# User Guide to the FGM measurements in the Cluster Active Archive (CAA)

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# Contents

# 1. Introduction

This document is the User Guide to the FGM (Fluxgate Magnetometer) datasets in the Cluster Active Archive (CAA). Its main purpose is to assist users in the interpretation of FGM CAA data products. All FGM datasets available on the CAA are listed in Appendix A. The dataset that is most frequently applicable for scientific studies is the 5VPS (five vectors per second) dataset, as discussed in Section 5.1

Preparation of the FGM CAA datasets is a time intensive activity requiring significant manpower and computing resources. One of the reasons for this is the extensive set of analyses required to calibrate DC-magnetometer data in flight, the relatively large number and unpredictable nature of fluxgate sensor calibration parameters do not lend themselves to purely automated calibration schemes ([1] for a full description). Another reason is the nature of the very large volume of data produced by the four Cluster instruments, which for the vast majority of the mission have been operational each and every orbit. Cluster is the first space mission to feature such multiple magnetometers with datasets that are comprehensive and well calibrated.

Until 2013, the large processing and interpretative analysis overhead associated with multiple magnetometer calibration meant that effort was mainly focussed on producing well calibrated data sets according to the CAA schedule, as opposed to investigating trends in the long term drift of the FGM calibration parameters. Since the FGM CAA data generation has now consistently caught up with that of the real-time mission, investigation of long term and statistical analysis of the FGM calibration parameters became possible and has been published [2]). Issues relating to FGM calibration are not discussed in detail in this document; these are presented in the accompanying Calibration Report [1].

# 2. Instrument Description

Each Cluster spacecraft carries an identical FGM instrument (Fluxgate Magnetometer) to measure the DC magnetic field vector [3, 4]. Each instrument, in turn, consists of two triaxial fluxgate magnetometers and an onboard data processing unit. In order to minimise the magnetic background of the spacecraft, one of the magnetometer sensors (the outboard, or OB sensor) is located at the end of one of the two 5.2 m radial booms of the spacecraft, the other (the inboard, or IB sensor) at 1.5 m inboard from the end of the boom. In the default configuration, the OB sensor is used as the Primary Sensor on all spacecraft. Data from both sensors are routinely downloaded, but the IB sensor data is deprecated to ~10x lower resolution than the OB data. The FGM datasets in the CAA from commissioning phase (December 2000) to the present consist of calibrated measurements from the OB sensors, which, with few exceptions, have been designated the Primary Sensor throughout the Cluster mission duration.

The IB and OB magnetometers can measure the three components of the field in six ranges with full scales and corresponding digital resolutions as shown in Table 1. From November 2000 to October 2006, ranges 2–4 were in regular use. Starting in November 2006, range 5 entered routine use. Starting in May 2008, range 6 entered routine use. Starting in December 2009, range 7 entered routine use. Neither range 6 nor range 7 was originally intended for use during the nominal mission hence these ranges were not fully calibrated on the ground. The determination of the offsets and gains for Ranges 6 and 7 are dependent on the Range 5 calibrated data.

| RANGE NUMBER | RANGE | RESOLUTION |
|---|---|---|
| 2 | - 64 nT to + 63.97 nT | $7.8\times10^{-3}$ nT |
| 3 | - 256 nT to + 255.87 nT | $3.1\times10^{-3}$ nT |
| 4 | - 1,024 nT to + 1,023.5 nT | 0.125 nT |
| 5 | - 4,096 nT to + 4,094 nT | 0.5 nT |
| 6 | - 16,385 to + 16,376 nT | 2 nT |
| 7 | -65,536 to + 65,536 nT | 8 nT |

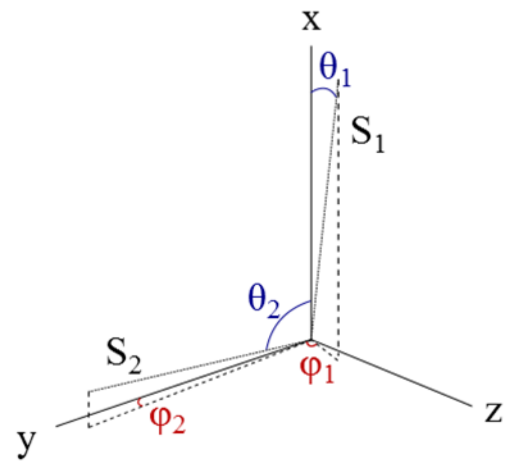
**Table 1: FGM Operating Ranges and Resolution**

The sampling of vectors from the magnetometer sensor designated as the primary sensor is carried out at a rate of 201.75 vectors/second. The full bandwidth of the sampled vectors cannot be routinely transmitted via the telemetry because of the limited telemetry rate allocation. The Central Processor Unit convolves the full bandwidth data with a Gaussian digital filter to match the rate and bandwidth of the transmitted vectors to the available telemetry rate. The full-resolution magnetic field dataset contains vectors normally either at 22 or 67 Hz resolution (for normal (NM) and burst (BM) modes, respectively).

