Evaluation of AIRS, MODIS, and HIRS 11 micron brightness temperature difference changes from 2002 through 2006

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ABSTRACT

In an effort to validate the accuracy and stability of AIRS data at low scene temperatures (200-250 K range), we evaluated brightness temperatures at 11 microns with Aqua MODIS band 31 and HIRS/3 channel 8 for Antarctic granules between September 2002 and May 2006. We found excellent agreement with MODIS (at the 0.2 K level) over the full temperature range in data from early in the Aqua mission. However, in more recent data, starting in April 2005, we found a scene temperature dependence in MODIS-AIRS brightness temperature differences, with a discrepancy of 1-1.5 K at 200 K. The comparison between AIRS and HIRS/3 (channel 8) on NOAA 16 for the same time period yields excellent agreement. The cause and time dependence of the disagreement with MODIS is under evaluation, but the change was coincident with a change in the MODIS production software from collection 4 to 5.

AIRS and MODIS (Flight Model 1) are onboard the EOS Aqua spacecraft, launched into a 1:30 PM polar orbit on May 4, 2002. AIRS has 2378 infrared channels with high spectral resolution (1200) covering the 3.7 to 15.4 micron wavelength range, with a nominal spatial resolution of 13.5 km. MODIS has 36 relatively broad spectral bands with spatial resolution of 1 km for the LWIR bands. HIRS/3 is onboard NOAA-16 (L), launched into a 2:00 PM polar orbit on Sep. 21, 2000.

Keywords: AIRS, MODIS, HIRS, spectrometer, radiometer, validation

1. INTRODUCTION

Discussion of global temperatures at the 100 mK absolute level with changes at the 10-20 mK/year level[1] requires that the absolute accuracy and long tem stability of supporting climate data sets and their underlying instrumentation must be of at least this quality. While the capability to radiometrically validate at the 100 mK level has been demonstrated for individual instruments[2], doing so across multiple instruments and/or platforms is somewhat more problematic. In this paper, as part of a study to validate the accuracy and stability of AIRS data at low scene temperatures, we utilize Antarctic overpasses to provide a common cold reference for comparison of AIRS and MODIS, both on the Aqua platform, and AIRS and HIRS/3, the latter on NOAA-16 (L). The high spectral resolution of AIRS allows the synthesis of broader bandpass spectral response functions, while differences in spatial resolution can be handled by either matching footprint centers without regard to spatial resolution, by averaging higher resolution footprints to create equivalent coarser sized footprints, or utilizing a combination – i.e., averaging to an intermediate resolution, and matching up with somewhat coarser footprints. Additionally, spatial uniformity and/or scan angle match-up constraints can be applied – but we chose to apply no additional constraints beyond a nearness criterion. This relatively straightforward approach appears to work well, resulting in agreement at the 0.2 K level. It is expected that the approach could be extended to other instruments/platforms, such as MODIS on Terra, IASI, as well as the CrIS and VIIRS on the NPOESS platforms.

AIRS and MODIS (Flight Model 1) are onboard the EOS Aqua spacecraft, launched into a 1:30 PM polar orbit on May 4, 2002. AIRS has 2378 infrared channels with high spectral resolution (~1200) covering the 3.7 to 15.4 micron wavelength range, with a nominal spatial resolution of 13.5 km at nadir. MODIS has 36 relatively broad spectral bands with spatial resolution of 1 km for the LWIR bands. HIRS/3 is onboard NOAA-16 (L), launched into a 2:00 PM polar orbit on Sep. 21, 2000. It has 20 channels, with the IR channels having a spatial resolution of 19 km. The orbits of the

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NOAA polar orbiters are not maintained at a constant ascending node. Aqua-MODIS band 31 has a central wavelength of 11.03 microns and HIRS/3 channel 8 has a central wavelength of 11.11 microns, both with bandwidths on the order of 0.5 microns.

