

GEOLOCATION ACCURACY OF GERB DATA

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ABSTRACT

The first Geostationary Earth Radiation Budget (GERB) experiment was launched on the Meteosat Second Generation (MSG-1) satellite in August 2002. GERB exists to make high accuracy measurements from geostationary orbit of the outgoing components of the Earth radiation budget at high temporal resolution.

The GERB pixel size is approximately 44 km at the sub-satellite point, but in the GERB processing the position of each pixel must be located to an accuracy of about one tenth of this. This is because of the need in the level 2 processing to co-locate the GERB data with data from the Spinning Enhanced Visible and Infra-Red Imager (SEVIRI) instrument on MSG. MSG is a spin-stabilised satellite, and since the time constant of the GERB detectors is relatively long, of order 4 milliseconds, a de-spin mirror is used to obtain a constant scene over the detector integration time. As a consequence, issues of timing, pointing and alignment all have to be taken into account when geolocating the GERB data.

This paper will explain the geolocation method devised to meet the required accuracy, the problems encountered in the initial data from GERB and the solutions being employed to overcome these problems.

1. INTRODUCTION

GERB (Geostationary Earth Radiation Budget) is an Announcement of Opportunity (AO) instrument on the Meteosat Second Generation (MSG) satellites. The first of four such instruments was launched on MSG-1 in August 2002 and is currently in geostationary orbit above 3.4° W. GERB has an 18° Field of View covering the entire Earth disk at a resolution corresponding to 44 km at nadir; the full Earth disk is covered by 256 x 256 pixels.

GERB has two broadband channels, achieved through use of a quartz filter: the TOTAL channel, where the filter remains out of the optical path, covers the wavelength range from 0.32 μm to beyond 100 μm , while the Short Wave (SW) channel, with the filter in the optical path, covers the range 0.32 μm to 4.0 μm . A Long Wave (LW) measurement (i.e. from 4.0 μm to beyond 100 μm) can then be derived by interpolation (in time and space) and subtraction.

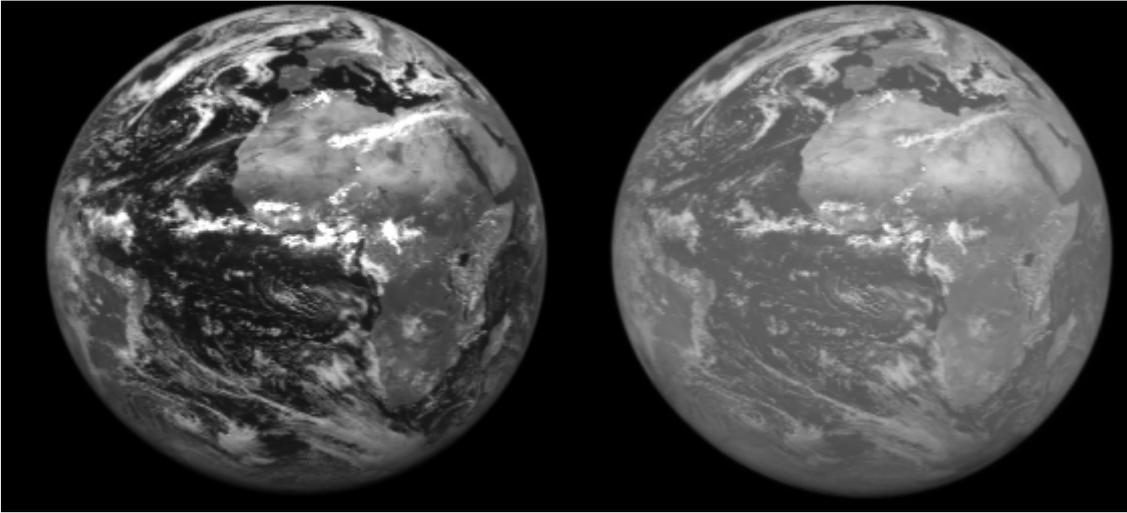


Figure 1: View of Earth as seen by GERB (midday, 18th May 2004), in Short Wave (left) and TOTAL (right) channels. Long Wave measurements can be obtained by interpolation and subtraction. The first GERB instrument is nominally positioned above 3.4° W and views Europe, Africa and the Atlantic Ocean, producing a single Earth image in a little under 3 minutes, and deriving products based on 6 images (3 in each channel) each 17 minutes.

