# Intercalibration of Broadband Geostationary Imagers using AIRS

Mat Gunshor, Tim Schmit*, Paul Menzel, Dave Tobin

Presented by Robert Knuteson

Cooperative Institute for Meteorological Satellite Studies
Space Science and Engineering Center
University of Wisconsin-Madison

* NOAA/NESDIS, Center for Satellite Applications and Research,
Advanced Satellite Products Branch, Madison, Wisconsin

# Published Reference

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# Introduction: The Purpose

- Intercalibration is the primary means by which the radiometric calibration accuracy of geostationary imagers can be assessed.
  - Especially important for Post Launch Tests (PLT)
- Geostationary Imagers play a role in improved space-based global observations
  - For weather and environmental applications
  - Expected to be used for global climate monitoring
  - Numerical Weather Prediction (NWP)

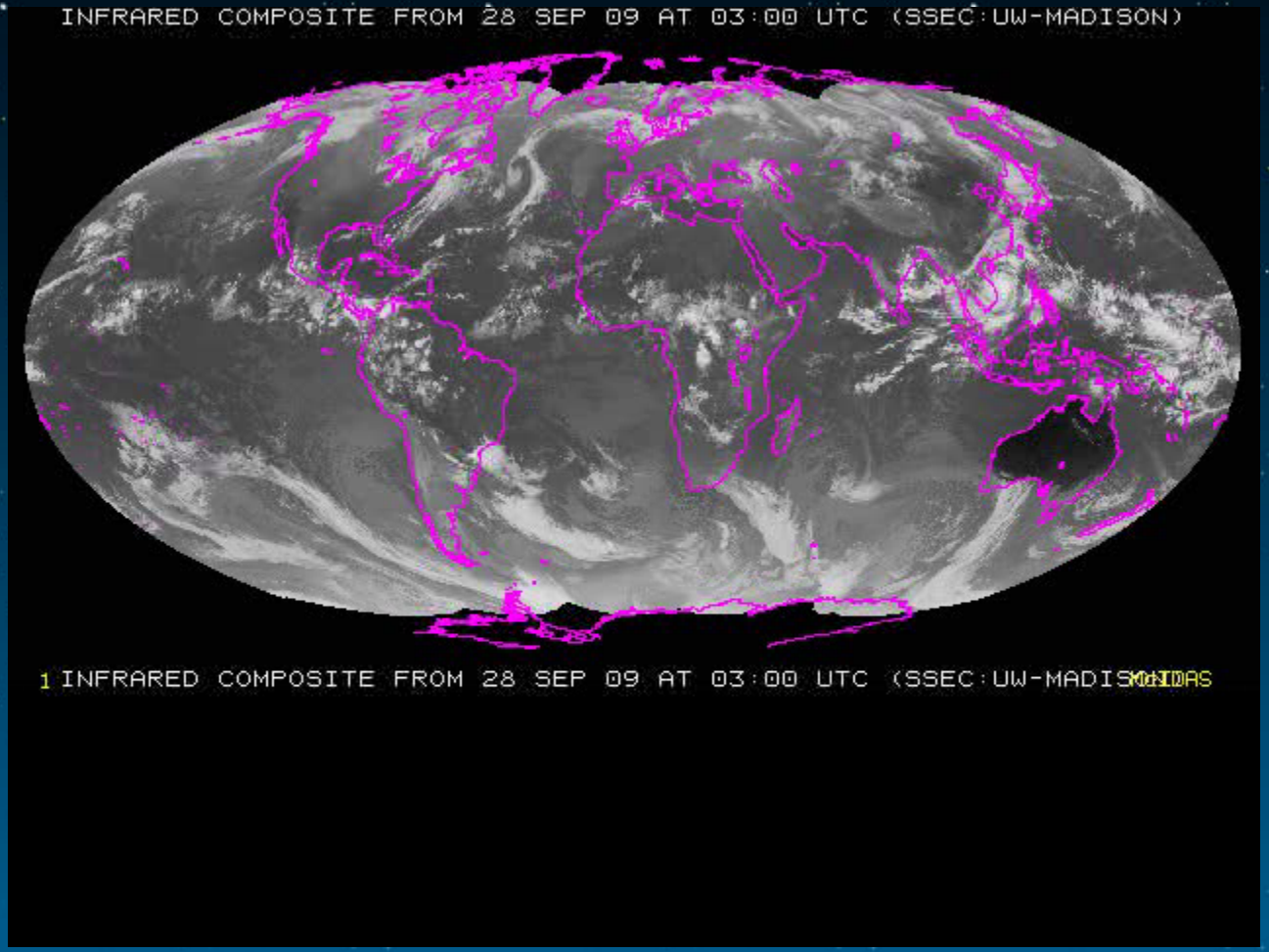
# Introduction

- The Cooperative Institute for Meteorological Satellite Studies (CIMSS) at UW-Madison has been involved in cal/val efforts such as intercalibration for several decades.
- In the past few years, the World Meteorological Organization (WMO) has taken on a more active, central role in this effort
  - GSICS (Global Space-based Inter-Calibration System)

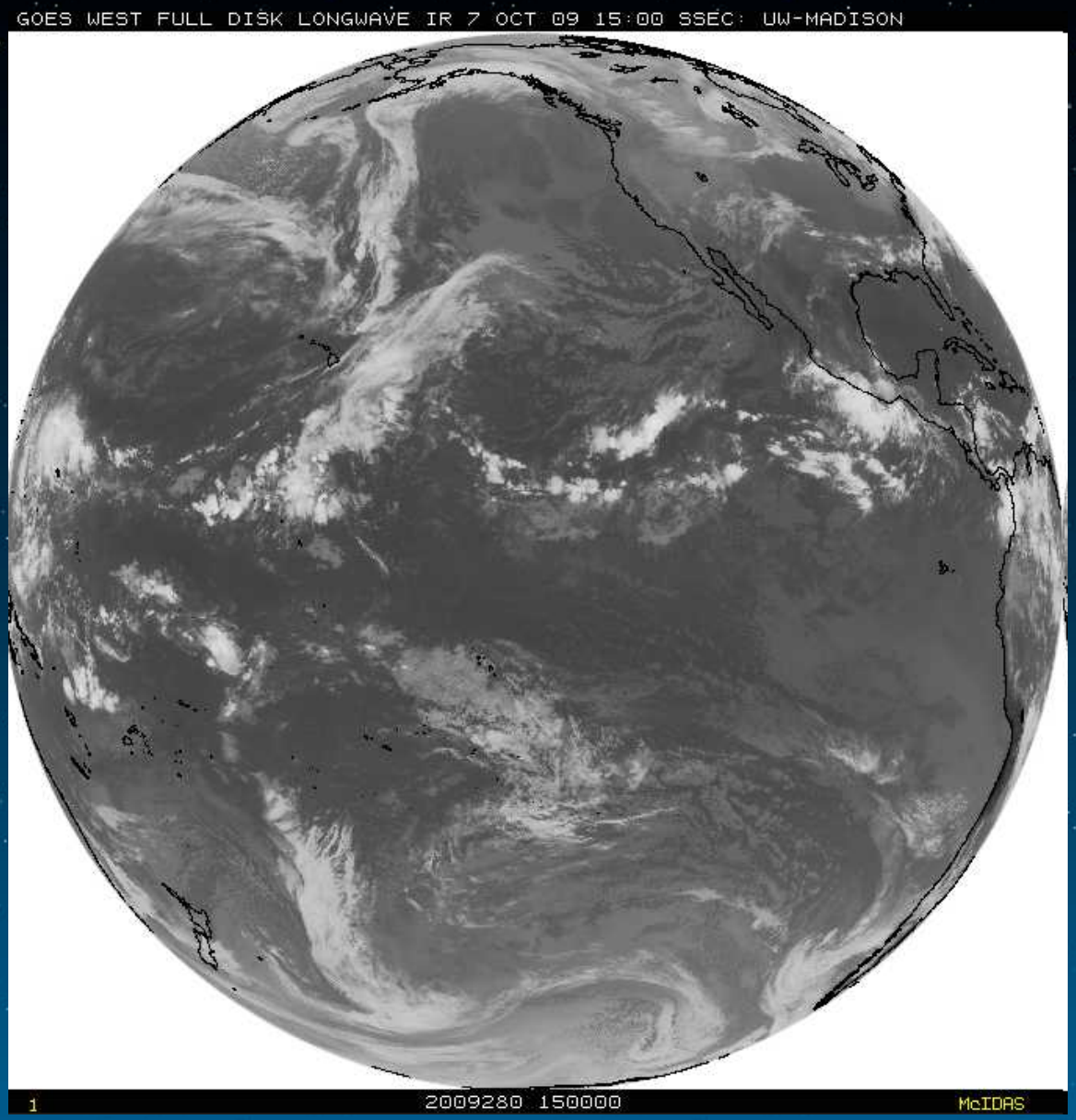
# Introduction: GSICS

- Mission
  - Assure high-quality, inter-calibrated measurements from the international constellation of operational satellites to support the GEOSS goal of increasing the accuracy and interoperability of environmental products and applications for societal benefit.
- Goal
  - The primary goal of GSICS is to improve the use of space-based global observations for weather, climate and environmental applications through operational inter-calibration of the space component of the WMO World Weather Watch (WWW) Global Observing System (GOS) and Global Earth Observing System of Systems (GEOSS).
- International Partners:
  - CMA – CNES – EUMETSAT – JMA – KMA – NASA - NOAA

