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Storm-time characteristics of the equatorial ionization anomaly in the East African sector

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Abstract

The equatorial ionization anomaly (EIA), inferred from the electron density profile, was used to study the ionospheric effect of 11 March 2011, 06 April 2011, 09 March 2012 and 01 October 2012 geomagnetic storms in the East African sector. The electron density profile was reconstructed from slant total electron content (sTEC) measurements using statistical linear inversion method. The sTEC measurements were recorded by a chain of ten ground-based GPS receivers deployed in the East African region in the latitude range of 6° S–20° N GeoLat (15.29° S–10.62° N geomagnetic latitude). The analysis of the effect of the storms on the EIA has demonstrated that the effect could be positive or negative. The sudden positive effects of the EIA, in terms of increasing the peak and widening the width, during storm events of 06 April 2011, 09 March 2012 and 01 October 2012 were observed dominantly due to prompt penetration electric fields to the magnetic equator, which were caused by a southward turning of the interplanetary magnetic field (B_z). The prolonged effects after the onset of the storm were attributed to disturbance dynamo electric field due to the storm-time neutral wind circulation. The depletion on the electron density profile during 11 March 2011 storm was due to a decrease in [O] to $[N_2]$ ratio in the thermosphere composition.

Keywords: Geomagnetic storm; sTEC; EIA

1. Introduction

The variability of the upper atmosphere can be described by the changes observed on both thermosphere and ionospheric parameters. Parameters such as the thermosphere neutral wind, neutral composition and ionospheric electric field depart from their normal patterns during magnetic storms. That means, they show different properties during magnetically quiet and disturbed conditions. The storm-related changes in these parameters can significantly affect the low latitude ionosphere phenomena including the equatorial ionization anomaly (EIA) (Kelley, 2009).

The EIA has two crests on both sides of the magnetic equator. These crests are formed by so called equatorial plasma fountain. The plasma fountain is an upward $\mathbf{E} \times \mathbf{B}$ drift force that pushes the plasma to higher altitudes, which then followed by a downward diffusion of plasma along the magnetic field lines to higher latitudes. The zonal electric field (**E**), which plays a great role in the upward drift of the plasma, has different characteristics and its storm time behaviors have attracted various researchers's

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attention (for example see Pedatella et al. (2006) and Guozhu et al. (2007)).

The strength and orientation of the zonal electric field would affect the plasma fountain, the EIA structure as well as the EIA's peak. In the presence of magnetic storms, the storm-related zonal electric fields may reduce or enhance the daytime eastward electric fields and thus result in a weaker or a stronger plasma fountain, respectively. The storm-related electric field can be resulted either from a short-lived prompt penetration electric field (PPEF) due to solar wind-magnetospheric coupling or from disturbed dynamo (DD) electric field. The PPEF is eastward in daytime and westward at night with the same orientation as the quiet time zonal electric field and has a life span of less than 2 h. In contrast, the DD electric field has an opposite polarity with the quiet time zonal electric field, usually observed several hours after the storm onset and persisting for several hours to more than a day. The DD electric field is driven by the storm-time changes in the global wind circulation in polar regions (e.g., Chien et al. (2000), Fejer and Scherliess (1995), Hanumath et al. (2002)).

In addition to the above mentioned storm-time electric fields, the disturbed thermospheric equator-ward neutral wind, that can transport the plasma from one hemisphere to the other depending on its magnitude and direction, can affect the low latitude ionosphere. Storm time continuous energy input in the high latitude ionosphere–thermosphere coupling system causes a rapid expansion of neutral atmosphere. This expansion may affect global distribution of [O] to $[N_2]$ ratio. Such disturbance in the neutral composition also affects the EIA positively by increasing the plasma density or negatively by decreasing the plasma density in accordance with the relative change of [O] to $[N_2]$ ratio distribution. The storm related change of [O] to $[N_2]$ ratio in succession affects the ionization process (Liiz et al., 2007; Sharma et al., 2011; Rakhee et al., 2010).

Hanumath et al. (2002) analyzed the severe magnetic storm of July 15, 2000. An impulsive and remarkably large downward motion of the F region occurred simultaneously at locations throughout the equatorial region in the Indian sector, in close association with a rapid ring current intensification. The abnormal midnight descent of equatorial F region indicative of a short-lived westward electric field disturbance is interpreted as the signature of prompt penetration electric fields associated primarily with impulsive ring current injections. The westward electric field disturbance in the Indian (midnight) sector occurred. The prompt electric field penetration to the magnetic equator both in the dusk and midnight sectors occurred in an environment already under the influence of ionospheric disturbance dynamo electric fields, illustrating the profound manner in which the equatorial F region plasma dynamics can get modified globally during the main phase of severe magnetic storms.

A report on the responses of the EIA during October–November 2003 super storms, in different Asian and Australia regions, is compiled by Zhao et al. (2005) using multi measurement techniques. They found that under strong disturbances the EIA was developed significantly due to penetration electric fields. Besides, there was a long lasting suppression of the EIA development due to equator-ward wind circulation that opposed to the poleward transport of ionization along the magnetic field lines. This in effect prevented the formation of the EIA and resulted in negative storm effects in the anomaly crest regions and positive storm effects near the equator.

The EIA responses during magnetic storms are extensively studied in the American and Asian longitude sectors. However, because of sparse distributions of ionosonde and other instruments that can be used in studying the ionosphere in the African sector, there is no adequate investigations on the EIA responses during storm events in that sector. Recently, because of the deployment of ground-based GPS receivers, the EIA-related investigations using GPS measurements can be carried out over the African continent as well. The main motivation of the current study is to capture the main storm-time characteristics of the EIA over Africa. This work will contribute to the comprehensive effort by the Washera Geospace and Radar Science Laboratory of the Bahir Dar University to develop a regional ionospheric specification system for East Africa. We have investigated the response of EIA over the African region to the magnetic storms of 11 March 2011, 06 April 2011, 09 March 2012 and 01 October 2012 by ionospheric tomography.

2. Instruments and data analysis

Ionospheric response to a particular geomagnetic storm can be inferred from its effect on ionospheric parameters and phenomena such as electron density, height of maximum electron density (hmF2), Equatorial ElectroJet (EEJ) and EIA (e.g., Liang et al. (2008)). In this study we have used the electron density profile as an indicator for the response of the ionosphere. The electron density profile is inverted from the sTEC data that we obtained from a chain of ten ground-based GPS receivers, (see Fig. 1), deployed in the latitude range of 6° S–20° N geographic latitude (15.29° S–10.62° N geomagnetic latitude) in the East African longitude. The sTEC measurements were obtained from the UNAVCO database (http://www.unavco.org/) and we used the data with elevation angle $\geqslant 45°$ from all PRNs available during the observations (Rama Rao et al., 2006). In the extraction of sTEC from GPS observables we have used dual frequency receivers since their calibration process minimizes ionospheric errors, which are the major source of error in GPS positioning (Klobuchar et al., 1996). As part of the calibration process, the sTEC measurements were corrected for the receiver and satellite biases using the method reported by Ciraolo et al. (2007). A statistical linear inversion of the electron density from sTEC using Bayesian statistical theory is carried out to obtain a maximum of a posterior estimate (MAP). We have presented the details on the