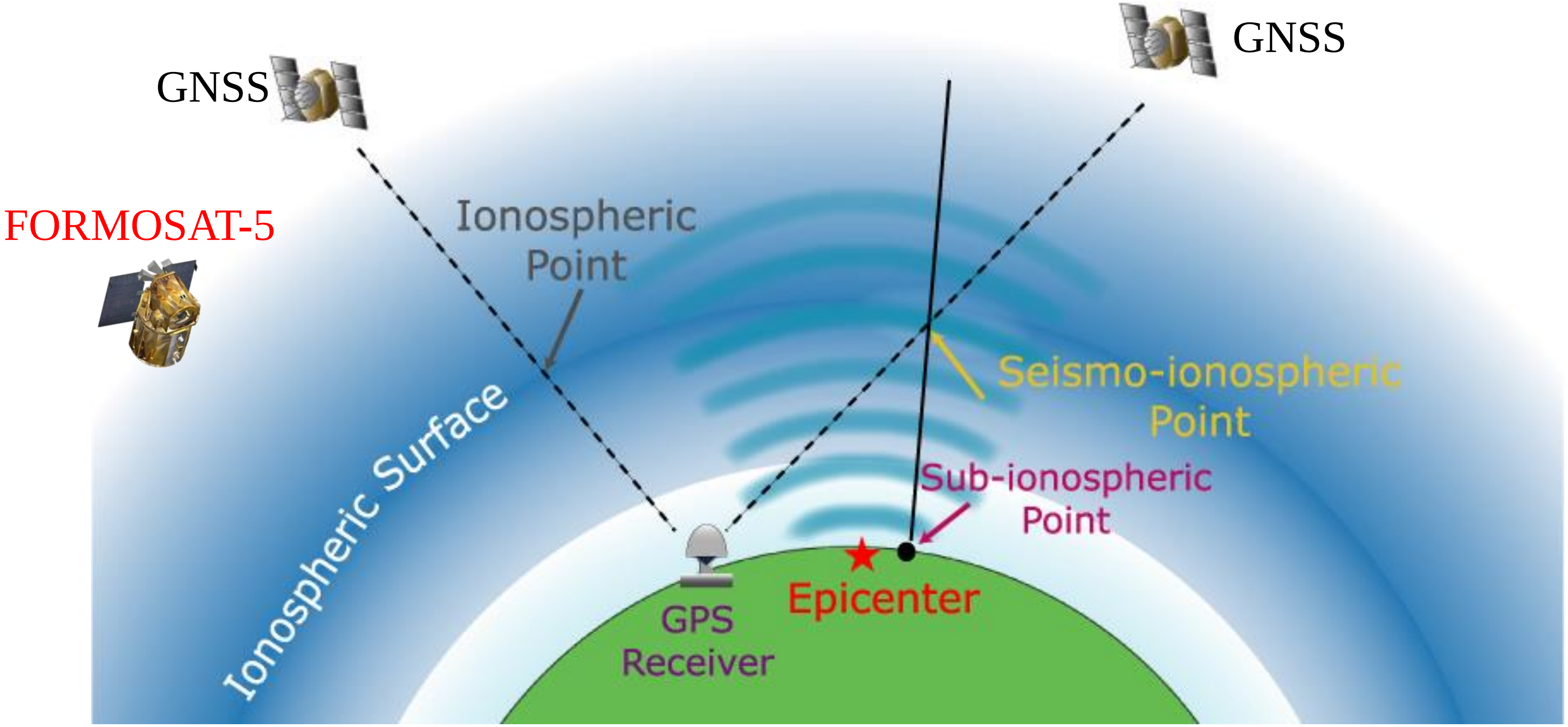
FOMOSAT-5 and FORMOSAT-7 Observations of Seismo-ionospheric Precursors



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Content

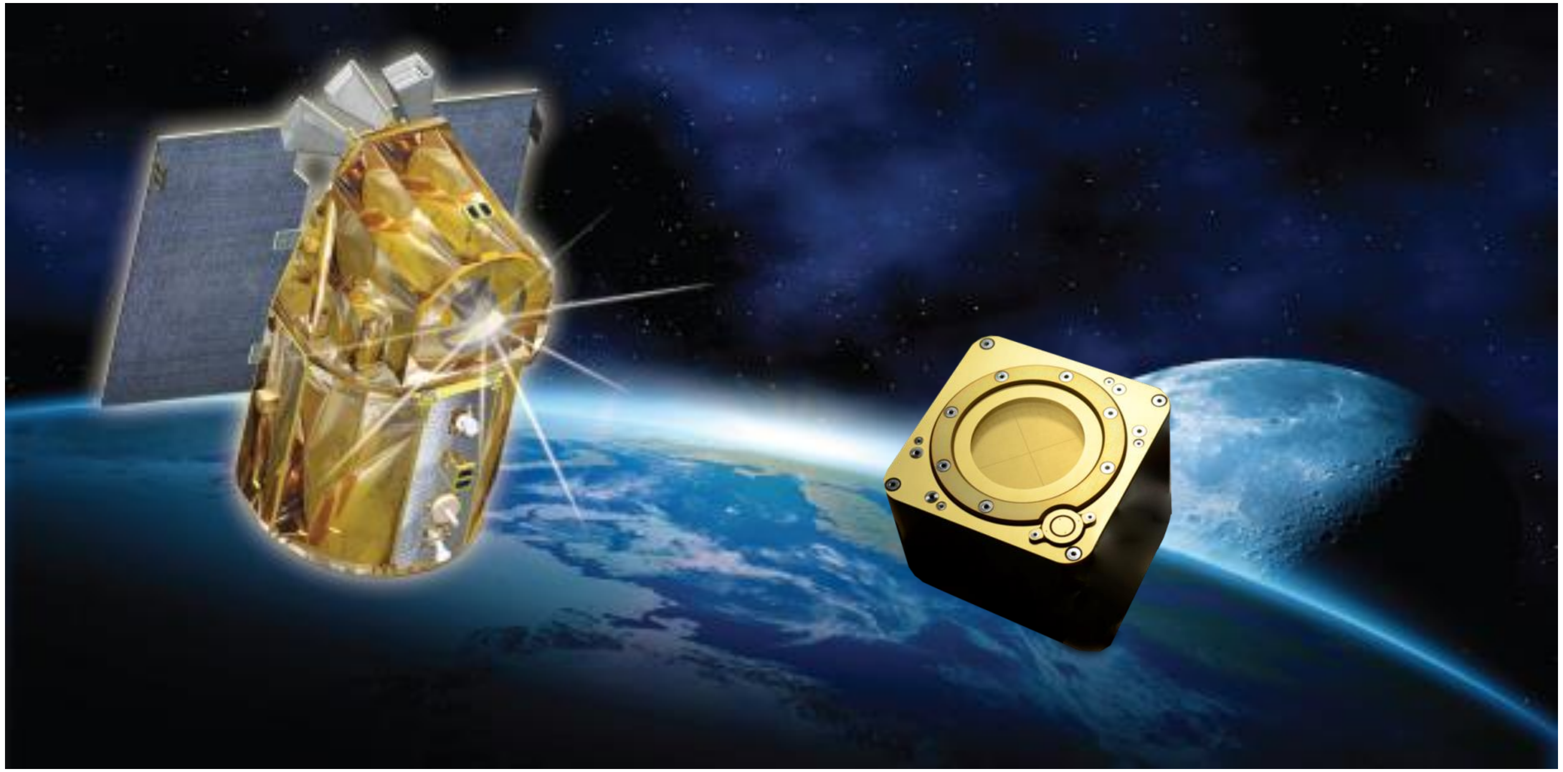
- FORMOSAT-5/Advanced Ionospheric Probe (F5/AIP)
- GIM TEC
- The 12 November 2017 M7.3 Iran-Iraq Border Earthquake

  - Temporal (characteristics) and spatial SIPs of GIM TEC

  - F5/AIP ion density and ion drift velocity
- Conclusion I
- FORMOSAT-7/COSMIC-2 TGRS and IVM
- The 14 November 2019 M7.1 Indonesia Earthquake
- Conclusion II

FORMOSAT-5
Advanced Ionospheric Probe (AIP)

二十年磨一針

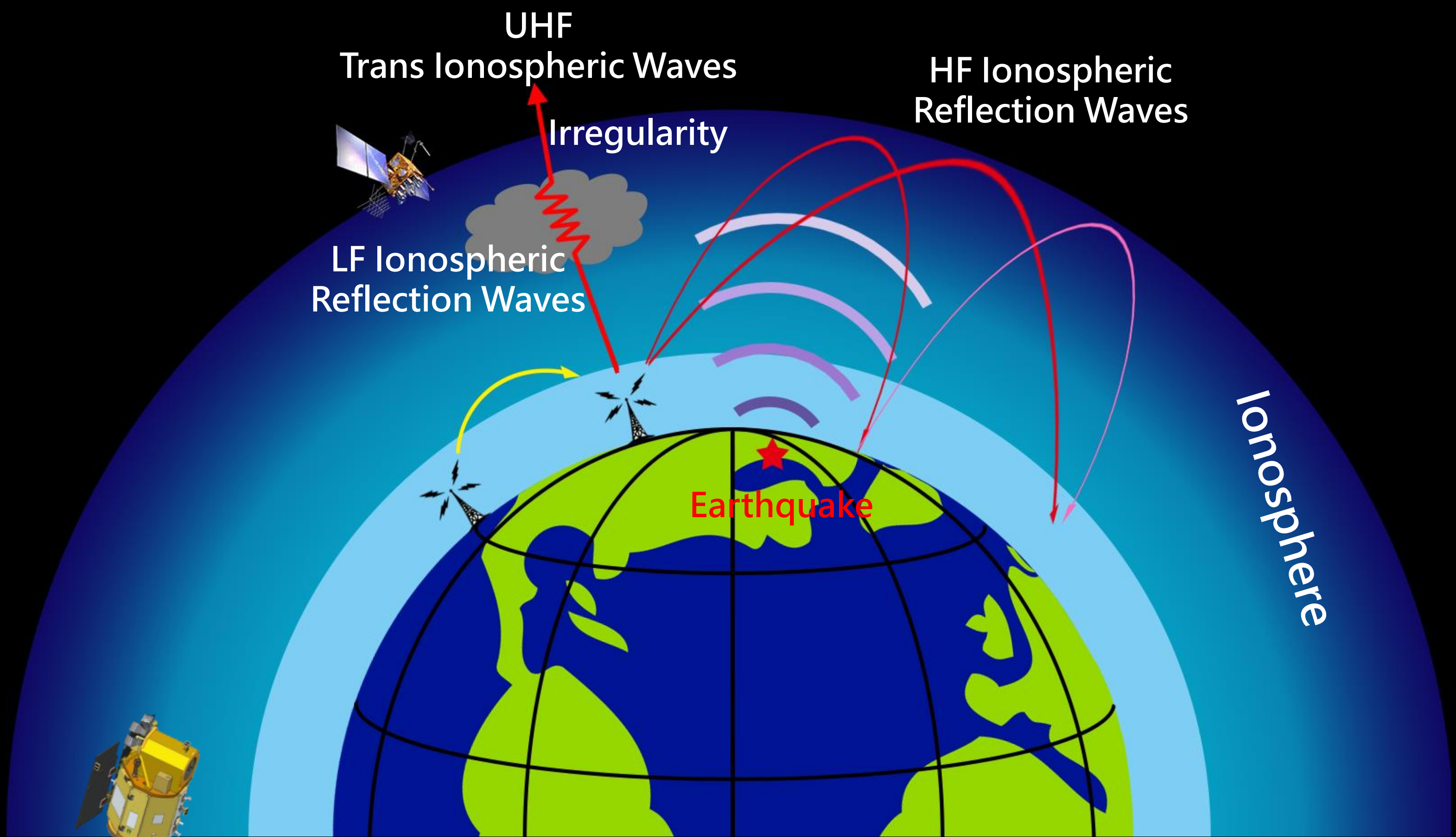


Altitude: 720km, Inclination: 98.28°, Mass: 555 kg.
Mission Payload: Optical Remote Sensing Imager (ORSI),
Science Payload: Advanced Ionospheric Probe (AIP)

FORMOSAT-5 (F5) launched on 25 August 2017 travels on a sun-synchronous orbit with 720 km altitude, 98.25-degree inclination, and 99-minute period.

FORMOSAT-5/AIP Science Mission

•**Space Weather-Plasma Structure/Dynamics and Irregularity**
(Communication, Positioning, and Navigation Monitoring Forecast)
•**Earthquake Precursor-Ionospheric Plasma Anomalies**
(Earthquake Forecast and Tsunami Early Warning)



FORMOSAT-5/AIP
(Advanced Ionospheric Probe)

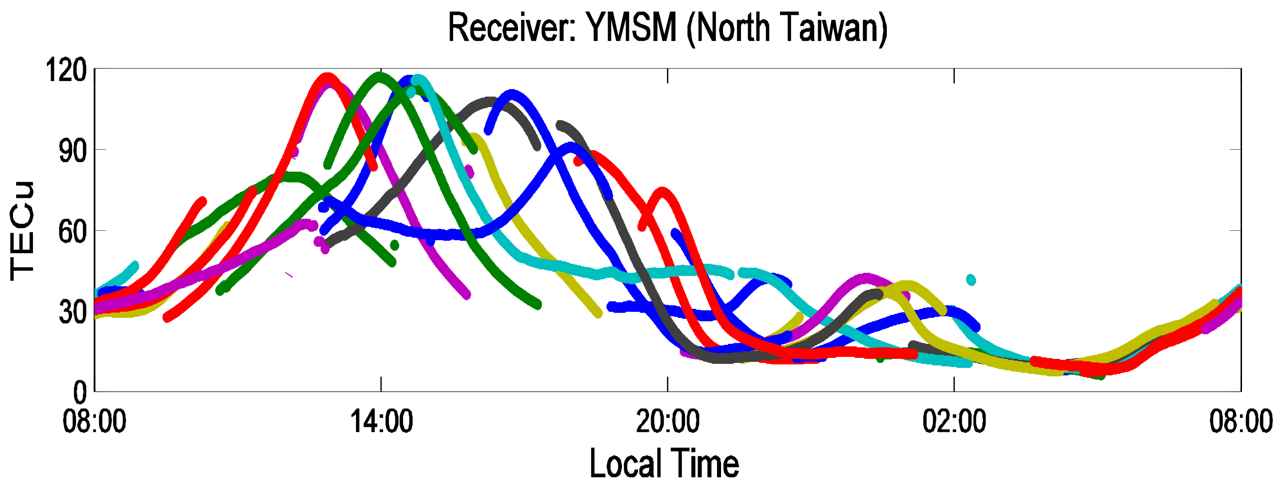
- Ion density
- Ion Temperature/composition
- 3D Ion Velocity
- Electron Temperature

