

ADDRESSING SPECTRAL GAPS WHEN USING AIRS FOR
INTERCALIBRATION OF OPERATIONAL GEOSTATIONARY IMAGERS

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1. INTRODUCTION

The ability to compare the measured radiances from different environmental satellite instruments has become increasingly important, as satellites traditionally used for weather monitoring have proven to be useful for a variety of weather, environmental, and climate applications. The Cooperative Institute for Meteorological Satellite Studies (CIMSS) has been intercalibrating the infrared window (IRW) and water vapor (WV) channels on geostationary satellites (GOES Imagers, METEOSAT, GMS-5) with a polar-orbiting satellite (NOAA HIRS and AVHRR) on a routine, automated basis using temporally and spatially collocated measurements. This paper presents early results on intercomparison of the geostationary instruments with high spectral resolution NASA AIRS (Atmospheric Infrared Sounder) data.

2. APPROACH

The intercalibration approach used has been described in prior AMS proceedings (Gunshor et al., 2001) and publications (Gunshor et al., 2004); it has been adapted for AIRS data. As before, requirements for intercal include collocation in space and time (within thirty minutes) within 10 degrees from nadir for each instrument 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 4 km in the east-west direction by a factor of 1.7, METEOSAT-5 and -7 have a nadir 5 km fov, and METEOSAT-8 has a nadir 3 km fov. Mean radiances are computed within the collocation area. Mean radiances are converted, via the inverse Planck function, into brightness temperatures and the temperature difference between the GEO and AIRS is calculated.

2.1 Advantage AIRS

The AIRS high spectral resolution data are convolved with the geostationary instrument's spectral response function (SRF). This mitigates the need for

the very difficult and error-prone correction for spectral response differences between two broadband instruments and has the considerable advantage of intercalibrating a broadband with data from a high spectral resolution instrument. After data are collected and collocated, AIRS data are convolved with the geo SRF and the resulting data then are 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 6. The AIRS instrument does not cover the entire spectral range 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 intercomparisons.

2.2 Filling The Spectral Gaps

For the most part, gaps in AIRS data are part of the instrument design. There are some small gaps due to bad detectors, which users can easily filter out with the relevant channel properties file (thus leaving a small gap). Small gaps from bad detectors do not noticeably affect comparison to a broadband instrument because relatively little information 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.

It is possible to obtain more accurate comparisons if the spectral gaps of the AIRS are filled. By filling the gaps with a calculated spectrum or a spectrum obtained via forward model calculations from atmospheric sounding, a more accurate comparison can be made. The initial undertaking, presented in this paper, has been to use an adjusted calculated spectrum, from the US Standard Atmosphere, for a few Meteosat-8 cases.

This method may not be the most sophisticated, but the results, discussed below, indicate that even this approximation represents an improvement in comparison skill (eg, a smaller difference between the various satellite measurements). 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

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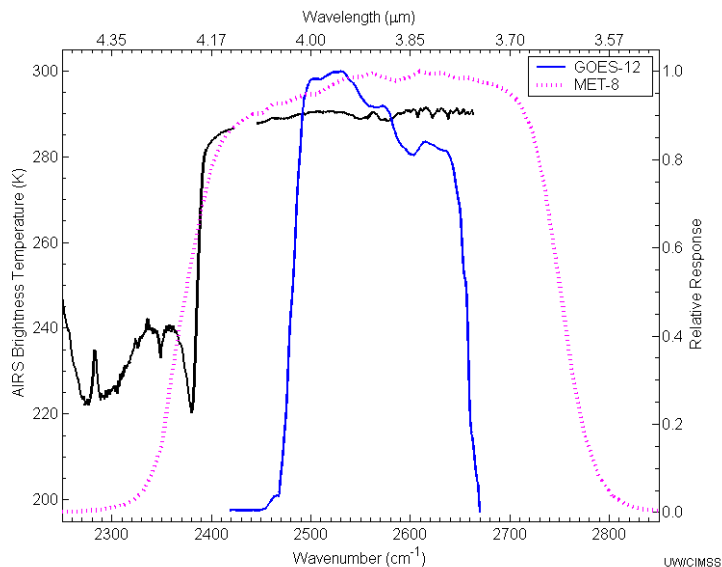


Figure 1. 3.9 μm band GOES-12 spectral response function plotted with representative AIRS brightness temperature spectrum. GOES-9 and GOES-10 have similar spectral coverage. Note that on the shortwave side, AIRS coverage ceases very close to the end of GOES spectral coverage but Meteosat-8 extends well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

