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Assessment of ionosphere models at Banting: Performance of IRI-2007, IRI-2012 and NeQuick 2 models during the ascending phase of Solar Cycle 24

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Abstract

The International Reference Ionosphere (IRI) and the NeQuick models have been recognised as the international standard for specifying Earth's ionospheric parameters. However, the performance of these ionosphere models needs to be validated due to data scarcity from South-East Asian region for model development. This work presents the performance evaluation of IRI-2007, IRI-2012 and NeQuick 2 in estimating ionospheric Total Electron Content (TEC) at Banting (Geographic: 2.78°N, 101.51°E; Geomagnetic: 7.11°S, 173.77°E). For this purpose, TEC values estimated from these models have been compared with TEC values derived from dual-frequency Global Positioning System (GPS) data for the year 2011 (ascending phase of Solar Cycle 24). The results show that equatorial TEC exhibits semi-annual, annual, and seasonal variations with maximum values appearing during equinoctial months and minimum during solstitial months. Generally, ionospheric TEC produced by IRI and NeQuick 2 models are in good agreement with observed TEC. For diurnal variation, the IRI-2007 and NeQuick 2 models show good agreement during post-noon and post-midnight, respectively. Good correlation is observed during noon-time for all models. Disagreements between ionospheric models and observed TEC are found during post-sunset and post-midnight periods, with TEC deviation in the level of 11–14 TECU can be anticipated at 95% probability. On the other hand, TEC calculation from IRI-2012 is better than IRI-2007 and NeQuick 2 for monthly variation. All models score correlation coefficient above 0.9 with the highest correlation noticed during solstitial months. TEC deviation above 10 and up to 15 TECU can be expected in October with 95% probability. Overall, this work reveals that IRI and NeQuick 2 models are capable of predicting TEC with good correlation in most cases.

Keywords: Equatorial ionosphere; Total Electron Content; IRI-2007; IRI-2012; NeQuick 2; GPS

1. Introduction

The equatorial and low latitude ionospheres show unique characteristics such as Equatorial Ionization Anomaly (EIA), plasma bubbles, and Pre-Reversal Enhancement (PRE). These features are strongly affected by several highly variable electrodynamic processes. In the equatorial and low-latitude ionosphere, where the magnetic field is horizontal, the EIA phenomenon (Appleton, 1946) is attributed to the equatorial plasma being lifted by upward $\mathbf{E} \times \mathbf{B}$ vertical drifts due to eastward electric field, thereafter diffuse down along the magnetic field line to higher latitudes under the influence of gravitational force. The formation of EIA is recognised as "fountain

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effect" creating two plasma peaks on both sides of the magnetic equator at approximately ±15° geomagnetic latitudes. Moreover, around sunset the sudden decrease in the conductivity of the E region gives rise to a post-sunset enhancement of the electrostatic fields. The enhanced field gives rise to increased vertical ion drifts, which lead to the occurrence of plasma bubbles or depletions in ion density due to the Rayleigh–Taylor instability (Stening, 2003). In addition, the eastward electric field get enhanced around dusk sector due to the sharp ionospheric conductivity gradient near the terminator, and this produces strong vertically upward drift, known as Pre-Reversal Enhancement, which can also redistribute the equatorial density structure (Fejer, 2011).

Accurate spatial and temporal TEC prediction using ionospheric model is crucial when measurements are not readily available. This is very important for wide varieties of application such as satellite-based navigation, positioning and communication systems. The International Reference Ionosphere (IRI) and the NeQuick models have been recognised as the international standard for specifying Earth's ionospheric parameters. IRI is the model recommended by the International Union of Radio Science (URSI) and by the International Standardization Organization (ISO) and will soon become the ISO standard for the ionosphere. IRI offers two options for f_oF_2: the International Radio Consultative Committee (CCIR) maps (Jones and Gallet, 1962) for the continents and the newer URSI maps (Rush et al., 1989) for the ocean areas. The CCIR maps are developed based on long-term ionosonde measurements mainly collected in the mid-latitude region of the northern hemisphere. Hence, the performance of those empirical ionosphere models needs careful validation due to very few observational data contributed from South-East Asia for model development.

