

From the Sun to the Earth: August 25, 2018 geomagnetic storm effects

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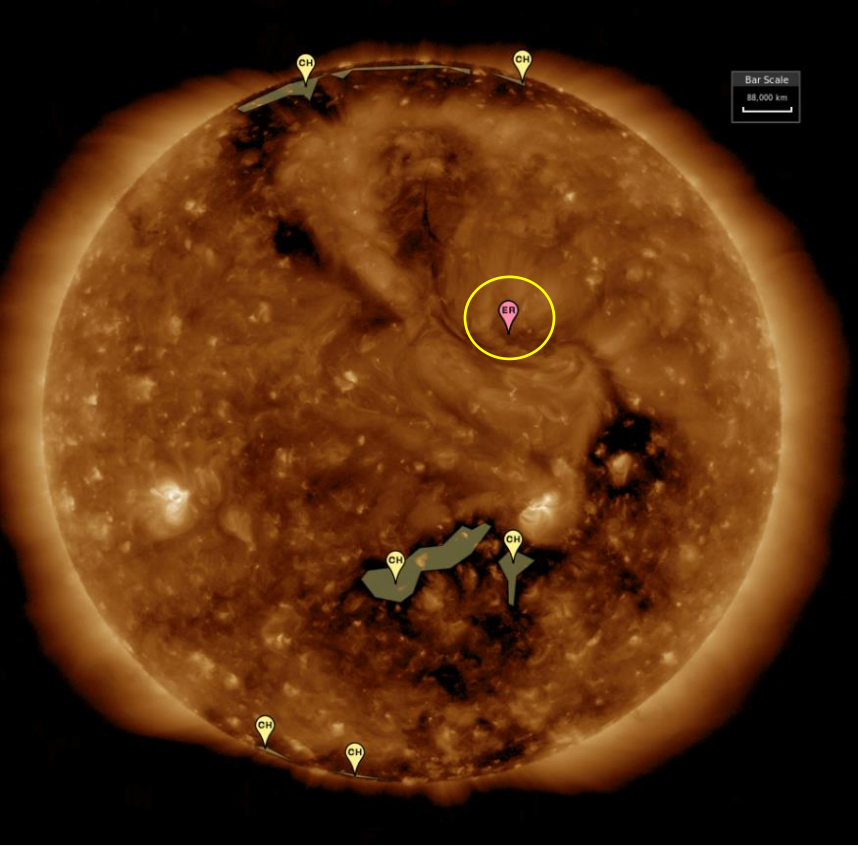
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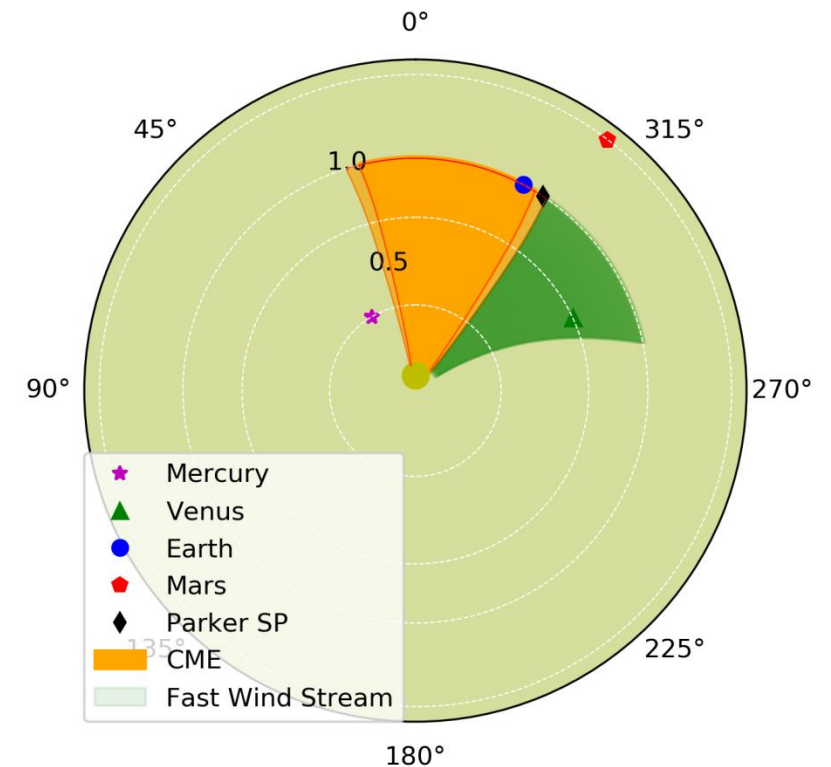
CME identification and its interplanetary propagation: the P-DBM model



