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The influence of Corotating Interaction Region (CIR) driven geomagnetic storms on the development of equatorial plasma bubbles (EPBs) over wide range of longitudes

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Abstract

Recurrent high speed solar wind streams from coronal holes on the Sun are more frequent and Geoeffective during the declining phase of solar cycle which interact with the ambient solar wind leading the formation of Corotating Interaction Regions (CIRs) in the interplanetary medium. These CIR-High Speed Stream (HSS) structures of enhanced density and magnetic fields, when they impinge up on the Earth's magnetosphere, can cause recurrent geomagnetic storms in the Geospace environment. In this study, we investigate the influence of two CIR-driven recurrent geomagnetic storms on the equatorial and low-latitude ionosphere in the context of the development of equatorial plasma bubbles over Indian and Asian longitudes. The results consistently indicate that prompt penetration of eastward electric fields into equatorial and low-latitudes under southward IMF Bz can occur even during the CIR-driven storms. Further, the penetration of eastward electric fields augments the evening pre-reversal enhancement and triggers the development of EPBs over wide longitudinal sectors where the local post-sunset hours coincide with the main phase of the storm. Similar results that are consistently observed during both the CIR-driven geomagnetic storms are reported and discussed in this paper.

Keywords: Corotating Interaction Regions (CIRs); Geomagnetic Storms; Equatorial Spread-F (ESF); Equatorial Plasma Bubbles (EPBs)

1. Introduction

Understanding the coupled solar wind–magnetosphere–thermosphere–ionosphere interactions is gained high importance in the recent past because of its complexity and varied impacts on Geospace environment that can affect the astronauts in space, payloads on board the satellites, space based communication and navigational systems as well as ground based power grid systems, etc. Geomagnetic storm is one of the important space weather phenomena and its impact on ionosphere–thermosphere system greatly varies with latitude, altitude, local time, season and the phase of the geomagnetic activity because of various neutral and electro-dynamic interactions are involved. The impact of geomagnetic storms on the equatorial and low-latitude ionosphere, particularly, the post-sunset development of equatorial plasma bubbles (EPBs) is another important space weather topic of interest that drawn great attention. The development/inhibition of post-sunset EPBs during geomagnetic storms is mainly controlled by the perturbations in the zonal electric field at the equator due to variable nature of coupling between high and low latitudes (Fejer et al., 1999; Tulasi Ram et al., 2008). The two prime mechanisms considered as

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responsible for the perturbations in the zonal electric field are prompt penetration electric fields (PPEFs) and ionospheric disturbance dynamo (IDD) processes. The former is due to dynamic interactions between the solar wind and the magnetosphere that leads to changes in the polar cap potential causing prompt penetration of electric fields into low latitudes (Kelley et al., 1979; Fejer and Scherliess, 1997; Kikuchi et al., 1996) giving rise to perturbations in the zonal electric fields. Whereas the later is due to global thermospheric circulation induced by joule heating at auroral latitudes that generates long-lived (several hours) electric field disturbances at mid and low latitudes by ionospheric wind dynamo action (Blanc and Richmond, 1980; Scherliess and Fejer, 1997; Maruyama et al., 2005, 2007; Klimenko and Klimenko, 2012).

The geomagnetic storms, which cause a global decrease of geomagnetic field by few tens to several hundreds of nT, are developed when the large quantities of solar wind plasma injects into Earth's magnetosphere and subsequent enhancement in the ring current. Grossly, the geomagnetic storms can be classified as due to two driving sources, Coronal Mass Ejections (CMEs) and Corotating Interaction Regions (CIRs). The CME is a massive ejection of solar wind particles from the active regions of Sun such as sunspot groups, often associate with solar flares. The massive stream of SW particles transfer the energy and momentum into magnetosphere and subsequent interactions cause intense geomagnetic storms. The CME-driven geomagnetic storms are generally intense and occur predominantly during the high solar activity periods (Vijaya Lekshmi et al., 2011) On the other hand, the CIR storms are weak in intensity and mainly caused by the high speed solar wind streams from the corotating Coronal holes (Lu et al., 2006 and Tsurutani et al., 2006a).

