Swarm-Echo MGF lv1b Data Product Description

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Section	**Item**	**Description of Item**

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Table of Exhibits

1 SCOPE

This document describes, in detail, the process used to calibrate the two fluxgate magnetometers (MGF) on the Swarm-Echo spacecraft. It also provides a description of the variables and flags found in the Swarm-like CDF data product, highlighting the differences from the Swarm L1b data product.

2 APPLICABLE AND REFERENCE DOCUMENTATION

[RD-1] SwarmE-RPT-002 Swarm-Echo MGF lv1b Data Calibration Validation Report

[RD-2] Finlay, C. C., Kloss, C., Olsen, N., Hammer, M. D., Tøffner-Clausen, L., Grayver, A., and Kuvshinov, A.: The CHAOS-7 geomagnetic field model and observed changes in the South Atlantic Anomaly, Earth Planets Space, 72, 156, https://doi.org/10.1186/s40623-020-01252-9, 2020.

[RD-3] Matzka, J., Stolle, C., Yamazaki, Y., Bronkalla, O. and Morschhauser, A.: The geomagnetic Kp index and derived indices of geomagnetic activity. Space Weather, https://doi.org/10.1029/2020SW002641, 2021.

[RD-4] Broadfoot, R. M., Miles, D. M., Holley, W., Howarth, A. D.: In-Situ Calibration of the Swarm-Echo Magnetometers, https://doi.org/10.5194/egusphere-2022-59, 2022.

3 INTRODUCTION

CAScade Smallsat and Ionospheric Polar Explorer (CASSIOPE) containing the enhanced Polar Outflow Probe (e-POP) instrument suite Yau and James (2015) was launched in 2013 by the Canadian Space Agency in partnership with the University of Calgary, Communication Research Center in Ottawa, Magellan Aerospace, and MDA, the prime contractor for the mission. In 2018, the European Space Agency (ESA) funded CASSIOPE operations and inducted it into the Swarm constellation as Swarm-Echo.

The scientific mission for the e-POP instrument suite is to study the Earth’s ionosphere, thermosphere, and magnetosphere. The e-POP suite contains an array of eight instruments which includes two fluxgate magnetometers (MGF) (Wallis et al., 2015) on a shared boom (Exhibit 1).

CASSIOPE uses reaction wheels to typically hold the spacecraft in a +Z-to-nadir orientation, and magnetorquers for periodic momentum dumping. Originally, four reaction wheels were used to steer the spacecraft. However, in August 2016 one of the wheels failed and the remaining three wheels were slowed to compensate for this. In February 2021 a second wheel failed which resulted in the remaining two being shut off while a solution to stabilize the spacecraft was found. In October 2021, the CASSIOPE operations team, in partnership with Magellan Aerospace, restored the spacecraft to a quasi-stabilized mode using a new control algorithm and increased rotation rates for the remaining two reaction wheels.

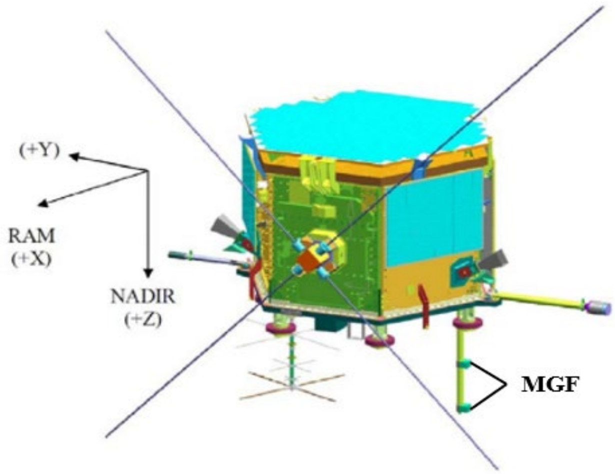

Exhibit 1: The CASSIOPE satellite showing the two MGF magnetometers mounted at different distances on a common deployable boom.

4 VECTOR CALIBRATION OF MAGNETOMETERS

Here we describe the process we implement to perform a full vector calibration of a three-axis magnetometer compared against a reference magnetic field. The vector calibration performed, and notation used is based on the method used by Olsen et al., (2003) .

