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Response of Scintillation and Total Electron Content (TEC) over Indian regions during the Quiet Days

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Abstract: GPS derived scintillation (S_4-Index) and TEC data recorded at different location in India (Delhi, Bhopal, Bangalore & Trivandrum). For the first time we are reporting scintillation and TEC activities during quiet days. Quiet days are define as a very low or negligible solar activity that is opposite of disturbed day. For the study of quiet days variations we analyses some space weather indices like Dst index , AE index, Kp Index and interplanetary magnetic field Bz. During the study on 6-7 august 2016 we noticed on 6 October Bz fluctuated between -1 to +2nT that means little bit disturbance occurred and next day on 7 October it was +3 to -2 nT. AE index was 500 on 6 October and it was decrease 290 on 7 October .Dst Value observed -16.5nT on 6 October in the mid night on 6 October it was -22nT. All this space weather parameter shows small scale space weather activities. For this study we are choosing two quiet days, 6-7 October 2016 and 25-26 august 2017. Both This quiet days are observed during the down phase of solar cycle 24th, during this study we noticed that maximum scintillation activities (< 1.5 and < 1) recorded at Bhopal and Bangalore station as compare to Delhi and Trivandrum stations and maximum TEC activities observed at Bhopal and Delhi during minor geomagnetic activity on 6-7 October 2016. The study of another quiet day 25-26 August 2017, we observed maximum scintillation activities (1.6 and 1) over Bhopal and Bangalore stations, at Delhi and Trivandrum stations we noticed minor scintillation activities (<0.5 and <0.3) and maximum TEC fluctuations recorded at Bhopal and Delhi stations as compare to

Bangalore and Trivandrum stations. Quiet days are not fully quiet days we can get some response in ionosphere at low mid-latitudes and EIA regions. This paper, for the first time, reports on scintillation and TEC characteristics observed at the L-band frequency of 1.575 GHz over the Indian region During 2 quiet days in 2016-2017. We present here the results for four stations on the scintillation and TEC characteristics of the L-band scintillations (S4 index), simultaneously measured by these receivers in the Indian region and the possible effects on GPS navigation.

Keywords: GPS, Scintillation, TEC, Quiet Days.

1. Introduction

Severe space weather induces perturbations in the composition, dynamics and geomagnetic field of the Earth's upper atmosphere, which sometimes causes serious threats to the global navigation and satellite communication systems. The Global Positioning System (GPS) is a satellite-based navigation system, which provides good positional accuracy of the user at any point of the globe, and at any given time using the L-band frequencies of L_1 (1575.42 MHz) and L_2 (1227.60MHz). The GPS positioning accuracies are subjected to various effects, like clock biases of the satellites and receivers, ionospheric and tropospheric delays, and receiver noise. Among these, the effects of accuracy degradation, due to group delay introduced by ionospheric total electron content (TEC) and ionospheric scintillations caused by small scale density irregularities. The Indian region encompasses the equatorial and low-latitude ionospheres. The morphology of the equatorial ionosphere is quite different from that of other latitudes because the magnetic field (B) at the equatorial region is nearly parallel to the Earth's surface. During daytime, the E-region dynamo electric field (E) is eastward. This field in the E-region and at off-equatorial latitudes maps along the magnetic field to F-region altitudes above the magnetic equator, resulting in $E \times B$ drift, which transports F-region plasma upward over the magnetic equator. The uplifted plasma over the equator then moves along magnetic field lines in response to gravity, diffusion, and pressure-gradient forces. As a result, the equatorial ionization anomaly is formed with reduced F-region ionization density at the magnetic equator and increased ionization at the two anomaly crests around ±15° in magnetic latitude to the north and south of the magnetic equator.

