CENTRO OSSERVAZIONI SPAZIALI DELLA TERRA

Multi-instrument observations of ionospheric disturbances caused by the 6 February 2023 Turkey earthquake

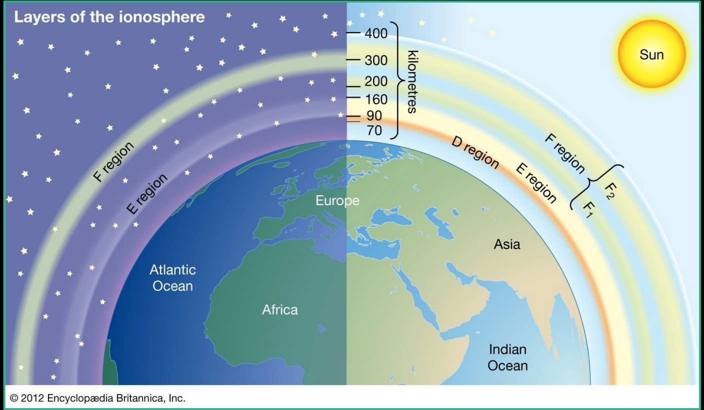
Marco Guerra, Claudio Cesaroni, Luca Spogli

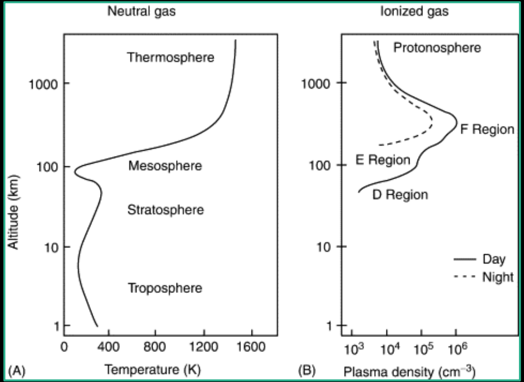
marco.guerra@ingv.it

2° TECHNICAL WORKSHOP COS, 27 June 2023

Background - Ionosphere

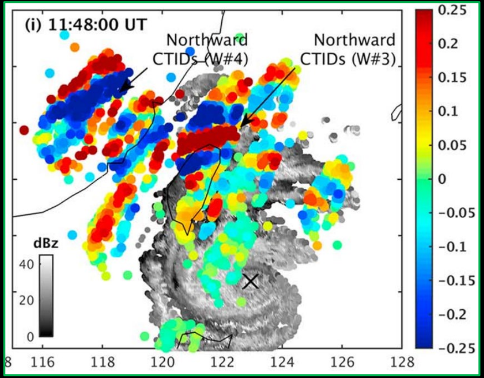
- Region of Earth's upper atmosphere, located approximately **60 to 1,000 kilometers**.
- Ionized **by solar radiation** (mainly UV and X-Rays), and made of **multiple layers**, each with different characteristics and properties.
- The layers are named the **D, E, and F layers**.
- Influenced by various factors, including **solar activity**, **geomagnetic storms**, and **time of day**.
- Plays a crucial role in **radio communication**, **satellite navigation systems**, and the **transmission of long-distance radio signals**.



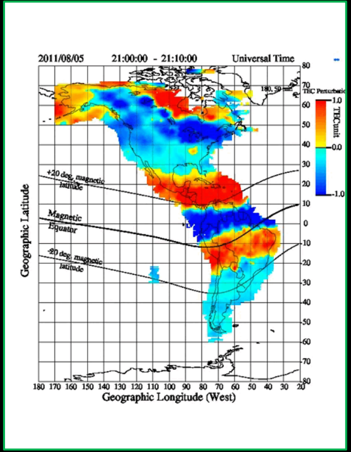


Background - Travelling ionospheric disturbances

- TIDs are **plasma density fluctuations** that propagate as waves through the ionosphere at a wide range of velocities and frequencies.
- Driven by **propagating atmospheric acoustic and gravity waves** generated by a large plethora of phenomena.
- Classified according to wavelength, period, amplitude, and propagation speed/direction into **Small, Medium, and Large scale.**
- TIDs are a major driver for **GNSS and HF degradation** at mid-latitudes.



