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Evaluation of the Effects of Earthquakes on Radon and Total Electron Content Values and Meteorological Changes on the North Anatolian Fault Zone, Türkiye

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Abstract: A cross-correlation analysis is proposed to analyse the relationships of soil Radon-222 gas, Ionospheric Total Electron Content (TEC), and some meteorological variables with earthquakes from the North Anatolian Fault Zone, Türkiye, one of the most active fault lines in the World. Statistically important results are obtained for Earthquake-Rn gas changes and Seismo-Ionospheric Coupling. In addition, we think that this study will be an important step for further studies on earthquake precursors.

Key words: Radon; Earthquake; TEC; Meteorology; Cross-correlation; Prediction; Precursor

Depremlerin Radon ve Toplam Elektron İçeriği Değerleri Üzerindeki Etkilerinin ve Meteorolojik Değişimlerin Değerlendirilmesi Kuzey Anadolu Fay Zonu, Türkiye

Özet: Bir çapraz-korelasyon analizi, toprak Radon-222 gazı, İyonosferik Toplam Elektron İçeriği (TEİ) ve bazı meteorolojik değişkenlerin, Türkiye'nin en aktif faylarından biri olan Kuzey Anadolu Fay Zonu, Türkiye'deki depremlerle ilişkisini analiz etmek için önerildi. Deprem-Rn gaz değişimleri ve Sismo-İyonosferik Bağlantısı için istatistiksel olarak önemli sonuçlar elde edildi. Ayrıca, bu çalışmanın deprem tahmini konusunda yapılacak daha sonraki çalışmalar için önemli bir adım olacağını düşünmekteyiz.

Anahtar kelimeler: Radon; Deprem; TEC; Meteoroloji; Çapraz Korelasyon; Kestirim; Öngörü.

1. Introduction:

Rn-222 is generated due to the nuclear decay of Radium (^{226}Ra) and Uranium (^{238}U) [1]. Radon gas (^{222}Rn) has the longest half-life (3.82 days) compere with daughters' [2], Rn has omnipresent occurrences is chemically uncertain is radioactive gas tasteless, colourless, odourless gas [1], [3]. Rn gas travels over large distances on the surface of the Earth through different methods. Such as diffusion, convection, or advection [4]. The soil with a lower and medium permeability, diffusion takes priority, but for soils with higher permeability, convection transport takes precedence [5]. Radon is also affected by tectonic plate activities, and meteorological parameters, for example, temperature, pressure and wind speed, precipitation, and humidity. The radon is also affected by seasonal variations. The impact of these parameters on Rn-222 emission dynamics ranges between several hours and several days [6]–[12].

TEC is an important parameter in the investigation of changes in the ionosphere. It observation provides a direct connection between seismo-ionospheric coupling and causes for understanding their relation. The ionosphere is a layer in the air atmosphere located at an altitude between 50 to 1000 km, with charged particles containing ions and electrons [13]. The TEC is defined as the total electron density between two points in a cylindrical tube with a cross-section of 1 m^2. The unit for measuring it is defined as (TECU), with 1 TECU equalling 10^{16} electrons per square meter [14]–[15]. The global positioning system is used extensively for ionosphere investigation [17]–[20].

Many researchers have noted that Rn-222 levels increase from a few hours to several weeks before earthquakes occur [6], [21]–[31]. Rn variations have been predicted as a valuable method as earthquake precursors in a different place in the world and confirmed [28], [32]–[38]. Examined worldwide land, water, and air radon analysis and confirmed that radon is a reliable predictor of the prediction of earthquakes in the future [39], [40].

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The purpose of this research is to determine a correlation between concentration of radon gas, the total electron density in the ionosphere, and variations with seismic activities, by considering meteorological parameters (underground and air atmospheric temperature with air pressure). Investigating all parameters together is innovation in this field on the North Anatolian Fault Zone, Türkiye.

2. Data Sources and Method of Analysis

One of the main areas for the slip of continents that form the neo-tectonic evolution of Türkiye and the East Mediterranean region is the North Anatolian Fault Zone (NAFZ, see **Error! Reference source not found.**). The s eismic activity of the region is heavy and poses a high risk to heavily populated areas. The NAFZ, is situated within 1500 km of the triple junction Karliova in eastern Anatolia to the Marmara Sea.

