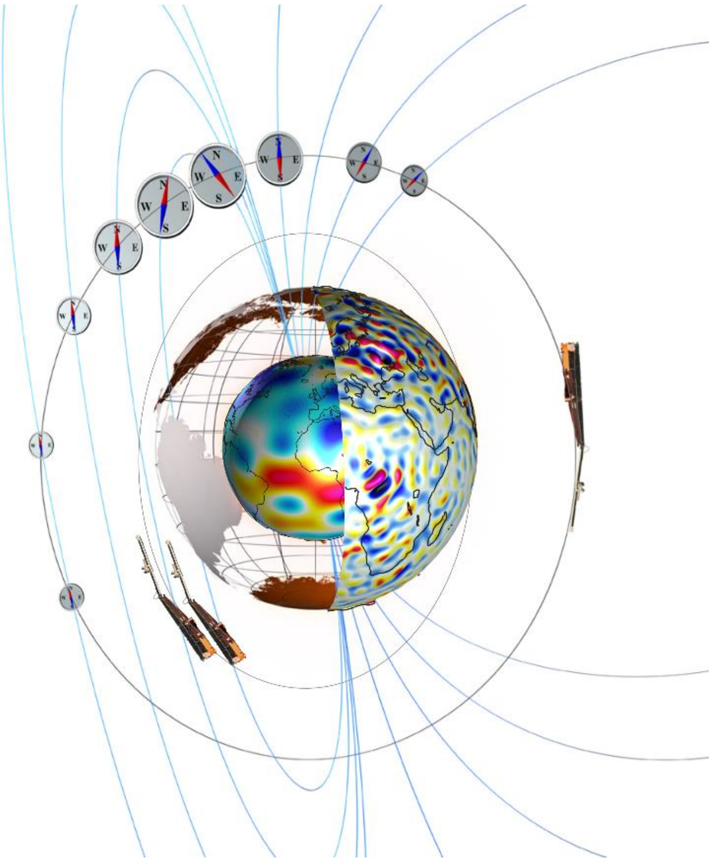
# Swarm DISC Weekly Report 2024/19: 2024/05/06 - 2024/05/12





**Abstract** : This is the **Swarm Data Innovation and Science Cluster** (Swarm DISC) Weekly report on Swarm products quality, covering the period from 06 May to 12 May 2024.


**Doc. No** : SW-RP-SER-GS-010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# AMENDMENT POLICY

This document shall be amended by releasing a new edition of the document in its entirety. The Amendment Record Sheet below records the history and issue status of this document.

**AMENDMENT RECORD SHEET**

| ISSUE | DATE | REASON |
|---|---|---|
| 1.0 | 09 Jul 2024 | First issue |

# 1. Introduction

This document refers to the activities carried out in the framework of the ESA Sensor Performance, Products and Algorithms (SPPA) Office [RD. 01].

Chapter 1 gives an overview on the outcomes from the annual Swarm Data Quality Workshop and reports the information on the current operational configuration and its future improvements. It also contains the list of used reference documents.

In Chapter 2, the Section 2.1 gives an overview of the general quality status of the Swarm mission instruments and products, while the main observations of the week are summarized in the Section 2.2.

The document also includes information on data quality for the three Swarm spacecraft, inferred from automated HTML quality reports, which are produced on daily basis for each product. If interested in accessing the reports via web or FTP, please contact the Swarm DISC team at the following email address: <swarm@eo-sppa.org>. Such data quality reports represent the main component of the Routine Quality Control performed by ESA SPPA (Chapter 3). A description of the implemented quality checks is given in [RD. 02], and references therein.

Based on specific findings of the routine quality control, or requests from other entities (i.e. Swarm Payload Data Ground Segment (PDGS), Flight Operation Segment (FOS), Mission Management, Post-Launch Support Office (PLSO), Expert Support Laboratories (ESL), Quality Working Groups (QWG), and user community), investigations on anomalies can be triggered. Preliminary characterisations on such anomalies are given in Chapter 4.

Information on Swarm Level 1B products can be found in [RD. 03].

**This weekly report is based on QC methods and diagnostics that tend to be continuously evolved and improved throughout the mission lifetime, reporting on the data quality, product evolutions, and status of the instruments on weekly basis.**

## 1.1 Annual Swarm Data Quality Workshop

The 13th Swarm Data Quality Workshop was held on 10-11-12 October 2023, hosted by the European Space Agency facility in Italy (ESA -ESRIN), located in Frascati. Thanks to the participation of more than 120 scientists and instruments' experts (in presence and remotely) from different institutions in Europe, America and Asia, the event has been a great success.

The DQW#13 has been a 3 days' workshop dedicated to Swarm Data Calibration and Validation topics.
All the topics related to Swarm-based science and applications, which used to be included in the full week DQW event, have been broadly and fruitfully discussed during the Swarm 10th Anniversary and Science Meeting, (https://www.swarm-anniversary-and-science.org), organized by ESA (with the support of Swarm Data Quality team) and hosted by DTU Space (Copenhagen, Denmark) from 8 to 12 April 2024.

The DQW#13, structured in 7 thematic sessions including talks and dedicated time slots for discussions, was instrumental in addressing the processing and use of Swarm data and defining a road map for future activities.
The main topics addressed during the workshop were related to:

- collecting feedback about Swarm L1B and L2-Cat2 data quality, targeting new processing algorithms and correction improvements,
- collecting innovative ideas for future Swarm-based activities, emerging applications, products, and services,

- promoting synergies with other satellite missions,
- discussing on future orbital constellation evolution.

More information on the Swarm DQW#13 outcomes, summary and recommendations will be published soon at https://swarmdisc.org/.

## 1.2 Current Operational configuration of monitored data:

| Processor | |
|---|---|
| **Name** | **Version** |
| L1BOP | v3.24p4 |
| L2-Cat2 | v01.20 |
| **Products** | |
| **Name** | **Baseline** |
| L0 inputs | 02 |
| L1B MAGNET and PLASMA | 06 |
| L1B ORBATT and ACCELE | 05 |
| L2-Cat2 EEF | 02 |
| L2-Cat2 IBI, FAC and TEC | 04 |
| **Others** | |
| Input auxiliary files | S/C A, CCDB 0029 (28/08/2023)<br>S/C B, CCDB 0030 (28/08/2023)<br>S/C C, CCDB 0030 (28/08/2023) |
| MPPF-CVQ | v03.13 (18/03/2022) |

## 1.3 Recent evolutions:

On 24/06/2023 an improved version (v3.24p5) of L1B Operational Processors was transferred into operation to fix two minor issues detected on the clock offset information stored inside the Position dataset of MODx_SC_1B operational product.

This patch contained an updated library that affected the computation of the quaternions describing the transformation between the STR and the NEC reference frames, causing a degradation of attitude and magnetic measurements with errors close to 10 arcminutes in attitude and up to 150 nT in B_NEC.
In order to restore the nominal data quality, a rollback from L1BOP 3.24p5 to 3.24p4 has been performed on 25 August 2023.

In addition, a further degradation of attitude (errors up to 8 arcseconds) and magnet (errors up to 3 nT in B_NEC) data has been identified in the data covering from October/December 2018 onward, when the STR were commanded to operate at 2 Hz sampling rate. Such degradation was introduced during the last full reprocessing when ORBATT and MAGNET data were processed with the STR_q_CHU parameters of the AUXxSW1_C_ CCDB file corresponding to a 1 Hz sampling rate.

This issue was fixed with an updated set of AUXxSW1_C_ CCDB files deployed in operation on 25 August 2023.

Together with the rollback to 3.24p4, this action restored the nominal attitude and magnetic data quality from 25 August 2023 onwards.

## 1.4 Reference documents

The following is a list of documents with a direct bearing on the content of this report. Where referenced in the text, these are identified as RD.n, where 'n' is the number in the list below:

[RD. 01] Sensor Performance, Products and Algorithms (SPPA), PGSI-GSOP-EOPG-TN-05-0025. Version 2.3.