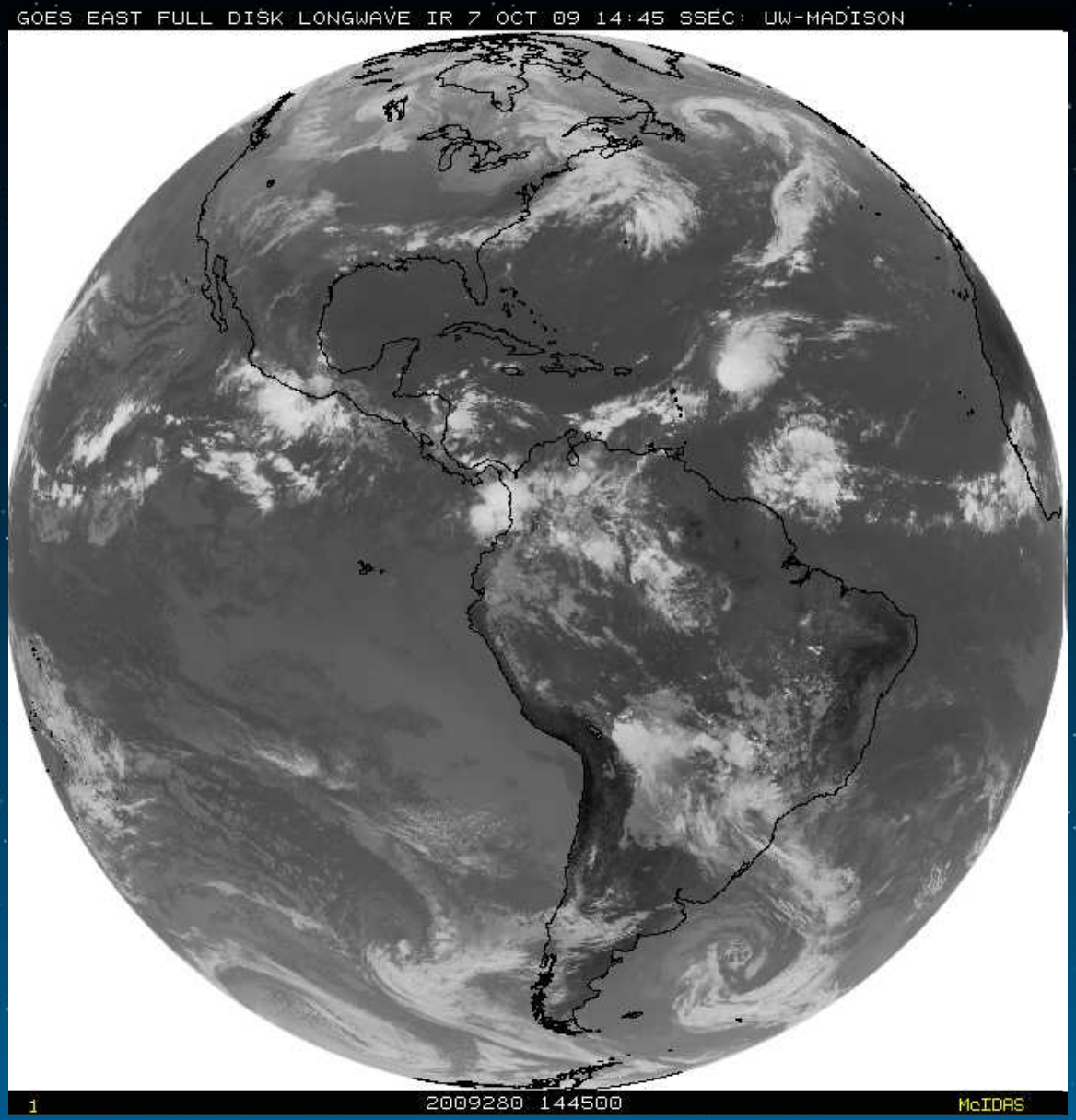
# We need satellite Inter-calibration to track the intensity of global weather systems.



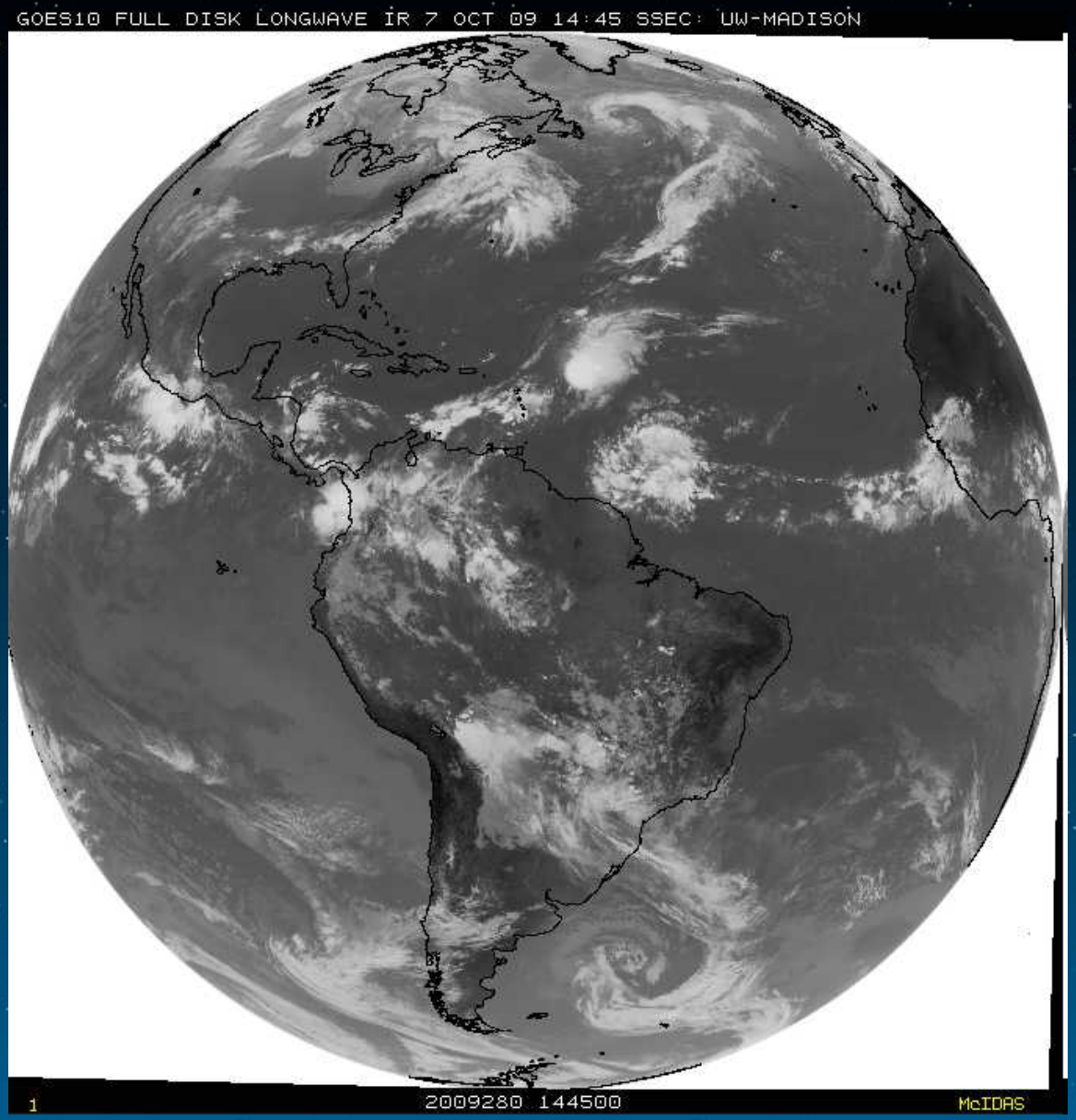
# GOES-WEST (GOES-11)



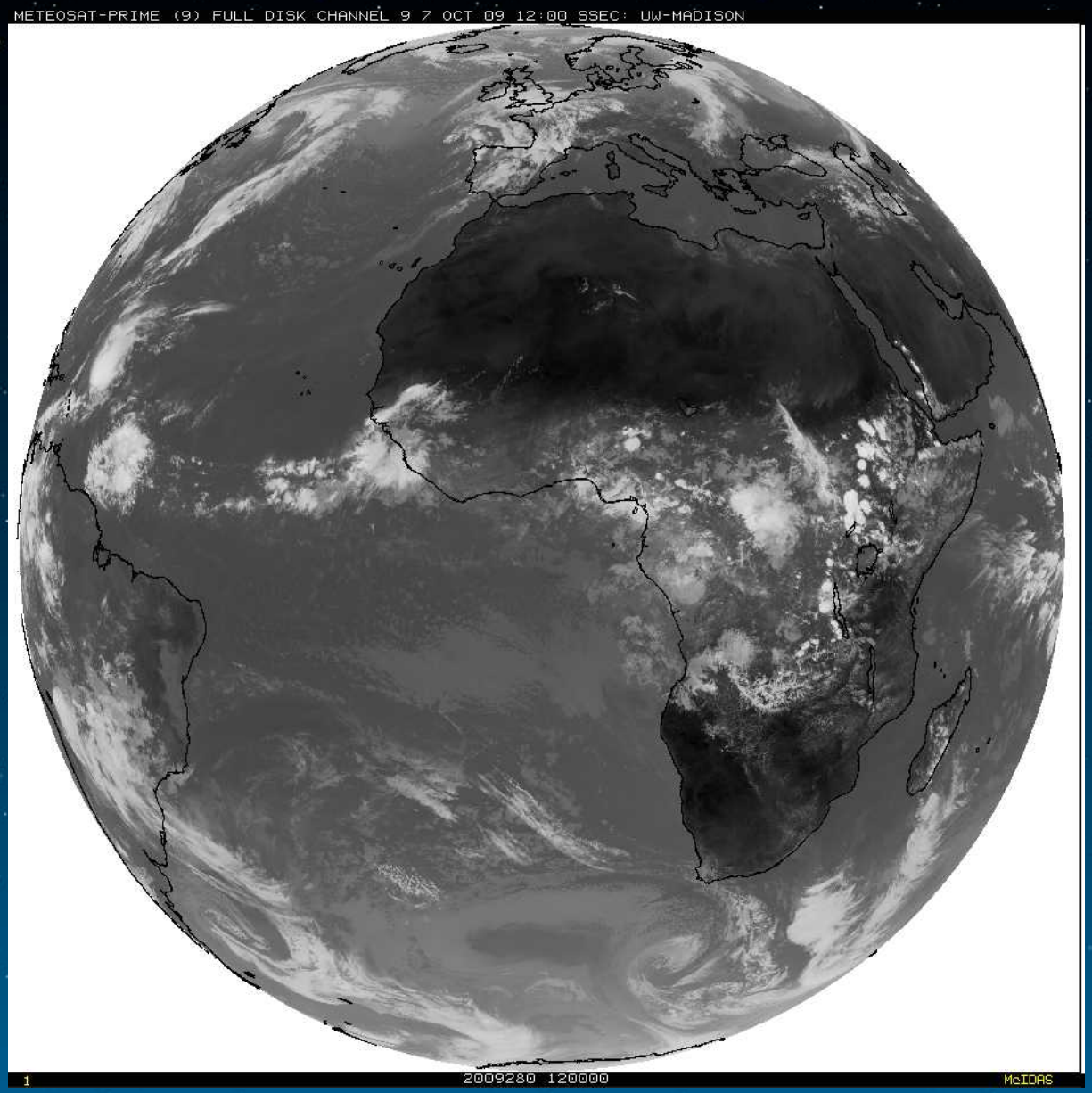
# GOES-EAST (GOES-12)



