



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

Abram Farley-Kalamazoo College

ASTRA Mentors: Irfan Azeem and
Adam Reynolds

Objectives

❖ Science

❖ Technology

❖ Applications

Bringing It All Together



- 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 indices
- Compare scintillation results from wavelet based analysis with Butterworth filtering



❖ Science

❖ Technology

❖ Applications

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BACKGROUND

Introduction to GPS

❖ Science

❖ Technology

❖ Applications

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- GPS used radio waves from 4 of 24 satellites with known orbits
 - Each with a specific PRN (pseudorandom noise) to differentiate the satellites
 - 4 are needed to calculate X,Y,Z and T
- Satellites uses two carrier frequencies L1 and L2
 - Dual frequency receivers can measure TEC
- GPS signals must propagate through ionosphere and atmosphere, causing diffraction and change of path length

Ionosphere

❖ Science

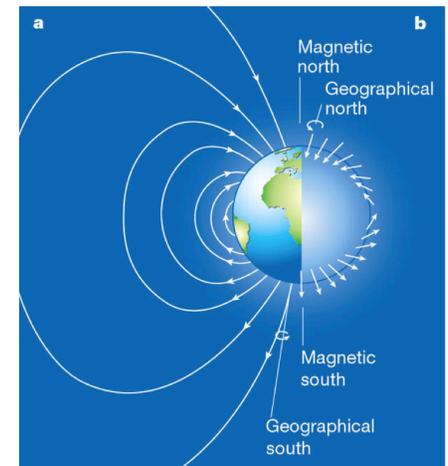
❖ Technology

❖ Applications

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- Section of upper atmosphere from about 75km-1000km
- Composed of ionized gases which is driven by the sun's solar radiation and space weather
 - Solar cycle, seasonal, and time dependence of ionosphere
- Various driving forces: electro-dynamics and charged particle entry
- Frequency dependent index of refractions



Scintillation

❖ Science

❖ Technology

❖ Applications

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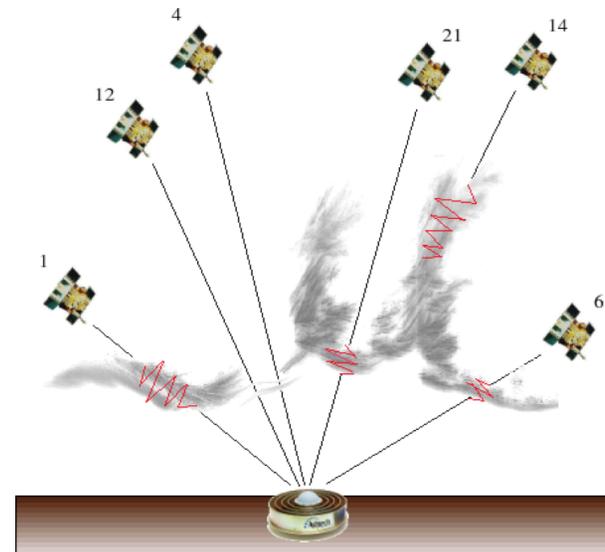
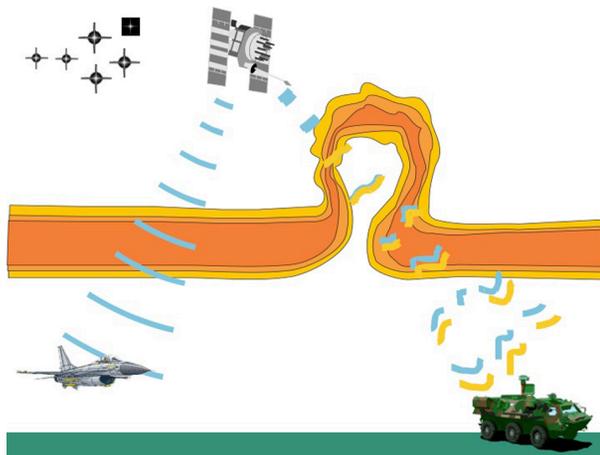
Dynamic nature of ionosphere



