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THE IMPORTANCE OF USING CLEAR RADIANCES AND NEAR-NADIR VIEWS FOR SATELLITE INTERCALIBRATION

This paper responds to Action 27.13 of CGMS XXVII requesting 'satellite operators performing cross-calibration to study the importance of cloud-clearing and near-nadir viewing for intercomparisons and to report to CGMS XXVIII'. It provides a detailed summary of the relevant studies performed by EUMETSAT. On the basis of those studies the paper concludes with regard to Action 27.13.

THE IMPORTANCE OF USING CLEAR RADIANCES AND NEAR-NADIR VIEWS FOR SATELLITE INTERCALIBRATION

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1 INTRODUCTION

This paper responds to Action 27.13 of CGMS XXVII requesting 'satellite operators performing cross-calibration to study the importance of cloud-clearing and near-nadir viewing for intercomparisons and to report to CGMS XXVIII'. It provides a detailed summary of the relevant studies performed by EUMETSAT. On the basis of those studies it provides conclusions with regard to Action 27.13. The paper goes beyond the very confined Action by discussing the intercalibration in a wider context.

Previous papers from EUMETSAT to CGMS have reported on satellite intercalibration. The issue of satellite intercalibration has been of particular interest to EUMETSAT, as a new on-board black-body calibration is only recently operationally in use. This new method is reported in EUM WP-28. Before the operational calibration of the Infrared Window (hereafter referred to as IR: 10.5 – 12.5 µm) and Water Vapour (WV: 5.7 – 7.1 µm) channel relied on vicarious calibration techniques as described by Gube et al. (1996) and Van de Berg et al. (1995). It has been argued that those techniques are prone to bias errors (e.g. Sohn et al., 2000) and, hence, satellite intercalibration studies are of great value to detect potential (relative) bias errors. More generally the need for satellite intercalibration has also been recognised by the International Satellite Cloud Climatology Project (ISCCP) (e.g. Desormeaux et al., 1993).

For the current Meteosat series the observed radiances, for both the IR and WV channel, are linearly related to the engineering unit "count" measured by the satellite:
$R = \alpha (c - c_0)$

where R represents the radiance in W/m^2/ster, α the calibration coefficient, c the measured count and c_0 is the so-called "space count', the radiometric offset of the instrument.

2 INTERSATELLITE CALIBRATION METHOD

The method compares the observations by two satellites over areas which are within the field of view of either satellite – the calibration targets. Ideally, these two measurements would be identical, provided that the two satellites have identical radiometers, same calibration and that the target is seen under identical viewing conditions at exactly the same time. In practice, the measurements will be different because:

i. The two satellites do not have the same spectral response. As the measured radiance is

$$R = \frac{\int R(\Theta)\ \Phi_\nu\ d\nu}{\int \Phi_\nu\ d\nu}$$

with R: radiance at the top of the atmosphere into the direction Θ of the satellite
Φ: filter response function
ν: wavenumber

the satellites will measure different radiances

ii. The satellites do normally not see a given calibration target at exactly the same time. A larger time difference implies changing atmospheric conditions, especially concerning the presence of clouds.

iii. The satellites do not have the same spatial resolution. The Meteosat IR channel has a spatial resolution of 5 km x 5 km, NOAA AVHRR a 1 km * 1 km resolution (LAC) or 3 km * 3 km resolution (GAC).

iv. The satellites do not necessarily view the same scene under the same viewing angle.

We are thus faced with the fact that we have to account for spectral response differences, for space and time constraints, and for the respective viewing geometry.

2.1 Correction for Spectral Response Differences

Generally speaking, the inter-satellite calibration method should of course only be applied to radiances measured by similar channels – in our case, all atmospheric window channels in the 10 – 12 µm range are of interest. However, even small differences in the satellite spectral response lead to different measurements, and the method has to account for that. Figure 1 shows the infrared window spectral response functions of Meteosat-7 IR and of channels 4 and 5 of the AVHRR instrument on board NOAA-14. Noticeable is the somewhat wider spectral response of the Meteosat IR filter compared to the respective two “split-window” channels.

The spectral response corrections are inferred from radiative transfer calculations which take the different filter functions into account. Test runs over a wide variety of atmospheric conditions have shown that there is a well-defined relationship between either two radiances of the above channels. These relationships can be described with simple linear functions (Tjemkes and Schmetz (1997), Figure 2 may serve as an example. The model results also show that – although the actual radiances decrease with increasing viewing angle – this linear relationship is practically maintained for viewing angles between 0º and 50º. This pretty much simplifies the spectral response correction, as a unique function describes any set of two instruments. The values used in this work are listed in Table 1.

