GENERATION OF GERB UNFILTERED RADIANCES AND FLUXES

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ABSTRACT

The Geostationary Earth Radiation Budget (GERB) instrument, to be launched on MSG-1 in October 2000, will be the first broad band radiometer in a geostationary orbit. GERB data will be processed in near real time in the GERB ground segment, distributed over the Rutherford Appleton Laboratories (RAL) and the Royal Meteorological Institute of Belgium (RMIB). RAL is responsable for the calibration of the measured filtered broad band radiances and for their geolocation. RMIB is responsable for the determination of unfiltered radiances and fluxes.

The RMIB part of the GERB ground segment consists of three subparts, named 'SEVIRI Processing', 'Gerb Processing' and 'Resolution Enhancement'. In the 'SEVIRI Processing' subpart, spectral modelling, scene identification and angular modelling, are performed based on SEVIRI narrow band radiances. In the 'GERB Processing' subpart, GERB and SEVIRI derived data are coregistrated in space and time, and unfiltered radiances and fluxes are determined at GERB space and time resolution. In the 'Resolution Enhancement' subpart unfiltered radiances and fluxes are derived at high spatial resolution (as a baseline 3X3 SEVIRI pixel resolution).

In this paper a general overview of the RMIB part of the GERB ground segment and of the derived products will be given. A more detailed description of the ‘Resolution Enhancement' subpart will be given in a separate poster.

1. INTRODUCTION

With GERB, time continuous broad band measurements of the earth will become available for the first time. Those will complement the existing data of broad band instruments on low earth orbit satellites – like ERBE [1], ScaRaB [2] and CERES [3] – in a unique way. The processing of GERB data is built on the experience gained from these low earth orbit instruments and will use the measured Angular Dependency Models (ADM’s) [4] to be derived from CERES.

The level 2 GERB output products – unfiltered radiances and radiative fluxes – will be useable for climate research as well as meteorology applications. As a necessary condition for the meteorology applications the GERB products are derived in near real time, i.e. the output products are available on the order of one or a few hours after the acquisition of the raw data.

Different categories of use of the GERB data can be anticipated:

1) Direct use of the data. Top of the atmosphere radiative fluxes are a required input e.g. for surface flux and hydrological (evapotranspiration) calculations.

2) Validation of atmospheric models. Radiative fluxes provide a quantitative measurements of the presence of clouds in the atmosphere. The representation of clouds in atmospheric models requires the parametrisation of time dependent processes [5], linked to the hydrological cycle and often driven by the surface diurnal temperature cycle.

The time complete sampling of GERB should allow a much tighter validation of these processes than what is possible with low earth orbit radiation budget data (e.g. [6]).

3) Assimilation in atmospheric models. Recently progress has been made in the direct assimilation of satellite longwave spectral radiances (e.g. [7]). This technique could be extended to the assimilation of GERB broad band longwave radiances, and maybe to the assimilation of GERB broadband shortwave fluxes.

This paper gives a short overview of the generation of GERB unfiltered radiances and fluxes. Section 2 gives an outline of the different processing steps, section 3 summarises the obtained accuracies and section 4 describes the different products that will be available for interested users.

2. OVERVIEW OF PROCESSING

Required processing steps.

The estimation of reflected solar and emitted thermal fluxes from single satellite broadband radiance measurements has been done previously for the ERBE, ScaRaB and CERES missions. The experience from these experiments learns that the following steps are required for the processing of GERB data:

- The calibration of the broadband radiances [8]. A 'total' radiance is measured in the spectral range 0-50 micron and a 'shortwave' radiance is measured in the spectral range 0-4 micron. The measured radiances are referred to as filtered radiances L^f.
  For the GERB instrument, the in-flight calibration of the broad band radiances will be performed at RAL.

