Data product description for MAGNETOMETER

ADITYA-L1

December, 2024

Generated by Magnetometer team

Version control sheet

Version	Date	Remarks
1.0	25th November, 2024	First version
1.1	11th December, 2024	Quality factor included in L2 data; XML details removed
1.2	30th December, 2024	Comparison with other dataset & caveats included

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List of abbreviations

ISSDC - Indian Space Science Data Center
MAG1 – magnetometer sensor 1
MAG2 – magnetometer sensor 2
IMF – Interplanetary Magnetic Field
MAG – Magnetometer
nT - nanoTesla
L0 – Level 0
L1 – Level 1
L2 – Level 2
ICD – Interface Control Document
SCCS – Spacecraft Coordinate System
TCT – Time Correlation Table
GSE – Geocentric Solar Ecliptic
GSM – Geocentric Solar Magnetospheric

1. Introduction

Magnetometer(MAG) is an instrument onboard Aditya-L1 that provides in-situ measurements of interplanetary magnetic field(IMF) at the location of the spacecraft. This payload is comprised of two identical tri-axial fluxgate magnetometers positioned on a boom at distances of 3 meters and 6 meters from the spacecraft. The sensor located at 6m is referred to as MAG1, whereas the sensor situated at 3 meters is identified as MAG2.

This document delineates the data products associated with the MAG instrument. The purpose of this document is to furnish the reader with an overview of the structure and format of the data products generated at the Payload Operation Centre of the instrument. The data in the specified format is rendered accessible for public use through the *Pradan* interface of Indian Space Science Data Center (ISSDC). The nomenclature for file naming, metadata attributes, and file formats has been established based on a finalized interface control document (ICD). The payload data is categorized into three levels: Level 0 (L0), Level 1 (L1), and Level 2 (L2). The Level 1 and Level 2 datasets are made available at ISSDC for user access. Level 0 data, which is essentially raw data from the spacecraft, is not directly suitable for scientific application .Consequently, the specifics of this dataset are not included within this document. The L1 data encompasses calibrated outputs from both MAG1 and MAG2, recorded at a fixed cadence of 128 milliseconds. However, it does not directly provide the science-ready data product, namely the interplanetary magnetic field (IMF). In contrast, the L2 data comprises calibrated and corrected outputs, which represent the IMF vector averaged over a 10-second interval. The payload team advocates for the utilization of L2 data, as it has been processed to meet the criteria for scientific readiness. The subsequent section contains a detailed description of the L1 and L2 products pertaining to the magnetometer. Users intending to engage with the Level 1 dataset are advised to consult the instrument team for further details.

2. Level 1 data product

The Level 1 product consists of a netCDF file that corresponds to the temporal extent of its Level 0 product. Typically, two Level 0 files with a coverage duration of 12 hours are available on a daily basis. Each Level 0 file is associated with a corresponding Level 1 file, thereby ensuring a one-to-one correspondence between the files. Furthermore, a preview image illustrating the time series plots of Bx, By, and Bz from MAG1 is provided for each netCDF file at Level 1.

The naming convention of the Level 1 output file is derived from its Level 0 counterpart. The specifics regarding the nomenclature and the fields contained within are described below:

2.1 L1 netCDF data file

Filename: The file naming convention follows the description mentioned in the ICD. It is as mentioned below:

L1_PLDXXSTNP#SATSTRIPVCAPIdYYDDDHHMMSSMSE_<obsId>_Vmn.nc

The details of each field in the above name are given in the following table:

Field Name	Field Width	Remarks
Payload identification	5	MAG91 for MAG
Station identification	3	
PACQ system identification	2	
STRIP ID	5	
Virtual Channel Id	2	
Application ID	4	
Year	2	Ground receive date and time of first frame for the file
Day of Year	3	
Hour	2	
Minute	2	
Seconds	2	
Milliseconds	3	
Observatinon ID	16	
Version number	3	
Extension	2	.nc

Table 1: Written above are details of each field in the L0 filename.

