J. Earth Syst. Sci. (2021)130 134
https://doi.org/10.1007/s12040-021-01645-8

Electron temperature and ion density perturbations prior to the *M*6.8 Eastern Honshu, Japan earthquake of July 23, 2008

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MS received 6 August 2020; revised 10 March 2021; accepted 20 March 2021

The Detection of Electromagnetic Emissions Transmitted from Earthquake Regions (DEMETER) microsatellite-monitored data (IAP and ISL) were employed in investigating pre- (30 days) and post- (10 days) perturbations in ionospheric parameters associated with the *M*6.8 Eastern Honshu (Japan) earthquake (EQ) of July 23, 2008. The results constrained by synchronously monitoring geomagnetic indices data: Kernnifzer digit and disturbance storm time (Dst), revealed strong seismic event-induced disturbances three weeks to 5 days before the seismic event. The geomagnetic indices data were used in filtering normal geomagnetic disturbances from the seismic counterparts, thereby constraining the interpretations. The total ion density measured in per cubic centimeter (cm^{-3}) recorded variations of 7.90, 4.51, and 5.92 on days-20, -19, and -16, respectively, from the earthquake day during the night time half orbit observations. Contemporaneously, perturbations of 8.81 were observed for electron temperature measured in Kelvin (K) five days afore the earthquake. The geomagnetically quiet state of the ionosphere during the pre-seismic days suggests that the observed disturbances are seismogenic. More researches should be encouraged in this area to deepen their applications in earthquake monitoring and prediction.

Keywords. DEMETER; earthquake; perturbation; ionosphere; geomagnetic anomaly.

1. Introduction

Earthquakes (EQ) have been known to constitute serious natural environmental hazard, threatening the existence of man on planet Earth, because thousands of lives and properties worth millions of Dollars are being destroyed annually around the globe. However, some of these earthquakes actually occurred with minimal or no fatality, such as the Honshu Japan earthquake of July 23, 2008. Though there was only one fatality, the economic effect incurred from this seismic event was enormous with 10,000 families left without electricity and numerous landslides recorded. Studies of ionospheric conditions preceding the occurrence of large earthquakes have continued to arouse the interest of geophysicists for several decades with the sole aim of accurately predicting this natural disaster and mitigating the loss of lives and properties. Probable queries from this unfortunate event are what would have transpired few weeks, days and hours to this disastrous seismic event? Did they just happen without indication? It is quite pertinent to mention here that scientists believe that every electromagnetic anomaly is a hallmark of some processes, which began weeks, days and hours before the main event (Akhoondzadeh *et al.* 2010; Ibanga *et al.* 2017; Thomas *et al.* 2020). In

Published online: 02 July 2021

preparation to earthquake event, enormous amount of energy is usually conveyed as a result of crustal movement and at the point of impact, a break down happens between the source of the energy and the environment. Studies clearly revealed that these variations before, during and after such events do have different physical and chemical effects on the lithosphere, atmosphere and ionosphere (Kamogawa 2006; Rozhnoi *et al.* 2009; Sarlis *et al.* 2010; Chmyrev *et al.* 2013; Ibanga *et al.* 2017), hence making their detection possible. Thus, anomalies in threshold state of lithospheric, atmospheric and ionospheric parameters can serve as earthquake precursor. If these ionospheric perturbations are factual and regular, then they could be used as short-term precursor, happening before, between and after the seismic events. Earthquake can be predicted through some geophysical and geochemical disparities in lithosphere, atmosphere and ionosphere during its preparatory stage. These seismic events related with lithospheric–atmospheric–ionospheric coupling (LAIC) perturbations are commonly interpreted as earthquake precursors. A lot has been reported on seismo-ionospheric and geomagnetic responses before, during and after earthquake from seismic LAIC anomalies (Parrot 1995; Hayakawa and Molchanov 2002; Pulinets and Boyarchuk 2004; Ibanga *et al.* 2017). There are various methods to study seismo-ionospheric anomalies notably among them are the statistical seismo-ionospheric analysis (Fujiwara *et al.* 2004; Liu *et al.* 2006; Shah and Jin 2015; Junaid *et al.* 2018), case-study analysis (Oyama *et al.* 2008), and physical model analysis, which explain ionospheric anomalies (Namgaladze *et al.* 2009; Kuo *et al.* 2011). However, the statistical approach really proves that there is a sure link between the EQ and associated anomalies. Conversely, the case studies and the physical model analyses are effective for depicting the physical background of the existing seismo-ionospheric anomalies. From the above submissions, seismic precursors are still debatable and there was no satellite mission for the detection of EQ-associated ionospheric abnormalities prior to the DEMETER satellite (Parrot 2012).