GERB exists to make accurate measurements of the outgoing components of the Earth radiation budget at high temporal resolution. Both the SW and LW components will be measured to an accuracy of 1%. GERB's position in geostationary orbit (unique for a radiation budget experiment) ensures that radiance and flux products can be generated continuously every (approximately) 15 minutes for the same region of the Earth's surface.

The requirement for accurate geolocation of the GERB pixels comes from the need in the level 2 GERB processing to match GERB pixels with SEVIRI pixels. This paper will describe the GERB scanning mechanism and the basic geolocation method employed to achieve this accuracy, before discussing particular problems of timing, pointing and alignment which are affecting the accuracy currently being attained. Finally, the current status and outlook for the geolocation accuracy is summarised.

2. THE GERB SCAN MIRROR

MSG is a spin-stabilised satellite, rotating at 100 revolutions per minute. The GERB detectors have a relatively long time constant (of order 4 ms) compared to SEVIRI, and require a constant view of order 40 ms to make their accurate radiometric measurements. A de-spin mirror is therefore needed, rotating at half the satellite rotation rate and in the opposite sense, in order to hold a fixed view of the Earth over the 40 ms detector integration time. The rotation rate of the de-spin mirror adjusts to match any variation in the MSG rotation rate. The demands on the system are increased because GERB is positioned on the outside of MSG, and MSG's 100 rpm rotation rate generates forces of 16g on the scan mirror bearings.

The de-spin mirror is also integral to the way GERB scans the Earth to generate a complete Earth image. The GERB instrument uses a columnar (north-south) detector of 256 pixels. One column of an Earth view is acquired on each rotation of MSG, i.e. every 0.6 seconds. One scan of the Earth is built up from 282 columns, in a little under 3 minutes. (256 columns are required to cover the Earth's disk itself: the remainder view space for calibration purposes.) The east-west position of each column is stepped (by 0.07°) by adjusting the phase of the de-spin mirror rotation relative to the MSG rotation. Alternate scans are either SW (filter in) or TOTAL (filter out).

Accurate measurement of the scan mirror operation is important for geolocation accuracy: the mirror phase is measured by using an onboard timing clock to measure the time delay between an initialisation pulse (the Start of Line (SOL) pulse, which will be discussed later) and the start of acquisition of the Earth image (referred to as Start of Earth (SOE)). Mirror positioning is also repeatedly measured over the 40 ms Earth acquisition period, to an accuracy of 0.05 GERB pixels.

The scan mirror rotation is found to be repeatable to about 0.07 GERB pixels. Within one rotation, there are ripples in the mirror motion of about 0.2 pixels which broaden the GERB Point Spread Function east-west. This broadening is measured, and accounted for when matching GERB and SEVIRI pixels in level 2 processing.

3. GERB DATA PROCESSING

GERB data processing is carried out in near real time, at two institutes. Level 1.5 processing, including geolocation, is carried out by the GERB Ground Segment Processing System (GGSPS) at the Rutherford Appleton Laboratory. The data are geolocated and calibrated to produce filtered radiance products. The GGSPS is described in a companion paper [2].

Level 2 processing takes place at the Royal Meteorological Institute of Belgium (RMIB). The RMIB GERB Processing system (RGP) uses SEVIRI data for scene identification and resolution enhancement, and generates unfiltered radiances and fluxes.

Currently, the RGP system is using an alternative geolocation method [1] at level 2, based on matching GERB data with SEVIRI data, and good to less than 0.5 GERB pixel. This alternative geolocation processing is being used pending resolution of the problems discussed in this paper.

4. GEOLOCATION METHOD

Geolocation means assigning a longitude and latitude to each pixel. It identifies the scene being viewed, and enables comparisons with other instruments. In the level 2 processing, GERB pixels are co-registered with the 3km (at nadir) SEVIRI pixels to produce a series of flux products, the highest resolution of which is on a 3x3 SEVIRI pixel scale (9 km). In order for the GERB and SEVIRI pixels to be reliably matched, the GERB geolocation accuracy needs to be about 0.1 GERB pixel.

