



## **INTERCALIBRATION OF GEOSTATIONARY IMAGERS VIA HIGH SPECTRAL RESOLUTION AIRS DATA**

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## INTERCALIBRATION OF GEOSTATIONARY IMAGERS VIA HIGH SPECTRAL RESOLUTION AIRS DATA

Mathew M. Gunshor<sup>1\*</sup>, Timothy J. Schmit<sup>2</sup>, W. Paul Menzel<sup>2</sup>, and David C. Tobin<sup>1</sup>

<sup>1</sup>CIMSS/Univ. of Wisconsin, Madison, WI

<sup>2</sup>NOAA/NESDIS/STAR Madison, WI

### 1. INTRODUCTION

Intercalibration of satellite radiances, which leads to an improved knowledge of calibration, is important for various global applications where data from more than one instrument are combined or compared. Comparisons between geostationary imagers and the high spectral-resolution Atmospheric InfraRed Sounder (AIRS), polar-orbiting on Aqua, provide an accurate estimate over existing intercalibration techniques. The high spectral-resolution nature of such an instrument allows more accurate comparisons of measured radiances to other instruments sharing the same spectral regions. AIRS has been proven to have absolute calibration accuracies of 0.1K in most bands. However, AIRS does not have complete spectral coverage. The channels on geostationary imagers where AIRS has spectral gaps, such as the water-vapor absorption region, are difficult to compare accurately. Recent intercalibration results for one of the world's newest geostationary imagers, Japan's MTSAT-1R, are presented as part of a global array of imagers. MTSAT-1R replaced GOES-9 operationally in the western Pacific in late 2005.

### 2. APPROACH

The intercalibration approach used has been described in prior CGMS documents (see CGMS XXXII NOAA-WP-20 for example) and publications (Gunshor et al., 2004); it is briefly described here for completeness. A single polar-orbiting instrument is used to intercalibrate an array of geostationary imagers. As before, requirements include collocation in space and time (within thirty minutes) within 10 degrees from nadir for both instruments in order to minimize viewing angle differences. Data from each satellite are averaged to an effective 100 km resolution to mitigate the effects of differing field of view (fov) sizes and sampling densities; AIRS has a nadir 13 km fov, GOES-9, -10, and -12 imagers over-sample the 4 km detectors in the east west by a factor of 1.7; METEOSAT-8 has a nadir 3 km fov; MTSAT has a nadir 4km fov. Mean radiances are computed within the collocation area and are converted, via the inverse Planck function, into brightness temperatures. Finally, the temperature difference between the GEO and AIRS is calculated.

#### 2.1 *Convolving AIRS*

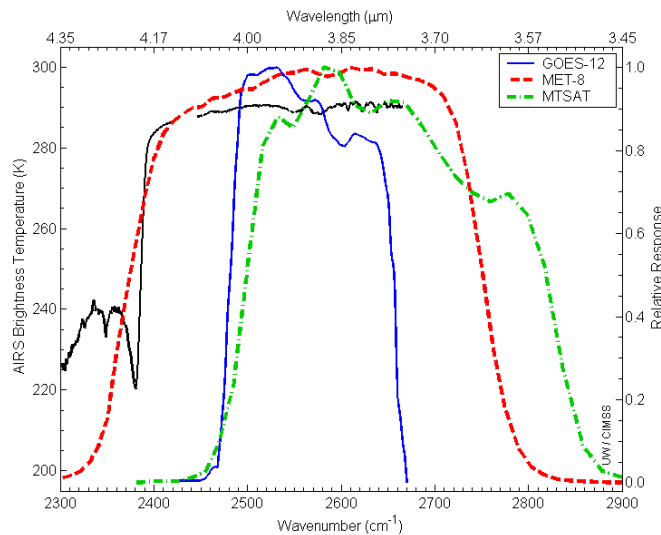
The AIRS high spectral resolution data are convolved with the geostationary instrument's spectral response function (SRF). This mitigates the need for the difficult correction for spectral response differences between two broadband instruments and is a considerable advantage of intercalibrating a broadband with a high spectral resolution instrument. After data are collocated and collected, AIRS is

convolved with the geo SRF and the resulting data are then averaged to an effective 100 km resolution. The mean radiance computed for the convolved AIRS data is converted into brightness temperature using the same inverse Planck function used for the GEO radiances.

