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Signatures of solar event at middle and low latitudes in the Europe-African sector, during geomagnetic storms, October 2013

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Abstract

This paper presents the variability of the total electron content, VTEC, the ROTI index (proxy of the scintillation index) and the transient variations of the Earth's magnetic field associated to the impacts of solar events during October 2013. The observations are from middle and low latitudes in European African longitude sector. During October 2013, there are four solar events reaching the Earth. The two first events, on October 2 and October 8 are CME, the third event on October 14, is a jet of fast solar wind flowing from a solar coronal hole, and the last event on October 30 is a slow solar wind with southward excursions of the Bz component of the interplanetary magnetic field, associated to CME passing near the Earth. For the four events, the variation of VTEC at middle latitudes is the same and presents an increase of VTEC at the time of the impact followed by a decrease of VTEC, lasting one or several days. At low latitudes, no clear common pattern for all the events appears. For the four events the variation of the ROTI index over Africa is different showing the asymmetry between West and East Africa. For the first event, on October 2, the scintillations are not inhibited, for the second and the fourth events on October 8 and 30, the scintillations are inhibited on East Africa and for the third event (high speed solar wind stream), on October 14, the scintillations are inhibited over the whole Africa. The available data allow the full explanation of the observations of October 14, indeed, on this day, there is no post sunset increase of the virtual height h′F2 at Ascension Island. There is no Pre Reversal Enhancement (PRE) of the eastward electric field; it is this electric field which moves up the F layer, the necessary condition for the existence of scintillation. The analysis of the variations of the Earth's magnetic field at low latitudes highlights the presence of the ionospheric disturbance dynamo on October 14, which produces a decrease of the Equatorial Electrojet, several hours after the impact of the high speed solar wind. The disturbance dynamo electric field (DDEF) is westward during the day and till after sunset and turns eastward around 22.30LT. So, on October 14, the westward DDEF inhibits the eastward regular electric field.

Keywords: Ionosphere; GPS_TEC; CME; Solar wind; Coronal hole; Geomagnetic storm

1. Introduction

In this paper we present the behavior of VTEC, ROTI index, virtual height h′ of the F_2 layer and transient variations of the Earth's magnetic field observed at middle and low latitudes during various solar events (CME, high speed solar wind or event with southward excursion of the Bz

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component of the interplanetary magnetic field, IMF). The data used were recorded in Europe Africa longitude sector.

The equatorial ionosphere presents some morphological particularities: (1) the existence of the equatorial ionization anomaly, EIA (Namba and Maeda, 1939; Appleton, 1946), (2) the existence of an ionospheric electric current flowing along the magnetic equator, the equatorial electrojet (EEJ) (Chapman, 1951) and (3) the existence of irregularities of plasma (Basu and Basu, 1981) which disturb the propagation of the electromagnetic signals and as a consequence disturb the GNSS signals. The electric field is the main parameter of the dynamics of the equatorial region and it strongly influences the development of the EIA as well as the equatorial electrojet and plasma irregularities.

During quiet magnetic periods, the EEJ flows along the magnetic equator. The EEJ is an eastward ionospheric electric current, in the E region, created by the ionospheric dynamo process (Stewart, 1882; Chapman and Bartels, 1940). Its amplitude is 2 times higher than the amplitude of the regular ionospheric currents at middle latitudes (Mazaudier and Blanc, 1982) which generates the Sq variation. The stronger amplitude of the EEJ is due to the existence of a reinforced conductivity at the equator, the conductivity of Cowling. The Cowling conductivity is the combination of Hall and Pedersen conductivities, but the EEJ is mainly an Eastward Hall current (Forbes, 1981; Onwumechili, 1997).

