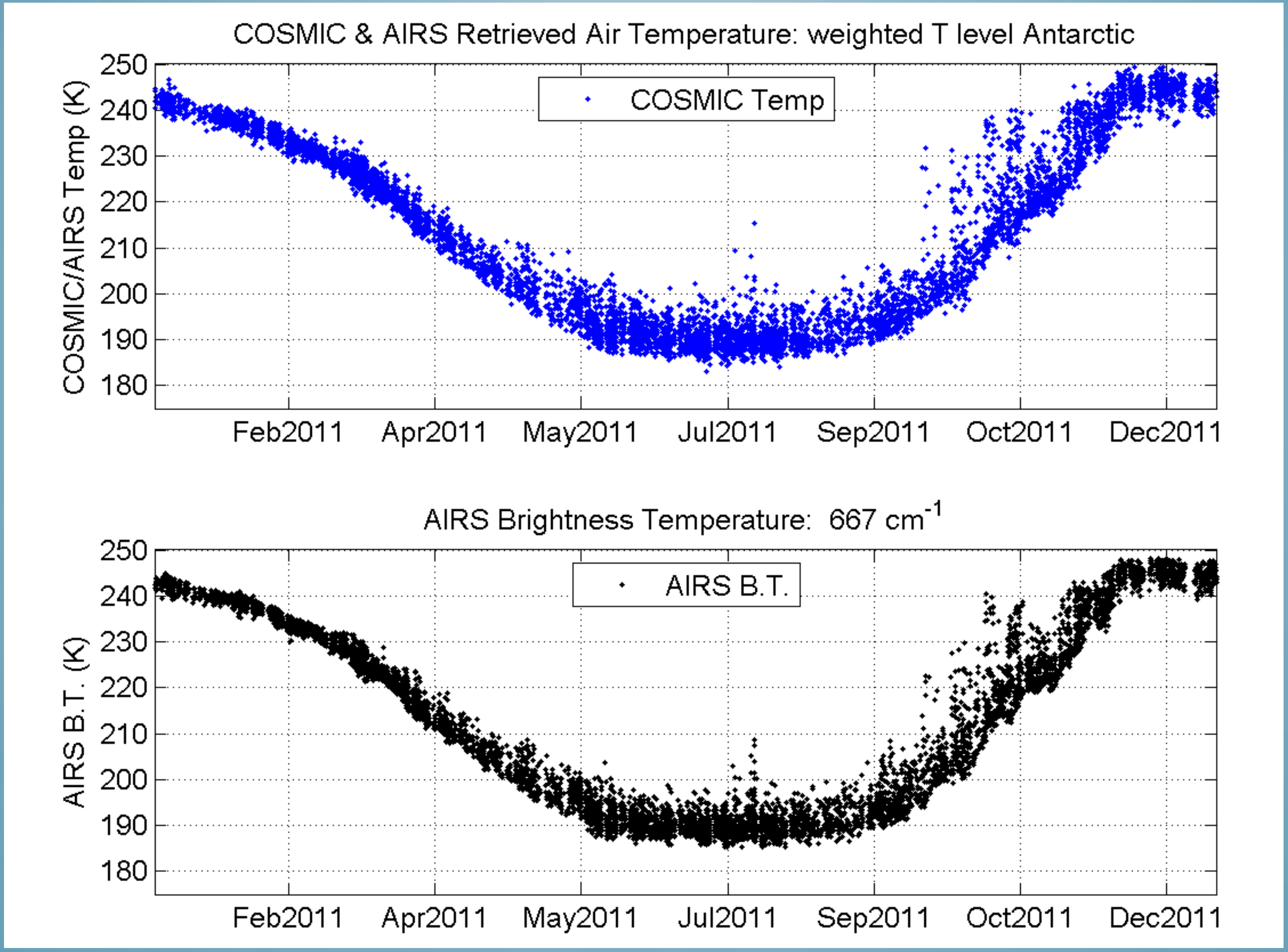
Radiative Transfer Model:

OSS (LBLRTM v12 with AER database)