- Separation of the reflected solar and the emitted thermal radiances. A synthetic 'longwave' radiance is computed by subtraction of the shortwave from the total radiance according to equation (1).

  $$L^f_{LW}=L^f_{TOT}-AL^f_{SW} \quad (1)$$

  The factor ‘A’ is defined such that L^f_{LW} is zero when a black body of 5800 K (close to the solar spectrum) is observed. For natural scenes, there will be a small contribution of reflected solar radiation to the synthetic long wave radiance L^f_{LW} and a small contribution of emitted thermal radiation to the short wave radiance L^f_{SW}.

- The removal of the effects of the non flat spectral responses of the shortwave and the synthetic longwave channel. This involves a modelling of the spectral distribution of the observed radiation. The estimated radiance that would be measured with an ideally flat spectral response is referred to as the unfiltered radiance L^{uf}. The ratio L^{uf}/L^f is referred to as the unfilter factor.

- The estimation of the fluxes from the observed radiances. This involves the modelling of the angular distribution of the observed radiation. This results in the estimation of a flux F. The ratio F/L^{uf} is referred to as the angular conversion factor or Angular Dependency Model (ADM). Currently it is foreseen that the best possible ADM's available for the processing of GERB data will be the ADM's derived from the CERES instrument on the TRMM satellite, using the VIRS imager for scene identification.

Unfilter and angular conversion methodology.

Maximally accurate unfiltered radiance and flux estimates are obtained from a combination of GERB and SEVIRI data. GERB provides accurate broad band measurements. SEVIRI provides good scene identification, which forms a *necessary* condition for appropriate ADM selection. A rational way to obtain the best combined estimate of the unfiltered radiance $L^{uf}_{GERB/SEVIRI}$ and of the broad band flux $F_{GERB/SEVIRI}$ is given by equations (2) and (3).

$$L^{uf}_{GERB/SEVIRI} = (L^{uf}_{SEVIRI}\ L^f_{GERB}) / L^f_{SEVIRI} \quad (2)$$
$$F_{GERB/SEVIRI} = (F_{SEVIRI}\ L^f_{GERB}) / L^f_{SEVIRI} \quad (3)$$

L^f_{GERB} is the basic filtered broad band GERB radiance (shortwave or synthetic longwave) measurement. L^f_{SEVIRI} is the estimate of the filtered broad band GERB radiance measurement, estimated from the SEVIRI spectral radiances only. L^{uf}_{SEVIRI} is the corresponding estimate of the unfiltered broad band radiance, estimated from the SEVIRI spectral radiances only. F_{SEVIRI} is the corresponding estimate of the unfiltered broad band flux, estimated from the SEVIRI spectral radiances only.

Equations (2) and (3) can be interpreted in two, strictly equivalent, ways:

- The GERB broad band radiance measurement L^{f}_{GERB} is converted to a broad band unfiltered radiance by multiplication with the SEVIRI derived unfiltering factor $L^{uf}_{SEVIRI} / L^{f}_{SEVIRI}$. The obtained unfiltered radiance $L^{uf}_{GERB/SEVIRI}$ is further converted to the broadband flux by multiplication with the SEVIRI derived angular conversion factor $F_{SEVIRI} / L^{uf}_{SEVIRI}$.

- The SEVIRI estimated unfiltered radiance L^{uf}_{SEVIRI} and broad band flux F_{SEVIRI} are corrected by the factor $L^{f}_{GERB} / L^{f}_{SEVIRI}$, which corrects the SEVIRI based spectral modelling by the GERB measurement.

Division into subsystems.

The RMIB GERB Processing (RGP) consists in total of three subsytems: 'RGP SEVIRI procesing', 'RGP GERB processing' and 'RGP Resolution Enhancement', to be executed in sequential order. See also figure 1.