It is known that near sunset, the dynamics of the equatorial ionosphere are dominated by the pre-reversal enhancement (Woodman[1]) of the vertical drift at the equator. During sunset, plasma densities and dynamo electric fields in the E-region decrease, and the anomaly begins to fade, and at this local time a dynamo electric field develops in the F-region. Polarization charges, set up by the conductivity gradients at the terminator, enhance the eastward electric field for about an hour after sunset. With the decreased ionization density in the E-region after sunset, vertical plasma density gradients form in the bottom side of the F-layer, resulting in the upward density gradients opposite in direction to the gravitational force. This configuration is Rayleigh-Taylor (RT) instability and allows plasma density irregularities to generate (Kelley et al.[2, 3], Huang and Kelley[4] Hysell[5]). The eastward post-sunset electric fields enhance the R-T instability, while westward fields quench it. These irregularities can grow to become large ionospheric depletions, often called equatorial plasma bubbles, which are elongated along the magnetic flux tubes. The variability in the PRE may dictate the onset or inhibition of these instabilities (Basu et al.[6] Hysell and Burcham[7] Fejer et al.[8]). The Indian region covers latitudes ranging from the magnetic equator to the northern anomaly crest and beyond, up to 27°N geomagnetic latitudes, and it is also known that scintillations are most severe at the locations around the anomaly crest where the electron density gradients are high (Aarons et al.[9] Basu et al.[10]). Small-scale irregularities in the electron content of the ionosphere, with spatial extents from a few meters to a few kilometers, can produce both refraction and diffraction effects on received GPS signals. The refraction changes the direction and speed of the propagation of an electromagnetic wave, and the diffraction gives rise to spatial fluctuations in the amplitude and phase of the received signal. The movement of the ionospheric irregularities relative to the signal path converts these spatial fluctuations, due to diffraction effects, into temporal fluctuations, which, due to the diffraction effects, are observed as scintillations in the GPS received signal (Wanninger[11]) A rapid fluctuation of amplitude and phase in radio signals can occur over the equatorial and low latitude region when passing through the ionosphere, this phenomenon is known as ionospheric scintillation and is based on the occurrence of plasma density irregularities in the ionosphere. The density irregularities are mostly indicators of the equatorial Spread-F (ESF) at altitudes ranging from 200 to 1000 km, with the primary disturbance region being between 250 and 400 km (Groves et al.[12]). By cause of the complex interaction between electric fields, the earth's magnetic field, and neutral winds, the ESF shows severe conditions within the F region of the ionosphere, extends to ±20° of the magnetic equator (Sridharan et al.[13]). The existence of enhanced eastward electric fields and meridional neutral winds at night induce disturbance in the ionosphere producing plasma bubbles containing irregularities of different size (McClure et al.[14]), which cause scintillations in the passing radio signal through the ionosphere(Zou[15]).Particularly strong ionospheric irregularities were caused by the intense geomagnetic storm producing wave-like propagating structures known as large-scale traveling ionospheric disturbances (LSTIDs). They represent the manifestation of gravity waves created in the Aurora zones in the Northern and Southern Hemispheres. Such disturbances at the auroral oval can become a source of strong LSTIDs propagating toward the Equator (Hunsucker[16] Hajkowicz and Hunsucker[17]). The most discussed source mechanisms for the excitation of LSTIDs are Joule heating, the Lorentz force (Oyama and Watkins[18]) and also particle heating has to be considered. As long as the complexity of interactions between electric and magnetic fields together with the thermospheric winds, the exact generation mechanisms of LSTIDs are only poorly understood till now. Several studies show that the ionospheric behavior during geomagnetic storms is changed from its normal behavior (Blagoveshchensky et al.[19]). The geomagnetic storm produces Thermospheric winds, creates electric currents and changes the structure in the upper atmosphere. Every one of them can make a non-normal variation in the photoionization, recombination, and transport processes causing an irregular change in the electron concentration of the ionosphere. Some main effects are the significant change in the neutral wind circulation and atmospheric composition affecting the rate of production and loss of ionization. These changes modify and redistribute the atmospheric electron density. The neutral winds can also cause the production of F-region electric fields through the mechanism of disturbance dynamo. Such electric fields can also redistribute the F-region plasma, affecting the production and loss rates, and causes Total Electron Content (TEC) to change (Galav et al.[20]). The ionospheric scintillation is enhanced by these electron density variation (Shang et al.[21]).The GPS signal at L-band frequencies is important for studying the features of ionospheric irregularities as it is affected by the irregularities of few hundred meters' scale sizes. Many researchers studied the GPS morphology based ionospheric scintillation in terms of S4 index at low latitude in different longitude regions. They found that the amplitude scintillation activity differs with magnetic activity, seasons, geographical location, local time and solar cycle (Tanna et al.[22] Hlubek et al.[23] Kriegel et al.[24]).

