# EUMETSAT REPORT ON SATELLITE CALIBRATION ANOMALIES

In response to CGMS action WGII 38.20

Working Paper Abstract

Tools to monitor EUMETSATs operational instruments are described for both the geostationary Meteosat and polar-orbiting Metop satellites. These include various instrument monitoring systems, which allow operators to check their housekeeping and calibration parameters. These are complemented by the Global Space-based Inter-Calibration System (GSICS) bias monitoring, which is currently being developed to allow operators and users to examine the results of comparisons with reference instruments to assess and correct the instruments' calibration.

EUMETSATs operational instruments performed well during the period 2010-2011, with only minor anomalies, which are reported. In addition to the degradation of the IR13.4 channel of Meteosat-9/SEVIRI, due to a build-up of ice contamination, its IR3.9 channel is developing a small bias, the cause of which is unknown. Also, a correction has been developed for the small inter-pixel calibration bias in Metop-A/IASI.

Plans for monitoring instruments on future EUMETSAT mission are also outlined.

Recommendations proposed:

1. There is a need for alignment and integration of instrument monitoring for the Sentinel Missions with other EUMETSAT systems.
2. Radiometric calibration corrections should also be implemented in EUMETSAT's reprocessing activities to generate Fundamental Climate Data Records (FCDRs).

# EUMETSAT report on satellite calibration anomalies

## 1 INTRODUCTION

Following Action 38.20, it is hoped that by exchanging methodologies between different satellite operating agencies, we can ultimately agree common standards for instrument monitoring, allowing consistent publication of results. This report represents a first step in this process, by outlining the systems currently in use at EUMETSAT for monitoring performance and calibration of the instruments on operational satellites. It then shows anomalies detected during the 12 month period from 2010-07-01/2011-06-30 and discusses the underlying causes and actions taken to resolve them.

This report does not include Jason-2 as it is not being monitored in detail at EUMETSAT, but by CNES and CLS.

## 2 MONITORING CURRENT OPERATIONAL SATELLITE INSTRUMENTS

### 2.1 MPEF Monitoring of Meteosat SEVIRI

#### 2.1.1 Calibration of Level 1.5 Image data and Population of Level 1.5 Headers

The End User Requirements specify that the "representation of the level 1.5 images pixels be 10 bits ... as linearised function of radiance". This implies the following objectives for the radiometric calibration of the level 1.5 images:

- to assure a linear relation between radiance and counts
- to assure an equalised response among detectors
- to apply the derived or received calibration information to the image data, therefore supplying a stable radiance- to- count relation for the Level 1.5 data.

##### 2.1.1.1 Blackbody Calibration of Infrared Channels

For the thermal infrared channels, blackbody derived absolute calibration is included with linearization and equalisation to calculate radiances from raw counts, in the nominal configuration. Only after this, the radiances (float values) are then scaled to level 1.5 pixels using a fixed linear scaling law. This ensures a linear relationship between radiance and level 1.5 counts (integer values). The scaling law is described by two parameters that are normally kept constant (baseline scaling). They are referred to as *Cal_Slope* and *Cal_Offset* in the level 1.5 header.

In the thermal infrared channels the user must note that *Cal_Slope* and *Cal_Offset* are fixed scaling factors that will normally not change. They are not related to the calibration process performed to correct the image radiometrically in L1.5 data.

For the solar channels (VIS06, VIS08, NIR16 and HRV), the L1.5 pixels are determined using the ground characterisation of the instrument whereas the *Cal_Slope* and *Cal_Offset* in the level 1.5 header are determined using vicarious calibration.

#### 2.1.1.2 Vicarious Calibration

Vicarious calibration coefficients are derived from a comparison of the level 1.5 image with other sources of information on the outgoing radiance of the earth/atmosphere. Currently, the Meteorological Product Extraction Facility MPEF creates vicarious calibration coefficients to be included into the L1.5 Image Header. All vicarious calibration information is based on level 1.5 images that are calibrated by the IMPF in the first instance. When the use of vicarious calibration is enabled in the IMPF, the content of the IMPF level 1.5 image pixels remains unchanged. It is the annotation that is modified. In this case, the numerical values of *Cal_Slope* and *Cal_Offset* in the level 1.5 header are changed according to the vicarious calibration.