2. METHOD

Since AIRS and MODIS share the Aqua platform, the match-up process is greatly simplified – there is no need to search for simultaneous or nearest overpasses. We selected Antarctic winter granules whose scene content was as cold as possible, primarily from the set of AIRS "focus days", and then implemented a match-up process based solely on a nearness criterion of 0.75 surface degrees (~8 km). We chose not to apply spatial uniformity restrictions or scan angle restrictions, with the expectation that the resultant increased scatter of the comparison data would be offset by a more meaningful sample size. The MODIS 1 km radiance product provides corresponding latitude/longitude data at 5 km resolution – for simplicity's sake, we averaged the 1 km pixels to 5x5 km pixels prior to performing the match-up with the AIRS ~15 km pixels, resulting in ~9 matches of MODIS averaged pixels to each AIRS pixel. The resulting matches were then averaged to create a pixel spatially equivalent to the AIRS pixel. MODIS data used was collection 4 for 2004 and prior, and collection 5 for 2005 and beyond.

Since the orbits of the NOAA polar orbiters are not maintained at a constant ascending node, the HIRS-AIRS match-up process is somewhat more complicated. A given AIRS granule may have up to two overpasses which are "nearby" in time, and the time separation and ground track orientation with respect to Aqua varies with mission time. Other HIRS-AIRS only studies[3] have made use of orbital perturbation models to determine the occurrence of simultaneous nadir overpasses between Aqua and the NOAA orbiters, however, since our initial interest was the comparison of MODIS with AIRS, we were limited to searching for the closest overpasses to the Aqua granules we had already selected. A similar nearness criterion was used (0.7 surface degrees), resulting in one HIRS match for each AIRS footprint. For the HIRS-AIRS comparison, we also imposed the additional constraint that all match-ups must be over the Antarctic continent, as we observed a marked increase in scatter in the brightness temperature differences over ocean, attributable to increased cloudiness over the ocean where the temporal and orbit track differences have greater impact. As application of this constraint primarily affected scene temperatures of > 240 K, it did not adversely affect the number of lost samples for the scene temperatures of interest. This additional constraint was not necessary for the MODIS-AIRS comparison, i.e., good results were achieved with granules which had some ocean/cloud content.

In order to compare radiances/brightness temperatures between the high resolution AIRS channels and the broadband MODIS and HIRS channels, a means of synthesizing equivalent MODIS and HIRS channels has to be employed. Both AIRS, HIRS and MODIS data are available in units of flux density. Conceptually the most straightforward means of making this comparison would be to integrate the AIRS spectral radiances over the MODIS passband, then divide the result by the integral over the MODIS passband. Convolution approaches of this type have been employed[3,4], but such approaches encounter difficulties where the spectral coverage of AIRS is not continuous and the gap falls within the broader bandpass of a MODIS or HIRS channel, as is the case for MODIS band 31 and HIRS/3 channel 8. Tobin[4] applied a convolution correction while Ciren[3] chose to compare only bands for which there were no AIRS gaps present. We chose to express the MODIS flux density as a linear combination of AIRS channels selected from within the MODIS passband. The coefficients are trained using spectra from 48 climatologies at six slant paths. For the 11 micron broadband window channel, excellent results were obtained using four AIRS channels. The selected channels have frequencies of 900, 912.7, 881, and 891 wavenumbers. The first two are window channels with water continuum absorption of ~3K; the last two are centered on weak water absorption lines, with a total absorption of ~5 K.

3. RESULTS

The calibration of AIRS and MODIS has been established at better than the 0.1 K level for MODIS band 31, for one day means of uniform scenes for two test days, 20020906 and 20040218[4]. Figure 1 shows an initial look at brightness temperature differences (MODIS band 31 – AIRS derived band 31 equivalent) vs. AIRS brightness temperature, using our comparison approach for mid-Atlantic ocean granule 176. This is a very cloudy scene with a great deal of structure, resulting in increased differences in areas of high gradient, nevertheless, the comparison looks very good down to the 200-210 K level; there is a very small bias and a small slope. MODIS b31 is 0.3 K warmer than AIRS at a scene temperature of 200 K, 0.1K colder at a scene temperature of 300 K.