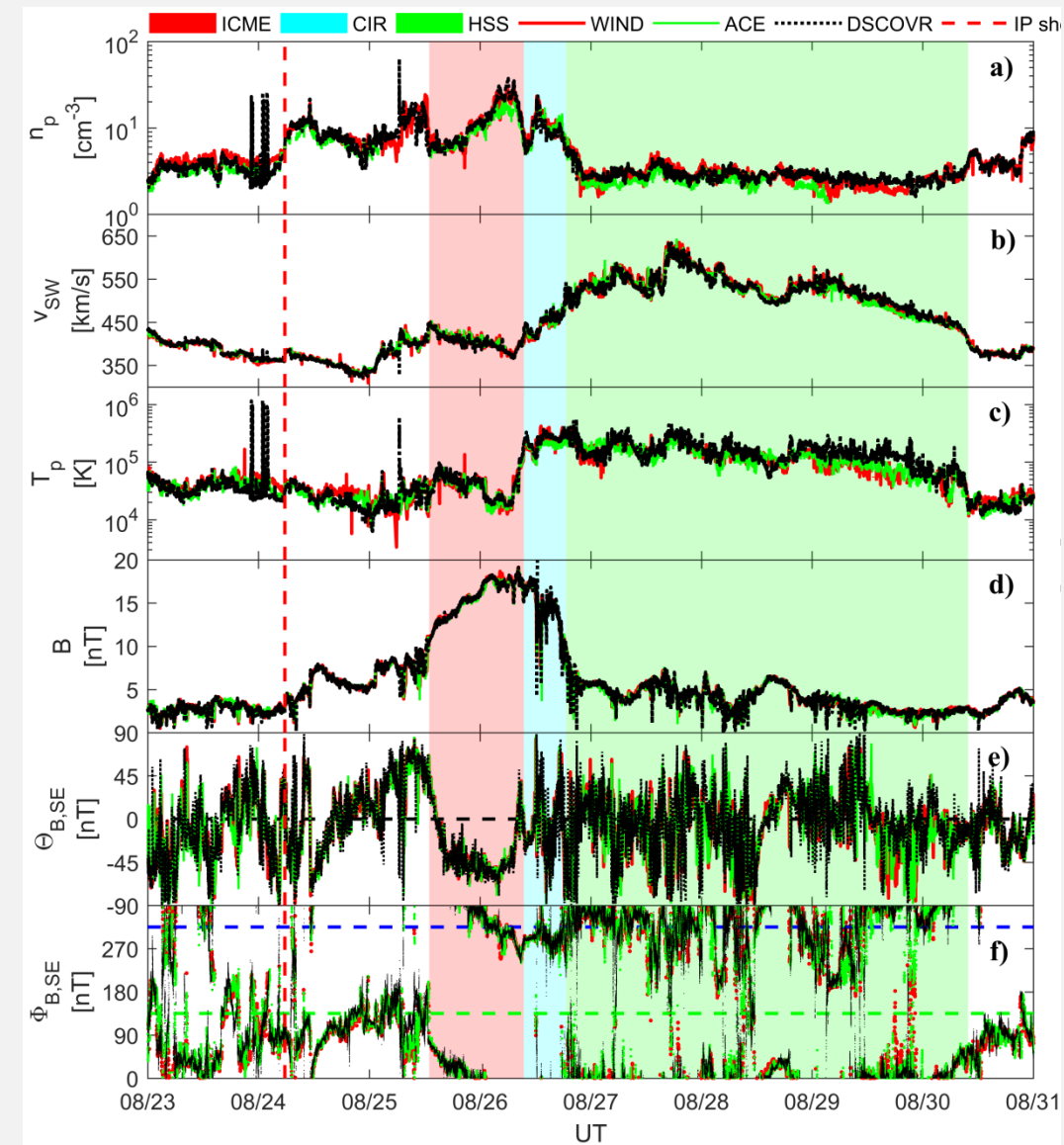
- The most probable source for the CME is a filament eruption observed at heliographic coordinates $\Theta=16^\circ$; $\Phi=14^\circ$ on the solar surface (yellow circle).

- We can deproject the CME velocity and estimate its radial velocity as $V_R=175 \pm 45$ km/s.
- We propagate the CME in the heliosphere, with the characteristics computed above and considering its interaction with either slow or fast solar wind for the whole duration of its travel and estimate its time to travel to 1AU and its velocity at arrival.
- We estimated an arrival time at 1 AU: 2018/08/25 16:00±03:00.**

CME expected at 1AU at: 2018-08-25 16:00:00 UT

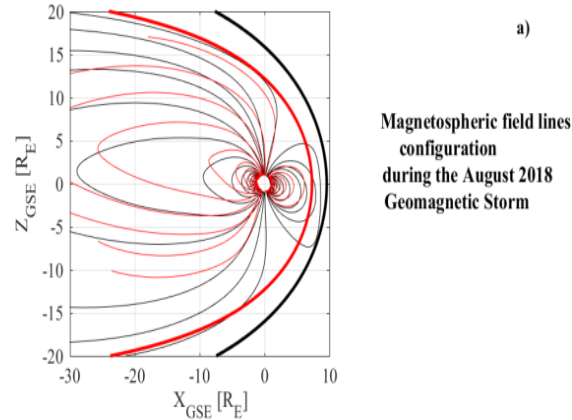


Solar Wind reconstruction at L1



- One Interplanetary Shocks (IP) preceded the ICME and a CIR:
 1. **IP**: 24/08 at 07:18 UT – Increase of all SW parameters;
 2. **ICME**: 25/08 at 16:31 UT – Rotation of Bz(IMF) and increase in the SW density and IMF amplitude;
 4. **CIR**: 26/08 at 12:02 UT – Increase in SW density, temperature and IMF amplitude. Rotation of the Bz (IMF).
- At ground one Sudden Impulses (SI) and strong geomagnetic storm:
 1. **One sudden increases** in the Sym-H at 07:50 UT;
 2. **Main Phase**: Sym-H=-202 nT;
 3. Recovery phase very long in time (31/08).
 4. High latitude Auroral activity (AE>2100 nT);
 5. Huge loading of the magnetotail current during the main phase of the GS;
 6. Long lasting unloading process of the magnetotail during the recovery phase of the GS.