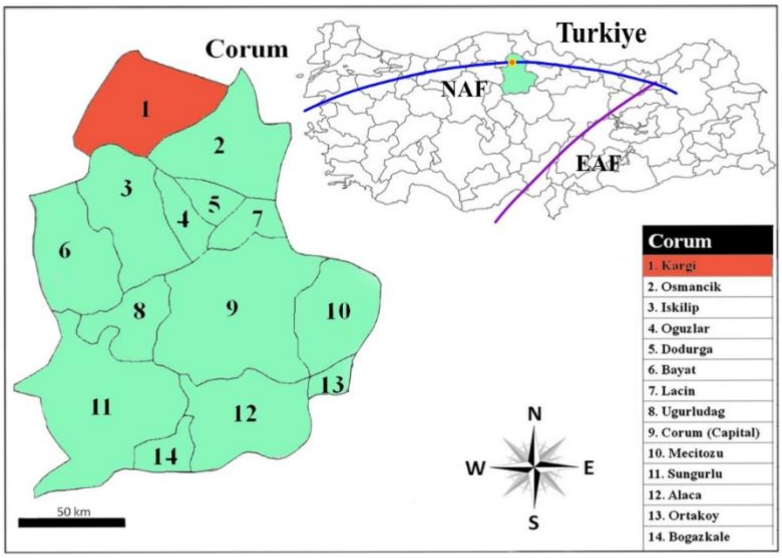

Figure 1 Study area Kargı Çorum province Türkiye

The study area is the district of Kargı is located (106 km) in the north of the Çorum province (39°54′20″ N, 34°04′28″ E) in the North-central Anatolia, Türkiye [42]. The location is shown in Figure 1. Çorum has a warm dry-summer continental climate with moderates to cool wet springs and light rain in the fall and spring. The hottest times in Çorum province are in July and August. The average daily temperature in these months is (21 °C). The coldest days of the year are experienced in January nearly (-4 °C). Annual rainfall is an average of (444 mm per square meter). The monthly average sunbathing hours are 200 h (Turkish State Meteorological Service, n.d.).

A cross-correlation method is a common approach for determining how closely or correlated two series are. To determine the degree of similarity the function lag correlation is used [43], [44]. Also in the literature, the cross-correlation plot as an essential method in identifying the relations between non-stationary time series, such as soil radon, and the effect meteorological data on it is used [45].

2.1. Earthquake, TEC, and radon gas measurements

During the observation period Dec 2008 to Dec 2009, the seismic activity in the Çorum -Kargı area obtained from the Boğaziçi Kandilli Observatory. During the observation period, 90 earthquakes are recorded with a magnitude between (3 to 4.4 M_L) the Richter scale (http://www.koeri.boun.edu.tr/scripts/lasteq.asp).

In this study, TEC was collected through IONOLAB (ionospheric research laboratory-Türkiye) (http://www.ionolab.org/index.php?page=index&language=en), in this laboratory, the online TEC measurement is provided in near real-time. The nearest station from the study area to measure TEC for the period (16 Dec 2008 to 31 Dec 2009) in the study area is Ankara TEC station. The TEC data are provided every 2.5 min daily for a station in the period days.

Radon gas (^{222}Rn) concentration data for the period Dec 2008-Dec 2009 in the Çorum -Kargı area was donated by the Ministry of Interior Disaster and Emergency Management Presidency (AFAD) (https://en.afad.gov.tr/).

Monitoring radon gas measurement was operated online. Data is transferred to the centre from all online stations. In this study, the Alpha Meter 611 detector (factory-made by Alpha Nuclear Company, Canada) was used to measurement radon gas (^{222}Rn). Soil radon gas was continually deliberated every 15 minutes by alpha meter detector.

3. Results and Discussions

In this study, an investigation of the relation between the soil radon gas concentration, meteorological parameters, and total electron content TEC with earthquakes and the cross-correlation between Rn concentrations with total electron content variation is provided. In addition, critical and statistically significant information for future Rn behaviour provides.

The earthquake data TEC and radon gas, in addition to the meteorological data, have been divided into three groups. Each group contains about 4 months of data, and the impact of earthquakes on these data will be discussed to find the cross-correlation between ^{222}Rn concentration and TEC data.

3.1. First group

The first group starts on (Dec 16, 2008, to Mar 31, 2009), numerous micro-earthquakes occurred with magnitude (3 to 4.3), with total electron content and ^{222}Rn gas concentration between (70 to 140 kBq.m^{-3}), atmosphere, pressure and underground (5, 10, 20, and 50 cm) temperature for the same period are shown in Error! Reference source not found..

