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Ionospheric scintillation observations over Kenyan region – Preliminary results

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Abstract

Ionospheric scintillation refers to the rapid fluctuations in the amplitude and phase of a satellite signal as it passes through small-scale plasma density irregularities in the ionosphere. By analyzing ionospheric scintillation observation datasets from satellite signals such as GPS signals we can study the morphology of ionospheric bubbles. At low latitudes, the diurnal behavior of scintillation is driven by the formation of large-scale equatorial density depletions which form one to two hours after sunset via the Rayleigh–Taylor instability mechanism near the magnetic equator. In this work we present ionospheric scintillation activity over Kenya using data derived from a newly installed scintillation monitor developed by CRIRP at Pwani University (39.78°E, 3.24°S) during the period August to December, 2014. The results reveal the scintillation activity mainly occurs from post-sunset to post-midnight hours, and ceases around 04:00 LT. We also found that the ionospheric scintillation tends to appear at the southwest and northwest of the station. These locations coincide with the southern part of the Equatorial Ionization Anomaly crest over Kenya region. The occurrence of post-midnight L-band scintillation events which are not linked to pre-midnight scintillation observations raises fundamental question on the mechanism and source of electric fields driving the plasma depletion under conditions of very low background electron density.

Keywords: Ionosphere; Scintillation; Low-latitude; Plasma depletions

1. Introduction

GPS scintillations at low latitudes are primarily associated with ionospheric irregularities with a spatial range extending from 100 km to less than 1 m (Kintner et al., 2007). The ionospheric irregularity develops shortly after sunset and propagates both upward and away from the dip equators driven by the electromagnetic equivalent of the Rayleigh–Taylor instability. As the lower density regions move upward into the higher density background ionosphere, it creates ionospheric irregularities which are commonly called as plasma bubbles. The existence of the plasma bubbles can be detected from the F-region electron density observations. The plasma bubbles are characterized by a dramatic drop of the electron density values along the line of sight that lasts for 10–60 min followed by a gradual recovery to the level preceding the reduction. Studies on the low-latitude F-region have associated the nighttime TEC depletion observations with plasma density depletions of equatorial origin (Dashora and Pandey, 2005; Beach and Kintner, 1999; Basu et al., 1999; Olwendo et al., 2012, etc.). The unique arrangement of the geomagnetic field and gravitational field at the dip equator combined with the electric field structure created by the interaction of thermospheric neutral winds and the ionosphere results into a number of fascinating physical phenomena such as

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ionospheric scintillation observations, equatorial electrojet, Equatorial Ionization Anomaly (EIA) and the evening plasma drift enhancement (Eccles, 1998).

The electrodynamics of the equatorial ionospheric E and F regions are mainly controlled by the electric fields generated by the plasma moving across the Earth's magnetic field pushed by the neutral wind. At the dip equator, the zonal electric field is of great significance for causing plasma to drift vertically which leads to the formation of the plasma fountain and the ionization anomaly crest. The zonal electric fields are also associated with the equatorial electrojet (EEJ); which is a narrow band of enhanced eastward current flowing in the E region within ±3° magnetic latitude (Eccles, 1998). The EEJ builds up after sunrise and maps the east-west electric field to the F-region altitude along the highly conducting geomagnetic field lines. Then the vertical E × B plasma drift forms under the interaction of this eastward electric field with the south-north component of the Earth's magnetic fields. During the daytime, the electric field is eastward and, therefore plasma drift is upward. The plasma drift reverses to downward at sunset. However, just before the drift reversal, the eastward drift is much enhanced. This enhancement is called the pre-reversal enhancement (PRE) of the F-region zonal electric field. The PRE is associated with the large uplift of the F-layer and the evening time resurgence of the EIA. The vertical uplift of the plasma layer helps in increasing the bottom side density gradient. Under certain conditions, a density perturbation on the bottom side of the F-layer can trigger the Rayleigh–Taylor (R–T) instability. Once the instability is triggered, density irregularities develop and field aligned depletions then bubble up through the F-layer (Schunk and Nagy, 2009).

Ionospheric density irregularities are a major impediment to satellite communication as they result in scattering of the incident radio waves. This leads to rapid fluctuations in the phase and amplitude of transionospheric radio signals, a phenomenon commonly known as ionospheric scintillation. Studies on the equatorial and low-latitude region using GPS signals have correlated the occurrence of the VHF scintillation with fluctuations in the Total Electron Content (TEC) (Dandekar and Groves, 2004). Since the TEC values are highest around the magnetic equator (more precisely, around the Appleton anomaly or the Equatorial Ionization Anomaly crests), any fluctuations in the TEC values at these latitudes would result in severe scintillation causing signal degradation. The data used for this study is from Pwani University near the Equatorial Ionization Anomaly crest and therefore well situated for the TEC and ionospheric scintillation observations. This is the motivation for the collaboration on ionospheric scintillation observations and analysis using satellite monitoring between China Research Institute of Radiowave Propagation (CRIRP, China) and Pwani University (Kenya). In this work we present the preliminary results for ionospheric scintillation observations over Kenya.

2. Data analysis

The Ionospheric scintillation is characterized by rapid fluctuations in the amplitude and phase of trans-ionospheric radio signals due to variations in the local index of refraction along the propagation path. The amplitude scintillation index which is commonly referred as the S_4 index is defined as the normalized standard deviation of the received signal intensity expressed as (Kintner et al., 2007);

$$S_4 = \frac{\sqrt{\langle I^2 \rangle - \langle I \rangle^2}}{\langle I \rangle} \tag{1}$$

where I represents the detrended signal intensity. The ionospheric scintillation monitor used for the work reported here was developed by China Research Institute of Radiowave Propagation (CRIRP). Its hardware is composed of a Canadian NovAtel dual-frequency OEM GPS receiver, a low-noise crystal oscillator, power supply, receiving feeding circuit and a computer. Its operational software consists of some functional modules for serial port communication, data acquisition, processing control, data preprocessing, data storage and visualization graphics display. The monitor records the intensity and phase of GPS L1 signals with a 50-Hz sampling frequency, as well as azimuth and elevation of the satellite. The real-time measurements are conveyed to the computer through the serial port. Then the mean value, maximum, minimum of signal amplitude and scintillation index are calculated. These calculated scintillation index and associated location information can be utilized to implement display, storage and callback as well as the judgment of whether an ionospheric scintillation event occurs. To filter out the high frequency noise effects in the amplitude and phase measurement dataset, a six-order Butterworth filter with a 0.1 Hz 3 dB cutoff frequency was used. Then the detrended data is used to obtain the amplitude scintillation index according to Eq. (1). The process to detrend the phase scintillation data is the same, but the filter is a high-pass filter. Then the phase scintillation index is computed as

$$\sigma_\varphi = \sqrt{\langle \varphi^2 \rangle - \langle \varphi \rangle^2}, \tag{2}$$

where φ represents the signal phase (in radians). More details about the filtering process and computation of scintillation index can be found in Van Dierendonck et al. (1993). At lower elevation multipath could be mistaken for scintillation. To avoid that, the dataset with elevation angle less than 20° is discarded.

3. Observations, results and discussion

3.1. General features of scintillation observations

Fig. 1 shows the diurnal variation of L-band scintillation index from all satellites in view on 9 and 17 August,