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IMPROVED PHASE AND AMPLITUDE SCINTILLATION INDEX DERIVED FROM WAVELET-DETRENDED HIGH LATITUDE GPS DATA

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Abstract. The accuracy and validity of scintillation indices (amplitude and phase) estimated using GPS signals depends heavily on the detrending method used and the selection of the cutoff frequency of the filter. A Butterworth filter with a constant cutoff frequency of 0.1 Hz (assumption of fixed Fresnel frequency) is commonly used in detrending GPS data. In this study, using high data-rate GPS measurements from high latitudes, the performance of the commonly used Butterworth filter is evaluated and compared with a new wavelet-based detrending method. We have considered around 90 scintillation events and compared phase and amplitude scintillation indices derived using Butterworth- and wavelet-based detrending methods. The correlation between amplitude and phase scintillation indices (S_4 and σ_ϕ) improved from 0.4 (using a Butterworth filter) to 0.7 (using the wavelet method). We also introduced an improved phase-scintillation index (σ_{CHAIN})) and compared it with the amplitude-scintillation index and the correlation between the amplitude and phase scintillation indices improved further (0.8). During the analysis we also noted the phase scintillation without amplitude scintillation phenomenon completely disappeared when using the wavelet-based detrending method. This confirms earlier suggestions that the lack of amplitude scintillations is due to improper detrending caused by the use of default constant cutoff frequencies using Butterworth filters, especially at high

latitudes. These results indicate that wavelet-based detrending is better suited for GPS scintillation signals and also that CHAIN is a better parameter to represent GPS phase scintillations at high latitudes.

1 INTRODUCTION

The Global Positioning System (GPS) is an ideal system to study ionospheric scintillations[1,2] at L band frequencies given its spatial and temporal availability. Commonly used scintillation indices are S4 (amplitude scintillation), which is the standard deviation of the amplitude signal divided by its mean, and σ_ϕ (phase scintillation), the standard deviation of the phase. An issue creating a concern for GPS scintillation studies in high latitudes is the occurrence of phase scintillations without amplitude scintillations[3,4]. This was thought to be explained on the basis of a weak scattering approximation[5] but recent studies[6,7] have indicated that it is the use of default cutoff frequencies in detrending filters designed for mid-latitudes that is causing these events. We also think that receivers that use Butterworth filters are not able to detrend precisely since these filters would not give an accurate result for a non-stationary signal[8]. In this study, we used wavelets to detrend scintillations since wavelet transforms preserve the information about local features of the signal[8,9,10]. GPS data used in this study was obtained from CHAIN[11] (Canadian High Arctic Ionospheric Network) GPS receivers. These receivers[11,12] are capable of reporting scintillation indices (S_4 and σ_ϕ) as well as log high rate (50 Hz) raw power and raw phase (ϕ) of the GPS L1 signal.

2 ANALYSIS AND RESULTS

As mentioned before, we used wavelets to detrend the raw signals and these wavelet-detrended measurements were then used to calculate the scintillation indices. Details about the continuous wavelet transformations we used can be obtained from previous studies[9,10,13]. Wavelet coefficients thus obtained are used to build up wavelet energy plots usually know as scalograms[9,10]. As previous studies[10] indicated, we saw a three-band scale structure in these scalograms namely large-scales, mid-scales and small-scales. In our study, we detrended both amplitude and phase signals by removing the large-scale band (trends) and small-scale band (noise), and then reconstructed the signals using just the wavelet coefficients related to the mid-scales (scintillations). Recently, [7] introduced a phase-scintillation index which was considered independent of the cutoff frequencies used in the detrending filters. In this study, we call it Forte's scintillation index, σ_{Forte} (1).

$$\sigma_{Forte} = \sqrt{\langle \frac{\partial \phi}{\partial t} \rangle^2} \tag{1}$$