The presented vector calibration utilizes the full vector information by minimizing the vector residuals between the measured field and a model field. Specifically, we minimize $|\Delta \boldsymbol{B}| = |\boldsymbol{B}_{CRF} - \boldsymbol{B}_{ref,CRF}|$ to obtain the calibration parameters, where $\boldsymbol{B}_{CRF}$ is the magnetic field vector in the common reference frame (CRF) and $\boldsymbol{B}_{ref,CRF}$ is a reference field in the same frame. Before the vector residuals can be minimized, we must first characterize the relationship between the raw sensor data (in the non-orthogonal reference frame) and the magnetic field vector. We assume that the raw sensor data have errors in offset (**b**), sensitivity (**S**), orthogonality (**P**), and rotation ($\boldsymbol{R_A}$).

Let **E** be the raw sensor data (in nT) that is related to the magnetic field vector $\boldsymbol{B}_{CRF}$ in the common reference frame by

$$\boldsymbol{E} = \boldsymbol{S P R_A B_{CRF}} + \boldsymbol{b} \tag{1}$$

where,

$$\boldsymbol{b} = \begin{pmatrix} b_1 \\ b_2 \\ b_3 \end{pmatrix} \tag{2}$$

is a vector of instrumental offsets (given in units of nT),

$$\mathbf{S} = \begin{vmatrix} \mathrm{S_x} & 0 & 0 \\ 0 & \mathrm{S_y} & 0 \\ 0 & 0 & \mathrm{S_z} \end{vmatrix} \tag{3}$$

is a diagonal matrix with each element representing a dimensionless scale value (often called sensitivity) for each magnetometer axis,

$$\boldsymbol{P} = \begin{vmatrix} 1 & 0 & 0 \\ -\sin(u_1) & \cos(u_1) & 0 \\ \sin(u_2) & \sin(u_3) & \sqrt{1-\sin^2(u_2)-\sin^2(u_3)} \end{vmatrix} \qquad (4)$$

is a matrix that describes the rotation of the magnetometer by angles u_1, u_2, u_3 (one for each axis pair) from a non-orthogonal frame into an orthogonal one, and $\boldsymbol{R_A}$ is a rotation matrix consisting of three separate Euler angles e_1, e_2, e_3 which describes the rotation between the magnetometer reference frame and the common reference frame ('1-2-3' in the case of MGF). The rotation parameters do not have any effect on the magnitude of the calibrated field, however, are necessary for the vector calibration to ensure the alignment of the frame of the sensor data and the reference field.

These 12 basic calibration parameters (3 sensitivities, 3 orthogonalities, 3 Euler angles, and 3 offsets) allow us to find the magnetic field vector in the common reference frame from the sensor data using

$$\boldsymbol{B_{CRF}} = \boldsymbol{R_A^{-1}}\boldsymbol{P^{-1}}\boldsymbol{S^{-1}}(\boldsymbol{E}-\boldsymbol{b}) \qquad (5)$$

with,

$$\boldsymbol{S^{-1}} = \begin{vmatrix} \frac{1}{S_x} & 0 & 0 \\ 0 & \frac{1}{S_y} & 0 \\ 0 & 0 & \frac{1}{S_z} \end{vmatrix} \qquad (6)$$

and,

$$\boldsymbol{P^{-1}} = \begin{vmatrix} 1 & 0 & 0 \\ \tan(u_1) & \frac{1}{\cos(u_1)} & 0 \\ -\frac{\sin(u_1)\sin(u_3)+\cos(u_1)\sin(u_2)}{\mathrm{w}\cos(u_1)} & -\frac{\sin(u_3)}{w\cos(u_1)} & \frac{1}{w} \end{vmatrix} \qquad (7)$$

Where $w = \sqrt{1-\sin^2(u_2)-\sin^2(u_3)}$ and $\boldsymbol{R_A^{-1}} = \boldsymbol{R_A^T}$ from the properties of rotation matrices.

