Inter-comparison of IASI and ATSR IR channels

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Abstract
Accurate measurements of TOA (Top of Atmosphere) radiances are critical, not only for producing global climate data records but also for producing variables that are the main input to NWP. Currently, the longest continuous data record comes from the AVHRR series of instruments which have measured TOA radiances since the late 70s. More recently, since the early 90s and 2000s, these observations have been complemented by the (A)ATSR series, IASI and many others. A key advantage of this overlapping measurement of TOA by multiple instruments is that it provides an opportunity to compare the TOA measured by them, identify biases and problems in the calibration of the instruments and correct any inconsistencies. For example, TOA collocations are used as part of GSICS (Global Spacebased Inter Calibration System) where IASI is used as one of the reference sources. Other recalibration efforts such as the NOAA CDR project to recalibrate the AVHRR are using the (A)ATSR series. However, to trust the recalibrated radiances it is vital that the accuracy of the reference sources is known.

In order to better understand the accuracy of these references we compare IASI with the AATSR. IASI is becoming a standard reference source and the AATSR is a sensor designed for climate studies, in particular to derive accurate Sea Surface Temperatures (SSTs), and has been shown to be accurate enough for climate work. By comparing radiances measured by AATSR and IASI over collocated pixels spanning over several months selected from years 2009 through 2011 this study demonstrates that there is a small angular dependence between the AATSR and IASI and that the IASI is accurate enough (minus a small bias) to be close to the AATSR pre-launch levels of accuracy. We also show a time dependent bias in the AATSR at low (<240K) temperatures and show a detailed study of the 12µm channel bias which is shown to range from +0.4K to -0.2K over the complete temperature range.

INTRODUCTION
Climate data records (CDR) produced from satellite measurements of TOA radiances are critical to understanding climate processes and climate change. The main advantage of a satellite produced CDR is that it is global in nature. However they come with two severe disadvantages. First, satellite measurements date back only till the late 70s and this time span is just enough to resolve climate change signal in time (Leroy et al. 2008). The second deterrence is the accuracy and stability of many of the early satellite instruments, which were designed more than 40 years ago and were not designed with climate levels of accuracy in mind. This can result in temporal and temperature dependent biases in the measured radiances. On the other hand some satellites were designed with climate studies in mind including the (A)ATSR series of instruments which was first launched in the early 90s and which has been shown to provide a climate ready CDR of SST. It might therefore be hoped that the (A)ATSR series can
provide climate accurate TOA radiances as well, although it must be borne in mind that the (A)ATSR series was designed to provide data for use in SST measurements and not for measurements of cold (cloud like) temperatures.

Recent advances in calibration methodologies are using TOA reference sources to address problems with sensor calibration. An example is the calibration developed by Mittaz and Harris (2011), which has demonstrated that under certain circumstances the AVHRRs can be brought close to thresholds of climate readiness. Other projects such as GSICS are trying to obtain corrections to sensor radiances for a wide range of satellites and uses IASI and AIRS as the TOA references. This brings us to the obvious question whether the references used in such studies (such as the AATSR and IASI) are stable and accurate (i.e. climate ready) enough to be used as accurate TOA reference sources.

A recent study by Illingsworth et al. (2009) used the AATSR as a benchmark and attempted to measure the IASI vs AATSR bias. By comparing radiances of IASI and AATSR of collocated pixels for a single orbit during 01/09/2007 this study concluded that the mean 11 μm and 12 μm IASI and AATSR measurements agree to within -0.05 K and 0.23K respectively in the SST range.

While this study succeeded in getting to a basic estimate of differences between IASI and the AATSR the wider question of possible variations with scan angle, scene temperature and time still needed to be addressed in order to form an opinion about the climate readiness of these instruments and their use for recalibration studies. In terms of the AATSR there are additional possible issues such as the known BT offset of order -0.2K in the 12μm channel when compared to the ATSR-2 (Nightingale and Birks 2004 and Smith 2007). However the variation of this offset w.r.t scene temperature and if a SRF shift can correct it is still not known.

