Journal of the Earth and Space Physics, Vol. 42, No. 4, Winter 2017, PP. 43-47

Observation of vertical electron density profile in inospheric E-layer during Indian-Ocean earthquake on December 2004 using CHAMP satellite

Yusoff Md, S. H.[1*], Lim, H. S.[2] and Yoon, T. L.[3]

1. Ph.D. Student, School of Aerospace Engineering, University Sains Malaysia
2. Associate Professor, School of Physics, University Sains Malaysia
3. Assistant Professor, School of Physics, University Sains Malaysia

(Received: 07 Nov 2015, Accepted: 18 Oct 2016)

Abstract

This paper describes the observation and analysis of vertical electron density before major earthquake above the Sumatra-Malaysia region during Indian Ocean major earthquake in 2004 in Aceh, Sumatra. The electron density profile in E-layer of ionosphere a few days before earthquake and a few hours after earthquake have been observed using the data from the CHAMP satellite. The data obtained from the CHAMP satellite based on GPS radio occultation technique, starting from 21st Dec, 2004 until 27th Dec, 2004, between 90 - 120 km altitude ranges. It is shown that significant anomaly can be detected as early as 3 days before the major earthquake above the preparation zone of earthquake epicentre through significant disturbances of the electron concentration in the ionosphere. In addition, the electron density in the ionosphere above the earthquake epicentre is observed to be very high during 8 hours before earthquake occurred. After a day of the earthquake occurrence, it is observed that the electron density decreases and the ionospheric region become more stable.

Keywords: Earthquake, CHAMP satellite, Ionosphere, Electron density.

1. Introduction

Electron density is one of the important parameters that is sensitive to the variations in D, E and F layers of ionosphere. The history of seismo-ionospheric coupling started in 1971 when (Antselevich, 1971) observed f_0E parameter and its variation before Tashkent 1966 earthquake. Large nuclear explosion, large volcanic eruption, earthquake with 7.0 and more magnitude as well as rocket launcher are found to excite atmospheric waves, that reach the ionospheric layers and coupling between neutral atmosphere and ionized plasma resulted the variations in the electron density. For large earthquake, seismic movement of Earth plate generate acoustic and gravity oscillations that propagate upwards to the ionosphere and any disturbance can be detected up to 10000 km (Pulinets and Boyarchuk, 2004). Since then an extensive research effort has been devoted to the seismo-ionospheric coupling phenomena (Pulinets, 2004). Recently, major data sources to study the variation of ionosphere are Total Electron Content from GPS receiver and F2 peak density (NmF2) (Li and Parrot, 2006), (Liu et al., 2006), (Hasbi et al., 2009), but several ionospheric parameter are reported to give anomalous behaviour before major earthquakes. Hegai et al., (2015) reported that vertical atmospheric electrostatic field is observed to be perturbed near the earthquake preparation zone prior to the major earthquake. Liu et al., (2015) observed the electron density perturbation during daytime and night time using DEMETER satellite during the 2008 Wenchuan earthquake and VLF propagation is detected and observed due to disturbane prior to the major earthquake (Hayakawa, 2005; Yamauchi et al., 2007; Hayakawa et al., 2010; Hayakawa et al., 2011; Schekotov and Hayakawa, 2015; Skeberis et al., 2015).

In addition, the disturbances in the ionopheric layers also observed during quiet condition (Q-disturbance) originating from atmospheric tides, gravity waves (Laštovička, 2006) and planetary waves (Charney and Drazin, 1961; Matsuno, 1970; Chen and Robinson, 1992; Karami et al., 2012) by neglecting the effects of solar radio flux F10.7 and geomagnetic Ap index. Later, Xu et al., (2015) discussed that the ionospheric variation caused by seismic activity observed more during daytime and variation observed in the night time caused by Q disturbances. This result shows the

*Corresponding author: E-mail: aeharwani@usm.my

positive possibility of inospheric disturbance for the earthquake precursor.

Figure 1 shows schematic acoustic gravity waves that occurred before and during the earthquake and how the ionosphere is influenced from the movement. However, the concentration of the electron in the ionosphere is observed to be high during maximum solar activity and becomes one of the important factors contributing to the ionospheric evolution. The short-time variation in the solar activity has been taken into account. Variation in the solar F10.7 solar radio flux and geomagnetic Ap index during the major earthquake might possibly be excluded.