Figure 1 shows detrended phase, σ_{Forte} and σ_{CHAIN} (see below) values for an ionospheric scintillation event on 25 November 2008 at Taloyoak ($69.54^{O}N, 266.54^{0}E, geog.$) between 6:10 UT and 6:40 UT on GPS satellite PRN 14. In this figure, one can see three scintillation signatures in the detrended phase with different scales of intensity. Now, if one observes the σ_{Forte} values, it is seen that all three scintillation signatures have very similar values. σ_{Forte} is providing these inaccurate results as it is only considering how fast phase is fluctuating. In our study, we introduce another new scintillation index, the CHAIN scintillation index (σ_{CHAIN}) (2), for our wavelet-detrended GPS data, which takes into account how large the phase fluctuations are as well as the rate of change of phase. In Figure 1, one can precisely infer the level of scintillation from the σ_{CHAIN} values.

$$\sigma_{CHAIN} = \sqrt{\langle (\frac{\partial \phi}{\partial t})^2 |\sigma| \rangle} \tag{2}$$

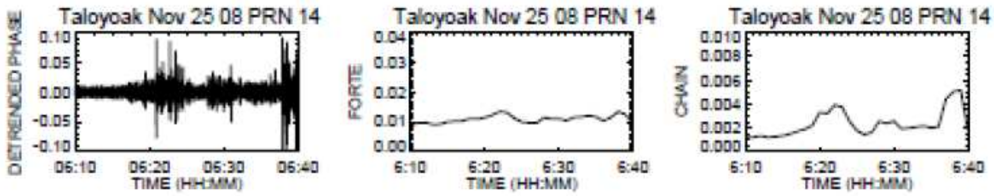

Figure 1: This figure shows detrended phase and the corresponding σ_{Forte} and σ_{CHAIN} values for active ionospheric periods.

To obtain a better understanding of the relation between amplitude scintillations and phase scintillations, we obtained correlation coefficients between amplitude scintillation index and different phase-scintillation indices used in this study. For this correlation analysis (Figure 2), we have used data from 90 scintillation events observed on different satellites from all CHAIN sites. It should be noted that whenever scintillation was observed in a particular hour, data from the whole hour was considered. Data associated with filter edge effects was discarded as was data obtained when satellites were below 20^o elevation angle or when there were phase cycle slips.

3 CONCLUSIONS

As predicted by previous works[8,9,10], we have shown that wavelet-based detrending is a better approach for estimating scintillation indices. Wavelets, when used for detrending, seem to eliminate slow trends and noise and leave behind information pertaining to scintillations only. Previous studies[6,7] have indicated that the slopes of power spectrum densities of both amplitude and phase scintillations have the same value for frequencies higher than the Fresnel frequency. So, if one can detrend both amplitude and phase scintillations precisely, a good correlation should be expected between them and this is seen when wavelets are used (Figure 2(b),2(c)). Phase scintillations without amplitude scintillations were observed in the data obtained from receivers located at high latitudes with low correlation (0.41) between amplitude and phase scintillations. These receivers[12] used Butterworth filters with default cutoff frequencies. When wavelet-detrended data was used, a significantly higher correlation (0.75) was observed. We further improved this correlation (0.82) by using σ_{CHAIN} (Figure 2(c)). These results show that an inaccurate method of detrending is likely responsible for the apparent occurrence of phase scintillations without amplitude scintillations and also that wavelets seem to be a better approach for detrending GPS signals with σ_{CHAIN} being a better indicator of GPS phase scintillations at high latitudes.

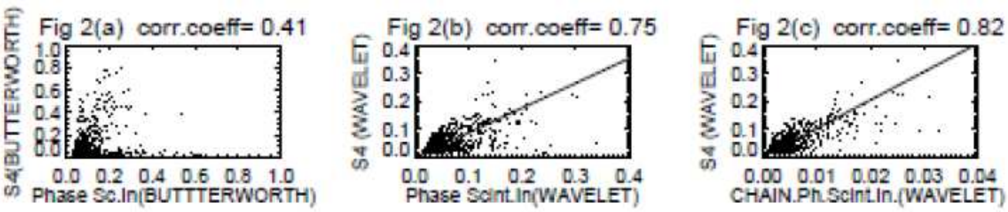

Figure 2: (a) shows the scatter plot of S_4 vs. σ_ϕ calculated from Butterworth-detrended data. (b) shows the scatter plot of S_4 vs. σ_ϕ calculated from wavelet-detrended data. (c) shows the scatter plot of wavelet-derived S_4

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