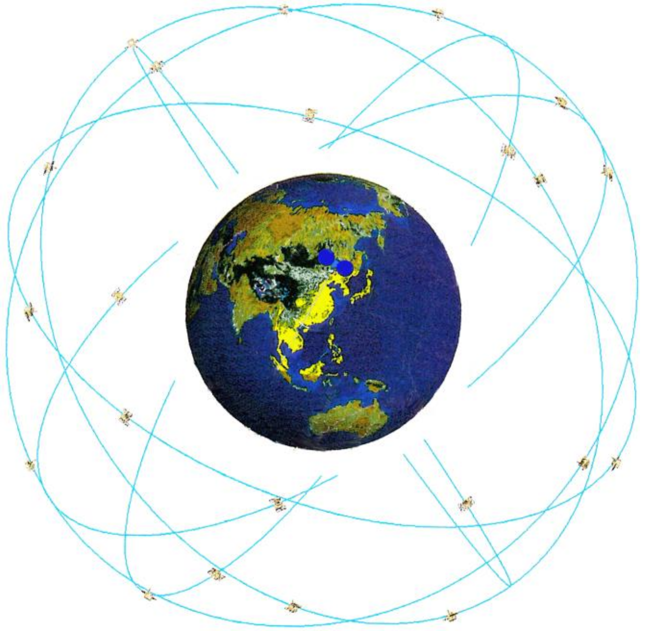
Sampling rate: 128/1024/8192

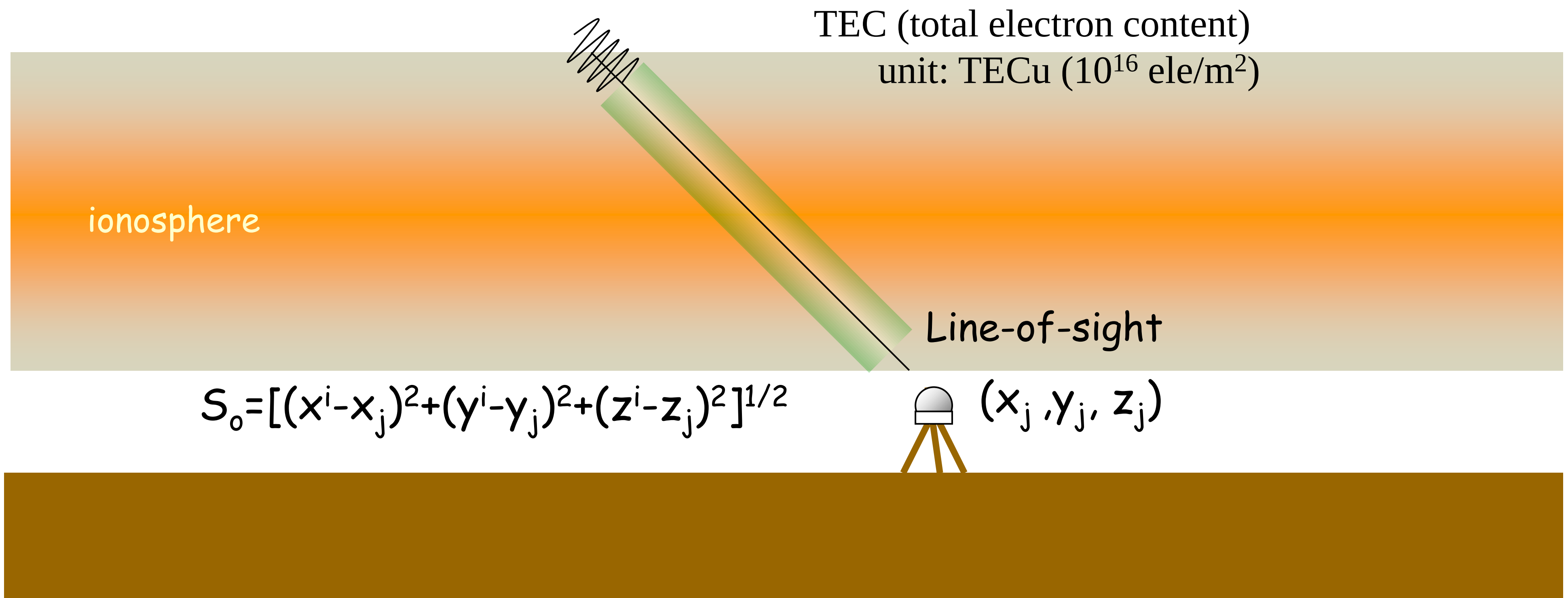
Data: after 1 November 2017

Most accurate Space Plasma Probe！

Ionospheric total electron content (TEC) derived from GNSS-GPS

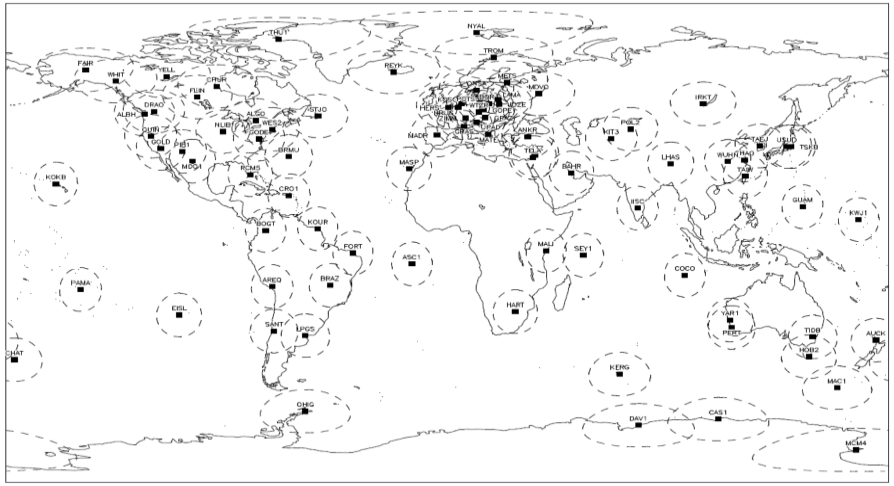






Global Ionosphere Map (GIM)

Worldwide 200 IGS GPS receivers

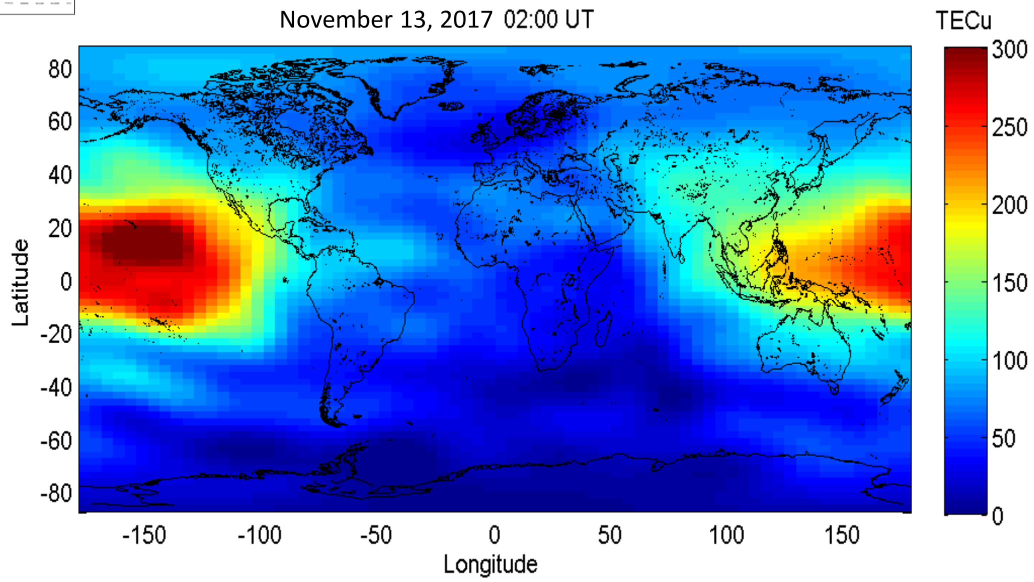


[Schaer, 1997]

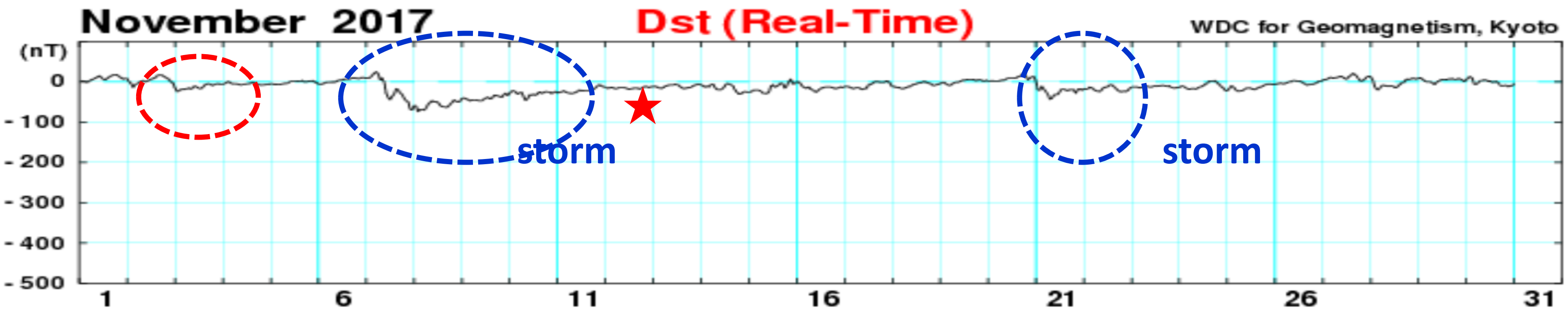
Center for Orbit Determination in Europe (CODE)

Time resolution: 1-hour
Spatial resolution: 2.5° latitude × 5° longitude

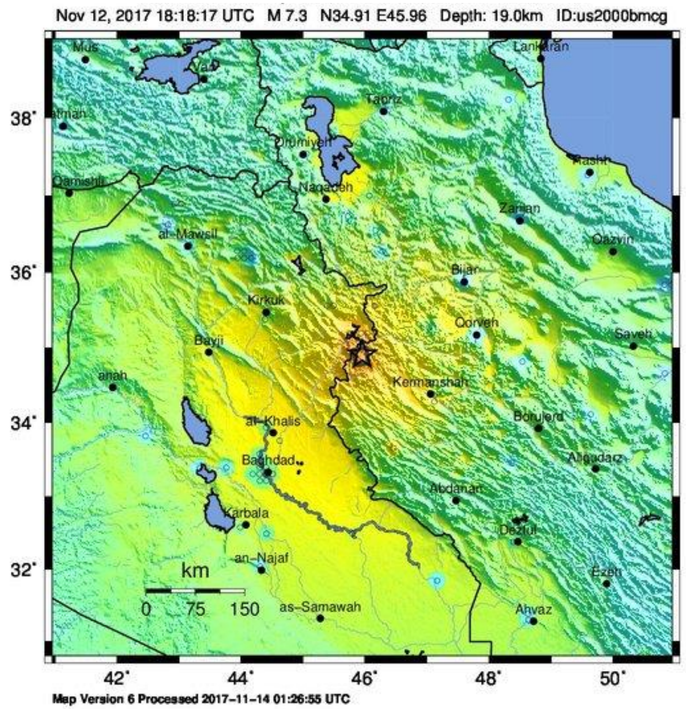
5183 (=73 x 71) lattices



The 12 November 2017 M7.3 Iran-Iraq Border Earthquake



34.9N, 46.0E



PERCEIVED SHAKING	Not felt	Weak	Light	Moderate	Strong	Very strong	Severe	Violent	Extreme
POTENTIAL DAMAGE	none	none	none	Very light	Light	Moderate	Mod./Heavy	Heavy	Very Heavy
PEAK ACC.(%g)	<0.05	0.3	2.8	6.2	12	22	40	75	>139
PEAK VEL.(cm/s)	<0.02	0.1	1.4	4.7	9.6	20	41	86	>178
INSTRUMENTAL INTENSITY	I	II–III	IV	V	VI	VII	VIII	IX	X+

Scale based upon Worden et al. (2012)

Death: 530
Serious Injury: 10018

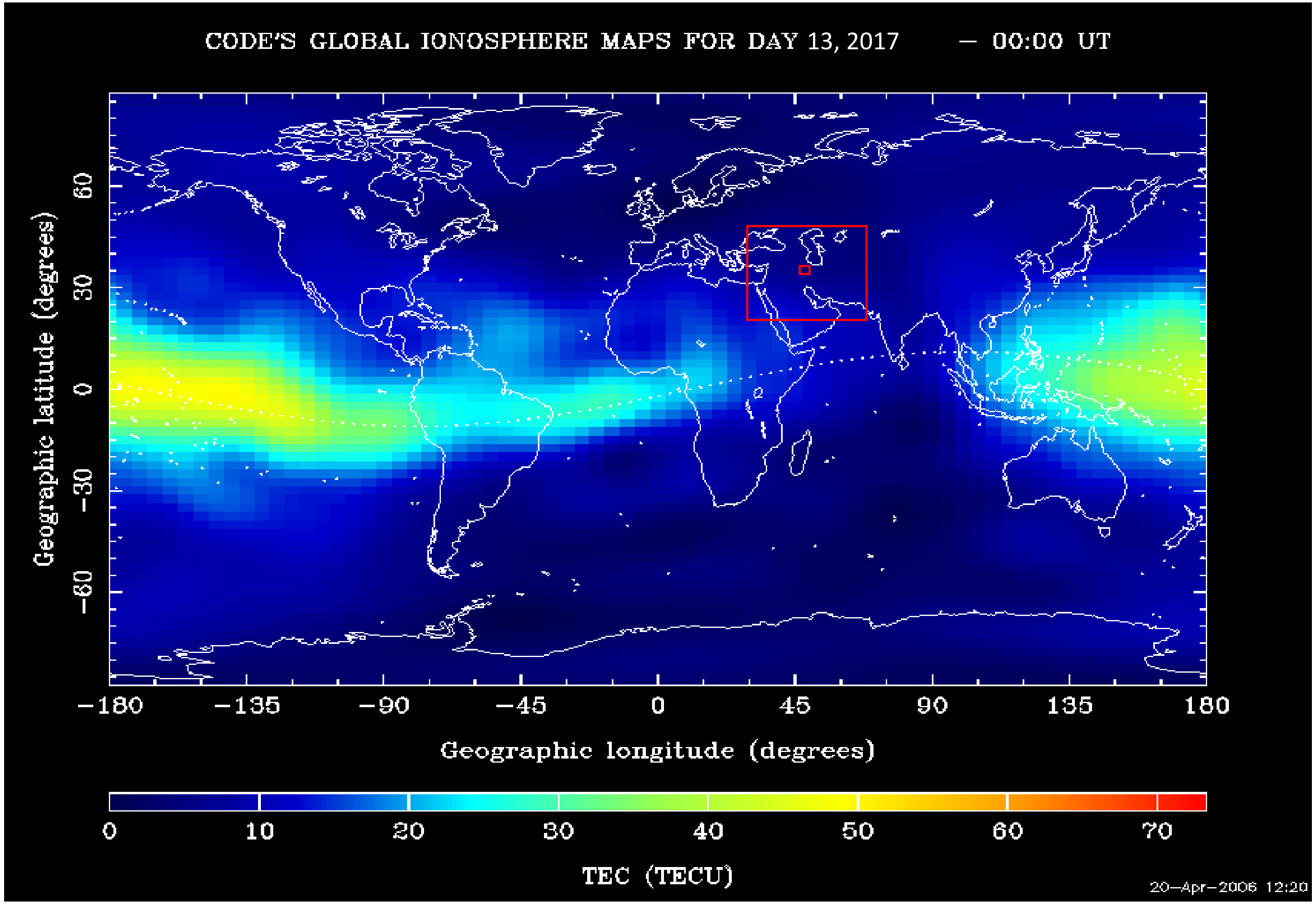
[USGS: https://earthquake.usgs.gov/earthquakes/eventpage/us2000bmcg#executive]

