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Moderate geomagnetic storms of January 22–25, 2012 and their influences on the wave components in ionosphere and upper stratosphere-mesosphere regions

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Abstract

Moderate geomagnetic storms occurred during January 22–25, 2012 period. The geomagnetic storms are characterized by different indices and parameters. The *SYM-H* value on January 22 increased abruptly to 67 nT at sudden storm commencement (*SSC*), followed by a sharp decrease to −87 nT. A second *SSC* on January 24 followed by a shock on January 25 was also observed. These *SSC*s before the main storms and the short recovery periods imply the geomagnetic storms are *CME*-driven. The sudden jump of solar wind dynamic pressure and IMF B_z are also consistent with occurrence of *CMEs*. This is also reflected in the change in total electron content (TEC) during the storm relative to quiet days globally. The response of the ionospheric to geomagnetic storms can also be detected from wave components that account for the majority of TEC variance during the period. The dominant coherent modes of TEC variability are diurnal and semidiurnal signals which account upto 83% and 30% of the total TEC variance over fairly exclusive ionospheric regions respectively. Comparison of TEC anomalies attributed to diurnal (DW1) and semidiurnal (SW2) tides, as well as stationary planetary waves (SPW1) at 12 UTC shows enhancement in the positive anomalies following the storm. Moreover, the impact of the geomagnetic storms are distinctly marked in the daily time series of amplitudes of DW1, SW2 and SPW1. The abrupt changes in amplitudes of DW1 (5 TECU) and SW2 (2 TECU) are observed within 20°S–20°N latitude band and along 20°N respectively while that of SPW1 is about 3 TECU. Coherent oscillation with a period of 2.4 days between interplanetary magnetic field and TEC was detected during the storm. This oscillation is also detected in the amplitudes of DW1 over EIA regions in both hemispheres. Eventhough upward coupling of quasi two day wave (QTDWs) of the same periodicity, known to have caused such oscillation, are detected in both ionosphere and upper stratosphere, this one can likely be attributed to the geomagnetic storm as it happens after the storm commencement. Moreover, further analysis has indicated that QTDWs in the ionosphere are strengthened as a result of coherent oscillation of interplanetary magnetic field with the same frequency as QTDWs. On the otherhand, occurrences of minor SSW and geomagnetic storms in quick succession complicated clear demarcation of attribution of the respective events to variability of QTDWs amplitudes over upper stratosphere.

Keywords: Geomagnetic storms; Ionosphere; QTDWs; Planetary waves; Amplitude modulation

1. Introduction

Radio wave has been dominant mode of communications for long time and has become increasingly vital in satellite communication and navigation infrastructure in recent times. The ionosphere region of the atmosphere is important medium for these technologies to function properly. In

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particularly electrons in the ionosphere are detrimental in radio wave propagation. However, the complex spatial distribution of these electrons over the ionosphere especially during enhanced solar activity severely affects the radio wave communication. In this regard, the neutral winds and electric fields are the main driving field in equatorial plasma distribution. The strength and prevailing directions of the neutral winds change with seasons and therefore show marked variation from one hemisphere to the other. This in turn induces north–south hemispheric asymmetry of the ionosphere at any given season in such away that stronger poleward wintertime winds favors stronger plasma anomaly crest in winter than summer hemispheres (Astafyeva, 2009 and references therein). The balance between electric field, resulting pressure gradient and gravity determine ultimately plasma distribution not only dynamically but also through control of the distribution of ionospheric constituents available for the photochemistry. For example, the eastward zonal electric field during day at the magnetic equator creates a steady upward $E \times B$ plasma drift until the pressure forces are strong enough along with gravity to force the plasma to slide down the magnetic field lines. This is indeed a well established understanding and how the ionization trough at the magnetic equator and plasma density enhancements at the EIA crests around $\pm 15^\circ$ magnetic latitudes are formed (e.g. Abdu et al., 1990 and references therein). The eastward electric field is enhanced shortly after sunset leading to the F-region plasma to drift to even higher altitudes.