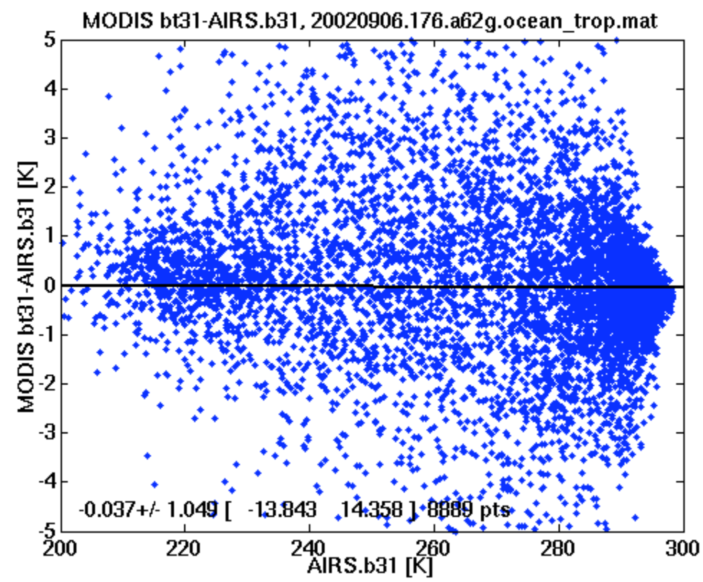

Fig. 1. Brightness temperature difference (MODIS band 31 – AIRS derived band 31 equivalent) vs. AIRS brightness temperature for mid-Atlantic ocean granule 176 on Sept. 6, 2002. There is a small bias of -0.04 K with a small slope. MODIS is warmer than the AIRS equivalent by 0.3 K at a scene temperature of 200 K, and 0.1 K colder at 300 K.

Figure 2 shows brightness temperature differences for Antarctic granule 72. There is relatively little scatter for this cold, dry granule, with little slope; the offset at 200 K is 0.2 K.

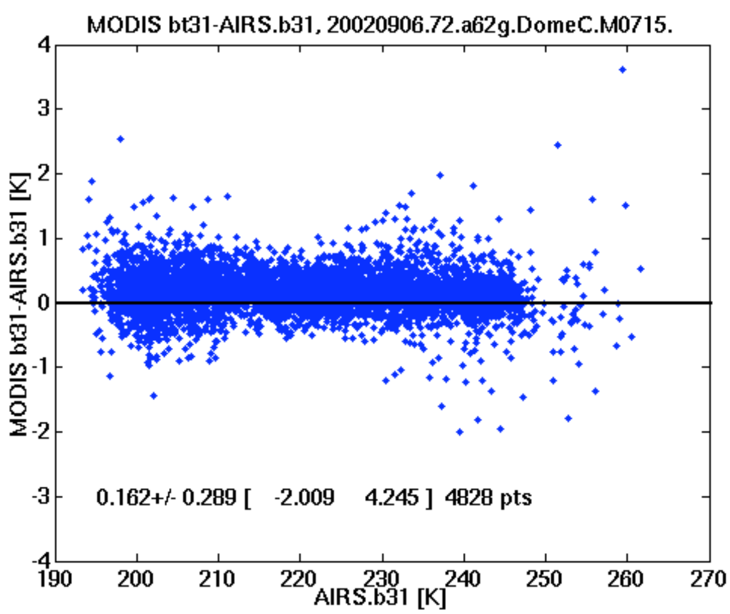

Fig. 2. Brightness temperature difference (MODIS band 31 – AIRS derived band 31 equivalent) vs. AIRS brightness temperature for Antarctic granule 72, also on Sept. 6, 2002. The offset at 200 K is 0.2 K.

Figure 3 shows a look at a more recent granule, the 1:30 PM New Orleans overpass of hurricane Katrina from 20050829 (AIRS granule 192). This granule looks much more complicated, with little offset between 250 and 300 K. The overlying curve is a quadratic fit to the data. At 200 K, MODIS band 31 is about 1.1 K warmer than the AIRS equivalent.

