SOSMAG

Data Description

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Change Record

Issue	Rev.	Date	Changed Para.	Remarks
1	0	2020-09-01	All	Document creation (skeleton only)
1	1	2020-09-11	All	First release
1	2	2020-10-08	All	First round of comments, added data accuracy statements, clarified a few text sections, removed caveat about missing flags (change tracking available)
1	3	2020-10-23	Table 3.1, chapter 4	Removed footnotes in table 3.1, updated citation to released publication in chapter 4.
1	4	2020-11-17	Title page, chapter 4	Added signatures and acknowledgements
1	5	2021-01-28	2,5 -	Corrected HPEN description Changed TOC and change record to header format
1	6	2023-02-08	7, 8	Added information about PySPEDAS and Portal retrieval
1	7	2024-01-24	4	Updated SWE helpdesk mail address

Table of Contents

1. Introduction

SOSMAG is a spacecraft mounted magnetometer system on the Korean satellite GEO-KOMPSAT-2A. This system uses the mathematical combination of multiple sensors to attenuate magnetic disturbance from a spacecraft with no magnetic cleanliness program. The SOSMAG ground processor, as described in this document, is the ground support software that downloads the data from the Korea Meteorological Administration (KMA), decompiles it, improves its accuracy by applying calibration and mathematical combination and provides the data to ESA's space weather services in form of files and database entries.

Data is processed regularly and it is provided within 5 minutes (real-time data), with a delay of one day (preliminary data) and fully calibrated after 98 days (final data).

2. Terms, definitions and abbreviated terms

- AMR Anisotropic Magneto-Resistive (sensor)
- ASCII American Standard Code for Information Interchange
- AUX AUXiliary data, in this case attitude and position
- DPU Data Processing Unit
- ESA European Space Agency
- FG FluxGate
- GK-2A GEO-KOMPSAT-2A, the spacecraft that SOSMAG is mounted on
- GSE Geocentric Solar Ecliptic
- IB InBoard
- HPEN Coordinate system of the GOES mission, with axes to (north) Pole, Earthward and Normal (East)
- KMA Korea Meteorological Administration
- KSEM Korea Space Environment Monitor
- NaN Not a Number
- MD Midnight Disturbance
- OB OutBoard
- SOSMAG Service Oriented Spacecraft Magnetometer
- SQL Structured Query Language, a database system
- UTC Coordinated Universal Time

3. Instrument Description

Detailed information about the SOSMAG instrument and the used data cleaning method can be found in Magnes et al., 2020 and Constantinescu et al., 2020 (see Section 4).

SOSMAG is a multi-sensor magnetometer with an approximately one meter long boom. The configuration as built for the GK-2A spacecraft (Figure 3–3) as part of the KSEM instrument suite contains two science grade, boom mounted fluxgate sensors, two anisotropic magnetoresistance sensors which are mounted within the spacecraft body, a deployable boom, which includes a specific mounting interface to avoid mismatches of the thermal expansion coefficients, and an electronics box with the data processing, power conversion and sensor front-end electronics.

The block diagram of the SOSMAG instrument is shown in Figure 3–1 and the main instrument parameters are listed in Table 3-1. Pictures of the SOSMAG qualification model and the boom mounted to the +X sidewall of the spacecraft are depicted in Figure 3–2 and Figure 3–3, respectively.

SOSMAG measures the magnetic field continuously with a maximum vector rate of 128 vectors per second at all four sensors, and it generates adequate housekeeping information. Within the Data Processing Unit (DPU), the magnetic field data can be filtered and decimated by a commandable integer factor. With e.g. a decimation factor of 128, it is reduced to 1 vector per second. The filter coefficients are equal to one over the decimation factor. It results in a transfer characteristics which is equivalent to a boxcar filter with rectangular windowing.

In addition, a cleaned vector can be calculated by the SOSMAG DPU. It is a linear combination of the measurements from all sensors. The data from the magnetic sensors are multiplied with a 3x3 calibration matrix and corrected for a static offset value before the cleaned vector is processed.