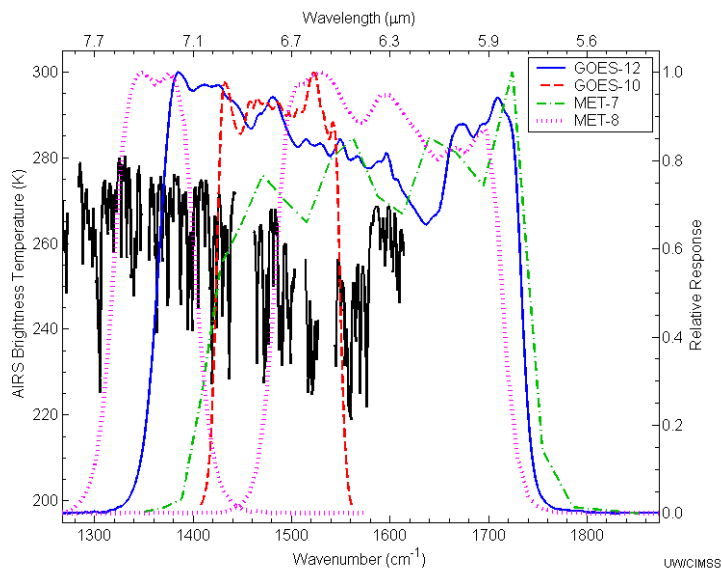


Figure 2. 6 to 7 μm band spectral response functions plotted with representative AIRS brightness temperature spectrum. GOES-9 has similar spectral coverage to GOES-10 and Meteosat-5 has similar spectral coverage to Meteosat-7. Unlike the other instruments, Meteosat-8 has a second band in this region. Note the large percentage of SRF not covered on the shortwave side by AIRS data for the wider responses of GOES-12 and Meteosat.

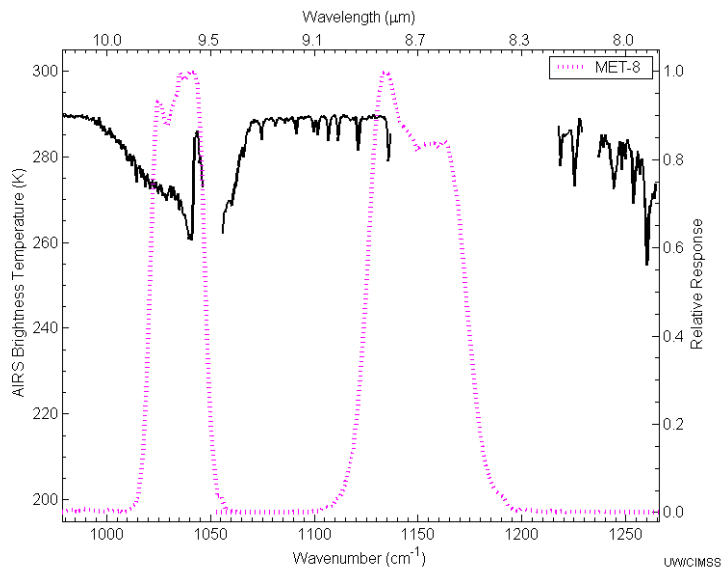


Figure 3. 8.7 and 9.7 μm band spectral response functions plotted with representative AIRS brightness temperature spectrum. Currently, Meteosat-8 is the only geostationary imager with coverage in this spectral region.