The fluxgate sensors are most sensitive in the range 0 Hz to 10 Hz. The instrument response at higher frequencies is given in the FGM Calibration Report [1]. The signal chain from the sensor acquisition to the telemetered data stream has two filter stages – an anti-aliasing analogue filter on the output of the sensor voltage and the DPU-implemented digital filter(s) described above (See Figures 5 and 6 in [5]). Caution is therefore required when interpreting FGM data in the frequency domain where the wave power will not be accurate above 5 Hz due to the filter cut-offs and it is likely the STAFF search coil dataset will be more accurate. For instance, sometimes the FGM data are provided at 67 Hz rate which is described as Burst mode. More information is available in the Calibration Report [1].

The in-flight calibration of FGM is based on an evaluation of all the possible sources of errors that occur in the measurement process, embodied in an "instrument model" representing the measurement processes of the magnetic field. Conceptually, the actual value of the ambient magnetic field vector at the location of the FGM sensor (given, for instance, in Geocentric Solar-Ecliptic, *GSE*, coordinates, as $\mathbf{B}_{GSE}$) is measured by the FGM output through the telemetry as a digitised vector **V**. This vector (the actual measurement) depends in a complex, but linear way on the alignment and orthogonality of the sensor axes with respect to the *GSE* coordinate system; on the scale factors and offsets of the sensors and electronics of FGM; and on the offsets introduced by the spacecraft's residual magnetism. The instrument model also needs to take into account the time and frequency response in the form of delays and effective bandwidth due to the magnetometers, the Analogue-to-Digital Converters, and the digital filtering process. The coordinate transformation from GSE into the (nearly, but not quite orthogonal see Figure 1 below) magnetometer sensor system (specific to each of the eight magnetometers on the four Cluster spacecraft) is a superposition of transformations that take into account also the misalignments introduced by the spacecraft, the magnetometer booms, sensor mounting and construction. All of which are required to be evaluated for each measured output vector.

Figure 1: The relationship between the orthogonal (x,y,z) and sensor ($S_1$,$S_2$,$S_3$) coordinate systems. The angles θ and φ for each sensor coordinate are defined in the same way. The task of producing calibrated data then comes down to determining the parameters in the calibration equation. There are six angles, three gains and three offsets. There is no single calibration analysis that can be used to calculate all of these parameters. S3 has been omitted for clarity. See [1] for more detail.




# 3. Instrument Operations

The default operational state of FGM is on and this has been the case for all four spacecraft since the beginning of nominal operations (2001). FGM commanding primarily involves the switching of the FGM operational mode in response to the preset data rate defined in the Cluster Master Science Plan in conjunction with available bandwidth on-board the spacecraft. The nominally used science modes are the default, 22 Hz (NM, mode C) and 67 Hz burst (BM, mode D) [6]. Mode changes occur simultaneously on all four spacecraft.

FGM operation has been continuous since nominal operations began, with all four instruments still working on the primary hardware chain. Only a small number of data gaps have been caused by irregular FGM instrument anomalies. The majority of gaps in the FGM data set are related to spacecraft or mission-related data gaps. For example, during 2001 and 2002 the spacecraft were only scheduled to record data during approximately 50% of the orbit. More recently, as the spacecraft power budget has become tighter with the degradation of on-board batteries, payload operations are ceased during spacecraft eclipses which introduces frequent gaps in data return even outside the eclipse intervals. There is no FGM data in the CAA from eclipse intervals.

# 4. Summary of Calibration and Processing procedures

The principle by which raw magnetic data in instrument sensor co-ordinates are converted into GSE co-ordinates through the derivation and application of a calibration transformation matrix is described in detail in [4]. To fully define the transformation for the three sensors, 9 matrix elements and 3 offsets are required. Some of these parameters are defined using measurements made before launch. In the developed approach it is not possible to determine the remaining calibration parameters through the application of a single method. A suite of developed analysis methods is utilised to determine the different parameters described within [6] and are referred to as:

- Spin axis offset determination by application of the method described by Hedgecock [9], applied when the spacecraft are in the solar wind.
- Spin axis offset monitoring through comparison with EDI and WHISPER. Some comparisons have been performed, but currently this method is not applied to the CAA datasets.
- Application of Fourier (Kepko) calibration analysis. This is applied to every orbit and most of the calibration parameters come from this method
- Refinement of calibration parameters based on jumps in B at changes in the instrument range.
- Inter-spacecraft calibration. Some comparisons have been performed, but currently this method is not applied to the CAA datasets.
- Calculation of short timescale refinement files.
- Data validation.

The time interval of data that is required for each calibration procedure varies between methods. The estimation of the offset on the spin-aligned sensor generally requires solar wind data taken over either 2 weeks or a month, depending on data coverage and quality. As a result, one calibration file per spacecraft is produced for each orbit from perigee to perigee. For further detail on the analysis methods see the FGM Calibration Report [1].