Ionospheric electron distribution is also affected by other geophysical process such as geomagnetic storms. Geomagnetic storms occur when there is a large sudden change in the solar wind dynamic pressure at the magnetopause. The geomagnetic *Dst* index is an excellent indicator of storm events. The main attribute of a magnetic storm is a clear decrease of the horizontal intensity of the magnetic field. The onset phase of a storm is often characterized by a short sudden increase of the *Dst* index (Forster and Jakowski, 2000). The interplanetary magnetic field (IMF) turns southward and intensifies to the extent that it can penetrate into low-latitude ionosphere during the main phase of geomagnetic storms. The subsequent reconnection between southward IMF and the Earth's magnetic field leads to a strong electric field which moves the equatorial F-region plasma upward thereby enhancing the fountain effect. As this happens during daytime, solar photoionization at lower altitudes replenishes this region and compensates for plasma lost to uplift. This mechanism has been discussed to have led to an overall increase in the ionosphere total electron content (TEC) (e.g. Astafyeva et al., 2007; Basu et al., 2007) and has been described as a main pathway for a number of intense geomagnetic storms (e.g. Tsurutani et al., 2004, 2007, 2008; Mannucci et al., 2005; Basu et al., 2007) where the sudden drop of B_z IMF accompanied by a significant TEC increase were observed.

Profound influences of geomagnetic storms can be observed in disturbances in the ionospheric F2 region electron density. These disturbances could involve either enhancement or depletion in electron density depending on whether positive or negative ionospheric storms generate them. Significant changes in electron density profile and total electron content (TEC) during geomagnetic storms are results of the complex interplay of injection of magnetospheric energy and energetic particles into the polar upper atmosphere directly, and influences from altered dynamic and chemical coupling processes of the thermosphere and ionosphere systems during the storm indirectly. There is general consensus that heating of the thermosphere due to high energy and momentum inputs alter thermospheric composition paving way for negative ionospheric storms to form. Equatorward propagation from auroral towards lower latitudes is found to be the main feature of the negative phase. In contrast, ionospheric positive phases are attributed to several processes such as vertical drift, plasma fluxes from the plasmasphere and downwelling triggered by storm-induced thermospheric circulation (e.g. Danilov and Belik, 1992; Danilov and Lastovicka, 2001). The formation of positive phase can also arise from suppression of the sunlit eastward electric field at low latitudes thereby weakening uplift of plasma. Such type of increase is observed during main phase of storm (e.g. Tsurutani et al., 2004 and references therein).

At low latitudes, another important factor that influences storm-time behavior of ionosphere are electric field disturbances. For instance, prompt penetration electric field and wind disturbance dynamo electric field can drastically modify the equatorial ionization anomaly (EIA). Interplanetary electric field can continuously penetrate to the low latitudes ionosphere (e.g. Huang et al., 2005a; Wei et al., 2008), which may lead to dramatic changes in the ionospheric vertical TEC (Tsurutani et al., 2004). Therefore, the combined effects of wind field, the composition changes and electrodynamics make the ionospheric phenomena rather complex in this region. The complexity is inherent in the fact that several mechanisms may operate together with different relative roles. Another important phenomenon in low latitude ionosphere is the formation of traveling atmospheric disturbances (TADs) in the thermosphere as a result of large amount of energy deposition in high latitudes during geomagnetic storms. These disturbances travel from their origin in high latitudes to low latitudes triggering perturbations in neutral winds on their way. The perturbation in neutral winds, as aforementioned, can then affect the plasma distribution directly and through the wind dynamo effect indirectly, resulting in ionospheric variations. However, the ionospheric wind dynamo is considered as an important and the main mechanism in the production of ionospheric electric currents and fields.

The positive and negative deviations during geomagnetic storms depend on the storm development phase. The large enhancement in foF2 values can be explained by the penetration of strong electric field at low latitudes (Sobral et al., 2001). The critical frequency foF2 at low latitudes were very different in periods when the B_z component turns