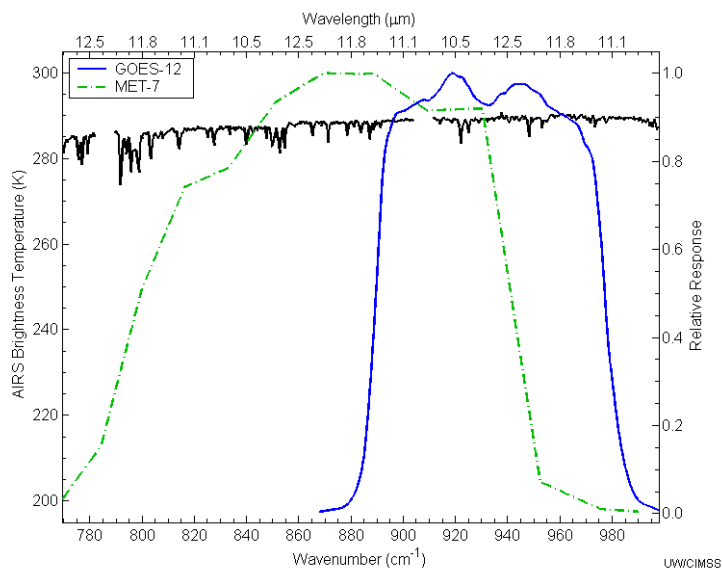


Figure 4. 11 μm band spectral response functions plotted with representative AIRS brightness temperature spectrum. GOES-9 and -10, as well as Meteosat-8, have similar spectral coverage to GOES-12 and Meteosat-5 has similar spectral coverage to Meteosat-7.

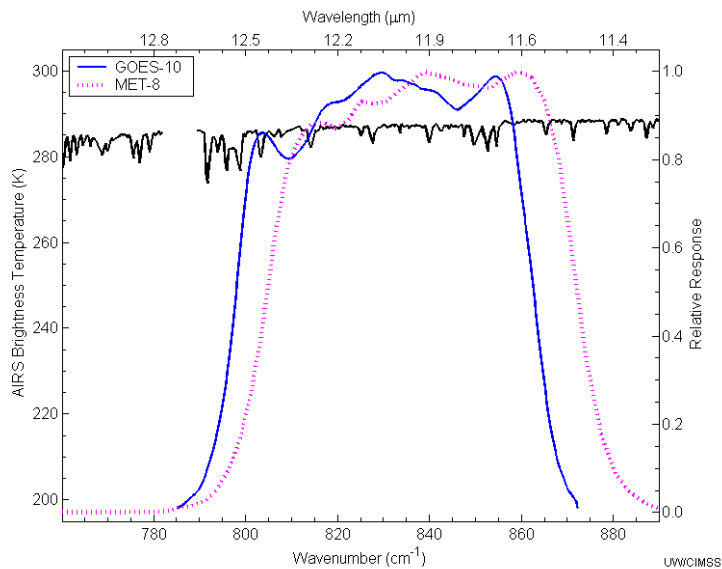


Figure 5. 12 μm band GOES-10 spectral response function plotted with representative AIRS brightness temperature spectrum. GOES-9 has similar spectral coverage to GOES-10.

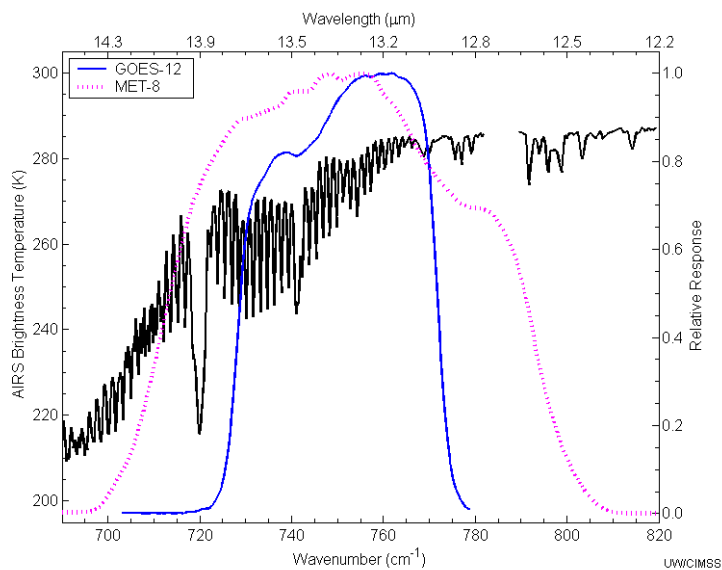


Figure 6. 13 μm band GOES-12 spectral response function plotted with representative AIRS brightness temperature spectrum.

weighted mean incrementally across the gap to the shortwave side, such that the shortwave endpoints also match (Allen Larar, personal communication).

Figure 7 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.

