GSICS Traceability Statement for IASI and AIRS

Doc.No. : EUM/MET/TEN/11/0157
Issue : v1A
Date : 6 October 2014
WBS :

EUMETSAT
Eumetsat-Allee 1, D-64295 Darmstadt, Germany
Tel: +49 6151 807-7
Fax: +49 6151 807 555
http://www.eumetsat.int

Document Change Record

Issue / Revision	*Date*	*DCN. No*	*Summary of Changes*
V1	15 March 2011		Initial Issue
V1A	6 October 2014		Inclusion of Table of Contents. Version released for publication on the EUMETSAT Website.

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1 INTRODUCTION

1.1 Purpose and Scope

This document provides a statement describing the suitability of the hyperspectral infrared spectrometers, IASI (Infrared Advanced Sounding Interferometer) and AIRS (Advanced InfraRed Sounder) as inter-calibration references for GSICS products.

Ideally this would describe the traceability chain to reference standards - preferably measurement standards based on the SI, or international system, of units. This is a long-term goal of GSICS. However, while both AIRS and IASI have been compared with various calibration references - both pre-flight and in-orbit - reference values with associated uncertainties that are traceable to SI standards have not been assigned. Therefore it is important to assess the characterisation and stability of these instruments, as these are key to their effectiveness as inter-calibration references.

1.2 Concept

IASI and/or AIRS is used as inter-calibration references in the following GSICS Products:

- GL01.1.0 EUMETSAT Inter-Calibration of Meteosat/SEVIRI with Metop/IASI;
- GL02.1.0 GSICS Correction for intercalibration of MTSAT IR channel; and
- GL03.1.0 GSICS Correction for GOES Imager IR Channels with AIRS/IASI.

As it is important to be able to deduce values and uncertainties related to calibration, knowledge of uncertainties related to these calibration references becomes necessary. In addition, as the use of calibration products expands in the international satellite community, creating clear product quality indicators that allow product users to determine whether or not the calibration product will meet the needs of their application is paramount. Typically, the definition of calibration reference uncertainty is a starting point for the creation of such quality indicators. For these reasons, this document is established to clearly state the limitations of, and define uncertainties to, the IASI and AIRS radiometric measurements.

1.3 On the Use of Multiple Inter-Calibration References

Some inter-calibration products use comparisons against multiple references. This can introduce metrological problems of traceability as the references can never be perfectly consistent. To overcome this, one of the reference instruments is defined as *the calibration reference* and all others are regarded as *calibration transfer standards*.

The concept for NOAA's products is that AIRS is used as a transfer standard to complement the inter-calibration against IASI as a reference. This allows collocations with GEO imagers to be generated over a range of the diurnal cycle, because of the differences in the orbits of the Aqua and Metop satellites carrying these instruments. This is particularly important for instruments on 3-axis-stabilised satellites, whose calibration can vary during the course of each day as the solar illumination of the spacecraft changes.

This approach needs to be accounted for when constructing the *uncertainty evaluation* required for products derived from multiple references.

1.4 Traceability to a Reference

The ideal of metrological traceability is to be able to link the measurements of a given instrument, through an unbroken chain of inter-comparisons with stated uncertainties, to a standard source (common reference) with sufficient stability for the intended use of the measurement results. For many quantities the common references are usually developed and maintained by the international network of metrology institutes. Another key component of traceability is to be able to periodically repeat this measurement process to ensure traceability through time. Once the traceability chain is broken - e.g. through the launch of a satellite instrument that has no in-orbit SI source - then traceability to an SI standard is lost. Hence, no current in-orbit satellite instruments used for environmental research, weather analysis or weather prediction are SI-traceable. So, although pre-launch comparisons against standard radiometers and standard targets are encouraged in future (they were not done for AIRS or IASI), these alone do not ensure traceability of the instruments in orbit.

Given this limitation, the satellite community is forced into a position to choose a satellite instrument that - through careful pre-launch laboratory characterization and calibration and/or periodic post-launch verification studies - is known for its quality and stability through its lifetime. Such intrinsic, or *community*, *reference standards* require evidence of this quality and stability, and it therefore becomes the responsibility of the satellite community to provide this evidence. It is important that the chosen reference is common to the later comparisons. The key issues in traceability to a community reference standard are documenting the pre-launch characterization of the instrument and providing a way to prove that the system is indeed stable to a certain degree. This sets the stage for instrument inter-comparability to this community reference.

1.5 Stability

In general, a good measurement device has the following properties:

1. It is stable between calibrations to a characterized reference
2. It has a high spatial and spectral resolution
3. It has only very small systematic deviations from its modeled response curve through its dynamic measurement range (well characterised linearity)
4. It has low noise (repeatable)

So it is stability, resolution, fidelity of response curve and low noise that "makes" a measurement device - and this is particularly true of an inter-calibration reference. How accurately you can measure with it depends on the actual calibration. Most of these properties can be verified without external reference (but with external reference the task is much easier). Only if these properties of the measurement device have been established, does it make sense to calibrate the instrument to a very high level.