File generation: The aforementioned file is produced through the extraction of the payload's raw data from the pld file located within the L0 tar file. Consequently, the filename is aligned with the pld filename, with the exception of a prefix denoted as 'L1_' and a suffix indicative of the version number '_Vmn'. In instances where file regeneration is necessitated by any circumstances, the version number is duly updated.

File description: The nc file consists of the processed output derived from the raw data. The raw data undergoes filtration to eliminate spikes and saturated samples, subsequently being converted into physical units of nanoTesla through the application of temperature-corrected calibration parameters to each component of the vectors originating from both MAG1 and MAG2. The resultant output is produced at the maximum cadence of 0.128 seconds and is represented within the spacecraft coordinate system (SCCS) frame. The instrument time corresponding to each vector output is transformed into Universal Time (UT) utilizing the time-correlation table (TCT) information that is accessible at L0.

Following is list of variables present in the file:

S. No.	Name	units	description
0	time	Seconds (UNIX time)	Epoch starts at Jan 1, 1970 00:00:00
1	B_yaw_mag1	nano tesla - nT	MAG1 component along the yaw axis of the spacecraft
2	B_roll_mag1	nano tesla - nT	MAG1 component along the roll axis of the spacecraft
3	B_pitch_mag1	nano tesla - nT	MAG1 component along the pitch axis of the spacecraft
4	B_yaw_mag2	nano tesla - nT	MAG2 component along the yaw axis of the spacecraft
5	B_roll_mag2	nano tesla - nT	MAG2 component along the roll axis of the spacecraft
6	B_pitch_mag2	nano tesla - nT	MAG2 component along the pitch axis of the spacecraft
7	B_yaw_mag1_error	nano tesla - nT	Uncertainty in MAG1 component along the yaw axis of the spacecraft
8	B_roll_mag1_error	nano tesla - nT	Uncertainty in MAG1 component along the roll axis of the spacecraft
9	B_pitch_mag1_error	nano tesla - nT	Uncertainty in MAG1 component along the pitch axis of the spacecraft
10	B_yaw_mag2_error	nano tesla - nT	Uncertainty in MAG2 component along the yaw axis of the spacecraft
11	B_roll_mag2_error	nano tesla - nT	Uncertainty in MAG2 component along the roll axis of the spacecraft
12	B_pitch_mag2_error	nano tesla - nT	Uncertainty in MAG2 component along the pitch axis of the spacecraft

Table 2: The table provides the list of available variables along with their attributes in the L1 netcdf file.

From the analysis of magnetic field components acquired during periods of relatively solar quiet conditions, the error associated with each component of the vector has been approximated at 0.3 nT. It is pertinent to acknowledge that this uncertainty encompasses sensor noise, AC fields produced by the spacecraft, fluctuations in sensor temperature, and the high-frequency component of the IMF. Until any further significant degradation in the magnetometer sensors is observed, this uncertainty value remains fixed for the data pertaining to the current epoch.

3. Level 2 data product

Level 2 data product for the instrument is a netCDF that spans a 24hour duration – 00:00 UT to 23:59:59 UT. Multiple L1 files are combined to generate this daily product. The filenaming convention for L2 is different from L1/L0. The details of the L2 netCDF file are provided below:

3.1 L2 netCDF data file

Filename: The nomenclature for file designation adheres to the specifications articulated within the ICD. The format is described as follows:

L2_AL1_MAG_YYYYMMDD_VMN.nc

File generation: The production of this file is accomplished by assimilating all Level 1 data files corresponding to the specified 24-hour interval. Consequently, the filename is dissociated from the Level 0 and Level 1 designations. All input files utilized in the formulation of the Level 2 product are cataloged within its XML (metadata) file. In instances where file regeneration is necessitated for any reason, the version number is modified accordingly, and the justification for regeneration is documented within the remarks section as metadata.

