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Earthquake induced dynamics at the ionosphere in presence of magnetic storm

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Abstract

The modifications induced in the dynamics of the ionosphere by the major Japan earthquake (EQ) of March 11, 2011 (epicenter at 38.322°N, 142.369°E, $M = 8.9$) in presence of a magnetic storm are examined by mapping latitudinal variations of F-layer ionization density (NmF2) from 22 stations covering the epicenter zone. The changes forced into the Total Electron Content (TEC) by the major EQ in the magnetic storm ambiance are also examined from the GPS data collected at Guwahati (26° 10′ N, 91° 45’ E), situated in the major fault system of East Asia. The contributions of pre-seismic electric field as well as of magnetic storm time electric field in the observed density variations are brought into the ambit of discussion. The influence of lower atmosphere in shaping TEC features during the study case is highlighted. The effects of solar activity on density variations during such complex ambiances are also addressed.

Keywords: NmF2; TEC; Earthquake; Magnetic storm; Ionosphere; Lower atmosphere

1. Introduction

Earthquakes (EQs) trigger complex dynamics in the atmosphere due to multi system coupling processes that link the lithosphere to upper atmosphere. Amongst many methods adopted for understanding EQ time system dynamics and for identifying EQ precursors, the electromagnetic (EM) approach (Zaslavski et al., 1998; Hayakawa, 1999; Devi et al., 2001; Liu et al., 2001; Ruzhin and Nomico, 2007; Hayakawa and Hobra, 2010; Devi et al., 2012 and references therein) provides a wide range of measurement possibilities that may respond from Ultra Low Frequencies (ULF) to Very High Frequencies (VHF). Here, one utilizes the High Frequency (HF) and VHF signal propagation properties in determination of ionization density and Total Electron Content (TEC), of the ionized medium. While HF propagation gives ionization content of a particular layer of the ionosphere, VHF propagation from satellite to a ground receiver provides information of the total columnar electron content (Liu et al., 2002; Naman et al., 2002; Devi et al., 2008) of the ionosphere. However, the parameters extracted from these observations during an EQ event need to be filtered out from solar geomagnetic influences (Devi et al., 2004, 2010a) because such disturbances modulate ionization density significantly. One of the factors associated with modification in ionospheric parameters prior to an EQ is the electric field generated by its preparatory processes. There are other hypotheses such as emission of radon from the lithosphere resulting to abnormal ionization in the atmosphere (Pulinets, 2009), for example. Added to these factors, there are also reports showing apparent modification in ionization due to pre earthquake influences on the lower atmosphere (Hayakawa and Molchanov, 2002; Devi et al., 2010a,b; Devi and Barbara, 2012).

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In general, the electric field is considered to be a significant factor in controlling ionization density in the equatorial region (Klimenko et al., 2006). Because, the $E \times B$ drift process generated by the equatorial electric field (E), could transport ionization from the equator to off equatorial region, thereby causing relatively lower density at the equator and a higher density zone at around 20° geomagnetic latitude. This phenomenon is known as the "Equatorial anomaly". Along with this E field, an electric field generated by the EQ preparatory processes may work in unison, resulting either to enhancement or depletion in the zonal electron content. Such anomaly effects may not have direct influence on ionization density near to the epicenter of mid latitude EQs, as in this case of study. But the relevance of such factors cannot be ruled out because anomaly width changes with solar geomagnetic environment (Walker and Chen, 1989; Min-Yun and Chang-Shou, 1991; Devi et al., 2002, 2011; Anderson et al., 2006) and it may extend to beyond the anomaly crest belt of ±20° geomagnetic latitude in a magnetic storm situation.