The coronal holes (CHs) are the dark areas on the Sun where the one end of heliographic magnetic fields lines open into interplanetary space, facilitating the SW particles to escape with high velocity (500–800 km/s) known as high speed streams (HSS). In addition to fast streams from CHs, the SW has dense low-speed streams (300–400 km/s) from the closed-field regions near the equator, known as equatorial coronal streamer belt. As the streams travel in the interplanetary space, the fast SW stream from CH encounters with the preceding ambient slow SW stream and an interaction region with enhanced density and magnetic fields is formed in the vicinity of border between the two streams (Tsurutani et al., 1995). A forward and reverse shock may also produce in the preceding slow stream and trailing fast stream, respectively. This structure of interaction corotates with the Sun, hence giving rise to the name Corotating Interaction Regions (CIRs). The classical features of CIRs are well described in literature (Kennel et al., 1985; Tsurutani et al., 1995, 2008). When CIR–HSS structure sweeps across the observing satellite (ACE), both the SW density and magnetic field strengths exhibit a sudden increase at the forward shock. At the stream interface which is the boundary between the slow solar wind and fast stream, the temperature and velocity increase sharply while the SW density exhibits a sharp decrease. Across the reverse shock, the SW density and magnetic field decreases while the velocity further increases or may remain at high levels. These are the typical features that are used to identify the CIR interfaces in the interplanetary solar wind parameters. Further, it should be mentioned here that all the CIR–HSS structures may or may not accompany with the forward and reverse shocks.

Since the CHs have tendency to rigidly rotate with Sun and persist for several solar rotations, the CIR interfaces also repeat for several solar rotations inducing recurrent geomagnetic disturbances at ∼27-day periodicity. When these CIR structures encounter the Earth's magnetosphere, the negative IMF Bz component of the Alfven waves within the HSS causes magnetic reconnection and trigger geomagnetic storms of moderate to weak intensities in the Geospace environment with the same periodicities (Tsurutani et al., 1995). The CIR driven geomagnetic storms are especially prominent during the declining phase of the solar cycle, when the polar CHs becomes large and extend to low latitude regions with tongue like extensions (Sheeley and Harvey, 1981; Richardson, 2004 and Tulasi Ram et al., 2010).

Despite their recurrent occurrence, the CIR-driven storms are only paid less attention in terms of its influence on post sunset equatorial plasma bubbles (EPBs) perhaps due to less-to-moderate levels of geomagnetic activity. In this paper, we investigate influence of two CIR-driven geomagnetic storms that have occurred recurrently on February 11, 2004 and March 9, 2004 on the development of post-sunset equatorial plasma bubbles using ground based and space borne in-situ observations.

2. Data

The interplanetary solar wind and magnetic field parameters measured by Atmospheric Composition Explorer (ACE) satellite at L1-point available through the National Space Science Data Center's OMNIWeb interface (http://nssdc.gsfc.nasa.gov/omniweb/) during the year 2004 were considered to identify the CIR features in this study. The low-latitude geomagnetic activity index, SymH-index is obtained from World Data Center for Geomagnetism, Kyoto University (http://wdc.kugi.kyoto-u.ac.jp/). Two ground based Ionsondes, one (Kel model) located at Indian equatorial station Trivandrum (8.5°N, 76.5°E and 0.7°N dip latitude) and another (DPS-4 model) at low-latitude station Hainan Is, China (19.4°N, 109°E and 13.4°N dip latitude) are examined for the occurrence of Equatorial Spread F (ESF) during the CIR driven geomagnetic storm periods. In order to examine the electric field perturbations, we have considered the Equatorial ElectroJet (EEJ) strength data derived from two ground based magnetometers from Indian network of magnetometers, one at the equatorial station Tirunelveli (8.7°N geog.latitude, 77.8°E geog.longitude and 0.6°N dip.latitude) and another at an