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Comparison of GPS-TEC observations over Addis Ababa with IRI-2012 model predictions during 2010–2013

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Abstract

This study presents Global Positioning System-Total Electron Content (GPS-TEC) observations over Addis Ababa (Lat: 9.03°N Lon: 38.77°E Mag. lat: 0.18°N) and an evaluation of the accuracy of International Reference Ionosphere-2012 (IRI-2012) model predictions during 2010–2013. Generally, on a diurnal scale, TEC recorded minimum values at 0400–0600 LT and maximum at 1400–1600 LT. Seasonally, TEC recorded maximum values during December solstice and September equinox, and minimum during June solstice. On a year-by-year basis, 2013 recorded the highest values of TEC for both the observed and the model measurements, while 2010 recorded the lowest, implying the solar activity dependence of TEC. Furthermore, we observed discrepancies in the comparison of the GPS-TEC measurements with those derived from IRI-2012 model, after the exclusion of the contributions of plasmaspheric electron content (PEC) from the GPS-observed TEC. All the three options of IRI-2012 model overestimated TEC during early morning and post-sunset hours. Comparatively, of the three options of IRI-2012 model, NeQuick appears to be the most accurate for TEC estimation over Addis Ababa, although at a very close performance capability with the IRI01 CORR option, while IRI2001 is the least accurate.
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Keywords: GPS-TEC; IRI-2012 model; Percentage deviations; Solar activity

1. Introduction

The study of ionospheric total electron content (TEC) is of great importance, because radio propagation via the ionosphere depends uniquely on the electron density of the ionosphere. Variations in the ionosphere often cause changes in ionospheric TEC, which negatively impact radio communication systems. A key application of the trans-ionospheric radio propagation is the global navigation satellite system (GNSS), which has the capability of providing precise navigation information. As of today, Global positioning system (GPS) is the most popular component of GNSS.

Currently, GPS is widely used for monitoring the ionosphere. GPS is a space-based radio positioning system that provides 24-hour three-dimensional position, velocity, and time information for users anywhere on the earth's surface. GPS consists of a constellation of twenty-four satellites on

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six orbital planes, with each satellite orbiting at 55° inclination. In this configuration, there is worldwide coverage since at least four satellites are available from any location on the earth's surface at all times. Each GPS satellite transmits a unique navigational signal centered on two L-band frequencies; L1: 1575.42MHz and L2: 1227.60MHz. The relative ionospheric delay of the two signals is proportional to the total amount of electrons along the ray path (i.e., TEC). GPS satellites are located at the altitude of 20,200km above the earth's surface, for this reason, the amount of free electrons along the GPS ray path is composed mainly of ionospheric electron content (IEC) and partly of plasmaspheric electron content (PEC) (Balan et al., 2002; Cherniak et al., 2012; Karia et al., 2015).

The position, velocity and time estimates obtained by a user of GPS depends on the satellite-receiver distance, signal multipath, tropospheric/ionospheric delays, satellite and receiver clock offsets, receiver clock errors, orbital errors, satellite geometry, number of visible satellites, phase ambiguity, as well as satellite and receiver biases (Sardon et al., 1994). There will be a bias for each of the two GPS frequencies and their difference produces systematic instrumental errors in the estimates of ionospheric delays, which is used in evaluating the electron content. GPS provides an important descriptive ionospheric parameter, the TEC, which has an over-bearing influence on the GPS-based communication and navigation systems (Akala et al., 2013).

The ionosphere over equatorial latitudes is highly dynamic, and consequently poses serious threats to communication and navigation systems, especially during disturbed intervals. In order to address these challenges, a proper understanding of ionospheric behavior over equatorial latitudes, and the intervening physical processes that lead to its continuous variability is important for effective forecasting (Akala et al., 2010a). A good empirical model can provide reliable simulation data for effective ionospheric study and forecasting. To this end, several ionospheric models (e.g., International Reference Ionosphere (IRI) (Bilitza, 2001), Field Line Inter-hemispheric Plasma (FLIP) model (Scali et al., 1997), Parameterized Ionospheric Model (PIM) (Daniell Jr. et al., 1995), Thermosphere-Ionosphere General Circulation Model (TIGCM) (Emery et al., 1996), and many others) have been developed. Out of these models, IRI is the most commonly used (Szuszczewicz et al., 1998). IRI is an international project sponsored by the Committee on Space Research (COSPAR) and the International Union on Radio Science (URSI). It provides values of electron density, electron content, electron and ion temperature, and ion composition as a function of height, location, local time, and sunspot number. The model is based on data from network of ground observations and in-situ measurements. The IRI-2012 model, which is the latest version of IRI model, provides three options for prediction of TEC, namely: IRI-2001, IRI01-Corr, and NeQuick (Coisson et al., 2008a).

Since IRI is a data driven model, the accuracy of the model in a specific region and/or time period depends on the availability of reliable data for that specific region and time. In other words, the model predictions may deviate significantly from real observations in regions and time periods that are not properly represented in the existing database (Bilitza et al., 2014). Large proportions of the input parameters that have been hitherto ingested into the model were from the mid- and high-latitudes, particularly, from the northern hemisphere, translating to comparative better performance of the model in the mid- and high-latitudes of the northern hemisphere than the low-latitude, and the southern hemisphere, in general (Bilitza and Reinisch, 2008). Paradoxically, even within the low-latitude region, a region that is not adequately represented in the IRI database, Africa is highly under-represented. This could be attributed to the sparse distribution of ionospheric sensors in Africa over the past years. Currently, the situation is being assuaged by the recent installation of GPS receivers across Africa, with the hope of beefing up the quantum of Africa-based ionospheric parameters in the IRI database over the next few years. IRI is regularly updated and improved during COSPAR-IRI sessions and/or IRI workshops, where new data and new modeling techniques are usually presented, and these meetings have led to several versions of IRI-model over time (Kenpankho et al., 2011; Bilitza, 2001; Radicella and Leitinger, 2001; Bhuyan and Borah, 2007; Bilitza and Reinisch, 2008; Coisson et al., 2008a,b). A brief history of the IRI project and description of the latest version of the model (IRI-2012) is presented in Bilitza et al. (2014).

Previously, few authors (e.g., Adewale et al., 2012; Okoh et al., 2012, 2013; Olwendo et al., 2013; Akala et al., 2013; Oyeyemi et al., 2013; Rabiu et al., 2014) have compared GPS-TEC measurements over the African equatorial ionization anomaly (EIA) region with those derived from IRI model. However, virtually all these efforts were concentrated within the inner flank of the EIA, particularly, within the southern part. Furthermore, these studies did not consider the effects of the plasmasphere on the GPS observations before comparison with IRI model, which is known to adopt 2000 km upper limit integration boundary. To this end, this study characterizes ionospheric TEC over Addis Ababa, an African GPS station that is located directly on the magnetic equator, during 2010–2013 on monthly, seasonal, and yearly scales, and also ascertains the accuracy of the three coefficients of IRI-2012 model (IRI01-corr, IRI2001 and NeQuick) over Addis Ababa, after the exclusion of the contributions of plasmaspheric electron content (PEC) from the GPS-observed TEC.

2. Data and methodology

The data used for this research were obtained from an African equatorial GPS station, Addis Ababa (Lat: 9.03° Lon: 38.77° Mag. lat: 0.18°, Ethiopia using a NovAtel

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