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Analysis of Longitudinal Advancement of the Peak Total Electron Content in the African Equatorial Anomaly Region Using Data From GPS Receivers and GIS Stations in Kenya

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Abstract

We investigated longitudinal advancement of the peak Total Electron Content (TEC) within the equatorial anomaly region of Kenya, based on the data from the two Scintillation Network Decision Aid (SCINDA) Global Positioning System (GPS) receivers at Jomo Kenyatta University of Agriculture & Technology (JKUAT): latitude −1.095, longitude 37.015, and at the University of Nairobi: latitude −1.274, longitude 36.808; and the two Geographical Information System (GIS) stations at Malindi: latitude −2.996, longitude 40.194, and at the Regional Center for Mapping of Resources for Development (RCMRD): latitude −1.221, longitude 36.893. The retrieved archived data from these stations were for 17th December 2009; and for 26th, 27th and 28th August 2010 —just after the solar minimum period of 2008. They were subjected to analysis by the GPS-TEC analysis application software provided by Boston College Research Institute (USA). Results reveal that the peak TEC within the region of study occurs between 8 a.m. and 10 a.m. The Coastal region experiences peak TEC earlier than Nairobi region. Slight variations were also observed on the TEC plots from various stations. It can be concluded that the peak TEC advances westwards within the equatorial anomaly region; these variations are due to plasma bubbles that take place from the east to west within the equatorial region.

Keywords: total electron content (TEC), equatorial anomaly region, plasma bubble, Kenya

1. Introduction

Total Electron Content (TEC) is defined as the total number of electrons integrated along the path from the receiver to each GPS. TEC is an indicator of ionospheric variability that is derived by the modified GPS signal through free electrons (Ya'acob et al., 2010). The ionosphere is the uppermost part of the atmosphere of the Earth, between the thermosphere and the exosphere. It starts to exist at heights of 50 to 1000 kilometers above the ground. At these heights, the atmosphere is so thin that free electrons can exist for short periods of time before they are captured by a nearby positive ion. The charged particles in this region are also produced by ionization of the gas present in the atmosphere, and this ionization phenomenon varies with solar intensity, seasonal changes, and solar cycle (Rajesh et al., 2009).

The Global Positioning System (GPS) is an existing worldwide radio navigation system formed by a constellation of 24 satellites and several ground stations. It is a part of the Global Navigation Satellite System (GNSS). The satellites are in six near-circular orbits 20,200 kilometers above the earth, way above the ionosphere. Global Positioning Systems (GPS) are widely used in Physics, Geography and Agriculture. In Physics, one of its applications is ionospheric total electron content (TEC) measurement (Wanninger, 1993; Ya'acob et al., 2010).

Equatorial anomaly is the occurrence of concentrated ionization in the ionosphere within the regions of approximately ±15 degrees of the dip equator (Da Costa et al., 2004; Lühr et al., 2003).

The Dip Equator is an imaginary line on the earth's surface on which both the geomagnetic vertical component and the inclination angle are zero (Deka et al., 2005). Kenya is at averagely 9 degrees below the dip equator, well within the equatorial anomaly region.

During the data period for this research, Kenya had two operational SCINDA GPS receiver stations: at the

University of Nairobi (UoN) and at the Jomo Kenyatta University of Agriculture and Technology (JKUAT); and two GIS stations: at the Regional Center for Mapping of Resources for Development (RCMRD) in the outskirts of Nairobi and at Malindi (Mal) in the Coastal region. All of these use the dual frequency receivers from which TEC can be determined.

In this study, the archived TEC data were retrieved from the two operational GPS receiver stations and the two GIS stations for the times when data were simultaneously available at the stations. Analyses were done to determine the peak TEC at the stations to ascertain the longitudinal advancement of TEC within the equatorial anomaly region located at the Geographical Equator (Kenya).

2. Data and Methodology

2.1 Data Retrieval and Archiving

For the purpose of this study, the four stations are coded as in Table 1.

Table 1. Codes of the GPS and GIS stations for the research

STATION	CODE
Jomo Kenyatta University of Agriculture and Technology	JKUAT
University of Nairobi	UoN
GIS station at Regional Center for Mapping of Resources for Development	RCMRD
Malindi GIS station	Mal

2.1.1 Data Retrieval From a GPS Receiver Computer

The GPS-SCINDA receiver stations archive the received data in the computer memory, which can be backed up onto the CDROM using the standard procedure provided by the Boston Research Institute. This procedure was adopted to capture the daily data from September, 2009 to September, 2010 for UoN and JKUAT SCINDA stations.

