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Variation of Electron Density before Large Earthquakes in Southeast Asia Observed by CHAMP Satellite from 2004 to 2009

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ABSTRACT

This project studies the behaviour of the pre-earthquake (EQ) ionospheric parameter by analysing the variation of electron density (Ne) measured by the CHAMP satellite, which is one of the satellites that collect in-situ data of Ne in the ionosphere. Data from two weeks before the main shock of an EQ are analysed to observe the pattern behaviour of the Ne before the EQs. Monitoring this parameter is one of the methods of observing the ionosphere for studying EQ precursors. The area of focus in this study is the Southeast Asian region, where EQs happen frequently. This study involves large EQs with a magnitude >7.5 that occurred within five years from 2004 until 2009. Significant anomalous behaviour of Ne was identified within 14 days prior to the EQs.

Keywords: Pre-earthquake; parameter; precursor study; CHAMP satellite; Southeast Asia region

INTRODUCTION

Studies on ionospheric precursors of earthquakes (EQs) began decades ago. Research has intensified over the years, as indicated by the increasing number of systems and methods of studying pre-EQ events (Klimenko et al. 2012; Hasbi et al. 2011).

Previous findings indicate that ionised particle, ion and electron profiles in the ionosphere can be easily disturbed due to solar activities (Guyer and Can 2013) and geomagnetic storms (Kumar and Parkinson 2017surveillance, navigation, and timing technology. Models struggle to predict changes in ionospheric densities at nearly all temporal and spatial scales, especially during geomagnetic storms. Here we combine a 50 year (1965–2015; Polekh et al. 2017)100–130°E we investigated the latitude-temporal dynamics of ionospheric disturbances during the 17–19 March 2015 severe two-step geomagnetic storm, and compared it with temporal dynamics of total electron content (TEC. Other findings suggest that despite low solar activity and minor geomagnetic storms, ionospheric disturbances can still be detected by ground-based sensors and satellites (Oyama et al. 2016; Khezri 2018). Ionospheric perturbation can be monitored and detected through methods such as total electron content (TEC) measured by a global positioning system receiver (Akir et al. 2017)leading to delays, poor signals or total loss of signals. The gradients in TEC are frequently associated with disturbance in the ionosphere which explains the space weather behavior and indirectly causes inefficient operations of ground and space based Global Navigation Satellite System (GNSS, space-borne extremely low frequency/ultra-low frequency/very low frequency (ELF/ULF/VLF) transmitter (Ibanga et al. 2018), ionosonde (Maruyama, Yusupov, and Akchurin 2016) and ground-based VLF transmitter (Potirakis et al. 2018).

TEC data obtained via radio occultation were used to find an ionospheric precursor for EQs (Klimenko et al. 2012; Ahmed et al. 2016; Chmyrev et al. 2013; Saradjian and Akhoondzadeh 2011). Previous studies that used TEC data have shown that EQs can be detected several weeks before they occur (Astafyeva and Heki 2011; Gousheva et al. 2006) while previous studies that utilized electron density (Ne) data were able to detected EQ much earlier, that is, a few hours or days before the events (Hasbi et al. 2011). Anomalies in both parameters can be detected using daytime data. Based on this study, Ne data for 14 days prior to the EQs are taken to analyze the behaviour of the focused parameter.

From the previous study, ionosphere anomaly is investigated by using parameter from the ground sensor and GPS signal that propagate through the ionosphere. Thus, this study is successfully conducted b using Ne data collected by the sensor that mounted on the satellite as the in-situ measurement. The in-situ measured Ne data increase the possibility of the EQ precursor to be more reliable.

The raw Ne data was collected from the satellite database to observe the Ne pattern before and during large EQs. Satellites such as DMSP, CHAMP, DEMETER, and Formosat-3/Cosmic routinely transmit data to ground stations to allow scientists to analyze the behaviour of electrons in the ionosphere (Oyama et al. 2016; A.K. Gwal et al. 2012). In this study, Ne and data from CHAMP satellite are used. The Ne data that were collected from the CHAMP satellite are obtained via in-situ measurement in the ionosphere based on the altitude of the orbiting satellite. A Langmuir probe is mounted on the CHAMP satellite to measure the Ne in the ionosphere.

