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Inter-comparison of Geostationary Observations with AIRS and IASI

In response to CGMS Action 36.13 (GSICS GPRCs should compare geostationary observations with both AIRS and IASI to demonstrate consistency and relative stability of AIRS and IASI.

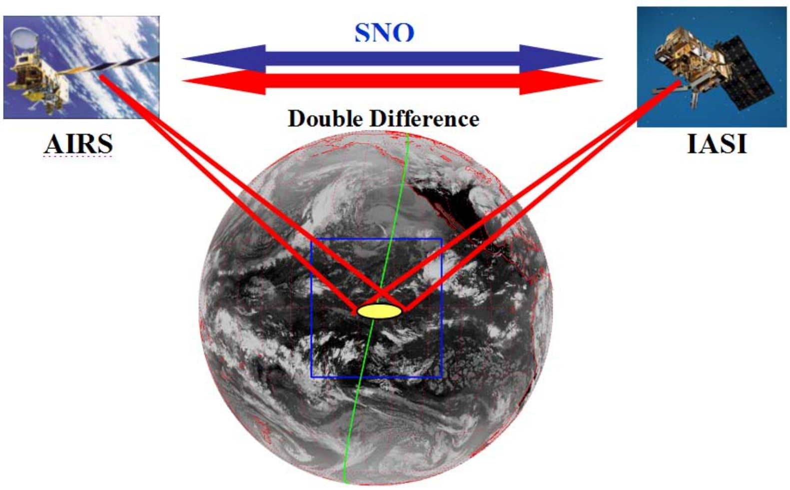
Summary of the Working Paper

During CGMS 36 it was recommended (i.e., Recommendation 36.13) that “GSICS GPRCs should compare geostationary observations with both AIRS and IASI to demonstrate consistency and relative stability of AIRS and IASI”. This report summarizes the efforts of using GSICS inter-calibration results to assess the consistency and relative stability of AIRS and IASI with the GOES instrument spectral coverage.

Inter-comparison of Geostationary Observations with AIRS and IASI

1 Introduction

In November 2007, a working paper NOAA-WP-12 was submitted to the 36th CGMS meeting at Gran Canaria, Spain, in response to CGMS Recommendation 35.04 (Satellite operators to explain significant discrepancies in satellite inter-calibration as part of their contribution to Global Space-based Inter-calibration System (GSICS)). This paper demonstrated the use of routine inter-calibration of GOES imagers with Infrared Atmospheric Sounding Interferometer (IASI) and Atmospheric Infrared Sounder (AIRS) to monitor the performance of geostationary instruments. It was noted that the GOES long-term performance is not stable, but changes over time. The paper showed the importance of GSICS to take the next step for making corrections to GOES for climate and weather applications. More important, the paper noted that, by comparing GOES with both IASI and AIRS, one can assess the relative stability of AIRS versus IASI at GOES spectral resolution, which is a powerful new approach for assessing the relative stability of both AIRS and IASI. All the CGMS members come to a recommendation that “all GSICS GPRCs should compare geostationary observations with both AIRS and IASI to demonstrate consistency and relative stability of AIRS and IASI.” In the present paper, an inter-comparison of AIRS and IASI with GOES imagers to assess consistency and relative stability of AIRS and IASI is presented to response this recommendation.



2 Background

Figure 1 Illustration of GSICS inter-calibration strategy.

Under the GSICS project within the World Meteorological Organization (WMO) Space Programme, the inter-calibration of geostationary imager infrared channels using AIRS and IASI are routinely performed at the Center for Satellite Applications and Research (STAR) of the National Environmental Satellite, Data and Information Service (NESDIS) in the National Oceanic and Atmospheric Administration (NOAA). This GISCS strategy is illustrated as a three-way comparison in Figure 1, which allows the inter-calibration to be cross-validated through a different pair of instruments and thus facilitate the analysis for bias root causes.