[RD. 02] Swarm MPPF-CVQ Monitoring Baseline Document, ST-ESA-SWARM-MBD-0001, Issue 1.7.

[RD. 03] Swarm Level 1B Product Definition, SW-RS-DSC-SY-0007, Issue 5.23.

[RD. 04] Olsen, N., H. Luhr, C.C. Finlay, T.J. Sabaka, I. Michaelis, J. Rauberg and L. Tøffner-Clausen, The CHAOS-4 geomagnetic field model, Geophys. J. Int. 197, 815–827, 2014

[RD. 05] https://earth.esa.int/documents/10174/1514862/Swarm-L1B-and-L2-operational-processors.pdf

# 2. Summary of the observations

## 2.1 Changes in the general status of Swarm instruments and Level 1B products quality

• The Absolute Scalar Magnetometer (ASM) on board Swarm Alpha is commanded in burst mode from 05/05/2024 at 00:00 UTC to 12/05/2024 at 00:00 UTC.

• The Absolute Scalar Magnetometer (ASM) on board Swarm Bravo is commanded in burst mode from 10/05/2024 at 00:00 UTC to 17/05/2024 at 00:00 UTC.

## 2.2 Relevant observations of the week 19 (06/05 - 12/05)

During the monitored week, a severe geomagnetic activity has been observed.

In particular, on 10$^{th}$ May 2024 a G5-class Geomagnetic Storm occurred, followed by other major events on 11$^{th}$ and 12$^{th}$ May 2024. Also known as "Mother's Day Storm", this was the strongest Geomagnetic Storm of the Solar Cycle #25 so far, with impact on geomagnetic field, ionospheric systems, and several other modifications and disturbances of near-Earth environment (auroras observed at low latitudes, TEC variations, etc.).

The event produced magnetic field fluctuations in the polar and equatorial regions, as visible in Figures 3-10, 3-11 and 3-12 (Section 3.3.5).

The effects of the storm are also visible in variations of electron temperature and density measurements, as shown in Figures 3-13, 3-14, 3-15 (Section 3.4.1).

Further details reported in Section 4.

# 3. Routine Quality control

## 3.1 Gaps analysis

- 9th May:

  F_ASM data stored in MAGx_LR_1B for Swarm Bravo is set to zero from 09/05/2024 at 23:59:29 to 10/05/2024 at 00:00:07 UTC. A data gap in MAGx_CA_1B production is present in the same time frame. This gap is related to the switch of the ASM to Burst/Vector Mode (see section 2.1)

- 11th May:

  Some small gaps (<1min.) have been observed in MAG products on the three spacecrafts ascribed to the magnetic field fluctuations due to the Geomagnetic Storm (see section 2.2).

  Small data gap on Swarm-B STR data from 00:28:26 to 00:28:43.

- 12th May:

  F_ASM data stored in MAGx_LR_1B for Swarm Alpha is set to zero from 11/05/2024 at 23:59:29 to 12/05/2024 at 00:00:24 UTC. A data gap in MAGx_CA_1B production is present in the same time frame. This gap is related to the switch of the ASM to Burst/Vector Mode (see section 2.1)

  Small data gaps on Swarm-A magnet data from 08:20:28 to 08:20:38 and from 08:42:22 to 08:42:36.

## 3.2 Orbit and Attitude Products

The relevant parameters that have been monitored are:

- Position difference between calculated Medium Accuracy orbits (MODx_SC_1B) and on-board solution (GPSxNAV_0). Threshold values for such differences have not been assessed yet: we have just monitored the average values and maximum variations within the week. For the time being we evaluated an anomaly should be raised if one (or more) of the following conditions occurs:
  - The average difference on a given day exceeds the position accuracy requirement for the mission (1.5 m),
  - The variability around the average is quite high: standard deviation threshold has been arbitrarily chosen to be twice the position accuracy requirement for the mission (2-sigma = 3 m).
  - At least 4-5 spikes are observed on a given day, exceeding +/- 50 m.
- Visual inspection of Star Tracker characterisation flags (STRxATT_1B)
- Deviation of the quaternion norm from unity (deviation threshold = +/- $10^{-9}$)
- Visual inspection of Euler Angles derived from quaternions.

### 3.2.1 Position Statistics

In Figure 3-1 and Figure 3-2 one can see the statistics of the differences between MOD and on-board solution positions for S/C A, B and C respectively. Figure 3-1 shows a cumulative trend of the maximum daily standard deviation for the past 30 days of operations of the MOD-NAV difference, while Figure 3-2 shows the daily maximum difference, in absolute value, of the MOD-NAV difference, always for the past 30 days of operations.

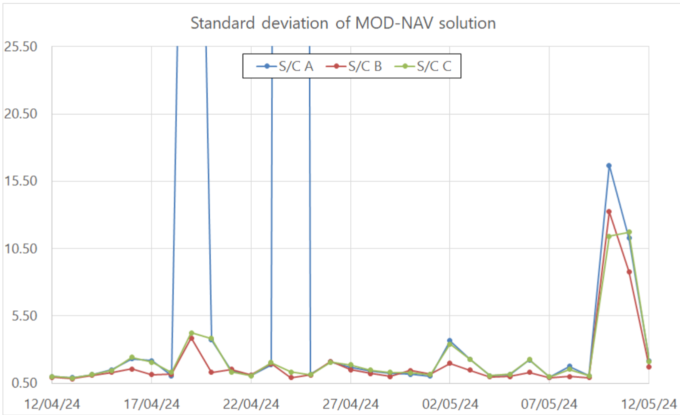


**Figure 3-1:** Plot of the standard deviation of the difference between MOD and NAV solutions for all satellites. Plot covers last month of operation.

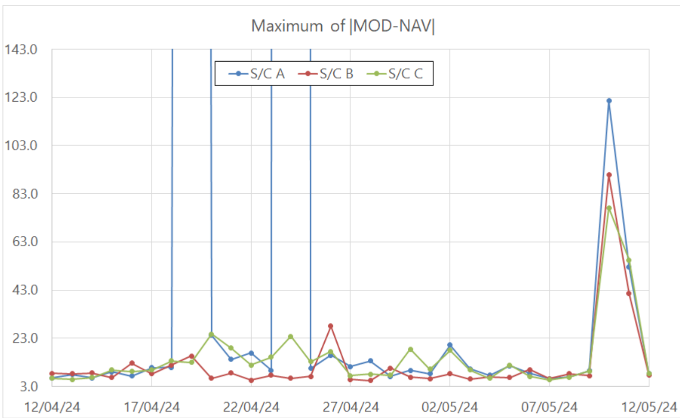


**Figure 3-2:** Plot of the maximum difference of the absolute value of the difference between MOD and NAV solutions for all satellites. Plot covers last month of operation.

### 3.2.2 Attitude observations

#### 3.2.2.1 Swarm A

Nominal. Nothing to report.

#### 3.2.2.2 Swarm B

Nominal. Nothing to report.

#### 3.2.2.3 Swarm C

Nominal. Nothing to report.

## 3.3 Magnetic Products

For the magnetic products, the weekly monitoring consists of:

- ASM instrument monitoring: quartz frequency (nominal range: [2.949E7 – 2.950E7] Hz) and ASM temperature (temperature range shall be: [-30;+50] °C, Rel. Variation shall not exceed: 0.1 °C/sec).
- VFM instrument monitoring: temperatures (Rel. Variation shall not exceed: 0.1 °C/sec).
- Visual inspection of daily time series of magnetic field intensity F, $B_{NEC}$ and $B_{VFM}$. Looking for gaps (or zero values in case of MAGx_LR_1B products), out-of-threshold values (i.e. exceeding +/- 60000 nT), and other strange features. Map plots of F and $B_{NEC}$ for the whole week are then displayed.
- Monitoring of the ASM-VFM known anomaly: visual inspection of $|B_{VFM}|$ - F taken from MAGx_CA_1B products and recording of daily maximum variations and standard deviations. If +/- 1 nT are exceed on a given day, an alert is raised. Map plots of the residuals are shown along with weekly time series of the residuals with and without the "dB_Sun" correction: in fact, at least a part of the discrepancies found in the measurements between ASM and VFM are modelled through a stray field (dB_Sun) that is a function of the orientation of the VFM wrt Sun.
- Comparison of magnetic data ($B_{NEC}$) with a model (Chaos7).

