Indian Journal of Radio & Space Physics
Vol 49, March-June 2020, pp 28-32

Analysis of anomalous ionospheric total electron content variation for earthquakes in South East Asian region with IGS network

Anjan Debnath*

North Eastern Space Applications Centre, Department of Space,
Government of India, Umiam, Meghalaya 793103, India

Received 10 July 2017

A study to find ionospheric Total Electron Content (TEC) anomaly around various earthquake days that occurred during January, 2016 to March, 2017 in the South East Asian region has been undertaken. Large magnitude shallow earthquakes have only been considered. In the study, VTEC data from IGS network has been analyzed with the help of IONOLABTEC software tool. The analysis has been done based on IGS stations that fall within Dobrovolsky Radius of each earthquake. The analysis has included geo magnetically quiet days only to take out all non-seismic effects in the ionosphere. The analysis has shown TEC irregularity few days around almost all earthquake events.

Keywords: VTEC, Dobrovolsky radius, IonolabTEC, IGS network

1 Introduction

Sensing of seismic-origin electromagnetic waves in the ionosphere through coupling via atmospheric layers and resulting anomaly in the ionization state of ionospheric region has a long history and goes back to as early as the 1920s and has been progressively established through multitude of evidences gathered over a long time and across many earthquake events[1-3]. Though initially, the reasons for such perturbations of the Ionosphere has not been clear, now many such mechanisms for propagation of seismically generated effects into the Upper Atmospheric Region has been proposed[4-6]. As mentioned frequently in literature, the electromagnetic phenomena have been distributed from ULF to VHF frequency region. The ionosphere, or plasma sphere, as called by many, is a layer of the atmosphere dominated by the presence of ionized particles that affect signal propagation through them by causing dispersion, delay, depolarization or amplitude and phase scintillation of the signal. Ionosphere is also influenced by various external disturbances i.e, solar activities like solar wind, coronal mass ejection, solar flares as well as geomagnetic activities[7,8]. After satellite remote sensing came into picture, many researchers have used this technique to validate such precursory signatures. The satellite-based observation of thermal anomaly, TEC values and other parameters gives a unique chance to observe earthquake precursory effects without disturbances and periodically[9].

*Corresponding author (E mail: anjan.debnath@nesac.gov.in)

2 Methodology

2.1 Earthquake, Observation area, Observation period and IGS station selection

For getting earthquake information, interactive portal of USGS Earthquake Browser[10] was used. In this exercise, earthquakes were chosen in three steps, first their Magnitude and Depth, only those earthquakes were chosen which were in magnitude more than 6.0 in Richter Scale and Shallow i.e, Those whose depth is maximum of 250 Km. Then, the period of observation was chosen. Earthquakes were chosen from 1 January 2016 to 14 March 2017. Then, the area of observation was chosen. For this study, the area around the South Eastern Asian Island region, especially the landmass covering South China Sea (Peninsular Malaysia, Indonesia, Mayanmar, Thailand, Vietnam, Combodia, Laos) and Andaman Sea (Singapore).

The whole Indian sub continental region was also considered. In latitude and Longitude extents, the area is from -11.492 °S to 35.889 °N and 67.148 °E to 122.695 °E. This region is quite earthquake prone as there are many active faults in the region. Also, the earthquakes in this region have been found to be of higher magnitude[11] (More than 6.0 Richter Scale) and Shallow (Depth less than 50 Km). Total 14 earthquakes were found meeting all given criteria during the observation period. Their Map is as shown in Fig. 1. In the Map, Each Earthquake with its epicenter and Magnitude of Quake with exact time of quake have been mentioned.

Now, in the selected region for earthquake, a Network Map of International GNSS Services (IGS) Stations was obtained. The IGS maintains repository of around 300 worldwide distributed dual frequency GNSS receivers' data. The data from these receivers has been obtained from IGS in Rinex format. For this work, cotemporal multi-station data from IGS network has been used. The GPS based earthquake prediction technique has been documented at many places in literature[12]. Table 1 lists the stations considered.

2.2 Observation Area determination, IGS Stations selection, Geomagnetic Quiet days selection for each earthquake:

In the next step, Dobrovolsky Radius[14] of each earthquake was computed using (1)

$$R = 10^{0.43M} \quad \text{... (1)}$$

Here, radius of earthquake preparation zone is represented by R and earthquake magnitude by M.Then, with the help of USGS Iteractive Earthquake Search Portal (Fig. 1) and online maping tools like free map tools, the IGS stations falling within R and 2R were determined. Table 2 summarizes these.