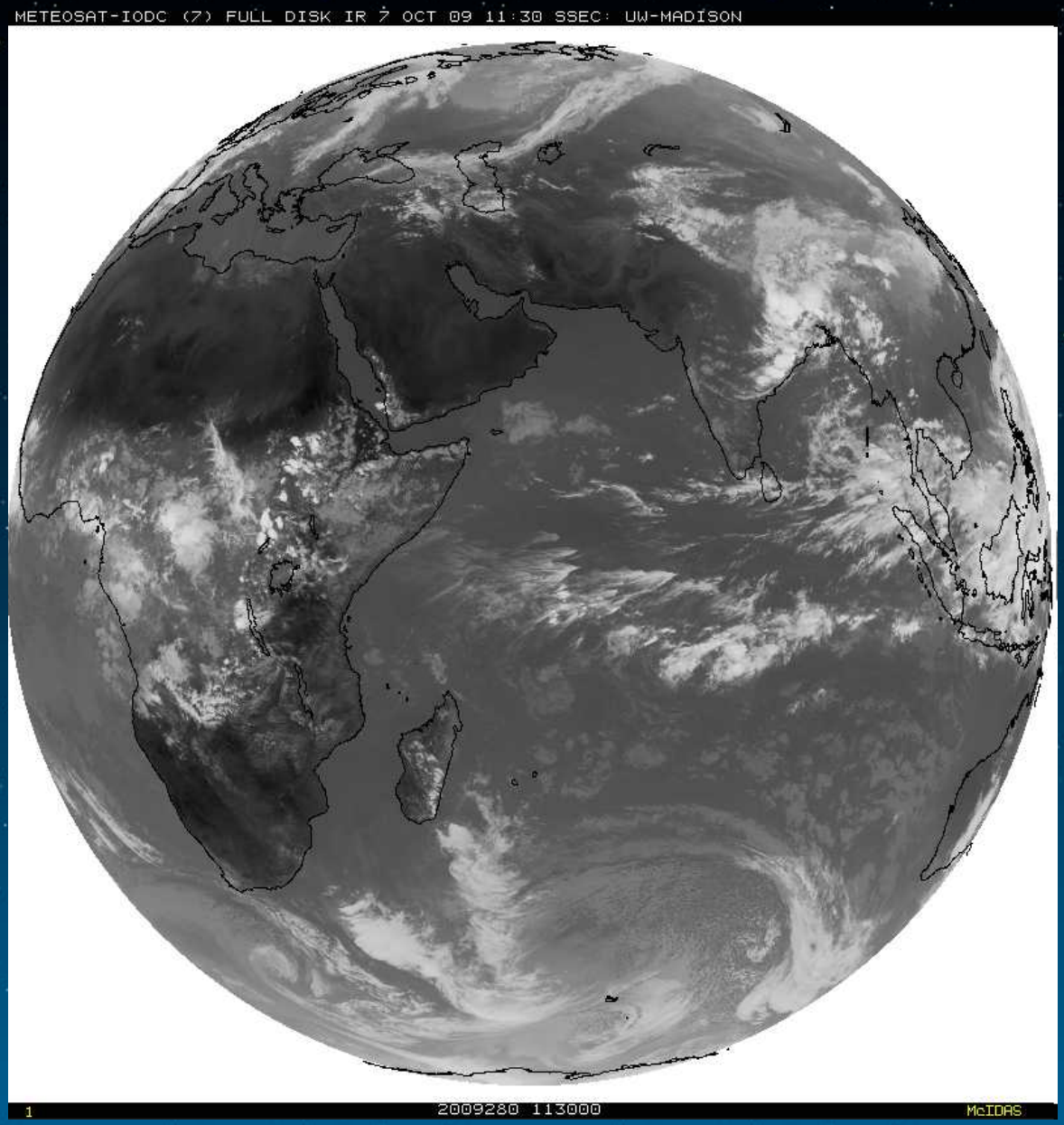
# GOES-SA (GOES-10)



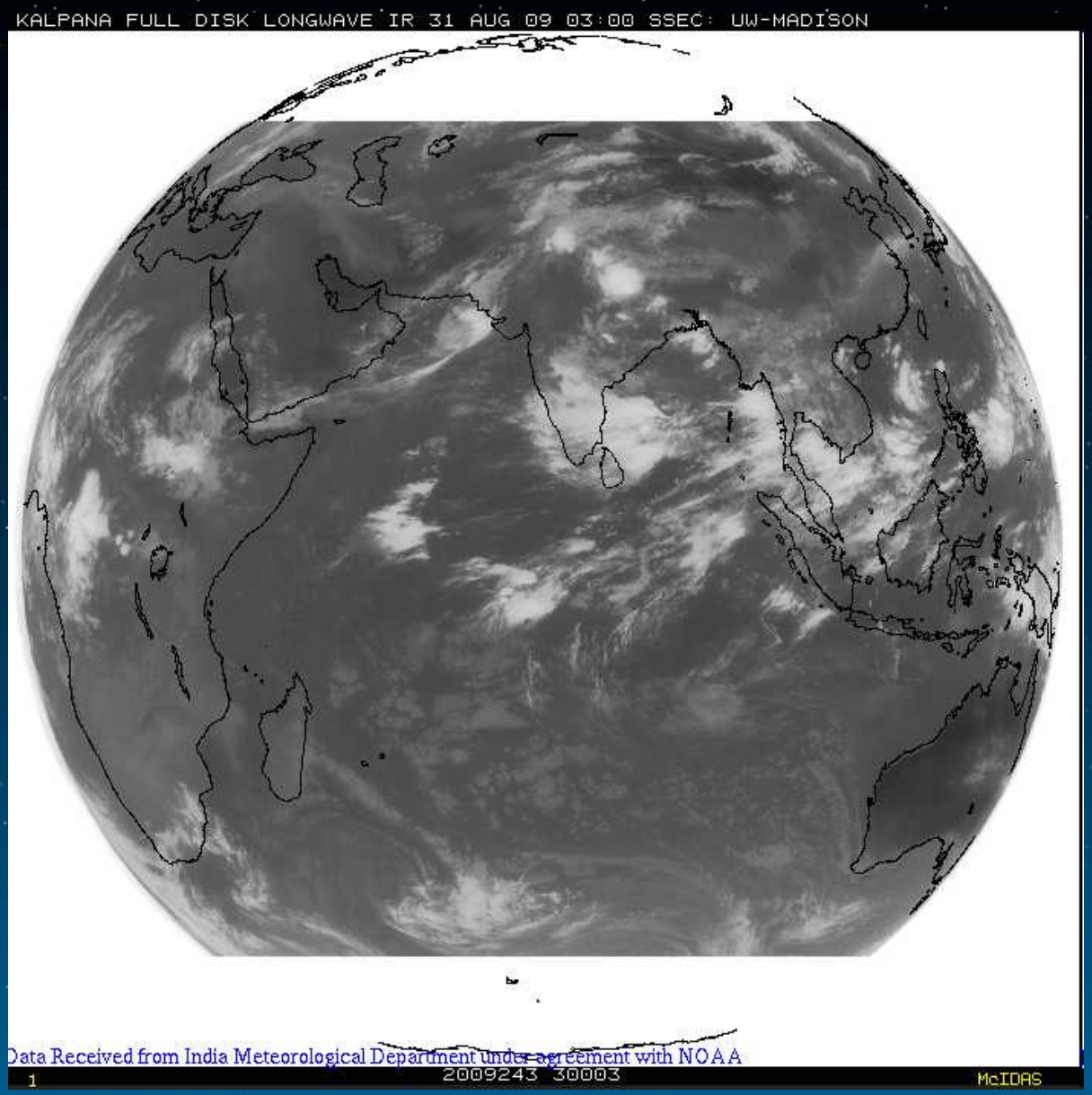
# METEOSAT-Prime (MET-9)



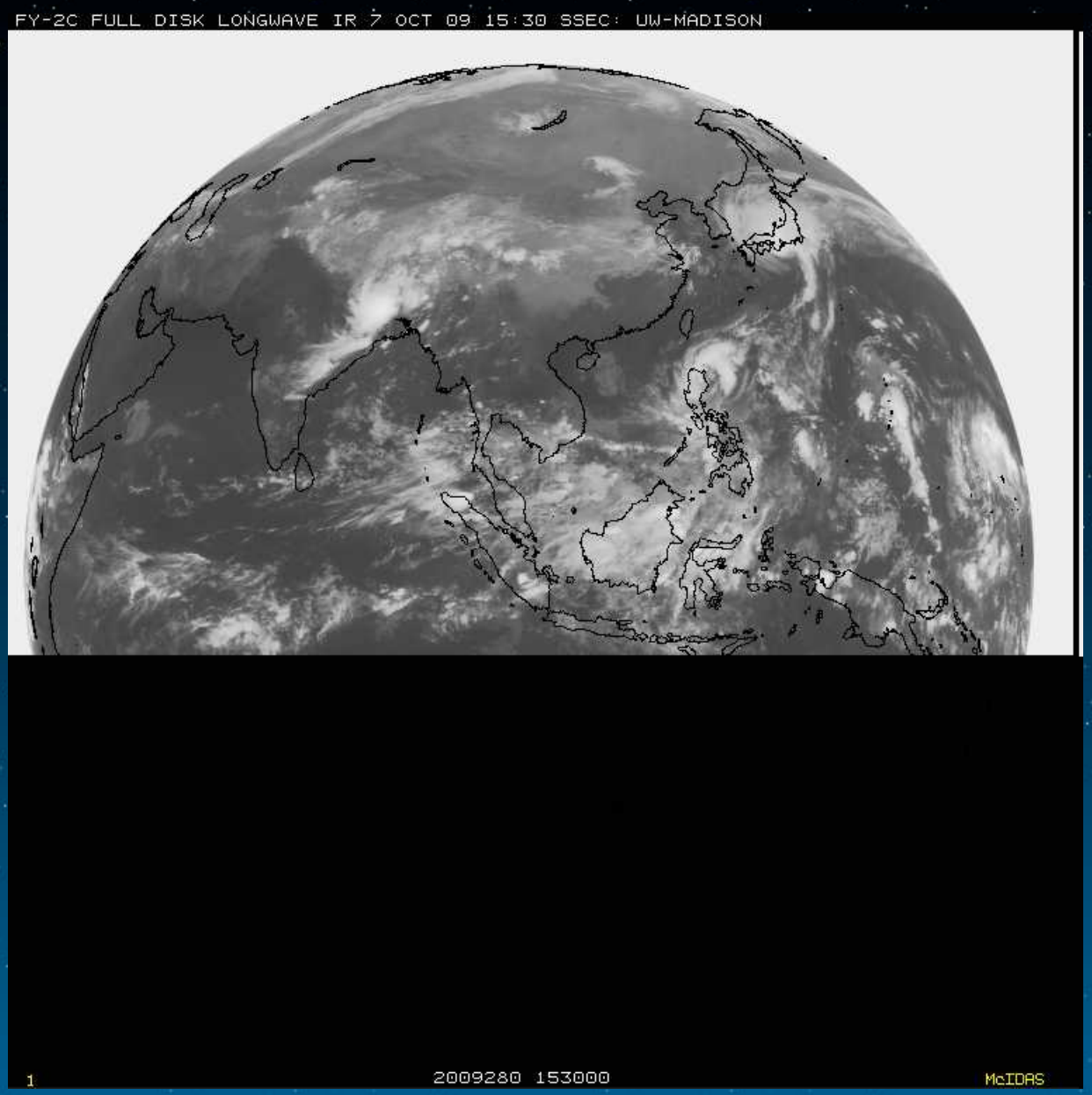
# METEOSAT-IODC (MET-7)



