Monthly Report on MSS-1A Magnetic Data Quality for September 2026

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1 Introduction

1.1 About This Report

This report presents data-quality results based on MSS-1A Level-2 products reprocessed as Version 07 (V07), applied to observations from September 2026. The assessment covers: (1) detection of data anomalies; (2) evaluation of the vector fluxgate magnetometer (VFM) and the absolute scalar instrument (ASM — the Coupled Dark State Magnetometer, CDSM); and (3) consistency checks between observed and modeled geomagnetic fields.

The scope of this report includes data processing procedures, statistical analysis, and visual inspections of daily magnetic field variations. In addition, the observed magnetic field (in the NEC frame) is compared with two geomagnetic field models: the real-time World Magnetic Model of Macau (WM3RT-2.1) [RD.02], independently developed by the Macau Institute of Space Technology and Application (MISTA) team, and the CHAOS-8.7 model [RD.03]. WM3RT-2.1 includes contributions from the core, lithosphere, magnetosphere, ionosphere, associated mantle induction, and ocean-tide-induced magnetic fields. For the CHAOS-8.7 comparison, contributions from the core, lithosphere, and ionosphere are included, together with an additional magnetospheric magnetic field (MMA) contribution [RD.04]. The residuals from both model comparisons are analyzed to quantitatively assess measurement–model consistency and identify potential calibration or data-quality issues.

Chapter 1 presents a general overview of the report and its main objectives. Chapter 2 focuses on in-orbit events and anomalies observed during satellite operation, such as changes in instrument temperature and disturbances and geomagnetic activity (e.g., magnetic storms). Chapter 3 provides a detailed assessment of the magnetic field data quality, including ΔF ($F_{ASM} - |\mathbf{B}_{VFM}|$) time series analysis, residual comparisons with the WM3RT-2.1 model and WM3RT-2.1 models, and visualization of these residuals. Chapter 4 summarizes the overall satellite data status for the month, highlighting any identified anomalies or quality issues.

1.2 Processor Evolution and Instrument Status

The VFM calibration processor was upgraded to version V07 and the entire Level-2 archive was reprocessed (V07) and released in October 2025. For example, an LR file name after the reprocessing looks like:

MSS1A_OPER_VFM_L2_MAG_SCI-LR_20231201T000000_20231201T235959_V0731.cdf

Details of dataset revisions and processor updates are documented in reference [RD.05]. The V07 L2-VFM and CDSM files for observations in September 2026 are the data object of this report and are publicly available from the MSS data portal (https://mss.must.edu.mo/data_download.html). In

September 2026, the satellite's magnetic-field instruments showed nominal operation according to instrument flags.

1.3 Reference

[RD.01] Swarm DISC Weekly Report. https://earth.esa.int/eogateway/search?text=&category=Search%20all&instrument=magnetometers,asm,vfm&sortby=NEWEST_FIRST

[RD.02] Yao, H. B., Xu, J. Y., Yang, C., Ren, Z. Y., and Zhang, K. (2025). A multisource geomagnetic field model incorporating ocean circulation-induced magnetic field. Earth Planet. Phys., 9(3), 550–563. https://doi.org/10.26464/epp2025029

[RD.03] Kloss, C., Finlay, C. C., Olsen, N., Tøffner-Clausen, L., Gillet, N., and Grayver, A. (2026). The CHAOS-8 geomagnetic field model.Earth, Planets and Space, 78, 21.https://doi.org/10.1186/s40623-025-02352-0

[RD.04] Swarm Level 2 Processing System - Intermediate validation of Swarm Level 2 Magnetospheric Field Product. https://ftp.space.dtu.dk/data/magnetic- satellites/Swarm/SCARF/CI MMA_VA/Year3/Li2C.pdf

[RD.05] MSS-1A VFM and CDSM Data Handbook. https://mss.must.edu.mo/image/handbook/MSS-1A%20VFM%20and%20CDSM%20Data%20Handbook-20251003.pdf

2 Event and Anomaly

2.1 Discrepancy of F between VFM and CDSM Data Files

In the published VFM and CDSM products, both files contain a scalar F. We denote the scalar from the CDSM file as F_{CDSM}, and the scalar from the VFM file as F_{VFM}. We define $\delta F = F_{CDSM} - F_{VFM}$ and report the daily mean and maximum of δF in Table 2-1.

Table 2-1: Discrepancy of scalar F between published VFM and CDSM data files in September 2026

Date	Count	Mean	Max
20260913	325	8.06154e-06	2e-05

"Count" indicates the number of data points that exceeded the discrepancy threshold on that day; "Mean δF" represents the average difference in magnetic field magnitude; and "Max δF" denotes the maximum discrepancy detected. Here, Max and Mean are in nT.

2.2 VFM Temperature Monitoring

Figure 2-1 shows the temperature variations for CDC, CSC, and EU during September 2026. The temperature variations remained within the normal range for the month. The maximum temperature observed for CDC was 3.33°C, for CSC 0.90°C, and for EU 28.65°C. The average temperatures were 2.31°C for CDC, -0.91°C for CSC, and 27.28°C for EU. The Huber-weighted RMS values were 0.57°C for CDC, 0.96°C for CSC, and 0.57°C for EU. Here we focus on temperature variability because short-term fluctuations can affect magnetometer calibration and instrument performance.

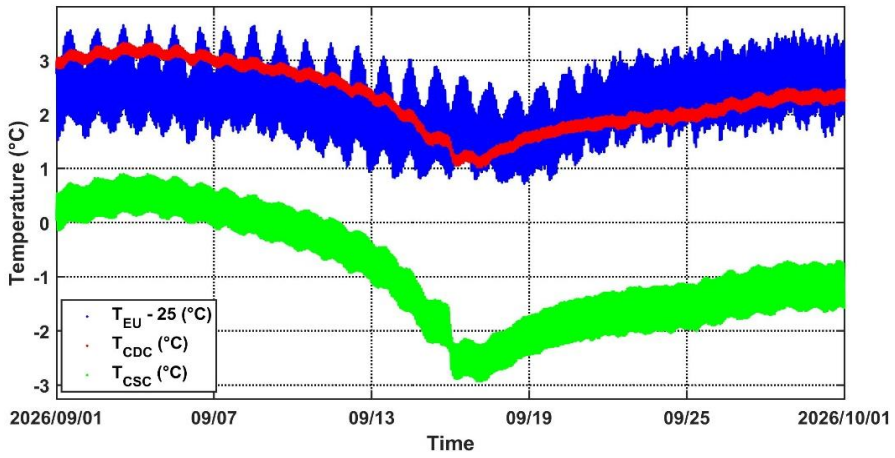


Figure 2-1: Temperature variations of CDC, CSC, and EU during September 2026. The temperature of EU is adjusted by subtracting 25°C.

2.3 Inter-boresight check

The attitude stability of the optical platform from November 2023 to September 2026 is evaluated by monitoring inter-boresight angles (IBAs). Figure 2-2 shows the three camera-pair IBAs (CHUA–CHUB, CHUA–CHUC, CHUB–CHUC, CHU = Camera Head Unit) for the period November 2023 to September 2026. The panels present time series of IBAs after mean removal; the legend of each panel reports the sample mean and the Huber-weighted RMS. Figure 2-3 shows the residual IBAs between the combined quaternion (the L2 VFM product q_NEC_CRF) and the quaternions from individual cameras. These residuals evaluate the improvement in both reliability and accuracy achieved by the combination algorithm relative to single-camera attitude determination. All time series were plotted using 60-s sampling for display clarity.