[1]

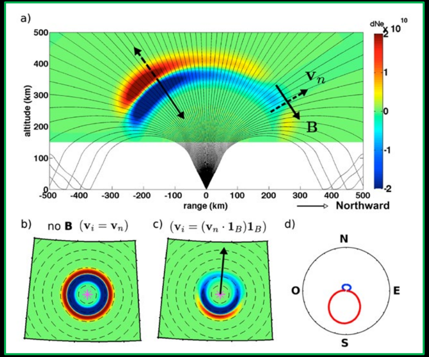


[2]

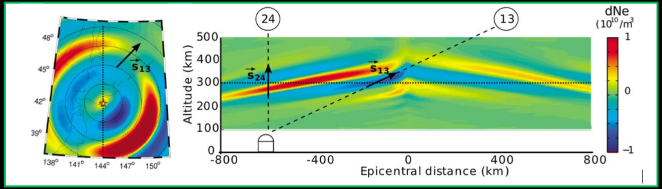
[1] Chou, et al. (2017), Concentric traveling ionosphere disturbances triggered by Super Typhoon Meranti (2016), Geophys. Res. Lett., 44, 1219–1226, doi:10.1002/2016GL072205.
[2] http://lisn.igp.gob.pe/miscellaneous/

Background – Earthquake induced TIDs

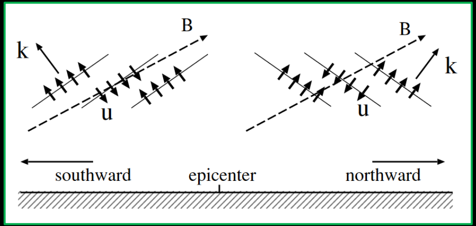
- Co-seismic ionospheric disturbances are generated by waves traveling vertically and then **accelerated** and **deflected horizontally** due to the **variation of atmospheric parameters** with altitude.
- **Rayleigh waves** propagating out from the epicenter can also generate acoustic-gravity waves propagating up to the ionosphere. These disturbances are **expected to propagate at the speed of the Rayleigh waves**, with a delay of around **ten minutes.**
- A **strong azimuthal difference** in the ionospheric response is expected due to the **plasma motion** being restricted mostly **along magnetic field lines**.



[3]



[4]

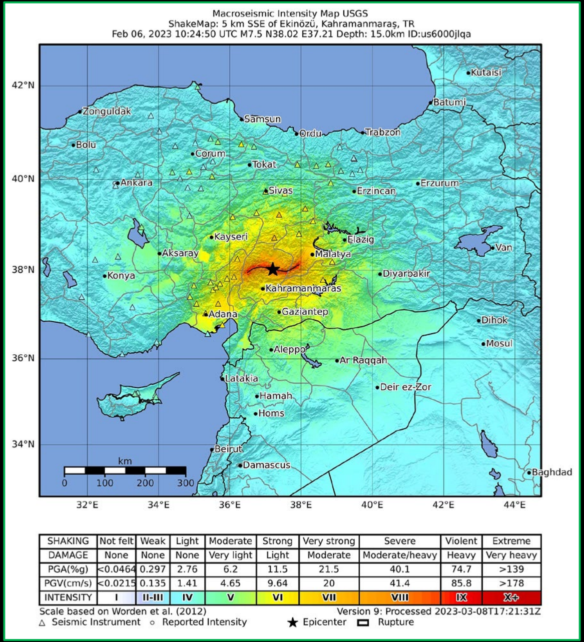


[5]