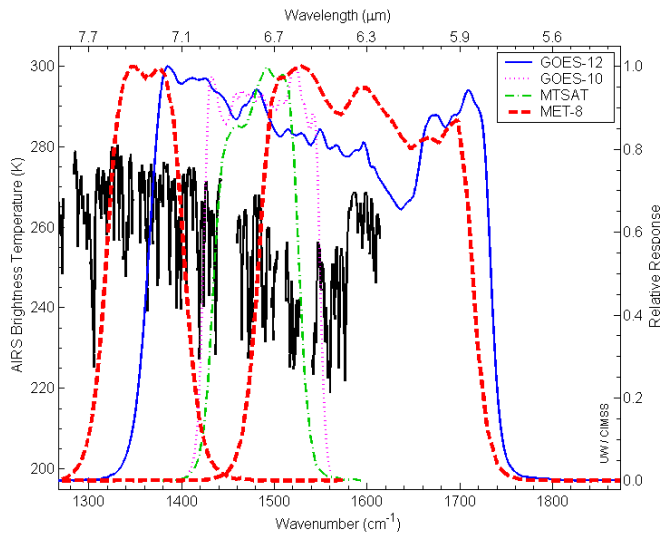
A representative AIRS spectrum is plotted with select spectral response functions from the geostationary instruments in Figures 1 through 5. The AIRS instrument does not cover the entire range of wavelengths covered by the geostationary instruments. The spectral range of the GEO infrared windows is covered completely, but there are large spectral gaps in the water vapor channel coverage (see Figure 2) that degrade the accuracy of the comparisons.

## 2.2 Filling the Spectral Gaps

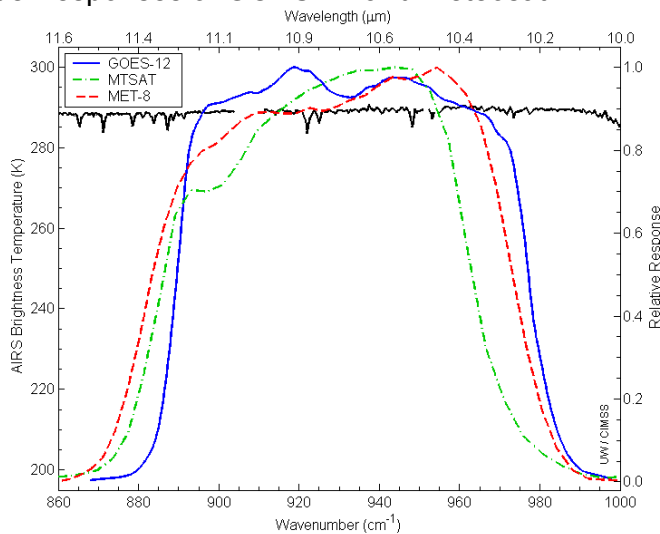
Most gaps in AIRS spectra are due to the original conception of the instrument. There are some small gaps due to bad detectors, which are filtered out with the relevant channel properties file or subsequent processing (thus leaving a small gap). Small gaps from bad detectors do not noticeably affect comparison to a broadband instrument because relatively little information from the earth/atmosphere is lost. However, gaps such as the one in the water vapor spectrum (Figure 2) pose a significant problem for comparison of AIRS to a broadband instrument in these wavelengths.



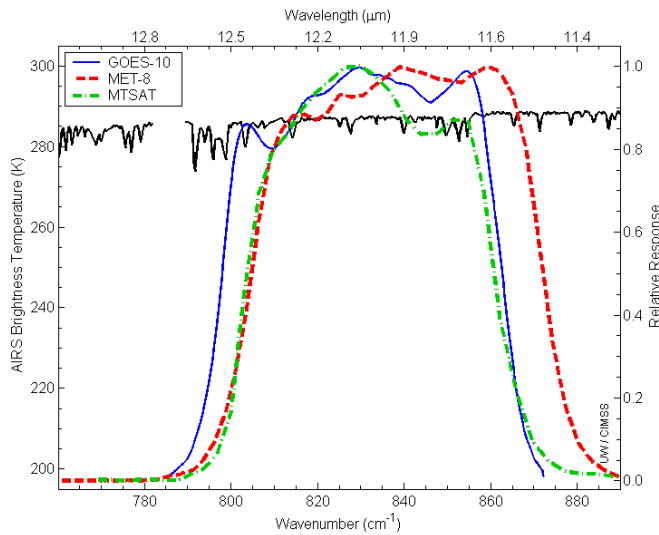
**Figure 1.** 3.9µm band spectral response functions plotted with sample AIRS brightness temperature spectrum. GOES-9 and GOES-10 have similar spectral coverage to GOES-12. Note that on the shortwave side, AIRS coverage ceases very close to the end of GOES spectral coverage but Meteosat-8 and MTSAT extend well beyond to the shortwave side.



