Journal of Atmospheric and Solar-Terrestrial Physics 138-139 (2016) 261–267

Contents lists available at ScienceDirect

Journal of Atmospheric and Solar-Terrestrial Physics

journal homepage: www.elsevier.com/locate/jastp

Trends of ionospheric irregularities over African low latitude region during quiet geomagnetic conditions

Patrick Mungufeni [a,*], John Bosco Habarulema [b,c], Edward Jurua [a]

[a] Mbarara University of Science and Technology, Mbarara, Uganda
[b] South African National Space Agency (SANSA) Space Science, 7200 Hermanus, South Africa
[c] Department of Physics and Electronics, Rhodes University, 6140 Grahamstown, South Africa

ARTICLE INFO

Article history:
Received 15 May 2015
Received in revised form
22 January 2016
Accepted 23 January 2016
Available online 27 January 2016

Keywords:
Ionosphere
Ionospheric irregularities
Low-latitude ionosphere

ABSTRACT

The occurrence patterns of ionospheric irregularities during quiet geomagnetic conditions over the African low latitude region were analysed. GNSS-derived Total Electron Content of the ionosphere data during the period 2001–2012 were used. The data were obtained from Libreville, Gabon (0.35°N, 9.68°E, geographic, 8.05°S, magnetic), Mbarara, Uganda (0.60°S, 30.74°E, geographic, 10.22°S, magnetic), and Malindi, Kenya (2.99°S, 40.19°E, geographic, 12.42°S, magnetic). The rate of change of total electron content index greater than 0.5 TECU/Min were considered as severe ionospheric irregularities. For most of the time, the strength of ionospheric irregularities in March equinox were greater than those during September equinox over East Africa and an opposite observation was made over West Africa. These asymmetries might be due to the direction of the meridional winds during equinoxes over the different stations. Severity of ionospheric irregularity reduced from west towards the east. This might have been related to the decreasing geomagnetic field strength from east towards the west. This is the first study that reveals the equinoctial asymmetry is different in the West and East African sectors. Moreover, the importance of this study lies in the fact that it has used extensive data to examine the isolated and unexplained earlier observations of equinoctial asymmetry and longitudinal variation of ionospheric irregularities over the African low latitude region.

1. Introduction

Ionospheric and tropospheric refractions are some of the major error sources that affect satellite-based positioning (Hofmann-Wellenhof et al., 2007). Due to variations in electron content density in the ionosphere (ionospheric irregularities), random scattering and diffraction of the waves that pass through it occur. The result is the random fluctuations in signal amplitude and phase, referred to as scintillations. Ionospheric irregularities mainly occur around the magnetic equator (equatorial ionosphere) during the pre-midnight period, in the auroral region during night-time, and in the polar cap at any time (Wernik et al., 2004).

The equatorial ionospheric F-region irregularities can cause spread-F on ionograms (equatorial spread-F (ESF)) (Burke et al., 2004; Cabrera et al., 2010). The bubbles of depleted plasma that appear as vertically elongated wedges in the equatorial ionosphere after sunset are commonly referred to as equatorial plasma bubbles (EPB) (Portillo et al., 2008). They drift upward from beneath the bottomside F layer to altitudes as high as 1500 km. The individual flux tubes in a vertical wedge are typically depleted along their entire north–south extents (Schunk and Nagy, 2009). Therefore, the occurrence of ESF are mainly driven by $\vec{E} \times \vec{B}$ plasma drift velocities (Vz) at the equatorial region, where $\vec{E}$ is the zonal electric field at the magnetic equator and $\vec{B}$ is the magnetic field at the equator (Farley, 1985; Schunk and Nagy, 2009).

Most studies in the African low latitude regions related to ionospheric irregularities have been done during geomagnetic storms and specific solar activity conditions (Wiens et al., 2006; Paznukhov et al., 2012; D'ujanga et al., 2012; Olwendo et al., 2013; Amabayo et al., 2014). The occurrence of EPBs observed simultaneously with L-band (Global Positioning System (GPS)) scintillations over Asmara, Eritrea (15.4°N, 38.9°E, geographic, and 7°N dip latitude) by Wiens et al. (2006) revealed that most probable occurrence and scintillations were around the equinoxes and least around the winter solstice. Their study also confirmed the longitudinal dependence of EPB occurrence in a particular season. Using data over Kampala, Uganda (0.34°N, 32.60°E, geographic, 9.29°S, magnetic) during the period 2011–2012, Amabayo et al. (2014) showed that the diurnal scintillation peaks between 17:00 and 22:00 Universal Time (UT), and the amplitude scintillation

* Corresponding author at: Mbarara University of Science and Technology, Mbarara, Uganda.
E-mail address: pmungufeni@gmail.com (P. Mungufeni).

http://dx.doi.org/10.1016/j.jastp.2016.01.015
1364-6826/

was more dominant than phase scintillation. Olwendo et al. (2013) investigated the seasonal variation of ionospheric scintillation by using data from a low latitude station in Nairobi, Kenya (36.8°E, 1.3°S, geographic, 10.8°S, magnetic) during the year 2011. They showed that amplitude scintillation at L-band frequencies is higher during the post sunset hours of the equinoctial months of March–April and September–October. Moreover, they observed that the occurrence of scintillation during March equinox was higher than during September equinox. Such equinoctial asymmetry was also observed over the Indian region by Sripathi et al. (2011). They found both the occurrence of scintillations and ROTI were greater in the vernal equinox than in the autumn equinox. In equatorial African region during the year 2010, Paznukhov et al. (2012) reported that most frequent scintillations occurred during equinoctial seasons, with a few weak scintillations occurring during the boreal summer time in West and East Africa. Scintillations in the West and East African sectors were noticeably weaker compared to Atlantic sector. Similarly, longitudinal variabilities in EPB occurrence rates were also detected by the polar-orbiting satellites of the Defense Meteorological Satellite Program (DMSP) during 1989–2002 in the Atlantic–African and Pacific sectors (Burke et al., 2004).