It is also possible to transmit raw data from all 4 sensors to ground such that the cleaned vector is calculated in ground processing. Description of the cleaning algorithms are available in Magnes et al. and Constantinescu et al. At the time of writing this document (2020-10-08) data is transmitted to ground both ways, as raw and cleaned data. If raw data is available, ground processing repeats the onboard combination process, with the possibility to use updated combination parameters even in retrospective.

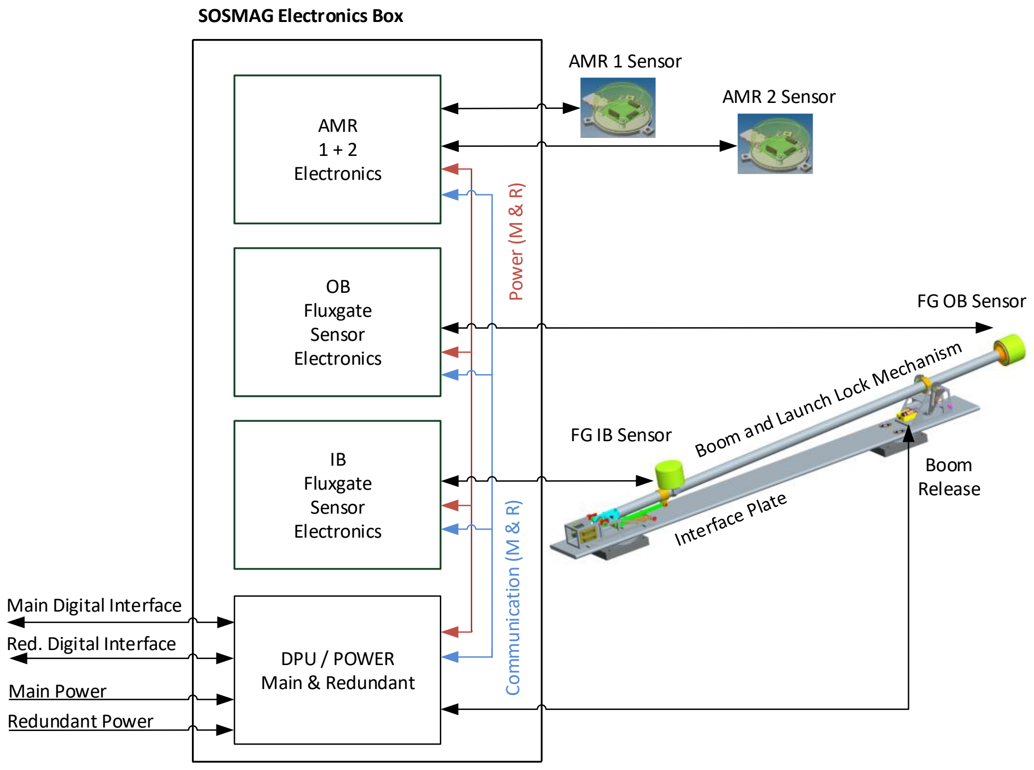


Figure 3–1, Block diagram of the SOSMAG instrument (AMR: Anisotropic Magneto-Resistance, DPU: Digital Processing Unit, FG: FluxGate, IB: InBoard, OB: OutBoard)