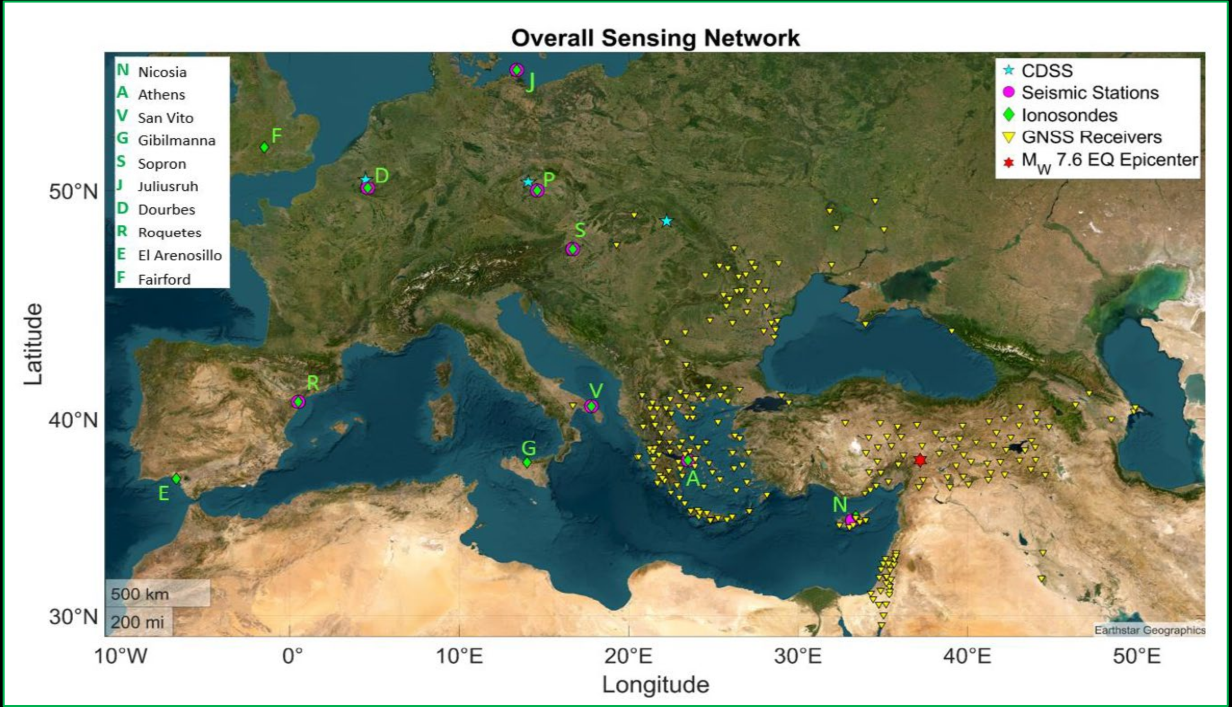
[3] Rolland et al.(2013). Discriminating the tectonic and non-tectonic contributions in the ionospheric signature of the 2011, Mw7.1, dip-slip Van earthquake, Eastern Turkey. Geophysical Research Letters.
[4] Rolland, et al. (2011). Detection and modeling of Rayleigh wave induced patterns in the ionosphere Detection and modeling of Rayleigh wave induced patterns in the ionosphere Detection and modeling of Rayleigh wave-induced patterns in the ionosphere. Journal of Geophysical Research Space Physics
[5] Otsuka, et al. (2006). GPS detection of total electron content variations over Indonesia and Thailand following the 26 December 2004 earthquake. In Earth Planets Space.

General features

- On **6 February 2023**, two earthquakes with magnitude MW > 7 occurred in Turkey.
- The first shock was recorded at **01:17 UT** with a magnitude of **7.8**
- The second shock happened at **10:24 UT** with **MW = 7.5**
- Earthquakes with **MW > 6.5** are **expected to generate co-seismic disturbances** in the ionosphere.
- Due to the low background ionization during night-time, **no clear TIDs for the first earthquake** have been identified.

