CGMS

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GSICS SCIENTIFIC ACHIEVEMENTS 2007/2008

In response to CGMS action/recommendation R35.02

During 2007/08, EUMETSAT has initiated routine inter-calibration of the infrared channels of Meteosat imagers and the Infrared Atmospheric Sounding Interferometer (IASI) on Metop-A. A method has also been developed to inter-calibrate the High-resolution Infrared Radiation Sounder (HIRS/4) and IASI, both operating on Metop-A. These direct comparisons of collocated observations from pairs of instruments with similar characteristics form part of EUMETSAT's inter-calibration strategy to ensure consistency amongst its products and between those of other operation meteorological satellites. This requires international coordination, which is achieved through the Global Space-based Inter-Calibration System (GSICS).

This paper presents key results for Meteosat-7, -8 and -9 during 2007, which demonstrate the reliability of the inter-calibration method and show it can be used to monitor the gradual change in calibration bias of the 13.4 µm channel of Meteosat-9. This has been shown to be consistent with the build up of ice contamination on the instrument's optical elements and can be reduced by performing periodic decontamination processes – warming the instrument's optics to drive off contamination. The modelling of this process, together with the inter-calibration monitoring can be used to help understand the mechanism responsible for the changing biases and develop and validate operational corrections. Promising first results for the inter-calibration of HIRS/4 and IASI on Metop-A are also shown.

GSICS Scientific Achievements 2007/2008

1. INTRODUCTION

In accordance with the implementation plan of the Global Space-Based Inter-Calibration System (GSICS) resulting from the proposal to CGMS-33 EUMETSAT has participated in a number of meetings to discuss the needs and activities. This paper describes the method of performing routine comparisons between pairs of collocated observations from instruments with similar characteristics to inter-calibrate them. Initially this work has concentrated on the infrared channels of the geostationary Meteosat imagers and the Infrared Atmospheric Sounding Interferometer (IASI) on Metop-A, for which key results will be presented.

An inter-calibration method has also been developed for the infrared channels of the High-resolution Infrared Radiation Sounder (HIRS/4) and IASI, both operating on Metop-A. This method provides an important tie of HIRS to the current reference instrument (IASI), as the climate monitoring community has great interest in using HIRS as an inter-calibration reference instrument because it provides a long time series of observations from satellites dating back to the late 1970's.

These direct comparisons of collocated observations from pairs of instruments with similar characteristics form part of EUMETSAT's inter-calibration strategy to ensure consistency amongst its products and between these and those of other operation meteorological satellites. Another approach is being investigated in parallel by placing a study contract with a Numerical Weather Prediction (NWP) centre to provide bias monitoring data, comparing the same observations with NWP model fields to allow indirect comparison of different observations over a broader range of conditions than may be achieved by direct comparisons. In this way any biases from the NWP or associated radiative transfer model will be minimised when comparing the relative biases for two instruments.

2. OPERATIONAL IMPLEMENTATION

Together with the GSICS Data Management Working Group, a generic data processing path has been identified, defining the baseline for inter-satellite inter-sensor inter-calibration. This allows the processes for each step to be specified in a hierarchical manner, building on common general principles to specific details for each instrument pair. Datasets from each step of this process may be exchanged between GSICS partners to ensure consistency. NetCDF formats are being defined to facilitate this exchange [See CGMS-36 EUM-WP-21].

Routine processing of operational Meteosat-IASI inter-calibration is now underway. Near-real-time results will shortly be published on the GSICS section of the EUMETSAT website: http://www.eumetsat.int/Home/Main/What_We_Do/InternationalRelations/CGMS/SP_1214310159208?l=en. This will then be linked to the central GSICS webpages, hosted by NOAA: http://www.star.nesdis.noaa.gov/smcd/spb/calibration/icvs/GSICS/ for dissemination – both amongst the GSICS partners and publically.