Irregularities and disturbances in electron concentrations



Fluctuations in GPS signals called Scintillation



Scintillation Indices

❖ Science

❖ Technology

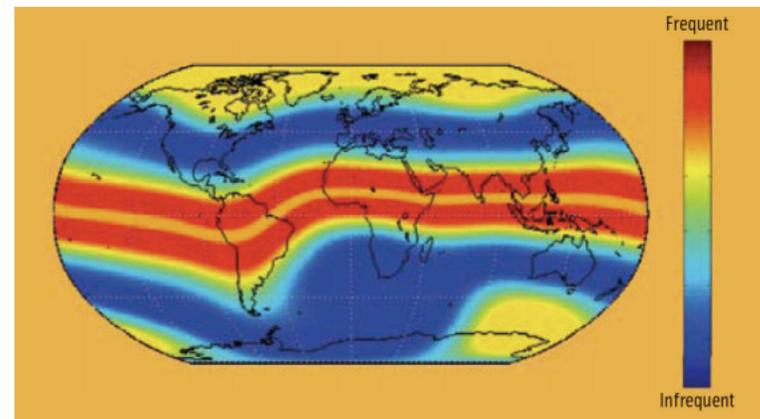
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- Scintillation is split and quantized into two indices
 - S4: measure of amplitude variation caused by diffraction
 - σ_ϕ : measure of phase variation caused by change in path length

- “Phase scintillation without amplitude scintillation at high Latitudes”



Global S4 frequency distribution

Introduction of Wavelets

❖ Science

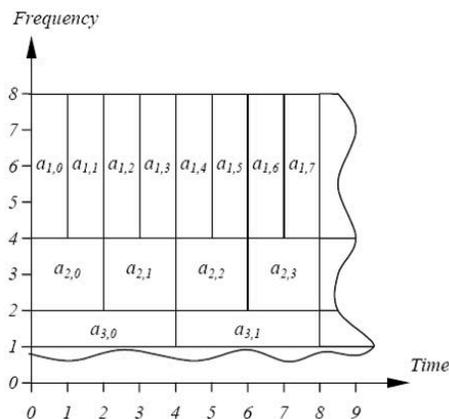
❖ Technology

❖ Applications

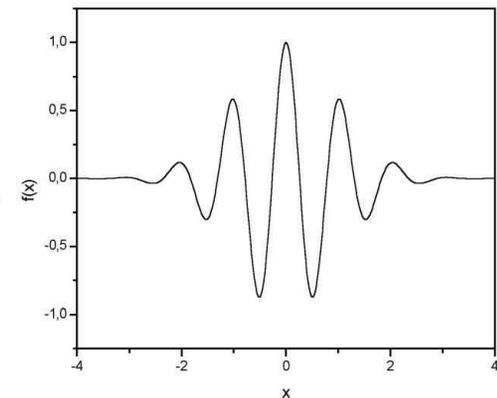
Bringing It All Together



- Similar to a Fourier Transformation but as a variable window size
- Provides high time and frequency resolution
 - Fourier must compromise on one or the other
- Scalograms allow us to see where power resides based on period
 - Can remove variations due to satellite motion, noise, multipath, etc to isolate scintillation events