Table 1 — List of IGS Sites under consideration[13]

Sr. No.	Station Code	Sr. No.	Station Code	Sr. No.	Station Code
01	LCK4	12	CUSV	23	HKSL
02	HYDE	13	EUSM	24	HKWS
03	IISC	14	ANMG	25	JFNG
04	SGOC	15	SIN1	26	SHAO
05	DGAR	16	BAKO	27	PIMO
06	LHAZ	17	JOG2	28	PPPC
07	KUNM	18	DLTV	29	BRUN
08	XIAN	19	XMIS	30	CPNM
09	JNAV	20	TCMS	31	BNOA
10	CMUM	21	CKSV		
11	PBRI	22	KMNM		

Based on these data, the stations' data was analyzed. As mentioned in tPhe literature, for all earthquakes, analysis of VTEC data 10 days previous to Earthquake event and 5 days post the earthquake has been done. Among the 15 day window, only geomagnetically quiet days were taken from World Data Centre for Geomagnetism, Kyoto, Japan[15]. There have been quite a plethora of literature stating the disturbance due to solar geomagnetic activities on the characteristic parameters of the ionosphere[15]. Therefore, only quiet days were analyzed. Further, to compare any observable deviation on the days under observation for each earthquake, a mean VTEC value (m) needs to be obtained for each

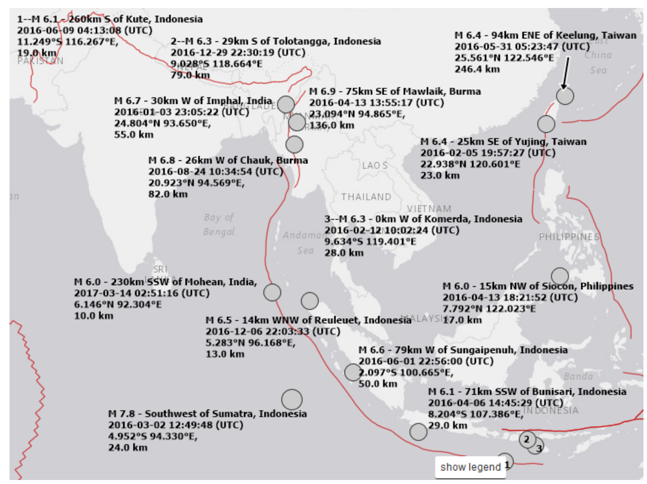

Fig. 1 — Map of Earthquake events in the observation area inside the observation period[10]

Table 2 — Description of Each Earthquake, dobrovolsky radius of each earthquake preparation zone, IGS stations within the radius and within twice the radius

Sr. No.	Earthquake Lat, Long & Magnitude	Dobrolsky Radius (Km)	IGS Stations within Dobrolsky Radius	IGS Stations Outside Dobrolsky Radius but within (2x Dobrolsky Radius) from Epicentre
01	6.15,92.3, 6.0	380.19	Nil	11, 13,14,15
02	-9.03,118.66,6.3	511.68	31	17
03	5.28,96.17,6.5	623.73	13,14	11,12,30,15
04	20.92,94.57,6.8	839.46	10	1,6,7,9,12,30
05	-11.25,116.27,6.1	419.76	31	17,19
06	-2.1,100.67,6.6	688.65	13,14,15	16,17,19
07	25.56,122.55,6.4	564.94	20,21,22	23,24,25,26,27
08	7.79,122.02,6	380.19	28	27,29,18
09	23.09,94.87,6.9	926.83	7,10	1,2,6,9,11,12
10	-8.2,107.39,6.1	419.76	16,17,19	31
11	-4.95,94.33,7.8	2259.44	12,16,17,19	
12	-9.63,119.40,6.3	511.68	31	16,17,19
13	22.94,120.60,6.4	564.94	20,21,22	23,24,25,26,27
14	24.80,93.65,6.7	760.33	6,7,10	1,9,11,12

Table 3 — List of IGS Sites analyzed for each earthquake based on Dobrovolsky Radius , Geomagnetic Quiet days considered for each earthquake and Quiet days considered for calculation of mean and standard deviation of VTEC value