Magnetospheric response

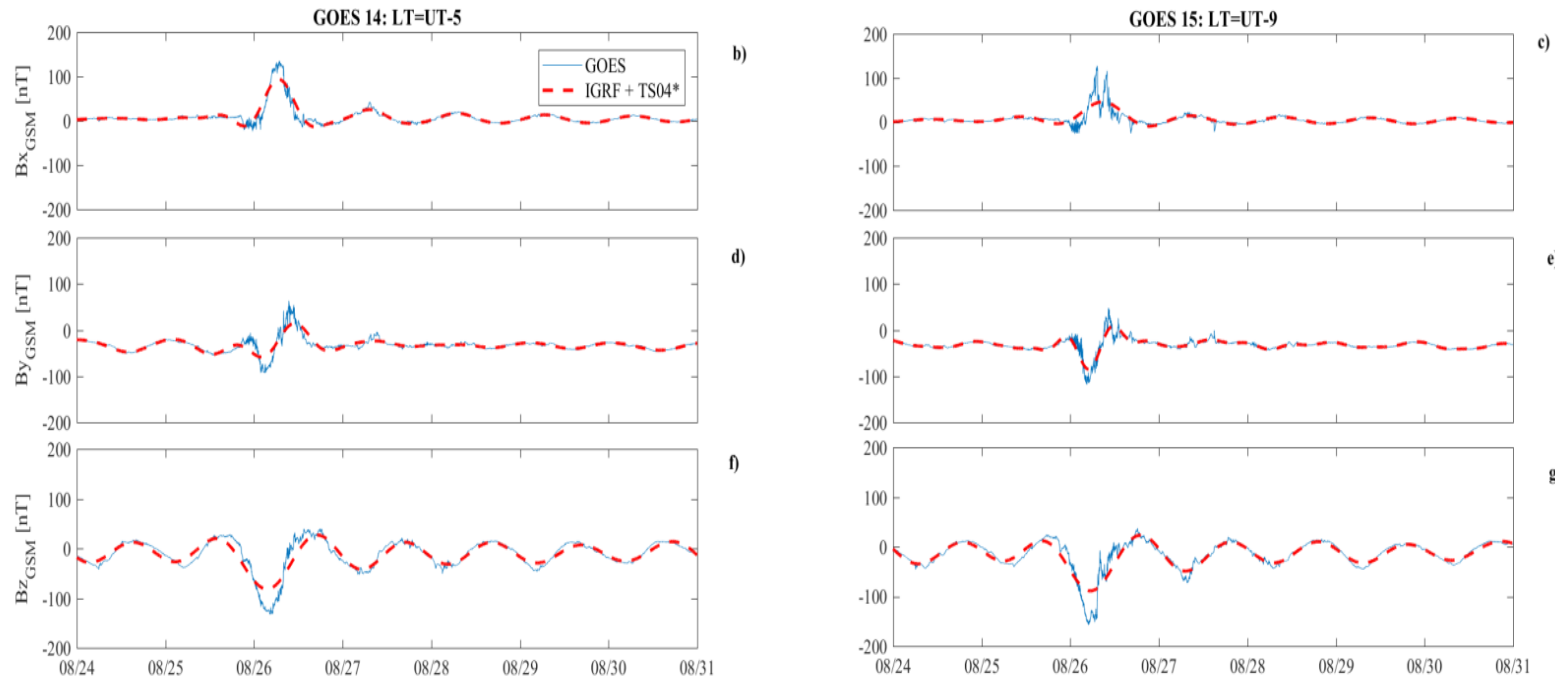


- Magnetosphere strongly compressed (red) with respect to SQ configuration (black) due to the SI [from 10 R_E to 6.8 R_E];
- Magnetosphere erosion (green) during the Main Phase due to southward rotation of B_z (IMF) [4.2 R_E];
- Close position of the hinging point [from 7 R_E to 4.5 R_E];

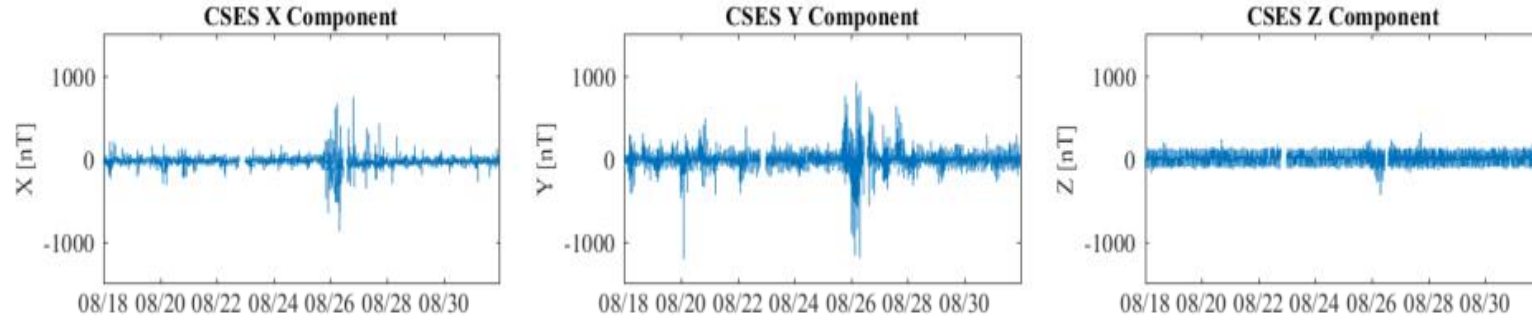
GOES response

- Clear huge variation of the magnetospheric field at both GOES 14 and GOES 15 spacecraft;
- The variations along X confirm the stretching of the magnetotail field lines;
- The variations along Y confirm the twisting of the magnetotail field lines;
- The variations along the Z component confirm the concurring compression of the magnetopause and action of the enhanced ring current;
- This scenario is confirmed by the simulation of a modified TS04 model (red dashed lines):

