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Comparison of observed TEC values with IRI-2007 TEC and IRI-2007 TEC with optional *fo*F2 measurements predictions at an equatorial region, Chumphon, Thailand

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Abstract

In this research, as part of working towards improving the IRI over equatorial region, the total electron content (TEC) derived from GPS measurements and IRI-2007 TEC predictions at Chumphon station (10.72°N, 99.37°E), Thailand, during 2004–2006 is analyzed. The seasonal variation of the IRI-2007 TEC predictions is compared with the TEC from the IRI-2007 TEC model with the option of the actual F2 plasma frequency (*fo*F2) measurements as well as the TEC from the GPS and International GNSS service (IGS). The Chumphon station is located at the equatorial region and the low latitude of 3.22°N. For a declining phase of the solar cycle (2004–2006), the study shows that the IRI-2007 TEC underestimates the IRI-2007 TEC with the *fo*F2 observation at the nighttime by about 5 TECU. The maximum differences are about 15 TECU during daytime and 5 TECU during nighttime. The overestimation is more evident at daytime than at nighttime. When compared in terms of the root-mean square error (RMSE), we find that the highest RMSE between GPS TEC and IRI 2007 TEC is 14.840 TECU at 1230 LT in 2004 and the lowest average between them is 1.318 TECU at 0630 LT in 2006. The noon bite-out phenomena are clearly seen in the IRI-2007 TEC with and without optional *fo*F2 measurements, but not on the GPS TEC and IGS TEC. The IRI TEC with optional *fo*F2 measurements gives the lowest RMSE values between IRI TEC predicted and TEC measurement. However, the TEC measurements (GPS TEC and IGS TEC) are more correct to use at Chumphon station.

Keywords: TEC; Equatorial ionosphere; IRI-2007 TEC, TEC comparison; TEC measurement

1. Introduction

Total electron content (TEC) is an important ionospheric parameter which directly affects the radio wave propagation through the ionosphere. For the equatorial region, TEC gradient is highly variable during the equatorial bubble phenomenon (Yeh et al., 1979; Das Gupta et al., 1983). TEC measurements assist in the development of ionospheric models such as the International Reference Ionosphere (IRI) (Bilitza, 2001; Bilitza and Reinisch, 2008). Many studies in the literature report the comparisons of the measured TEC data obtained from different techniques at various locations with the models such as the IRI models (Bilitza et al., 1998; Belehaki et al., 2003, 2004; Ezquer et al., 1998, 2004; Gulyaeva et al., 2002; Huang and Reinisch, 2001; Jakowski et al., 1998; Jodogne et al., 2004; Mosert et al., 2004; Orus et al., 2003; Sethi et al., 2001; Sobral and Abdu, 1990; Sobral et al., 1997, 2003). However, Chumphon station, Thailand, is at the equatorial region which has under the equatorial ionization anomaly (EIA) influence. Then, the comparison of IRI-2007 TEC model and the IRI-2007 TEC with option on the actual F2 plasma frequency (*fo*F2) measurements is

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important to be made. The GPS TEC value is determined up to the satellite altitude (20,200 km) that includes the plasmaspheric contribution, while the IRI-2007 TEC is only up 2000 km. So GPS TEC is generally larger than the IRI TEC.

The purpose of this research paper is to compare the TEC obtained from the IRI-2007 model (Bilitza, 2001; Bilitza and Reinisch, 2008) with the IRI-2007 TEC with optional *fo*F2 measurements at the equatorial region in Chumphon station, Thailand and the IGS TEC. The monitoring Chumphon station is a part of the South East Asia Low Latitude Ionosphere Observation Network (SEALION) (Maruyama et al., 2007). SEALION aims to observe, monitor and forecast the ionospheric variation in the Asia Pacific region near the magnetic equator. It is a joint project among the following institutions and countries: National Institute of Information and Communications Technology (NICT), Japan, King Mongkut's Institute of Technology Ladkrabang (KMITL), Thailand, Chiang Mai University (CMU), Thailand, National Institute of Aeronautics and Space (LAPAN), Indonesia, Hanoi Institute of Geophysics (HIG), Vietnamese Academy of Science and Technology, Vietnam, Center for Space Science and Applied Research (CSSAR), Chinese Academy of Sciences, China, and Kyoto University, Japan. The measured *fo*F2 data from 2004–2006 are used and optionally added to the IRI models based on the seasonal variation.

