High Accuracy IR Radiances for Weather & Climate

Part 2: Airborne validation of IASI and AIRS (JAIVEx) & the role for future benchmark satellites (CLARREO)

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Perspective

- <u>**Era of High Spectral Resolution IR Sounding from space is here and impacting forecasts**</u>
  (AIRS, IASI, soon followed by CrIS & hopefully GIFTS)
- **<u>The High information content</u> allows retrieval of trace gases, cloud and surface properties, in addition to temperature and water vapor profiles– *stems from broad spectral coverage, low noise, and <u>high absolute accuracy</u>***
- **<u>A new standard in absolute accuracy</u> is being demonstrated with aircraft sensors referenced to NIST [Part 1]– a few 0.1 K 3-sigma is possible using the fundamental advantages of high resolution, good blackbodies, & atmospheric spectral calibration)**
- <u>**An exciting new Climate Mission has emerged**</u>

Topics

1. **Radiance Validation from high spectral resolution aircraft observations**: ***a sound foundation for advanced retrieval capability***

   - **Joint Airborne IASI Validation Experiment (JAIVEx) and aircraft instrument introduction**
   - **JAIVEx results for IASI on MetOp-A: 14 April - 4 May 2007**

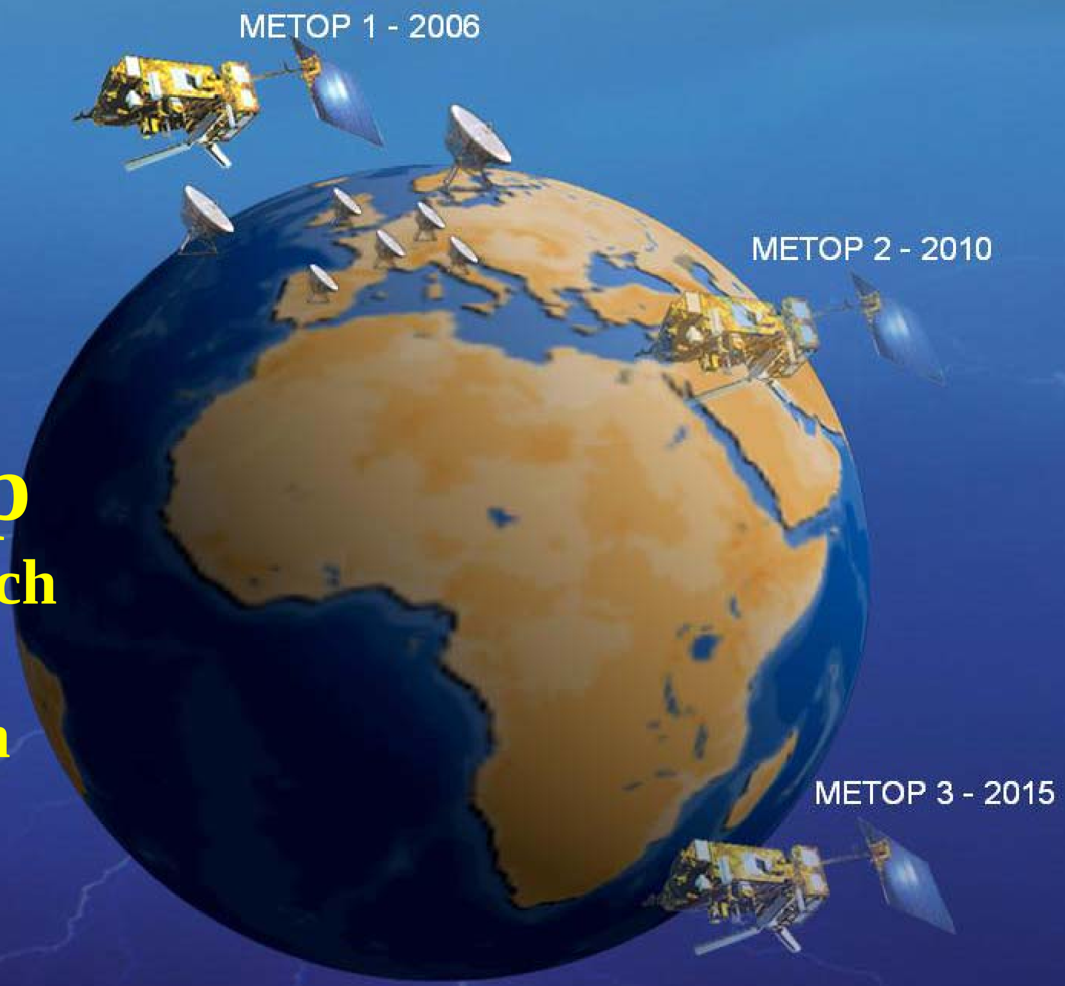
2. **The CLARREO benchmark Climate Mission: A logical extension of demonstrated high accuracy, spectrally resolved radiance measurement capability—** ***presents a new retrieval challenge*** ***(To avoid biases*, the Climate change signal is the spatial and temporal average of nadir radiances—This signal needs interpretation in terms of climate forcing and response mechanisms)***
   ****averages of current retrievals would have large, poorly understood biases***

1. Radiance Validation from high spectral resolution aircraft observations:

a sound foundation for advanced retrieval capability

METOP

- Eumetsat Polar System Elements
- 14 years of operation
- >95% reliability on 5 years