2.2 Collocation in Space and Time

The present method uses tight collocation criteria in both space and time. Collocation in space is done using the satellites' operational navigation or earth location, and radiances are averaged over 5 x 5 AVHRR GAC (global area coverage) pixels. The corresponding Meteosat measurement is taken from those Meteosat pixels which fall into the 5 x 5 pixel bins. Time collocation is such that the Meteosat image closest to the respective NOAA scan time is used. Sections 3.1 and 3.3 will come back to these points.

2.3 Viewing Geometry

Only those targets are retained which are seen within a viewing angle of less that 50º and with an absolute difference of viewing angles between the two satellites of less than 5º. The implication of these selections is further discussed in section 3.2.

To summarise the method, the following steps are taken for a given pair of two images form two satellites:

5 x 5 pixel areas of the AVHRR or GOES image are retained as a valid calibration target if
- (a) the area is seen with a viewing angle of less than 50º by either satellite;
- (b) the viewing angles do not differ by more than 5º;
- (c) the mean AVHRR radiance over this target is taken (using the operational calibration of these instruments), the radiance is mapped into the Meteosat spectral response using the coefficients of Table 1;
- (d) the mean Meteosat count of the respective Meteosat pixels is taken, space count is subtracted;
- (e) a 'local' Meteosat inter-satellite calibration coefficient is computed as the ratio of radiance and count value;
- (f) a 'final' inter-satellite calibration coefficient is derived as the mean over all local coefficients for the considered image pair.

Figure 3 shows as example the locations of possible calibration targets within a NOAA-14 orbit across the Meteosat field of view. The selected viewing geometries constrain the targets to two strips east and west of the sub-satellite track.

3 APPLICATION

This section presents results for a variety of image pairs and discusses the implications of the processing constraints mentioned above.

A set of cases compares both Meteosat satellites with NOAA-14 AVHRR (in the GAC resolution) over the time period of one month during 1998. Before the actual cross-calibration, the data of both satellite images were additionally processed with a scenes analysis software. The scenes analysis algorithm is described in detail by Lutz (1999). The objective here was to identify only those targets as valid calibration targets, which, in addition to the above mentioned constraints, are identified as a cloud-free sea surface so that only horizontally homogeneous surfaces are compared.

Table 2 lists the results obtained for these seven comparisons of Meteosat-7 with NOAA-14 AVHRR and of the five comparisons of Meteosat-5 with AVHRR.

3.1 Cloud Information and Time Collocation

As mentioned before, the above results were obtained from cloud-free sea surface type calibration targets. Time differences between individual scans were never larger than 45 minutes, and it can be expected that the sea surface temperature does not drastically change over that time. However, if all calibration targets irrespective of any cloud information are regarded, time becomes more important: Clouds move into (or out of) the field of view of individual pixels rather quickly. Also, land surfaces in the field of view can heat up or cool down quickly, e.g. over desert areas. Thus, to ensure that both satellites view the same scene (i.e. temperature), the regarded pixel groups should be scanned within a short time interval between the two satellites. The following may assess this point more quantitatively:

For the Meteosat-5/AVHRR case on 16 September 1998, the NOAA orbit was such that it travelled south to north across the Indian Ocean and was thus in line with the Meteosat scan direction. Time differences between the selected calibration targets were always less than 5 minutes. Using ‘all-sky’ targets instead of the cloud-free targets results in calibration coefficient of:

α(all sky) = 0.074510 $\pm$ 0.00109

compared to the previously cited

α(clear sky, sea surface) = 0.074613 $\pm$ 0.00108.

These values apply to AVHRR channel 4. The given uncertainties are the uncertainty due to the scatter of the individual radiance/count pairs processed for the entire image. Compared to this overall uncertainty, the two calibration values agree very well, and their difference would only account for a temperature difference of less than 0.1 K.

Opposed to this is a case with a large time difference: For the Meteosat-7/AVHRR comparison on 19 August 1998 (morning case), the NOAA orbit was opposite to the Meteosat scan direction, and the time difference is for some targets as large as 45 minutes. The ‘all-sky’ result for this case is

α(all sky) = 0.107104 $\pm$ 0.001805

compared to

α(clear sky, sea surface) = 0.107313 $\pm$ 0.000667

Although the mean values do not show any dramatic difference, the uncertainty due to scatter of course increases with larger time differences.

