IR Satellite Inter-Calibration:
A High Spectral Resolution Perspective

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UW-Madison / SSEC / CIMSS

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22-23 January 2007

THE UNIVERSITY of WISCONSIN MADISON

SSEC

CIMSS

Introduction

- The Challenge: to provide highly sensitive climate reference observations that can be continued for decades to quantify global/regional climate change
- High spectral resolution offers inherent advantages for absolute calibration (Goody and Haskins, 1998)
- Working to provide benchmark calibration observations from aircraft and Geo and Leo orbit
- Benchmark observations with high spectral resolution and wide spectral coverage allows transfer of calibration to other sensors
- i.e. we don’t want to be voting

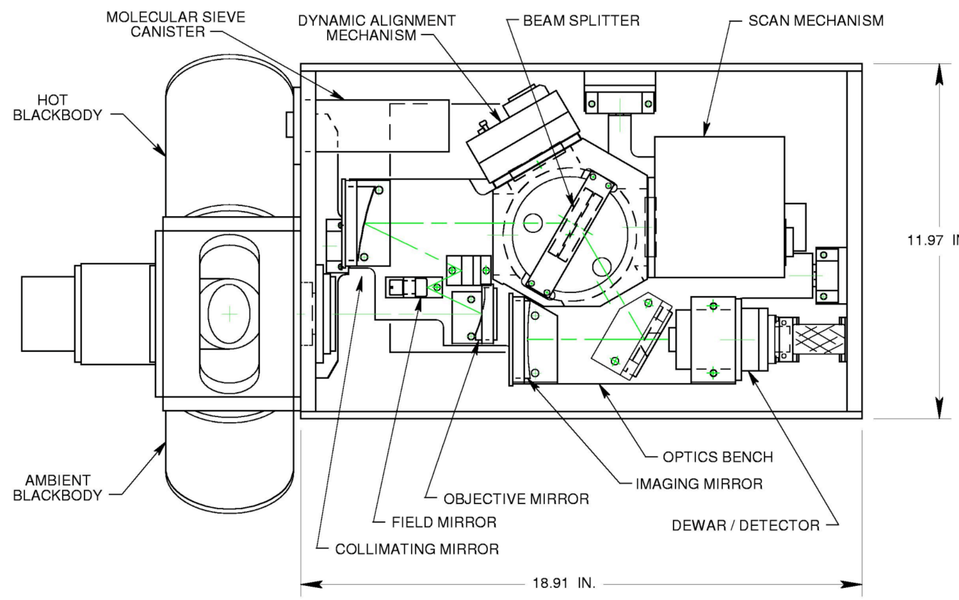
Infrared calibration for climate: a perspective on present and future high-spectral resolution instruments, Revercomb et al., Proc. SPIE Vol 6405, 640501, Dec 2006.

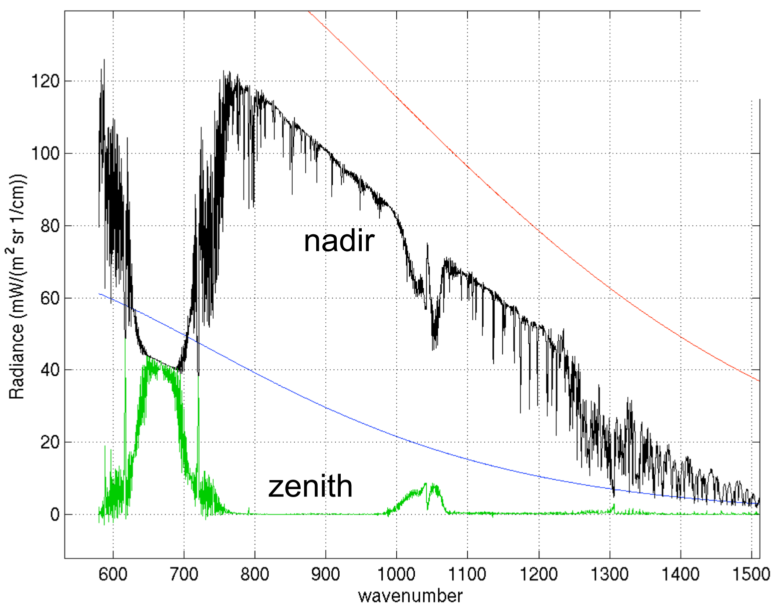
Outline

- High altitude aircraft-based satellite validation
  - the Scanning-HIS, Intro and Calibration Accuracy
  - Direct NIST radiance traceability
  - AIRS Validation
- NASA Aqua Radiance Evaluations
  - AIRS / MODIS
  - AIRS / CERES
  - AIRS spectral gap fill technique
- Future opportunities
  - GIFTS
  - Benchmark climate mission
- Summary

Scanning-High resolution Interferometer Sounder (S-HIS)

- HIS and AERI heritage
- 0.5 cm^{-1} resolution
- 580-3000 cm^{-1} coverage with three spectral bands
- 100 mrad FOV (~2 km diameter from 20 km)
- programmable cross track downward and zenith viewing
- 1998 to present on NASA ER-2, Proteus, and NASA WB-57
- In-field calibrated spectra





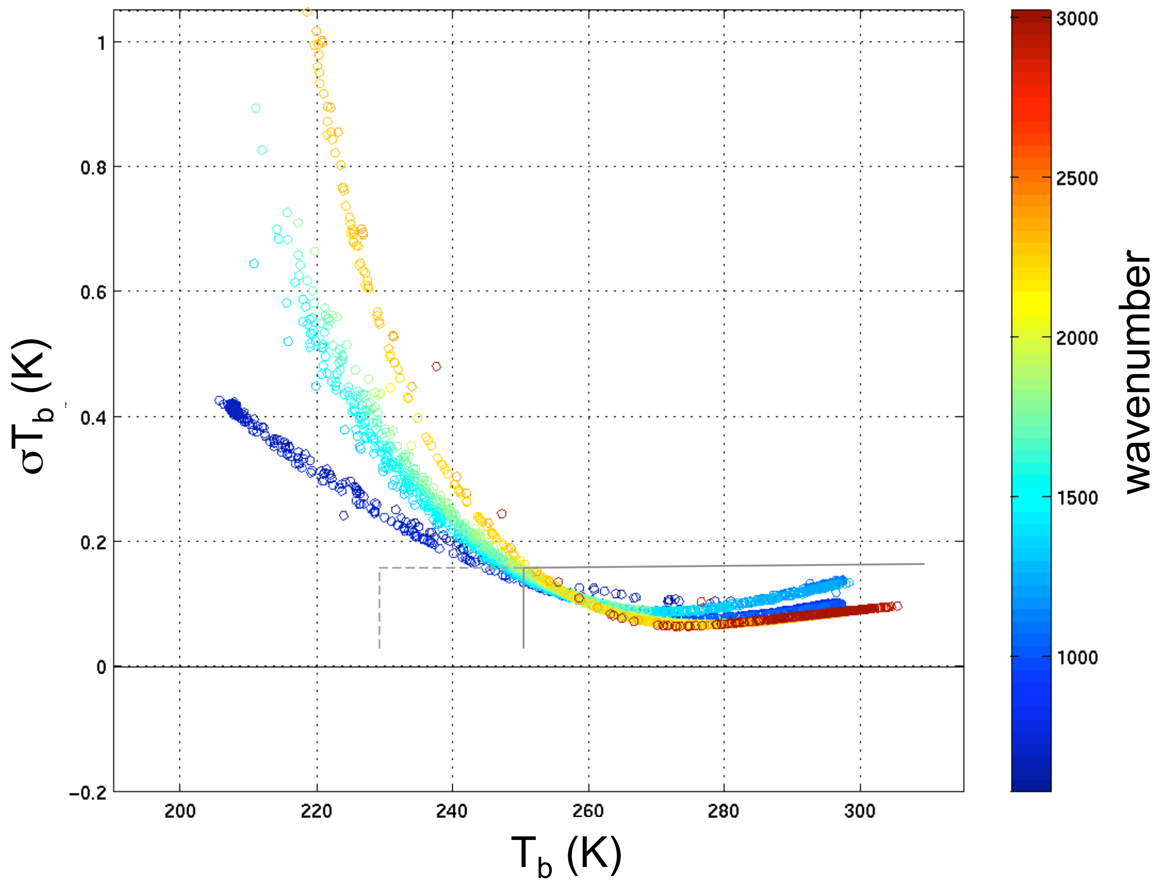
S-HIS on WB-57 wing pod

S-HIS Absolute Radiometric Uncertainty
for typical Earth scene spectrum

****Formal 3-sigma absolute uncertainties, similar to that detailed for AERI in Best et al. CALCON 2003**

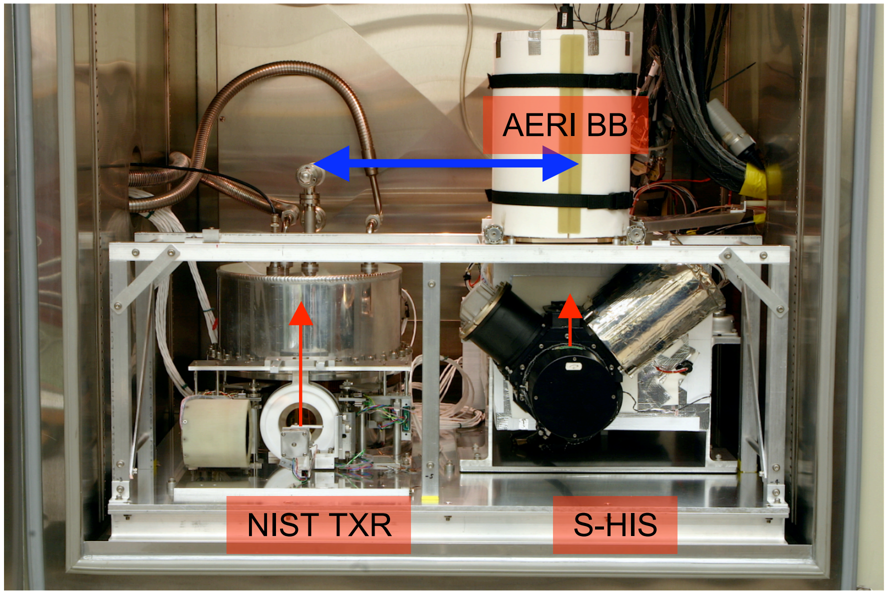
T_{ABB} = 260 K
T_{HBB} = 310 K

σT_{BB} = 0.10 K
$\sigma \varepsilon_{BB}$ = 0.0010
σT_{refl} = 5 K
10% nonlinearity

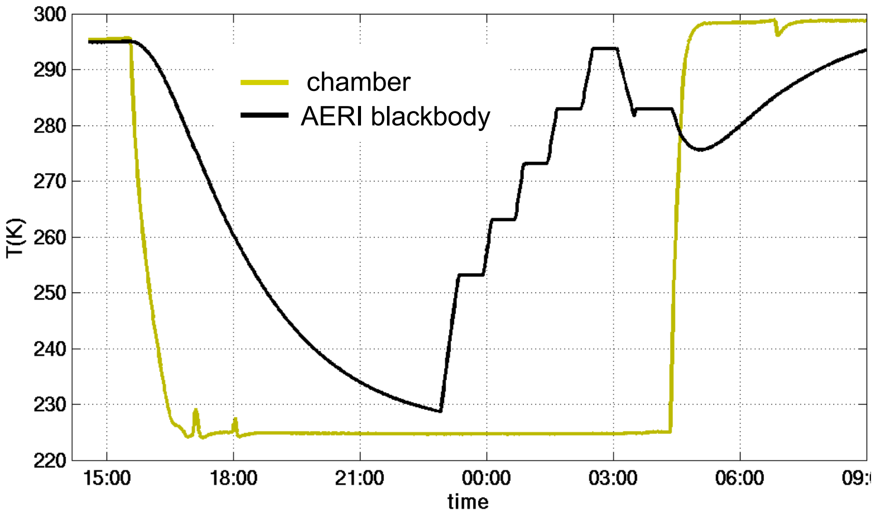


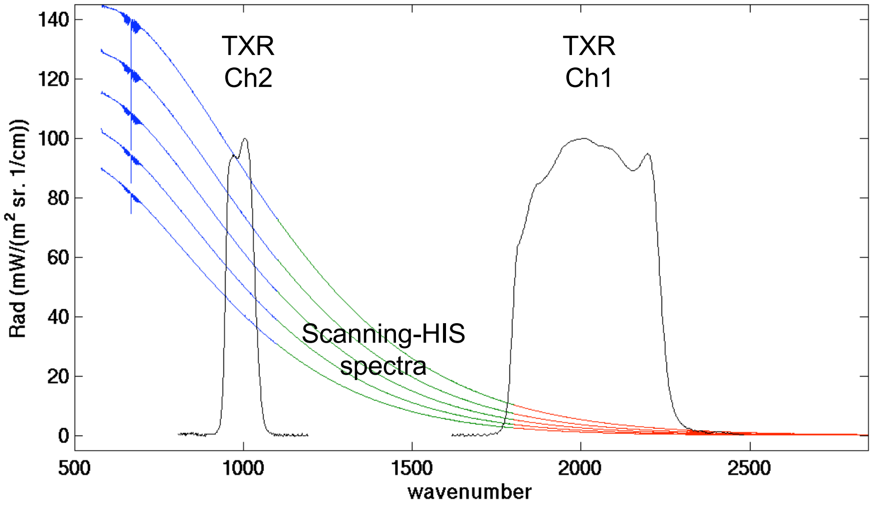
The NIST Connection

Perform **periodic end-to-end radiance evaluations** under flight-like conditions with NIST transfer sensors such that satellite validation analyses are traceable to the NIST radiance scale