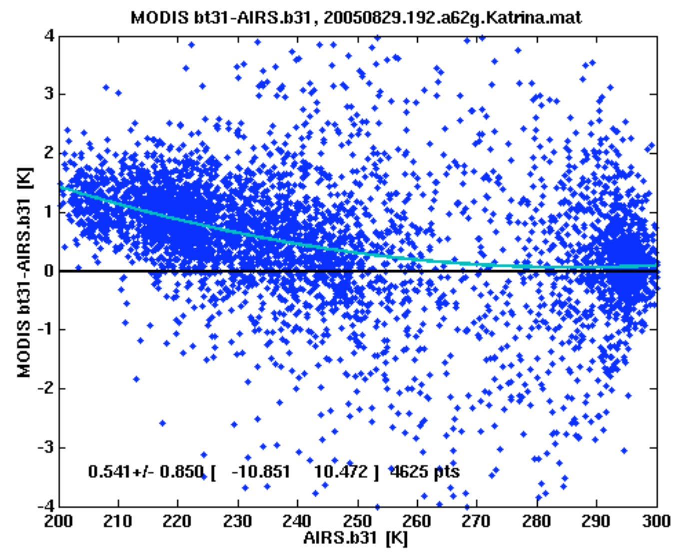

Fig. 3. Brightness temperature difference (MODIS band 31 – AIRS derived band 31 equivalent) vs. AIRS brightness temperature for hurricane Katrina granule 192 on Aug. 29, 2005. At 200 K, MODIS band 31 is about 1.1 K warmer than the AIRS equivalent.

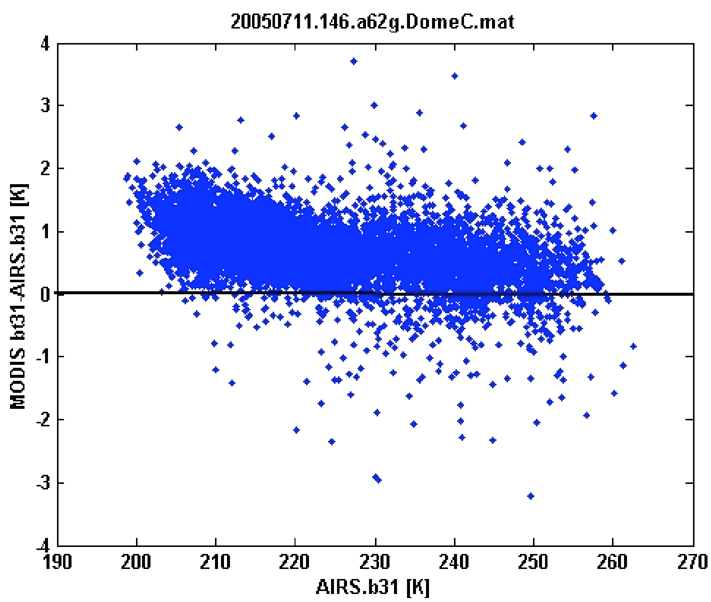

Fig. 4. Brightness temperature difference (MODIS band 31 – AIRS derived band 31 equivalent) vs. AIRS brightness temperature for Antarctic granule 146 on July 11, 2005. At 200 K, MODIS band 31 is also 1.1 K warmer than the AIRS equivalent.

Figure 4 confirms the offset for an Antarctic granule on 20050711, which also shows an offset of 1.1 K at 200 K. Therefore a change occurred between September of 2002 and July of 2005. We then expanded the data set to see if there was a systematic difference, or if this was a result of instability or uncertainty in the method. In order to develop a reliable trend point, only Antarctic granules which had a significant number of match-ups at or near to scene temperatures of 200 K were included, resulting in a data set with gaps during the Antarctic summer months. The offset at 200 K was determined by a linear fit to the data. The trend of this offset is shown in Figure 5. A shift of ~1 K occurs during the Antarctic summer of 2004/2005. HIRS-AIRS comparisons were made for selected granules of interest along the timeline and overlaid on the same plot. In the case of HIRS-AIRS, the mean difference for the data set is overlaid – this is reasonable since the comparison in this instance is flat as a function of scene temperature (not shown). Prior to the offset change, MODIS-AIRS agreed to within 0.2 K +/- 0.2 K. After the level change, the agreement is 1.1 +/- 0.2 K. The HIRS-AIRS difference appears to be steady also at about 0.2 K +/- 0.2 K. The gaps during the Antarctic summers are a limitation which can potentially be overcome by trending deep convective clouds, which provide about 6000 data points per day for AIRS[5], with temperatures of ~200 K at 11 microns. However, this approach has not been tested, and is likely only viable for same-satellite comparisons, as inter-satellite comparisons would likely suffer from the same increased scatter in cloudy scenes experienced in making the HIRS-AIRS comparison.