Morlet
Wavelet,
example
of mother
wavelet



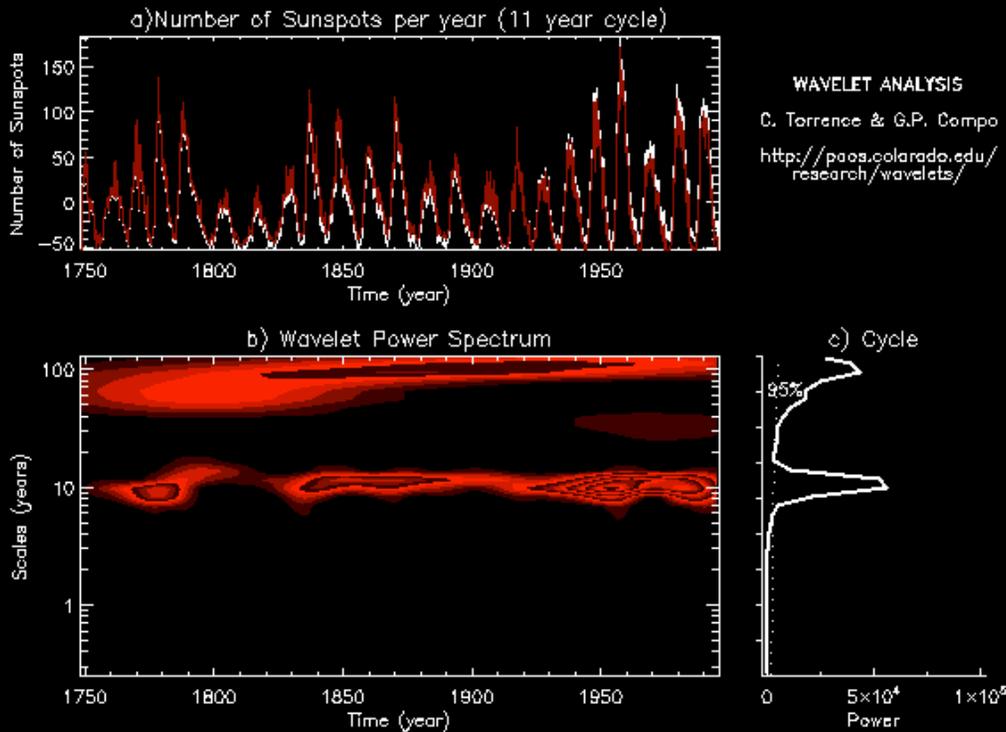
A Familiar Comparison

❖ Science

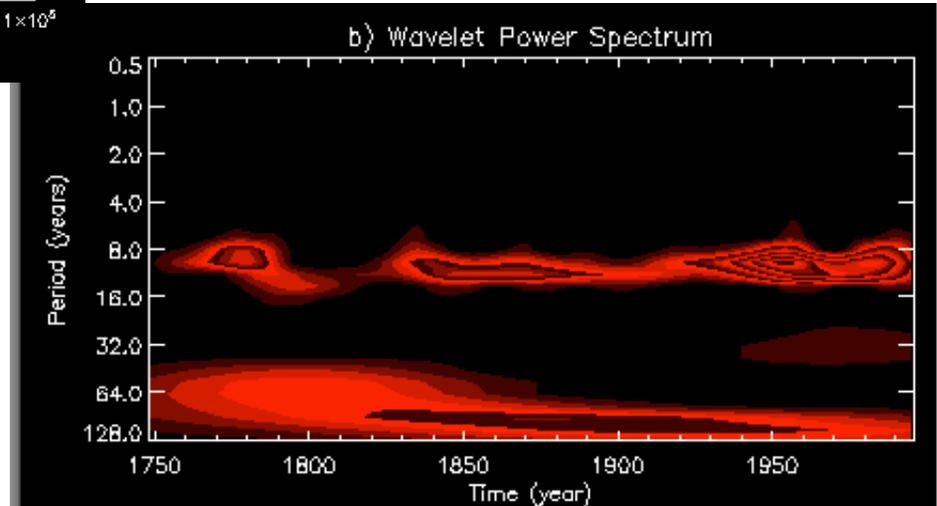
❖ Technology

❖ Applications

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- Contour plots of power, time, scales and power, time, period for sunspot number data starting in 1748



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

Motivation

❖ Science

❖ Technology

❖ Applications

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- A recent article: “Improved amplitude- and phase-scintillation indices derived from wavelet detrended high-latitude GPS data”, by Mushini, Jayachandran, Langley, MacDougall, Pokhotelov (GPS Solutions, 2012)
 - Claim: Phase scintillation without amplitude scintillation at high Latitudes is a result of improper detrending
- Traditional detrending
 - High pass filter (Butterworth filter) with cutoff frequency of .1Hz designed for low and mid latitudes
- Higher correlation between $S4$ and σ_ϕ were found for 50Hz receivers in Northern Canada with the use of wavelet detrending

