A characteristic analysis of low-latitude NavIC signal intensity fading

Deepthi Ayyagari* and Abhirup Datta(1)
(1) Department of Astronomy, Astrophysics and Space Engineering, IIT Indore, Madhya Pradesh -453552, India

Abstract

The current work for the first time aims to characterize the ionospheric scintillation on NavIC signals using Nakagami and $\alpha - \mu$ distribution as a representation of the fading effect. A clear depiction of the fading effect caused by scintillation on NavIC signals for an intense geomagnetic storm where the Dst Index has dropped to a minimum value of 124nT. The observed values of carrier to noise ratio (dB-Hz) for PRNs 2, 5 and 6 have dropped below 30 dB-Hz and have approached to value of zero between 22:00 to 0 LT(h). The severity of $S_4$ index during that time peaked beyond the value of 0.5 as observed from PRN 2 of NavIC and the value of intensity fading that has reached up to -8dB. This paper lays the foundation for the intensity fading study of NavIC signals over region near EIA and another region near to magnetic equator on September 8, 2017.

1 Introduction

Ionospheric scintillations cause rapid changes in the phase and amplitude of the radio signal as it travels through the ionosphere. This phenomenon is dominant near equatorial regions ranging from -20° to 20° latitude and the auroral zone spanning from 55° to 90° latitude. It is difficult to predict and model ionospheric scintillations in the Equatorial ionization anomaly (EIA) regions due to the variability of many factors such as solar activity, interplanetary magnetic field conditions, local electric field, conductivity, convection processes, and wave interactions. Several researchers have used GPS data to study the phenomenon of ionospheric scintillation, as well as its causes and effects during extreme geomagnetic activity, over last few decades.[1]

2 Data and Locations of Observations

A multi-constellation, multi-frequency NavIC receiver provided by Space Applications Centre, ISRO, intercepting GPS L1, NavIC L5, and NavIC S1 (2492.028 MHz) signals, has been operational at DAASE in the Indian Institute of Technology, Indore, since May 2017. In addition to the NavIC data from the Indore (Lat:22.52°N, Lon:75.92°E; Magnetic dip:32.23°N) station[2], the current study makes use of NavIC data from the Osmania University (OU), Hyderabad (Lat: 17.40°N, Lon: 78.51°E; Magnetic dip: 21.69°N) station as shown in Figure1.

3 Scintillation Events: Selection Criteria

In support with NOAA scales, 27 days are selected out of 607 days analysed spanning from September 1, 2017 to September 30, 2019 for both the stations, based on the following[3, 4]:

1. The masking angle is set to 20° to reduce multipath effects for elevation in the data sets and the $S_4$ is filtered so that the threshold value for $S_4$ = 0.3.
2. The event does not qualify as a scintillation event unless it remains above this threshold value for at least 30 seconds, and any event that begins within five minutes of the previous event is not treated as a separate event in order to avoid certain interference effects.
3. The $S_4$ events observed from multiple satellites at the same time are analysed separately.
4. For the analysis, events with a loss-of-lock (LoL) lasting more than 120 seconds are considered.

The LoL is defined in this work as the receiver’s ability to lose track of a transmitting satellite. For the duration of this time interval, the receiver will be unable to log any phase or pseudorange observations. Following the above criteria and analysing the entire 25 months of NavIC Indore observations, only 27 days qualify as scintillation events, i.e., only 4% of the nights in the total duration of the scintillations...
have been detected in the analysis, and these occurrences were chosen based on the distribution along the period of the study. In this paper we present the observational analysis a typical scintillation event occurred on September 8, 2017.

4 Analyzing and Characterizing: Amplitude Scintillation

On of the pre-dominant mechanisms which generate the amplitude scintillation in the equatorial and low latitude regions is the Pre-reversal Enhancement. This is generated as a result of the enhancement in the vertical E×B drift due to the eastward electric field at the sunset terminator generating Equatorial Plasma Bubble (EPB) and Equatorial Spread F (ESF) around this time[5]. The ionospheric TEC is derived by extracting ground-based observables from raw data files of NavIC. For each slant path between the satellite and the receiver, a slant TEC can be calculated with an assumption that the ionosphere is a thin shell (at 350 km altitude). The rate of change of slant TEC (ROT)10, provides an estimate of the ionospheric disturbances. In fact, a rate of slant TEC index that takes into account the average altitude). The rate of change of slant TEC index by the following notation where $\alpha$ is the modulus of sum of the multipath components and $\mu$ is the number of multipath components and the al pha − mu probability density function, assuming that the average signal power (or intensity) $r^2$ is equal to 1 for $E[R^2] = 1$ is defined as[11]:

$$f(r) = \frac{\alpha \mu - 1}{\varepsilon \mu^\beta} \exp\left( - \frac{r^\alpha}{\varepsilon \mu^\beta} \right),$$

where

$$\varepsilon = \frac{\Gamma(\mu)}{\Gamma(\mu + 2/\alpha)}$$

in which $\Gamma(.)$ is the gamma function. $S_\alpha$ index characterizes the strength of amplitude scintillation where the intensity of received signal $I = |r|^2$. The Nakagami-m parameter in the Nakagami distribution can be related to $S_\alpha$ index by the following notation where $m = 1/S^2_\alpha$ and the relation to estimate this is given below[11]

$$m = \frac{E^2(r^2)}{E(r^4) - E^2(r^2)}$$

By comparing Eq.4 with Eq 7, the left-hand side of equation (4) can be derived from field data for randomly chosen values of the parameter $\beta$, which provides the order of system of $r$ to be determined. In fact, when the left-hand side
of equation (4) for \( \beta = 2 \) is compared to the right-hand side of equation, the following results are obtained[11, 12]:

\[
\begin{align*}
S_{4c}^2 &= \frac{\Gamma(\mu)\Gamma(\mu + 4/\alpha) - \Gamma^2(\mu + 2/\alpha)}{\Gamma^2(\mu + 2/\alpha)} \tag{5}
\end{align*}
\]

If \( \alpha = 2 \) in the above equation (5) and the properties of the gamma function are used, the value of the left hand side of the same equation implies \( 1/\mu = 1/m \), which is the condition for the Nakagami-m distribution.

Figure 4. Intensity fading occurrences along with the \( \alpha - \mu \) distributions and the Nakagami-m distribution as observed by NavIC PRNs’ over Indore on September 8, 2017.

Figure 5. Intensity fading occurrences along with the \( \alpha - \mu \) distributions and the Nakagami-m distribution as observed by NavIC PRNs’ over Hyderabad on September 8, 2017.

5 Conclusions

A systematic study over the variable low-latitude region surrounding the EIA and the magnetic equator is essential to understand the low latitude and equatorial ionosphere. A study using NavIC, for the first time, under low solar activity conditions is presented here. Our work demonstrates how difficult it is for the receiver to retain lock as signal quality degrades. As a result, defining the statistics of these fades is crucial for estimating the effects of these phenomena and aid in the development of processing techniques and positioning algorithms that will reduce these effects in the receiver.

6 Acknowledgements

DA acknowledges the INSPIRE fellowship from the Department of Science and Technology, which she used to pursue her research. The authors also thank SAC, ISRO for providing the NavIC ACCORD receiver to the Department of Astronomy, Astrophysics, and Space Engineering, IIT Indore, under the NGP-17 project. The authors wholeheartedly thank Dr. P. Naveen Kumar for providing NavIC Osmania University (OU) Hyderabad station’s data.

References


A Calculating Amplitude Scintillation: $S_4$, index, ROT, ROTI and Scattering Coefficients

The $S_4$ index is then calculated defined as the signal’s normalised variance of intensity, which is expressed as[1, 7]:

$$S_4 = \sqrt{\langle S_i^2 \rangle - \langle S_i \rangle^2} / \langle S_i \rangle$$

where $S_i$ is the intensity of the signal which is given as

$$S_i = 10^{0.1C/N_0}$$

Now subtracting equation (8) from equation (6) the real estimate for $S_4$ is obtained as shown below which is the ambient noise ($S_{AN}$) free index:

$$S_{4c} = S_4 - S_{AN}$$

ROT and ROTI[13] values are calculated as given in equations below where in equation (10) $STEC_{r+1}$ and $STEC_r$ are slant TEC at $r+1$ and $r$ time epochs; $\Delta r$ time interval; usually the unit of ROT is TECU/min and in equation (11) where $\langle ROT \rangle$ denotes averaging ROT during $N$ epochs.

$$ROT = \frac{STEC_{r+1} - STEC_r}{\Delta r}$$

$$ROTI = \sqrt{\langle ROT^2 \rangle - \langle ROT \rangle^2}$$

A scattering coefficient[14] across a pair of frequencies was later defined as the difference of $C/N_0$ fluctuations normalised with respect to the amount of those fluctuations, based on these computed $C/N_0$ deviations. The formula for scattering coefficient is given by (12) where $a$ is the $C/N_0$ deviations calculated from one frequency is substituted and $b$ is the $C/N_0$ deviations calculated from second frequency respectively. Here $S_{ab}$ is a dimensionless quantity with values near zero suggesting good similarity between the signals.

$$S_{ab} = \frac{a - b}{a + b}$$