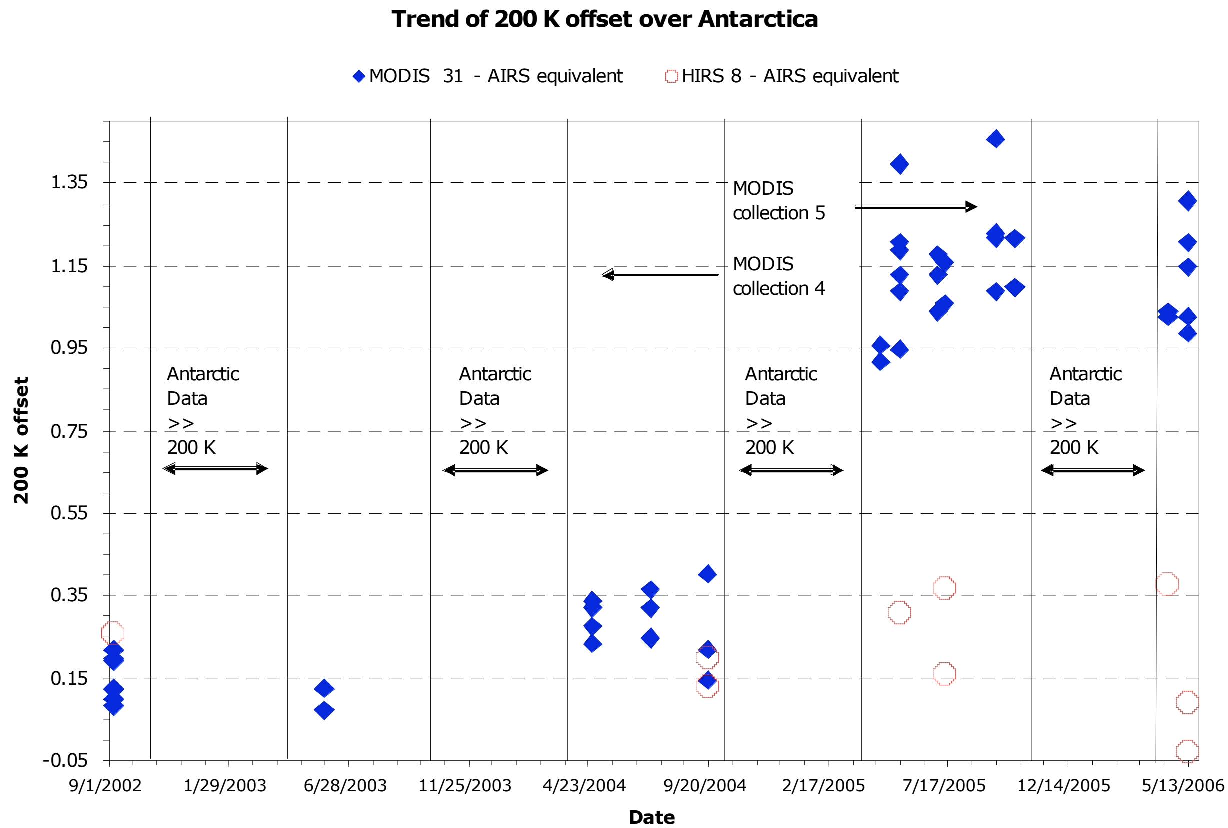

Fig. 5. Trend plot of the 200 K offset of brightness temperature differences (MODIS band 31 – AIRS derived band 31 equivalent) and (HIRS/3 channel 8 – AIRS derived ch. 8 equivalent) from 20020906 to 20060511.

5. DISCUSSION

We draw three conclusions from the above results:

1) that when restricting our attention to Antarctic land regions and using a linear combination of the higher spectral resolution AIRS channels to make equivalent channels for broader band radiometers, brightness temperature comparisons are achievable at the 200 mK level, without taking into consideration whether the footprints are clear or cloudy, even for a cross-platform comparison. For the HIRS-AIRS cross-platform comparison, the temporal separation between overpasses were up to 50 minutes.