In this paper, the electron density profile collected from the CHAMP satellite is observed during pre-major earthquake event in Aceh, Sumatera on 26th December 2004. To date, there is no paper published using the data of vertical electron density obtained from the CHAMP satellite before and during the 2004 major earthquake on Sumatera region. The comparison during quiet condition and seismically perturbed is analysed and conclusions based on these analysis are given.

2. The data

CHAMP satellite is a short form of CHAllenging Minisatellite Payload and has been launched from Cosmodrome Pbsetsk on July 15, 2000, owned by Germany. This satellite uses low earth orbit (LEO) in circular and near polar orbit that makes it suitable to study ionospheric ionization on global scale. The CHAMP applies the GPS radio occultation technique to profile ionospheric electron density from satellite orbit's height down to the ground. The on-board payload of CHAMP generated Earth's gravity and magnetic field data and derived information of global magnetic field model, temperature and electron density distribution using GPS radio occultation technique (Jakowski et al., 2002). The GPS data of CHAMP's and the result of data analysis can be retrieved from the ISDC website (http://www.gfz-potsdam.de/en/home/). In this paper, vertical electron density profiles (EDPs) from GPS ionospheric radio occultation (IRO) measurements on-board satellites with code IVP are used to study the ionospheric ionization above earthquake epicentre in Aceh, Sumatera. The data collected in the range of latitude of -10˚ and 10˚ and longitude 80˚ and 110˚ for the time span 21st December 2004 until 27th December 2004. The data collection is between 90 km to 120 km in altitude. Figure 2 shows the map of the area affected by the earthquake and the ionosphere region above the earthquake epicentre in Sumatra-Malaysia regions where the data have been collected using the GPS radio.

3. Result and analysis

Ionosphere electron density (Ne (h)) collected from CHAMP satellite database have been observed and analysed. Data are collected in between 23rd Dec 2004 until 26th Dec 2004 during daytime and night time. The vertical electron density behaviour is also found to depend on solar activity during the day and can be detected with higher value of electron density and the disturbance can be observed by high electron density on daytime.

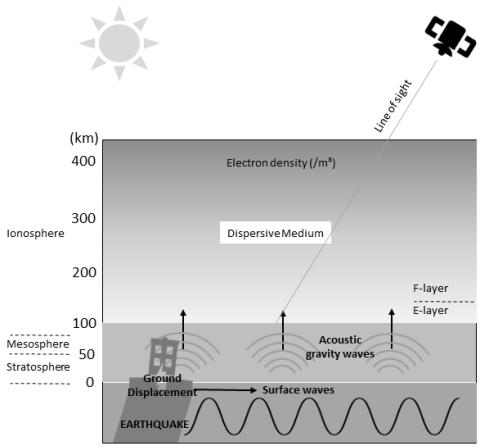


Figure 1. Acoustic gravity wave due to the large earthquake that propagate up to the ionosphere and disturbs the ionospheric electron density.

