ID. 59236

The cross-calibration and validation of CSES/Swarm magnetic field and plasma data

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PRESENTED BY: Chao Xiong from Wuhan University
on behalf of CSES-Swarm joint CAL/VAL team

Chinese members (6)

Title	First name	Last name	Affiliation
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Prof.	Zhima	Zeren	NINH – National Institute of Natural Hazards, the Ministry of Emergency Management of China
Prof.	Rui	Yan	NINH
Prof.	Bin	Zhou	NSSC – National Space Science Center, Chinese Academy of Sciences
Prof.	Chao	Liu	NSSC
Associated Prof.	Fan	Yin	WHU - Wu Han University

European members (6)

Title	First name	Last name	Affiliation
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Prof.	Chao	Xiong	GFZ （now at Wuhan University）
Dr.	Juan	Rodriguez-Zuluaga	GFZ (now at Johns Hopkins University)
Prof.	Angelo	De Santis	INGV – National Institute of Geophysics and Volcanology
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Dr.	Gianfranco	Cianchini	INGV

Chinese Young scientist (2)

Title	First name	Last name	Affiliation
Associate Prof.	YanYan	Yang	NINH – National Institute of Natural Hazards, the Ministry of Emergency Management of China
Dr.	Jie	Wang	NINH

European Young scientist (1)

Title	First name	Last name	Affiliation
Dr.	Giulia D’	Angelo	INAF-IAPS -National Institute of Astrophysics

Content

The the project's objectives

1) To cross-calibration/validation of ionospheric magnetic field and plasma parameters;

2) Jointly develop algorithms to eliminate the artificial influences from platforms;

3) Jointly develop and optimize the data processing tools for the magnetometers and Langmuir probe onboard CSES;

4) Jointly compare the simultaneous measurements of CSES and Swarm during active magnetic conditions;

5) Jointly study the details of some ionospheric structures;

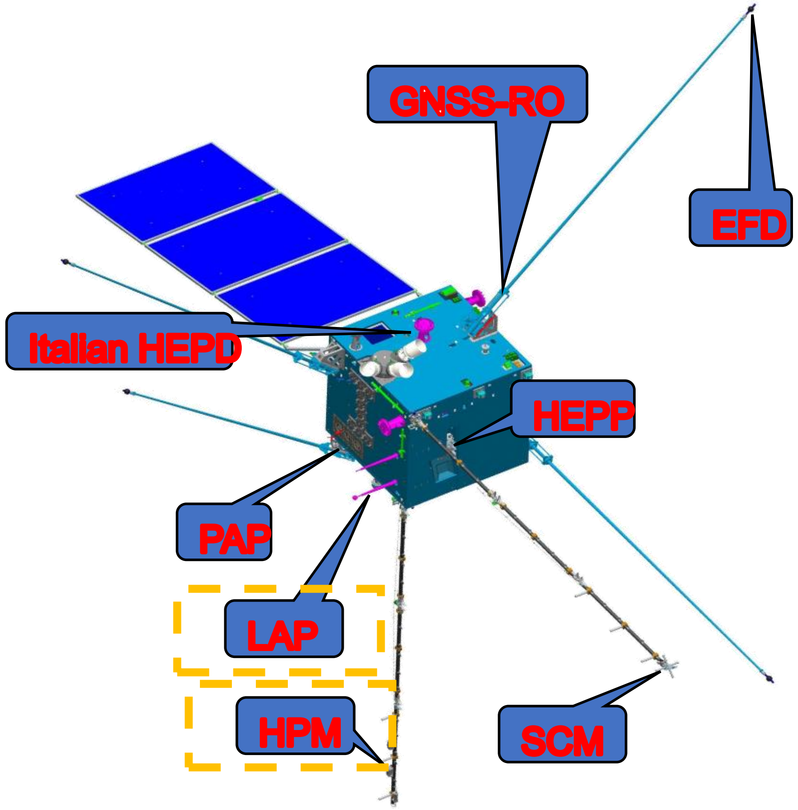
6) To use the potential of working with CSES magnetic data for regional and global magnetic field modeling;

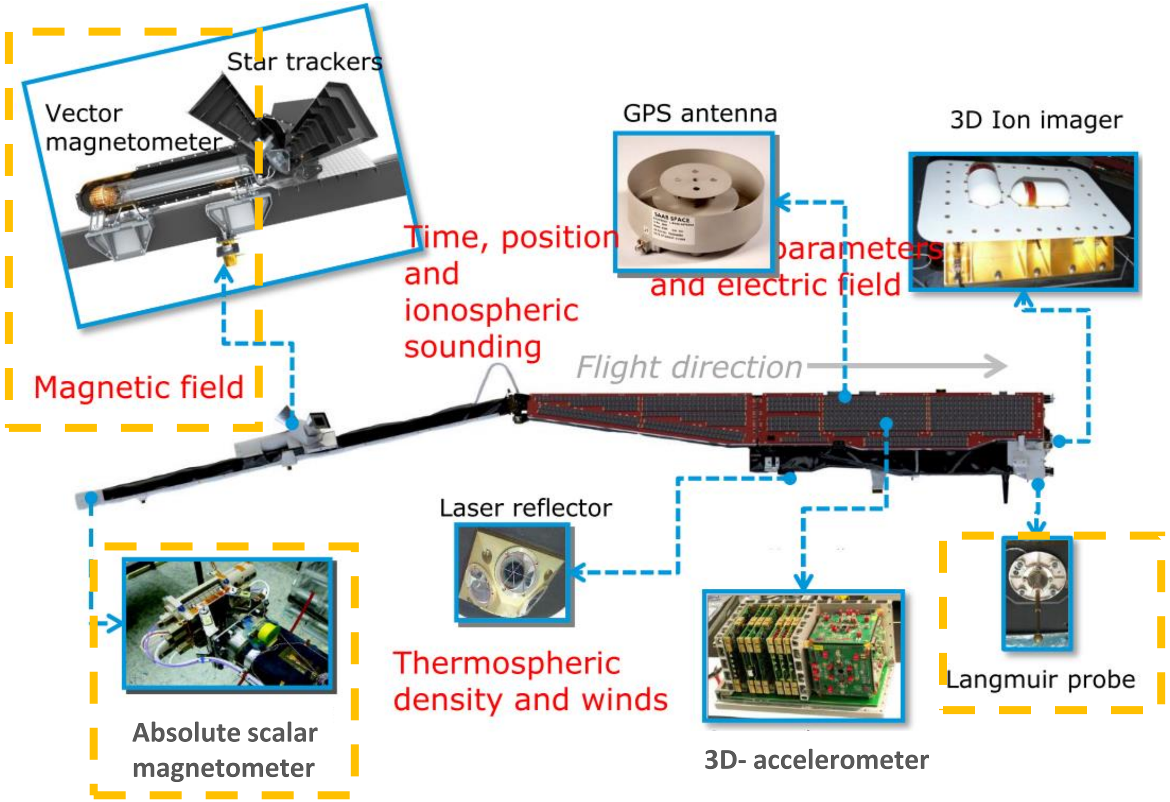
7) To explore the possibility for generating higher level scientific products from the magnetic measurements.

The the project’s objectives

CSES-01: launched into a sun-synchronous circular orbit on 2 Feb. 2018 with an initial altitude of ~507 km (*Shen et al.*, 2018a, b).

The Swarm mission was launched on 22 Nov 2013, with three spacecraft at altitudes from 460 to 530 km (*Knudsen et al.*, 2017).





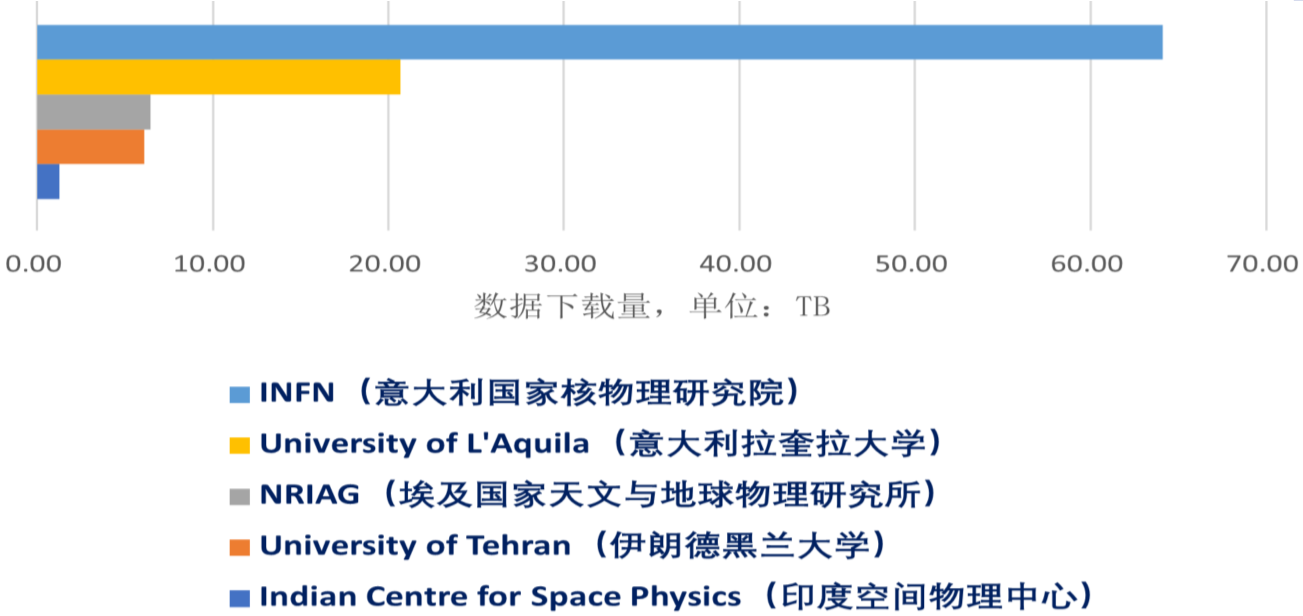
(*Rune et al.*, 2018)

EO Data Delivery

Data access

CSES: ESA Third Party Missions	**No. Scenes**
1. ZH-1: magnetic data	30 half-orbits per day, about 5 years
2. ZH-1: plasma data	30 half-orbits per day, about 4 years
Website: **https**: //www.leos.ac.cn	

Swarm	No. Scenes
1. Swarm A/B/C:magnetic field data	1 file per day, about 10 years
2. Swarm A/B/C: plasma data	1 file per day, about 10 years
Website: http://swarm-diss.eo.esa.int	



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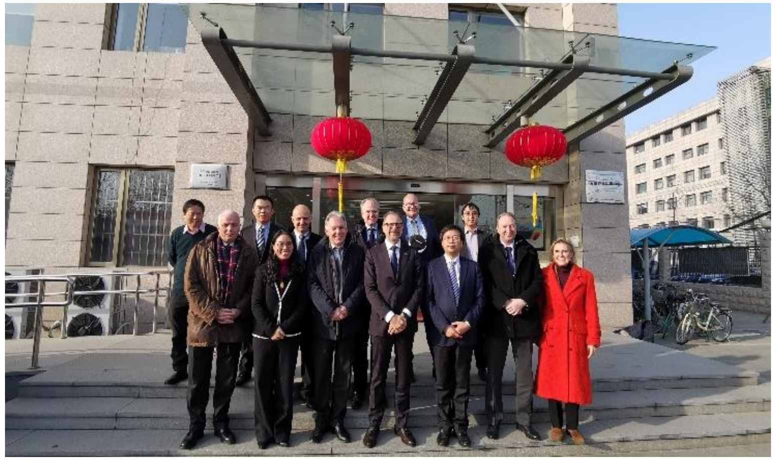
1. Project objectives
2. Overview of CSES/Swarm cooperation activities
3. Outcomes of CSES/Swarm cooperation
4. Proposals for next-step bilateral cooperation

Swarm/CSES cooperation activities

(1) Oct. 21 to 25, 2019, ISSI-BJ annual workshop

(2) ESA EO visiting ICD in Jan.15, 2020

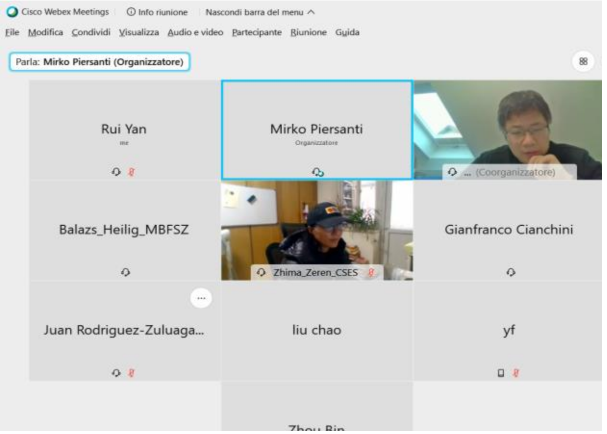


(3) CNSA-ESA virtual meeting on space cooperation on June. 2020

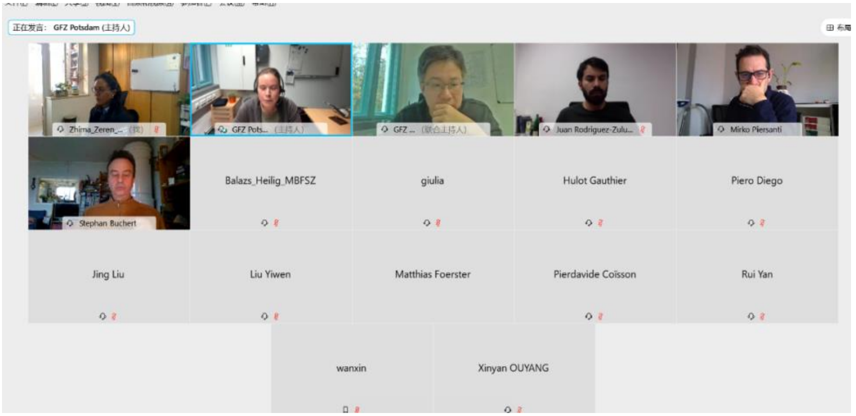
(4) CNSA-ESA
Dragon 5 project
Approved: June 2020
kick off: July 2020