The accuracy of the calibration depends on a number of factors including:

1. Data coverage - Extensive data gaps (e.g. due to eclipse periods) can have a strong negative impact on the calibration particularly in the Kepko method [2].
2. Data characteristics - Most corrections to the calibration parameters are small. Therefore power within the natural signal can make it difficult to identify the correction to the calibration matrix that is required.
3. Spread of **B** and |B| within the data - The majority of calibration techniques require measurements over a range of magnetic field magnitudes and directions. A narrow spread in either of these can adversely impact the quality of the calibration.

The time over which the calibration is calculated depends on each of these three factors. Poor data coverage might, for example, suggest that using data over a longer period would be helpful. However, all the calibration methods assume that the underlying calibration parameters do not change over the period of data being analysed. If there is a change in calibration parameters during the interval of analysis, then since only a single estimate of the parameters is derived, some part of that period will be less well calibrated.

In 2014, we completed a long-term study on the calibration and housekeeping parameters of the Cluster FGM data on all four spacecraft. This work has been published in Geoscientific Instrumentation, Methods and Data Systems.[2] It was found that the parameters were very stable over the eleven years of mission data under study (February 2001 to February 2012), giving confidence both in the calibration method and the measurement accuracy. The offset drift in C1 was found to be ~0.2 nT/year for the most sensitive instrument ranges while the offset drifts of C2, C3 and C4 are negligible. The study also allowed periods of poor calibration to be identified, corrected, and resubmitted to the CAA. Fortunately these periods were few (67 orbits out of ~1900). Redelivery took place between September and December 2013.

CAVF (caveat file) files are utilised to flag poor quality data after calibration and validation, and as a routine indicator of data quality respectively. It is strongly recommended that users check the caveat files when selecting datasets for scientific use.

# 5. Key Science and Supporting Datasets

The primary FGM data products are simply magnetic field vector in GSE at different data rates (primary data products), plus calibration and quality indicator support data products.

## 5.1. Primary data products

The primary FGM data products consist of magnetic field data products at three different time resolutions. Each of the three data products is processed independently but each data product is calibrated using the same calibration file.

The highest resolution magnetic field data product (Cx_CP_FGM_FULL), where *x* denotes spacecraft number (1 to 4), contains data that has no time averaging applied. If the instrument is in normal mode (NM) the data is at 22.4 Hz resolution and if it is in burst mode (BM) the data is at 67.2 Hz resolution. The second magnetic field data product (Cx_CP_FGM_5VPS) is averaged to a time resolution of 5 vectors/second and the third magnetic field data product (Cx_CP_FGM_SPIN) is averaged over one spacecraft spin where the spin phase for averaging is the same as that used for the Prime Parameter data (+26.367 deg. with respect to the sun reference pulse). The averaging for the 5VPS and SPIN data sets is done within the FGM data processing software, and uses a boxcar average. Each of the three primary data products consists of various columns of data, structured as follows:

- Time (ISO time)
- Half interval of time over which magnetic field is averaged, in s
- Magnetic field vector GSE(X) component in nT
- Magnetic field vector GSE(Y) component in nT
- Magnetic field vector GSE(Z) component in nT
- Magnetic field vector magnitude in nT
- Position vector GSE(X) component in km
- Position vector GSE(Y) component in km
- Position vector GSE(Z) component in km
- FGM range (unitless: 2,3,4,5,6 or 7 corresponding to the ranges used in flight)
- FGM Telemetry Mode (unitless: 15, 18, 22 or 67)

It should be noted that for the spacecraft position, values are rounded to 100 m by the FGM processing software, which is the known absolute accuracy of the spacecraft position as quoted by ESA. This can sometimes cause an unrealistic step-wise variation in the spacecraft position data and in the separations between spacecraft. Users may wish to smooth the data or to plot the position data from the spacecraft trajectory files instead of from within the FGM data products.

An example of a bow shock crossing observed by spacecraft 1 is shown in Figure 2, with SPIN and 5VPS data products plotted on the same graph. On this scale full resolution data are indistinguishable from the 5 vectors/second averaged data, and this illustrated the case that for many scientific studies the 5VPS data product is the appropriate one to use.