The twelve calibration parameters can now be obtained by minimizing the difference of the squared residuals

$$\left\|\boldsymbol{B_{CRF}} - \boldsymbol{B_{REF,CRF}}\right\|^2 \qquad (8)$$

in a least squares sense.

Obtaining the parameters this way involves solving a set of non-linear equations which will be dependent on initial guess parameters. However, following the procedure outlined in Olsen et al., (2020), equation (5) can be rewritten as

$$\boldsymbol{R_A^{-1}}\boldsymbol{P^{-1}}\boldsymbol{S^{-1}}(\boldsymbol{E}-\boldsymbol{b}) = \boldsymbol{AE} + \tilde{\boldsymbol{b}} \qquad (9)$$

where $\boldsymbol{A} = \boldsymbol{R_A^{-1}}\boldsymbol{P^{-1}}\boldsymbol{S^{-1}}$ is a 3x3 matrix and $\tilde{\boldsymbol{b}} = -\boldsymbol{Ab}$. This now allows the equation to be solved as a linear inverse problem which is no longer dependent on initial guess parameters.

The calibration parameters can then be determined by reforming the linearized results of $\boldsymbol{A}$ into matrix form and decomposing using QL decomposition which decomposes $\boldsymbol{A}$ into two matrices. It should be noted that there are other ways that the matrix can be decomposed yielding different matrix forms (QR, LQ, LU, etc). However, QL decomposition matches the form of the matrices used to originally create $\boldsymbol{A}$. As such, we can set $\boldsymbol{Q} = \boldsymbol{R_A^{-1}}$ and $\boldsymbol{L} = \boldsymbol{P^{-1}}\boldsymbol{S^{-1}}$. From there, the three Euler angles can be obtained from the elements of $\boldsymbol{Q}$ and since $\boldsymbol{L}$ is a lower triangular matrix, which combines two separate matrices. We must use the knowledge that the three sensitivities must be positive, then the orthogonalities and sensitivities can be solved for using algebra. Lastly, the offsets can be obtained from $\boldsymbol{b} = -\boldsymbol{A}^{-1}\tilde{\boldsymbol{b}}$.

In addition to the twelve basic calibration parameters, other missions such as Cryosat-2 (Olsen et al., 2020) and Ørsted (Olsen et al., 2003) have had success expanding equation (9) to consider additional effects due to non-linearities and cross-talk and expanding individual terms to take temporal variations as well as effects from external sources such as temperature and stray current from the solar panels and batteries into consideration. These additional parameters should reduce outliers in the data and improve the overall fit with the reference field as well as reduce the deltas of the individual calibration parameters. For the current data however, we will focus on the improvements in the data fidelity from the 12 basic parameters only with the inclusion of the additional terms and regularization being considered in future releases.

5 ATTITUDE PRE-PROCESSING

Primary attitude data are provided by a micro Advanced Stellar Compass (μASC) with two camera heads provided by the Technical University of Denmark (DTU). The position of the camera heads is on the Y-axis of the spacecraft (Exhibit 2), separated by 130° in the Y-Z plane, with the optical axis 25° from the X-Y plane. The coordinate system that defines this spacecraft (SC) coordinate system is +X points towards ram, +Z points out the faceplate, +Y completes the right-handed coordinate system (see Exhibit 1 & Exhibit 2 for direction reference).

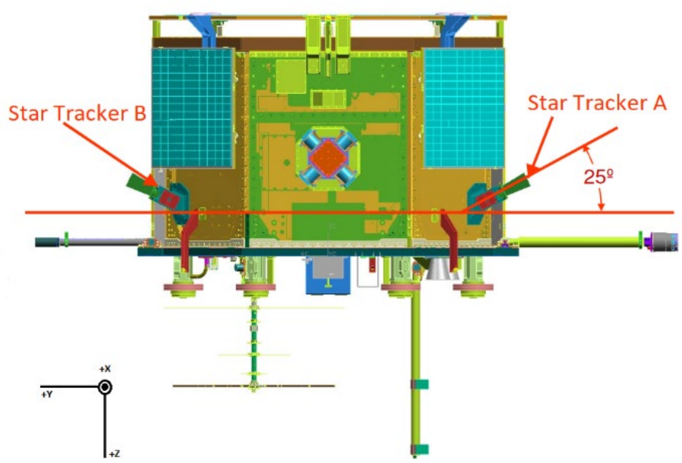

Exhibit 2: Location of the two star-tracker camera heads.

