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Anomalous variation of ionosphere for cyclones over Indian region – Case study

M. Noor Riswana[1], V. Muthulakshmi[2], S. Mohanasundari[3] and E. Karthikeyan[4].

[1,2,3,4] Centre for Geotechnology, Manonmaniam Sundaranar University, Abishekapatti, Tirunelveli, Tamilnadu- 627012, India.

Abstract

Many advanced international investigations of the link between tropical cyclones and the ionosphere are connected with extreme difficulties. The possible mechanism of the tropical cyclone effect on ionosphere caused mainly due to the gravity waves and other related phenomena. In this study the three tropical cyclones namely Helen, Lehar and Phyan occurred over the Indian sector. The cyclone Helen and Lehar are the successive cyclones take place in the year 2013 whereas the cyclone Phyan takes place in the year 2009. Total electron content in the ionosphere perturbs due to the effect of tropical cyclone passage near the GPS receivers. As cyclone reaches near the land modifies the total electron content in the ionosphere due to the gravity waves. Gravity waves generated due to the convection activity and travels vertically to the height of ionosphere induce the change of electron content. The total electron content before the cyclone observed to be quiet normal behaviour whereas after the landfall of the cyclone the total electron content diminishes and gets minimum than the background value. We observed the TECU value of these cyclones is consistently to decrease after the landfall day. Gravity waves generated due to the some factors in the troposphere redistribute the total electron content by increasing the neutral particles over certain ionospheric height.

Keywords: Cyclone, VTEC and DST

1. Introduction

In convective motion, thunderstorms, lightning, strong electric fields between the clouds and the earth, air-sea interaction processes leads to many directly and indirectly caused changes at different altitude domains and geographical location. There are number of studies of the tropical cyclone (TC) manipulate on ionosphere indicating electrical and electromagnetic effects [Isaev et al., 2002]. In ionospheric investigations, the analyses are based on calculations of the TEC variations using Global Positioning System (GPS) technology (Zakharov et al., 2012). The ionosphere is highly modified and modulated by the upward propagating waves that created different meteorological processes in the troposphere.

Due to the high spatial and timescale variability, they range from small scale aural waves with periods of minutes to large scale terrestrial waves with periods of days. Atmospheric waves are originated due to periodic heating and cooling of the Earth's atmosphere and surface dynamics. Atmospheric waves are propagated into the ionosphere mostly directly, and the planetary waves can be propagating upward to the F region heights only indirectly. The waves may be altered during upward propagation via nonlinear interactions, particularly in the mesosphere and lower thermosphere (MLT) region [Lastovicka, 2006]. However, there are experimental evidences of atmospheric waves penetrating up to the F2 layer of height [Afraimovich et al., 2000] are detected that gravity waves in the F region by using ionosonde and radars. Hence the convective activity is one of the most important tropospheric sources of atmospheric waves especially gravity waves [Fritts and Nastrom, 1992]. It generates the waves in vertical and horizontal scales throughout the full range of phase speeds and wave frequencies. The low frequency waves are observed in the middle atmosphere at large horizontal distances from the convective source [Fritts and Alexander, 2003]. The effect of the underlying atmosphere on ionosphere is highly influenced by the neutral particle dynamics, as the number of neutrals in the lower atmosphere highly exceeds the ionized particles by several orders of magnitude.

Among the different disturbances of meteorological origin, tropical cyclones are one of the most intense and powerful possible dynamical sources which influence the ionosphere from below. Over the Indian region, a low pressure system is classified based on the maximum sustained wind speed (V) and the pressure deficit/number of closed isobars (P) associated with the system. At definite phases of tropical cyclone development and perturbations in the meteorological parameters to initiate the turbulence of electrical conductivity. The tropical cyclones have some region specific names viz., “hurricanes” over the Atlantic Ocean and “typhoon” over the Pacific Ocean. Tropical cyclone(TC) should be considered to be an extended and lasting disturbance (not a point instantaneous disturbance) having its effect spread over a zone (1000-2000km westward or eastward from the TC location) whose localization depends on the disturbance propagation direction. There are many proposed mechanisms through which tropical cyclones can affect the ionosphere from below. Within the zone of a tropical cyclone, the vertical largescale convection of cloudy atmosphere generates upward transport of charged water drops and aerosols which perturbs the atmosphere ionosphere electric circuit. Also, the strong convective cells of a tropical cyclone zone produce a wide spectrum of gravity waves (GWs) at tropospheric altitude which can propagate up to the F region. TC inspired GWs can propagate upward to the ionospheric height as well as horizontal distances of hundreds and thousands of kilometers [Mao et al., 2010; Perevalova and Ishin, 2009; Vaninadart et al., 2011] and manifest themselves as traveling ionospheric disturbances (TIDs).