Specifically, the convolved AIRS and IASI radiances are compared with the geostationary imager radiance measurements using common spatial and temporal collocation criteria. Ideally, if IASI and AIRS are perfectly calibrated and consistent to each other, they should characterize the calibration bias of a stable geostationary imager exactly in the same way. Consequently, the difference between AIRS and IASI radiance bias relative to a given geostationary imager should be close a zero level regardless of the calibration bias of geostationary imager. In other words, in addition to evaluating the calibration accuracy of geostationary imager infrared channels, the GSICS inter-calibration results can be used to indirectly compare AIRS and IASI in the spectral channels of geostationary imagers through a double difference method, in which the geostationary imagers are played as transfer radiometers (indicated by the blue arrow in Figure 1).

More important, this approach, though it is limited the stability of transfer targets (e.g., transfer radiometers), has the advantage of being able to extend the comparison beyond the polar region to different climate regimes (e.g., warm tropical scenes) through an appropriate transfer target, thus complementing the simultaneously nadir overpass (SNO) method.

3 Methodology

Three major steps are involved for the inter-comparison of AIRS and IASI radiance using geostationary imagers as transfer radiometers, including 1) spectral convolution; 2) spatial and temporal collocation for AIRS/IASI and GOES Imagers observations; and 3) statistical calculations. These three steps are described in this section.

3.1 Spectral convolution

The objective of spectral convolution is to integrate the hyperspectral radiance spectrum to match the broadband GOES Imager SRF and make it comparable with the GOES Imager observations. Given the hyperspectral radiance *R(ν)* at each wavenumber *ν*, it can be convolved with the GOES Imager SRF *S(ν)* to generate the IASI- or AIRS-simulated GOES imager water vapor channel radiance L as

$$L = \frac{\int_{\nu_1}^{\nu_2} R(\nu)S(\nu)d\nu}{\int_{\nu_1}^{\nu_2} S(\nu)d\nu} \qquad (1)$$

where ν_1 and ν_2 are band pass limits.

3.2 Spatial and temporal collocation

In the second step, the AIRS and IASI measurements are collocated to the GOES observations in space, time, and view geometry. The strategy is to find the geostationary satellite measurements that fall inside the pixels of the polar orbiting satellites by minimizing the observation time and view geometry difference. First, the time difference between IASI/AIRS and geostationary observations is required to be less than 300 seconds in this study. Second, the relative difference between the secant of the two zenith angles from geostationary and polar orbiting satellites is set less than 0.01, which is expressed as */cos(geo_zen)/cos(leo_zen)-1/*, where *geo_zen* and *leo_zen* represent the view zenith angles of geostationary and polar orbiting satellites. Thirdly, a uniform environment surrounding the collocated measurements is chosen to compensate for minor violations of collocation and concurrence criteria

3.3 Statistical calculation

For each collocated AIRS/IASI-GOES FOV, the brightness temperatures (BTs) are computed from the IASI/AIRS-convolved radiance and the mean GOES radiance, respectively. The BT differences between AIRS/IASI and the GOES Imager are derived. Given hundreds of collocations for each day, the mean BT difference is calculated, which represents the GOES observation bias relative to AIRS and IASI. The double-differences between the AIRS and IASI radiances relative to the GOES imagers in term of BT is defined as,

$$\Delta T = < BT_{GEOS} - BT_{AIRS} >_{mean} - < BT_{GEOS} - BT_{IASI} >_{mean}, \qquad (2)$$

where, BT_{AIRS}, BT_{IASI}, and BT_{GOES} are the BT values from AIRS, IASI, and the GOES Imagers for one collocation pairs. Note that the subscript of "mean" indicates an average over a day. In order to cancel out the impacts of the transfer radiometers, the transfer radiometer must be stable during the AIRS/IASI-GOES collocation. Thus, only day-time data are used to avoid midnight blackbody effects.