Most of the data or results might be influenced by geomagnetic disturbance because the ionosphere is affected by geomagnetic activity. In considering the effects of geomagnetic disturbances on Ne variations, geomagnetic indices such as Kp, Ap and Dst are used to distinguish among the effects of pre-EQs (Elliott et al. 2013).

The focus area in this study is the Southeast Asian region, with a longitude within 90°E to 120°E and a latitude within 10°N to 10°S (Figure1). EQs occur more frequently in this region than in other areas, thus providing additional chances to investigate the behaviour of plasma density variations in large frequent EQs. The purpose of this project is to observe the Ne pattern (14 days) before the EQs. During the studied period, solar activity is observed to be quiet and any anomalies in the ionosphere are solely due to the Earth's seismic activity, which disturbs the geomagnetic field.

METHODOLOGY

RANGE OF DATA COLLECTION

All the EQs that occurred in the Southeast Asian region from 2004–2009 are recorded in this study. The EQs with a magnitude of more than 7.5 are filtered for selection, and the only criterion is for the EQs to have occurred in the Indonesian region (Table 1). The electron density (Ne) data measured by the CHAMP satellite were analyzed for the EQs. The Ne data from the CHAMP satellite were measured in-situ in the F-layer of the ionosphere at the radius of the Earth ranged of 200–500 km from the Earth. The orbit paths of the CHAMP satellite for five days from 12 to

TABLE 1. List of EQs from 2004–2009.

Year	Date	Time (UTC)	Location	Latitude	Longitude	Magnitude	Depth (km)
2004	26 Dec 2004	00:58:50	West Coast of Northern Sumatra	3.30N	95.78E	8.5	10
2005	28 Mar 2005	16:09:36	Northern Sumatra	2.08N	97.01E	8.7	30
2006	17 Jul 2006	08:19:25	South of Java	9.31S	107.28E	7.7	10
	08 Aug 2007	17:04:58	Java	5.96S	107.65E	7.5	289
2007	12 Sep 2007	11:10:26	Southern Sumatra	4.51S	101.38E	8.4	30
	12 Sep 2007	23:49:01	Mentawai Islands Regency	2.52S	100.96E	7.8	10
2009	30 Sep 2009	10:16:10	Sumatra	0.71N	99.97E	7.6	90