3. KEY RESULTS FOR METEOSAT

3.1 Inter-Calibration of Meteosat Imagers with IASI during 2007

CGMS-35 EUM-WP-19 reported the use of IASI to simulate radiances observed by Meteosat Second Generation (MSG) SEVIRI instruments. This has been extended to include uncertainty estimation and now covers Meteosat-7, -8 and -9 for most of 2007. In this method, the mean and variance of the radiances in the Meteosat pixels closest to each IASI Instantaneous Field of View are calculated. This is repeated for all IASI pixels within ±30° latitude/longitude of the geostationary sub-satellite point where the instruments' view angles are within 2°. No filtering is applied to the data, so it now includes cloudy as well as clear scenes to cover a fuller range of radiances. A weighted linear regression is then calculated between the IASI and Meteosat radiances, accounting for the variance of the scene. This is used to estimate the mean difference between the instruments' radiances for a reference scene, together with an estimate of its uncertainty, which are finally converted to brightness temperatures (as above) as presented below.

The reference scene radiances have been derived for typical clear-sky scenes within the domain of the inter-comparison, as shown in Table 1. These statistics were found to be independent of the method of filtering the data. This validates the decision not to filter the data. As the difference between the instruments can depend on scene radiance, the regression method has also been applied to estimate the mean difference for cloudy scenes with lower radiances (T_b=200 K). However, the results were found to be highly variable for most channels.

Table 1 Brightness Temperatures,* T_b*, for Reference Scenes and Mean Difference between Meteosat and IASI during 2007.

Channel (µm)		3.9¶	6.2	7.3	8.7	9.7	10.8	12.0	13.4
Ref Scene T_{bref} (K)		290	240	260	290	270	290	290	270
Meteosat-7	Mean Bias (K)		**+2.57**				**-1.63**		
	Std. Dev. (K)		0.12				0.19		
Meteosat-8	Mean Bias (K)	**0.46**	**0.56**	**0.77**	**0.22**	0.19	**0.16**	0.13	-0.13
	Std. Dev. (K)	0.09	0.08	0.18	0.09	0.14	0.07	0.07	0.16
Meteosat-9	Mean Bias (K)	0.17	**0.61**	**0.25**	0.02	0.00	0.03	0.05	**-1.63**
	Std. Dev. (K)	0.10	0.05	0.04	0.04	0.07	0.06	0.06	0.26

¶ IASI response is limited to 2760 cm^{-1}, which underestimates radiance of a 290 K scene in 3.9 µm channel by 0.17 K.

The results in Table 1 are consistent with CGMS-35 EUM-WP-19 despite the different method: showing a large bias in the 13.4 µm channel of Meteosat-9, which was the operational geostationary satellite at 0° longitude for most of this period. The time series in Figure 3 show the biases in this and the 3.9 µm channels change during 2007, followed by a sudden recovery following the decontamination procedure of 3-11 December. The biases in the other channels remain constant, with small standard deviations ~0.05 K, and are similar to those found for Meteosat-8 (MSG1). All Meteosat biases show slow variations, which may be modelled using a Kalman Filter based on inter-calibration with IASI on a ~weekly basis.