Methodology of Project

Science

Technology

Applications

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- Step 1: Develop program to calculate σ_{ϕ} with high pass filter for raw phase data in Boulder
- Step 2: Add elevation mask and account for cycle slips
 - Compare with receiver values
- Step 3: Incorporate Wavelet detrending
 - Replicate parameters outlined in Mushini et al (2012)
- Step 4: Use both methods for a scintillation event in Alaska
- Step 5: Repeat for S4
 - modified S4 calculation
 - Use same scale ranges as σ_{ϕ}
- Final Step: Find correlation of indices



❖ Science

❖ Technology

❖ Applications

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RESULTS

Scintillation in Boulder

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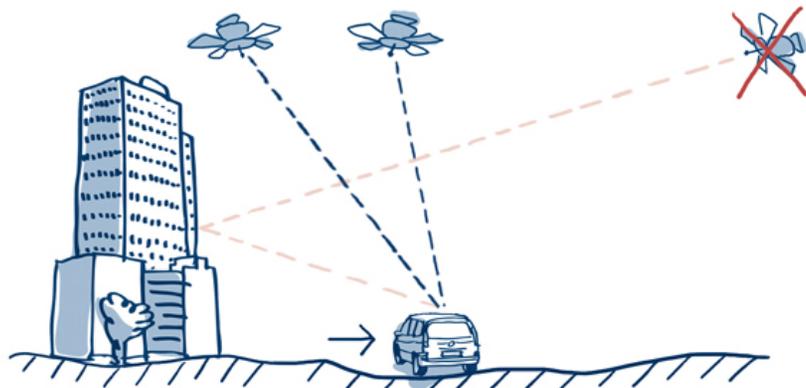
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❖ Applications

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- Measure scintillation for all present PRNs
 - Cycle Slips
 - Elevation Mask (15 degrees)
- Detrend using 3rd order polynomial fit
- σ_φ and S4 both variations of Standard Deviation of detrended signal



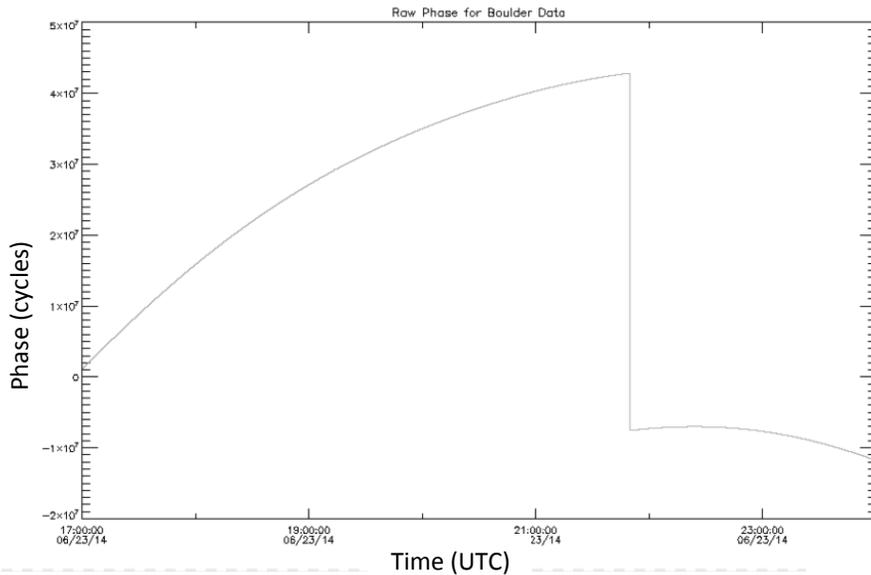
Cycle Slips and Elevation Mask In Boulder