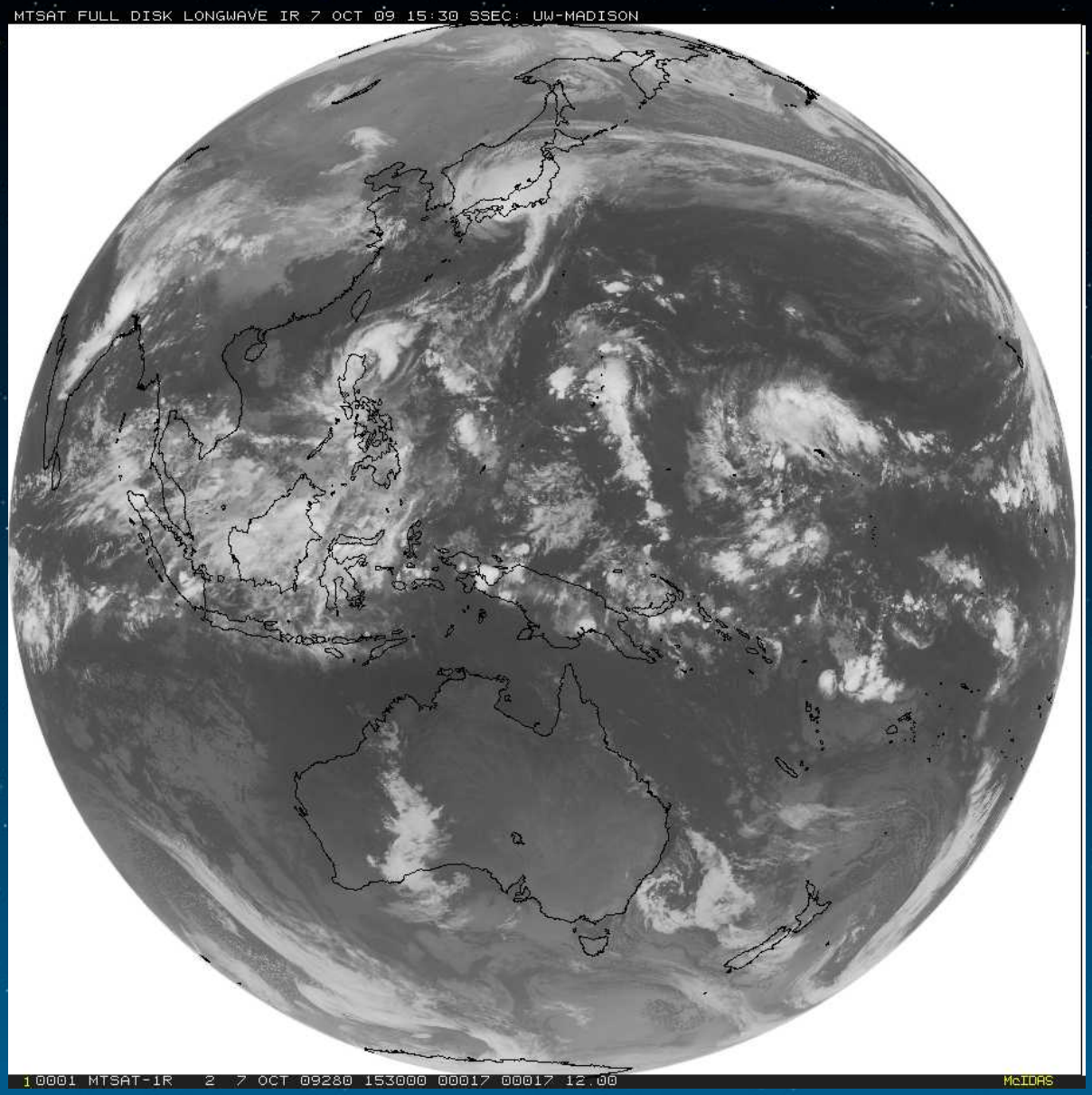
# India (KALPANA-1)



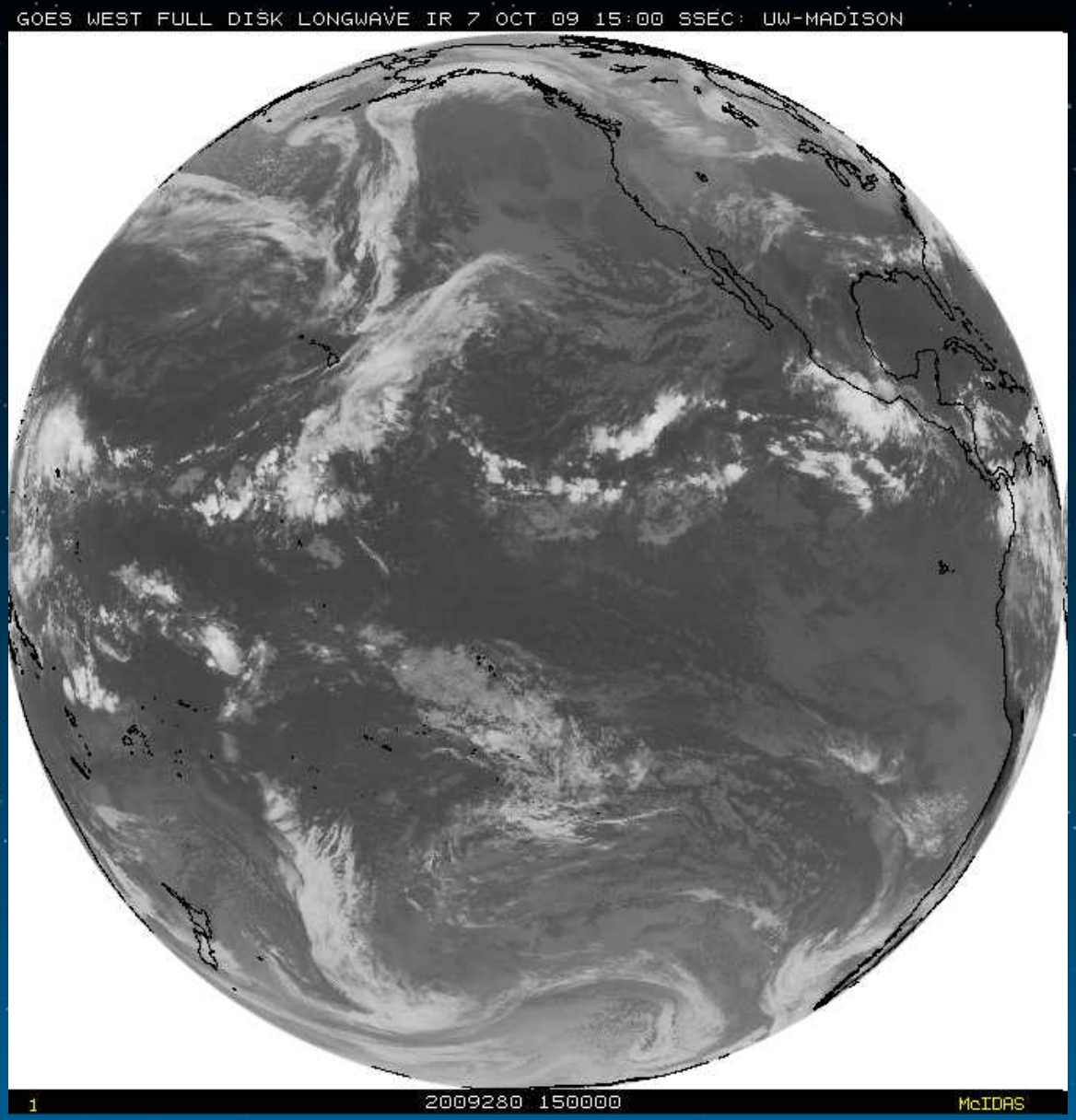
# China GEO FY2C



# Japan GEO MTSAT



# GOES-WEST (GOES-11)



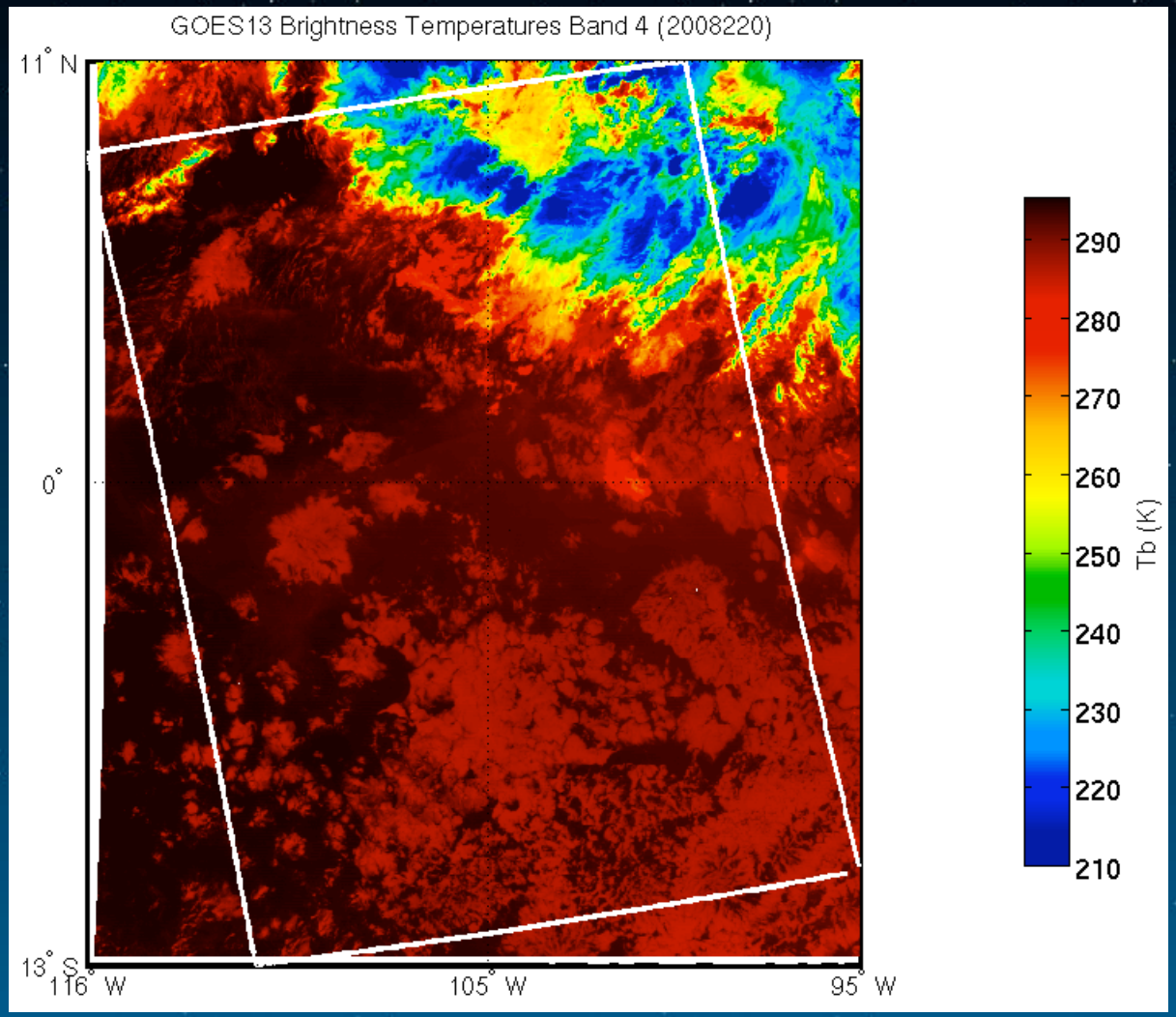
# Methodology: GEO – AIRS Intercal

- Collocation in time and space.
  - Within 30 minutes at geostationary subpoint (GSNO – Geostationary Simultaneous Nadir Observation)
  - Low Satellite View Angles (< 14)
- Spatial smoothing
  - 100km "running average" mitigates the negative effects of poor spatial and temporal collocation, poor navigation, and spatial resolution differences.
  - Average radiances, not temperatures.
  - Compare a common area around the GEO sub-point, not "pixel to pixel" comparisons
- "Convolve" AIRS Radiance spectra with GEO Spectral Response Function.
  - Compare mean scene brightness temperatures (converted from mean scene radiances).