2) the 200 mK level of sensitivity achievable with this approach is at the threshold of being useful in validating climate data sets. Discussion of global temperatures at the 100 mK absolute level with changes at the 10-20 mK/year level[1] requires that the absolute accuracy and long term stability of supporting climate data sets and their underlying instrumentation must be of at least this quality. In principle, the calibration can be transferred between platforms using one year of overlapping data. If a bias is observed during the one year overlap period, it is unlikely that it can be measured to better than 10% of the bias. Assuming a 5 year instrument life, the spread of the uncertainty or error in the bias correction produces a slope uncertainty of the bias error divided by five. If the bias was 200 mK, as was determined in the analysis presented above for the 2002-2004 period, the bias uncertainty is 20 mK, and the resulting false trend is 4

mK/year. This result would allow measurement stability competitive with the 10-20 mK/year global warming trends being discussed.

3) the method is useful as a measure of stability, sensitive enough to detect subtle changes in instrument performance, calibration, or data product generation software. With regards to the change in MODIS-AIRS brightness temperature differences, a 1 K shift for scene temperatures of 200 K is seen between late ’04 and early ’05. In trying to understand the cause of the shift, we first questioned the validity of the approach of creating the MODIS and HIRS equivalent flux density using a linear combination of selected AIRS channels. The initial excellent agreement with MODIS and the stability of the HIRS-AIRS differences for the time period under evaluation tend to rule out a procedural error and a change in AIRS.

Radiometric validation at 200 K is difficult. The MODIS specifications required radiometric performance requirements to be met over the range 0.3 Ltyp (typical radiance) to 0.9 Lmax (maximum radiance). While 0.3 Ltyp is about 235 K for band 31, well above the 200 K point of interest of this study, the preflight characterization was performed down to temperatures of 170 K. At the lower temperatures the calibration residuals, though larger, were still a fraction of a percent. For MODIS band 31 and HIRS/3 channel 8, a 1 K shift at 200 K corresponds to a 3% shift in the radiance, which is large in comparison to the MODIS preflight calibration residuals. A number of possible causes for the difference come to mind. Since the radiance at 200 K is weighted towards to longwave cuton of the bandpass filter, a change in MODIS band 31 response is one possibility. The effective MODIS band 31 response is from the convolution of the filter response function with the detector response function. Both are temperature sensitive. However, the preliminary evaluation of the MODIS telemetry shows no indication for such an abrupt change. The fact that the shift decreases at higher scene temperatures to below 0.2 K at 260 K indicates that we are dealing with a shift in the zero point (offset error). The in-flight calibration coefficients were updated from the pre-flight cal coefficients based on in-flight on-board blackbody warmup/cooldowns over the temperature range of 270-315 K, which has the potential to affect the calibration at temperatures beyond this range, but the coefficients have not been changed since late ’02. However, the pre-shift data set is entirely based on MODIS collection 4, while the post-shift data set is entirely based on collection 5, which seems to indicate the change lies with the different product generation software versions. While there were indications that the shift may have started occurring in late ’04, the scene temperatures were >> 200 K, and it can not be determined from the examination of the Antarctic granules. Ultimately, further analysis is required, both into the calibration coefficients and as to whether there are significant V4//V5 differences. The MODIS Characterization Support Team (MCST) is currently performing an analysis to examine and characterize calibration differences between the V4 and V5 calibration coefficient look-up tables at low temperatures, which may assist with the understanding of the differences.

6. SUMMARY

A method of inter-instrument, cross-platform calibration/validation at the stressing calibration point of 200 K using Antarctic scenes appears viable to the 0.2 K level, which is at the threshold level required to perform climate studies. When limiting comparisons to the Antarctic continent, no constraints other than a nearness criterion were required for either same-platform comparisons (MODIS-AIRS) or for cross-platform comparisons (HIRS-AIRS), when the nearest overpass in time was selected. The high spectral resolution of AIRS allowed the synthesis of broader bandpass spectral response functions such as those of MODIS and HIRS via a linear combination of selected AIRS channels. It is expected the approach used could be extended to other instruments/platforms, such as MODIS on Terra, IASI, as well as the CrIS and VIIRS on the NPOESS platforms.

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