IASI on Metop

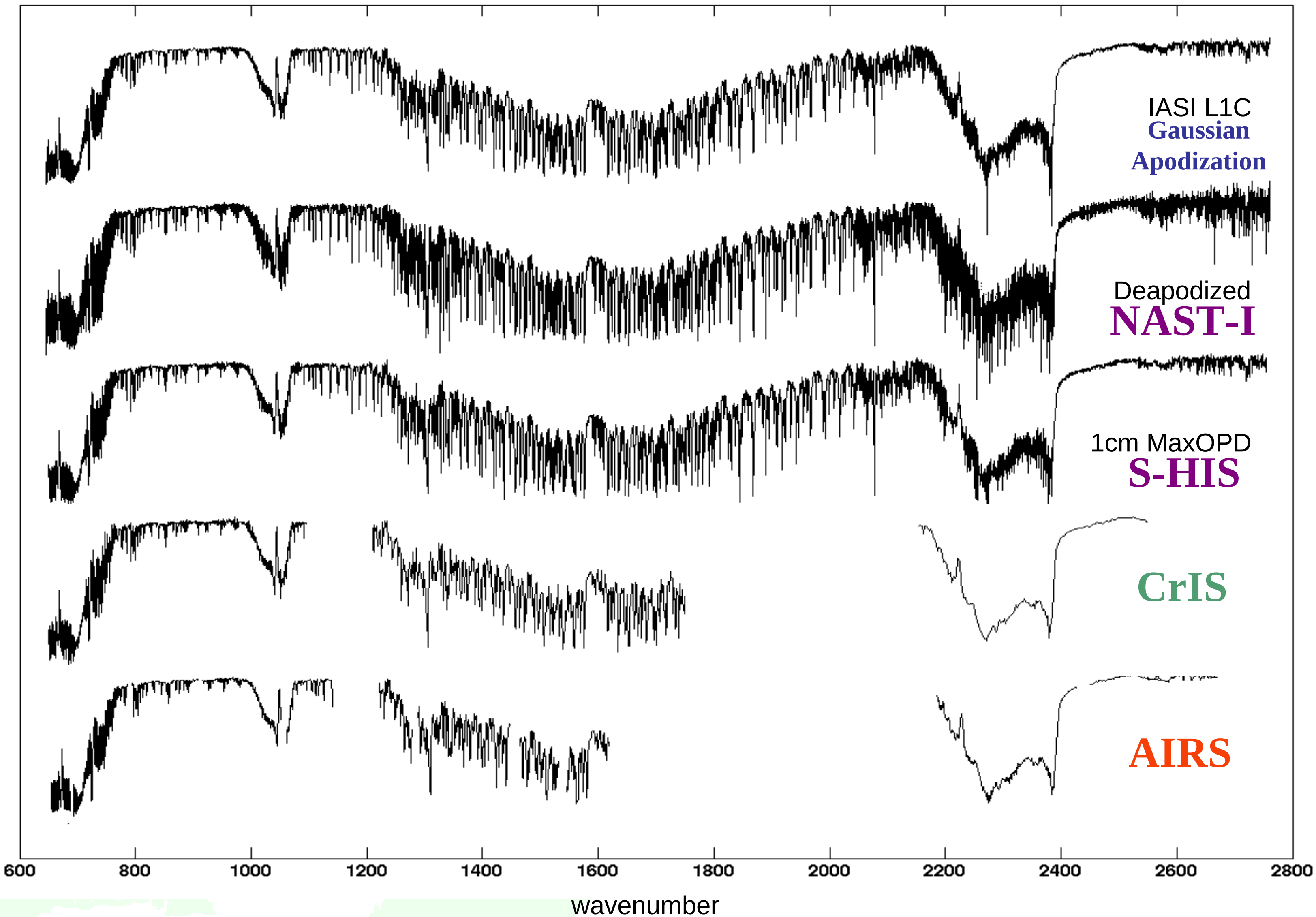
19 October 2006 launch

- full cross-track scan
- 2x2 12 km pixels
  sample 50x50 km

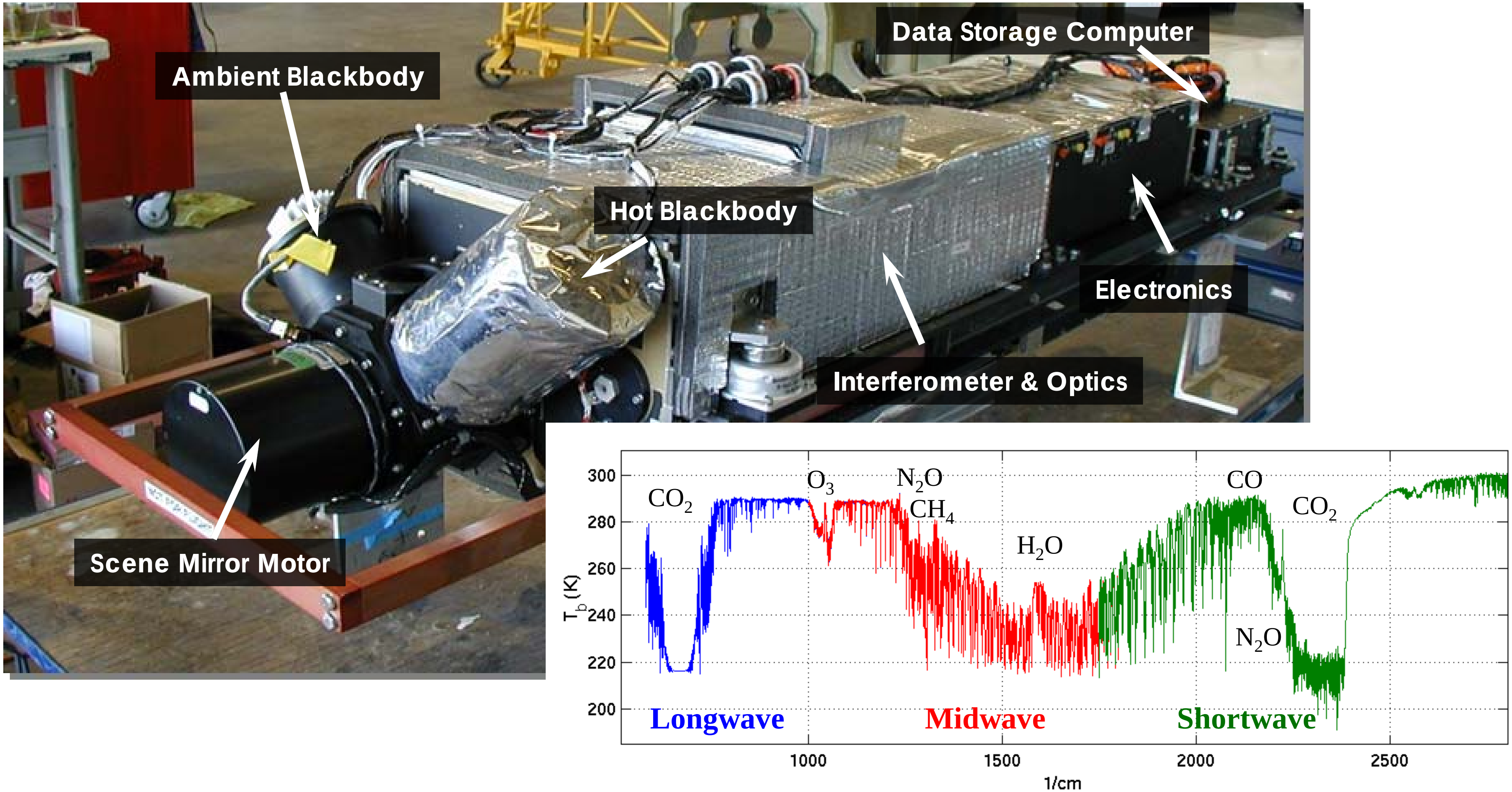
Joint Airborne IASI Validation Experiment (JAIVEx)

- **What:** Metop and Aqua satellite under-flights for radiance and retrieval validation
- **Who:** NPOESS Airborne Sounder Testbed team (NAST-I/M & S-HIS on NASA WB57) & UK team (ARIES on Facility for Airborne Atmospheric Measurements BAe146-301)
- **When:** 14 April to 4 May 2007
- **Where:** Comparisons over the Gulf of Mexico and Oklahoma ARM site reached from Houston airbase

IASI T_b Spectrum:
Processed to represent S-HIS & NAST-I, AIRS & CrIS



Scanning HIS Aircraft Instrument:
Inter-comparisons connect high res. sensor calibrations



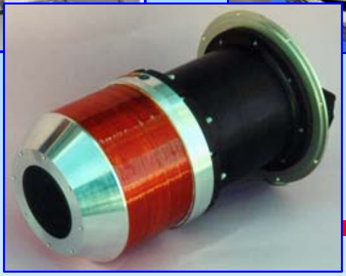
SSEC Spectrometer Ties to NIST
(See Best, et al., Part 1)

Ground-based

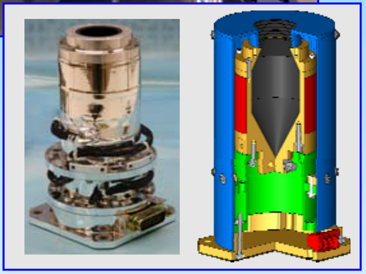
High-altitude Aircraft

Spaceflight

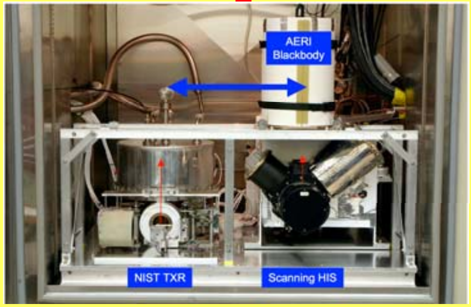
NIST
Waterbath
Blackbody



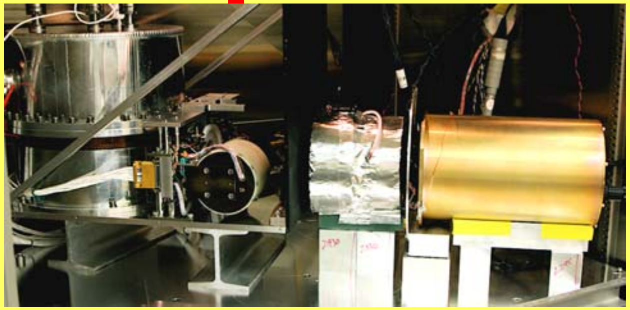
NIST
TXR



< 0.06 K error (293 to 333 K)



< 0.06 K error (220 to 333 K)

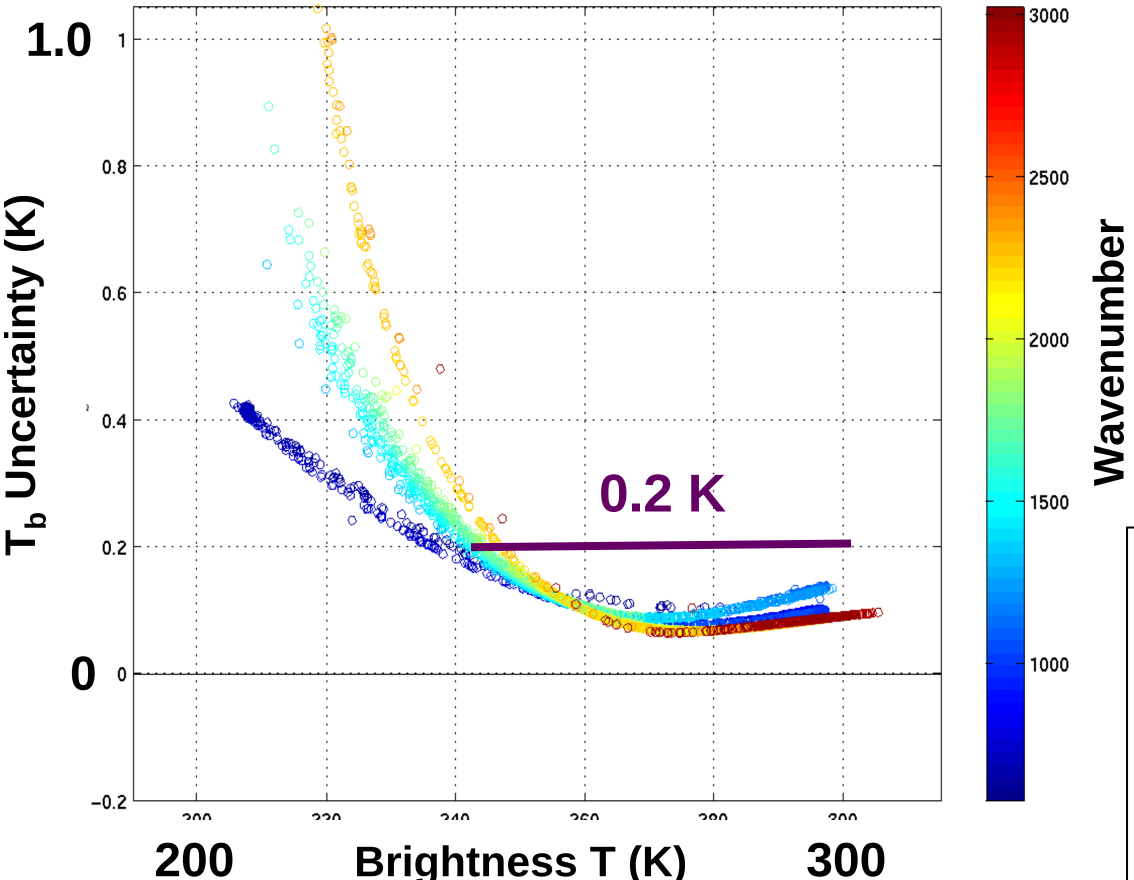


ε > 0.9994 (within estimated uncertainty)