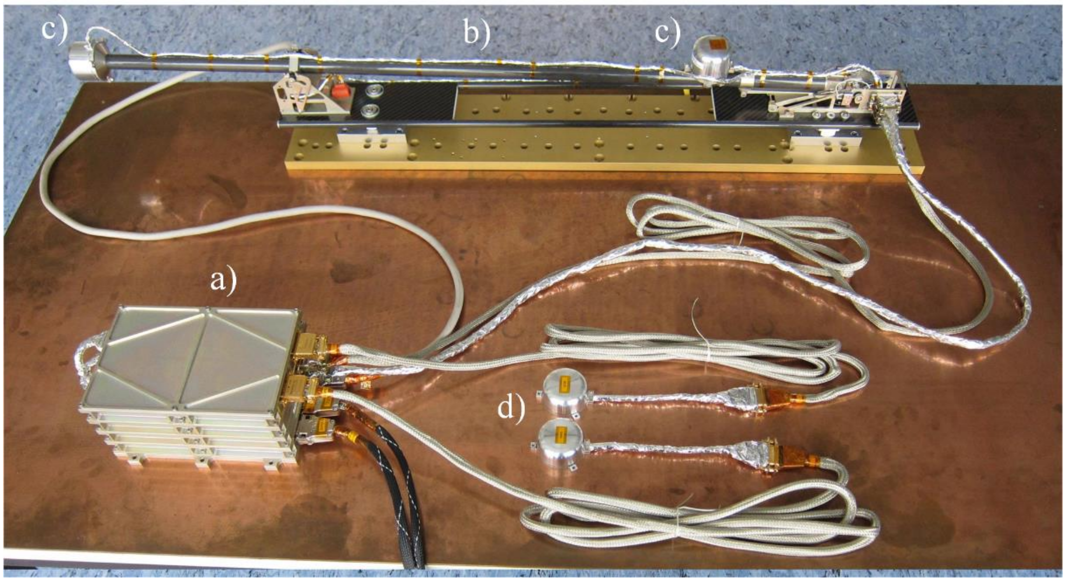
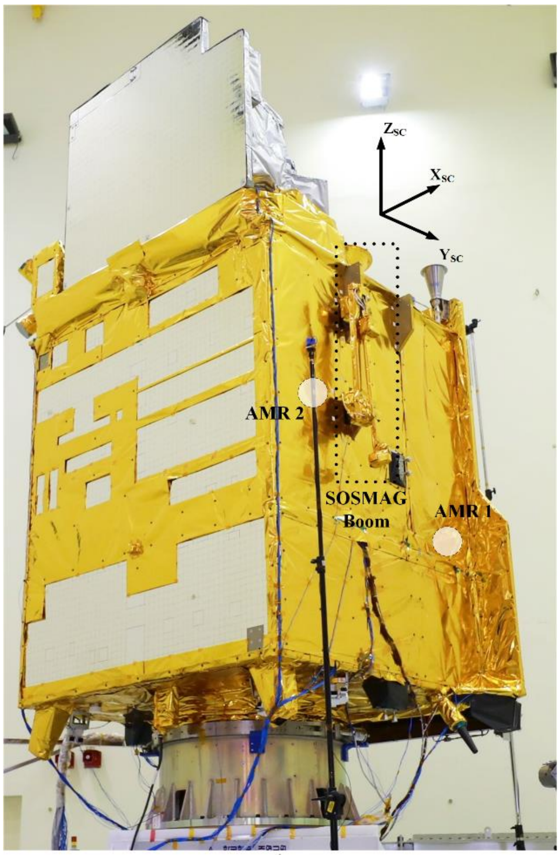


Figure 3–2, Picture of the SOSMAG qualification model with a) electronics box, b) boom with carbon fibre based interface plate, c) two fluxgate sensors mounted onto the boom and d) two anisotropic magnetoresistance sensors

Figure 3–3, GK-2A spacecraft during a pre-launch test campaign. The stowed SOSMAG boom with the two fluxgate sensors is indicated with a dotted rectangle. The approximate mounting position of the two AMR sensors within the spacecraft is shown by two white dots. The AMR 1 sensor is located near the +X/+Y corner of the spacecraft and the AMR 2 is mounted close to the +X side wall next to the launch lock of the boom.



Parameter	Performance
Power consumption	8.25 W
Mass:	
Electronics box	3211 g
Boom with two fluxgate sensors	1316 g
AMR sensors 1 and 2 with harness	366 g
Fluxgate and boom release harness	589 g
Total	5482 g
Envelope dimensions	
Electronics box	170 x 255 x 110 mm^3
Boom with two fluxgate sensors	1182 x 96 x 147 mm^3
Maximum vector rate	128 vectors/second
Noise density at 1 Hz	
Fluxgate sensors	< 10 pT $Hz^{-0.5}$
AMR sensors	< 220 pT $Hz^{-0.5}$
Range	±65,000 nT
Quantization resolution	
Fluxgate sensors	7.8 pT
AMR sensors	62 pT

Table 3-1, Main instrument parameters

4. Acknowledgements and Instrument Related Publications

SOSMAG data is made available via ESA's Space Safety Programme and its provision forms part of the ESA Space Weather Service System.

