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Investigation of TEC variations over the magnetic equatorial and equatorial anomaly regions of the African sector

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Abstract

This paper presents the annual, seasonal and diurnal variations in ionospheric TEC along the African equatorial region. The study also investigated the effects of a geomagnetic storm on ionospheric TEC values. Dual-frequency GPS derived TEC data obtained from four stations within the African equatorial region for the high solar activity year 2012 were used in this study. Annual variations showed TEC having two peaks in the equinoctial months, while minima values were observed in the summer and winter solstices. The diurnal pattern showed a pre-dawn minimum, a steady increase from about sunrise to an afternoon maximum and then a gradual fall after sunset to attain a minimum just before sunrise. Nighttime enhancements of TEC were observed mostly in the equinoctial months. There was comparably higher percentage TEC variability during nighttime than daytime and highest during equinoxes, moderate in winter and least during summer solstice. TEC was observed to exhibit a good correlation with geomagnetic storm indices.

Keywords: Total electron content; Equatorial anomaly; Magnetic equatorial; Geomagnetic storm

1. Introduction

The Earth's atmosphere contains free charged particles within an altitude range of about 60–1000 km above the Earth's surface (Goodman, 2005). These charged particles are generated by the process of photoionization. Photoionization occurs when short wavelength solar radiations such as X-rays and UV radiations interact with and knock-off electrons from the shells of neutral particles lingering in the upper atmosphere. This leaves behind a partially ionized region called the ionosphere (Memarzadeh, 2009). The presence of these free charged particles within the Earth's ionosphere pose severe effects on radio signals traveling through this medium, causing effects such as range errors, scintillations, Faraday rotation, absorption, ionospheric Doppler shift, refraction and waveform distortion of the signals (Doherty, 2010). The magnitude of these ionospheric effects on satellite communication, satellite tracking and navigational control application are directly proportional to the total electron content (TEC) (Bagiya et al., 2009). TEC is the most dominant ionospheric component that affects GPS signal propagations (Seemala and Delay, 2010). TEC is defined as a measure of the total number of electrons in a unit area along the line of sight of GPS signal from space satellite to ground receiver (Bhuyan and Borah, 2007). Ionospheric TEC values exhibit significant variations with solar cycle, season, local time, altitude, latitude, longitude and geomagnetic activity (Sardar et al., 2012).

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The Earth's ionosphere along the equatorial (low latitude) region is quite unique and different from that at the mid and high latitudes (Chakraborty and Hajra, 2009). This is because the low latitude ionospheric F-region is dominated by a phenomenon called equatorial ionization anomaly (EIA), which is characterized by an electron density trough region around the magnetic equator, and a dual band of enhanced electron density (crest regions) at about 15° north and south of the trough as shown in Fig. 1 (Schunk and Nagy, 2000). The EIA is formed as a result of the diurnal variation of the zonal electric field, which primarily points eastward during the day and reverses at night. In conjunction with the horizontal northward geomagnetic field at equatorial latitudes, the ionospheric plasma is lifted upward by vertical $E \times B$ drift (Stolle et al., 2008).

Once the plasma is transported to higher altitudes, it diffuses downward along the geomagnetic field lines into both hemispheres due to gravitational and pressure gradient forces (Goodman, 2005). This combination of electromagnetic drift and diffusion produces a fountain like pattern of plasma motion called the equatorial fountain effect, leaving region around the magnetic equator with little electron density concentration and higher electron density concentrations at the crests or equatorial anomaly regions (Schunk and Nagy, 2000). This implies that ionospheric effects are higher around the equatorial crests than at the trough region or magnetic equator. However, the latitudes of the anomaly crests and strength of the anomaly vary with condition of the day, season of the year and solar activity (Chakraborty and Hajra, 2009).

