Using AIRS and IASI data to evaluate absolute radiometric accuracy and stability for climate applications[1]

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Abstract

The creation of multi-decadal data sets for climate research requires better than 100 mK absolute calibration accuracy for the full range of spectral temperatures encountered under global conditions. Validation that this accuracy is achieved by the operational hyperspectral sounders from polar orbit is facilitated by comparing data from two instruments. Extreme radiometric calibration stability is critical to allow a long time series of noisy, but presumably long-term accurate truth measurements to be used for the validation of absolute accuracy at the 100 mK level. We use the RTGSST in the tropical oceans as ground truth. The difference between the AIRS derived sst2616 and the RTGSST based on six years of data shows a systematic cold bias of about 250 mK, but better than 4 mK/year stability. The double difference between AIRS and the RTGSST and IASI and the RTGSST with less than one year of data already allows statements at the 100 mK absolute level. It shows a 60 mK difference between the AIRS and the IASI calibration at 2616 cm^{-1} and 300 K, with a statistically insignificant 20 mK shift in six months.

Keyword list: Hyperspectral, infrared, polar orbiter, EOS Aqua, Metop-A, calibration

Introduction

Data from hyperspectral sounders have the potential of providing great insight into the response of the Earth Climate System to changes due to variations in the solar output or the increase in the CO2 level. Changes in these quantities are on a multi-decadal scale with a nominal trend of 100 mK/decade [1], but considerably larger inter-annual variability. Significant statements of change relative to 100 mK /decade anticipated changes requires absolute calibration at the 30 mK level. Changes on this amplitude scale can be measured reliably during the lifetime of a single instrument, but the nominal lifespan of any one instrument may only be five years. The creation of a climate quality record to measure changes on a longer time scale requires the combination of data from a sequence of hyperspectral instruments. Even if an instrument could be designed to achieve NIST traceable absolute accuracy at the 30 mK level, and even if this accuracy was demonstrated during pre-launch testing, the harsh environment in orbit require that this accuracy by validated throughout the life of an instrument. Validation of the absolute radiometric accuracy is made somewhat easier if there is a one year or more overlap between an instruments of established accuracy and stability with the next instrument in a sequence. This allows a statement about relative accuracy and relative stability during the overlap period. We evaluate the potential of relative calibration evaluation using data from the Atmospheric Infrared Sounder (AIRS, [2]) and the Infared Atmospheric Sounder Interferometer (IASI, [3]). AIRS was launched in May 2002 on the EOS Aqua spacecraft into a 705 km altitude sun-synchronous polar orbit with a 1:30 PM ascending node. IASI was launched in October 2006 on Metop-A into a 825 km altitude sun-synchronous polar orbit with a 9:30 AM ascending node.

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Approach

The direct validation of the absolute radiometric accuracy at the 30 mK level with an instrument in Earth orbit requires even better absolute accuracy for the ground-truth and an extremely accurate correction for atmospheric absorption. If the radiometric performance of the instrument is extremely stable, then a long time series of measurements can be used to validate that absolute accuracy at this level is actually achieved. For AIRS we have used the Real Time Global SST (RTGSST) from NCEP [4] to monitor the absolute calibration accuracy using the 2616 cm^{-1} atmospheric window region [5]. The sst2616 is based on the observed brightness temperature at 2616 cm-1, corrected for atmospheric water vapor transmission effects (typically 0.25 K), surface skin effect (0.17 K based on Donlon et al 2002 [6], diurnal offset effect (0.12K for the 1:30 AM night overpass based on Kennedy et al. 2007 [7] and emissivity effects (typically 0.5 K) using the Masuda 1988 sea surface emissivity [8]. Additional insight into the accuracy of the radiometric calibration, which requires less time, can be obtained using a double difference: We use IASI data to create an sst2616.iasi and compare the result with the RTGSST. The stt2616.iasi were generated conceptually the same way as AIRS, but with a 0.01 K correction for the 9:30 PM overpass. Unlike for AIRS, which uses the window channel at 2616.3 cm^{-1} and the 2607.7 cm^{-1} water vapor channel , the IASI noise is very high in the 2616 cm^{-1} region. By averaging 93 good window channels and 43 good water vapor channels in the 2600-2650 cm^{-1} region a good sst2616.iasi can be derived. The AIRS and IASI data were selected with a cloud screening filter which uses the spatial coherence of the 3x3 footprints for AIRS and 2x2 footprints from IASI in a 45 km diameter . The thresholds for the filters were set to yield about a 1% clear fraction for the tropical night ocean data. AIRS and IASI are in different orbit and clouds change, but the double difference (sst2616.airs-rtgsst)-(sst2616.iasi-rtgsst) under strictly clear conditions allows a direct daily comparison of the AIRS and IASI radiometric accuracy at 2616 cm^{-1}. The potential error in the RTGSST and common uncertainties in the cloud filtering, skin effect, diurnal correction, emissivity correction and transmission correction largely cancel in the double difference.