2. Observation method

2.1. *fo*F2 observational data

The *fo*F2 measurements are made at Chumphon campus, KMITL, located at longitude 99.37°E and latitude 10.72°N, Thailand. The magnetic latitude for Chumphon station is 3.22°N, close to the equatorial magnetic latitude. The *fo*F2 are measured from the frequency-modulated continuous wave (FMCW) ionosonde.

The ionosonde transmits radio waves from 2 to 30 MHz and receives echoes from the ionosphere to provide the bottomside plasma density profile every 15 min. The data are automatically uploaded to KMITL in Bangkok to be analyzed (Kenpankho et al., 2011). The observation parameters are summarized Saito and Maruyama (2006). The seasonal variations of *fo*F2 are measured for 2004–2006, corresponding to the declining part of low solar activity. The study period is divided into three seasons: equinox (March, April, September, and October), summer (May, June, July, and August), and winter (January, February, November, and December).

2.2. IRI TEC data

With the objective of establishing an international standard for the specification of ionospheric parameters based on all worldwide available data from ground-based as well as satellite observations, the International Reference Ionosphere (IRI) project was initiated by the Committee on Space Research (COSPAR) and by the International Union of Radio Science (URSI) in the late sixties (Bilitza and Reinisch, 2008). COSPAR and URSI specifically asked for an empirical IRI model to avoid the uncertainties of the evolving theoretical understanding of ionospheric processes and coupling to the regimes below and above. The IRI model is continually upgraded as new data and new modeling approaches become available and this process has resulted in several major milestone editions of IRI (Rawer et al., 1978a,b, 1981; Bilitza et al., 1990; Bilitza, 2001; Bilitza and Rawer, 1996; Bilitza and Reinisch, 2008; Bilitza and McKinnell, 2011) progressing from a set of tables for typical conditions, to a global model for all phases of the solar cycle. More information about the IRI project including information about the IRI Newsletter and the IRI electronic mailer can be found on the IRI homepage at http://IRI.gsfc.nasa.gov/.

The IRI TEC predictions (IRI TEC) are calculated from the IRI-2007 models (Bilitza and Reinisch, 2008), using the location, dates, and period of time, as inputs to the model. The IRI-2007, a new empirical standard model of the ionosphere, is improved from the limitations of the previous IRI-2001 model. To predict the IRI TEC from IRI-2007, we can access the site at http://ccmc.gsfc.nasa.gov/modelweb/models/iri_vitmo.php/ more recently also as an interactive web interface accessible from the IRI homepage. The highest recent update is the IRI-2012 model which we can access the file at http://spdf.gsfc.nasa.gov/pub/models/iri/iri2012/. In this work, we use the IRI-2007 TEC predictions and the IRI-2007 TEC with optional F2 plasma frequency (*fo*F2) measurement. The IRI model permits the use of *fo*F2 data as input. In the selecting option, we choose the NeQuick option of the IRI 2007.

2.3. GPS TEC data

The GPS TEC data are obtained from the GPS receiver (10.72°N, 99.37°E) from 2004 to 2006. Total electron content (TEC) is defined as the total electrons (electron/m^2) in a vertical column of 1-m^2 cross-section (Goodwin et al., 1995). This definition for TEC is actually the definition of the vertical TEC (VTEC) through the piercing point with the obliquity factor (Lin, 2001; Brunini et al., 2004; Cabrera et al., 2005). The slant TEC (STEC) is defined as the line integral of the electron density from a GPS satellite to a receiver above a user-specified elevation cut-off angle (usually 45°) (Cabrera et al., 2005; Jin and Park, 2007; Zeilhofer et al., 2009). In the GPS system, every satellite transmits the signals on two frequencies ($f_1 = 1575.42$ MHz and $f_2 = 1227.60$ MHz). The dual-frequency GPS receiver is used in a GPS TEC measurement system which consists of a micro strip antenna, an amplifier, a TEC Meter, and a computer. The GPS receiver works when it continuously receives 4–12 GPS signals that will lead to the computation of the STEC values.