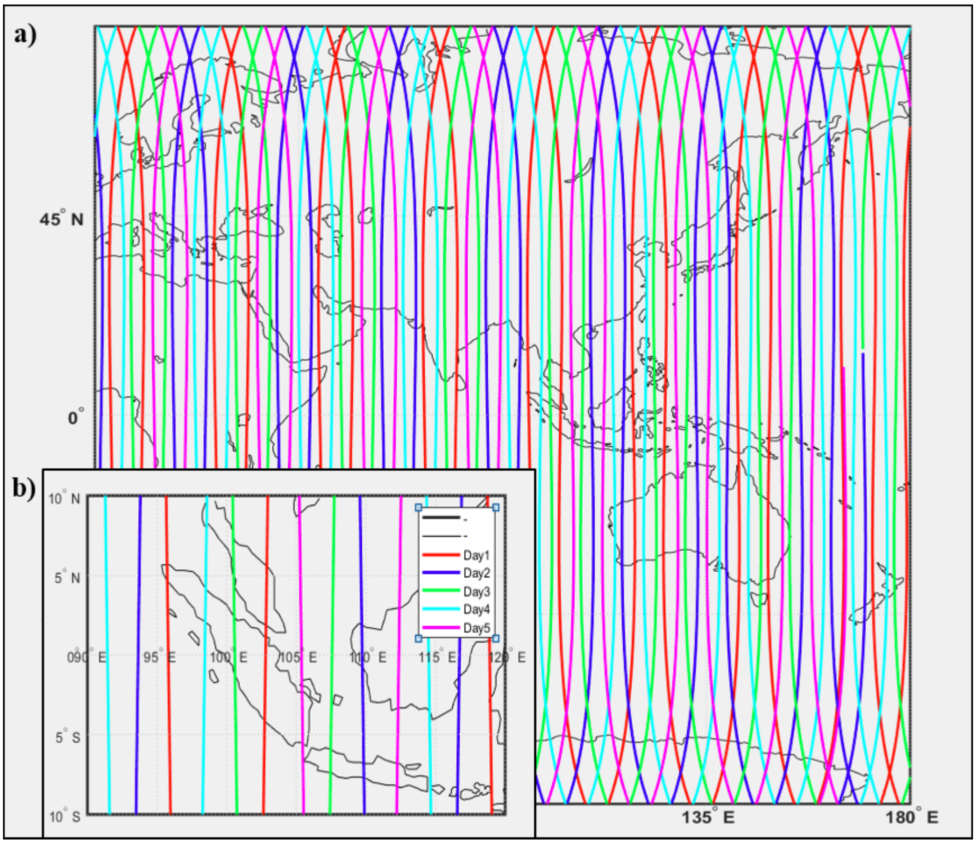

FIGURE 1. CHAMP satellite orbit for five days from 12 to 16 December 2004 (a) the global view and (b) the focused region

16 December 2004 are shown in Figure 1. The CHAMP satellite passes through the region of this study (longitude – 90°E to 120°E, latitude – 10°N to 10°S) at an average of 2 to 4 times per day.

RESULT AND DISCUSSION

The variation of the Ne value for two weeks before the EQ events occurred is shown in Figures 2, 3, 4, 5, 6 and 7.

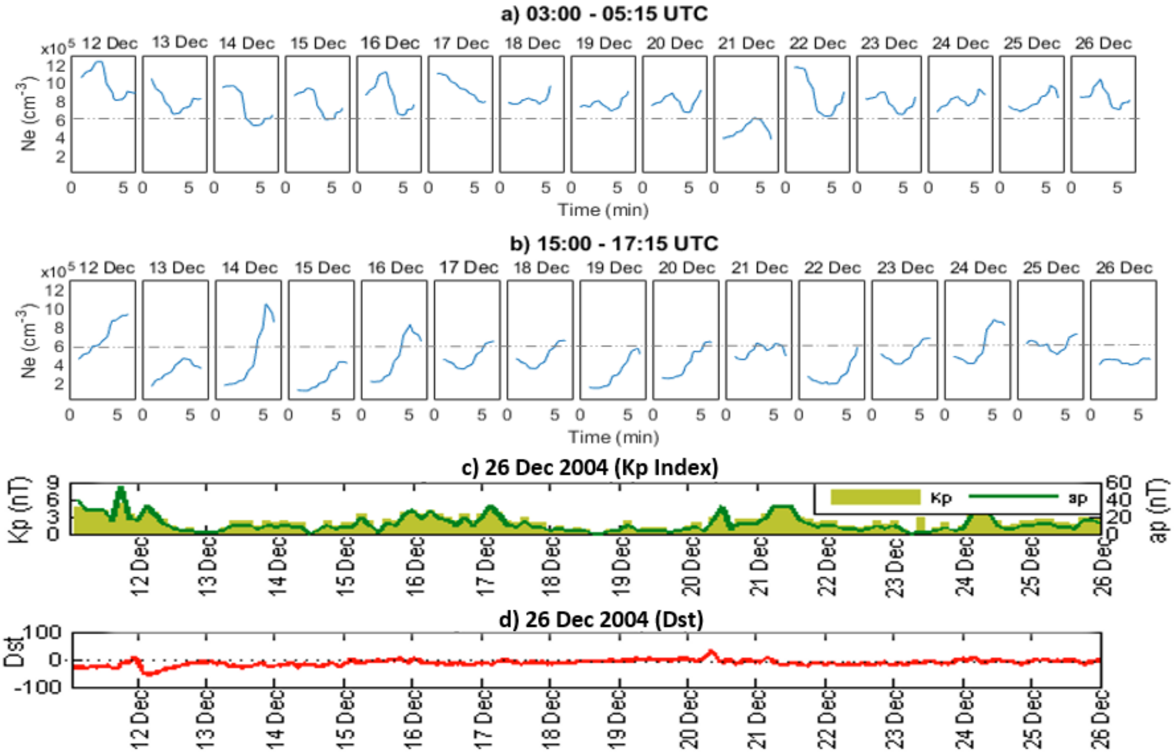

FIGURE 2. CHAMP Ne data along with Kp and Dst geomagnetic indices during the 14 days prior to the EQ on 26 December 2004. The negative anomaly of Ne was observed on 21 December 2004.