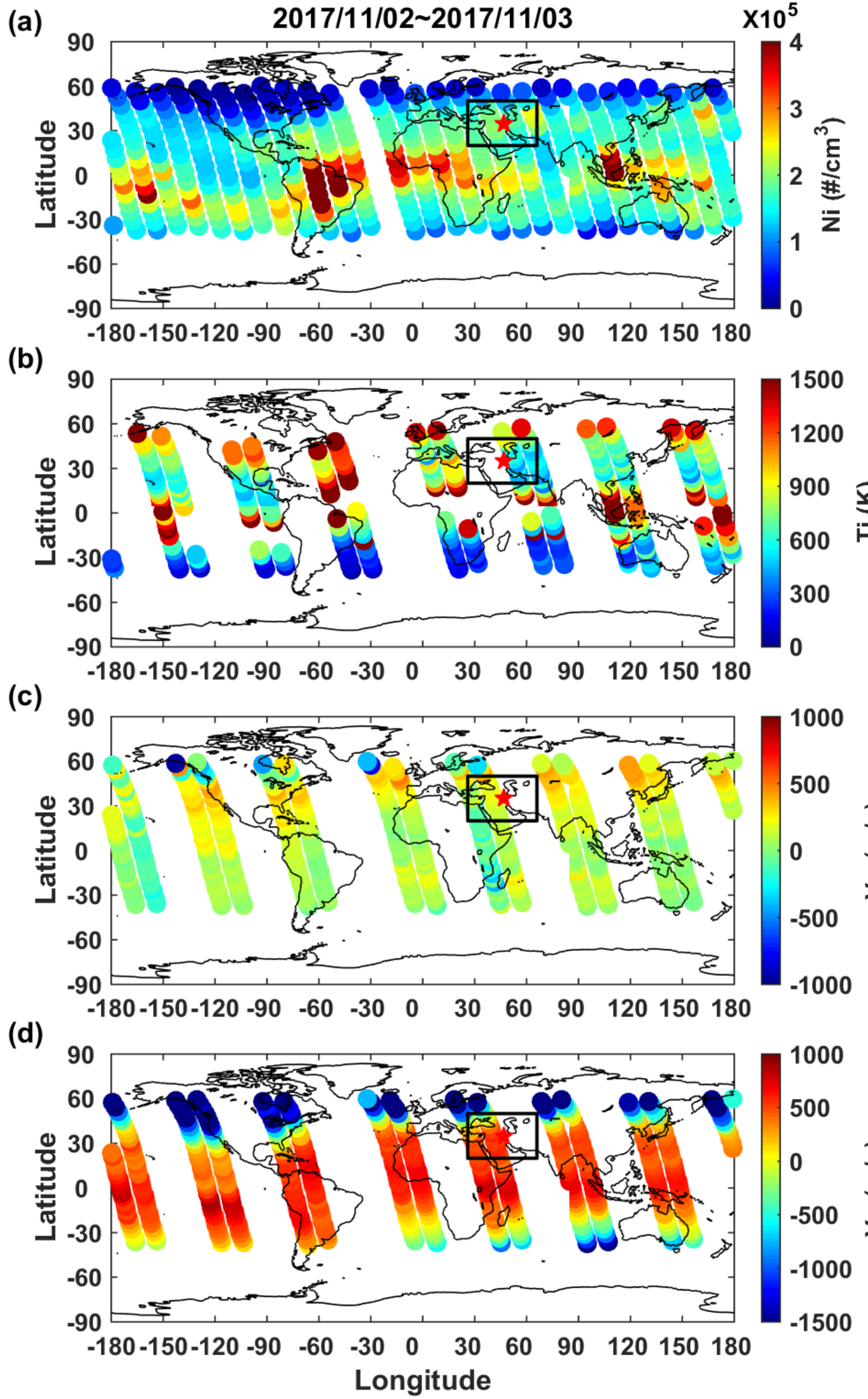
Global Ionosphere Map of the GNSS TEC

5183
grids

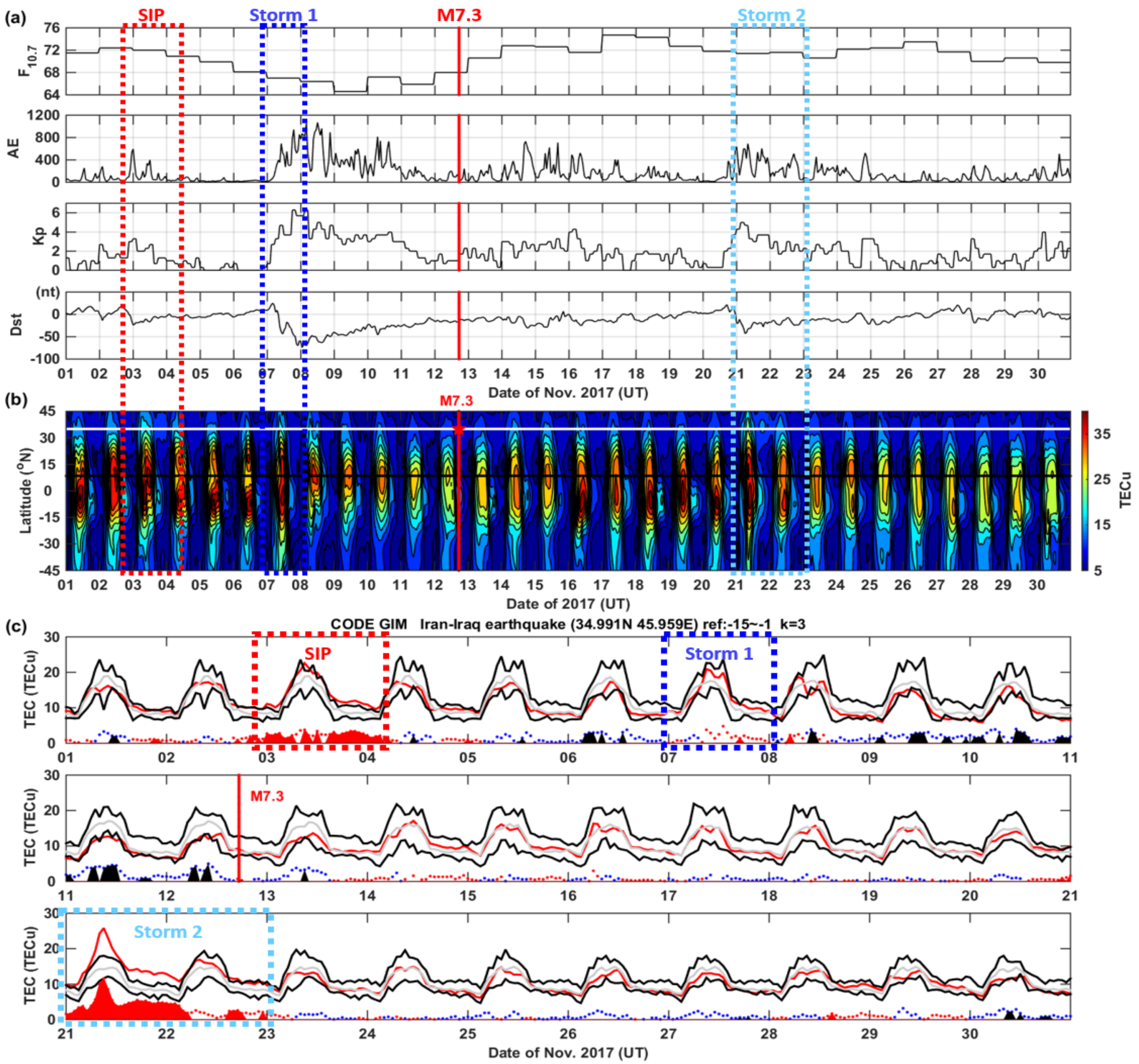
2.5°x5°
x2-hour

34.9°N, 46.0°E
20-50°N x 25-65°E

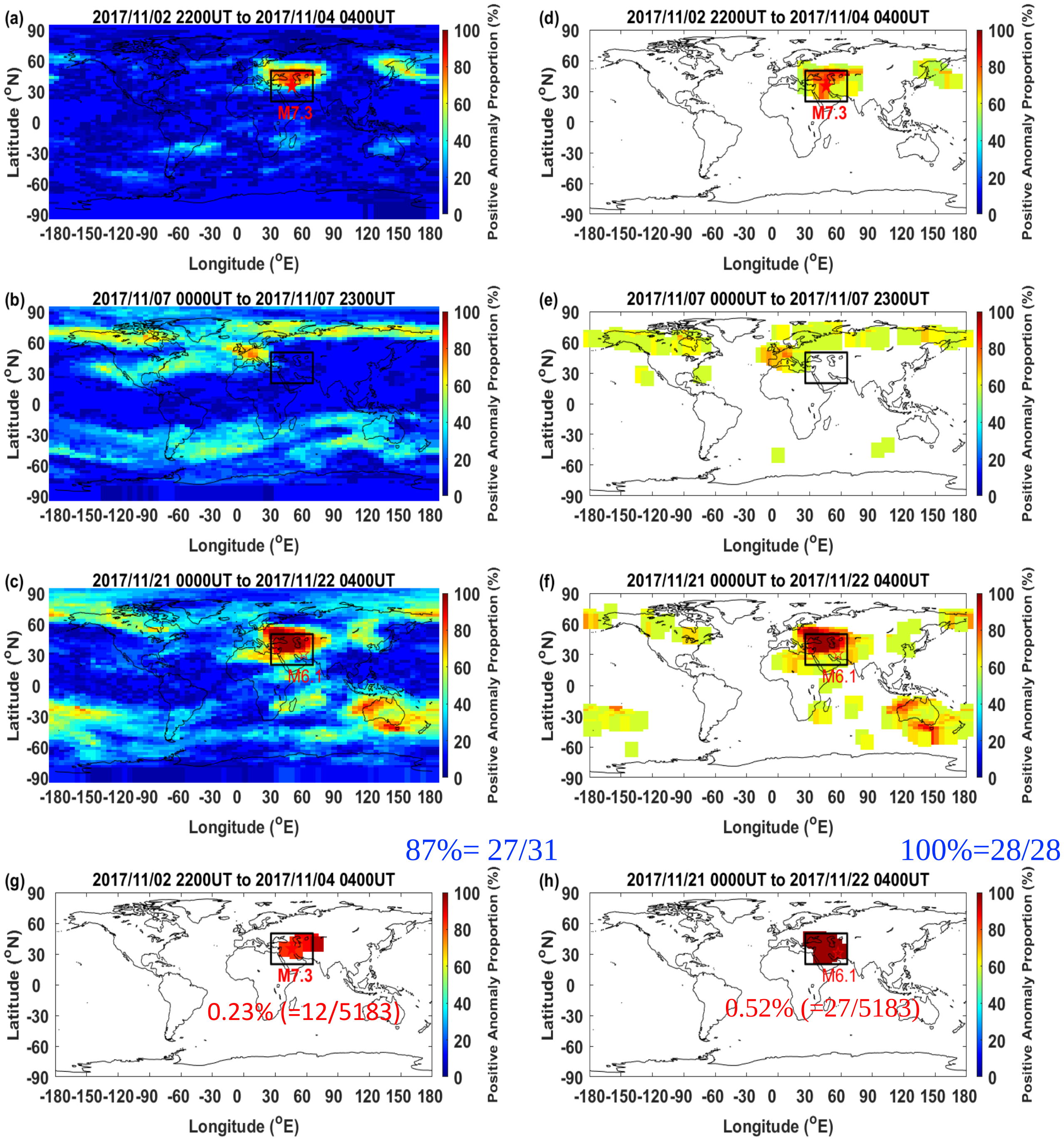




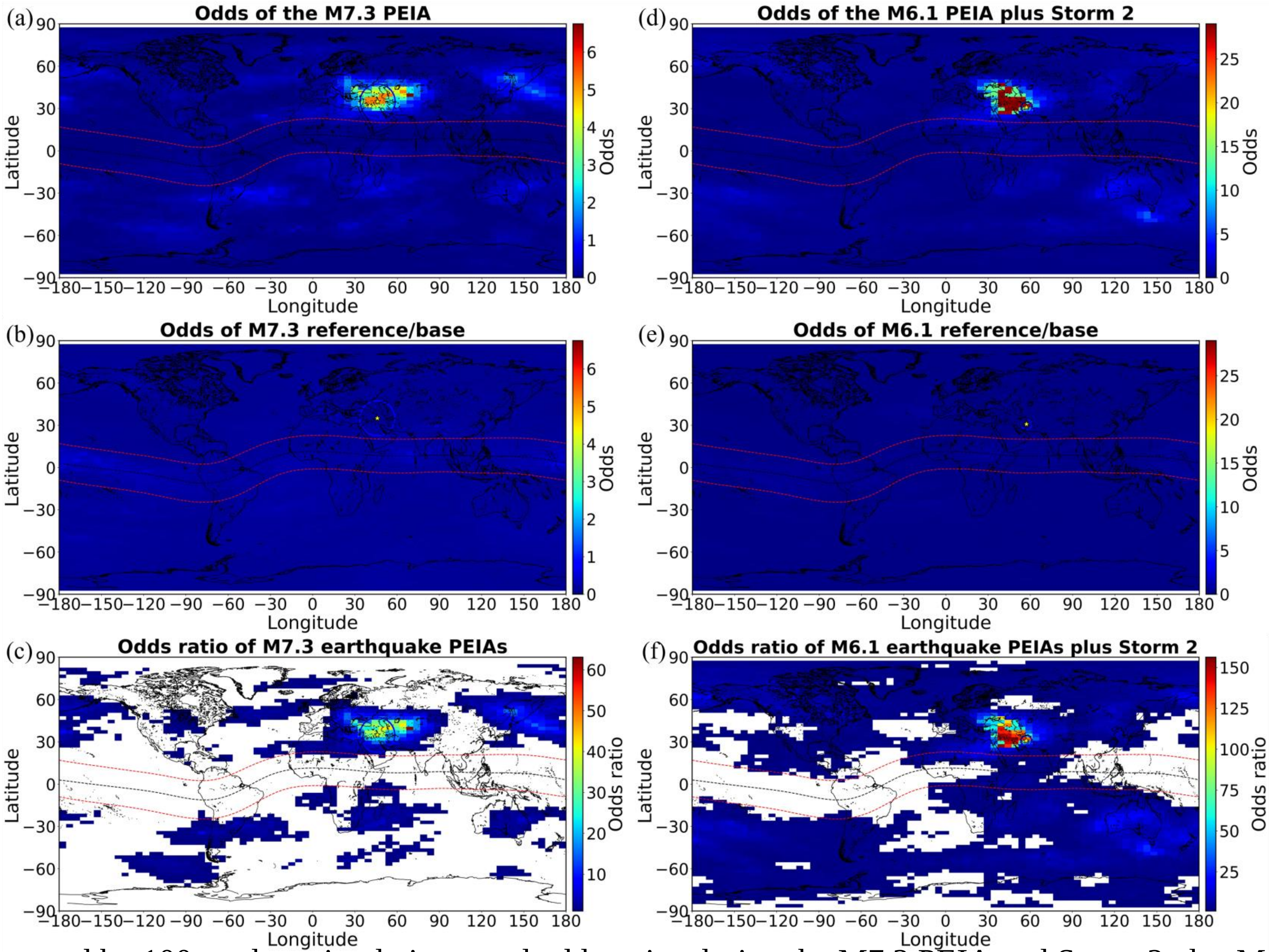
Global observations of F5/AIP (a) ion density (N_i), (b) ion temperature (T_i), (c) downward drift (V_D), and (d) eastward ion drift (V_E) probed at 22:30 LT on 2-3 November 2017. The red star denotes the epicenter of the 12 November 2017 M7.3 Iran-Iraq Border earthquake. The black rectangle represents the study area around the epicenter.