Swarm/CSES cooperation activities

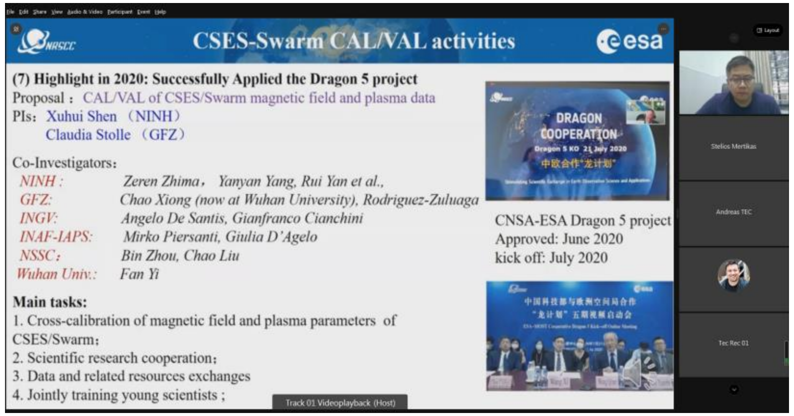
(5) The 1st joint working seminar, October, 2020



(6) The 2nd joint working seminar, December, 2020



(7)The Dragon 2021 symposium, July, 2021



CSES-Swarm CAL/VAL activities

(7) Highlight in 2020: Successfully Applied the Dragon 5 project

Proposal：CAL/VAL of CSES/Swarm magnetic field and plasma data
PIs：Xuhui Shen （NINH）
Claudia Stolle （GFZ）

Co-Investigators：
NINH : *Zeren Zhima， Yanyan Yang, Rui Yan et al.,*
GFZ: *Chao Xiong (now at Wuhan University), Rodriguez-Zuluaga*
INGV: *Angelo De Santis, Gianfranco Cianchini*
INAF-IAPS: *Mirko Piersanti, Giulia D'Agelo*
NSSC： *Bin Zhou, Chao Liu*
Wuhan Univ.: *Fan Yi*

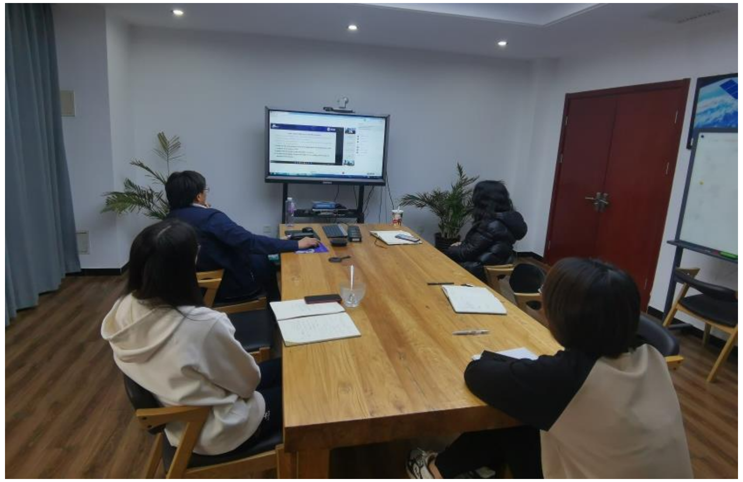
Main tasks:
1. Cross-calibration of magnetic field and plasma parameters of CSES/Swarm；
2. Scientific research cooperation；
3. Data and related resources exchanges
4. Jointly training young scientists ;

CNSA-ESA Dragon 5 project
Approved: June 2020
kick off: July 2020

(5) Swarm 11th workshop, October, Athens, 2021

(9) CSES 5th workshop, October, Guiyang, 2021

(10)The Dragon 2022 symposium, Oct., 2022



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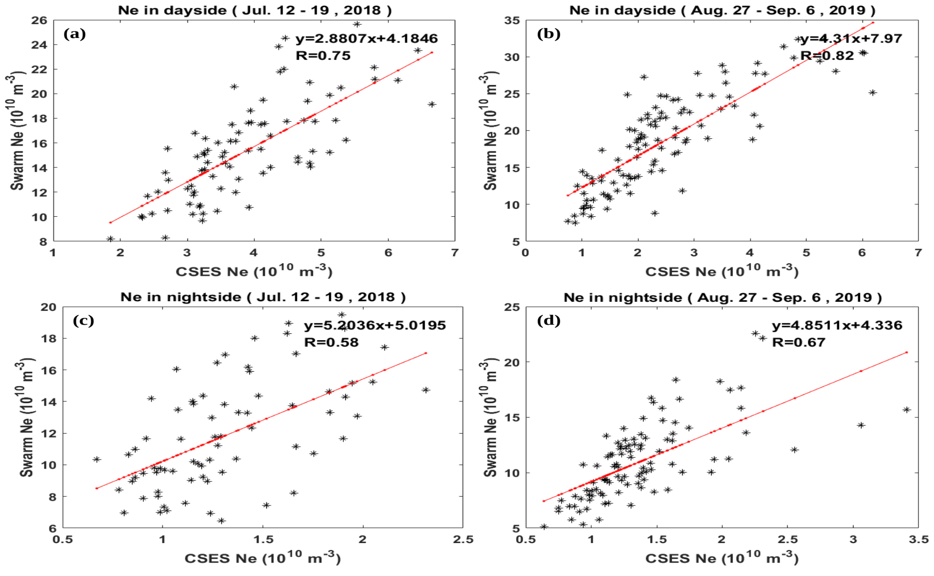
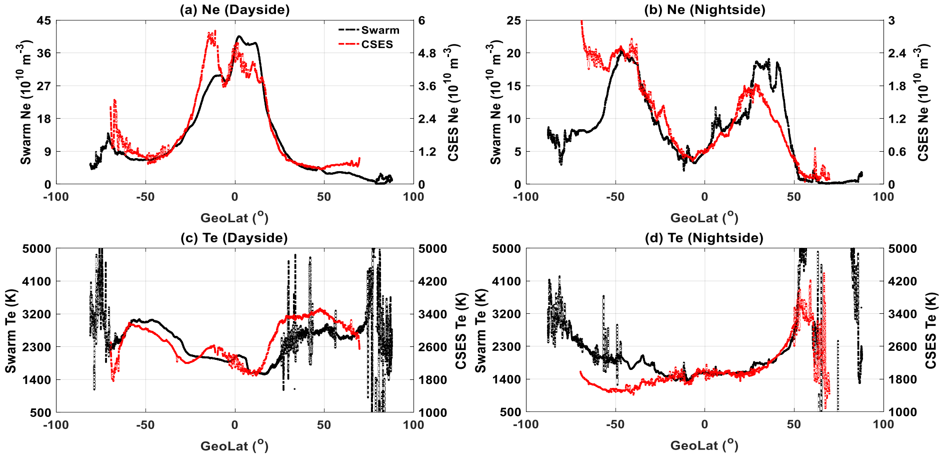
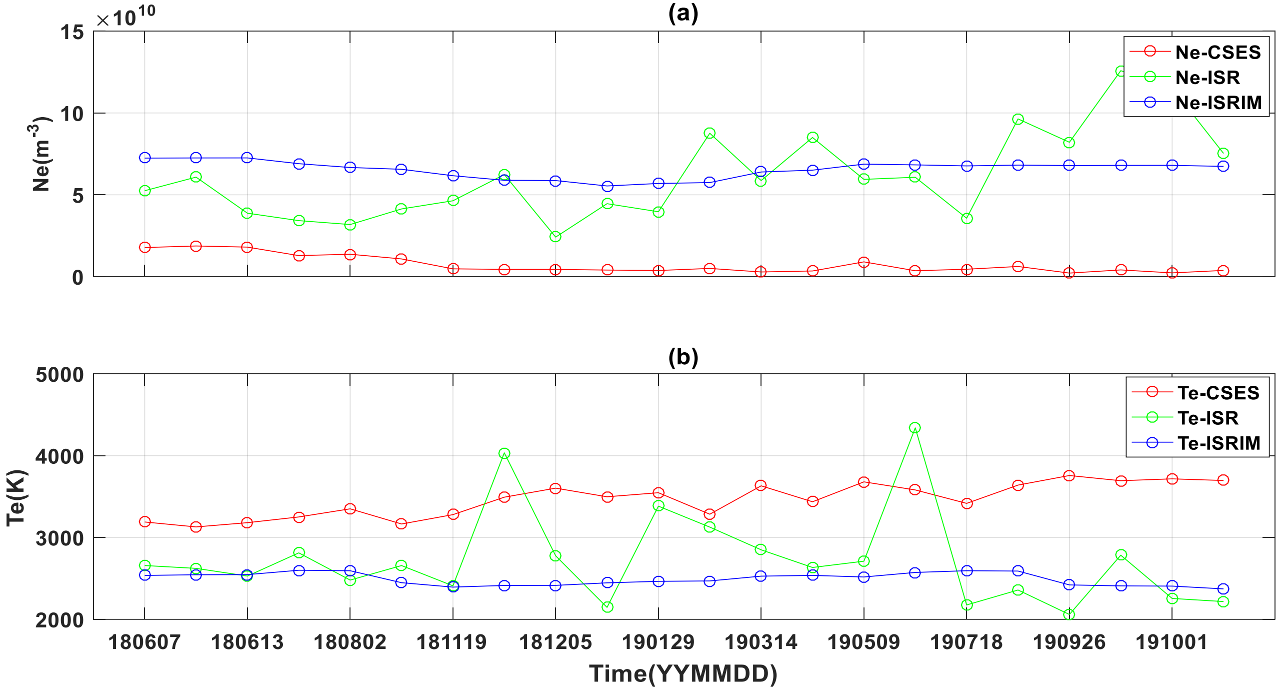
1. Objectives
2. Overview of CSES/Swarm cooperation activities
3. Outcomes of CSES/Swarm cooperation
    - Plasma data
    - Magnetic field data
    - Publications and young scientists achievements
4. Proposals for next-step bilateral cooperation

Validation and data quality control of Plasma data





The comparison of *Ne/Te* measurements from CSES (red) and Swarm (black) within the closest orbits at closest local time in Nov. 25, 2018

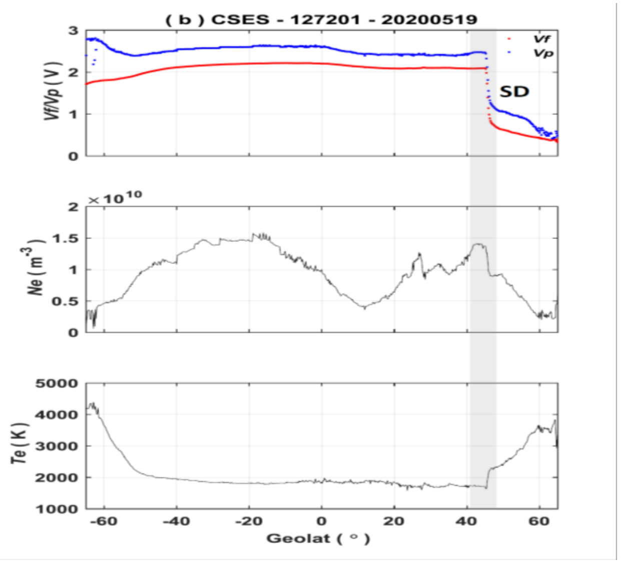


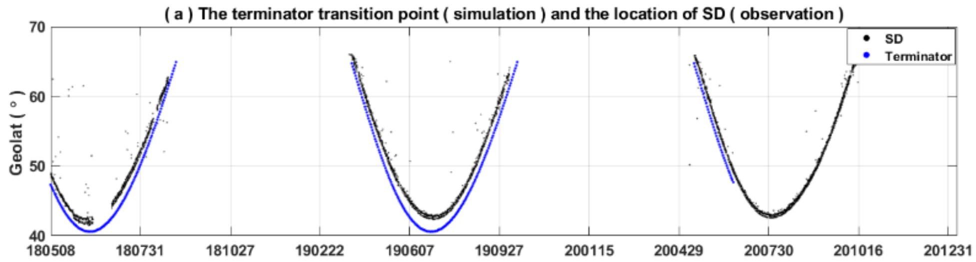
The dayside Ne from CSES is nearly 60% lower (on average) than the values of ISR, but the Te values from CSES are about several hundred K higher than that measured by ISR.