Science

Technology

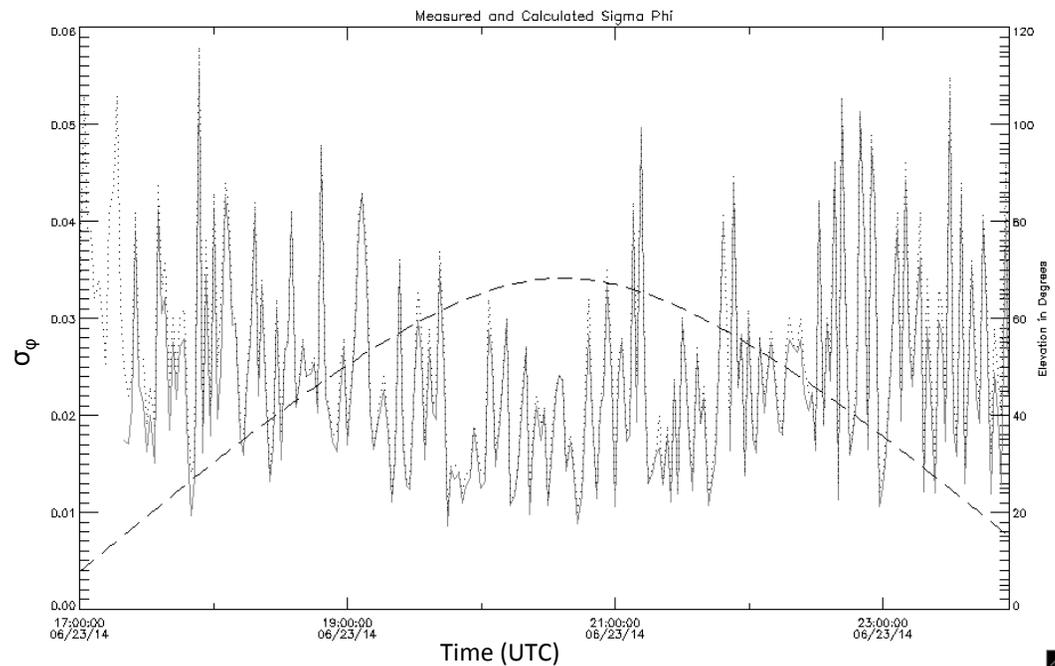
Applications

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Raw phase for PRN 28 with local clock update, cycle slip, and satellite motion