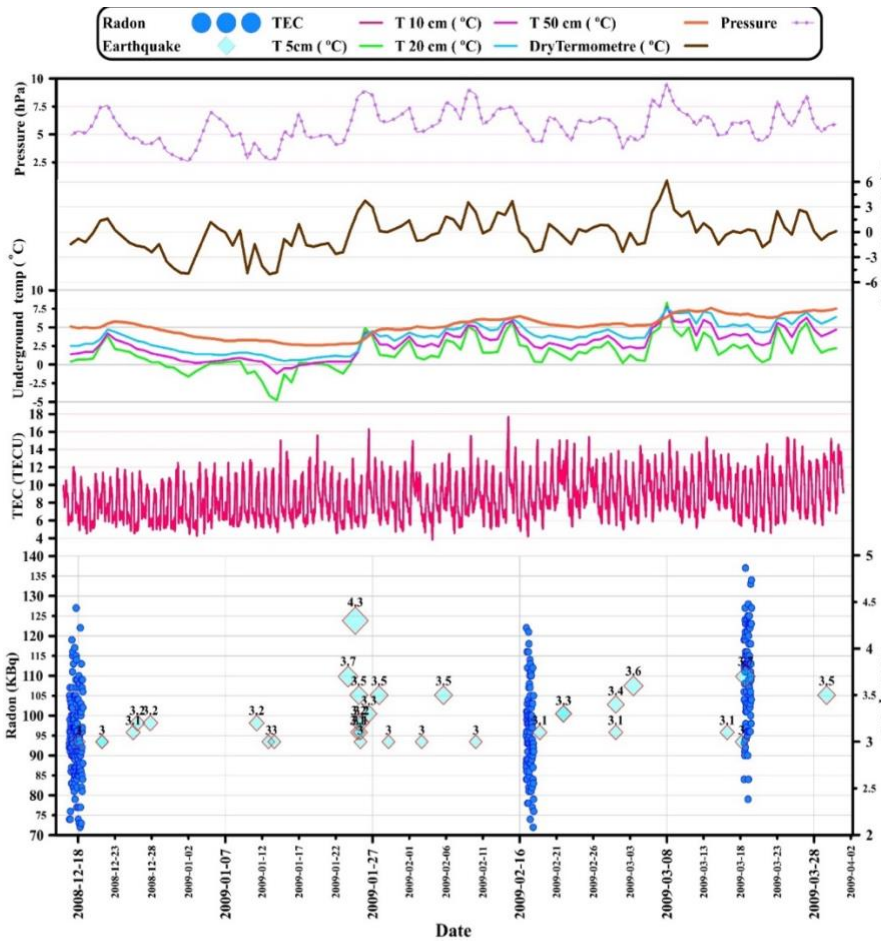

Figure 2. Radon, TEC, Temp of soil (5, 10, 20, and 50 cm) and Pressure with Earthquakes for the first group

During the observation time, there is no abnormal change in the pressure and total underground and atmospheric temperature. Otherwise, the total electron content for some days recorded a high magnitude value. To find the correlation between the parameters we divide the first group into the same small groups based on the availability of all parameters at the same time. The first group A graph is shown in the figure below Error! Reference source not found..