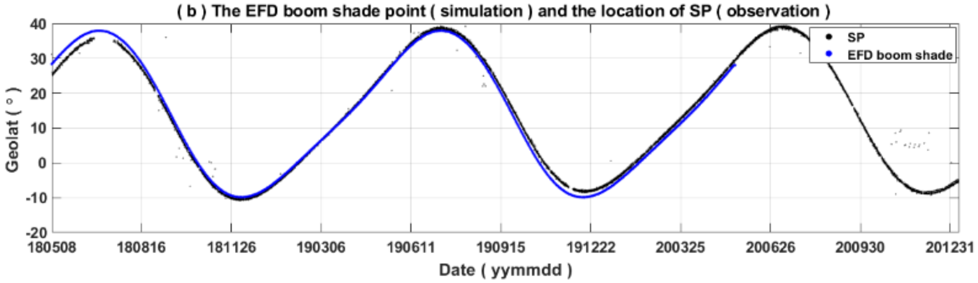
1. **Quite very similar latitudinal variations and good correlations**
2. **Lower CSES *Ne* than Swarm *Ne*, *Te* measurements the same range**

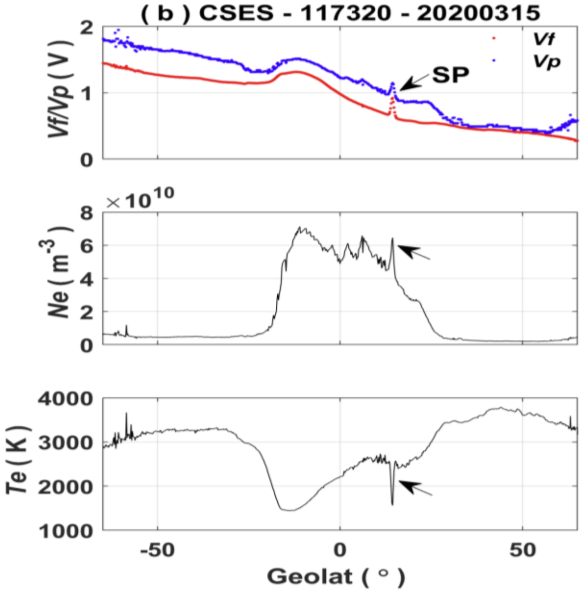
[Yan et al., JGR, 2020]

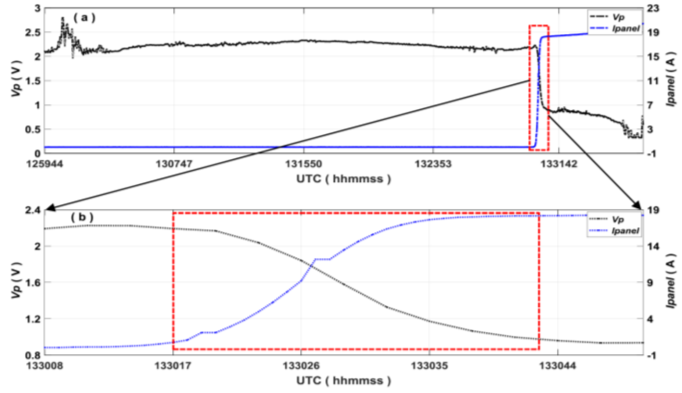
The regular features recorded by LAP onboard CSES


(b) CSES - 127201 - 20200519


(a) The terminator transition point (simulation) and the location of SD (observation)

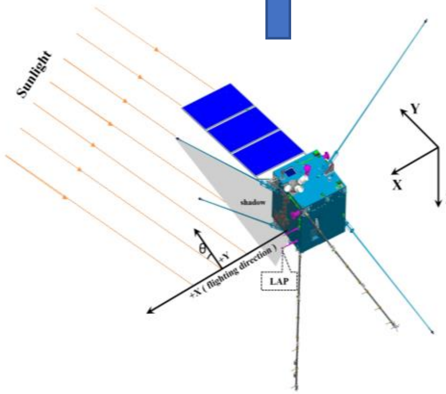

(b) The EFD boom shade point (simulation) and the location of SP (observation)


(b) CSES - 117320 - 20200315



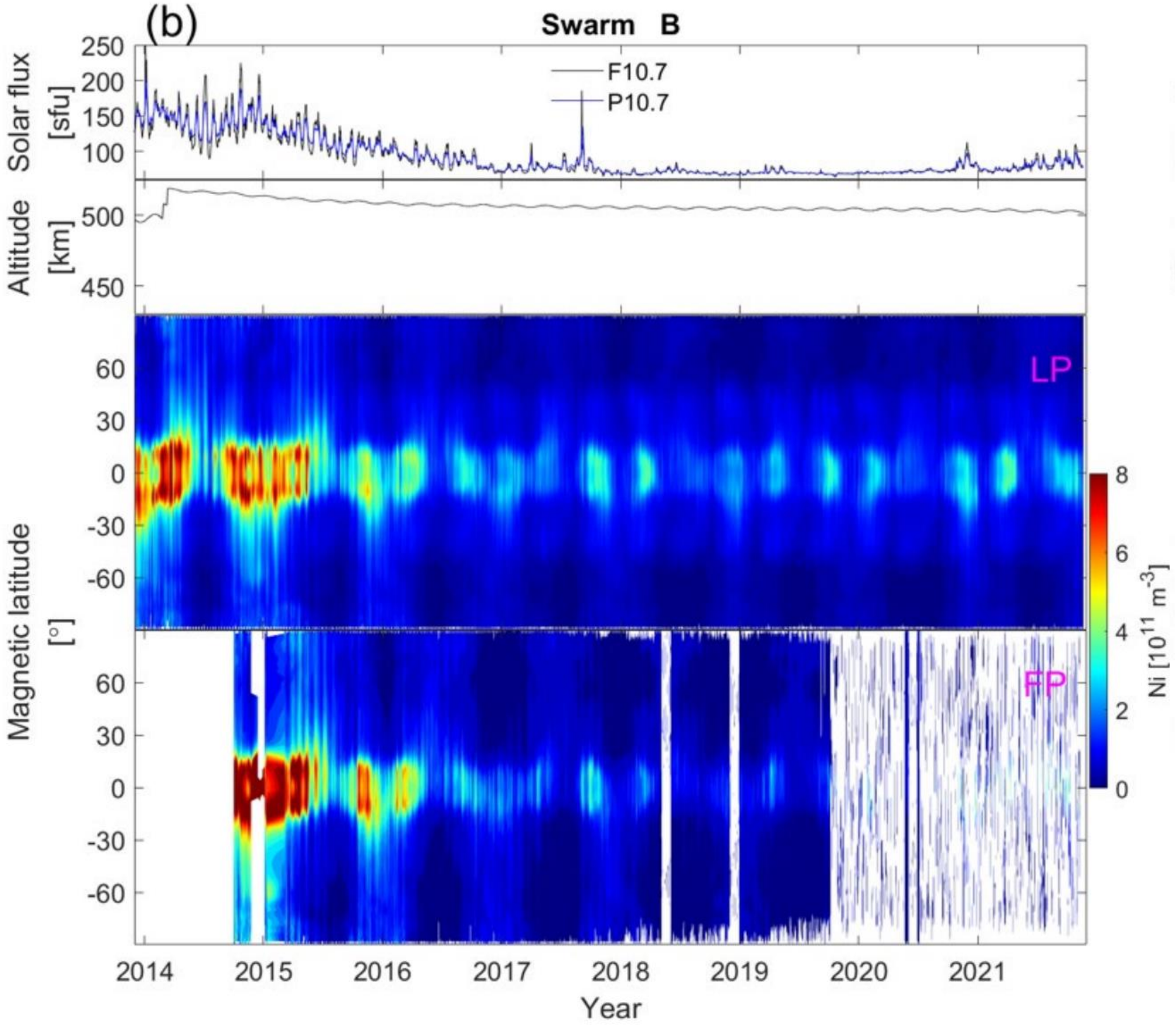
The SD is caused by satellite-current system adjustment due to the solar illumination change at the terminator transition point.

The SP is caused by instantaneous illumination changes of probe surface when the boom of the electric field detector installed in the windward panel shades the Langmuir probe.



[Yan et al., JGR, 2022]

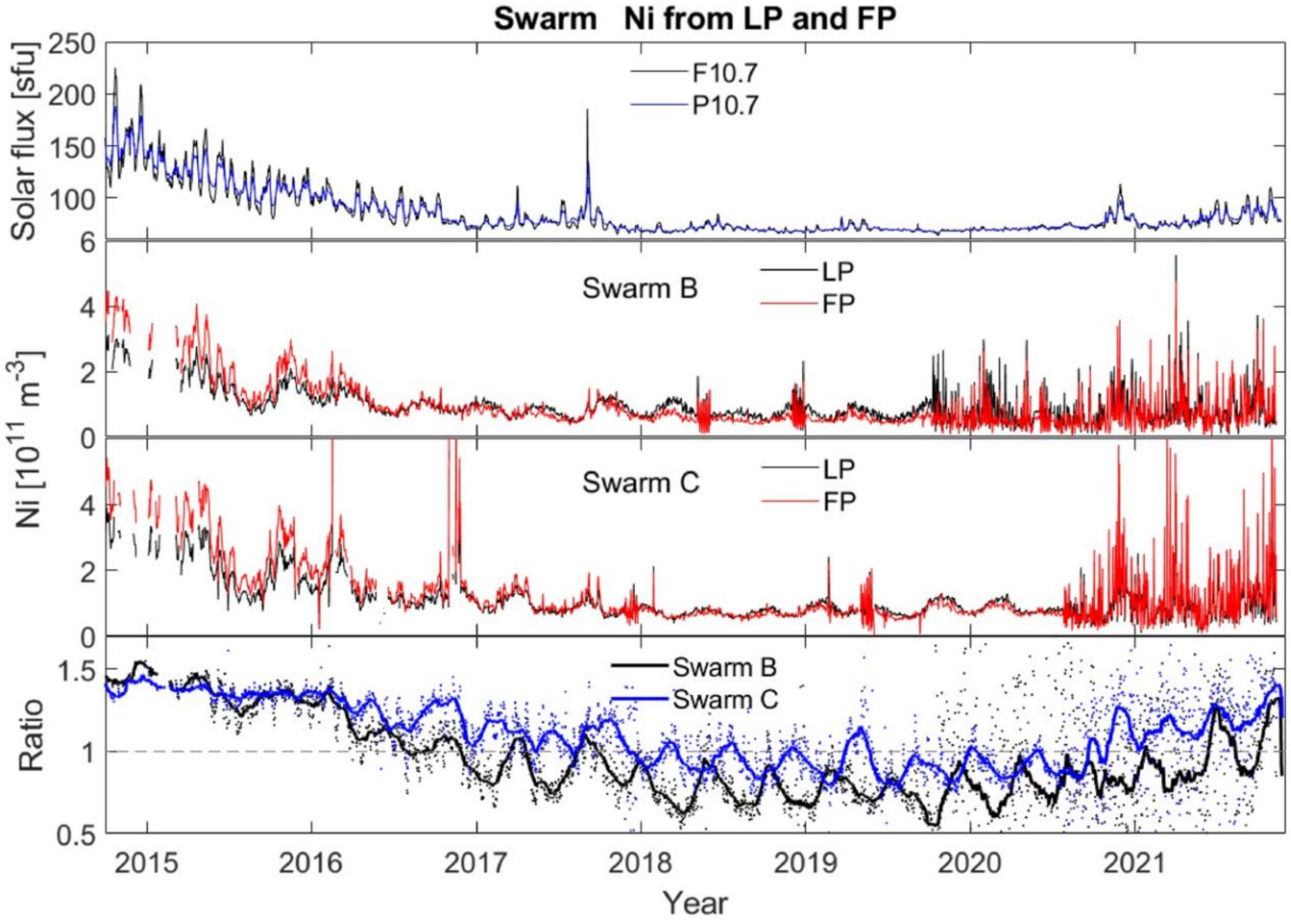
4. Influence on the plasma density measurements: Swarm

