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Unusual noon-time bite-outs in the ionospheric electron density around the anomaly crest locations over the Indian and Brazilian sectors during quiet conditions – A case study

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ABSTRACT

The present case study reports the unusual noon-time electron density bite-out events during 12th–18th April 2004 around the anomaly crest locations which are not observed over the geomagnetic equator. These bite-out events at the crest locations occurred on three consecutive days under solar and geomagnetically quiet conditions over the Indian and Brazilian sectors. The bite-out events are observed with a delay of two days over the Brazilian sector when compared with those in the Indian sector. The duration of these TEC bite-outs is found to vary around 5 h in the Indian sector while it is around 3 h in the Brazilian sector. Over Raipur in the Indian sector, the bite-out is found to be very strong (~30 TECU) on 13th April 2004, where the TEC drops to nearly 50% of the corresponding day maximum TEC. The diurnal variations of dTEC have also shown significant differences during the occurrence of noon-time TEC bite-outs. Simultaneous Equatorial Electrojet (EEJ) variations over the Indian and Brazilian sectors have also been studied. The ionosonde data over the equatorial and anomaly crest locations has been analyzed to understand the F-layer behavior during the occurrence of TEC bite-outs. Significant drop in the F-layer peak density and heights are observed during the TEC bite-outs while the minimum height of the bottom side F-layer do not show considerable differences. Further, the variations of vertical electron density profiles are studied to explain the F-layer characteristics that resulted in the noon-time bite-outs over the anomaly crest locations.

1. Introduction

The Earth's ionosphere consists sufficient number of electrons that can effect the trans-ionospheric radio wave propagation. Ionospheric electron density varies significantly with time, season, latitude, longitude and solar activity. When compared with the high latitudes, the equatorial and low latitude ionosphere exhibits significant short and long term variability due to the presence of the dynamical processes namely the Equatorial Electrojet (EEJ), Equatorial Ionization Anomaly (EIA), Equatorial Spread-F (ESF) etc.,

Equatorial Electrojet is a narrow band of jet-like current flowing at the E-region altitudes during day-time over the dip equator. The magnetic field lines are horizontal over the equator and results in the fountain effect in combination with the perpendicular eastward electric field. Under the fountain effect, the plasma over the equator is lifted to the higher altitudes where the recombination rates are low. Thus uplifted plasma diffuses along the magnetic field lines to form two crests around ±20° on either sides of the equator along with a trough over the equator (Appleton, 1946). This phenomena is known as the EIA, under the presence of which, the electron density increases from equator to the anomaly crest and decreases beyond with large latitudinal gradients. The EIA characteristics vary significantly from one day to the other resulting in the large spatiotemporal variabilities in electron density distribution over the low latitudes. For the past few decades, the EIA phenomena and its consequences are well established and the diurnal, seasonal, latitudinal and solar activity variations of electron density have been investigated by several workers from different parts of the globe (Balan and Bailey, 1995; Abdu et al., 1996; Davies and Hartman, 1997; Mannucci et al., 1998; Rishbeth and Mendillo, 2001; Brunini et al., 2003; Jee et al., 2005; Rama Rao et al., 2006; Yue et al., 2007; Bagiya Mala et al., 2009; Venkatesh et al., 2014).

In addition to aforementioned quite time phenomena, geomagnetically disturbed conditions produce large variabilities in the electron density distribution that could persist for few days. One of the most important disturbed conditions that can cause intense effects on the ionosphere is the geomagnetic storms.

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Geomagnetic storms originate in the solar corona and occur in the entire sun-earth system, including the Earth's upper atmosphere. During the geomagnetic storms, there exists a large and sudden increase in the solar wind speed which disturbs the earth's magnetosphere (Schunk and Sojka, 1996). The ionospheric response during storms is classified as two major types. If the electron density increases as a result of storm dynamics, it is called as 'positive ionospheric storm' and a decrease in electron density is called as 'negative ionospheric storm'. Extensive studies on the effects of positive and negative ionospheric storms have been carried out by several researchers (Rishbeth and Field, 1997; Danilov, 2001; Liu et al., 2004 and references there in). Positive ionospheric storms occur at different locations dependent on the local time, latitude, season, storm phase etc., (Mikhailov et al., 1994; de Abreu et al., 2014). Negative ionospheric storms are generally observed during severe geomagnetic storms (Batista et al., 1991; Sahai et al., 2005; de Jesus et al., 2013).

As it is described above, the ionospheric electron density over the equatorial and low latitude sectors exhibit significant day-to-day and spatiotemporal variability in the presence of the dynamical equatorial phenomena during quite time. During the disturbed conditions, the electron density variations are characterized with sudden and rapid changes lasting for few days. Apart from these usual short and long term characteristics, several unusual phenomenon over the equatorial and low latitude sectors have attracted considerable interest of the ionospheric scientist for the past few decades. One of the most widely investigated unusual ionospheric phenomena is the post-midnight electron density enhancements. Statistical studies on N_mF_2 and TEC night-time enhancements are performed by different scientists (Balan and Rao, 1987; Balan et al., 1991; Su et al., 1994; Prasad et al., 1998; Mikhailov et al., 2000; Luan et al., 2008; Liu et al., 2013; Perna et al., 2014). Post-midnight uplift in the F-layer near the magnetic equator and midnight temperature maxima (MTM) are other unusual phenomenon over the equatorial and low latitudes (Sastri et al., 1994; Fesen, 1996; MacDougall et al., 1998; Nicolls et al., 2006). Typical structures in ionograms have also been reported by different researchers (Calvert and Cohen., 1961; Fagundes et al., 2012). An unusual event of sudden and large increase in post-midnight electron density during August 2007 is studied by Pezzopane et al. (2011) which was named by them as the "impulsive enhancement". Similar type of events during August to 2010 to January 2012 have been investigated by Perna et al. (2014). They reported these enhancements around the crest of the EIA during quiet and medium geomagnetic conditions. Perna et al. (2014) have also reported that during medium-high geomagnetic conditions, the enhancements are seen around the anomaly crest as well as near the equator.