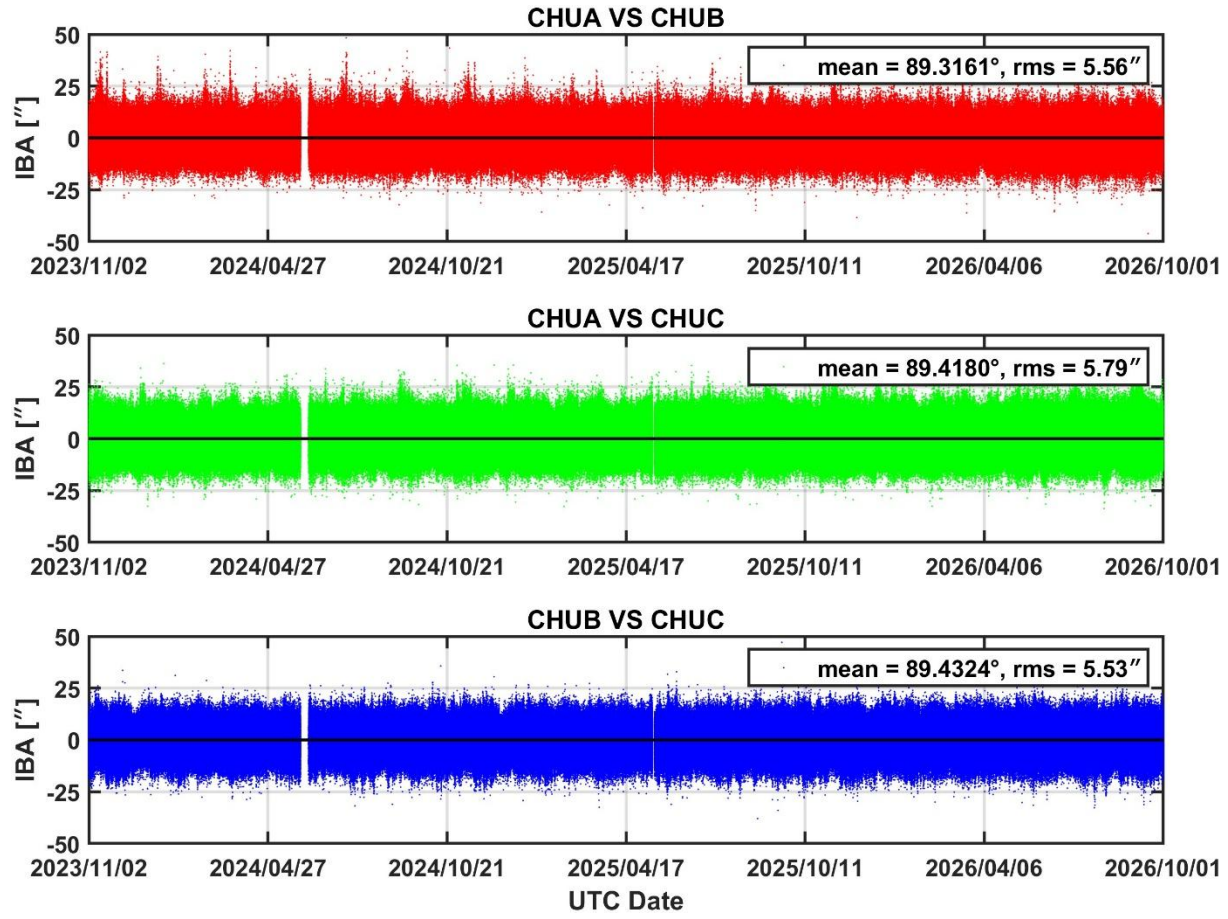


Figure 2-2: Time series of inter-boresight angles (IBA) between the three star-tracker Camera Head Units (CHU): CHUA–CHUB, CHUA–CHUC, and CHUB–CHUC. Values are per-series mean removed and shown in arc-sec. Sampling for plotting: 60 s.

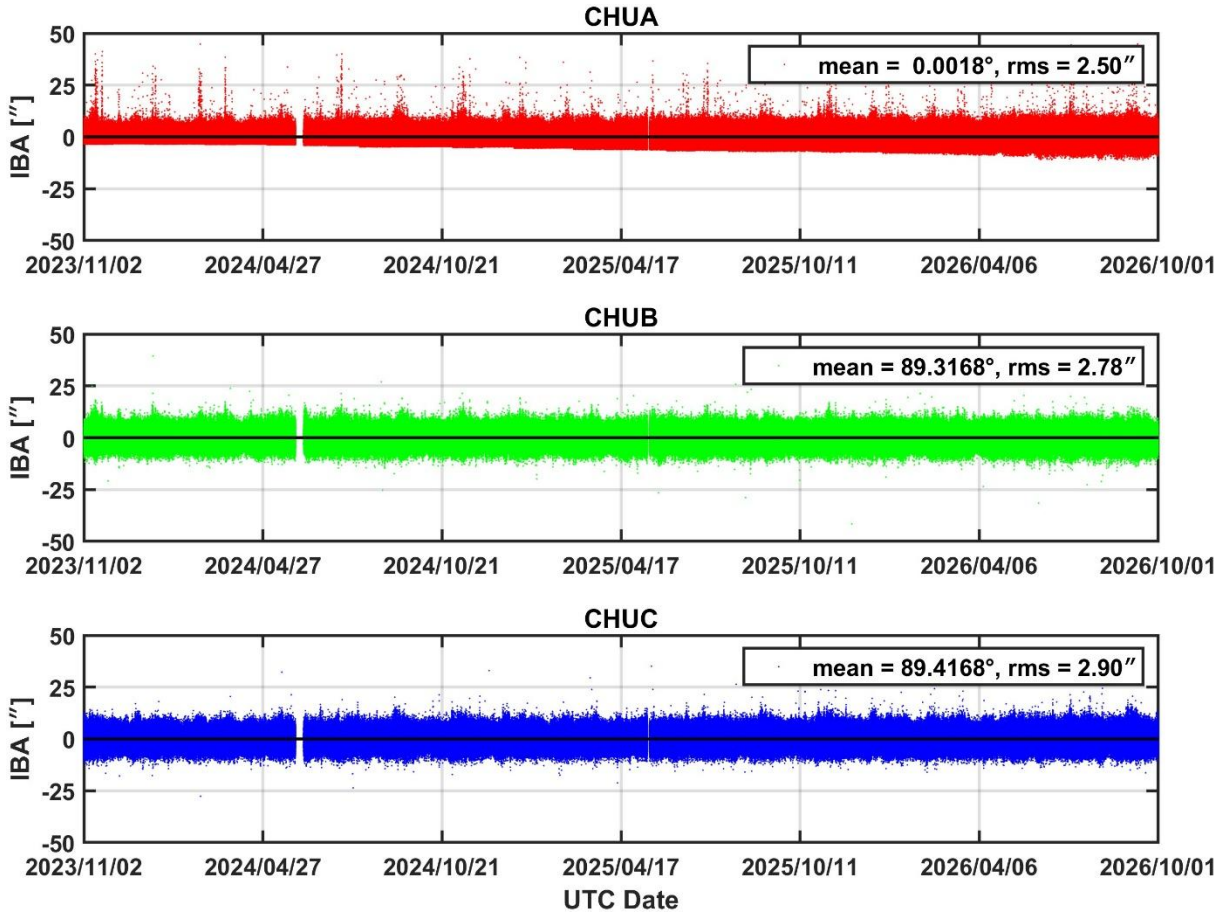


Figure 2-3: Residual IBA time series between the combined quaternion (q_NEC_CRF, L2 VFM) and each single-camera quaternion (units: arc-sec). Small residuals (≲10 arc-sec) indicate good platform stability and effective attitude combination.