### 3.3.1 VFM-ASM anomaly

- S/C A – violation of:
    - VFM-ASM residuals threshold on 10/05, 12/05.
- S/C B – violation of:
    - VFM-ASM residuals threshold on 06/05, 07/05, 08/05, 09/05, 10/05, 11/05, 12/05;
    - mean value of residuals threshold on 06/05, 07/05, 08/05, 09/05, 10/05, 11/05, 12/05.

#### 3.3.1.1 ASM-VFM difference statistics

The ASM-VFM difference is defined as follow:

$dF = |B_{VFM}| - F_{ASM}$

Figure 3-3 and Figure 3-4 show the daily mean (circles) and standard deviation (crosses) of dF of the last month for Swarm A and Swarm B respectively.

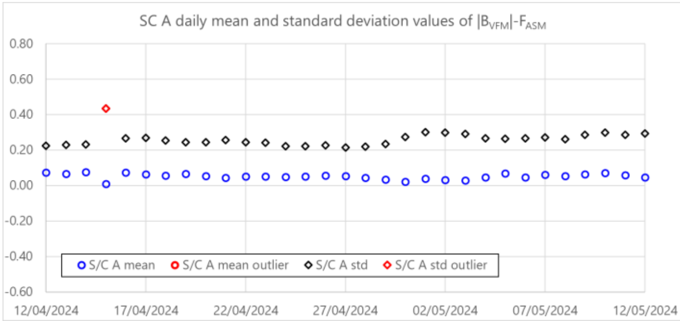


**Figure 3-3:** Daily mean and standard deviation values of ASM-VFM residuals (defined as dF=|$B_{VFM}$|-$F_{ASM}$) for S/C A.

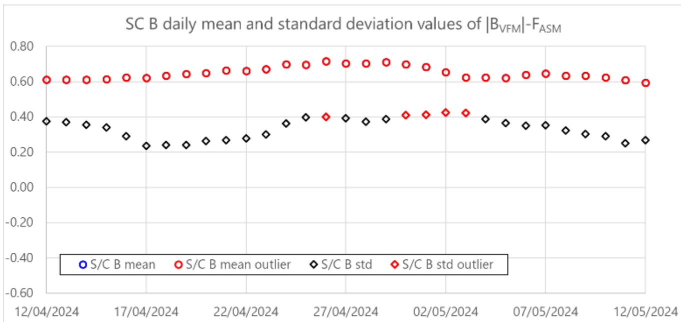


**Figure 3-4:** Daily mean and standard deviation values of ASM-VFM residuals (defined as dF=|$B_{VFM}$|-$F_{ASM}$) for S/C B.

### 3.3.1.2 Swarm A

The daily peak-to-peak difference around the week stays within [-4.78 - 0.71] nT. Below follow two plots of such differences for current week (Figure 3-5).

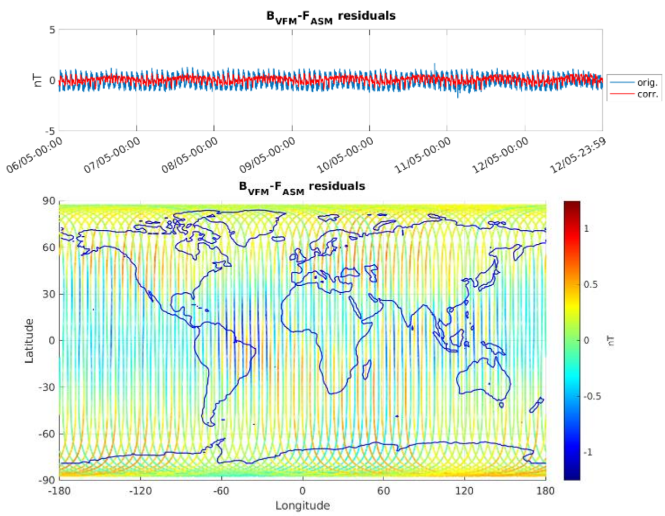


**Figure 3-5:** ASM-VFM residuals for S/C A, during monitoring period 06/05-12/05. In top figure are plotted: difference between |B_VFM| and F_ASM (without dB_Sun correction) (blue colour), and the residuals with dB_Sun corrections (red colour). In bottom figure residuals are presented on the world map.

#### 3.3.1.3 Swarm B

The daily peak-to-peak difference around the week stays within [-1.36 - 2.15] nT. Below follow two plots of such differences for current week (Figure 3-6).

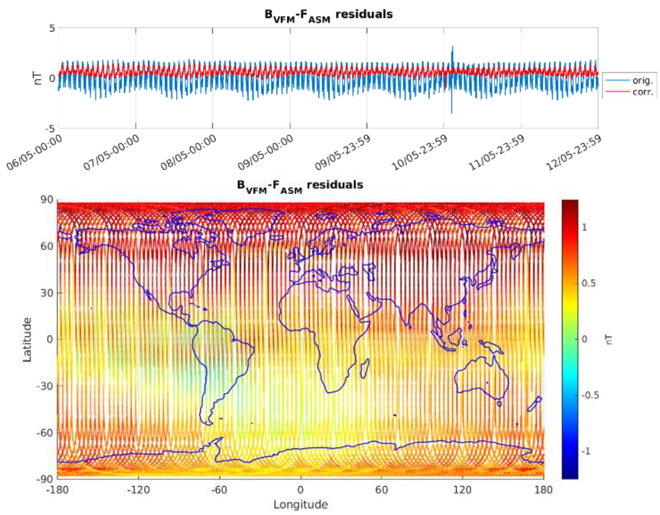


**Figure 3-6:** ASM-VFM residuals for S/C B, during monitoring period 06/05-12/05. In top figure are plotted: difference between |B_VFM| and F_ASM (without dB_Sun correction) (blue colour), and the residuals with dB_Sun corrections (red colour). In bottom figure residuals are presented on the world map.

#### 3.3.1.4 Swarm C

No data because ASM is switched off.

### 3.3.2 ASM Instrument parameters: quartz frequency and ASM temperature (ASMAVEC_0)

For S/C A and B, the temperature and quartz frequency behaved as expected.

### 3.3.3 VFM Instrument parameters: VFM temperatures (MAG_CA)

The VFM instrument parameters important for monitoring the instrument health are the VFM sensor temperatures: T_CDC, T_CSC and T_EU.

For S/C A, B and C, for reported period, the temperatures behaved as expected.

### 3.3.4 Magnetic time series visual inspection

#### 3.3.4.1 Swarm A

Map plots of magnetic field measurement for week 19 for S/C A can be seen in Figure 3-7 below.