In metrology, one can only compare values which are linked to the same reference. So what one needs inside the system is only relative stability of the common reference and link all measurements you want to compare to that reference. If this reference is drifting[1], all values are drifting and you will not be able to tell the difference if the reference or the measured values are changing. So we aim to choose the most stable reference we can find. The stability of the common reference can be determined from a target known to be relatively stable and well characterised (e.g. internal blackbody), which need not be SI traceable. Full traceability to an external reference can be added later if it becomes available.

[1]In practise one has two choices to deal with the instability of the reference. One can either define the reference to be the value of the blackbody at a specific point in time or one can define the reference to be the artefact independent of time (like the kg). For the first option one needs an estimate of the possible drift over time, which . This leads to an increasing uncertainty of the reference with time, which must be accounted for if the drift is significant compared to other uncertainty components.

If the drift is small compared to all other uncertainties or if the quantification of the drift is impossible and comparability in time is not the main focus then the drift might be ignored and the artefact becomes part of the reference and it is then treated as if it were stable in time. This might lead to some inconsistency problems and the need to increase the uncertainties of the measurements later.

2 IASI

2.1 IASI Pre-flight characterisation

IASI is carefully designed with on-board calibration, including corrections for non-linearity and scan mirror reflectivity. The design is described by Siméoni et al. [2004]. In particular, the on-board blackbody reference is designed to achieve brightness temperature knowledge of <0.12K.

Although no side-by-side measurement of IASI with a SI-traceable radiometer have been performed, extensive tests were done in thermal vacuum to fully characterise IASI before launch. These are described by Blumstein et al. [2004]. These included comparison against an external large area reference blackbody (HBB), equipped with Platinum Resistance Thermometers (PRTs) traceable to SI standards. The emissivity of this HBB was also deduced from paint coupon measurements and optical calculations. This blackbody was controllable over the range 80-330K with uncertainties due to temperature of 20mK, uniformity of 50mK and non-blackness of 100mK. This, together with view of two cold reference targets allow corrections to be derived for non-linearity and scan mirror reflectivity changes. After these corrections IASI radiances were found to be within 0.25K of the temperature of the HBB at 300K for all wavelengths. For 260K scenes, the differences were much smaller (<±0.05K).

The three IASI flight models (for Metop-A, -B and -C) were tested on ground on three occasions over a period of approximately 3 years, with the same methods and same blackbody references. The results were very consistent - differences of less than 0.1 K between the 3 instruments and over the whole range of tested scene temperature 220-300K.
IASI In-flight validation

Blumstein et al. [2007] analyses the performance of IASI in orbit. They demonstrate that the absolute calibration errors of IASI are well within specifications (<0.5K). Further analysis of in-flight calibration data viewing the on-board calibration blackbody and two space views confirmed orbital stability is within 0.04K peak-to-peak in every case. These views are also used in-flight for the correction of the changing reflectivity of the scan mirror. Comparisons with AVHRR demonstrated that IASI's inter-pixel calibration is <0.1K.

Larar et al. [2010] described comparisons of IASI observations with those of the NPOESS Airborne Sounder Test - Interferometer (NAST-I) conducted during the Joint Airborne IASI Validation Experiment (JAIVEx) calibration validation campaign. They reported mean differences (NAST-I - IASI) of 0.02K, 0.14K and 0.09K in the long-wave (910–980cm^{-1}), mid-wave (1355–1440cm^{-1}) and short-wave (2390–2490cm^{-1}) window regions, respectively.

There are many other papers available in the literature from independent sources about IASI radiance validation with other satellites or airplane instruments (e.g. in ACP Journal, special issue on IASI: Vol. 9, 2009) as well as NWP bias monitoring.

3 AIRS

AIRS, being of the same generation as IASI , and launched 4 years before IASI, has been characterised in a very similar way - both pre-launch and in-flight. And, like IASI, no SI-traceable end-to-end test of AIRS was done before launch. On the other hand, the characterisation tests were also well documented.

3.1 AIRS Pre-launch characterisation

The pre-flight radiometric characterisation of AIRS is described in Pagano et al. [2008]. The basic principle of of these tests was to transfer the calibration from a Large Area Blackbody (LABB) to the On-Board Calibrator (OBC) blackbody. The LABB theoretical emissivity is in excess of 0.9999 and temperature uncertainty is less than 30mK, as measured by NIST-traceable Platinum Resistance Thermometers (PRTs) located on the internal surfaces. The radiometric accuracy predictions for AIRS based on the OBC, LABB, and pre-flight measurements give an accuracy of 0.2K (k=3). The non-linear terms of AIRS calibration were characterised pre-flight and have not changed in flight. However, an update is being considered that will improve accuracy.