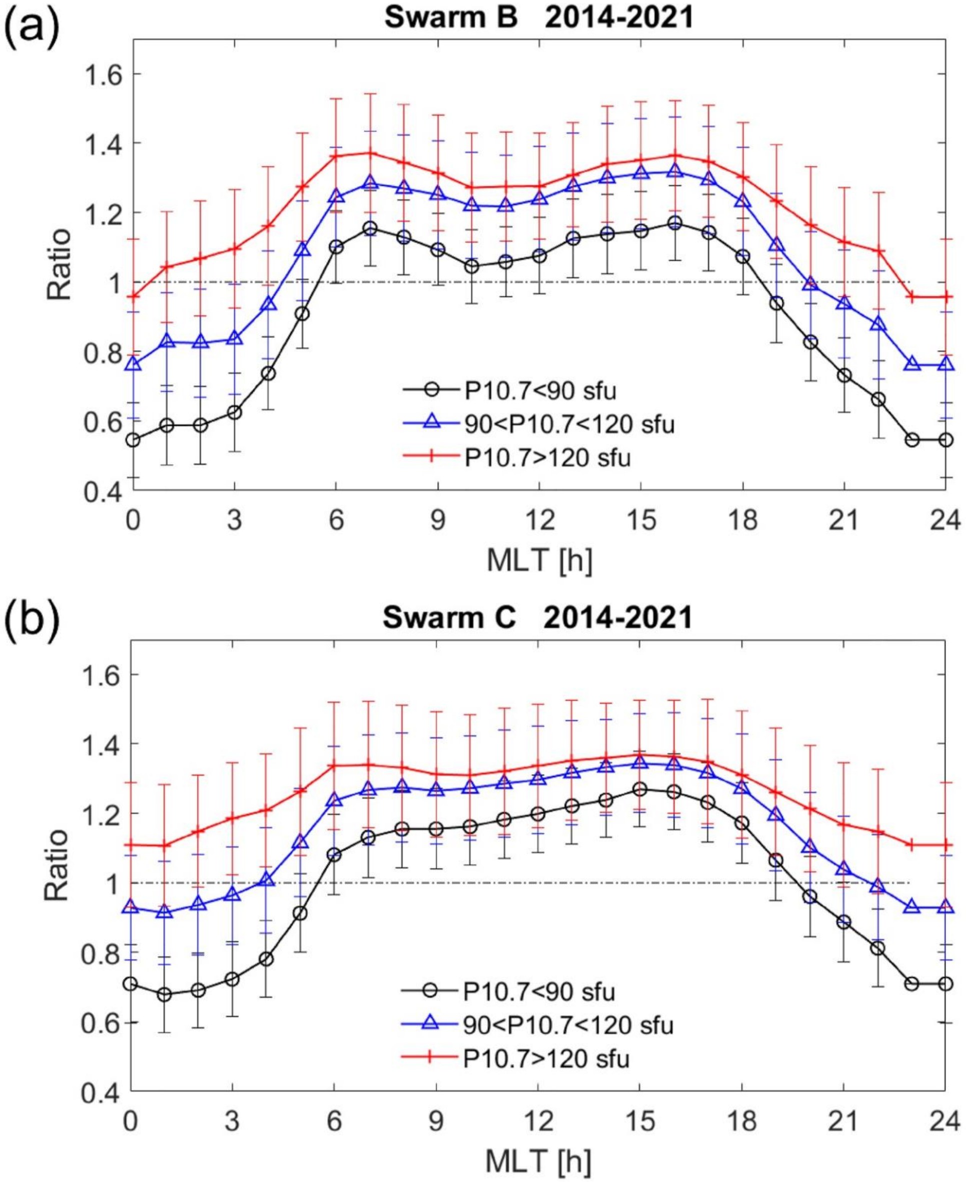


[Xiong et al., 2022, JGR]

- Xiong et al. (2022) showed that the FP densities had very low bias compared to the ISR electron densities
- Therefore, we can use the FP data as reference to calibrate the LP densities
- This calibration would depend on many parameters, and therefore machine learning would be a very good tool to learn these dependencies
- The FP densities are only available for several orbits per day, mainly before 2020, and therefore the data are more sparse
- **However, there is enough data to train a neural network, which would give a ratio between FP and LP densities**

4. Influence on the in situ plasma density measurements: Swarm





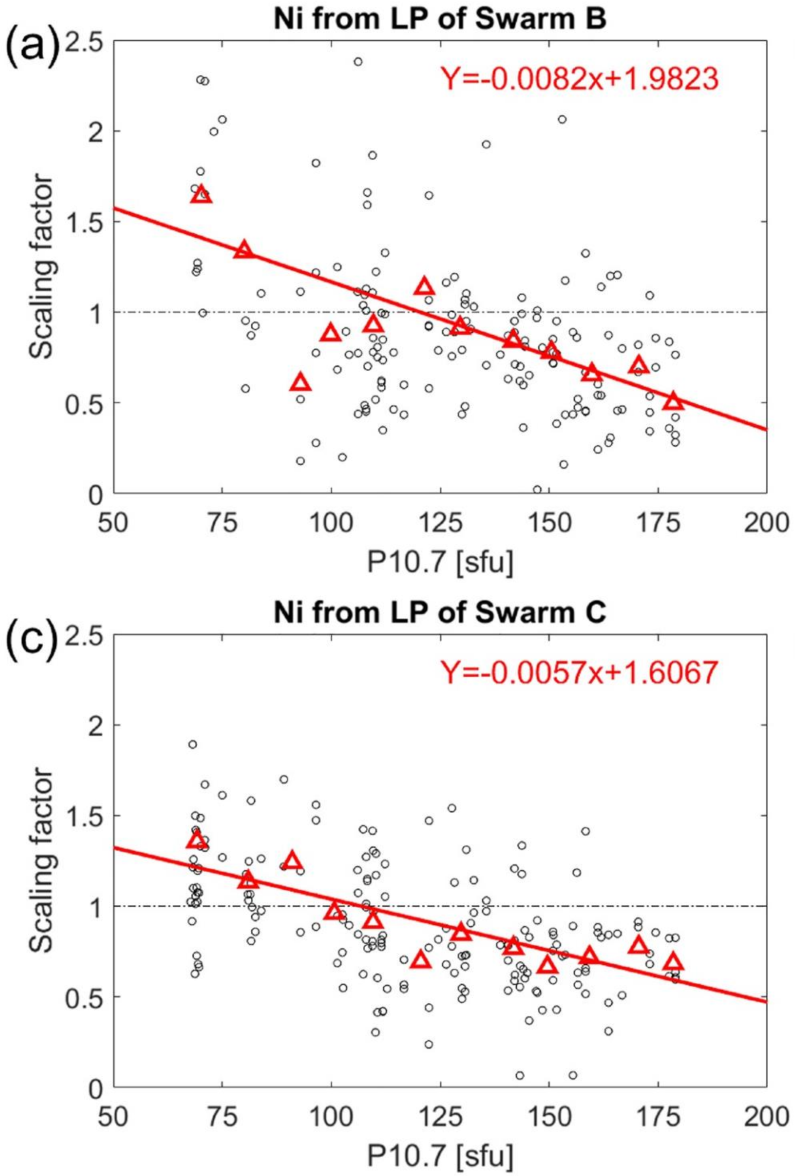
Influence on the in situ plasma density measurements: Swarm

$$\mathrm{Ni}_{\mathrm{LP}} = \frac{m_i u_i}{2\pi (e r_p)^2} d_{\mathrm{ion}}$$

We suggest that the solar flux dependence of LP-derived Ni is related to the ion compositions change at Swarm altitude, which has not been properly accounted for in the LP processing algorithm. More light ions (e.g., H+), diffusing down from the plasmasphere to the Swarm altitude, seem to cause the overestimation of Ni from LP during low solar activity.

$$\mathrm{Swarm\,B}\ :\ \mathrm{Ni}_{\mathrm{LPcorr}} = -0.0082 \times V_{P10.7} + 1.9823$$

$$\mathrm{Swarm\,A\,and\,C}\ :\ \mathrm{Ni}_{\mathrm{LPcorr}} = -0.0057 \times V_{p10.7} + 1.6067$$



Validation and data quality control of Plasma data

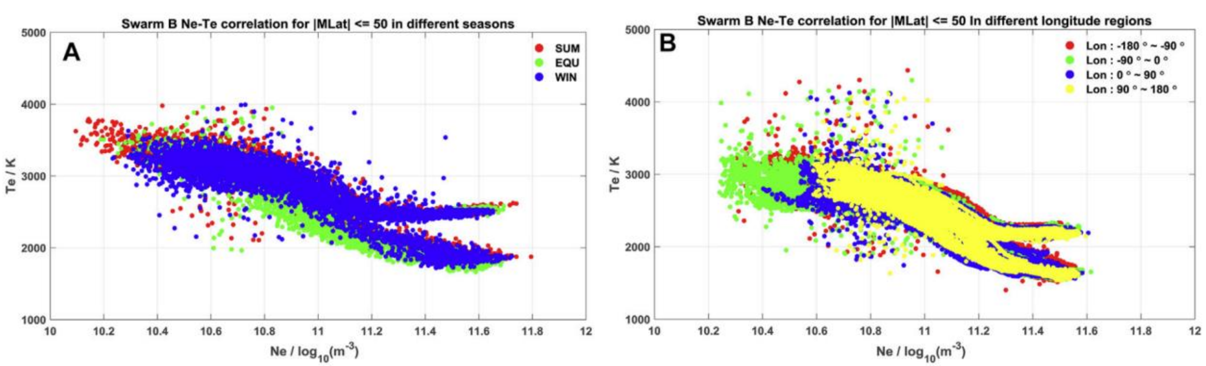
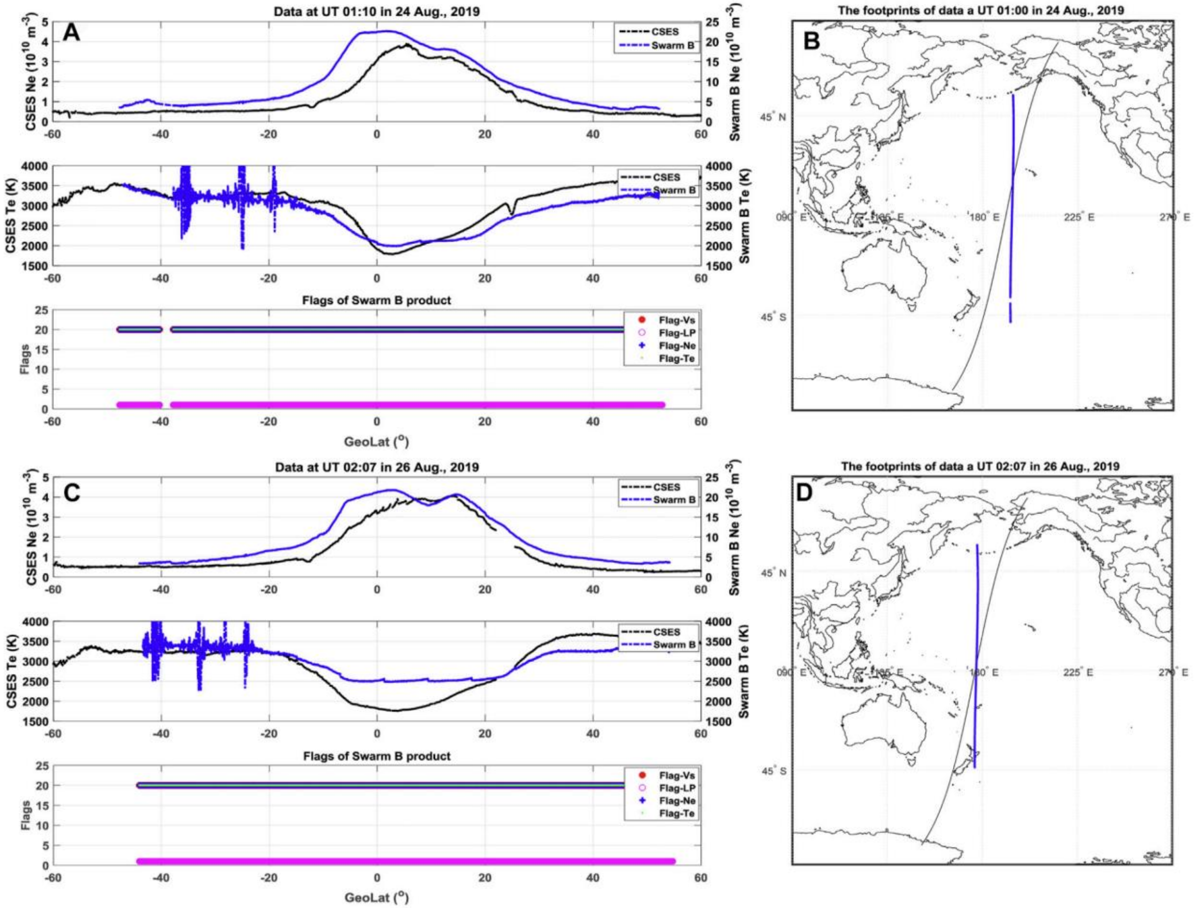


FIGURE 9 | Scatter plot of *Ne* and *Te* as measured by Swarm B. Each data point is confined into within the |MLAT|≤ 50° at around 14:00LT. **(A)** The observations during equinoxes, June solstice and December solstice are marked with green, red and blue. **(B)** The observations in different longitude regions including -180° ~ -90°, -90° ~ 0°, 0° ~ 90°, 90°~ 180° are marked with red, green, blue and yellow.