2.1.2 Data Retrieval From the International Data Center

All GPS and GIS receiver stations are configured to archive their data at the International Data center at the website: ftp://cddis.gsfc.nasa.gov/gps/data. Here the Receiver Independent Exchange (RINEX) (Hatanaka, 2008) observation files are available for various durations including: hourly, daily and monthly.

The corresponding (RINEX) navigation file(s) are obtained from the International GNSS Service (IGS) data site: ftp://cddis.gsfc.nasa.gov/pub/gps/data/.

Differential Code Bias (DCB) files are obtained from website ftp://ftp.unibe.ch/aiub/CODE/. They are also available for the same durations as the RINEX files.

From the stated sites, we downloaded archived GIS daily data for RCMRD and Mal for the period spanning September, 2009 to September, 2010. The archived data come in compressed form; hence the standard decompressing procedure was adopted to decompress them.

2.2 Data Quality Control

Each day's data for the whole duration were thoroughly examined for each of the four stations; and only days with at least 22 consecutive hours of available data were selected for analysis.

For proper comparison of the longitudinal TEC behavior, we took only those days for which data were simultaneously available for all the four stations.

Consequently, consistent and matching data for all the stations were only found for 17th December 2009; and for 26th, 27th and 28th August 2010.

2.3 Data Analysis

The data were subjected to analysis method developed by The Boston College Institute for Scientific Research (BCISR), USA.

2.3.1 The BCISR Tec Analysis Method

This method uses the GPS-TEC analysis application, developed by Institute for Scientific Research, Boston

College.

The application software, its features and other details are obtainable from: http://seemala.blogspot.com. For this research, the RINEX GPS-TEC program version 2.0 was used.

2.3.2 Configuration and Running of the RINEX GPS-TEC Program Version 2.0

A measure of TEC of the ionosphere along the ray path from the Satellite to the GPS receiver is the slant TEC, which is recorded by the receiver. Applications require this to be converted to vertical TEC, for which suitable mapping functions are employed. However, this conversion introduces errors.

To execute the vertical TEC calculations, the program calculates the elevation and azimuth angles of the satellite from the RINEX navigation files that correspond to the RINEX observation files of any station as obtained from the IGS data site.

The program requires the differential code bias (DCB) files to calculate receiver and inter-channel biases for the various satellites, which hence eliminate the errors due to conversion from slant to vertical TEC. The DCB files are provided by the IGS code website: ftp://ftp.unibe.ch/aiub/CODE/. This program is capable of generating the DCB files if they are not available in the specified site.

The program downloads the required RINEX navigation and DCB files from website automatically into the original data observation folder. It then plots the vertical TEC values on screen and writes ASCII (American Standard Code for Information Interchange) output files in the same directory of data file, that is the cmn file (TEC output file) and the std file (mean TEC output file). It then integrates the generated cmn and std files to produce plots which are displayed on the screen shot of the program.

For this study, only the RINEX observation files were downloaded manually, therefore the program was allowed to download the RINEX navigation and DCB files from the internet.

3. Results and Discussions

In this research, the data used to generate the plots were those of 17th December 2009; 26th, 27th and 28th August 2010. These dates had good consistent data for most of the hours of the day for all the stations. This study required such matching data from all the stations for a particular day.