Variations in TEC along magnetic equatorial and equatorial anomaly regions have been more extensively studied in Asia (e.g. DasGupta et al., 2007; Liu and Chen, 2009; Walker et al., 1994; Tsai et al., 2001; Zhang et al., 2009; and Bagiya et al., 2009 etc) and South America (e.g. Natali and Meza, 2011; Walker et al., 1994; de Abreu et al., 2014; Sahai et al., 2007) than in Africa. These studies indicate that equatorial anomaly regions manifest remarkable diurnal and seasonal TEC variations, with TEC on both northern and southern equatorial anomaly crests yielding maxima values during the equinoctial months. In

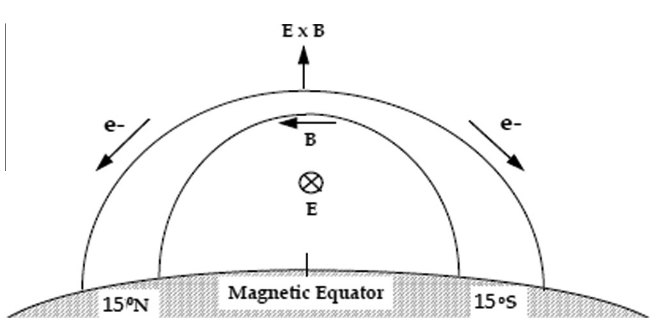

Fig. 1. Illustration of the equatorial fountain effect which gives rise to the equatorial anomaly. E and B represent the electric and magnetic field vectors respectively.

Africa, limited studies (e.g. Fayose et al., 2012; Adewale et al., 2011; Ouattara and Fleury, 2011; Okonkwo and Ugwuanyi, 2012; Zoundi et al., 2012; D'ujanga et al., 2012; Oron et al., 2013 etc) were carried out to understand its ionospheric phenomena and irregularities showed a significant diurnal and seasonal TEC variations. The highest day-to-day TEC values were observed around 18:00 UT and highest seasonal values exhibited during equinoctial months, moderate in the summer solstice and least in the winter solstice. Much as these studies were conducted, there is still need for further studies to investigate the diurnal and seasonal variations of TEC as well as the effects of varying geomagnetic activities on TEC within the region.

In this study, the annual, seasonal and diurnal variations in ionospheric TEC values along the African equatorial region for the high solar activity year 2012 were investigated using dual-frequency GPS derived data obtained from four stations. These stations include; Addis Ababa (Ethiopia), Malindi (Kenya), Lusaka (Zambia), and Kampala (Uganda). The study also investigated the effects of a geomagnetic storm on ionospheric TEC values for the same period. Details of the stations and data used are further discussed in the following section.

2. Data and methods of analysis

The data used in this study were obtained from operational Scintillation Network Decision Aid (SCINDA) and International GNSS Services (IGS) GPS receiver stations located within the region of interest. These stations are Addis Ababa (Ethiopia), Malindi (Kenya), Kampala (Uganda), and Lusaka (Zambia). The codes ADIS, MAL2, KAMP and ZAMB were used to respectively represent the stations. The coordinates of these stations are given in Table 1. Fig. 2 shows a map of Africa indicating the geographic locations of the GPS receivers.

The IGS data were obtained using Scripps Orbit and Permanent Array Center (SOPAC) website (http://www.sopac.ucsd.edu) while SCINDA data was obtained from a dual frequency NovAtel GPS receiver installed in Kampala by the US Air Force Research Laboratory (AFRL) at the Department of Physics, Makerere University. Solar F10.7 flux data was obtained from the Earth Orientation Parameters and Space Weather (website: http://celestrak.com/spacedata/). The Dst and Kp indices were obtained from the website http://swdcwww.kugi.kyoto-u.ac.jp.

GPS data obtained from the stations are available in a zipped Receiver INdependent EXchange Format (RINEX) files (Hofmann-Wellenhof et al., 1997). The RINEX observation files obtained from these stations were processed by the Gopi GPS–TEC analysis application software, version 2.2 (Gopi, 2010). This software calculates and removes satellite and receiver biases from Differential Code Bias (DCB) IGS code files and calculates the inter-channel biases for different satellites in the receiver.