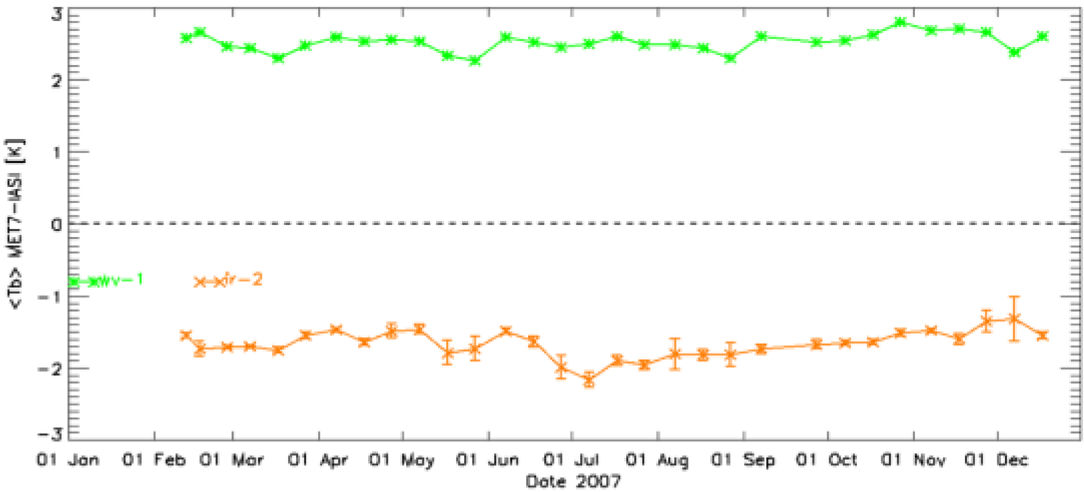

Figure 1 Time series of brightness temperature differences between Meteosat-7-IASI for Reference Scene radiances as above. Each Meteosat infrared channel is shown in a different colour, with different symbols, following the legend. Error bars represent statistical uncertainty on each mean bias (may be very small).

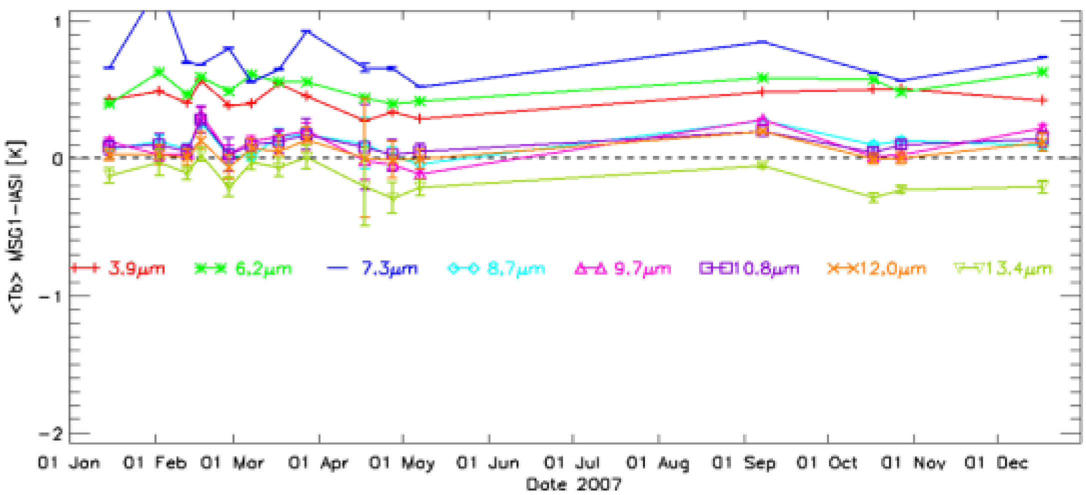

Figure 2 As above, but for Meteosat-8 (MSG1)

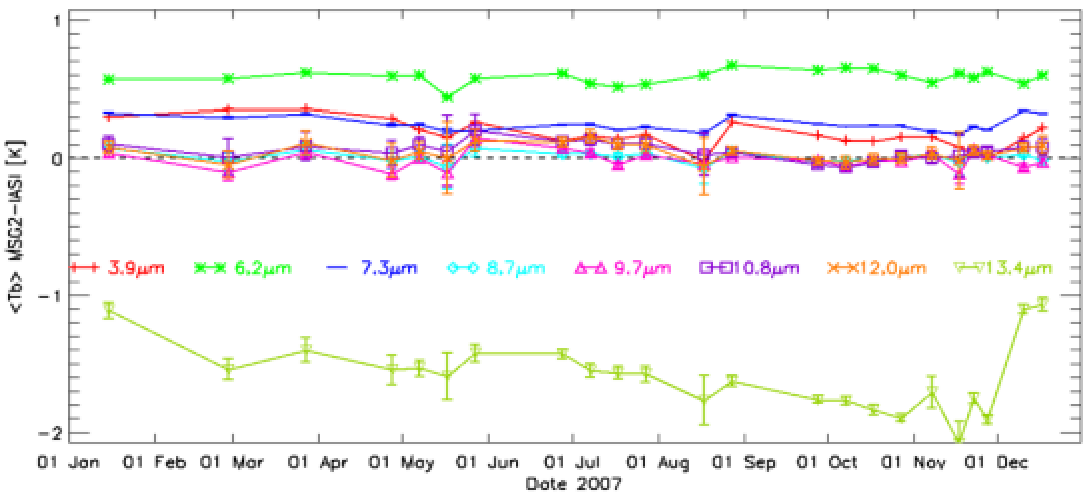

Figure 3 As above, but for Meteosat-9 (MSG2)