4 Inter-calibration capabilities

The first example begins with GOES-12 Channel 6 (13.3 µm), shown in Figure 2. The time series plot of GOES-AIRS BT difference (indicated by the red dots) depicts a sudden change around 2 July 2007 (jump from ~-2.5 K to ~-1.0 K). After that, the BT difference remained relatively const (~-1.0 K) for a while, and then began to gradually decrease after April 2008. The comparison of these two sensors cannot alone determine which instrument, either AIRS or GOES-12 Imager, caused the cold bias. In other words, additional information is needed to identify the root cause of the bias. The GOES and IASI inter-calibration (represented by the blue dots) time series indicate the same features, which confirms that this cold bias is caused by the GOES-12 Imager. A further investigation indicates that the GOES-12 Imager experienced a decontamination procedure from 2 July to 4 July 2007, where certain internal components were warmed up in an attempt to drive off contaminants (mainly water ice). This instrument change apparently impacted the GOES-12 calibration accuracy, which was confirmed by both IASI and AIRS. It is particularly interesting that the double difference time series (shown in by the black dots in Figure 2) removes the sudden change and the later gradual decrease of bias, and remains constant during the whole time period. This suggests the excellent calibration of IASI and AIRS because both can track well the GOES Imager calibration bias in spite of the sudden or gradual change.

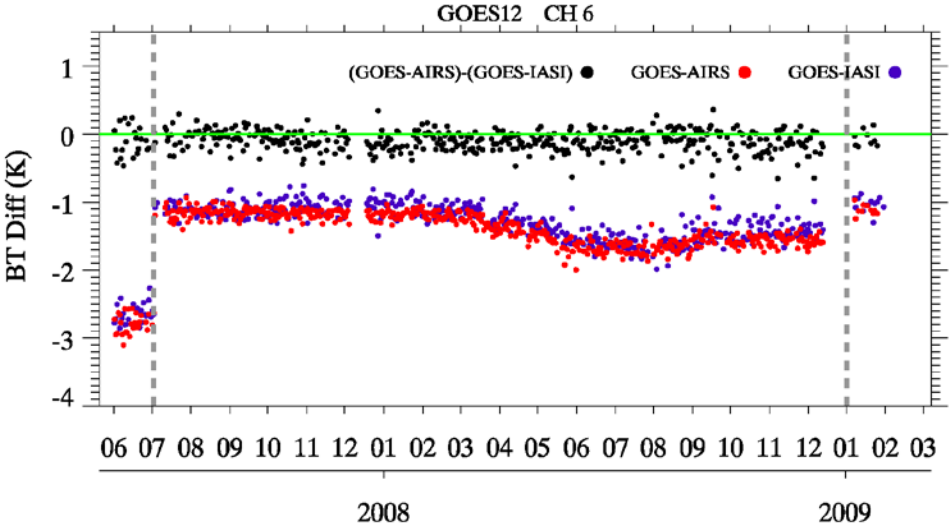


Figure 2 Time series of the GOES-AIRS and GOES-IASI daily mean BT difference as well as their double difference for the GOES-12 13.3µm Channel. The dashed horizontal green line indicates the zero value. The dashed vertical line indicates the date of 4 July 2007 and 2 January 2009 , when the GOES-12 decontamination was performed.

Figure 3, GOES-11 Channel 3 (6.7 µm), is another example to show this capability. There are pronounced fluctuations along the GOES-AIRS and GOES-IASI BT time series (represented by the red and blue dots), indicating that they are caused by the change of the GOES-11 Imager. After investigation, we found that the detector patch temperature of GOES-11 was raised from 91 K to 99 K in the summertime and lowered from 99 K to 91 K in the wintertime, indicated by the blue arrows in Figure 3. Since the radiator is facing to the north satellite, it runs warmer in the summertime, making the patch temperature float. The float patch temperature often causes a variable instrument noise. As a trade-off, the patch temperature is raised in summer in order to keep the stable (constant) patch temperature. It is expected that the GOES calibration accuracy should not be impacted during this patch temperature change. However, both IASI and AIRS successfully track the calibration accuracy change caused by the patch temperature change. More interesting, the IASI and AIRS double difference are not impacted and is still consistent before and after the GOES-11 patch temperature was changed. The above discussion further demonstrates that systematic errors related to the calibration accuracy of the transfer radiometer calibration are cancelled out through the double difference calculations. These results have been encouraging enough to merit further investigation of the IASI and AIRS radiance difference through the double difference.