During the evaluation of tropical cyclones, the globally observed GWs have periods of 6h to 2.5days, vertical wavelengths of 1-3km, and horizontal wavelengths <1000km [Ming et al., 2010]. Acoustic-gravity waves with periods of 10-20min were recorded at horizontal distances up to 2000km from a tropical cyclone in the F region of ionosphere [Xiao et al., 2007; Perevalova and Ishin, 2009] and the internal gravity waves with periods of 10min to 11.00 pm were recorded at large distances from tropical cyclone formation regions [Perevalova and Ishin, 2009]. In general, a growth of ionospheric parameters (100%) can be observed from the inception of the tropical cyclone to full grown activity and after that, the parameters begin to fall (50%) above the tropical cyclone localization area and around. In light of the above discussion, we find to study on the possible effects of tropical cyclones on the ionosphere over the Indian sector, which is also influenced by a strong equatorial anomaly. So, it is inspired us to investigate the matter a little further.

2. Data processing methods

In order to investigate the ionospheric changes with respect to tropical cyclone we need TEC data of the particular receiver which is nearest to the TC affected areas. The TEC is the number of electrons in a column of one meter-squared cross-section along a trans-ionospheric path centered on the GPS signal path and it is expressed in TEC unit (TECU) i.e. 1 TECU $=10^{16}$ m^{-2}. It can be obtained from GNSS and satellite born altimeters signals. We used TEC data of GPS receiver of International GNSS Service (IGS) station HYDE (Hyderabad, India) and SGOC station from Sri Lanka. A GPS receiver tracks up to 11 GPS satellites at the L_1 & L_2 as 1575.42 MHz and 1227.60 MHz frequencies simultaneously. GPS-derived TEC observed at ground stations. The TEC calculation has included the DCB values ((i.e.) differential code biases values). The receiver is programmed to provide TEC data for the time interval of 1 minute. The receiver provides the slant TEC (STEC) after the satellite and receiver bias correction. These STEC measurements exhibit to noticeable elevation of angle-dependence.

The latitudes and longitudes of ionospheric pierce points (IPP) have been calculated from the RINEX observation and navigate the data by using standard coordinate transformation formula [Hofmann-Wellenhof et al. 2001].The IPP form a 2D irregular grid and short satellite arcs are often impacted by carrier-phase cycle slips and depending on the size and location of the phase breaks, often the short arcs need to be discarded by the software. Thus, in general the dayside ionosphere will parade higher TEC values than the night side.

Many observations can be shown that the greatest universal ionization happens about 2 hours after local noon. The latitude defines as the inclination of the Earth to the Sun. The slant TEC (STEC) has been changed to vertical TEC (VTEC) by taking the projection from the slant to vertical using a suitable mapping function at different IPP can be calculated using thin shell model [Klobuchar, 1986] according to equation (1)

$$VTEC = \frac{STEC-(Br+Bs)}{S\ (El)} \qquad (1)$$

Where,

B_r and B_s are receivers and satellite biases,

El is the elevation angle of the satellite in degrees,

S (El) is the obliquity factor with zenith angle at the IPP.

The obliquity factor S (El) (or mapping function) is defined as in equation (2)

$$S\ (El) = \frac{1}{COS(x)} \qquad (2)$$

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$$= \frac{1}{\sqrt{[1-\{\frac{R.COS(El)}{R}+h\}^2]}} \qquad (3)$$

Where,
R → Earth's mean radius (6378 km),
H →height of the ionospheric shell above the Earth's surface (350 km),
X → zenith angle,
El → elevation angle of the satellite in degree.
For the conversion of STEC to VTEC the shell height is valid for Indian low latitude regions [Rama Rao et al. 2006b] 3% error produced in VTEC at mid latitude. Apart from this the large electron density rise present in the equatorial region could also be responsible for the error when STEC converted to VTEC. Since, TEC variation may be affected by multipath, tropo-scatter and water vapor at low elevation angles, we have thus taken the satellite elevation angle high enough so that it only allow rays with 350 km pierce points within ±1° of the receiver location.

In this study the different vertical TEC measurements in the cell round the receiver are averaged to estimate the TEC above the receiver. At different elevation angles of the satellite the length of the signal path through the ionosphere increases with lower elevation angles .The geomagnetic index during the event period is seen and quite normal and lies within the range of ±40nT.