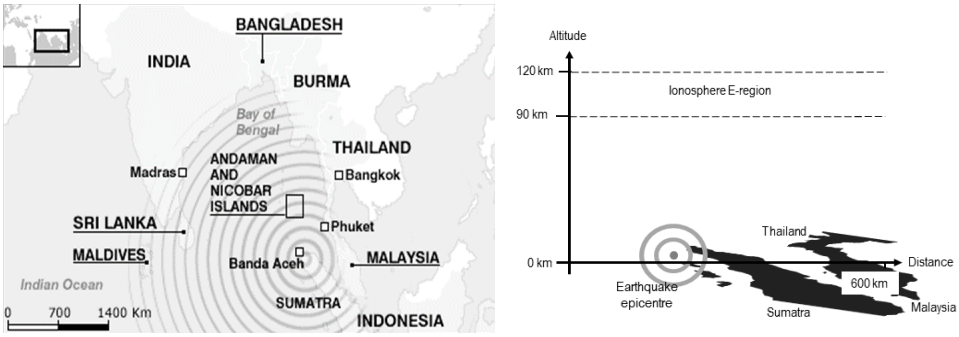
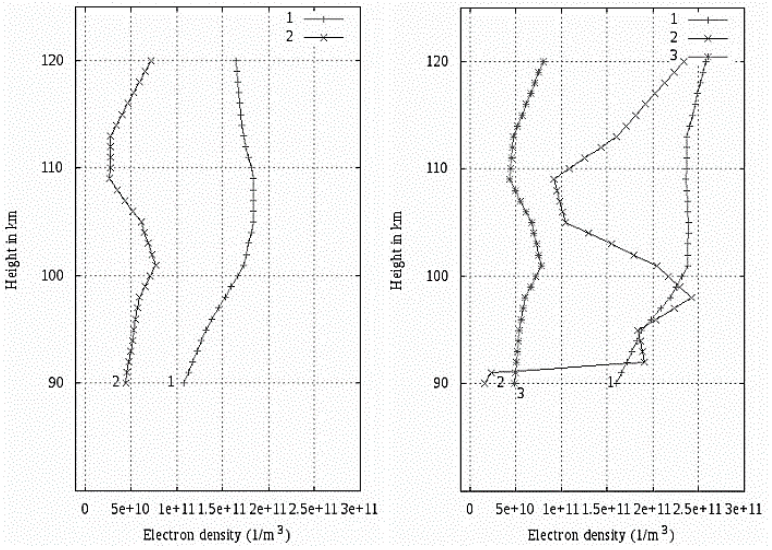


Figure 2. The area of ionosphere modelling above the Aceh 2004 earthquake epicentre



(a) **(b)**

Figure 3. Variations of the electron density a few days before earthquake. (a) 21st Dec, 2004 at 05:03 UTC at label 1 and at 16:35 UTC at label 2, (b) 23rd Dec, 2004 at 03:00 UTC at label 1, 23rd Dec, 2004 at 16:01 UTC at label 2 and 24th Dec, 2004 at 15:03 UTC at label 3.

Figure 3 shows the data variation of ionospheric electron density collected a few days before the major Indian Ocean earthquake started 21st Dec to 24th Dec, 2004. However, there is no data available on 22nd Dec, 2004. The data collected on 21st Dec, 2004 started on 05:03:35 UTC and end on 05:09:16 UTC at latitude in between -1.62˚N and 6.27˚N, longitude 82.74˚E and 74.07˚E with frequency, f_0F2 between 3.1 MHz and 3.8 MHz. This day can be considered as quiet condition with low concentration of the electron in the ionosphere and the lowest value recorded is 2.714e+10 m^{-3}. While, the data collected on 23rd Dec, 2004, 3 days before earthquake, started on 03:00:56 UTC and ended on 03:06:03 UTC in between -6.49˚N, 107.70˚E and 4.42˚N and 99.11˚E with f_0F2 in between 3.7 MHz-4.5 MHz is observed. During this time where the local time is 11:00, electron density is at 2.423e+11 m^{-3} and recorded as the highest value within a week before earthquake on 26th Dec, 2004. In addition, electron density data value collected at 16:01:33 UTC or 00:01 local time in approximately same latitude and longitude and frequency between 3.9 MHz to 4.1 MHz shows obviously disturbed on the same range of height. According to space weather live (http://www.spaceweatherlive.com/en/archive/2004/12/23/rsga), solar activity on this day is very low-to-low and possibility of anomaly caused by solar activity can be neglected. Also variation in the solar F10.7 solar radio flux and geomagnetic Ap index during the major earthquake are excluded.

This perturbation can be considered as seismically disturbed due to the pre-earthquake preparation. On figure 2(b) label 3, this data collected on 24th Dec, 2004 at 15:03:19 UTC and ended on 15:08:53 UTC is considered as quiet condition. The electron density is on average 5.96e+10 m^{-3} and no significant disturbance is observed.