Physically, small IBA fluctuations reflect the mechanical/thermal stability of the optical bench and the internal consistency of the quaternion-combination strategy. If residuals between the combined quaternion and the single-camera quaternions remain within ±10 arc-sec, the platform stability and the combination algorithm can be regarded as sufficient for VFM alignment requirements. In our re-analysis for November 2023 to September 2026, the combined-vs-single-camera residuals are largely confined within ±10 arc-sec, indicating stable platform performance and satisfactory behavior of the attitude-combination method.

2.4 Geomagnetic Activity

Figure 2-4 illustrates the temporal evolution of geomagnetic activity during September 2026, as captured by the Kp index (black line, left axis) and the RC index (blue dashed line, right axis). Several

moderate geomagnetic disturbances were recorded during the month, with Kp values reaching up to 5.0. The RC index reached values as low as -56 nT.

The Kp index can be downloaded from https://kp.gfz-potsdam.de/en/data, and the RC index from http://www.spacecenter.dk/files/magnetic-models/RC/current/.

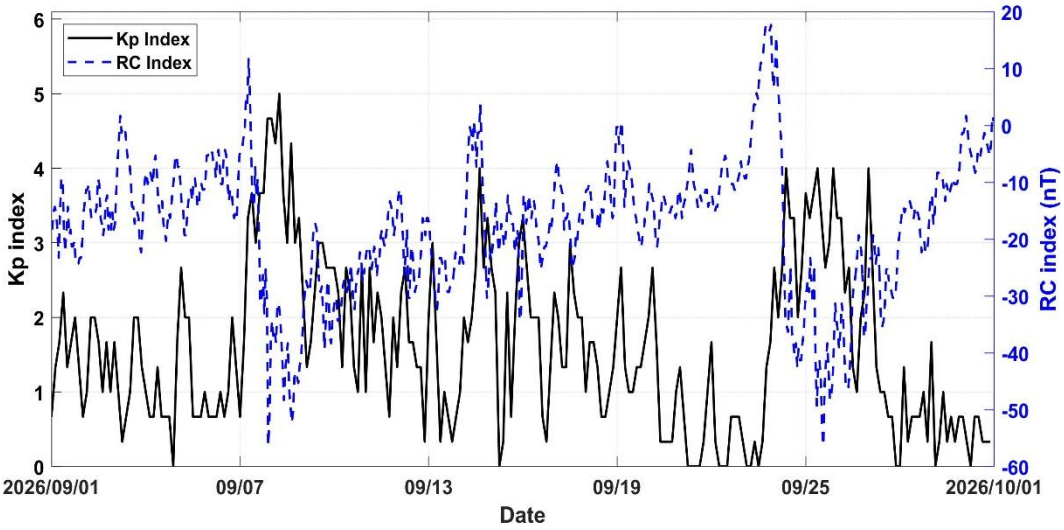


Figure 2-4: Kp (black) and RC (blue) indices showing geomagnetic activity during September 2026.

3 Magnetic Products

This chapter focuses on the quality inspection of the officially released Level 2 scalar (CDSM) and vector (VFM) magnetic field products from the MSS-1A satellite. The analyses aim to assess the temporal stability, detect anomalies, and ensure the reliability of the magnetic measurements. The monitoring includes the following key aspects:

- **Data Range Check:** The scalar magnetic field intensity F and the VFM vector magnitude |B_VFM| are checked against the expected range of 18,000–60,000 nT. The individual NEC components are separately inspected for anomalous values. In addition, the satellite's orbit is verified to remain within the expected spatial coverage (latitude $\leqslant 41°$, altitude between 415–495 km). To help identify unusual events or anomalous behavior, additional statistics of the Flag_B quality indicator are compiled for further analysis.
- **ΔF Time Series Inspection**: Daily time series of the residuals $\Delta F = F_{ASM} - |\mathbf{B}_{VFM}|$ are visually inspected to monitor the differences between the ASM and VFM. For each day, the mean variation and standard deviation of ΔF are recorded. An alert is raised if the daily mean or RMS of ΔF exceeds ±1 nT. A time series of the RMS of ΔF is then generated.
- **ΔF Statistical Summary**: Mean and standard deviations of ΔF are analyzed over both the current month and the entire available period (since November 2023), providing an overview of the long-term performance of the instruments and highlighting temporal or spatial anomalies.
- **Magnetic Component Inspection**: Daily and monthly variations of the magnetic intensity F and the three $\mathbf{B}_{NEC}$ components are visualized to identify potential jumps, gaps, or systematic errors.
- **Model Residual Analysis**: The observed $\mathbf{B}_{NEC}$ field is compared with the WM3RT-2.1 model and WM3RT-2.1 models, and residual maps are computed and plotted to reveal geophysical signals or potential instrument deviations.

3.1 Out-of-threshold Values

(1) Values outside 18,000–60,000 nT: No out-of-threshold values were detected in the NEC vector components, in the scalar field F derived from CDSM, or in field intensity calculated from $\mathbf{B}_{VFM}$ within the Level-2 data for September 2026.

(2) All recorded values fall within the normal operating bounds:

- $|\text{latitude}| \leqslant 41°$
- $415\ \text{km} \leqslant \text{height} \leqslant 495\ \text{km}$

No positional anomalies were detected this month, indicating nominal satellite orbit and data acquisition.

(3) The Flag_B indicator is used to assess the quality of the magnetic field measurements on board MSS-1A. Each Flag_B value denotes a specific anomaly or condition observed during data acquisition. The flags are defined as follows:

- 0: nominal;
- 1: data is derived through interpolation;
- 2: outliers when $|F_{ASM} - |\mathbf{B}_{VFM}|| > 1$ nT;
- 3: interpolated data points with $|F_{ASM} - |\mathbf{B}_{VFM}|| > 1$ nT;
- 4: position fault when h < 415 km or h > 495 km or abs(latitude) > 41°, where h is satellite height.

For each day in September 2026, the number of observations corresponding to each Flag_B level was counted (expected 86,400 samples/day at 1-Hz); results are summarized in Table 3-1.

Table 3-1: Summary of Flag_B Statistics for September 2026

DATE	num_FlagB_eq0	num_FlagB_eq1	num_FlagB_eq2	num_FlagB_eq3	num_FlagB_eq4
20260901	85641	0	759	0	0
20260902	85593	2	805	0	0
20260903	85759	0	641	0	0
20260904	85910	0	490	0	0
20260905	85809	0	591	0	0
20260906	86183	2	215	0	0
20260907	85962	0	438	0	0
20260908	86046	0	354	0	0
20260909	86022	0	378	0	0
20260910	86165	0	235	0	0
20260911	86045	0	355	0	0
20260912	86001	0	399	0	0
20260913	85878	0	522	0	0
20260914	85605	0	795	0	0
20260915	85776	0	624	0	0
20260916	85010	11	1348	31	0
20260917	85519	0	881	0	0
20260918	85579	2	819	0	0
20260919	85562	0	838	0	0

20260920	84947	0	1453	0	0
20260921	83873	2	2525	0	0
20260922	83552	0	2848	0	0
20260923	82700	20	3680	0	0
20260924	84565	0	1835	0	0
20260925	85236	0	1164	0	0
20260926	84248	0	2152	0	0
20260927	84663	2	1735	0	0
20260928	84843	2	1555	0	0
20260929	85965	0	435	0	0
20260930	84789	0	1611	0	0

DATE indicates the observation date in the format yyyymmdd. num_FlagB_eq0 represents the total number of records with Flag_B = 0, indicating nominal measurements. Other columns follow the same convention, referring to different Flag_B levels.