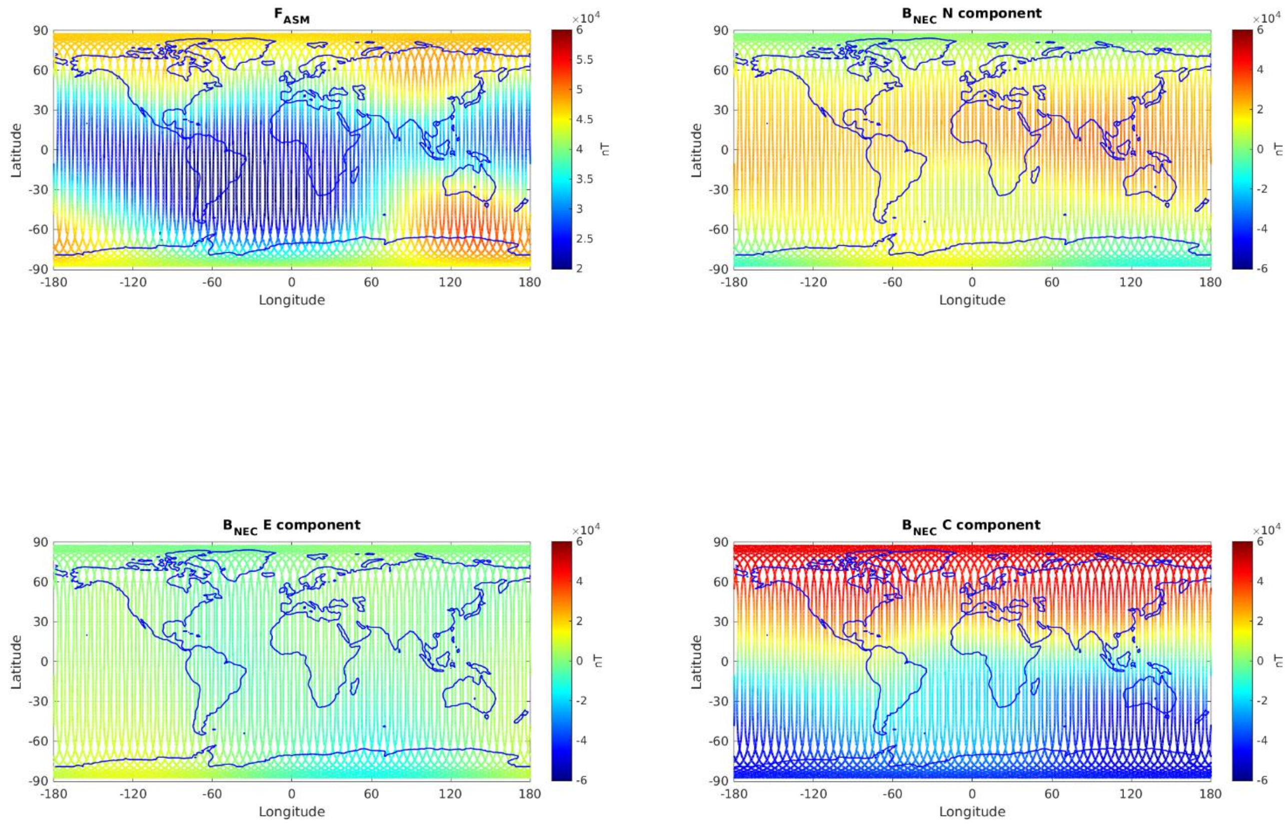


**Figure 3-7:** S/C A, world map plots of the geomagnetic field and components measured during monitoring period 06/05-12/05. From top to bottom: F-magnetic field from ASM measurement, $B_{NEC}$ components (North, East, and Centre) of magnetic field from VFM measurement.

### 3.3.4.2 Swarm B

Map plots of magnetic field measurement for week 19 for S/C B can be seen in Figure 3-8 below.

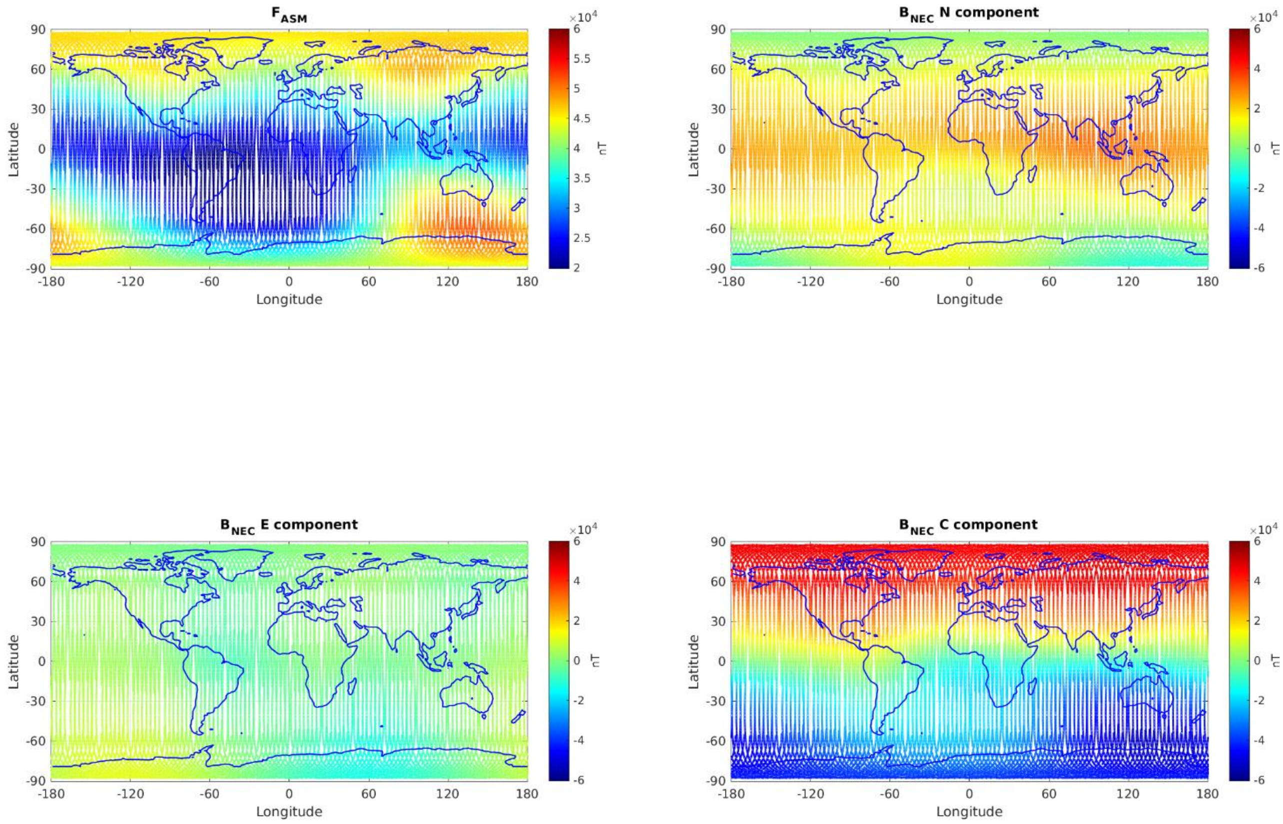


**Figure 3-8:** S/C B, world map plots of the geomagnetic field and components measured during monitoring period 06/05-12/05. From top to bottom: F-magnetic field from ASM measurement, $B_{NEC}$ components (North, East, and Centre) of magnetic field from VFM measurement.

#### 3.3.4.3 Swarm C

Map plots of magnetic field measurement for week 19 for S/C C can be seen in Figure 3-9.

