Ionospheric Variability under extreme space weather conditions

S. Banerjee, S. K. Chakraborty
Maharaja Srischandra College, Kolkata-700003

Abstract

The ionospheric effects of 13 intense geomagnetic (CME, CIR) storms (Dst < -100 nT) during the years 2011-2015 on ionospheric total electron content (TEC) as well as occurrence of scintillation from stations distributed over a latitudinal and longitudinal span (~10º-30ºN and ~75º-95ºE) of Indian zone (RPMC: 22.65°N, 88.36°E; Port Blair: 11.3ºN, 92.4ºE; IISC Bangalore: 13.0ºN, 77.3ºE; Lucknow: 26.5ºN, 80.5ºE; Lassah: 29.5ºN, 91.06ºE) are reported. The deviations of the diurnal TEC from the quiet days mean values yield the signature of the storm contribution. The distinguishing features are reflected in the variability of scintillation occurrence and TEC in the main phases as well as recovery phases. During the main phase positive storm effects of ~19% at equatorial stations and ~27% around the anomaly crest and in the recovery phases positive deviation ~54.5% at Port Blair, ~63.6% at Bangalore, ~54.5% at RPMC, ~45.4% at Lucknow and ~45.4% at Lassah are observed. TEC deviation amplitudes exhibit good correspondence with the estimated energy coupling (ϵ) function. Magnetometer data of Trivandrum(8.7ºN, 77.8ºE) and Dalat (11.94ºN, 108.48ºE) reflect that the main phase results may be discussed in terms of electric field modulation due to both the under shielding and over shielding conditions. The relative distribution of molecular / atomic species, disturbance dynamo field and neutral dynamics contribute to the variability well into recovery phase. The dominant contribution in TEC variability around the present location arises from the field of disturbance dynamo origin. Maximum composition changes of 40% from the quiet days is detected using GUVI data. A correspondence is revealed between the variation of interplanetary parameters and the ionospheric variabilities at the low latitude region.

1. Introduction

During the severe space weather events the response of the ionosphere is rather very complicated due to unpredictable changes in electric field, composition, density, ionosphere-thermosphere circulation to name a few but these are very important issues related to space weather studies. One of the important parameter to study ionospheric state changes is the total electron content (TEC). Though TEC is an integral characteristics (electron content from satellite to ground receiver), the main contribution of its variation arises from the F-region. Hence it is treated one of the important diagnostic tool for ionospheric state both in local and global perspective. Another fascinating feature of geomagnetic storm is the evolution/ inhibition of electron density irregularities leading to equatorial spread F (ESF) / scintillations hampering navigation capabilities. The response of the ionosphere to each space weather event appears to be different. Further investigation of individual cases as well as studies on statistical basis is still important to understand ionospheric behaviour under extreme weather conditions and to develop space weather model.

The aim of the present work is to reveal the features of TEC variability in the equatorial low latitude ionosphere along with the characteristics of scintillation occurrence around the EIA crest region of eastern Indian longitude sector during the 13 intense geomagnetic storm events. The intense storms characterized by Dst < -100 nT are distributed in different local time and seasons during 2011 to 2015. Attempts have been made to extract the distinctive features of TEC variability and to relate the same with the magnetospheric energy input chapman parameter (ε).

2. Data

To characterize different storm events various solar wind parameters such as Vsw (solar wind Velocity), Psw (soloar wind pressure), IMF Bz (Interplanetary magnetic field- z component), AE are downloaded from the website of https://spdf.gsfc.nasa.gov/. SYM-H and Dst available with the website wdc.kugi.kyoto-u.ac are used. To have an idea of electric field variation magnetometer H-field data from website www.wdciig.res.in/ are downloaded. GNSS TEC received at Raja Peary Mohan College (22.65°N, 88.36°E) as well as GIM TEC data available at IGS website are also downloaded. VHF (250.650 MHz) as well as GNSS scintillation data are recorded at RPMC. C/NOFs electron density data for few storm are provided by Dr. Pat. TEC deviations are estimated from the quiet days mean levels and same is normalized with respect to mean value, 20% of which is considered to dictate day-to-day variability.

3. Results

The result of analysis are presented in the following subsections briefly considering both the case as well as statistical features. The case study pertains to one equinoctial event below shown in figure 1, 2 and 3.

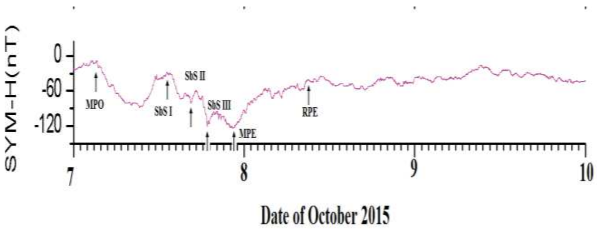

Figure 1: SYM-H (nT) parameter of October 2015 storm

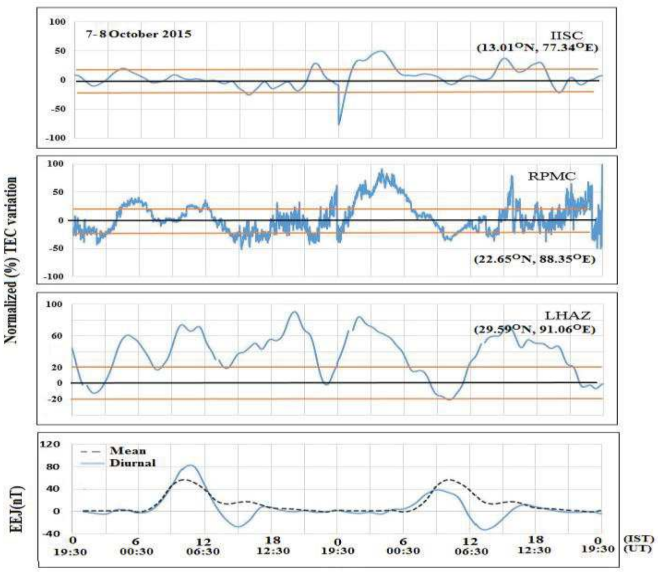

Figure 2: Ionospheric effects associated with the geomagnetic storm at equatorial, anomaly and beyond anomaly region along with Electrojet field variation of October.