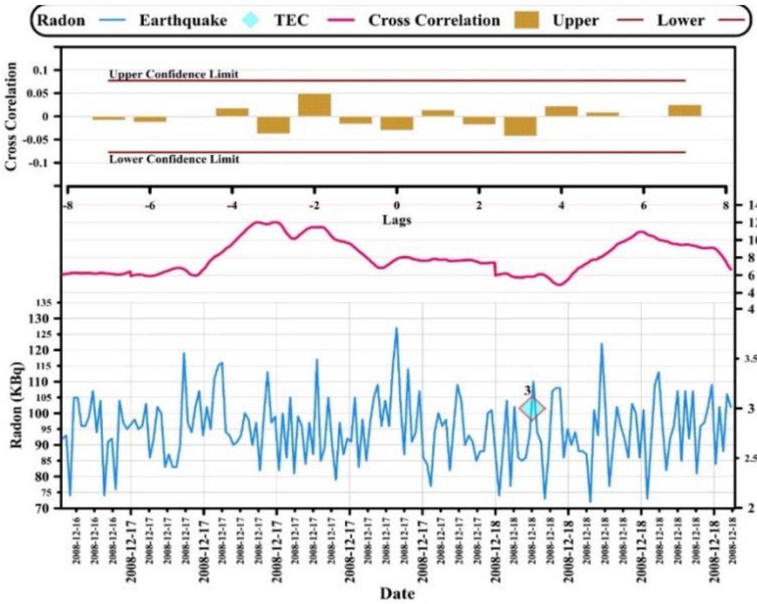

Figure 3 First group A cross-correlation for the data

We can see in **Error! Reference source not found.** that the radon gas concentration one day before the earthquake with magnitude (3 M_L) recorded a small anomaly reaching approximately (127 kBq.m^{-3}), but the total electron content for the same period slowly start to decrease. Soil and atmosphere temperature differences and air pressure are nearly stable. Therefore, the cross-correlation between Rn gas and TEC would not record the anomaly path through the confidence bound.

For Error! Reference source not found. (first group B) exactly when the earthquake with a magnitude (3.7 M_L) occurs release gases due to the pressure of tectonic plates causing for emanation process and the radon gas concentration increase up to (137 kBq.m^{-3}), but in contrast, the TEC gradually decrease. The cross-correlation for this variation did not show any anomaly between them.

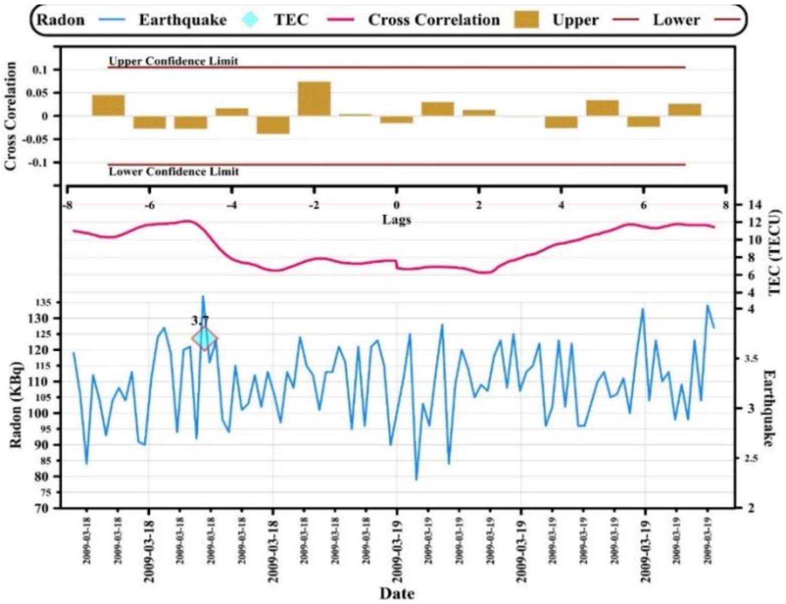

Figure 4 First group B cross-correlation for the data

3.2. Second group

The second group starts on (Apr 1, 2009, to Aug 31, 2009); many micro-earthquakes occurred with a magnitude (3 - 4.4 M_L), with TEC and radon gas concentrations varying between (60 to 270 kBq.m^{-3}). Air atmosphere and underground soil temperature record almost (8 °C) increment in the temperature this unique change for both underground and air is not helpful for transferee radon gas upward by the convection process. All data for the same period are shown in Error! Reference source not found..

