Improved Algorithms for Amplitude- and Phase-Scintillation Indices of GPS Signals

Abram Farley: Kalamazoo College
Mentors: I. Azeem, and Adam Reynolds, ASTRA LLC, Boulder, CO

Introduction

GPS radio signals traversing an irregular ionospheric medium are subject to modulations which can result in rapid fluctuations or scintillations of both amplitude and phase of the received signal. Figure 1 illustrates scintillation producing ionospheric irregularities. Figure 2 shows the rapid fluctuation in amplitudes of both the L1 and L2C GPS signals during November scintillation events recorded by ASTRA’s CASES receiver at Jicamarca Radio Observatory Peru (11.952° S, 76.876° W). Study of the scintillations is of importance not only to applications involving use of the transionospheric propagation channel but also to an understanding of the processes responsible for the ionospheric irregularities. Conventional understanding of GPS signals suggests that amplitude scintillation occurs more frequently at low latitudes and phase scintillation is more prominent at high latitudes. Scintillation studies at high latitudes have reported high $\sigma_a$ and low $S_4$ leading to “phase scintillations without amplitude scintillations.” Arguments have been made that this condition of “phase scintillation without amplitude scintillation” is a result of improper detrending at high latitudes. In a recent paper, Mushini, et al. (2012) used wavelet based detrending methods to investigate the relative strength of amplitude and phase scintillations in the Canadian Arctic region. The wavelet based detrended data from Mushini, et al. (2012) showed a greater correlation between $S_4$ and $\sigma_a$. In this study, we implement a wavelet-based detrending scheme and analyze data from ASTRA CASES GPS receivers in Alaska to estimate $S_4$ and $\sigma_a$. We compare these results with previous estimates of scintillation indices to identify the differences between the two processing schemes.

Definitions

GPS Positioning - GPS receivers use radio waves from 4 or more satellites (each with a unique PRN) to calculate its position by calculating the transmission times of the signals from known satellite positions. Four satellites must be within “sight” in order to calculate its X,Y, and Z coordinates as well as adjust for clock errors between receiver and satellite.

Ionosphere - The ionosphere is a region of the upper atmosphere between 75-1000km. The ionosphere is composed of ionized gases which are created primarily by the Sun’s solar radiation and influenced by space weather.

GPS scintillation – Rapid variations in received GPS signal’s amplitude or phase. Scintillations are often categorized as follows:

- $S_4$-measure of amplitude variation caused by diffraction
- $\sigma_a$-measure of phase variation caused by change in path length

Scintillation at High-, Mid- and Low-Latitudes:

The ionosphere is driven by different processes at different latitude regions. Low latitudes are driven primarily by the electro dynamic forces. Amplitudes scintillations occur most frequently at low latitudes. At high latitudes, due to the topology of the open field, the solar wind plays a significant role in driving the ionosphere. At high latitudes phase scintillations are most prominent. In terms of ionospheric scintillations, the mid-latitude region is generally very quiet.

Global distribution of $S_4$-occurrence frequency.

Previous Work

Previous work has been done with wavelet-based detrending to provide "Improved amplitude- and phase-scintillation indices from high-latitude GPS data" [Mushini et al., 2012]. The paper used GPS data from the Canadian High Arctic Ionospheric Network (CHAIN) and compared GPS scintillation indices computed using traditional Butterworth filters and a wavelet detrending method. It was shown that using a wavelet analysis to detrend the data using scales between 0.9-5 for both $S_4$ and $\sigma_a$ increased the correlation between them. The study suggested that the cutoff frequency used in the butterworth filtering scheme overestimates the value of $\sigma_a$ and that the condition of “phase scintillation without amplitude scintillation” is due to inaccurate detrending.

Motivation

We propose to implement the wavelet detrending scheme and apply it to the data collected from ASTRA’s CASES receivers in Alaska and verify the findings of Mushini et al. [2012].

Objectives

- Develop improved algorithms for phase and amplitude scintillation indices for GPS signals
- Use wavelet detrending methods to isolate scintillation events and research how wavelet detrending methods compare to traditional detrending methods used at mid- and low-latitudes
- Investigate the effects of the scale sizes in wavelet detrending on scintillation amplitudes.
- Compare scintillation results from wavelet based analysis and Butterworth filtering.

Results

The following data was taken from a CASES receiver of ASTRA in Gakona, Alaska on March, 17th 2013.

- This study used scales 0.9-5, 0.9-15, 0.9-30, 0.9-50 and 0.9-80. Below are the plots of detrended amplitude and $S_4$ comparison plots.
- Blue Line=Receiver measured value
- Yellow Line=Simplified $S_4$ calculation with high pass filter
- White Line=Wavelet detrended value

Wavelet scalogram showing what frequencies (or scales) have the greatest power.

Conclusions and Findings

- The optimal scale range of 0.9-5 for scintillation was not the most accurate for CASES data, rather a larger scale range must be used to include all of this scintillation event.
- Using the scale range of 0.9-80, both $S_4$ and $\sigma_a$ could be calculated closest to the receiver values.
- A high correlation was found with the wavelet detrended values, but only for scintillation events less than 0.3 as shown in Mushini et al (2012).

References


Wavelet software was provided by C. Torrence and G. Compo, And is available at URL:http://paos.colorado.edu/research/wavelets/.