3.2 AIRS In-flight validation

Also, like IASI, there have been numerous post-launch calibration/validation activities to characterise the performance of AIRS. In fact, some of these activities were common with IASI. The best collection of papers on this subject is in the JGR Special Issue on Validation of AIRS Observations. Vol.111 (2006) with 5 articles on the L1b validation.

For example, Larar et al. [2010] also described comparisons of AIRS observations with those of the NPOESS Airborne Sounder Testbed - Interferometer (NAST-I) conducted during the JAIVEx calibration validation campaign. They reported mean differences (NAST-I - AIRS) of 0.16K, 0.10K and 0.05K in the long-wave (910–980cm^{-1}), mid-wave (1355–1440cm^{-1}) and short-wave (2390–2490cm^{-1}) window regions, respectively.

4 CONSISTENCY OF AIRS-IASI

AIRS and IASI are independent instruments, with different designs based on different measurement principles, operating on different satellites launched at different times in different orbits. This is both an advantage and a disadvantage. It is an advantage because we can monitor the relative biases between the observations of each instrument over time, so we can demonstrate their relative stability. As the two systems are independent, if these biases are stable with time, although not certain, it is likely that each instrument is stable since the two systems are independent and their biases are stable with time. It is also a disadvantage because these differences make it difficult to compare their observations. The following possibilities exist:

1. Comparison of global or regional average observations
2. Comparison of collocated observations, either
   a. in pairs of similar channels, or
   b. averaged over spectral bands (e.g. GEO channels)
3. Comparison of observations from each instrument against a common reference, such as
   a. Synthetic observations generated from collocated in situ sensors and a radiative transfer model (RTM)
   b. Synthetic observations generated from a RTM and numerical weather prediction (NWP) model
   c. Collocated observations of a geostationary imager
   d. An airborne instrument of similar design

4.1 Comparison of global or regional average observations

This is a poor choice, due to the orbital differences, which cause the instruments to sample different phases of the diurnal cycle.

All the other methods are useful and complementary because each one involves some biases either in the measurements or in the distribution of the input scenes. Some example results are reviewed below.

4.2 Direct Comparison of Collocated Observations

4.2.1 Comparison of collocated observations in pairs of similar channels

This has been investigated by D. Tobin (Space Science and Engineering Center), based on SNO observations, and Simultaneous Off-Nadir Overpass (SONO) observations. Although these are limited to polar regions, given sufficiently long periods, they generate enough collocations to cover a range of radiances similar to that found over the globe as a whole. They concluded that SNOs provide a simple and accurate method to inter-compare and evaluate IASI and AIRS, showing mean differences generally on the order of a few tenth of degrees K or less over full spectral range. This is shown in Figure 1.

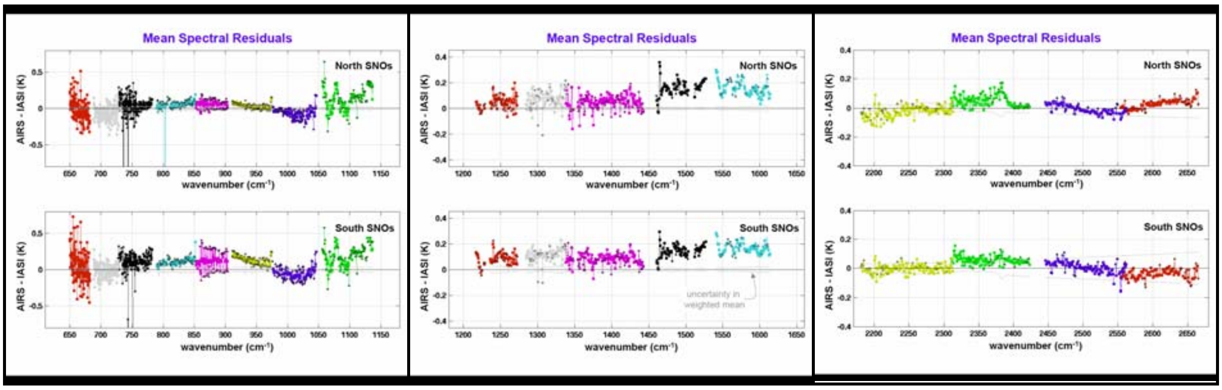

Figure 1: Mean AIRS-IASI Brightness Temperature Differences in comparable channels in three spectral bands

4.2.2 Comparison of collocated observations averaged over spectral bands

This was used during the commissioning of IASI, as reported by Blumstein et al. [2007], who showed that comparisons with pseudo-channels from Simultaneous Nadir Overpasses (SNOs) with AIRS showed differences <0.1K.