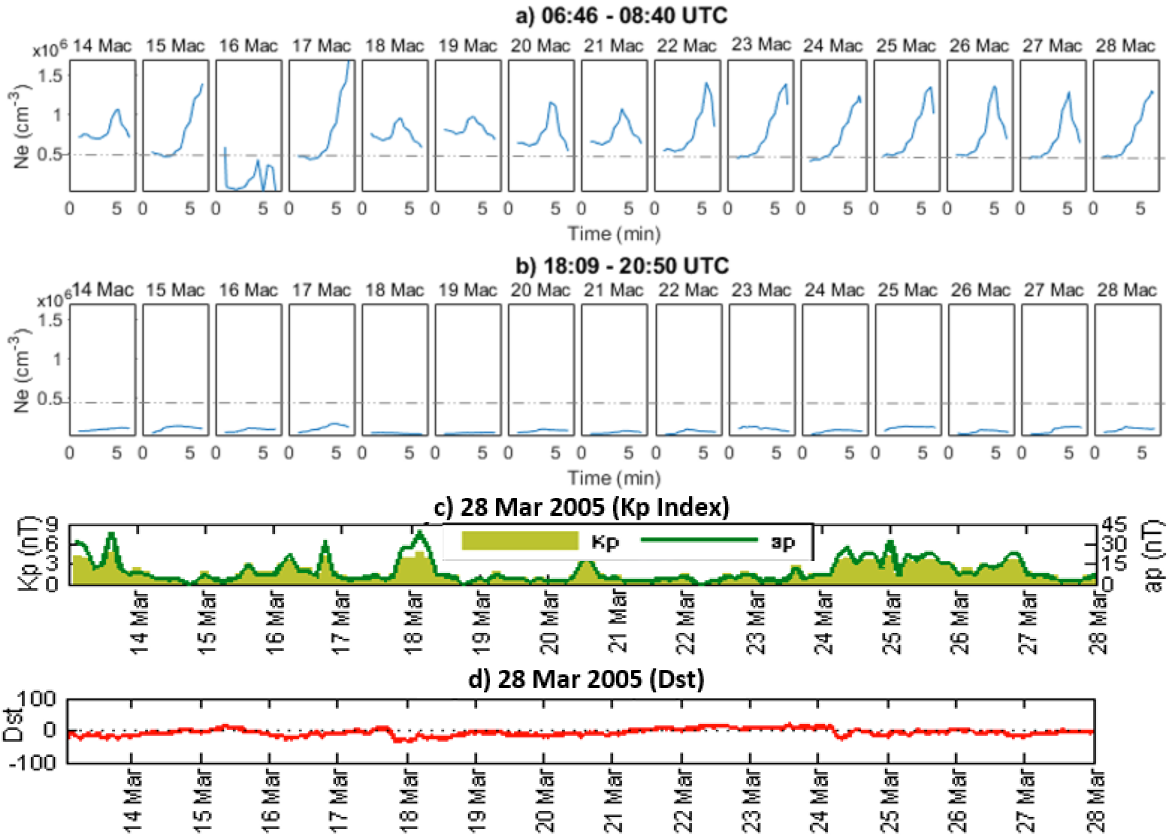

FIGURE 3. CHAMP Ne data along with Kp and Dst geomagnetic indices during the 14 days prior to the EQ on 28 March 2005. The negative anomaly was observed on 16 March 2005.