In operations, the vicarious calibration information is used for the solar channels only, as there is no on-board calibration source. Therefore, the level 1.5 image pixels are populated using the instrument ground characterisation. Then, the annotation in the header (*Cal_Slope* and *Cal_Offset*) is replaced by values obtained from the vicarious calibration based on level 1.5 image data. For the thermal channels, the vicarious calibration is used for monitoring.

### 2.1.2 Calibration Monitoring On Image Level

In order to monitor the absolute calibration, it is necessary to compare to a reference outside of the calibration process. In this case, it is the vicarious calibration feedback provided by the MPEF. The vicarious calibration coefficients in all IR channels except the IR9.7 channel are based on meteorological data from a forecast model supplemented with sea surface temperature. In the WV6.2 channel, radiosondes measurements are used instead, whereas in the IR9.7 channel ozonesondes are used. In all cases calibration coefficients are computed as the ratio between the outgoing clear sky radiance extracted from tables generated by the radiative transfer model and the mean observed digital counts of all clear sky pixels in the corresponding area.

As for solar channels, this feedback is actually used as prime calibration; it is not suitable for monitoring. As a consequence, the solar calibration is not monitored.

The thermal channels can be monitored using the calibration feedback, as this is not used for the primary calibration which is based on the on-board blackbody. Within the thermal channels, only the IR window channels (IR10.8 and IR12.0) are fully trusted as here the quality of the calibration feedback is considered highest.

In the RSS service, the calibration feedback for the thermal channels has so far not been reliable due to the lack of geographical coverage of clear sky ocean. Improvements have been made and should been available soon. Vicarious calibrations to support the solar channels are performed at the rare occasions of full disk scanning.

Images that could not be produced to the nominal level of quality for whatever reason are normally flagged as such automatically. In parallel, if any non nominal quality was identified users would be notified through the usual channels. These events are considered exceptional and are not summarised in this report.

Figures 1 shows the comparison between the MPEF created vicarious calibration and the actual calibration of the IR 10.8 and IR12.0 channels of Meteosat 9. The result is expressed in Kelvin. Positive numbers indicate that the vicarious suggest warmer images. During the reporting periods of the second half of the year 2010 and the first half of the year 2011, there is a good agreement and no significant degradation.