Tobin showed that the mean difference between AIRS and IASI brightness temperatures in the 1460-1527cm^{-1} band of AIRS module M-04b was found to be 0.15K and there are no significant long-term changes in the differences over the 3-year period 2007 to 2010 (0.9±5.6mK/year), as shown in Fig 2.

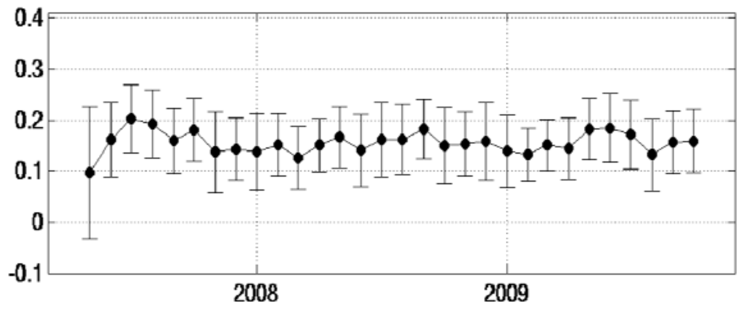

Figure 2: Time Series of Monthly Mean Brightness Temperature Difference (1460-1527 cm^{-1})

This method has also been investigated by Bob Iacovazzi (NOAA), again based on SNOs. Results of these are on the web, covering the period from launch of IASI to April 2009 at:
http://www.star.nesdis.noaa.gov/smcd/GCC/infrared_sounder/aqua-metopa-iasi.html
These results are rather more scattered, because of the stricter collocation criteria used, resulting in fewer samples.

4.3 Comparison of observations from each instrument against a common reference

4.3.1 Double-differencing against synthetic observations generated from collocated in situ sensors and a RTM

This has limited application, given the relatively small number of samples available, and the large atmospheric and surface variability. However, comparisons with radiosondes have been performed at LMD.

4.3.2 Double-differencing against synthetic observations generated from a RTM and NWP model

This is currently under investigation at EUMETSAT. Results are expected to be available by the end of 2011. However, again, this may be limited by the accuracy of the representation of the diurnal cycle in the NWP model.

4.3.3 Double-differencing against collocated observations of a geostationary imager

This was used by Wang et al., [2010]. They showed that the brightness temperature biases between AIRS and IASI within the GOES imager spectral range are less than 0.1 K (mostly <0.05K), although the AIRS measurements are slightly warmer than those of IASI.

4.3.4 Double-differencing against collocated observations of an airborne spectrometer

Tobin [2007] described the Scanning High-resolution Interferometer Sounder (S-HIS) and NPOESS Airborne Sounder Testbed - Interferometer (NAST-I). These are spectrometers capable of operation on high-altitude aircraft and have been inter-compared with AIRS and IASI. For example, data from the Joint Airborne IASI Validation Experiment (JAIVEx) suggested the IASI absolute calibration is accurate to 0.1 to 0.2 K, which is not statistically significant compared to the calibration and inter-comparison accuracy of the aircraft data. S-HIS has also been compared with the NIST Transfer Radiometer (TXR) in the laboratory, by viewing a highly stable blackbody over a wide range of scene temperatures, while operating S-HIS under typical flight conditions. The test results show brightness temperature differences between the TXR and the S-HIS to be, on average, less than 40mK.

Larar et al. [2010] extended their analysis to use NAST-I as a transfer standard, allowing the indirect comparison of AIRS and IASI observations in a double-differencing method. These implied band differences between AIRS and IASI on the order of less than 0.05K in the mid- and long-wave window regions. They claimed these results are similar to that inferred by other approaches (i.e., which reported agreement between IASI and AIRS to better than 0.1K) using SNO analysis in polar regions or NWP model fields for removing scene evolution in other regions (e.g., Strow et al., 2008; Aumann et al., 2008; and Elliott et al., 2009).

5 CONCLUSIONS

Both AIRS and IASI are high spectral-resolution instruments, which have been characterised in a well-documented way pre-launch, which suggest their calibrations had uncertainties of the order of 0.1K.

The relative stability of AIRS and IASI was been clearly demonstrated by numerous methods. This confirms the feasibility of the approach adopted by NOAA of using AIRS as an addition transfer reference to supplement the collocations available using IASI alone, which allows better characterisation of any diurnal variations in the calibration of the monitored instrument.

Furthermore, we chose to define IASI as the reference standard for this class of GSICS inter-calibration products - effectively defining it as the *truth*. Although the absolute calibration of neither AIRS or IASI cannot be directly demonstrated and full uncertainties have not been assigned.

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