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Variations of total electron content in the equatorial anomaly region in Thailand

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Abstract

This paper presents the first results of total electron content (TEC), derived by analyzing dual frequency Novatel GSV4004 GPS receiver's data which were installed by the SCINDA project, located at the Asian Institute of Technology, Bangkok (AITB, 14.079N, 100.612E) and Chiang Mai University, Chiang Mai (CHGM, 18.480N, 98.570E) with magnetic latitude of 4.13°N and 8.61°N respectively in Thailand, for the year 2011. These two stations are separated by 657 km in the equatorial anomaly region. The highest TEC values occurred from 1500 to 1900 LT throughout the study period. The diurnal, monthly and seasonal GPS-TEC have been plotted and analyzed. The diurnal peaks in GPS-TEC is observed to be maximum during equinoctial months (March, April, September and October) and minimum in solstice months (January, February, June, July and December). These high TEC values have been attributed to the solar extreme ultra-violet ionization coupled with the upward vertical $E \times B$ drift. A comparison of both station's TEC has been carried out and found that CHGM station experiences higher values of TEC than AITB station, due to formation of ionization crest over the CHGM station. Also, TEC values have shown increasing trend due to approaching solar maximum. These results from both stations were also compared with the TEC derived from the International Reference Ionosphere's (IRI) recently released, IRI-2012 model. Results have shown positive correlation with IRI-2012 model. Although, IRI-model does not show any response to geomagnetic activity, the IRI model normally remains smooth and underestimates TEC during a storm.

Keywords: Equatorial ionization anomaly (EIA); GPS-TEC; IRI-2012; GPS SCINDA

1. Introduction

The equatorial and low latitude ionosphere is always of a keen interest to many researchers across the world, because of its unique features, exhibited in its electron density and temperature. The equatorial ionization anomaly (EIA), the plasma fountain and the equatorial electrojet among others are topic of common interests in the investigation of the equatorial and low latitude ionosphere. The geomagnetic field lines being horizontally orientated at the equator and the shift between the geomagnetic and geographic equator is understood to be reason behind these observed features and their longitudinal variations. EIA is characterized by trough at the geomagnetic equator and two peaks (ionization crests) on either side of the equator at about 15° magnetic latitudes (Appleton, 1946). Mitra (1946) suggested that the trough exists because plasma produced by photo ionization at great heights over the geomagnetic equator diffuses downwards and outwards on either side of the geomagnetic equator. This causes the depletion at the geomagnetic equator and formation of ionization crests. Martyn (1947) has briefed that the mutually perpendicular east–west electric field and north–south geomagnetic field give rise to an upward electrodynamic ($\mathbf{E} \times \mathbf{B}$ [E being the eastward electric field and $\boldsymbol{B}$

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being the northward magnetic field intensity]) drift of plasma during the daytime. As the plasma is lifted to greater heights, it diffuses along geomagnetic field lines towards north and south of the magnetic equator at higher latitudes under the influence of gravity and pressure gradients and produces the equatorial ionization anomaly. The ionization crests in both hemispheres occur at lower altitudes and become weaker with height. The intensity of the anomaly can be determined by the ratio of the electron density at the crest-to-trough. The crest-to-trough ratio is highest near the altitude of the F2 region peak and declines both upward and downward. The crest-to-trough ratio and the latitudinal location of the anomaly crests vary with the space weather activities (Su et al., 1995). The EIA is also asymmetric about the magnetic equator caused by field aligned plasma flow due to neutral winds (Balan, 1995).