S-HIS Absolute Radiometric Uncertainty

for typical Earth scene spectrum

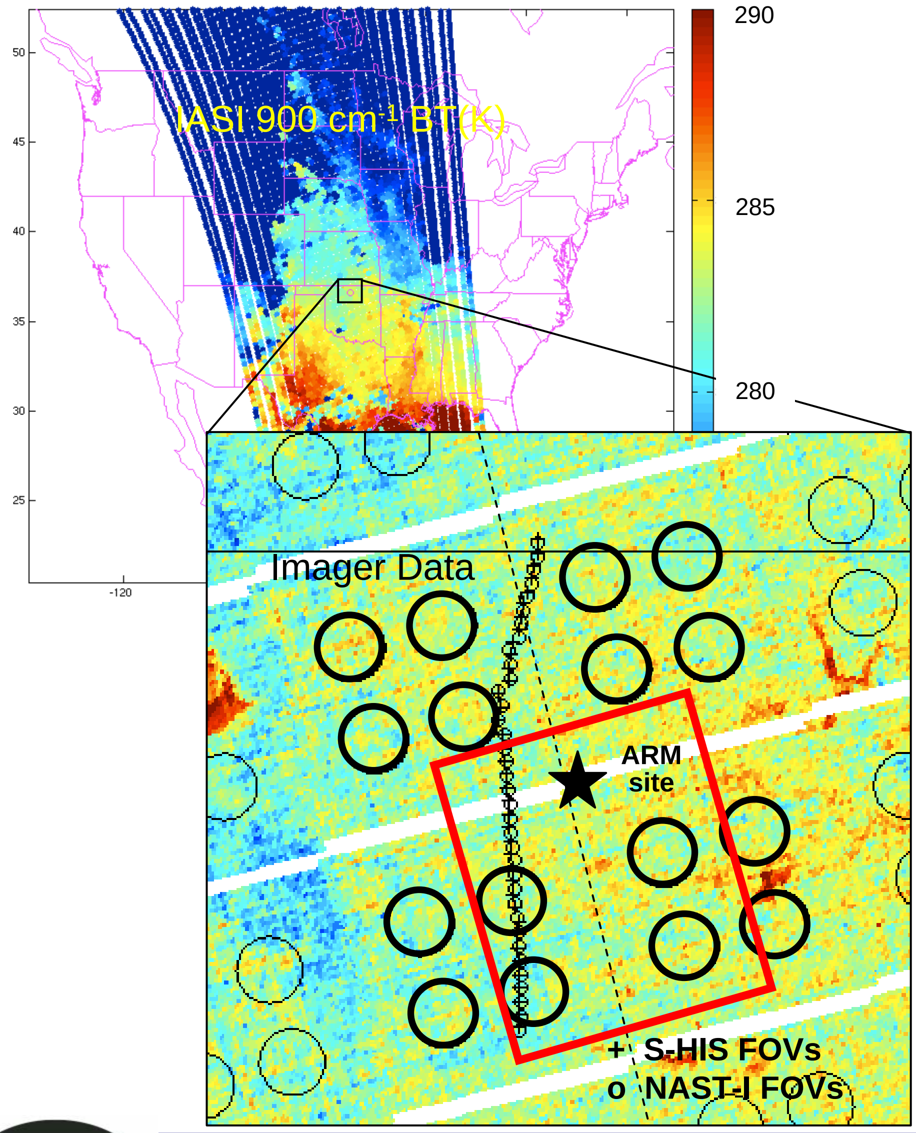
****Formal 3-sigma absolute uncertainties, similar to that detailed for AERI in Best et al. CALCON 2003**