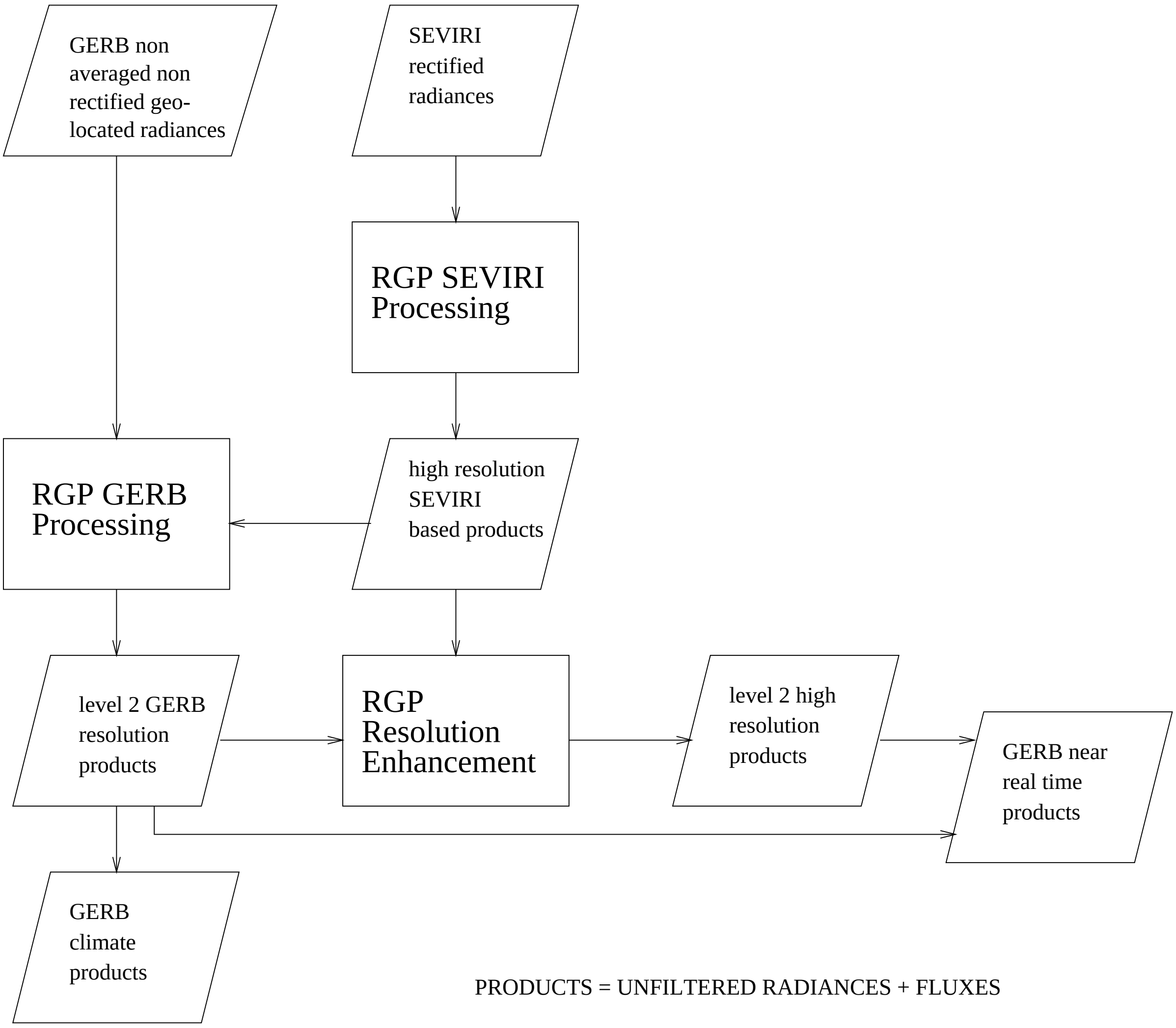

Fig 1 : Division into susbsystems of the RMIB GERB Processing. The three blocks 'RGP SEVIRI Processing', 'RGP GERB Processing' and 'RGP Resolution Enhancement' are executed in sequential order.

The subsystem 'RGP SEVIRI Processing' has as input full resolution SEVIRI spectrally narrowband radiances and as output SEVIRI pixel resolution filtered radiance estimates and broadband unfiltered radiance and flux estimates. Those outputs are referred to as 'high resolution SEVIRI based products'.