We address these issues by considering collocations over a wide temperature range (210K-310K) and with time scale spanning over parts of three years (2009, 2010, 2011). In the next two sections first we give a brief description of the AATSR and the IASI instruments and then in the following section we describe our inter-comparison method. The results of the inter-comparison are presented after these sections. The results section first addresses the issue of scan angle dependence of the IASI AATSR bias. Subsequently the temperature and time dependence of the IASI AATSR bias is presented in addition to the impact of SRF shift on the temperature dependent bias of the 12 μm channel.

INSTRUMENTS AND COLLOCATION METHOD

Advanced Along Track Scanning Radiometer (AATSR)

The Advanced Along Track Scanning Radiometer (AATSR) was designed to be a climate ready satellite. It was launched onboard ENVISAT in 2002. Since then till May 2012 it had been observing the earth in four visible (0.555 μm , 0.659 μm, 0.865 μm, and 1.61 μm) and three IR bands (3.7 μm, 11μm and 12 μm) and provided continuity to the earlier launches of ATSRs (launched in 1991, 1995). This instrument is described in detail by Smith et al. (2001,2012).

The AATSR is designed to provide an accurate count to radiance conversion within the SST temperature range. This is because it has two accurate black bodies that are situated at either edge of the SST temperature range that acts as calibration references. This helps in pinning down the detector non linearity to a small range that lies between the two blackbodies and hence reduce calibration errors. In addition the AATSR has as conical scan and views a location at two zenith angles. It produces two swaths (500 Km each) at nadir and forward view. Locations of the forward view are viewed again at nadir
as the satellite moves forward and these two measurements can be used to determine the impact of atmospheric attenuation beyond the standard water vapor component normally determined in single view measurements. Further details of the AATSR can be found in Smith et al. (2012).

**Infrared Atmospheric Sounding Interferometer (IASI)**

The IASI is a hyper spectral instrument that is recognized by the GSICS as a benchmark for inter-satellite comparison of TOA (e.g. Wu et al. 2009). It works on the principle of a Michelson's interferometer and was launched onboard Metop-A in 2006. It consists of a Fourier Transform Spectrometer with an imaging system. The Fourier transform spectrometer provides infrared spectra between 645 and 2760 cm\(^{-1}\) (3.6 µm to 15.5 µm) at resolution of 0.25 µm. (EUMETSAT 2012)

**Collocation Method**

The main idea of the collocation method is to identify locations on the earth that have been observed at nearly the same time by the IASI and the AATSR and then compare the measurements. Given the fact that the IASI footprint on the ground is larger (12 km at Nadir) than the AATSR (which is re-sampled to make it 1 km everywhere on the swath), several AATSR pixels fall within each IASI pixel. In order to ensure scene uniformity within the IASI footprint, thresholds are set regarding the standard deviation within the IASI footprint as well as in a perimeter and thresholds on time and viewing angle (zenith angle) are also applied (Table 1). An IASI pixel that has AATSR pixels that pass these thresholds are then considered for comparisons and are called collocated IASI pixels. In the end the IASI spectrum for these collocations is integrated over the AATSR SRF to get IASI representative radiances. These radiances are then compared with the mean radiances of the AATSR that are collocated with the IASI pixel.

<table>
<thead>
<tr>
<th>Thresholds</th>
<th>Value</th>
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<tbody>
<tr>
<td>SD Collocated Pixels</td>
<td>&lt; 0.5 K</td>
</tr>
<tr>
<td>SD Perimeter</td>
<td>&lt; 1 K</td>
</tr>
<tr>
<td>Time Difference</td>
<td>&lt; 15 Mins</td>
</tr>
<tr>
<td>Time Span</td>
<td>Winter and Summer of 2009-2011</td>
</tr>
<tr>
<td>Sat Zenith Angle difference</td>
<td>1°</td>
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*Table 1: Thresholds applied on collocated AATSR pixels in a single IASI pixel*