For further data-related information or enquiries contact the SWE Service Helpdesk. E-mail: helpdesk.swe@esa.int

All publications and presentations using SOSMAG data should acknowledge the ESA Space Safety Programme. Furthermore, the users are kindly asked to cite the following publications, if SOSMAG data is used in scientific publications.

Magnes, W., O. Hillenmaier, H.-U. Auster, P. Brown, S. Kraft, J. Seon, M. Delva, et al. 'Space Weather Magnetometer Aboard GEO-KOMPSAT-2A'. *Space Science Reviews*, 216, 119 (2020). https://doi.org/10.1007/s11214-020-00742-2.

Constantinescu, O. D., H.-U. Auster, M. Delva, O. Hillenmaier, W. Magnes, and F. Plaschke. 'Principal Component Gradiometer Technique for Removal of Spacecraft-Generated Disturbances from Magnetic Field Data'. *Geoscientific Instrumentation, Methods and Data Systems Discussions*, 25 May 2020, 1–26. https://doi.org/10.5194/gi-2020-10.

For further information about space weather in the ESA Space Safety Programme see: www.esa.int/spaceweather
Access the SWE Portal here: https://swe.ssa.esa.int

5. Data Description

5.1. Basic Data Structure

Data is given as 3-axis vector of magnetic field (B) in nT in HPEN (north pole, earthward, normal=east) and GSE (geocentric solar ecliptic) coordinates, together with UTC time stamps and satellite position in GSE.

In addition, data flags are given for calibration quality as well as data caveats identified during processing.

5.2. Data Timeliness

Data from SOSMAG is available in three different flavors with different delays and calibration qualities.

- Real-time data is provided with a delay of up to 5 minutes. This data uses the latest available calibration and cleaning factors with an age of up to 98 days. These calibration and cleaning factors were not determined for the current data and may not be fully accurate.
- Preliminary data is provided with a delay of up to 2 days. Also this data uses old calibration and cleaning factors, but attempts to close all gaps that may have occurred in real-time data transmission.
- Final data is provided with a delay of 98 days. This data uses updated calibrations and cleaning factors that were determined specifically for this data. In addition, the signal is examined for residual distortion and periods with distortion are flagged.
  The delay of 98 days gives sufficient time to request measurement data that was missed due to various service outages. The final data might therefore be even more complete than preliminary data.
- Final data supersedes preliminary data, i.e. these data sets share the same storage and final data is considered as updated version of preliminary data.

5.3. Data Accuracy

Data accuracy is given as peak amplitude of the residual error in the data.

Residual Error in Data	DC (<0.1 mHz)	AC (>0.1 mHz) w/o flag	AC (>0.1 mHz) with flag
Final	< 5 nT	< 1 nT	≤ 1, 3 or 5 nT
Preliminary/Real-time	< 8 nT	< 7 nT	n/a

Table 5-1 Data Accuracy of Real-Time, Preliminary and Final Data

Data accuracy depends on the usage of current or outdated calibration (in final and preliminary/real-time data) and the presence/absence of flags, which are only available in final data. This means that the value of the worst-case flag has to be assumed as long as no flag is present.

The quality impact of outdated calibration in real-time and preliminary data is hard to predict, as the operational situation aboard GK-2A might change without notice. Nevertheless an estimate can be given using actually observed changes in calibration and cleaning over the first 1.5 years of mission time. Table 5-1 gives the potential impact of using outdated calibration for preliminary/real-time data.