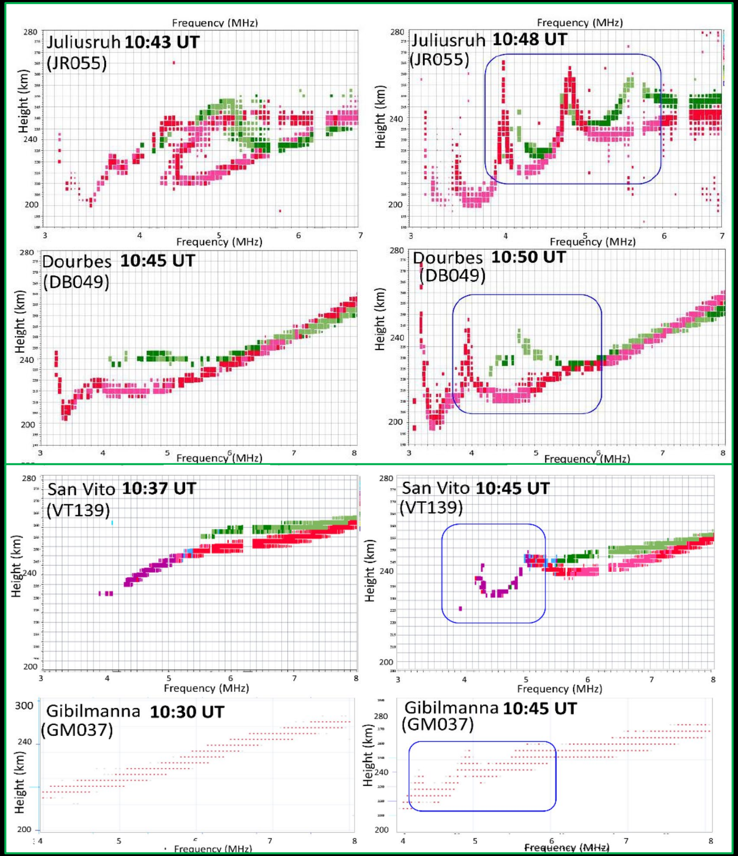


Instruments network

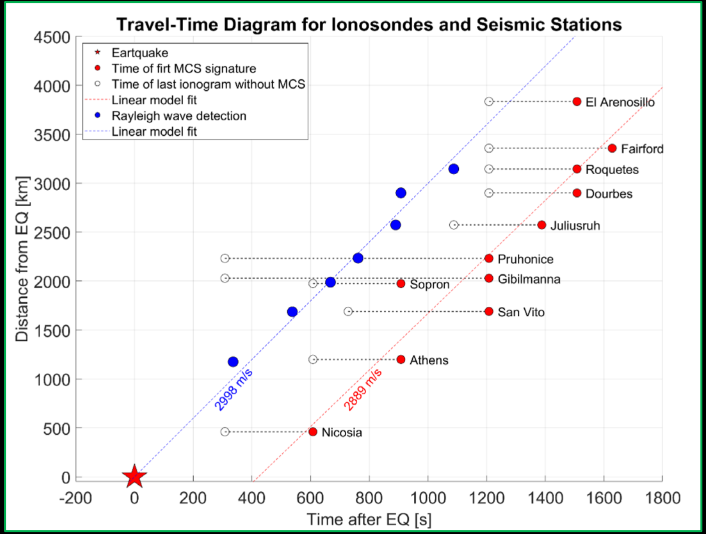


- We used **three different kinds of instruments** to detect the ionospheric response to the earthquake: **GNSS receivers**, **ionosondes**, and **CDSS**.
- In addition, we used as well **seismic stations** to track the seismic wave propagation.

Single ionosondes – Multi Cusp Signatures

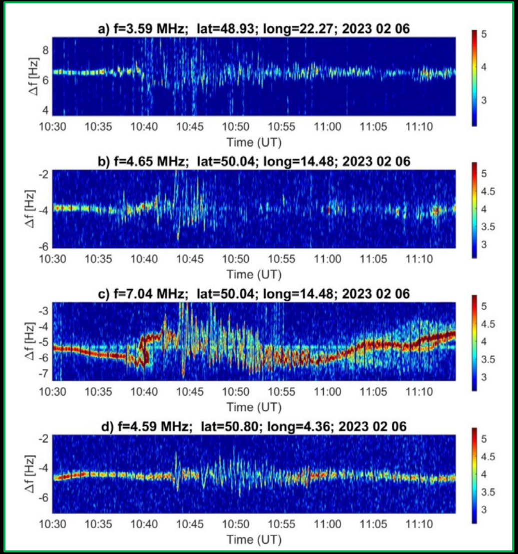


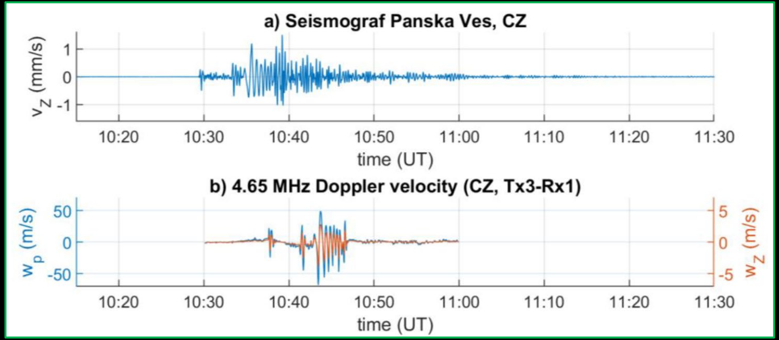
- **MCSs** are a **deformation on ionograms**, which appear as **additional cusps** that can be attributed to **electron density irregularities** giving rise to stationary points of inflection in the vertical electron density profile.
- Considering ionograms from all ionosondes involved, we were able to detect "**clear" MCS** on ionograms from **almost all stations.**
- Thanks to the seismic network, we were able to **correlate** the **MCS** with the passage of the **Rayleigh wave**.