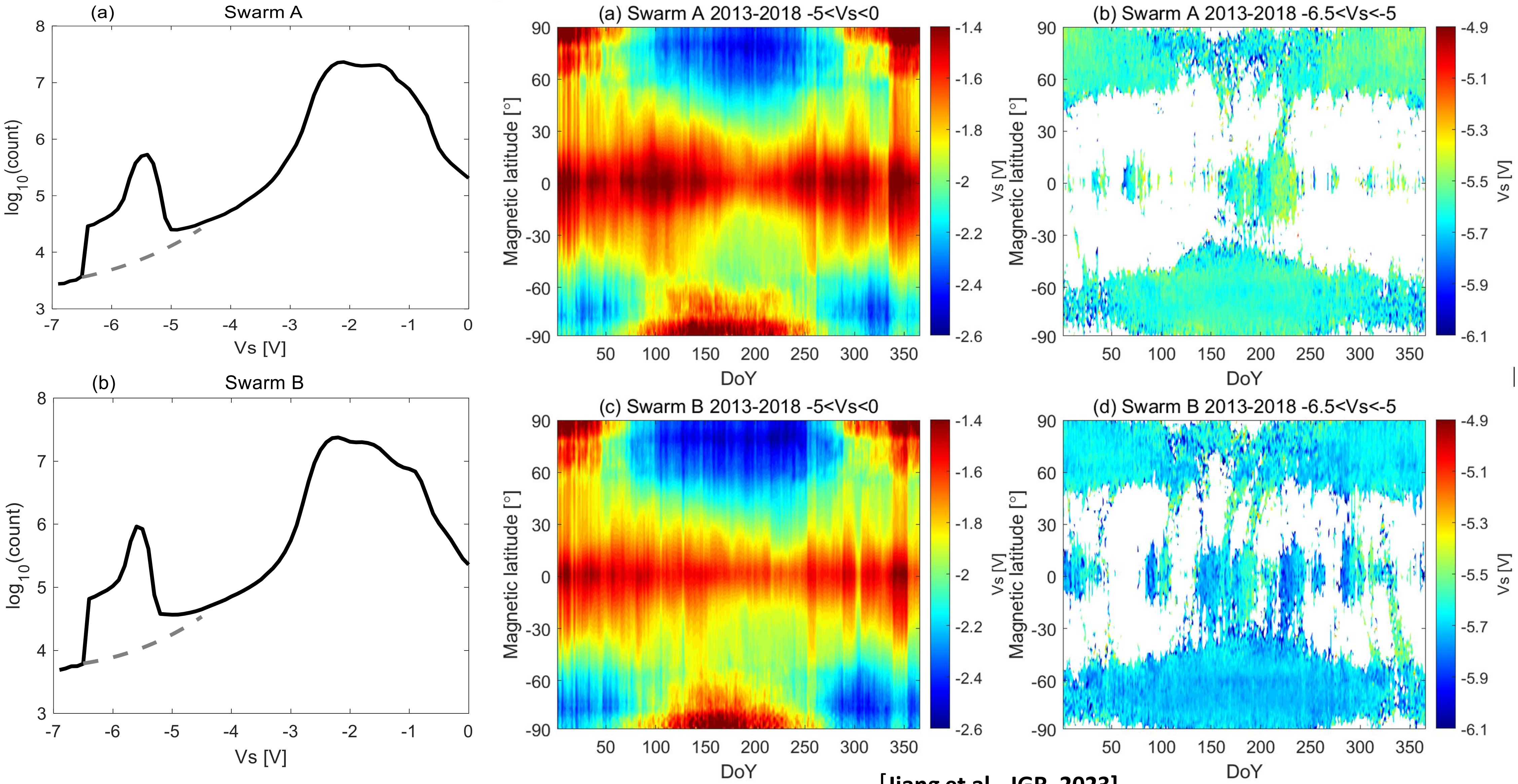
Two prominent features of the Ne/Te relation observed by Swarm satellites are: a) when Ne is larger than 1×10^{11} m^{-3} , Te are grouped into two branches at equatorial and low latitudes; b) when Ne is lower than 1×10^{11} m^{-3} , Te sometimes becomes very scatter at low and middle latitudes.



Detailed analysis reveals that the flags used in the Swarm Level-1B plasma density product cannot well distinguish the two abnormal features of Te, implying further efforts are needed for the Swarm Te data calibration.

[Yan et al., Front. Earth Sci , 2022]

Scientific study : spacecraft potential at LEO altitudes



[Jiang et al., JGR, 2023]

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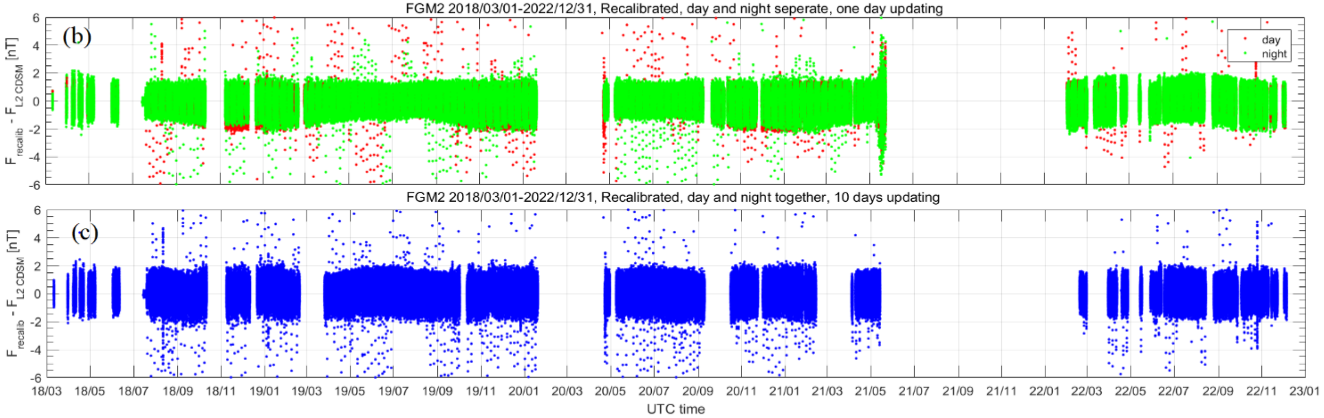
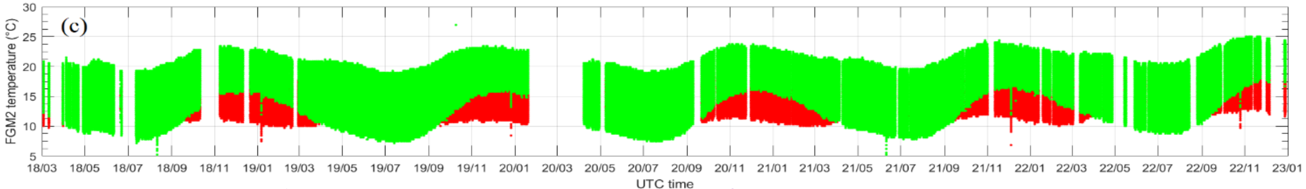
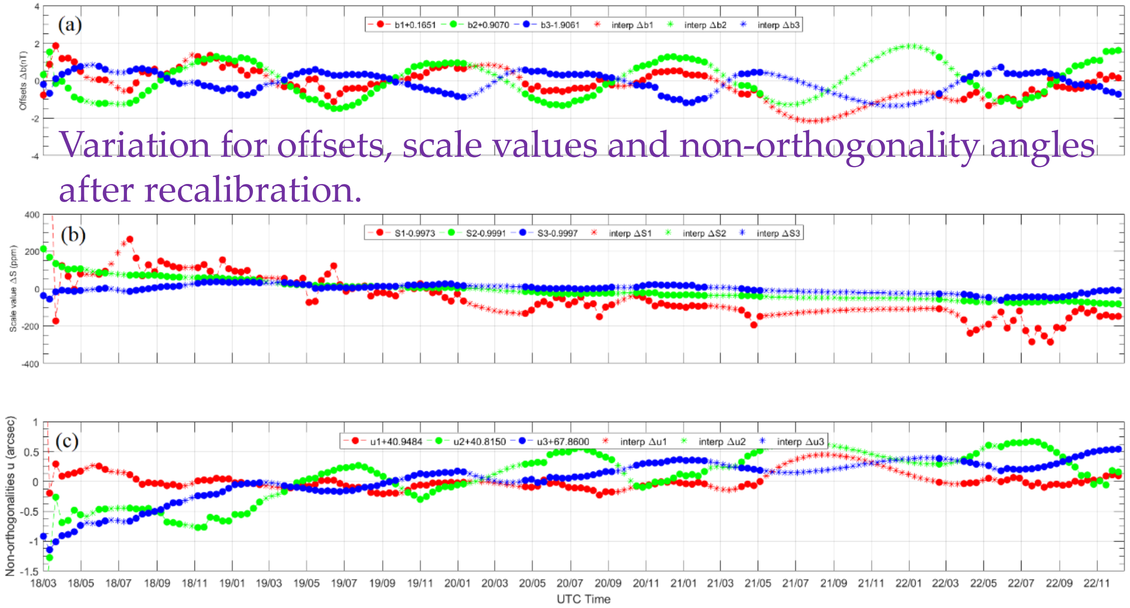
Main Optimization of the HPM in-flight calibration



The magnetic field intensity residual before and after recalibration



The temperature variation of FGM sensor

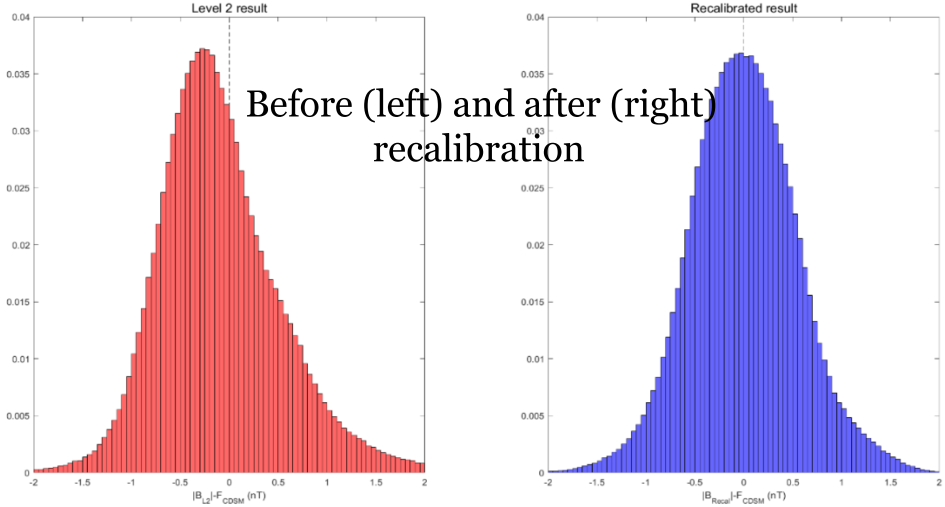


Variation for offsets, scale values and non-orthogonality angles after recalibration.

Main optimization of FGM intrinsic parameters:

- Further consider temperature correction for the offsets and the scale factors
- Prolong the updating period of the calibration parameters from one day to 10 days (and without dayside and nightside data separation)

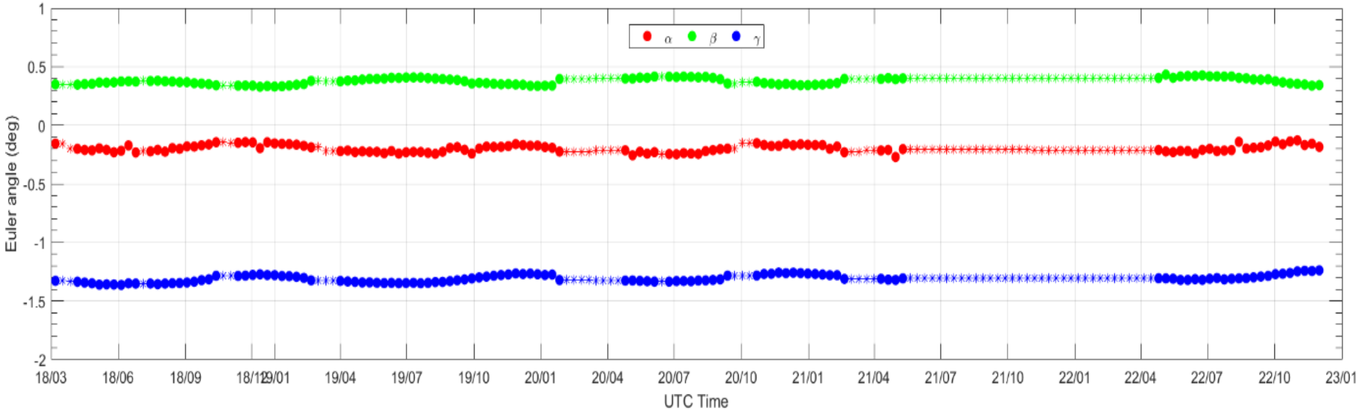
The typical variation is ±2 nT for the offsets, less than 200 ppm (most of the time is less than 100 ppm) for the scale values and ±0.0002 deg (about 0.7 arcsecs) for the non-orthogonality angles.



Before (left) and after (right) recalibration

After the recalibration, the residuals become more standard Gaussian and more central distributed. For about 93% datasets, the residual field is less than 1nT.

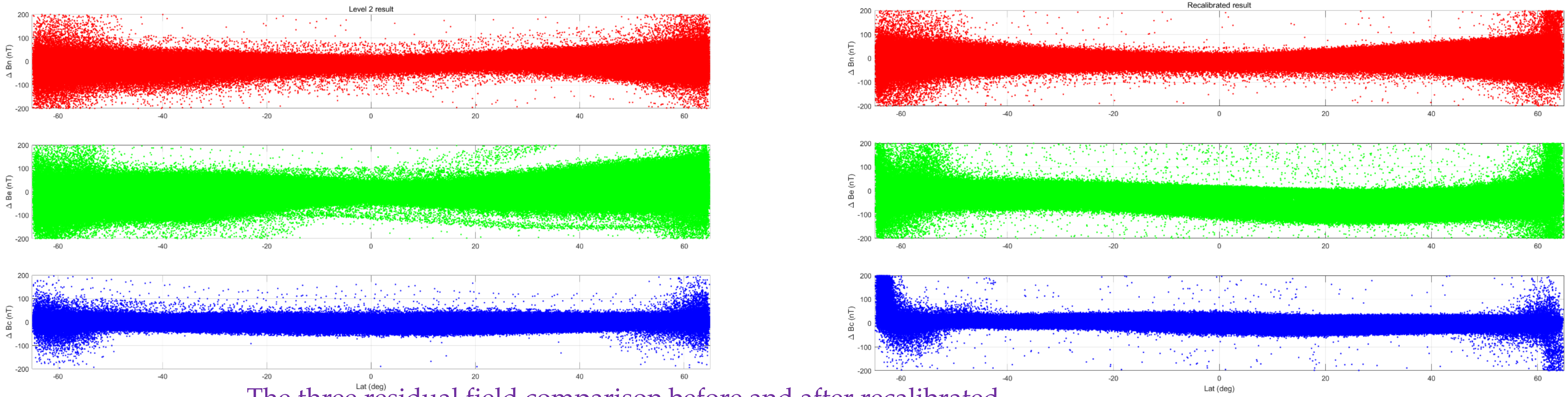
Main Optimization of the HPM in-flight calibration



The variation of in-orbit estimated three Euler angles for the alignment of the FGM sensor

Main optimization of Euler angle estimation:

- Solve the Euler angles along with global geomagnetic field modeling, no longer depend on other geomagnetic field models
- Extend the updating period of Euler angles from one day to 10 days
- When there is no CDSM data, the alignment of FGM is still possible by interpolation of model parameters.



