UNIVERSITY OF BASILICATA

# STATISTICAL ANALYSIS FOR THE IDENTIFICATION OF PRECURSORY SIGNATURES OF EARTHQUAKE OCCURRENCE IN TOTAL ELECTRON CONTENT (TEC)

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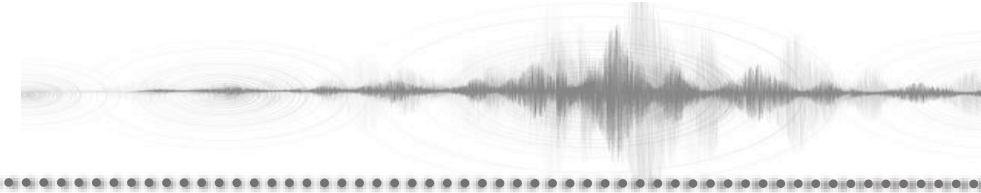
# 1 INTRODUCTION

*This work aims to investigate the possible correlation between ionospheric Total Electron Content anomalies and Earthquake occurrence by means of a statistical approach based on the classic* **Sliding InterQuartile Range (IQR) method** *(Liu et al., 2004).*

*As first application, are presented in this work the results related to a* **20-year analysis** *performed over* **central Italy** *using GPS-TEC data.*

*The IQR method has been reformulated and adapted to try to improve the goodness of fit of the model to the series of "sliding windows observations", considering:*

- *their (possible) non-gaussianity,*
- *the solar activity variation.*



# 2 METHOD

Given:

$$\Delta TEC = TEC - MM_{TEC}$$

The **Sliding Windows** index related to the observed **TEC** ($SW_{TEC}$) is calculated as follows:

$$SW_{TEC} = \begin{cases} \dfrac{\Delta TEC}{n * (MM_{TEC} - LQ_{TEC})}, & \Delta TEC < 0 \\ \dfrac{\Delta TEC}{n * (UQ_{TEC} - MM_{TEC})}, & \Delta TEC \geq 0 \end{cases}$$

Where:

- *TEC* is the observed vTEC under investigation;
- $MM_{TEC}$ is the 27-day Moving Median of the vTEC values measured in the same time-slot of the one under investigation.
- Given a 27-Day Moving Sample of *TEC* values measured in the same time-slot of the one under investigation: $MM_{TEC}$, $LQ_{TEC}$ and $UQ_{TEC}$ are respectively the (Moving) Median, Lower and Upper Quartiles of the sample.
- *n* is a small integer adapted to the site under investigation

# 2 METHOD

By applying a similar normalization, is calculated the $SW_{F10.7}$ index using the F10.7 data. The $SW_{F10.7}$ is, then, subtracted to the $SW_{TEC}$ for the purpose of deducting the effects of solar activity.

The resulting $TEC_{Index}$ is obtained as follows:

$$TEC_{Index} = SW_{TEC} - SW_{F10.7}$$

- IDENTIFICATION RULE

To identify a TEC Anomaly, the following requirements must be satisfied:

TECIndex > k (In this study k = 4,5);

Minimum time persistence = 1 hour

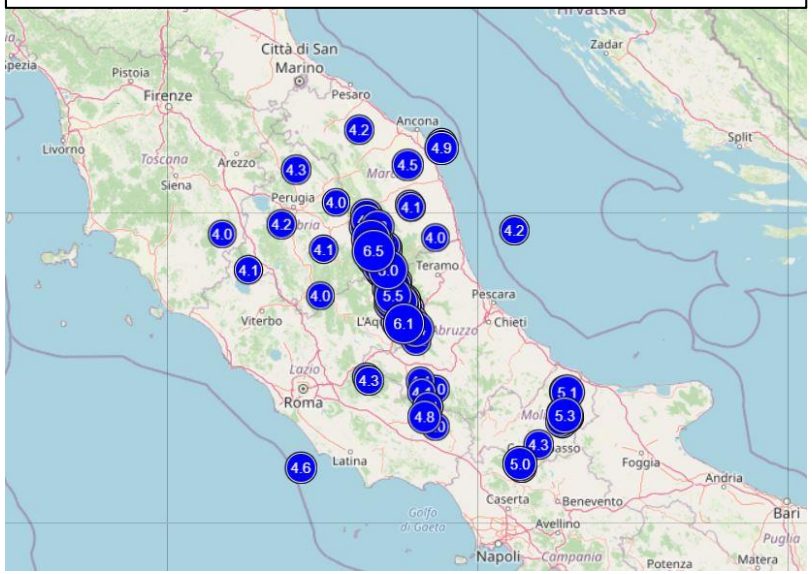
- CORRELATION RULE

Each TEC Anomaly observed from the single GPS-station is considered possibly related to seismic activity if an earthquake of M ≥ 4 occurs within a temporal window of ±30 days and within a distance D < 150 km;