Impact per Axis	Peak-to-peak within 1.5 years	Worst prelim. to final within 98 days
DC	7.8 nT	3 nT
AC	2 nT	2 nT

Table 5-2 Potential errors caused by using preliminary Cleaning/Calibration

Definition:

- DC impact is given as the residual offset that is not covered by the last offset estimate
- AC impact is given as the residual amplitude of an otherwise cleaned disturber, i.e. cleaned disturbers might become visible and/or residual disturbance is increased by the given amount.
- Peak-to-peak values give the overall changes over the first 1.5 years of the mission. This gives a rough estimate of the worst case changes that are to be expected.
- Worst preliminary to final difference: This is the worst observed difference between preliminary and final data, caused by changes over the 98 days of calibration delay. This is based on the assumption that no new and unknown disturber shows up during the 98 days.

5.4. Data Traceability, Versioning and Archiving

All data is subject to versioning and traceability, but old versions and traceability data are not available to the public.

- Data may be updated without notice.
- Changes in data are reflected using the “preliminary/final” column and a data version number.

Archiving of used data is considered as user responsibility. Old data versions are available, but should only be requested in exceptional cases.

5.5. Data Format

Data is provided as SQL database.

5.6. Database Tables

Database tables are available for real-time data and there is a shared table for preliminary/final data. The table layout is identical for all tables.

Column-Name	SQL Data-Type	Unit	Content	Comments
utc	timestamptz		Timestamp of the measurement in UTC.	
version	smallint		The version number of the ASCII file that this data originates from	Version is always 0 for real-time data
b_gse_x	float4	nT	The X component of the magnetic field in the GSE frame in nT.	
b_gse_y	float4	nT	The Y component of the magnetic field in the GSE frame in nT.	
b_gse_z	float4	nT	The Z component of the magnetic field in the GSE frame in nT.	
b_hpen_p	float4	nT	The magnetic field component, which points towards the north pole in the horizontal system (HPEN) in nT.	
b_hpen_e	float4	nT	The magnetic field component, which points towards the centre of Earth in the horizontal system (HPEN).	
b_hpen_n	float4	nT	The magnetic field component, which points towards east in the horizontal system (HPEN).	
position_x	float4	km	The x component of the position of the spacecraft in the GSE frame.	
Position_y	float4	km	The y component of the position of the spacecraft in the GSE frame.	
position_z	float4	km	The z component of the position of the spacecraft in the GSE frame.	
data_flags	integer		Gives additional information about the data (see Chapter 5.7)	
final	boolean		Defines the data row as final (True) or preliminary (False). Real-time data is always preliminary.	Only set to true for final data in daily table

Table 5-3 SQL server table

5.7. Data Flags

Data flags are given as integer number and individual flags are set as bits within this number. Bit numbering starts with the least significant bit. Individual flags can be retrieved by using logic operators and bitmasks.

The actual flag value is the sum of all set values (all unset values are 0). A specific value can be retrieved by using the value in column 2 as binary bitmask.

Bit	Value, if set (bitmask)	Interpretation, if unset/set	Description
0	1	Valid / NaNfilled	A larger gap was filled with NaN values. Bit 3 is also set in these cases.
1	2	Time uncorrected / time corrected	Time stamps were corrected to remove time stamp jitter caused by low onboard time stamp resolution.
2	4	Normal data / Suspicious Data	Some strange behavior was detected, e.g. too high variation to be natural. This data should be used with caution.
3	8	Normal / NaN Data	A few NaN samples were filled in, but there is sufficient data around it and the gap is considered minor.
4	16	Sampling rate linearized / not linearized	The time stamps of this data were adjusted so that the time stamps match the estimated sampling rate. This flag is set almost all the time.
5	32	Real/Interpolated AUX data used	Attitude data is used for attitude/position information. If this bit is set, there was a gap in Attitude data. These gaps are quite common (state of Sept. 2020).
6	64	No major attitude gaps / attitude gap> 5 minutes (only valid if bit 5 is set)	The gap in attitude data was > 5 minutes. These gaps are quite common (state of Sept. 2020).
7	128	Attitude for this day / No attitude for this day (only valid if bit 5+6 are set)	Only valid if bit 6 is set. • Unset: The gap was > 5minutes, but there was some attitude data on this day. • Set: There was no attitude data at all for this day and the nominal geostationary position was used instead
8	256	Accuracy 5 nT OK/Warning	Distortion occurred at this time. Accuracy is no better than ±5 nT. This flag is only available in final data.