3.2 Ice contamination of the IR13.4 channel of Meteosat Second Generation

These inter-calibration results can be used to test the hypothesis that the change in biases are due to water ice condensing on the surfaces of the cold optics after outgassing from other material on the satellite. However, since the rates of outgassing and condensation are unknown, it is not possible to estimate the probable ice thickness on purely theoretic grounds. Differential absorption by this ice layer would modify the instrument's spectral response function (SRF). Although much of this would be accounted for in the internal calibration against black bodies, signals from channels in atmospheric absorption bands could remain biased.

CNES provided results of an ice transmission model used on IASI. This model has compared very well with the IASI measurements for a range of ice thicknesses from 12 nm to 3.7 µm, except for the short wavelength range (<4 µm). The modelled transmissions for 10 different ice thicknesses are plotted together in Figure 4, which also shows the SRFs of the infrared channels on Meteosat-8 (MSG1).

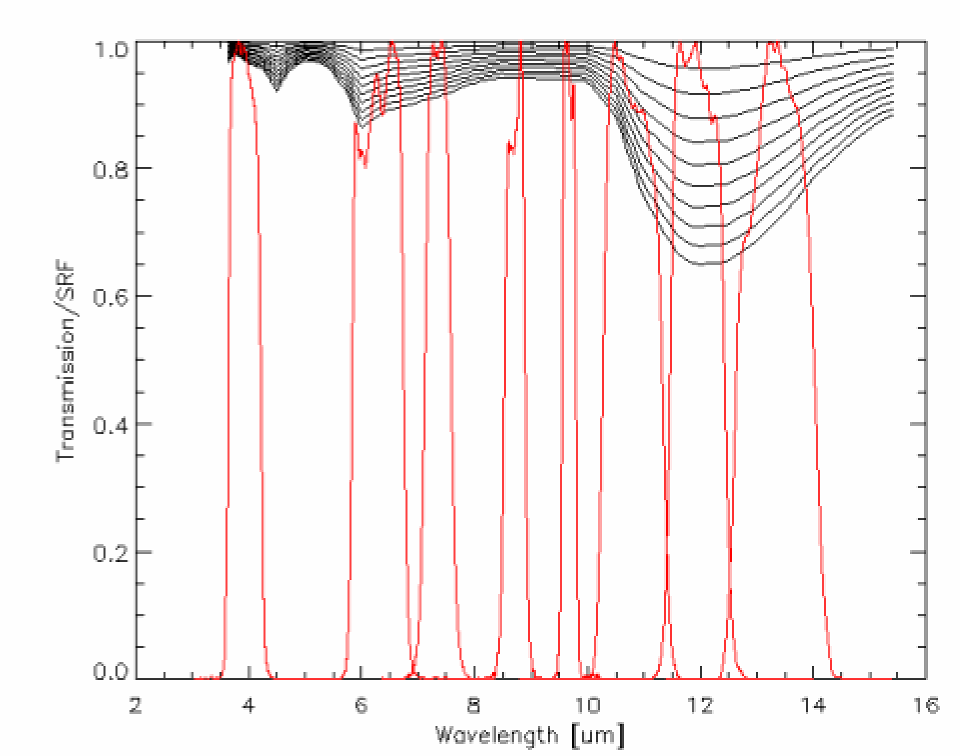

Figure 4 Transmission spectra of ice layers of different thicknesses (black): 0.1, 0.2, 0.3, 0.4, 0.5, 0.6, 0.7, 0.8, 0.9, 1.0 µm layers. Spectral Response Functions of Meteosat-8 infrared channels (red).