# 3 RESULTS

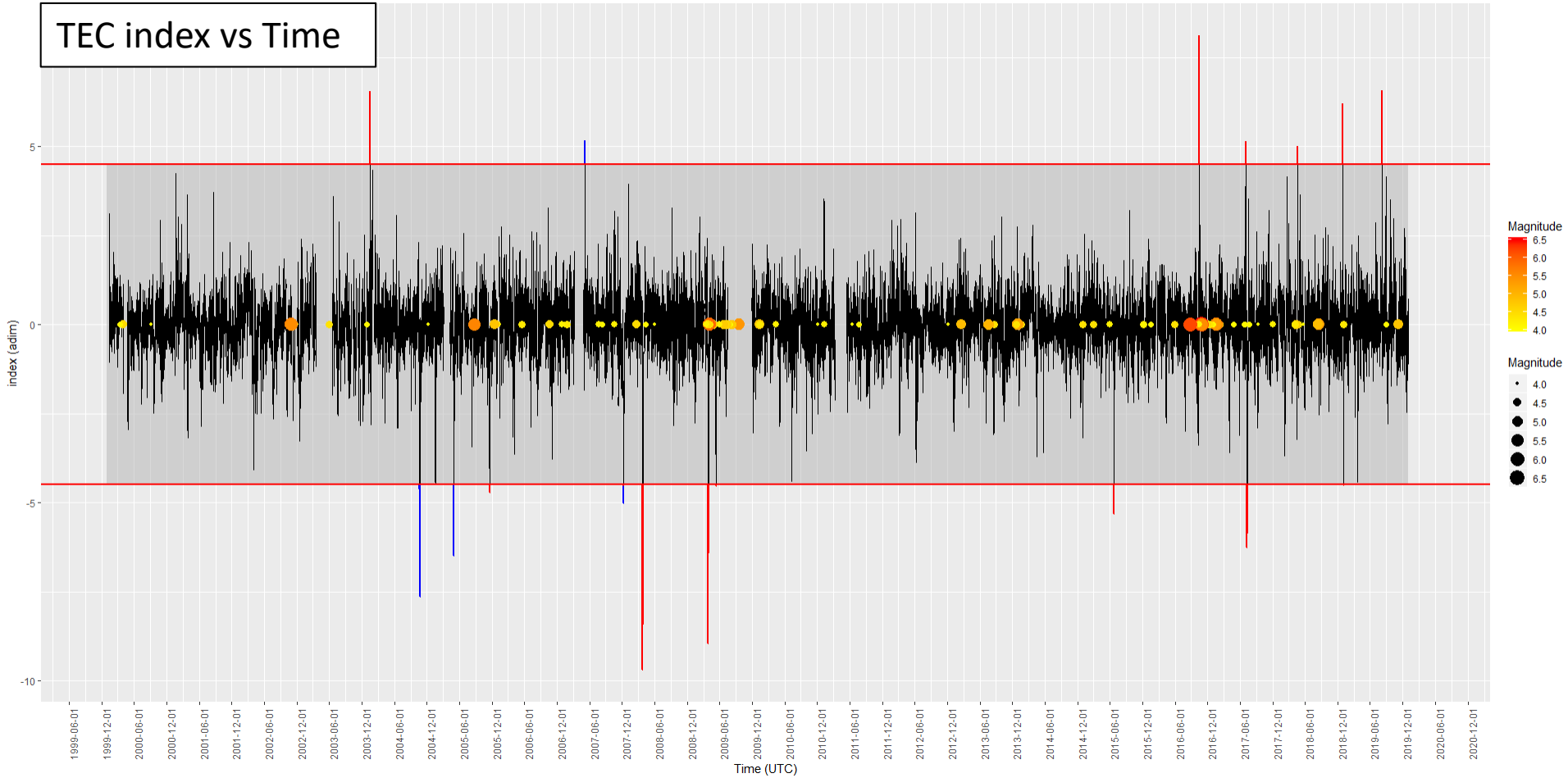
The analysis performed by applying previously established correlation rules to all the 285 “hourly” anomalies identified on the whole time series of TEC observations highlighted that the **73% of TEC index anomalies are in apparent space-time relations with earthquake (M≥4)** occurrence and the 27% of anomalies apparently are not related to documented seismic activity (false positives). The total number of seismic events recorded is 216.

Spatial distribution of the earthquakes




*The figure above shows the spatial distribution of the M≥4 earthquakes occurred in the space-time interval investigated.*

