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Total electron content variations in equatorial anomaly region

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Abstract

Diurnal variations in the total electron content (TEC) at Makerere University (00°19′N, 32°40′E, Geo Dip −22°), Uganda, have been investigated using a NovAtel GSV400B GPS receiver for the year 2010. The highest TEC values occurred from 13h00 to 17h00 local time (LT) throughout the year, with the highest values being exhibited during equinoctial months. In addition, there was some correlation between this high TEC and the moderate storms that occurred in 2010. These high TEC values have been attributed to the solar EUV ionization coupled with the upward vertical ExB drift. Nighttime enhancements were also found to be seasonally dependant, attaining maximum values during equinoctial months. These results were also compared with modeled TEC values by the IRI-2007 model. The modeled values were in good agreement with the measured values except for these two points: (1) the model had a short-fall in predicting the nighttime enhancements; and (2) the model's minimum TEC did not coincide with the measured minimum in most of the months. Observed TEC depletions were found to correlate with an increase in the S_4 index and have been identified as a manifestation of the plasma density depletions of the equatorial origin.

Keywords: Total electron content (TEC); TEC depletions; Equatorial plasma bubbles

1. Introduction

The Sun emits highly conducting plasma at supersonic speeds, which can be well over 1000 kms^{-1}, into the interplanetary space as a result of corona mass ejections and solar flares (Gopalswamy et al., 2002). Some of these solar eruptions can have energies that are greater than 10 MeV proton and ion intensities (Kahler, 1994).

The emitted plasma moves with the interplanetary magnetic field, causing the solar wind to expand with the solar magnetic field and is for the most part deflected around the Earth when the solar wind hits the Earth's magnetic field. In actual fact, the Earth is protected from the solar wind by its magnetic shield called the magnetosphere. However, some of the particles get to gyrate about the field lines from North to South back and forth and due to incomplete containment in the magnetic bottle, some particles leak into the Earth's lower atmosphere at the poles. This leads to an observed glow at the poles known as aurora. The leakage of these particles into the Earth's atmosphere can cause disturbances in the ionosphere as well as geomagnetic storms which are some of the manifestations of Space Weather. Space Weather refers to conditions on the Sun and in the solar wind, magnetosphere, ionosphere, and thermosphere that can influence the performance and reliability of space-borne and ground-based technological systems, and can endanger human life or health.

Ionospheric scintillations occur when the GPS signal travels through small scale irregularities in electron density in the ionosphere, typically in the evening and night time especially in the equatorial region (Wong, 2009). Associated with irregularities that produce scintillation effects are large plasma depletions in the ionospheric range delay that may severely limit the operations of systems such as

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the GNSS. Ionospheric scintillation is the rapid fluctuation of a signal as it passes through the ionospheric region that is embedded with plasma density irregularities. Research using GPS satellites has revealed occurrence of UHF scintillations and fluctuations in the total electron content (TEC) in the equatorial region around ±15° magnetic latitude. This region is also known as the equatorial anomaly region or the Appleton anomaly (Doherty, 2009; Paznukhov et al., 2011; Dashora and Pandey, 2005). The equatorial anomaly occurs when vertical drift velocities lift the F-region plasma to higher altitudes over the equator. Pressure gradients and gravity force the heightened plasma downwards along magnetic field lines, leading to highly variable drift velocities.

The plasma density irregularities which encompass a wide range of scale sizes (from a few cm to a few hundred km) are referred to as the Equatorial spread F (ESF). Plasma depletions, commonly referred to as equatorial plasma bubbles (EPB), are the irregularities of the largest scale sizes (up to a hundred km) that are associated with the ESF in which the plasma density can be lowered up to three orders of magnitude compared to the background (Dashora and Pandey, 2005). Dabas et al. (2003) used VHF scintillations to detect the growth of equatorial plasma bubbles and the associated ionospheric irregularities. The presence of plasma irregularities within these depletions disrupts satellite communication by scattering radio signals that pass through them.

Due to the lack of long-term, dependable ionospheric measurements in Africa, the dynamics of African ionosphere has not been properly characterized. With GPS ground based stations now available within equatorial Africa, scientists now have an opportunity to characterize the ionospheric behavior over equatorial Africa. An initial report giving results towards the establishment of the climatology of ionospheric irregularities over Africa has been documented (Paznukhov et al., 2011).

A SCINDA GPS receiver was installed at the Department of Physics, Makerere University in Kampala, Uganda, during late 2009. Makerere University is located (00°19′N, 32°40′E, Geomagnetic Dip −22° at the geographic equator, in the Lake Victoria zone. Its location at the Equator has generated interest to measure the UHF scintillations and TEC measurements at this station. In this study we present results of the diurnal and seasonal variation of TEC and relate the GPS scintillations to the occurrence of EPBs during 2010. The results have been compared with those modeled by the International Reference Ionosphere (IRI) model, IRI-2007, for the validation of the model's prediction of TEC over the station.

2. Experimental details

GPS scintillations and total electron content (TEC) have been measured using a high data-rate NovAtel GSV400B GPS receiver situated at Makerere University, Kampala. It is a real-time GPS data acquisition and ionospheric analysis system for SCINDA, and computes ionospheric parameters S_4 and TEC using the full temporal resolution of the receiver. The TEC is computed from the combined L1 (1,575 MHz) and L2 (1,228 MHz) pseudo ranges and carrier phase. The equipment is suited for studying several parameters simultaneously, but this study will focus on the S_4 index and TEC measurements.

A statistical measure of the intensity of amplitude scintillations is given by S_4, which is the fractional fluctuation of the signal due to ionospheric modulation. The scintillation index, S_4, is given by:

$$S_4 = \frac{\sqrt{\langle I^2 \rangle - \langle I^2 \rangle}}{\langle I \rangle}, \tag{1}$$

where I is the intensity of the signal. The ionospheric statistics are obtained by the following constants: (S_4, TEC_P, TEC_φ), where TEC_P is the differential pseudorange, and TEC_φ, the differential carrier phase, all given in TEC units.

The total electron content (TEC), is defined as the number of electrons in a column of 1 m^2 cross-section, from the height of the GPS satellite (~20,000 km) to the receiver on the ground (Radicella, 2009), where *1 TEC unit* = 10^{16} electrons/m^2. When the TEC varies, the phase and group velocities of signals from the satellites are affected (Doherty, 2009). Estimation of the absolute TEC using GPS involves two steps: the leveling the phases to pseudorange gives the relative TEC, given by:

$$TEC_R = TEC\phi + < TECR - TEC\phi > \tag{2}$$

and the estimation or removal of instrumental biases (calibration) gives the absolute TEC given by:

$$TEC = TEC_R - (b_R + b_S), \tag{3}$$

where b_R and b_S are the receiver/station bias and satellite bias, respectively (Groves and Carrano, 2009).

The total electron content analysis has been carried out using the Gopi GPS-TEC analysis application software, version 1.45 (Gopi, 2010). The program gives plots of vertical TEC on the screen and writes ASCII output files which are used for further analysis of the data. Results presented here show the diurnal variation of TEC and the nighttime TEC depletions measured by the dual frequency GPS receiver stationed at the equator during 2010.

3. The IRI-2007 model

The International Reference Ionosphere, IRI, is an international empirical standard model for the specification of ionospheric parameters, and can provide average values of electron density, electron content, electron and ion temperature, and ion composition as a function of height, location, local time, and sunspot number for magnetically quiet conditions. Details of the model can be obtained at http://IRI.gsfc.nasa.gov. The IRI model has evolved over time and improvements have been made through the ingestion of all worldwide available data