3.2 ASM – VFM Anomaly

To validate the physical consistency between vector and scalar magnetic measurements, we define the residual ΔF as the difference between the scalar measurement F_{ASM} and the magnitude of the VFM vector field $|\mathbf{B}_{VFM}|$, such that $\Delta F = F_{ASM} - |\mathbf{B}_{VFM}|$.

It is worth noting that we use δF to denote the difference in the scalar field F between the L2 CDSM file and the L2 VFM file, while ΔF is used to represent the difference between the scalar field F and the vector field strength $|\mathbf{B}|$ in the L2 VFM file.

Under ideal calibration conditions, ΔF should remain close to zero, indicating that the vector magnetometer's sensitivities (scale factors), offsets and non-orthogonalities have been properly corrected. Systematic or large residuals may reflect issues in vector calibration, external disturbances—such as sunlight-induced perturbations, or instrumental failures.

Figure 3-1 shows the temporal evolution of ΔF throughout September 2026 using unscreened VFM and CDSM data, displaying the original range of variation without applying any filtering to the data. Most values fluctuate within ± 1 nT, but occasional spikes appear, indicating short-term disturbances or outliers in the measurements. Overall, the data distribution is centered around zero, suggesting that the instrument calibration is generally stable.

To monitor calibration performance and detect possible anomalies, four key statistics are computed daily throughout the month:

- The minimum and maximum values of ΔF, indicating the range of deviations;

- The mean and root-mean-square (RMS) values of ΔF, quantifying the average daily bias and variability.

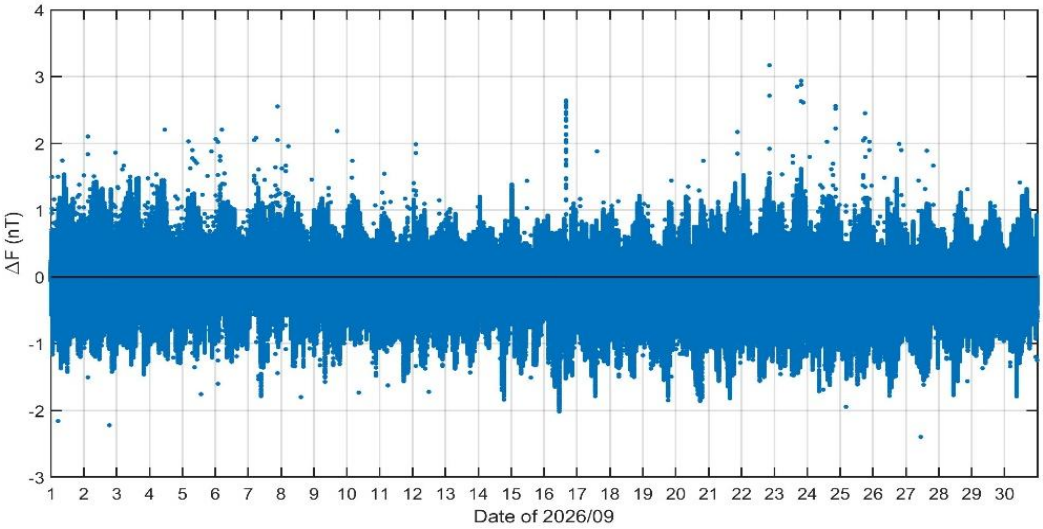


Figure 3-1: Temporal variation of ΔF calculated from unscreened VFM and CDSM data in September 2026.

The table below presents the daily statistical summary of scalar magnetic residuals for September 2026, displaying the daily minimum, maximum, mean, and Huber-weighted RMS values of ΔF. The last row of the table provides a summary of the overall statistics for the entire month. All statistics were computed after applying a uniform data screening, retaining only samples with F and $|\mathbf{B}_{VFM}|$<52,000 nT and |ΔF| ⩽ 20 nT; the same criteria are used throughout the subsequent ΔF analyses.

Table 3-2: Daily statistics of ΔF for September 2026 (Unit: nT)

Date	**20260901**	**20260902**	**20260903**	**20260904**	**20260905**	**20260906**	**20260907**	**20260908**
Min	-2.159	-2.221	-1.462	-1.293	-1.758	-1.600	-1.785	-1.798
Max	1.743	2.102	1.664	2.206	2.031	2.204	2.554	1.959
Mean	0.066	0.092	0.036	0.049	0.058	0.051	0.056	0.088
RMS	0.268	0.263	0.284	0.272	0.262	0.252	0.252	0.269
Date	**20260909**	**20260910**	**20260911**	**20260912**	**20260913**	**20260914**	**20260915**	**20260916**
Min	-1.575	-1.731	-1.625	-1.723	-1.431	-1.839	-1.511	-2.018
Max	2.185	1.739	1.544	1.987	1.050	1.203	1.439	2.640
Mean	0.075	0.041	-0.095	-0.089	-0.116	-0.083	-0.139	-0.132
RMS	0.269	0.277	0.268	0.278	0.276	0.271	0.265	0.278
Date	**20260917**	**20260918**	**20260919**	**20260920**	**20260921**	**20260922**	**20260923**	**20260924**
Min	-1.785	-1.502	-1.849	-1.857	-1.823	-1.558	-1.475	-1.712
Max	1.879	1.216	1.441	1.741	2.171	3.171	2.934	2.557
Mean	-0.114	-0.163	-0.178	-0.170	-0.131	-0.087	-0.077	-0.069

RMS	0.318	0.309	0.302	0.334	0.368	0.376	0.376	0.353
Date	**20260925**	**20260926**	**20260927**	**20260928**	**20260929**	**20260930**		**202609**
Min	-1.946	-1.781	-2.397	-1.771	-1.368	-1.790		-2.397
Max	2.450	1.991	1.889	1.314	1.106	1.412		3.171
Mean	-0.117	-0.136	-0.166	-0.173	-0.139	-0.152		-0.066
RMS	0.325	0.319	0.304	0.287	0.278	0.273		0.308

Violation of ΔF threshold:

- Mean residuals (absolute value>1 nT): no violations.
- RMS residuals (>1 nT): no violations.

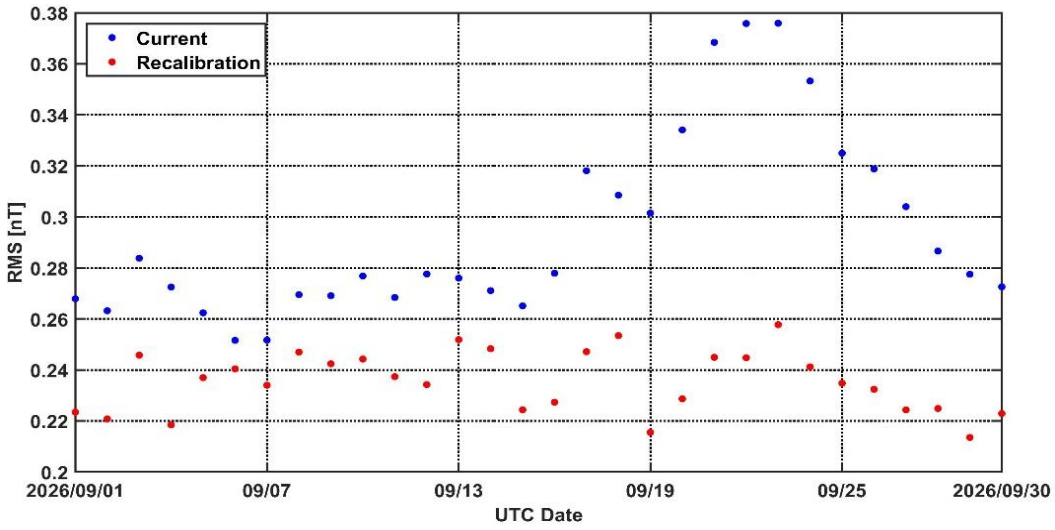


Figure 3-2: ΔF RMS statistics of MSS-1A Level 2 data (blue) and daily in-flight recalibration results (red) for September 2026.