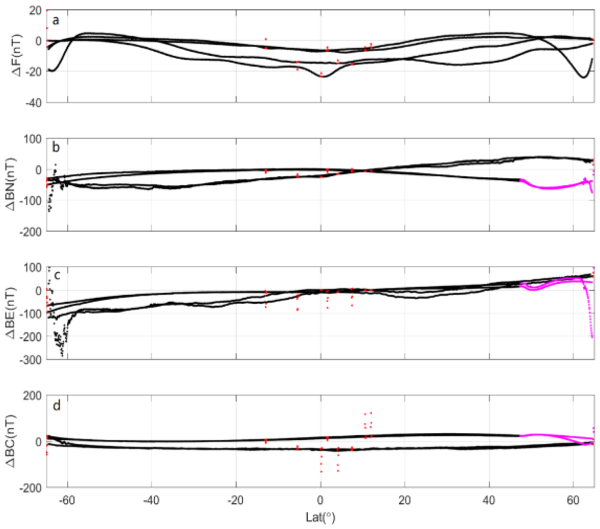
The three residual field comparison before and after recalibrated

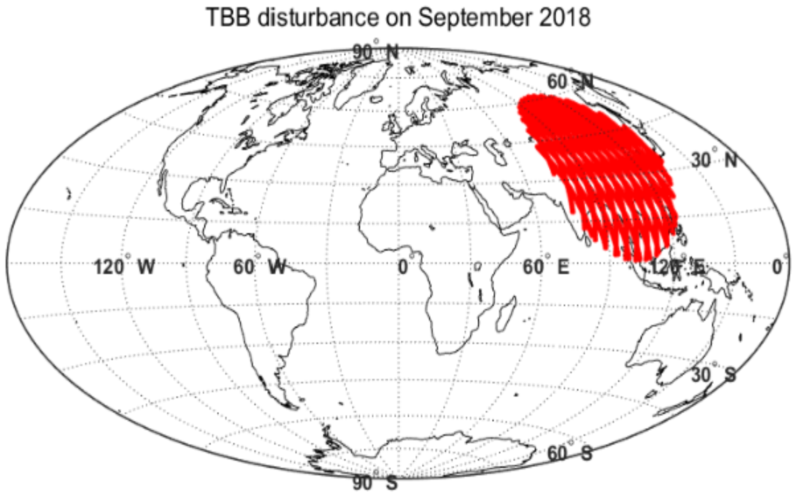
In the new calibration scheme, the latitudinal trend for the east component is improved to some extent.

Validation and data quality control of magnetic field data

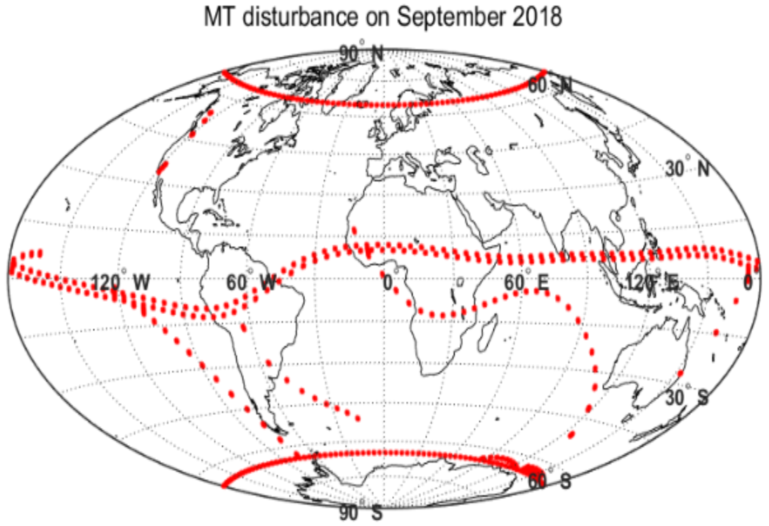
Three disturbance sources:

- Magnetic Torque
- Tri-Band Beacon
- Ground shadow

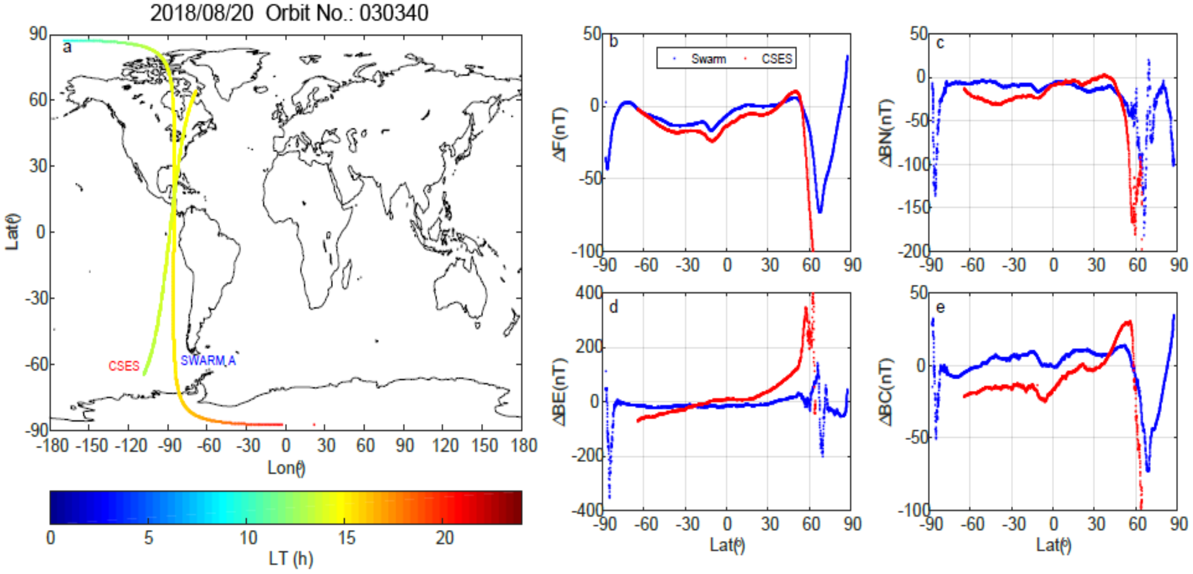


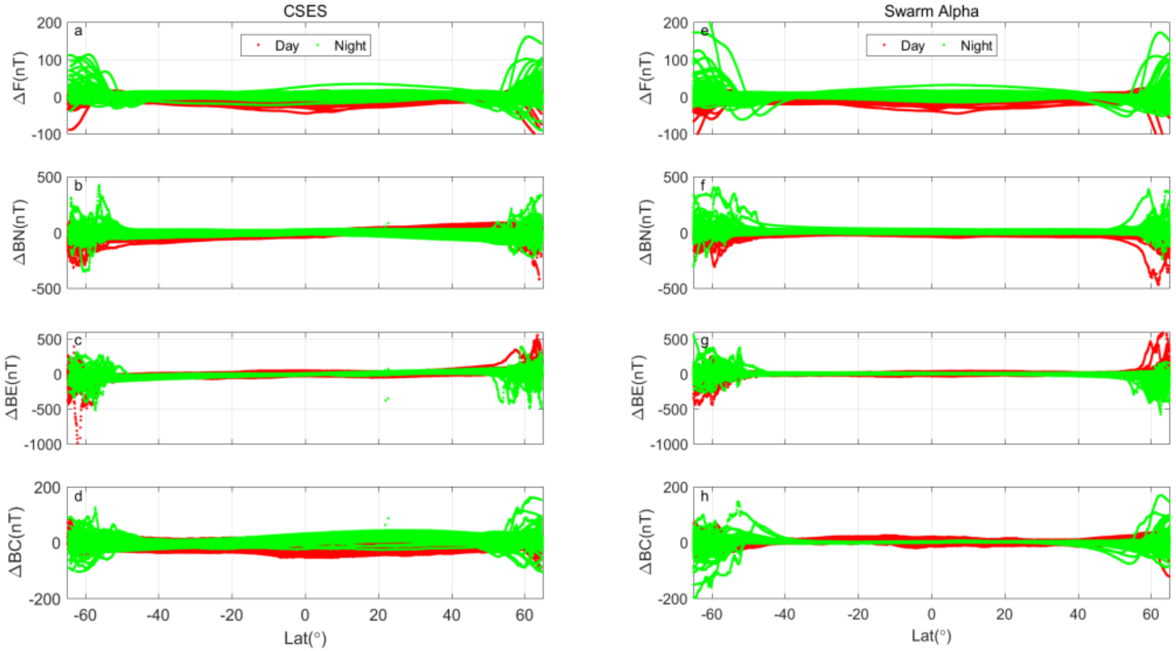

TBB disturbance on September 2018

- Disturbances from the MT basically concentrate near the magnetic equator and latitudes around 65º
- Disturbances from the TBB only occur above the Chinese territory
- Users are suggested to properly check Flags when using HPM data.


MT disturbance on September 2018

The residual field (observations minus CHAOS-6-x7 model) for the magnetic field intensity and the three vector components (in NEC frame)





- ➢ The main trend of the residual field is consistent for CSES and Swarm
- ➢ The CDSM scalar data is very good

Upper: CSES and Swarm residual field for the intensity and three vector components (for latitude<65°)

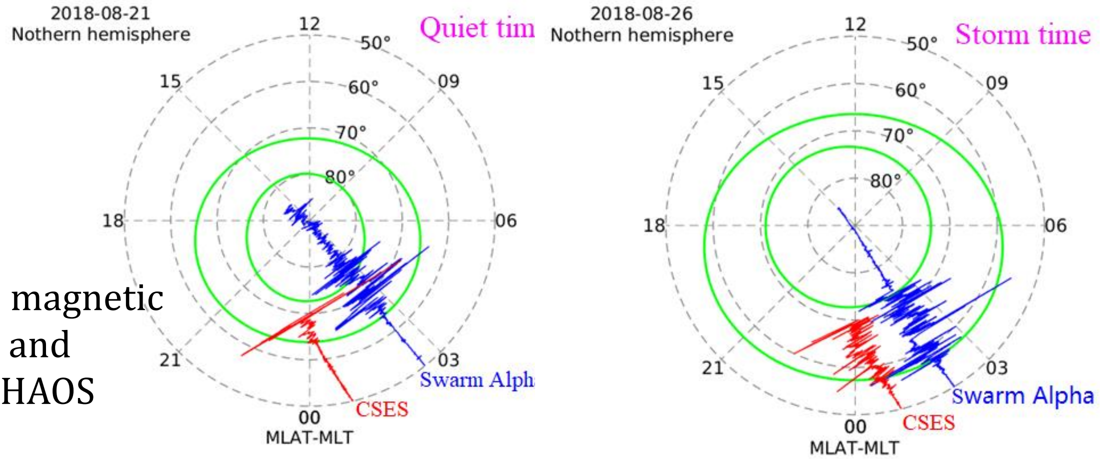
Scientific study : ionosphere current systems

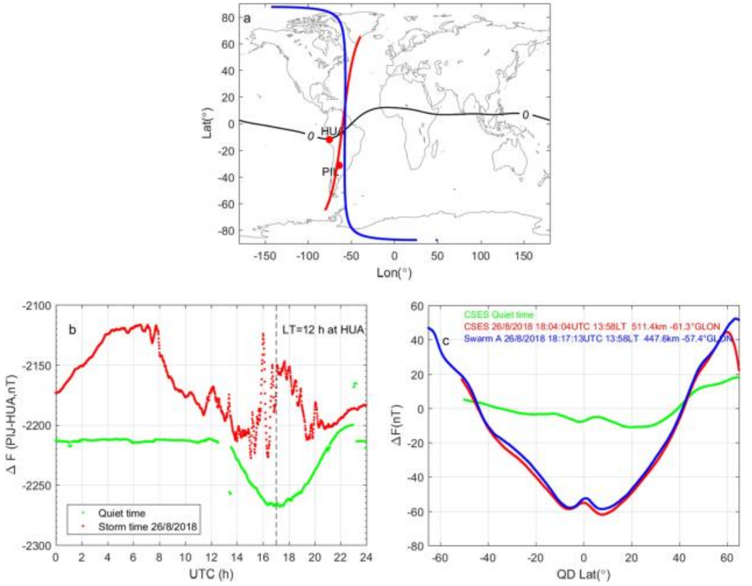
- Estimate FACs

$$j_r = \frac{1}{\mu_0 v_x}\frac{dB_\phi}{dt},$$

$$j_{FAC} = j_r / \sin(I)$$

is the residual of the eastward magnetic field after removal of core, crustal and magnetospheric fields using the CHAOS model

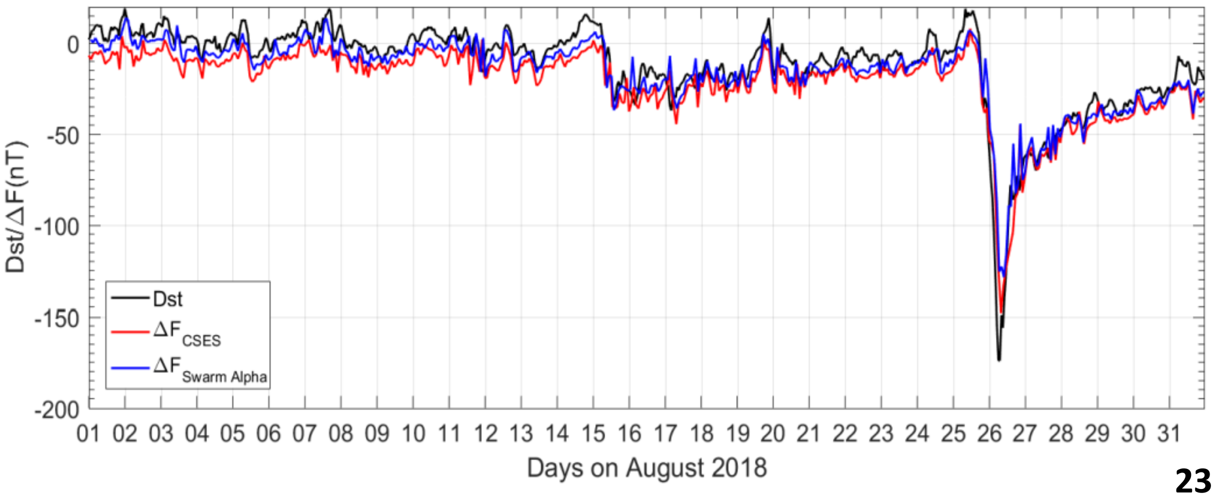




- FACs observed on CSES and Swarm is consistent with model results;
- During Storm time (strong activities), clear equatorward movement of FACs can be observed.