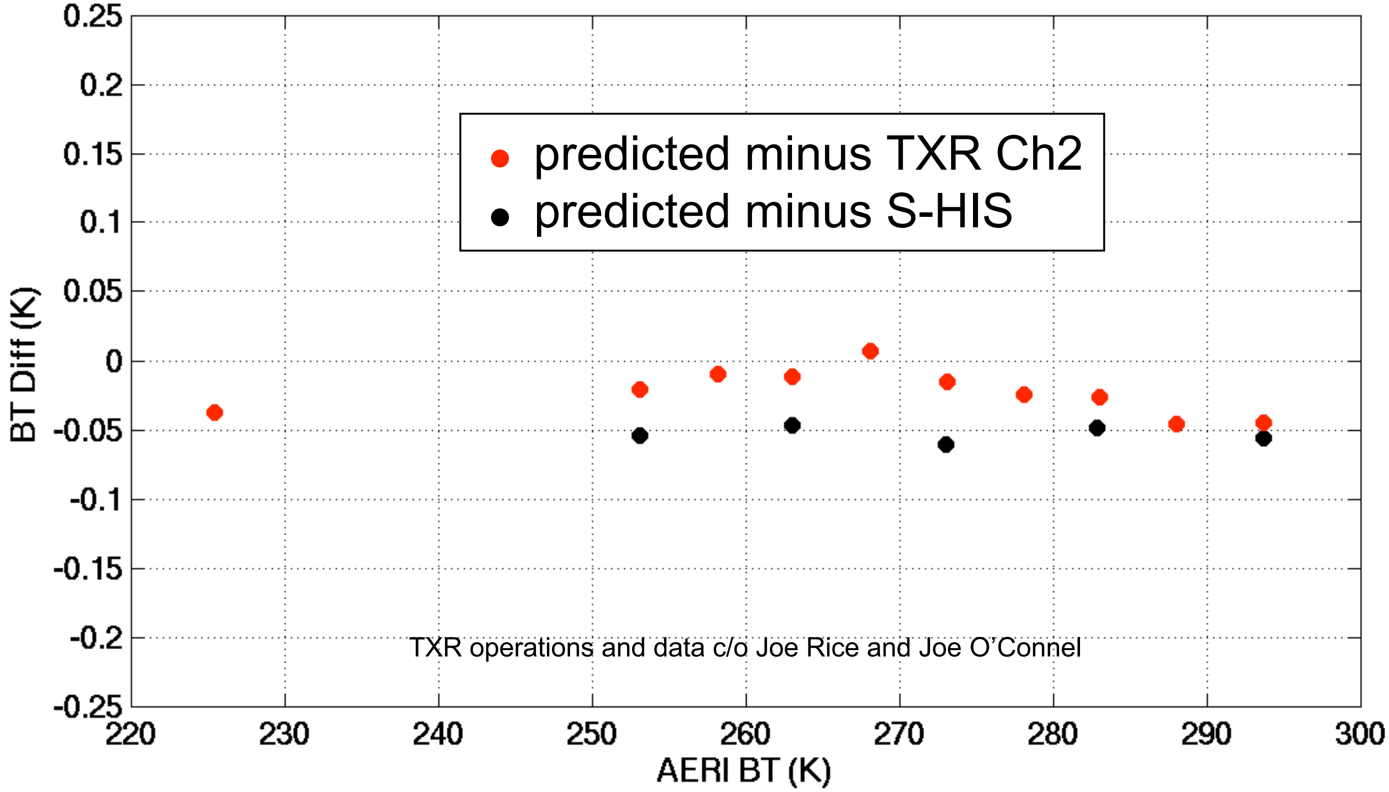


January 2007, testing at UW/SSEC





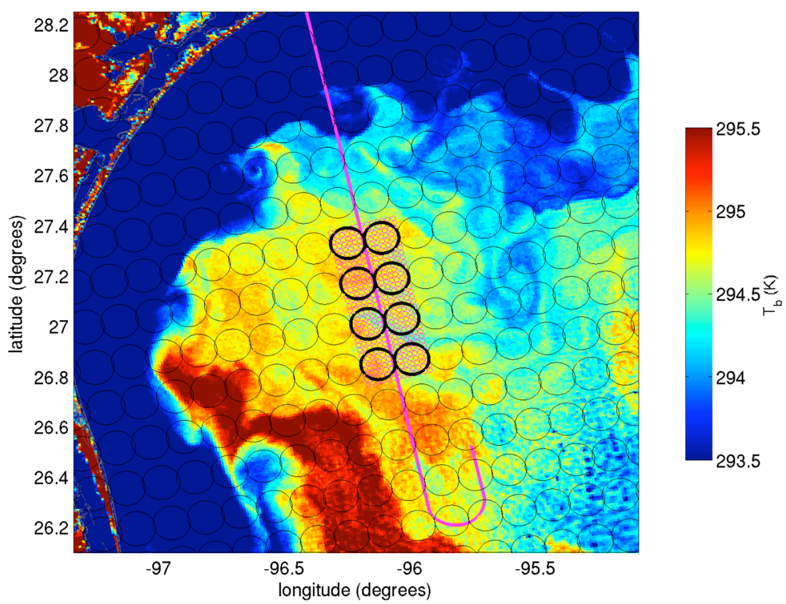
Preliminary results from January 2007

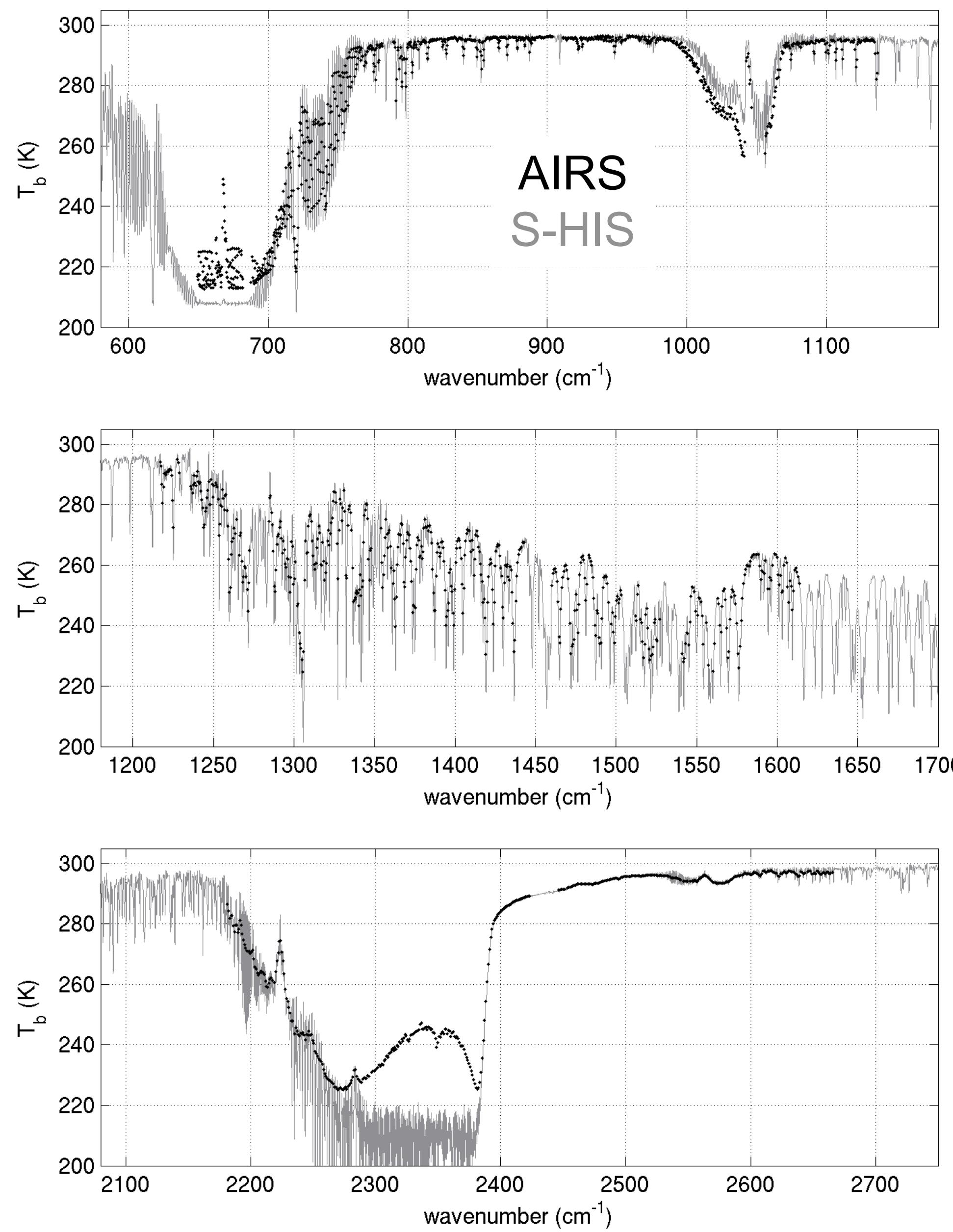


- mean agreement between TXR and S-HIS of ~30 mK, well less than propagated 3-sigma uncertainties
- TXR uncertainty _at this stage of processing_ is ~0.2 K
- larger mean diffs (~0.15K) in Ch1 under investigation

AIRS underflight
21 November 2002
Gulf of Mexico

AIRS / S-HIS comparison, without accounting for viewing geometry or spectral resolution/sampling differences:





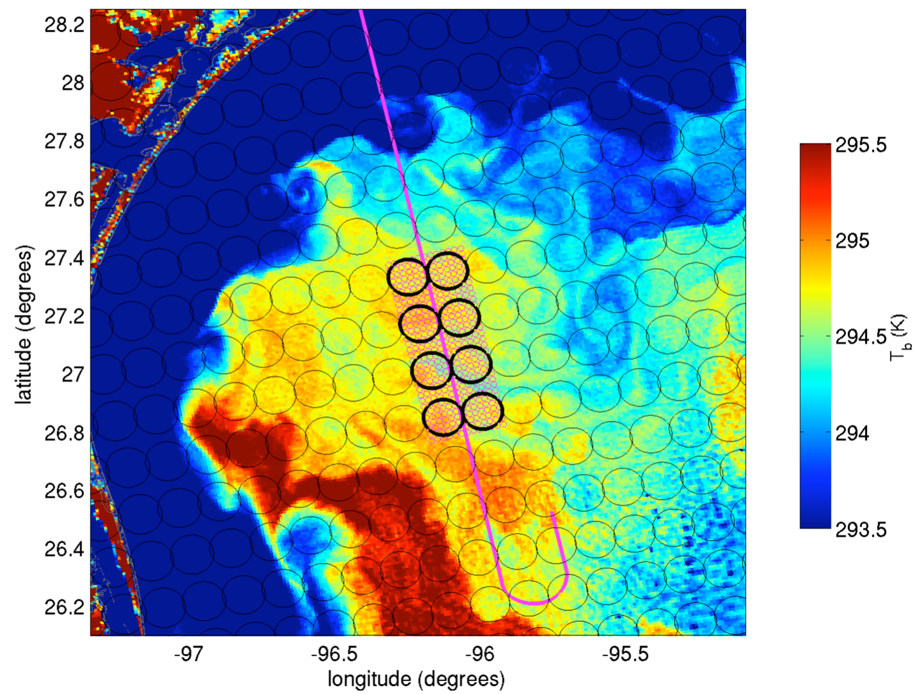
Tobin, D.C., et al. (2006), Radiometric and spectral validation of Atmospheric Infrared Sounder observations with the aircraft-based Scanning High-Resolution Interferometer Sounder, *J. Geophys. Res.*, *111*, D09S02, doi:10.1029/2005JD006094

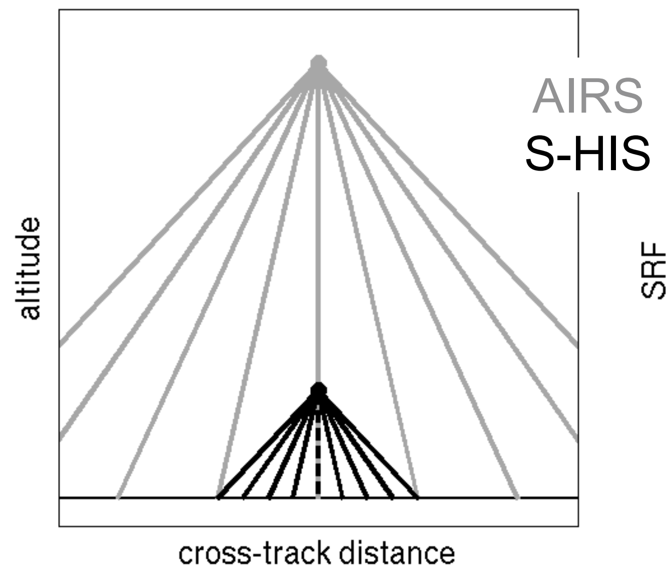
8 AIRS FOVs and 416 collocated S-HIS FOVs selected for comparison.

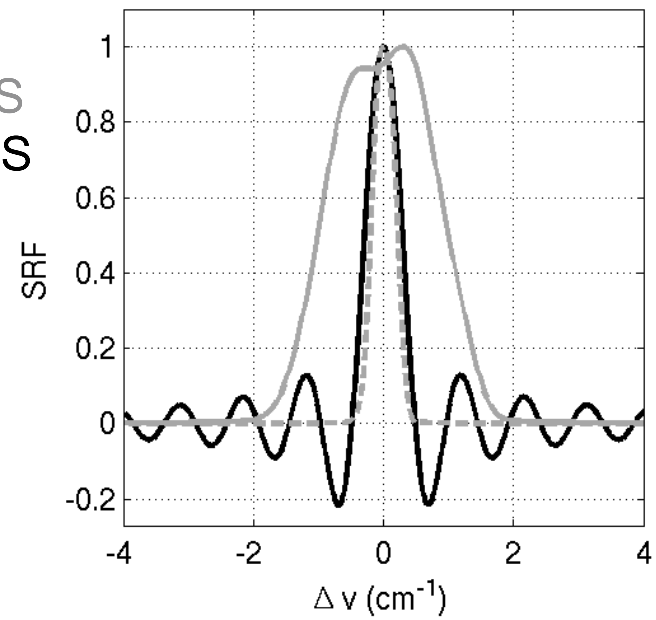
AIRS at 705 km, near nadir

S-HIS at 20.0 km, 13 view angles covering ±30°

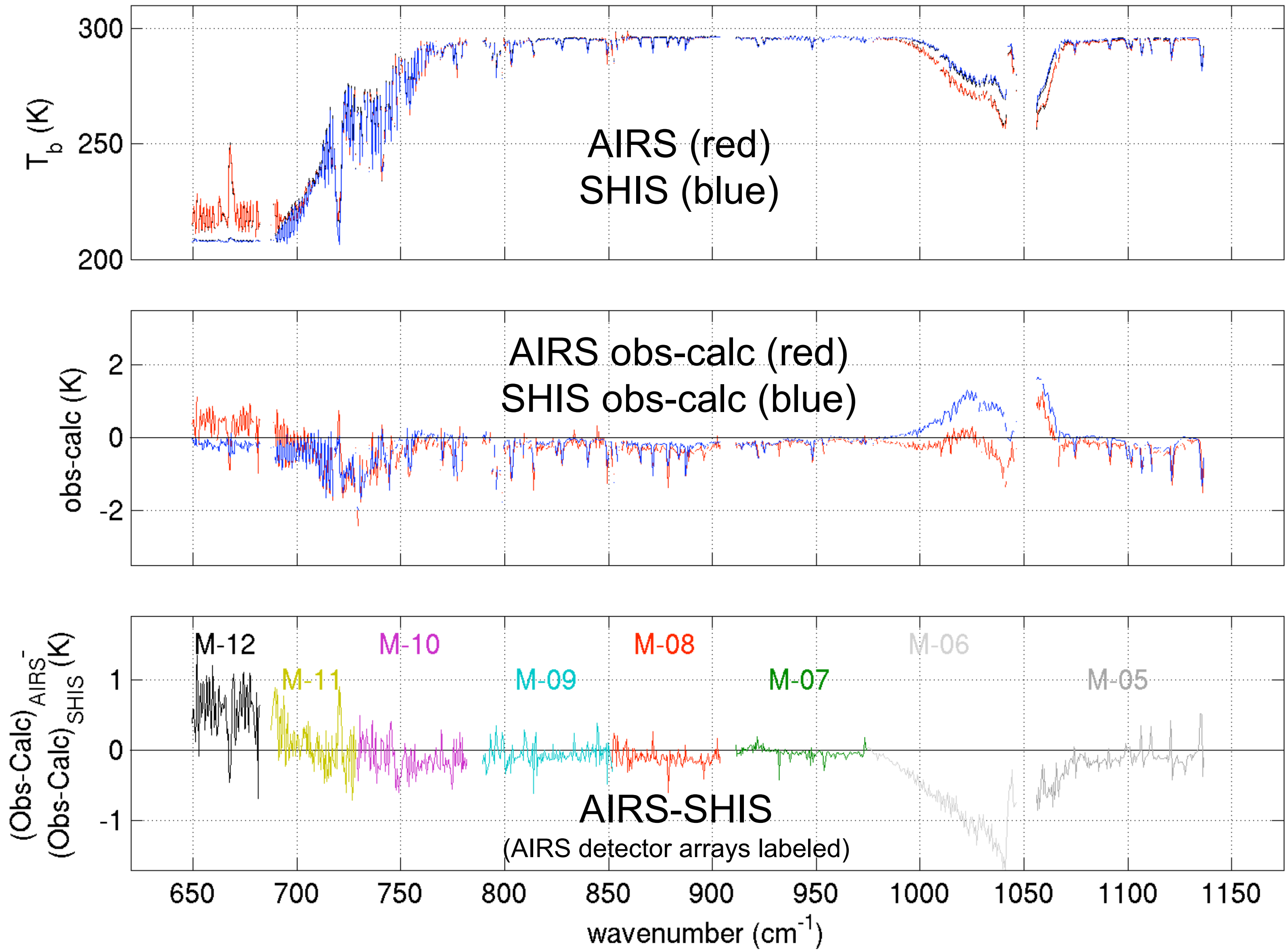
$(Obs_{AIRS}-Calc_{AIRS}) \otimes SRF_{SHIS}$ - $(Obs_{SHIS}-Calc_{SHIS}) \otimes SRF_{AIRS}$







AIRS / S-HIS comparison, accounting for viewing geometry and spectral resolution/sampling differences.