Sr. No.	Eq. Day(T)	Days (T-10 Days, T+5 Days)	Site(s) Analyzed	Q-Days (T-10 to T+5)	Days taken for calculating mean (T-30 to T-10)
01	2017-03-14	2017-03-05 to 2017-03-19	PBRI	13,14,16,17,18,19	2017-02-14,15,21,25,26
02	2016-12-29	2016-12-20 to 2017-01-03	JOG2	30,2	2016-11-29, 2016-12-1,2,3,4,5,13,14
03	2016-12-06	2016-11-28 to 2016-12-11	PBRI	28,5,6,7,8	2016-11-6,7,16,17,18,19,20
04	2016-08-24	2016-08-15 to 2016-08-29	CUSV	15,16,19,20,22,27,28	2016-07-26,27,30,31, 2016-08-01
05	2016-06-09	2016-05-30 to 2016-06-14	JOG2	1,2,3,4,9	2016-05-11,12,13,20,22,24
06	2016-06-01	2016-05-21 to 2016-06-06	JOG2	23,24,25,26,1,2,3,4	2016-05-04,05,11,12,13
07	2016-05-31	2016-05-21 to 2016-06-05	JOG2	23,24,25,26,1,2,3,4	2016-05-04,05,11,12,13
08	2016-04-13	2016-04-04 to 2016-04-18	PPPC	9,11,18	2016-03-13,22,24,25,26
09	2016-04-13	2016-04-04 to 2016-04-18	JOG2	9,11,18	2016-03-13,22,24,25,26
10	2016-04-06	2016-03-28 to 2016-04-11	JOG2, XMIS	31,1,9,11	2016-03-09,13,22,24,25,26
11	2016-03-02	2016-02-20 to 2016-03-07	CUSV, JOG2, XMIS	20,21,22,25,27,28,29,3,4,5	2016-02-02,04,10,20
12	2016-12-29	2016-12-19 to 2017-01-03	JOG2, XMIS	30,2	2016-11-29, 2016-12-1, 2, 3, 4, 5, 13,14
13	2016-02-05	2016-01-27 to 2016-02-10	TCMS	27,29,30,2,4,10	2016-01-15,16,17,18,25,26
14	2016-01-03	2015-12-25 to 2016-01-08	LHAZ	28,29,30,4	2015-12-03,04,13,16,17,18

station that gives a base for statistical comparison. For this purpose, at least 5 quiet days has been taken in an interval starting one month before and ending 10 days after each earthquake. Standard deviation (σ) of these days has also been calculated and two plots giving m±2σ has been obtained. The days around earthquake have been compared with these three plots. Any day's VTEC values, if found beyond the m±2σ margin, has been considered to be abnormal and anomalous[16]. Table 3 summarizes these things.

2.3 Calculation of VTEC at IGS Site that are close to Earthquake Epicentre with IONOLABTEC V1.25

The major work in the study has been anaysis of VTEC values against mean values. For this, daily VTEC files for each station has been obtained with the IONOLAB TEC tool. It is an open-source software freely downloadable from the official webite of Ionolab group[17]. The IONOLAB is a group of electrical engineers and scientists of various study areas, mainly from from Hacettepe University, Bilkent University of Turkey, getting together to do research in the challenging area of the earth's ionosphere. Mainly, they give space weather services related to the Ionosphere at their comprehensive web portal http://www.Ionolab.org for the research community. They provide various tools for helping researchers with value added outputs and easy coputational analysis to aid their work related to ionosphere, like IONOLAB TEC, IRI-Plas, IRI-Plas HmF2, FoF2, TEC/W-Index Maps, IRI Plas STEC Service[17]. With the IONOLAB-TEC tool[17], we computed the VTEC files for each IGS Station for all the days mentioned in Table 3. These VTEC values against time has been plotted using MATLAB software. These plots are then analyzed to capture irregularities in the VTEC values of stations following the procedure mentioned in literature[19,20].

3 Results

With the analysis, different varieties of results were obtained. Some results show strong anomaly in VTEC values few days prior to Earthquake events while for some earthquake, not much anomaly was found. It was, in general, observed that VTEC anomaly was found for larger magnitude earthquakes in general (6.5 magnitude and above) and in stations which are close to the earthquake epicentre. Figure 2 show one such anomalous VTEC trend obtained.