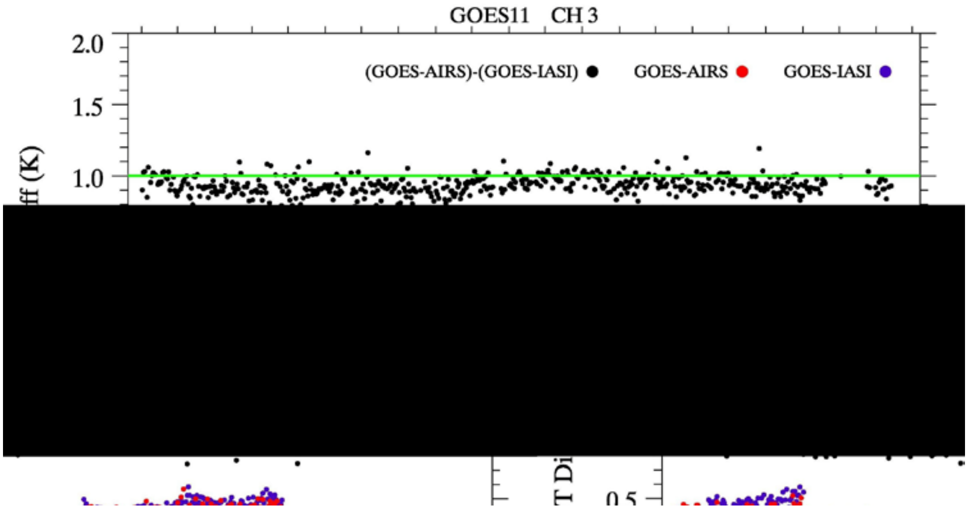


Figure 3 Same as Figure 2 but for GOES-11 6.7μm channel. Note that the double difference has been displaced with 1.0 K. The black arrows designate the time when the GOES-11 detector patch temperature was changed.

In summary, the above discussion demonstrates that the difference of GOES-AIRS and GOES-IASI can track well the AIRS and IASI radiance difference in spite of sudden change or gradual variation of GOES Imager calibration accuracy.

5 Relative difference between AIRS and IASI

The statistics of the double difference, which are used to characterize the IASI and AIRS radiance difference in term of BT within the GOES Imager spectral channels, are summarized in Table 1. Histograms of the double differences are shown as the grey bars in Figure 4 and overlaid with fitted Gaussian distributions. The reduced chi-squared $\chi^2_\upsilon = \chi^2/\upsilon$, where χ^2 is the chi-squared statistic and υ the degrees of freedom, can be used to describe the goodness of fit of the computed values to the data. Ideally, a value of $\chi^2_\upsilon=1$ implies the best-fit of for the given data. Values of χ^2_υ much larger than 1 result from large deviations from the assumed distribution and may indicate poor measurements, incorrect assignment of uncertainties, or an incorrect choice of probability function. The calculated χ^2_υ values range from 1.53-2.83 (given in Figure 4), indicating that the distributions of the double differences approximate a normal or Gaussian distribution in practice. Therefore, it is possible to use the Student's *t* test to estimate the 95% confidence interval of those differences using

$$\sigma_{95\%} = \pm t_{0.025}\frac{\sigma}{\sqrt{N}} \qquad (3),$$

where $t_{0.025}$ is the student's t critical point for a large sample number and equals 1.96, σ is the standard deviation of the double differences, and N is the sample number. The null hypothesis is that the difference in the mean values of both the GOES-AIRS and GOES-IASI BT difference is zero (or that the mean values are equal). The formula given above for the error estimation is, however, only correct if the individual data points are unrelated, or statistically independent. A common and relatively simple method that is can be used to correct the autocorrelation effects by determining the effective sample size N_{eff}

$$N_{eff} = N(1-R_1)/(1+R_1) \qquad (4),$$

where R_1 is the lag-1 autocorrelation coefficient and N is the sample number from the data. The adjusted 95% confidence level based on the above method is given in Table 1.

