# THE STATUS OF CLUSTER FGM DATA SUBMISSIONS TO THE CAA

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## ABSTRACT

The FGM contribution to the Cluster Active Archive consists of 3 main magnetic field data products and a set of auxiliary data products. The three primary magnetic field data products contain the magnetic field in GSE coordinates at three different time resolutions. The first data product has full resolution data which can be at 22Hz or 67Hz depending on the mode of the instrument. The second data product has data at 5Hz and the third data product at spin resolution. All data products are validated for scientific use. Presented here is an outline of the procedure used to create these data products. A description of the calibration techniques used to produce the required calibration files is also set out as this forms a major part of the production procedure. In addition the present status of data products submitted to the CAA is presented along with a projection of what will be submitted in the near future.

## 1. PROCEDURE FOR MAIN DATA PRODUCT PRODUCTION

The Cluster Active Archive is providing data from each instrument on the cluster spacecraft in a single data format type. This format is the cluster exchange format(CEF-2) and as well as the scientific data from each instrument, the files also contain a wealth of information about the instrument and data product in a header. This information will allow users of the archive data in many years time to use the data to its fullest extent. The FGM data production procedure must then lead ultimately to the production of data files in the CEF format.

The three main FGM data products contain magnetic field data at full resolution, 5Hz and spin resolution respectively. All three data products are produced using the same general procedure which consists of three stages. The fist stage is the calibration analysis which is the most time intensive stage. There are several possible calibration analysis methods which could be applied but certain methods can only performed on a particular type of data from a specific plasma region. The determination of calibration parameters is discussed in more detail in section 2.

The second stage of the production procedure is the data processing. This is done using the same calibration file for all three data products and data is processed in periods of 1 orbit from perigee to perigee. The standard FGM data processing software is used except for one new function which is used to output the data in CEF format. In addition to this a perl scipt has been written which controls the inputs and output from the data processing pipeline.

Finally the processed data is validated for scientific use by visually inspecting the 5 vectors/s data. This is a compromise between using the high resolution data which is very slow to plot and the spin resolution data which does not contain the same level of detail and may average away small features that should be removed. Data are plotted one orbit at a time and the 4 spacecraft data plotted together. The data are visually inspected by looking at periods of data approximately 30 minutes to 3 hours depending on what magnetospheric region is being considered. In the sheath region for instance, there tends to be high levels of magnetic fluctuations which makes it more difficult to spot possible bad data points unless smaller regions of data are considered. During this process the timing of bad data points are recorded. The bad data points are then removed from the 3 data products and the recorded time intervals are inserted into the VALF CEF files which are an auxiliary data product.

## 2. THE CALIBRATION ANALYSIS

### 2.1 The calibration problem

The aim of in-flight calibration is to convert the three components of the measured magnetic field vector from engineering units in an approximately orthogonal coordinate system into the physical units of nT in a precisely orthogonal coordinate system. The full description of the engineering model which describes this transformation is presented in the paper Balogh et al. (2001). The 3 elevation angles $\theta$, one for each sensor component, and 3 azimuthal angles $\varphi$, can be used to transform the sensor magnetic field components into an orthogonal coordinate system. The 3 gains G and three offsets O convert the field into nT. The full transformation between sensor(subscript S) magnetic field components and the orthogonalised magnetic field components in nT(subscripts x, y and z) is shown in equation 1. The angles are defined in the same way as in the paper Kepko et al. (1996). Equation 1

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summarises the calibration problem. There are 12 calibration parameters to be determined in order to calibration the FGM data but there are also 3 independent instrument ranges. Each range has a different set of values for the calibration parameters.

$$\begin{pmatrix} B_{S1} \\ B_{S2} \\ B_{S3} \end{pmatrix} = \begin{pmatrix} G_1\cos\theta_1 & G_1\sin\theta_1\cos\phi_1 & G_1\sin\theta_1\sin\phi_1 \\ G_2\cos\theta_2 & G_2\sin\theta_2\cos\phi_2 & G_2\sin\theta_2\cos\phi_2 \\ G_3\cos\theta_3 & G_3\sin\theta_3\cos\phi_3 & G_3\sin\theta_3\cos\phi_3 \end{pmatrix}\begin{pmatrix} B_x \\ B_y \\ B_z \end{pmatrix} + \begin{pmatrix} O_1 \\ O_2 \\ O_3 \end{pmatrix} \quad (1)$$