The GERB geolocation method relies on knowledge of the position and orientation of the satellite, and the direction of line of sight for each of the 256 individual GERB detectors. Apart from initial tunings, the geolocation method makes no reference to the observed image. The observed image can be used, though, to validate the geolocation.

The surface of the Earth is represented by an ellipsoid. This ellipsoid is defined by a polar radius (R_p) and an equatorial radius (R_E). It is defined in an Earth-fixed and centred coordinate frame with z axis through the north pole, x axis through 0° longitude and y axis through +90° longitude (such that xyz is a right-handed set).

The position of MSG, and tilt of the spin axis (attitude), of the satellite is already determined in this reference frame by MSG. The values are available in the header of the SEVIRI Level 1.5 Image product; this header is available to the GGSPS via the RGP system, which uses the SEVIRI Level 1.5 image in its processing and extracts the header and forwards it for use by the GGSPS. The values are in the form of a series of Chebychev coefficients, which define the time variation of these parameters from the recent past into the near future, to an accuracy better than 2 km for orbit parameters. Handling time variations are necessary because MSG-1's orbit does deviate from an ideal geostationary orbit: for example, the orbital inclination is currently about 0.8°, and will drift with time.

The direction of the line of sight of each GERB pixel is determined from the relative pointing directions of the GERB pixels, together with timing information to fix where GERB is looking east-west. The relative pointing directions have already been determined in an instrument reference frame from ground measurements at Imperial College (see Section 6). The timing information is the measurement of mirror phase as described in Section 2.

Once these three elements are determined, it is straightforward to find the point at which each GERB detector line of sight intersects the Earth ellipsoid, and calculate a corresponding longitude and latitude.

A number of problems affecting the calculation of the pixel line of sight have impacted on the GERB processing: variations in a satellite timing pulse (the Start of Line pulse) have affected the calculation of where GERB is looking east/west; comparisons with the RMIB geolocation method suggest that there are systematic differences between the optical distortions seen and those expected from ground PSF measurements; and there is known to be a significant misalignment between the MSG spin axis and the axis of the GERB de-spin mirror. These issues will be discussed in the following sections.

5. EAST-WEST DRIFTS AND THE START OF LINE PULSE

As already described, the east-west position of the GERB column is set by the phase of the de-spin mirror, and is measured from the time between the Start of Line (SOL) pulse and the beginning of acquisition of the Earth image (Start of Earth, or SOE). This phase also depends on the satellite rotation rate.

The SOL pulse is a timing pulse generated approximately 135.7° in advance of the centre of the Earth (as seen by GERB) by Sun and Earth sensors on MSG. It was an assumption of the GERB geolocation algorithms that the Earth would be centred consistently in the GERB (and SEVIRI) images by this pulse.

In practice, three anomalies have been observed which disrupt this centring: there is a rapid oscillation in centring around midnight, due to stray light in the Earth Sensor Unit (ESU); there is a diurnal oscillation in centring, arising when the spin axis of the satellite is not exactly perpendicular to the orbital plane; and there is a jump in centring when swapping between ESUs (MSG has two ESUs, only one of which is active at any given time). These effects are illustrated in the centring plots shown below.