Although reports abound on pre-earthquake ionospheric perturbations for several earthquakes events since 1970s, it is not enough to conclude that these abnormalities are actually linked to the forthcoming earthquake since the ionospheric F2 layer has significant day-to-day variation (Forbes *et al.* 2000; Rishbeth and Mendillo 2001; Mendillo *et al.* 2002). Hence, the detected anomaly may also result from other driving forces like geomagnetic disturbances. In this paper, the efficacy of the IAP and ISL sensors of the DEMETER satellite is utilized in the study of a magnitude 6.8 earthquake that hit Honshu Japan (figure 1) at 15:26 UTC (3.26 pm local time) on July 23, 2008 which destroyed electric power lines leading to 10,000 families in blackout, while the geomagnetic indices of Kp and Dst were used to screen for deceitful alarm.

2. Data and method of analysis

2.1 *Data*

Data of IAP and ISL experiments from DEMETER satellite and geomagnetic index (Dst and Kp) were analyzed for pre-earthquake ionospheric anomaly. The DEMETER mission ended in 2009, but data are archived at Centre de Données de la Physique des Plasmas (CDPP) and can be accessed through the web server (http://demeter.cnrs-orleans.fr/). The data are organized and plotted in half orbits (Cussac *et al.* 2006). CDPP offers vast array of data to examine variations in electromagnetic emissions; production of plasma inhomogeneities and other ionospheric phenomena associated with seismic events (Varotsos *et al.* 2014). Its high sensitivity promotes the reliability of its data. In this research, data from the IAP and ISL sensors in the burst mode were used. However, there were some days that the satellites operated on safe mode and on such days, there were no records of any experiments (Parrot 2012; Ibanga *et al.* 2017). Data of Dst and Kp are used to estimate the effects of geomagnetic activity. Dst data with time resolution of 1 hr are used to describe the geomagnetic activity in the middle and low latitude regions. Moderate magnetic storm occurs when the Dst values are less than −50 nT, while great geomagnetic storm occurs when the Dst data surpass −100 nT (Richardson *et al.* 2006). Kp data with time resolution of 3 hrs indicate the global geomagnetic activity. Kp value spans from 0 (low activity) to 9 (strong activity). Kp index is <3 when the geomagnetic activity is quiet (Rostoker 1972).

2.2 *Methodology*

The earthquake event used in this study had relevant information including time of occurrence, geographic location and magnitude of event,

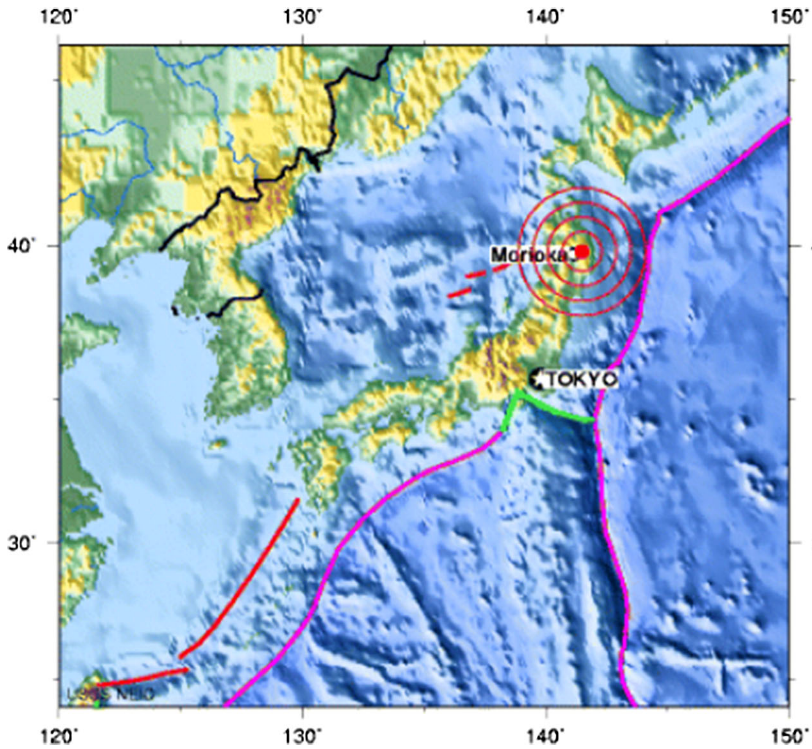

Figure 1. Map showing the epicenter of the studied earthquake (M6.8 Eastern Honshu, Japan earthquake of July 23, 2008).

