Validation of TOA radiative fluxes from the GERB instrument.

S. Dewitte\textsuperscript{1}, N. Clerbaux, L. Gonzalez, A. Ipe, C. Bertrand, A. Joukoff

Royal Meteorological Institute of Belgium, Department of Observations, Section Remote Sensing from Space, Ringlaan 3, B-1180 Brussels, Belgium.

Abstract

The Geostationary Earth Radiation Budget (GERB) instrument on the Meteosat Second Generation (MSG) satellite is dedicated to the accurate measurement of the energy fluxes of the reflected solar radiation and of the emitted thermal radiation at the Top Of the Atmosphere (TOA). The error on the TOA fluxes is dominated by the uncertainty on the Angular Dependency Models (ADM's) that are used to convert the directional GERB radiances into hemispherically integrated fluxes.

We validate the emitted thermal GERB TOA fluxes by comparing them with colocated fluxes from the Clouds and Earth’s Radiant Energy System (CERES) instruments on the polar Terra and Aqua satellites. For a given location on earth and a given time of day, the GERB viewing geometry is fixed, while the CERES viewing geometry is variable. Hence the statistical comparison of GERB and CERES fluxes yields a direct estimation of the GERB TOA flux accuracy.

1 Introduction

The Meteosat Second Generation (MSG) satellite carries two instruments: the Spinning Enhanced Visible and InfraRed Imager (SEVIRI) and the Geostationary Earth Radiation Budget (GERB) instrument. The GERB instrument is the first broadband radiometer in a geostationary orbit, providing the necessary temporal resolution to study radiative processes in the atmosphere and on the earth’s surface.

The GERB data is processed in near real time in a distributed ground segment, which consists of the Gerb Ground Segment Processing System (GGSPS) and the RMIB Gerb Processing (RGP) system. Within the RGP unfiltered broadband GERB radiances and fluxes are derived. An overview of the RGP - as developed before the launch of GERB - is given in [1].

Currently GERB is in its validation phase. A first validation of the unfiltered radiances was given in [2]. The next step is the validation of the fluxes. This paper gives a first validation of the emitted thermal fluxes.

2 Angular conversion method

Among the quantities that can be derived from the GERB measurements, we have the emitted thermal radiance $L_{\text{th}}$. The emitted thermal flux $F_{\text{th}}$ is derived as

$$F_{\text{th}} = \frac{\pi L_{\text{th}}}{R(\theta_{vz}, \text{scene})}$$ (1)

$L_{\text{th}}$ and $R(\theta_{vz}, \text{scene})$ generally decrease with increasing viewing zenith angle $\theta_{vz}$ - this is referred to as the limb darkening of the emitted thermal radiation. The specific form of the limb darkening function is scene type dependent.

\textsuperscript{1}Email: Steven.Dewitte@oma.be
Within the RGP the model limb darkening function is obtained using the approach of [3]. In this approach the limb darkening is modelled as $R(\theta_{\text{vz}}, L_i)$, where $L_i$ are the SEVIRI spectral channel radiances. $L_i$ can be considered as an implicit scene identification. $R(\theta_{\text{vz}}, L_i)$ is calculated as the best fit to a large number of plane parallel radiative transfer calculations.

3 Validation of GERB emitted thermal flux

3.1 Used data

The Clouds and Earth’s Radiant Energy System (CERES), [4], provides a series of broadband radiometers - similar to GERB - on low earth orbit satellites. The GERB emitted thermal fluxes are validated by colocation with emitted thermal fluxes from the CERES Flight Model 2 (FM 2) on the Terra satellite - available since 2000 - and from the CERES Flight Model 3 (FM 3) on the Aqua satellite - available since 2002.

The FM2 and FM3 instruments were selected since they are used in a special Rotating Azimuth Plane Scan (RAPS) mode, which allows CERES views from a maximally varying direction.