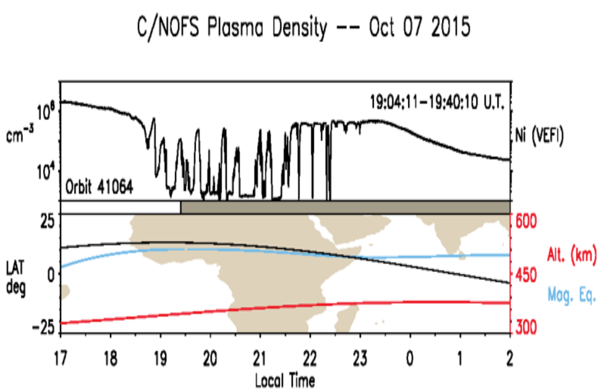

Figure 3: Spatial variation of C/NOFS plasma density

The main points of analysis are

(i) The autumnal equinoctial event on 7th October 2015 is a gradual commencement CIR driven geomagnetic storm having long duration recovery phase with characteristics IMF Bz fluctuations.

(ii) The storm is characterizes by multi-step main phase development (initiation at ~3:15 UT ,8:45IST on 7th Oct) in concurrence with signatures of multi-enhancement in P_{sw} and southward turning of Bz separated by less geo-effective conditions in solar wind driver.

(iii) The prevailing high positive IEF reflects direct and repeatable ionospheric effects.

(iv) Initiation of main phase is followed by enhanced EEJ and afternoon CEJ in the Indian longitude sector.

(v) The second and 3rd sub-storm at 16:32 UT and 18:50 UT exhibit negligible EEJ activity.

(vi) Though TEC values exhibit enhancement around the EIA crest in the initial main phase no such significant effect is detected at low latitude region.

(vii) At LHAZ positive effect throughout the main phase may signify mechanical effect of equator-ward neutral wind but near EIA crest contribution of PPE as dictated by AE is also prominent.

(viii) A fast storm recovery started after 2230 UT on 7th October, 2015.

(ix) Recovery phase is characterized by reduced EEJ and evolution of CEJ in pre to afternoon sector.

(x) The continuation of enhancement in TEC of all stations up to early morning period in the initial recovery phase may be fossil main phase and mechanical equator ward neutral wind effects preceded by ULF fluctuations in IMF Bz under positive turning of IEF.

(xi) The decreasing trend thereafter in TEC and equator ward shift of EIA crest following CEJ event suggest DD and over-shielding electric field contributions.

(xii) No scintillation is recorded at RPMC in both phases but CNOF data exhibit irregularity activities in western longitude sector on 7th October.

(xiii) The zonal disturbance wind superposed on eastward dynamo wind may reduce the PRE amplitude for seeding plasma irregularity in the recovery phase.

4. Statistical results

The storm event are categorized on the basis of local time of occurrence of 1) main phase (MPO) 2) the recovery phase / end of main phase (MPE). Both the enhancement and decrement in TEC are observed. The results of statistical analysis are shown below in a tabular form.

Table 1:

Deviation during Main Phase

Local Time Sector	No of Storm	Percentage of Positive Deviation	Percentage of Negative Deviation	No Deviation
Morning to afternoon (0530-1200 LT)	7	85.71	14.29	0
Sunset to pre-midnight(1830-2330LT)	3	66.67	0	33.33
Midnight to post-midnight (0030-0430 LT)	3	0	0	100

Table 2:

Deviation during recovery phase

Local Time Sector	No of Storm	Percentage of Positive Deviation	Percentage of Negative Deviation	No Deviation
Morning to afternoon (0530-1200 LT)	7	57.14	28.57	14.28
Sunset to pre-midnight(1830-2330LT)	3	0	100	0
Midnight to post-midnight (0030-0430 LT)	3	0	0	100

The main driven of ionospheric variability is the energy input in the magnetosphere from the solar wind. An approximate index of input energy may be obtained through the Chapman ε parameter. Under present investigation and attempt is made to find any correspondence between TEC deviation (ΔTEC) and ε. Only the deviation amplitude is considered and the results are depicted in figure 4. The figures demonstrate that

(i) TEC deviation amplitudes in both enhancement and decrement exhibit good correspondence with a correlation coefficient r=0.64 for Port Blair and 0.6 for RPMC) with the estimated energy coupling function.

(ii) The results are significant at 99% significant level Two-Sample Assuming Unequal Variances.

5. Summary

The result of case as well as statistical analysis may be summarized as

(i) High solar wind dynamic pressure with steady southward IMF Bz having larger magnitude during the main phase of storms simulates several geomagnetic storm activity

(ii) The main phase TEC variability is mainly characterized by enhancement over the quiet day's level. The enhancement is reflected at all the low latitude stations with maximum around the anomaly crest.

(iii) The electric field modification under the disturbance dynamo origin seems to play vital role to dictate TEC variability in the recovery phases around the present location.

(iv) A correspondence is revealed between the variation of interplanetary parameters and the ionospheric variabilities at the low latitude region. The distinguishing features are also reflected in the variability of scintillation occurrence and TEC in the main phases as well as recovery phases of the storm events studied.

6. Acknowledgements

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