Figure 3-2 presents the Huber-weighted root-mean-square (RMS) of ΔF for MSS-1A Level 2 VFM data in September 2026 (blue dots). The daily in-flight recalibration results (red dots) show reduced RMS values compared with the baseline processing. This improvement is more likely attributable to imperfect original calibration parameters; daily recalibration reduces calibration-related residuals.

For overall data calibration (blue dots), a quality filter was applied to remove physically unreasonable data points. This ensured that outliers would not bias the calibration results. The same screening criteria were also applied in the daily nine-parameter recalibration. In addition, the use of the Huber weighting scheme further improves robustness by down-weighting residuals from outlier points during RMS computation.

Figure 3-3 displays the temporal variation of ΔF RMS values in VFM files since November 2, 2023. Overall, the RMS variation of MSS-1A data remains stable.

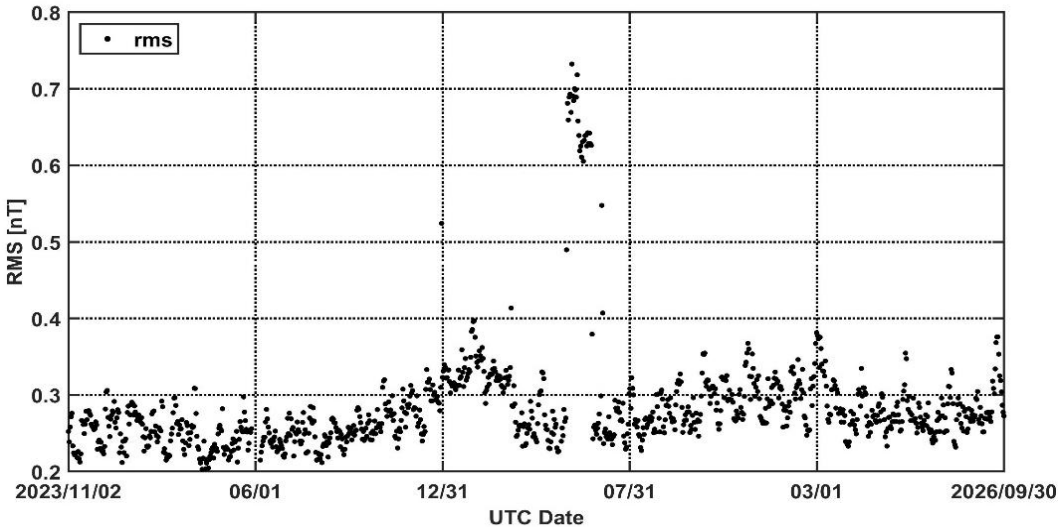


Figure 3-3: Temporal evolution of ΔF RMS values in VFM data from November 2023 to September 2026.

3.3 ASM – VFM Difference Statistics

Figure 3-4 shows the daily mean (circles) and standard deviation (crosses) of ΔF of September 2026. Figure 3-5 extends this analysis by presenting the daily mean and standard deviation values of ΔF from November 2023 to September 2026. The subsequent two plots (Figures 3-6 and 3-7) present ΔF analyses for September 2026. Figure 3-6 shows the time series for the month, with daytime and nighttime measurements represented by red and blue dots, respectively. The residuals primarily remain within ±2 nT, though occasional outliers are present. Statistical metrics displayed in the top-left corner indicate consistent mean and RMS values for both daytime and nighttime ΔF throughout the month. Figure 3-7 illustrates the spatial distribution of ΔF across longitude and latitude coordinates.

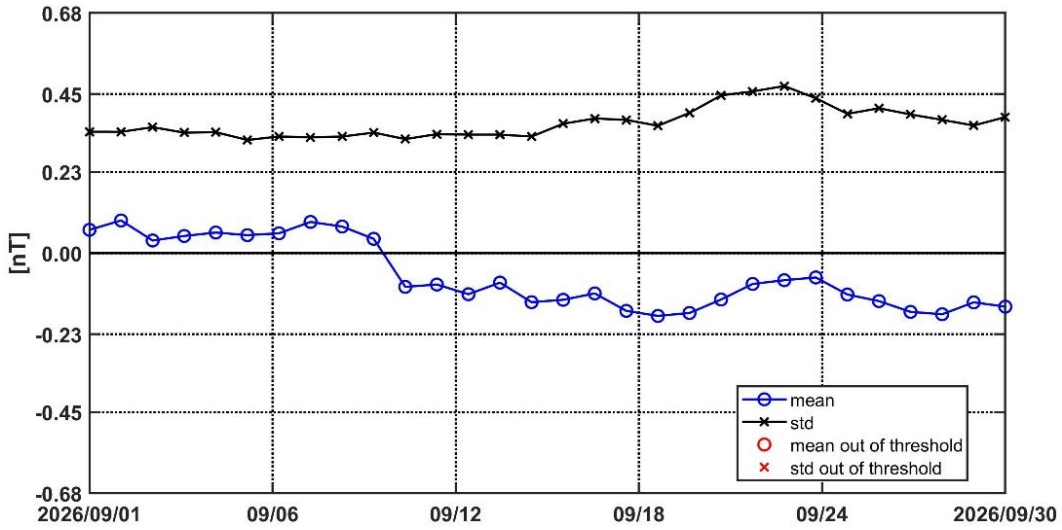


Figure 3-4: Daily mean and standard deviation values of ΔF in September 2026. Red circles and crosses indicate days where the absolute values of the mean and root-mean-square (RMS) residuals exceed 1 nT. (This situation does not occur during this month). The standard deviation shown is computed as the sample standard deviation (divided by n–1).

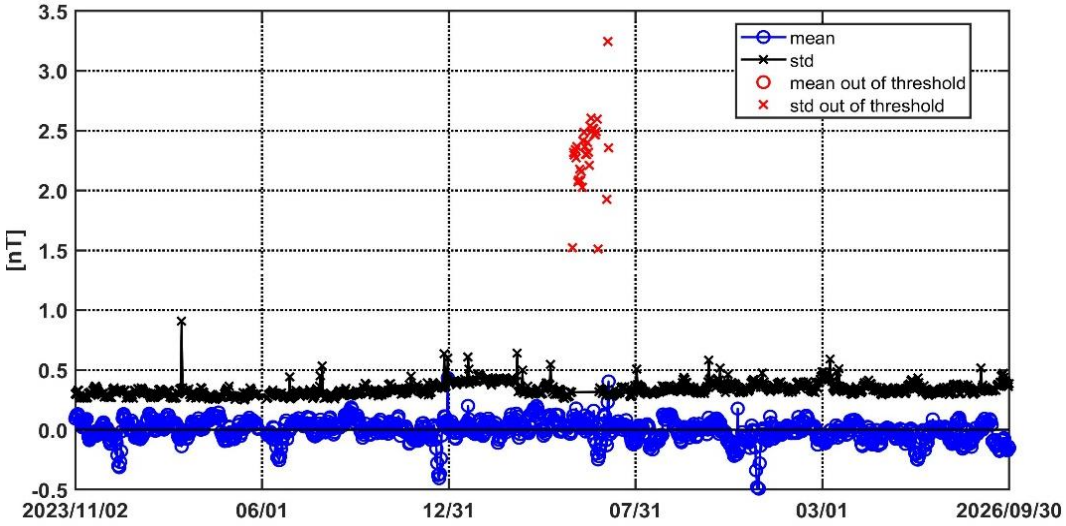


Figure 3-5: Daily mean and standard deviation values of ΔF from November 2023 up to September 2026.