**INTER-COMPARISON RESULTS**

**Scan Angle dependencies**

As part of the ongoing AVHRR recalibration activity (at NOAA) that uses the new calibration methodology developed by Mittaz and Harris (2011), comparisons of AVHRR radiance were made with IASI radiances and have shown that the AVHRR-IASI bias demonstrated a strong scan angle dependence at cold (cloud like) temperatures. Such a dependence has also been seen in earlier works by Wang & Cao (2008) and Blumstein et al. (2007). While the exact cause of this scan angle dependence is beyond the scope of this work, the important thing from the point of view of re-calibration is to know whether this scan angle dependence was caused by IASI or the AVHRR. Since it is thought that the AATSR does not have any significant scan angle effect, the AATSR/IASI comparison provides us with the opportunity to see if there is any significant IASI scan angle dependent bias and hence determine the scale of any AVHRR scan angle dependence, if any.
Figure 1: Shows a comparison of AVHRR IASI scan angle bias showing a small scan angle dependence. Values shown at 55 Deg satza are the mean of bias computed from collocations from the forward view of AATSR.

Fig.1 shows AATSR-IASI bias vs scan angle for two temperature ranges (200-230K and 265-300K) and shows a small scan angle bias. Since IASI has to correct for a response versus scan angle (RVS) effect, this small bias is presumably due to a small residual error in the IASI RVS correction. It can also be seen that for the 200K-230K temperature range, the AATSR-IASI bias vs scan angle is much smaller (a few tenths at high zenith angles) than the corresponding bias seen in the AVHRR IASI comparison (see Mittaz and Harris 2011). For this temperature range, the AVHRR-IASI scan angle bias grows up to 1.3 K in magnitude at the extreme zenith angles while over the SST (265K-300K) temperature range scan angle dependence is small. It suggests that the scan angle dependence of the AVHRR IASI bias is dominated by an AVHRR effect and is not primarily an IASI effect.

Temperature dependence of the AATSR-IASI bias

The 11 and 12 μm channels both demonstrate different characteristics w.r.t scene temperatures. While the 11 μm AATSR IASI difference remains stable and approximately linear across most of the observed temperature range of 200K-300K (except for a dip 200-220 K Fig. 2) with the mean difference remaining nearly 0.06K, the 12 μm channel demonstrates a clear temperature dependent trend (Fig. 3, Fig. 4).

11 Micron

Figure 2: Shows the temperature dependent bias of the AATSR-IASI (K) for the 11μm channel. The two black circles show the approximate temperatures of the black bodies and the line shows the mean offset.
From the point of view of calibration, the AATSR – IASI difference acquires special significance because for the 11 µm channel the bias variability w.r.t temperature is quite similar (Fig. 3) to what was observed in the pre-launch calibration in particular at the low [210-230K] temperature range where the tail is replicated.

Figure 3: Shows the similarity of the Temperature difference between AATSR -IASI minus an offset of 0.125 K (i.e post launch) and pre-launch (Smith, et al. 2012). Note that the binning applied here is consistent with the AATSR prelaunch data but different from that shown in Figure 2.

Since the AATSR pre-launch has a known negative bias of the order of 0.0-0.05K referenced to SI calibrated sources and the inter-comparison of IASI-AATSR inter-comparison shows a positive bias of the order of 0.06K (Fig. 2), the observed positive IASI-AATSR bias is likely to be an IASI bias relative to the AATSR. Since in the SST temperature regime the AATSR is thought to be absolutely accurate to a few hundredths of a degree the implication is that IASI when corrected for this small bias can generate radiances that are almost as accurate as prelaunch data to within a few hundredths of a degree.

