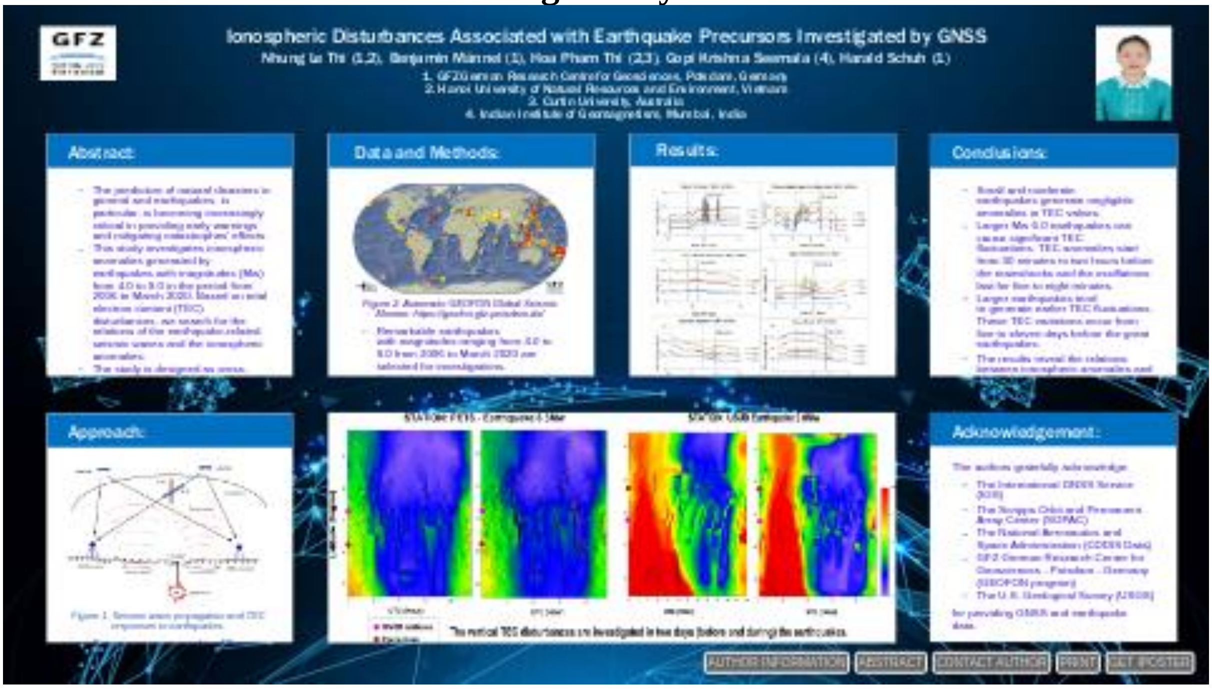
Ionospheric Disturbances Associated with Earthquake Precursors Investigated by GNSS



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E-Poster presented at:

Abstract:

- The prediction of natural disasters in general and earthquakes, in particular, is becoming increasingly critical in providing early warnings and mitigating catastrophes' effects.
- This study investigates ionospheric anomalies generated by earthquakes with magnitudes (Mw) from 4.0 to 9.0 in the period from 2006 to March 2020. Based on total electron content (TEC) disturbances, we search for the relations of the earthquake-related seismic waves and the ionospheric anomalies.
- The study is designed as cross-sectional investigations, in which the global earthquakes are randomly collected by the cluster sampling method. The selected data ensure strict conditions of size, equivalence. Probability and statistics are applied to filter, classify and analyse data.
- The results indicate that ionospheric fluctuations at the regions occurring earthquakes with magnitudes greater than 6.0 Mw are significant. Depending on the magnitude and frequency of shocks, these TEC anomalies appear before the mainshocks from a few days to two weeks.

Approach:

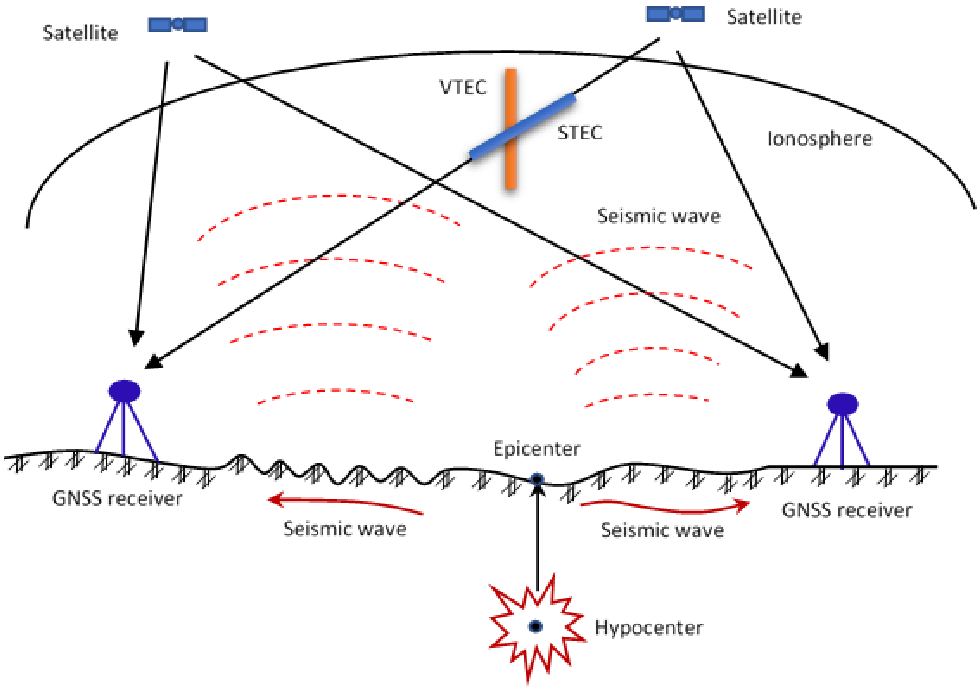


Figure 1. Seismic wave propagation and TEC responses to earthquakes.

- Seismic waves spread in different directions in the space. These waves can cause ionospheric disturbances.
- TEC (Total Electron Content) anomalies are analyzed by using GNSS (Global Navigation Satellite Systems) data to determine the relationships between ionospheric disturbances and earthquake-related seismic waves.

Data and Methods:

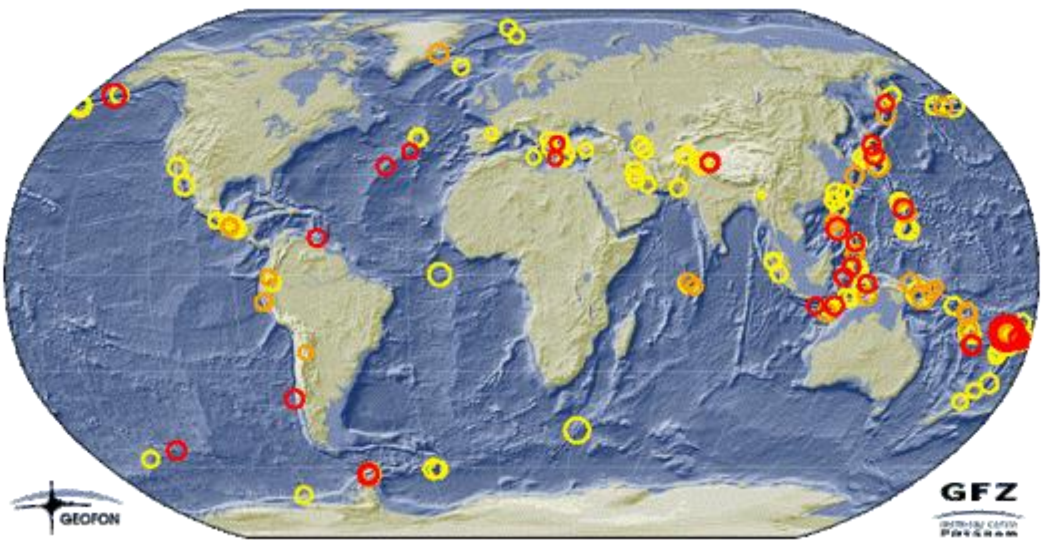


Figure 2. Automatic GEOFON Global Seismic Monitor (https://geofon.gfz-potsdam.de)

- Remarkable earthquakes with magnitudes ranging from 4.0 to 9.0 from 2006 to March 2020 are selected for investigations.
- Data of earthquakes include epicenter locations, hypocenter depths, magnitudes, the foreshocks, mainshocks, and aftershocks of earthquakes.
- We use the Coordinated Universal time (UTC) as a common time frame for both GNSS and earthquake data.

