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Prediction of ionospheric scintillation using neural network over East African region during ascending phase of sunspot cycle 24

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Abstract

VHF and GPS-SCINDA receivers located both at Nairobi (36.8°E, 1.3°S) in Kenya and at Kampala (32.57°E, 0.335°N) in Uganda were used to investigate ionospheric scintillation and forecast scintillations of a few hundred meter-scale irregularities associated with equatorial ionospheric irregularities for the period 2011 and 2012. VHF scintillations was characterized by long duration of activity and slow fading that lasted till early morning hours (05:00 LT). Furthermore, different percentage occurrence of scintillations in some months were observed, but found that weak scintillation ($0.2 < S_4 \leqslant 0.4$) was more dominant throughout the period. The occurrence of scintillations was more dominant in the equinox season than in the solstice season which had the same trend as the sunspot number. The enhancement of pre-midnight scintillations during magnetically disturbed and quiet periods was also observed and found to be seasonal and local time dependent. An attempt was made to develop a model of percentage occurrence of scintillations for the ascending phase of solar cycle 24 using neural network and the modeled data for the occurrence of scintillations was found to match well with original data.

Keywords: VHF scintillations; L-band scintillations; Neural network

1. Introduction

During a period of solar maximum, solar radiation increases and this in turn increases the irregularities in the ionosphere. These ionospheric irregularities are mainly experienced in the equatorial ionization anomaly (EIA) region. These ionospheric irregularities are known to cause scintillations of radio signals and can affect communications and navigation signals, hence degrading the performance of global navigation satellite systems (GNSS) (Basu et al., 1988). These irregularities have not been fully studied in the East African region and therefore there is need to accurately investigate and identify these irregularities using GPS and VHF data and develop a model for the occurrence probability of the ionospheric scintillation activities over the region.

Studies by various groups (Basu et al., 2001; Groves et al., 1997; Huang et al., 2002) have shown that scintillations predominantly occur in a band approximately ±20° of the magnetic equator and in the polar and aurora regions. Results from these studies have also shown that equatorial scintillations are produced by irregularities created by bubbles of low density plasma that form at the bottom of the F-region ionization layer and penetrate upwards through the denser top-side ionosphere, just after sunset. As the plasma is lifted upwards, it diffuses downward along geomagnetic field lines towards higher latitudes under the influence of gravity and pressure gradients and produces what is known as the equatorial ionization anomaly. This creates two peaks of ionization on either side of the magnetic equator, leaving the a depletion at the equator. Plasma density irregularities which encompass a wide range

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of scale sizes are referred to as the Equatorial spread-F (ESF) (Valladares et al., 2004). Scintillations are also found to be strongest from local sunset until just after midnight, and during periods of high solar activity (Valladares et al., 1996). To investigate these irregularities, GPS receiver and VHF antennas were used to record and determine these scintillations in the same areas. A model used to predict scintillation, will help to warn users of the probable times scintillations might take place.

The irregularities in the night-time equatorial ionosphere in East Africa have not been fully studied to understand their occurrence pattern and varying characteristics from one night to another. The irregularities that have been studied are found to vary with season, latitude, longitude, solar and magnetic activity, thus causing scintillations on very high frequency (VHF), and L- band signals (Huang et al., 2002; Lee et al., 2005; D'ujanga and Taabu, 2014; Olwendo et al., 2013). The ionospheric irregularities span a large range of scale sizes extending over several orders of magnitude. Of these, the intermediate scale length (100 m to a few km) irregularities cause scintillation effects on UHF and L-band signals. Systems used to observe scintillations on UHF/VHF signal, transmitted from a geostationary satellite and recorded using single and spaced ground receiver systems have been extensively used to monitor the intermediate scale length irregularities (Basu and Kelley, 1979; Aarons et al., 1983; Gupta et al., 2008).

Ionospheric irregularities are of serious concern to communication and navigation systems because they affect the amplitude and phase of the satellite signals as they pass through the ionosphere. The amplitude variation may induce signal fading, and when the depth of fading exceeds the fading margin of a receiving system, message errors are encountered (Yeh and Liu, 1982) and if navigation depends on only the GPS, then the amplitude fluctuations may lead to data loss and cycle slips (Aarons and Basu, 1994).

The GPS satellites are known to transmit signals that propagate through the ionosphere which exists at about 60 km to 1,500 km above the Earth's surface (Warnant et al., 2007). The free electrons populating this region of the atmosphere affect the propagation of the signals, changing their velocity and direction of travel. Due to the inhomogeneity of the propagation medium in the ionosphere, the GPS signal does not travel along a perfectly straight line (Ioannides and Strangeways, 2000). The effects of the ionosphere can cause range-rate errors for users of the GPS satellites who require high accuracy measurements (Bradford et al., 1996). A GPS receiver can track up to 11 GPS Coarse/Acquisition (C/A) code signals at L1 frequency (1575.42 MHz) and collect data at every one minute interval and the data can be used to obtain the statistical parameters like scintillation index (S_4), and the standard deviation of phase and receiver lock, for each satellite being tracked. The S_4 index is defined as the standard deviation of normalized intensity of the signal and is used to monitor the strength of amplitude scintillation on the L1 frequency (Sripathi et al., 2011).

VHF spaced receiver scintillation instrument can provide details about the nature of the irregularities such as maximum cross-correction between intensity variation recorded by two receivers, turbulence parameter and mean zonal drift velocity in addition to the S_4 (Briggs, 1992). These small-scale ionospheric irregularities cause degradation of radio signals on trans-ionospheric links and they are formed at the bottom of the F region during post-sunset period due to the Rayleigh–Taylor gravitational instability mechanism. During post-sunset, the lower regions of the F-layer recombine more rapidly than the upper regions, leading to an unstable situation similar to a heavy fluid being supported on a lighter fluid. This situation eventually leads to the formation of plasma depleted flux tubes (plasma bubbles) which are forced upwards through the denser upper regions making the development of post-sunset equatorial spread F (Abdu et al., 2006).

The study of different characteristics of irregularities during magnetic storm gives insight into the role of electric fields of magnetospheric origin (De Paula et al., 2004) in the irregularity process and is of interest in the impact on global VHF/UHF communication systems (Basu et al., 2001). One important parameter responsible for the growth of ionospheric plasma instabilities after sunset is the equatorial upward vertical plasma drift (Abdu et al., 2006) which is driven by the F-layer dynamo zonal (eastward) electric field, known as the pre-reversal electric field.

The scintillation intensity index, S_4, is defined as the standard deviation of the signal intensity, I, taken over 60 s, normalized by the mean signal intensity over this same interval. S_4 proxy is got from;

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

Models are needed to forecast ionospheric scintillations in the equatorial region given the fact that severe scintillations have been recorded within this region. These scintillations affect space based communications and navigation systems. Das et al. (2010) used artificial neural network for probability occurrence of scintillations from the rising and the lowering solar cycle 23. Pietrella (2012) developed a short-term ionospheric forecasting empirical regional model (IFEM) to predict the state of the critical frequency of F2 layer (foF2) under different geomagnetic conditions in Europe. Oyeyemi et al. (2005) used artificial neural network for prediction of foF2 over Nigeria.

The use of NNs is generally motivated by their principal ability to deal with non-linear behavior, thereby establishing and modeling the non-linear dynamical processes. These non-linear behaviors are associated with the F2 region of the ionosphere due to its non-linear dynamic processes arising from solar photon flux, geomagnetic activity and global thermospheric circulation. Feed forward NNs with back propagation have been previously used to solve many problems in Geophysics (Das et al., 2010).