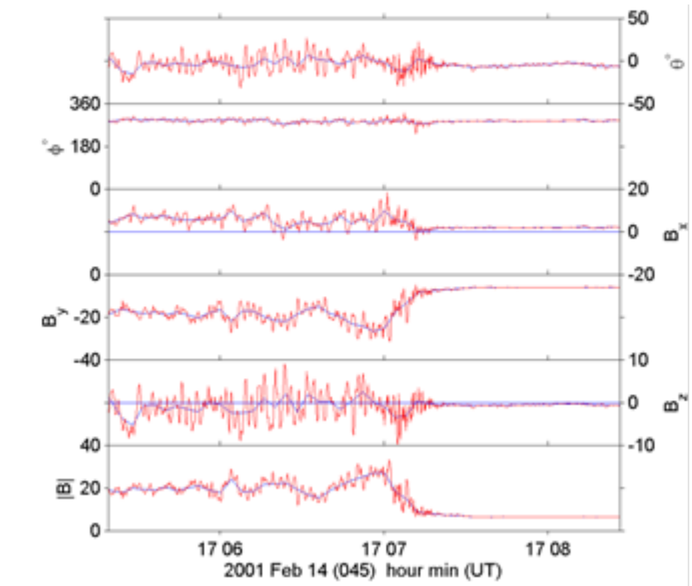



Figure 2: An example bow shock crossing from Cluster 1 on February 15 2001. Spin averaged data are shown in blue, and 5 vectors/second data are shown in red. On this scale FULL resolution data are indistinguishable from the 5VPS data.

**Accuracy of the magnetic field vector**

The routinely achieved relative accuracy level between the four spacecraft for well calibrated science data in instrument Ranges 2, 3 and 4 is estimated to be:

- 0.2 – 2 nT (|B| < 200nT)
- 2-40 nT (200nT <|B| < 4000nT)

Cross-calibration results from a survey of over a hundred intervals indicate a discrepancy of less than 1% between FGM and EDI in nearly all cases, and across multiple instrument modes/ranges. There are a number of signatures that indicate that there are residual errors in the calibration parameters. The spin axis offset is particularly difficult to determine. It can be calculated using solar wind data as described in [9] but long intervals of data are needed, either 2 weeks or a month. Therefore the quality of agreement of the 4 spacecraft when they are all situated in the solar wind can vary over this time if either the data coverage does not lead to a good estimation of the spin axis offset, or the offset changes. Figure 3 shows an example where the magnetic field measured at spacecraft 4 (magenta) is systematically different in $B_z$, which is approximately aligned with the spin axis. However, the agreement between the traces is substantially better during other parts of the same orbit. We are still investigating the consequences of using the method in [9] on the accuracy of the calibration parameters, but it is possible that it might depend on the direction of the magnetic field. The absolute accuracy is under continuous study with the agreements between FGM and EDI/WHISPER discussed in Section 5.1 of the Calibration Report [1].

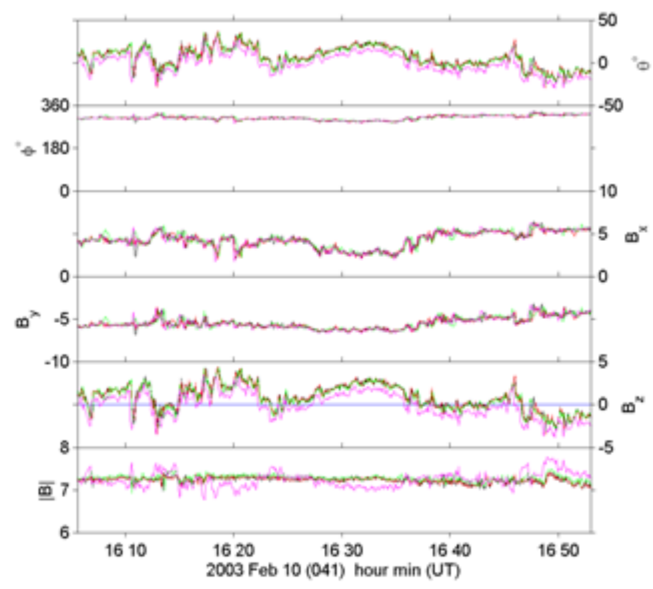



Figure 3: An example of a systematic, non-physical offset between the $B_Z$ component measured at Cluster 4 and the other 3 spacecraft. This discrepancy does not continue for the whole period of solar wind data

**Presence of spin tone in the magnetic field vector**

Spin tone may be seen in the data on occasion- this usually indicates a small residual error in the calibration, typically due to calibration drifts occurring on timescales much shorter than that of a single orbit. The highest case of spin tone occurs during perigee when the spacecraft pass through maximum |B| where it might commonly be of the order of 0.4 nT. Where it occurs elsewhere during an orbit it will typically be less than 0.1 - 0.2 nT. Larger values occur in recent years when measurements have been made in Range 6 and Range 7. Spin tone is particularly common during orbits that contain eclipses, especially if the instrument has had to be switched off. In this case the spin tone often exceeds the limits given above, and a caveat file is prepared for that orbit. An example of small amplitude residual spin tone is shown in Figure 4. The spectrogram in Figure 5 shows the whole of this orbit, and the residual signal at the spin frequency can be seen when natural background signal is low, such as in the magnetosphere. This plot also illustrates that the levels of spin tone in Range 4 are different at the start and the end of the orbit. This arises from a small change in Range 4 calibration parameters within the single orbit. In recent years, where the spacecraft experience more eclipses, and especially if the payload has to be switched off, this effect has become more pronounced, and visible spin tone during some part of the orbit has become more common as a result. Finally, the two intervals of broadband wave power correspond to the magnetosheath.