From the DST index confirms that the event occurs in the quiet geomagnetic days only. The ionosphere is best described in the framework of magnetic synchronizes of magnetic latitude and magnetic local time and it can be seen as relatively calm period.

3. Observational Result:

3.1Cyclone Helen and Lehar**:**
The TEC variation in the ionosphere noticed as an evidence during the tropical cyclone events. The two successive cyclones namely cyclone Helen and Lehar formed in Bay of Bengal.

Firstly the TC Helen forms a trough on 16th November over Bay of Bengal near Andaman and Nicobar islands. On next day it became organized as a low pressure area and intensified as a severe cyclonic storm over the Bay of Bengal with active inter tropical convergence zone. The TC crossed Andhra Pradesh coast close to south of Machilipatnam near at latitude 16.1 N and 81.2E on 22ndNovember 2013 (day 326). As the cyclone falls on the land is taken as landfall day and it weakened rapidly after the landfall and hence caused less rainfall over the coastal Andhra Pradesh. The path of the cyclone Helen and Lehar is represented in fig.1 and fig.2 respectively.

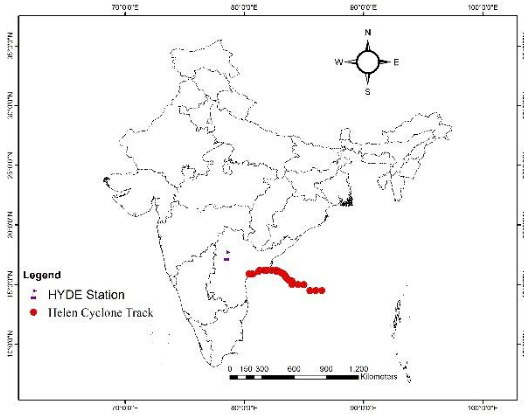

fig 1. TC Helen trajectory over Bay of Bengal and over the land during 15 November to December 5, 2013

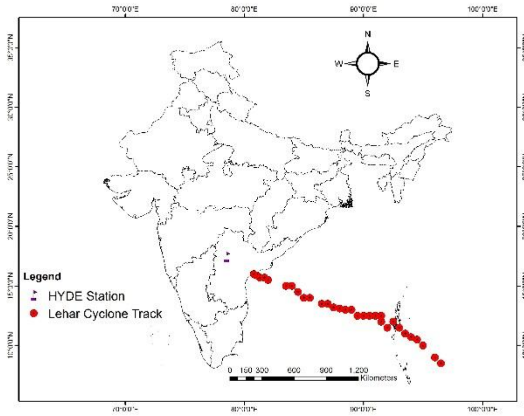

fig 2. TC Lehar trajectory over Bay of Bengal and over the land during 15 November to December 5, 2013

This study brings the interest behind the trend of the cyclonic effect on the ionosphere to notice in brief. The data of TEC for both cyclones has been obtained from the respective station during magnetic quite days. The wind speed of the cyclone Helen ranges from 50 kmph to 100 kmph on 19th to 21st November 2013(Day 323 to 325) and then the wind speed decreases after the landfall day 23rd November 2013 (Day 326) Shown in Fig.3

After the cyclone Helen weakens and the successive cyclone Lehar also affects the same place near the coast of Machilipatnam. It forms trough on 21st November over south Andaman Nicobar Islands. On the next day, organized as a low pressure area and intensified as a severe cyclonic storm near Andaman Nicobar Islands with active inter tropical convergence zone. The cyclone Lehar formed over the south Andaman Nicobar Islands on 23rd evening. It rapidly weakened from 27th afternoon and crossed Andhra Pradesh coast close to south of Machilipatnam near latitude

15.5N and longitude 82.0E on 28th November 2013(Day 332). It rapidly weakened over the sea from the stage of very severe cyclonic storm to depression. It leads to the change in TEC values. The intensity of the cyclone Lehar gets decreased after the landfall. The TEC values gets normal after the effect of the cyclone.

The wind speed of the cyclone Lehar ranges from 40 kmph to 130 kmph on 23rd to 26th November, 2013 (Day 327 to 330) and then the wind speed range decreases up to 50 kmph after the landfall day 27th November 2013 (Day 331).

Both cyclone Helen and Lehar, the TEC variations observed from the nearby receiver location of Hyderabad.