This paper, for the first time, reports on scintillation and TEC characteristics observed at the L-band frequency of 1.575 GHz over the Indian region During 2 quiet days in 2016-2017. We present here the results for four stations on the scintillation and TEC characteristics of the L-band scintillations (S_4 index), simultaneously measured by these receivers in the Indian region and the possible effects on GPS navigation.

2 . Data and Methodology

The primary data set of the present study is the Global Positioning System (GPS)-derived TEC and S4-index over four different stations across India during the October (6-7)-2016 and August (25-26)-2017 periods. These stations are representing regions from near equator (NE) to low-mid latitudes. And stations are low-latitude stations, Bangalore, Bhopal and Delhi and the equatorial station, Trivandrum. Bhopal is located in the vicinity of the EIA crest.

Table 1. Details on the Locations of Different Stations and Instruments There at, Used in the Present Study

Station	Geographic latitude	Geographic longitude	Geomagnetic latitude	Geomagnetic longitude	Instrument
Trivandrum	08.47∘N	76.92∘E	00.05∘S	149.74∘E	GPS
Bangalore	12.95∘N	77.68∘E	04.33∘N	150.87∘E	GPS
Bhopal	23.28∘N	77.34∘E	14.59∘N	151.44∘E	GPS
Delhi	28.56∘N	77.22∘E	19.84∘N	151.83∘E	GPS

The GPS receivers installed at these stations (Table 1) provide the ionospheric Slant TEC (STEC) at one minute intervals. The STEC is the total number of electrons in a column of unit cross sectional area along the satellite ray path. It is calculated by using the difference between the carrier phases (L1 and L2) of the two frequencies. As slant TEC is dependent on the ray path geometry through the ionosphere, it is desirable to calculate an equivalent vertical value of TEC, which is independent of the elevation of the ray path. The vertical TEC is obtained by taking the projection from the slant to vertical using a thin shell model, assuming a height of 350 km following the technique given by Klobuchar[25].

(2.1) $$\textit{Vertical TEC}\ (VTEC) = STEC \times \mathrm{Cos}\left(arc\,\mathrm{Sin}\left(\frac{R_e \cos\theta}{R_e + h_{\max}}\right)\right),$$

where $R_e = 6378$ km, $h =$ elevation angle of GPS satellite at the ground station and h_{max} is the height of Ionospheric penetration point (IPP) usually assumed to be 350–400 km(Jain et al.[26] and references therein).Only the satellite ray paths with elevation angles greater than 45° are chosen in the calculation of the VTEC in this study.

Amplitude scintillation is measured by S_4 index defined as the standard deviation of the received signal power normalized to average signal power. The S4 index is computed over 60 s intervals. Since S_4 index is affected by ambient noise, two related indices are recorded namely total S_4 [$(S_4)_{\text{total}}$] and correction to S_4 [$(S_4)_{\text{correction}}$]. The corrected S_4 (ambient noise free) is then calculated as follows:

(2.2) $$X = S_{4total}^2 - S_{4correction}^2,$$

(2.3) $$S_{4corrected} = \begin{cases} \sqrt{X}, & if \quad X > 0 \\ 0, & if \quad X \leq 0 \end{cases}$$

The basic interplanetary and geomagnetic parameters are obtained from the NASA/GSFC Web and World Data Center, Kyoto University.