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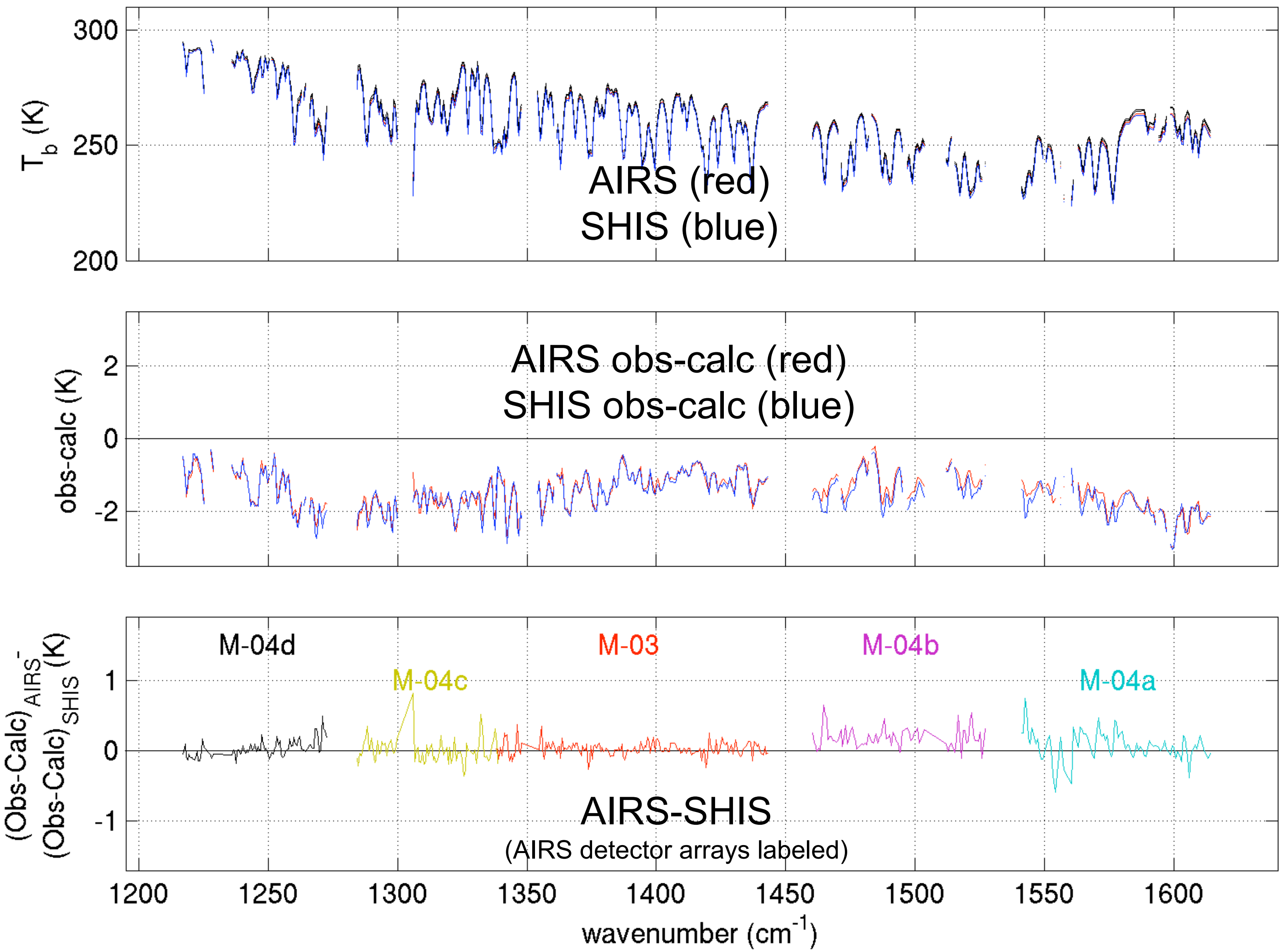
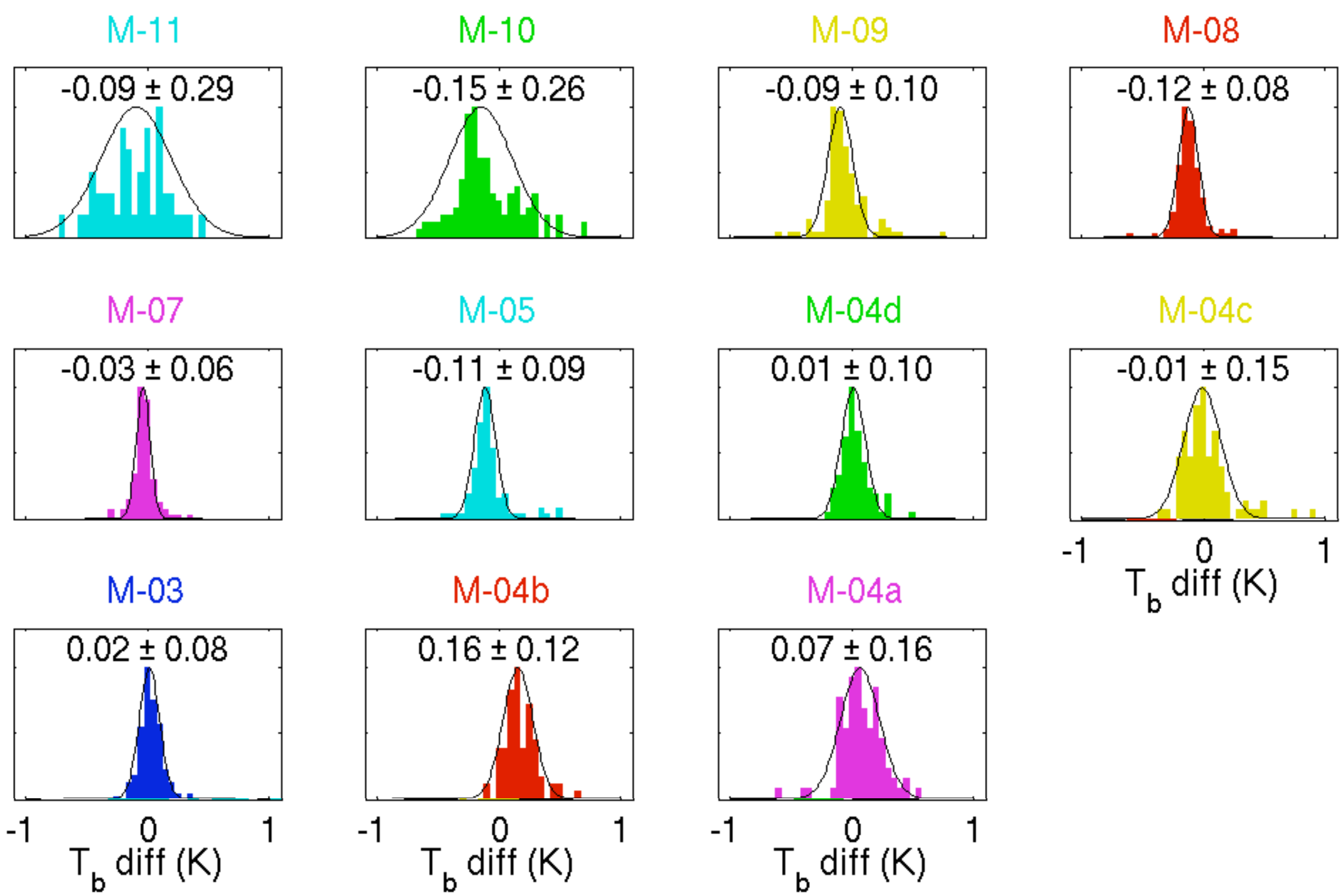
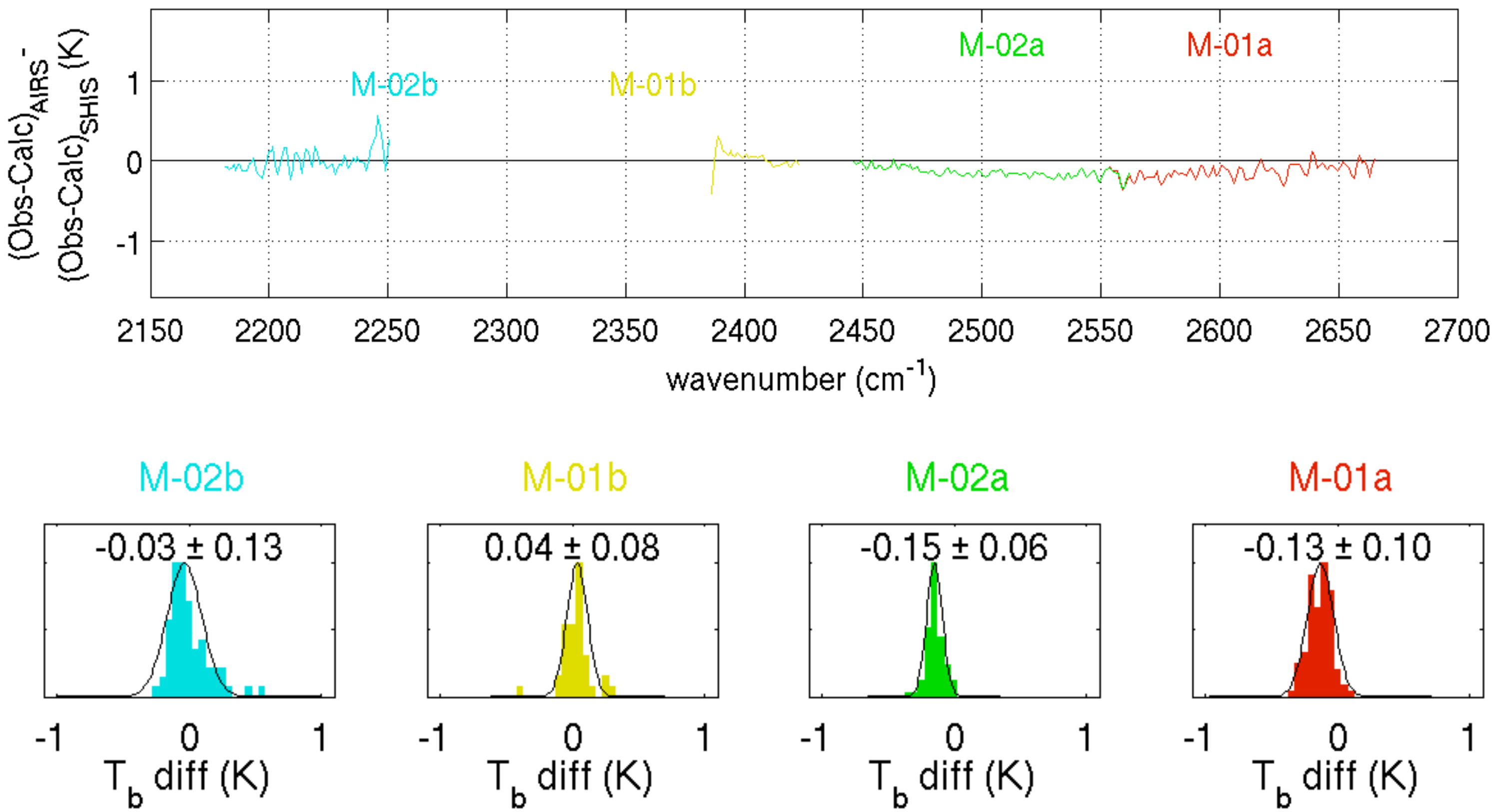