Table 1 Double-differences statistics between the AIRS and IASI radiances relative to the GOES-11 and -12 Imagers in term of BT.

	GOES-11			GOES-12		
	Ch 3	Ch 4	Ch 5	Ch 3	Ch 4	Ch 6
Central wavelength (μm)	6.7	10.7	12.0	6.5	10.7	13.3
Sample Number	405	402	400	388	384	388
Lag1 auto-coefficients	0.157	0.066	0.140	0.260	0.253	0.084
Mean (K)	-0.0641	-0.0432	-0.0095	-0.0490	-0.0419	-0.0884
Standard Deviation (K)	0.0649	0.1092	0.1341	0.0770	0.1733	0.1478
95% Confidence Interval (K)	0.0063	0.0107	0.0131	0.0077	0.0173	0.0147
Adjusted 95% Confidence Interval (K)	0.0074	0.0114	0.0151	0.0100	0.0224	0.0160

At the 95% confidence level, the mean values of the IASI-AIRS brightness temperature differences are -0.0641±0.0074 K, -0.0432 ± 0.0114 K, and -0.0095±0.0151 K for GOES-11 6.7, 10.7, and 12.0 μm channels, and -0.0490±0.0100 K, -0.0419±0.0224 K, -0.0884±0.0160 K for GOES-12 6.5, 10.7, and 13.3 μm channels. The above results show that AIRS and IASI have best agreement within GOES-11 12.0 μm channel (Channel 5), i.e. -0.0095 ± 0.0151 K. For the CO_2 absorption channel (GOES-12 Channel 6 at 13.3 μm), the AIRS and IASI has a relatively larger cold bias -0.0884 ± 0.0160 K than other channels. Generally speaking, the radiance difference between AIRS and IASI within the GOES Imager channels is less than 0.1K while AIRS is slightly warmer than IASI. Note that the largest uncertainty value is found for GOES-12 10.7 μm channel while the two water vapor channels have the smallest values, which is due to scene inhomogeneity as discussed above. This suggests that the preciseness of the double difference is impacted by scene uniformity, which is a key factor to control the uncertainties caused by the minor violations of collocation and concurrence, as well as the view geometry difference.