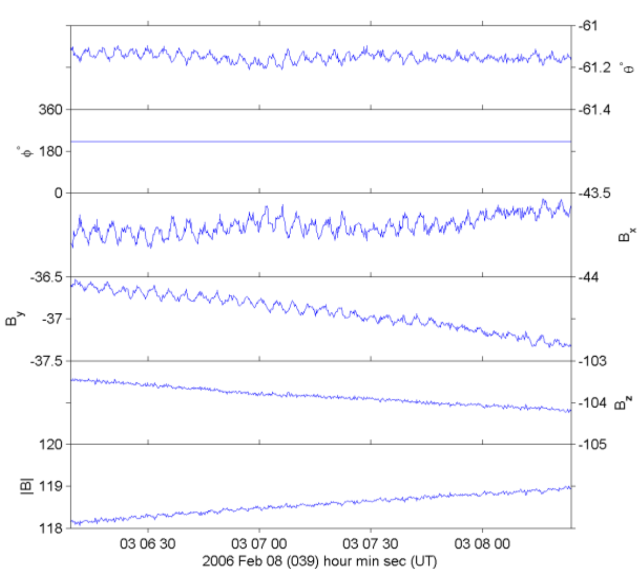



Figure 4: An example of small amplitude residual spin tone in Cluster 2 data on 8 Feb 2006

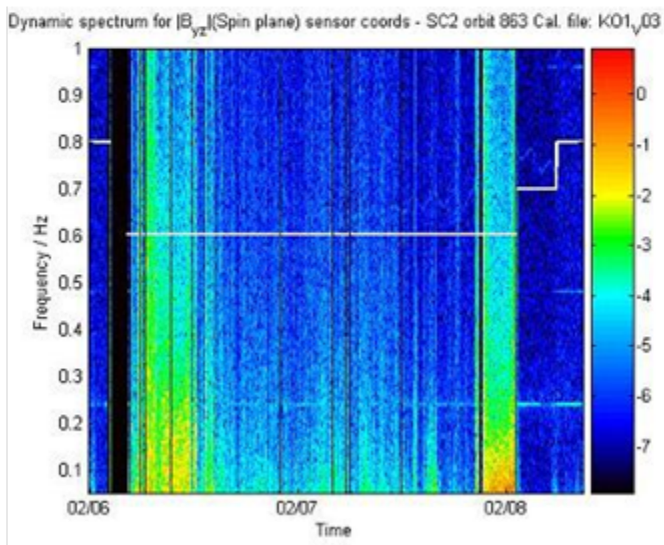



Figure 5: A spectrogram of data from the orbit containing the interval above. The white horizontal lines indicate instrument range, with Range 2 as the lowest line, and each step indicating a higher range. The high broadband wave power in Range 3 is a signature of the disturbed field in the magnetosheath. The interval shown in Figure 4 occurs in Range 3 on Feb 8th (on the right hand side of the plot)

**Instrument noise level**

The instrument noise level above 1Hz is of the order $1\text{x}10^{-4}\text{nT}^2/\text{Hz}$ (10pT/√Hz). This may be compared with a digital resolution of 7.8pT in the highest resolution Range 2. Usually the absolute instrument noise floor will only be seen in quiet solar wind conditions. An example is given from spacecraft 1 and 2 in Figure 6. The irregular 'bursty-ness' on the data is the signature of the noise floor. Users are reminded that the FGM instruments are comprised of DC magnetometers. At very low frequencies (below 1 Hz), the FGM data produce high-quality, low-noise data. However, users who are interested in investigating higher frequency AC magnetic phenomena would be advised to consult the STAFF User Guide for guidance on which instrument data to use for a particular frequency.

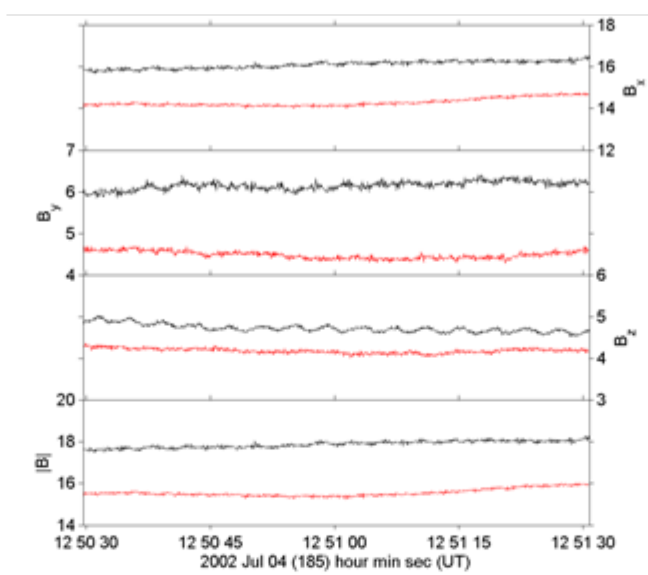



Figure 6: FULL resolution data from Cluster 1 (black) and Cluster 2 (red) during a period of very quiet natural signal allowing the signature of the noise floor to be seen. The residual signal at the spin frequency on Cluster 1 that arises from a spacecraft source can be seen clearly in this plot.