Also, during magnetic quiet periods the regular electric field is generated by the ionospheric dynamo. During the daytime the east–west electric field and the north–south geomagnetic field produce the lift of plasma in E ionospheric region by vertical E X B drift. At higher altitudes in F region, the plasma diffuses downward along the geomagnetic field lines into both hemispheres under the influence of gravity and pressure gradients, this produces the EIA which is characterized by an electron density trough at the magnetic equator, and two crests of enhanced electron density at about $\pm 15°$ magnetic latitudes.

Another important phenomenon of the equatorial ionosphere is the existence of an increase in the zonal electric field post sunset, the prereversal enhancement (PRE) which causes a strong upward vertical drift (Vz), and a rapid rise up of the F layer. This fact leads to the creation of irregularities in the plasma density (Kelley et al., 2009). The first observations of this large upward vertical drift were made by Woodman (1970) with the incoherent scatter sounder of Jicamarca. Depending on the scale size irregularities, different observations are made, "*the meter scale size irregularities producing plumes in the VHF backscatter radar maps, the decameter sizes that give rise to the spread F echoes in the ionograms, and the hectometer to kilometer sizes produce VHF and UHF radio wave scintillation (Abdu et al., 1983)*". Recently, Chatterjee and Chakraborty (2013) and Chatterjee et al. (2014) studied the scintillations near the crest of the EIA in India, during quiet magnetic days; in their work, they connected EIA, EEJ and scintillations. They found that a post sunset enhancement of the TEC and afternoon enhancement in EEJ are good precursors for postsunset occurrence of scintillation.

During magnetic disturbed periods, the equatorial ionosphere is strongly influenced by auroral phenomena and as a consequence the equatorial electric field is disturbed. Two main disturbance processes are well known (1) the prompt penetration of the magnetospheric electric field, PPEF (Vasyliunas, 1970; Fejer et al., 1983; Mazaudier et al., 1984; Mazaudier,1985) and (2) the disturbance dynamo electric field, DDEF (Blanc and Richmond, 1980; Fejer et al., 1983; Sastri, 1988; Mazaudier and Venkateswaran, 1990), related mainly to the Joule heating produced by auroral electrojets (Testud et al., 1975). The PPEF and DDEF disturb the ionospheric electric currents systems and as a consequence produce magnetic disturbance observed with ground magnetometers. The magnetic disturbance associated to the PPEF is the DP_2 (Nishida et al., 1966; Nishida, 1968) and the one associated to the DDEF is the Ionospheric disturbance Dynamo, D_{dyn} (Mayaud, 1980; Fambitakoye et al., 1990; Le Huy and Amory-Mazaudier 2005). The main features of the magnetic disturbance associated to the DDEF are an anti Sq circulation at low latitude and a reverse electrojet at equatorial latitudes. Theoretical studies of D_{dyn} (Blanc and Richmond, 1980; Fang et al., 2008; Zaka et al., 2010a,b) reproduced the anti Sq circulation and a reverse EEJ.

In this paper we analyzed the crucial parameters necessary to understand the impact of solar events on Equatorial ionosphere, VTEC, the ROTI index as a proxy of scintillation, the virtual height h′ of the F2 in order to know the existence or non existence of PRE of the vertical drift, and the transient variations of the Earth's magnetic field in order to know the presence or not of the PPEF and DDEF.

The second part of the paper is devoted to the data sample and data processing, the third part presents the results, and then there are the discussion and the conclusion.

2. Data sources and data processing

2.1. Data sources

We analyze the signature of solar events on ionospheric ionization and Earth's magnetic field during October 2013.

The satellite data from SOHO are used to determine the existence of CME and coronal hole recorded at the surface of the sun www.nasa.gov/mission_pages/soho/, and some informations from the space weather website http://spaceweather.com to determine the solar events reaching the Earth. The solar wind speed and Bz component of the interplanetary magnetic field (IMF) recorded on board the satellite ACE (http://omniweb.gsfc.nasa.gov/) are used to characterize the solar wind.

The magnetic indices SSC, Hsym, AU, AL, AE, Kp and Am/km are extracted from Data Analysis International Union of Geodesy and Geophysics (IUGG) website