3. Results and Discussion

Quiet days are defined by very low solar activity as compare to disturb days. For the study of quiet days variations we analyses some space weather indices in figure 1, like Dst index , AE index, Kp Index and interplanetary magnetic field Bz. During the study on 6-7 august 2016 we noticed on 6 October Bz fluctuated between -1 to +2nT that means little bit disturbance occurred and next day on 7 October it was +3 to -2 nT. AE index was 500 on 6 October and it was decrease 290 on 7 October .Dst Value observed -16.5nT on 6 October and on 7 October it was -22nT. All this space weather parameter shows small scale space weather activities.

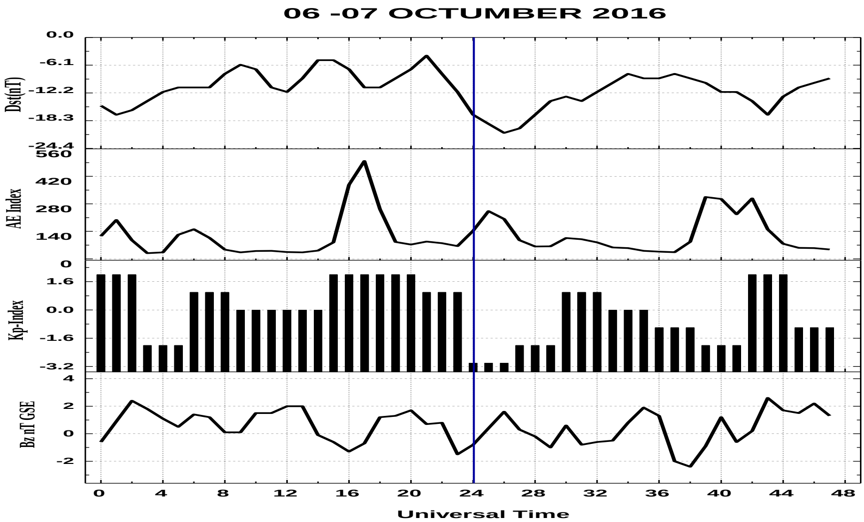

Figure 1. Space weather indices response during quiet days 6-7 October 2016.

This small scale activity impact on earth's ionosphere, we observed s4 index at Bhopal was 0.9 at 11 UT and for Bangalore it was 0.85 at1UT same value observed 12UT, at Delhi station s4 index value was 0.40 at 2UT on 6 October. On next day on 7 October we seen 0.49 s4 index at between 0-4 UT, again s4 value increase up to 1.5 at between 13-14UT at Bhopal. At Bangalore station we observed same value 0.98 at between 0-4 UT, and 0.95 at between 9-12 UT, At Trivandrum station we observed 0.2 at between 16-19UT As shown in figure 2.