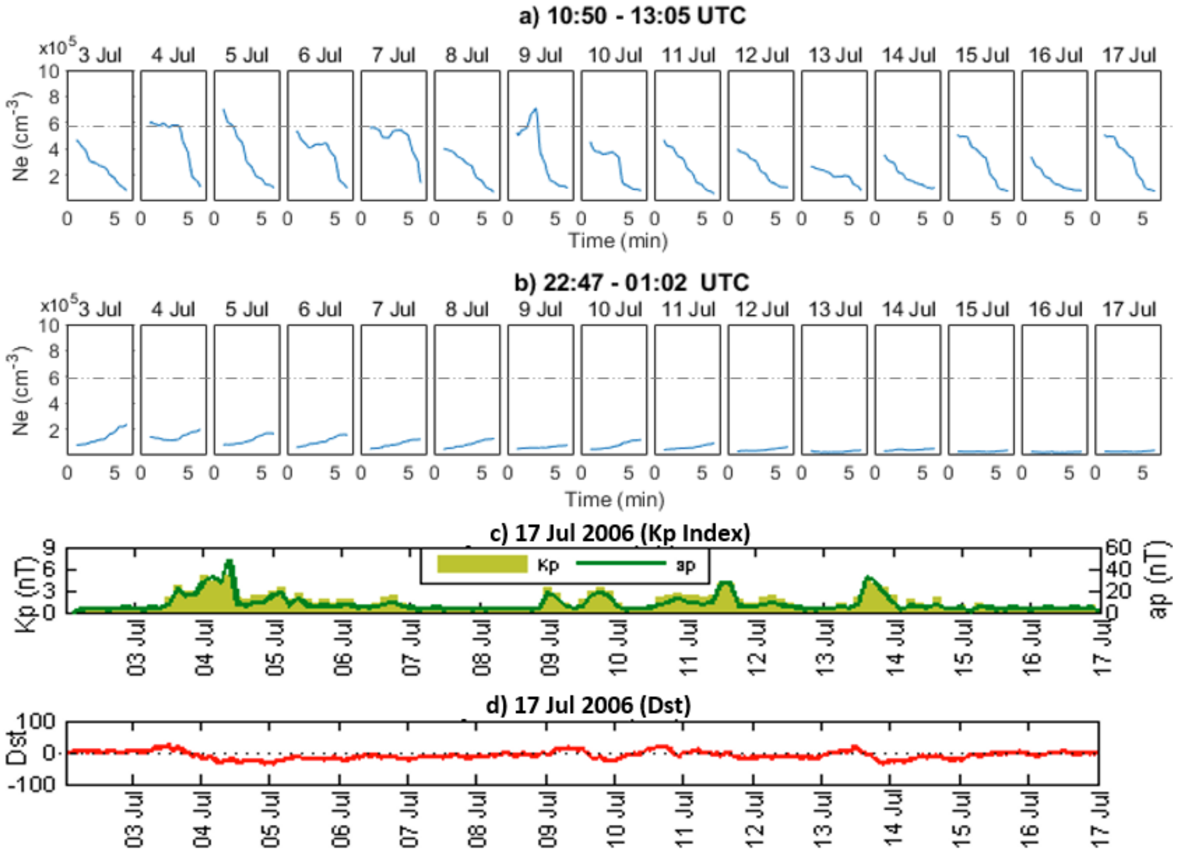

FIGURE 4. CHAMP Ne data along with Kp and Dst geomagnetic indices during the 14 days prior to the EQ on 17 July 2006. The positive anomaly was observed on 5 and 9 July 2006.