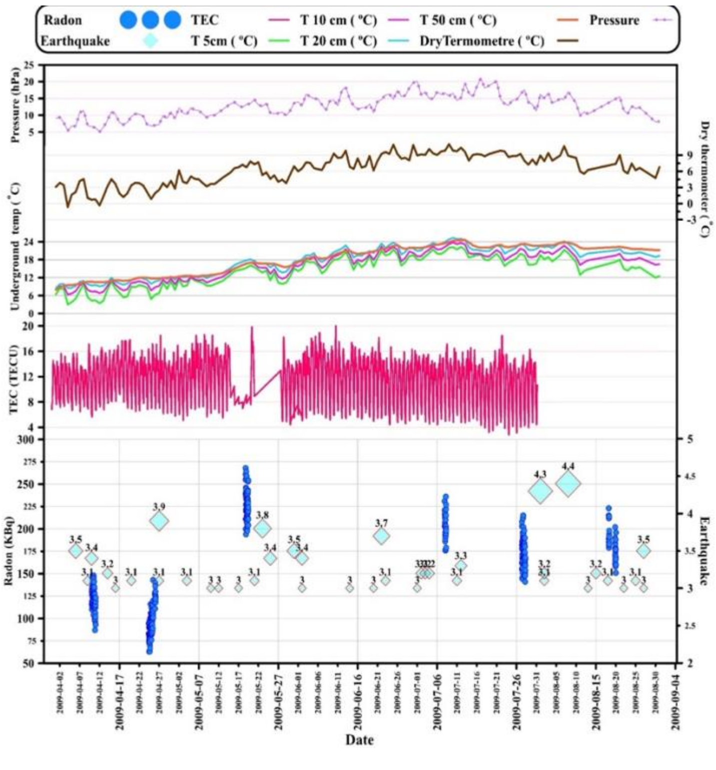

Figure 5. Radon, TEC, Temp of soil (5, 10, 20, and 50 cm), and Pressure with Earthquakes for the second group

We see from the figure above that the increase in the temperature causes the increase in pressure because the variation in the temperature is directly proportional to the variation in the air atmosphere pressure. There are some missing data in the total electron concentration data the reason behind this is some technical issue in the IONOLAB (Hacettepe University,Electrical and Electronics Engineering Department). To deal with the relation between parameters in the second group we magnify apportion of the data when we have all available data (earthquake, Rn, and TEC) for the same period. So, the relations are shown in Error! Reference source not found. (second group A).

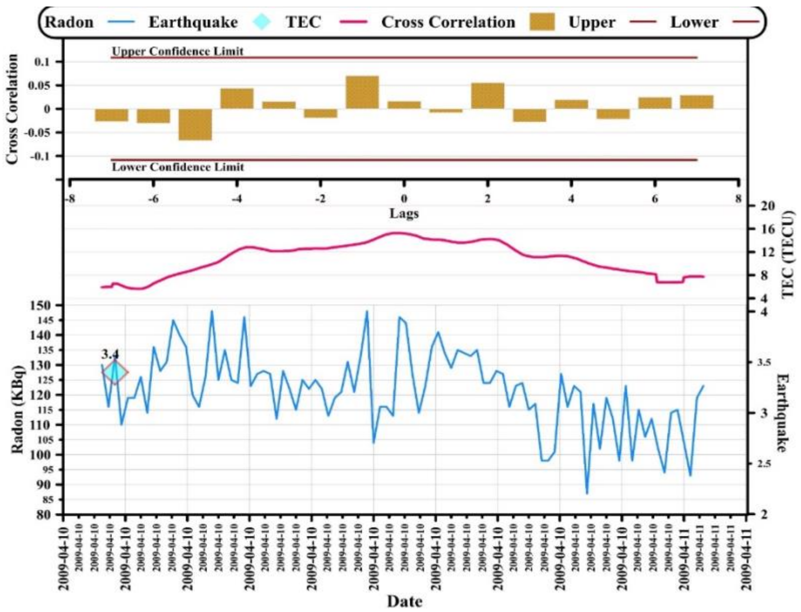

Figure 6 Second group **A** cross-correlation for the data

As may be seen in the figure above, the effect of an earthquake with a magnitude 3.4 on the relation between ^{222}Rn data and TEC can be seen on the same day after the earthquake occurred. The pressure is produced in the tectonic plates by the effect of earthquakes caused for moving the radon gas in the soil pores toward the earth's surface and then into the air. This movement of radon gas is the main cause of the ionization of the air atmosphere as well as the increment in the total electron content. This relationship is confirmed in the study [12], [46]. In addition, the cross-correlation between radon gas and TEC did not record any anomaly.

3.3. Third group

The third group starts from (Sep 1, 2009, to Dec 31, 2009), and (11 micro-earthquakes) occurred with a magnitude (3 – 3.6 M_L), with TEC and radon concentrations for the same period of time are presented in **Error! Reference source not found.**.