Results

Figure 1 shows the mean and stdev of (sst2616-rtgsst) for the 2616 cm^{-1} for the 0-30N tropical oceans for the first six years of AIRS data. Under strictly clear nighttime conditions, the sst2616 tracks the RTGSST with a typical cold bias of 0.25 K and stdev of 0.4 K. The six year trend in the data is only 2.2 mK/year with a one sigma uncertainty of 2 mK/year, i.e. any trend in the AIRS data has a 4 mK/year upper limit.

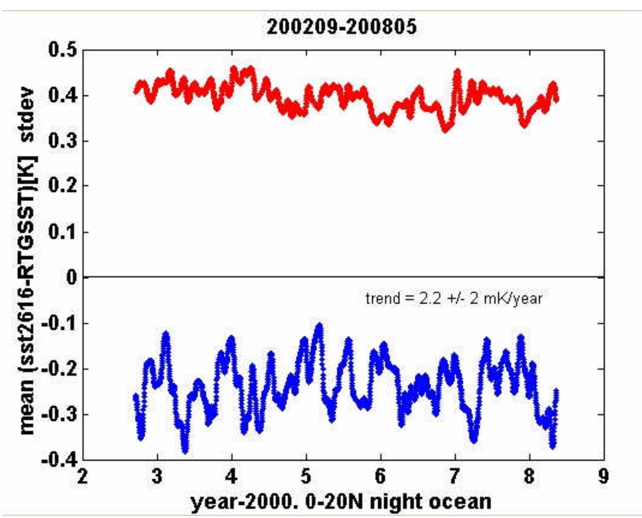

Figure 1. AIRS sst2616-RTGSST. Data from each day create one mean and standard deviation of about 2500 matchups of sst2616 with the RTGSST under strictly cloud-free conditions. The resulting time sequence was passed through a 16 day filter to smooth out the effect of the 16 day orbit repeat cycle of the EOS Aqua spacecraft.

We tested the double difference method for IASI and AIRS data with 90 days of data from May-July 2007, the first three months of routine IASI data availability and 90 days of data from November 2007-January 2008. Data from IASI now exists through July 2008, but the analysis was not ready for this paper. The result is shown in Figure 2, for AIRS as the blue circles, for IASI as the red crosses. Each data point is the is the mean of about 5000 points from each day for 180 days, and thus represents a statistically very strong data set.

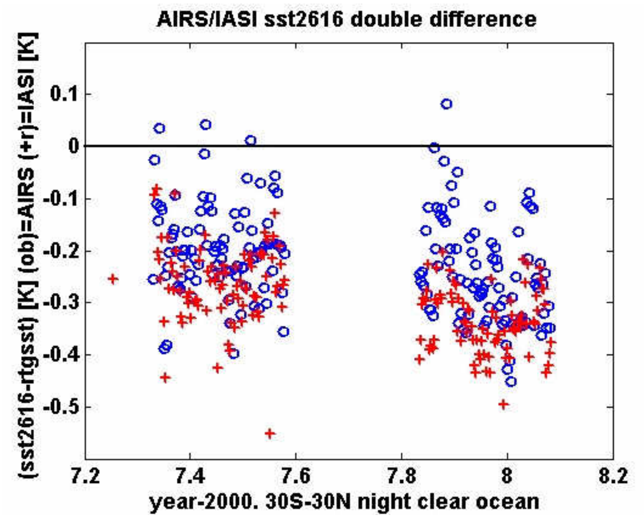

Figure 2. The sst2616 from AIRS (blue circles) and the sst2616 from IASI (red crosses) show a high degree of correlation. Seasonally variable cloud leaks or RTGSST artifacts are highly suppressed by the double difference, if the sst calculations and the cloud filtering are done consistently.

Results of the double difference are summarized in Table 1.