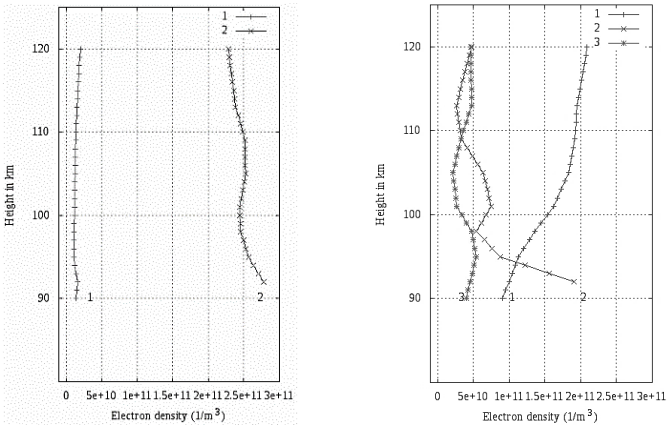


Figure 4. Variation on electron density in ionosphere a day before earthquake and a few hours after earthquake (a) 25th Dec, 2004 at 02:31 UTC on label and at 15:29 UTC on label 2 (b) 26th Dec, 2004 at 04:33 UTC on label 1, at 16:04 UTC on label 2 and 27th Dec, 2004 at 16:32 UTC on label 3.

Figure 4(a) shows the electron density in the ionosphere on 25th Dec, 2004, a day before the earthquake. At 02:31 UTC or 10:31 local time, the electron density is on average 1.42e+10 and no variations are observed, however, at 15:29 UTC or 23:29 local time, the electron density is increasing to almost a maximum value. This is 8 hours and half before the major earthquake that destroyed Aceh that occurred on 26th Dec, 2004 at 00:58 UTC or 08:58 local time. In figure 3(b), label 1 and label 2 show the electron density data on 26th Dec, 2004 at 04:33 UTC and 16:04 UTC respectively. At 04:33 UTC, the electron density value increasing gradually from 9.112e+10 m^{-3} at 90 km to 2.09e+11 m^{-3} at 120 km. However, after approximately 11 hours, the electron density value significantly decreased on 27th Dec at 16:32 UTC to an average 4.0e+10 m^{-3}. The lower values of the electron density in the ionospheric heights after the major earthquake suggest that the ionosphere has returned into its normal condition.

4. Conclusion

The electron density profile obtained from CHAMP satellite 5 days before the major earthquake occurrence on Indian Ocean have been observed and analysed. The observation of electron density profile indicated that significant disturbance occurred in the electron density profile in the ionosphere within the range of 90 km up to 120 km in height above the earthquake epicentre in Aceh, Sumatera, 3 days before earthquake. Besides disturbance, very high concentrations of electron density have been detected 8 hours before the event compare to the quiet condition day where the electron density is quite low. Since the solar activity is very low within the day and no activity of volcanic eruption or large explosion happened in the area of the earthquake epicentre, this phenomena of disturbance in electron density can be concluded that it happened due to the seismic movement below the ground layer in the area of the earthquake epicentre that can be detected as early as 3 days before to a few hours before the event.

References

Antselevich, M., 1971, The influence of Tashkent earthquake on the earth's magnetic field and the ionosphere, Tashkent earthquake 26 April 1966, FAN Publ, 187-188.

Charney, J. G. and Drazin, P. G., 1961, Propagation of planetary-scale disturbances from the lower into the upper atmosphere, Journal of Geophysical Research, 66(1), 83-109.

Chen, P. and Robinson, W. A., 1992, Propagation of planetary waves between the troposphere and stratosphere, Journal of the Atmospheric Sciences, 49(24), 2533-2545.

Hasbi, A. M., Momani, M. A., Ali, M. A. M. and Misran, N., 2009, The relationship between the ionospheric and magnetic disturbances during the 28 March 2005 Sumatran earthquake, Space Science and Communication, 2009, IconSpace 2009, International Conference on.

Hayakawa, M., 2005, The use of

subionospheric VLF/LF propagation as the means to study ionospheric perturbations associated with earthquakes, Recent Advances in Space Technologies, 2005. RAST 2005. Proceedings of 2nd International Conference on.