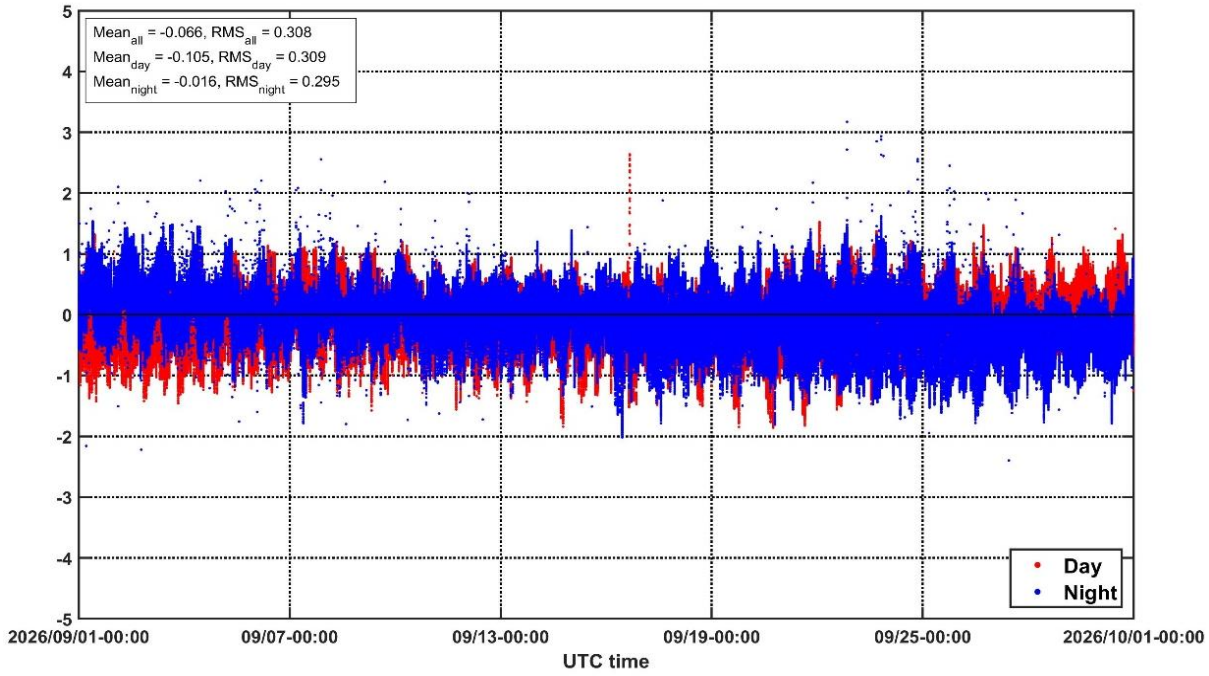


Figure 3-6: ΔF time series during September 2026 (unit: nT). Red and blue dots represent daytime and nighttime measurements, respectively.

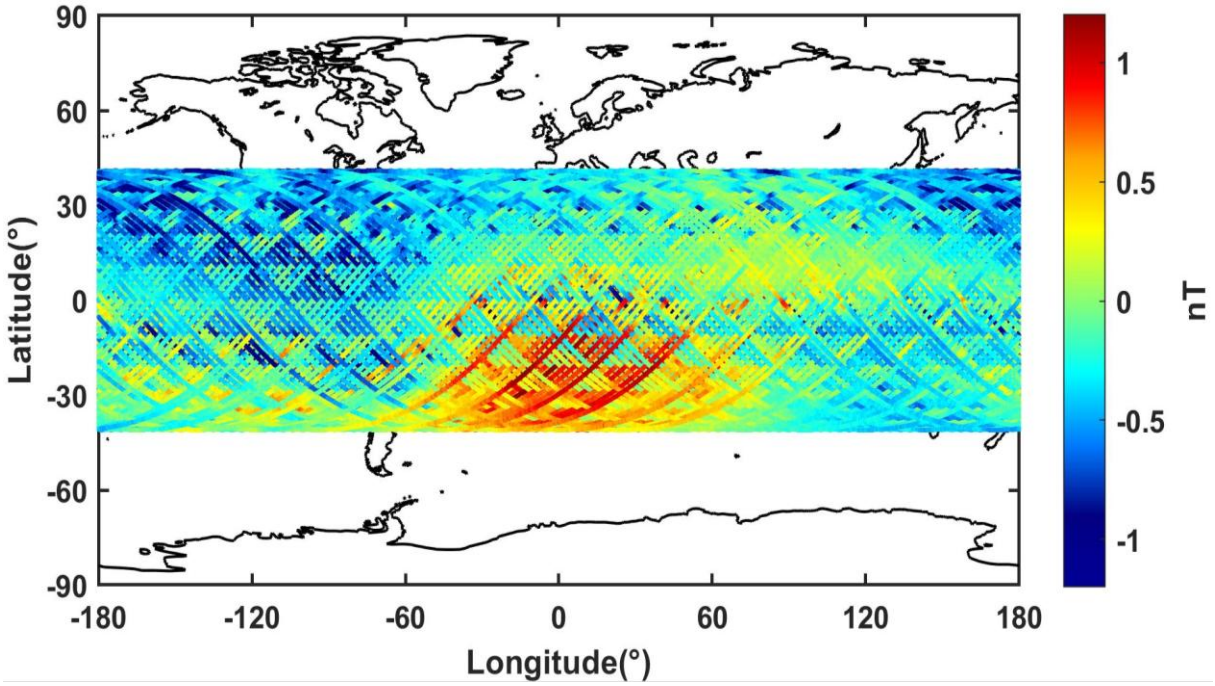


Figure 3-7: Residuals ΔF for September 2026 are plotted on the world map.

3.4 Magnetic Components Visual Inspection

Below are four sub-figures showing global maps of variables F_{ASM} and $\mathbf{B}_{NEC}$ for September 2026. The scalar field F_{ASM} is derived from ASM measurements, and the $\mathbf{B}_{NEC}$ components are obtained from VFM measurements in the NEC frame. Visual inspection confirms that the measured magnetic field is broadly consistent with current geomagnetic model outputs and reveals no large-scale artifacts in the data.