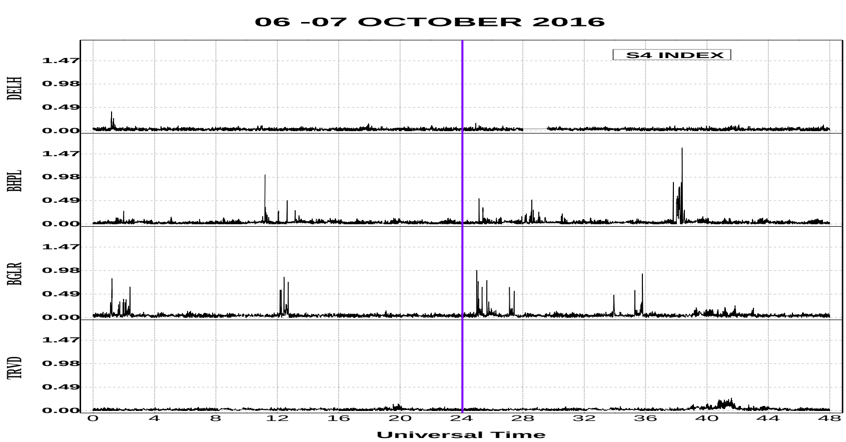

Figure 2. Scintillation activity on 6-7 October 2016

For the study of TEC we observed maximum fluctuation at Bhopal station 74 (TECU) on 6 October between 8UT- 12UT. Over Delhi station it was observed at 45 TECU at 9UT. During the study of 6 October we did not get any fluctuation at Bangalore and Trivandrum, same observation we observed on next day 7 October that time we also observed maximum fluctuation in TEC at Bhopal station 55 TECU at 8UT-12UT. At Delhi station it was 48 TECU between 8UT-12UT. This fluctuation was very low at Bangalore and Trivandrum stations shown in figure 3.

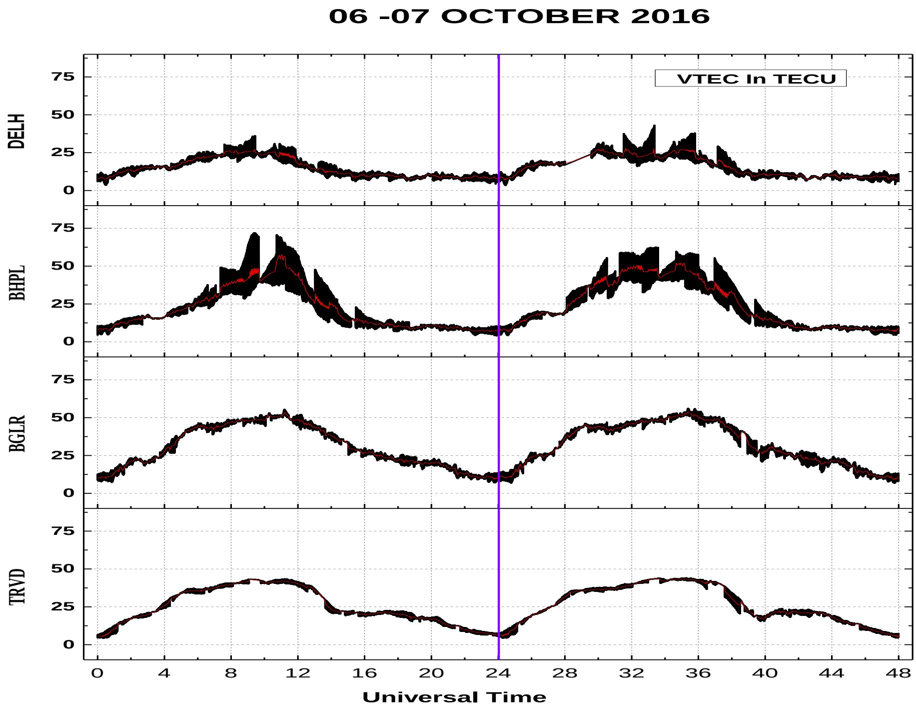

Figure 3. TEC response during the quiet days on 6-7 October 2016

Next quite days were observed in 25-26 August 2017. During the study of space weather indices on these days we observed minimum value of Dst is -15nT on 25 august. AE index was 300, Kp index 1.5 and interplanetary magnetic field Bz -2.5 nT. Next day on 26 august Dst fluctuated -6.7nT to 0nT. AE index was 140, Kp index 1.5 and Bz 3.8nT as shown in figure 4.

