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POSSIBLE POST-SEISMIC EFFECTS IN SOME OF GEOPHYSICAL QUANTITIES RELATED TO THE EARTHQUAKE ON 29 DECEMBER 2020

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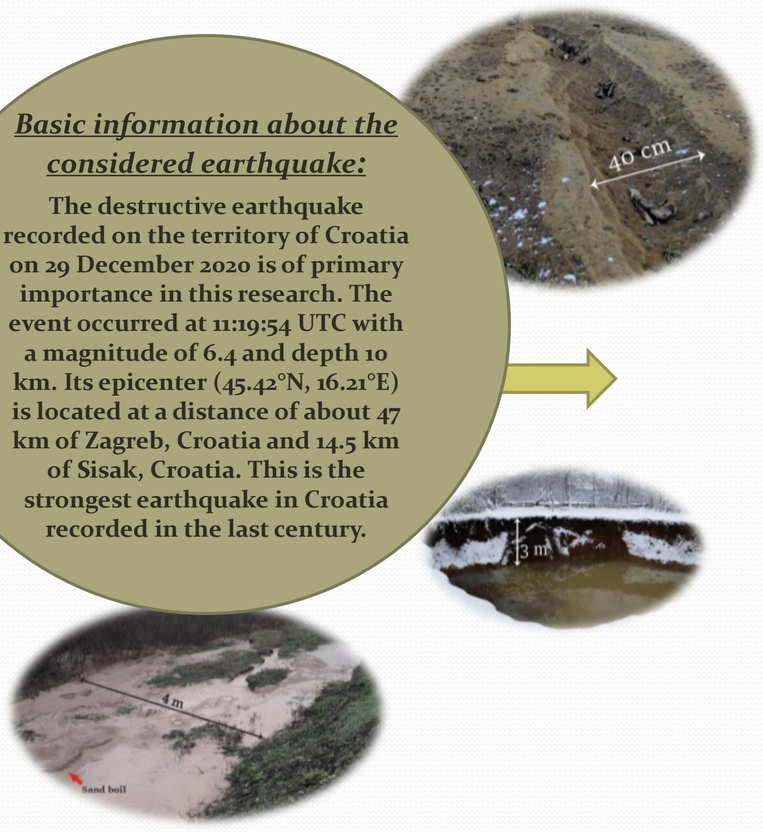
The main idea of the present investigation is to study the relationship between post- seismic effects as a result of Petrinja, Croatia earthquake occurred on 29 December 2020 in some ionospheric parameters. Two types of ionospheric data were used: the critical frequency of the F2 region (foF2), obtained from the vertical sounding of the ionosphere and Total Electron Content (TEC) data. The ionospheric response is studied by the relative deviation of both quantities foF2 and TEC. The results of the ionospheric parameter behavior show the following: a) a positive anomaly is observed in both ionospheric characteristics; b) the most significant positive response is observed at ionospheric stations closer to the epicenter; c) the delay of the observed post-seismic ionospheric effect increases with distance from the epicenter in both data used. The observed anomalies in the behavior of considered ionospheric parameters could be associated with the considered lithospheric phenomenon because the selected period is with completely quiet geomagnetic conditions. The results of this research gives additional insight into the Lithosphere-Atmosphere-Ionosphere Coupling during Earthquake processes.

Basic information about the considered earthquake:

The destructive earthquake recorded on the territory of Croatia on 29 December 2020 is of primary importance in this research. The event occurred at 11:19:54 UTC with a magnitude of 6.4 and depth 10 km. Its epicenter (45.42°N, 16.21°E) is located at a distance of about 47 km of Zagreb, Croatia and 14.5 km of Sisak, Croatia. This is the strongest earthquake in Croatia recorded in the last century.



Unlike variations in the relative TEC, which is an integral of the ionospheric electron density for the entire ionosphere along a line vertical to a given point on the Earth's surface, foF2 shows some delay in its response. In addition, for each of the ionospheric stations, the Standard Deviation (STD) is shown, which allows to see what the dispersion of the data is compared to the mean value. The illustrated variations of the individual stations show a similar response to TEC, but with some differences, namely:

- **The positive response of all ionospheric stations shows a delay compared to that of TEC. The hypothesis to explain this effect is that the observed delay is most likely related to the distance of the points from the epicenter. Due to the fact that the closest coordinate to the epicenter is the TEC point, it is expected that a response of this parameter will be registered first;**
- **It is noticed that as the selected points move away from the epicenter, the response delay becomes greater. Stations RO041 and VT139 (which are slightly closer in coordinates) show positive relative foF2 values slightly before the other stations DB049 and EB040;**
- **The maximum positive response also shows some delay in its manifestation with distance from the epicenter. It occurs most rapidly in TEC (around 03UT). After about an hour at 04UT, a maximum in the relative foF2 is observed in the ionospheric data;**
- **The most significant positive response of about 0.6 is observed at stations RO041 and VT139, while in the more distant DB049 and EB040 stations it reaches about 0.4;**

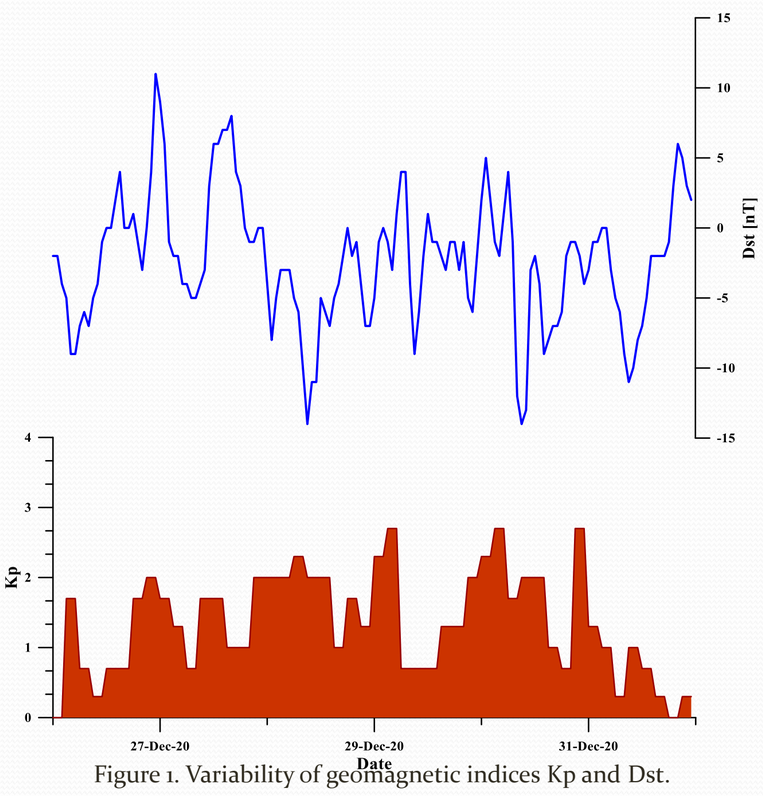


Figure 1. Variability of geomagnetic indices Kp and Dst.

Geomagnetic indices.

Well-studied effects of the solar influences on the Earth's magnetosphere, ionosphere and atmosphere give reason to analyze the behavior of the geomagnetic indices before and after the registered earthquake on 29 December 2020.
Fig.1 shows the behavior of the indices Kp (bottom panel) and Dst (top panel) for the period 26-31 December 2020.
As can be seen from the figure Kp index does not reach 3, and Dst has values up to -15nT. According to the accepted classification for both indices no geomagnetic disturbance was registered during the entire considered interval.
The obtained results, which show geomagnetically quiet conditions, allow to analyze the ionospheric parameters and hypothesize that the obtained anomalies in their behavior are due to post-seismic effects.

Selection of specific data in the analysis of the ionosphere.

After the behavior of the geomagnetic indices do not indicate the presence of a geomagnetic storm, the next step is an analysis of the behavior of the ionospheric parameters TEC and foF2. For this purpose, data from selected ionospheric stations obtained by GIRO were used.
Table 1 presents information about the used point data for the foF2 quantity from the ionospheric stations selected as close as possible to the epicenter of the Croatian earthquake.
Besides the ionosonde foF2 data we also use the TEC data from the CODE database as the closest to the epicenter point with coordinate (45°N, 15°E) is selected.

Station Code	Country	GEO Latitude	GEO Longitude
RO041	Rome, Italy	41.9	12.5
VT139	San Vito, Italy	40.6	17.8
EB040	Roquetes, Spain	40.8	0.5
DB049	Dourbes, Belgium	50.1	4.6

Table 1. List of used ionospheric stations received by GIRO.