The GERB/CERES comparisons were done using the so-called edition 1 ES8 CERES files. These comparisons were only during night from 19 Dec. 2003 up to 31 March 2004. The CERES fluxes were corrected for their in-flight responsivity change (+0.88 % for FM2, +0.34 % for FM3).

CERES fluxes with improved accuracy (compared to the CERES ES8) are available in the so-called CERES SSF files. Since the CERES SSF files are not yet available for the comparison with GERB, GERB is compared to the CERES SSF indirectly trough the CERES ES8. CERES SSF fluxes were compared with ES8 edition 2 files during December 2002 for CERES FM2 yielding an average ratio of the fluxes (ES8/SSF)=1.0086.

3.2 Mean comparison

Figure 1 shows the scatterplot of colocated GERB and CERES FM2 ES8 emitted thermal fluxes. The best linear fit trough the origin has a 95% confidence interval of $(\text{GERB})/(\text{CERES ES8 FM2}) = 0.989 +/- 0.002$. The ratio to the CERES SSF is estimated as $(\text{GERB})/(\text{CERES SSF FM2}) = ((\text{GERB})/(\text{CERES ES8 FM2})) \times ((\text{CERES ES8 FM2})/(\text{CERES SSF FM2})) = 0.997 +/- 0.002$.

Similarly, for the the comparison with CERES FM3 a 95% confidence interval of $(\text{GERB})/(\text{CERES SSF FM3}) = 0.991 +/- 0.003$ is obtained.
The target accuracies of the GERB and CERES radiances are 0.5%. Hence GERB and CERES are allowed to differ $2 \times 0.5\% = 1\%$ if one does not even consider angular conversion errors. The mean GERB/CERES ratios found above for the FM2 and FM3 instruments both agree within this target radiance accuracy, which is the best validation result one could hope for.

### 3.3 Regional distribution

The excellent agreement between GERB and CERES emitted thermal fluxes found in the previous section is obtained as an average over all colocation points. Additional information on the regional distribution of the GERB/(CERES FM2) ratio is given in the left image of figure 2. For reference, in the right image of figure 3.3, the mean GERB flux that was compared to the mean CERES flux is given. Notice that the right image has an inverse greyscale coding. One can notice a strong anticorrelation in the center of both images. The central GERB/CERES ratio is high when the central mean GERB thermal flux is low, and vice versa. Near the limbs of the image, a positive correlation is obtained. The limb GERB/CERES ratio is low when the limb mean GERB thermal flux is low.

Figure 1: Red dots: colocated values of emitted thermal flux from the CERES FM2 and GERB instruments. Blue line: best linear fit through origin.

Figure 2: Left: Image of GERB/(CERES FM2) ratio. Right: Image of average GERB flux for corresponding points.
3.4 Viewing zenith dependence

The results of the previous section suggest there exists a residual limb darkening for cold clouds. To investigate this further we have defined 'cold' scenes, as scenes for which the mean GERB thermal flux is below 220 W/m², and 'warm' scenes as scenes for which the mean GERB thermal flux is above 220 W/m². The mean GERB/(CERES ES8) ratio as a function of the GERB viewing zenith angle is given in figure 3, separately for 'warm' and 'cold' scenes and for the FM2 and FM3 instrument.

It can be seen that the FM2 and FM3 results are very similar. Near a GERB viewing zenith angle of 50 degrees all curves cross near the ratio GERB/(CERES ES8) close to the ratio (CERES SSF)/(CERES ES8) = 1/1.0086, so there is a good correspondence between GERB and the CERES SSF near this viewing zenith angle. For the 'warm' scenes, a residual limb darkening of the GERB fluxes of about +/- 1% exists. For the 'cold' scenes a residual limb darkening of the GERB fluxes of about +/- 4% exists.

3.5 Distribution per scene type

In the previous section we have studied the errors for the mean fluxes over a 2.5 month period. To study the systematic part of the instantaneous errors for specific scene types, we show in figure 4 the images of the GERB/CERES ratios calculated separately for three intervals of the instantaneous emitted thermal fluxes:

1. 'Cold instantaneous' fluxes below 150 W/m². The image of the GERB/CERES ratio for this class is shown at the left of figure 4.