closest orbits to the epicenter (at a resolution of 20° for longitude and 10° for latitude) were selected 30 days afore and 10 days after the earthquake. The time frame was well chosen to allow ample time in observing the ionospheric-plasma parameter from its normal to abnormal state allowing segregation of seismic anomalies from the natural anomalies, supposing the former to occur at the end of the period. Various investigative time frame ranging from 5 days to 2 months have been used to monitor the ionosphere, but primarily, reports on seismo-electromagnetic differences are perceived 3 weeks or less to the earthquake day (Rong *et al.* 2008; Píša *et al.* 2011; Parrot 2012; Ibanga *et al.* 2017). The total ion density (Oxygen, Hydrogen and Helium ions from the IAP Sensor) and electron temperature from ISL sensor were obtained by downloading data files from the DEMETER website. Data from each orbit were confined to the two modes (survey and burst), but only the burst mode data were used in this study.

To ascertain any significant anomalous trends, the daily values were bounded by the confidence intervals of mean and standard deviation. The bounds are calculated by the mean (μ) and standard deviation (σ) of 30 days before and 10 days after the observed day using the equation.

$$X_u = \mu + 2\sigma, \tag{1}$$

$$X_l = \mu - 2\sigma, \tag{2}$$

$$X_l < x < X_u \rightarrow -2 < \frac{(x-\mu)}{\sigma} < 2; \quad Dx = \frac{(x-\mu)}{\sigma}, \tag{3}$$

where x, X_u, X_l, and Dx are parameter values, upper bound, lower bound and differential of x, respectively. From equation (3), if the absolute value of Dx is greater than 2 (i.e., $|Dx| > 2$), then the behaviour of x is considered to be anomalous. In this work, total ion density from IAP (Plasma Analyzer) and electron temperature measurements from the ISL (Langmuir probe) sensors of the DEMETER satellite were employed to check the EQ anomalies. The EQ preparation zone for the M6.8 Eastern Honshu, Japan seismic event of July, 23 2008 was derived from the formula given by Dobrovolsky *et al.* (1979):

$$R = 10^{0.43M}, \tag{4}$$

where R is the radius of the EQ preparation zone and M is its magnitude. From equation (4), the radius of EQ preparation zone depends only on the EQ magnitude, i.e., the stronger the earthquake, the larger its preparation zone and vice versa. During the research, we made sure that all selected orbits were within EQ preparation zone.

3. Results

Results obtained from the investigation are presented in two-dimensional plots (figures 2(i, ii) and 3). In figure 2, the black vertically dotted lines indicate the earthquake day (July 23, 2008). The ordinate of each panel displays days prior and post the seismic event, while the median and the bounds (upper and lower) are indicated with red and lilac horizontal lines, respectively. The abscissa represents plasma parameters (i) electron temperature derived from the measurements of the ISL experiment, (ii) total ion density derived from measurements of the IAP experiment during (a) night and (b) day. Figure 3 has four panels; panel one gives time series of Dst index; panel two gives the abnormal Dst, panel three shows time series of Kp index, while panel four shows the abnormal Kp index.

4. Discussion

Perturbations in the plasma parameters of the ionosphere (total ion density and Electron temperature) obtained from IAP and ISL experiments of the DEMETER satellite data clearly presented itself 20 days to 5 days afore the Eastern Honshu Japan EQ of July 23, 2008 above the locality of the forthcoming EQ. The ISL device where the electron temperature was measured (figure 2i), presented an anomalous value of 8.81, 5 days prior to the EQ. Similarly, from the IAP sensor, unusual ionospheric variations were detected 20, 19, and 16 days with numerical values of 7.90, 4.51, and 5.92, respectively (figure 2ii). These values were quite abnormal having exceeded the background of normal variations (upper and lower bounds). Results obtained were constrained by synchronously monitoring of geomagnetic indices data since ionospheric response to geomagnetic storm activities, unlike that of seismogenic nature, is not localized. Hence, its response is usually monitored and reported globally (Pulinets and Legen'ka 2003). Thus, from internationally reported geomagnetic indices: Disturbance storm time (Dst) and