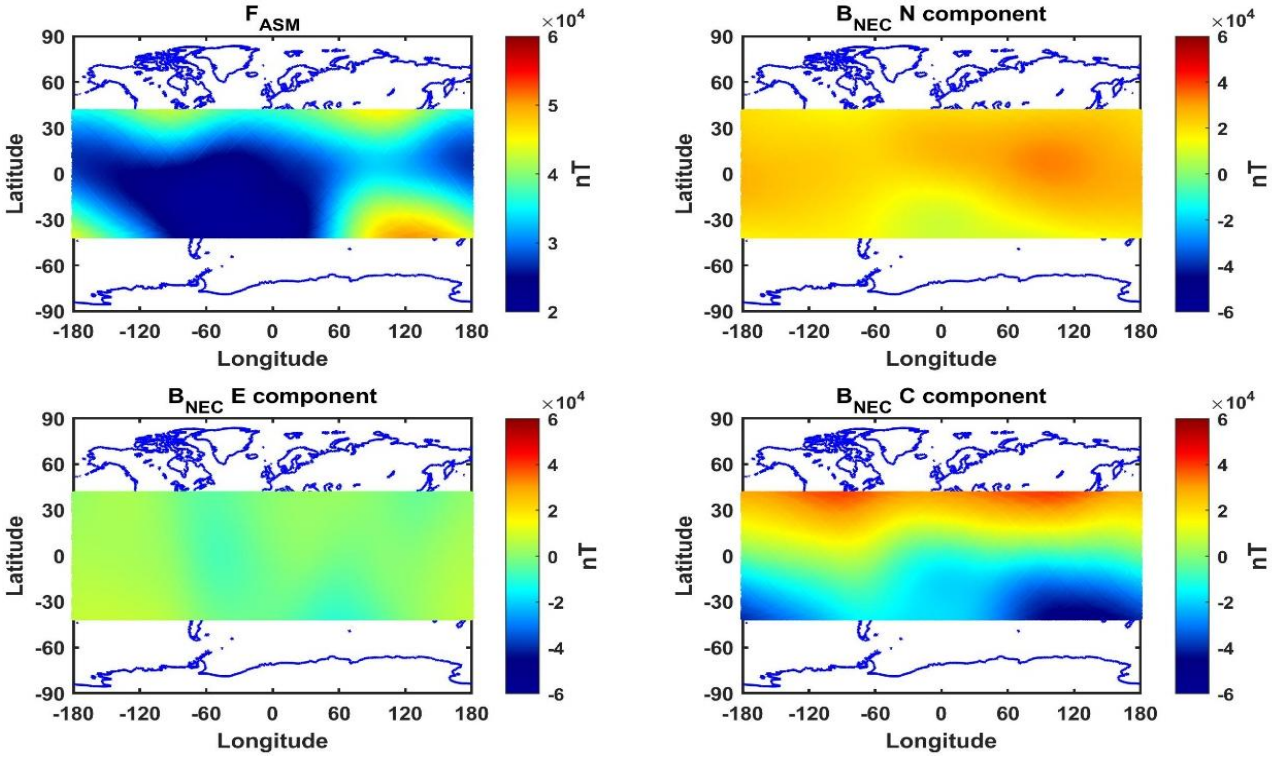


Figure 3-8: World map plots of the geomagnetic field and components for September 2026. From top to bottom: F_{ASM} from ASM measurement, and B_N, B_E, B_C components in the NEC frame from VFM measurement.

3.5 B_{NEC} – WM3RT-2.1/CHAOS-8.7 Model Residuals

Figures 3-9 and 3-10 compare MSS-1A magnetic field measurements with two geomagnetic field models, CHAOS-8.7 and WM3RT-2.1, during September 2026. The WM3RT-2.1 model includes the main field, the lithospheric field up to spherical-harmonic degree 80, magnetospheric contributions and their associated mantle-induced fields, the ionospheric field, and the M2 ocean-tide-induced magnetic field. For the CHAOS-8.7 comparison, contributions from the main field, lithospheric field, and ionospheric field are included, together with an additional magnetospheric magnetic field (MMA) contribution [RD.04].

Figure 3-9 presents the magnetic field residuals $\Delta B = \mathbf{B}_{NEC} - \mathbf{B}_{model}$ as a function of UTC time, while Figure 3-10 shows the same residuals as a function of colatitude. The residuals are calculated as the differences between the observed magnetic field and the corresponding model predictions. From top to bottom, the four panels display the northward (ΔB_N), eastward (ΔB_E), downward (ΔB_C), and scalar (ΔF_{CHAOS}, $\Delta F_{WM3RT-2.1}$) residuals. Red and blue dots represent the residuals relative to CHAOS-8.7 and WM3RT-2.1, respectively. The scalar residual ΔF is defined as the difference between the ASM scalar magnetic field measurement F_{ASM}, stored in the VFM Level-2 product, and the magnetic field intensity predicted by the corresponding model. The statistical annotations show the mean and Huber-weighted RMS of the residuals.

In September 2026, both models showed generally similar residual patterns. The Huber-weighted RMS values for ΔB_N, ΔB_E and ΔB_C were 6.27, 6.73, and 4.10 nT for CHAOS-8.7, compared with 5.86, 6.71, and 3.59 nT for WM3RT-2.1, respectively. For the scalar residuals, the Huber-weighted RMS values were 4.55 nT for CHAOS-8.7 and 4.93 nT for WM3RT-2.1. Overall, WM3RT-2.1 exhibited slightly lower Huber-weighted RMS values for the three vector components, while CHAOS-8.7 showed a slightly lower value for the scalar residuals.