Gulf of Mexico Validation case: 2002.11.21



Night-time case summary: Shortwave

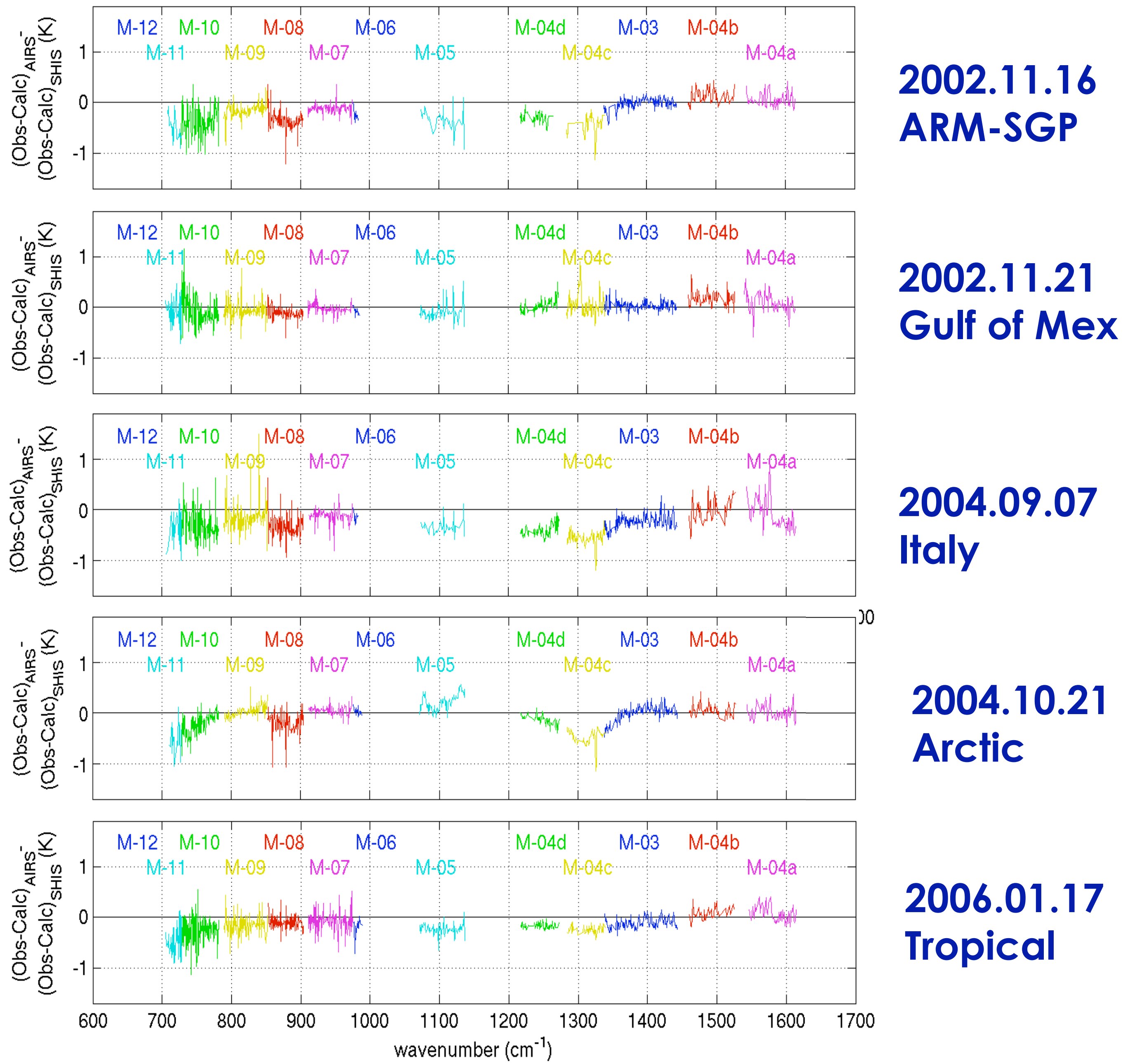


<u>1st Direct SW Radiance Validation</u>

Excellent agreement for night-time comparison from Adriex/Italy campaign

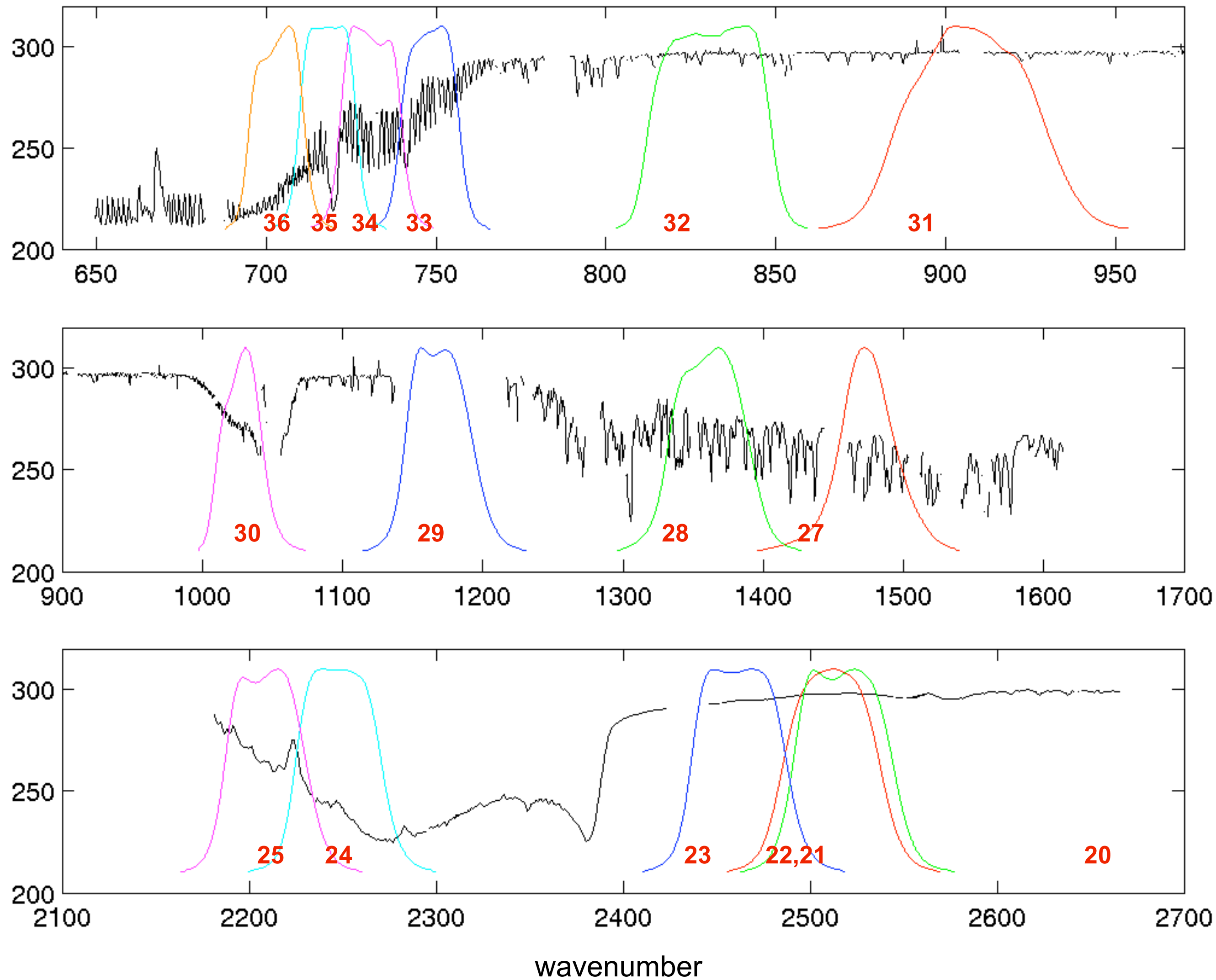
AIRS-SHIS Summary

- Radiance validation is remarkably good
- Includes Tropical to Arctic conditions
- ~5 other cases not shown
- Extends over > 4 years
- Provides basis for using AIRS as on-orbit transfer standard



Vinson et al., 2006, Techniques used in improving the radiance validation of Atmospheric Infrared Sounder (AIRS) observations with the Scanning High- Resolution Interferometer Sounder (S-HIS), *Proc.* SPIE Vol. 6405, 640505, Dec. 2006.

A sample AIRS brightness temperature spectrum overlaid with the Aqua MODIS Spectral Response Functions

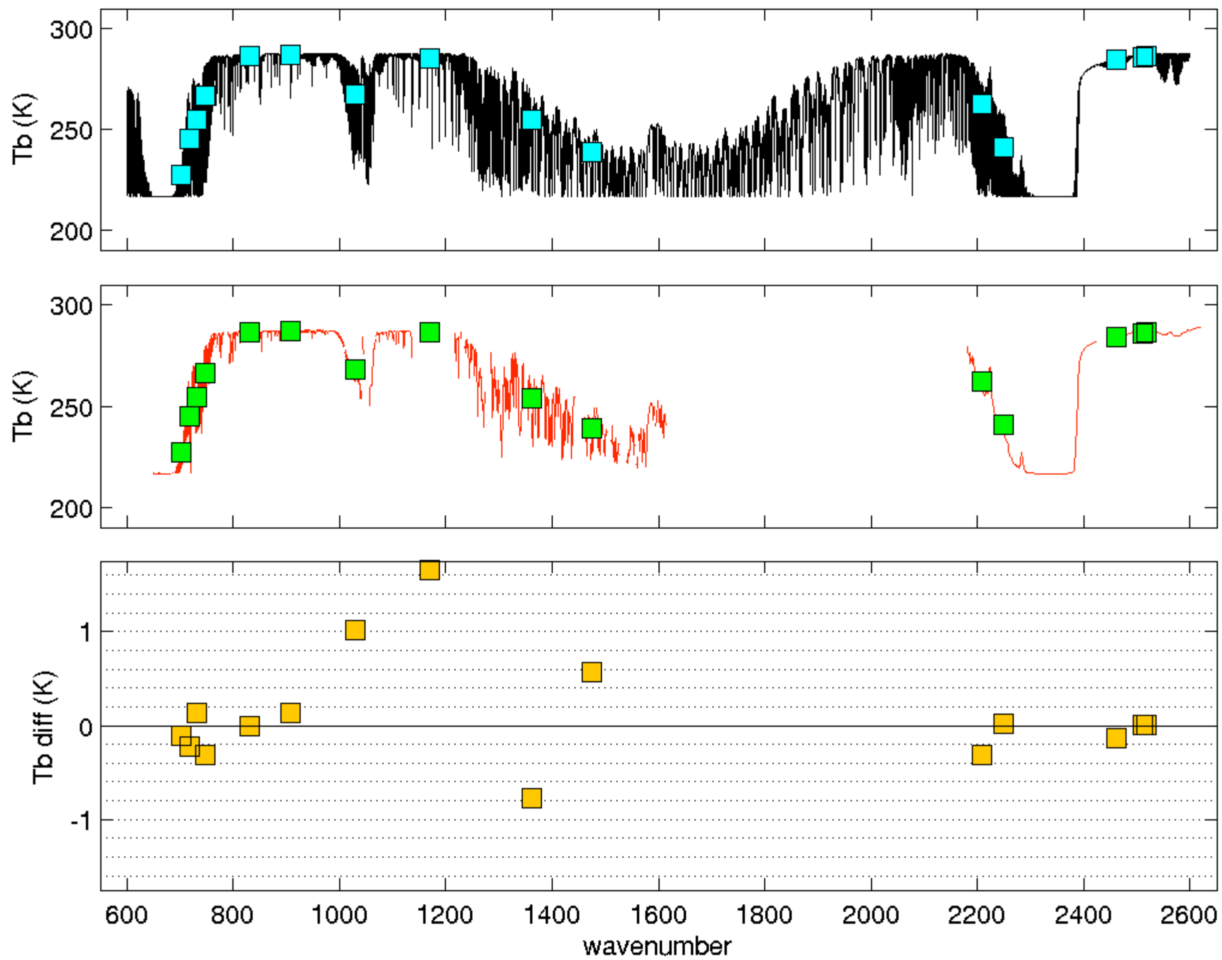


Tobin, D.C., H. E. Revercomb, C. C. Moeller, and T. Pagano (2006), Use of Atmospheric Infrared Sounder high-spectral resolution spectra to assess the calibration of Moderate resolution Imaging Spectroradiometer on EOS Aqua, *J. Geophys. Res.*, *111*, D09S05, doi:10.1029/2005JD006095

To match the MODIS spectral resolution, the AIRS spectra are convolved with the MODIS SRFs

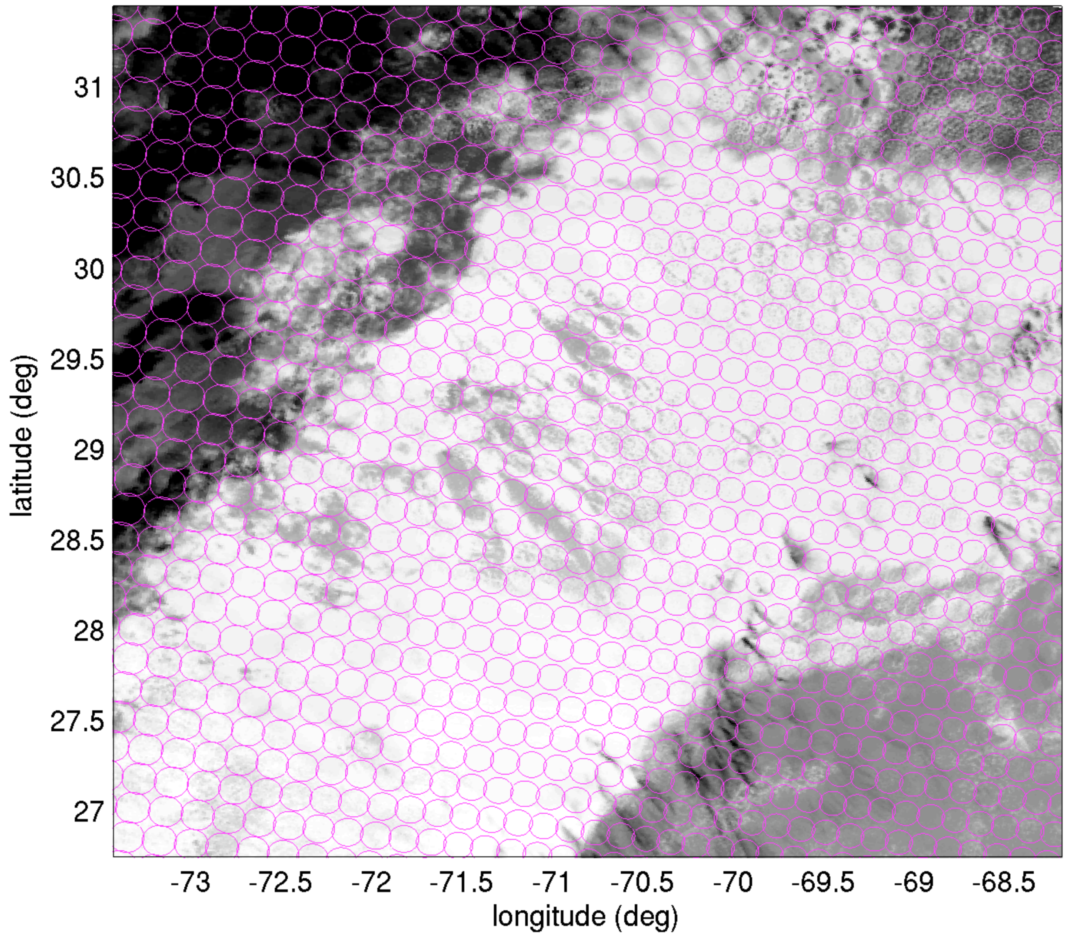
$$R_{MONO} \otimes SRF_{MODIS} - (R_{MONO} \otimes SRF_{AIRS}) \otimes SRF_{MODIS}$$

Convolution Correction: factor that accounts for small gaps in AIRS spectra when convolving AIRS radiance spectra with the MODIS SRFs.