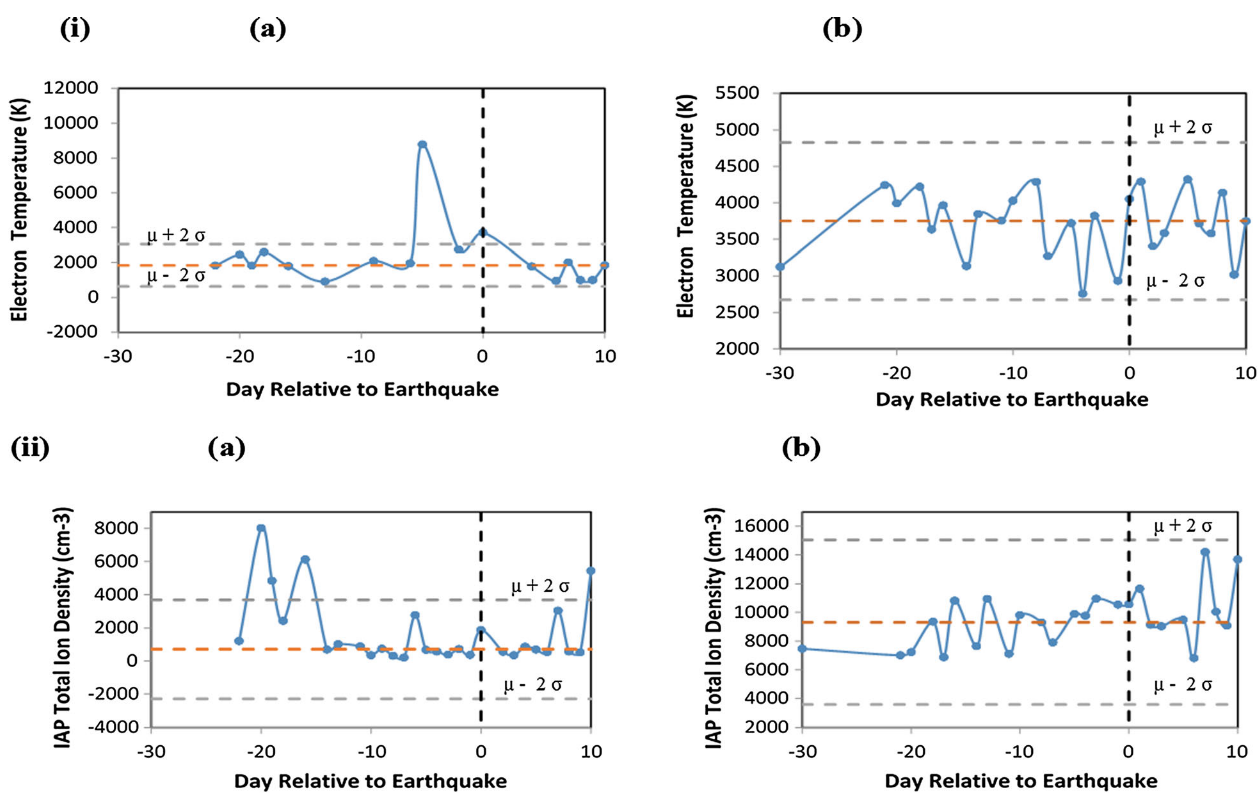

Figure 2. Results of DEMETER data analysis for Eastern Honshu, Japan earthquake of July 23, 2008 (from June 23 to August 2nd 2008).