12 Micron

Immediately after the launch of the AATSR aboard the ENVISAT it was found that the 12 µm channel had an apparent BT offset ~ -0.2K when compared with the ATSR-2. It was verified by Smith (2007) to be an AATSR effect.
However, our analysis has shown that the BT offset is strongly temperature dependent and steadily grows to about 0.4K as we move to cold temperatures down to 200K (Fig. 4). At SST temperatures the bias is negative and taking into account the small (0.06K) IASI bias discussed above is approximately consistent with the previously known bias of -0.2K. Among the possible reasons of this effect is that spectral response function has undergone a shift or a possible long wave leak has developed post launch (Smith 2007). While a complete analysis of the impact of the long wave leak in the SRF is planned we have run experiments to see what the impact of shifting the SRF in either direction is on the bias.

![Figure 5: Shows the impact of moving the SRF by adding wave numbers to the original SRF](image)

Two sets of experiments were conducted. In the first set the SRF was shifted by +n wave numbers (where n=1,2,3,4,5,6). The second set of experiments the SRF was shifted by –n wave numbers (where n=-1,-2,-3,-4,-5,-6). Fig.5 shows the impact of shifting the SRF on the AATSR–IASI bias for each ‘+n’. The temperature dependence of the bias is preserved right up-till a shift of +6 wave number is applied. A similar conclusion was drawn with the –n shifts (not shown) and the overall conclusion is that SRF shift is not a solution to the temperature dependent bias. In terms of using the AATSR 12µm for recalibration, it must be noted that the temperature dependent bias is very stable (with the caveats discussed below) and an empirical approach can explored. A polynomial of deg 6 can be a good fit to the variability (Fig. 4).

**Temporal dependence of AATSR IASI bias**

Collocations were produced for several months of the year 2009, 2010 and 2011. These months can be crudely classified as being summer and winter months. Fig.6 shows the change in the bias for the 11 and 12 µm channels.
CONCLUSIONS AND DISCUSSION

Using AATSR IASI collocations that spanned nine months spread over 2009, 2010 and 2011 we have analyzed the dependence of the AATSR-IASI biases on scan angle, scene temperature and time on a wide temperature range of 200K-300K. This analysis is directly aligned with the ongoing AVHRR re-calibration activity at NOAA were IASI and AATSR are used as TOA reference sources.

Our analysis has shown that there is very small dependence of bias with scan angle (Fig. 1). This has lead to our first conclusion that the dependence of the IASI AVHRR bias that was earlier documented by Blumstein et al. (2007), Wang and Cao (2008) and later by Mittaz and Harris (2011) is primarily an AVHRR effect and not an IASI effect.

We next analyzed the temperature dependence of the IASI AATSR bias for the 11 μm and 12 μm channels (Fig. 2, Fig. 3 and Fig. 4). Across the full temperature range of 200K to 300K, for the 11 μm, the IASI and the AATSR agree to within ~0.06 K. Further, the shape of the bias curve is very similar to the pre-launch calibration of the AATSR. This comparison captures the low temp dip and the SST range cusp realistically, thus suggesting that IASI (Fig. 3) can act like a pre-launch reference.

We also comprehensively analyzed the known BT offset of the AATSR 12 μm over the entire 200K- 300K range. Fig. 4 shows that this BT offset, which was earlier estimated to be of the order of -0.2K (Nightingale and Birks, 2004), actually varies with scene temperature and can grow up to +0.4K at low temperatures (~210 K). Our attempts to remove this temperature dependent BT offset have revealed that shifting the SRF (in either directions) does not remove this bias. However the bias is stable and empirical solutions can be used.

Finally, Fig. 6 shows the temporal dependence of the AATSR IASI bias. The time is crudely divided into winter and summer months and we have shown a clear dependence of the bias at low temperatures (200K -240K) on time/season. At SST temperatures there is no significant time dependence due to the two blackbody calibration system utilized by the AATSR.
REFERENCES


Smith, D.L, ( 20 07), Effect of long wavelength response in AATSR filters on brightness temperature measurements, AATSR Technical Note, PO-TN-RAL-AT-0541, Issue 1.0, Rutherford Appleton Laboratory