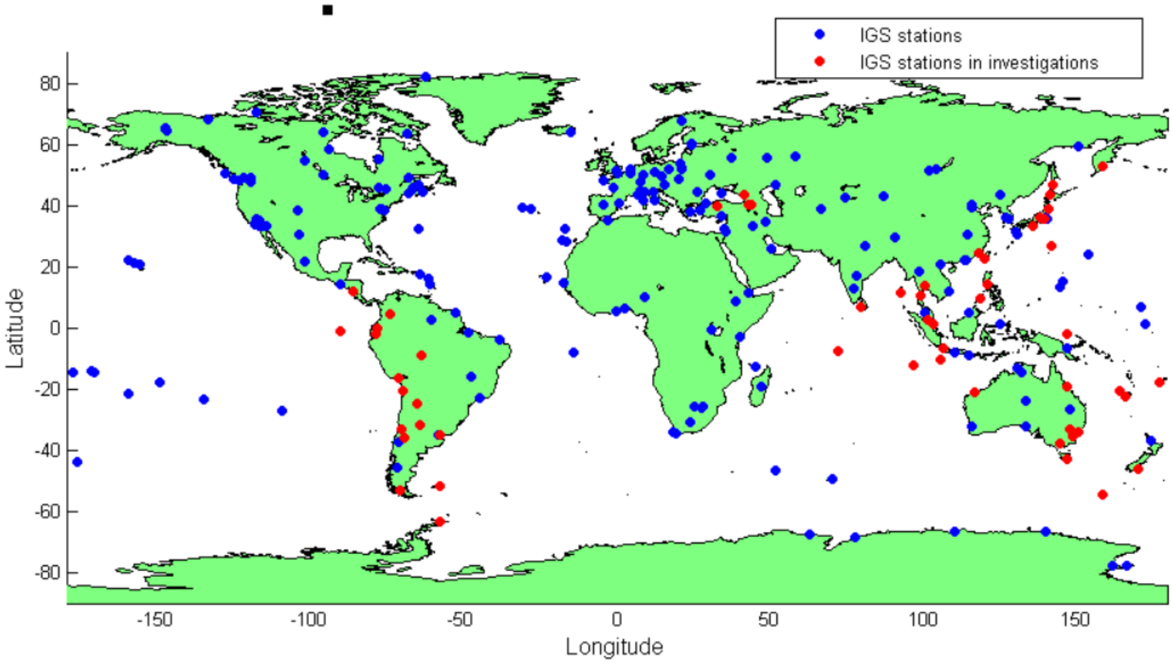


Figure 3. The IGS network

- Data of 54 permanent GNSS stations from the IGS (International GNSS Service) network are used to investigate TEC fluctuations linked to earthquakes.
- TEC data of at least three GNSS stations near the epicentre are utilized in the analysis of each earthquake.

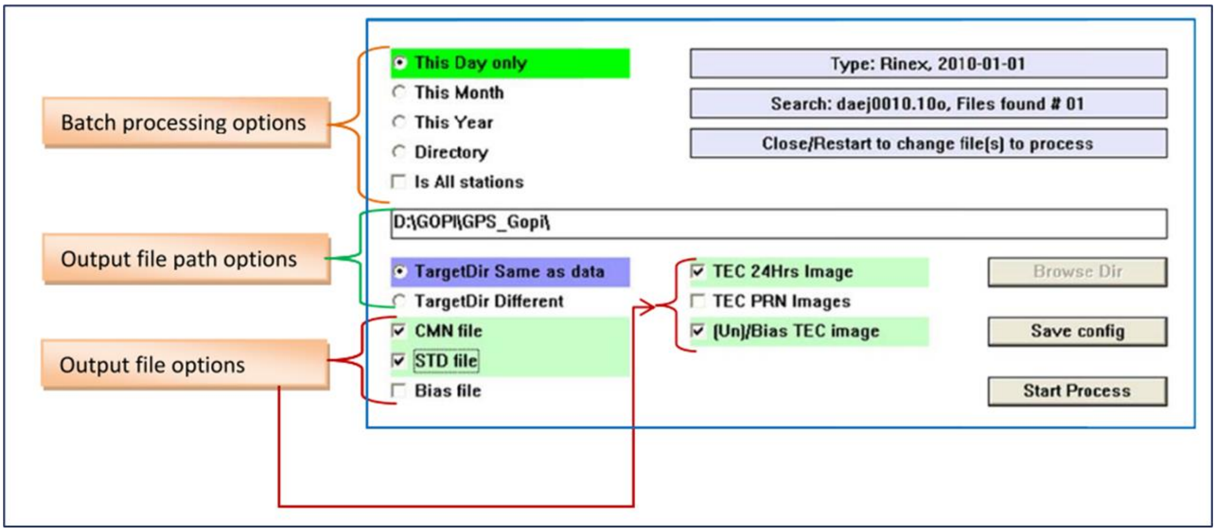


Figure 4. GPS-TEC analysis software

- The software uses GNSS data to compute TEC values. These TEC data are basic to analyze the relationships between ionospheric anomalies and earthquake-related seismic waves.