OSS Jacobians using ERA Base state

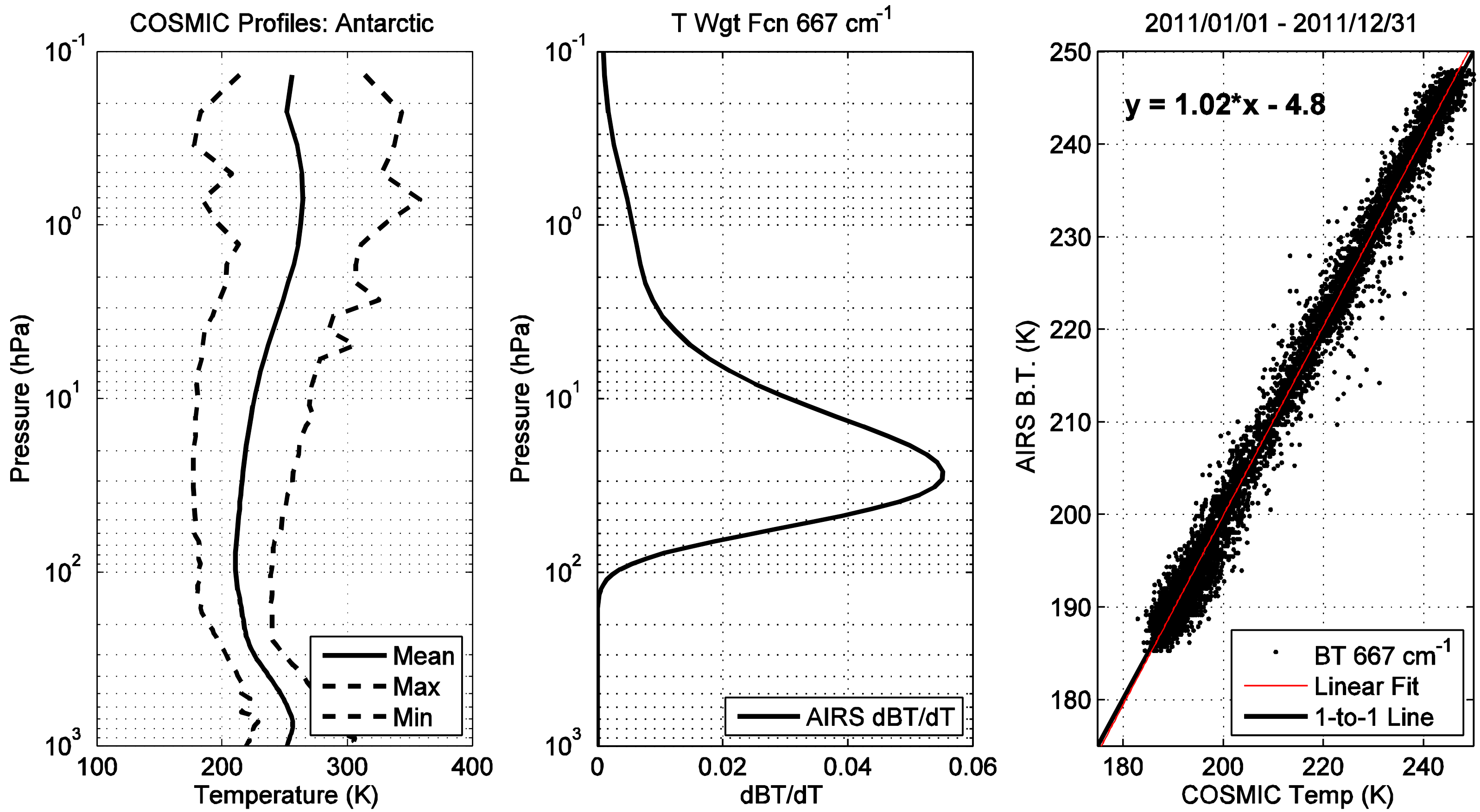


AIRS and COSMIC BT Annual/Zonal Time Series: Antarctica



Co-located IR BT and weighted COSMIC temperatures can be used for time series trend analysis to confirm trends seen in the individual AIRS or COSMIC datasets.

GPS/IR Matchup Dataset Example: Antarctica



COSMIC profiles for Antarctica during Jan-Dec 2011 are matched with AIRS spectra. Each COSMIC dry temperature profile is weighted using calculated dBT/dT profile for a single AIRS channel (667.0 cm^{-1}) selected to peak in the lower stratosphere.

This work is in progress and the results will be reported at a future meeting.

CONCLUSIONS

- The hyperspectral InfraRed observations from AIRS, IASI, and CrIS can provide the natural continuation of the SSU sensor for the IR monitoring of stratospheric temperature change with much better radiometric and spectral accuracy.
- GPS RO and IR can be used as a useful reference for each other. The error characteristics compliment each other.
- Further work needs to be performed to verify the observed radiance trends through intercomparison of IR sensors and comparison to GPS radio occultation profiles.
- The methods developed here should prove useful for the analysis of CLARREO IR and GPS RO datasets in the future.