File description: The nc file encompasses the interplanetary magnetic field data acquired from the six-meter sensor -MAG1. The Level 1 data undergoes transformation into standardized frames, specifically Geocentric Solar Ecliptic (GSE) and Geocentric Solar Magnetospheric (GSM) formats. The resultant output is a decadal average of the Level 1 data. Level 2 data is additionally made available in the SCCS frame.

The next page contains the list of variables present in the L2 nc file:

S.No.	Name	units	description
0	time	Seconds (UNIX time)	Epoch starts at Jan 1, 1970 00:00:00, bin-width = 10second
1	Bx_gse	nano tesla - nT	Field component along the X-axis in GSE frame
2	By_gse	nano tesla - nT	Field component along the Y-axis in GSE frame
3	Bz_gse	nano tesla - nT	Field component along the Z-axis in GSE frame
4	Bx_gsm	nano tesla - nT	Field component along the X-axis in GSM frame
5	By_gsm	nano tesla - nT	Field component along the Y-axis in GSM frame
6	Bz_gsm	nano tesla - nT	Field component along the Z-axis in GSM frame
7	Bx_gse_error	nano tesla - nT	Uncertainty in Field component along the X-axis in GSE frame
8	By_gse_error	nano tesla - nT	Uncertainty in Field component along the Y-axis in GSE frame
9	Bz_gse_error	nano tesla - nT	Uncertainty in Field component along the Z-axis in GSE frame
10	Bx_gsm_error	nano tesla - nT	Uncertainty in Field component along the X-axis in GSM frame
11	By_gsm_error	nano tesla - nT	Uncertainty in Field component along the Y-axis in GSM frame
12	Bz_gsm_error	nano tesla - nT	Uncertainty in Field component along the Z-axis in GSM frame
13	x_gse	kilometers - km	X coordinate of spacecraft in GSE frame
14	y_gse	kilometers - km	Y coordinate of spacecraft in GSE frame
15	z_gse	kilometers - km	Z coordinate of spacecraft in GSE frame
16	x_gsm	kilometers - km	Z coordinate of spacecraft in GSM frame
17	y_gsm	kilometers - km	Y coordinate of spacecraft in GSM frame
18	z_gsm	kilometers - km	Z coordinate of spacecraft in GSM frame
19	Quality_flag_10s_data	Binary	Quality factor for the sample(10s).Binary value; 0 = Bad/missing data; 1 = Valid data

Table 3: The table provides the list of available variables along with their attributes in the L2 netcdf file.

The uncertainty in the magnetic field values at L2 is combination of errors propagated from L1 data, the uncertainty in the zero offset at a gien epoch, and the error in spacecraft attitude information provided in spice kernels. After including all these factors, a net uncertainty of 0.5 nT is considered for the L2 data. It may change if the zero offset of the sensors changes over time. Continuous monitoring of quiet-time data from both the sensors is done to estimate and refine the calibration parameters. Major regeneration of the data is only envisaged if the zero offsets are updated, specifically upon the observation of any discernible changes in the data.

4. Data quality

Quality of data is one of the variables made available in the L2 netCDF file. There are two kinds of quality factors provided to the users. One is a an overall quality factor for the dataset. It is given as percentage of samples in the dataset that are either missing or invalid data. It is provided as part of the global attributes of the nc file with the name ‘missing_data_percentage’. This value is converted to a range of 1-10 and incorporated into a metadata file. This is mainly done to maintain a homogenous definition across all payloads of Aditya-L1. Description of the process to estimate quality factor is given below:

The quality factor for Magnetometer level1/2 data ranges between 1 - 10, with 1 being the lowest quality and 10 being the highest quality. The flag is generated by using outputs from both MAG1 and MAG2. For each output datapoint the magnetic field vectors from both the sensors are compared in all three axes [yaw,roll, and pitch]. Component-wise ratios[eg:Mag1_yaw'/Mag2_yaw'] of the derivative of the output is constrained with an expected range. The range that safely segregrates the changes in IMF from the changes due to spacecraft subsytems is estimated from ground measurements of the spacecraft generated magnetic field and by application of dual magnetometer method to the onboard data. If the ratios are out of range, then those particular vectors are not considered good science data. The quality also depends on other factors like availablity of auxillary data. Conversion of rawdata to magnetic field requires sensor and electronics temperature information. The absence of Housekeeping (HK) data adversely affects the quality. The presence of missing samples serves as another criterion for evaluating data quality. In case of L2 data, if the samples being used in averaging are missing/bad, then the resultant L2 data degrades in quality.The quality factor is determined by mapping the quantity of poor or missing samples onto the scale of 1 to 10.

Quantification of the quality factor is done in the following manner:

Quality level	**Description**
1- 7	Poor quality ; > 50 % bad samples
8	Average quality ; 25 - 50 % bad/missing samples
9	Good quality ; 10 - 25 % bad/missing samples
10	Very good quality ; < 10 % bad/missing samples

Table 4: The table gives the quality factor definitions for the instruments data products.

The second quality factor is the instantaneous sample quality. This is provided for each data sample at L2. It is derived through the application of Good-Time-Interval (GTI) constraints on the data. It is essentially a quality flag which is either 0 or 1, with 0 = bad/missing sample and 1 = valid data.

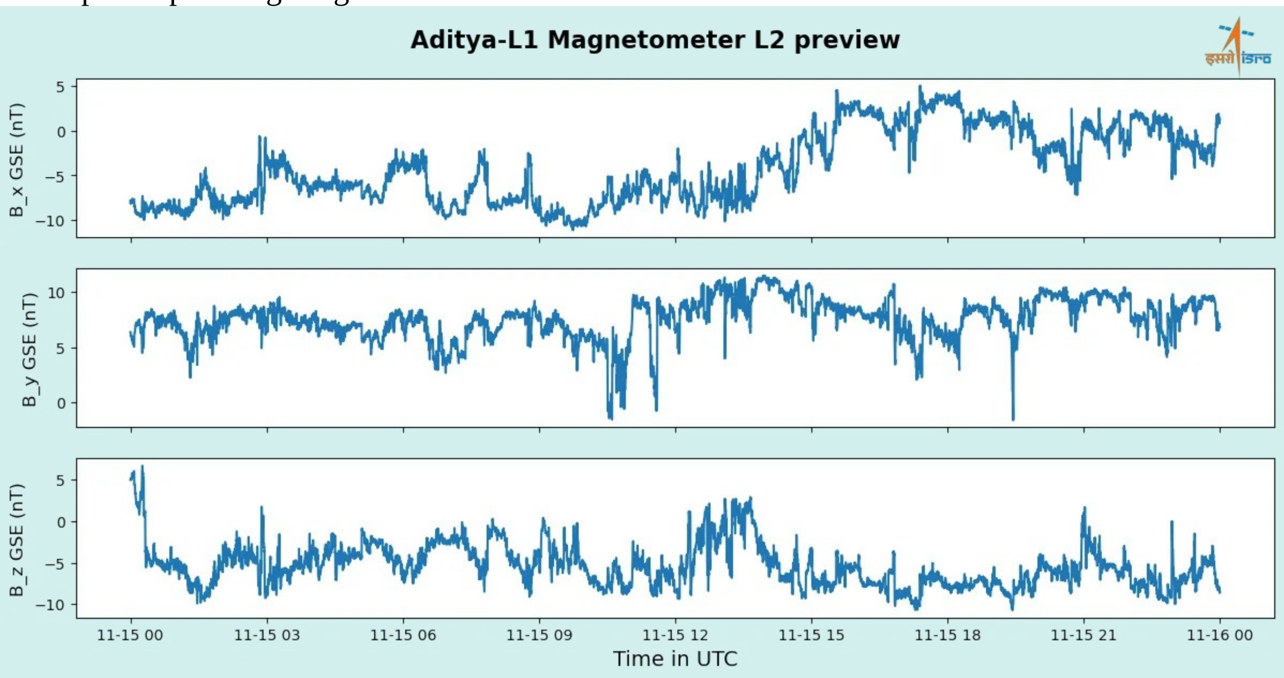
Note: This quantification of quality is non-standard and depends on the observation duration as well(especially for Level1 data). These definitions may change with time depending on the long-term performance of the instrument.