The star trackers return attitude quaternions referencing the J2000 celestial frame(q_{j2000}) that are corrected for thermal effects and merged, using SLERP, into a shared common reference frame (CRF) . The CRF contains a small known offset regarding its alignment with the SC frame, and it should be noted that while both frames contain the same direction convention CRF refers to the SC coordinate system from the perspective of the merged quaternions, including any uncertainties in the merged solution.

The quaternions are then rotated into the International Terrestrial Reference Frame (ITRF) ($q_{ITRF\rightarrow CRF}$) which follows the convention from the Swarm L1b product definition [SW-RS-DSC-SY-0007] with +X defined towards Greenwich meridian, +Y along 90° East meridian, and +Z towards the north pole. Details regarding the process involved in generating these quaternions can be found in (ePOP 2021).

One additional rotation is performed for the final MGF data product CDF which rotates the quaternions from ITRF to the position dependent North East Center (NEC) frame, following the definition in the Swarm Level 1b Processor Algorithms document [SW-RS-DSC-SY-0002, Issue 6.11]

The matrix terms are then converted into quaternions $q_{NEC \to ITRF}$ and multiplied with the $q_{ITRF \to SC}$ to make $q_{NEC \to SC}$ quaternions which are included in the MGF data product. The daily attitude files in CDF format containing the $q_{ITRF \to SC}$ quaternions and the daily ITRF position files in SP3 format are publicly available at https://epop-data.phys.ucalgary.ca/ .

The attitude quaternion files contain additional information that provides us with the source of the attitude data so that we may determine the accuracy of the provided quaternion, the roll, pitch, yaw, and the time between each signal to account for data dropouts.

6 DATA SELECTION AND CALIBRATION

Prior to calibrating the sensors, the data are corrected for digital feedback transients that occur when converting the signal from analog to digital (Miles et al., 2019). Then, we reduce the data to one sample per second, and bin it into seven-day intervals. The data are then culled using information from the attitude, bus telemetry, and location files, as well as conditions given by the Kp and Disturbance storm time (Dst) indices. For calibration we select data that falls within $\pm 55°$ latitude during geomagnetically quiet times. We consider geomagnetically quiet to be when the Kp index does not exceed 3 or the Dst index does not exceed a change of 3 nT per hour when the data were taken. From the attitude files we flag any data where the attitude solution was not generated by at least one of the star tracker cameras due to the large (up to 30°) error in solutions generated from the Coarse Sun Sensors (CSS) as mentioned in section 4. We also flag any data where the solution has dropped out for greater than ten seconds or there is greater than ten seconds until the next signal is obtained due to potentially large errors when interpolating the attitude solution. Lastly, we flag any data where the angular rotation rate of the spacecraft exceeds 0.03 degrees/sec. Exhibit 3 shows these flags and the effect they have on the data. From the Bus telemetry files we flag any data where the magnetorquers were engaged while the sensors were taking data, since the magnetorquers saturate the sensor readings (Exhibit 4) rendering the data unusable.

For a reference field we use the Chaos-7.7 field model (Finlay et al., 2020) which includes contributions from the core, lithospheric, and external (such as large-scale magnetosphere) fields. We select data that falls within $\pm 55°$ latitude as the Chaos model does not contain terms to account for disturbances in the polar regions.