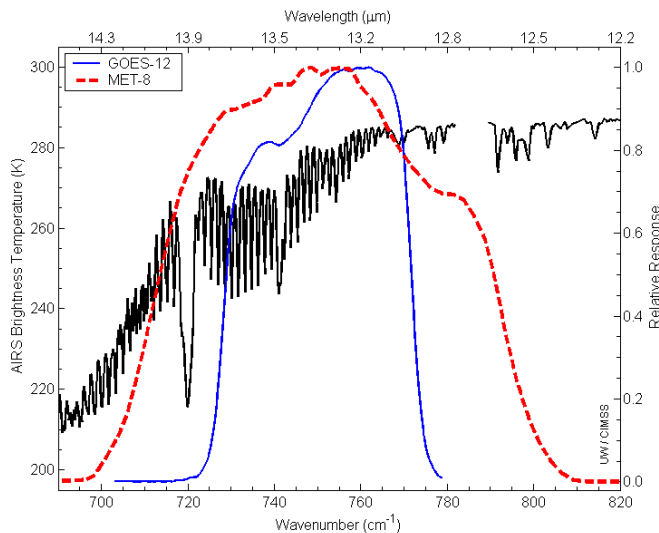
**Figure 2.** 6 to 7µm band spectral response functions plotted with sample AIRS brightness temperature spectrum. GOES-9 has similar spectral coverage to GOES-10. Unlike the other instruments, Meteosat-8 has a second band in this region. Note the large percentage of SRF not covered on the shortwave side by AIRS data for the wider responses of GOES-12 and Meteosat.



**Figure 3.** 11µm band spectral response functions plotted with sample AIRS brightness temperature spectrum. GOES-9 and -10 have similar spectral coverage to GOES-12.



**Figure 4.** 12 $\mu$ m band spectral response functions plotted with sample AIRS brightness temperature spectrum. GOES-9 has similar spectral coverage to GOES-10.



**Figure 5.** 13 $\mu$ m band spectral response functions plotted with sample AIRS brightness temperature spectrum.

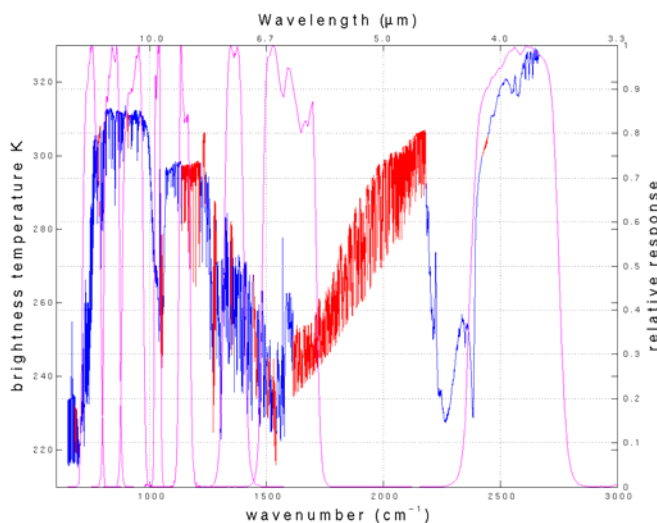
It is possible to obtain more accurate comparisons in the spectral regions of AIRS gaps. By filling gaps with a calculated spectrum or a spectrum obtained by reversing an atmospheric sounding, a more accurate comparison can be made. A good approximation of the spectra in the gaps can be obtained by reversing an AIRS retrieval using a forward model. AIRS retrievals are available in 3x3 grids for an AIRS granule for clear sky scenes. This limits their usefulness and coupled with the time required to run the forward model this approach is not very practical. The undertaking here has been to use a calculated spectrum, from the US Standard Atmosphere, and adjust it to each field of view's spectrum. In a single test case, this adjusted US Standard Atmosphere yielded very similar results when filling the spectral gaps to those obtained from an AIRS retrieval.