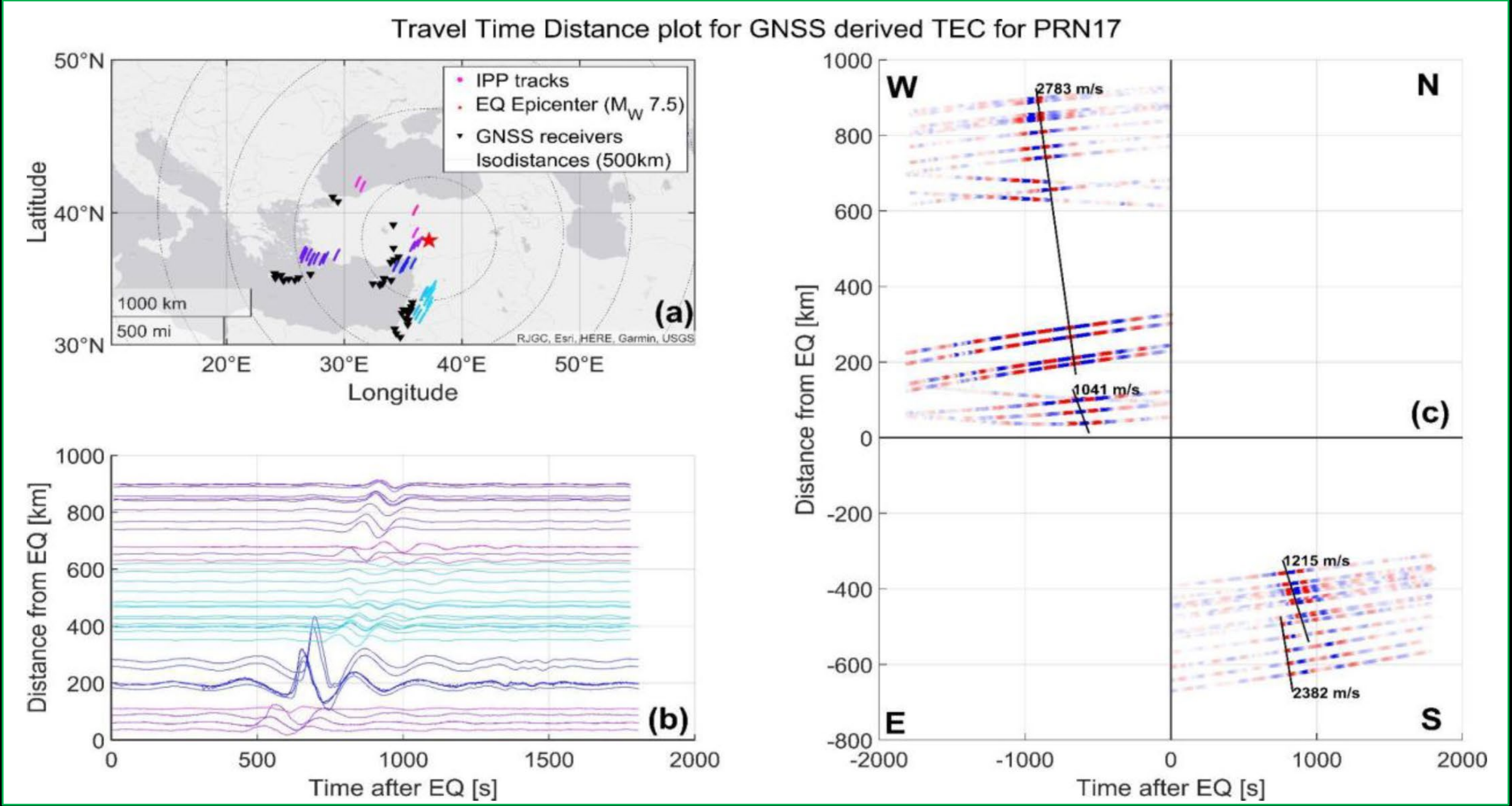
CDSS – Infrasound signatures

- Clear **infrasound signature** after around 10:40 in **CDSS spectrogram**
- High correlation between Panska Ves CDSS and colocated seismic station measurements.
- CDSS is the only technique showing **P, S, and Rayleigh-induced** signatures.
- Time delay in accordance with the **expected time of vertical propagation** of neutral waves (**7-8 minutes**).

