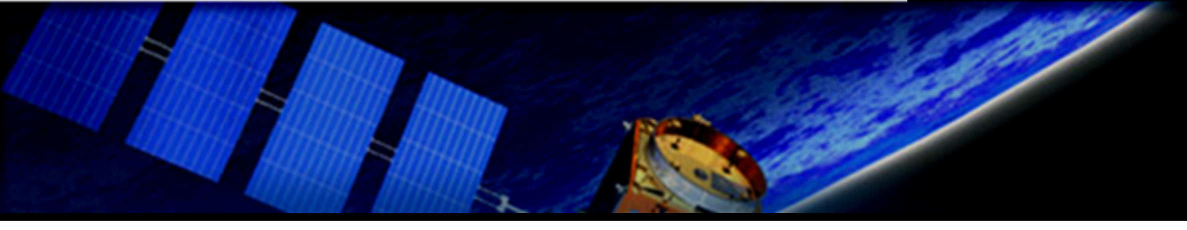

Improved Algorithms for Amplitude- and Phase-Scintillation Indices of GPS Signals

❖Science
❖ Technology
❖ Applications
Bringing It All Together

ASTRA

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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 σ_φ and low S4 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 base detrended data from Mushini, et al. (2012) showed a greater correlation between S4 and σ_φ. In this study, we implement a wavelet-based detrending scheme and analyze data from ASTRA CASES GPS receivers in Alaska to estimate S4 and σ_φ. We compare these results with previous estimates of scintillation indices to identify the differences between the two processing schemes.

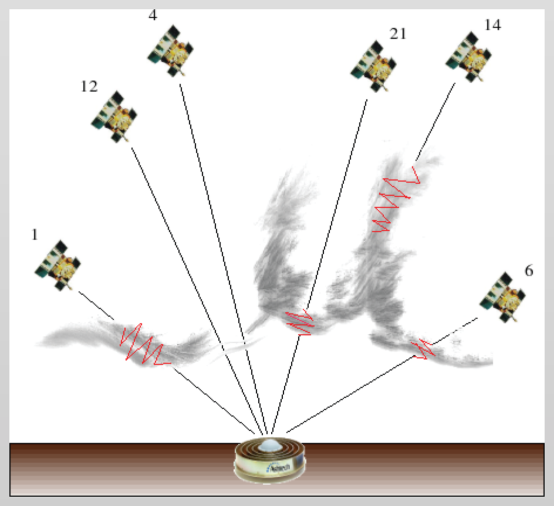


Figure 1. GPS signals undergoing localized scintillation

GRID003 CASES Jicamarca – Nov. 9 2011

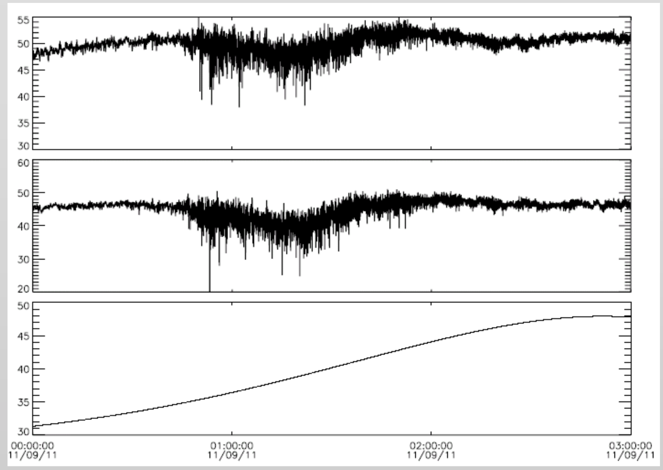


Figure 2. Fading of the L1 and L2C signals recorded by a CASES receiver at Jicamaraca.