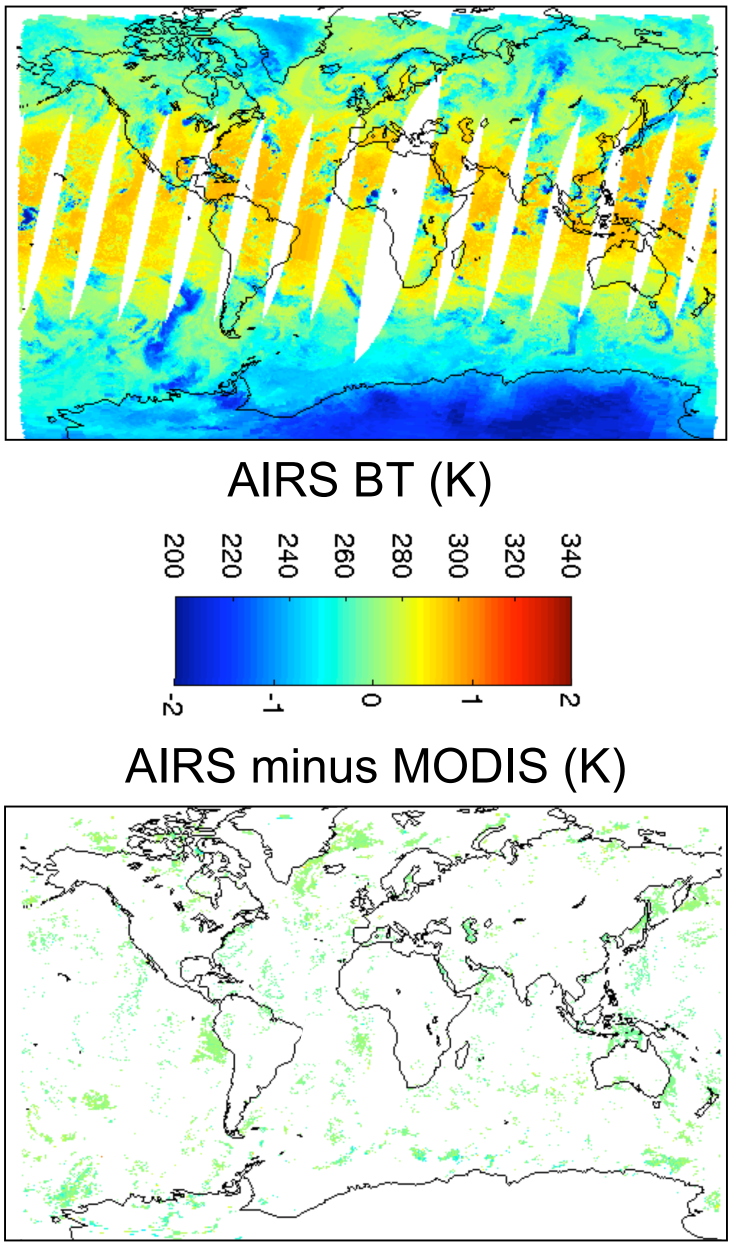


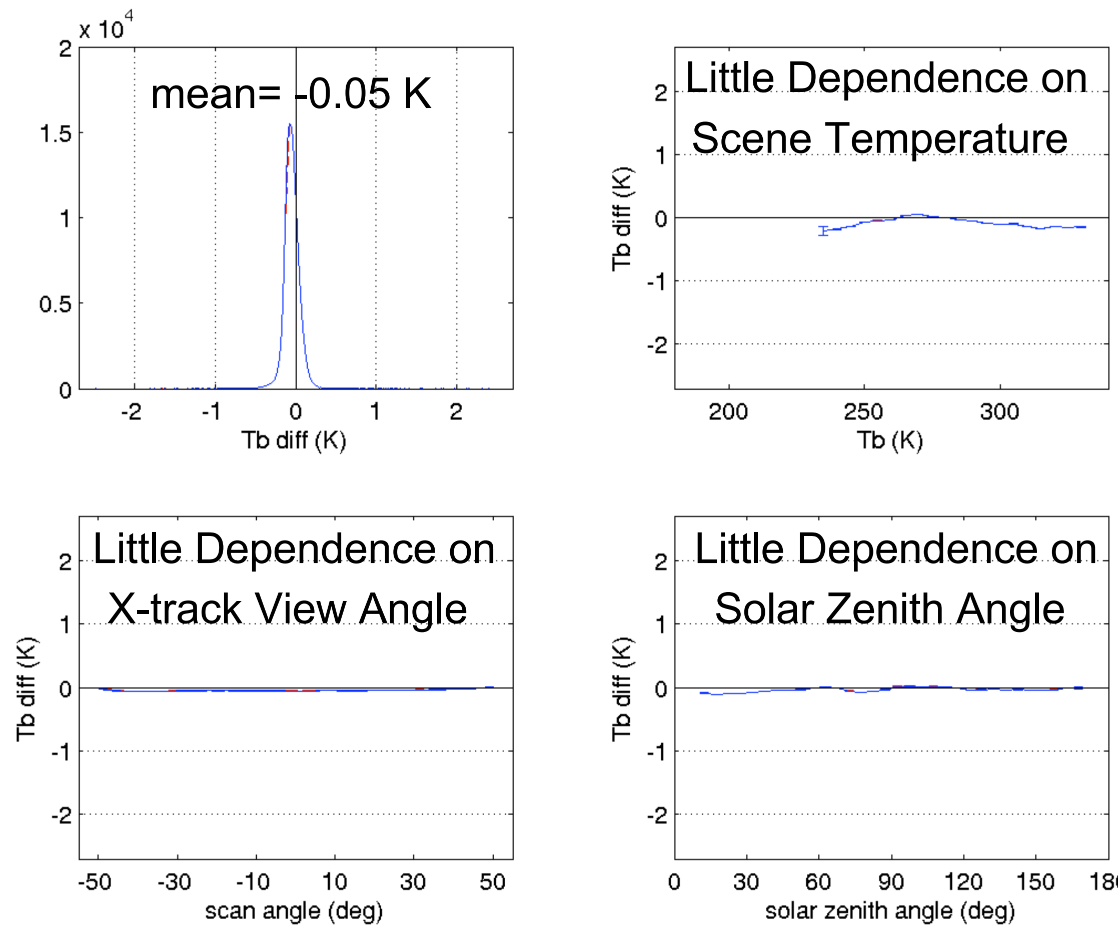
The 1 km MODIS data is collocated with AIRS by representing the AIRS FOVs as slightly oversized circular footprints, and computing the mean MODIS value within those footprints for each band.

Spatially uniform scenes are selected by requiring the standard deviation of the MODIS data within each AIRS footprint to be 0.2K or less.

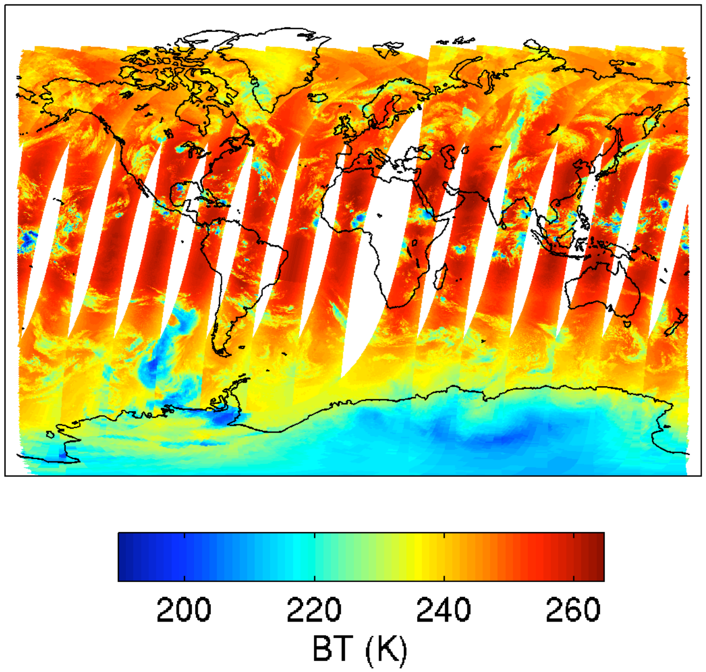


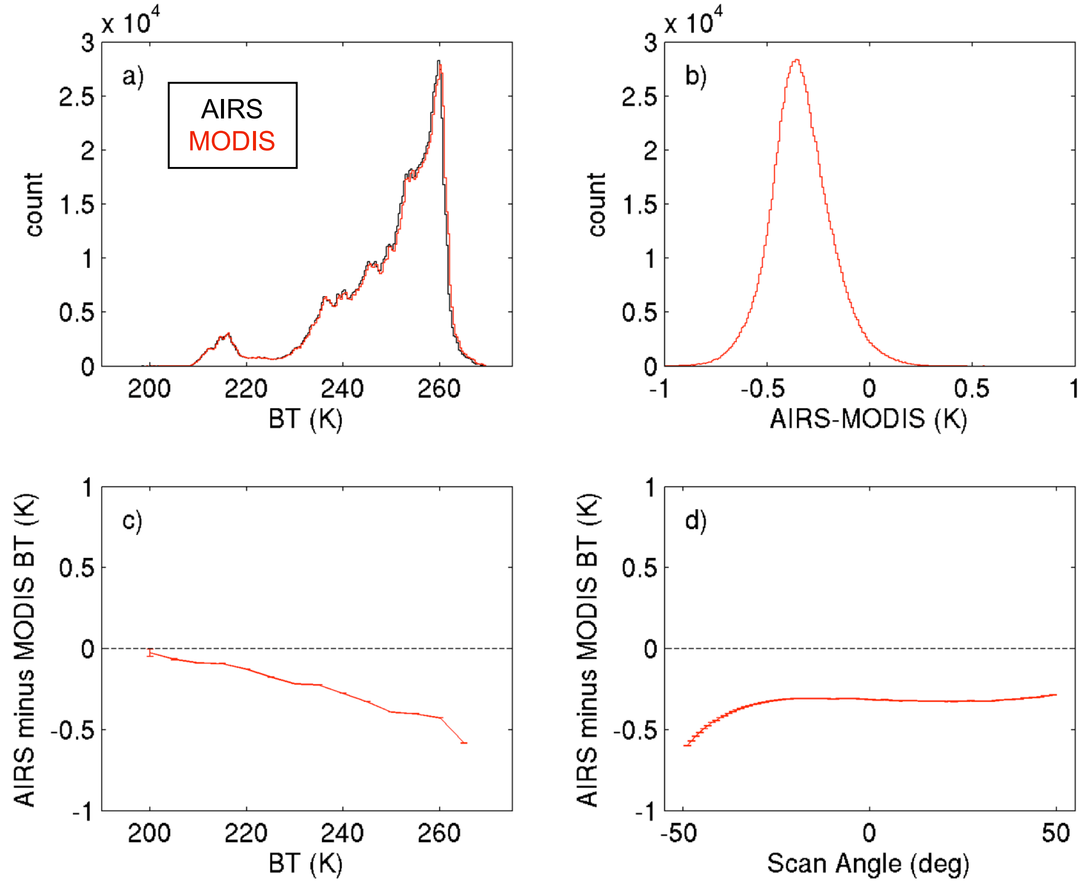
Example comparisons for band 22 (4.0 μm) on 6 Sept 2002.

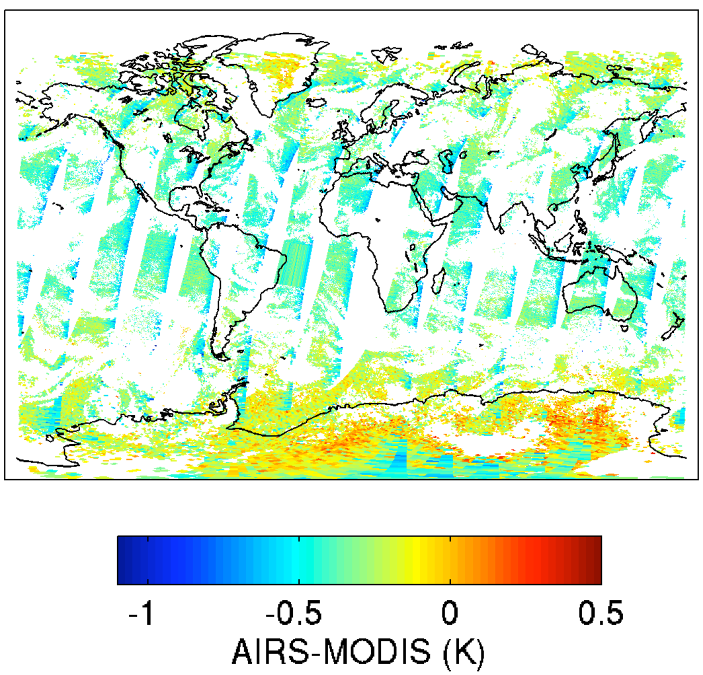




Example comparisons for band 34 (13.7 μm) on 6 Sept 2002.





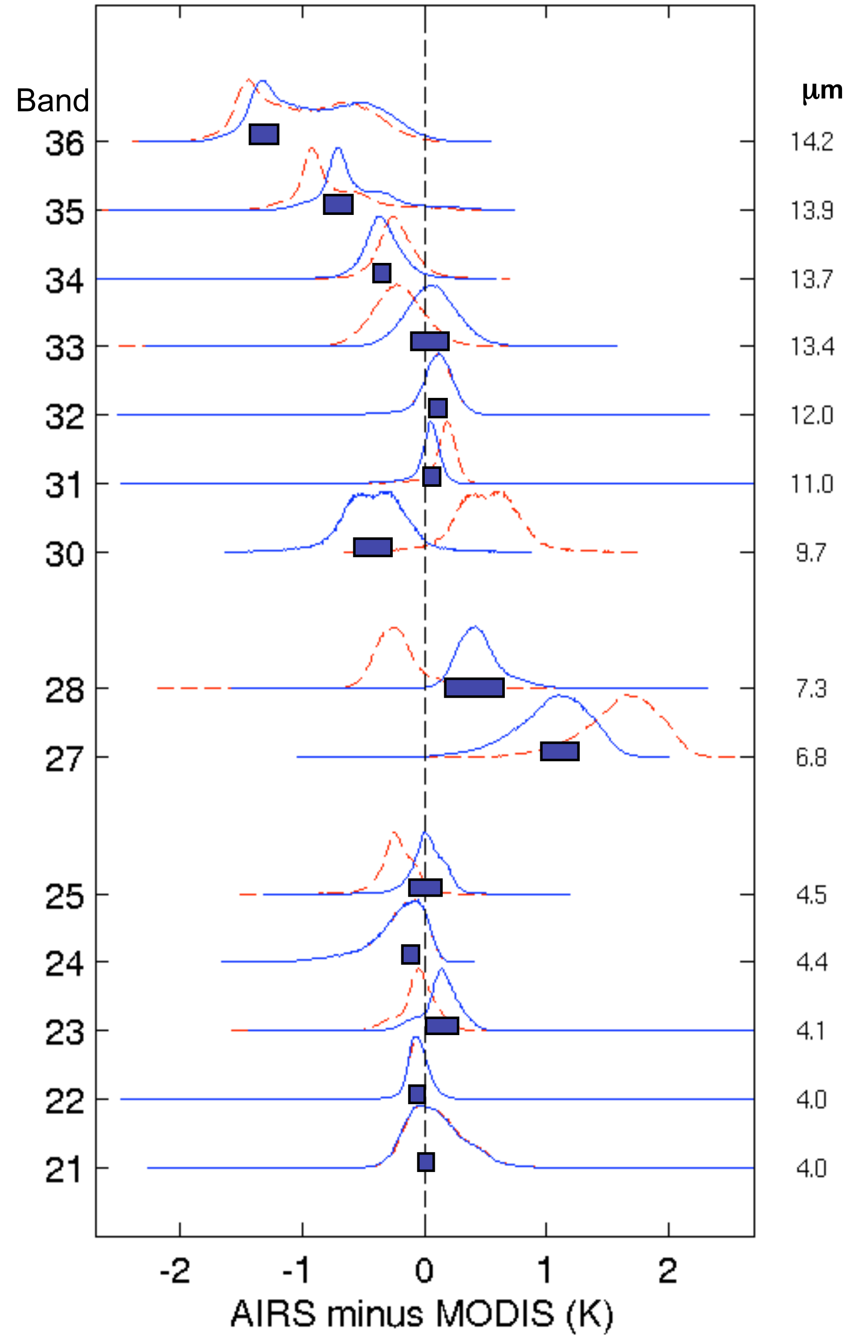


Summary of AIRS-MODIS mean Tb differences

Red=without accounting for convolution error
Blue=accounting for convolution error with mean correction from standard atmospheres