$$L_i = \frac{\int_{v_1}^{v_2} R(v) S_i(v) dv}{\int_{v_1}^{v_2} S_i(v) dv}$$

# GOES-13 Imager 11μm

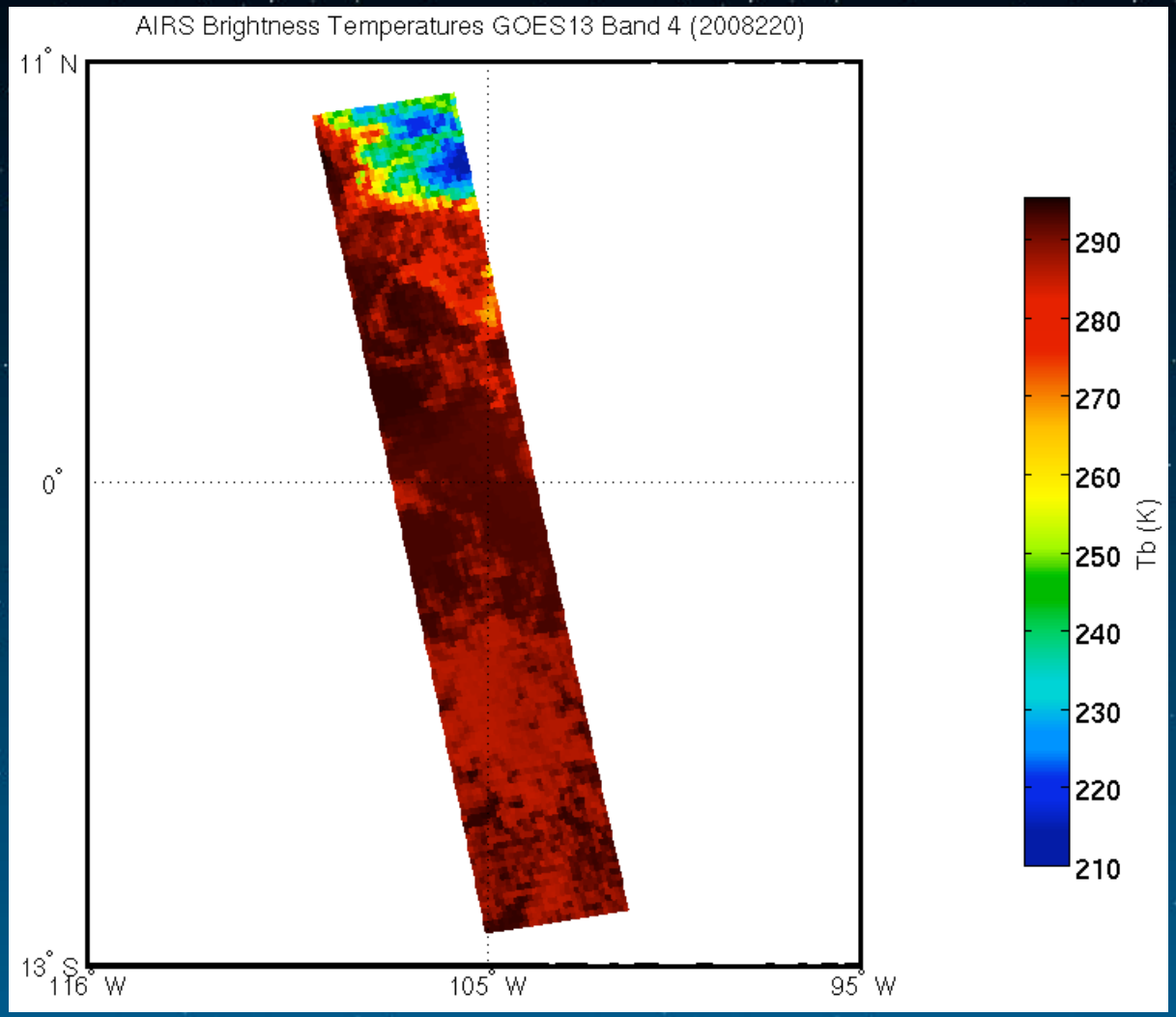
- AIRS Granule outline shown
- GOES-13 sub-satellite point is at 105 West




07 August 2008 at 20:45UTC

# AIRS convolved with GOES-13 Imager

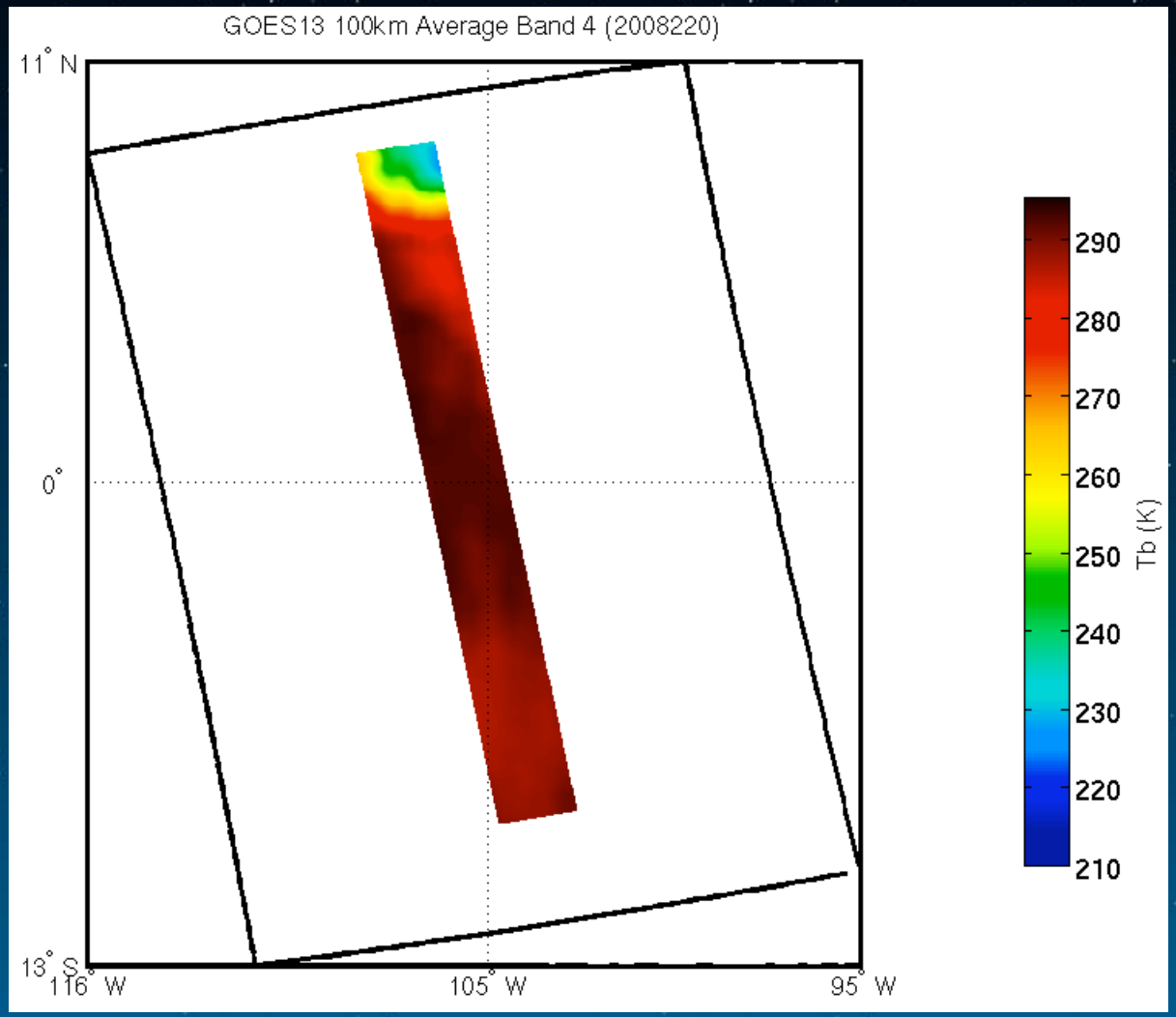
- AIRS Granule narrowed to save memory and processing time
- GOES-13 sub-satellite point is at 105 West




Granule 206 (20:36UTC)

# GOES-13 comparison area

- Data are spatially smoothed to an approximate 100-km resolution
- Each FOV becomes the average of the 100x100km around it and the image retains the same number of FOVs
- Only data that fall within the boundaries of 10N to 10S and AIRS Scan angles +/- 10 degrees of nadir are used in the comparison area

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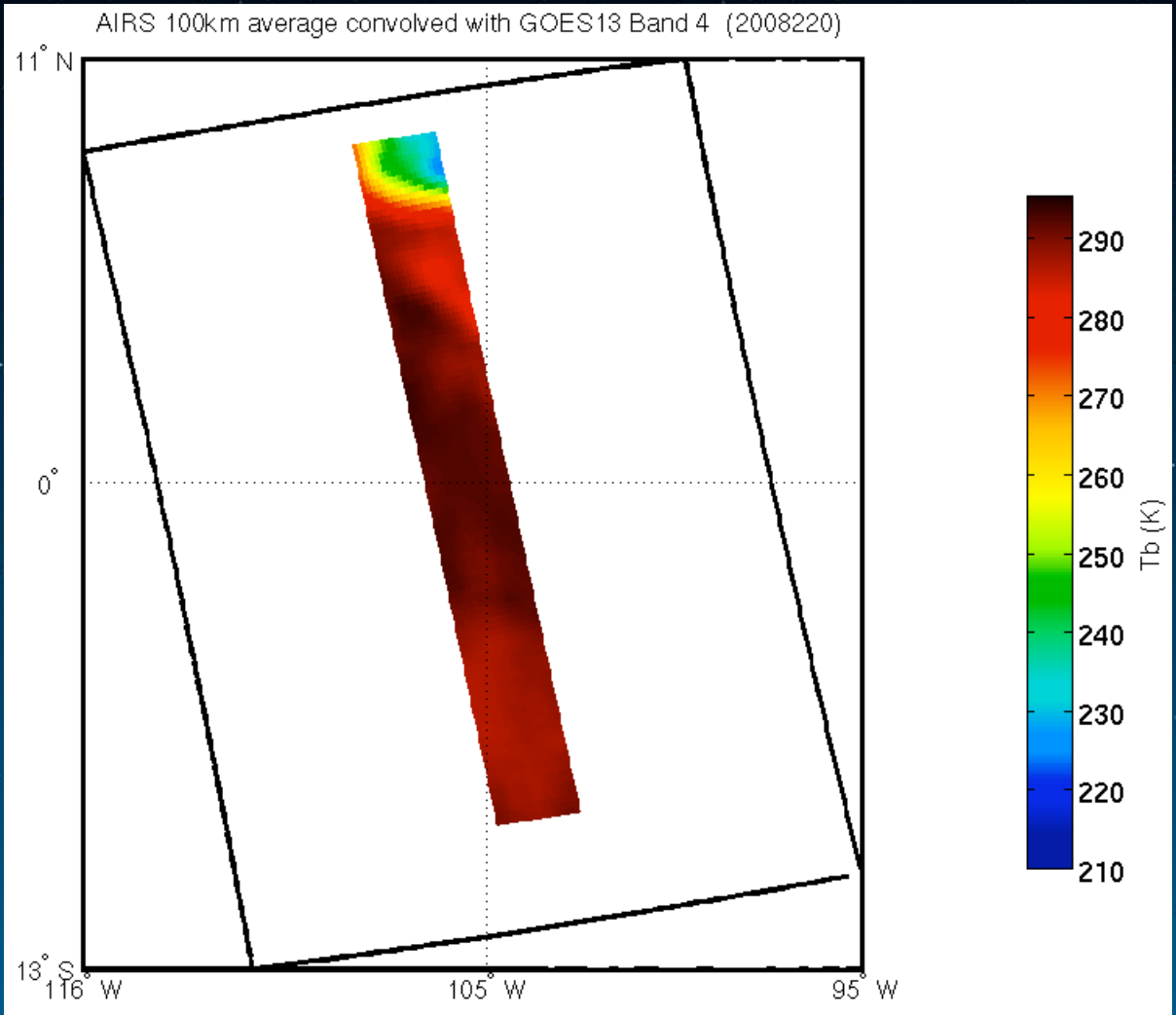
# AIRS comparison area

- For a single case, such as this one, the mean of the data (radiances) in this comparison area is calculated for both GOES and AIRS.
- The means are converted to brightness temperatures using the inverse Planck equation
- The comparison is reported as a difference (GOES mean – AIRS mean)

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A single case can be a useful measurement, but as we build more and more comparison cases over time we gain confidence in the mean difference.