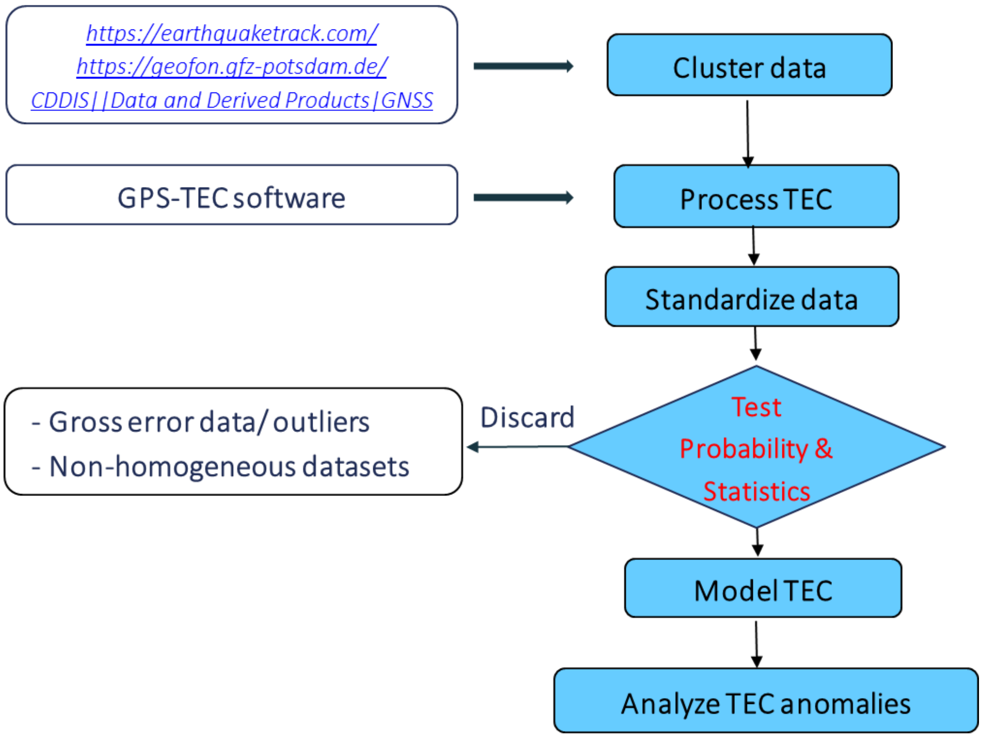


Figure 5. The main six-step processing

Investigation Design:

- 3 -12 hours: around the mainshocks of earthquakes
- 3 days: before, during, and after the earthquakes
- 30 days: preceding to the earthquakes

Cluster sampling:

- Regions: earthquake locations
- Magnitudes: ranging from 4.0 to 9.0Mw

Sample requirements:

- Size: 54 permanent GNSS stations used for investigating the earthquakes with magnitudes ranging from 4.0 to 9.0.
- Equivalence: the distance from the monitoring stations to the epicentre, the depth of hypocenter among investigated earthquakes, the accuracy of data sets.

Results:

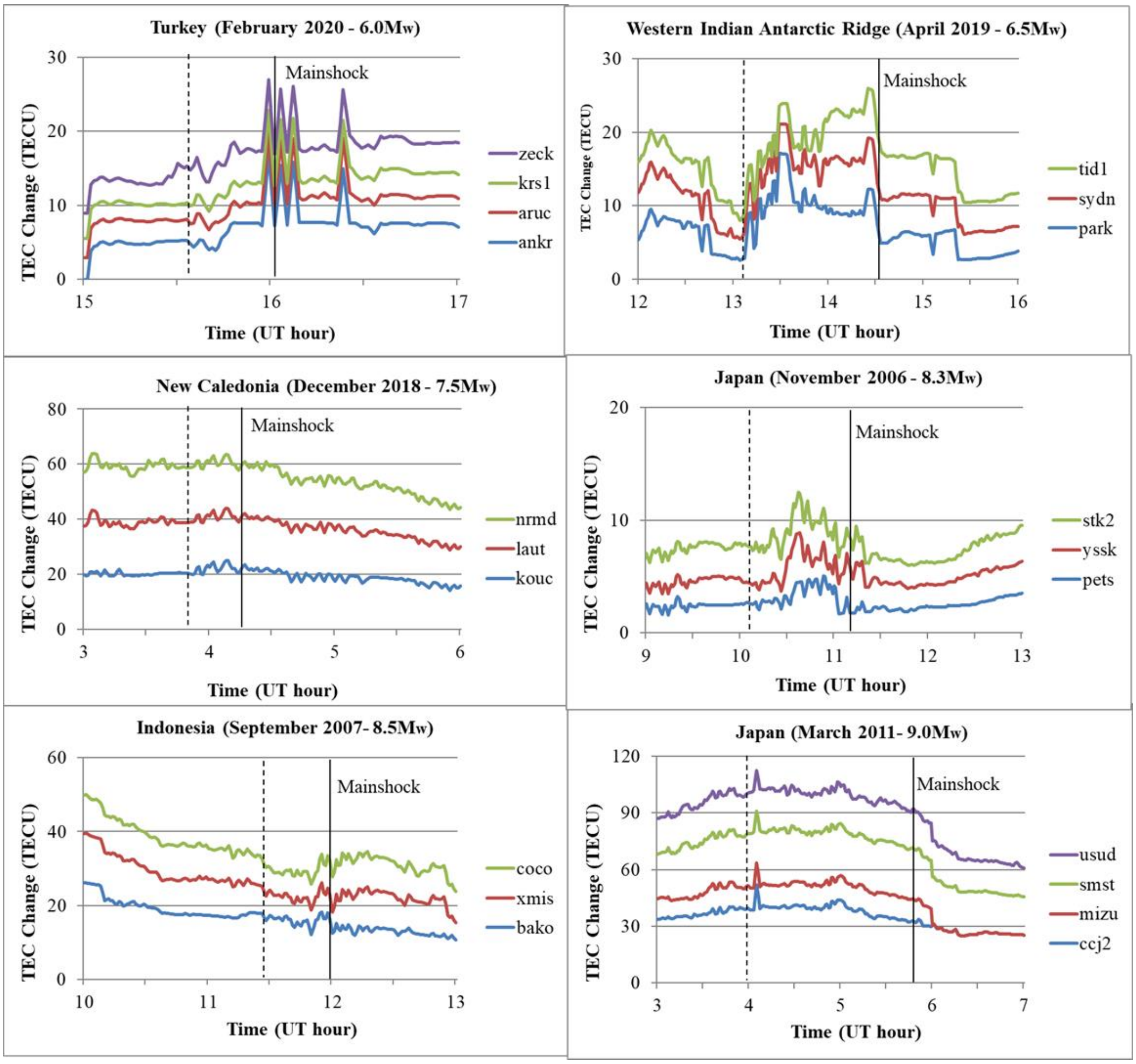


Figure 6. The TEC anomaly responses of the earthquakes ranging from 6.0 Mw to 9.0 Mw. The hypocenter depth of these earthquakes is approximately 10 km.