This method may not be the most sophisticated, but the results, discussed below, indicate that even this empirical approach represents an improvement in comparison skill. The calculated spectrum must be adjusted to fit the end points of the gap in the observed spectra. The adjustment is made by shifting the calculated spectrum's radiances to fit the end point on the longwave side and then applying a weighted mean incrementally across the gap to the shortwave side, such that the shortwave endpoints also match.

Figure 6 shows the difference between a sample AIRS spectrum before and after gaps were filled using this method by a spectrum calculated from the US Standard Atmosphere.

### 3. RESULTS

The results section presents the mean brightness temperature differences for the various geostationary spectral bands for an array of global geostationary imagers. The first section contains results where spectral gaps have not been filled or accounted for in any way. This is followed by a section with results where spectral gaps have been filled by the method mentioned in section 2.2 above. There are relatively fewer comparisons for GOES-10 due in part to the eclipse schedule between September and October and the coincident time of the Aqua morning overpass. There are relatively fewer comparisons for MTSAT because that data has only recently become available.



**Figure 6.** Meteosat-8 spectral response functions (magenta) plotted along with an AIRS sample spectrum (blue) with spectral gaps filled with the adjusted US Standard Atmosphere spectrum (red).

#### 3.1 Ignoring the Spectral Gaps

Intercalibration results for the geostationary satellites GOES-9, -10, -12, Meteosat-8 and MTSAT-1R (between 1 June 2005 and 1 November 2005) using convolved AIRS data are shown in tables 1-4 below. The  $\Delta T_{bb}$  is the average of all cases for the indicated satellite and a negative sign indicates the convolved measurements from AIRS are warmer than those from the geostationary instrument on average.

The standard deviation is the deviation about the mean. Differences for the infrared window bands (Table 1) are generally smaller than those found for other bands, as was found in broadband comparisons to NOAA AVHRR and HIRS as well (Gunshor et al., 2004). The differences for the water vapor channels in Table 2 are larger, as expected, since the gaps in AIRS spectral coverage (Figure 2) account for most of the temperature differences and given the larger atmospheric moisture variability. The effect is exacerbated for the spectrally wider response on GOES-12 because a higher percentage of the SRF falls in the spectral gap, outside AIRS spectral coverage. GOES-12 does not have a 12 $\mu\text{m}$  “Dirty Window” band, which was replaced with the 13 $\mu\text{m}$  band (Schmit et al. 2002; Hillger et al. 2003); results for the other instruments are in Table 3. The results for the 3.9 $\mu\text{m}$  bands (Table 4) are separated into “Day versus Night” because that band is particularly sensitive to reflected solar energy during the day and the nighttime results are more meaningful toward understanding calibration accuracy. The MET-8 and MTSAT instruments are not compared to AIRS in the 3.9 $\mu\text{m}$  band since their spectral response functions extend beyond the end of AIRS coverage in the shortwave region. For the 13.3 $\mu\text{m}$  band (not shown) GOES-12 was found to have a mean difference  $\Delta T_{\text{bb}}$  of  $-1.4\text{K}$  and a standard deviation of  $0.5\text{K}$  for 52 cases and MET-8 was found to have a mean difference  $\Delta T_{\text{bb}}$  of  $0.5\text{K}$  and a standard deviation of  $0.1\text{K}$  for 68 cases.

Geo:	GOES-10	GOES-12	MET-8	MTSAT	GOES-9
N	17	52	68	13	65
$\Delta T_{\text{bb}}$ (K)	-0.3	-0.1	0.4	-0.5	-0.4
STD (K)	0.2	0.5	0.1	0.6	0.9

**Table 1.** IR Window (11 $\mu\text{m}$ ) band results.  $\Delta T_{\text{bb}}$  (GEO minus AIRS) is the mean of N cases.