We use iteratively re-weighted least squares to minimize the difference in the vector residuals between the sensor data and the Chaos model for each seven-day interval.

$$\boldsymbol{d}^{\boldsymbol{T}}\boldsymbol{W}\boldsymbol{d} \tag{11}$$

Where **d** is the residual vector $\boldsymbol{B}_{\boldsymbol{CRF}} - \boldsymbol{B}_{\boldsymbol{Chaos}}$, containing all of the selected data for the seven-day interval and **W** is a weight matrix. We use Huber weights (Huber, 1981) where the elements of the weight matrix are determined by the following criteria

$$\boldsymbol{W} = \begin{cases} |\boldsymbol{r}|^{-\boldsymbol{1}} & \boldsymbol{r} > 1 \\ 1 & \boldsymbol{r} \le 1 \end{cases} \tag{12a}$$

where **r** is determined from a combination of the residuals (**d**), the leverage (**h**), the median absolute deviation of the residuals (**s**), and a tuning constant (c) and is given by

$$\boldsymbol{r} = \boldsymbol{d}\left(c\boldsymbol{s}\sqrt{1-\boldsymbol{h}}\right)^{-\boldsymbol{1}} \tag{12b}$$

with $c = 1.345$ (Holland & Welsch, 1977).

The resulting calibration parameters are then compared to the mission average. If the orthogonality values deviate from the mission average by $\pm 0.1°$ or more, the calibration solution is determined to be non-physical and the sensor data are calibrated using the mission average instead.

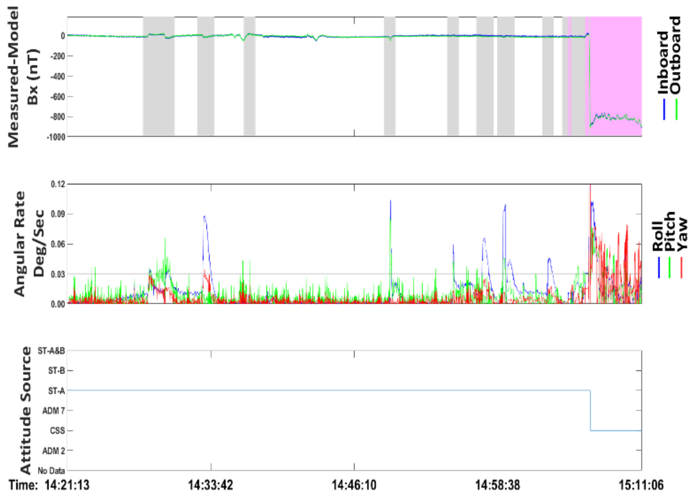

Exhibit 3: Flags, Angular Rotation Rates, & Attitude Sources.

Exhibit 3: (Top) The various flags applicable to the sensor data. Gray represents points where the angular rotation rate of the satellite exceeds 0.03 degrees/sec. Pink represents places where the attitude solution was not generated by at least one star-tracker camera or where it has been longer than ten seconds since the last attitude signal has been received or it will be longer than ten seconds until the next attitude signal will be generated or the magnetorquers are active. (Middle) The angular rotation rate corresponding to the data in the top plot. (Bottom) The seven potential attitude sources for the data. The potential errors in the attitude solution derived from CSS versus one of the star-tracker cameras is clearly shown.

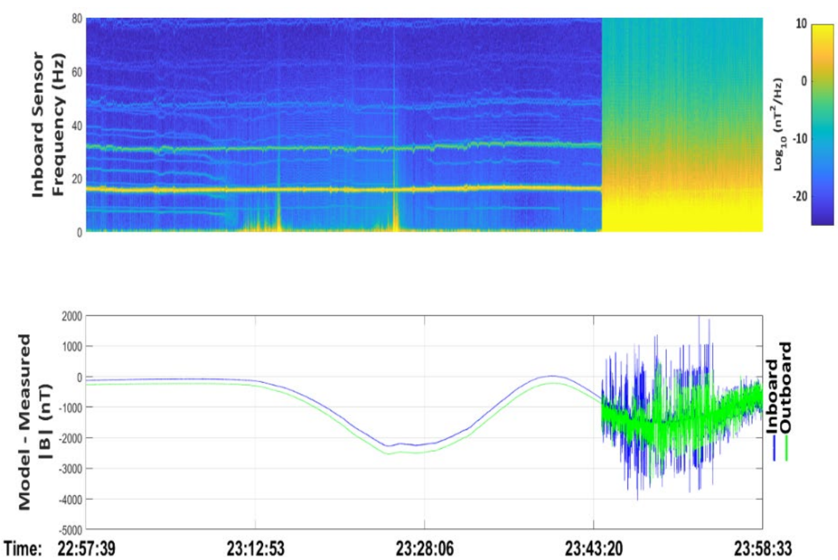

Exhibit 4: An instance where the magnetorquers on the spacecraft were engaged while the sensor was taking data.