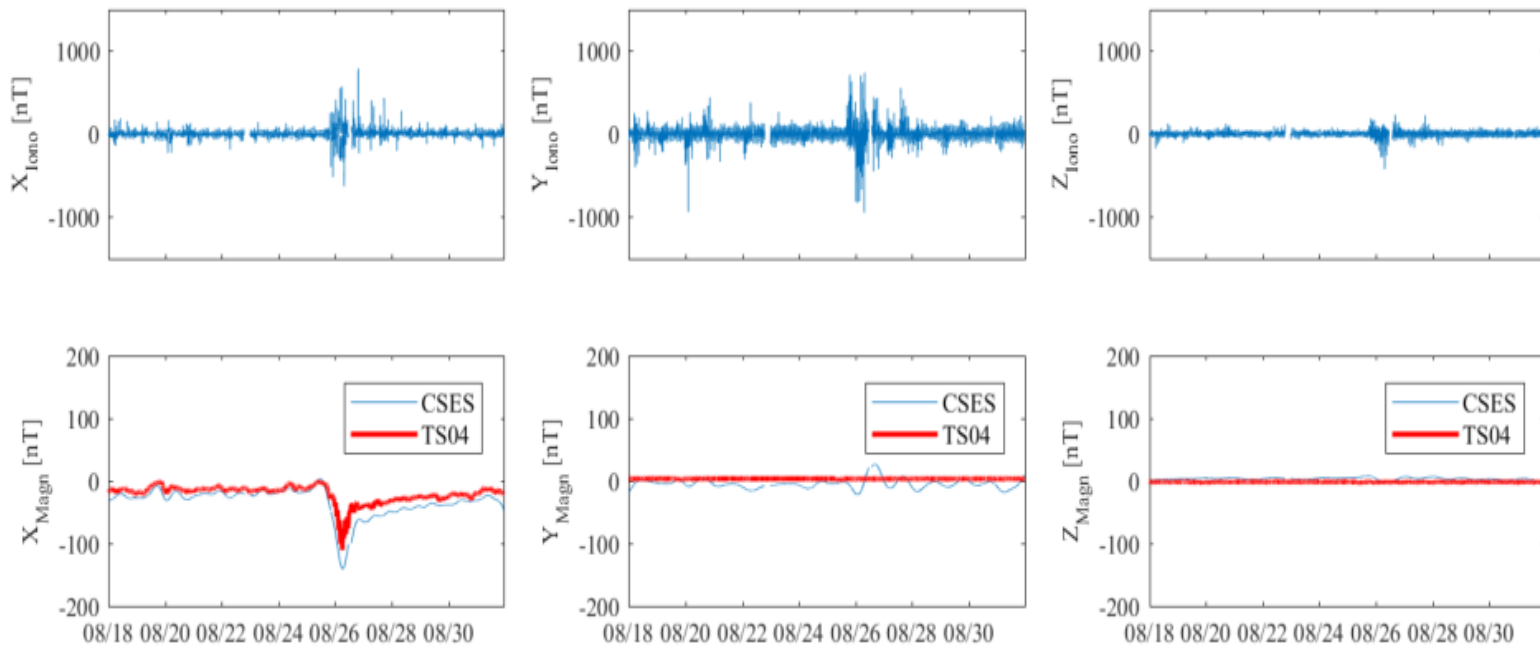
1. during the SI, magnetic field reproduced by the magnetopause current strongly compressed by SW.
2. During the MF, magnetic field reproduced by the sum of the ring current and tail current.



Magnetospheric and Ionospheric Response at CSES orbit

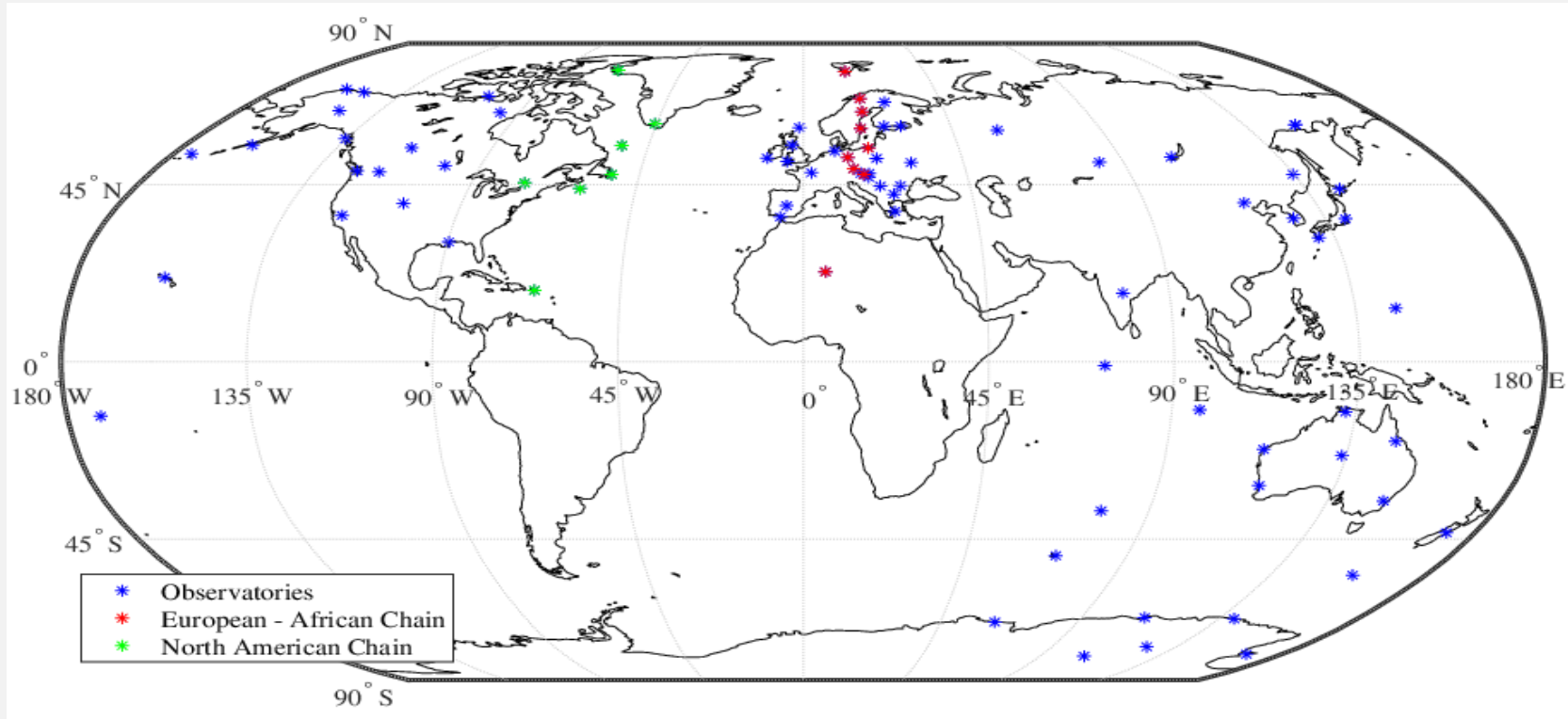


MA.I.GIC.