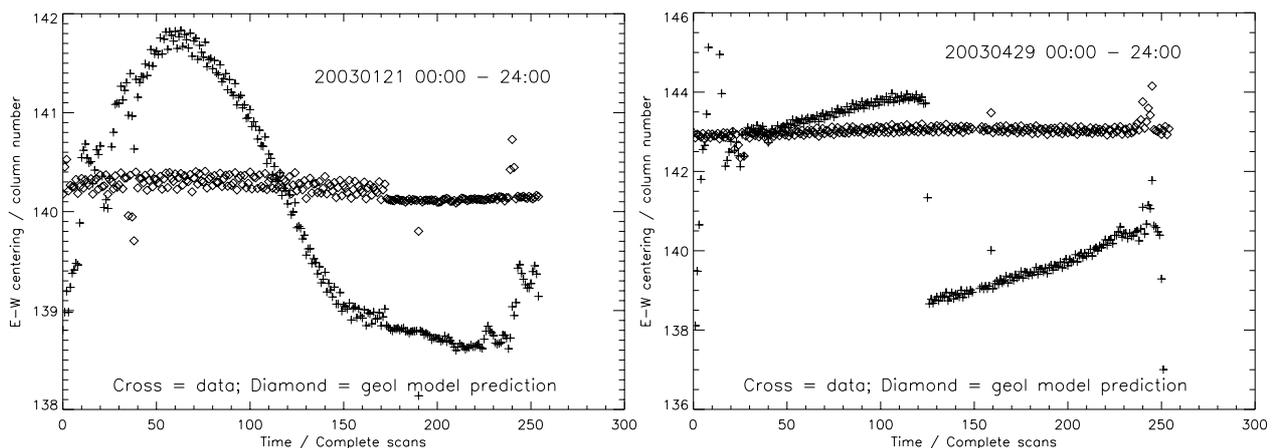


Figure 2: These plots show the variation in centring (east-west) over 24 hours, for 21st January 2003 (left) and 29th April 2003 (right), as measured from the observed TOTAL channel GERB image (crosses) and from the Earth disk flagged by the geolocation processing (diamonds), measured in terms of image column number of centre of disk (y axis) against TOTAL channel scan number (x axis). The plots illustrate the midnight oscillation and diurnal variation effects, and the right hand plot also shows the jump following an ESU swap.

At start of commissioning, these effects could give geolocation errors in excess of 4 GERB pixels (around 200 km at nadir). From November 2003, a number of interim measures were taken, both on the GGSPS and operationally at EUMETSAT, to reduce these errors to less than 1 GERB pixel. RMIB also introduced their own geolocation into the level 2 RGP processing at this point.

A solution much more accurate than 1 GERB pixel was, however, required. For SEVIRI, the Image Processing Facility (IMPF) uses a spin model to predict when the SOL pulse should have arrived (CSOL). The difference between this and its actual arrival time (TSOL) is the correction required; this difference is referred to as TSOL Jitter. A temporary interface has now been implemented to transfer these TSOL Jitter values to the GGSPS, and from 6th May 2004 these values have been used in the GGSPS processing. Implementation of a more permanent interface is currently under consideration.

The east-west centring with the new TSOL Jitter information is much improved, and corrects all three of the problems described above. Systematic differences of around ± 0.2 GERB pixels remain, however, between the observed Earth centre and that predicted by the geolocation model; these differences are currently under study.

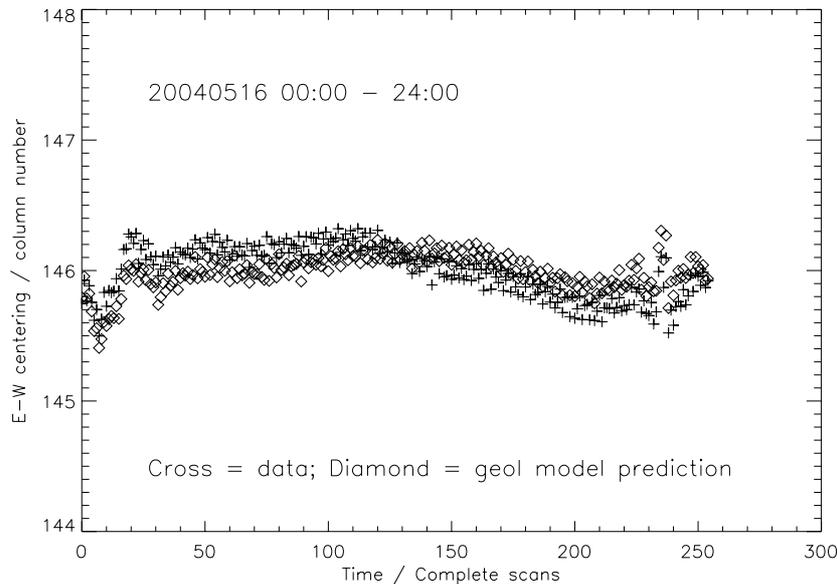


Figure 3: East-west centring plot for 16 May 2004, following introduction of the TSOL Jitter correction. The observed Earth centre (crosses) and geolocation model (diamonds) now agree to 0.2 GERB pixels. The systematics behind the remaining differences are currently under study.