Global Positioning System (GPS) observations by dual frequency receivers can be utilized to calculate the estimates of GPS derived ionospheric total electron content (GPS TEC).GPS-TEC is considered as an essential parameter for characterizing ionosphere and has been recommended as an input in assimilative models of the ionosphere (Misra and Enge, 2006). The expansion and variation of the EIA in electron density is reflected in TEC as the F region forms the largest part of TEC. TEC is a measure of the total number of electrons in a cylinder with a cross section of 1 m^2 centered on the line of sight from the transmitter on a satellite to a terrestrial receiver (Bhuyan and Borah, 2007). The dispersive medium of the ionosphere causes a frequency-dependent time delay and phase shift on radio waves passing through it. The relative ionospheric delay of the signal is proportional to the total electron content along the ray path (Theodore and Paul, 1999). The GPS TEC measured along the line of sight of the GPS satellite signal, termed as the slant TEC, is then transformed to the vertical TEC at the Ionospheric Pierce Point (IPP) i.e., the points where the ray paths intersect the shell model of the ionosphere. To characterize TEC over a given GPS station, Vertical TEC (VTEC) is considered as a robust parameter. The TEC is a good indicator of the geographical distribution of the ionosphere's ionization. The TEC data being continuous, can be used to understand long term characteristics and the variations of the ionosphere on a broad range of timescales: diurnal, daily, seasonal, annual, solar cycle and long term (Luhr and Xiong, 2010; Xu et al., 2012). In the last decade, many researchers have studied on the diurnal, seasonal and annual variations of TEC in low-latitude region (Arunpold et al., 2014; Chauhan and Singh, 2010; da Costa et al., 2004; Ezquer et al., 2004; Rama Rao et al., 2006; Xu et al., 2012). Many others offered comparison results of the measured TEC data obtained from different resources at various geographic locations with various models, such as the IRI models (Bilitza et al., 1998; Jakowski et al., 1998; Ezquer et al., 1998, 2004; Huang and Reinisch, 2001; Jodogne et al., 2004; Mosert et al., 2004).

2. Data utilized and method of analysis

2.1. GPS TEC data

This work covers the period of 2011, the year of increasing solar activity. The data used have been recorded by a Novatel GPS receiver (model GSV 4004B) installed by the SCINDA project in Asian Institute of Technology, (AIT, 14.079N, 100.612E) and Chiang Mai University, (CHGM, 18.480N, 98.570E), Thailand. The Air Force Research Laboratory of USA has established Scintillation Network and Decision Aid (SCINDA), as a set-up of ground based stations that monitor trans-ionospheric signals at the VHF and L Band frequencies. The main purpose of SCINDA is to serve as regional specification and short term forecasts of scintillation occurring onto VHF and L Band frequencies i.e., especially on communication and navigation signals. The SCINDA ground stations are generally positioned between the ionization crests of the Appleton anomaly, as these locations experience the strongest global levels of scintillation (Carrano, 2007).

Total electron content (TEC), is one of the most important parameters used in the study of the characteristics of the ionosphere and is defined as the integral of the electron number density along the signal path from a satellite to a receiver (Carrano and Groves, 2006), where 1 TECU unit = 1016 electrons/m2. TEC is computed from the combined L1 (1575 MHz) and L2 (1228 MHz) pseudo ranges and carrier phase of GPS signal. The phase and group velocities of the signals from satellites are affected as TEC varies. The GPS-SCINDA software calculates relative TEC (TEC_R) as well as the differential pseudorange and differential phase along with other ionospheric statistics that can be utilized to retrieve more accurate TEC in post-processing. The relative TEC measurement calculated by SCINDA software are based on every 60 s averages of the differential pseudo-ranges (DPR) and differential carrier phase (DCP). The DPR is leveled to the DCP using all the data for each continuous phase arc:

$$TEC_R = DCP + (DPR - DCP)_{ARC} \tag{i}$$

After processing the relative TEC, the calibrated TEC is obtained by subtraction of the satellite BS and receiver BR differential code biases (DCB) from the relative TEC as follows:

$$TEC = TEC_R - A(B_R - B_S) \tag{ii}$$

where A is a constant which is equivalent to 2.854 TECU/ns. Using the single layer approximation for the ionosphere, the calibrated slant TEC is then transformed to vertical TEC as follows:

$$TEC_v(B_R) = [TEC_R - A(B_R - B_S)]/M(\epsilon, h) \tag{iii}$$

where $M(\varepsilon, h)$ is the single layer mapping function of the ionosphere, which is defined as