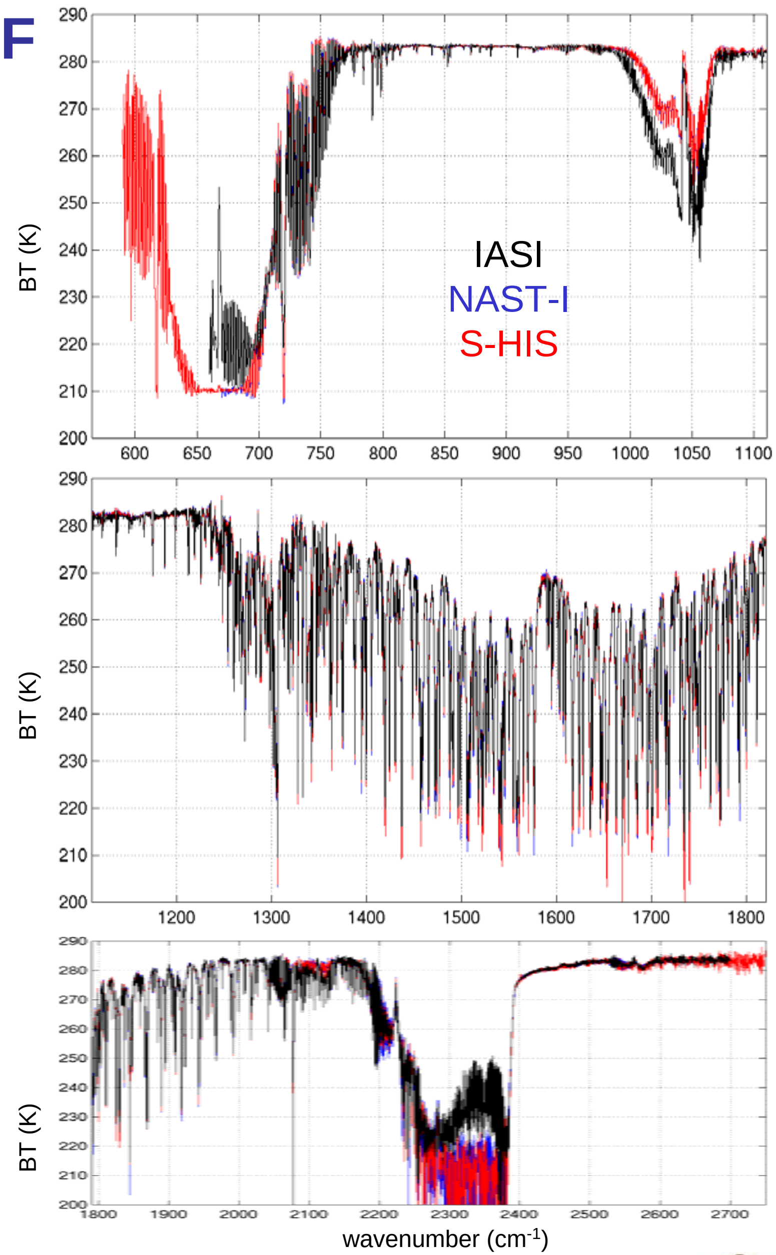


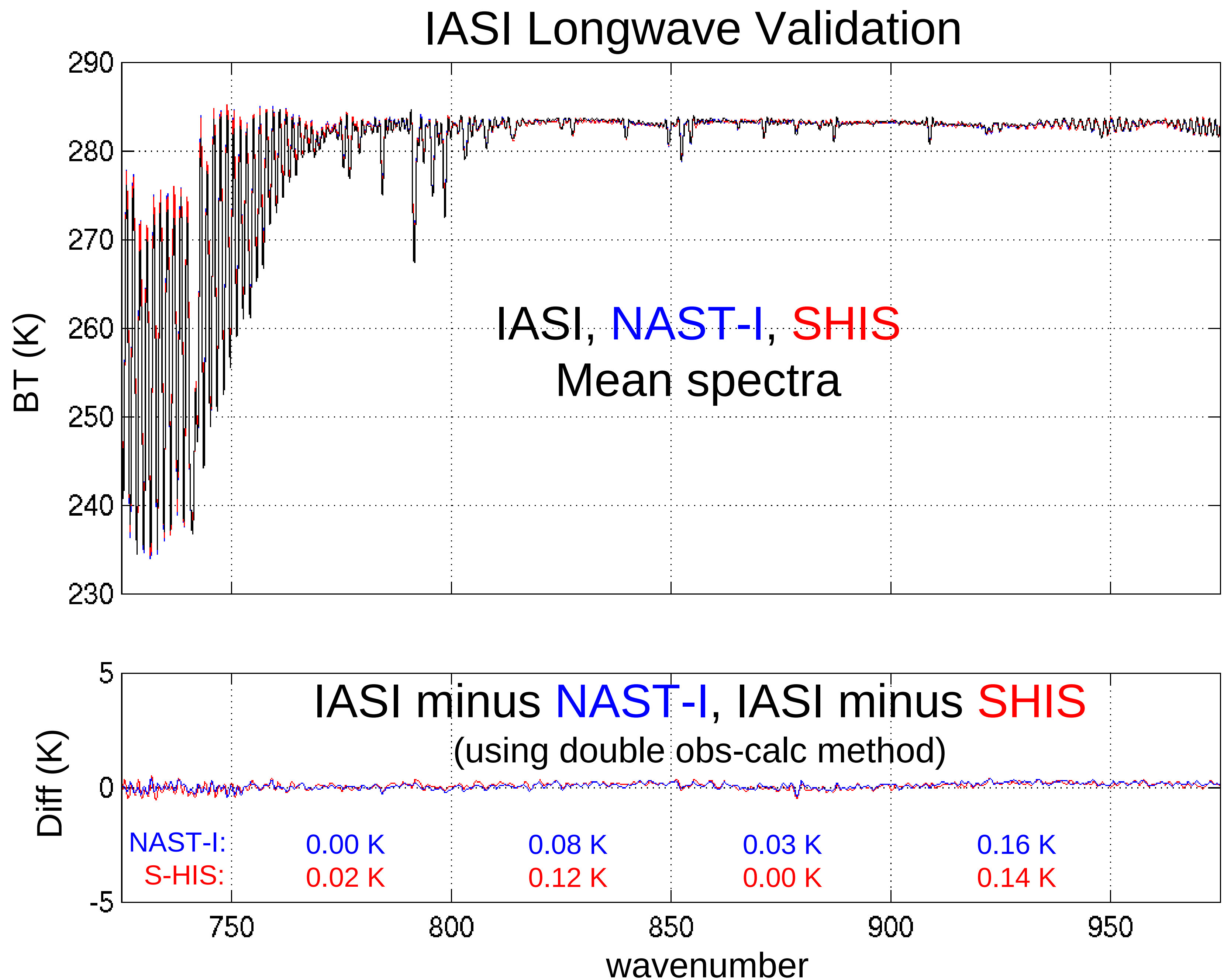
T_{ABB}= 260 K
T_{HBB}= 310 K

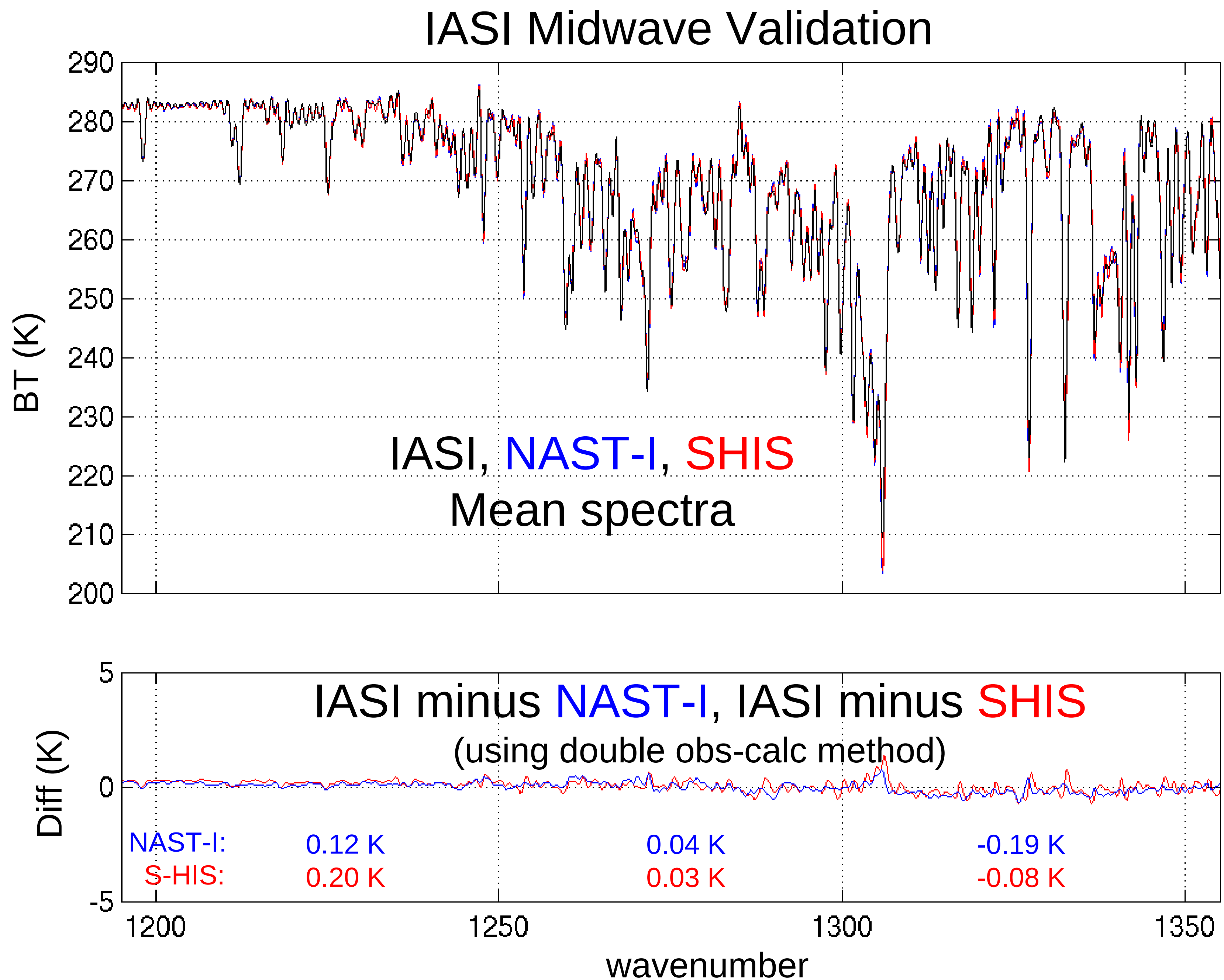
σT_{BB} = 0.10 K
$\sigma \varepsilon_{BB}$ = 0.0010
σT_{refl} = 5 K
10% nonlinearity