The fig.3(a) indicates the wind speed of the cyclone Helen and Lehar for the successive days. Also the cyclone forms on the magnetic quiet days confirm there is no magnetic disturbance as the DST falls under ±40nT. The cyclone Helen crosses the coast on the day 326 of year 2013 and cyclone Lehar falls on the land on the Day 331. The fig.3(b) depicts that the raw VTEC and the monthly mean of VTEC anomaly over the period of cyclone time. We observed that raw VTEC falls below the value of monthly mean of VTEC after the landfall day. Fig.3(c) shows the mean deviation of Raw VTEC and the monthly mean of VTEC in the graphical form for every day from the occurrence of cyclone. As the two cyclones occurs successively and the VTEC values decreases as high as 14 TECU after the landfall of cyclone Lehar.

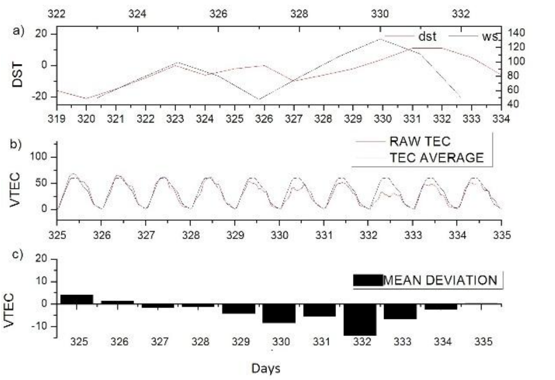

Fig 3. (a) Geomagnetic activity index Dst and the maximum sustained surface wind velocities V (bold line), (b) variation of Raw TEC (Red line) and Average TEC (Blue line), and (c)mean deviation of VTEC of, during the period of TC Helen and Lehar from November15 to December5, 2013.

The decrease in VTEC anomaly continues until the cyclonic effect over the region. VTEC anomaly observed to be increases after the cyclonic effect and the behavior retains as normal.

3.2Cyclone Phyan

Phyan is a successive cyclone takes place near to the southwest of Colombo in Sri Lanka on November 9, 2009(Day 313) the disruption had enhance into a Depression. Early on November 11, 2009 (Day 315) the Phyan had entered its peak intensity of 95kmph. The cyclone follows a long path and later the cyclone becomes weakened after the landfall.

Fig.4 indicates the DST index of the cyclone Phyan. As it confirms that the cyclone forms on the magnetic quiet days from the DST index and the value ranges within ±40nT. The cyclone Phyan crosses the coast on the day 315 of the year 2009.

Fig.3(b) depicts that the raw VTEC and the monthly mean of VTEC anomaly over the period of cyclone time. We observed that raw VTEC falls below the value of monthly mean of VTEC after the landfall day.

Fig.3c shows the mean deviation of Raw VTEC and the monthly mean of VTEC in the graphical form for every day from the occurrence of cyclone.

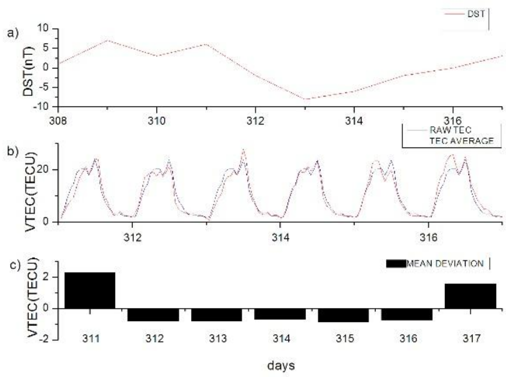

Fig 4. (a) Geomagnetic activity index Dst, (b) variation of Raw TEC (Red line) and Average TEC (Blue line), and (c) mean deviation of VTEC, during the period of TC Phyan from 9 to 11 November 2009

As the cyclone occurs the VTEC values tends to decreased for 0.85 TECU after the landfall day of the cyclone Phyan. The decreased VTEC observed to be constant over the period of days and then retained to the normal behavior after the cyclone passes away to the receiver.

4. Results and discussions

In this paper, the ionospheric variations observed during powerful tropical cyclone and hurricanes in Andhra Pradesh and Sri Lanka. The study of the correlation between the ionospheres in the troposphere is very interesting. We analyze the ionospheric responses to three selected tropical cyclone during which the geomagnetic condition is very quite. The results show that after tropical cyclones Helen, Lehar and Phyan. It increases first and then decreases the magnitude and the duration of such disturbance seem to be positively correlated