- X is directed along the geomagnetic North-South direction, Y is directed along the geomagnetic East-West direction, Z is directed along the geomagnetic vertical direction (downward).
- We removed the CHAOS-6 internal model (core+crustal).
- **We applied the MA.I.GIC. Model [Piersanti et al., 2019] to discriminate between ionospheric and magnetospheric origin contribution at CSES orbit.**
- As expected the greater variation is along the horizontal components.
- Magnetospheric: dominated by: the Ring current contribution (X strong decreases) during the main phase; the Ring + Tail currents during the recovery phase.
- Ionospheric: dominated by the DP-2 ionospheric current system

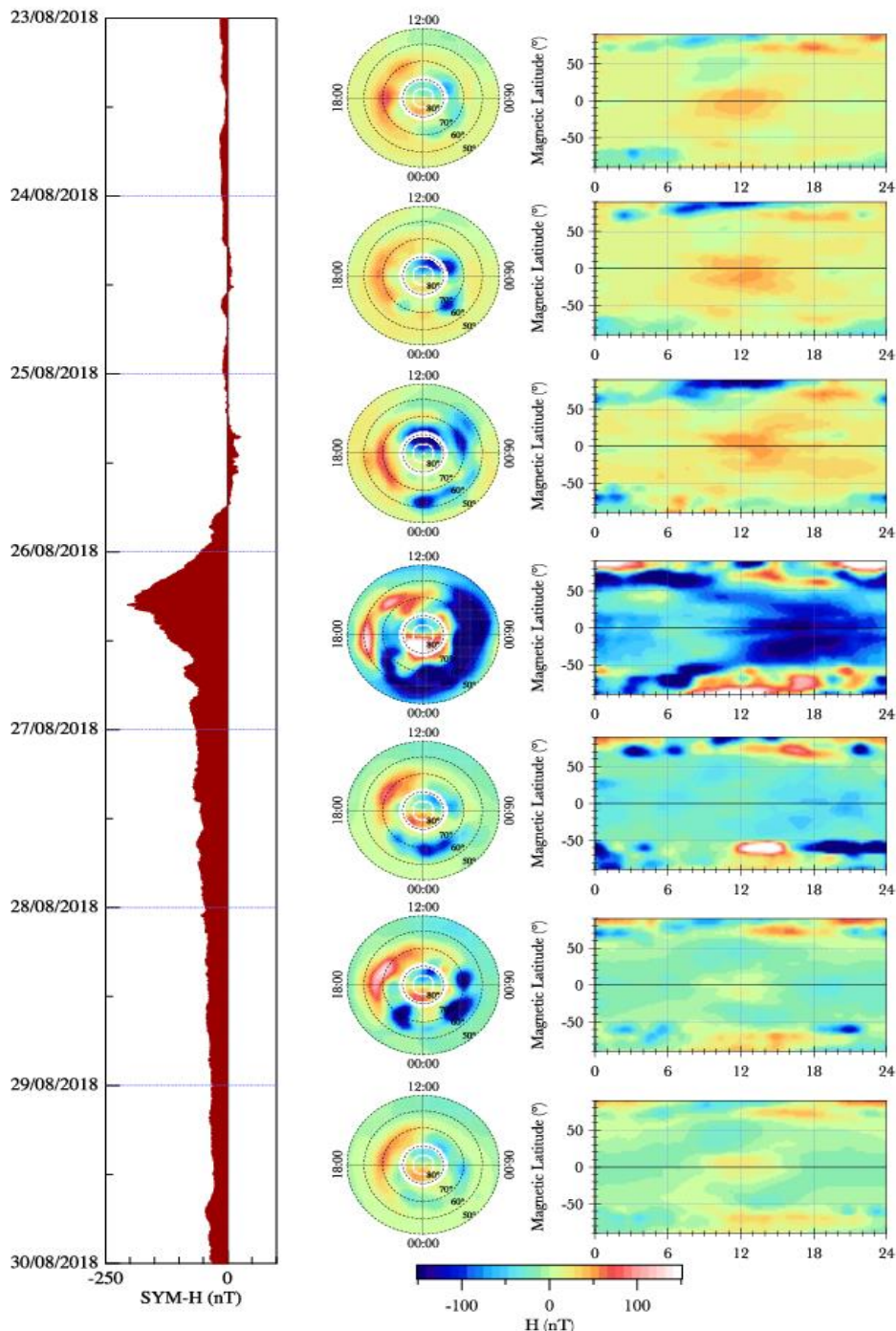
Ground stations views



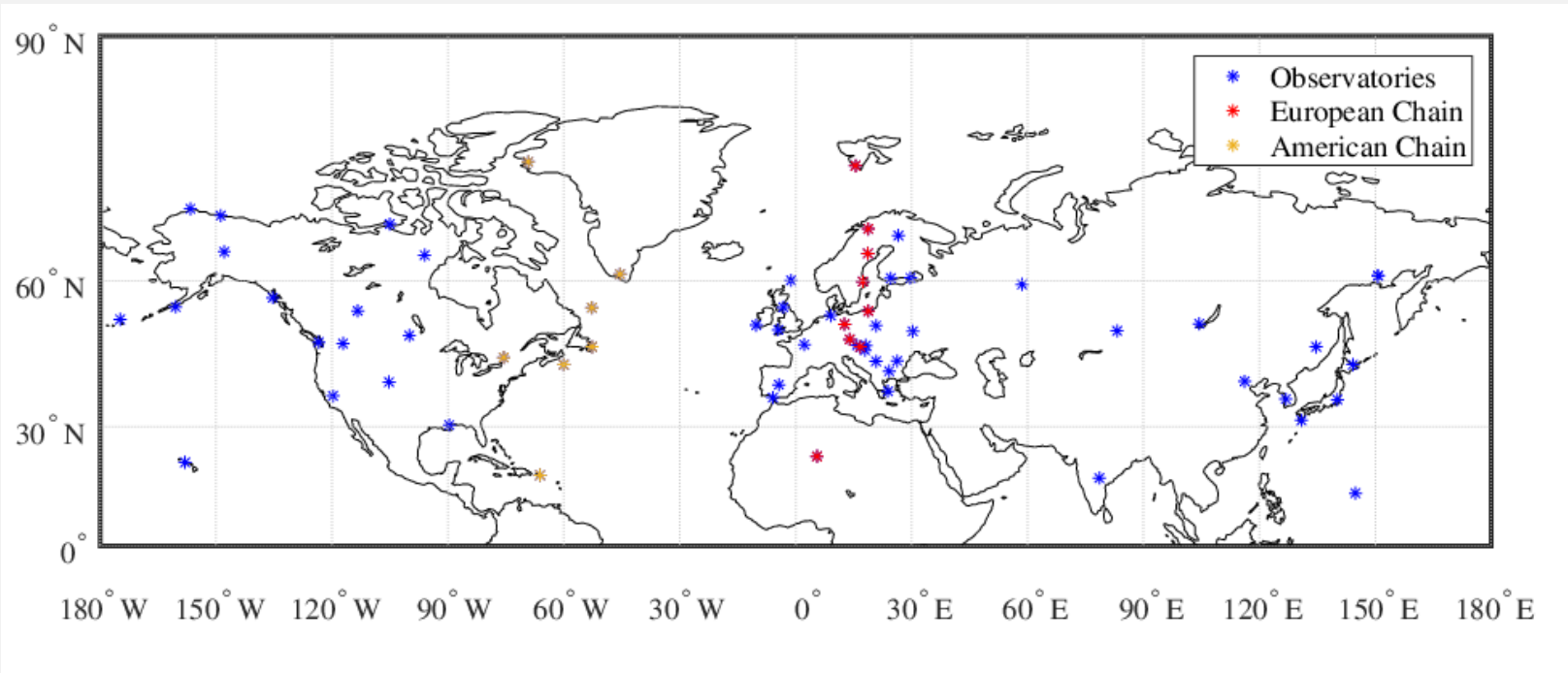
- We selected 82 ground magnetometers (INTERMAGNET);
- We analyzed the ground magnetic response;
- Red and green stars represent two magnetometric array along almost the same meridian used to study the effects of GIC at ground.