6. PIXEL LINES OF SIGHT AND OPTICAL DISTORTIONS

The relative pointing directions of each of the GERB pixels were determined from Point Spread Function (PSF) measurements during ground calibration. The PSF measurements were made by Imperial College, using a SW (633 nm) Helium-Neon laser, and were made with a sampling of 0.2 GERB pixels and an accuracy of 0.1 pixels. The image space viewed by the detector column is slightly curved, because of the off-axis optics of the GERB telescope: the ends of the column are separated east-west from the middle by about 3 GERB pixels. The effects of zero gravity, and the 16g pull on the instrument due to the MSG rotation, were modelled, and were found to broaden slightly the PSFs.

In flight, these optical distortions can be checked by looking at details in the GERB image. One simple way is to check the geolocation for observed coastlines against their known positions. A more sophisticated check is performed by RMIB. This involves comparing the GERB image against the rectified level 1.5 SEVIRI image, and using this to refit the geolocation using their own parametrisation [1]. (This method of comparison forms the basis for the independent geolocation method currently in use by the RGP at Level 2 - see Section 3).

Comparisons between the GGSPS and RMIB geolocations show the following. The RMIB fits suggest that the geolocation should be compressed north-south, by about 2 GERB pixels over the length of the array, with respect to the current geolocation based on the original pixel pointing data. There are also differences in azimuth up and down the array, which would be indicative of a rotation (the top of the array needs to move west and the bottom east) were it not for the fact that the observed differences do not vary linearly along the array. These effects are currently contributing errors of up to a GERB pixel towards the north and south ends of the image.

Further study and checks need to be applied to these results, but this method may be used to determine corrections to the GGSPS geolocation, and ultimately to validate it.

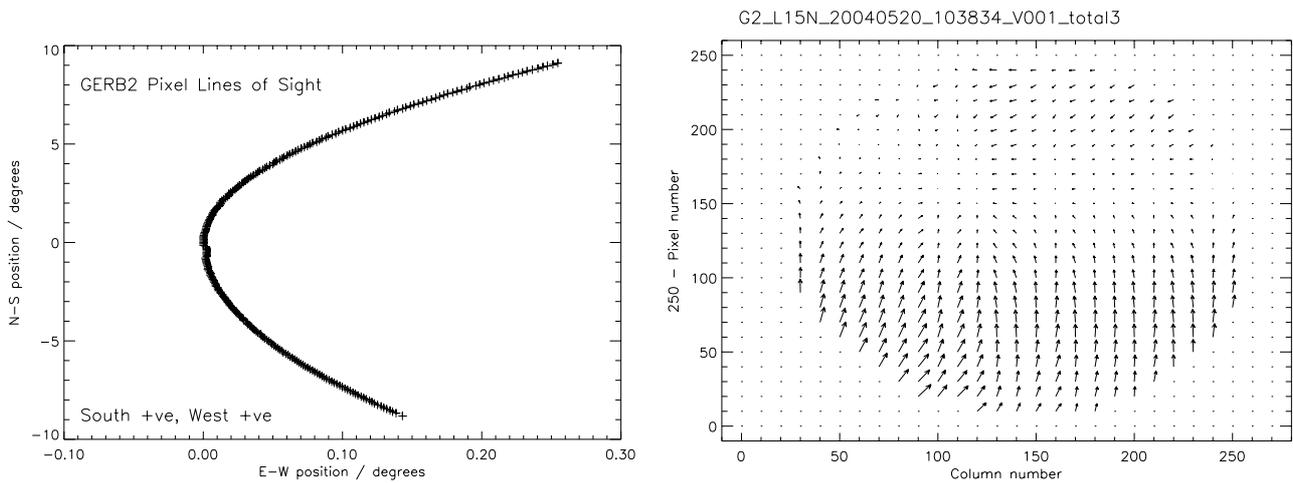


Figure 4: (Left) Plot of elevation versus azimuth of line of sight of each of the 256 pixels for the GERB instrument on MSG-1. The ends of the column are displaced in azimuth by about 3 GERB pixels with respect to the centre of the column. (Right) Plot of vector field showing differences in geolocation between fit at RMIB and the initial GGSPS geolocation. Each tenth row and column is shown. Arrows show the required translation to move a particular pixel from its GGSPS location to its RMIB one.