Geo:	GOES-10	GOES-12	MET-8	MTSAT	GOES-9
N	17	52	68	12	65
$\Delta T_{bb}$ (K)	2.0	-5.9	0.6	1.8	1.5
STD (K)	0.3	0.3	0.1	0.2	0.4

**Table 2.** Water Vapor (~6.9 $\mu$ m) band results.  $\Delta T_{bb}$  (GEO minus AIRS) is the mean of N cases.

Geo:	GOES-10	GOES-12	MET-8	MTSAT	GOES-9
N	17	-	68	12	65
$\Delta T_{bb}$ (K)	0.1	-	0.6	0.1	-0.2
STD (K)	0.2	-	0.1	0.7	0.9

**Table 3.** “Dirty Window” (12 $\mu$ m) band results.  $\Delta T_{bb}$  (GEO minus AIRS) is the mean of N cases.

Geo:	GOES-10	GOES-12	GOES-9
N	17	51	64
$\Delta T_{bb}$ (K)	0.8	-0.9	0.8
STD (K)	1.0	1.7	2.3
N (Day)	17	20	37
$\Delta T_{bb}$ (K) (Day)	0.8	-1.3	1.5
STD (K) (Day)	1.0	2.5	2.9
N (Night)	0	31	27
$\Delta T_{bb}$ (K) (Night)	-	-0.7	-0.1
STD (K) (Night)	-	0.7	0.5

**Table 4.** Shortwave window (3.9 $\mu$ m) band results.  $\Delta T_{bb}$  (GEO minus AIRS) is the mean of N cases. Day and night are determined by local sunrise and sunset times.

### 3.2 Results With Spectral Gaps Filled.

Intercalibration results for the geostationary satellites GOES-9, -10, -12, Meteosat-8 and MTSAT-1R (between 1 June 2005 and 1 November 2005) using convolved AIRS data where gaps are filled with an adjusted US Standard Atmosphere spectra are shown in tables 5 and 6 below. There is a slight improvement in the comparisons for the infrared window bands on these instruments (Table 5). The differences for the water vapor channels in Table 6 are largely improved by the gap-filling technique. However, the gap-filling technique had no noticeable effect on the results for the 3.9 $\mu$ m, 12 $\mu$ m, or 13 $\mu$ m bands.

Geo:	GOES-10	GOES-12	MET-8	MTSAT	GOES-9
N	17	52	68	13	65
$\Delta T_{bb}$ (K)	-0.2	0.0	0.4	-0.4	-0.3
STD (K)	0.1	0.5	0.1	0.6	0.9

**Table 5.** IR Window (11 $\mu$ m) band results with AIRS spectral gaps filled.  $\Delta T_{bb}$  (GEO minus AIRS) is the mean of N cases.