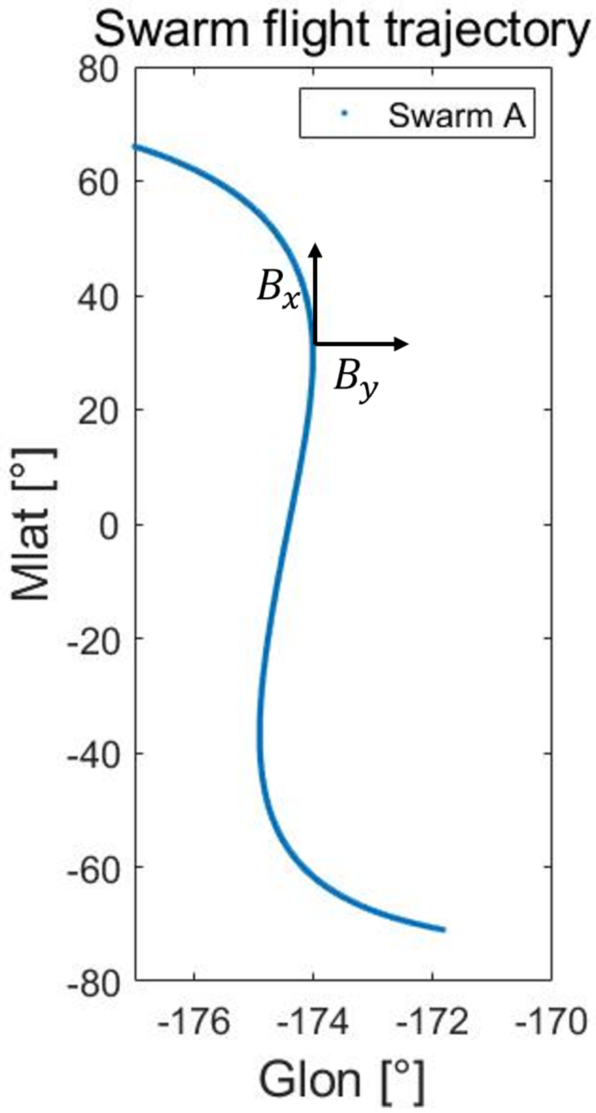
- Study EEJ (CEJ)+Sq

- Using magnetic field intensity data, we can also produce estimates of the Dst index on an orbit-by-orbit basis
- Night time orbits
- For each orbit, the magnetic field data at dipole latitude 0° is chosen as the dataset
- Use CHAOS-6-x7 model to remove core and crust field



[Yang et al., JGR, 2021]

Scientific study : ionosphere current systems



The traditional form of Ampère's law, the curl-**B** relation, was employed to calculate the vertical current density,

$$\mathrm{j_z} = \frac{1}{\mu_0}\left[\frac{\partial B_y}{\partial x} - \frac{\partial B_x}{\partial y}\right] \qquad (1)$$

With only one satellite, the equation can be reduced to

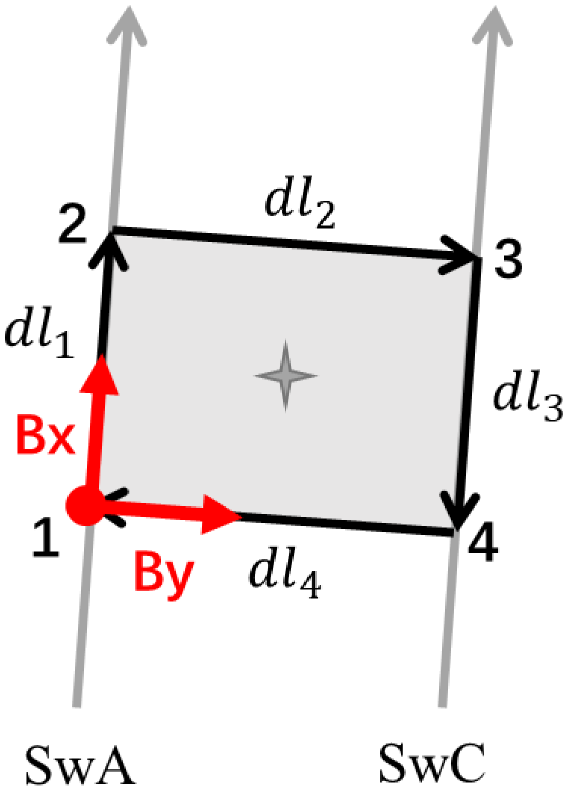
$$\mathrm{j_z} = \frac{1}{\mu_0}\frac{1}{v_x}\frac{\partial B_y}{\partial t} \qquad (2)$$

Assumptions:

- the recorded ΔB_y variations represent spatial gradients (not temporal variations).
- ΔB_y is caused entirely by the current traversed (not by external sources).
- the traversed currents are organized in elongated sheets perpendicular to the flight direction.

[Lühr et al.,1996; 2020]

Scientific study : ionosphere current systems



The vertical current density estimates are derived by applying Ampère's ring integral:

$$j_z = \frac{1}{\mu_0 A}\oint \boldsymbol{B}\cdot\boldsymbol{dl} \qquad (1)$$

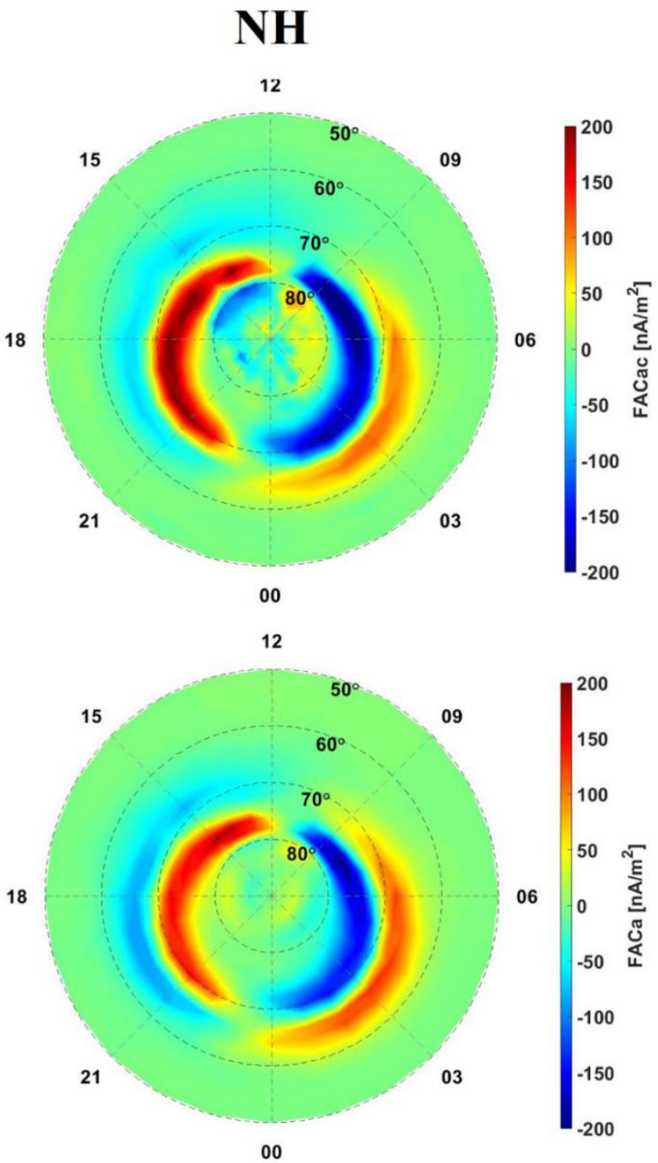
In the practical calculation ,the discrete form is used

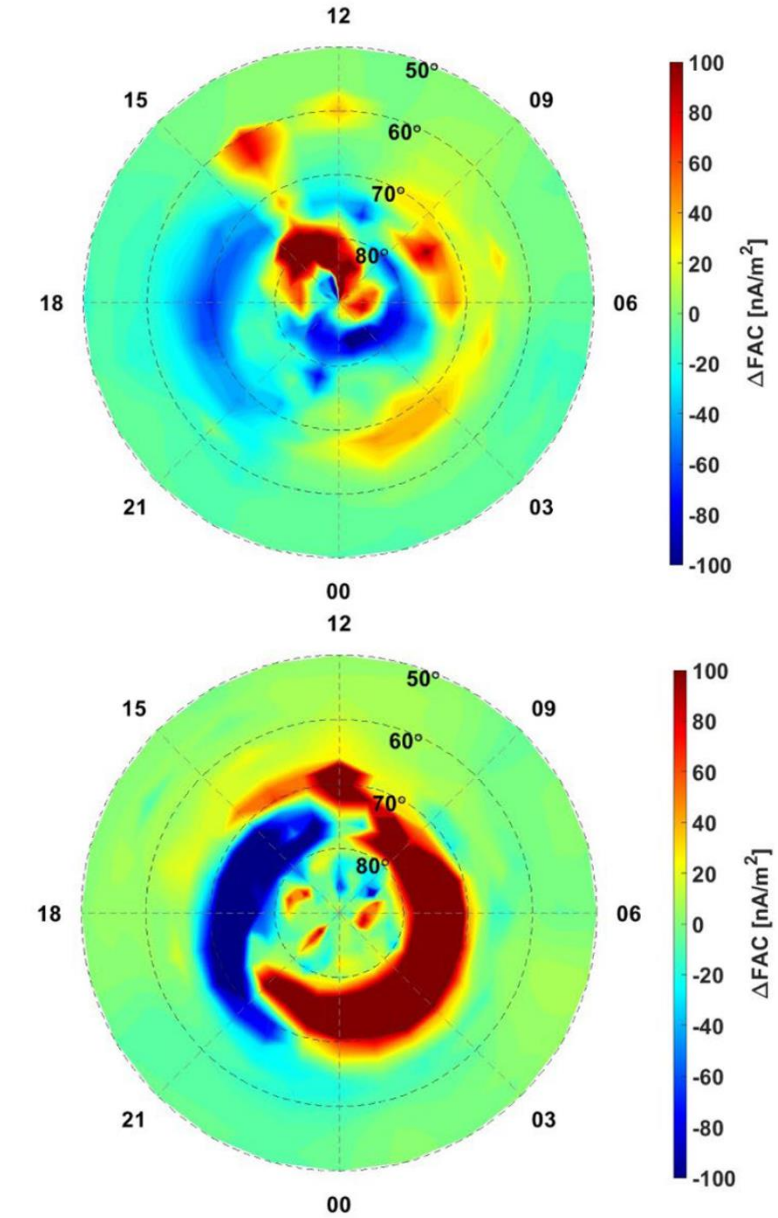
$$j_z = \frac{1}{2\mu_0 A}[(B_{x1} + B_{x2})dl_1 + (B_{y2} + B_{y3})dl_2$$

$$-(B_{x3} + B_{x4})dl_3 - [(B_{y4} + B_{y1})dl_4] \qquad (2)$$

[Ritter et al.,2013]

Scientific study : ionosphere current systems





[Xiong et al., JGR, 2023]