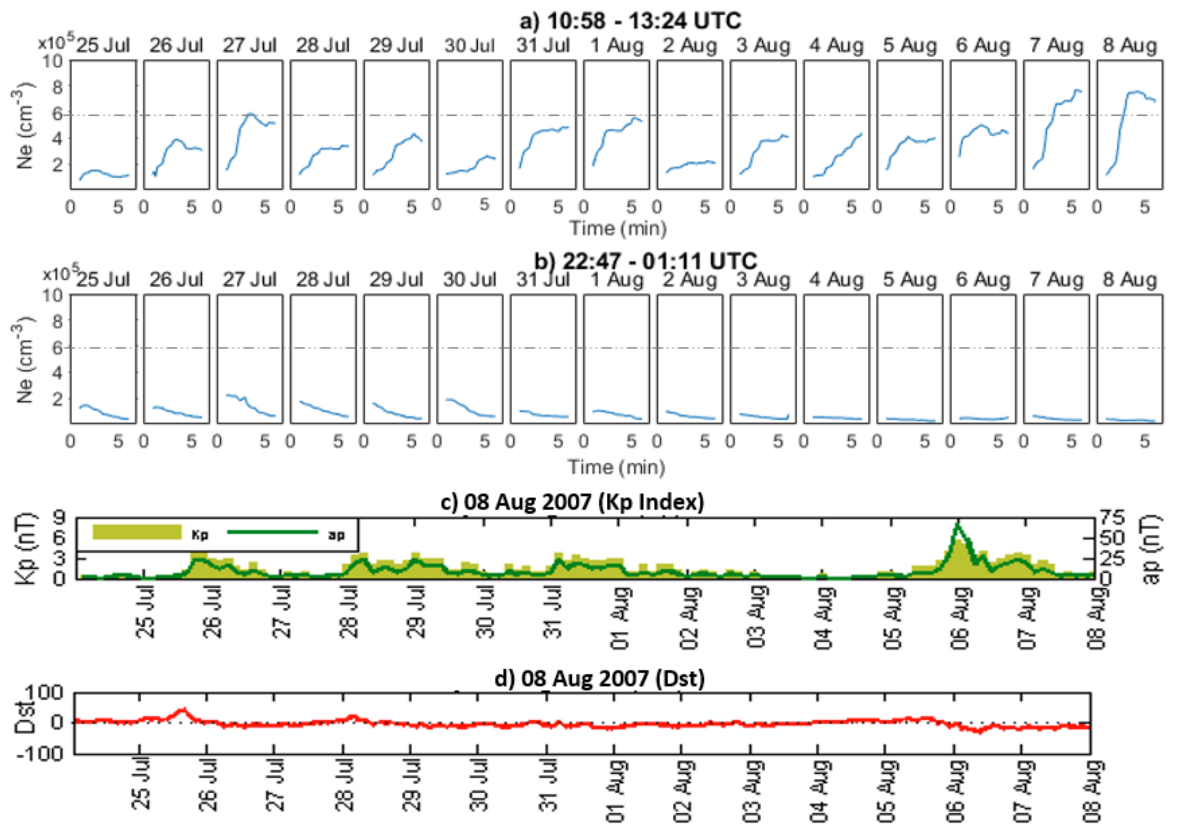

FIGURE 5. CHAMP Ne data along with Kp and Dst geomagnetic indices during the 14 days prior to the EQ on 08 August 2007. The positive anomaly was observed on 7 and 8 August 2007.

The x-axis of a) and b) in the figures represents the time in minutes for each collected data, while the y-axis is the value of the Ne collected by the CHAMP satellite.

Figure 2 shows the variation of parameter Ne for the two different local times for a large EQ with a magnitude of 8.5. Based on Figure 2a, most of the Ne values are above 6×10^5 cm^{-3}. However, the value of Ne on 21 December 2004 shows a negative anomaly with the range value of the other days, which is below 6×10^5 cm^{-3}. Meanwhile, the value of Ne in Figure 2b is below 6×10^5 cm^{-3}. The value of Ne on 12, 14, 16, and 24 December is slightly higher than that for the whole two weeks from the recorded data. The value of the Kp index and Dst is slightly higher on 12 December.