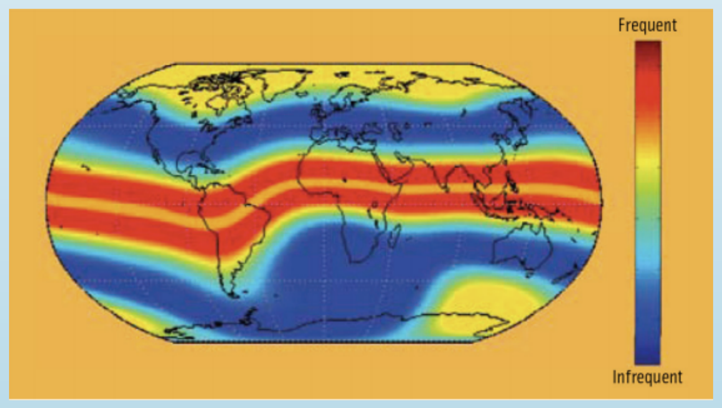
Definitions

GPS Positioning - GPS receivers use radio waves from 4 or more satellites (each with a unique PRN) to calculate it's position by calculating the transmission times of the signals from know 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:

S4-measure of amplitude variation caused by diffraction
σ_φ-measure of phase variation caused by change in path length



Global distribution of S4 occurrence frequency.

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.

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 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 .09-5 for both S4 and σ_φ increased the correlation between them. The study suggested that the cutoff frequency used in the butterworth filtering scheme overestimates the value of σ_φ and that the condition of "phase scintillation without amplitude scintillation" is due to inaccurate detrending.

Motivation

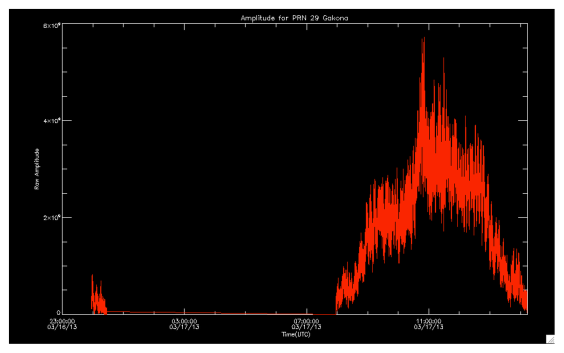
We propose to implement the wavelet detrending scheme and apply it to the data collected from ASTRA's CASES receivers is Alaska and verify the findings of Mushini et al. [2012].

Objectives

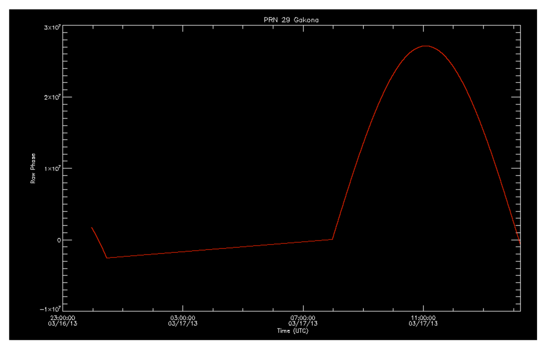
- Develop improved algorithms for phase and amplitude scintillation indices for GPS signals
- Use wavelet detrending methods to isolate scintillation events and research how wavelet detrending methods compare to traditional detrending methods used at mid- and low-latitudes
- Investigate the effects of 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.