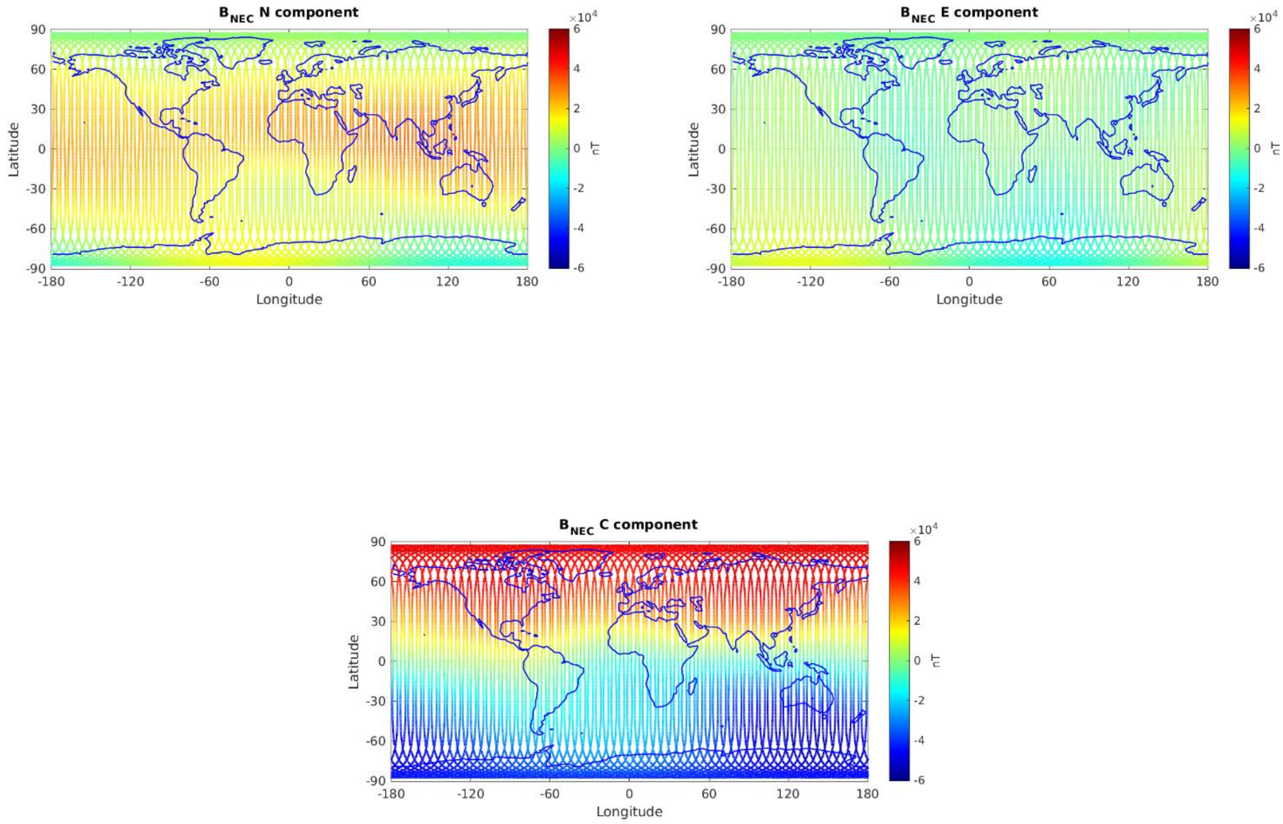


**Figure 3-9:** S/C C, world map plots of the geomagnetic field and components measured during monitoring period 06/05-12/05. From top to bottom: $B_{NEC}$ components (North, East, and Centre) of magnetic field from VFM measurement.

### 3.3.5 $B_{NEC}$ vs Chaos7 model residuals

The magnetic field measurement is compared to magnetic field estimated from the Chaos7 global geomagnetic field model (only Core and Crustal contributions). Currently in the monitoring routines the external contribution based on Dst index is not taken into account.

Left side of Figure 3-10, Figure 3-11 and Figure 3-12 show field residuals $dB=B_{NEC} - B_{Chaos}$ (all versus co-latitude in degrees), from top to bottom: 1) Br, 2) Bθ and 3) Bφ.

As a general feature one can see the field residuals to be steady and usually below 50 nT at low and middle latitudes, up to |55| - |60| degrees; then the residual increases at high latitudes because the Chaos model does not take into account the contribution from the external field ([RD. 04]).

Right side of Figure 3-10, Figure 3-11 and Figure 3-12 show, from top to bottom, the time series on first day of the week of: (1-2-3) residuals of $B_{NEC}$-$B_{Chaos}$ by components, related to S/C A, B and C respectively.

The component most affected by residual spikes and variations is $B\theta_{NEC}$, i.e. the component that shows the variations of the field wrt to co-latitude. At high latitudes, the order of magnitude of the variability is about +/- 200 nT.

### 3.3.5.1 Swarm A

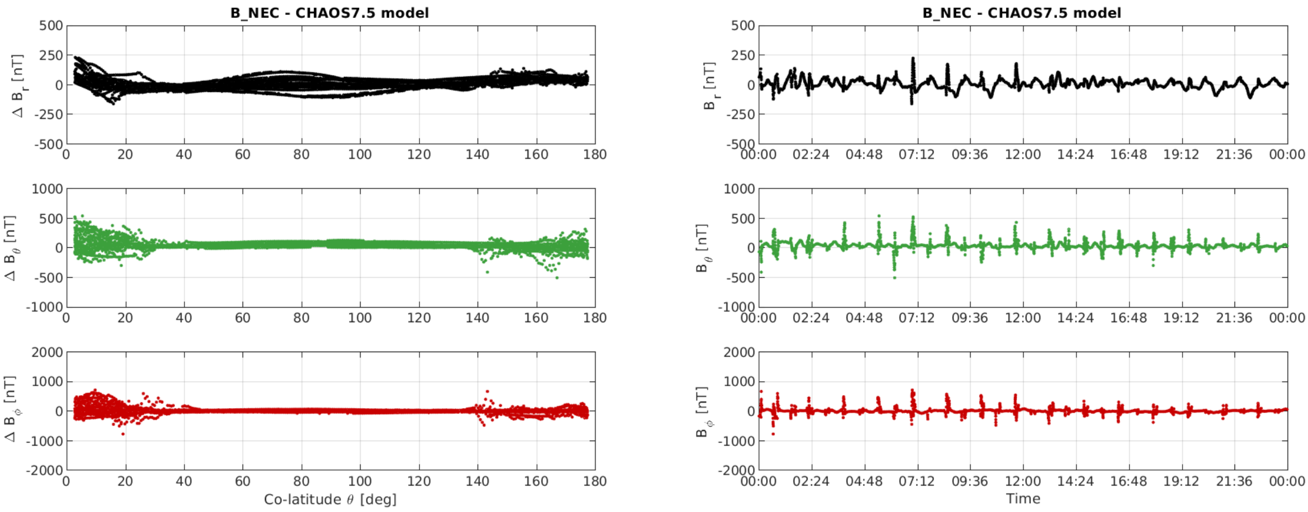


**Figure 3-10:** S/C A day 06/05: time series of $B_{NEC}$ – $B_{Chaos}$ residuals (right) and $B_{NEC}$ - $B_{Chaos}$ vs colatitude (left).

### 3.3.5.2 Swarm B

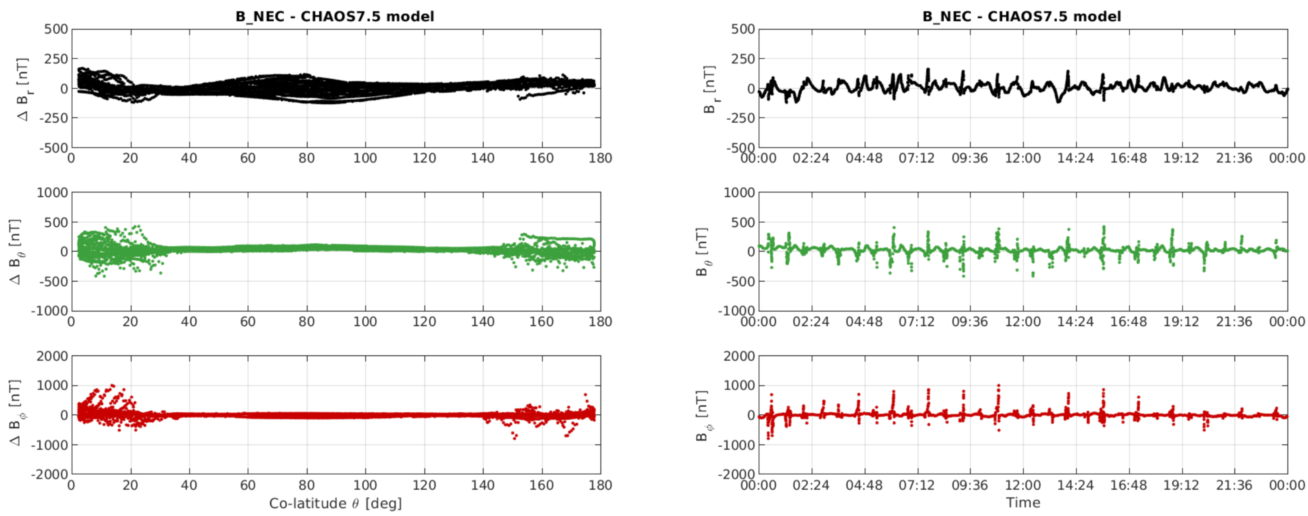


**Figure 3-11:** S/C B day 06/05: time series of $B_{NEC}$ – $B_{Chaos}$ residuals (right) and $B_{NEC}$ - $B_{Chaos}$ vs colatitude (left).