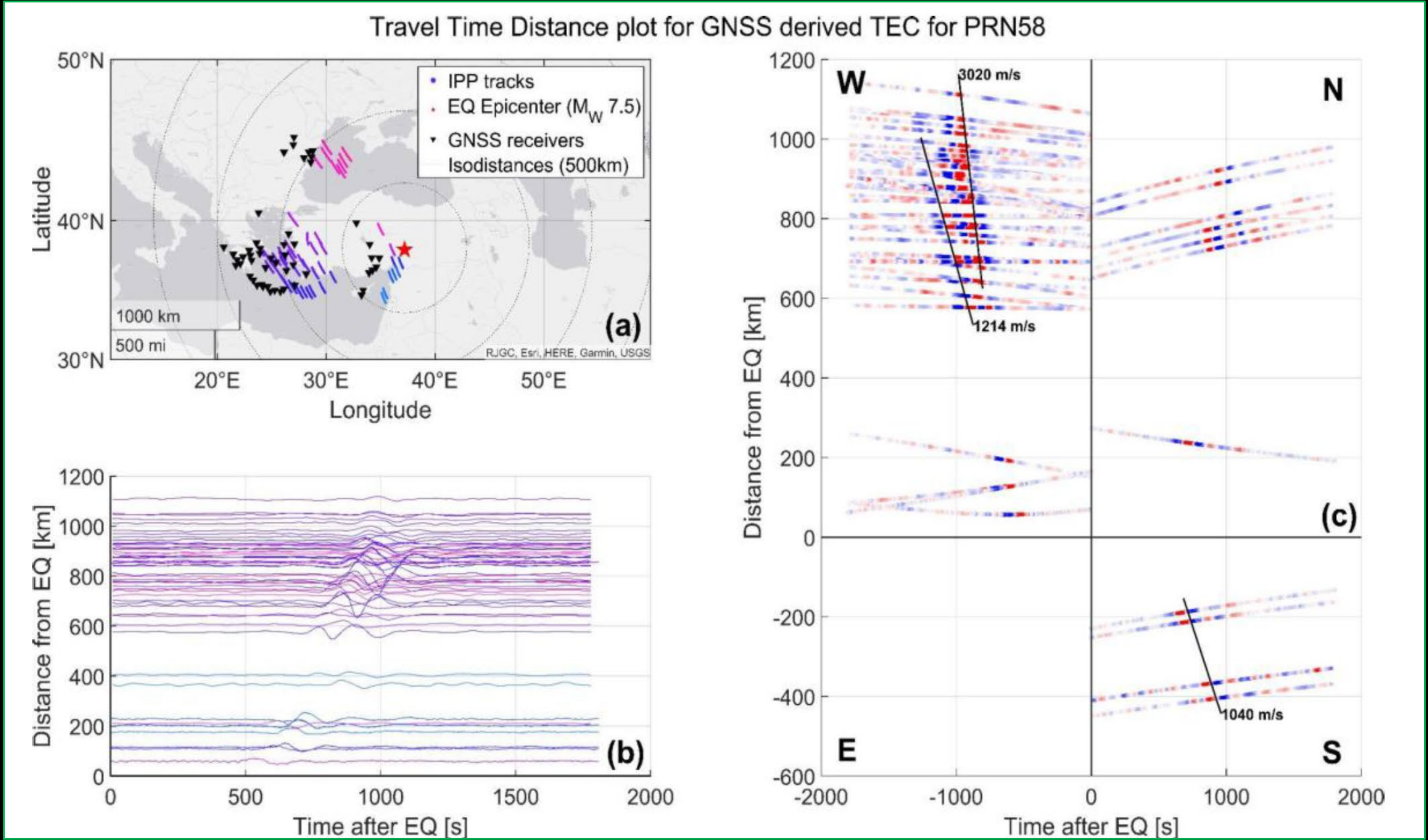




GNSS – Earthquake and Rayleigh waves induced TIDs



GNSS – Earthquake and Rayleigh waves induced TIDs



Conclusions

- The **networks of different instruments** allowed us to study **several aspects** of the **earthquake-induced** various **ionospheric disturbances**.
- The first one (near-field) was detected by **GNSS stations** and propagated at **1.2 km/s**.
- It showed a **clear anisotropy in the azimuth of propagation**, as almost no clear signature is visible north of the epicenter.
- The second type of TID is the one related to **Rayleigh waves**, which were detected by **all instruments**, and the propagation speed is **3 km/s**.
- Using CDSS, it was possible to detect **infrasound signatures** associated with waves (P-S) not discernable in the TEC data or even in the ionograms.
- It is key to use multiple instruments to observe the entire spectrum of ionospheric disturbances generated by seismic events.