Sigma Phi values with elevation mask and satellite tracking



S4 from Boulder CASES

Science

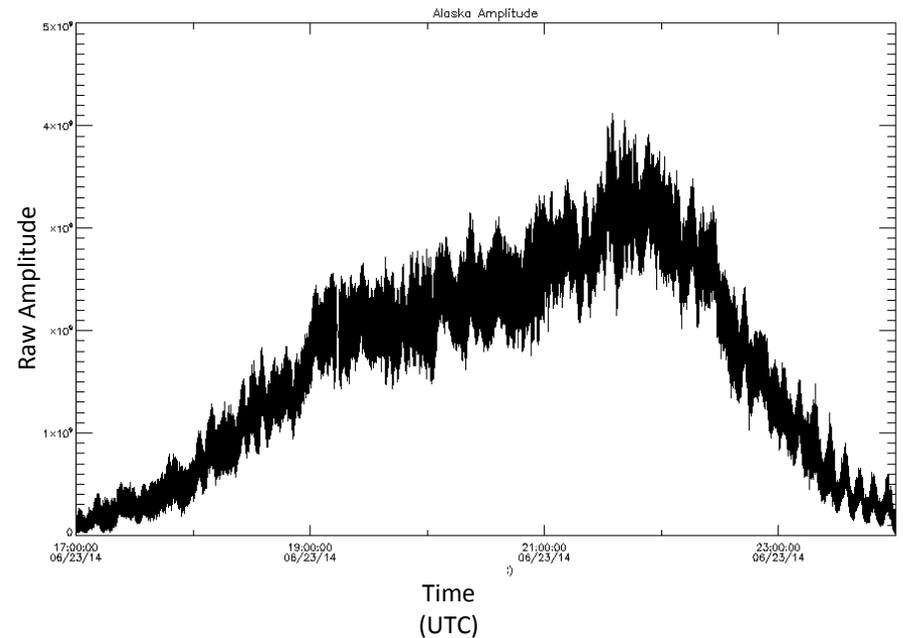
Technology

Applications

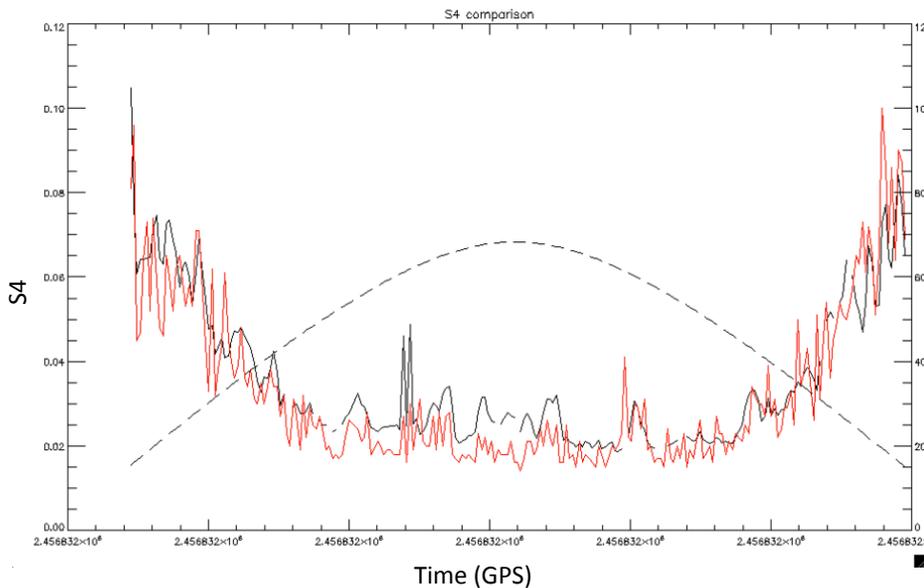
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Raw Amplitude
(arbitrary units) for
PRN 28 with satellite
motion



S4 values with
elevation mask and
satellite tracking



Wavelet Analysis Set-up

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❖ Technology

❖ Applications

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- 100 Hz Signal from Gakona, AK on March 17th, 2013
- 3rd order Polynomial was used to remove satellite motion
- Various Wavelet scale ranges
 - .09 s-5 s, .09 s-15 s, .09 s -30 s, .09 s-50 s, .09 s-80 s
 - Scales of .09 s or less represent noise and high frequency oscillations
- 600 scales needed to accurately reconstruct signal
 - (step size .125)
- 100 second windows

Scales, Period, and Frequency

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❖ Technology

❖ Applications

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Scales (sec)	Periods (sec)	Frequencies (Hz)
.09-5 (gt .09 and le 5)	~0.0983-4.850	~10.173-0.2062
.09-15	~0.0983-14.960	~10.173-0.0668
.09-30	~0.0983-29.920	~10.173-0.0334
.09-50	~0.0983-50.319	~10.173-0.0199
.09-80	~0.0983-77.603	~10.173-0.0128