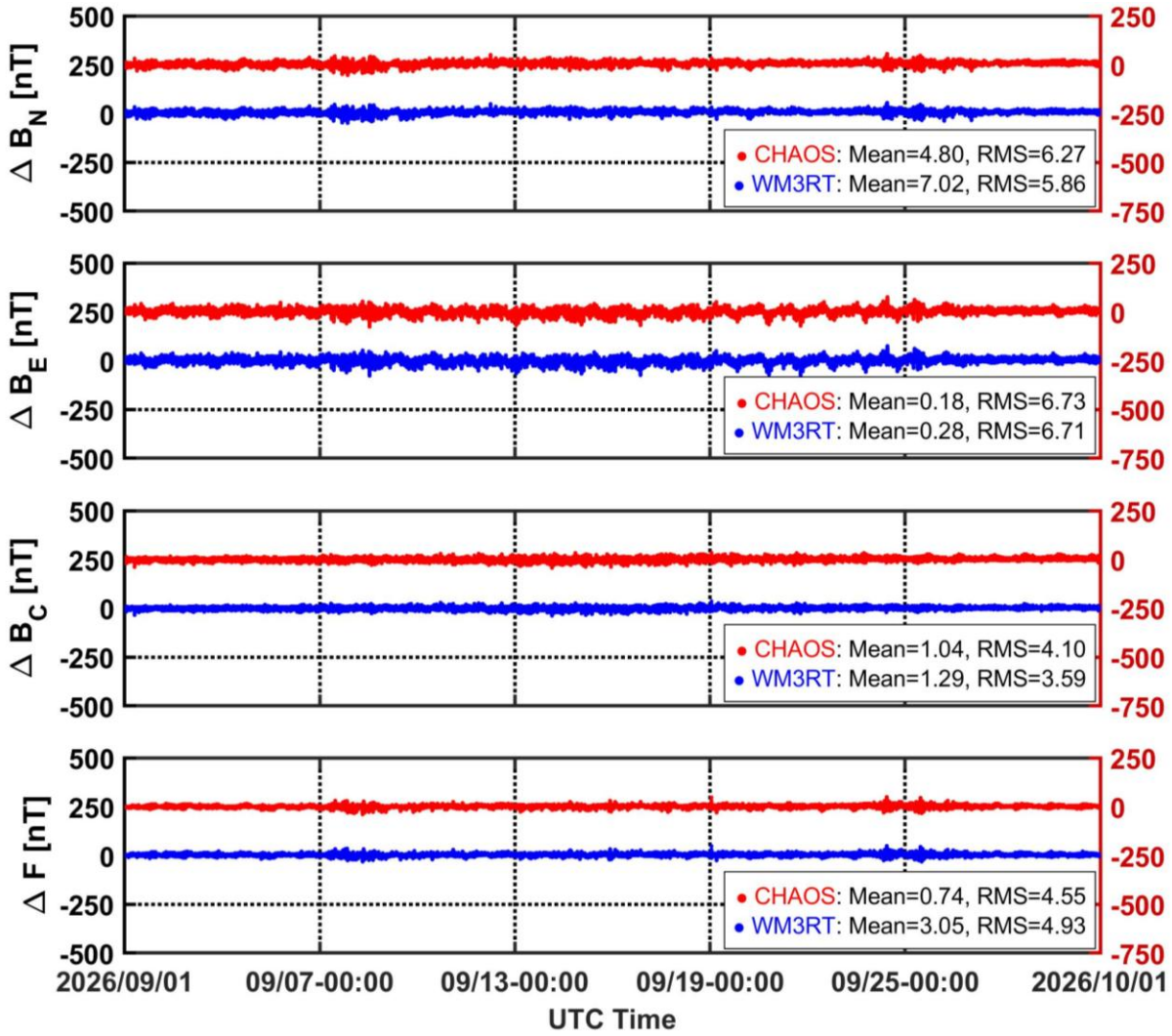


Figure 3-9: Temporal variations of MSS-1A magnetic field residuals relative to CHAOS-8.7 (red) and WM3RT-2.1 (blue) during September 2026. From top to bottom: differences of northward, eastward, downward and scalar components.

Figure 3-9 illustrates residual amplitudes that remain stable under predominantly quiet geomagnetic conditions. No significant storm-related enhancements are observed during this month, and similar behavior is evident in Swarm data.

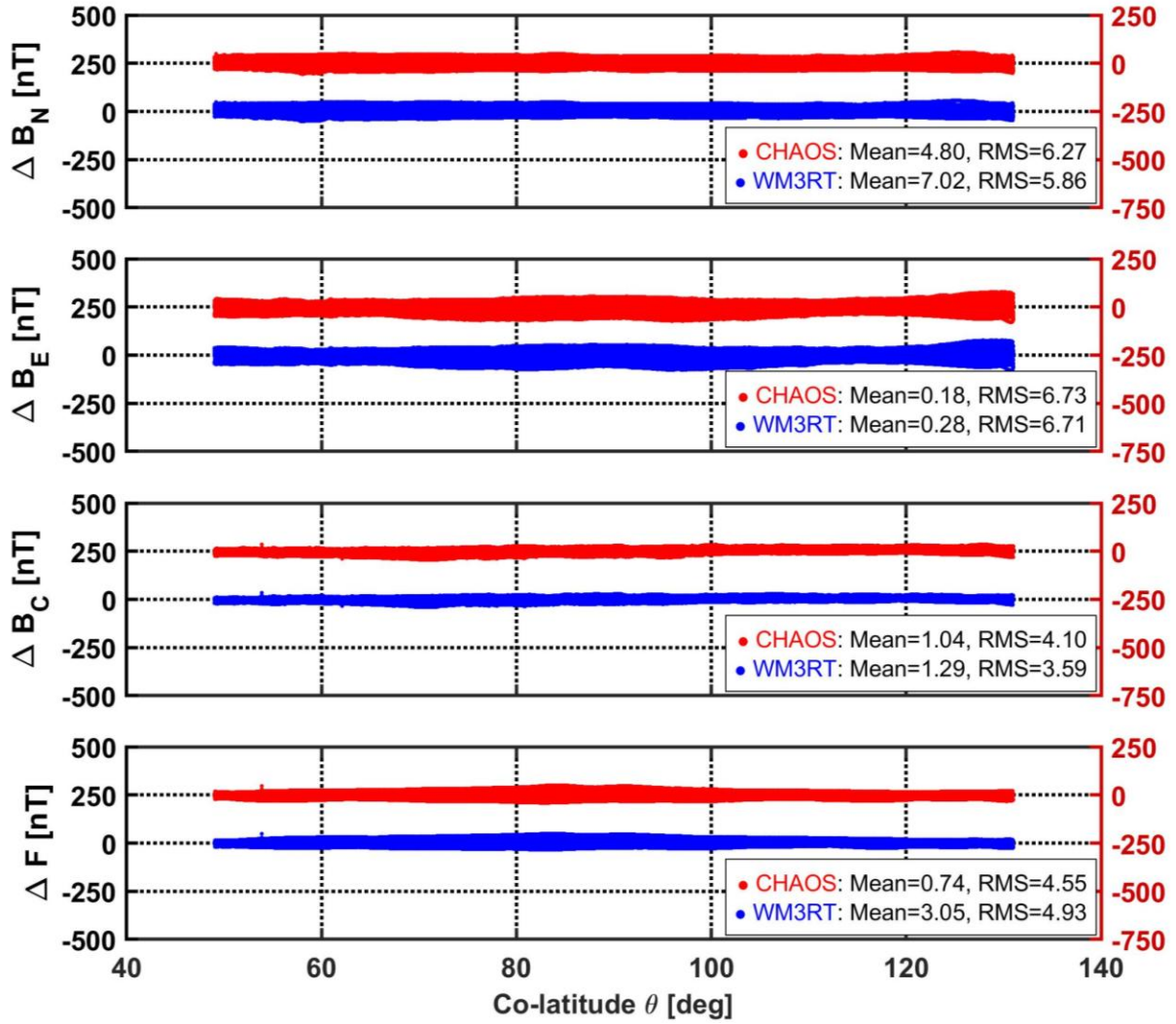


Figure 3-10: Magnetic field residuals as a function of colatitude relative to CHAOS-8.7 (red) and WM3RT-2.1 (blue) during September 2026. From top to bottom: differences of northward, eastward, downward and scalar components.

Figure 3-10 presents the magnetic field residuals between MSS-1A measurements and the two geomagnetic field models as a function of colatitude. Both models exhibit generally similar residual distributions across the observed latitude range.

4 Summary

This report provides a comprehensive assessment of the MSS-1A satellite magnetic field data quality during September 2026. The main findings are as follows:

- **Data Integrity:**
  No physically unrealistic values were found in the $\mathbf{B}_{\mathrm{NEC}}$, $\mathbf{B}_{\mathrm{VFM}}$, or scalar (F) components of the Level-2 data. No out-of-threshold in VFM products were observed this month. Scalar–vector differences remained consistently within acceptable bounds.

- **Satellite Position Check:**
  Satellite altitude and latitude were checked against thresholds of 415–495 km and |latitude| $\leqslant$ 41°. No positional anomalies were detected in September 2026, and the data can be used with confidence.

- **Instrument Performance:**
  The VFM and ASM instruments operated normally throughout the month. Temperature readings from CDC, CSC, and EU remained stable. The upgraded Level-2 data processor (Version 07) functioned as expected, and the dataset showed no signs of data loss or systematic drift.

- **Calibration and Model Residuals:**
  Overall, daily mean and Huber-weighted RMS values of ΔF were generally within ± 1 nT during September 2026, and no values exceeded 10 nT. Daily in-flight recalibration using LR data further reduced ΔF scatter. Comparisons with both the CHAOS-8.7 and WM3RT-2.1 models also showed that residuals in the NEC frame were generally within expected bounds, with comparable results from the two models.

In conclusion, the MSS-1A magnetic field data for September 2026 is complete and of high quality.