Radiances were simulated by convolving a typical radiance spectrum observed by IASI in clear sky with MSG SRFs – initially unperturbed, then modifying the SRFs by convolving them with the transmission spectra for various ice thicknesses. This was repeated for the black body calibration reference to establish the change in gain expected. Finally, the expected brightness temperatures (T_bs) were calculated for each MSG channel and compared with those using the original, unperturbed, SRFs.

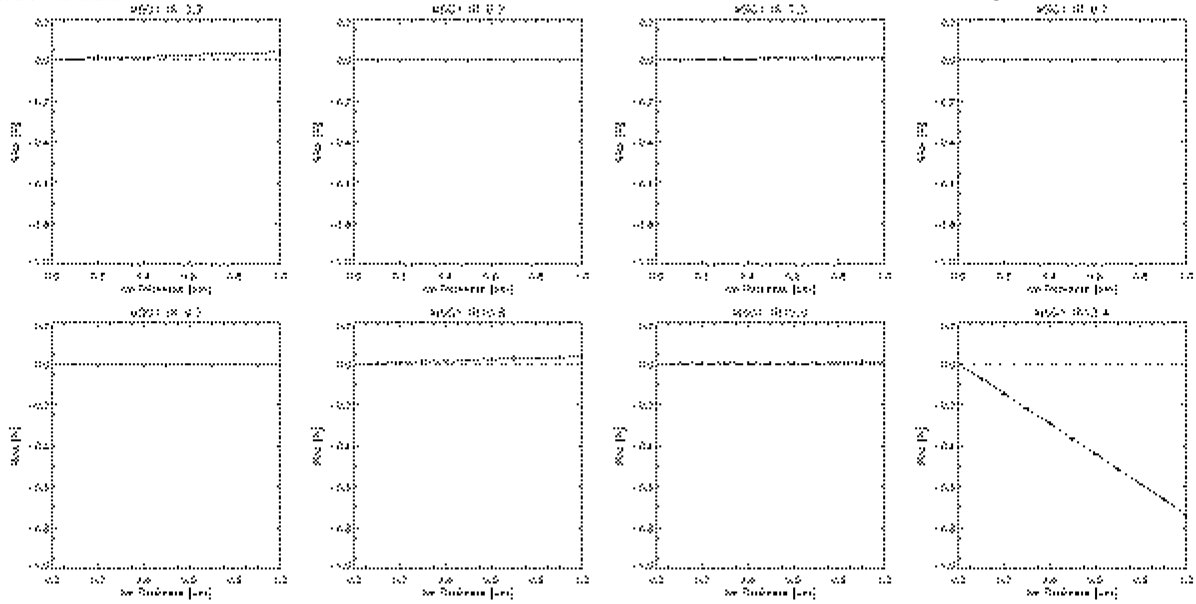

Figure 5 Bias in brightness temperatures modelled by modifying Meteosat-8's SRF by the transmission of different thicknesses of ice, following the model described above. Solid line with crosses shows the predicted differences in brightness temperature compared with the uncontaminated instrument, accounting for calibration gain changes. The dotted line shows the result without accounting for these gain changes.

The brightness temperature biases modelled in this way for each MSG channel are plotted in Figure 5 as a function of ice thickness. These predictions closely resemble the observed biases for Meteosat-9 in Figure 3: i.e. The IR13.4 channel shows a bias that changed at a rate of -0.7 K/yr, while other channels remained relatively unaffected by ice contamination. These results are consistent with the gradual build-up of a layer of ice ~1 µm thick over the year. This ice layer was removed by heating the optics during the decontamination process, after which the biases returned to their nominal values.

This theory is further supported by the independent observation that the gain of the IR12.0 channel changed following the decontamination procedure in a way consistent with a 50% transmission loss. From Figure 4 we see this is consistent with transmission through an ice layer ~1 µm thick, similar to that required to produce a change in bias of ~0.7 K for typical scene radiances, as shown in Figure 5.