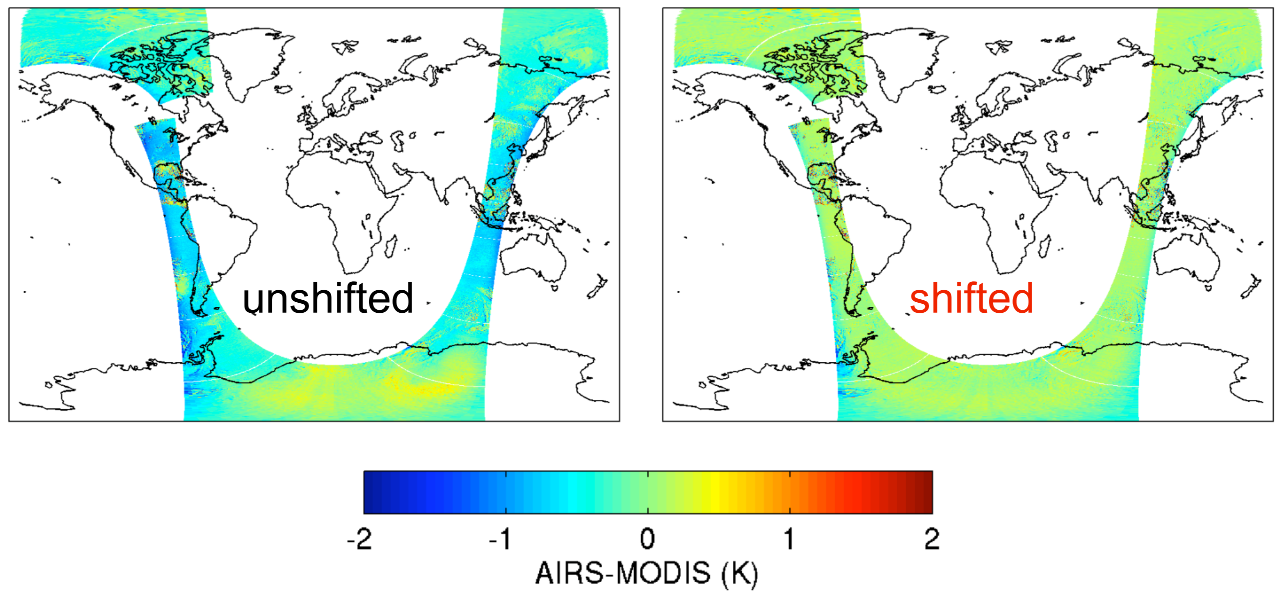
p-p Convolution Error (CE) Estimate

Band	Diff	CE	Diff	Std	N
21	0.10	-0.01	0.09	0.23	187487
22	-0.05	-0.00	-0.05	0.10	210762
23	-0.05	0.19	0.14	0.16	244064
24	-0.23	0.00	-0.22	0.24	559547
25	-0.22	0.25	0.03	0.13	453068
27	1.62	-0.57	1.05	0.30	1044122
28	-0.19	0.67	0.48	0.25	1149593
30	0.51	-0.93	-0.41	0.26	172064
31	0.16	-0.13	0.03	0.12	322522
32	0.10	0.00	0.10	0.16	330994
33	-0.21	0.28	0.07	0.21	716940
34	-0.23	-0.11	-0.34	0.15	1089663
35	-0.78	0.21	-0.57	0.28	1318406
36	-0.99	0.12	-0.88	0.43	1980369

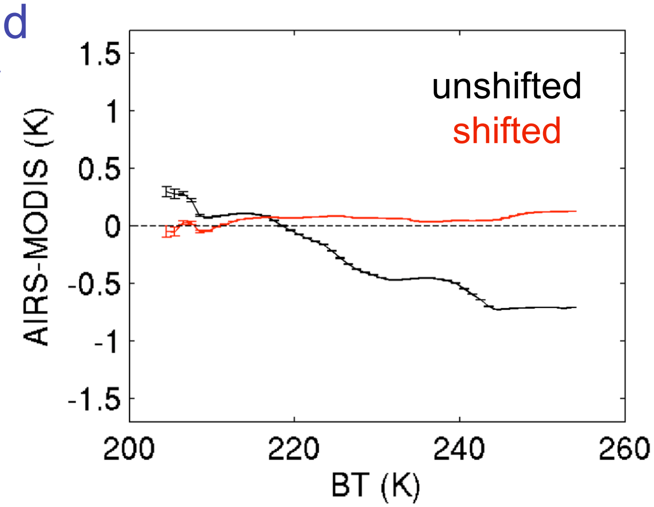


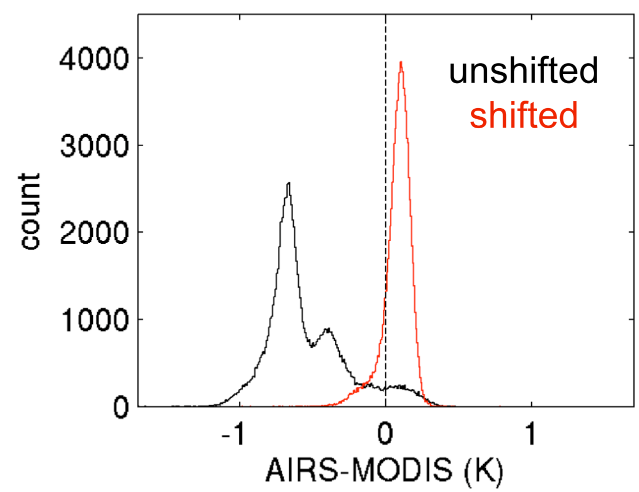
Band 35 (13.9 μm)

brightness temperature differences for one orbit of data on 6 Sept 2002 using (1) the nominal MODIS SRF and (2) the MODIS SRF shifted by +0.8 cm^{-1}.

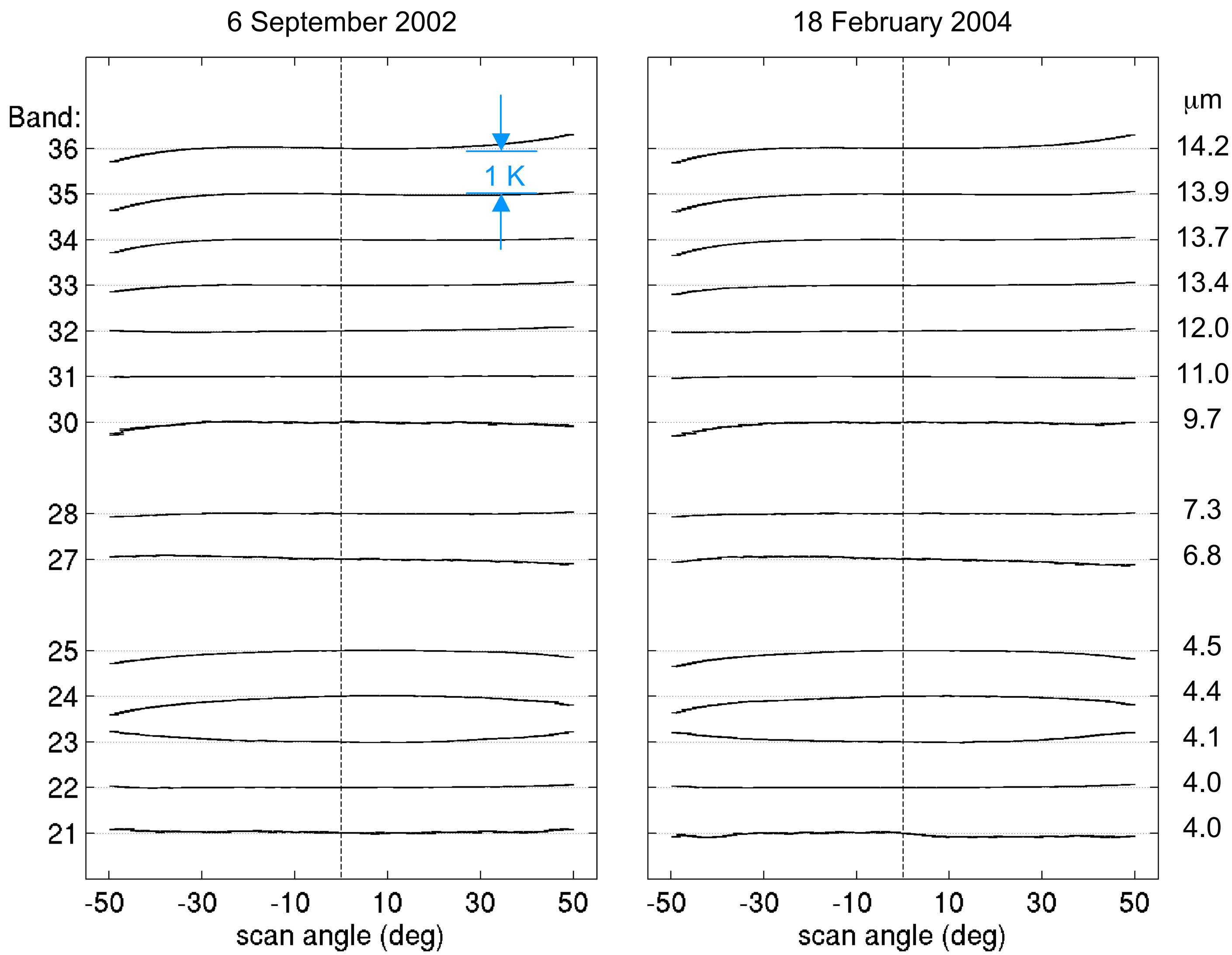


MODIS SRF out-of-band response also currently being investigated.

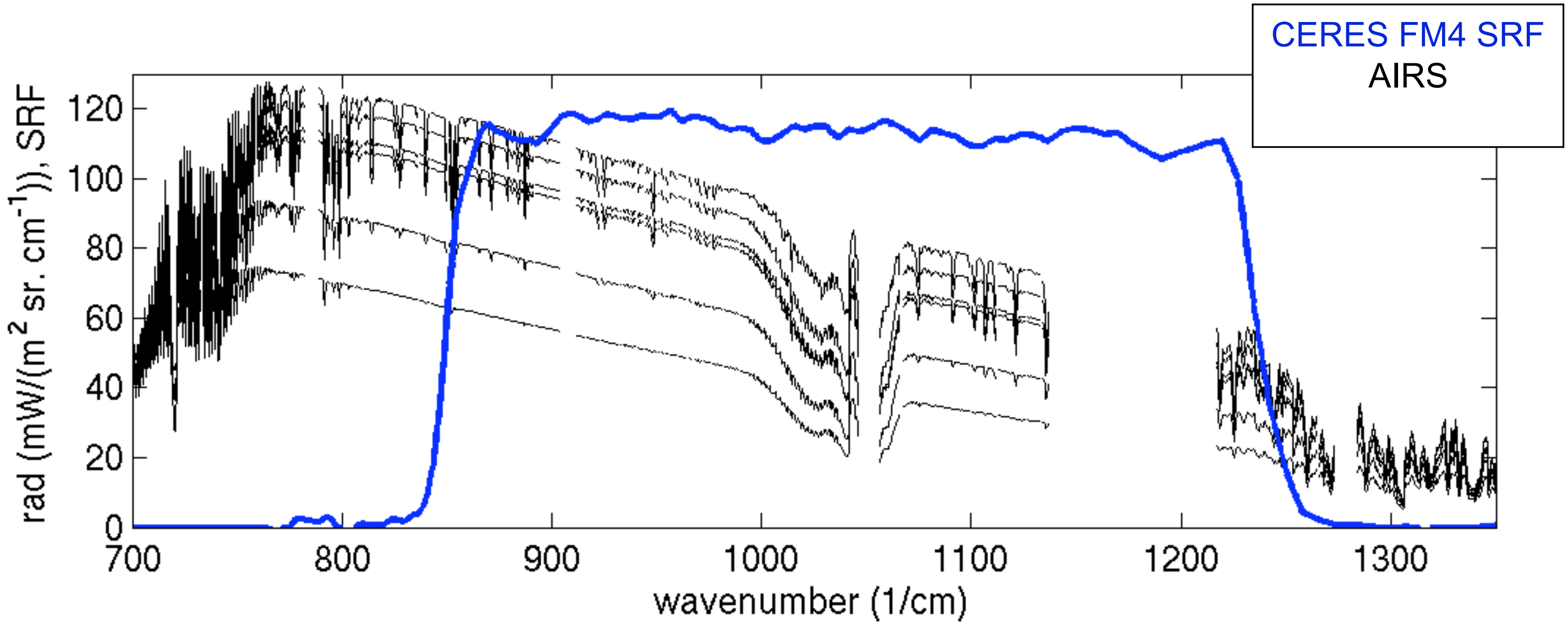




Brightness temperature differences as a function of scan angle.