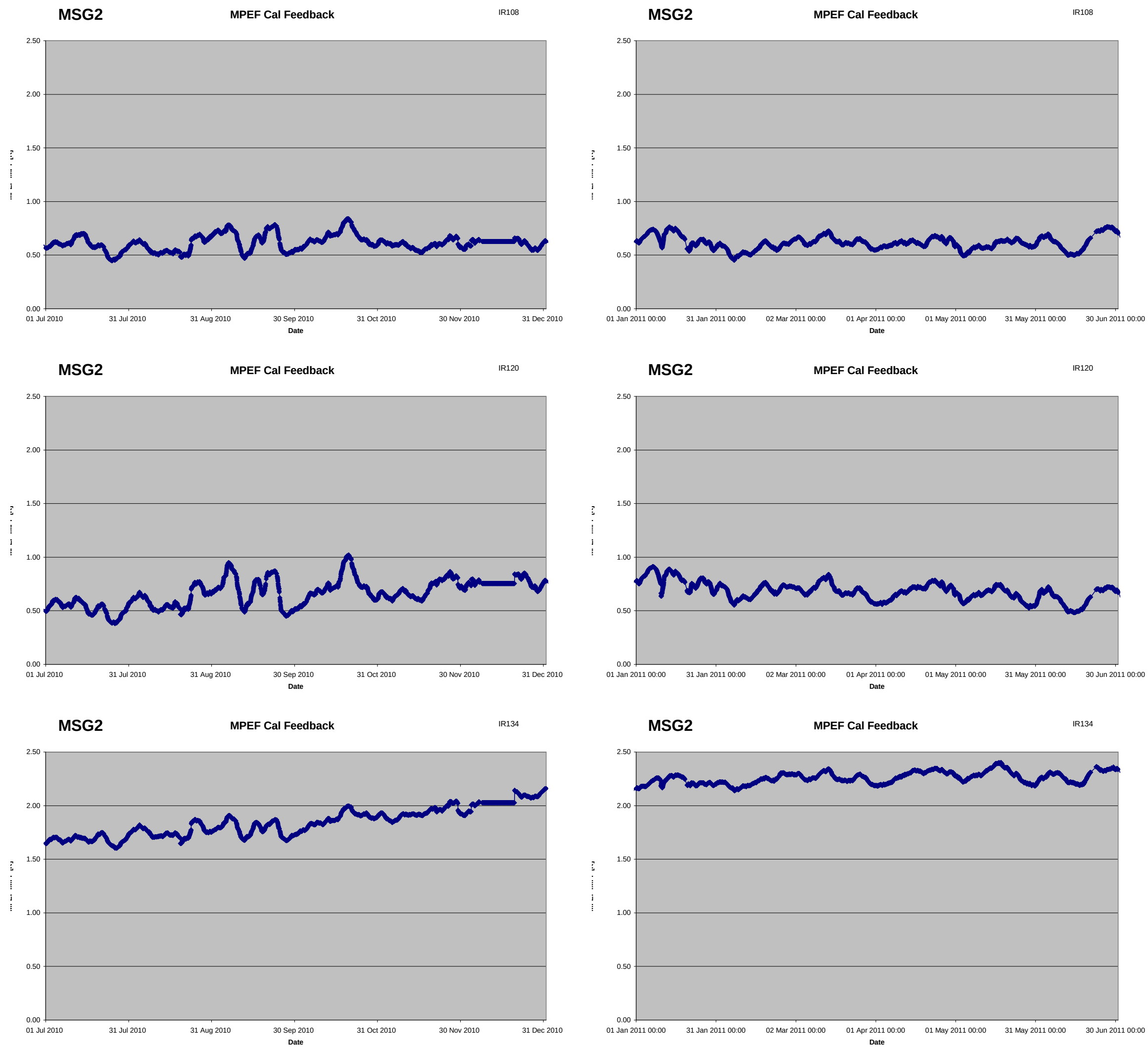


***Figure 1 Calibration Monitoring of Meteosat 9 by Comparison of Images to MPEF Vicarious Results for the second half of 2010 (left) and first half of 2011 (right): Channels IR10.8 (top row) and IR 12.0 (middle row) and IR 13.4 (bottom row)***

Although the vicarious calibration information for the IR13.4 is not used operationally, it can be used for investigative purposes. From Figure 1 an evident trend towards a higher values is visible. Even without relying on the absolute value, it is obvious that there is a change on instrument level over the months. This is an effect coming from a change of the spectral response function of the channel IR 13.4 caused by the accumulation of contaminants in the optical path. As the on-board blackbody source and the atmosphere do have significant differences in spectral shape, this effect is not compensated for. These trends are consistent with the GSICS Bias Monitoring results shown in Figure 2.

## 2.2 GSICS Bias Monitoring

EUMETSAT is actively engaged in developing the Global Space-based Inter-Calibration System (GSICS), which is an initiative of WMO and CGMS, aiming to harmonise the calibration of Earth observing satellite instruments though international coordination. In addition to providing products to correct the calibration of different sensors to be consistent with selected references, GSICS also generates Bias Monitoring products, which allow the relative biases of instruments to visualised as time series. These allow the detection and investigation of sudden as well as gradual changes in instruments' calibration.

GSICS Bias Monitoring available from a page on the EUMETSAT website:
http://www.eumetsat.int/Home/Main/DataProducts/Calibration/Inter-calibraton/GSICSBiasMeteosatIRInter-calibration/
Allows users to monitor the bias of each infrared channel of the current Meteosat imagers with respect to Metop-A/IASI. These biases are evaluated for standard radiance scenes corresponding to clear sky conditions in a standard atmosphere. Examples are shown in Figure 2.