Ground response

- We applied the MA.I.G.I.C. model to remove the geomagnetic field of internal origin in order to focus on both the magnetospheric and ionospheric contribution;
- The main contributions to this external field are the polar ionospheric currents (polar electrojets) and the magnetospheric currents (Ring current).
- The maps reported in the central panels show the effect due to the **eastward and westward electrojets**.
- These two polar current systems are always present but their intensities **increase during the main phase of the geomagnetic storm**.
- The right panels show the effect due to the ring current that is responsible for a decrease of the magnetic field intensity at low and mid latitudes.
- The increasing of the ring current (westward direction) produces a strong depression of the horizontal field magnitude at mid/low-latitudes of the map on August 26,
- In the days after the perturbation associated with the ring current is still visible, although its amplitude rapidly decreases.

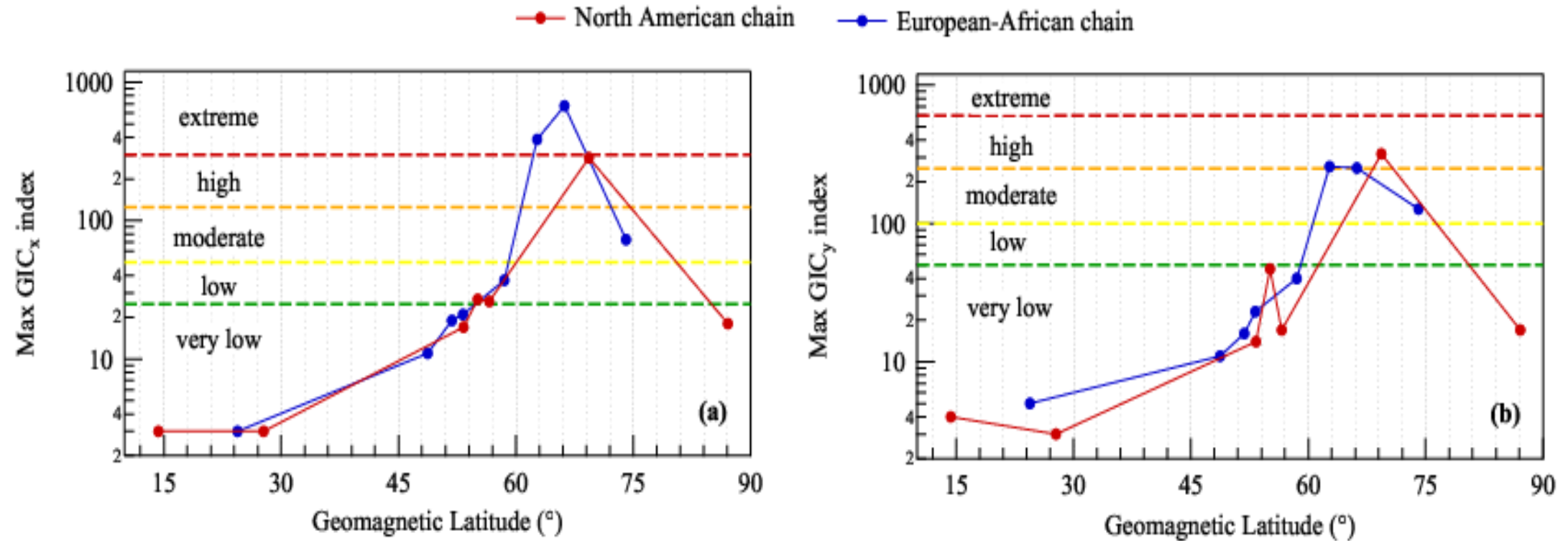


Geomagnetically Induced currents



We evaluated the GIC index [Tozzi et al., 2018] over the European and North American sectors, at different geomagnetic latitudes and along almost the same geomagnetic meridian.

GIC over Europe during the Main Phase.



This results are in agreement with Pulkkinen et al., [2012], Viljanen and Pirjola [2001] and Piersanti and Carter [2018].