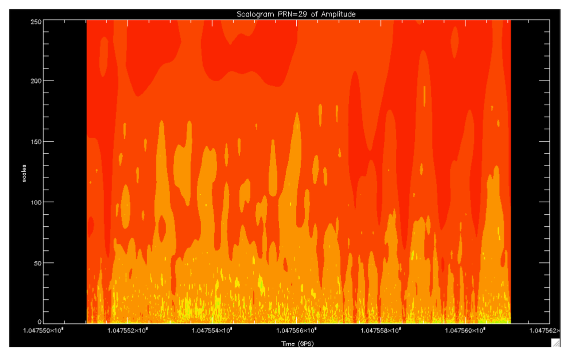


Raw Amplitude of PRN 29 with significant satellite motion

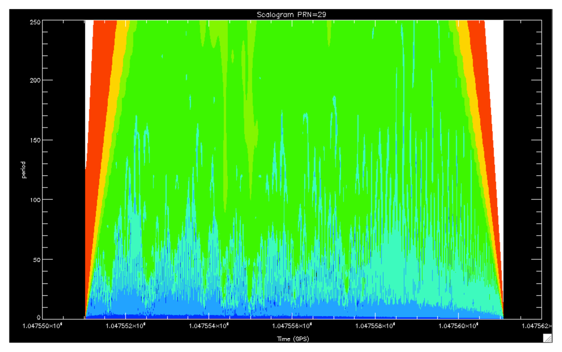


Raw Phase of PRN 29 (cycles) with significant satellite motion

Wavelet scalogram showing what frequencies (or scales) have the greatest power. Scalogram allows identification of dominant periodicities in the raw GPS signal.
High scales represent low frequency fluctuations due to factors such as satellite motion
Low scales represent high frequency fluctuations due to factors like noise.