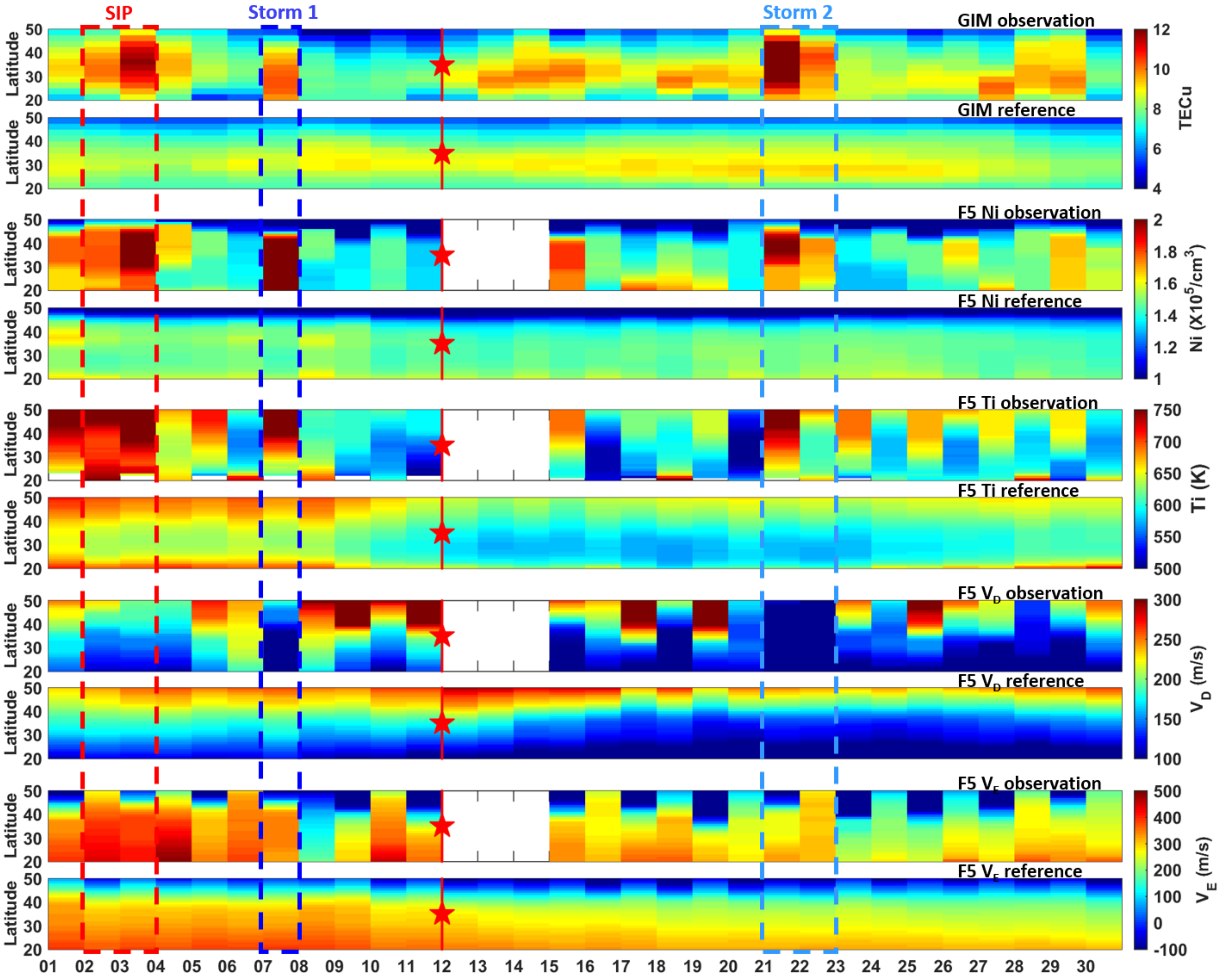
The solar radio flux, magnetic condition, and ionospheric TEC variations in November 2017.



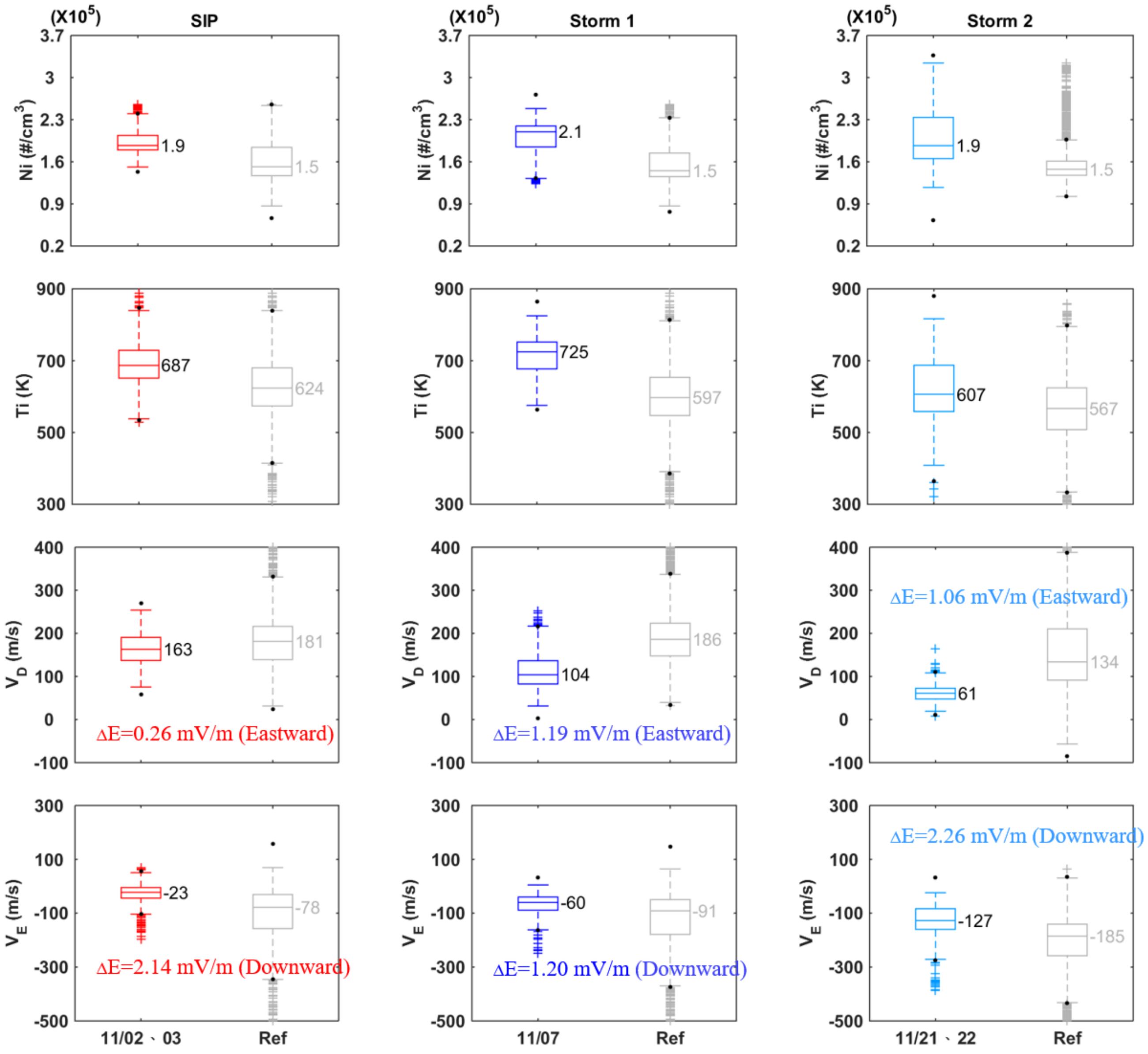
Distributions of positive GIM TEC anomaly occurrence percentages during periods of (a), (d), and (f), the M7.3 SIPs from 22:00UT on 2 November to 04:00UT on 4 November 2017; (b) and (e), Storm 1 from 00:00UT on 7 November to 23:00UT on 7 November 2017; and (c), (f), and (h) Storm 2 from 00:00UT on 21 November to 23:00UT on 22 November 2017. (a)-(c) without any percentage threshold, (d)-(e) with the percentage threshold of 50%, (f) the top occurrences percentage of 77%, and (h) the top occurrences percentage of 100% The solid and open red stars denote the epicenter of the 12 November 2017 M7.3 earthquake and 1 December 2017 M6.1 earthquake, respectively.



Odds, odds bases constructed by 100 random simulations, and odds ratios during the M7.3 PEIA and Storm 2 plus M6.1 PEIA periods. (a) Odds in the M7.3 PEIA period, (b) Mean odds of the M7.3 reference/base, (c) Odds ratio of M7.3 earthquake PEIAs, (d) Odds in the M6.1 PEIA plus Storm 2 period, (e) Mean odds of M6.1 reference/base, and (f) Odds ratios of Storm 2 plus M6.1 earthquake PEIAs. White lattices denote ratios of odds being smaller than one.



GIM TEC and F5/AIP data and their associated references. The reference is the moving median 7 days before and after the observation day inside the rectangular area.



Box plots of the observation (left-hand side color box) and the associated reference (right-hand side gray box) of the ion density (top row), ion temperature (second row), downward velocity (third row), and eastward velocity (bottom row) during the M7.3 earthqu ake SIP (left column), Storm 1 (central column) and Storm 2 (right column).

Conclusion I

- The GIM TEC significantly/anomalously increases over the epicenter 7-9 days before the 12 November 2017 M7.3 Iran-Iraq Border Earthquake, which suggests that the temporal SIP of the earthquake has been detected.
- The GIM TEC positive anomalies frequently appear (87%) over the epicenter specifically (0.23%), which confirms the spatial SIP being observed.
- A well agreement of increases in the FORMOSAT-5/AIP ion density and the GIM TEC over the 12 November 2017 M7.3 Iran-Iraq Border Earthquake suggests the ion density, ion temperature, and ion velocity might be useful to study SIPs of global large earthquakes.
- The ion velocity can be the other vector quantity for detecting SIPs and deriving the seismo-generated electric field via the dynamo process **E** = - **V** x **B**.
- The seismo-generated electric field of 0.26 mV/m eastward and the prompt penetration electric field of 1.19 mV/m eastward for the first time are simultaneously estimated.
- Results show that the ionospheric weather can be modulated by electric fields from above of the space/magnetosphere and below of the atmosphere/lithosphere.

FORMOSAT-7/COSMIC-2

- **FORMOSAT-7/COSMIC-2 Constellation was launch on June 25, 2019 (Taiwan Time: April 15 2006) at Kennedy Space Center, U.S.A.**

- **Maneuvered into six different orbital planes (inclination ~24°) for optimal low latitude coverage (at ~550 km altitude).**

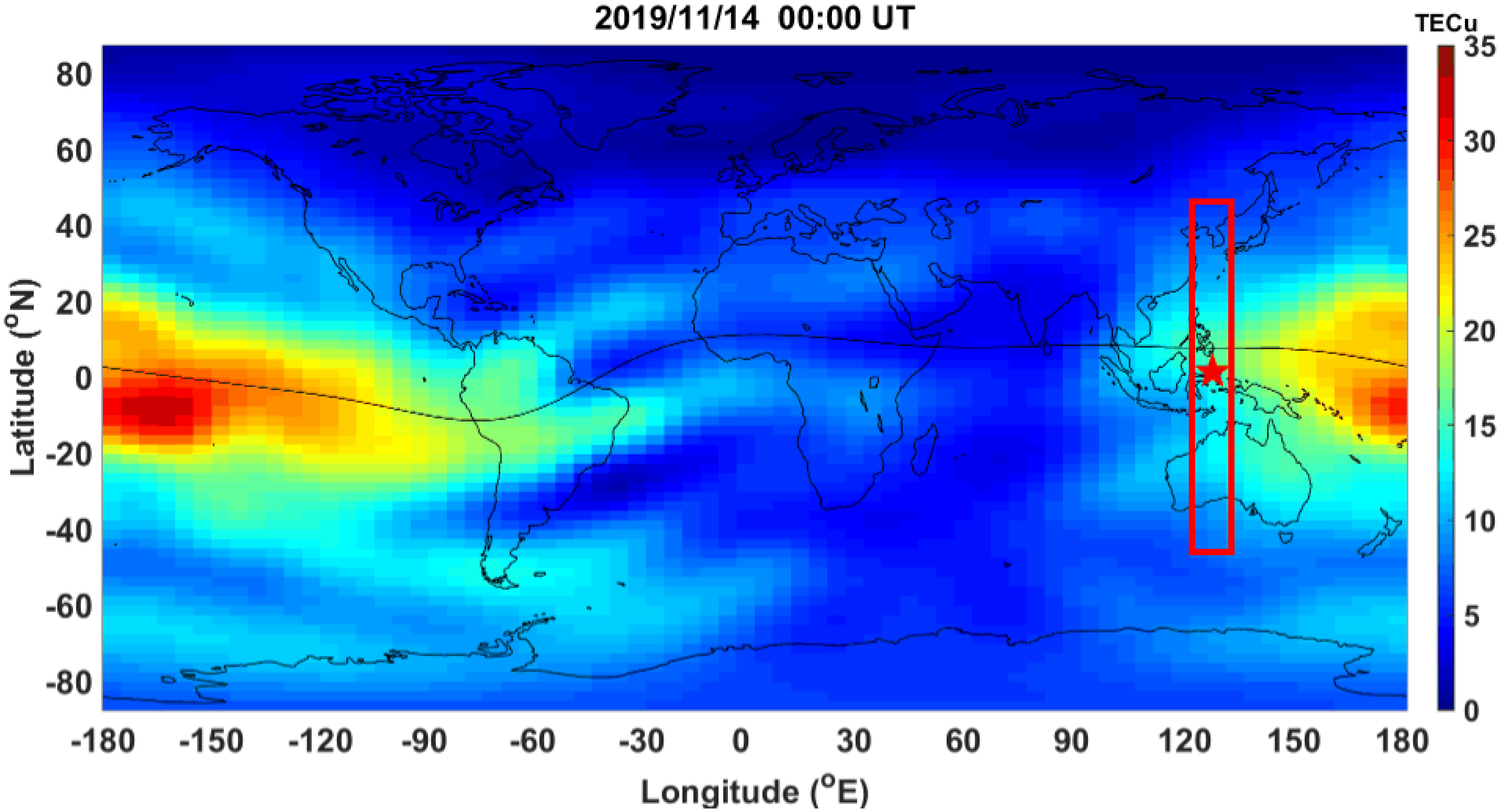
- **Payload:**

  Tri-GNSS Radio occultation System (TGRS)

  Ion Velocity Meter (IVM)

  Radio Frequency Beacon (RFB)

GIM TEC on 14 November 2019



14 November 2019 M7.1 Indonesia Earthquake

$$\boldsymbol{UB = M + k(UQ - M)}$$

$$\boldsymbol{LB = M - k(M - LQ)}$$

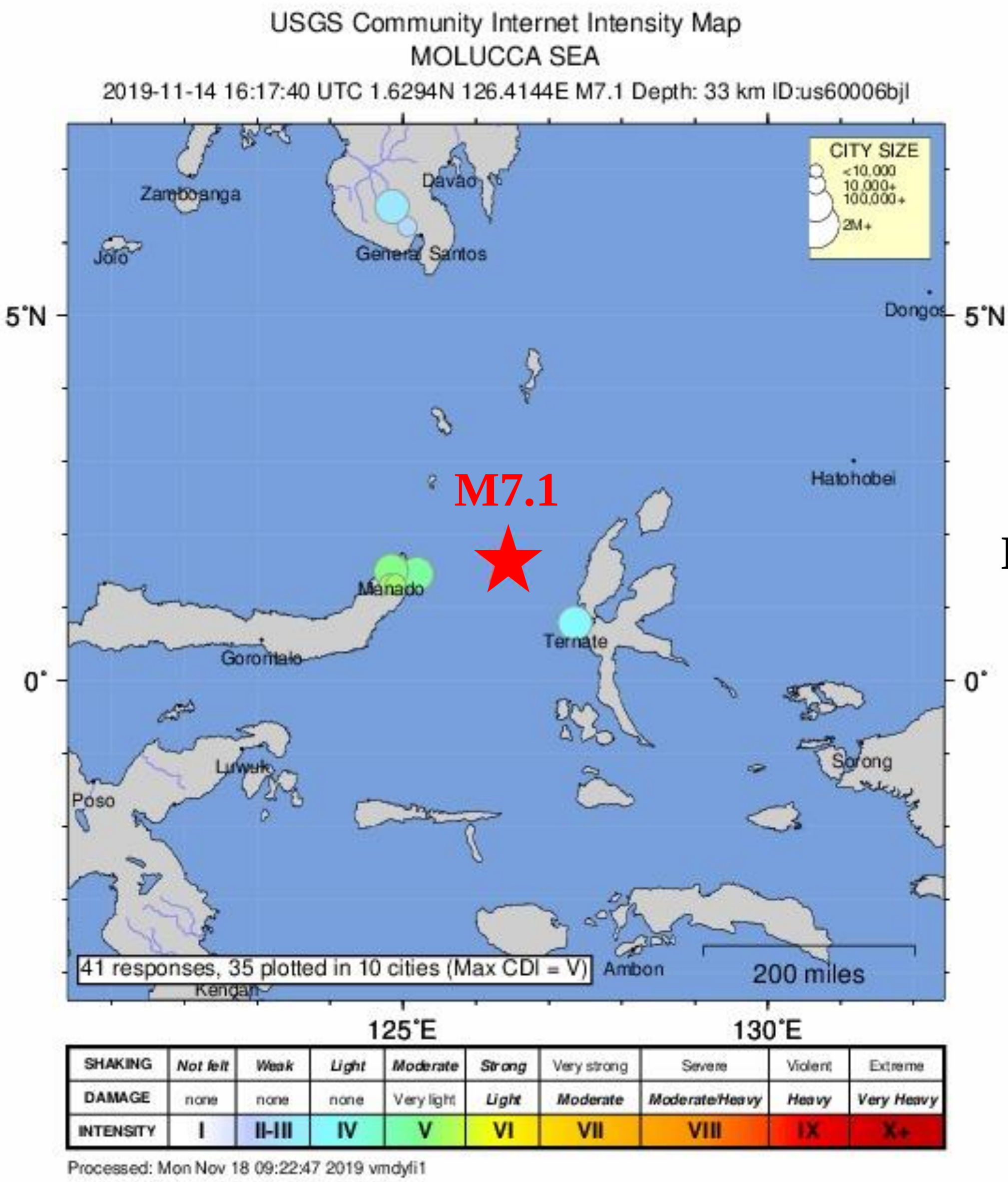
LQ: first quartile (25%)