4. KEY RESULTS FOR INTER-CALIBRATION OF HIRS-IASI

As both HIRS/4 and the Infrared Atmospheric Sounding Interferometer (IASI) operate on Metop-A, a global inter-calibration dataset can be derived allowing us to investigate the sensitivity of the HIRS calibration, relative to IASI, to various instrumental and geophysical parameters. Observations from HIRS and IASI on Metop-A are simultaneous to within 15 s, and they can share the same viewing angle to within 0.75°. However, because of their different instrument scan patterns and Fields of View (FOV), there can be significant geolocation differences between their pixels. In order to minimize data uncertainty, it is important to maximize the number of representative collocated pixels in the analysis, while reducing the negative impact of poor data collocation in highly inhomogeneous scenes. These criteria can be satisfied in the regression method by using a relatively large inter-pixel geolocation distance, and defining a representative *environment* to estimate the uncertainty introduced by geographic misalignment of each collocated pixel.

The collocation method adopted here compares HIRS pixels with area-averaged IASI pixels. Only HIRS pixels within boxes marked by the centres of a set of 4 IASI instantaneous FOV (iFOV) are taken. These HIRS pixels are compared with the mean radiance of the 4 IASI iFOV, which are also used to define the *environment*.

The radiances of each collocated HIRS pixel are compared to the IASI radiance spectra, convolved with HIRS spectral response functions (SRFs), in the following manner. For each HIRS channel, the HIRS and IASI radiances for a given collocated pair of data are weighted by the inverse of the radiance variance of the IASI pixels within its *environment*. Regressions are calculated between all collocated pairs of data within one orbital period. The slope of these regressions is not generally equal to 1. So to facilitate comparisons, reference scene radiances, have been derived, corresponding to typical radiances observed in clear sky conditions, as shown in Table 2.

Table 2 Reference scene Tb and relative biases of HIRS-IASI for two Metop orbits. Typical 1-σ uncertainty on bias ~0.01 K. The largest biases emphasized in bold.

HIRS Channel	Reference Scene, T_{bref} [K]	HIRS-IASI bias at T_{bref} [K]	
		2007-04-27 19:38-	2008-05-07 20:56-
1	230	-0.35	-0.06
2	220	-0.22	-0.06
3	215	-0.03	-0.04
4	225	0.12	0.04
5	240	**0.60**	**0.61**
6	255	0.22	0.18
7	265	0.20	0.23
8	285	0.08	0.10
9	260	0.00	-0.01
10	280	0.18	0.21
11	260	0.02	0.01
12	235	-0.25	-0.32
13	275	-0.03	-0.06
14	260	0.04	0.02
15	250	**-0.80**	**-0.76**
16	240	**-0.46**	**-0.45**
17	280	0.11	0.13
18	285	0.09	0.11
19	290	0.02	-0.02

The regression coefficients are applied to estimate the relative bias of HIRS-IASI for T_{bref}. The T_b biases for two cases, each comprising the night-time part of a Metop-A orbit, are shown in Table 2. All biases were found to be less than 1 K. In the second case, from approximately one year later, the first two channels had changed significantly. However, the other channels remained remarkably constant, with RMS differences of 0.03 K.

These encouraging first results suggest it may be possible to use HIRS/4 as an inter-calibration reference instrument, as it has small, stable biases, which can be modeled simply.

5. CONCLUSIONS

Within the framework of GSICS, a method has been developed to inter-calibrate the infrared channels of Meteosat and HIRS sensors using the Infrared Atmospheric Sounding Interferometer (IASI) on Metop-A. This method has been shown to produce reliable results with low uncertainties and provides the capability of monitoring changes in the relative calibration of the instruments. Furthermore, the inter-calibration datasets have allowed the testing of a hypothetical bias mechanism affecting the IR13.4 channel of Meteosat-9 and the development of operational corrections. The first results of the inter-calibration of HIRS-IASI are also encouraging as they suggest HIRS may be able to provide a stabile reference for the re-calibration of archived observations from other infrared instruments, and may provide an important source of climate-monitoring datasets.

CGMS is invited to take note of EUMETSAT’s scientific achievements within GSICS during 2007/2008 and to comment accordingly.

6. REFERENCES

Status of GSICS Implementation at EUMETSAT, CGMS-35 EUM-WP-19, Agenda Item II/7, Discussed in WG II, 2007.

GSICS data management achievements 2007/2008, CGMS-36 EUM-WP-21, Agenda Item II/2, 2008.