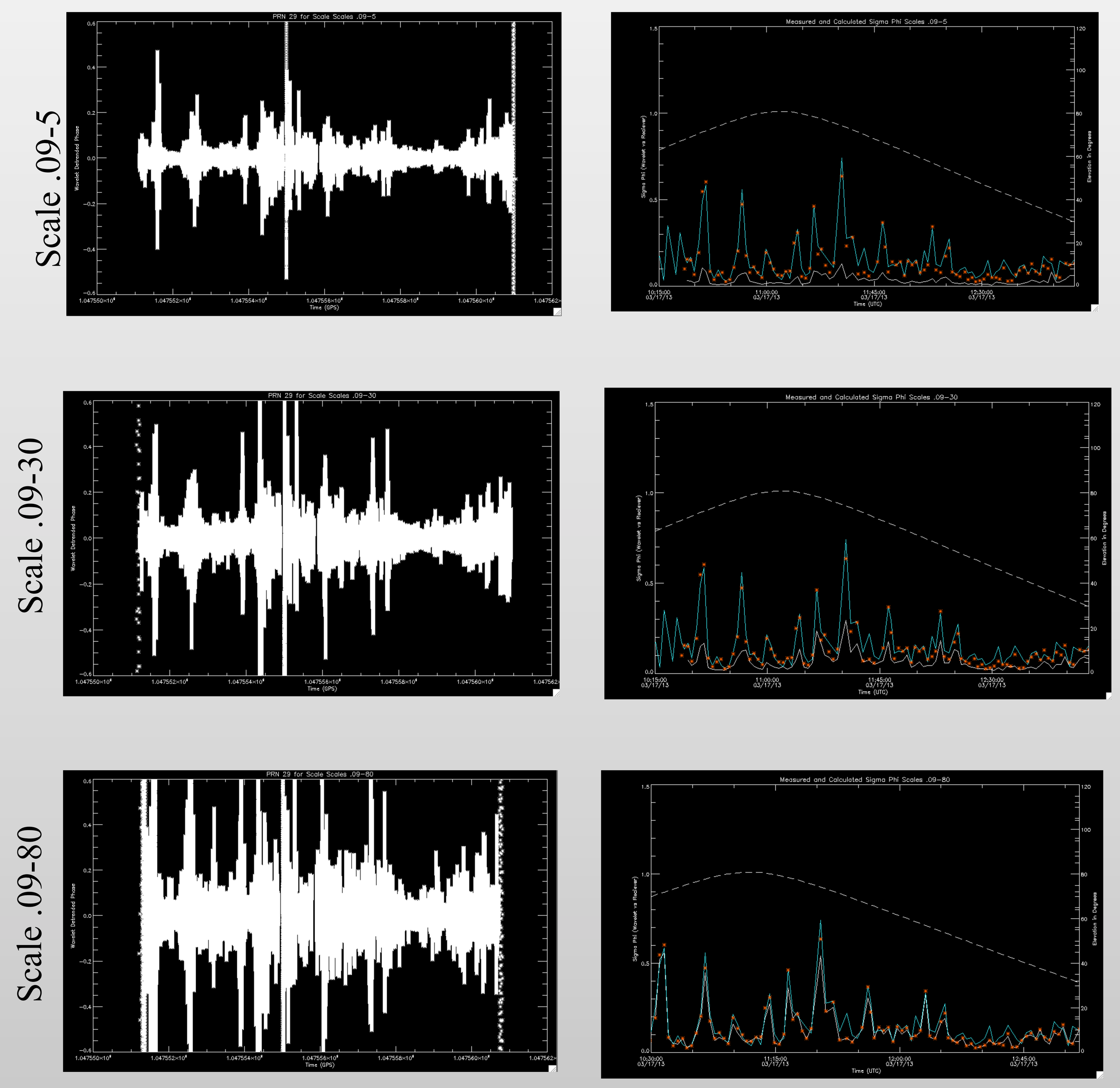


Amplitude Scalogram of scales 0-250

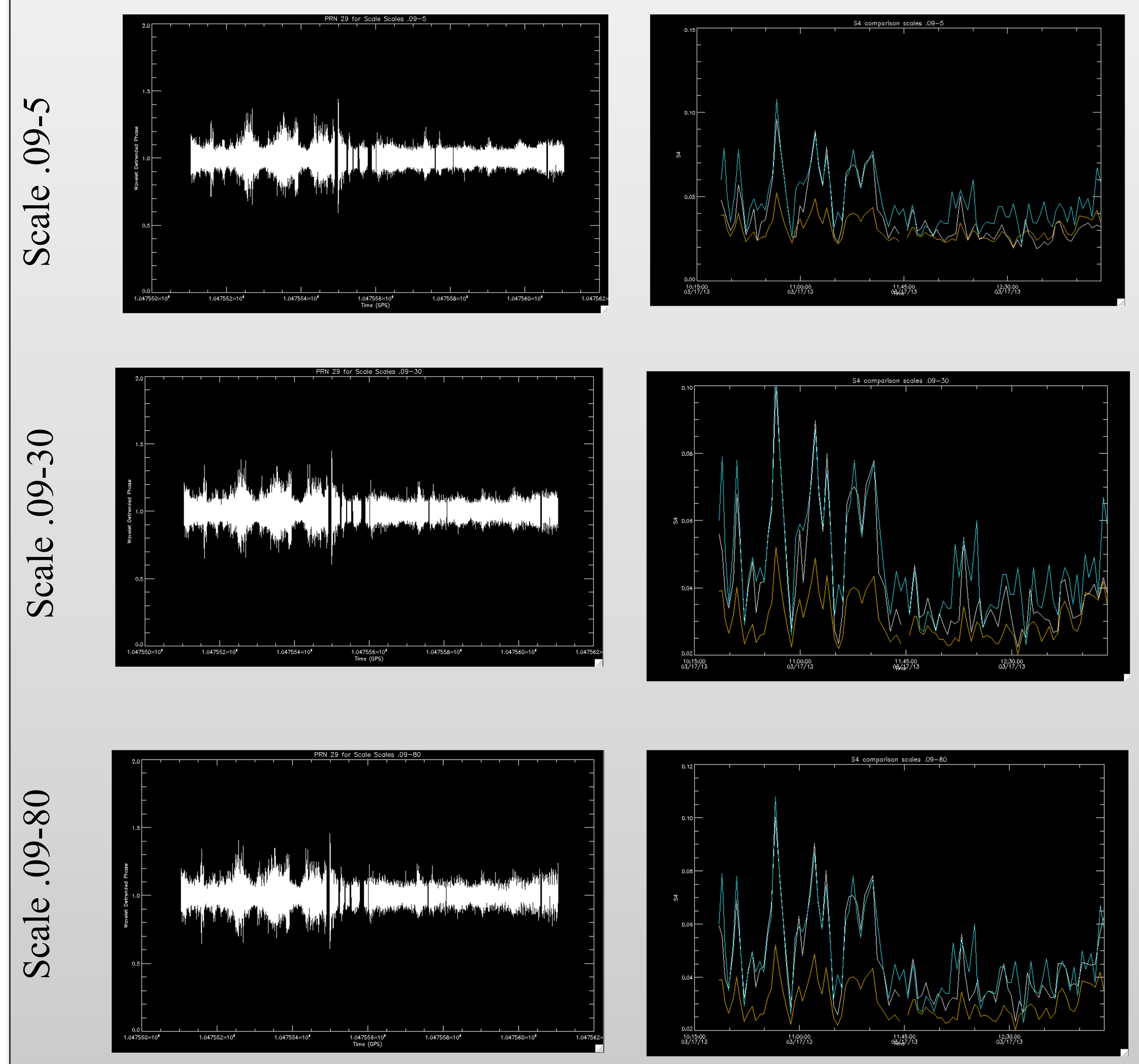


Phase Scalogram of scales 0-250

This study used scales .09-5, .09-15,. 09-30, .09-50 and .09-80. Below are the plots of detrened phase and σ_φ comparison plots.
Blue Line=Receiver measured value
Orange Stars=Calculated measurement only removing polynomial fit (high pass)
White Line=Wavelet detrended value

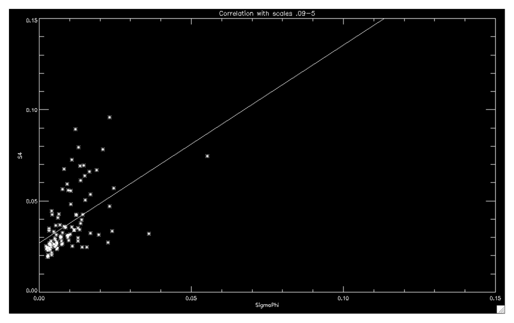


This study used scales .09-5, .09-15,. 09-30, .09-50 and .09-80. Below are the plots of detrened amplitude and S4 comparison plots.
Blue Line=Receiver measured value
Yellow Line=Simplified S4 calculation with high pass
White Line=Wavelet detrended value



Correlation Plots

Scale Range	Correlation Coefficient
Receiver Band-Pass	0.118967
.09-5	0.641979
.09-15	0.451540
. 09-30	0.414726
. 09-50	0.432209
. 09-80	0.403695



Wavelet Values Correlation Plot (.09-5)
Correlation coefficient: 0.641979

Conclusions and Findings

- The optimal scale range of .09-5 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 .09-80, both S4 and σ_φ 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 such as shown in Mishini et al (2012)

References

Sajan C. Mushini, P. T. Jayachandran, R. B. Langley, J. W. MacDougall, D. Pokhotelov, Improved amplitude- and phase-scintillation indices derived from wavelet detrended high-latitude GPS data, GPS Solutions, 16, pp 363-373 2012. doi:10.1007/s10291-011-0238-4.

Tiwari, R.; Strangeways, H.J.; Tiwari, S.; Boussakta, S.; Skone, S., "GPS L1 phase scintillation using wavelet analysis at high latitude," *Systems, Signal Processing and their Applications (WOSSPA), 2011 7th International Workshop on* , vol., no., pp.227,230, 9-11 May 2011
doi: 10.1109/WOSSPA.2011.5931458.

Massimo Materassi, Cathryn N. Mitchell, Wavelet analysis of GPS amplitude scintillation: A case study, Radio Science, 42, 2007, DOI: 10.1029/2005RS003415.

Misra, Pratap, and Per Enge. "Chapters: 1-4, 7." *Global Positioning System: Signals, Measurements, and Performance*. Lincoln, MA: Ganga-Jamuna, 2001. N. pag. Print.

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

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