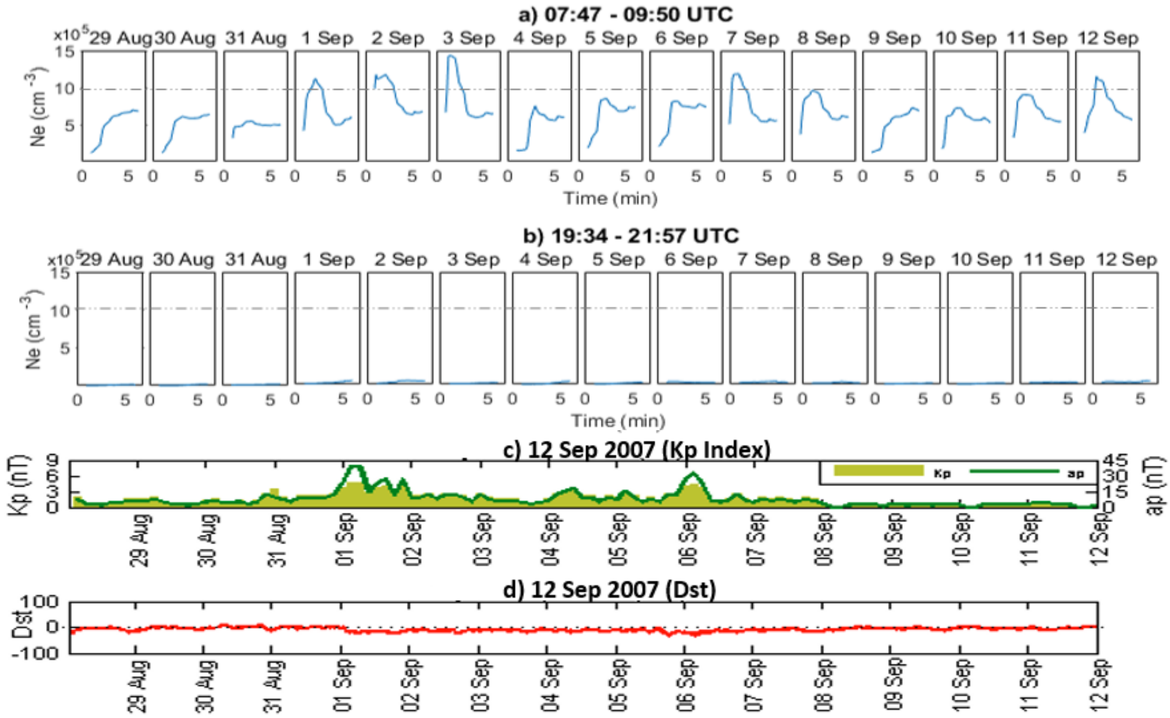

FIGURE 6. CHAMP's Ne data along with Kp and Dst geomagnetic indices during the 14 days prior to the EQ on 12 September 2007. The positive anomaly was observed two weeks before the event.

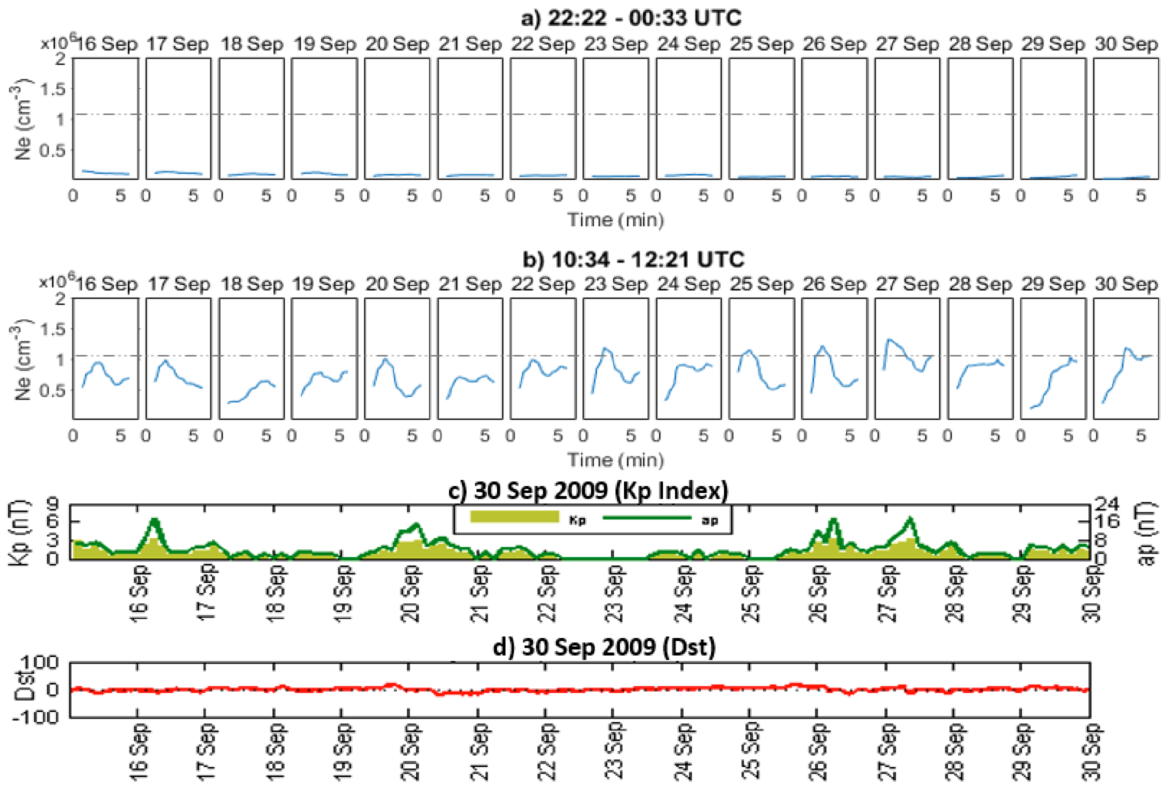

FIGURE 7. CHAMP's Ne data along with Kp and Dst geomagnetic indices during the 14 days prior to the EQ on 30 September 2009. The positive anomaly was observed but does not have a visible pattern.

