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TEC based Phase Jitter for GNSS Receiver

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ABSTRACT

An approach to mitigate the effect of ionospheric scintillation on GNSS users in the European region using TEC at 1 Hz rate is presented. The TEC in the study is derived using raw GPS observations obtained from the EUREF. The study also presents derivation of block-map warning of the expected standard deviation of phase jitter in carrier tracking loops which information would help to mitigate scintillation effects in GPS software receivers.

Key words: GPS, Ionospheric Scintillation, GNSS, GPS Software Receiver.

1 INTRODUCTION

Scintillation indices are often measured over one minute which for phase is the standard deviation in radians over this period and for amplitude (S4 index) the normalized standard deviation of the intensity. During the scintillation, the intensity of a received GPS signal is reduced so that it sometimes falls below the sensitivity (threshold) of the receiver. This and/or the addition of extra disturbance of the phase of the signal, also associated with the scintillation, can cause the carrier tracking loop of a GPS receiver to lose lock.

In the GPS receiver, the front end down-converts the GPS frequency to a lower intermediate frequency (IF) which is then used in acquisition and demodulation of the navigation data stream in the code and carrier tracking loops in order to determine the receivers position. The equation (1) mathematically represents the GPS signal (single frequency CA code) $S(t)$ at the IF frequency without any additional noise or ionospheric scintillation. However, during ionospheric scintillation, extra phase and/ or amplitude distort the GPS signal $S(t)$, modifying it to the new signal $R(t)$ as shown in equation (2):

$$S\left(t\right) = AC\left(t\right)D\left(t\right)\cos\left(\omega_{IF}t+\phi\right) \tag{1}$$

where A is the received amplitude, $C(t)$ is C/A code, ω_{IF} is the down converted (from $L1/L2$) carrier frequency, $D(t)$ is the navigation data bit at 50Hz sample rate and is ϕ phase due to Doppler.

$$R\left(t\right) = A\delta AC\left(t\right)D\left(t\right)\cos\left(\omega_{IF}t + \phi + \phi_I + \phi_o\right) \tag{2}$$

where δA and ϕ_I characterize extra amplitude and extra phase modulation due to ionospheric scintillation, while ϕ_o phase variation due to other sources; its effect is considered to be very small and so is neglected in this study. The $R(t)$ signal passes through the code and carrier tracking loop and then after the C/A code is removed using the code delay loop, the signal passes through the comparator in the carrier tracking loop. Basically, it compares the incoming phase ϕ_{IF}, and ϕ_f ($\phi_e = \phi_{IF} - \phi_f$) generated by NCO (Numerically Control Oscillator), which is theoretically equal to the IF frequency. During phase scintillation, ϕ_{IF} (the phase in equation 2) can be very large and so also then is the phase error ϕ_e which of course depends on ϕ_f from the NCO. The value of ϕ_f can be controlled if one knows the scintillation level or at least have received some regional alarm index. Although it is not possible for generic GPS receivers to mitigate scintillation effects, studies have shown that ionospheric scintillation can be mitigated using GPS software receivers which basically update their loop parameters e.g. increasing the loop bandwidth based on some prediction model such as WBMOD or a regional alarm index. The next section discusses how such a regional model can be used by a software receiver to mitigate ionospheric scintillation.

2 EXPERIMENTAL SETUP AND METHODOLOGY

Over the last two decades, the strength of scintillation from ionospheric irregularities has been extensively studied using the time derivative of TEC (Total Electron Content) and this has been correlated with ionospheric scintillation[1, 2]. In a recent study, Tiwari et al. derived an analogous phase scintillation index $\sigma_{\phi a}$ (in radians) given in equation (3) using high pass filtered RoT at 1 Hz rate[3]. The study shows a good correlation with phase scintillation observed during geomagnetic storms in the high latitude region, together with its consequent standard deviation of phase jitter on the PLL loop of a GPS receiver during moderate to strong phase scintillation.

$$\sigma_{\phi a} = \left[\varpi\left(\chi\left(M\right), v_p\right) \times \sigma_{VTEC'_{HPF}}\right] \tag{3}$$

where $\varpi\left(\chi\left(M\right), v_p\right)$ is the elevation weighted function given in equation (4):

$$\varpi\left(\chi\left(M\right), v_p\right) = \frac{2\pi S\ 40.3}{cf} \times \left[\chi\left(M\right), v_p\right] \tag{4}$$

where S is a proportionality constant 0.003, and $\chi\left(M\right)$ is the mapping function in equation (5) and is based on SV elevation angle at two consecutive epochs, v_p is IPP velocity.

$$\chi\left(M\right) = \frac{1}{\left(M_i M_{i+1}\right)^2} \tag{5}$$

The derived index seems useful model for estimating standard deviation of phase jitter on a PLL as in equation (8)[3].

$$[\sigma_{R\phi}] = 1.8\sigma_{\phi a} + 6.6 \qquad (6)$$

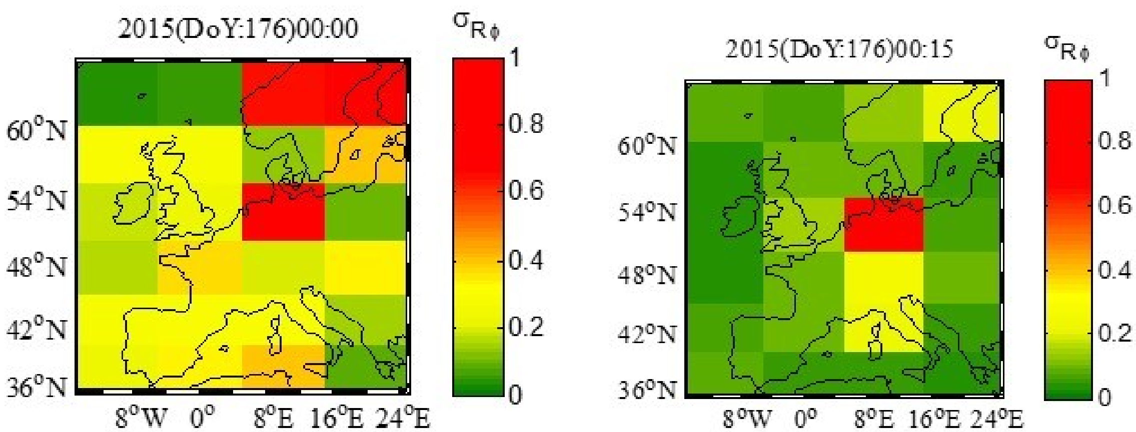

Figure 1: Phase jitter usng TEC based index on 25 June, 2015.

3 SUMMARY

In Figure 1, the phase jitter for an event recorded on 25 June 2015 is observed using TEC derived index. Further in this study the strong, moderate and weak scintillation events will be discussed in addition to the statistical analysis to test the reliability of the TEC based phase jitter.

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