4 Discussion

As it is clear from the table above, VTEC anomaly is not seen uniformly for all incidents, however, for some incidents, it is marked. Also, anomaly has been seen in many forms. Sometimes, the VTEC value has peaked above normal limits a few days before the earthquake, sometimes an oscillatory nature of VTEC variation have been found where alternate days have shown increasing and decreasing trend. In some cases, multiple peaks have been observed. Also, sometimes, the timing of peaking of VTEC has shifted to an earlier or later time in a day. However, it is worth noting that the anomalous effect has not been seen for stations which were a long way outside dobrovolsky radius for each earthquake epicentre which shows a spatial limit of propagation of such effects. This may be used to identify the epicentre of earthquakes by continuosly

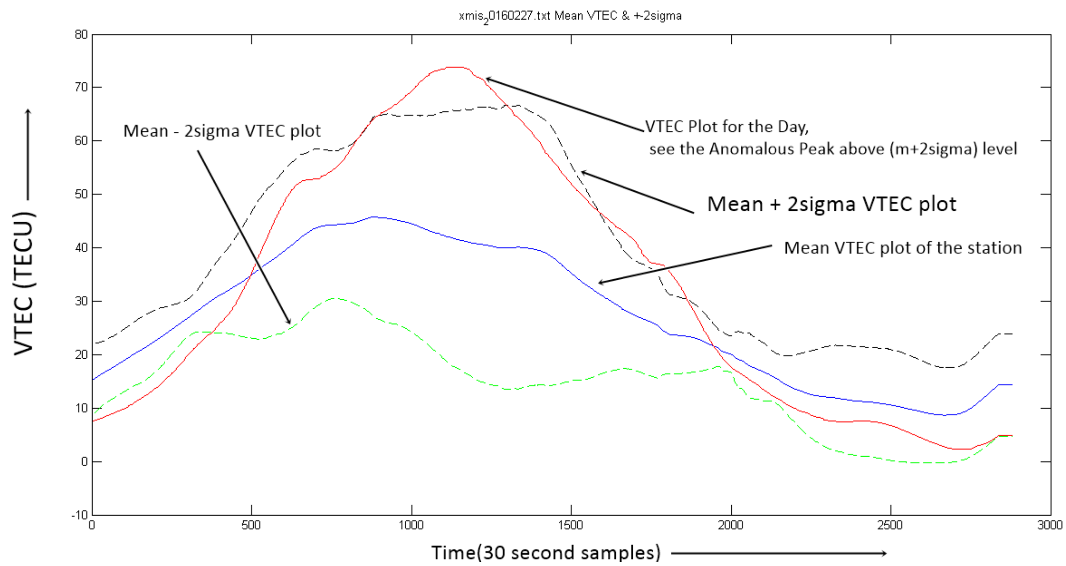

Fig. 2 — VTEC Anomaly example

Table 4 — Summary of VTEC anomaly for the earthquakes under observation:

Sr. No.	EQ Mag.	D.R. (Km)	IGS Station Code & Distance from epicentre(Km) to IGS station	Dst index wise condition	TEC anomaly
01	6.0	384	11,611	No magnetic storm, stable Dst pattern around earthquake day	No TEC anomaly oserved, All 8 days values are almost same
02	6.3	511	17, 922	do	Appreciable drop between the two days' VTEC values observed(8.0 TECU at Noon Peak value) but both values are within normal limits
03	6.5	623	11,802	do	Multiple peak observed 1 day before earthquake, not much anomaly seen
04	6.8	839.46	12,1018	Magnetic fluctuation on 23rd , 1 day prior to earthquake observed	Anomalous peak, both in sense of magnitude ad time observed 5-9 days prior to earthquake, the peaking time shifts around 5 days before earthquake to a different time and shifts back towards the anomalous time 2 days before the event.
05	6.1	419.76	17,754	Magnetic fluctuation seen on Earthquake day	Anomalous flucuation between 01-06-2016 and 02-06-2016, 7 days before Eq event observed(magnitude difference about 15 TECU) and remained to the low value till 04-06-2016 and was found normal on 08-06-2016.
06	6.6	688.6523	17,1244	Magnetic fluctuation not seen	Anomalous variation of occurrence of Noon peak observed, magnitude of peak also varies greatly, VTEC value at Noon peak increases continuously till earthquake day and decreases after earthquake
07	6.4	564.937	20,178	Slight magnetic fluccuation seen	Anomalous VTEC variation seen
08	6.0	380.1894	28,422	Slight magnetic fluccuation seen	Oscillations in Noon time peak observed
09	6.9	926.8298	17,3820	Slight magnetic fluccuation seen	No TEC Anomaly seen
10	6.1	419.759	17,333, 19,311	Slight magnetic fluccuation seen	Not much anomaly seen for station JOG2, For XMIS, anomalous variation observed from 09-04-2016 to 11-04-2016.
11	7.8	2259.436	12,2187;17, 1798;19,1392	Slight magnetic fluccuation seen on Earthquake day	Maximum VTEC anomaly seen for station XMIS, closest to epicentre, then to sation JOG2, at station CUSV, least effect was seen.
12	6.3	511.6818	19,1503;17,1103	Slight magnetic fluccuation seen	Anomalous decrease in the noon VTEC value recorded at both sites(10 TECU)
13	6.4	564.937	20, 211	Negligible magnetic fluccuation seen	Continuous oscillation from low value to high value in VTEC observed in Noon peak, which is anomalous. On 10-02-2017, VTEC peak is anomalously high.
14	6.7	760.3263	6,596	Slight magneic fluccuation seen	Anomalous oscillations seen in VTEC variations 7-8 days before the Earthquake