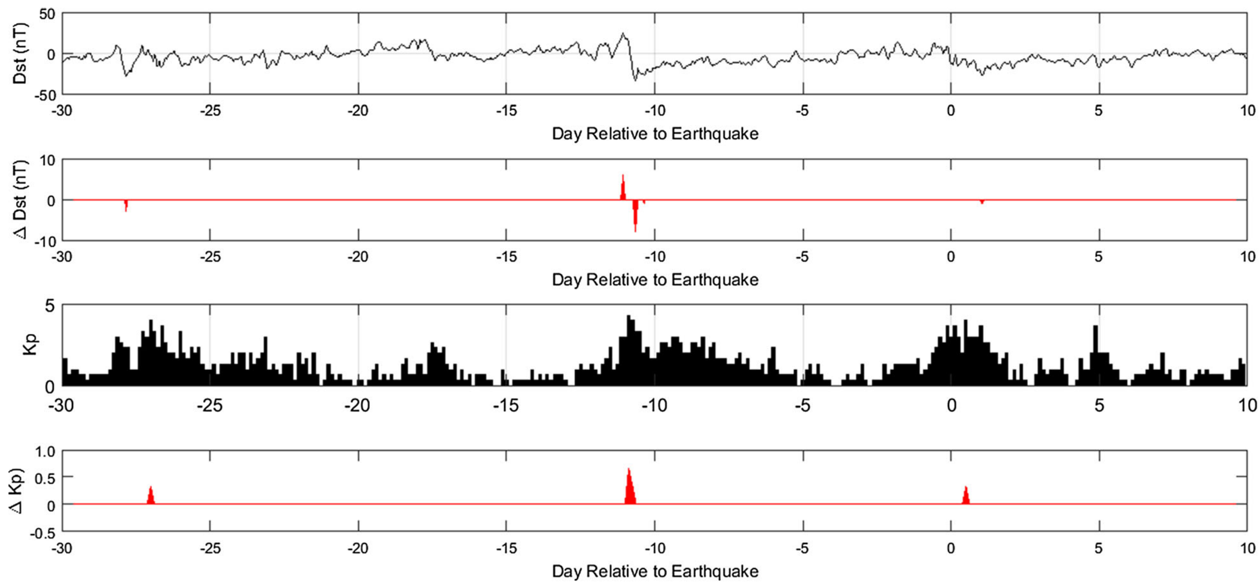

Figure 3. Disturbance of geomagnetic activity from June 23 to August 2, 2008 (UTC). 1st panel is the Dst index time series, 2nd panel is the abnormal Dst index, 3rd panel is the Kp index time series, and 4th panel is the abnormal Kp index.

Planetary index (Kp), the influence of geomagnetic storms on ionospheric plasma parameters were secluded from those induced by impending localized seismic activities. To this, as evident in figure 3, all the recorded anomalous values days before the seismic event occurred in quiet geomagnetic conditions as the Dst displayed 4.375, 7.833, −5.458, −8.958 nT, while the Kp index gave 0.542, 0.750, 0.458 and 0.750 on days 20, 19, 16 and 5, respectively. It is noteworthy that all observed irregularities (both in electron temperature and total ion density) were detected in the night time half orbits (figure 2a), which affirms that the signals were better depicted in the night. This report is consistent with that of Pulinets and Boyarchuk (2004), Ibanga *et al.* (2017) showing that the efficiency of the anomalous electric field penetration into the ionosphere at night is higher than in daytime. The unusual variations observed in the investigated parameters from the DEMETER data had only positive signs in both experiments.

5. Conclusion

Ionospheric plasma parameters have been investigated for possible seismo-induced perturbations before *M*6.8 Eastern Honshu earthquake of July 23, 2008. From the study, striking ionospheric perturbations were revealed in quiet geomagnetic conditions 3 weeks to 5 days before the said earthquake, implying that the event is seismogenic. This timeframe has provided enough room for proper planning by citizens/inhabitants in a way to mitigating the loss incurred by such an unfortunate event like the electricity failure in more than 10,000 homes. However, it is important to have in mind, that the ionosphere exhibits complex behaviour even during quiet geomagnetic condition and the measured parameters sometimes display variations in quiet seismic condition that can be associated with other unknown factors. The seismogenic anomalies represented in this paper are promising for the short-term prediction, but attention has to be paid to further investigation required to obtain a more precise regional model of quiet time for ionosphere to classify seismic precursors from the background of daily variations.

Acknowledgements

The authors acknowledge the NOAA for the geomagnetic index and CNRS/LPC2E for the DEMETER data. We are also grateful to the editor and reviewers for their constructive criticisms that helped in improving the quality of the manuscript.

Author statement

AEA and JET conceived the study, designed the framework and searched for DEMETER data.

AME used appropriate software programs to interpret the data, while NJG puts together the write-up using the processed data and performed grammar checks as well as work on the references.

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Corresponding editor: Anand Joshi