The all-sky method has the advantage, that the tedious ‘scenes-analysis’ pre-processing can be omitted. Furthermore, the method will of course give much more calibration targets over a wider dynamic range of radiances, so that the mean calibration coefficient extracted from that can be considered more significant. This latter point is especially important when this method is applied to HIRS data where – due to the large size of the HIRS pixel – only much less targets can be found than for AVHRR (see section 3.6).

3.2 Viewing Geometry

The viewing angle difference threshold of 5º was initially rather randomly chosen to find a compromise between a sufficient number of targets and not too large differences. Setting this threshold to a smaller value, however, does not significantly change the result. An example is the Meteosat-5/AVHRR comparison of 21 August 1998:

Setting the viewing angle difference threshold consecutively to 1º, 2º, 3º, 4º, and 5º, the results are (for channel4, clear sky method):

$\alpha(1^o) = 0.075541 \pm 0.001377$
$\alpha(2^o) = 0.075542 \pm 0.001294$
$\alpha(3^o) = 0.075527 \pm 0.001252$
$\alpha(4^o) = 0.075523 \pm 0.001223$
$\alpha(5^o) = 0.075521 \pm 0.001220$

This shows no significant change neither in the mean coefficient nor in the uncertainty due to scatter if the angle threshold is made stricter than 5º. The threshold of 5º is thus retained for all other results presented in this document.

Also, the analysed cases never show a dependency of the target calibration coefficients with absolute viewing angle, as long as the latter is kept to less than 50º. Figure 4 may serve as an example.

3.3 Collocation in Space

Any collocation of individual sets of pixels of two satellites can only be as accurate, as the navigation of the respective satellite image is. An estimate, in how far a navigation uncertainty influences the overall result was done as follows:

The original location of the NOAA AVHRR pixels were offset by an integer number, and the thus obtained new mean radiance was still correlated with the Meteosat count of the original position, thus mimicking a navigation uncertainty of that integer number of pixels. Table 3 shows the resulting mean calibration coefficients and their uncertainties for the case of 18 August 1998 (Meteosat-7/AVHRR) for an offset of up to 5 pixels. The example shows that an uncertainty in the order of 2-3 AVHRR pixels can be still accepted, while beyond 4 pixels the mean value starts to become more different from the original one, and also the scatter of the data points increases (as would be expected).

4 CONCLUSIONS

The conclusions from the studies at EUMETSAT with regard to CGMS Action 27.13 are as follows:

- ‘all-sky’ target areas can be used for the satellite inter-calibration and provide essentially the same result. However, the use of ‘all-sky’ targets makes the time collocation between the two satellite observations more critical because cloud movement could cause substantial differences in brightness temperatures. A time window of the order of 5 (maximum10) minutes seems a good value for the all-sky satellite inter-calibration. Naturally the all-sky comparisons also show a larger noise in the inter-calibration, which may however be compensated by the larger number of collocations.
- There is no need to confine the satellite inter-calibration to near-nadir observations provided. In fact this study shows that, at least for the IR window radiances, a tightening of thresholds for viewing angles differences from 5° to 1° does not change the inter-calibration.

As a further remark it is noted that close observation times may also be required over land, because land surfaces in the field of view can heat up or cool down quickly, e.g. over desert areas. Thus, to ensure that both satellites view the same scene (i.e. temperature), the regarded pixel groups should be scanned within a short time interval between the two satellites.

5 REFERENCES

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ANNEX

Table 1**:** Spectral response coefficients (describing a linear relation by intercept and slope) for application to Meteosat-7 IR, coefficients apply to radiance units $mW/m^2/ster/cm^{-1}$

	NOAA-14 AVHRR ch. 4	NOAA-14 AVHRR ch. 5
Intercept	5.5275	-3.7798
Slope	1.03836	0.98421

Spectral response coefficients (describing a linear relation by intercept and slope) for application to Meteosat-5 IR, coefficients apply to radiance units $mW/m^2/ster/cm^{-1}$

	NOAA-14 AVHRR ch. 4	NOAA-14 AVHRR ch. 5
Intercept	4.2093	-5.1031
Slope	1.03560	0.98141

Table 2: Intersatellite calibration coefficients α obtained during August/September 1998 for Meteosat-5 and -7 IR using NOAA-14 AVHRR (GAC) channels 4 and 5. Given are also the Meteosat operational coefficients and the difference between the two coefficients (units: $W/m^2/ster/count$):

For Meteosat-7:

Date	AVHRR channel	α (oper)	α (intersatellite)	deviation from α(oper) (%)
17 August 1998	4	0.104661	0.107498	2.71
	5		0.105623	0.92
18 August 1998	4	0.104661	0.107312	2.53
	5		0.105301	0.61
18 August 1998	4	0.104661	0.107441	2.66
	5		0.105583	0.88
19 August 1998	4	0.104661	0.107313	2.53
	5		0.105815	1.10
19 August 1998	4	0.104661	0.107472	2.69
	5		0.105430	0.73
24 August 1998	4	0.104661	0.107815	3.01
	5		0.105625	0.92
16 September 1998	4	0.104584	0.106398	1.73
	5		0.104844	0.25

For Meteosat-5:

Date	AVHRR channel	α (oper)	α (intersatellite)	deviation from α(oper) (%)
20 August 1998	4	0.072948	0.075499	3.40
	5		0.074457	2.07
21 August 1998	4	0.073152	0.075521	3.24
	5		0.074343	1.63
24 August 1998	4	0.073366	0.075388	2.76
	5		0.073540	0.24
26 August 1998	4	0.073142	0.075968	3.86
	5		0.074136	1.36
16 September 1998	4	0.072611	0.074613	2.76
	5		0.073577	1.33

Table 3: Intersatellite calibration coefficients and their uncertainties for 18 August 1998 (Meteosat-7 using AVHRR channel 4) using an increasing number of pixel offset in the spatial collocation.

Pixel Offset	α(intersatellite)	$\Delta\alpha$(intersatellite)
0 (original)	0.107441	0.000117
1	0.107393	0.000190
2	0.107273	0.000755
3	0.107101	0.000809
4	0.106894	0.001688
5	0.106676	0.002451

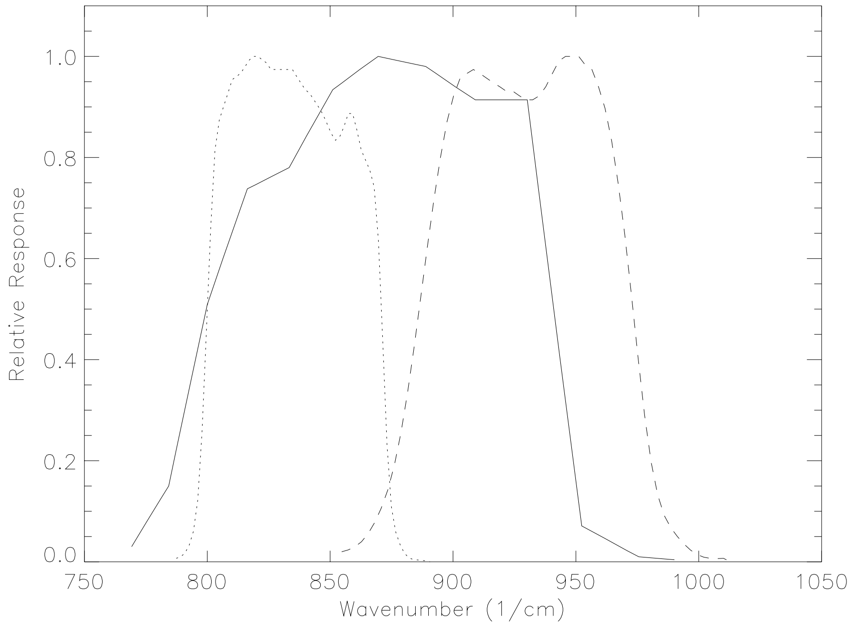

Figure 1: Meteosat-7 IR (full line) together with NOAA-14 AVHRR channel 4 (dashed) and channel 5 (dotted) response.

