ICE CONTAMINATION OF METEOSAT/SEVIRI IR13.4 CHANNEL IMPLIED BY INTER-CALIBRATION AGAINST METOP/IASI

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ABSTRACT

The inter-calibration of the infrared channels of the geostationary Meteosat/SEVIRI satellite instruments shows most channels are radiometrically consistent with Metop-A/IASI, which is used as a reference instrument. However, the 13.4 μm channel shows a cold bias of ~1 K in warm scenes, which changes with time. This is shown to be consistent with the contamination of SEVIRI by a layer of ice ~1 μm thick building up on the optics, which is believed to have condensed from water outgassed from the spacecraft. This modifies the spectral response functions and hence the weighting functions of channels in stronger atmospheric absorption bands, thus introducing an apparent calibration error. Analysis of the radiometer's gain using views of the on board black body source and cold space confirm a loss consistent with transmission through a layer of comparable thickness, which also increases the radiometric noise – especially for channels near the 12 μm libration band of water ice. Inter-calibration, such as the Global Space-based Inter-Calibration System (GSICS) Correction, offers an empirical method to correct this bias.

Index Terms**—**Calibration, Decontamination, Earth Observing System, Infrared image sensors, Radiometers, Satellites

1. INTRODUCTION

The inter-calibration of the SEVIRI imagers on Meteosat-8 and -9 with Metop/IASI [1] revealed biases in the 13.4 μm channels, which grow larger with time and change abruptly after decontamination procedures. This supports the theory that the bias can be (at least partly) explained by a build-up of ice in the cold optics due to condensation of outgassing material from the spacecraft. This paper considers this theory of contamination and attempts to model its impact on the calibration bias of SEVIRI's infrared (IR) channels. These predictions are compared with observations – both in the form of inter-calibration of SEVIRI with IASI, and by examination of SEVIRI's relative gain changes before and after decontamination procedures.

2. DECONTAMINATION PROCEDURES

Condensation of particle or chemical contamination on the cold optics of the SEVIRI must be periodically removed to ensure that the instrument remains within the acceptable mission limits. The process is relatively simple, however it does take several days and can be carried out up to twice a year to obviate this degradation. Heaters are employed to warm the detector optics causing the contaminants to evaporate, after which the instrument is allowed to cool down back to 95 K. Meteosat-8 and -9 were launched on 2002-08-28 and 2005-12-21, respectively. Spacecraft decontaminations have been performed on Meteosat-8 between 2005-01-10/13, 2006-01-09/12 and 2008-01-07/10 and on Meteosat-9 between 2006-06/26/27, 2006-12-11/14, 2007-12-03/10 and 2008-12-01/04.

3. THEORY

The basic hypothesis to be tested here is that the change in bias of the SEVIRI channels is due to a build-up of ice, which condenses on the surfaces of the cold optics after outgassing from other material on the satellite. This process has been known about since at least the time of Meteosat First Generation [2]. This material is most likely to be water ice [3]. However, since the rates of outgassing and condensation are unknown, it is not possible to estimate the ice thickness on purely theoretic grounds. Furthermore, it is not known exactly where in the instrument optics the ice is likely to condense, although in SEVIRI, the first surfaces to trap contaminants are the optical bandpass filters inside the cold IR optical bench [4]. The contamination will affect both the gain of the associated channels, as well as their Spectral Response Functions (SRFs), which will influence the radiometric noise and bias of the instrument's final calibrated radiances.

Differential absorption by this ice layer modifies the instrument's SRF. Although much of this is compensated for in the calibration processes, whereby the instrument's view of cold space and a hot black body are used to derive its gain and offset, any unidentified changes in the SRF could bias the observed scene radiances.