Exhibit 4: (Top) The power-spectral plot for the inboard sensor. The magnetorquers were engaged after 23:43:20. The horizontal lines at 19 Hz, 37 Hz, etc represent the reaction wheel harmonics seen in the data prior to the first wheel failure (Bottom) The residual plot of the magnitude for the inboard and outboard sensors showing the effects of the magnetorquers on the measured data.

7 DATA PRODUCT DEFINITION AND DESCRIPTION

The Swarm-Echo dataset follows the format and usage conventions of the Swarm Level 1B product definitions as much as possible, though, owing to differences in the platforms and sensors, some adjustments are necessary. Swarm-Echo carries two fluxgate magnetometers but lacks an absolute scalar field sensor.

Exhibit 5 below compares CDF variables in the Low-Rate (1 Hz), version 2.1 Swarm-Echo products with the corresponding Swarm-Alpha files. Low Rate (LR) version 2.1 products have the following file name pattern:

SW_OPER_MAGE_LR_1B_*yyyymmdd*T000000_*yyyymmdd*T235959_0201_MDR_MAG_LR.cdf ,

where *yyyymmdd* represents the concatenated 4-digit year, 2-digit month of year, and 2-digit day of month for the data coverage period, which is always one UTC day. Each file defines a coverage period, but data are almost never present for the entire period. Gaps exist and are denoted merely by the absence of data values, not by fill.

Swarm L1B, Low Rate Product Variable	Present in Alpha L1b	Present in Echo L1b	Note
ASM_Freq_Dev	✓		No scalar magnetometer on Swarm-Echo
Att_error	✓	✓	
B_VFM	✓	*	Replaced with **B_inboard_CRF**, **B_outboard_CRF**, see table below.
B_NEC	✓	*	As **B_NEC_Out** in Swarm-Echo, values from outboard sensor only in version 2.1 products.
B_error	✓	✓	
F,F_error	✓		No scalar magnetometer on Swarm-Echo
Flags_B	✓	✓	Bit-field flags are different on Swarm-Echo, see table in section 7
Flags_Platform	✓	*	Variable is zero filled for Swarm-Echo version 2.1 CDFs
Flags_q	✓	✓	Bit-field flags are different on Swarm-Echo, see table in section 7
Latitude, Longitude, Radius	✓	✓	
Timestamp	✓	✓	
SyncStatus	✓	*	Variable is zero filled for Swarm-Echo version 2.1 CDFs
dB_AOCS	✓		Swarm-Echo magnetorquer activity flagged but not quantified or removed
dB_Sun	✓		
dB_Other	✓	*	Variable is NaN filled for Swarm-Echo version 2.1 CDFs
dF_AOCS, dF_Other	✓		No scalar magnetometer on Swarm-Echo
q_NEC_CRF	✓	✓	

Exhibit 5: Swarm-Alpha to Swarm-Echo Variable Comparison

The presence of a second vector sensor requires additional variables not present in the single fluxgate Swarm-Alpha products. In addition, CHAOS model field values are included in version 2.1 Swarm-Echo products for convenience. All additional variables are summarized in Exhibit 6 below.

Swarm-Echo Additional Variable	Corresponding Swarm-Alpha Variable	Usage
B_inboard_CRF, B_outboard_CRF	**B_VRF**	Vector field from each sensor in spacecraft coordinate frame as defined in Exhibit 1. If only a single value is desired, the outboard sensor is recommended as it should contain less satellite bus noise.
B_NEC_Out	**B_NEC**	Calibrated outboard sensor values rotated into NEC, this is **the primary** product variable.
B_model_NEC	**-**	Useful for generating residuals from CHAOS model
CalInboard, CalOutboard	**-**	The 4x3 rotation and scaling matrices used to compute calibrated CRF values from uncalibrated CRF input data. These are then rotated into the NEC frame.

