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REPORT ON INVESTIGATIONS ON SPECTRAL REPSONSE FUNCTIONS OF CURRENT AND PREVIOUS SATELLITES

This paper responds to Action 27.14 of CGMS XXVII requesting 'all satellite operators to initiate investigations whether spectral response functions (SRF) of current and previous satellites are potentially erroneous and quantify the error if possible'. Here we present various findings of relevance to Action 27.14. First we present figures for the accuracy of the Meteosat IR and WV SRFs. Secondly we recall the problem with previous Meteosat VIS SRFs.

REPORT ON INVESTIGATIONS ON SPECTRAL RESPONSE FUNCTIONS OF CURRENT AND PREVIOUS METEOSAT SATELLITES

1. INTRODUCTION

This paper responds to Action 27.14 of CGMS XXVII requesting ‘all satellite operators to initiate investigations whether spectral response functions (SRF) of current and previous satellites are potentially erroneous and quantify the error if possible’. The action arose from the suspicion or firm knowledge of shortcomings and inaccuracies in the actual spectral response functions of operational satellites. It is felt that this issue has been neglected for a long time. The neglect of a proper and accurate characterisation of spectral response functions can be tolerated when using a satellite radiometer simply in a qualitative manner, e.g. for the evaluation of image data. Small uncertainties in the SRF may not cause major problems in the derivation of operational products either, due to compensating effect (e.g. geophysical calibration and validation using other products), however the SRF needs to be known accurately when longer term satellite data are used for climate analysis.

Here we present various findings of relevance to Action 27.14. First we present figures for the accuracy of the Meteosat IR and WV SRFs. Secondly we recall the problem with previous Meteosat VIS SRFs.

2. IR AND WV CHANNEL SPECTRAL RESPONSE OF THE METEOSAT SATELLITES

The relative spectral responses of the Meteosat IR and WV channels are not measured but computed as the overall response from the measurements obtained on each component which are detectors and the optical components (mirrors, lenses).

The responses are measured at two temperatures: 85 K and 110 K for Meteosat-5 and Meteosat–6, 90 K and 97 K for Meteosat-7. The final response functions are tabulated in the following way:

- for Meteosat-5: 28 values between 8.00 µm and 14.75 µm at 0.25 µ spacing for IR
  21 values between 3.00 µm and 8.00 µm at 0.25 µm spacing for WV
- for Metoesat-6: 28 values between 8.00 µm and 14.75 µm at 0.25 µ spacing for IR
  19 values between 3.00 µm and 8.50 µm at 0.25 µm spacing for WV
- for Meteosat-7: 17 values between 10.00 µm and 14.00 µm at 0.25 µm spacing for IR
  22 values between 5.40 µm and 7.50 µm at 0.10 µm spacing for WV

The overall accuracy of these measurements are ±10% for Metesoat-5 and Meteosat–6, and ±6% for Meteosat-7, as quoted by the manufacturer.

The detector spectral response measurements exhibit a high frequency oscillation with a period of 2 cm^{-1} (i.e. about 0.03 µm for the IR channel and 0.008 µm for the WV channel). These oscillations have a peak to peak amplitude of about 10% of the maximum response. These oscillations are not reflected by the tabulated filter functions, which just present an average.

3. SOLAR SPECTRAL RESPONSE FUNCTION OF METEOSAT

The vicarious calibration of broadband instruments such as the radiometer on board Meteosat, the European meteorological geostationary satellite, requires the characterisation of both the Sensor Spectral Response (SSR) and the calibration target spectral radiance at the top of the atmosphere. The Meteosat satellites have been designed more than 20 years ago, essentially for operational imagery purposes. Hence, the SSR was originally poorly measured, in particular for the visible (VIS) channel. Consequently, the calibration of this band suffers from a lack of reliable SSR values, at least for the VIS detectors of the Meteosat-5 and –6 radiometers. It is indeed very likely that the pre-launch SSR characterisation of these two radiometers is erroneous. It is therefore suggested to replace these curves by the response of the Meteosat-7 radiometer VIS channel, which has been accurately measured. The impact of this modification on the VIS channel vicarious calibration of Meteosat-5 and -6 is discussed in this paper.