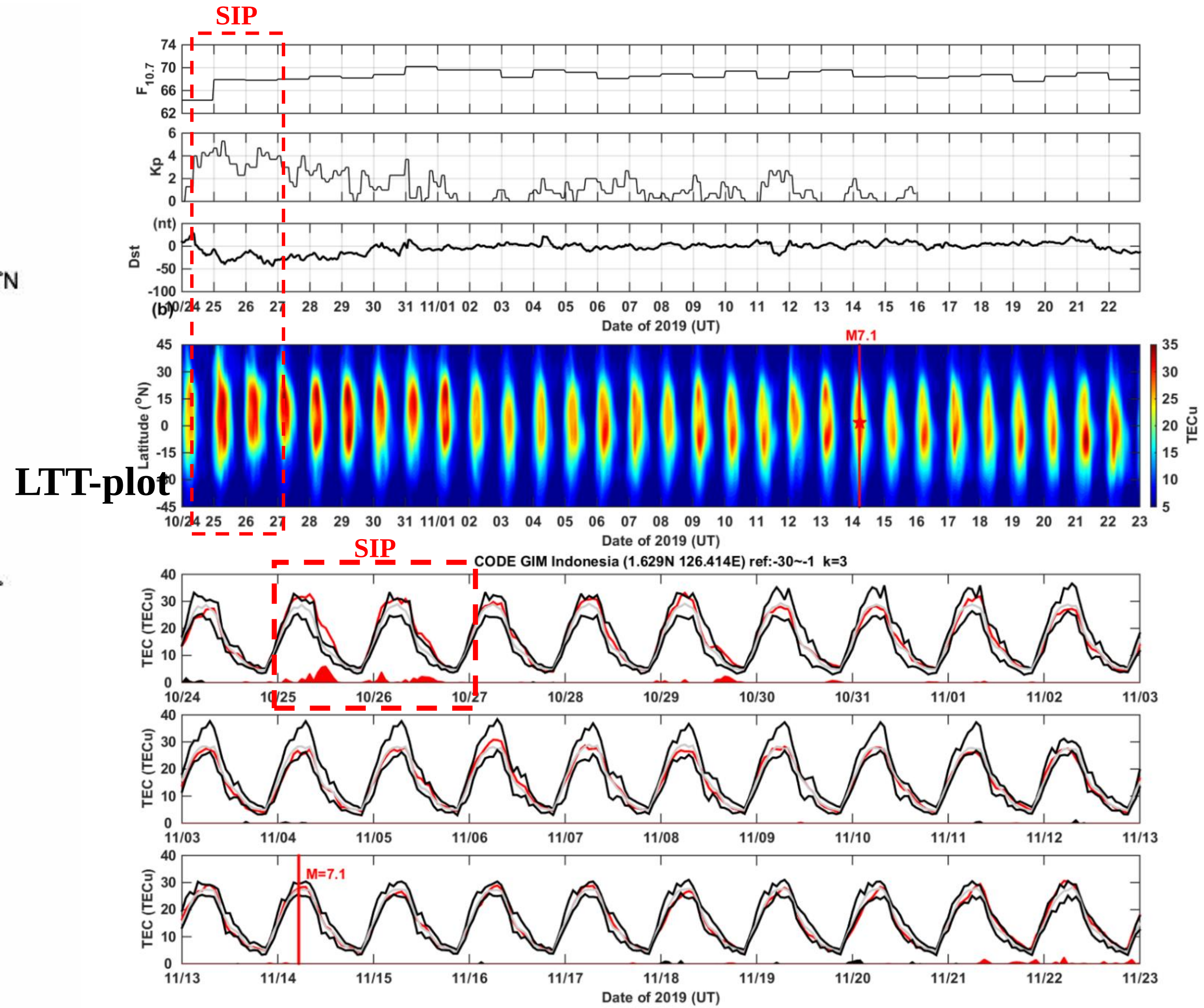
M: second quartile (50%)

UQ: third quartile (75%)

k: threshold constant

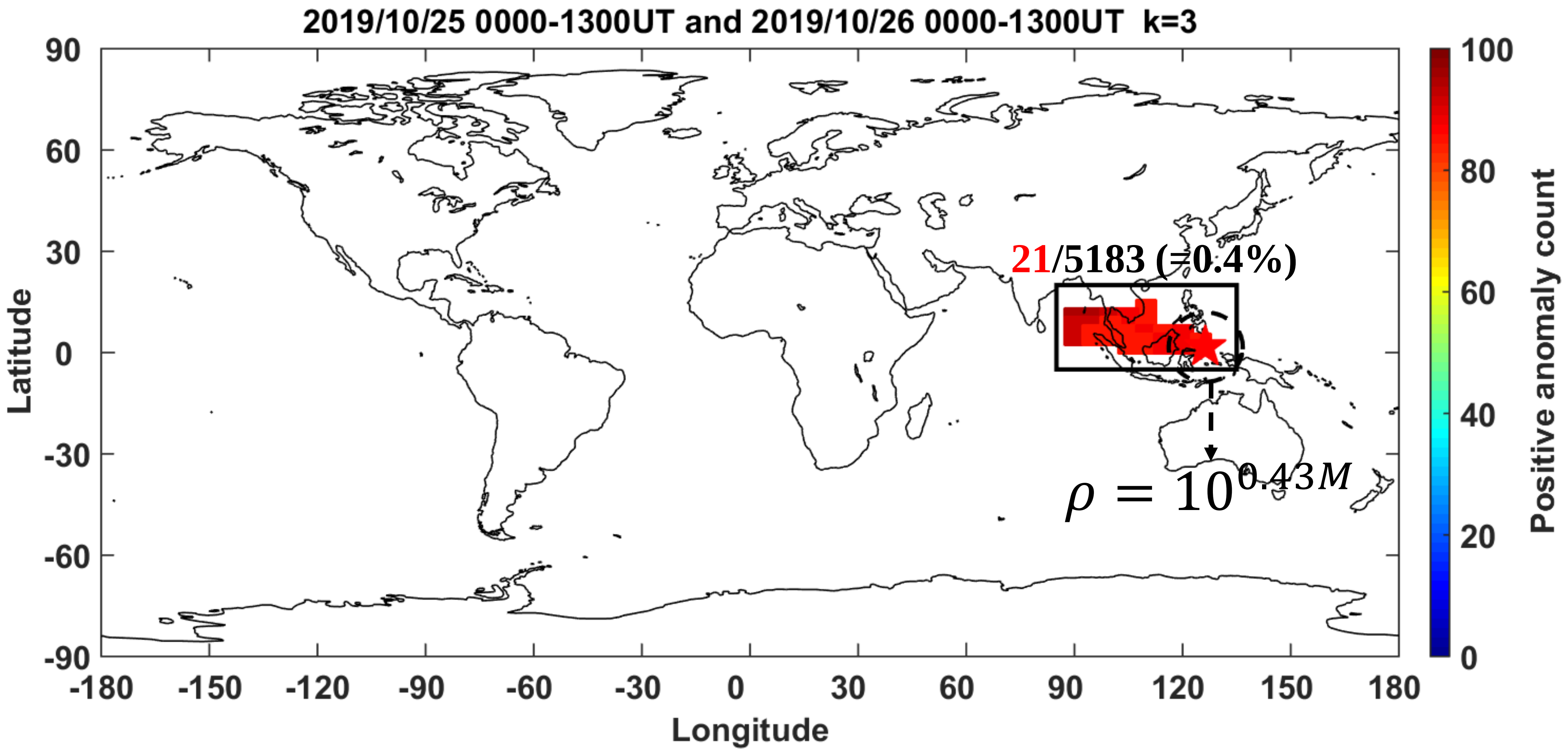
SIPs of the 14 November 2019 M7.1 Indonesia Earthquake



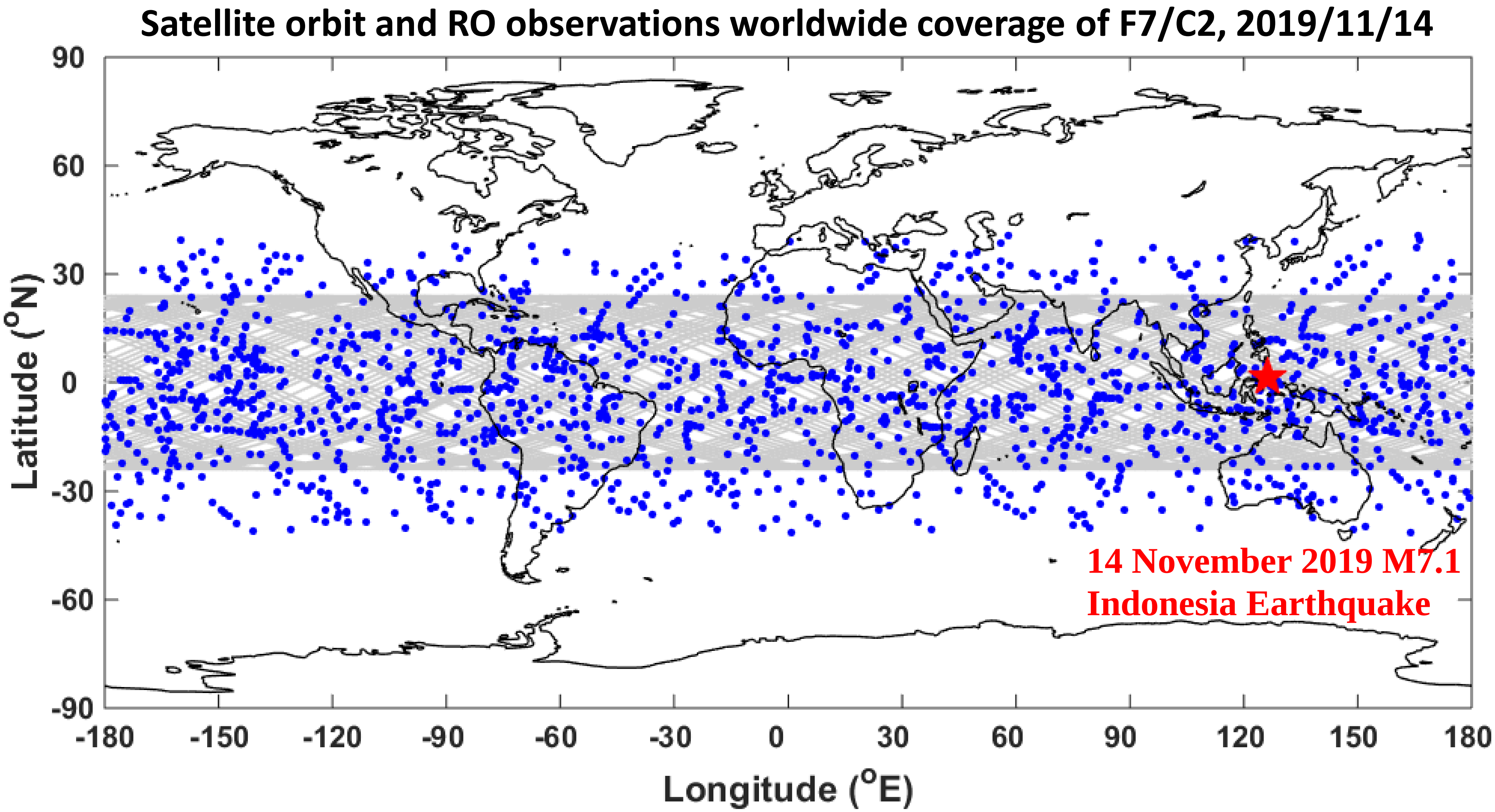


A spatial analysis of GIM TEC D-20~D-19 before the 14 November 2019 M7.1 Indonesia Earthquake

D-20 to D-19: 27/28 (=96.4%)



RO and IVM observations of FORMOSAT-7/COSMIC-2

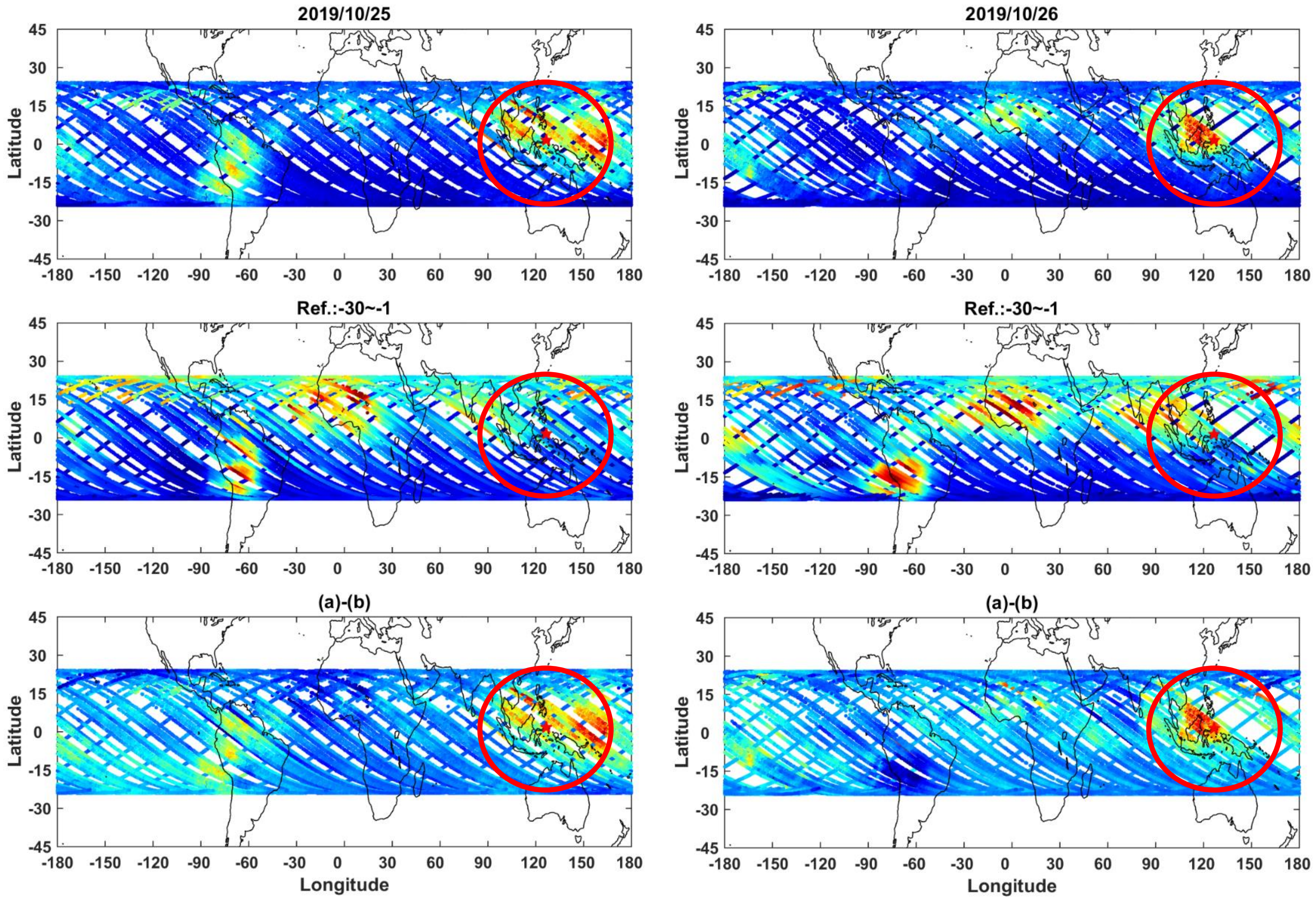


A spatial analysis of F7/C2 Ni D-20~D-19 before the 14 November 2019 M7.1 Indonesia Earthquake