Further, a magnetic storm may also increase or decrease ionization density (known as positive and negative ionospheric effects) (Heelis et al., 2009; Huang et al., 2010), but the changes appear in the global frame. Observations show that the effects are largely dependent on latitude, the severity and onset time of Main Phase (MP) (Lanzerotti et al., 1975; Prolss, 1993; Mandillo and Narvaez, 2009) of a storm. Modifications in atmospheric dynamics during magnetic storms take place through various processes like generation of equatorward neutral wind due to heating of high latitude thermosphere, Prompt Penetration of high latitude Electric field (PPE) to lower latitudes, development of Disturbances in Dynamo Electric field (DDE) to name a few (Forbes, 1989; Lin et al., 2003; Abdu et al., 2006, 2012). Therefore, during an EQ event that occurs when magnetic storm is active in the background, the ionosphere is influenced by (i) electric fields which originate at the magnetosphere, (ii) the disturbed dynamo field and (iii) electric field of EQ preparatory sources. There are also reports of VLF emissions associated with earthquakes that could reach even up to magnetosphere (Parrot and Mogilevsky, 1989). Therefore, isolation and labeling of earthquake contributions either to electron density or to that of TEC at a background of magnetic storm are difficult exercises.

The paper addresses these aspects by analyzing ionization density (NmF2) variations from a number of stations around the epicenter zone of major Japan EQ (Tohoku earthquake) of March 11, 2011 (epicenter at 38.322°N, 142.369°E and $M = 8.9$) that occurred in presence of a magnetic storm. The earthquake time TEC data from Guwahati (26° 10′ N, 91° 45′ E) situated in the anomaly crest zone, are also analysed along with foF2 results. The station Guwahati also lies in seismic fault-line system of east Asia.

2. Analysis and result

The very strong Japan EQ of March 11, 2011, was preceded by another event of March 9. Two significant magnetic storms occurred also in this month i.e., on March 1 and 11, 2011 as shown by DST variations of Fig. 1. The coincidence of the major EQ of March 11 with the magnetic storm as displayed in Fig. 1 is a rare occasion that offers a unique opportunity for understanding the physics and dynamics of the atmosphere in such an ambiance.

2.1. NmF2 variations prior to and during EQ and magnetic storm events

In search of EQ and storm time modifications in the upper atmospheric dynamics, the variations of NmF2 of 22 stations covering a wide geographical zone within 62°N to 66°S and 96–169°E around and beyond the epicenter were mapped and the ratio of daily NmF2 with respect to its monthly mean value ($NmF2_{mean}$), i.e., $NmF2/NmF2_{mean}$ was calculated. Fig. 2 displays the excursion of this ratio observed from a number of stations during the period of March 10–12, 2011 i.e., covering the day of the major EQ that coincides with the magnetic storm (the vertical line gives the time of occurrence of the EQ). The negative excursion of the $NmF2/NmF2_{mean}$ ratio as shown by black shades in Fig. 2 at the high latitude station of Yakutsk prior to and during the March 11 EQ, suggests reduction of F-layer density. The $NmF2/NmF2_{mean}$ ratio has gone positive indicating enhancement of density of F-layer, marked by red shades in Fig. 2 as we move down in latitudes near to the epicenter. But, the magnitude of $NmF2/NmF2_{mean}$ ratio had again gone to negative values at stations like Okinawa and Darwin suggesting a reduction in F-layer density when the relative distance of the observing station with epicenter had increased. This character persisted to higher latitudes in the southern hemisphere. The shifts of negative to positive ionospheric effects with changes of relative position between epicenter and the observing stations, are displayed in Fig. 3, by presenting NmF2 variations in March-2011, from three representative

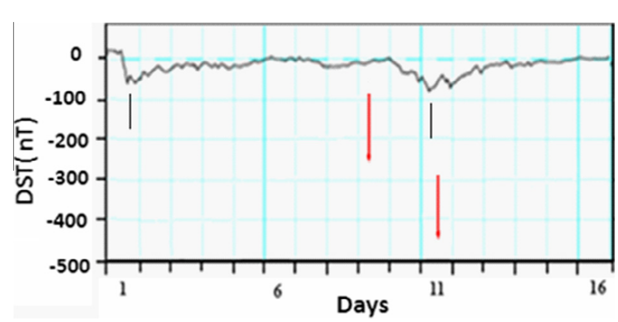

Fig. 1. Displays DST variations for March 2011. The events of magnetic storm and Japan EQ that occurred in this month are marked by black and red bars respectively. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)