Note that on spacecraft 1 the FGM data has a small residual spin ripple. This is not due to a calibration error but a real effect caused by spacecraft interference. It is not present on the other Cluster spacecraft; it doesn't occur in the data from spacecraft 2 in this plot for example; and is believed to be due to design differences in the spacecraft 1 flight build compared with the other Cluster spacecraft (spacecraft 1 is a version of the original Cluster spacecraft).

## 5.2. Support data products

There are several support data products produced for FGM data that give additional information about the magnetic field data products or about the calibration used to generate the data. There are two data products that provide interval times for data gaps in the FGM data. The first product (Cx_CQ_FGM_GAPF) lists the data gaps that are introduced at the processing stage. These can arise for a number of reasons: the instrument being off, no data having been retrieved from the spacecraft (this occurred often in 2001 and 2002), or there being insufficient information for the data to be processed, for example data taken during an eclipse cannot be processed. Very short gaps also occur when the instrument changes range. The second product (Cx_CQ_FGM_VALF) lists time periods where bad data have been removed at the data validation stage. These intervals are typically only a few seconds long, and often arise from a data packet having become corrupted.

Caveat files (Cx_CQ_FGM_CAVF) are produced for periods of data when the calibration is known to be changing on short timescales near eclipses and for other events when visible effects have been observed in the data. These file types are described in more detail below.

## 5.3. Caveat files (CAVF)

CAVF files are generated for intervals of data when the calibration procedure is compromised, often for one of the reasons listed in section 4. The signatures of poor calibration at this level are generally either a visible signal at the spacecraft spin frequency, or a spread of magnetic field values between the four spacecraft while they are in a region when we would expect all spacecraft to measure the same average magnetic field. The latter is most commonly seen in the solar wind.

Within a CAVF file for a particular spacecraft for a particular interval, the signature of poor calibration, and (where possible) the cause are given. Common reasons for caveats are:

1. Spacecraft eclipses, where the temperature change experienced by the instrument during short or particularly long eclipses can often lead to a small but significant change in calibration parameters during that orbit. This leads to a larger than normal residual spin tone in the data that can be identified at the validation stage.
2. Spacecraft manoeuvres can also cause changes in the calibration parameters, leading to a similar signature as in 1.
3. An unexplained spread in sensor spin axis magnetic field data exceeding 0.25 nT is seen between the four spacecraft. This signature can generally only be seen in the solar wind where the magnetic field magnitude is low, and the magnetic field data are very quiet. This can arise if the spin axis offset changes during the two weeks or 1 month over which the spin axis offset calibration method is applied. However, poor data coverage might also influence the accuracy with which the spin axis offset can be estimated.
4. Unexplained instances where higher than normal spin tone is observed. These occur occasionally. For example, bursty spin noise has been observed on spacecraft 4 since September 2010 and there appears to be no correlation to FGM or platform commanding. The periods are therefore caveated and are under continued investigation.

All data sets have been regenerated with caveat files generated through comparison to signal-to-noise ratio thresholds in Ranges 2 and 3 and mean spin power thresholds in the higher ranges. This is now the general procedure. Previous to this date caveats were manually produced for a period of interest when an extreme amount of spin tone was observed during validation. The thresholds for spin tone above which caveats will be generated are given in Table 2. Reasons for the high spin tone will then be identified where possible. For the signal-to-noise ratio (SNR) the signal is the amplitude of the spin tone and the noise is the background field. The mean spin power is the integrated power around the spin frequency. In noisy regions there is high power across low frequencies, which is why SNR is used in the lower ranges. Eclipse periods will be determined and compared to the periods of high spin tone and if a correlation occurs the message in the caveat file reflects this ("This may be related to calibration parameter shifts caused by eclipses."). The Range 2 through 7 intervals have been compared to the spin tone in the respective spectrograms and were found to be able to identify high spin tone periods.

| | | *Dayside (2001-2015)* | *Tail (2001-2015)* |
|---|---|---|---|
| **Range** | **Threshold type** | **Dec-Apr** | **May-Nov** |
| R2 | mean SNR | 4 | 11 |
| R3 | mean SNR | 24 | 25 |
| R4 | mean spin power (nT^2/Hz) | 0.4 | 0.7 |
| R5 | mean spin power | 0.4 | 0.7 |
| R6 | mean spin power | 4.0 | 4.0 |
| R7 | mean spin power | 10 | 10 |

**Table 2: Signal-to-Noise Ratio and mean spin power caveat thresholds for all six ranges, utilized in the newly regenerated and now generally used CAVF files**

There are a few exceptions to the Range 4 thresholds. These are the dayside 2001 and tail 2003 seasons when the FGM was in a noisy region and the field strength was high enough to trigger a switch from Range 3 to Range 4. For these periods a mean signal-to-noise ratio of 15 and 20 respectively were used instead.