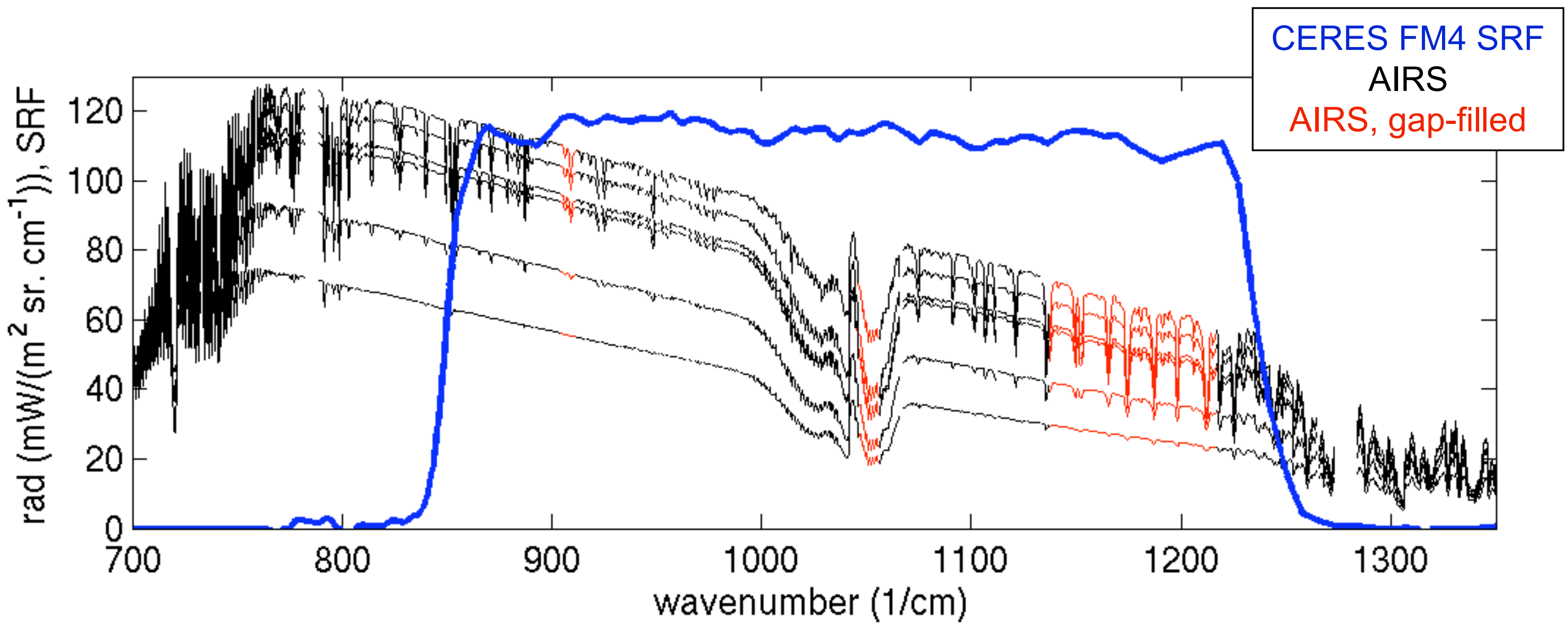
Cross-Comparisons with CERES Window Channel Radiances:



Convolution Errors (K):

	AIRS
Tropical	-0.44
MLS	-0.52
MLW	-1.07
SAS	-0.80
SAW	-1.77
US.Std	-0.70

Cross-Comparisons with CERES Window Channel Radiances:

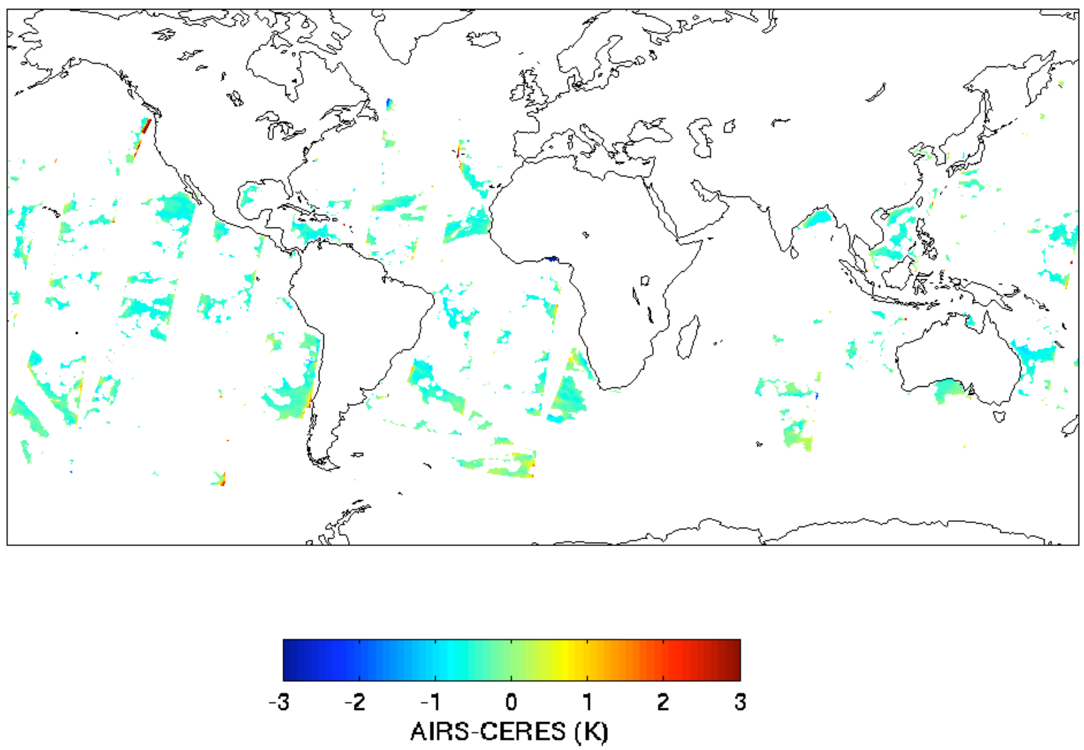


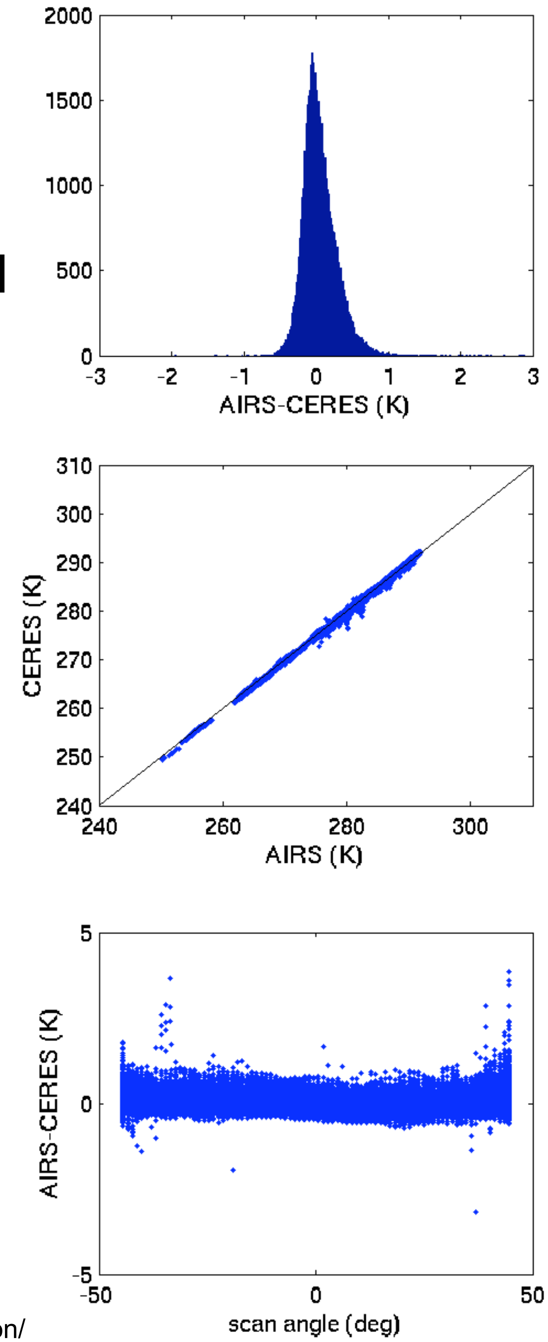
Convolution Errors (K):

	AIRS	AIRS, gap-filled
Tropical	-0.44	0.11
MLS	-0.52	0.12
MLW	-1.07	-0.01
SAS	-0.80	0.11
SAW	-1.77	-0.03
US.Std	-0.70	0.05

AIRS / CERES-FM4 Window Channel Comparisons

18 Feb 2004, Nighttime, Ocean only, 60S to 60 N





Tobin et al., 2005, Proc. CALCON Technical Proceedings, http://www.sdl.usu.edu/conferences/calcon/

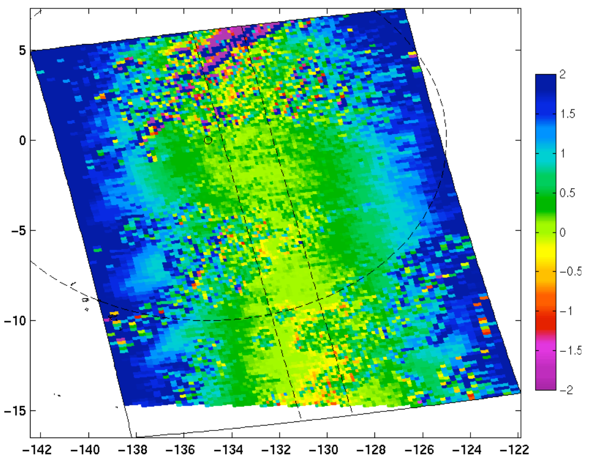
status

- AIRS intercal approaches incorporated into CIMSS Geo/Leo Intercal project
  - AIRS / GOES-10 example
- AIRS / HIRS evaluations in progress w/r/t HIRS derived cloud product issues
- Plan to continue/extend with IASI and CrIS
  - IASI aircraft validation campaign planned for April

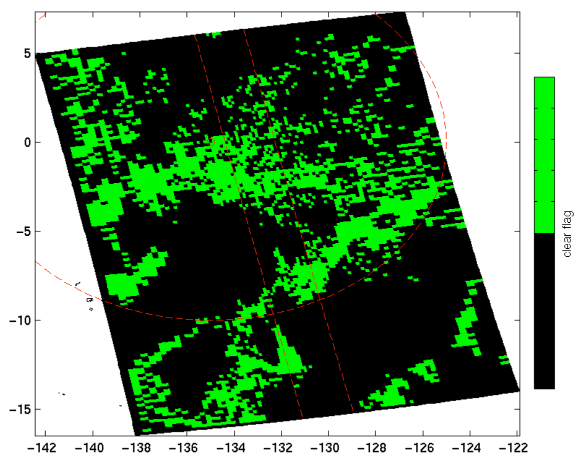
AIRS/GOES-10 Comparison

2002.09.06 Granule 224, Band 4 (~10.7μm)

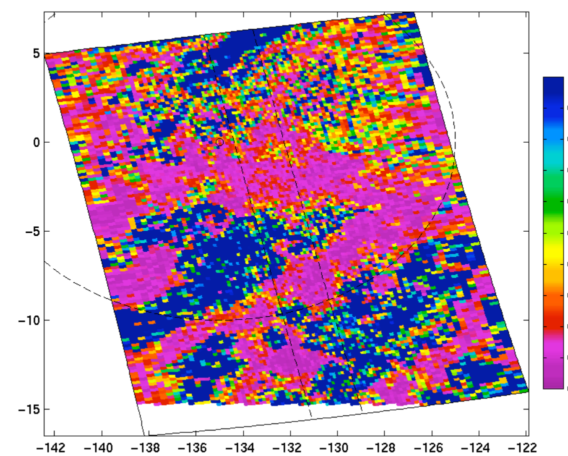
AIRS Tb - GOES Tb (K)

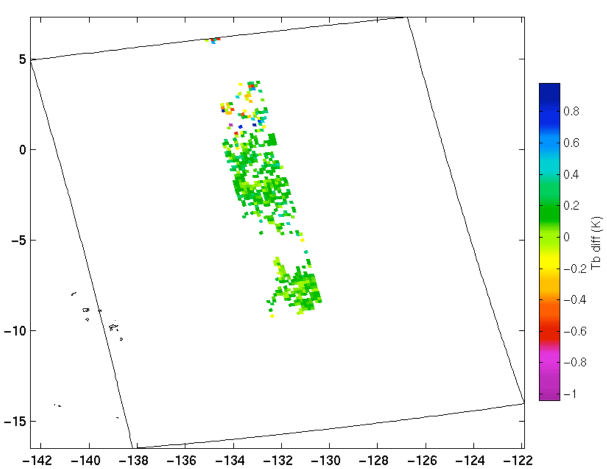


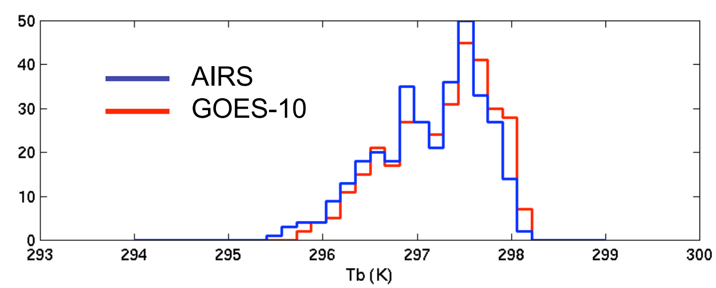
AIRS Cloud Flag

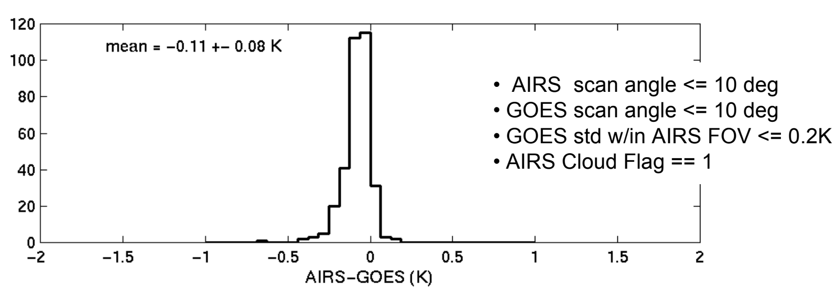


GOES variability w/in AIRS FOVs







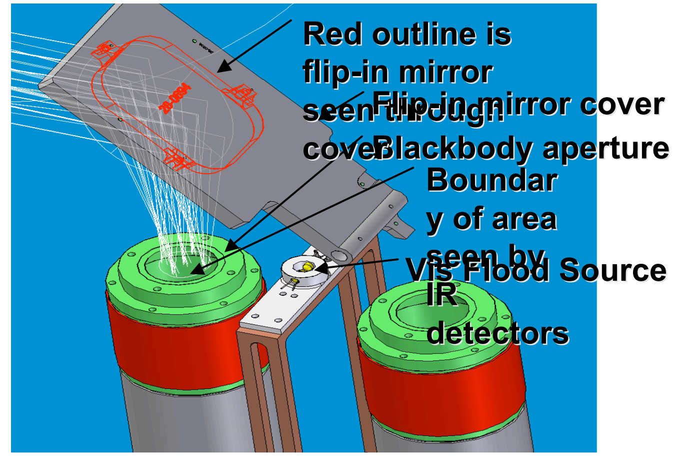


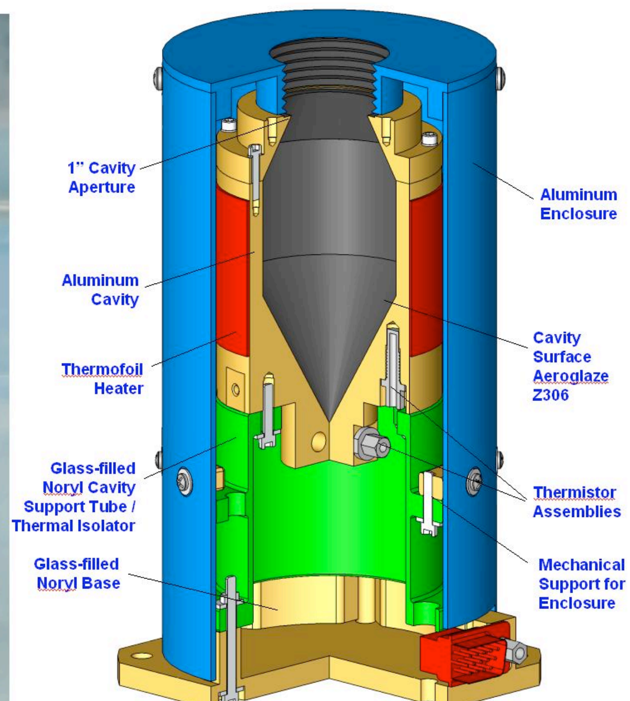
GIFTS

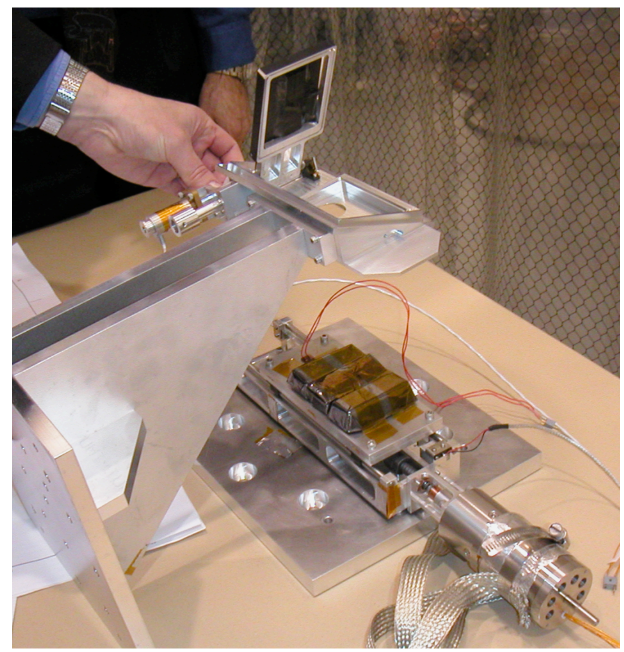
- Plane mirror FTS with 128x128 detector arrays yielding 80,000 high spectral resolution spectra per minute from Geo orbit
- Advanced Geo Sounder with two orders of magnitude advantage over current GOES (t by 5, z by 3, x & y by 2.5 = 93)
- Recommended for flight by the recent NAS Decadal Survey for Earth sciences
- An important but un-stated requirement of an advanced Geo sounder is **its use for global systems inter-calibrations**