The subsystem 'RGP GERB Processing' has as input the GERB measured filtered broadband radiances as well as the high resolution SEVIRI based products, and as output GERB broadband unfiltered radiances and fluxes. Those outputs are referred to as 'level 2 GERB resolution products'.

The subsystem 'Resolution enhancement' has as input the high resolution SEVIRI based unfiltered radiance and flux estimates and the level 2 GERB resolution unfiltered radiances and fluxes and as output fluxes at 3 x 3 SEVIRI pixel resolution that are compatible with the level 2 GERB resolution fluxes. Those outputs are referred to as 'level 2 high resolution products'. In the following sections a brief description of the function of each of the subsystems is given.

SEVIRI Processing.

In this subsystem the spectral modelling, as well as the scene identification and the associated angular modelling will be done on the basis of SEVIRI data.

The inputs for this subsystem are the SEVIRI images.

For the spectral modelling, 6 quantities are estimated from SEVIRI Narrow Band (NB) images [9] :

- $L^f_{SW,sol,SEVIRI}$, the dominating contribution of the reflected solar radiation to the SW radiance
- $L^f_{SW,th,SEVIRI}$, the small contribution of the emitted thermal radiation to the SW radiance
- $L^f_{LW,th,SEVIRI}$, the dominating contribution of the emitted thermal radiation to the LW radiance
- $L^f_{LW,sol,SEVIRI}$, the small contribution of the reflected solar radiation to the LW radiance
- $L_{sol,SEVIRI}$, the unfiltered reflected solar radiance estimate
- $L_{th,SEVIRI}$, the unfiltered emitted thermal radiance estimate

Filtered radiance estimates are obtained as:

$$L^F_{SW,SEVIRI} = L^F_{SW,sol,SEVIRI} + L^F_{SW,th,SEVIRI} \quad (4)$$
$$L^F_{LW,SEVIRI} = L^F_{LW,th,SEVIRI} + L^F_{LW,sol,SEVIRI} \quad (5)$$

The spectral modelling consists in obtaining the estimate of the broad band filtered radiance L^f_{SEVIRI} (x_S,y_S,t_S) and of the unfilter factor L^{uf}_{SEVIRI} (x_S,y_S,t_S) / L^f_{SEVIRI} (x_S,y_S,t_S) .

The angular modelling consists in modelling the angular conversion factor F_{SEVIRI}/ L^{uf}_{SEVIRI}. The spectral modelling as well as the longwave angular modelling are based on plane parallel radiative transfer modelling. The SBDART radiative transfer tool has been used

For the shortwave angular modelling, the ADM's derived from the CERES/VIRS combination on TRMM will be used. Cloud optical properties will be derived from every SEVIRI pixel, with resolution at nadir of 3 km, comparable with the determination of cloud optical properties from every VIRS pixel on TRMM, with resolution at nadir of 2 km. For cloudy scenes the ADM's will be applied over windows of 3x3 SEVIRI pixels, which have a similar spatial resolution - around 10 km at nadir - as the CERES broadband radiometer on TRMM.

The outputs of this subsystem are SEVIRI based estimates of the GERB filtered radiances (shortwave and synthetic long wave), the unfiltered radiances (reflected solar and emitted thermal), as well as the unfiltered broadband fluxes (reflected solar and emitted thermal) at SEVIRI pixel resolution. Thus the outputs are images of L^f_{SEVIRI} , L^{uf}_{SEVIRI} and F_{SEVIRI} .

In this subsystem all the physical scene modelling is concentrated.

GERB Processing.

In this subsystem, GERB broad band radiance measurements are combined with SEVIRI based models [10].

'(x_S,y_S,t_S)' is used to refer to SEVIRI time and space sampling. '(x_G,y_G,t_G)' is used to refer to GERB time and space sampling.

The inputs for this subsystem are the images of the GERB total and shortwave radiances L^f_{GERB} (x_G,y_G,t_G), the images of the SEVIRI based estimates of the shortwave and synthetic longwave radiances L^f_{SEVIRI} (x_S,y_S,t_S), of the reflected solar and emitted thermal unfiltered radiances L^{uf}_{SEVIRI} (x_S,y_S,t_S) and of the fluxes F_{SEVIRI} (x_S,y_S,t_S).