5. Outreach data product

The outreach product of the magnetometer is an image that illustrates the temporal variations of Bx, By, and Bz over a continuous 24-hour period. This image is derived from the L2 data product, thereby categorizing it as a daily file that utilizes L2 data as its fundamental input.

The outreach product materializes as a png file that depicts the timeseries plots of Bx, By, and Bz within the GSE coordinate system for the given day (spanning 24 hours). The generation of this plot follows the implementation of GTI flag on the L2 data, consequently facilitating a visualization that exclusively represents valid data records.

A sample output image is given below:



6. Data processing code

For the benefit of students who intend to use MAG data, a jupyter-notebook(python3) is provided for data visualization. The notebook is available under the ‘Other downloads’ section of the webpage. After downloading science level data (L2) of the instrument, the notebook can be used to load data, combine data from mutiple files/days, and then plot its variables. This resource is intended to help beginners to kickstart their data analysis process of MAG data.

The notebook has been tested on Linux Mint/Ubuntu platform, with Python 3.11.5.

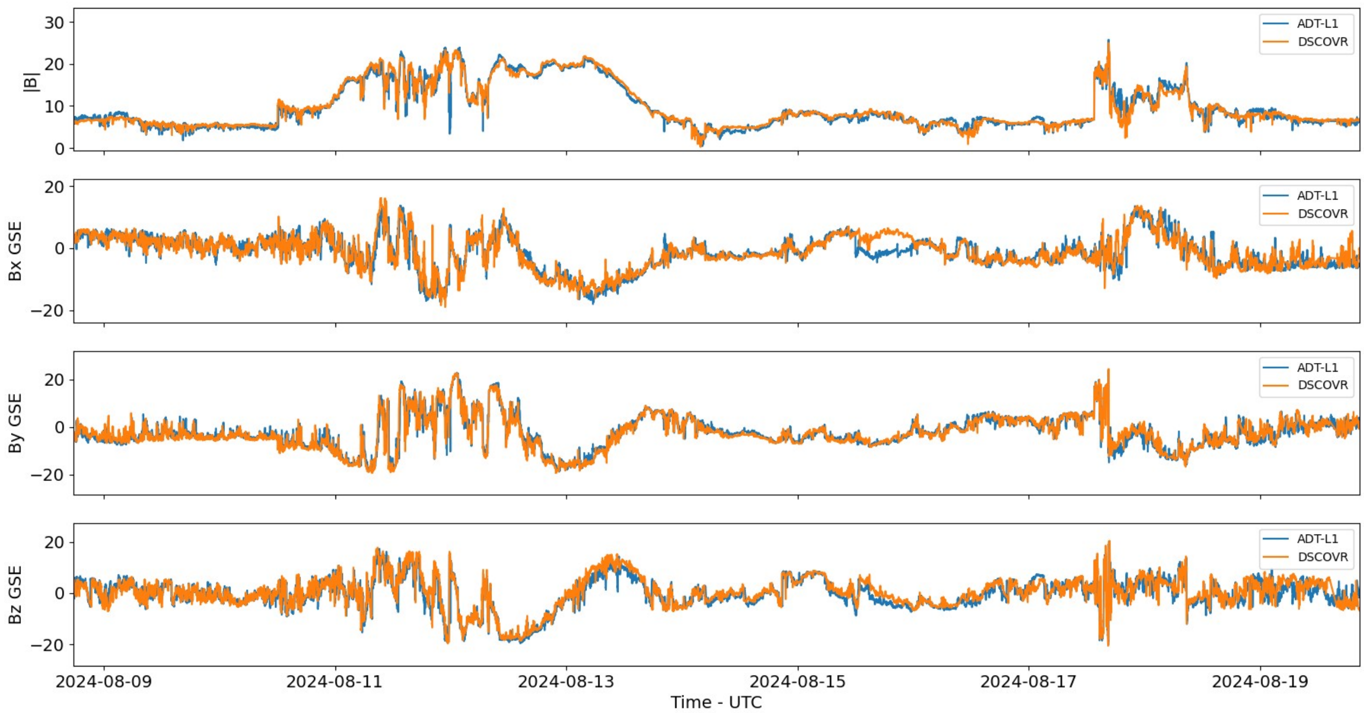
In case of any issues related to the scripts, please contact the Magnetometer team.