It seems long-term trends in the occurrence of ionospheric irregularities has not been determined over the African low latitude region. This study investigated for quiet geomagnetic conditions, trends in Occurrence of Ionospheric Irregularities (OII) during 2001–2012 in the African low latitude region. Emphasis was then put on examining and explaining the less studied features such as longitudinal differences in the strength of ionospheric irregularities and the equinoctial asymmetries in the strength of ionospheric irregularities. Such long-term studies of the trends of occurrence patterns of ionospheric irregularities provide concrete understanding of ionospheric irregularities over the region. In Section 2, the data sources and the analyses techniques used in this study are discussed.

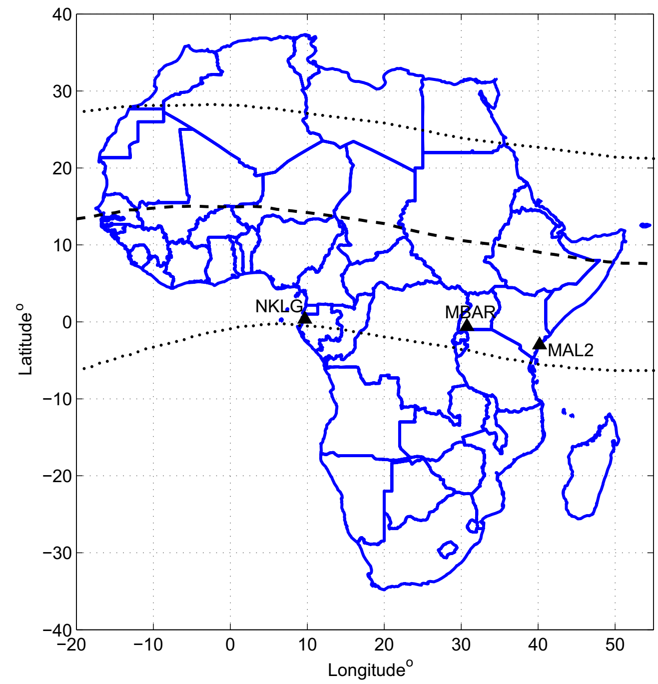

Fig. 1. African map showing (i) locations of IGS stations (triangles) MBAR, NKLG, and MAL2, (ii) the geomagnetic equator (dashed line), (iii) the anomaly crests geomagnetic latitudes $\pm 15°$ (dotted lines).

Table 1
GNSS receivers used in the study.

Station location	Country	Code	Geog. lat (°)	Geog. lon (°)	Mag. lat (°)
Libreville	Gabon	NKLG	0.35	9.68	−8.05
Mbarara	Uganda	MBAR	−0.60	30.74	−10.22
Malindi	Kenya	MAL2	−2.99	40.19	−12.42

2. The data and analyses

2.1. The data

The Receiver INdependent EXchange (RINEX) data files (navigation and observation) used in this study were obtained from the International GNSS Service (IGS) for Geodynamics stations at Libreville, Gabon (NKLG), Mbarara, Uganda (MBAR), and Malindi, Kenya (MAL2). Note that before the year 2009, MAL2 was known as MALI. The method of extracting the Vertical Total Electron Content (VTEC) from the data files in this study are similar to that found in Seemala and Valladares (2011). Quiet geomagnetic days were identified by examining the 3 hourly Kp index obtained from the World Data Center of Kyoto, Japan.[1] The TEC data for quiet geomagnetic days ($Kp \leq 3$) were considered in order to isolate the OII due to storms (Li et al., 2008). Fig. 1 shows the geographic distribution of the data sites, the geomagnetic equator with a dashed line, and the anomaly crests at geomagnetic latitudes ($\pm 15°$) in Africa with dotted lines.

Table 1 presents the summary of information about data sites used in this study.

2.2. Analyses of data

The rate of change of TEC index (ROTI) which was derived from the rate of change of total electron content (ROT) were used to represent ionospheric irregularities. These two indices have already been extensively discussed in Aarons et al. (1996); Pi et al. (1997); Basu et al. (1999); Zou and Wang (2009); Mungufeni et al. (2015). Before computing the ROTI, VTEC measurements with satellite elevation angle greater than 30° were considered in order to minimize the effects of multi-path on the observations, and the analyses were further limited to measurements made from satellites that were locked on for greater than 4 min to allow the receivers' detrending filter to stabilize, in case it had lost lock on the carrier phase.

The ROTI values for all satellites in view at the end of every 5 min (basic interval for computing the ROTI) were averaged to obtain 5 min resolution data for a day. Furthermore, the median of ROTI values every 5 min of all the days in the month with data were determined to represent ROTI for that month with a resolution of 5 min. The monthly median ROTI values are referred to as monthly ROTI from this point onwards. Fig. 2 shows the number of days with available data that were used in computing the monthly ROTI at NKLG (panel (a)), MBAR (panel (b)), and MAL2 (panel (c)) during 2001–2012. The horizontal and the vertical axes indicate the number of days with data and the year, respectively. No horizontal blue bar indicates missing data. The monthly ROTI computed using data of more than 5 days provided fairly good representation of ROTI of the month. So, we categorised such months as well represented. For example, in Fig. 2, October, 2002, February–June, 2003 are categorised as not well represented over NKLG (Fig. 2(a)). There are also similar observations for MBAR (May–June in Fig. 2(b)) and MAL2 (January in Fig. 2(c)) in different years.

[1] http://swdcwww.kugi.kyoto-u.ac.jp/