observation

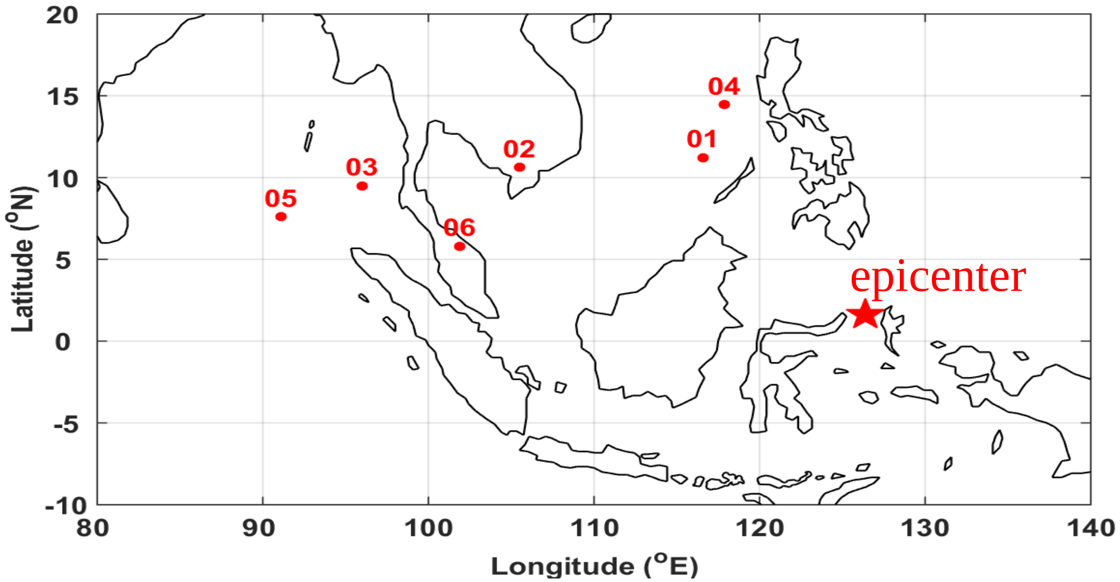
reference

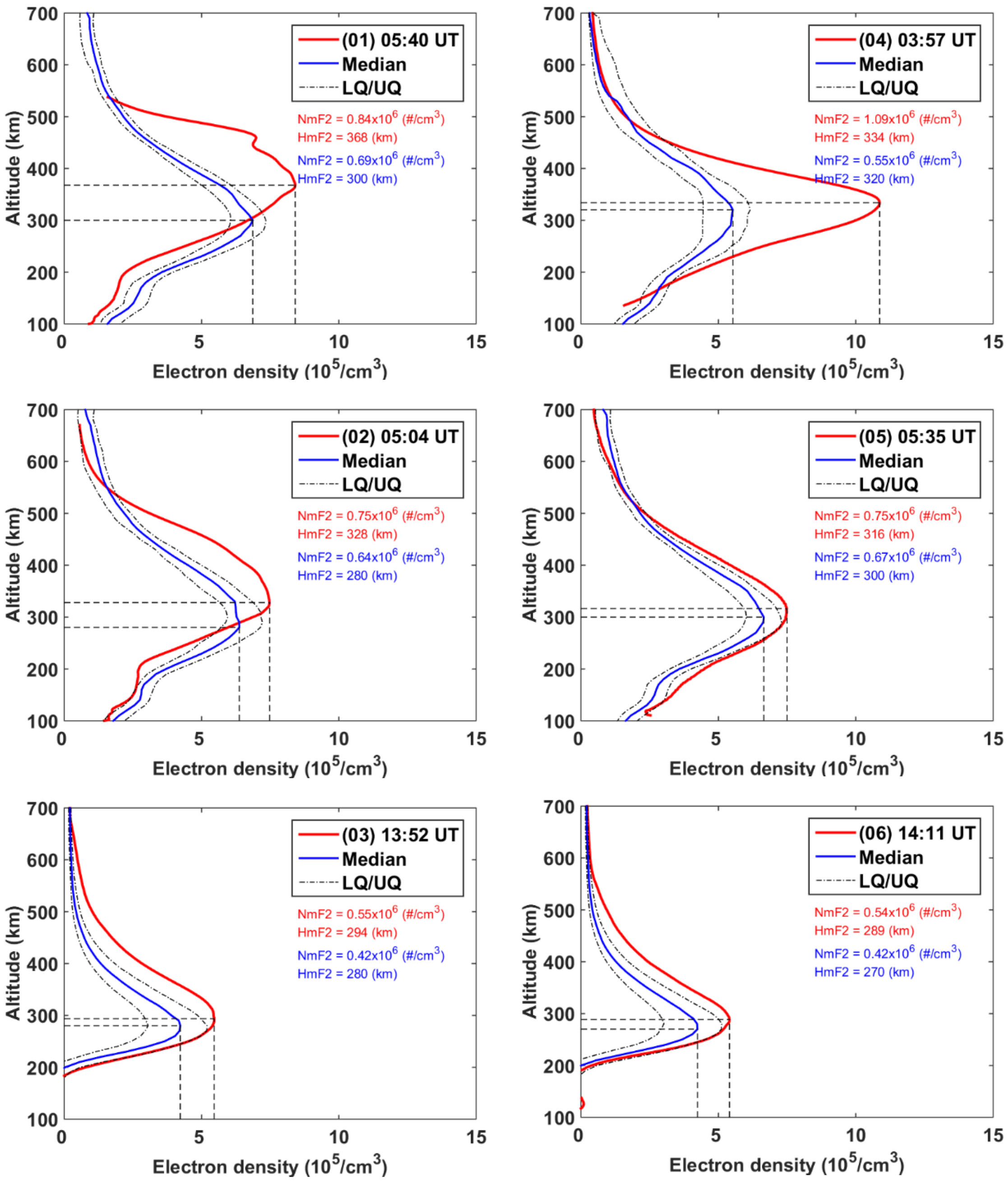
difference

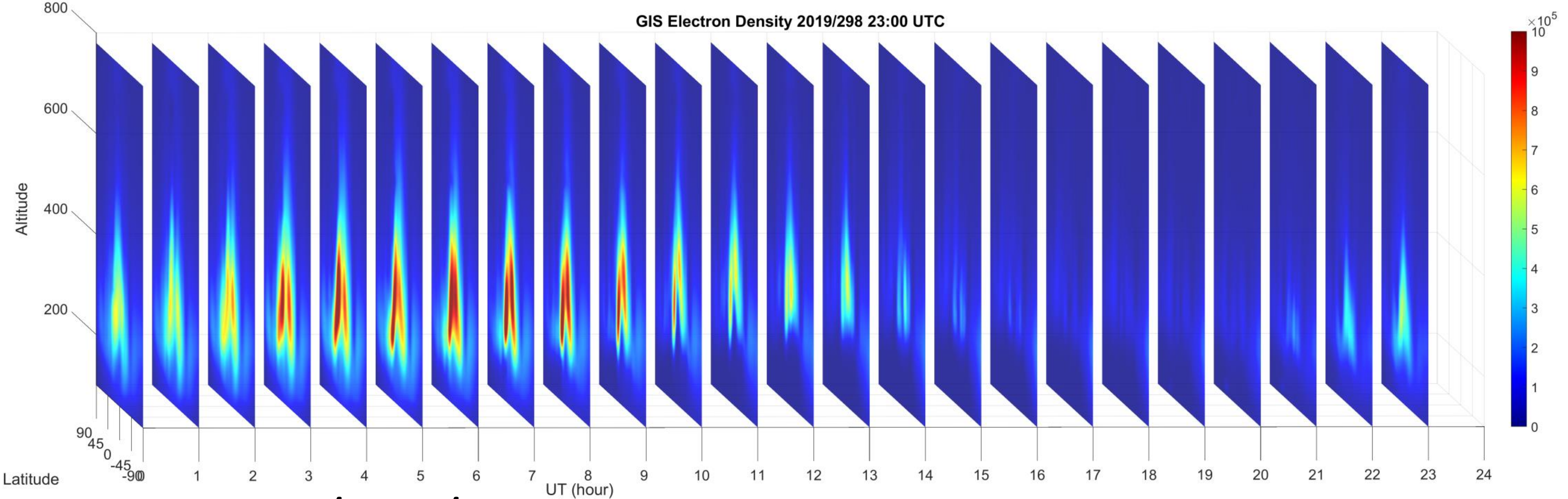


F7/C2 electron density profiles observed over the epicenter on October 25-26 (19-20 days before the 14 November 2019 M7.1 Indonesia earthquake)

- Electron density profiles observed over the epicenter during period of 0300-0500 UT and 1300-1400 UT
- The ionospheric F2 peak electron density (NmF2) significantly increases.
- The ionospheric F2 peak height (hmF2) ascends about 10-70 km.

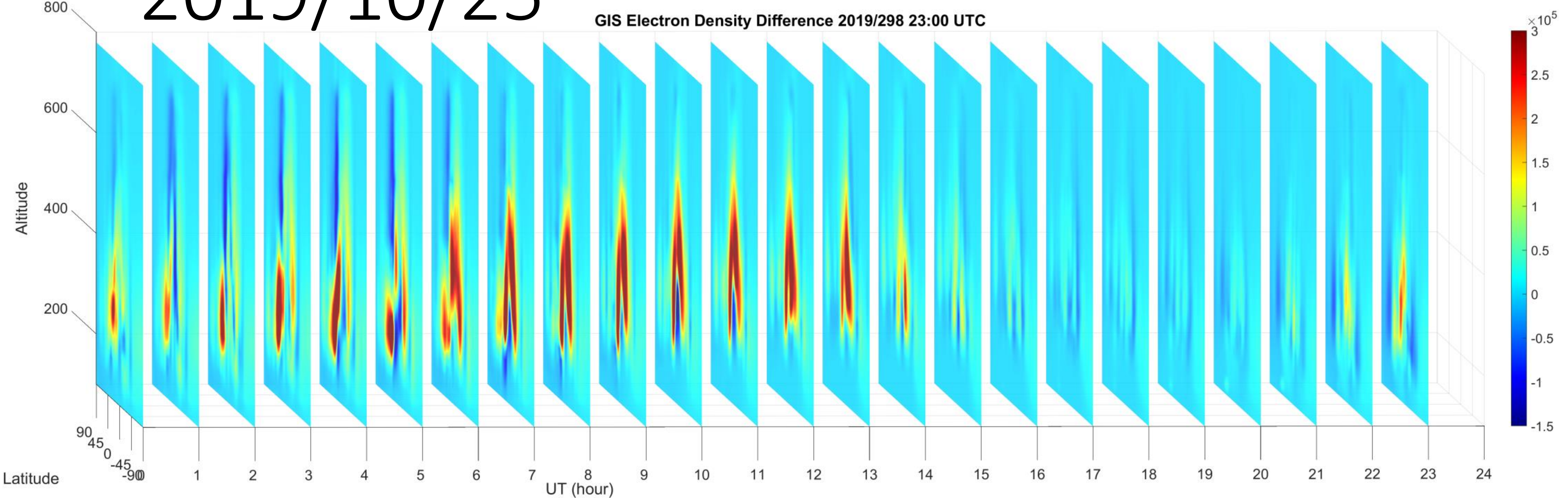






GIS Electron Density 2019/298 23:00 UTC
Altitude
Latitude
UT (hour)
×10^5

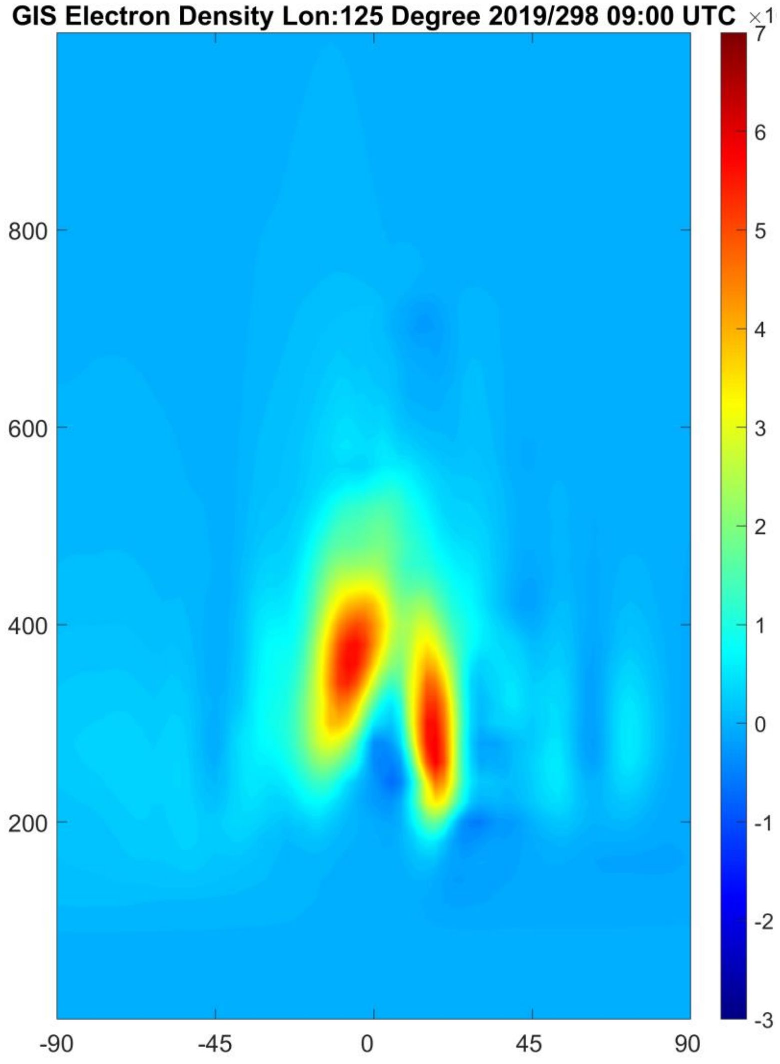
2019/10/25



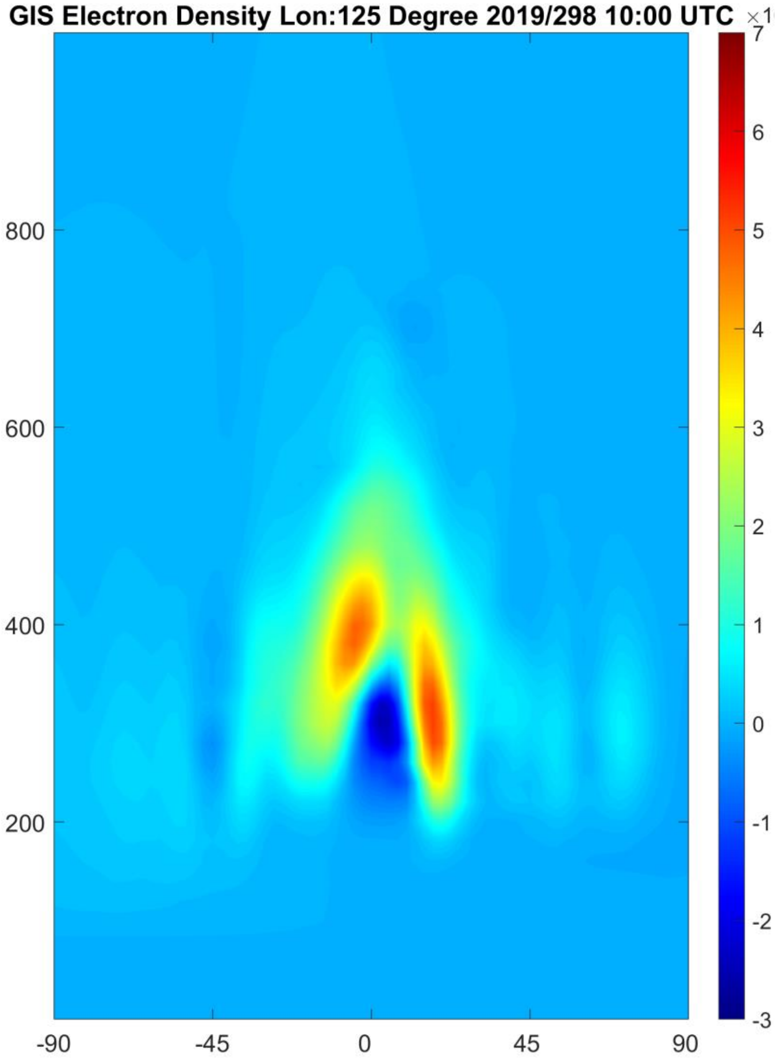
GIS Electron Density Difference 2019/298 23:00 UTC
Altitude
Latitude
UT (hour)
×10^5