MetOp overpass of Oklahoma ARM CF
19 April 2007

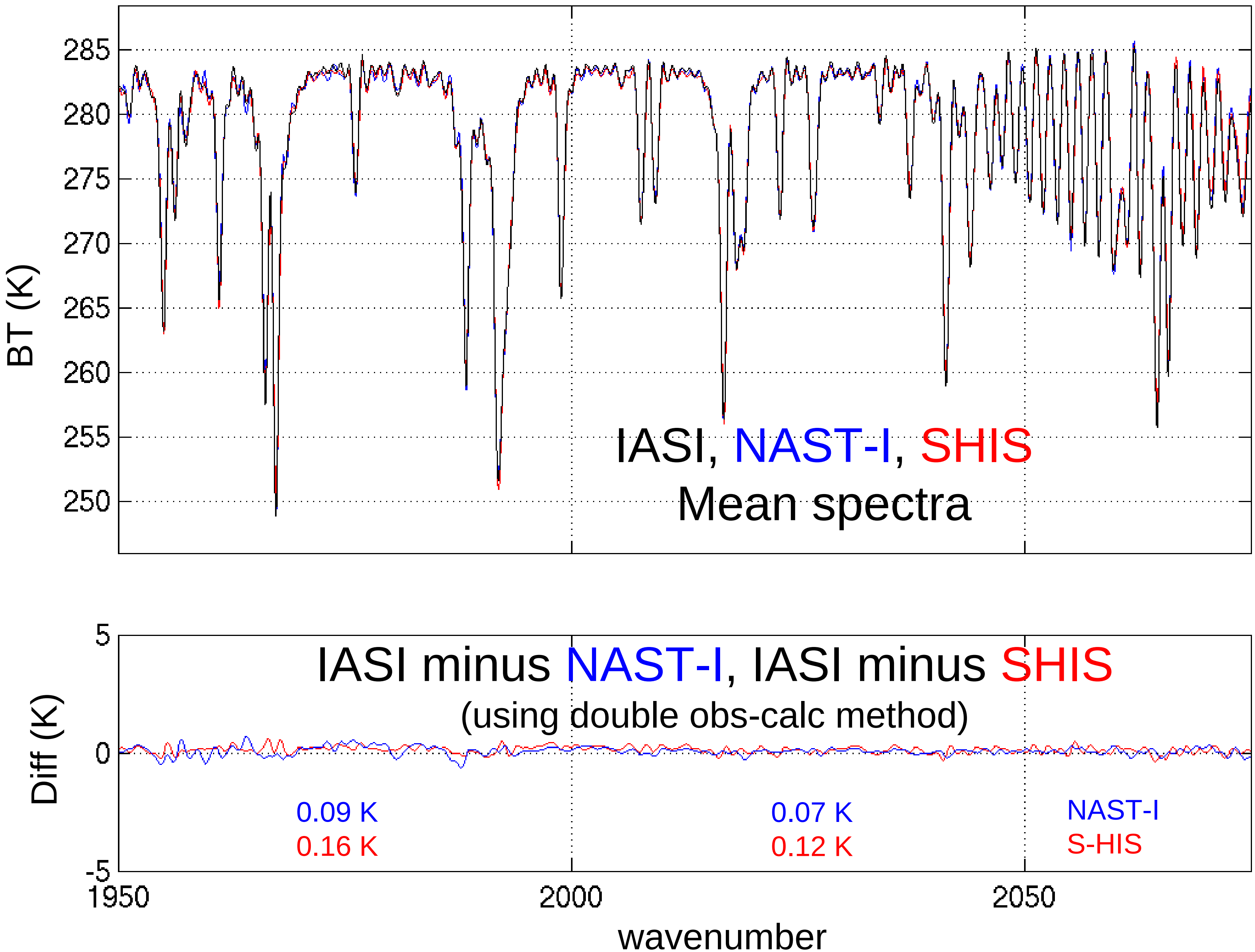




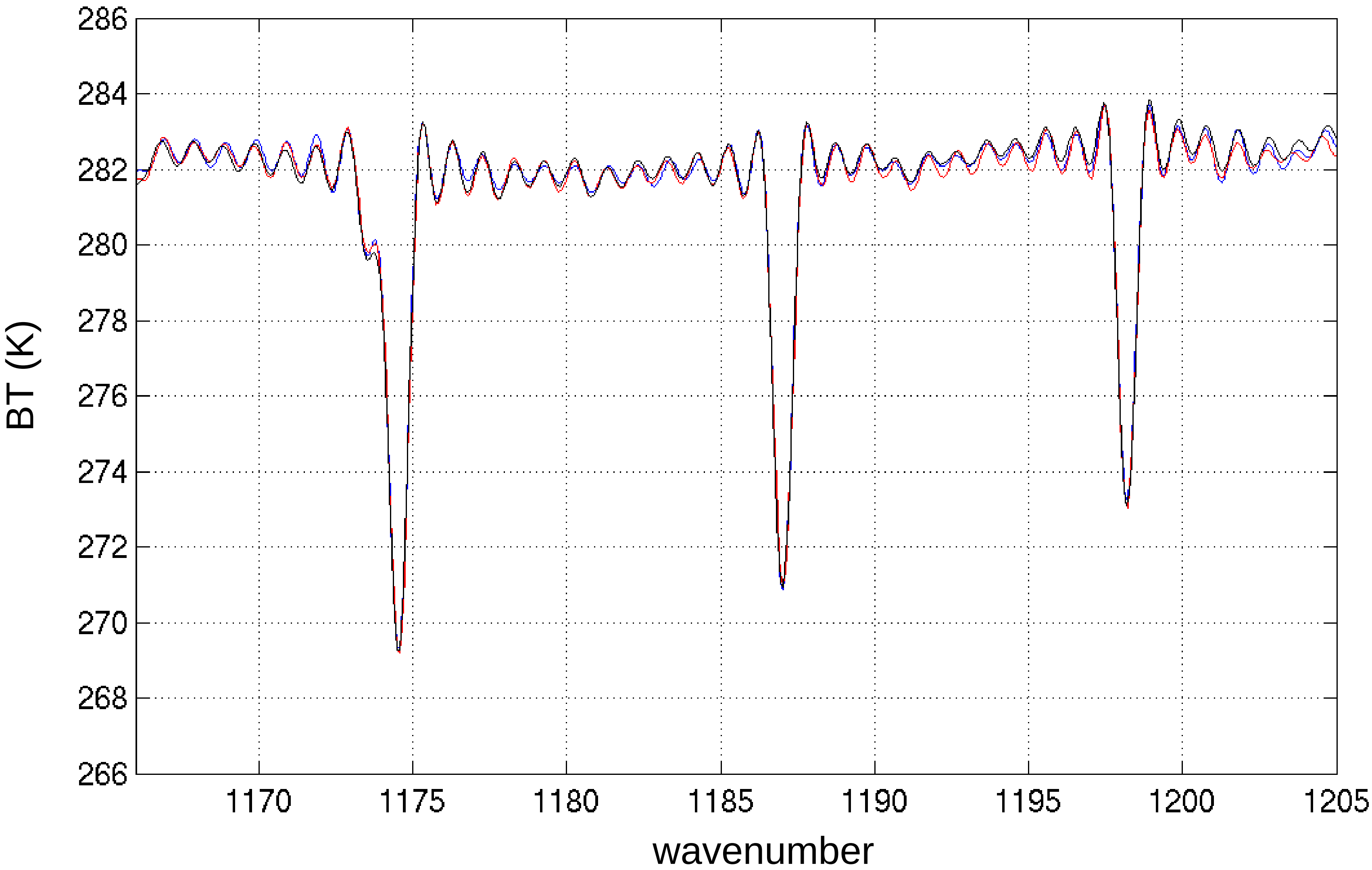

IASI Longwave Validation
IASI, NAST-I, SHIS
Mean spectra
BT (K)
290
280
270
260
250
240
230
IASI minus NAST-I, IASI minus SHIS
(using double obs-calc method)
Diff (K)
5
0
-5
NAST-I:
S-HIS:
0.00 K
0.02 K
0.08 K
0.12 K
0.03 K
0.00 K
0.16 K
0.14 K
750
800
850
900
950
wavenumber


IASI Midwave Validation
290
280
270
260
250
240
230
220
210
200
BT (K)
IASI, NAST-I, SHIS
Mean spectra
5
0
-5
Diff (K)
IASI minus NAST-I, IASI minus SHIS
(using double obs-calc method)
NAST-I:
S-HIS:
0.12 K
0.20 K
0.04 K
0.03 K
-0.19 K
-0.08 K
1200
1250
1300
1350
wavenumber

IASI Shortwave Validation



IASI, NASTI, and SHIS



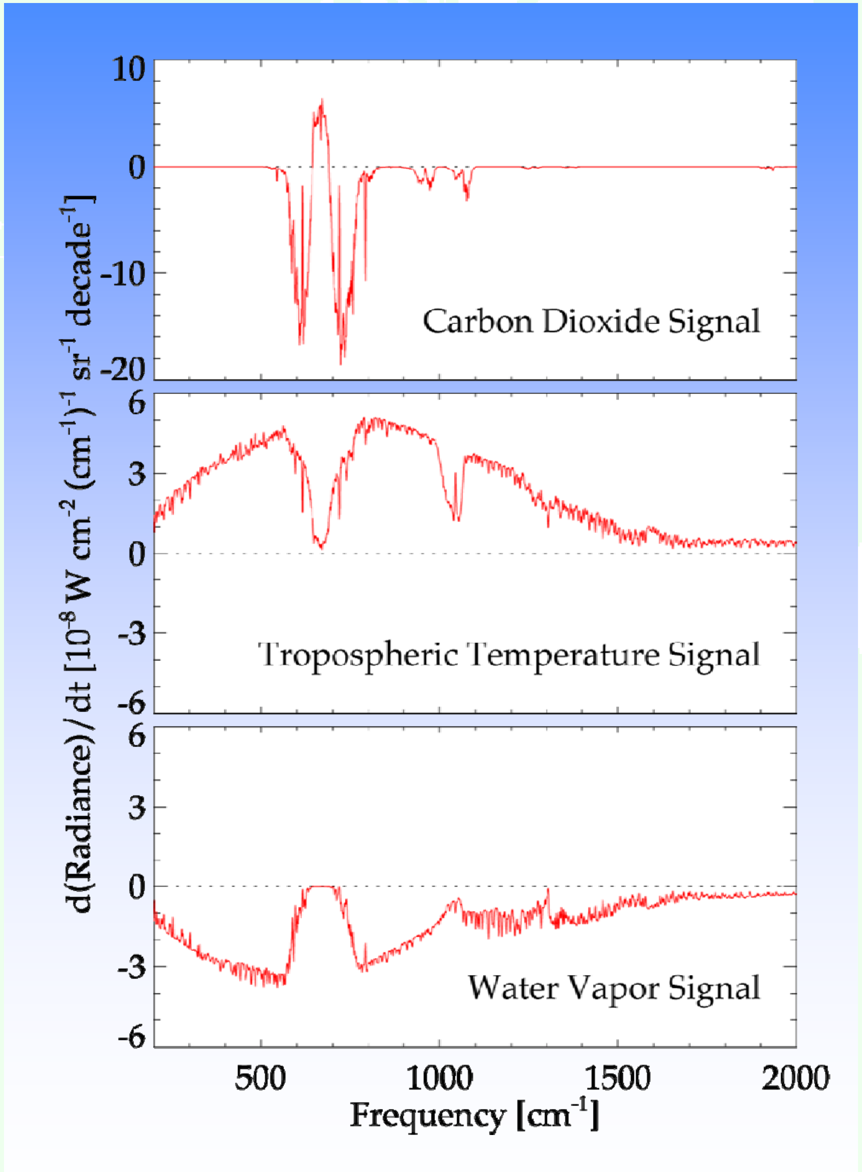
Aircraft Radiance Validation Results Summary

- **Aircraft Validation** (of high resolution spectra): New, highly accurate capability proven 2002-2007
- **AIRS**: Differences from Scanning HIS generally <0.2 K with small standard deviations [Tobin et al., JGR, 2006]
- **TES**: Better than 0.5 K agreement in most regions (also characterized small, spectrally correlated noise from variable sample-position-errors) [Shephard et al., JGR, submitted April 2007]
- **IASI**: These preliminary results are comparable to AIRS validation results with higher spectral resolution & contiguous spectral coverage

AIRS/IASI Validation Conclusions

- Modern spaceborne, aircraft and ground-based spectrometers demonstrate great strides in calibration accuracy for weather & climate sensors
- The technical heritage provides a strong foundation for new climate missions like CLARREO
- **But, currently planned measurements cannot perform the CLARREO mission—we need to**
  (1) <u>remove the far IR blind spot</u>,
  (2) <u>provide higher accuracy, proven in orbit</u>; &
  (3) couple these advances with
  <u>unbiased spatial and temporal sampling</u>