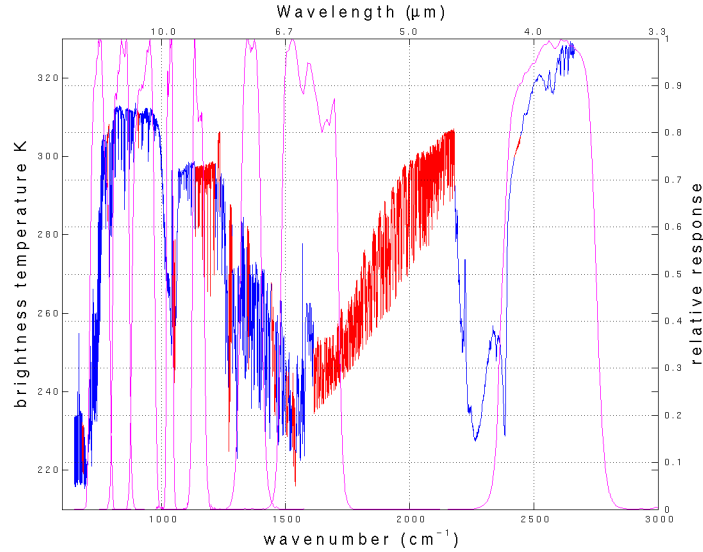


Figure 7. Meteosat-8 spectral response functions (magenta) plotted along with an AIRS sample spectrum (blue) with spectral gaps filled with the adjusted US Standard Atmosphere spectrum (red).

3. RESULTS

Presented first are results, excluding Meteosat-8, where spectral gaps have not been filled. Then the results for Meteosat-8 where gaps have been filled are presented.

3.1 Early results with spectral gaps

Intercalibration results for the geostationary satellites GOES-9, -10, -12, Meteosat-5, and -7 (between 21 January 2004 and 25 March 2004) using convolved AIRS data are shown in the tables below. In Table 2 there are much fewer comparisons for Meteosat-7 in the water vapor channel; this is due to a scheduling conflict and fewer images satisfy the temporal data collection requirement. The ΔT_{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. The standard deviation is the deviation about the mean. Differences for the infrared window bands are smaller, as was found in the broadband intercomparisons also (Gunshor et al., 2004). The results for the water vapor channels in Table 2 are, as expected, larger since the gaps in AIRS spectral coverage (Figure 2) account for most of the temperature differences. The effect is exacerbated for the wider channels on GOES-12 and Meteosat because a higher percentage of the SRF falls in the spectral gap. The results for the 3.9 μm bands 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 reliable. The GOES-12 13.3 μm band (not shown) was found to have a mean difference ΔT_{bb} of -0.75K and a standard deviation of 0.38K for 15 cases.

Geo:	GOES-9	GOES-10	GOES-12	MET-7	MET-5
N	14	16	15	14	16
ΔT_{bb} (K)	-0.6	-0.1	-0.1	-0.9	-1.9
STD (K)	1.0	0.4	0.6	0.4	0.6

Table 1. 11 μm band results. ΔT_{bb} (GEO minus AIRS) is the mean of N cases.

Geo:	GOES-9	GOES-10	GOES-12	MET-7	MET-5
N	14	16	15	6	16
ΔT_{bb} (K)	-1.3	-1.4	-9.9	-7.2	-9.3
STD (K)	0.4	0.2	0.5	0.5	2.4

Table 2. 6 μm band results. ΔT_{bb} (GEO minus AIRS) is the mean of N cases.

Geo:	GOES-9	GOES-10
N	14	16
ΔT_{bb} (K)	-0.5	0.3
STD(K)	1.0	0.3

Table 3. 12 μm band results. ΔT_{bb} (GEO minus AIRS) is the mean of N cases.

Geo:	GOES-9	GOES-10	GOES-12
N	8	16	14
N (Day)	7	11	8
N (Night)	1	5	6
ΔT_{bb} (K)	-1.0	-0.1	-0.6
ΔT_{bb} (K) (Day)	-1.2	-0.3	-1.1
ΔT_{bb} (K) (Night)	0.4	0.4	0.1
STD (K)	1.0	0.4	0.7
STD (K) (Day)	0.9	0.4	0.5
STD (K) (Night)	NA	0.2	0.3

Table 4. 3.9 μm band results. ΔT_{bb} (GEO minus AIRS) is the mean of N cases. Day and night are determined by local sunrise and sunset times.