- Figure 6 illustrates the ionospheric anomalies associated with earthquakes within a few hours around the mainshocks. The right side of the graphs lists the names of GNSS stations. Adjacent curves have separated to avoid overlap, and the last line on each graph shows real TEC values.
- The results indicate that TEC changes are negligible for small and moderate earthquakes.
- For larger 6Mw earthquakes with clear precursors, TEC variations are significant. The TEC values calculated at different GNSS stations surrounding the earthquake regions tend to exhibit similar variations. The fluctuations between two consecutive TEC values (△TEC) range from 3.2 TECU to 14.5 TECU. These amplitudes are three to five times greater than △TEC. The oscillations persist for around five to eight minutes.
- The results show that there is no proportional relationship between the earthquake magnitudes and the levels of TEC fluctuations.

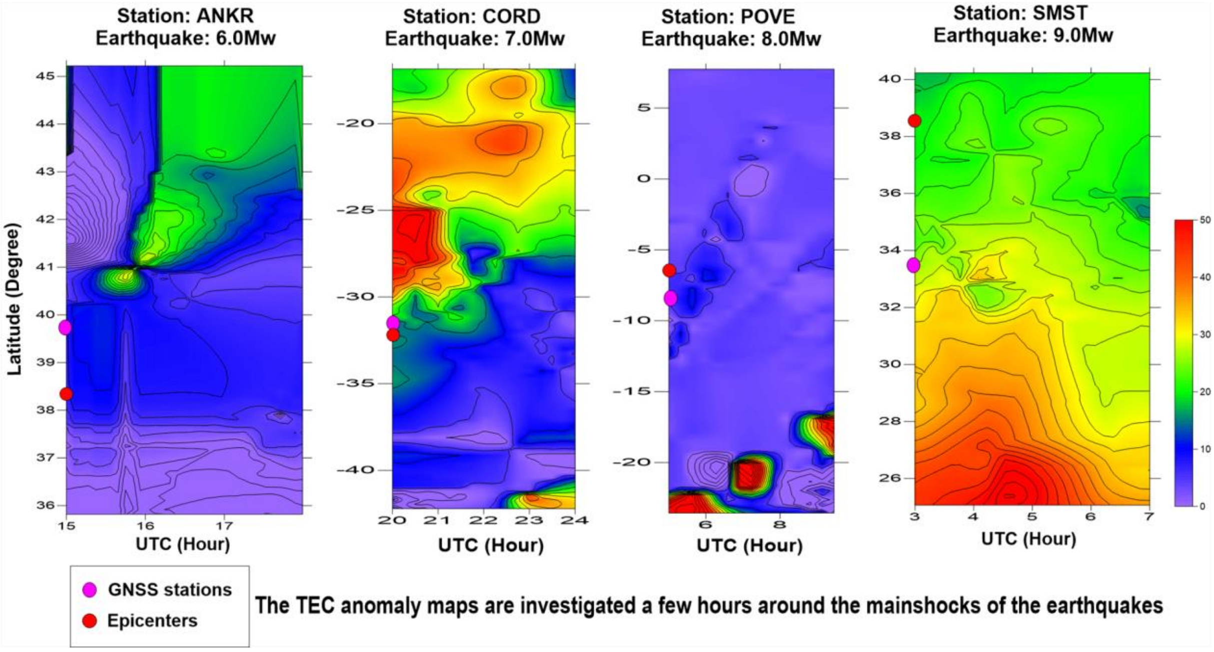


Figure 7. TEC anomaly map observed at GNSS stations in a few hours around the mainshock of the earthquakes.

- Figure 7 shows the ionospheric anomalies occurring around the mainshocks. TEC fluctuations start from 30 minutes to 2 hours before the mainshocks and last beyond this time.
- Further investigations are needed to determine the impacts of earthquake-related seismic waves on the ionosphere in altitude.