2. The CLARREO Mission

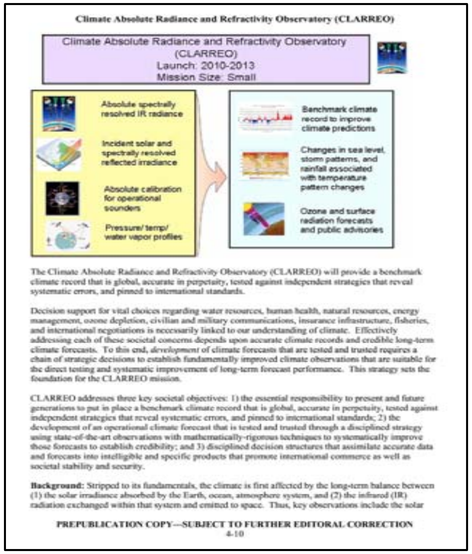


IR spectral signature identifies change and conveys information about what has changed

Climate Absolute Radiance and Refractivity Observatory (CLARREO):

features Spectrally Resolved Radiance and GPS measurements

NASA is pursuing CLARREO as a promising new start, based on the NRC "Decadal Survey" Report—Also strongly recommended by ASIC3, edited by George Ohring



Climate Absolute Radiance and Refractivity Observatory (CLARREO)

Climate Absolute Radiance and Refractivity Observatory (CLARREO)
Launch: 2010-2013
Mission Size: Small

The Climate Absolute Radiance and Refractivity Observatory (CLARREO) will provide a benchmark climate record that is global, accurate in perpetuity, tested against independent strategies that reveal systematic errors, and pinned to international standards.

Decision support for vital choices regarding water resources, human health, natural resources, energy management, ozone depletion, civilian and military communications, insurance infrastructure, fisheries, and international negotiations is necessarily linked to our understanding of climate. Effectively addressing each of these societal concerns depends upon accurate climate records and credible long-term climate forecasts. To this end, *development* of climate forecasts that are tested and trusted requires a chain of strategic decisions to establish fundamentally improved climate observations that are suitable for the direct testing and systematic improvement of long-term forecast performance. This strategy sets the foundation for the CLARREO mission.

CLARREO addresses three key societal objectives: 1) the essential responsibility to present and future generations to put in place a benchmark climate record that is global, accurate in perpetuity, tested against independent strategies that reveal systematic errors, and pinned to international standards; 2) the development of an operational climate forecast that is tested and trusted through a disciplined strategy using state-of-the-art observations with mathematically-rigorous techniques to systematically improve those forecasts to establish credibility; and 3) disciplined decision structures that assimilate accurate data and forecasts into intelligible and specific products that promote international commerce as well as societal stability and security.

Background: Stripped to its fundamentals, the climate is first affected by the long-term balance between (1) the solar irradiance absorbed by the Earth, ocean, atmosphere system, and (2) the infrared (IR) radiation exchanged within that system and emitted to space. Thus, key observations include the solar

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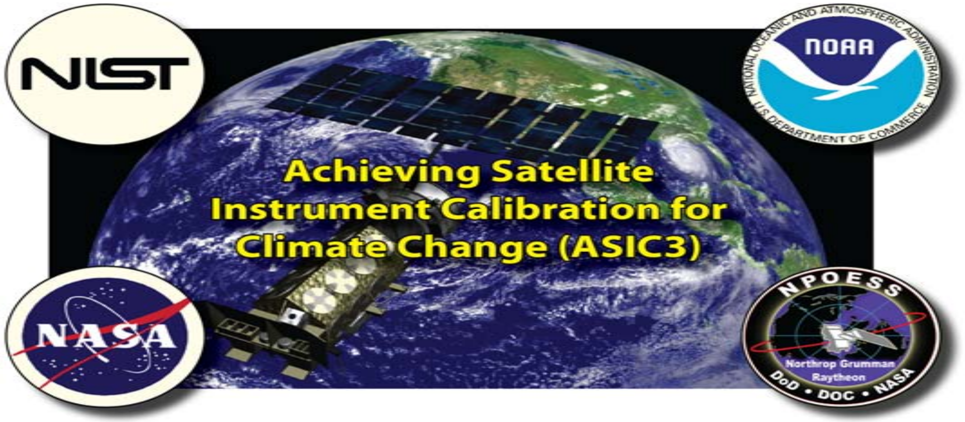


CLARREO Goal

- **Establish highly accurate global bench-mark measurements from satellite that detect and characterize climate change over decadal time scales**
  - Determine annual regional changes on scales of order 15ºx30º latitude/longitude
  - Determine seasonal changes (bi-monthly) on larger scales of order 50ºx50º

CLARREO: New Paradigms for benchmark climate measurements

1) **Maximize information content**, rather than monitoring total radiative energy budget (e.g. spectrally resolved nadir radiances covering large parts of the spectrum as a product, rather than total IR or Solar fluxes)

2) **Emphasize high absolute accuracy of measurements, proven on orbit** to minimize detection time and to relieve need for mission overlap (e.g. maintain SI measurements with on-orbit calibration validation)

3) **Deploy a new orbital configuration** optimized for global coverage and to minimize sampling bias [e.g. equally spaced, truly polar orbits (90º inclination) giving global coverage and equal time of day sampling every 2 months—explicit diurnal cycle measurement]

CLARREO General IR Science Drivers

- **<u>Information Content</u>:** Capture the spectral signatures of regional and seasonal climate change that can be associated with physical climate forcing and response mechanisms (to unequivocally detect change and refine climate models)
- **<u>Absolute Accuracy</u>:** <0.1 K 2-sigma brightness T for combined measurement and sampling uncertainty (each <0.1 K 3-sigma) for annual averages of 15ºx30º lat/long regions (to achieve goal of resolving a climate change signal in the decadal time frame)
- **<u>Calibration transfer to other spaceborne IR sensors:</u>** Accuracy approaching the measurement accuracy of CLARREO using Simultaneous Nadir Overpasses (to enhance value of sounders for climate process studies-actually drives few requirements)

Basic IR Requirements (1)

- **Spectral Coverage:** 3-50 μm or 200-3000 cm^{-1} (includes Far IR to capture most of the information content and emitted energy)
- **Spectral Resolution:** ~0.5 cm^{-1} (1 cm max OPD) (to capture atmospheric stability, aid in achieving high radiometric accuracy, and allow accurate spectral calibration from atmospheric lines)
- **Spectral Sampling:** Nyquist sampled (to achieve standard spectral scale for multiple instruments)

Basic IR Requirements (2)

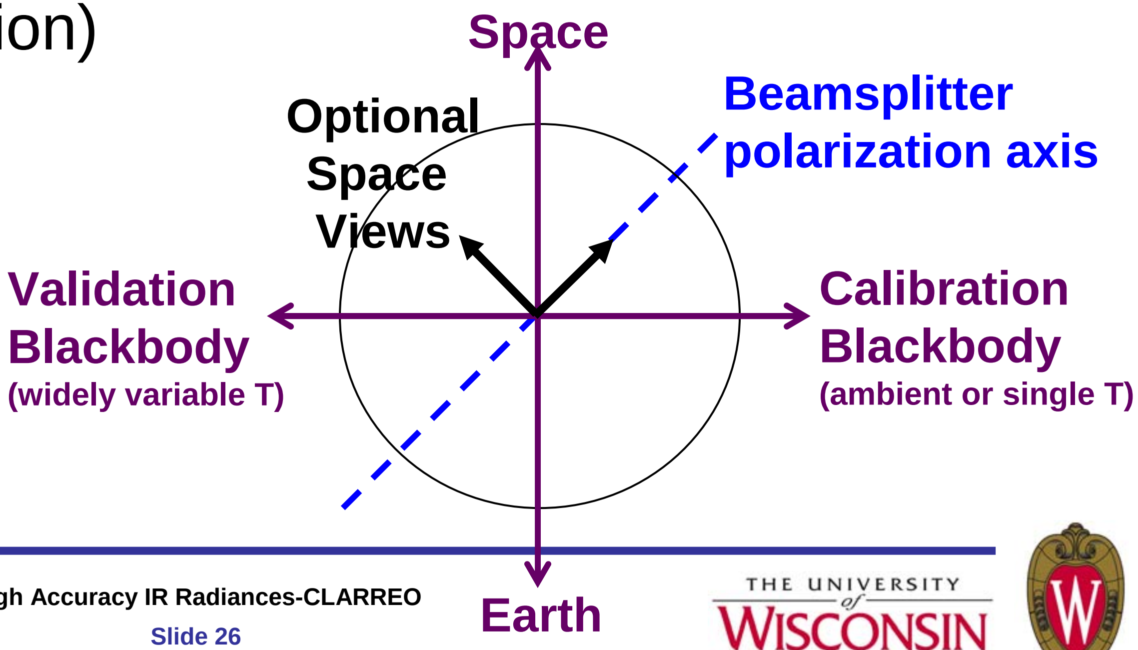
- **Spatial Footprint & Angular Sampling:** Order 100 km or less, nadir only (no strong sensitivity to footprint size, nadir only captures information content)
- **Spatial Coverage:** Complete global sampling (to not miss critical high latitude regions)
- **Orbits:** 3 90º inclination orbits spaced 60º apart (to minimize sampling biases that RSS with measurement uncertainty)
- **Temporal Resolution and Sampling:** < 15 sec resolution and < 60 sec intervals (adequate to reduce sampling errors and noise)