# Error Analysis
## Scene Uniformity

- Scene uniformity was determined from the standard deviation about the mean of the radiances in the comparison area.
- Comparing GOES-12 scene uniformity to the GEO–AIRS brightness temperature difference showed there was not a statistically significant correlation between the two for any bands.
- In the GSICS method of pixel-to-pixel comparisons, scene uniformity is considered significant and pixels with non-homogenous scenes are not used in their statistics.

# Error Analysis
## Dependency on overpass timing

- In general, reducing the time between observations yielded tighter results (mean closer to 0K, lower standard deviation)
- For GOES-12 between Jan 2006 and Oct 2007 there were 174 cases which spanned scanning time differences of approximately 8s to 24.5 min

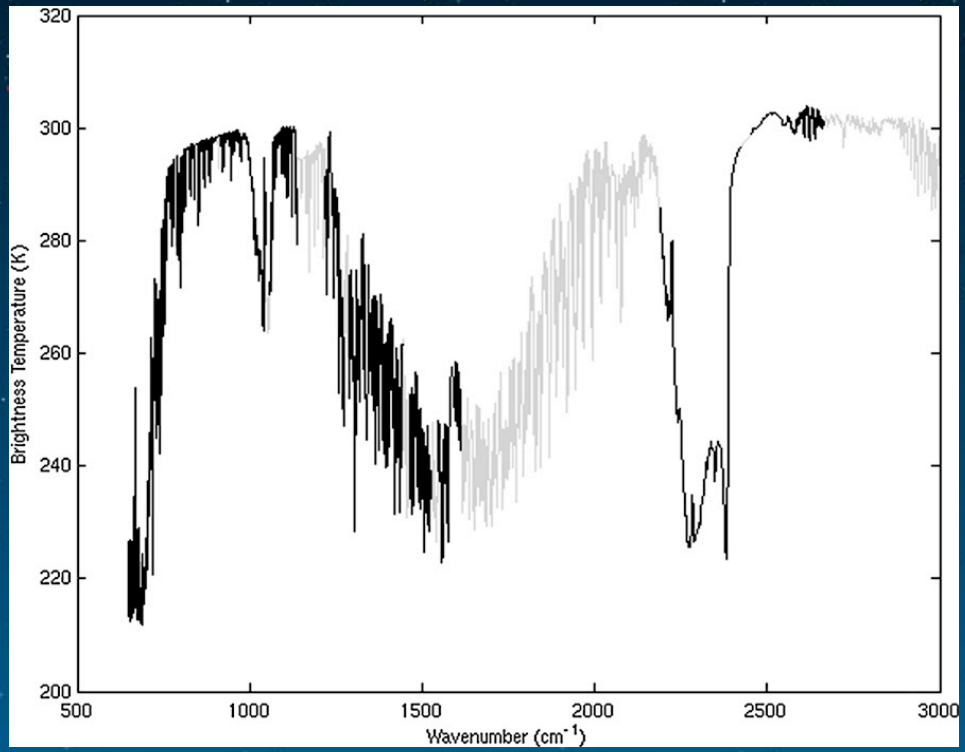
| GOES-12 IR Window | ΔTbb (K) | Std dev (K) | N |
|---|---|---|---|
| 30 min | -0.08 | 0.68 | 174 |
| 15-min | -0.02 | 0.46 | 91 |
| 10-min | 0.01 | 0.47 | 73 |
| 5-min | 0.02 | 0.35 | 46 |

# Accounting for AIRS spectral gaps

- AIRS has spectral gaps in parts of nearly every Geostationary Imager bands spectral response function (SRF).
- The current method to deal with this is to insert some calculated spectral information into the gaps.
- The US Standard Atmosphere (USSA) was used, which was convolved with mock Gaussian AIRS SRFs, and adjusted with a weighted average across the gaps to fit the spectra of each AIRS FOV.

# Accounting for AIRS spectral gaps

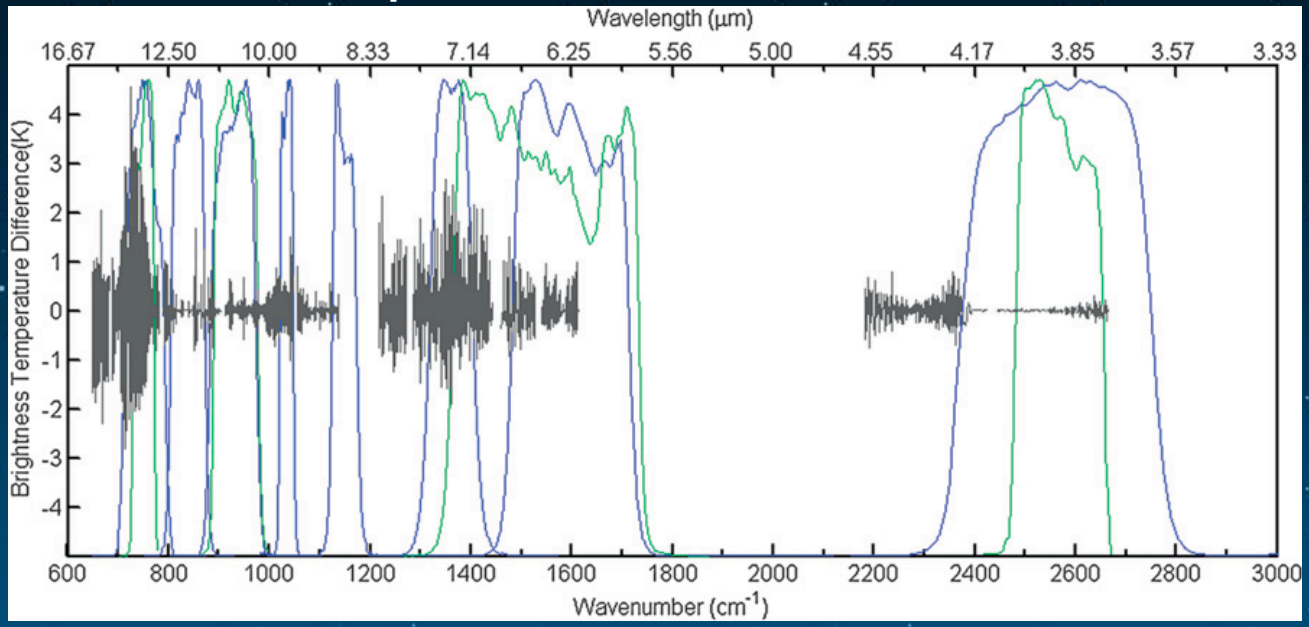
- Here is a sample AIRS spectrum (black) with the USSA spectrum inserted (gray)




There is room for improvement in this method; colleagues at JMA have implemented an improved method based on this which is what GSICS has since implemented.

# Accounting for AIRS spectral gaps

- How well do mock gaussian AIRS SRFs compare to a set of real AIRS SRFs?



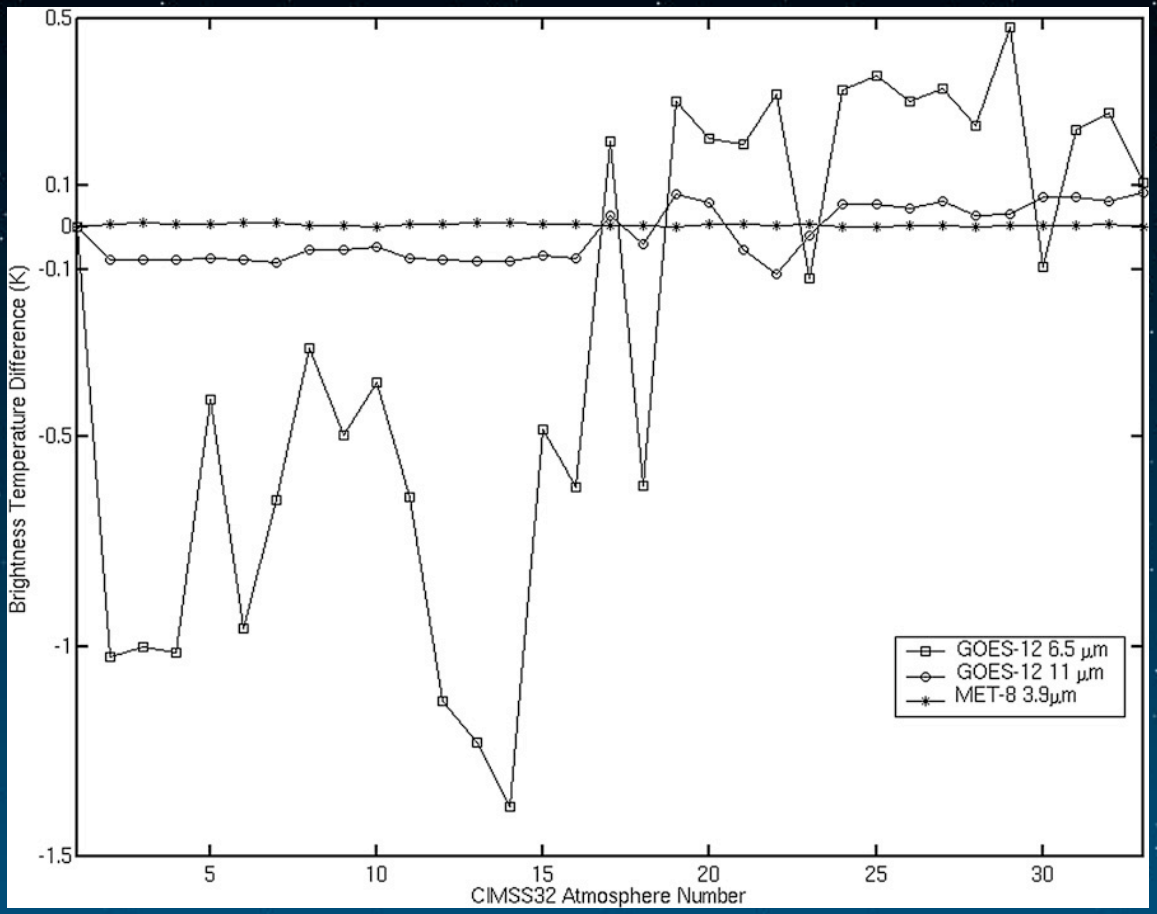

GOES-12 imager (green) and Meteosat-8 (blue) SRFs shown with the brightness temperature difference of AIRS real SRFs convolved with the USSA spectrum subtracted from AIRS mock SRFs convolved with the USSA spectrum for each AIRS channel.