7. Calibration data

To guarantee that the net sensor offset is accurately estimated, a calibration procedure is undertaken by executing rotations of the spacecraft about the orthogonal axes of the spacecraft coordinate system. These rotations are conducted periodically to refresh the calibration database(caldb). The regeneration of datasets occurs whenever an update to the caldb is implemented. It is important to note that datasets generated during the calibration interval are not made available for dissemination.

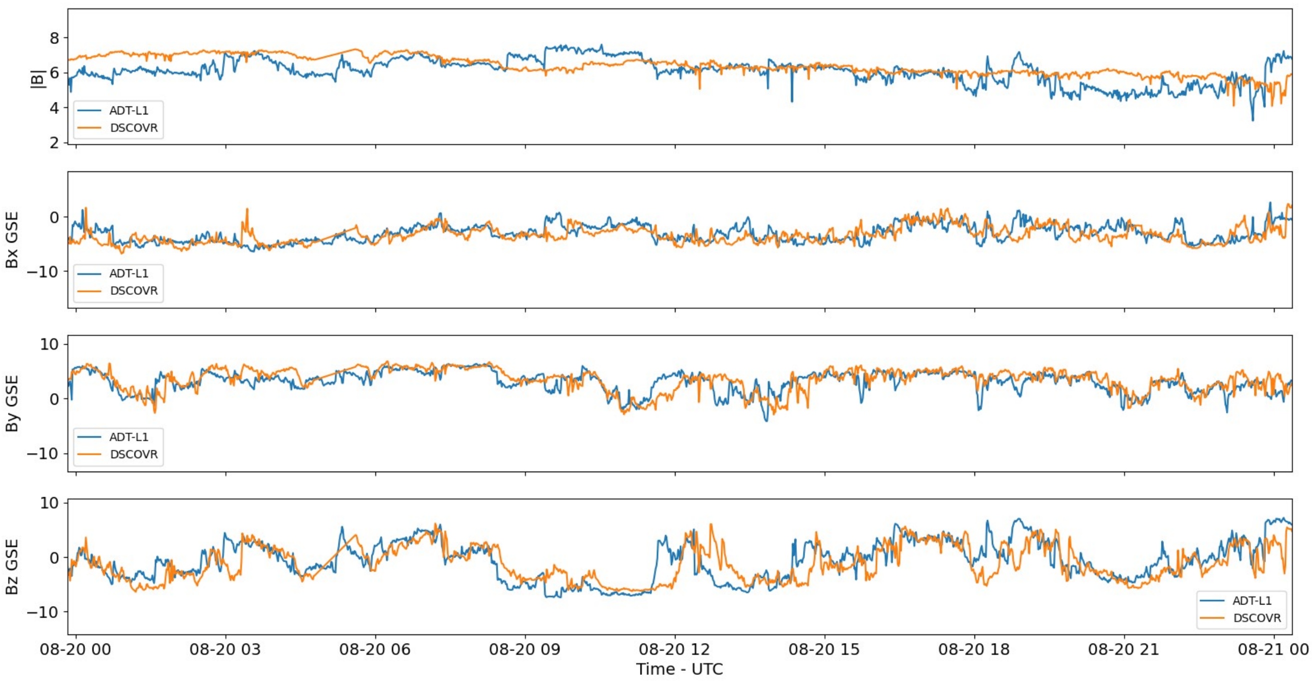
8. Comparison with contemporary data

After the preliminary establishment of calibration parameters utilizing instrumental data derived from spacecraft rotational exercises, regular datasets are compared with Magnetometers on other spacecraft at L1 – DSCOVR, ACE, or WIND. The comparison is also used to derive any long-term trends in magnetometer sensors performance that are not already incorporated in the caldb. This comparison implicitly assumes that the long-term(monthly or longer) trends of contemporary magnetometers are true and valid. Data from DSCOVR's magnetometer is used here to demonstrate the comparison during solar-active and solar-quiet periods.



The above figure shows component-wise comparison of IMF – Bx, By, Bz, and total magnitude between Aditya-L1 and DSCOVR data in GSE frame. The data shown here is 1-minute averaged data from both the instruments. It is seen that both the dataset are well-correlated.

Using multi-spacecraft IMF data, it can be seen that the large-scale magnetic structures like CMEs, shocks, magnetic clouds, etc., have a high degree of correlation (Pearson correlation coefficient, r ~ 0.9); however, this correlation does not extend to data obtained during quiet-time conditions.



The above figure shows a data comparison for a quiet-time duration of 24 hour in August, 2024. Though, visually one can note certain trends component-wise, the field magnitude shows different profiles. These differences may be attributed to the physical processes governing the propagation of solar wind and magnetic fields through interplanetary space, as well as potential discrepancies arising from the instruments themselves.