# 6. Recommendations

As the FGM datasets are reasonably simple and well defined they do not require a detailed set of recommendations in terms of which data sets to use, where/when to use them and how to interpret them. A typical approach to starting out working with FGM CAA data might involve:

- Retrieve and plot FGM data for a particular interval of interest. Preliminary spin resolution data (C[n]_PP_FGM) are stored in the CAA for completeness, but we suggest that users choose the recalibrated data, most usually 5VPS or SPIN is appropriate, if they are available.
- Check whether a CAVF file has been provided for this interval. This is delivered automatically as a separate file if there are caveats during the requested interval.

The routinely achieved relative accuracy level between the four spacecraft for well calibrated science data in instrument Ranges 2, 3 and 4 is estimated to be:

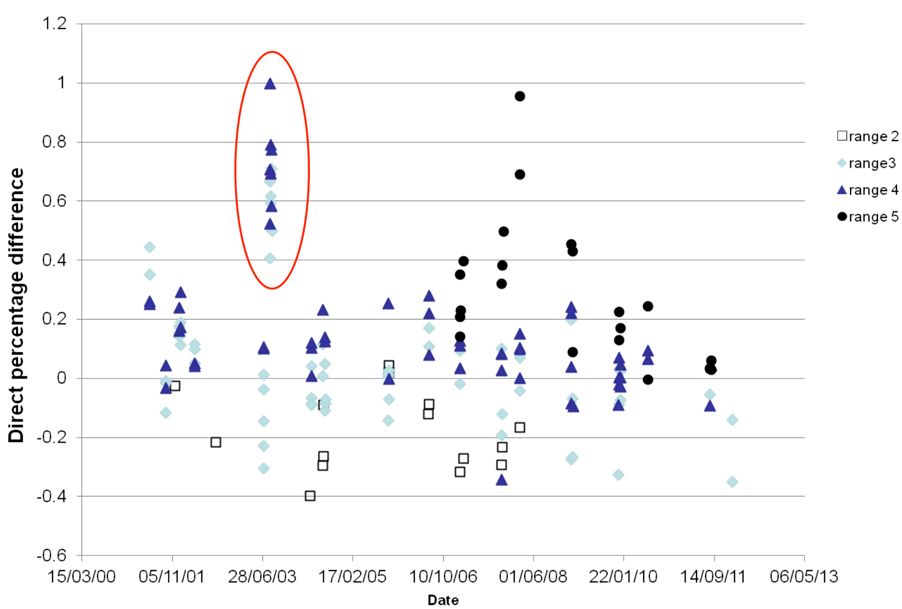
- 0.2 – 2 nT (|B| < 200nT)
- 2-40 nT (200nT <|B| < 4000nT)

As part of our cross-calibration efforts, a large number of data intervals (> 100) in C3 and C1 have been surveyed from 2001 to 2011 to compare the total B field measurements of FGM and EDI. The criteria applied to the data intervals were as follows:

- Small or no gaps in both FGM and EDI data
- Constant FGM range and EDI CRF mode
- Minimum of 20 minutes in duration
- 2-3 months between intervals
- C3 intervals selected first and C1 intervals used if the first three criteria were met

The percentage difference between FGM and EDI were calculated thusly: $(B_{EDI} - B_{FGM})/B_{EDI} * 100 = \Delta B_{EDI\text{-}FGM}$. The results for C3, plotted against the date and categorised according to FGM range, are shown below in Figure 7.

Figure 7: FGM-EDI comparison for C3.




It can be seen from this plot that $\Delta B_{EDI\text{-}FGM}$ ranges from -0.4% to 1.0% with no consistency. Additionally, $\Delta B_{EDI\text{-}FGM}$ seems to increase with FGM range. The case of August 2003 (circled in red) stands out, as it shows by far the largest $\Delta B_{EDI\text{-}FGM}$. This is true on both spacecraft as shown below in Figure 8. August 2003 is therefore not a good benchmark for treatment of differences between FGM and EDI.