#### 3.3.5.3 Swarm C

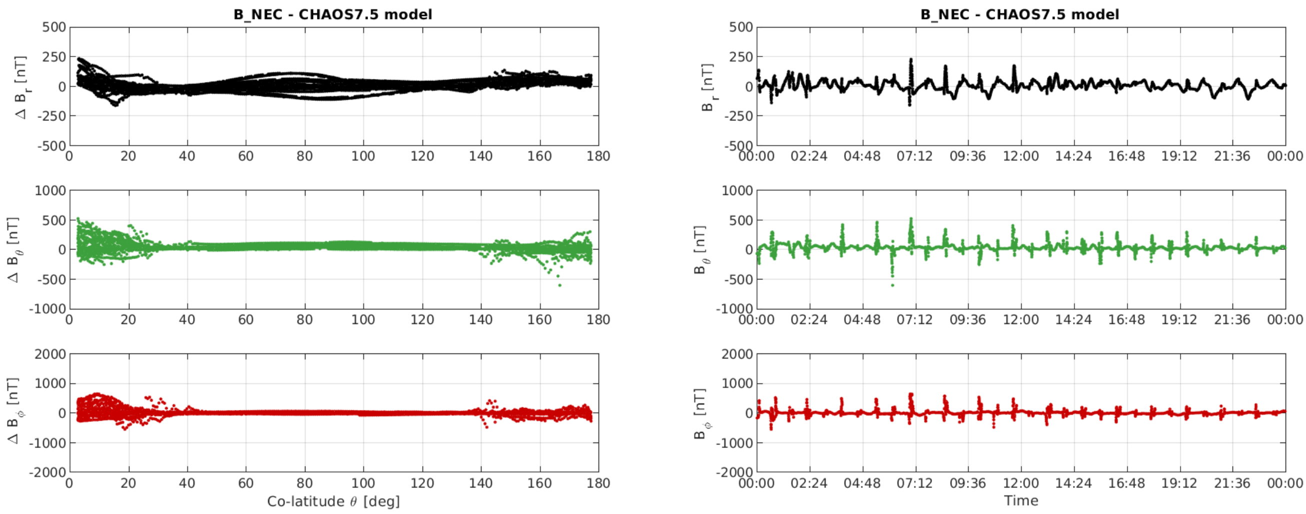


**Figure 3-12:** S/C C day 06/05: time series of $B_{NEC} - B_{Chaos}$ residuals (right) and $B_{NEC} - B_{Chaos}$ vs colatitude (left)

## 3.4 Plasma Products

The monitored plasma products are the electron density (Ne) and electron temperature (Te) measured by the EFI-LP instruments. The monitoring of the data is done on different temporal basis (daily, weekly, monthly, yearly) in order to have a comprehensive view on the data quality. Here we report only two examples of the performed data monitoring, which are the most representative of the data quality.

Figures from Figure 3-13 to Figure 3-15 show the weekly profiles of the electron density and temperature as a function of time for the last week of operations. Data have been down sampled from 0.5s to 2min in order to have a clearer representation (grey lines). Also, the 20 minutes moving window average is shown in the figures (black points). From these figures, it is possible to see if there are measurements with large discrepancies from the average behaviour, and their time location. Information on the local magnetic time is reported in the captions.

Figures from Figure 3-16 to Figure 3-18 show the variations of the electron density and temperature as a function of the latitudes in quasi-dipole (QD) coordinate system, during the last week of operation. These analyses are useful to study the dependence of the variables on the QD magnetic coordinate system.

These analyses are shown for the ascending (upper panels) and descending (bottom panels) phase orbits, separately.

It is visible that sometimes the electron temperature reaches very high values, exceeding ten thousand Kelvin, particularly at high latitudes. The nature of this feature is currently under investigation.

### 3.4.1 Plasma time series visual inspection

#### 3.4.1.1 Swarm A

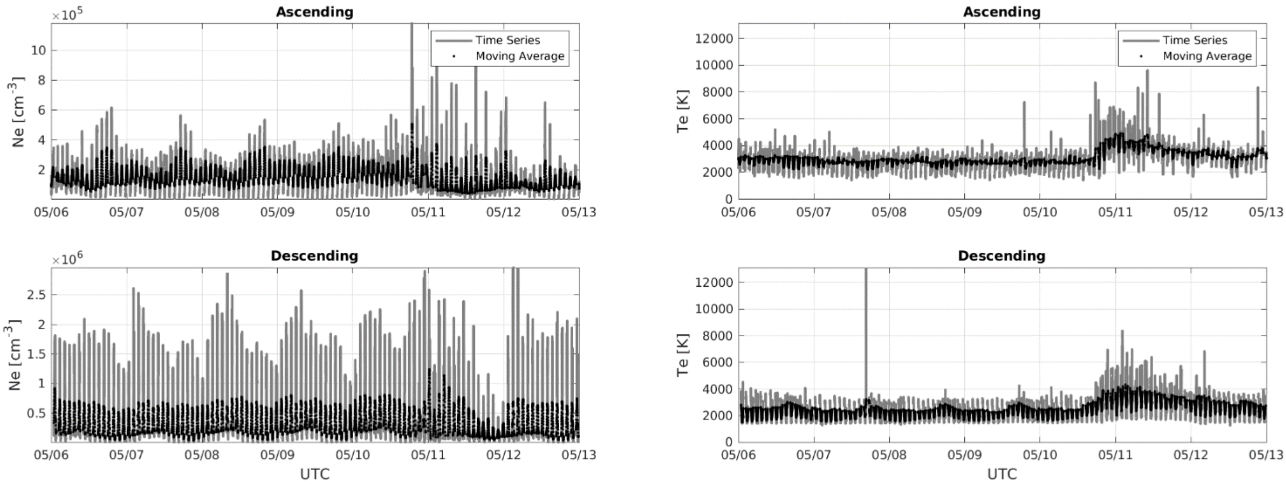


**Figure 3-13:** The panels show the electron density (left) and temperature (right) weekly time series (grey lines) together with the 20 min moving windows average (black lines). The analysis is made separately for ascending (upper panels) and descending (bottom panels) orbits. The average magnetic local time during the week is 7:30 a.m. for ascending phase and 7:30 p.m. for descending phase.