Exhibit 6: Additional Swarm-Echo Variables

Swarm-Echo full resolution data are collected at 160 Hz from both sensors. High Rate (HR) version 2.1 product files have the name pattern:

SW_OPER_MAGE_HR_1B_*yyyymmdd*T000000_*yyyymmdd*T235959_0201_MDR_MAG_HR.cdf ,

where *yyyymmdd* has the same meaning as previously stated for the Low Rate products. Coverage periods and gaps are also handled in the same manner as described for LR product files. Other than containing roughly 160 times as much data, HR product content is the same as the LR product files, thus the same variable definitions apply.

In addition to data variables, each product carries a few useful global attributes, a subset of which are described in Exhibit 7 below. Of particular importance is the **CalFilter_Torquer** attribute which, so far, is always 1 but should be watched closely by any Swarm-Echo data product user. Any product file with a **CalFilter_Torquer** value of 0 is suspect and should be excluded for many use cases. This flag will be unnecessary in future revisions when all torquer intervals are excluded automatically.

Global Attribute	Dimensionality	Purpose
Abs_Orbit_Start	1	The number of the orbit in which the coverage period for this file begins, i.e. the orbit number at UTC 00:00:00 of this day.
Abs_Orbit_Stop	1	The number of the orbit in which the coverage period for this file ends, i.e. the orbit number at UTC 00:00:00 of the next day.
CalFilter_Attitude_max_sec	1	Filter criteria for calibration bootstrapping for the data in this product file. Any data for which a star-tracker attitude solution was more than X seconds away were excluded from the calibration set, where X is this value.
CalFilter_MaxRot_deg_per_sec	1	Filter criteria for calibration bootstrapping for the data in this product file. Any data for which the satellite is rotating more than X degrees/second were excluded from the calibration set, where X is this value.
CalFilter_Torquer	1	Filter criteria for calibration bootstrapping for the data in this product file. If set to 1, then housekeeping data were available to defined magnetorquer operational periods and thus torquer firing periods could

Global Attribute	Dimensionality	Purpose
		be excluded from the calibration set. If 0, torquers could be operational without the calibration code being aware of this fact.
Cal_Dynamic	1	If 1, at least part of the data in this file were included in the in-situ calibration process. If 0, a static calibration was used that most likely does not include data from this coverage period.
Events_Beg	1xN	Though product files have gaps, continuous data periods coincide with scheduled observations. This array provides the start time of each scheduled observation that contributed to this product file.
Events_End	1xN	This is the corresponding end time array for each scheduled observation.

Exhibit 7: Selected Swarm-Echo Global Attributes

8 FLAGS AND DATA USAGE

The data flags mentioned in Section 5 are assigned bit values and included in both the high and low rate CDFs. This section will describe each flag, provide the source it is obtained from, list the bit value(s) assigned to it, and discuss the impact it has on the viability. For visual representations of these flags, see Exhibit 3 and Exhibit 4.

Flag	Description	Source	Bit Value	Data Impact
Flags_B	No flagged issues	**any**	0	The data are useful in all cases.
	Clipped measurement replaced with interpolated value	**MGF_*_v2.*.*.lv2**	4[1]	This represents sensor data that have been interpolated. The data is not useful for case studies or trending.
	Padding around active magnetotorquer times	**CAS_Bus_Telemetry_*_1.*.*.cdf.zip**	64[1]	The data are not viable in any case
	Torquer command active		128[1]	
Flags_q	No flagged issues	**CAS_AttQuat_*_1.*.*.cdf.zip**	0	The data are useful in all cases.
	Padding around rotations above 0.030 deg/sec		1	The data may still be useful for case studies but should not be used for trending.
	Spacecraft rotation exceeds 0.030 deg/sec		2	
	Padding for missing definitive attitude solution		16	This flag combines instances where either the attitude solution was not generated by at least one star
	Missing definitive attitude solution		32	

Flag	Description	Source	Bit Value	Data Impact
				tracker camera, or it has been longer than 10 seconds since the last attitude update, or will be longer than 10 seconds until the next attitude update. The data are not viable in any case due to large uncertainties.