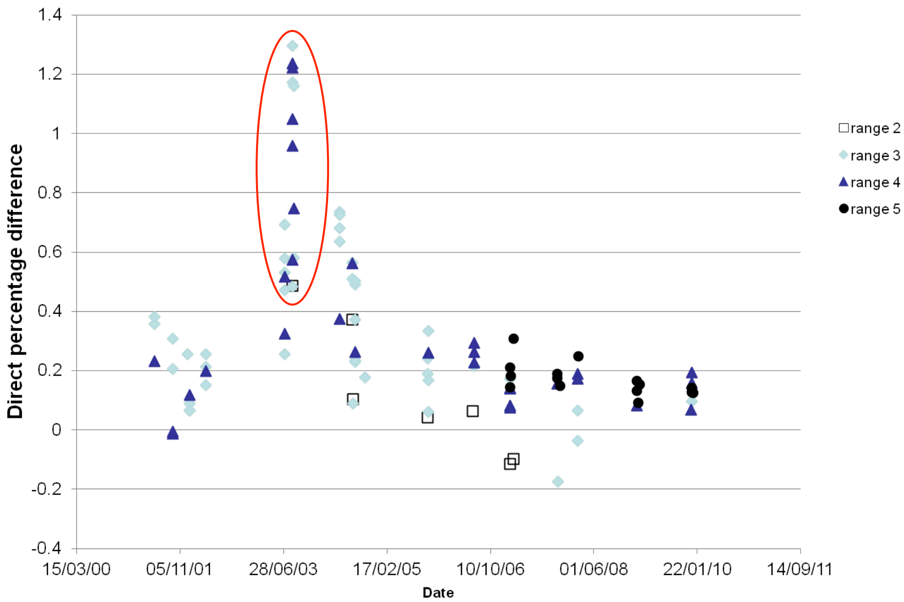



Figure 8: FGM-EDI comparison for C1.

In C1, apart from the anomalously large $\Delta B_{EDI-FGM}$ values for August 2003, the percentage difference shows no dependency on FGM range. This is also true for the EDI CRF mode (not shown here). The range of $\Delta B_{EDI-FGM}$ is slightly different from that observed in C3: -0.2% to 1.3%. Still, there is no consistent trend observed in the eleven years of data surveyed in the direct percentage difference between FGM and EDI.

Further study, including identifying more intervals, intervals in higher FGM range and EDI CRF modes, correlation with trajectory information and a comparison with WHISPER and STAFF data should be carried out in future as part of our ongoing cross-calibration efforts.

Spin tone may be seen in the data on occasion- this usually indicates a small residual error in the calibration, typically due to calibration drifts occurring on timescales much shorter than that of a single orbit. A reason for such spin tone after the calibration has been done is normally that the calibration parameters are changing within an orbit e.g. due to an eclipse period and a spacecraft manoeuvre. The highest case of spin tone occurs during perigee when the spacecraft pass through maximum |B| where it may reach up to 0.4 nT. Where it occurs elsewhere during an orbit it will generally be less than 0.1nT. Larger values occur in recent years when measurements have been made in Range 6 and Range 7. If spin tone that exceeds the thresholds described in section 5.4 is found within a period of interest (a given range), a caveat will be automatically produced along with the data that forewarns the user as to the nature of the excessive spin tone.

The instrument noise level above 1Hz is of the order $1 \times 10^{-4} nT^2/Hz$ (10pT/√Hz) (see Figure 5). This may be compared with a digital resolution of 7.8pT in the highest resolution Range 2.

Other points to bear in mind while using FGM CAA data include:

- *Burst Mode Data*: Highest resolution data in BM are primarily designed for use in time series analysis, for example discontinuity analyses at the bow shock or magnetopause. CAA users wishing to study waves in the frequency range above ~5 Hz should note that FGM is a DC instrument, and that filters within the instrument will significantly attenuate wave power above this frequency. It is recommended that data from the STAFF instrument be used to analyse waves in this frequency range.

- *Use of spectrograms*: If the user produces a spectrogram of data retrieved from the CAA there may still be residual power at spin (~0.25 Hz) and twice spin (~0.5Hz) frequencies. If a particular narrow band signal is seen at either of these frequencies, it is likely that it arises from small calibration errors and is not natural in origin. It is noted that this it is not possible to distinguish power between natural signal and calibration error at these frequencies. The FGM team does not recommend the use of 67 Hz for spectrograms.

# 7. References

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# Appendix A

The FGM datasets stored in the CAA/CSA are:

| **Dataset name** | **Dataset title** |
|---|---|
| Science datasets | |
| C[n]_CP_FGM_5VPS | Magnetic field, 5 vectors/second resolution |
| C[n]_CP_FGM_SPIN | Magnetic field, spin resolution |
| C[n]_CP_FGM_FULL | Magnetic field, full resolution |
| Auxiliary datasets | |
| C[n]_CQ_FGM_CAVF | Magnetic field, high spin tone caveats |
| C[n]_CQ_FGM_GAPF | Magnetic field data missing from processed data set |
| C[n]_CQ_FGM_VALF | Magnetic field data removed by validation process |
| C[n]_CC_FGM_CALF | FGM Calibration Files |
| C[n]_PP_FGM | Preliminary Magnetic Field data (Spin resolution) |
| C[n]_SP_FGM | Preliminary Magnetic Field data (1 minute resolution) |