3.1 Suggested modification

The visible band spectral response of Meteosat radiometers is essentially determined by the properties of the telescope optics and the silicon photo-diode detector. Figure (1) shows the spectral response of the Meteosat -5 to -7 VIS detectors. All these silicon detectors have been produced in the same batch and should, therefore, have identical spectral behaviour. The shape of Meteosat-5 and -6 SSR is, however, quite different from Meteosat-7 SSR, as seen in Figure (1).

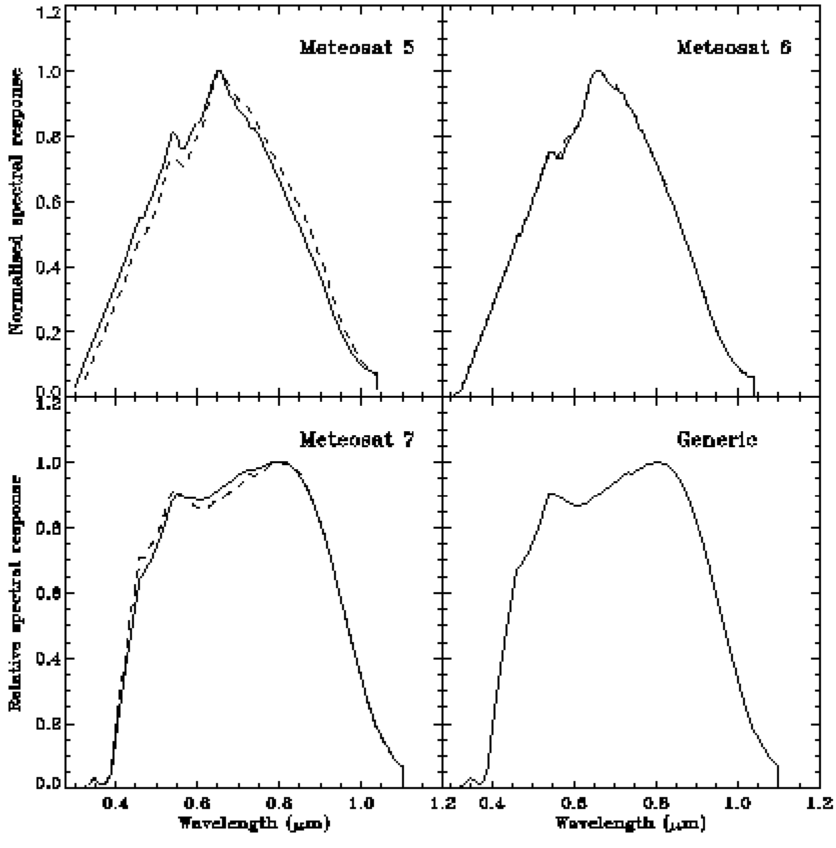

Figure 1: VIS 1 (solid line) and VIS 2 (dashed line) spectral response (optics plus detector) of the METEOSAT-5, -6 and –7 radiometers. The “generic” curve corresponds to the mean spectral response of the four VIS

detectors of the Meteosat-7 radiometer.

The SSR characterisation of Meteosat-7 has benefited from improved pre-launch measurement techniques. The spectral response has been acquired with an error of ±5% and with a variation from detector to detector smaller than 10%, according to the instrument's main supplier. Unfortunately, these improved techniques were not used for the Meteosat-5 and -6 VIS detectors. As a result, the sensor response curves are more reliable for Meteosat-7 than for Meteosat-5 and –6 radiometers.

It is therefore suggested to replace the SSR of Meteosat-5 and -6 by the mean value of the four detector spectral responses of Meteosat-7. This new SSR will be referred to as the "generic" SSR. It is expected that this modification should affect the derived effective radiance and therefore the sensor calibration. The effective radiance L_s is defined here as

$$L_s = \int r(\lambda)\, L(\lambda) d\lambda$$

where L_s is the incoming spectral radiance and L_s the normalised SSR. The impact of this correction on L_s has been assessed over two targets that exhibit different spectral behaviour. The first target is a sea surface located in North. The second target is a bright desert located in Tunisia. The proposed correction affects L_s differently as a function of the target spectral behaviour. Its impact on the sensor vicarious calibration is quantified in the next section.