Scientific study : magnetic field disturbance before Earthquake

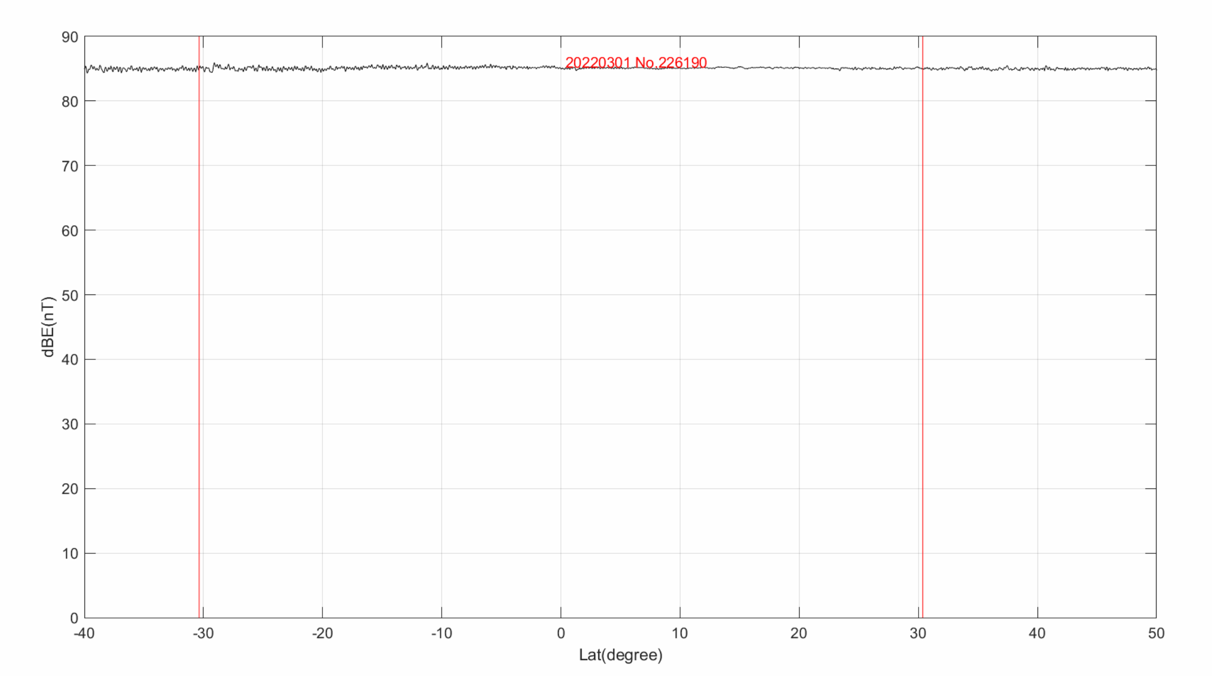
Ms 6.1 Lushan EQ on 1 June 2022 17: 00 UTC

Location: 30.37°N， 102.94W°

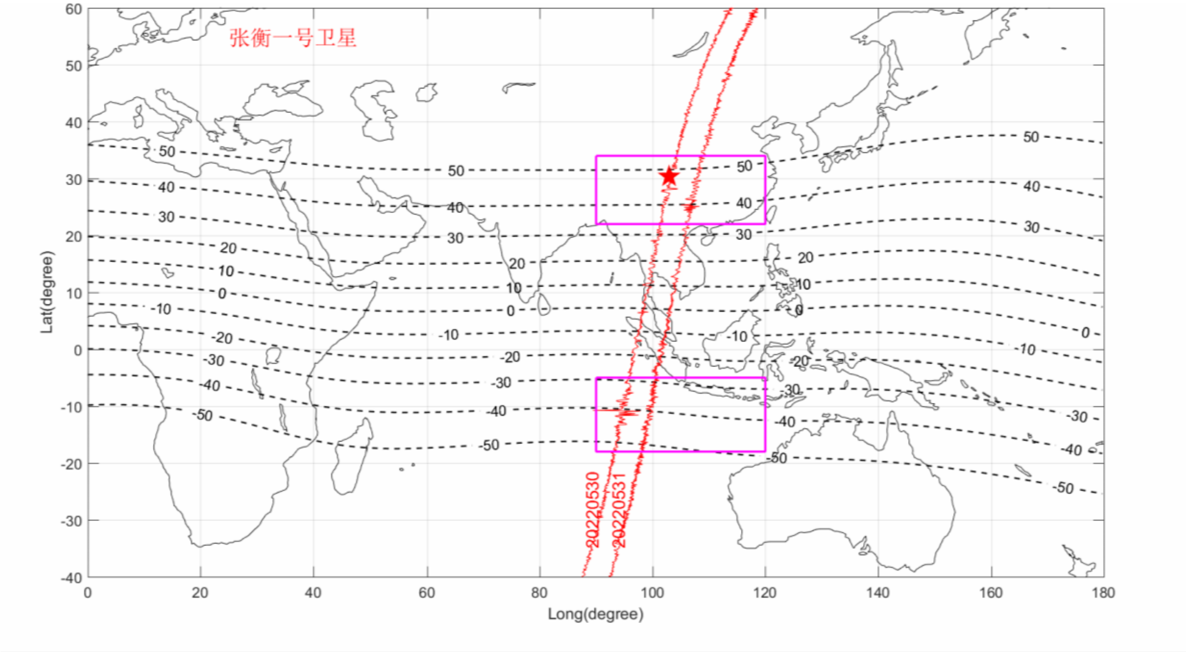
Depth: 17km

Both CSES and Swarm observed clear disturbance

Before 30 May 2022, magnetic field is very quiet



Spatial distribution of the magnetic field disturbance: CSES and Swarm



Clear magnetic field disturbance is observed 2 days before the EQ

Content

1. The the project’s objectives

2. Overview of CSES/Swarm cooperation activities

3. Outcomes of CSES/Swarm cooperation

   - ➢ Plasma data

   - ➢ Magnetic field data

   - ➢ Publications and young scientists achievements

4. Proposals for next-step bilateral cooperation

Paper with Published (32)

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3. *Diego P., Huang, J., Piersanti, M., Badoni, D., Zhima Z., Yan, R., Rebustini, G., Ammendola, R., Candidi, M., Guan, Y., Lei, J., Masciantonio, G., Bertello, I. , De Santis, C., Ubertini, P., Shen X. and Picozza, P. (2021). The Electric Field Detector on board the China Seismo Electromagnetic Satellite: In-Orbit Results and validation,Instruments,5,1. https://dx.doi.org/10.3390/instruments 5010001.*
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Young scientists contributions in Dragon 5

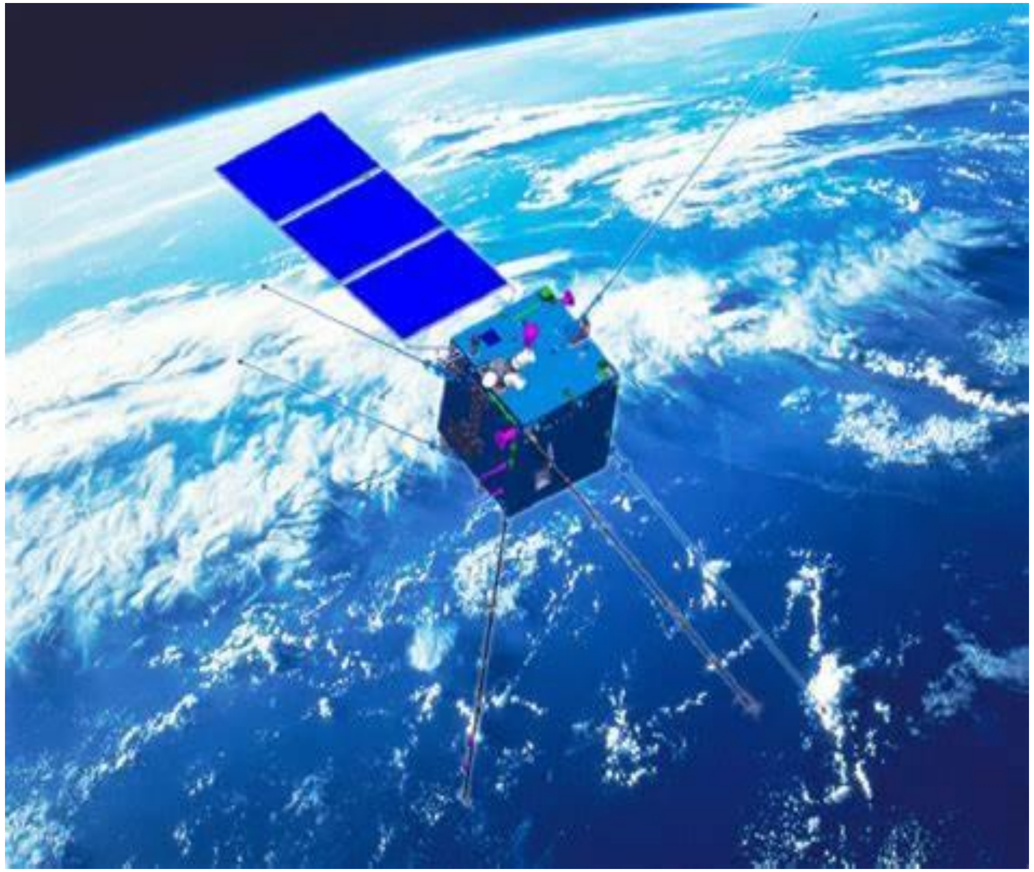
Name	Institution	Poster title	Contribution including period of research
YanYan Yang	**NINH – National Institute of Natural Hazards, the Ministry of Emergency Management of China**	**An Improved In-flight Calibration Scheme for CSES Magnetic Field data**	has carried out cross cal/val of CSES/Swarm magnetic field data and fished global geomagnetic field modeling using both CSES and Swarm data
Jie Wang	**NINH**		has completed post-doc study and built a global lithospheric magnetic field model based on CSES scalar magnetic data, now continues working at CSES team.
Keying Zhu	**NINH**		has completed master's thesis and graduated based on the LAP data calibration and scientific research.
Fangxian Lv	**NINH**		have completed master's thesis and graduated based on magnetic field data calibration and scientific research.
Giulia D' Angelo	**INAF-IAPS -National Institute of Astrophysics**		Using the plasma density data from Swarm and CSES for investigating the ionospheric small-scale irregularities.

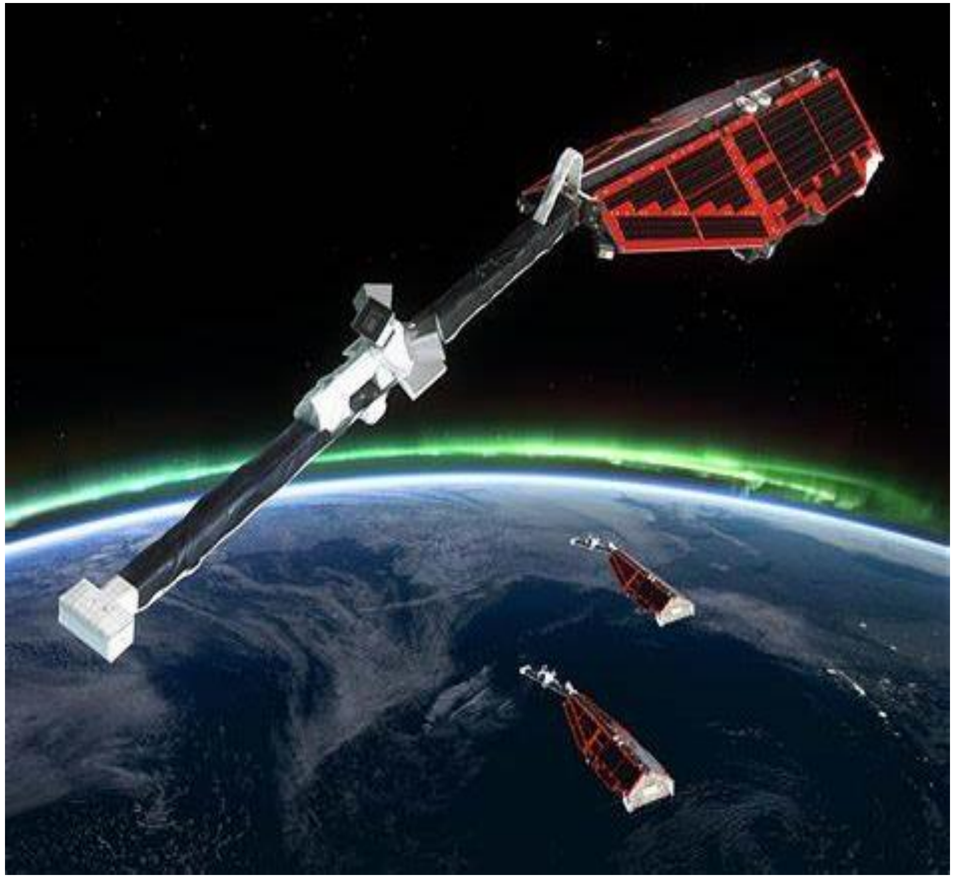
Content

1. The the project's objectives
2. Overview of CSES/Swarm cooperation activities
3. Outcomes of CSES/Swarm cooperation
4. Proposals for next-step bilateral cooperation

Goal: achieve high-level scientific outcomes

1. Jointly carry on the magnetic field, plasma data validation between Swarm and CSES;
2. Jointly modeling of geomagnetic field or ionosphere;
3. Jointly carry on the comprehensive studies on natural disaster events, e.g., earthquakes, volcano, geo-magnetic storms etc.;
4. Jointly develop and optimize the data processing tools for the magnetometers and Langmuir probe onboard CSES;
5. **Jointly investigating the ionospheric structures and related physical processes;**
6. **To explore the possibility for generating higher level scientific products from the magnetic measurements of CSES.**





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