9	512	Accuracy 3 nT OK/Warning	Rapid temperature gradients occurred at the sensor. Accuracy is no better than ±3 nT. This flag is only available in final data.
10	1024	Distortion 1 nT OK/Warning	There are jumps of up to ±1 nT in the data. This flag is only available in final data.
11	2048	Manual Accuracy Flag OK/Warning	Manual Data Accuracy Warning: This data was considered as potentially inaccurate by manual analysis. The accuracy level depends on the detected anomaly and cannot be expressed as flag. This flag is only available in final data.
-	-	-	Other flags that might come up over time.

Table 5-4 Data Flag List

6. Caveats

6.1. Known Disturbances

Figure 6–1 shows the table of disturbances, taken from Constantinescu et al. 2020 (see Section 4). This table gives the amplitude of disturbances in the SOSMAG sensors as well as the amplitude in the final data product. Automated flagging marks the edges of the respective disturbances for the MD leading/trailing edge (bit 10) and the step like disturbance (bit 10).

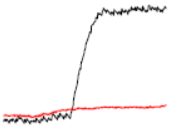
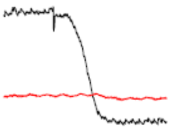
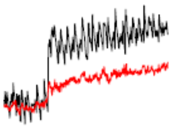
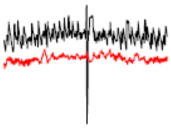
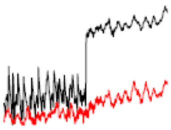
disturbance class		component	AMR 1	AMR 2	FGMI	FGMO	corrected
			magnitude (nT)				
MD leading ramp		x	−612.0	−117.8	−36.7	−15.1	−0.1
		y	−1352.8	−7.2	−28.1	−20.2	−0.6
		z	467.3	166.8	35.7	22.2	1.7
		module	1556.6	204.3	58.4	33.6	1.8
MD trailing ramp		x	764.5	145.2	45.1	17.6	−0.8
		y	1684.0	10.8	35.1	24.7	0.2
		z	−548.7	−203.8	−42.9	−26.0	−0.8
		module	1929.1	250.5	71.5	40.0	1.1
steps		x	5.8	24.0	4.6	0.4	1.0
		y	3.3	13.5	2.6	1.7	0.6
		z	3.9	22.2	8.7	1.9	0.7
		module	7.7	35.4	10.2	2.5	1.3
spikes		x	4.3	−6.4	−5.4	0.6	−0.2
		y	2.2	−2.0	−4.7	−1.8	−0.2
		z	1.9	−4.1	−11.8	−4.6	−0.1
		module	5.2	7.9	13.8	4.9	0.3
high frequency		x		0.7	1.4	0.4	0.1
		y		0.1	1.1	0.3	0.0
		z		0.3	1.5	0.7	0.1
		module		0.8	2.3	0.9	0.1

Figure 6–1 SOSMAG known disturbances, from Constantinescu et al. 2020[1]

In addition to spacecraft generated disturbances, the sensor shows temperature generated oscillations, which are caused by a daily temperature drop from +30°C to -90°C when going through the spacecraft shadow phase. These temperature drops are outside of the design scope of the sensor and cause disturbances in the order of 3-6 nT. Figure 6–2 shows examples of these variations for several days. For this plot, data of each day was shifted by 7 nT (relative to the next day) for comparison purposes.

These variations are flagged using bit 9.