Calibration uses two internal blackbodies and space view

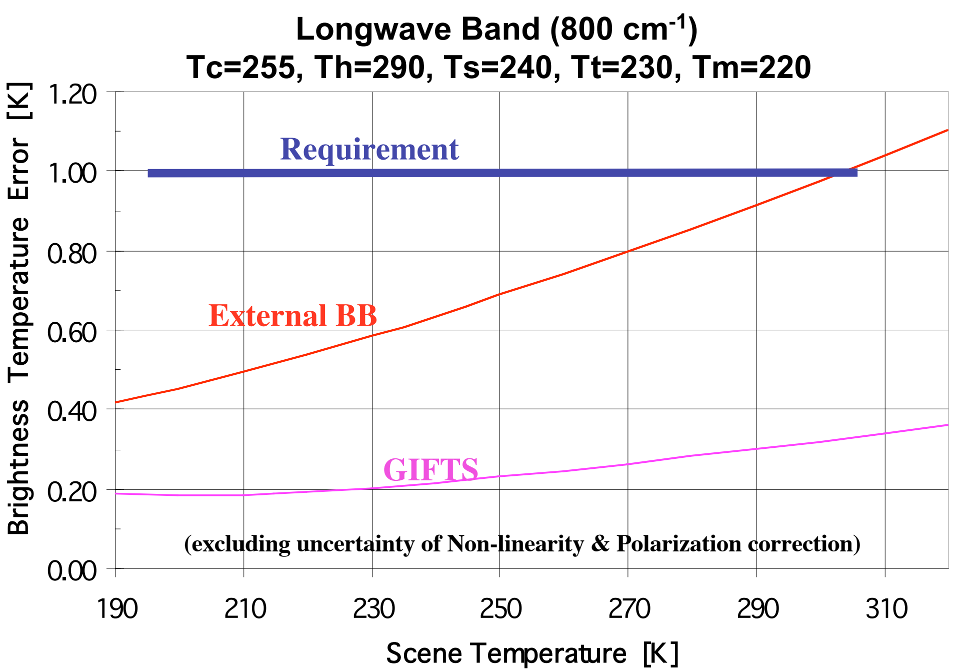
- Two small, high emissivity, nearly isothermal cavities replace normal large external source
- Located behind the telescope and viewed via a small flip-in mirror

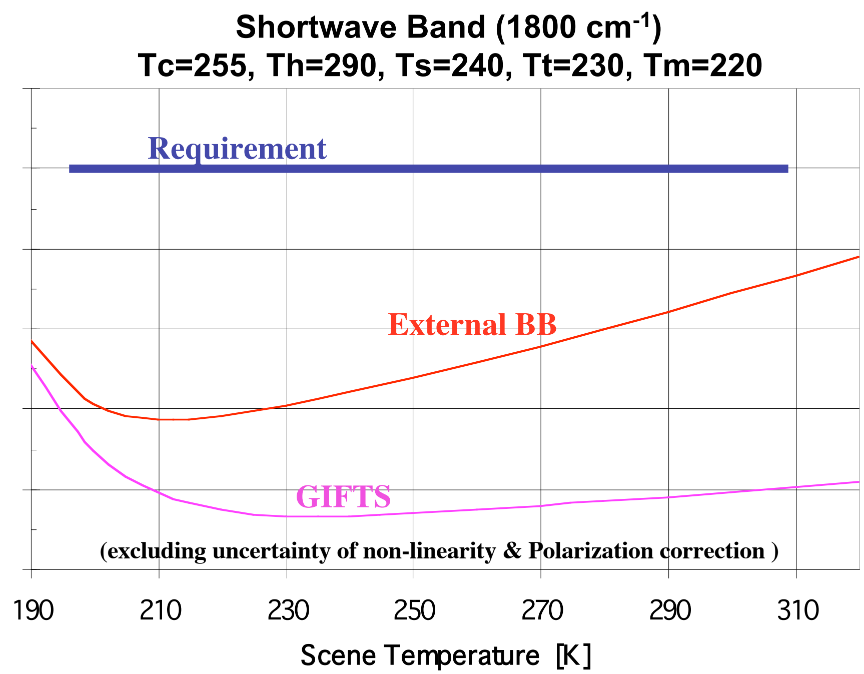




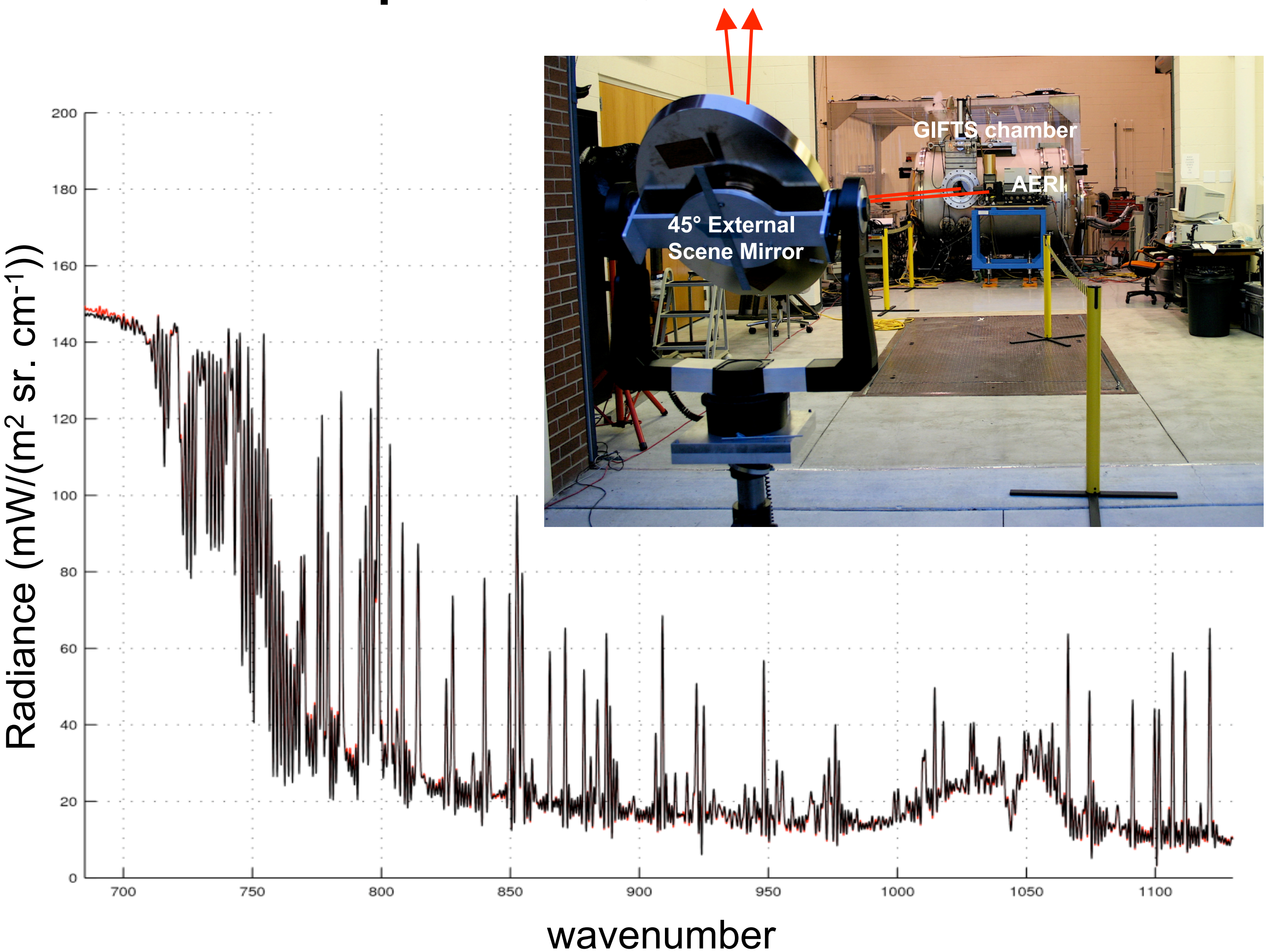


GIFTS Absolute Calibration Uncertainty Estimates

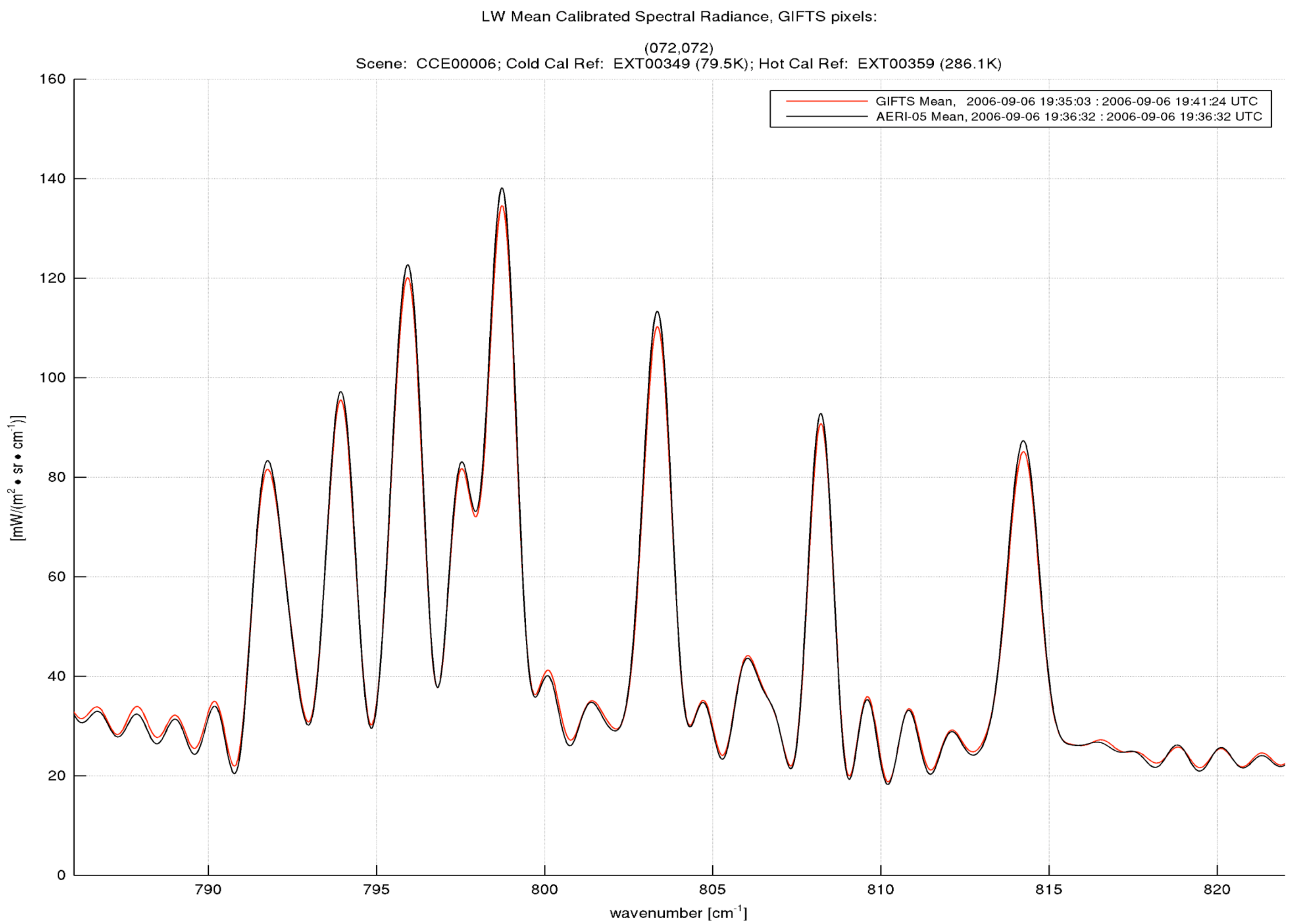




LW Comparison, GIFTS - AERI-05



LW Comparison, GIFTS and AERI-05



Benchmark Climate Observing System

Why improved accuracy, if we are doing this well?

- Time to unequivocally quantify climate change is proportional to uncertainty (e.g. 30 years can go to 10 years by reducing uncertainty from 0.3 to 0.1 K)
- We can do better, if it has the priority
- Results need to be unassailable to have societal impact: This implies the need to employ in-orbit tests of the critical blackbody reference accuracy

➢ ASIC3 recommendation

➢ Recommended by decadal survey

Benchmark mission

- In-orbit verification of key calibration properties
  - Dual sensors
  - Blackbody T, using phase change materials
  - Blackbody emissivity, using sources for reflectivity measurements
  - Linearity, using out-of-band harmonics
- Design considerations for Intercal
  - Orbit providing local time coverage and crossing operational sun-synchronous orbits to allow inter-comparisons for a range of sites/conditions
  - Broad and continuous spectral coverage
  - Off-nadir pointing
  - Footprint size and noise performance

Summary

- Dramatic improvements in current research and future operational satellite IR measurements have much to offer climate applications
- Coupling reasonably high spectral resolution with broad spectral coverage makes it possible to achieve very high accuracy with high information content
- These new capabilities offer the potential to unify the entire international complement of IR observations from different instruments and platforms
- Future missions from both Geo and Leo offer the ability to improve on these standards