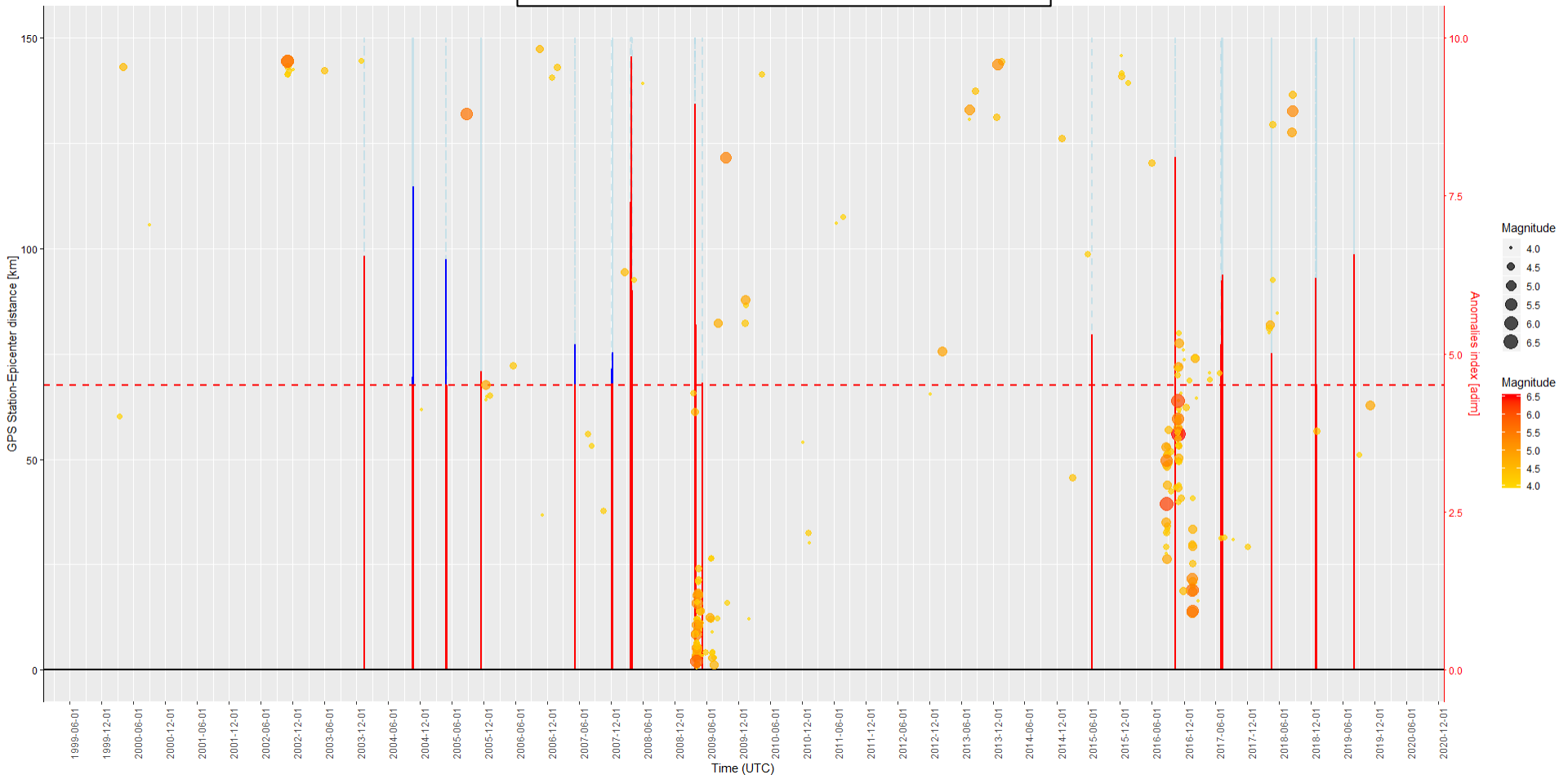
# 3 RESULTS




*The graph shows the trend of the TEC index during the 20 years analyzed. The black line represents the TEC index, the vertical red lines represent the anomalies detected, the blue lines represent the false positives, the horizontal red lines the upper and lower thresholds.*
*On the horizontal axis is also reported the temporal distribution of the earthquakes occurred in the selected magnitude-space-time interval. In order to make the graph more readable, the magnitude of the earthquakes has been scaled both in size and in color, as shown in legend.*

# 3 RESULTS

## TEC anomalies vs Earthquakes




*The graph shows the magnitude-space-time correlation between earthquakes and detected anomalies.*

- *The primary y axis is related to the points (earthquakes) and quantifies the distance of the GPS station from the earthquake epicenter. In order to make the graph more readable, the magnitude of the earthquakes has been scaled both in size and in color, as shown in legend.*
- *The secondary y axis is related to the detected TEC anomalies. All anomalies are transposed on the positive side of the y axis.*

*The solid red lines represent the anomalies detected, the solid blue lines represent the false positives, The dotted red line represents the threshold.*

# 4 CONCLUSION

*Particularly interesting is the presence of* **marked anomalies** *during the seismic swarms of 2009 and 2016 (moreover accompanied by earthquakes of M > 6 and very close to the GPS station), which seems to confirm that the correlations detected are non-casual. However, further statistical analyzes are being carried out on the subject.*

*The next step is to analyze other seismically active areas to further test the performances of the method. However, the scarce diffusion of GPS-stations and/or the absence of historical data in many seismically active areas does not help, especially if, the close correlation between anomaly detection and station-epicenter distance, was confirmed.*

*The results obtained appear to be promising and, if confirmed, the method will be part of a multi-parameter integrated system for time-Dependent Assessment of Seismic Hazard (t-DASH).*