- The mean difference is 0.02K with a standard deviation of 0.6K; the max is 4.6 K.
- Convolving with Geo SRFs is forgiving – even in the 13.3um region the difference after convolving is less than 0.1K
- Some bands really can't be compared to AIRS, such as the 8.7um band on Meteosat-8.

# Error Analysis
## Spectral Convolution and Gap Filling

- The CIMSS-32 – A set of 32 atmospheric profiles (converted to AIRS-like spectra) from various global climate regimes – were used to determine how well the gap-filling method worked.
- It was determined that for most GEO bands (3.9, 11, 12, and 13um regions) the gap filling method produced errors calculating radiance to less than 0.1K equivalent brightness temperature in the CIMSS-32 atmosphere types.
  - The exceptions were for the relatively broad water vapor channels and Meteosat's 6.2 and 8.7um bands where the spectral gaps comprise most of the band's spectral coverage.

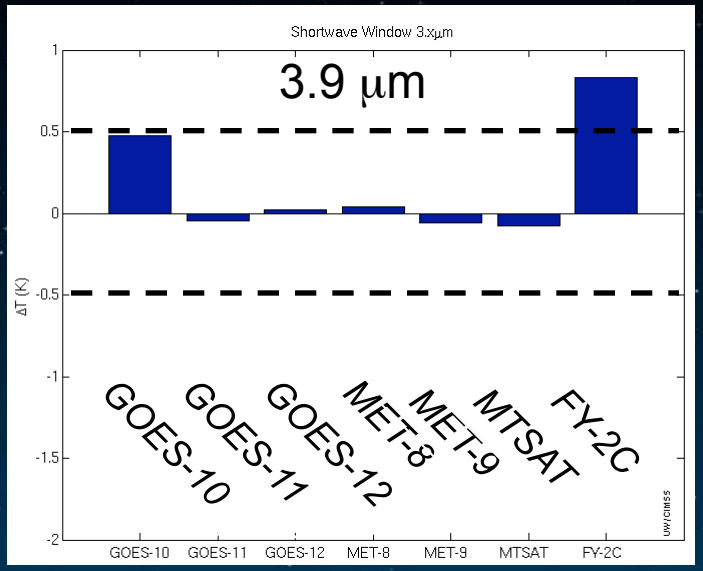
# Error Analysis: Spectral Gaps

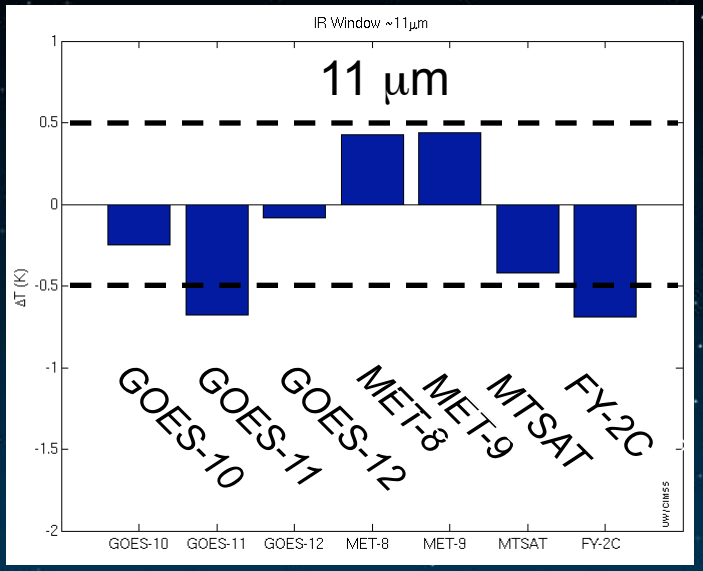


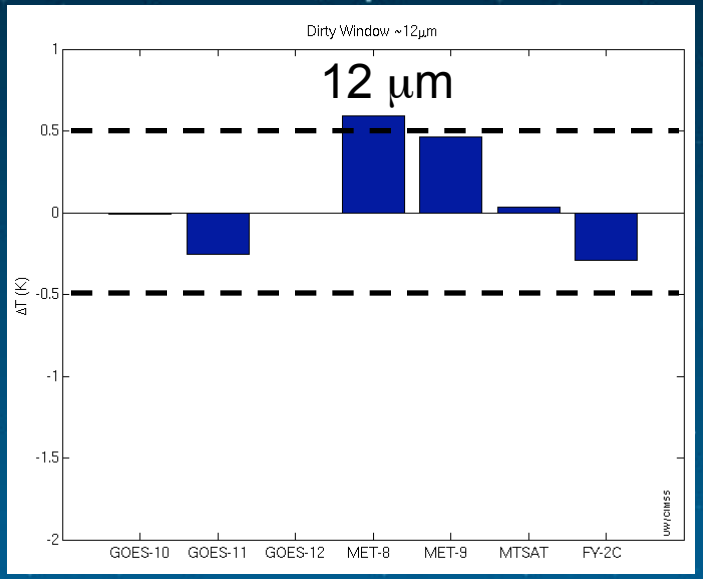

- Atmospheres 25 and 27-32 are tropical… with errors in the water vapor band around 0.3K.
- This method certainly does not seem suitable for this band in many other types of atmospheres.
- Atmosphere 1 is the USSA

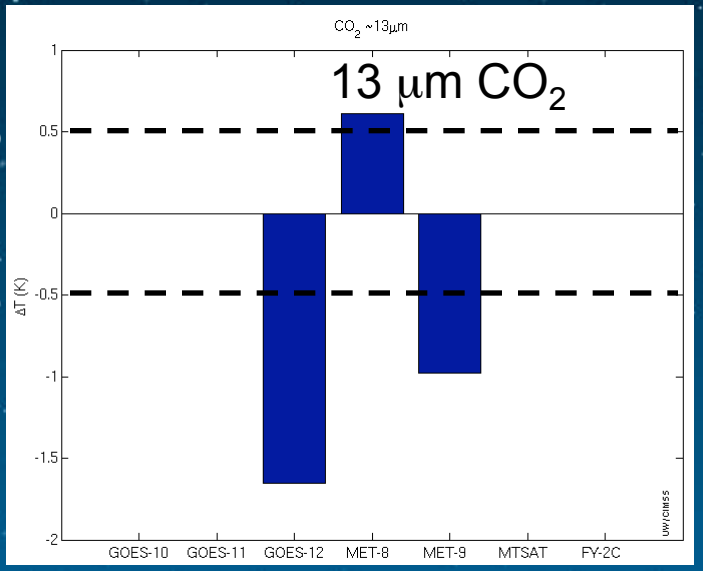
Comparison of the two sets of CIMSS-32 spectra (each convolved with mock AIRS SRFs and one then gap filled with the adjusted USSA - one without spectral gaps) which were convolved with GEO SRFs and differenced. IR Window (circles), water vapor band (squares), and the shortwave window (asterisks) are shown. Differences are less than 0.1 K for all the bands except for the water vapor bands and the Meteosat 8.7-um band (not shown).