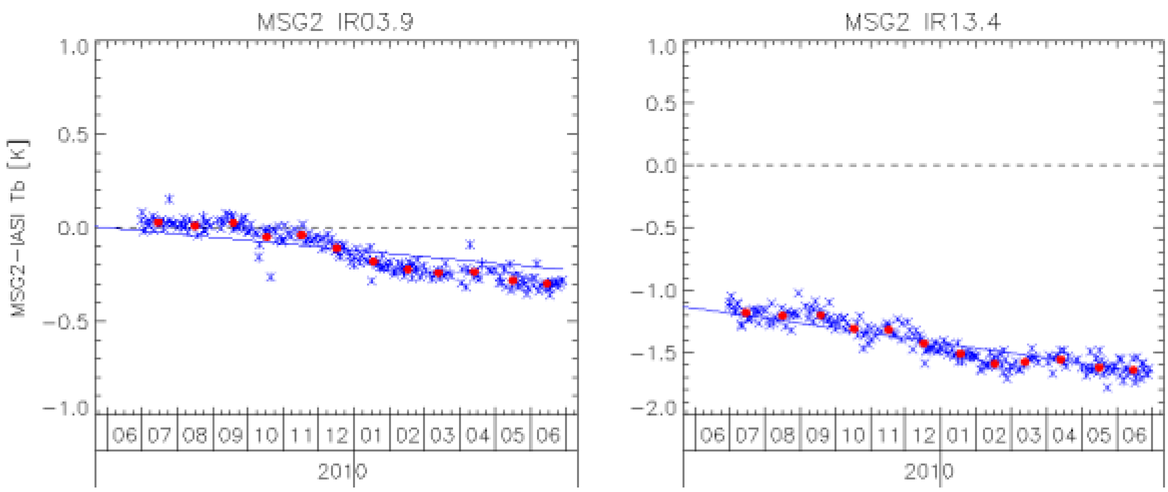


***Figure 2 – Time Series of bias in two channels of Meteosat-9/SEVIRI (MSG2) relative to Metop-A/IASI reference: 3.9 µm (left panel) and 13.4 µm (right panel). Biases are evaluated for clear sky standard atmosphere conditions at nadir and expressed as brightness temperature differences (K).***

Figure 2 shows a continued growth of the negative bias in the IR13.4 channel, which has been accompanied by a degradation of this channel's gain associated with build up of water ice contamination on the cold optics. This introduces increasing losses in the optical path, but also modifies the spectral response function of the SEVIRI channels, which affects the apparent calibration of the IR13.4 channel, as it is on the edge of the CO2 absorption band [EUM/MET/REP/08/0196].

Since the end of 2010, the IR3.9 channel has also started to develop a negative bias with respect to IASI. Although this channel is also with an ice absorption band, it is only expected to introduce a small calibration bias – and in the opposite sense [EUM/MET/REP/08/0196]. The underlying reason for this change is still under investigation.

Currently the SEVIRI Solar Channel Calibration system [Govaerts et al., 2001] relies mostly in views of selected desert targets, which are assumed to be invariant since characterisation by POLDER observations. However, recent studies [e.g. Ham and Sohn, 2010] have suggested the radiances of the VIS0.6 channels of Meteosat-8 and -9 may be underestimated by 6-7%. Although this is within the specified calibration limits of <±10%, this bias can be significant for some quantitative applications. It is expected that the GSICS Correction currently under development will allow the calibration of these channels to be improved.

## 2.3 Operational Monitoring of Metop Instruments

### 2.3.1 Monitoring at EUMETSAT and ECMWF

Operational monitoring of all Level 1 products from Metop instruments is providing daily performance monitoring reports. Statistics of all product quality flags, performance indicators of all on-board calibration processes are included. IASI radiance monitoring compares suitable selected instrument spectra with spectra simulated by runs of radiative transfer model RTTOV, based on ECMWF forecast atmosphere state. The selection is limited to fully clear sky samples at night time; the full spectra are compared.

Daily reports for GOME-2 and IASI are publicly available at http://oiswww.eumetsat.org/epsreports/html/index.php?instrument=GOME and http://oiswww.eumetsat.org/epsreports/html/index.php?instrument=IASI, respectively. Other reports are available internally and their dissemination on the Web site is planned.

The ECMWF contributes to Metop-A product monitoring with Web pages (http://www.ecmwf.int/products/forecasts/d/charts/monitoring/satellite/) monitoring satellite products against the ECMWF analysis; parameters are departure from first guess and from analysis (mean and standard deviation) and normalised standard-deviation of observation. Metop-A products monitored include GRAS radio-occultations, IASI, HIRS, AMSU-A and MHS radiance, GOME-2 ozone, ASCAT winds and soil moisture.

### 2.3.2 IASI level 1C radiances inter-pixel calibration anomaly

#### 2.3.2.1 Observation

Since July 2007, inter-pixel radiance differences in the IASI level 1C products exceeding 0.1 K were observed in some regions of the spectra. (Note that this inter-pixel difference is lower than 0.1% in terms of radiance.) This was not a non-conformance at instrument level because inter-pixel radiometry is specified on black body targets, and the inter-pixel difference was observed on atmospheric spectra. However, some applications, in particular trace gas retrievals using channels above 2000 cm-1 are affected. This point is also worth addressing in the frame of IASI reprocessing in order to produce hyperspectral climatological data records.