3.2 Impact on the radiometer calibration

The calibration of an instrument is the determination of the relation between the effective radiance L_s, and the radiometer output, with

$$L_s = c_s\,(DC - DC_0),$$

where c_s is the calibration coefficient ($Wm^{-2}sr^{-1}$/COUNT) and DC_0 is the offset or zero intercept. Since c_s relates the digital output DC to the effective radiance L_s, it should not depend on the spectral variations of the incoming radiance $L(\lambda)$, if the radiometer responds linearly with respect to intensity.

The impact of the proposed change on the calibration coefficient has c_s been evaluated over the two calibration targets. To reduce the instrumental noise effects and calculated radiance error on the VIS channel calibration, from several tens up to several hundreds of images have been processed for each satellite according to the target type.

	Original SSR			Generic SSR		
	sea	bright desert		Sea	Bright desert	
	c_s	c_s	R	C_s	c_s	R
M-5 1995	0.87±0.089	0.71±0.015	1.23±0.128	0.87±0.091	0.85±0.016	1.02±0.109
M-6 1997	0.82±0.070	0.71±0.015	1.15±0.102	0.86±0.073	0.85±0.018	1.01±0.089
M-7 1998	0.87±0.110	0.86±0.023	1.01±0.131			

Table 1: Calibration coefficients c_s ($Wm^{-2}sr^{-1}$/COUNT) derived from meteosat-5 in 1995, Meteosat-6 in 1997 and Meteosat-7 in 1998 over sea and bright desert. R is the ratio between c_s derived over sea and desert.

The values of c_s and its error are shown in Table (1) for the different processed periods and targets. This table shows also $R = c_{s,SEA}/c_{s,DESERT}$, the ratio between the calibration coefficients derived over sea and desert. For the case of a linear response of the sensor with respect to intensity, R should be equal to one, whatever the value of L_s. For Meteosat-5 and -6, R is in the range of 1.15 - 1.23 when the calibration coefficients are derived using the original SSRs.

These results indicate an inconsistency in the sensor calibration since the departure of *R* from one is larger than its estimated error.

The VIS detectors of Meteosat-5 and -6 have been designed with a specified signal to noise ratio (SNR) greater than 200:1 at 80% of the maximum signal level at the nominal gain. This SNR corresponds to theoretical measurement errors smaller than 1 count. In practice, these specifications seem to be respected. Both sea and bright desert calibration sites consist of a 3×3 pixel window. Over sea, the standard deviation of the observed digital counts does not exceed 0.5. Over the desert site, the standard deviation is 0.8, but may be affected by the target inhomogeneity. The detector and digitiser linearity may also affect the observed signal. According to the pre-launch characterisation, the non-linearity of the radiometer electronics is less than ±0.5 counts. Assuming no error in the radiative transfer computation, a theoretical instrumental noise or non-linearity of at least 2 (10) counts over sea (desert) is necessary to explain the discrepancy of *R* as derived with the original SSRs. Such an instrumental failure is not realistic.

When c_s is derived using the generic SSR for Meteosat-5 and -6 radiometers, the value of *R* is close to one (right column of Table 1). These values compare well with the value of *R* derived for Meteosat-7. These results show that the proposed spectral correction improves the consistency of the Meteosat-5 and -6 sensor calibration.

4. CONCLUSION

The paper responds to Action 27.14 of CGMS XXVII requesting ‘all satellite operators to initiate investigations whether spectral response functions (SRF) of current and previous satellites are potentially erroneous and quantify the error if possible’. Various findings of relevance to Action 27.14 have been presented. First figures for the accuracy of the Meteosat IR and WV SRFs are presented. Further analysis is needed to study the implications of those errors, e.g. on satellite inter-calibration.

As a second item we recall the problem with previous Meteosat VIS SRFs. It has been shown that the vicarious calibration of the Meteosat-5 and -6 VIS channel is inconsistent, most likely because of inaccuracies of the original SSRs.

It is suggested that:

- for future satellites special care is given to measuring the spectral filter response functions.
- With regard to current and previous satellites investigations are encouraged to assess the error bars of the spectral response functions.

Such efforts are indispensable if the satellite data are used for climatological and climate analysis from different satellites.