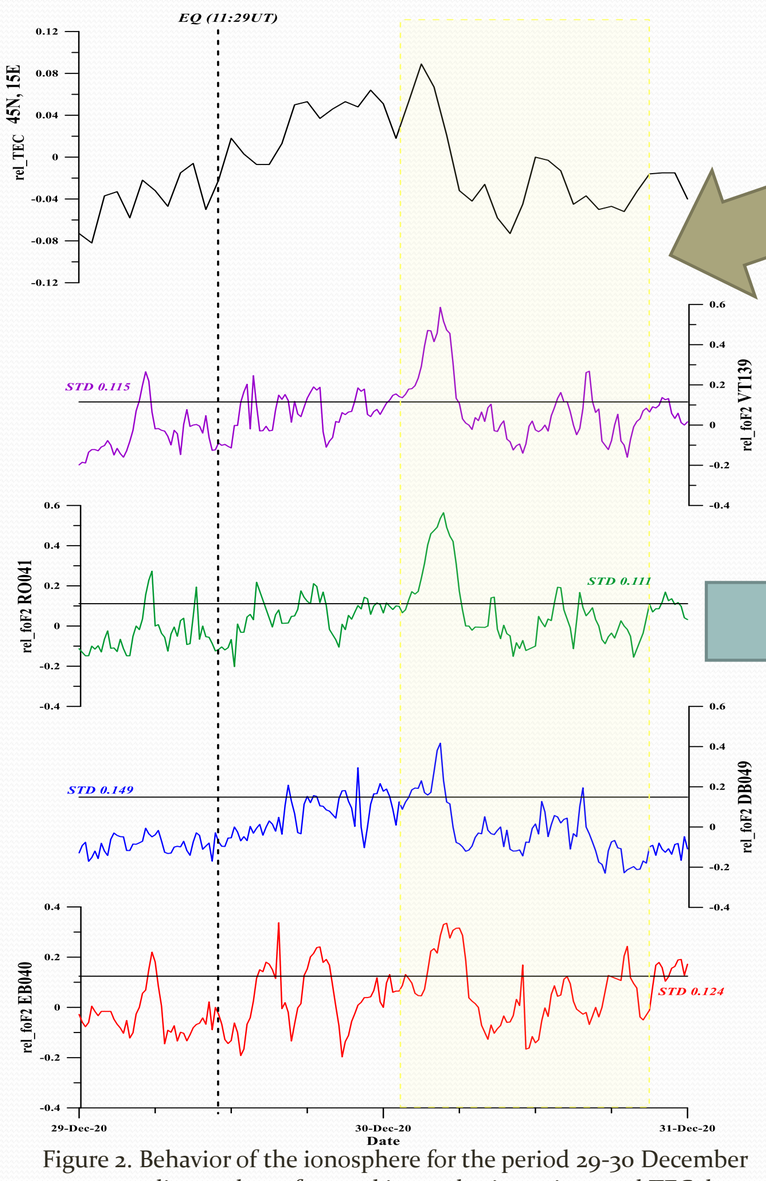


Figure 2. Behavior of the ionosphere for the period 29-30 December 2020 according to data of several ionospheric stations and TEC data.

Investigation of the ionospheric response for specific selected points.

The main idea of this study is to analyze the possibility of a relationship between the ionospheric response in the days after the earthquake near Zagreb, Croatia on 29 December 2020. For the purpose Fig. 2 presents the comparison of the behavior of the relative values of the data from the ionospheric stations and TEC for the available points near the epicenter of the earthquake. From the behavior of the relative TEC, whose coordinates almost coincide with those of the earthquake (45°N, 15°E), it can be seen that positive values are observed shortly after 12UT on 29 December 2020- i.e. immediately after the seismic event occurred. The quantity has its most significant positive value in the night hours around 03UT on 30 December 2020, reaching around 0.1.

You can download the file from here:

Conclusions: **This study presents the ionospheric response most probably produced by the earthquake in Croatia on 29 December 2020. The ionospheric anomaly over European region covered by latitudes of 40.6°N-50.1°N and longitudes of 0.5E° -17.8°E are investigated. For this purpose two types of data, foF2 and TEC, have been used for the time interval 29-31 December. The ionospheric response in both parameters is presented by relative deviations of foF2 and TEC. The results clearly show the presence of a positive response in the parameters under consideration. This positive anomaly occurs first at the point with the closest coordinates to the earthquake epicenter and the delay increases away from the epicenter. The larger magnitudes are observed in ionosondes closer to the epicenter and the response decreases with distance to the epicenter.**
The results found in the present study give us the opportunity to clarify the view of the ionospheric anomalies most probably related to the Croatian earthquake. The knowledge about the possible sources of the variability of the critical frequency of the ionosphere is extremely important for high frequency radio wave propagation and satellite navigation.

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