#### 2.3.2.2 Analysis

After some investigations, the on-ground processing algorithm was found not able to fully correct the impact of the cube corner constant offset. The two main differences between cube corner constant shear effect and others are the introduction of:

- A translation of the position of the $Zpd$ ($xzpd \neq 0$) and consequently even after the normalization, the contrast at $Zpd$ is no more 1. A side effect of this normalization is that all values of the apodisation function are affected. This normalization is necessary to take into account the radiometric calibration in the ISRF;
- An important asymmetry in the apodisation function: This is not fully representative of the processing occurring before the on-ground correction. Indeed, assuming the radiometric calibration is done correctly in the DPS, the phase has been removed and the spectrum should be almost real (only noise introduces a residual imaginary part). Therefore, the interferogram is no more dissymmetric. That means that the self-apodisation function considered in on-ground processing should be symmetrical with respect to $xzpd$. It was not the case in operational ground processing.

#### 2.3.2.3 Solution

The solution was to symmetrise the Self Apodisation Function (SAF) used to apodise the spectra in the on-ground processing and to resample by taking into account the true $xzpd$, even if that last point has only a minor impact.

In order to avoid modifying the operational ground processing software, CNES has implemented the symmetrisation of SAF and $xzpd$ re-sampling through the Spectral Data Base (ODB), the one used since 2011-02-07.

#### 2.3.2.4 Results

The inter-pixel signature has been largely reduced, especially in band 3. This has a positive impact, in particular on the retrieved CO total column in the IASI L2 trace gas products.

Note that a very small residual inter-pixel effect can still be observed, mostly in the difference between P1/P2 and P3/P4. It is mostly due to the “ghost effect” which is not corrected by the operational ground processing. The residual signatures are mostly seen in B1 and B3. The main reason for not correcting that effect is because its phase at $Zpd$ is different for all spectra and cannot be simply and accurately estimated in-flight.

#### 2.3.2.5 Outlook

It is planned to reprocess the IASI archive from the start of the mission, in the 2012/13 time frame. This will provide for a correction of the inter-pixel calibration anomaly in the IASI products from 2007 to 2010.