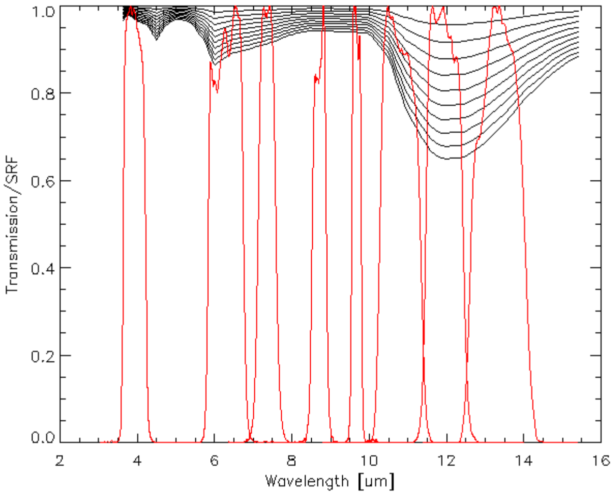

Figure 1. Transmittance spectra of ice layers of different thicknesses (black): 0.1 to 1.0 µm layers (thickest layers have lowest transmittance) and Spectral Response Functions (SRFs) of Meteosat-8 infrared channels (red).

The radiance, Li, measured in channel i of an uncontaminated instrument, with SRF, ri,ν, viewing a scene with radiance spectrum, Lν, is:

$$L_i = \frac{\int L_\nu r_{i,\nu} d\nu}{\int r_{i,\nu} d\nu} \qquad (1)$$

Viewing the hot black body, with radiance Bν(TH), the uncontaminated instrument sees a radiance, Li,H:

$$L_{i,H} = \frac{\int B_\nu(T_H) r_{i,\nu} d\nu}{\int r_{i,\nu} d\nu} \qquad (2)$$

Viewing this scene when the SRF is convolved with an ice transmittance, τν, the radiance, Li,H’, is:

$$L'_{i,H} = \frac{\int B_\nu(T_H) r_{i,\nu} \tau_\nu d\nu}{\int r_{i,\nu} \tau_\nu d\nu} \qquad (3)$$

Assuming the space view radiances remain zero, the apparent gain of the instrument, Gi=L’i,H/ L’i,H , is applied to calculate the apparent radiance of a scene, Li’:

$$L_i' = \frac{\int L_\nu r_{i,\nu} \tau_\nu d\nu}{\int r_{i,\nu} \tau_\nu d\nu} \frac{L'_{i,H}}{L_{i,H}} \qquad (4)$$

4. ICE TRANSMITTANCE MODEL

In this study we use the composite model of ice optical constants compiled from various observations by Warren and Brandt [5]. Although these are strictly only valid at 266 K and are temperature dependent, no quantitative data was found for ice at temperatures close to those of SEVIRI’s cold optics. Additionally, thin films of ice can introduce interference effects, which can modify its transmittance – especially where its thickness approaches the wavelength of radiation. These have not been accounted for in this analysis, as the optical characteristics of the underlying surface are not known. Figure 1 shows the transmittance spectra of layers of various ice thickness from 0.1 to 1.0 µm, superimposed on the SRFs of the 8 IR channels of Meteosat/SEVIRI.

5. PREDICTED AND OBSERVED GAIN AND BIAS CHANGES IN METEOSAT/SEVIRI

To evaluate the difference between L_i' and L_i, a typical scene radiance spectrum, L_ν, was taken from a single IASI observation (on 2007-07-07 21:00 at 0°N, 0°S). $L' - L$ was evaluated over the range of ice transmittance spectra, $\tau_{i,\nu}$, given in Figure 1. The results are expressed in terms of brightness temperatures in Figure 2.

Only the 13.4 µm channel, which is on an ice librational band, is predicted to be sensitive to contamination because the ice modifies the SRF, and hence weighting function, of this channel, which lies on the edge of an atmospheric CO2 absorption band. The resulting ~0.7 K change in bias of the 13.4 µm channel bias for an ice thickness of 1 µm is consistent with the changes observed in the inter-calibration of Meteosat-9/SEVIRI during the 2007 decontamination, which showed a trend of -0.72 K/yr. The only other channel with a statistically significant trend was IR3.9 (-0.30 K/yr), which was not expected from the model results shown in Figure 2 – probably because thin film effects influence the transmittance of ice layers in this channel.

Inter-calibration results after each decontamination procedure confirm the bias in both these channels briefly return to values comparable to those found after the previous decontamination before continuing to degrade. Although Meteosat-9 was launched later than Meteosat-8, the IR13.4 channel of both instruments showed jumps of ~ +0.8 K during the decontamination procedures of December 2007 and January 2008, respectively.