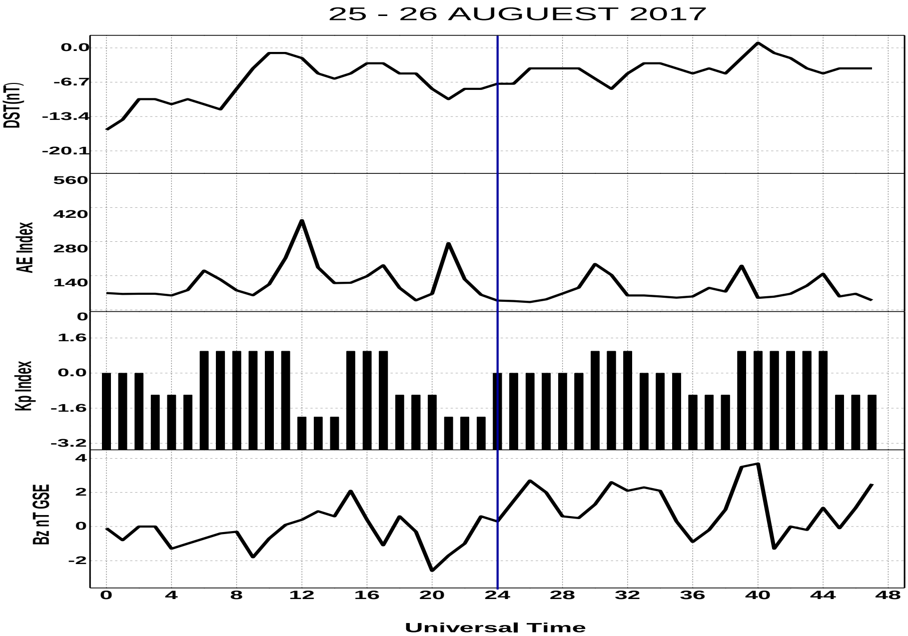

Figure 4. Space Weather indices response on 25-26 August 2017

According to space weather indices we observed scintillation on 4 station, we observed major scintillation activity on Bhopal station, maximum scintillation observed 0.98 at 11 UT, at Delhi station maximum scintillation was observed on 0.49 at 7 UT , 15UT and 18UT, scintillation activities was very low at Bangalore and Trivandrum stations (<0.3) figure 5. Next day on 26 august maximum scintillation activities observed at Bhopal and Bangalore stations, maximum S4- index was 1.5 at Bhopal and 0.98 at Bangalore stations at 1UT. Minor S4 index activities observed at Delhi and Trivandrum stations that was <0.4 shown in figure 5. It may be noticed that for the occurrence of weak scintillations over the magnetic equator, Trivandrum is maximum compared to the occurrence of weak scintillations at the crest region. Here it may be mentioned that due to the geographic shape of India, the number of GPS receiver stations are less, limiting the spatial coverage. At the anomaly crest regions, the accumulated F-region ionization, transported from the equator, is high, resulting in high electron density gradients and small-scale irregularities, giving rise to the generation of strong scintillations at the L-band frequency of 1.5 GHz.