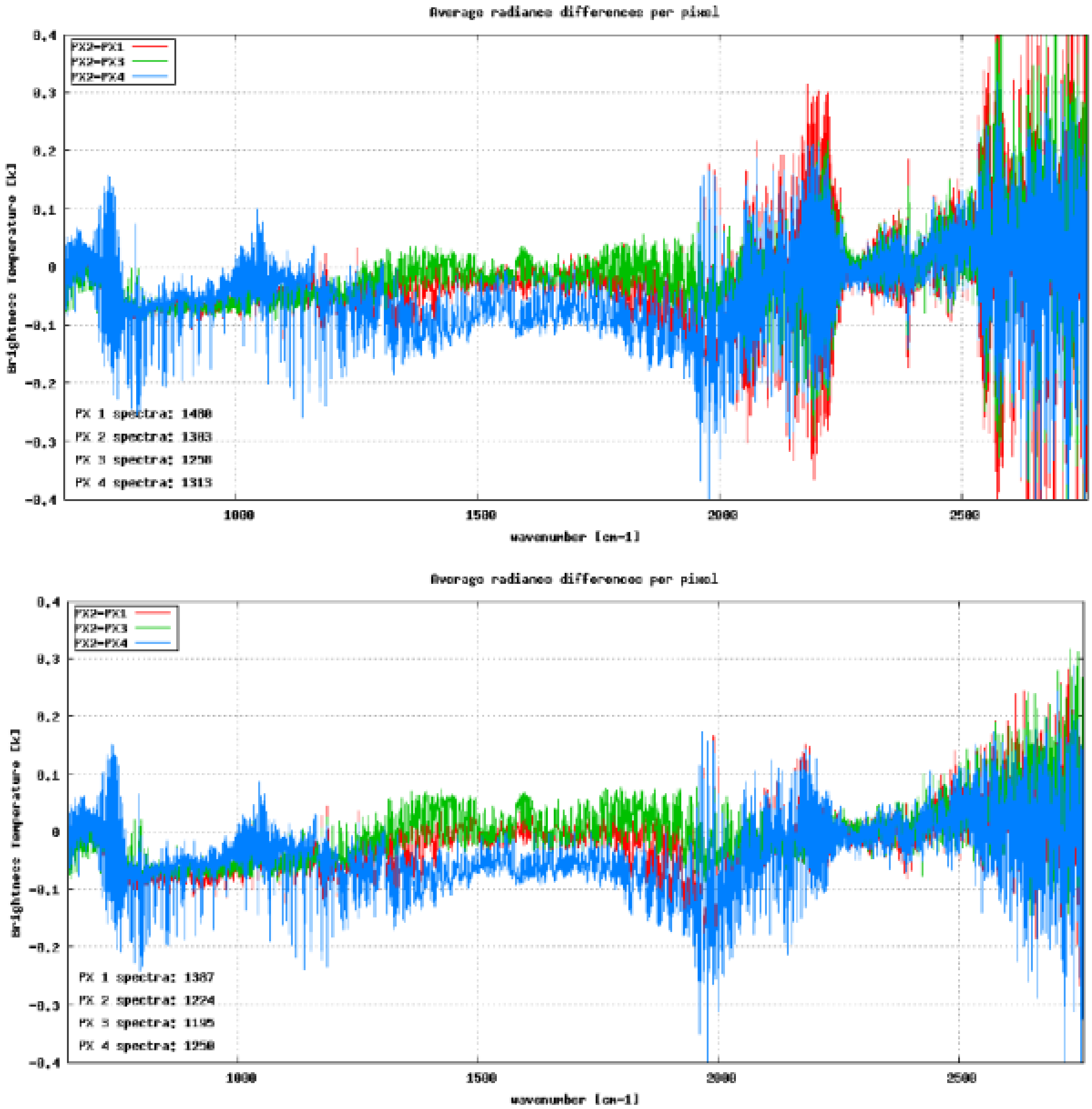


***Figure 3 Plot of the spectral distribution of average inter-pixel differences based on radiance monitoring, without (top) and with (bottom) the correction described in § above. The reference pixel is pixel 2.***

## 1.1 Process for Investigating Anomalies Reported by Users' Feedback

All anomalies or queries raised by users on the EUMETSAT products are analysed by the help desk, supported by experts. In particular, any potential anomaly is investigated in depth by the experts using in-house tools. If confirmed, it triggers activities for its correction in the operational system – for recurrent anomalies – and/or user documentation. The anomaly correction. once designed and validated, will be bundled with other changes in a processor release which is eventually introduced in the near-real time production systems. Reprocessing is performed with major releases.

# 3 PLANS FOR MONITORING FUTURE SATELLITE INSTRUMENTS

## 3.1 Plans for Development of GSICS Products for other Instruments/Channels

Inter-calibration products for the channels of Meteosat/SEVIRI in the reflected solar band are currently under development within GSICS. Various methods are being reviewed with the intention that some combination of them will be used to generate prototype GSICS Correction and Bias Monitoring products during 2012.

Developments are also underway at EUMETSAT to generate GSICS products from the routine inter-comparison of HIRS and AVHRR with IASI onboard Metop-A. These take advantage of the numerous collocated observations available from pairs of instruments operating on the same satellite platform and are expected to provide robust products, which tie the calibration of all infrared sensors on each Metop platform to a common reference (Metop-A/IASI).

## 3.2 Plans for Transition from Metop-A to Metop-B

A strategy has been developed at EUMETSAT to transfer the inter-calibration reference instrument from Metop-A/IASI to Metop-B/IASI. Because the satellites carrying these instruments will follow each other in offset orbits, direct comparison of collocated observations will not be possible. Instead, the relative difference in their calibration will be evaluated using *double-differencing* statistics against the common reference of Meteosat-9/SEVIRI and a *delta correction* functions derived to allow inter-calibration products generated with the reference instrument on one satellite to be transferable to the other.

# 4 CONCLUSIONS

A diverse suite of monitoring tools currently allow instrument operators to check their performance. These are being supplemented by GSICS Bias Monitoring products, which allow operators and users to check the instruments' calibration with respect to other, *reference* instruments. Anomalies identified in by these monitoring tools are investigated in a more thorough analysis by instrument engineers, which often result in corrections being developed – either physically-based or empirical. Corrections of this type should be implemented in EUMETSAT's reprocessing activities to generate Fundamental Climate Data Records (FCDRs).

Looking forward, there is a need for alignment and integration of instrument monitoring for the Sentinel Missions.

# 5 REFERENCES

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