The performances of the IRI and NeQuick models in predicting the characteristics of the ionosphere using GPS have been investigated at different regions for different solar activity conditions (Dai and Ma, 1994; Ezquer et al., 2004; Bhuyan and Borah, 2007; Bidaine and Warnant, 2010; Sethi et al., 2011; Scidá et al., 2012; D'Ujanga et al., 2012; Olwendo et al., 2012a, 2012b; Akala et al., 2013; Nigussie et al., 2013). However, to the best of the authors' knowledge, such extensive assessment on the latest IRI and NeQuick 2 models has not been undertaken in the South-East Asian region, particularly Malaysia. This has limited the understanding of models' ability in predicting TEC in this region. The focus of this paper is to investigate the capability of the IRI and NeQuick 2 models to predict ionospheric TEC over Banting, Malaysia. This is carried out by comparing the diurnal variation and monthly means of TEC calculated from these models with observed TEC estimated from Global Positioning System (GPS).

2. Data and methods of analysis

This study focuses on an equatorial station located at Banting (BANT) (Geographic coordinate: 2.78°N, 101.51°E; Geomagnetic coordinate: 7.11°S, 173.77°E) as shown in Fig. 1. Data for the year 2011 which correspond to the ascending phase of Solar Cycle 24 has been considered. The TEC estimated from IRI-2007, IRI-2012 and NeQuick 2 models for the same location and period are compared with the GPS-derived TEC (GPS-TEC henceforth).

2.1. GPS-TEC

Adopted from Musa et al. (2012), the dual-frequency (L1 and L2) GPS data obtained from the Malaysian GNSS Real-Time Kinematic network (MyRTKnet) BANT station have been processed using Bernese GPS software version 5.0 (Dach et al., 2007). Processing parameters and strategy for this purpose are tabulated in Table 1. The slant TEC ($STEC$) in TECU ($1\ \text{TECU} = 10^{16}\ \text{electron/m}^2$) obtained from code and carrier phase observations via the geometry-free (L4) linear combination are in Eqs. (1) and (2), respectively.

$$STEC(P)^i_A = \frac{f_1^2 f_2^2}{40.3(f_1^2 - f_2^2)}\left[\left(P2^i_A - P1^i_A\right) - c\cdot(DCB_A + DCB^i)\right] \quad (1)$$

$$STEC(\Phi)^i_A = \frac{f_1^2 f_2^2}{40.3(f_1^2 - f_2^2)}\left[\Phi_1 - \Phi_2 - (\lambda_1 N_1 - \lambda_2 N_2) - c\cdot(DCB_A + DCB^i)\right] \quad (2)$$

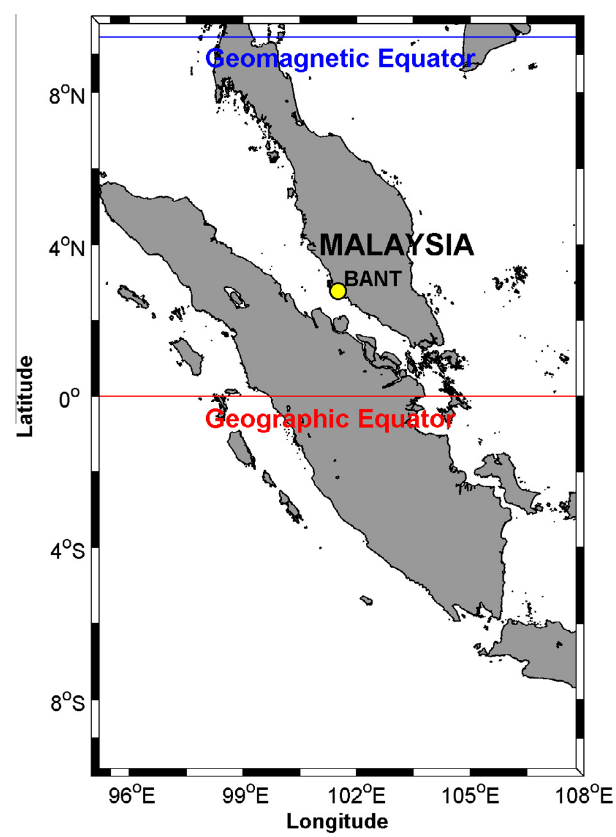

Fig. 1. The location of GPS station at Banting (BANT) (Geographic coordinate: 2.78°N, 101.51°E; Geomagnetic coordinate: 7.11°S, 173.77°E).