Exhibit 8: Flag Descriptions

1. The variable description in the CDF for the version 2.1 release is incorrect. The value listed in the table is correct.

Specific questions about the usefulness of data for case studies or trending should be directed to the MGF science team.

9 PLOTTING DATA PRODUCTS

Swarm-Echo data products are Common Data Format (CDF) files. The basic file format is defined by the NASA Space Physics Data Facility (https://cdf.gsfc.nasa.gov). The file format itself is flexible and supports arbitrary data array names, dimensions and metadata schemes. Except as noted in section 6, Swarm-Echo products follow the Swarm Level 1B product definitions as defined in the Swarm Product Data Handbook which may be found on the ESA Earth Online site[1]. Each variable is also documented with attributes from the ISTP (International Solar-Terrestrial Physics) metadata set. Together these provide for compatibility with VirES and well as other commonly available CDF file readers.

9.1 Matlab Example

Swarm-Echo product files do not use newer CDF features such as TT2000 variables and thus should be readable via MATLAB without installing any extra modules. The following example demonstrates plotting NEC values only when all data quality flags are zero.

```
name = 'SW_TEST_MAGE_LR_1B_20180101T000000_20180101T235959_0201_MDR_MAG_LR.cdf';

vars = {'Timestamp','B_NEC_Out','Flags_B','Flags_q'};

% Read variables of interest, reading epoch times as datenum values is more efficient

data = cdfread(name, 'Variables', vars, 'ConvertEpochToDatenum', 1, 'CombineRecords', 1);

% Convert datenum to standard datetime values if desired.

time = datetime(data{1}, 'ConvertFrom', 'datenum','TimeZone','UTCLeapSeconds');

B_nec = data{2};

flags_B = data{3};

flags_q = data{4};

% plot the north component where flags are zero

idx_no_flags = (flags_B == 0) & (flags_q == 0);
```

```
plot(time(idx_no_flags), B_nec(idx_no_flags,1));
```

9.2 Python Example

The following example uses the pycdf module originally from the spacepy[2] toolkit. This module is also available in the das2, and mazer4py libraries as well. Like the previous example, data are filtered by both attitude and value flags.

```
import matplotlib.pyplot as plt

from spacepy import pycdf

cdf = pycdf.CDF(SW_TEST_MAGE_LR_1B_20180101T000000_20180101T235959_0201_MDR_MAG_LR.cdf')

time = cdf['Timestamp'][:]

B_nec = cdf['B_NEC_Out'][:]

# Plot the north component when all data where flags are zero

idx_no_flags = (cdf['Flags_B'][:] == 0) & (cdf['Flags_q'][:] == 0)

plt.plot(time[idx_no_flags], B_nec[idx_no_flags,0])
```

1. https://earth.esa.int/eogateway/missions/swarm/product-data-handbook/level-1b-product-definitions
2. https://github.com/spacepy/spacepy

9.3 IDL Example

The following IDL 8.7 example loads data from a low-rate file and plots a single component. Note that the row and column indexes in the example below are invented compared to the MATLAB and Python examples above.

```
cdf = cdf_open('SW_TEST_MAGE_LR_1B_20180101T000000_20180101T235959_0201_MDR_MAG_LR.cdf')

; get number of records

cdf_control, cdf, var='Timestamp',get_var_info=info

nrecs = info.maxrec+1

cdf_varget, cdf, 'Timestamp', time_epoch, rec_count=nrecs

time = cdf_epoch_tojuldays(time_epoch)

cdf_varget, cdf, 'B_NEC_Out', B_nec, rec_count=nrecs

cdf_varget, cdf, 'Flags_B', flags_B, rec_count=nrecs

cdf_varget, cdf, 'Flags_q', flags_q, rec_count=nrecs


; Coercing IDL into legible date-time axes annotations

_ = label_date(date_format=['%H:%I','%Y-%N-%D'])


; plot north component of all data where flags are zero

idx_no_flags = where( flags_q eq 0 and flags_B eq 0)

plot, time[idx_no_flags], B_nec[0,idx_no_flags], xtickunits=['Time','Time'], $

      xtickformat='LABEL_DATE'
```

10 REFERENCE DOCUMENTS

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