to the wind power. Finally, the increase of the turbo pause due to the tropical cyclone activities is introduced to explain such phenomena. The reason why the TEC increases first in the case of Helen, Lehar and Phyan needs to be further discussed.
The analysis highlights our observation on the possible effects of tropical cyclone Helen, Lehar and Phyan on equatorial ionosphere in Indian sector. In our observation periods show a comparison between ionospheric TEC variations of tropical cyclone in unaffected days with a tropical cyclone affected days. The 24 hours raw VTEC variation shows a sharp decrease the value on the day of landfall compared to the other days of observation.
Since the TC is an extended and lasting disturbance, this overall decrease from background persisted on the next day of the landfall. We quantified this observation with average VTEC deviation from the background value, which is the monthly mean of VTEC of the respective to months. All the TC unaffected days before the landfall of the two tropical cyclones, has very low average VTEC deviations from background value.
As the geomagnetic conditions of these days were quiet, and the low variations could be due to the day-to-day variability in the ionosphere. On the landfall day, when the TCs passed over the location of the receivers, we observed maximum average VTEC deviation below the background value Interpretation can also show that the TEC can moreover reduce or grow (or both) in the troubled section [Ruzhin et al., 2014]. Perevalova et al., 2014] observed that there is a threshold magnitude (near 6.5) below which there is no pronounced earthquake-induced wave TEC disturbances. At low magnitudes, seismic energy is likely to be insufficient to generate waves in the neutral atmosphere which are able to induce the TEC disturbances at the level of background fluctuations.
In the case of our observation, with the help of data from United States Geological Survey (USGS) we noted that there was no earthquake of magnitude above 6.5 during the period of 19-28 November 2013 (before and during TC Helen and Lehar) and during 9-11November 2009 (before and during TC Phyan) within areas of several km radius form the location of the GPS receivers. So we are confident that no effects of earthquake were present in our observed VTEC anomaly.
We observed the anomalous reduction in VTEC on the landfall day on which the maximum sustained surface wind velocity is also observed due to reduce gradually. It is apparent that with reduction of the sustained surface wind, the ejection of neutral particles from terminator will also reduce as the neutral particles from the terminator will gradually loose energy.
We would like to point out the fact that in our analysis, we have shown the anomaly of the landfall day compared it with the tropical cyclone unaffected days before and after the landfall. So before the landfall, our region of observation was completely affected by the disturbing factors generated by landfall of TCs. Although after the landfall of the TCs the ejection of neutral particles from terminator reduces with reduction of the sustained surface wind, the amount of perturbations present during the active stage of the cyclone after landfall is sufficient to reduce the electron content of the ionosphere.
So in our observation, the decrease in VTEC during the active days of the TCs after landfall is completely distinguishable compared to the TC unaffected days. The above discussion clearly shows that for all the three TCs, there was intense convective activity observed over the land region after the landfall of the TCs when the TCs were in their active stages. So the convective activity is very well correlated with the observed depletion in VTEC on the landfall day.
Since with increase in convective activity, all the mechanisms which reduce the ionospheric electron content increases; it is obvious to observe a drastic decrease in VTEC on the landfall compared to the other days when no convective activity was there over the lands. This investigation further solidifies our observation of the anomaly in VTEC on the landfall day of TC.

5. Conclusion

In the main, we discovered an average fall of VTEC value beneath from the monthly mean after the day of the landfall of TCs. We determined that the disturbance began when the storm was a Tropical Depression (TD) and ahead it was described as a TC. Our observations noted that the amplitude anomalies can presence both in the day and night time.
From our observation the effect of TCs seen after the landfall and the number of charged particles in the ionosphere decreases significantly in an average fall of VTEC rate below the monthly mean. To the extent that the turbulences formed by the landfall of TCs are alarmed, the magnitude of VTEC decrement created by the TCs over Bay of Bengal is much higher from the preceding published results. Also, the diminution in the VTEC values is produced by those cyclones which had the highest tracks over the Bay of Bengal.
The radio transmissions potency varies owing to the perturbations in the ionosphere caused by the

possessions of TC's also. The perturbations of disruption caused by TCs on the ionosphere for large scale set our inspection can evidence on the variations in TEC. TEC values gets normal after the effect of the cyclone and the data of more number of GPS receivers around a TC exaggerated region and modeling efforts are wanted to examined quantitatively the effect of TC on ionosphere. Also to recognize the feasible mechanisms allied with such perturbation to lengthen this work further.
From our observation we can say that the total electron content (TEC) in the ionosphere was increasing in the negative order after the landfall day of the cyclones.

Acknowledgement

International GNSS service (IGS), 1992. GNSS Final Combined Clock Solution (Every 1 minute) product NASA CDDIS. Available from <<ftp://cddis.gsfc.nasa.gov/ >>

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