In the GERB processing the calculations are done at the shortwave acquisition times and geolocations.

The synthetic long wave radiance is calculated by application of equation (1), after interpolation of the measured total radiances towards the GERB shortwave acquisition times and geolocations.

Correction factors $c(x_G,y_G,t_G) = L^f_{GERB} (x_G,y_G,t_G) / L^f_{SEVIRI} (x_G,y_G,t_G)$ - needed for application of equations (2) and (3) – are calculated, after interpolation of $L^f_{SEVIRI} (x_S,y_S,t_S)$, $L^{uf}_{SEVIRI} (x_S,y_S,t_S)$ and $F_{SEVIRI} (x_S,y_S,t_S)$ radiances towards the GERB shortwave acquistion times and geolocations.

15 minute means of the spectral correction factors are calculated, in order to reach the target GERB signal to noise ratio. The unfiltered radiances and fluxes are calculated by application of equations (2) and (3) using the mean spectral correction factors.

The outputs for this subsytem are the images of the correction factors $c(x_G,y_G,t_G) = L^f_{GERB} (x_G,y_G,t_G) / L^f_{SEVIRI} (x_G,y_G,t_G)$ at GERB footprint level and of the level 2 15 minute mean fluxes $F_{GERB/SEVIRI} (x_G,y_G,t_G)$ at GERB footprint resolution.

In this subsystem all the GERB-SEVIRI coregistration is concentrated.

Resolution Enhancement.

In this subsystem, the resolution of the level 2 fluxes is improved by use of SEVIRI high resolution information. The inputs for this subsystem are the correction factors at GERB spatial resolution $c(x_G,y_G,t_G) = L^f_{GERB} (x_G,y_G,t_G) / L^f_{SEVIRI} (x_G,y_G,t_G)$ and the high resolution SEVIRI based estimates of the unfiltered radiance $L^{uf}_{SEVIRI} (x_S,y_S,t_S)$ and of the flux $F_{SEVIRI} (x_S,y_S,t_S)$.

More details on this subsystem are given in the accompanying paper [11].

The outputs for this subsytem are the level 2 15 minute snapshot high resolution fluxes $F_{GERB/SEVIRI} (x_S,y_S,t_S)$ and unfiltered radiances $L^{uf}_{GERB/SEVIRI} (x_S,y_S,t_S)$.

In this subsytem all the resolution enhancement of GERB by SEVIRI is concentrated.

3. ERROR SOURCES AND ESTIMATED ACCURACIES

The RMIB GERB Processing derives unfiltered radiances and fluxes from geolocated filtered radiances. Multiple error sources contribute to the errors on the final products [12]. The error sources that are inherent to process of flux estimation from a broad band radiometer are:

- calibration of filtered radiances
- thermal/solar radiance separation
- spectral unfiltering
- radiance to flux conversion

The resulting errors on the unfiltered radiances are summarised in table 1, those on the fluxes are summarised in table 2a (nadir view) and 2b (viewing zenith angle of 50 degrees). The viewing zenith angle of 50 degrees – which is the optimum observation angle in terms of flux errors – is representative for the METEOSAT view of Europe.

	thermal radiance	solar radiance
error on absolute scale	0.46 %	1.75 %
noise level (1 sigma)	0.22 W/m2sr	0.30 W/m2sr

Table 1. Summary of errors on the unfiltered radiances due to calibration of filtered radiances, thermal/solar radiance separation and spectral unfiltering.

NADIR VIEW	thermal flux	solar flux
error on absolute scale	8.3 %	10.7 %
noise level (1 sigma)	6.2 W/m2	10 W/m2

Table 2a. Summary of errors on the nadir view fluxes due to calibration of filtered radiances, thermal/solar radiance separation, spectral unfiltering and radiance to flux conversion.