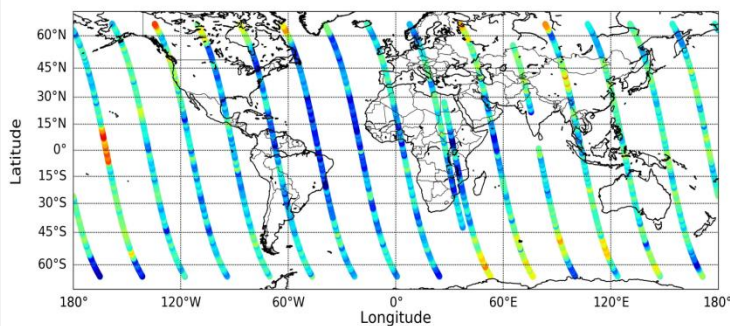
Conclusions

- The solar event occurred on August 20, 2018 has been capable to increase the intensity of the various electric current systems flowing in the magnetosphere and ionosphere activating a chain of processes which cover a wide range of time and spatial scales and, at the same time, to activate strong interactions between various regions within the solar-terrestrial system;
- The long reconnection process at the dayside magnetopause led to an increase of magnetospheric circulation, to an injection of particles into the inner magnetosphere and more in general provided free energy which was stored in the magnetosphere and led to a worldwide magnetic disturbance;
- The development of such disturbance has led to an increase of currents in the ionosphere accompanied by the auroral activity and by a shift equatorward of the auroral electrojets and to the growth of the ring current;
- The amplitude of GICs has reached values corresponding to "high" and "extreme" risk levels above 60°N of geomagnetic latitude;
- This kind of comprehensive analysis plays a key role to better understand the complexity of the processes occurring in the Sun-Earth system that determines the geoeffectiveness of solar activity manifestations.
- **This work has been accepted and is in press at ANN. GEO.**
- *It is available at <https://doi.org/10.5194/angeo-2019-165-RC1>*

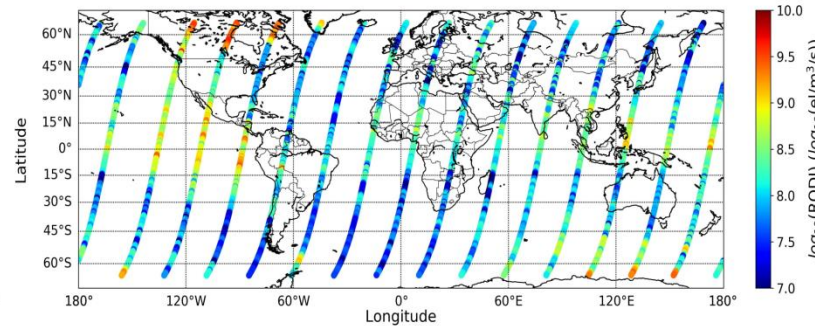
Back Up Slides

Ionospheric Response at LEO orbit

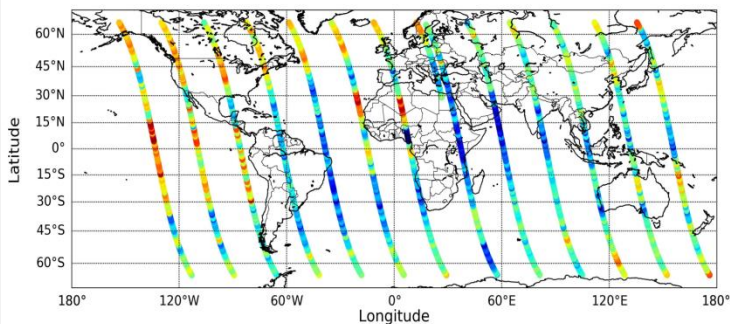
Scatter RODI, 25 August 2018, 02 LT, CSES



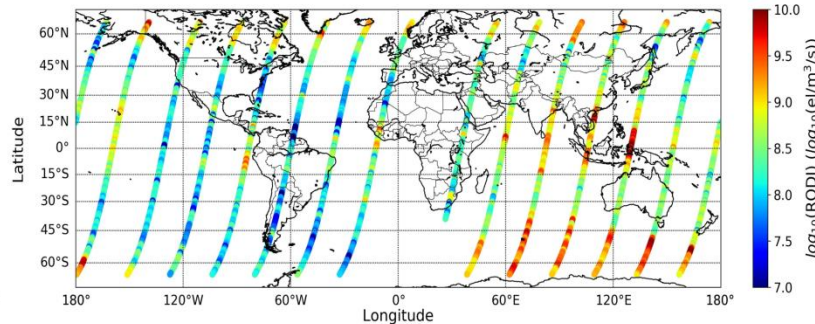
Scatter RODI, 25 August 2018, 14 LT, CSES



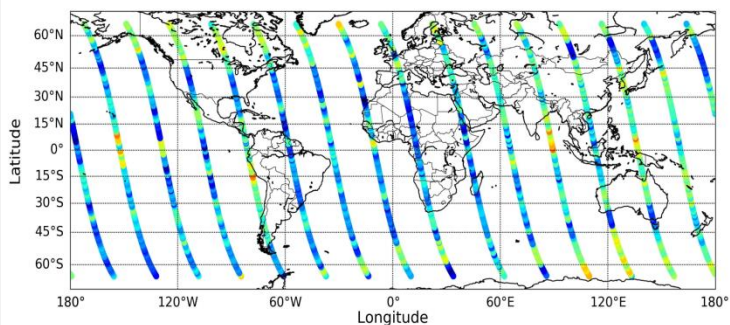
Scatter RODI, 26 August 2018, 02 LT, CSES



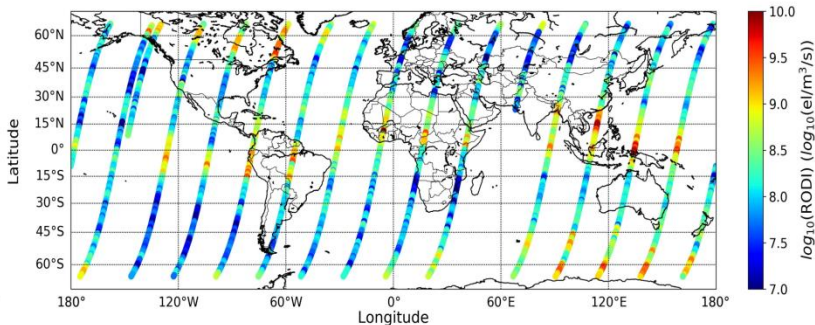
Scatter RODI, 26 August 2018, 14 LT, CSES