There is no single calibration analysis method that can provide an estimate for all the calibration parameters. There are several methods which when used in combination give estimates or information about most of the calibration parameters that need to be calculated. Figure 1 summarises the ultimate calibration procedure to be used for the calculation of calibration parameters to be applied to the data which is to be submitted to the cluster active archive. The procedures for the solar wind analysis, Fourier analysis(Kepko et al. 1996), range change jump analysis, intercalibration and the production of calibration refinement files have been developed or are being developed in collaboration with colleagues from UCLA(private communication, H. K. Schwartzl, K. Khurana, M. Kivelson). The EDI/FGM analysis has been developed in collaboration with the EDI archive developer(private communication , E. Georgescu). The solar wind analysis provides an estimate of the correction to the spin axis offset during the part of the year when Cluster goes into the solar wind. During the magneto-tail season a different method needs to be used to calculate this spin axis offset correction. The analysis of EDI and FGM data together can give some information about spin axis offsets and the intercalibration gives estimates of the correction to the spin axis offsets when it is possible to use it. The periods of data when intercalibration can be used are quite rare as the spacecraft separation must be small. Also only data in regions when there is expected to be no currents present can be used, namely in the lobes. The Fourier analysis method can be used to calculate a significant proportion of the calibration parameters. Eight of the twelve calibration parameters can be calculated for each instrument range using this method although two of the parameters are only relative values. Jumps in the magnetic field components found at range changes can be used to improve some of the other calibration parameters and intercalibration can be used in certain regions to estimate a number of parameters. At this stage the calibration files have been created with a validity that extends for the period of 1 orbit, perigee to perigee. It has been found that some calibration parameters can change and produce spin harmonic signatures in the data within an orbit. The calibration refinement files contain corrections to the orbit calibration files on short time scales which takes account of these changes in calibration. Two of these calibration methods are discussed in more detail in sections 2.2 and 2.3.

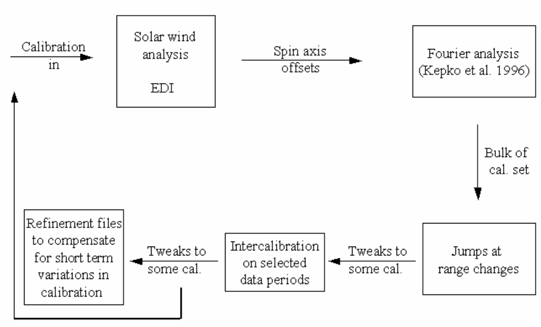


Figure 1: Overview of the ultimate calibration procedure for the cluster active data.

## 2.2 Solar wind calibration analysis

The solar wind calibration analysis provides a correction to the spin axis offset for each of the 4 Cluster spacecraft. The method exploits a natural property of the solar wind and allows the calculation of the correction to an offset of a non-spinning sensor(Hedgecock, 1975). The solar wind is known to contain fluctuations which are predominantly rotational. Rotational fluctuations appear in the FGM data as fluctuations in the magnetic field components but with no signature in the magnetic field magnitude. This means that there should be no correlation between the magnetic field magnitude and any of the magnetic field components. However if there is an offset, in the spin axis magnetic field for instance then a correlation exists between this field component and the magnetic field magnitude. The spin axis offset correction can then be found by calculating the offset required to remove the correlation between the field component and the magnetic field magnitude.

The key to producing good results using this method is in the selection of data to be used in the analysis. The data selection method used here was developed by colleagues from UCLA(private communication, H. K. Schwartzl, K. Khurana, M. Kivelson). This method uses the correlation effect between the spin axis magnetic field and the magnetic field magnitude discussed above in order to extract the most suitable data for the solar wind analysis. In reality the solar wind does also contain compressive fluctuations in some regions and this correlation data selection techniques selects the periods of data which contain most clearly rotational fluctuations.

Figure 2 shows the FGM data for the 4 cluster spacecraft after the solar wind analysis has been done and the spin axis offset correction applied. These results show that the analysis has worked well in this case and the spin axis magnetic field component, which in this case is the z-axis, has approximately the same values for all 4 spacecraft. The four spacecraft data have their standard colours in figure 2. The small amplitude sinusoidal wave in the spacecraft 1 data is due to a small spacecraft field and cannot be removed with the calibration analysis applied in this case. A further refinement can be made to the spin axis offsets by applying a calibration method which uses the 4 spacecraft data together and finds the minimum set of offsets that can be applied to three of the spacecraft spin axis fields in order to bring the fields as close together as possible. The scale sizes of the structures in the solar wind are large compared to the inter-spacecraft distances so all 4 spacecraft should measure approximately the same field. This solar wind refinement can only be used on periods of solar wind data which are very smooth. This requires extra data selection to be done before this method can be applied and it may be possible that during some periods, suitable solar wind data cannot be found.