Meteosat-9 Channel	IR3.9	IR6.2	IR7.3	IR8.7	IR9.7	IR10.8	IR12.0	IR13.4
Gain Change	5.3%	10.0%	6.0%	5.7%	2.3%	23.0%	50.3%	30.0%
Ice Thickness (µm)	0.5	0.6	0.5	0.7	0.3	1.0	0.8	0.6

Table 1 – Gain changed measured following December 2007 decontamination of Meteosat-9 and implied ice thickness.

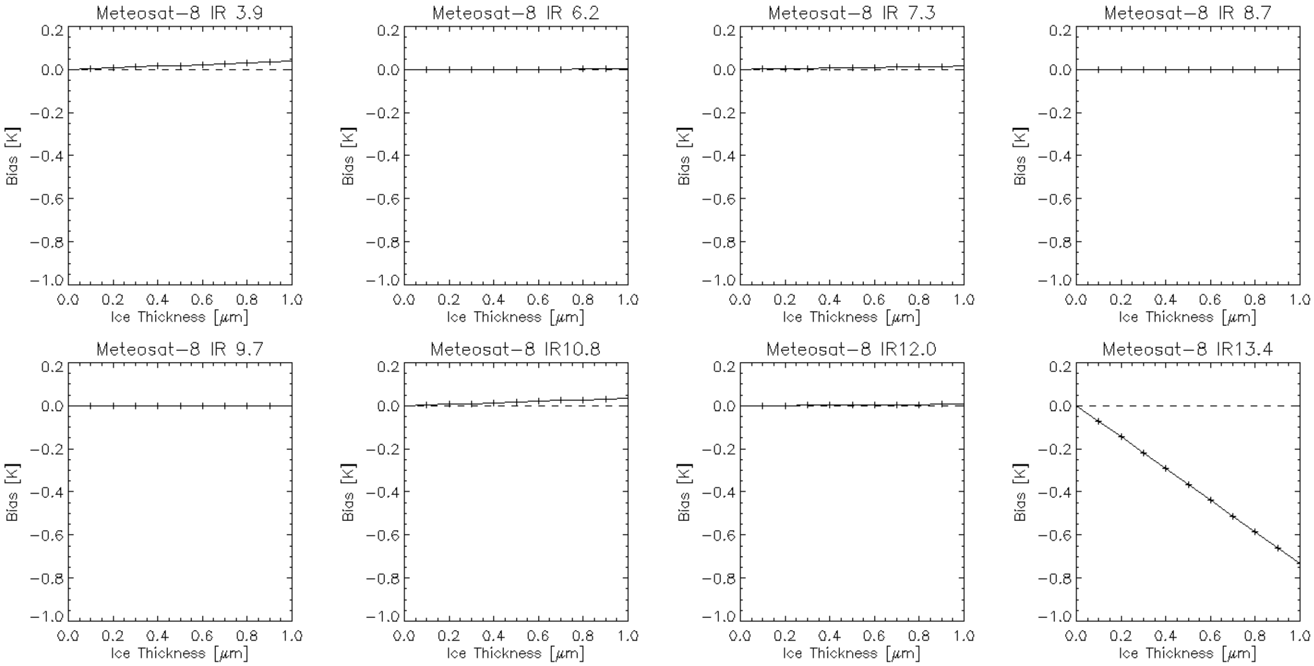

Figure 1 – Bias in brightness temperatures modelled by modifying Meteosat-8's SRF by the transmittance of different thicknesses of ice, following the model described above. Solid line with crosses shows the predicted differences in brightness temperature compared with the uncontaminated instrument, accounting for calibration gain changes.

Table 1 shows a 50% change in gain in the 12.0 µm channel following the decontamination, which implies from Figure 1 that the ice layer was ~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 2.

6. CONCLUSIONS

Changes in the gain of Meteosat/SEVIRI's IR channels and the bias of its IR13.4 channel (by inter-calibration with Metop/IASI) are shown to be consistent with contamination of its optics by the build-up of an ice layer ~1 µm thick during the period between decontaminations. It may be possible to extend the simple model presented here to account for observed changes in the IR3.9 channel by including thin film effects.

7. REFERENCES

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