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IRI-vTEC versus GPS-vTEC for Nigerian SCINDA GPS stations

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Abstract

Following the recent proliferation of dual-frequency GPS (Global Positioning System) receiver systems across the African continent, there is a growing number of papers that compare vertical Total Electron Content (vTEC) values derived from the International Reference Ionosphere (IRI) model with those obtained from the GPS receiver measurements. In this work we report an investigation of IRI-vTEC versus GPS-vTEC comparisons for three Nigerian SCINDAGPS stations (Nsukka, Ilorin, and Lagos) for which data are available in the year 2012, and present a further review of the differences/similarities observed between them. Since a major interest in this work is to use the GPS measurements to improve the predictions of the IRI model for the region, we present a detailed regression analysis of differences between the two sources in a manner that will benefit this application.

Keywords: Total Electron Content; GPS TEC; IRI TEC; International Reference Ionosphere; Nigeria; SCINDA GPS

1. Introduction

Given its dispersive nature, the ionosphere plays very important roles in our communication lives today; trans-ionospheric radio waves reaching us from satellites and systems in outer space experience frequency-dependent group delays. These delays translate to various effects on our communication systems. For single frequency GPS (Global Positioning System) receivers, the delays translate to errors in the positioning system which could have fatal consequences for satellite-augmented landing in the aviation industry. In the field of observational radio astronomy, radio signals arriving widely separated radio antennas during VLBI (Very Long Baseline Interferometry) do so out of phase and could lead to misrepresentation of results if not corrected. Such systems require the forecasting of ionospheric conditions over each receiving antenna so as to correct for any errors in astrometric parameters caused by the ionosphere and derived from the astrometric observables such as the difference in arrival times of a wavefront at the receiving antennas (Adam, 2003).

In the recent years, there has been significant increase in the number of dual-frequency GPS receivers installed in the African continent for research purpose. This has sparked interest in comparing data from these GPS receivers with data from models and other equipment (e.g. McKinnell et al., 2007; Rabiu et al., 2011, 2014; Okoh et al., 2012; Olwendo et al., 2012, 2013; Okonkwo and Ugwuanyi, 2012; Ouattara et al., 2012; Akala et al., 2013, etc) and also in using data from these receivers to improve data from

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models and other equipment (e.g. Opperman et al., 2007; Okoh et al., 2013).

TEC (Total Electron Content) is an important parameter of the ionosphere that indicates the time delay experienced by radio signals in propagating through given paths through the ionosphere. Quantitatively, it is the total number of electrons between two points in the ionosphere in an imaginary cylinder with a unit cross-sectional area. The S.I. unit is electrons/m^2, where 10^{16} electrons/m^2 = 1 TEC unit (TECU). The delays of GPS signals relative to free-space propagation are proportional to the TEC along the signal path, a consideration that has made dual frequency GPS receivers an instrument for measuring TEC values in ionospheric research. GPS signals that transverse the ionosphere carry signatures of the dynamic medium and thus offer opportunities for ionospheric research (Bhuyan and Rashmi, 2007; Petit et al., 1988).

2. Data

GPS-vTEC data used in this work are obtained from the following 3 SCINDA GPS receiver stations in Nigeria: Nsukka, Ilorin and Lagos. There are currently 5 SCINDA (Scintillation Network Decision Aid) GPS stations in Nigeria located at Nsukka (6.87°N, 7.38°E), Ilorin (8.50°N, 4.55°E), Lagos (6.45°N, 3.38°E), Akure (7.25°N, 5.20°E), and Ile-Ife (7.47°N, 4.57°E). For year 2012, vertical TEC (vTEC) data are available from the first three stations, but not from the last two stations. In this work, we compare GPS-vTEC measurements from the three stations with corresponding vTEC predictions from the IRI (International Reference Ionosphere) model. Fig. 1 illustrates the location of the stations on the Nigerian map. Stations with available GPS-vTEC data for year 2012 are in green, while those without GPS-vTEC data for year 2012 are in black. A description of data sources used in this work is presented in this section.

2.1. SCINDA GPS receivers

The Air Force Research Laboratory (AFRL) established the Scintillation Network and Decision Aid (SCINDA) as a network of ground-based GPS receiver systems to provide regional specification and short term forecasts of scintillation to operational users in real time (Carrano and Groves, 2006). As an enhancement to standard GPS data delivery services like the IGS (International GPS Service), SCINDA GPS receivers are deployed with additional software called "GPS-SCINDA" to provide measurements of S_4 (Scintillation index), TEC, and ROTI (rate of change of TEC index), as well as receiver position in real-time using the full temporal resolution available for each parameter; all ionospheric parameters are computed in near real-time, thereby enabling the use of receivers with high internal data sampling rates at remote stations with low bandwidth internet connections. At the same time, the real-time processing avoids the man-hours and cost normally required to post-process large volumes of raw data (Carrano and Groves, 2006).

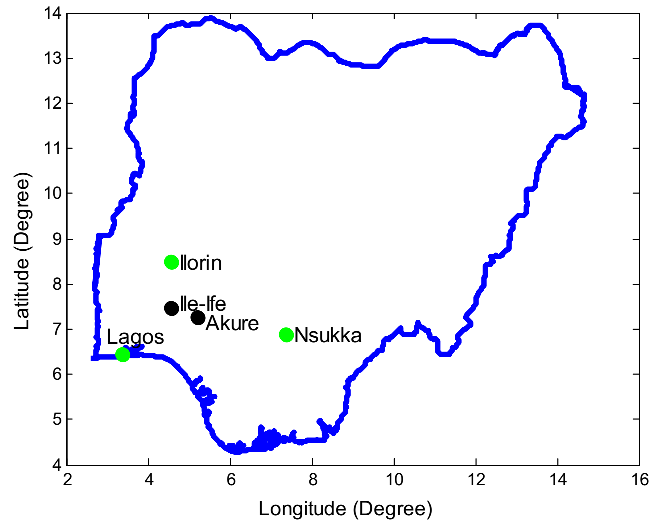

Fig. 1. Locations of SCINDA GPS receivers in Nigeria. Stations with available GPS data used in this work are in green, while stations with no available GPS data are in black. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

AFRL-SCINDA GPS receiver systems are also deployed with additional software called WinTEC-P (Carrano et al., 2009) that computes and calibrates vertical TEC measurements from the system, and uses the Kalman filter approach to provide an estimation of the ionospheric TEC by removing the plasmaspheric TEC contribution (Carrano et al., 2009). Plasmaspheric TEC is computed by numerically integrating the electron density along the line of sight from the GPS receiver to each satellite starting from 700 km up to the GPS orbital altitude of 20,200 km. Detailed description of the AFRL-SCINDA GPS receiver systems and associated software are contained in the works of Carrano and Groves (2006) and Carrano et al. (2009).

2.2. The IRI model

The IRI model represents monthly averages of electron density, electron temperature, ion composition, ionospheric TEC, etc, and describes variations in altitude (50–1500 km), latitude, longitude, date, time, etc (Bilitza and McKinnell, 2011). The model is an empirical one developed using available data from all around the world, and has been widely accepted as a dependable ionospheric model (Bilitza, 2001; Bilitza and Reinisch, 2008). The IRI model is however more accurate in predicting the bottom-side ionosphere than the topside ionosphere since it is derived mostly from ionosonde data, and as such not a very good candidate for topside ionospheric modeling as is evident in the works of Mosert et al. (2007) and Kailiang and Jianming (1994). The NeQuick model (Hochegger et al., 2000; Radicella and Leitinger, 2001) is used by some