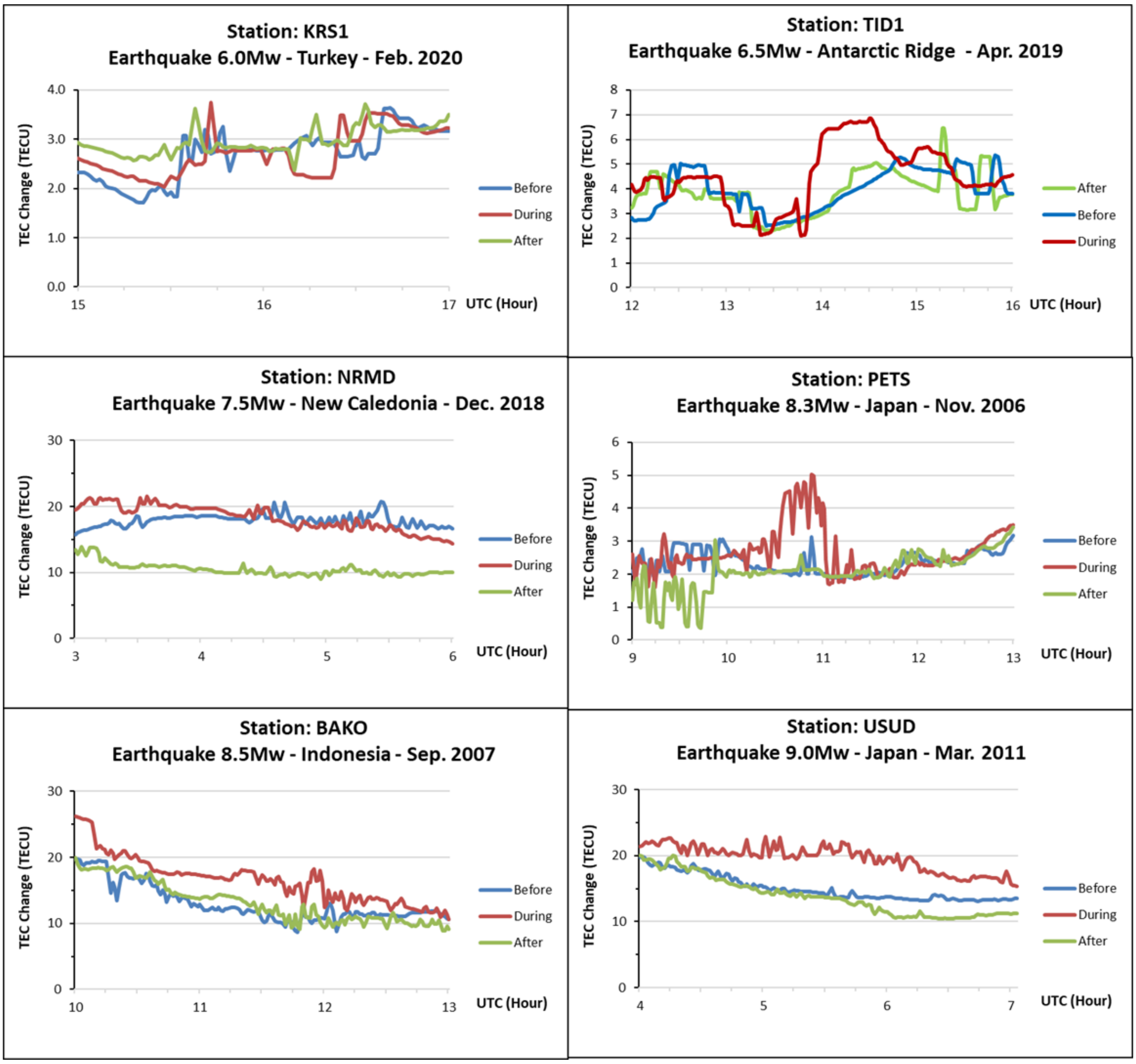


Figure 8. The TEC disturbances observed in three days (before, during, and after the earthquakes) at GNSS stations.

- Figure 8 presents the TEC disturbances at the time around the mainshocks in three days (before, during and after the earthquakes). In general, the most striking TEC fluctuations are on the same day as the earthquakes.
- Based on various areas, the mean TEC values on the day before the earthquakes are often higher (from 2 to 43 TECU) than other days.