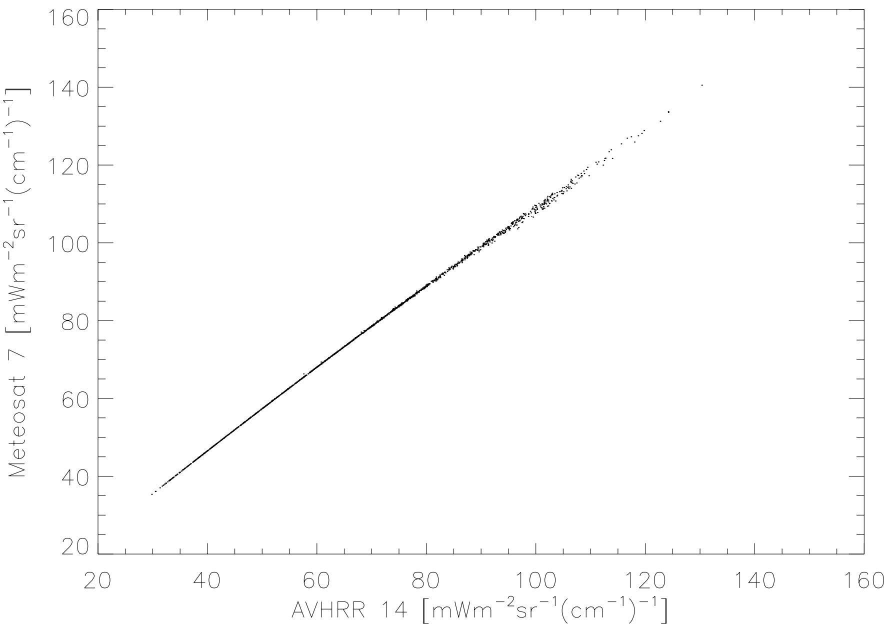

Figure 2: Spectral response correction for NOAA-14 AVHRR channel 4 with respect to Meteosat-7 IR. Dots show radiation model results for the TIGR profile ('Thermodynamic Initial Guess Retrieval') for a viewing angle of 0.

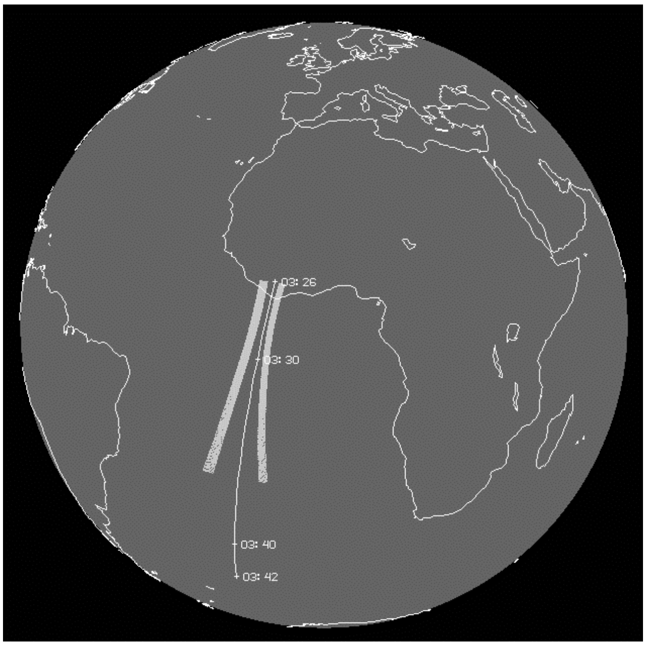

Figure 3: Calibration targets fulfilling the viewing geometry conditions to the right and left of a NOAA-14 subsatellite track within the Meteosat-7 field of view. Example is for 19 August 1998.

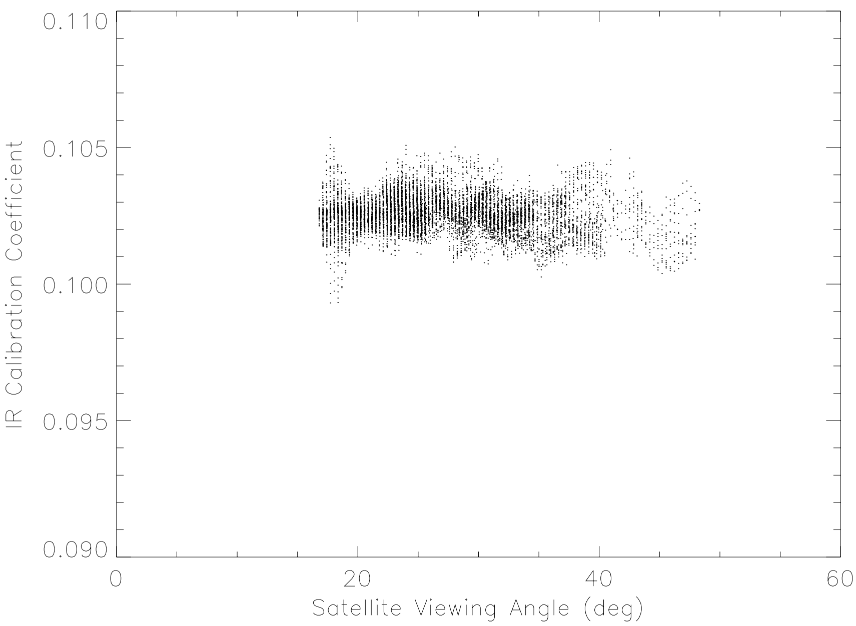

Figure 4: Local calibration coefficients over the processed range of viewing angles for the Meteosat-7 AVHRR channel 4 comparison on 19 August 1998.