Scatter RODI, 27 August 2018, 02 LT, CSES



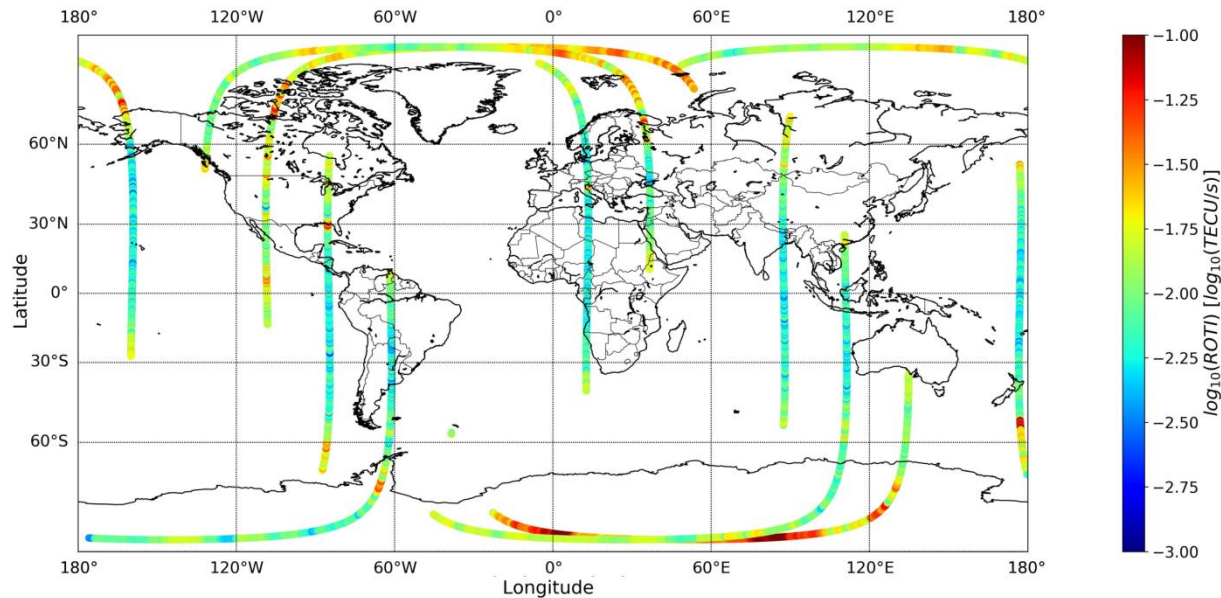
Scatter RODI, 27 August 2018, 14 LT, CSES



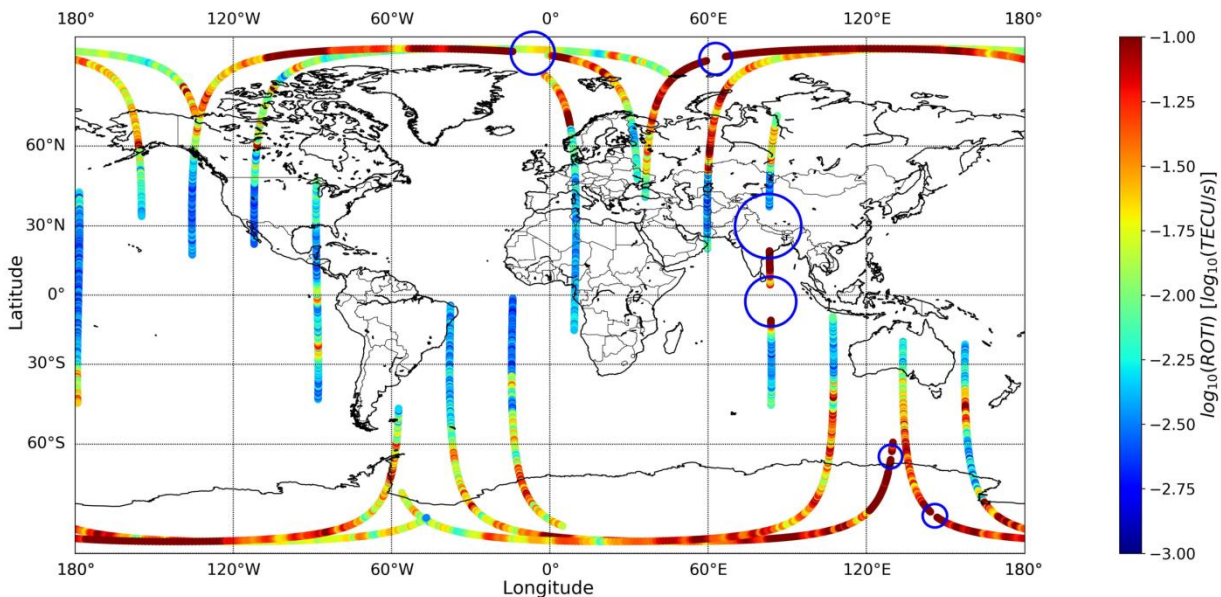
- The ionospheric plasma is often characterized by irregularities and fluctuations in the plasma density, especially during active solar conditions.
- In order to characterize such irregularities, we evaluated the RODI, a parameter derived from the electron density recorded by the CSES satellite.
- Figure shows RODI values for August 25, 26, and 27, 2018, in which nighttime semi-orbits (02:00 LT) are shown separately from daytime semi-orbits (14:00 LT).
- **High RODI values during the main phase of the storm (August 25 and 26, 2018), for both nighttime and daytime, is clearly seen;**
- on August 27, 2018, the RODI comes back to lower values.
- **This behaviour can be explained in terms of the presence, during the main phase, of ionospheric irregularities, especially at auroral and low latitudes.**

Ionospheric Response at LEO orbit

Scatter ROTI, 26 August 2018, Global, Swarm A, PRN=8



Scatter ROTI, 17 March 2015, Global, Swarm A, PRN=17



- To understand whether this significant increase of irregularities could have caused space weather effects on navigational systems, we have considered vertical total electron content (vTEC) data measured by Swarm satellites to look for some loss of lock on GPS.
- Only vTEC data with corresponding elevation angles 50° have been taken into account.
- We have considered vTEC data recorded by each of the three satellites (A, B, and C) of the Swarm constellation and corresponding to each PRN satellite in view.
- We evaluated the rate of change of TEC index (ROTI) values from Swarm A for PRN 8 on August 26, 2018 (upper panel), and for PRN 15 on March 17, 2015 (lower panel).
- **No loss of lock (saturation of ROTI) has been found, contrary to what happened, for instance, during the well-known and much more intense St. Patrick storm occurred on March 17, 2015 where vTEC measurements highlighted many loss of lock.**