#### 3.4.1.2 Swarm B

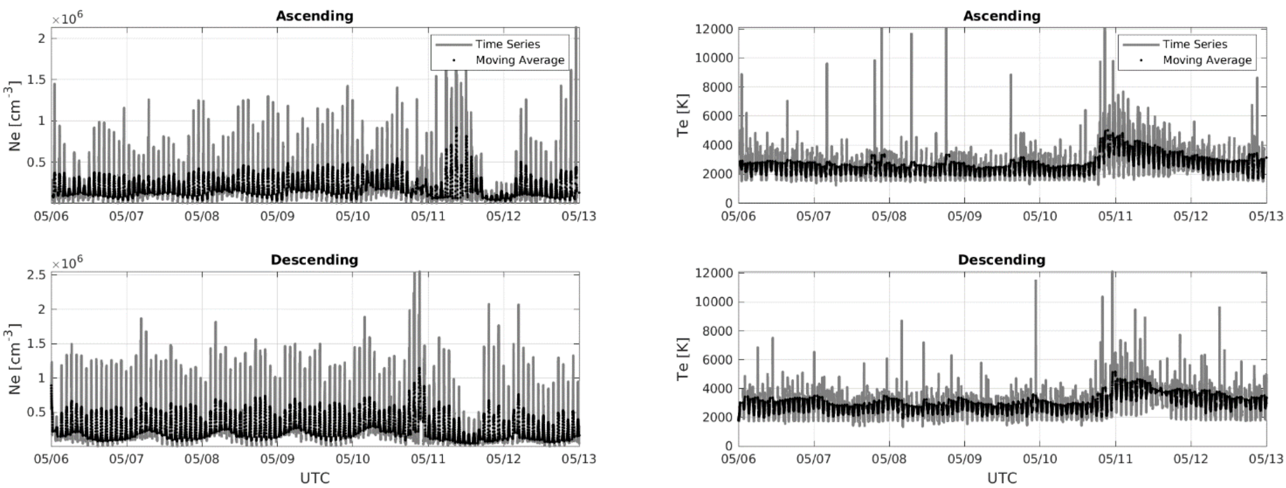


**Figure 3-14:** The panels show the electron density (left) and temperature (right) weekly time series (grey lines) together with the 20 min moving windows average (black lines). The analysis is made separately for ascending (upper panels) and descending (bottom panels) orbits. The average magnetic local time during the week is 11 a.m. for descending phase and 11 p.m. for ascending phase.

#### 3.4.1.3 Swarm C

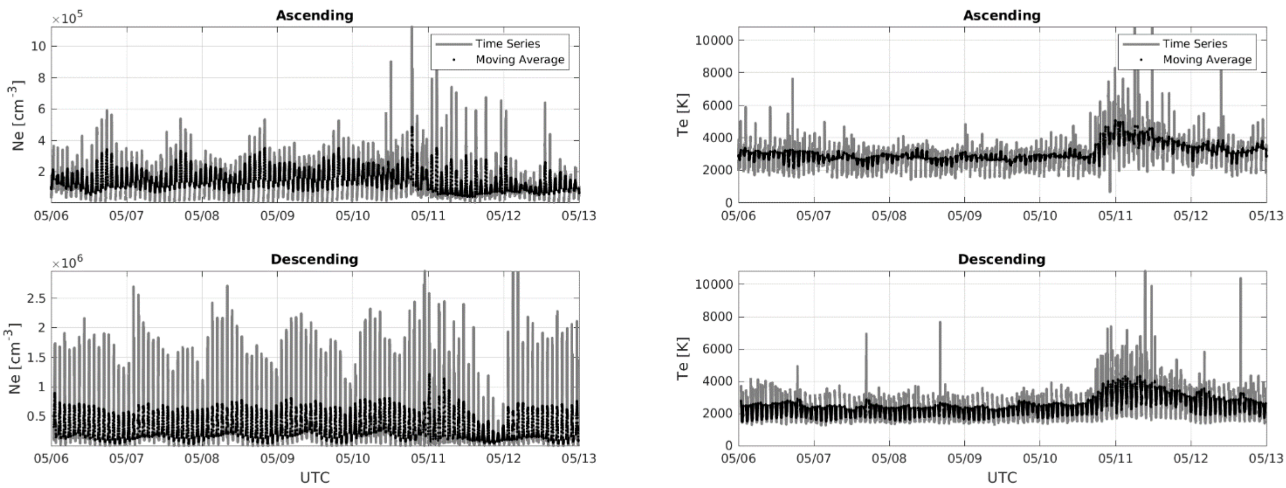


**Figure 3-15:** The panels show the electron density (left) and temperature (right) weekly time series (grey lines) together with the 20 min moving windows average (black lines). The analysis is made separately for ascending (upper panels) and descending (bottom panels) orbits. The average magnetic local time during the week is 7:30 a.m. for ascending phase and 7:30 p.m. for descending phase.

### 3.4.2 Plasma products latitudinal variations

#### 3.4.2.1 Swarm A

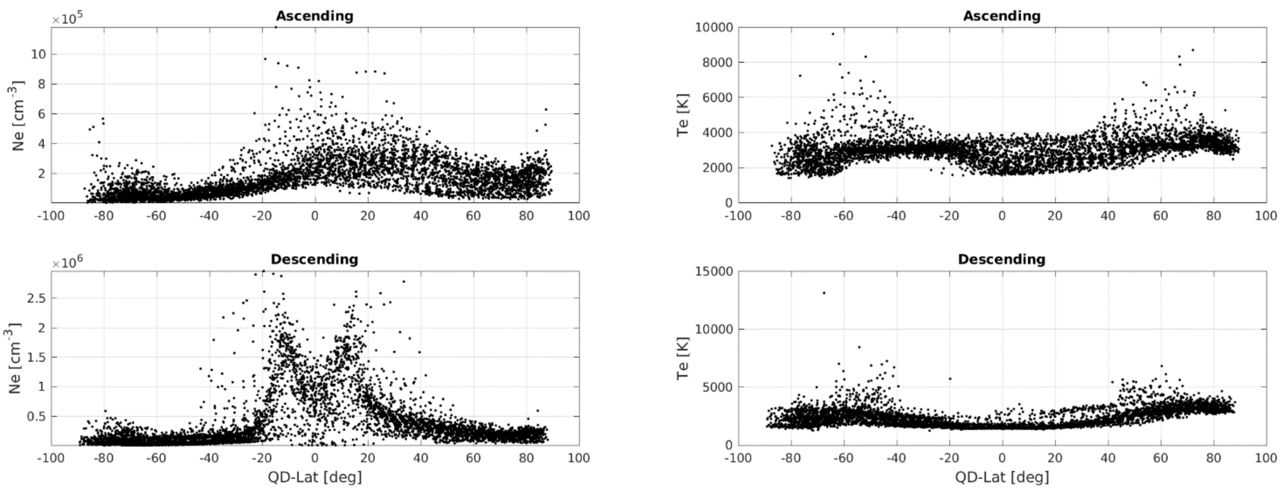


**Figure 3-16:** The panels shown the electron density (left) and temperature (right) profile as a function of QD Latitudes for the last week of operation. The analysis is made separately for ascending (upper panels) and descending (bottom panels) orbits.

### 3.4.2.2 Swarm B

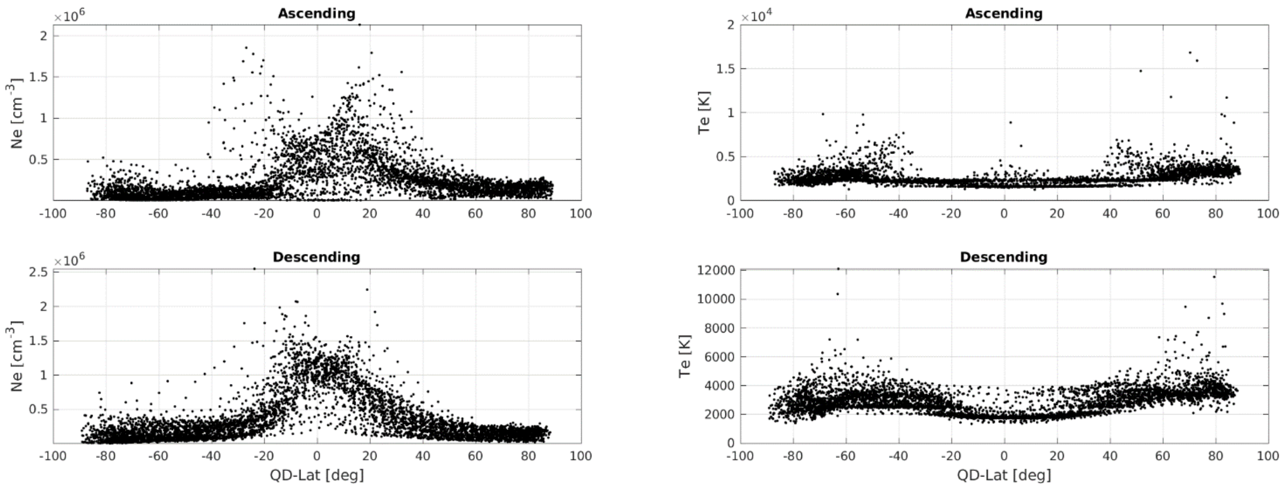


**Figure 3-17:** The panels shown the electron density (left) and temperature (right) profile as a function of QD Latitudes for the last week of operation. The analysis is made separately for ascending (upper panels) and descending (bottom panels) orbits.