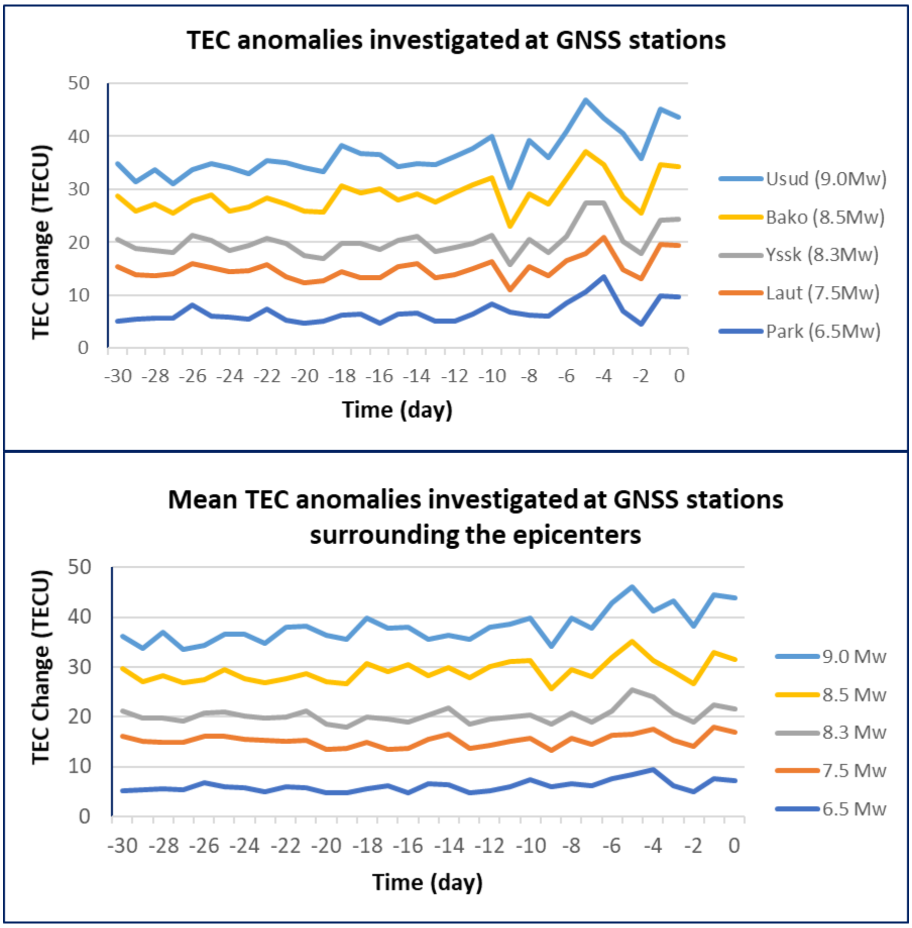


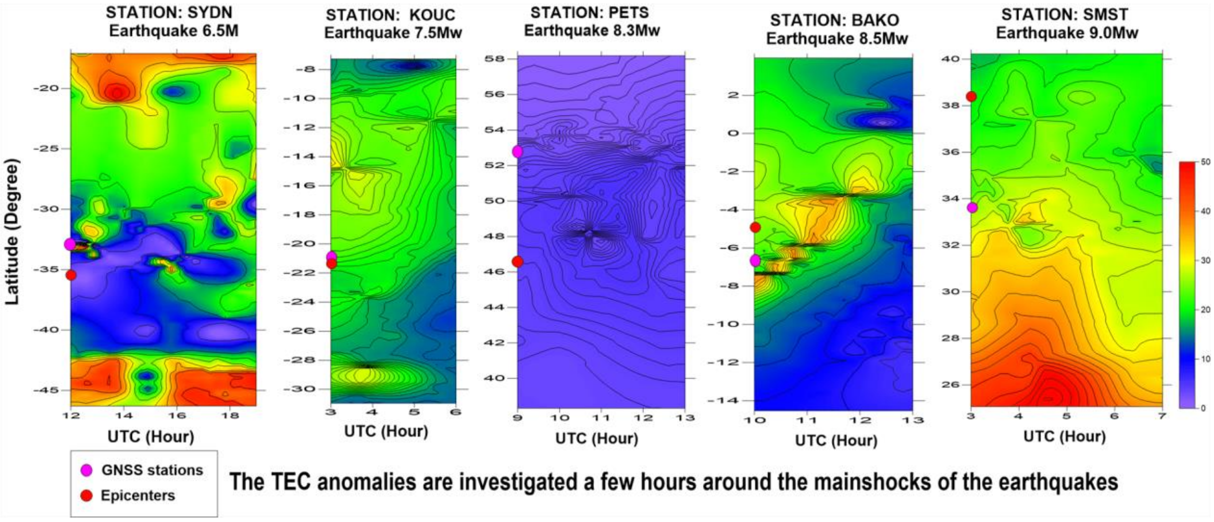
Figure 9. The TEC fluctuations observed in 30 days preceding to the earthquakes.

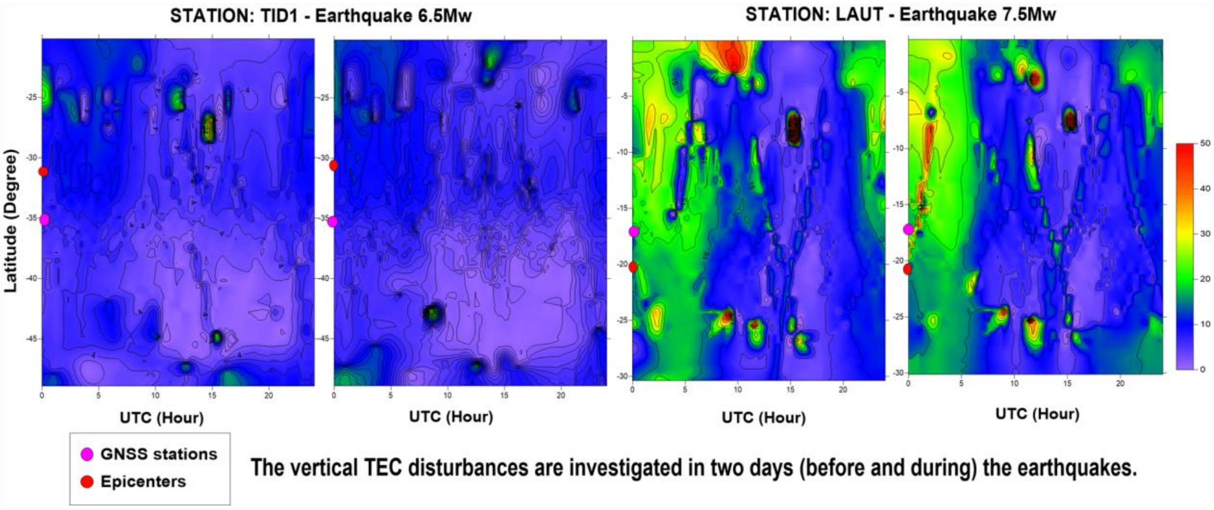
- The larger earthquakes tend to generate earlier TEC fluctuations. These TEC variations occur from 5 to 11 days before earthquakes with magnitudes from 6.5 to 9.0 respectively.