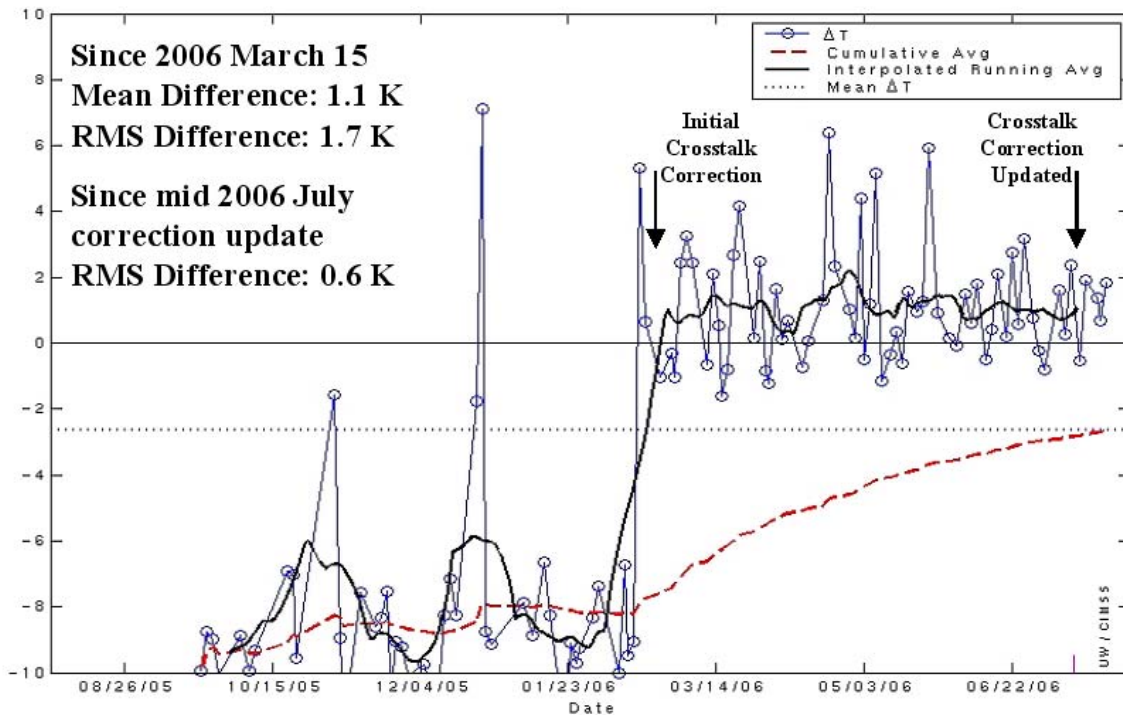


Geo:	GOES-10	GOES-12	MET-8	MTSAT	GOES-9
N	17	52	68	12	65
$\Delta T_{bb}$ (K)	0.4	0.2	0.5	0.4	0.9
STD (K)	0.2	0.7	0.1	0.3	0.5

Table 6. Water Vapor ( $\sim 6.9\mu\text{m}$ ) band results with AIRS spectral gaps filled.  $\Delta T_{bb}$  (GEO minus AIRS) is the mean of N cases.

### 3.3 MTSAT-1R Shortwave ( $3.7\mu\text{m}$ ) Band Crosstalk

The remote sensing community has shown keen interest in the calibration accuracy of MTSAT due to some uncertainties in how the instrument was performing early in its operational life. The interest stems from the desire to continue products that were being produced with GOES-9. The gap-filling technique was expanded to extrapolate out past AIRS shortwave coverage to gain insight into MTSAT's performance in this band. It was discovered by system engineers that MTSAT had a crosstalk problem in the shortwave band coming from the water vapor band. Two separate fixes have been implemented to address the crosstalk problem (Jeff Puschell, Raytheon, personal communication). Both showed an improvement in MTSAT's shortwave comparison to AIRS and the results are comparable to those from GOES-9 (Figure 7). There may still be a problem with the calibration in very cold temperatures where the crosstalk signal overwhelms the weak signal in that band at those temperatures, but that has not been quantified as of yet.



## 4. DISCUSSION

The relevance of intercalibration work was highlighted in 2006 when requests from industry, government, and academia came as MTSAT transitioned into operations,

replacing GOES-9. The importance of communicating results became clear as scientists and engineers with a wide range of interests made inquiries. There is more than a passive interest in satellite calibration performance and this is especially apparent when a problem arises, such as the crosstalk problem on MTSAT's shortwave channel that caused brightness temperature biases on the order of 10K. It is important for the satellite community to have lines of communication open between the various government(s), industry, and academic partners so that problems such as this can be discovered and addressed in a timely fashion.

The comparisons of these GEOs to AIRS show that the GEO instruments generally compare very well (within 1K) to AIRS and, vicariously, to each other in all bands where comparisons are feasible. They compare most favorably in the infrared window channel. Using a simple gap-filling technique they compare even more favorably and even compare well in the water vapor channel. The most similar comparisons (mean differences closest to 0 K) are for the GOES instruments, particularly GOES-10 and -12. The most consistent results in most channels (smallest standard deviation) are for Meteosat-8. Consistency may actually be a better measure of calibration accuracy and stability.

The results for the shortwave ( $\sim 3.9\mu\text{m}$ ) bands, sensitive to reflected solar radiation, show correlation between  $\Delta T_{\text{bb}}$  and time of comparison. The results are much more reliable at night, when neither instrument can be affected by incoming reflected solar radiation.

The results are highly dependent upon the accuracy of GEO SRF measurements and the presence (or lack thereof) of spectral gaps in the AIRS data. Spectral gaps in the AIRS data can be partially accounted for successfully by filling in artificial spectral data adjusted to fit the observed spectra. The most accurate comparisons would be made possible by having high spectral resolution data with no gaps in spectral coverage. Such an instrument is IASI with almost 8,000 channels (Amato et al, 1995).

Intercalibration with AIRS is a very powerful calibration tool as AIRS calibration is generally considered to be within 0.1K (Tobin et al. 2006a). The method devised and described herein to fill AIRS spectral gaps is still being developed and a comparison to the convolution correction method developed by Tobin et al. (2006b) will be part of future endeavors.

CIMSS intercalibrates geostationary instruments daily with NOAA-15 and -16 HIRS and AVHRR; time series plots and other information reside at:

<http://cimss.ssec.wisc.edu/goes/intercal>.

## 5. ACKNOWLEDGEMENTS

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