2. 'Medium instantaneous' fluxes between 150 W/m² and 250 W/m². The image of the GERB/CERES ratio for this class is shown in the center of figure 4.

3. 'Warm instantaneous' fluxes between above 250 W/m². The image of the GERB/CERES ratio for this class is shown at the right of figure 4.
A white color in the images of figure 4 indicates no data.

For the 'cold instantaneous' GERB/CERES ratio (left image of figure 3.5) a strong overestimation up to 20% (pale blue color) of GERB relative to CERES is measured for the tropical cold clouds near the GERB nadir.

For the 'medium instantaneous' GERB/CERES ratio (mid image of figure 3.5) the GERB/CERES ratio is close to 1 (green color) in the regions were the error for the 'cold instantaneous' cases is high, but there is an overestimation up to 10% (dark blue color) at the borders of those regions. Also some limb darkening (red color indicating 10 % underestimation near the limbs) is present.

For the 'warm instantaneous' GERB/CERES ratio (right image of figure 3.5), corresponding to clear sky or low cloud situations, the GERB/CERES is mostly close to 1 (green color), except near the borders where there is some limb darkening (red color).

### 3.6 Theoretical interpretation

To understand and possibly correct the high errors found in the previous section we can compare them with the theoretical errors from our radiance to flux conversion method described in [3]. Figure 3.6 is reproduced from [3] and gives the scatterplot of the theoretical $R(\theta_{vz} = 0^\circ, \text{scene})$ as a function of the emitted thermal radiance $L_{th}$ for different scene realisations. The scene type of a particular realisation is indicated by the coding of the scatter points at the right of the plot, e.g. scatter points indicated by a red triangle belong to the 'high-thin' scene type, which means 'high and thin clouds'.
Most of the scatter points in figure 3.6 are aligned along the green dashed line. Exceptions are, in order of importance: high thin clouds - indicated by red triangles, high mid (medium thick) clouds - indicated by grey triangles, and mid (medium high) thin clouds - indicated by light blue squares.

The dashed green line gives an indication of the model limb darkening function that is used to convert radiance to flux. The deviation for an individual scene of a scatter point (real limb darkening factor) from the dashed green line (applied limb darkening factor) gives an indication of the error on the flux estimation that can be made for that individual scene. It can be concluded that instantaneous errors of 20% for the nadir flux estimates do occur theoretically for certain thin high clouds (thin cirrus clouds). It is likely that these theoretical errors for thin cirrus clouds give the explanation of the practical error in the previous section. To possibly diminish these practical errors, it is worthwhile to explicitly detect thin cirrus clouds using the SEVIRI spectral channels (e.g. the channels at 10.8 and 12 micron) and to relate them to the GERB thermal flux errors which we have revealed in the present study.

4 Conclusions

We have validated the GERB fluxes by comparison with those of the CERES FM2 and FM3 instruments. The overall agreement between GERB and CERES SSF fluxes seems to be better than 1 %, which is excellent. We obtain the same excellent agreement for GERB fluxes obtained from radiances with a viewing zenith angle around 50 degrees.

Further we have investigated the viewing zenith angle dependence of the mean GERB fluxes. For warm cases, we find an acceptable residual limb darkening of +/- 1%. For cold cases, we find a residual limb darkening of the mean fluxes +/- 4%, which is higher than desired.

We have further analysed the underlying errors on the instantaneous fluxes, where we can find systematic errors up to 20 % for the coldest clouds and near nadir views.

The obtained errors seem consistent with the errors that we can expect theoretically from radiative transfer calculations. For a possible improvement of the errors, a better detection of thin cirrus clouds seems necessary.

References


Acknowledgments

All CERES products used for this study were obtained from the NASA Langley Distributed Active Archive Center. The Belgian contribution to the GERB project is supported by the Belgian Science Policy Office (DWTC/SSTC) through the PRODEX program.