- Further investigations of the earthquakes with magnitudes smaller than 7.5 are necessary to estimate the relations between TEC anomalies and precursors. The foreshocks of these earthquakes are often sparse, and precursor signs are not significant enough to cause ionospheric anomalies at every monitoring station, especially, when GNSS stations are located far away from epicenters.

Conclusions:

- Small and moderate earthquakes generate negligible anomalies in TEC values.
- Larger Mw 6.0 earthquakes can cause significant TEC fluctuations. TEC anomalies start from 30 minutes to two hours before the mainshocks and the oscillations last for five to eight minutes.
- Larger earthquakes tend to generate earlier TEC fluctuations. These TEC variations occur from five to eleven days before the great earthquakes.
- The results reveal the relations between ionospheric anomalies and earthquake-related seismic waves. The findings are the base to filter TEC anomalies generated by earthquakes in building ionospheric models. The findings of the research open up a promising possibility for GNSS applications in studying TEC anomalies linked to earthquake precursors.


STATION: SYDN
Earthquake 6.5M
STATION: KOUC
Earthquake 7.5Mw
STATION: PETS
Earthquake 8.3Mw
STATION: BAKO
Earthquake 8.5Mw
STATION: SMST
Earthquake 9.0Mw
Latitude (Degree)
UTC (Hour)
GNSS stations
Epicenters
The TEC anomalies are investigated a few hours around the mainshocks of the earthquakes


STATION: TID1 - Earthquake 6.5Mw
STATION: LAUT - Earthquake 7.5Mw
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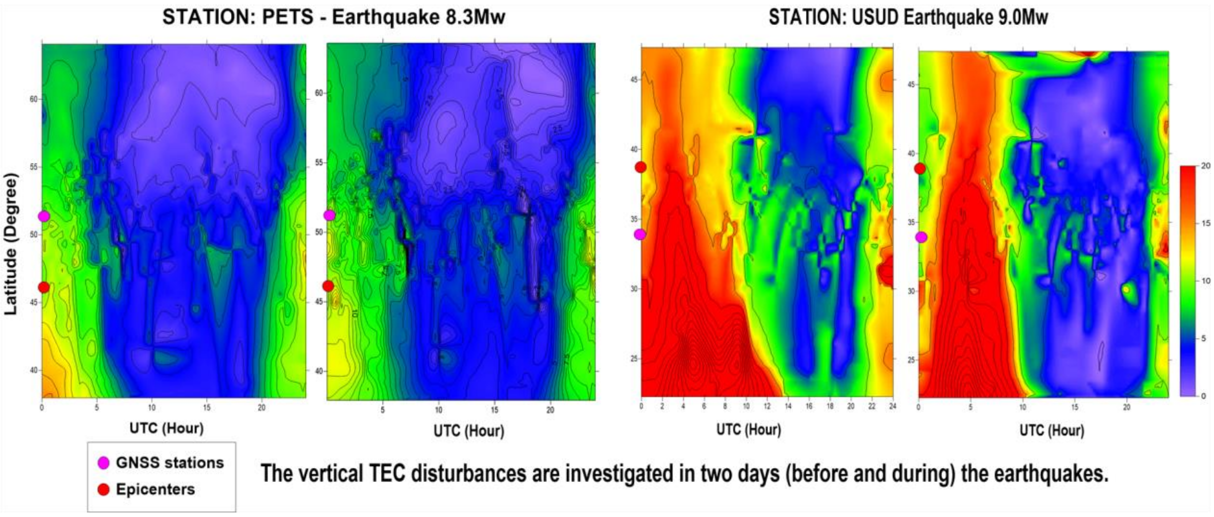
GNSS stations
Epicenters
The vertical TEC disturbances are investigated in two days (before and during) the earthquakes.


STATION: PETS - Earthquake 8.3Mw
STATION: USUD Earthquake 9.0Mw
Latitude (Degree)
UTC (Hour)
GNSS stations
Epicenters
The vertical TEC disturbances are investigated in two days (before and during) the earthquakes.

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- The U.S. Geological Survey (USGS)

for providing GNSS and earthquake data.

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