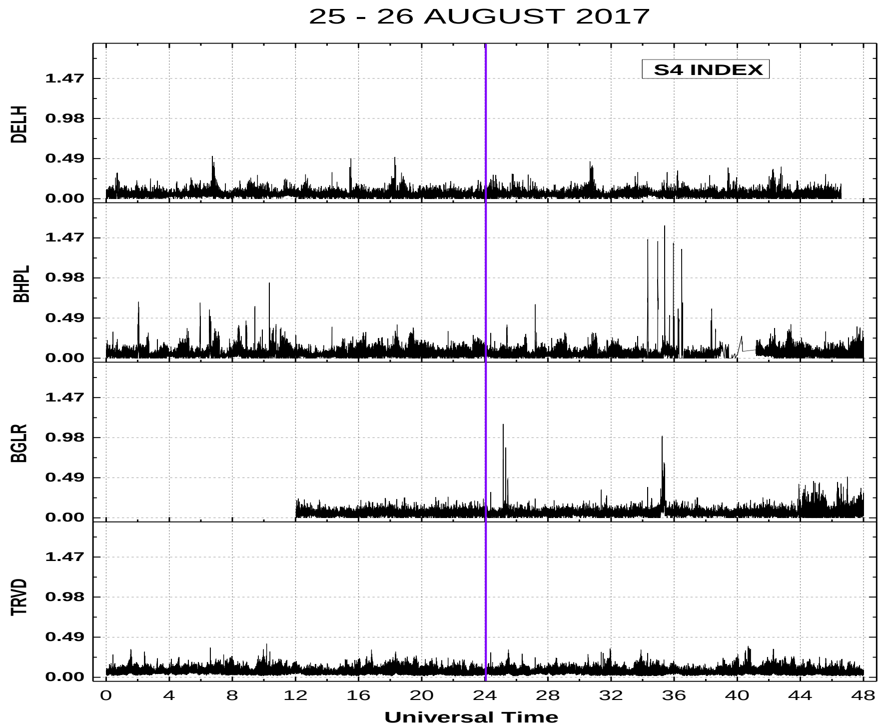

Figure 5. S_4 -Index response on 25-26 August 2017

During the study of TEC on 25 -26 august we observed maximum TEC at Bhopal and Delhi stations on 25 august it was 50 TECU and 49 TECU between 8UT-12 UT, we did not get any good response at Trivendrum and Bangalore stations. On next day on 26 august we noticed fluctuations at Bhopal and Delhi stations. It was 45 TECU at Bhopal and 40 TECU at Delhi. Minor fluctuations we can see at Bangalore and Trivendrum stations we got regular routine of TEC showing in figure 6.

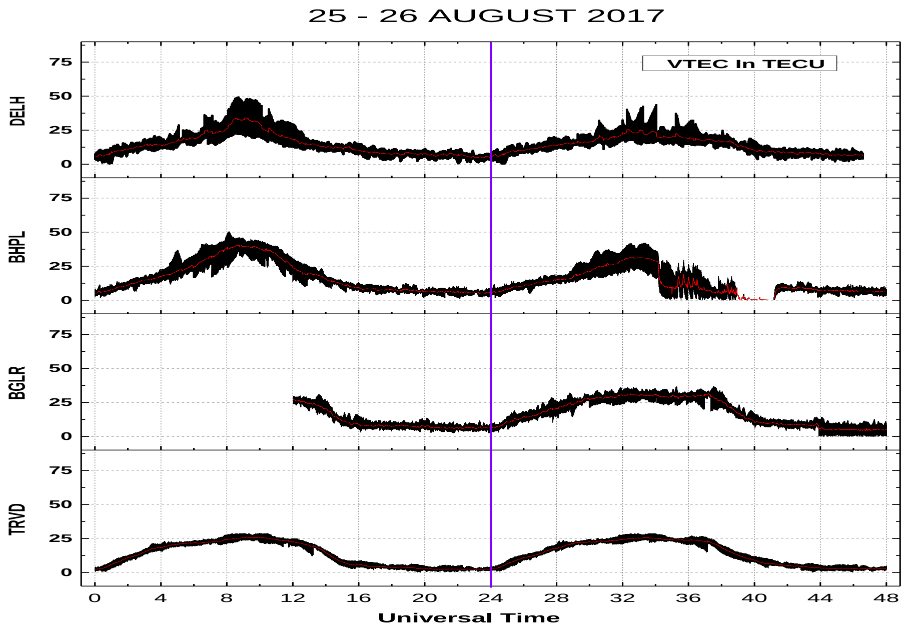

Figure 6. TEC response on 25-26 August 2017

4. Conclusion

Quiet days are define as a very low or negligible solar activity that is opposite of disturbed day. During quiet days study our conclusion is following:

(i) Quiet days are not fully quiet days we can get some response in ionosphere at low mid-latitudes and EIA regions.
(ii) Scintillation activity is high as compere to TEC.
(iii) Day time scintillation activity observed.
(iv) TEC enhancement is found before minor disturbances on GPS Signals.

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