# Results: GEO – AIRS Intercal

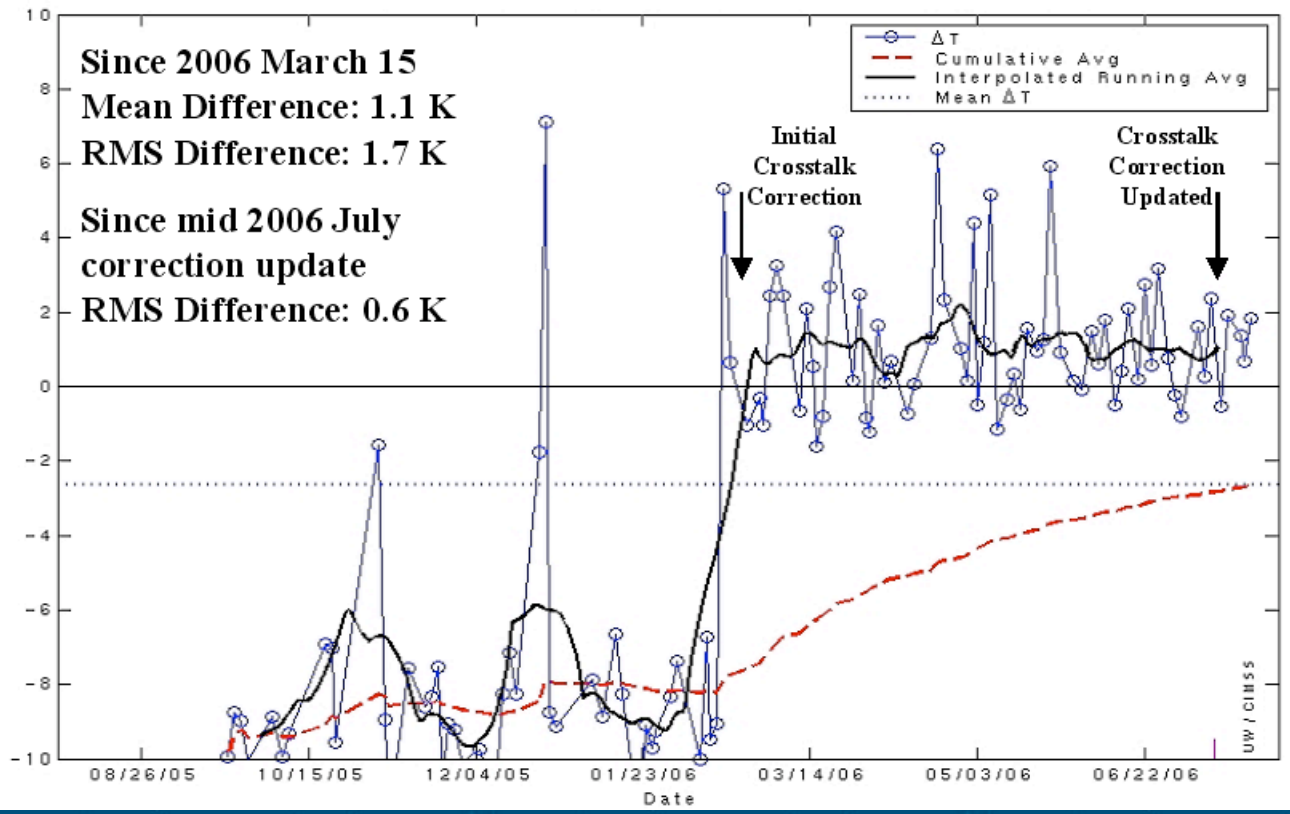


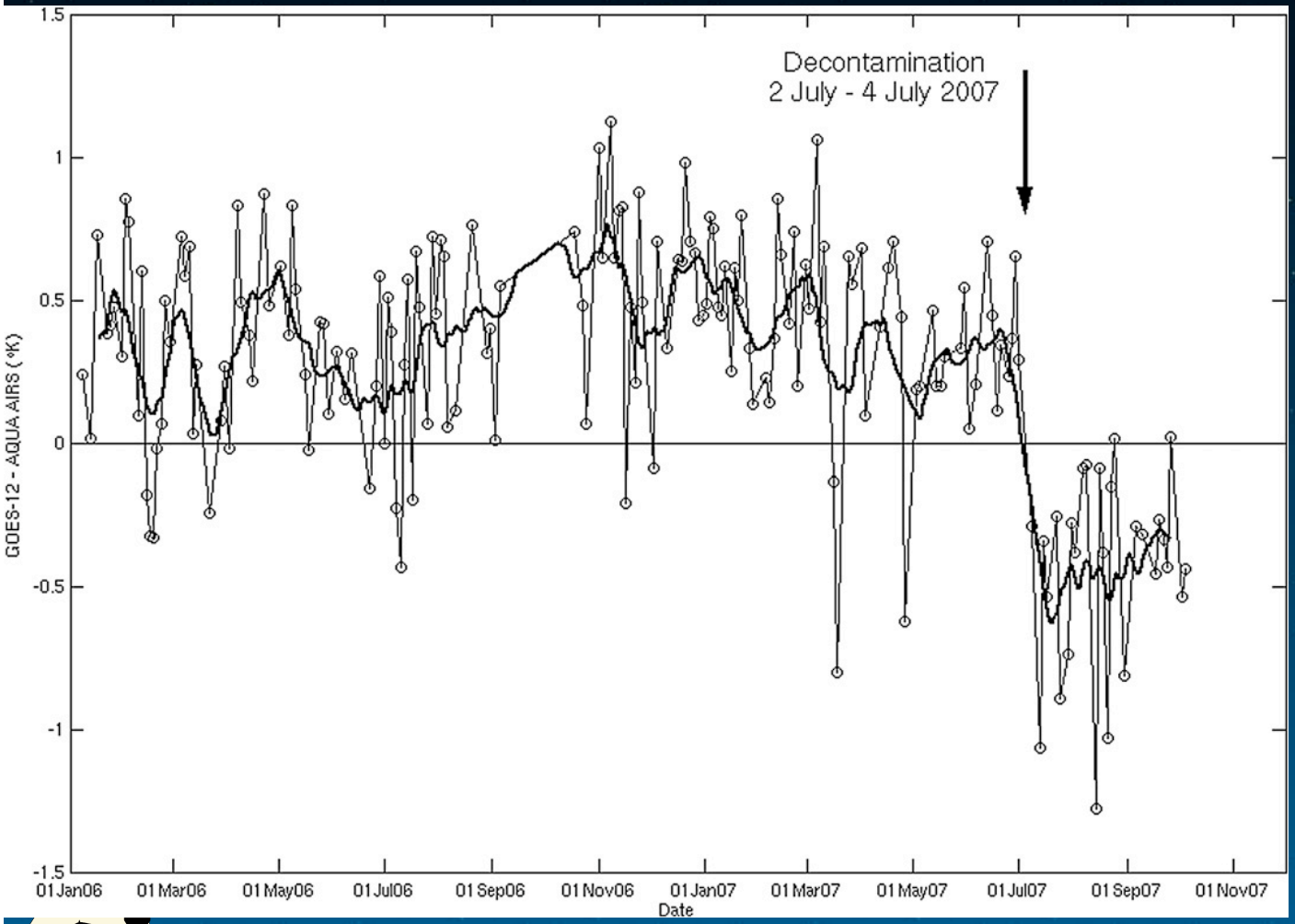



# Results: MTSAT-1R's Shortwave Band




- There is cross-talk in the 3.7um band from the water vapor band.
- This was discovered via GEO-AIRS intercal and the fixes were verified with this method as well.
- Two fixes were implemented and the data compare much better with AIRS today.

# Results: GOES decontamination

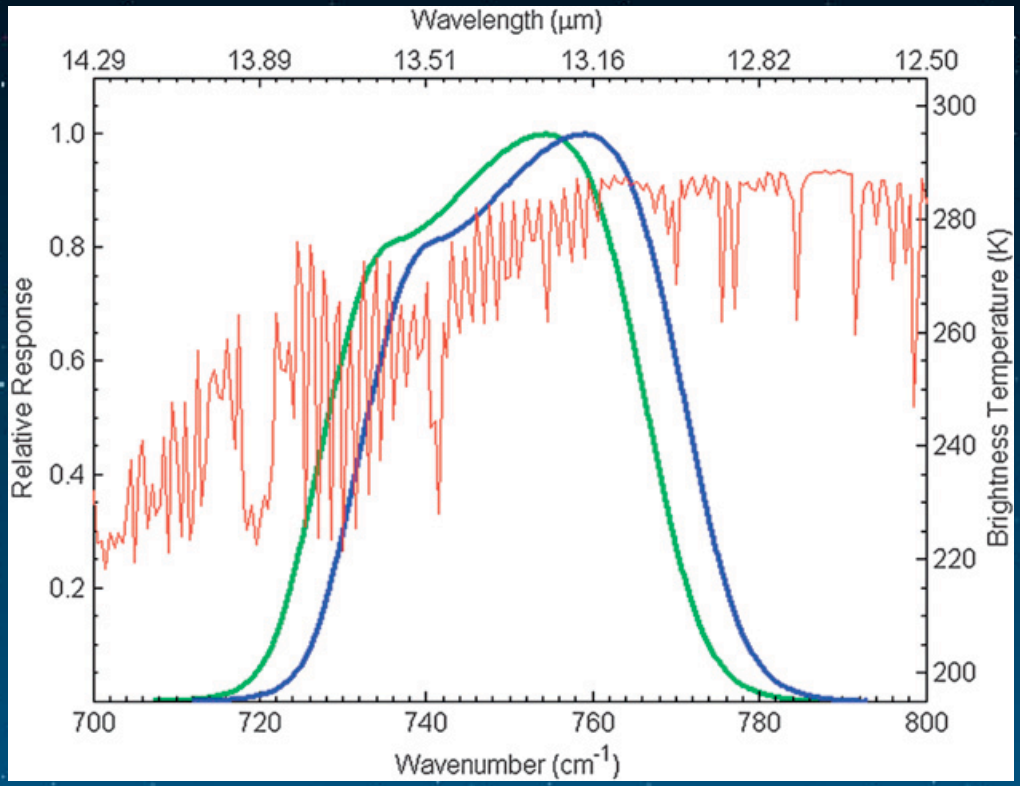



- GOES-12 went through decontamination 2-4 July 2007. This had a noticeable effect on the results in all bands (water vapor band time series shown)

# Results: Geo SRF uncertainty

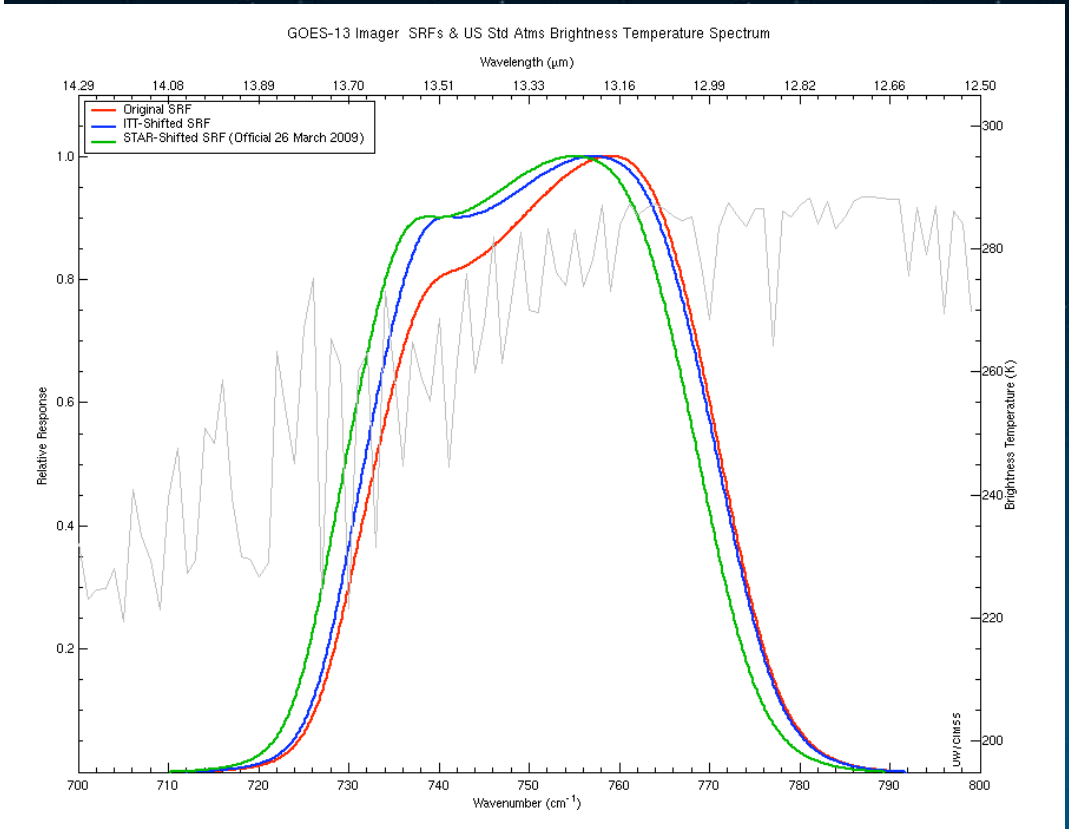
- There is an expanding body of evidence pointing to Geo SRF uncertainty as the main cause for most Geo Imager calibration inaccuracies.
- During the GOES-13 PLT it was discovered that the 13.3um band compared very poorly to AIRS (approximately 2.4K too cold). However, by shifting the SRF it was shown that the comparisons could be made better

# Results: Geo SRF uncertainty




- GOES-13 imager band 6 (13.3 um) SRF (blue) and the shifted SRF (green) shifted 24.7 $cm^{-1}$ (to approximately 13.4 um). By shifting the spectral response this amount, the mean Tbb difference for all 19 cases, becomes 0.0 K.
- This analysis led ITT to produce a new SRF which was both shifted to longer wavelength and had a slightly altered shape.

# Results: Geo SRF uncertainty




- ITT's new SRF was an improvement, but further analysis using AIRS revealed that it too needed to be shifted to longer wavelengths.
- This exemplifies the perfect marriage of GEO-LEO intercalibration and how it can affect operational meteorological products.
- AIRS helped GOES fix a 2.4 K bias in this band.
- This type of analysis could be applied to all GEO bands
- Changing the SRF of an operational instrument is non-trivial, but could have climate study implications

# Conclusions:

- Most geostationary imagers are calibrated within their specifications (usually considered 1K accuracy).
  - Accuracy required for climate studies is generally considered to be much tighter (order of 0.1 K) and intercalibration with a known standard such as AIRS can allow retrospective alterations to operational calibration (shifting SRFs for instance) to hopefully meet those standards.
- Due to the calibration accuracy of AIRS, GEO-LEO intercalibration techniques are vastly improved. This is continuing with METOP IASI without having to fill in as many spectral gaps.
- AIRS allowed the geostationary community to have the confidence to make alterations to two imagers: GOES-13 pre-operations and MTSAT-1R during operations.
- Currently MTSAT-2 and GOES-14 are in post launch test. This method will be applied to GOES-14, with particular interest paid to the 13.3um imager band, when the science portion of that test is conducted this winter.