2019/10/25

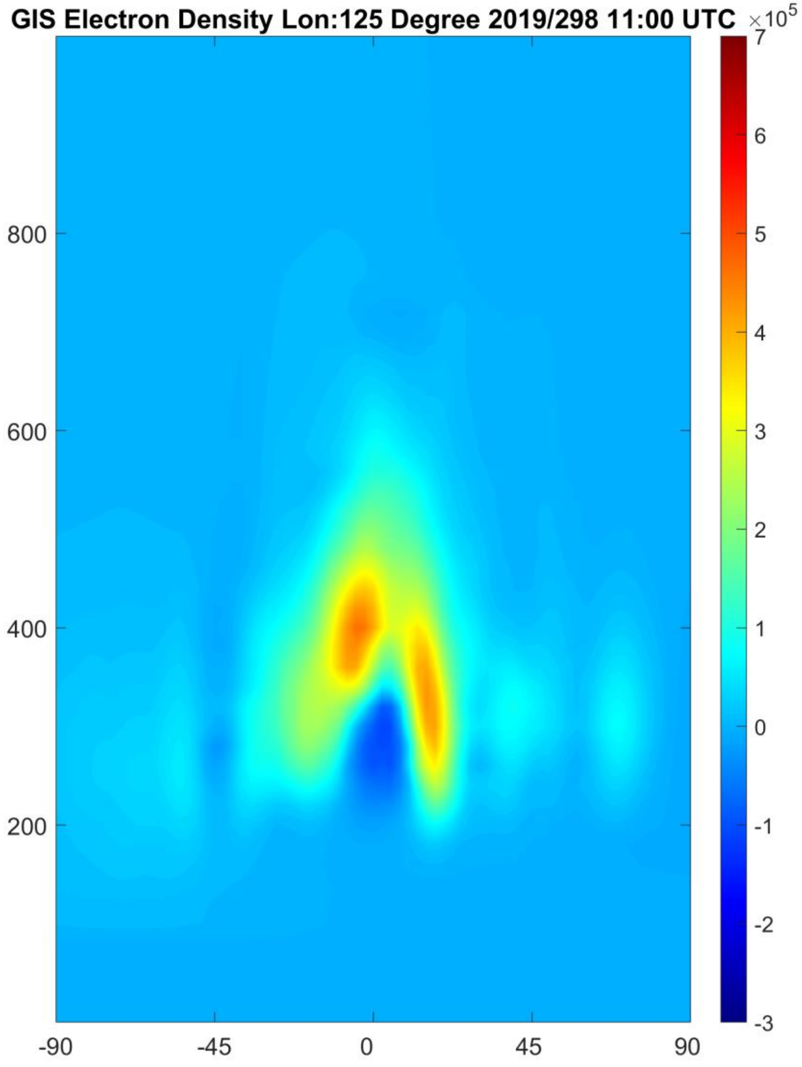
09UT

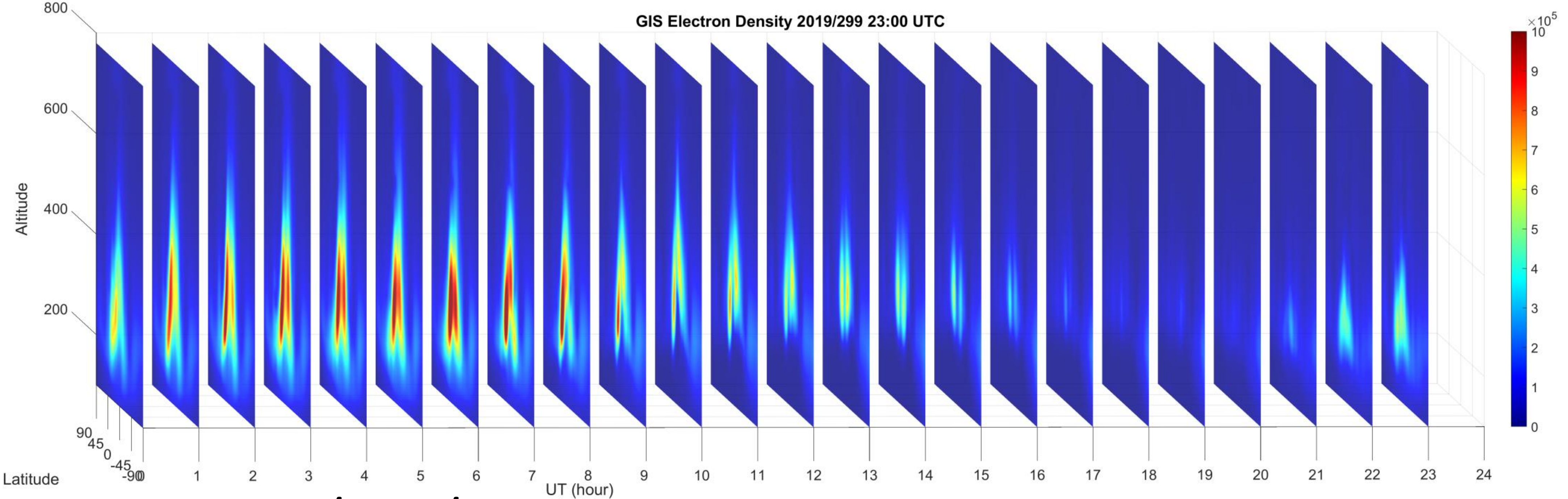


10UT

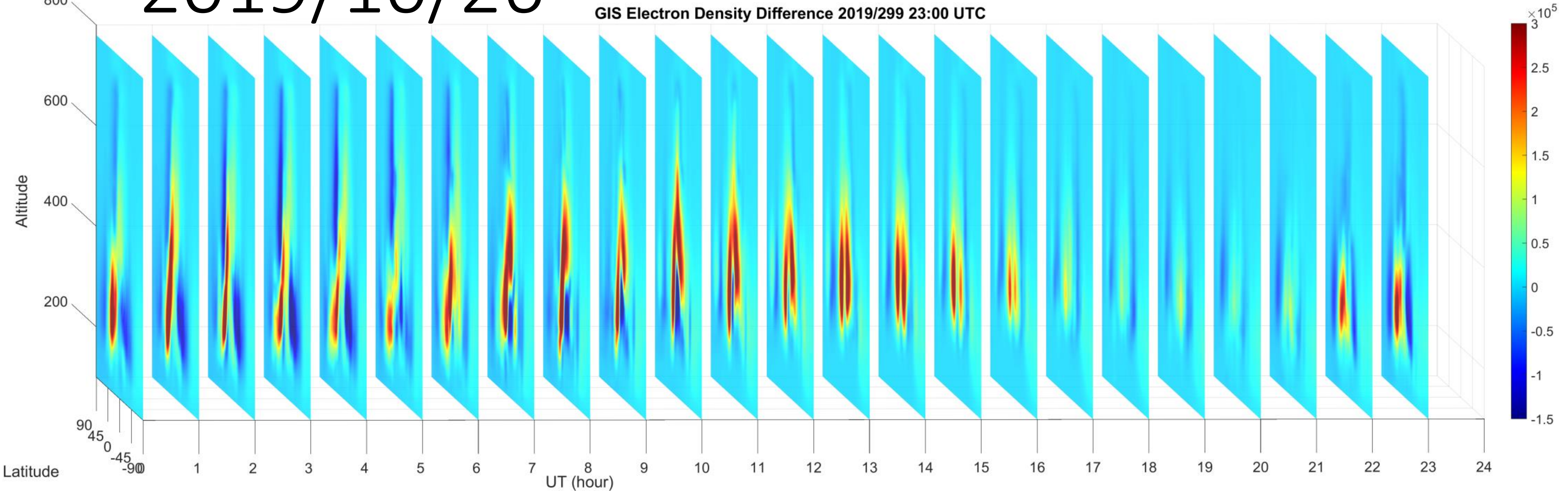


11UT



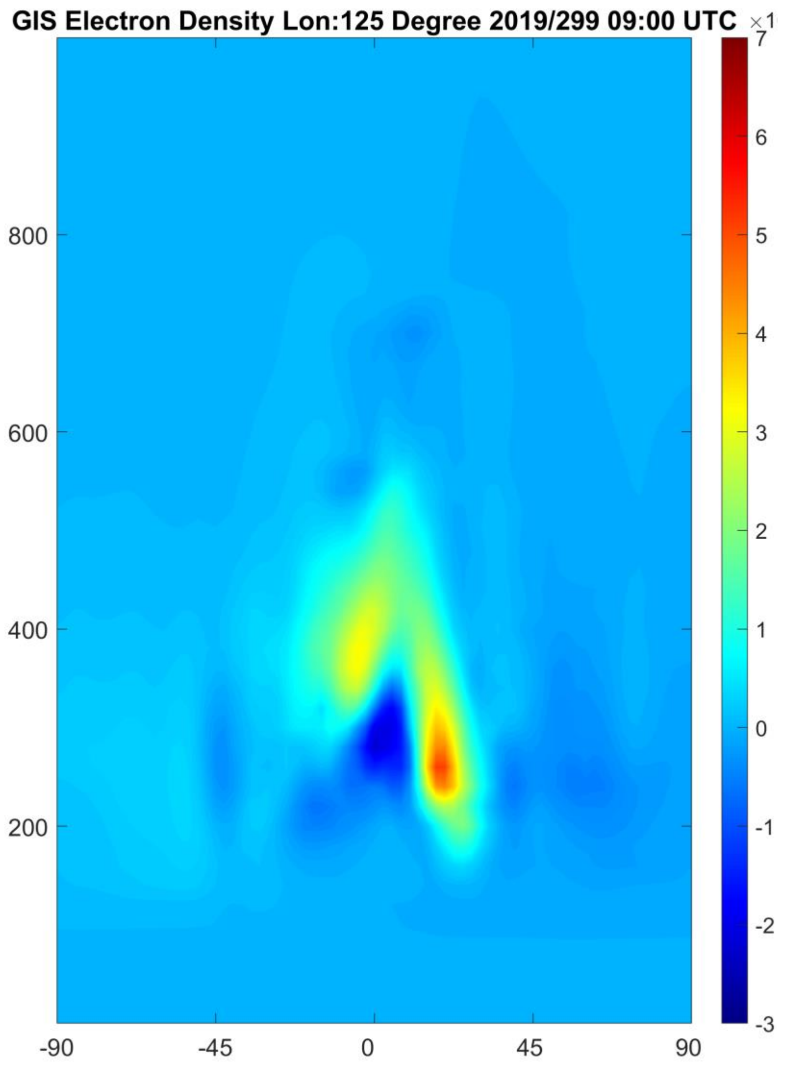

GIS Electron Density 2019/299 23:00 UTC
Altitude
Latitude
UT (hour)
×10^5

2019/10/26

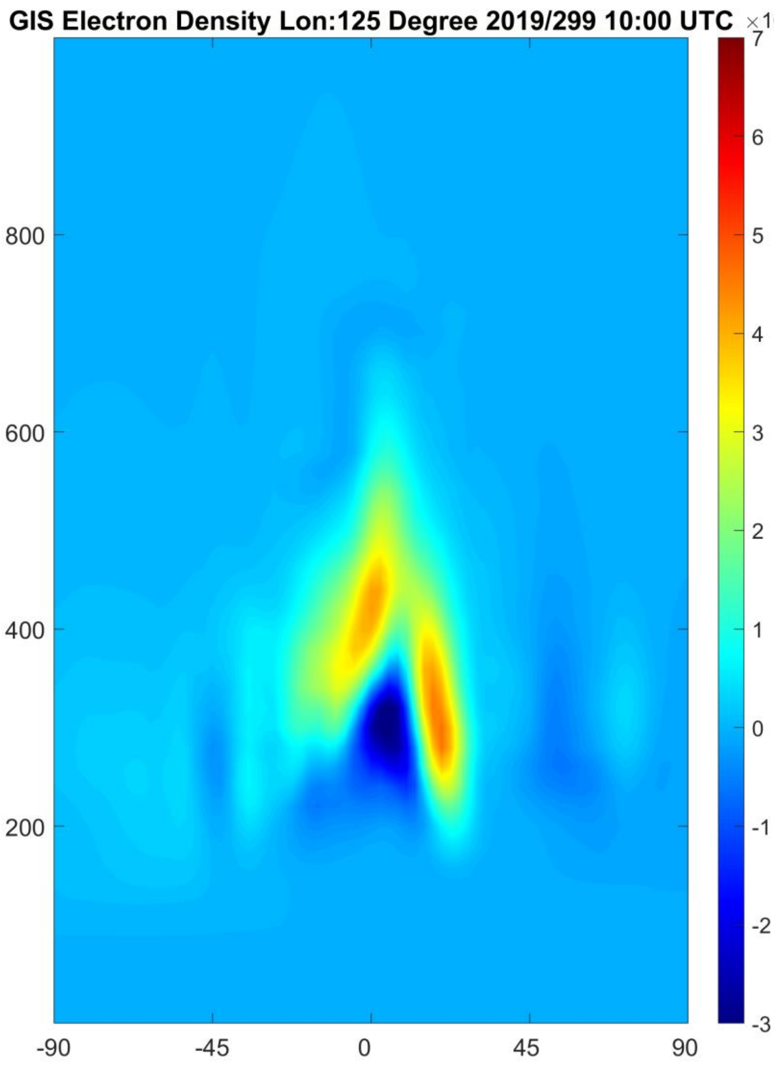

GIS Electron Density Difference 2019/299 23:00 UTC
Altitude
Latitude
UT (hour)
×10^5