50º VIEW	thermal flux	solar flux
error on absolute scale	1.7 %	6.2 %
noise level (1 sigma)	1.2 W/m2	5.1 W/m2

Table 2b. Summary of errors on the 50º view fluxes due to calibration of filtered radiances, thermal/solar radiance separation, spectral unfiltering and radiance to flux conversion.

Particular additional error sources are:

- effect of different spectral responses for different detector cells
- effect of non repeatability of pointing

The spectral responses of the different detector cells are slightly different. This is taken into account in the RMIB GERB processing in a two step approach. In the SEVIRI processing (step 1) the used spectral response is the *mean* of the individual GERB detector cell responses. In the GERB processing (step 2), the individual detector cell spectral response is related to the mean spectral response. This approach greatly simplifies the processing, while it introduces a worst case error of 0.5 % [13].

The longwave filtered radiance must be calculated as the difference between a total radiance and the short wave radiance contribution to the total channel – see equation (1). The total radiance and the short wave radiance are measured by the same detector at different times. In between the total and the shortwave measurement the pixel can move. If a simple difference between pixels is calculated, a spurious short wave contribution remains in the calculated long wave radiance. In [14], the resulting error is calculated for the worst case, this is the most contrasted short wave scene - a bright cloud over ocean with overhead sun. In the RMIB GERB Processing, GERB pixels with large longwave errors due to this effect will be detected and eliminated thanks to the use of the SEVIRI longwave radiance estimates. GERB pixels with long wave radiance errors above 3% can safely be detected.

4. USER PRODUCTS AND SERVICES

An RMIB On Line Short-term Service (ROLLS) will be set up. The purpose of the on-line services is to give users access to the RMIB produced radiances and fluxes within the short term delay of one month after measurement. Access to the ROLSS will be via FTP.

If the products are more than 1 month old, they will be archived by the RAL based GGSPS (GERB Ground Segment Processing System) .

Products exist in four categories of space and time sampling :

- N: nominal GERB resolution. These products are defined as a 15 minute average, obtained by averaging three consecutive GERB measurements. The products have GERB spatial resolution, geolocated on the Rectified Grid computed by RAL (cf. L1.5 ARG product). The spatial shape of one pixel is the average of the 3 GERB footprints that have contributed to it.
  In this category, thermal and solar fluxes for archival and long term distribution by the GGSPS are defined. These fluxes are defined to be compatible with the GERB filtered radiances (L1.5 ARG product) derived by the GGSPS.

- SHI: standard high resolution. These products are defined as 15 minute snapshots at SEVIRI acquisition times. The products have 3x3 SEVIRI pixels spatial resolution. The product is defined in a window over Europe.
  In this category, thermal and solar fluxes and radiances are defined. These fluxes and radiances are defined to be compatible with the SEVIRI radiance images. They can e.g. be used together with SEVIRI derived cloud products.

- F: fixed GERB resolution. These products are defined as averages over exact 15 minute bins (first bin: 00:00-00:15 UTC etc.). The products have roughly GERB spatial resolution, i.e. the pixels are geolocated on a rectified grid and are an average of 5x5 SHI pixels (see above); the grid resolution is thus 247x247. The spatial shape of one pixel is an exact square at nadir. The dimension of this square is the GERB sampling distance, i.e. close to 50 km.
  In this category, thermal and solar fluxes and radiances, are defined. These fluxes and radiances are defined for easy comparison with model output.

- NSHI: non standard high resolution. In this category, an archive product, is defined. This is not intended for routine distribution. This product is defined over the full MSG disc, as 15 minute snapshots at SEVIRI acquisition times. The product has 3x3 SEVIRI pixels spatial resolution.

5. CONCLUSIONS

A near real time GERB processing system will be available by the launch of MSG-1. State of the art accuracies will be obtained thanks to the use of SEVIRI imager data and the anticipated CERES ADM's. Unfiltered radiances and fluxes will be available both in near real time trough the ROLSS server and in delayed time through the GGSPS.

6. ACKNOWLEDGEMENTS

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