3.2 METEOSAT-8 results with spectral gaps filled

There are eight infrared bands on the recently launched METEOSAT-8 ranging from the 3.9 to the 13.4 μm band (Schmetz, 2002). Comparisons to AIRS are most problematic for the 3.9, 6.2, and 8.7 μm due to the gaps in AIRS spectral coverage. For the 3.9 μm band, AIRS coverage does not extend far enough into the shortwave side of the band for an adequate comparison and the method mentioned above for filling the gap cannot be applied since there is no shortwave endpoint to meet (Figure 7). Thus no attempt is made at filling the spectral gap for the 3.9 μm band and comparisons in this channel are not an accurate representation of MET-8 calibration or capability. Similarly for the 8.7 μm and 6.2 μm MET-8 bands, most of the entire bandwidth falls within an AIRS spectral gap. While the gap can be filled, the comparisons in these channels are mostly between the MET-8 data and a calculated spectrum that's been adjusted to fit data outside of the MET-8 spectral bandwidth. The 8.7 μm band is nearly entirely within an AIRS spectral gap and the 6.2 μm band is more than 50% within the largest AIRS spectral gap on the shortwave side of the water vapor spectrum. For these reasons, filling the spectral gaps still does not produce a satisfactorily meaningful comparison, though an improvement is seen. For one case filling the gaps in the 6.2 μm band resulted in an improvement in the comparison (difference closer to 0) between convolved AIRS and MET-8 of approximately 5K. For the 8.7 μm band the improvement was approximately 0.7K.

The remaining infrared bands on MET-8 (7.3, 9.7, 10.8, 12.1, and 13.4 μm) either did not require AIRS spectral gaps to be filled or comparisons were improved by gaps being filled. The 10.8, 12.1, and 13.4 μm bands do not have significant gaps in AIRS coverage. Additionally, the radiance spectrum at 10.8 and 12.1 μm is relatively flat and thus the gap filling method is most likely applied most accurately here. The differences in the comparisons between AIRS and MET-8 in these bands were not significantly affected whether the spectral gaps were filled or not. In the 13.4 μm band the difference was very small, only 0.1K. The comparisons for the 7.3 and 9.7 μm bands showed that filling the gaps could improve the comparisons between AIRS and MET-8 by approximately 0.5K.

The mean brightness temperature differences between convolved AIRS (with spectral gaps filled by an adjusted calculated spectrum for the U.S. Standard Atmosphere) and MET-8 data are shown in Table 5. With the exception of the three bands with the most complicated spectral gap situations, MET-8 compares very well with AIRS; well within the specified radiometric calibration accuracy of 1K for the other bands.

4. DISCUSSION

Intercomparison of GEO and AIRS data finds that the GEO instruments generally compare most favorably in the infrared window channel. The best comparisons (differences closest to 0 K) in that channel are for the GOES instruments, particularly GOES-10 and -12.

MET-8 Band Number	Central Wavelength (μm)	N	ΔTbb (K)
4	4.2	6	2.5
5	6.2	3	3.2
6	7.3	8	0.2
7	8.7	8	1.2
8	9.7	8	0.3
9	10.8	8	0.5
10	12.1	8	0.6
11	13.4	8	0.5

Table 5. Mean of the differences between MET-8 and AIRS data. Bands 4, 5, and 7 are difficult to compare due to gaps in AIRS spectral coverage and these results should not be considered a reflection of MET-8 accuracy in those wavelengths. Cases (N) were in April and May of 2004.

The 3.9 μm band, sensitive to reflected solar radiation, shows correlation between ΔTbb and time of comparison. The correlation is strongest for GOES-12. The correlation for GOES-10 is not as strong, possibly due to the fact that the data was collected very close to sunrise and sunset times.

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 the IASI with almost 8000 channels (Amato et al, 1995).

5. CONCLUSIONS/FUTURE WORK

Intercalibration with AIRS is a very powerful calibration tool as AIRS calibration is generally considered to be very accurate. The method devised and described herein to fill AIRS spectral gaps is still being developed. For bands for which filling the spectral gap is useful, such as the 7.6 μm band on MET-8, it would be desirable to use spectra specific to the day/time/region being studied, as opposed to something generic such as the US Standard Atmosphere. Though preliminary calculations for one case study have shown very little difference between the results using the adjusted US Standard Atmosphere and the adjusted Standard Tropical Atmosphere. The authors plan to use AIRS retrieval or numerical weather prediction data to recreate the atmospheric spectrum, fill the gaps, and test whether there is any improvement in the calculation over using a standard atmosphere. Comparisons such as this are a useful beginning but confidence in radiometric calibration for these geostationary instruments would be better obtained with more cases.

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>.

6. ACKNOWLEDGEMENTS

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