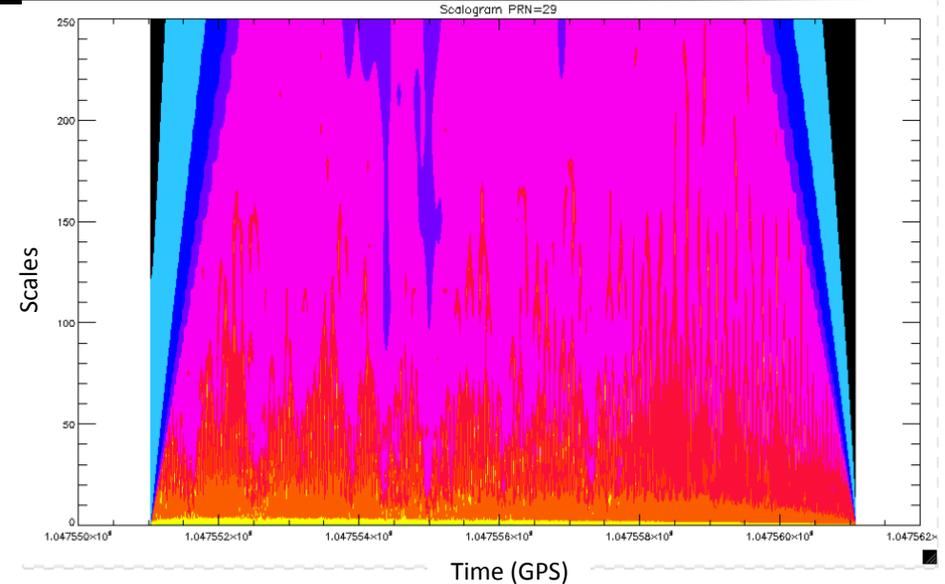
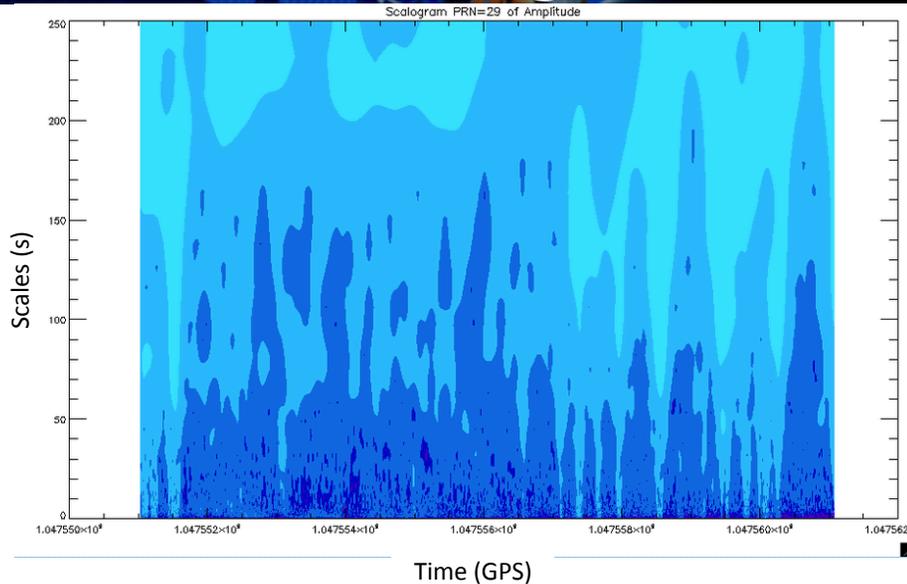
Phase and Amplitude Scalogram

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❖ Technology

❖ Applications

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- Scalogram of amplitude power on the left and phase power on the right. Scales correspond to periods, however, it is not a simple linear relationship. Low scales (small period and high frequency oscillations) are removed below scale of .09.
- High scales (large period with lower frequency oscillations) are removed about scales of 5, 15, 30, 50, and 80.