Figure 3a indicates that the average value of Ne is above 0.5×10^6 cm^{-3}. However, on 16 March, the value dropped below 0.5×10^6 cm^{-3}, which was detected 12 days before the EQs occurred. Figure 3b shows that the data is in a steady pattern and within the range below 0.5×10^6 cm^{-3}. Figures 3c and 3d indicate that the Kp index and Dst value do not show any significant disturbance on 16 and 25 March. The value of the Kp index on 25 December is still lower than 3. Figure 4a shows that a slightly higher value of Ne, which is above 6×10 cm^3, was observed 8 and 12 days before the EQs. The value of Ne in Figure 4b has a similar profile to that in Figure 3b.

Figure 5a shows that some perturbation happened about a day and a few hours before the event. On 8 August, the CHAMP satellite passed through the event region from 10:59 to 11:05 UTC. The EQs took place about 6 hours after the satellite passed through the region. However, the value of the Kp index and Dst peaked three and two days before the EQs with values of 6- and 41 nT, respectively. Figure 6a shows an average value of Ne with the value of 10×10^5 cm^{-3}. The behaviour of Ne for both Figures 6a and 6b from 1 to 8 September shows that some perturbation occurred, as can be seen clearly on 1, 2, 3 and 7 September. The value of Ne exceeds the average value of Ne in the two weeks. However, the values of Kp index and Dst during the period are also more apparent than in the other days.

The behaviour of Ne pattern in Figure 7a is expectedly low, as shown on the graph. Figure 7b shows perturbations on 23, 25, 26, 27 and 30 September, a week before the day of the EQ. The Ne values exceeded the normal value of two weeks before the EQs, which is above 1×10^6 cm^{-3}. The Kp index value on 26 and 27 September indicates a sudden increase to a value of 3.3. Even though the Kp index value showed more disturbances throughout the two weeks, the Ne value does not show any related reaction.

The pre-EQ profiles are observed for each of the EQs in five years from 2004 until 2009. Most of the Ne profiles show that perturbation occurred either in the morning or evening from 0000 UTC until 1330 UTC (0800–2030 local time). The pattern of the Ne shows sudden changes in either positive or negative profiles. Positive profiles of Ne are above the dotted line in the graph (abnormal profile within two weeks' data), while negative profiles are below the level line. The perturbation of the Ne value was observed 7 to 14 days before the day of the EQs, and changes were found 2 to 3 days before the EQs. The obvious perturbation in the Ne profile occurred due to the movement of plasma from the lithosphere to the ionosphere through the acoustic gravity wave via lithosphere–atmosphere–ionosphere coupling. A few days before the EQs, the Earth crust already exhibited slight movements, thus causing the Ne profile to show perturbations in the ionosphere.

On the basis of the results from Figure 2, 3, 4, 5, 6 and 7, the observed Ne variations can be considered possible pre-EQ ionosphere anomalies, while Kp and Dst indices show quiet solar activity.

This current study suggested that through the utilization large period data coverage as well as data from other satellites for in-situ measurement and together with the data from ground sensors, the observation of ionospheric anomalies due to pre-EQs can be enhanced for further studies on EQ precursors.

CONCLUSION

Various precursors for ionospheric observation, such as CHAMP, DEMETER and FORMOSAT3/COSMIC satellites, were developed. A large amount of data (in-situ measurement) were collected to study the ionospheric behaviour. In this study, the pre-EQ ionospheric profiles of Ne observed in the Southeast Asian region show that the Ne profile changes remarkably, with decreasing or increasing (within a week or two weeks) before the major EQs. The Ne profile confirms that a perturbation occurred within at least 14 days before the EQs with a magnitude >7.5. However, the Ne profile needs to be taken into the consideration. This is because of the several factors that have the potential to disturb the particles movement in the ionosphere. The behaviour of Ne can also be monitored during quiet conditions (with no EQs occurrence in the study region) or post-EQs to validate the recent data. The study of this behaviour validates possible seismo-ionospheric anomalies because of the availability of a large amount of satellite and ground-based data.

DECLARATION OF COMPETING INTEREST

None.

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