### 3.4.2.3 Swarm C

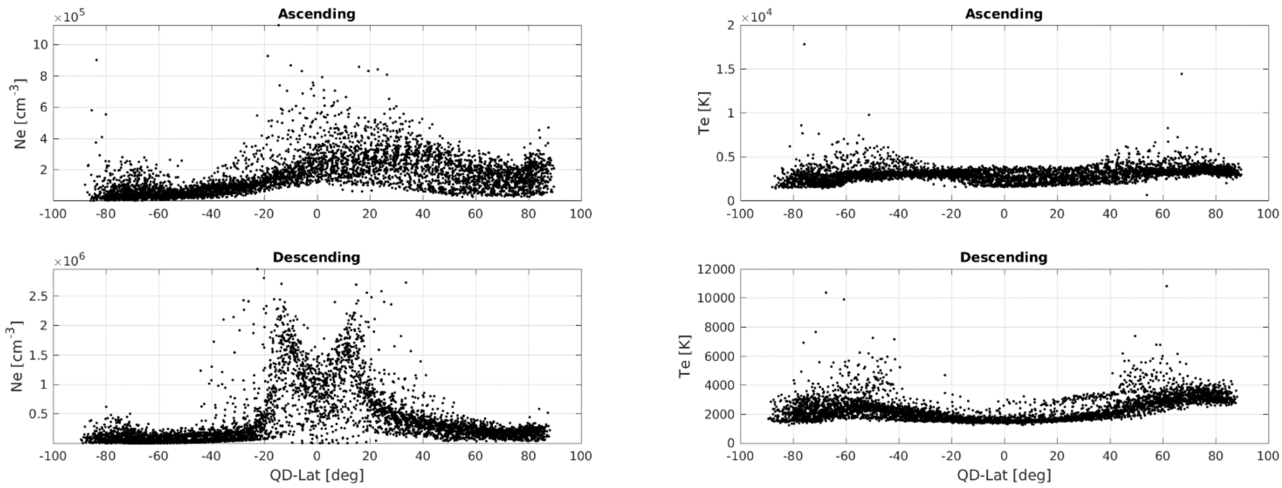


**Figure 3-18:** The panels shown the electron density (left) and temperature (right) profile as a function of QD Latitudes for the last week of operation. The analysis is made separately for ascending (upper panels) and descending (bottom panels) orbits.

# 4. Special Investigations

The Geomagnetic Storm occurred between 10th and 11th May 2024 has been analysed with Swarm magnetic field data and plasma data.

Figure 4-1 shows the variation of geomagnetic field through the difference between the scalar magnetic field measured by Swarm-B and Chaos model for internal field.

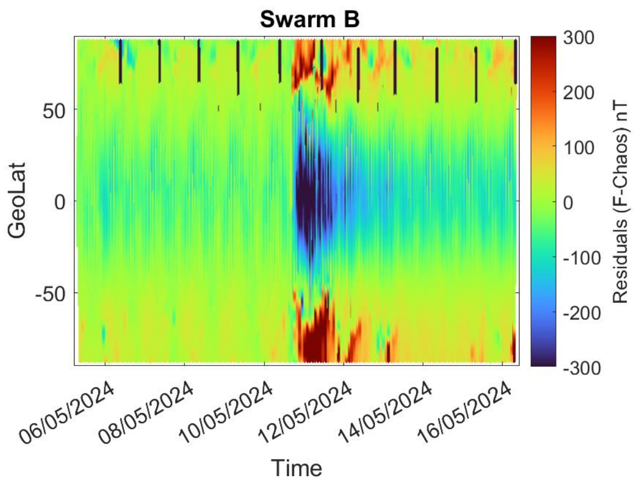


**Figure 4-1** Difference between scalar magnetic field measured by Swarm-B and Chaos model for internal field in the period 6th and 16th May 2024, showing the effects of the Geomagnetic Storm occurred between 10th and 11th May 2024.

Red points indicate areas where the magnetic field is stronger with respect to Chaos model, while blue points show its weakening, over time.

The figure shows that, starting from 10th May, there has been a moderate geomagnetic activity at the poles, with increase of the magnetic field (red areas) up to latitudes corresponding to Northern Europe and New Zealand. While a weakening of the magnetic field is observed at mid- and equatorial latitudes (blue areas).

Figure 4-2 displays the Swarm three satellites' measurements of electron density and temperature. It shows the impact of the storm with respect to ionospheric disturbances, with an increase in density observed on 11th May and a subsequent decrease at the end of the day, while an enhancement of the temperature values is registered in correspondence of the beginning of the storm on 11th May.

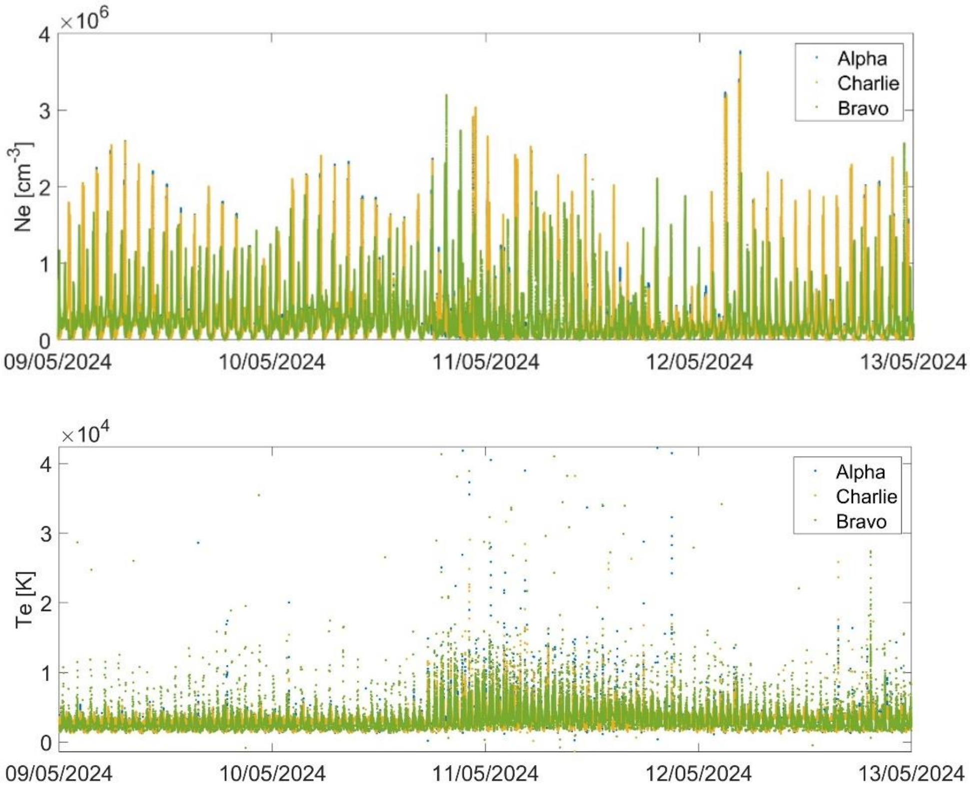


Figure 4-2 Measurements of electron density (top) and temperature (bottom) from Swarm three satellites in the period between 9th and 13th May 2024.

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