	AIRS - RTGSST	IASI - RTGSST	AIRS - IASI
May, June, July 2007	-0.201 ± 0.008 K	-0.263± 0.008	
Nov, Dec 2007, Jan 2008	-0.262 ± 0.011 K	-0.344± 0.008	
Seasonal difference	0.061 ± 0.014 K	0.081 ± 0.008 K	20 ± 16 mK

Table 1. Summary of the AIRS-RTGSST and IASI-RTGSST bias for two three month time periods. The stated one sigma uncertainty of the mean for each data set. The 20 mK shift between the IASI and AIRS results is not statistically significant.

Discussion

Inspection of Figure 1 shows that (sst2616-rtgsst) has a cold bias of about 0.25 K and is not random, but has a peak-to-peak modulation in the bias of about 0.2 K with indications of an annual pattern. In spite of this variability we can deduce a very significant lack of a long term trend in (sst2616-rtgsst): The six year trend in the data is only 2.2 mK/year with a one sigma uncertainty of 2 mK/year, i.e. any trend in the AIRS data has a 4 mK/year upper limit. This figure shows the criticality of the need for extreme radiometric stability to make measure stability relative to truth sources which are accurate, but less than perfectly stable. Since the sst2616 is the measurement of the sst and the RTGSST represents the sst based on buoy and ship reports, the bias and the annual modulation in the difference need to be explained. An analysis of the cold bias as function of the reflected radiance from the AIRS visible light sensor was used to show that the cold bias is explained within 30 mK by a residual cloud leak into the presumed to be cloud free data [5].

There are three potential reasons for the annual modulation of the bias: 1) the annual variation in the solar beta angle, which causes the AIRS external temperatures to annually fluctuate by about 4 K, causes a change in the optical alignment. 2) there is a seasonally variable component in the RTGSST algorithm's input data set and 3) there is a seasonally variable cloud leak in the cloud detection algorithm. Since the temperatures of the AIRS optical bench and detectors are actively regulated within 100 mK, the first explanation is not likely correct.

There is a cold bias in AIRS-RTGSST of about 200 mK, 60 mK smaller than the cold bias of IASI-RTGSST. On AIRS we have used data from the AIRS visible light sensor to show that this cold bias is due to residual cloud contamination in the presumed to be cloud free data. The calibration difference of 60 mK at 2616 cm^{-1} between IASI and AIRS is very small.

The bias from IASI and AIRS relative to the RTGSST shows a high degree of correlation. As a simple metric of this correlation we take the differences between the first and second 90 day data period, as shown in Table 1. The cold bias for AIRS increased by 61 mK, while the cold bias for IASI increased by 81 mK. Since the stability of the AIRS data at 2616 cm^{-1} were established at the better than 4 mK/year level, the 61 mK shift is an artifact of the RTGSST. The double difference reveals a shift of 20 mK in the IASI data which is statistically not significant.

From the viewpoint of climate quality validation it is interesting to note that the double difference method of comparing an instrument with long-term established calibration accuracy and stability (AIRS) with another instrument (IASI) allows distinctions at the 20 mK level with less than one year of data. Analysis of the full first year data overlap between IASI and AIRS is in progress, but was not ready in time for this paper. While the data selected were from the tropical oceans, i.e. at about 299 K, the method can be extended with the RTGSST to cover the 275-305 K range. There are obvious extensions to this method using other transfer standards. Currently under evaluation are IASI AIRS double differences using the surface temperature reported every six minutes by an Automatic Weather Station (AWS) on Dome Charlie in Antarctica. This data covers the 200-260 K temperature range. Validation of the 240-260 K brightness temperature region is particularly important for climate applications, since this temperature range is typical of the Earth seen from space.

Conclusion

The creation of multi-decadal data sets for climate research requires better than 100 mK absolute calibration accuracy for the full range of spectral temperatures encountered under global conditions. Validation that this accuracy is achieved by the operational hyperspectral sounders from polar orbit is facilitated by comparing data from two instruments in orbit. Extreme radiometric calibration stability is critical to enable use of a long time series of noisy, but presumably long-term accurate truth measurements for the validation of absolute accuracy at the 100 mK level. We use the RTGSST in the tropical oceans as ground truth. The difference between the AIRS derived sst2616 and the RTGSST based on six years of data shows a systematic cold bias of about 250 mK, but better than 4 mK/year stability. The double difference between AIRS and the RTGSST and IASI and the RTGSST with less than one year of data already allows statements at the 100 mK absolute level. It shows a 60 mK difference between the AIRS and the IASI calibration at 2616 cm^{-1} and 300 K brightness temperature, with a statistically insignificant 20 mK shiftin six months.

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