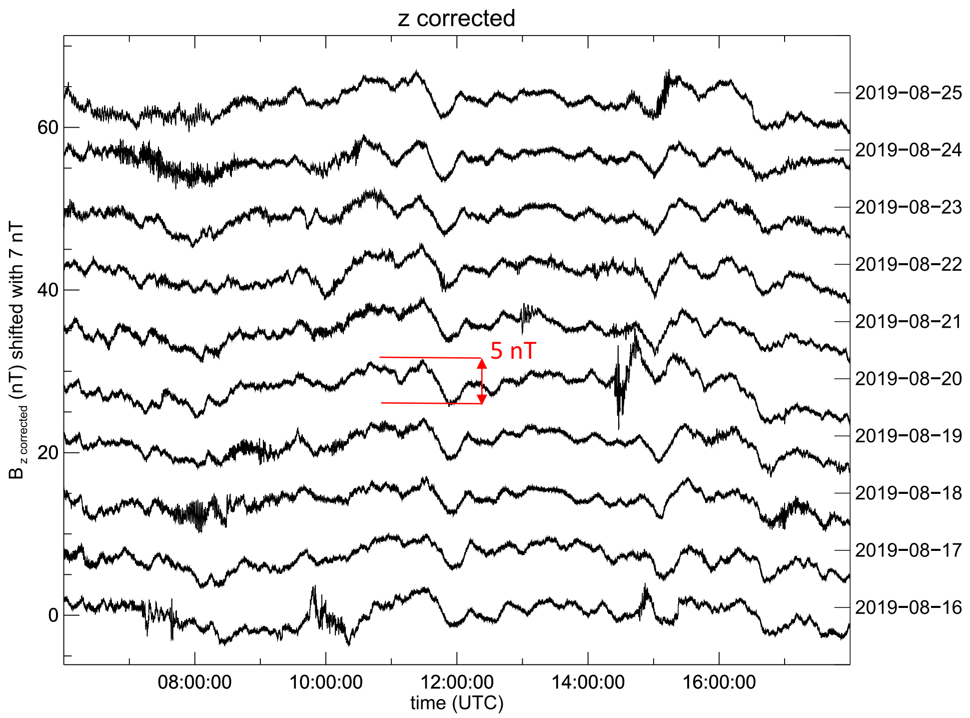


Figure 6–2 Example of sensor offset oscillations triggered by temperature gradients around dawn during ten consecutive days with relatively quiet geomagnetic conditions (Magnes et al., 2020)[2]

[2] Graphics: CC BY 4.0, https://creativecommons.org/licenses/by/4.0/

7. Data Retrieval using the Portal HAPI

SOSMAG data can be retrieved from the portal using the heliophysics application programming interface (HAPI). The newest description of this API is available at:

https://swe.ssa.esa.int/documents

Document title: "Programmatic access to SWE data from ESA's Distributed Space Weather Sensor System (D3S) using HAPI". The description contains specifications and programming examples how to retrieve authentication and data using bash and Python scripts.

General information about SOSMAG can be retrieve at:

https://swe.ssa.esa.int/sosmag

8. Data Retrieval using PySpedas

This information was verified in January 2023. Syntax or retrieval options/methods might change at later dates.

8.1. Description

PySPEDAS (and its IDL variant SPEDAS) is an analysis software for heliophysics and magnetospheric analysis, that can retrieve and process data from multiple spacecraft.

Retrieval of SOSMAG data is possible using PySPEDAS, but requires registration at the ESA portal.

The use of SPEDAS (IDL) is unfortunately not possible due to a reported, but unresolved bug in IDL (status end of January 2023).

8.2. Getting PySPEDAS

PySPEDAS and instructions for installation can be retrieved at:

https://github.com/spedas/pyspedas

8.3. Add your registration data do PySPEDAS

SOSMAG is part of an optional ESA program, therefore ESA is required to give feedback about data usage statistics to the countries that signed for this program. User registration is used for these statistics.

You need to add your username and password in one of the PySPEDAS files:

File:	pyspedas/sosmag/load.py
Variable structure:	sosmag_parameters
	Username
	Password

At the time of writing, this structure is located in line 42 and following.

8.4. Code Snippet

The use of SOSMAG within SPEDAS is quite easy and just requires to import required libraries and execute a load command. The example below also includes a simple plot for the retrieved data.

```
from pytplot import tplot
from pyspedas import sosmag_load
tplot_ok, var_names = sosmag_load(trange=['2023-01-11 00:00:00', '2023-01-11 23:59:00'], datatype='recalib')
tplot(var_names)
```