The present study reports the unusual ionospheric features that are quite different from various unusual characteristics described above. The unusual noon-time bite-outs in the electron density over the anomaly crest locations during quiet conditions are reported over the Indian (Northern hemisphere) and Brazilian (Southern hemisphere) sectors. The noon-time bite-outs are observed both in TEC and F-layer peak density. It is interesting in the present study that the bite-outs are observed around the anomaly crest locations while such signatures are not seen over the equator. The noon-time bite-outs at the equatorial and low latitudes have been investigated by several researchers for the past many years (Rao, 1963; Das Gupta et al., 1975; Rajaram and Rastogi, 1977; Rastogi et al., 1979; Radicella and Adeniyi, 1999; Balan and Bailey, 1995; Lee et al., 2008; Mukherjee et al., 2010; Lee and Reinisch, 2012). It has been reported by many researchers that the enhancement of eastward electric field over the geomagnetic equator causes the noon-time bite-outs in electron density over the equatorial latitudes. It has also been reported by some researchers that the bite-outs are present in N_mF_2 while are absent in TEC (Anderson, 1981; Lee, 2012). In the present case study, the bite-out events are quite different from the previous studies since the bite-outs are observed only around the anomaly crest locations with their absence over the geomagnetic equator and the bite outs are seen both in TEC and N_mF_2. These unusual bite-out events over the Indian and Brazilian sectors are studied using the Global Positioning System (GPS) and ionosonde data from different locations and the corresponding results are discussed.

2. Database

The present paper deals with the electron density variations during 12th–18th April 2004 (mean $Rz=45$), a low solar activity period. The GPS-TEC data from different locations covering the equatorial and anomaly crest regions over the Indian and Brazilian sectors are considered. Details of all the stations used for the present study are given in Table 1 along with the geographic co-ordinates and the geomagnetic dip. latitudes. Dual frequency measurements at L_1 (1575.42 MHz) and L_2 (1227.60 MHz) from the GPS receivers at different locations are analyzed to derive the TEC values using the differential delay technique as detailed in Seemala and Valladeres (2011). The GPS-TEC data over the Indian sector (10 min time resolution) is from the network of receivers installed jointly by the Indian Space Research Organization (ISRO) and the Airport Authority of India (AAI) under the Indian GAGAN program for making continuous measurements of TEC and S_4-index. The GPS-TEC data over the Brazilian sector (6 min time resolution) is downloaded from the database of Instituto Brasileiro de Geografia e Estatistica (IBGE) network (http://www.ibge.gov.br/home/geociencias/geodesia/rbmc/rbmc_est.php) except for the station Cachoera Paulista (CHPI). The GPS-TEC data over CHPI is considered from the IGS network and is downloaded from the GSFC NASA website (ftp://cddis.gsfc.nasa.gov/pub/gps/data/daily/). The local time zone in the Indian sector is 'UT+5:30' while it is 'UT-3:00' in the Brazilian sector.

The Equatorial Electrojet (EEJ) variations over the Indian and Brazilian sectors have also been studied during the considered period. Horizontal components of the earth's magnetic field measurements over an equatorial station Tirunelveli and an off equatorial station Alibag in the Indian sector and from an

Table 1
The list of GPS Receivers, magnetometers and ionosonde stations used in the present study along with geographic co-ordinates and geomagnetic dip latitude values.

Station name	Code	Geog. Lat.	Geog. Long.	Dip Lat.
Dual frequency GPS Receiver Locations				
Trivandrum	TRIV	8.4°N	76.9°E	0.3°N
Waltair	WLTR	17.7°N	83.3°E	11.5°N
Mumbai	MUMB	19.1°N	72.8°E	13.7°N
Raipur	RAIP	21.2°N	81.7°E	15.9°N
Lucknow	LUCK	26.7°N	81.7°E	22.7°N
Belem	BELE	1.2°S	311.7°E	1.9°S
Vicosa	VICO	20.5°S	317.4°E	17.7°S
Cachoeira Paulista	CHPI	22.7°S	315.0°E	18.1°S
Presedente Prudente	UEPP	22.7°S	308.6°E	14.9°S
Curitiba	PARA	25.3°S	310.8°E	17.9°S
Magnetometer Locations				
Tirunelveli	TNVL	8.7°N	77.8°E	0.4°N
Alibag	ALBG	18.6°N	72.8°E	13.1°N
Sao Luis	SALU	2.5°S	315.8°E	0.6°S
Vassouras	VSSR	22.4°S	43.6°W	15.3°S
Ionsonde Locations				
Sao Luis	SALU	2.5°S	315.8°E	0.6°S
Sao Jose dos Campos	SJSP	23.1°S	314.5°E	18.1°S
Cachoeira Paulista	CHPI	22.7°S	315.0°E	18.1°S