Basic IR Requirements (3)

- **Spectrometer Approach:** 2 Fourier Transform Spectrometers
  (dual FTS sensors to detect unexpected drifts and give full spectral coverage with noise performance needed for calibration transfer and on-orbit characterization testing)
- **Noise:** NEdT(10 sec) < 1.5 K for climate record,
  < 1.0 K for cal transfer
  (not very demanding)
- **Detectors:** Pyroelectric for one FTS and cryogenic PV MCT and/or InSb for the other

Basic IR Requirements (4)

- **On-orbit characterization:** provide non-linearity and polarization test capability
  - Non-linearity from Out-of-band Harmonics and variable temperature blackbody
  - Polarization from multiple space view directions (design also minimizes effects of gold scene mirror induced polarization)

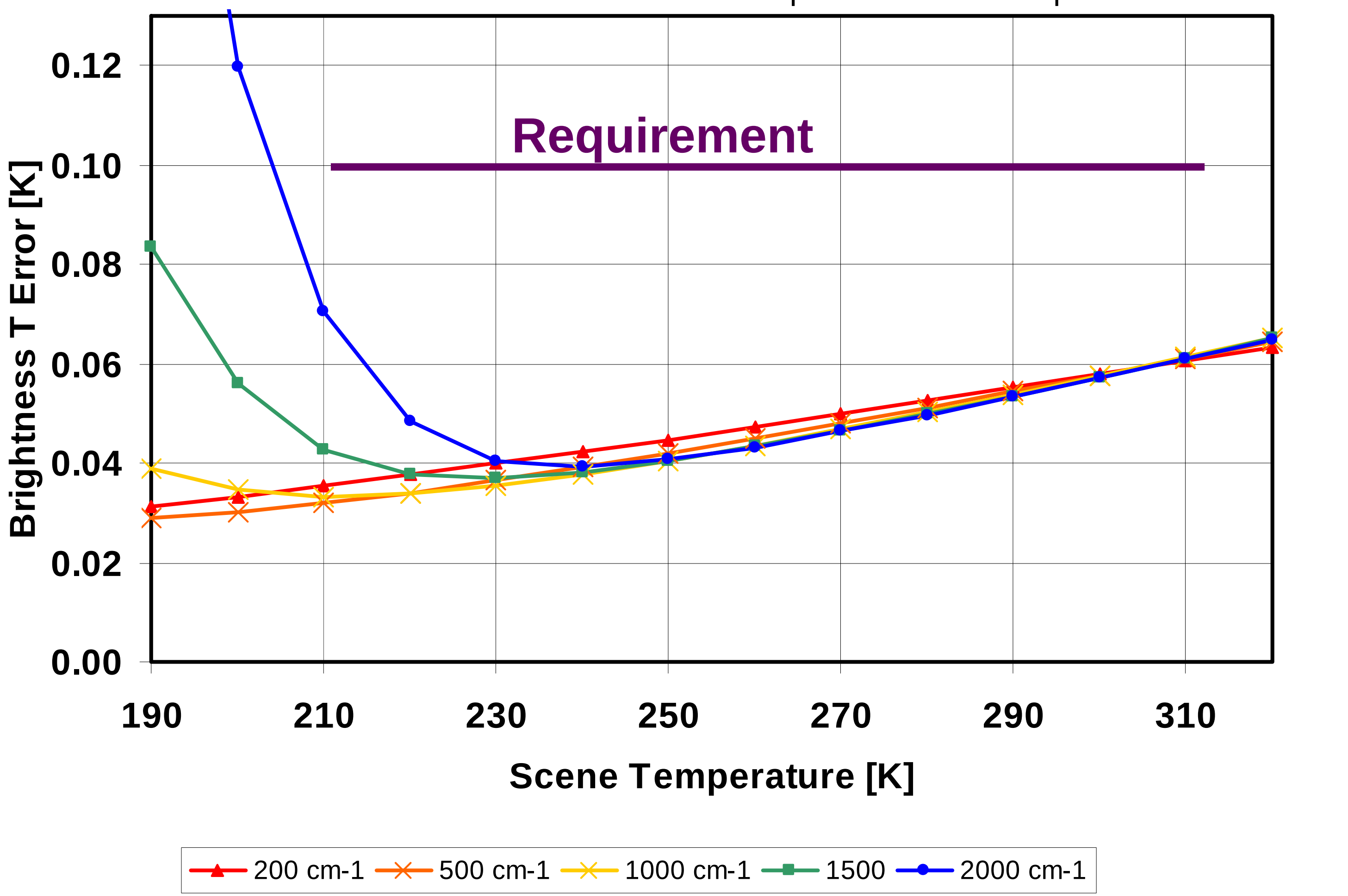


Basic IR Requirements (5)

- **Pre-launch Calibration/Validation:** Characterization against NIST primary infrared standards and evaluation of flight blackbodies with NIST facilities (recent "best practice")
- **On-orbit Calibration:**
  Onboard warm blackbody reference (~300K), with phase change temperature calibration, plus space view, supplimented with characterization testing (to detect any slow changes)
- **Validation, On-orbit:**
  Variable-temperature standard blackbody, with on-orbit absolute T calibration and reflectivity measurement (to maintain SI measurements on orbit)

CLARREO Expected Calibration Uncertainty:
Based on GIFTS Spaceflight Calibration Blackbody Design

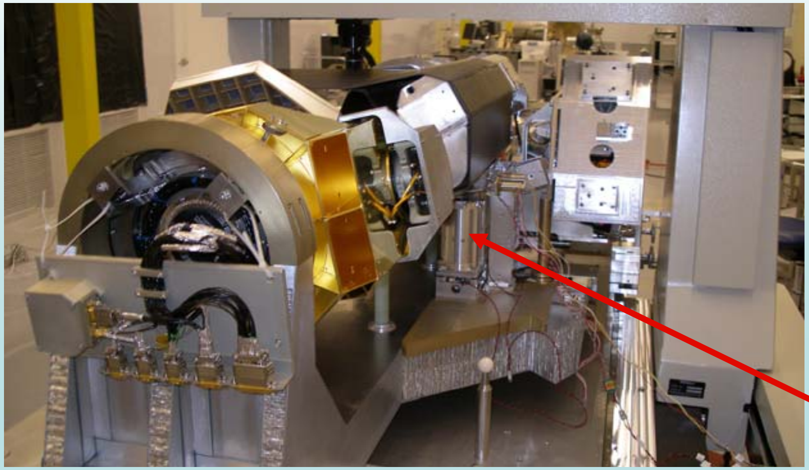
T_{HBB}=300K, $T_{Structure}$=285K, $\delta T_{Telescope}$=0.02K, ε_{Space} =0.00010



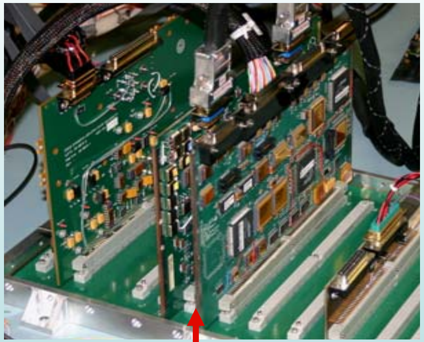
UW-SSEC Developed GIFTS EDU Blackbody

Performance Significantly Exceeds Specifications

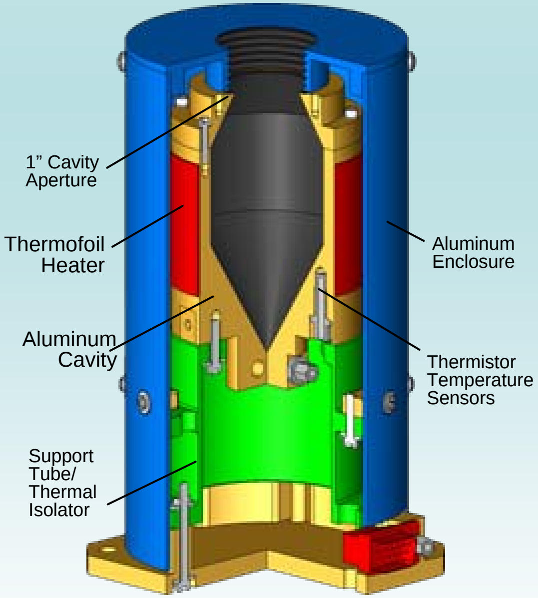
GIFTS Engineering Development Unit



Blackbody Controller Card



Blackbody (2)



Key Parameter	Specification	As Delivered
Measurement Range	233 to 313 K	233 to 313 K
Temperature Uncertainty	< 0.1 K (3 σ)	< 0.056 K
Blackbody Emissivity	> 0.996	> 0.999
Emissivity Uncertainty	< 0.002 (3 σ)	< 0.00072
Entrance Aperture	1.0 inch	1.0 inch
Mass (2 BBs + controller)	< 2.4 kg	2.1 kg
Power (average/max)	< 2.2/5.2 W	2.2/5.2 W