monitoring the stations in which anomaly is being seen and connecting them to get a circular region and reverse calculating from the Dobrovolsky equation. But for this method, the magnitude of the earthquake is also required. For this, further study has to be done whether the anomaly magnitude is related to magnitude of earthquake in any way. Also, for many earthquakes, no anomaly has been found though they were both large in magnitude (6.9). This may be due to their high depth (136KM) and place of generation. Generally, earthquakes generated on the sea surface have been found to be more promising to leave a signature in the ionospheric region. Also, it has to be mentioned that due to non-availability of data from many IGS stations, a comparative analysis could not be done.

References

1 Gokhberg M B, Morgunov Y A, Yoshino T & Tomizawa T, J Geophys. Res, 87 (1982) 7824.
2 Liu J Y, Chen Y I, Chou Y J & Tsai H F, *Geophysical Research Letters*, 28 (2001) 1383.
3 Devi M, Barbara A K, Depueva A, Ruzhin Yu Ya & Depuev V, *International Journal of Remote Sensing*, 3 (2010) 3589.
4 Molchanov et. al, *Natural Hazards and Earth System Sciences* (2004) 4: 757
5 Namgaladze A A, Shagimuratov I I, Zakharenkova I E, Zolotov O V, Martynenko O V, XXIV IUGG General Assembly, Perugia, Italy, 02-13 July 2007, Session JSS010, 2007.
6 Hayakawa M. (Ed.), Scientific Publishing Company (TERRAPUB), Tokyo, 1999.
7 Davies K, Space Sci Rev, 25 (1980) 357.
8 Deshpande S D, and Mitra A P, *Journal of Atmophere & Terrestrial Physics*, 34 (1972) 255.
9 Parrot M, Adv. Space Res., 15 (11) (1995) 35.
10 https://earthquake.usgs.gov/earthquakes/search/
11 Singh O P, Chauhan V, Singh B, *Indian Journal of Radio & Space Physics*, 42 (2013) 131.
12 Jusoh Mohamad hazaimv, Ya'acob Norsuzila, Sood Hasnida, Sulaiman Ahmad Asari, Baba Noor Hasimah, Amang Robi'atin Adaviah & Khan Zuhoni Ismail, 2008 IEEE International RF & Microwave Conference, Kuala Lumpur, (2008) 372.
13 http://www.igs.org/network.html
14 Dobrovolsky IP, Zubkov SI & Miachkin VI, Pure & applied geophysics, 117 (1979) 1025.
15 http://www.wdc.kugi.kyoto-u.ac.jp/qddays.html
16 Sharma DK, Sharma PK, Rai J, Garg SC, *Indian Journal of Radio & Space Physics*, 37 (2008) 319.
17 http://www.ionolab.org
18 Arikan F, Arikan O, Guliyeva T L, Karatay S, Mosna Z, 2016 URSI Asia-Pacific Radio Science Conference, Seoul, Korea, 21-25 (2016) 1136.
19 Devi M , Barman M & Barbara A, *J Atmos Sol-Terr Phys*, 64 (2002) 1413.
20 Devi M, Barbara A K, Kashyap P, Depueva A, Ruzhin Yu Ya & Depuev V, *Advances of Geosciences*, 27 (2011) 69.