2019/10/26

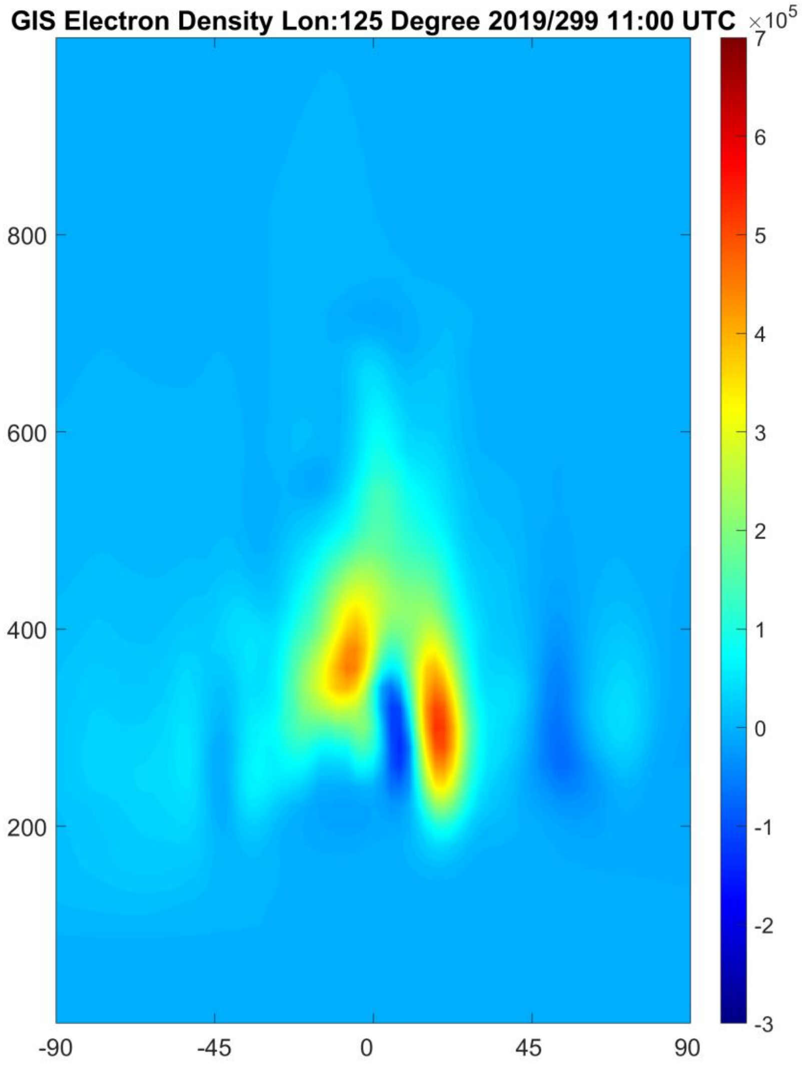
09UT



10UT



11UT



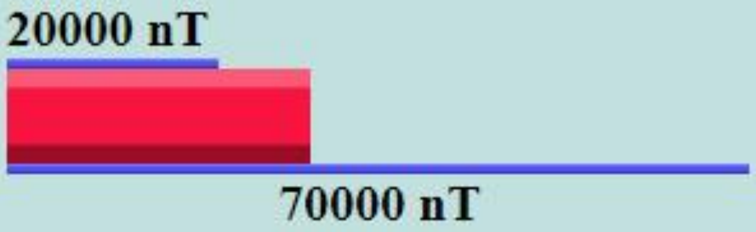
Geomagnetic elements Lat.: 2.050N Long.: 126.067E Altitude: 700.000km Year:2019 (Prediction) (IGRF)

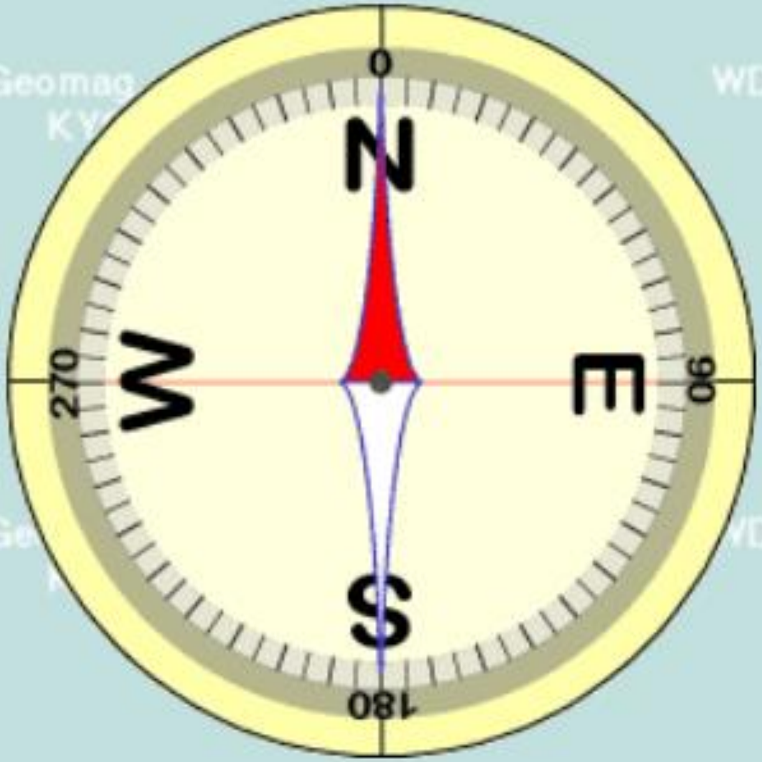
dynamo theory：

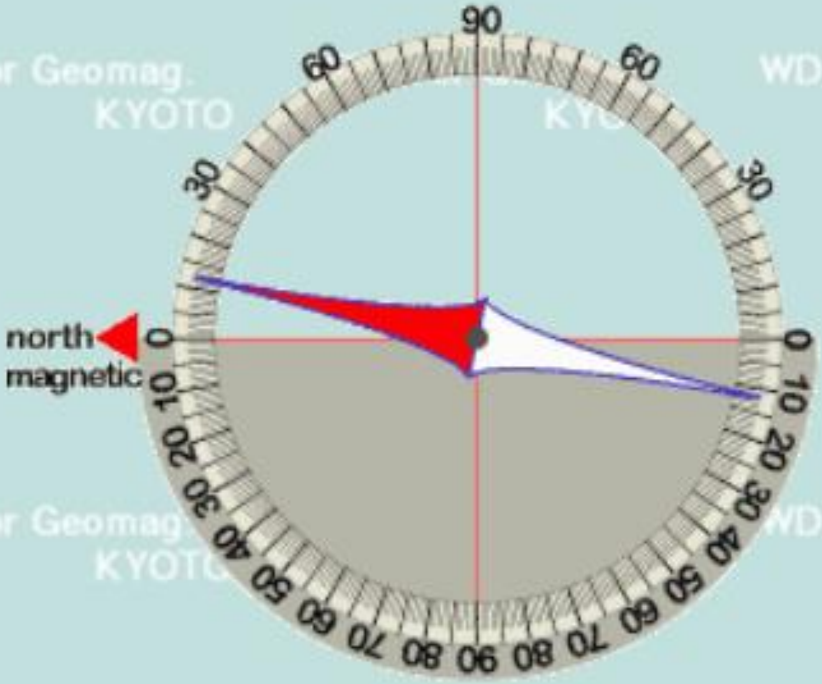
$$E = -V \times B$$

V： the ion velocity

B： the Earth's magnetic field







$$\Delta E_{east} = \Delta U * 28525.8 * 10^{-9} * 10^{3} * \sin(-11.911^{o})\ mV/m;\ \sin(-11.911^{o}) = 0.2062$$

Total Intensity (F): 28525.8 nT

Declination (D): 0.316°

Inclination (I): -11.911°

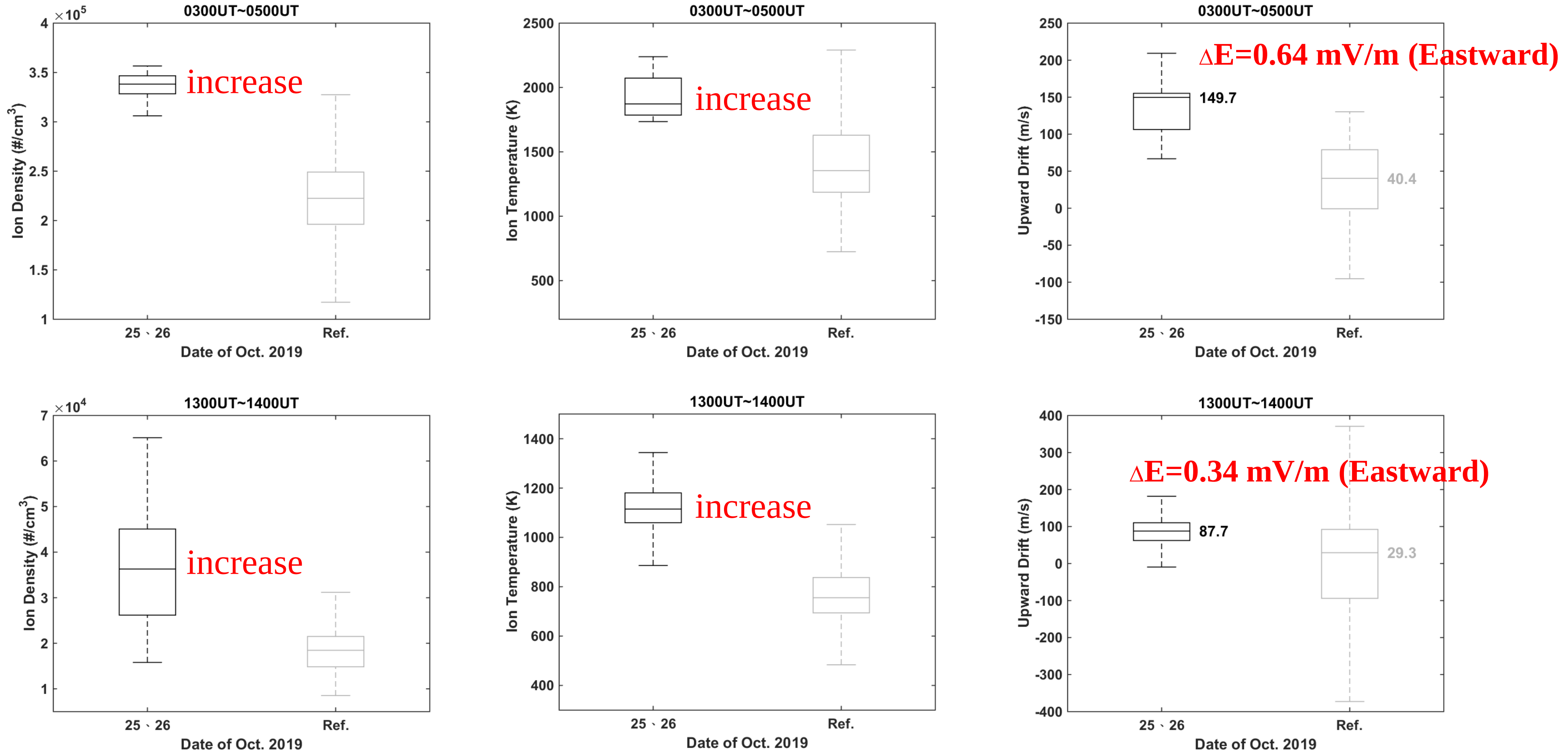
Northward (X): 27911.2 nT

Eastward (Y): 154.1 nT

Downward (Z): -5887.4 nT

Horizontal (H): 27911.6 nT

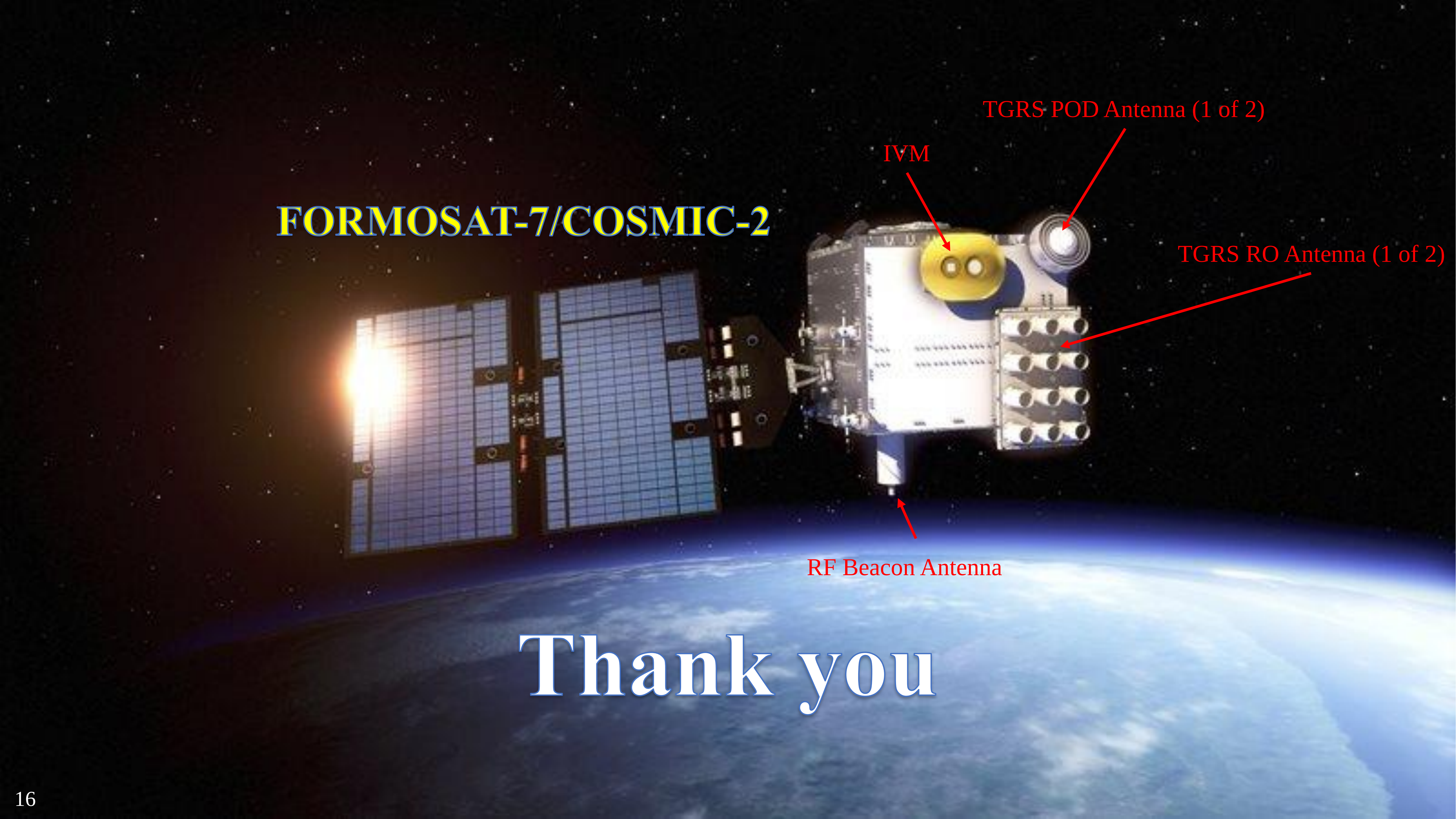
F7/C2 IVM ion density, temperature, and drift during October 25-26



Conclusion II

- The GIM TEC and F7/C2 RO NmF2 significantly increase specifically over the epicenter on 25-26 October (D-20~D-19), which indicates SIPs of the 14 November 2019 M7.1 Indonesia Earthquake being detected.
- The F7/C2 RO electron density profiles upward motions suggest that the eastward electric fields have been enhanced during the SIP days of the 2019 M7.1 Indonesia earthquake.
- The seismo-generated electric fields of the 2019 M7.1 Indonesia earthquake are 0.34-0.64 mV/m eastward.
- The GIM TEC and F7/C2 RO electron destiny profiles can be used to examine ionospheric plasma structures/dynamics three dimensionally, detect SIPs, and locate possible forthcoming large earthquakes.
- Satellite in situ plasma probing, especially vector quantities, such as plasma drifts, electric fields, magnetic fields, etc. can be used to find possible causal mechanisms of the detected SIPs.
- **RO electron density profiles and IVM observations of six small satellites of F7/C2 shall open a new chapter for detecting seismo-ionospheric precursors of plasma and finding possible associated causal mechanisms.**

FORMOSAT-7/COSMIC-2



Thank you