Separate Validation blackbody

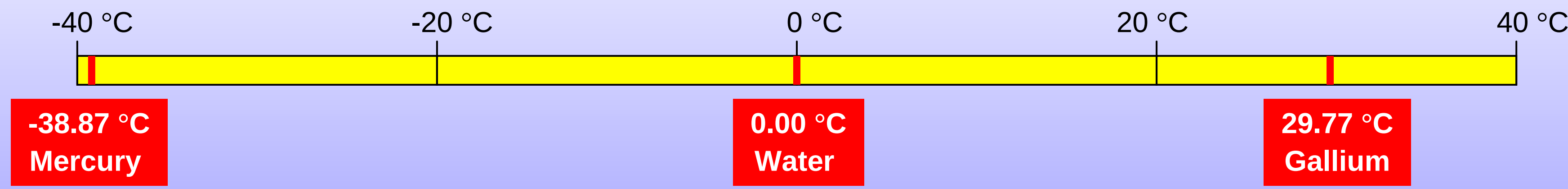
- Provides capability to validate or correct SI measurement on-orbit
  - New On-orbit Temperature Calibration technique is based on fundamental phase change principles
  - Normal Reflectivity/Emissivity is measured on-orbit

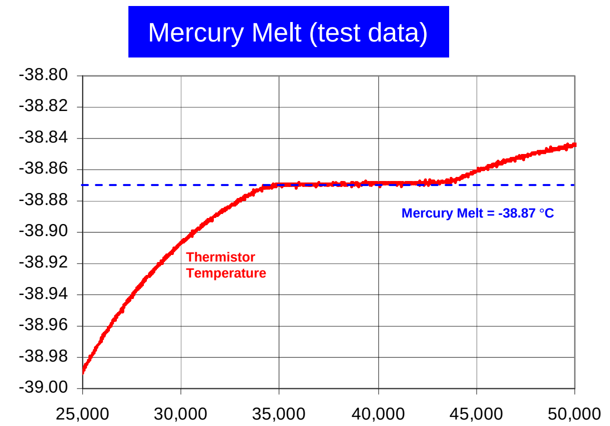
On-orbit, full dynamic range T calibration

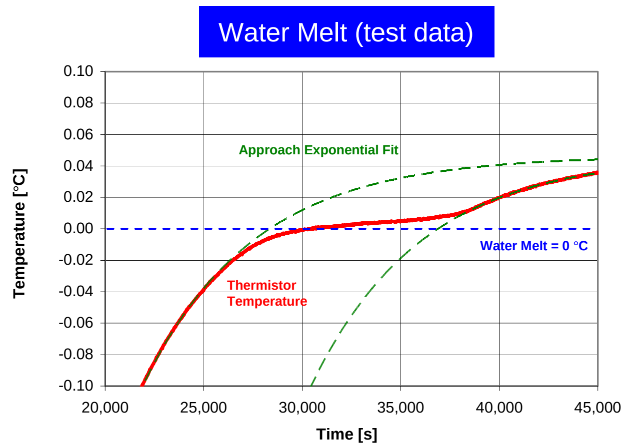
- New concept, uses phase change of three small material reservoirs integrally coupled into the GIFTS blackbody
- Detection of 3 phase changes used to calibrate the three unknowns in the thermistor resistance to T response function
- Proven accuracy is better than 10 mK
- Compatible with GIFTS blackbody flight design

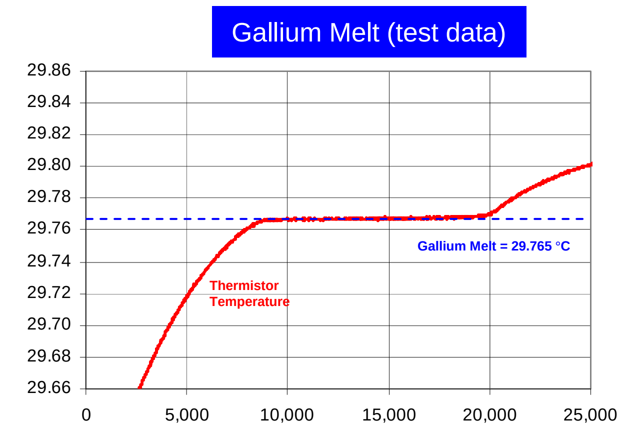
3 Melt Points Calibrate Wide Dynamic Range

(using GIFTS BB Configuration)



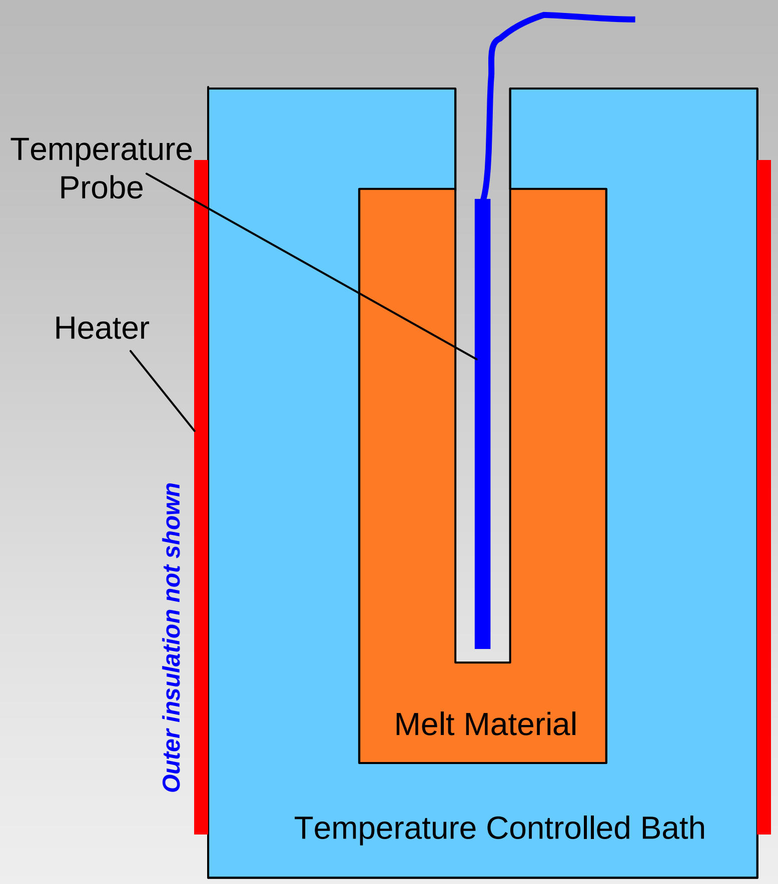




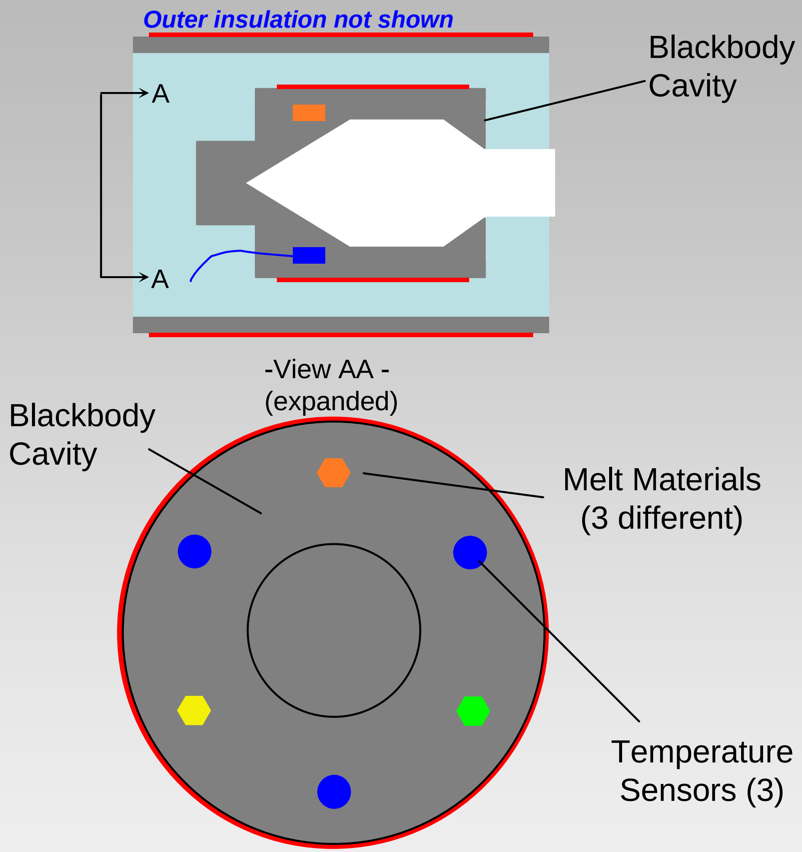


Melt Signatures Provide Absolute Temperature Calibration Accuracies better than 10 mK for full atmospheric Temperature Range

Comparison to Traditional Approach



Traditional Laboratory Calibration Scheme



New Blackbody Calibration Scheme

CLARREO Summary

- An excellent, low cost, climate benchmark mission has been defined and has good technical readiness
- The mission is based on several new observing paradigms
- One key is an on-orbit calibration validation reference source, and an exciting new approach for on-orbit temperature calibration is now available for assuring the accuracy of that reference
- Corresponding new retrieval methods are under development to interpret the signatures of climate change (regional means of nadir radiances) in terms of climate forcing and response mechanisms. For climate, <u>mean errors or biases must be minimized</u> rather than standard deviations.