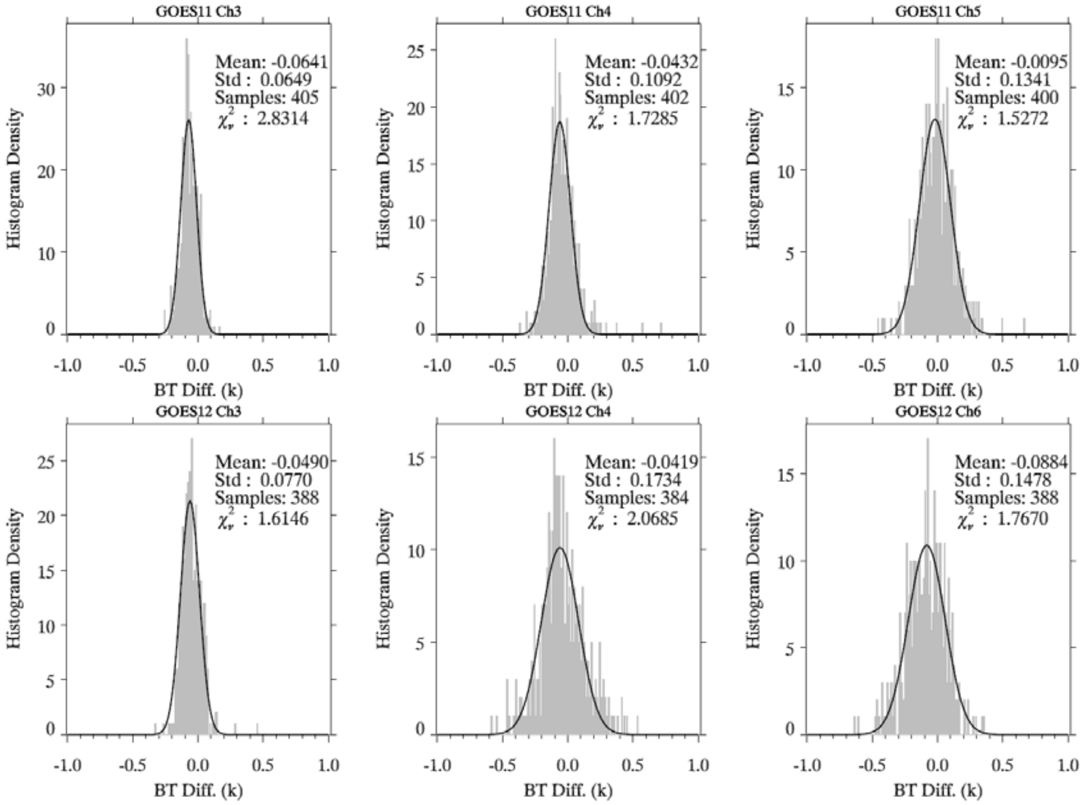


Figure 4 Histograms of the double difference between GOES-AIRS and GOES-IASI (the grey bars), overlaid with computed Gaussian distributions (the black curves). The title of each panel denotes the instrument name and channel number. The mean, standard deviation, sample number, and reduced Chi-square parameter are listed. Note that the bin size is 0.01 K.

6 Summary

Quantifying the radiometric difference and creating a calibration link between AIRS and IASI are crucial for creating fundamental climate data records and establishing the space-based calibration standard. This study proposes a method to compare AIRS and IASI in the tropical regions using the GOES Imagers as transfer radiometers. Specifically, the AIRS and IASI radiances are convolved with the GOES Imager spectral response function and are compared with the geostationary imager radiance measurements with common spatial and temporal collocation criteria. The double difference between AIRS and IASI radiance bias relative to the GOES Imagers are used to quantify the radiometric difference of the AIRS and IASI radiance measurements in term of BT. The results indicate that the calculated double difference is not affected by the GOES-Imager calibration bias. This study demonstrates that stable geostationary instruments can be used as transfer radiometers to inter-compare polar-orbiting hyperspectral instruments on different satellite platforms for warm scenes in tropical regions, which complements the direct comparison of IASI and AIRS using the simultaneous nadir overpass (SNO) technique.

It is not possible, from this study, to address the absolute calibration accuracy for both the AIRS and IASI instruments by means of inter-satellite comparison results. We thus focus on analyzing the relative bias between IASI and AIRS within the GOES Imager spectral coverage during a 16-month time period. The results indicate that, at the 95% confidence level, the mean values of the IASI-AIRS brightness temperature differences are -0.0641±0.0074 K, -0.0432 ± 0.0114 K, and -0.0095±0.0151 K for GOES-11 6.7, 10.7, and 12.0µm channels, and -0.0490±0.0100 K, -0.0419±0.0224 K, -0.0884±0.0160 K for GOES-12

6.5, 10.7, and 13.3 µm channels for typical warm scenes. This suggests that the radiance difference between AIRS and IASI within the GOES Imager channels is less than 0.1K while AIRS is slightly warmer than IASI.

As a final note, we would like to point out that, due to the huge volume of AIRS, IASI, and geostationary imager data, this study is only limited to the GOES Imagers. Second, the approach used in this study cannot be performed at the finest spectral scale, but instead is limited to the spectral coverage of transfer radiometers. Finally, the diurnal variation of the GOES Imager calibration further confines the comparison to the longwave IR spectral region. In the future, with the GOES-R Advance Baseline Imager, which has more spectral coverage and stable calibration, and the progress of the GSICS program, this method can be further extended to link the AIRS, IASI, and CrIS towards generating fundamental climate data records.