When using quiet-time data from the Aditya-L1 magnetometer, the users must exercise caution in interpreting any sharp/sudden features (like spikes, very large values of |B|, highly-correlated signatures in all three components of the magnetic field). The pipeline includes good-time-interval filtering based on several constraints on HK and science data at Level2 data only. Despite the implementation of GTI, there remains a possibility of invalid data samples infiltrating the final product, particularly during periods of solar quiescence. Moreover, users are suggested to consider supplementary in-situ dataset related to solar wind plasma parameters to ascertain the validity of the quiet-time IMF from Aditya-L1.

9. Caveats

- As mentioned above, the data pipeline includes several measures to filter and determine the samples that can be considered as valid. Notwithstanding these measures, invalid samples with a good quality flag can still be present, especially in the quiet-time data.
- The conversion of IMF from spacecraft frame to standard frames like GSE/GSM is done using SPICE kernels. In instances where the attitude kernels are erroneous or interpolated for specific temporal segments, the L2 product may consequently display inaccurate values.
- The L1 data product may exhibit transient spikes in the data due to spacecraft operations. These are filtered at the L2 data by median filtering and then averaging over several samples. Thus, the L2 product is an averaged data where high-frequency IMF fluctuations are removed/smoothened.

- Do not consider any high frequency periodicities(~ greater than 1Hz) in L1 data to be IMF related. They are mostly spacecraft induced frequencies.
- This magnetometer captures the large-scale magnetic field structures in IMF very well. But, small-scale and high-frequency features of IMF may not be having sufficient SNR to be captured well.

10. Data regeneration

Following are the scenarios for data product regeneration for Magnetometer:

a. Availability of higher version Level 0 (.pld files) data. These files may fill any data gaps that existed in their previous versions.

b. Availability of revised SPICE kernels and HK files.

c. Modifications in calibration parameters. This is particularly anticipated when sensor offsets exhibit gradual alterations over time.

The regenerated dataset shall reflect an updated version number within their filenames, contingent upon the nature of the revision—whether major or minor. If there are multiple files for a given duration, users are recommended to use the highest version.