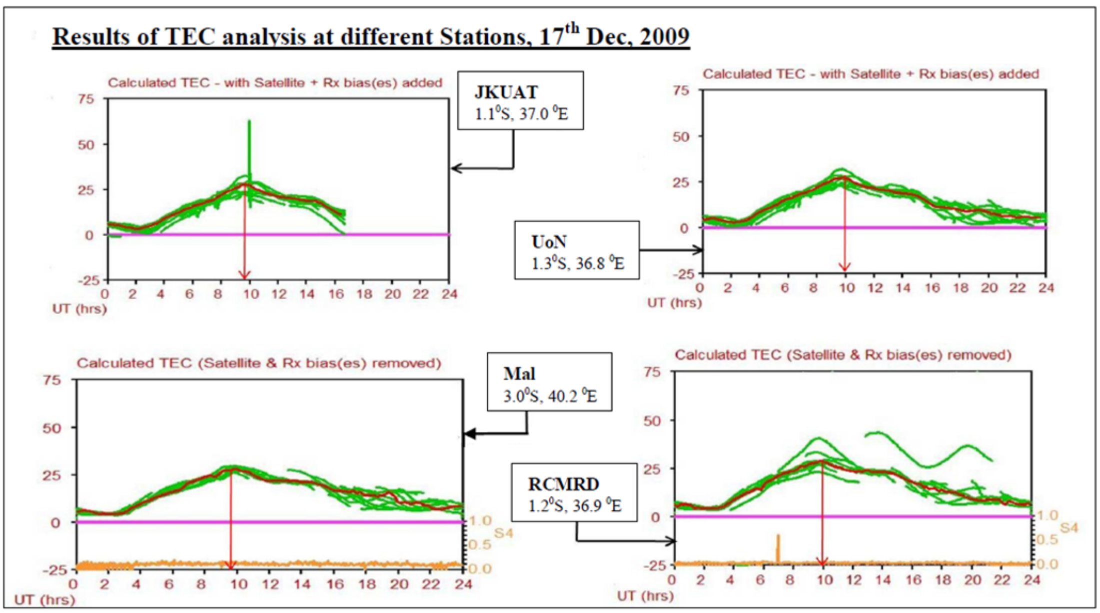

Figure 1. 17th December 2009

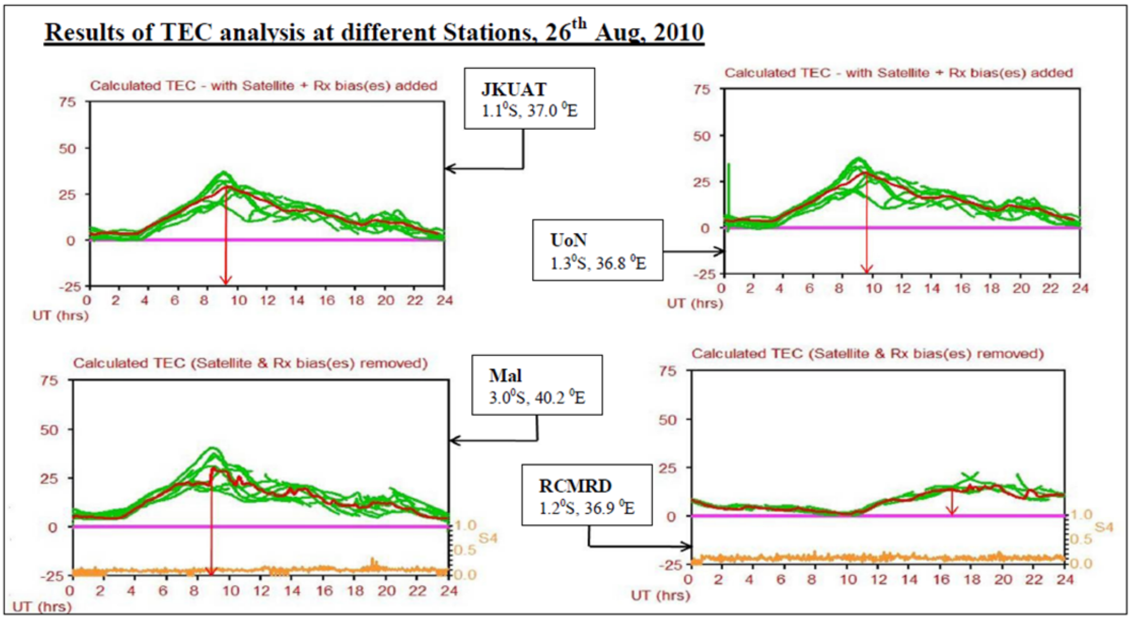

Figure 2. 26th August 2010

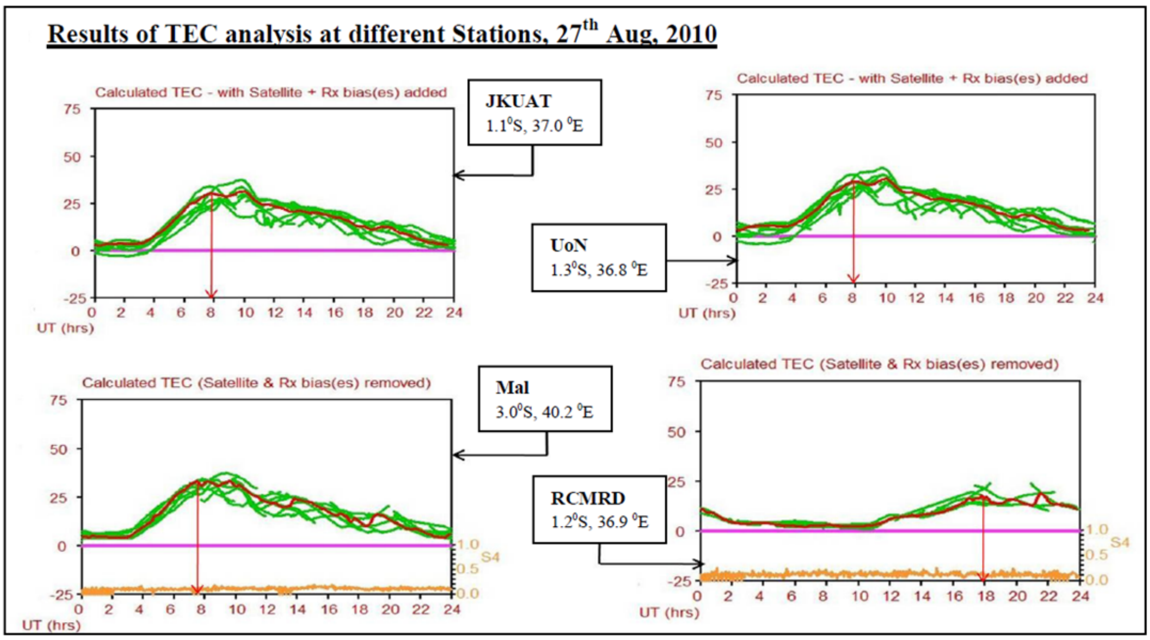

Figure 3. 27th August 2010

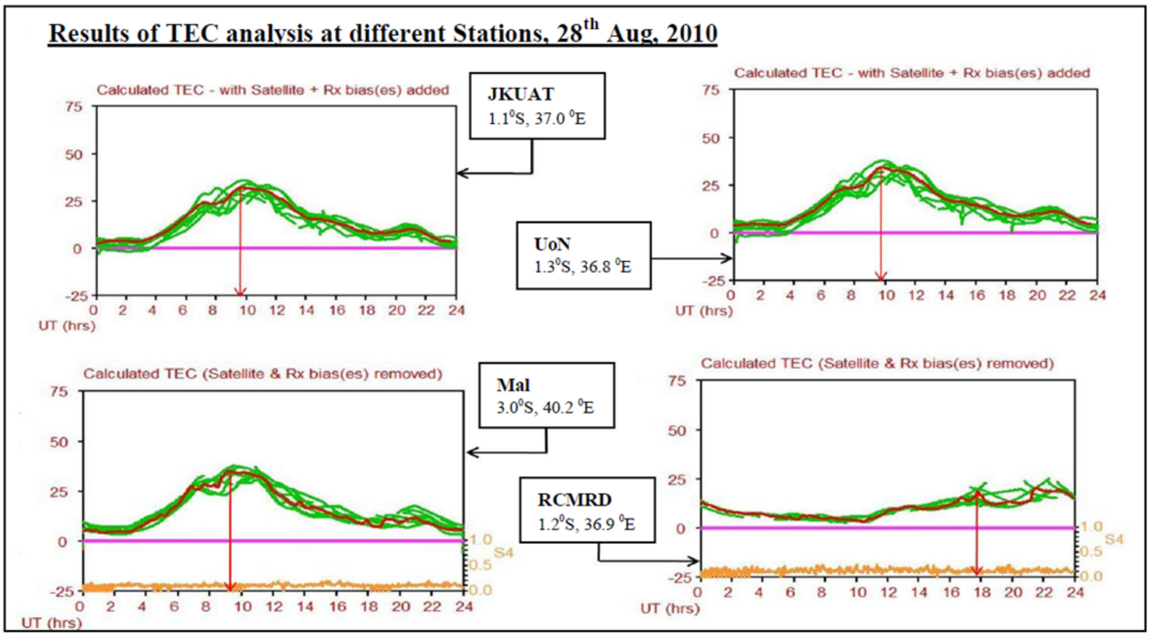

Figure 4. 28th August 2010

It was observed from the plots that the peak values of TEC occur earlier at stations that are more easterly, and the trend advances westwards. The average time for peak TEC in the four Kenyan stations for the month of August, 2010 varied from 9:00 a.m. (most eastern station, Mal) to 10:00 a.m. (most western station, UoN). Rufus et al. (2012) while investigating variation of TEC and their effects on GNSS over Akure, Nigeria (7.15°N, 5.12°E) observed that during the month of August, 2010 peak TEC occurred at 1400 hours, which is 1600 hours, Kenyan time. This validates the observation that the longitudinal advancement of peak TEC is from East to West within the African Equatorial anomaly region. The East-West advancement of peak TEC was also reported by Rupesh et al. (2008) for the Polar Regions. Similar report was proclaimed by De Rezende et al. (2007) within the Brazilian region, which is not within the African continent.

The sudden and abnormally high vertical TEC peaks from specific PRNs in JKUAT and RCMRD as observed on the plots of 17th December, 2009 is explicable in terms of occurrence of Multipaths. Dashora et al. (2005), and De Rezende et al. (2007) assert that only portions of the signal that travel along the direct path from the satellite are useful; all other contributions are the so called "multipaths". The abnormally high TEC observed are due to the multipaths and not caused by the atmosphere.