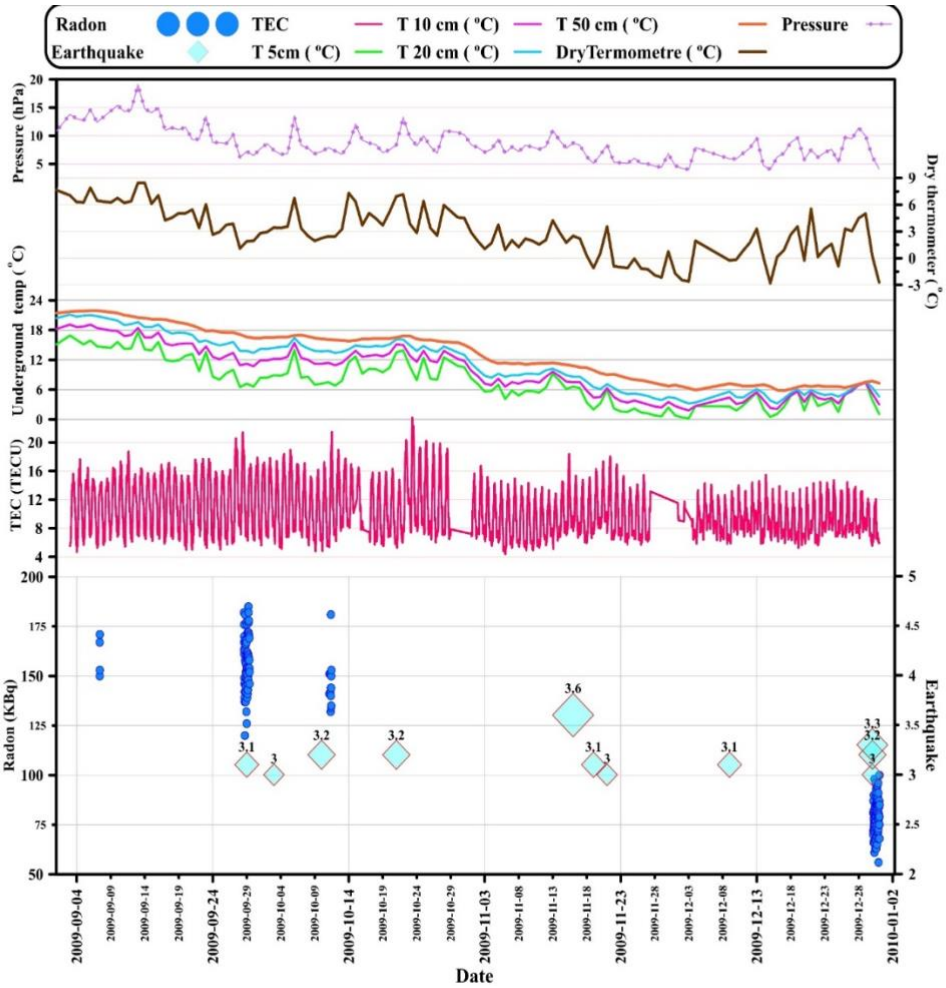

Figure 7. Radon, TEC, Temp of soil (5, 10, 20, and 50 cm) and Pressure with Earthquakes for the Third group

From the **Error! Reference source not found.**, we can see the variation of meteorological data especially the average underground temperature and air atmosphere temperature due to seasonal change starting to decrease gradually, and we can see the effect of this change on the radon gas emission from soil to the atmosphere, the maximum radon gas concentration reaches only (100 kBq.m^{-3}) on the end of 2009. The process of Rn gas movement by the convection is slowed down in this case. The missing data in the TEC can be seen in the graph, the cause is a technical issue in the IONOLAB.

The third group graph has two subgroups (third group A and third group B). In the third group A, the cross-correlation between the parameters is shown in Error! Reference source not found. and an earthquake with a magnitude of (3.1 M_L) is recorded. The reason the earthquake epicentre in the Marmara, and it is very far from the Çorum station in our study area the effect of the earthquake on the radon gas concentration cannot be seen. In contrast, the TEC magnitude starts to decrease one day before the earthquake, and after the earthquake occurs steadily increases to the previous magnitude. The reason for the changing in the TEC is the radon gas diffusion and emission reduced under decompression and raises during compressing earth tectonic plates. So, when the radon gas as a main source of ionization in the atmosphere decreases directly to make an impact on the TEC magnitude. There is no strong correlation between TEC and radon emanation.