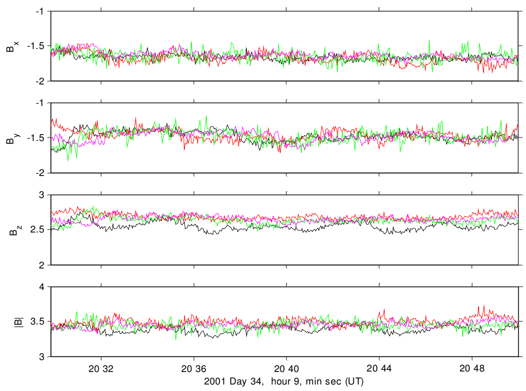


Figure 2: FGM data for 4 Cluster spacecraft after spin axis offset correction has been applied. Top three panels are the magnetic field components in GSE coordinates. The fourth panel is the magnetic field magnitude. The four spacecraft are plotted with their standard colours.

### 2.3 Range change jump analysis

After the Fourier analysis calibration results have been applied to the data it is possible that jumps in the magnetic field components can be seen at instrument range changes. These jumps indicate that some of the calibration parameters which at this point of the calibration procedure are undetermined, are incorrect. The size of the jumps in each magnetic field component at the range changes can be used to better determine these calibration parameters.

The procedure for reducing these jumps at range changes and improving a set of calibration parameters again was developed by colleagues from UCLA(private communication, H. K. Schwartzl, K. Khurana, M. Kivelson) and we then implemented it for use with the cluster active archive. Figure 3 shows an example of the jumps that can be seen at a range change before the calibration parameters have been modified. In the case of figure 3 the data is for a spacecraft 1 range 3 to 4 change.

In order to apply this calibration analysis, the FGM data either side of the range jumps is extracted. The jump in the magnetic field in each sensor component must then be estimated for all the selected range changes. In practice this is done manually by using plotting tools to look at each component separately where the plots superimpose 5vectors/s data and spin resolution data. The reason this must be done manually is that the least squares fits in general do not do a good job particularly when there are variations in the field. The statistics from a set of range jumps are then used to estimate the corrections to a set of calibration parameters. The calibration parameters that can be modified using this method are the spin axis gain and offset and the spin plane azimuthal angle and relative gain. The corrections are split between the upper and lower ranges for both range 2 to 3 changes and range 3 to 4 changes so there are some parameters in some ranges which are not estimated.

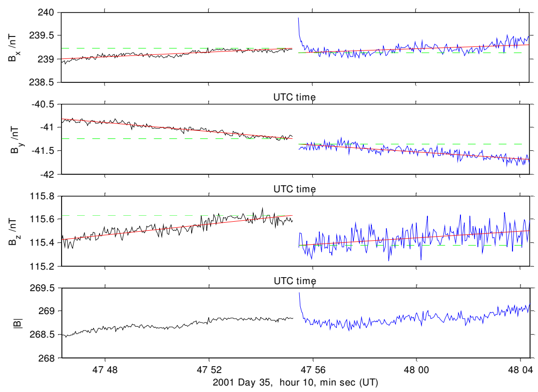


Figure 3: Example range change jumps in spacecraft 1 data for range 3 to 4 change. The black lines are lower range data and the blue upper range data. Red lines are least squares fit to the data and the green is the fitted field value at the range change. The top three panels are the magnetic field components in sensor coordinates and the bottom panel is the magnetic field magnitude.

## 3. PRESENT DATA PRODUCTION STATUS

Three months worth of FGM data have been submitted to the Cluster Active Archive at this time. Both calibration files and processed and validated data have been submitted for the period 30/01/01 to 01/05/01 which covers the orbits 93 to 130. For these orbits of data which have been submitted only the solar wind and Fourier analysis calibration methods have been used.

The estimated production rate for the calibration files which have been created using just the solar wind and Fourier analysis method is approximately 24 hours per orbit calibration file. The data processing step is relatively quick and several orbits can be processed per night. The validation takes approximately one day to validate the three data products for one orbit .

A significant amount of progress has been made in the previous 3 months with the development of the calibration analysis methods. The solar wind and Fourier analysis methods are in use within the standard calibration procedure. Following a recent visit and collaboration with UCLA the solar wind refinement and range jump analysis methods are now under final testing. Progress has been made with the production procedure for creating high time resolution refinement calibration files but more development and testing is required. The recent collaboration with UCLA has also initialised the implementation of intercalibration between the four spacecraft. The analysis method using EDI and FGM data together is now producing results which can provide some information about the spin axis offsets.

## 4. FUTURE PROJECTION OF PRODUCTION STATUS

The best present estimate for the completion of the 2001 magneto-tail season data is the end of 2005. It is also anticipated that some data from the following dayside season will also be submitted by the end of 2005. The new calibration methods to be used in the magneto-tail data production are inputs from the EDI/FGM analysis and some results from the intercalibration. The range jump analysis will be used in the production of all the new calibration files and the solar wind refinement method will be used in the following day side season provided suitable data exists to use it. It is anticipated that the rate at which the whole calibration procedure can be done for a particular period will increase as the procedure becomes more routine.

## REFERENCES

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