Hayakawa, M., Kasahara, Y., Nakamura, T., Hobara, Y., Rozhnoi, A., Solovieva, M. and Molchanov, O. A., 2010, On the correlation between ionospheric perturbations as detected by subionospheric VLF/LF signals and earthquakes as characterized by seismic intensity, Journal of Atmospheric and Solar-Terrestrial Physics, 72(13), 982-987.

Hayakawa, M., Kasahara, Y., Nakamura, T., Muto, F., Horie, T., Maekawa, S., Hobara, Y., Rozhnoi, A. A., Solovieva, M. and Molchanov, O. A., 2011, A statistical study on the correlation between lower ionospheric perturbations as seen by subionospheric VLF/LF propagation and earthquakes, General Assembly and Scientific Symposium, 2011 XXXth URSI.

Hegai, V., Kim, V. and Liu, J. Y., 2015, On a possible seismomagnetic effect in the topside ionosphere, Advances in Space Research, 56(8), 1707-1713.

Jakowski, N., Wehrenpfennig, A., Heise, S., Reigber, Ch., Lühr, H., Grunwaldt, L. and Meehan, T. K., 2002, GPS radio occultation measurements of the ionosphere from CHAMP: Early results, Geophysical Research Letters, 29(10), 95-91-95-94.

Karami, K., Ghader, S., Bidokhti, A. A., Joghataei, M., Neyestani, A. and Mohammadabadi, A., 2012, Planetary and tidal wave-type oscillations in the ionospheric sporadic E layers over Tehran region, Journal of Geophysical Research, Space Physics 117(A4).

Laštovička, J., 2006, Forcing of the ionosphere by waves from below, Journal of Atmospheric and Solar-Terrestrial Physics, 68(3), 479-497.

Li, F. and Parrot, M., 2006, Total electron content variations observed by a DORIS station during the 2004 Sumatra–Andaman earthquake, Journal of Geodesy, 80(8-11), 487-495.

Liu, J., Chen, Y., Huang, C. C., Parrot, M., Shen, X. H., Pulinets, S. A., Yang, Q. S. and Ho, Y. Y., 2015, A spatial analysis on seismo-ionospheric anomalies observed by DEMETER during the 2008 M8. 0 Wenchuan earthquake, Journal of Asian Earth Sciences, 114(2), 414-419.

Liu, J. Y., Tsai, Y. B., Ma, K. F., Chen, Y. I., Tsai, H. F., Lin, C. H., Kamogawa, M. and Lee, C. P., 2006, Ionospheric GPS total electron content (TEC) disturbances triggered by the 26 December 2004 Indian Ocean tsunami, Journal of Geophysical Research, Space Physics, 111(A5).

Matsuno, T., 1970, Vertical propagation of stationary planetary waves in the winter Northern Hemisphere, Journal of the atmospheric sciences, 27(6), 871-883.

Pulinets, S., 2004, Ionospheric precursors of earthquakes; recent advances in theory and practical applications, Terrestrial Atmospheric and Oceanic Sciences, 15(3), 413-436.

Pulinets, S. and Boyarchuk, K., 2004, Ionospheric precursors of earthquakes, Springer Science & Business Media.

Schekotov, A. and Hayakawa, M., 2015, Seismo-meteo-electromagnetic phenomena observed during a 5-year interval around the 2011 Tohoku earthquake, Physics and Chemistry of the Earth, Parts A/B/C.

Skeberis, C., Zaharis, Z. D., Xenos, T. D., Spatalas, S. and Contadakis, M.E., 2015, A qualitative study of seismic-ionospheric precursor phenomena monitored by a very close to the epicenter VLF and LF receiver, Physics and Chemistry of the Earth, Parts A/B/C.

Xu, T., Hu, Y., Wang, F. F., Chen, Z. and Wu, J., 2015, Is there any difference in local time variation in ionospheric F2-layer disturbances between earthquake-induced and Q-disturbance events? Annales Geophysicae, Copernicus GmbH.

Yamauchi, T., Maekawa, S., Horie, T., Hayakawa, M. and Soloviev, O., 2007, Subionospheric VLF/LF monitoring of ionospheric perturbations for the 2004 Mid-Niigata earthquake and their structure and dynamics, Journal of Atmospheric and Solar-Terrestrial Physics, 69(7), 793-802.