7. AXIS MISALIGNMENTS

If there is a misalignment between the de-spin mirror axis and the satellite spin axis, then there will be a movement of the GERB Line of Sight during the 40 ms Earth acquisition, predominantly in a North-South direction. The displacement of the line of sight would vary sinusoidally over the full 600 ms of the satellite rotation. The effect of this is either a displacement of the line of sight from that expected, or a movement of the line of sight during the Earth acquisition (smearing), or some combination of the two. Which of these is observed depends on the orientation of the axis misalignment.

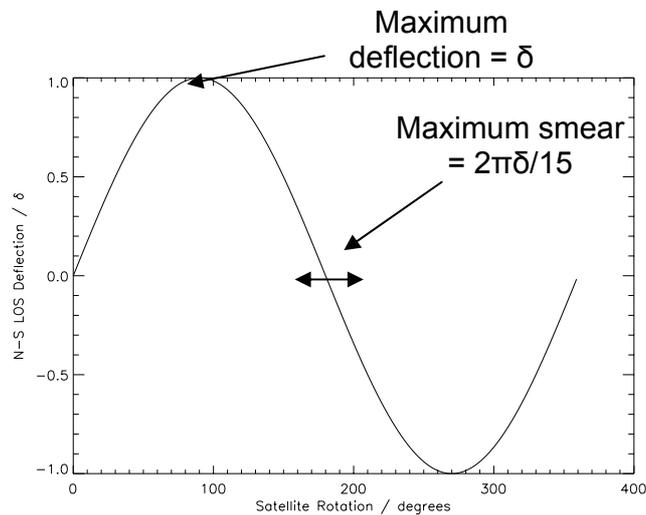


Figure 5: Effect on GERB Line of Sight North-South (y axis) of an axis misalignment δ , plotted against satellite rotation, for one rotation. The orientation of the axis misalignment fixes the relation of this sinusoid to the 40 ms Earth acquisition.

As illustrated in Figure 5, if the misalignment is tilted towards or away from the Earth, the 40 ms Earth acquisition would occur at the point of maximum deflection (δ for a misalignment of δ), but there would be little change in this deflection during the 40 ms acquisition (little smear). If, however, the misalignment is

tilted sideways in relation to the Earth, then the deflection in the line of sight would not be great, but it would change much more considerably over the acquisition period, giving rise to a smear of up to $2\pi\delta/15$.

The biggest component misalignment is that between the MSG structural axis and the MSG spin axis. This misalignment will also change with time, as fuel is used up during manoeuvres. Misalignments will be handled in the GERB processing using a series of reference frame transformations, but are not yet included pending knowledge of the orientation of the MSG structure-spin misalignment. Smearing of the pixels north-south will be accounted for when matching GERB pixels to SEVIRI pixels in level 2 processing.

8. SUMMARY

The GERB Level 1.5 geolocation accuracy was originally affected by anomalies in the generation of the satellite Start of Line pulse, and errors initially exceeded 4 GERB pixels in particular circumstances. Following the recent introduction into the Level 1.5 processing of TSOL Jitter information provided by EUMETSAT, these anomalies are being corrected for almost completely; study of a 0.2 GERB pixel systematic is still progressing.

The RGP has been using an independent geolocation method for the level 2 GERB products, which has an accuracy of less than 0.5 GERB pixel.

The level 1.5 geolocation accuracy is currently about 1 GERB pixel. Tuning of alignment parameters and optical distortions using comparisons with SEVIRI data provided by RMIB will now proceed. Spin axis misalignment information will also be incorporated. The target is to attain an accuracy of 0.1 GERB pixel by the first data release in late 2004 or early 2005.

9. ACKNOWLEDGEMENTS

This work would not have been possible without the help of colleagues at EUMETSAT, Imperial College and RMIB.

Development of the GGSPS, and its operation for the first GERB instrument, have been funded by the United Kingdom Natural Environment Research Council (NERC) and the European Commission (Framework IV).

10. REFERENCES

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