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Characterization of ionospheric scintillation at a geomagnetic equatorial region station

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Abstract

In this study, we analyzed ionospheric scintillation at Bahir Dar station, Ethiopia (11.6°N, 37.38°E) using GPS-SCINDA data between August 2010 and July 2011. We found that small scale variation in TEC caused high ionospheric scintillation, rather than large scale variation. We studied the daily and monthly variations in the scintillation index S_4 during this year, which showed that scintillation was a post-sunset phenomenon on equinoctial days, with high activity during the March equinox. The scintillation activity observed on solstice days was relatively low and almost constant throughout the day with low post-sunset activity levels. Our analysis of the seasonal and annual scintillation characteristics showed that intense activity occurred in March and April. We also studied the dependence of the scintillation index on the satellite elevation angle and found that scintillation was high for low angles but low for high elevation angles.

Keywords: Elevation angle; Equinox; Ionospheric scintillation; Scintillation index S_4; Solstice; Spread F

1. Introduction

When a GPS signal passes through the Earth's ionosphere it encounters time-varying electron density irregularities, and thus it exhibits rapid fluctuations in amplitude and phase, which are not consistent with the source strength (Li et al., 2010; Kintner et al., 2007). This rapid fluctuation in amplitude and phase is called ionospheric scintillation (Moraes et al., 2012; Seo et al., 2007) and it can affect ground to satellite-based communications such as radio communications and navigation, as well as space weather in general. When the scintillation intensity is very high, the signal will be very weak and the receiver will not receive the signal in extreme conditions, which is called a loss of lock (inability to receive signals from GPS satellites) (Kintner et al., 2007). According to Fresnel diffraction theory, the incident signal can be considered as a plane wave divided into different zones called Fresnel zones, which is expressed mathematically as:

$$\rho_n = \sqrt{n\lambda L}, \tag{1}$$

where ρ_n is the size of the Fresnel zones, n is an integer, L is the distance from the receiver on the ground to the irregularity region in the ionosphere, which is about 350 km (i.e., the height of the F_2 peak), and λ is the wavelength of the GPS signal. At a GPS L1 frequency of 1575.42 M Hz ($\lambda = 0.19$ m), ρ_1 will be 259 m; therefore, a GPS signal passing through irregularities comparable to this size (first Fresnel zone) will be diffracted with different phases. When signals with different phases reach the receiver at the same time, they will interfere with each other and degrade the signal quality. The satellite, ionosphere, and the Earth are all moving with respect to each other, so the receiver experiences alternating periods of constructive or

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destructive interference, which results in fluctuations in the phase and amplitude of the signal received (Moraes et al., 2012; Kintner et al., 2007).

Scintillation is caused by irregular electron densities in the ionosphere, but it can also be caused by the so-called multipath effect (Ackah et al., 2011), which occurs when a GPS signal from a satellite is reflected back to the receiver and it interferes with the signal that is received directly.

As shown in Fig. 1, signals reflected at an oblique incident angle reach the receiver and thus the antenna reads the scintillation. According to Wernik et al. (2008) and Aquino et al. (2009), the multi-path effect is dominant at a satellite elevation angle of less than 30° because a signal from a satellite at a low elevation angle is more likely to encounter obstacles such as mountains and buildings than a signal from a satellite at a high elevation angle. Thus, by observing the day-to-day scintillation pattern, we can differentiate between scintillation caused by the multipath effect or due to ionospheric irregularities. The multipath effect tends to repeat from day to day because it is a function of the relative satellite receiver positioning, which repeats every 24 h (Kintner et al., 2007), so the satellite will be at the same location and elevation angle at the same time each day.

The fluctuations in the signal intensity or severity of amplitude scintillation are measured by the scintillation intensity index S_4, which is defined as the normalized variance of the signal power (Moraes et al., 2012; Wernik, 2004):

$$S_4 = \sqrt{\frac{\langle I^2 \rangle + \langle I \rangle^2}{\langle I \rangle^2}}, \tag{2}$$

where I is the signal intensity (amplitude squared) averaged for 60 s. However, according to Kintner et al. (2007), this time can be larger or smaller than this value. The time period must be long compared with the Fresnel length divided by the irregularity drift velocity. Therefore, the intensity averaging time must be long compared with the time taken for the irregularity region to fully cross a signal that passes through the ionosphere (Kintner et al., 2007). As shown by Eq. (2), S_4 is the signal intensity standard deviation divided by the signal intensity mean, which provides us with the fractional intensity fluctuation. The value of S_4 ranges between 0 and 1, where $S_4 = 0$ indicates no intensity modulation (change) and $S_4 = 1$ indicates that the signal intensity is 100% modulated (Carrano and Groves, 2006).

Ionospheric scintillation activity occurs mainly in equatorial and high latitude regions of the Earth (Li et al., 2010; Aquino et al., 2009; Kintner et al., 2007). At high latitudes, it occurs due to electron precipitation from the solar wind into the ionosphere. In this region, irregularities at altitudes of 100–500 km lead to scintillation (Skone and Jong, 2000). In equatorial and low latitude regions, scintillation is related to the spread F (Aquino et al., 2009; Kintner et al., 2007). A brief discussion of the spread F and ionospheric scintillation was provided by Alfonsi et al. (2013). According to their findings based on observations in Tucumán, Argentina, there were correspondences between the frequency spread F and amplitude of the scintillation peaks at around 10:00–11:00 UT (06:00–07:00 LT) during the summer and at equinoxes, but slightly later at 12:00 UT (08:00 LT) in the winter.

2. Data and analysis method

The Scintillation Network and Decision Aid (SCINDA) is a network of ground-based GPS receivers installed around equatorial regions. This network of GPS receivers monitors scintillation at the UHF and L-band frequencies in the equatorial region ionosphere. The equatorial and low latitude regions experience the highest global levels of scintillation, so the receivers are positioned between the ionization crests of the Appleton anomaly (Carrano and Groves, 2006).

This network was established by the US Air Force Research Laboratory and it is monitored by this organization (Carrano and Groves, 2006). The data used in this study were obtained from a dual frequency GPS receiver installed in Bahir Dar, Ethiopia (geographic: 11.60°N, 37.38°E, and geomagnetic: 8.08°N, 111.57°E), which is one of the many receivers in the SCINDA network. The

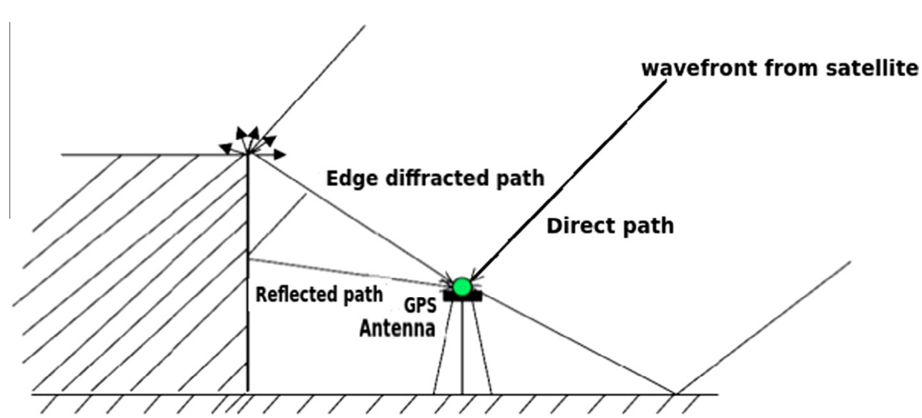

Fig. 1. Schematic diagram showing the multipath effect (adopted from Ackah et al. (2011)).