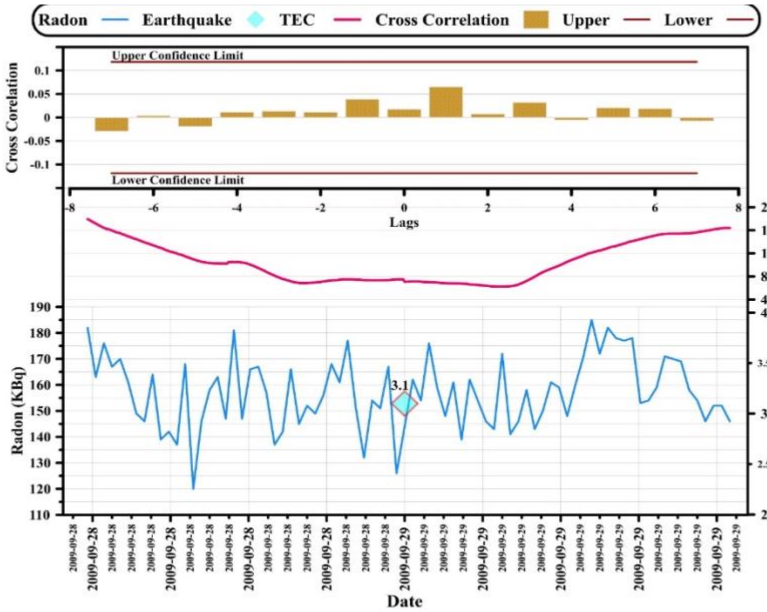

Figure 8 Third group A cross-correlation for the data

In Error! Reference source not found. (Third group B graph) there are three earthquakes' magnitudes (3.3, 3 .2, and 3 M_L), and the total radon concentration variation in response to seismic activity is (45 kBq.m^{-3}), this variation is normal because radioactive materials such as Rn and parents disintegrate randomly. Therefore, the low influence of seismic activity on the radon gas is due to the epicentre distance from Çorum station and the depth of the focus. In another hand, earthquakes in the epicentre affect air ionization. The TEC start to fall in the mid-day on (Dec 31, 2009) this response is incongruous with total electron daily variation and directly related to changes in the radon concentration in the epicentre area transferred to the atmosphere. The cross correlation between the parameters is stay between the confidence bounds.

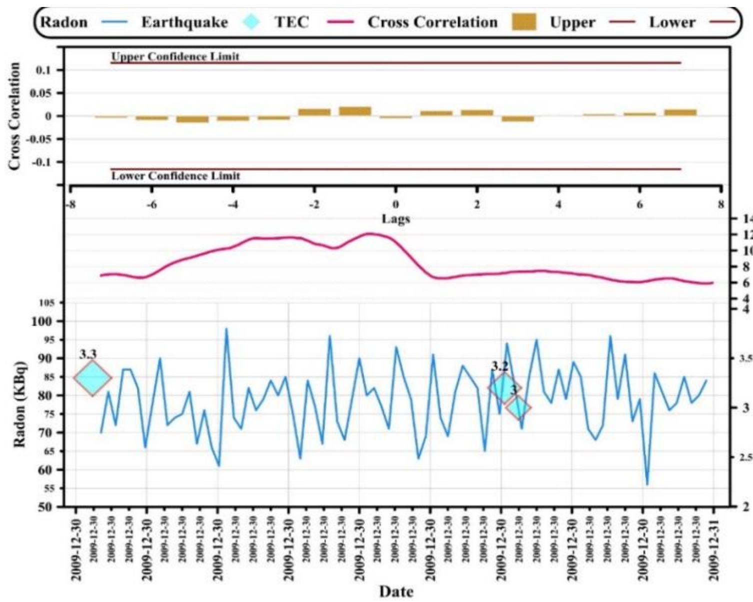

Figure 9 Third group B cross-correlation for the data

4. Conclusions

The relations between Earthquake-TEC-Rn were tried to be explained through find the cross-correlation between Rn emanations with total electron condition under the effect of seismic activity. Seismo-Ionospheric Coupling studies have a critical place in earthquake predictions. In this study, we examined a triple change relation under the effect of microearthquakes.

A significant number of scientists has studied the changes caused by earthquakes in the ionosphere. However, we could not find any studies that examined for finding the correlation between the three variables outside of our research group. We think this research will be an important step to fill a critical gap in this area. The important results we have achieved can be listed as follows:

1. There is no significant correlation between TEC-Rn under the influence of microearthquakes.
2. The meteorological data especially air atmosphere pressure has a very low effect on the TEC-Rn anomalies.
3. The earthquake's epicentre distance and focal depth are inversely proportional to radon gas concentration.
4. We recommend for researchers in the future studies further develop, and work on the external magnetic effects such as (geomagnetic activity, disturbance time storm, and solar flux) on the ionospheric TEC distributions.

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