Inconsistencies in the RCMRD plots of 26th to 28th August, 2010 could be attributed to Equipment errors or other unknown reasons that are open for future investigations. The plots have not been taken into consideration while arriving at conclusions of this study.

The differences in the TEC readings and peak times on the plots can be explained on the basis of ionospheric bubbles. Ionospheric plasma irregularities or bubbles are regions within the ionosphere with depleted plasma density. They are generated at the magnetic Equator after sunset due to plasma instabilities (De Rezende et al., 2007; Guozhu et al., 2007; Da Costa et al., 2004).

Early in the evening, just after the sunset, irregularities that cause spread F and VHF scintillations begin to appear below the F peak. Then, through some nonlinear processes these disturbances in electron density develop into regions of low density and start to rise to the topside rapidly, leaving behind a trail of irregularities extending to several hundred kilometers. These density depleted regions are the so-called bubbles, in which irregular structures of electron density with sharp gradients exist (Afraimovich et al., 2002; Rajesh et al., 2009).

When fully formed, the bubbles appear as wedge like structures that extend upward from the F peak. This is thought to be as a result of Rayleigh-Taylor instability as Da Costa et al. (2004) reports. These bubbles appear mostly before midnight.

Radio waves propagating through developed bubbles are subject to interactions with sharp gradients as well as small irregular structures of the electron density. Very intense amplitude scintillations are therefore observed (Rupesh et al., 2008; Afraimovich et al., 2002).

The bubbles are thought to occur as a result of the Rayleigh Taylor instability (Matsieviskii et al., 1989). This is instability of an interface between two fluids of different densities, which occurs when the lighter fluid is pushing the heavier fluid. The equivalent situation occurs when gravity is acting on two fluids of different density—with the dense fluid above the less dense fluid, causing the former to gradually be pulled by gravity towards the bottom of the later. This can be illustrated when water is added into a jar of oil; it will tend to penetrate through the oil and settle at the bottom, giving rise to the finger-like formations called the Rayleigh-Taylor fingers.

As the instability develops, downward-moving irregularities ("dimples") are quickly magnified into sets of inter-penetrating Rayleigh-Taylor fingers. Therefore the Rayleigh-Taylor instability is sometimes qualified to be a fingering instability. The upward-moving, lighter material is shaped like mushroom caps (Sharp, 1984).

4. Conclusion

1) The study has shown that there is peak TEC advancement from the East towards the West.
2) The TEC variations observed are attributed to the ionospheric bubbles occurring in the Equatorial ionosphere.
3) Inconsistencies in the RCMRD plots of 26^{th} to 28^{th} August, 2010 are subject to further investigations.

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