Sigma Phi various scale ranges

Science

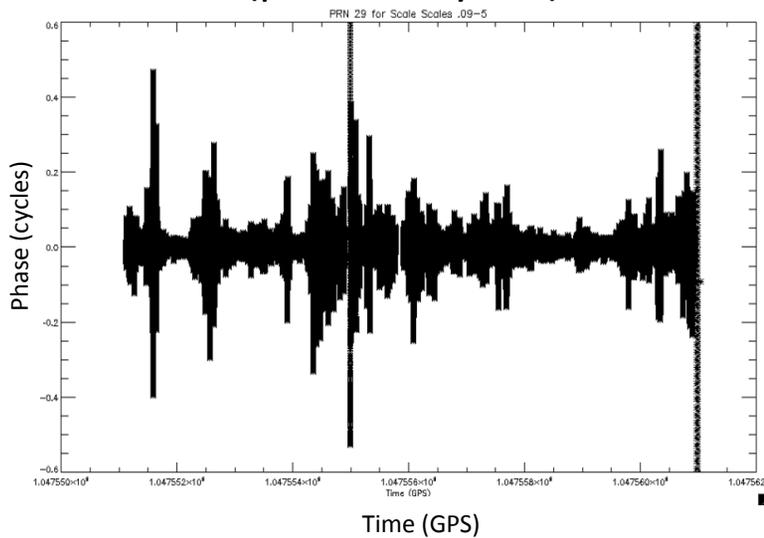
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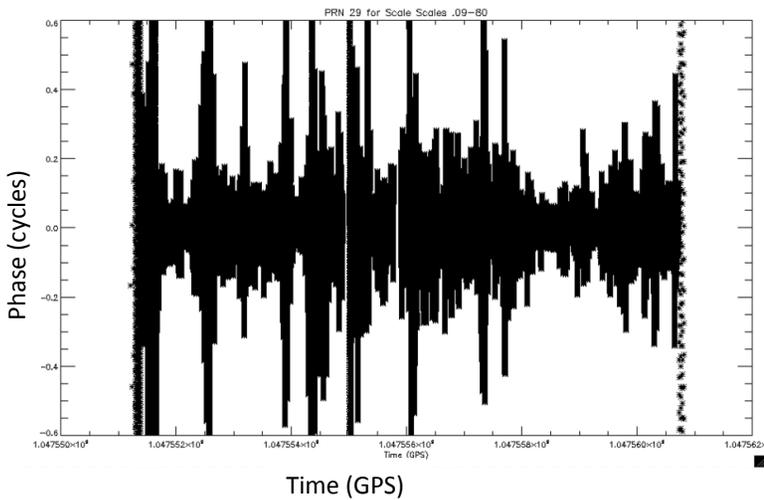
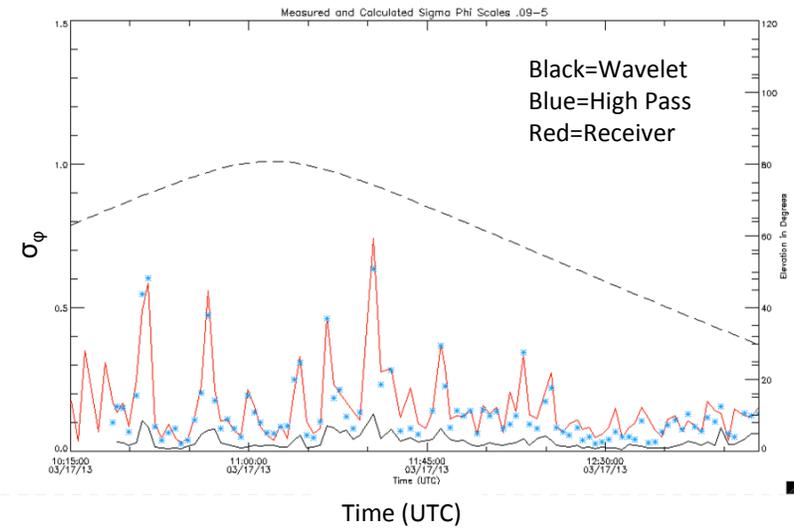


Reconstructed Detrended Signal
(phase in cycles)

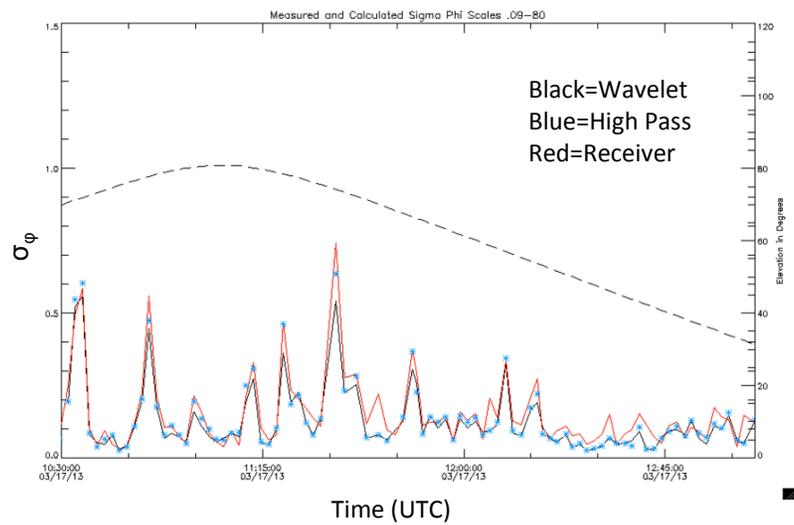


Scales
.09-5

σ_ϕ for receiver, high pass, and wavelet



Scales
.09-80



S4 for Various Scale Ranges

Science

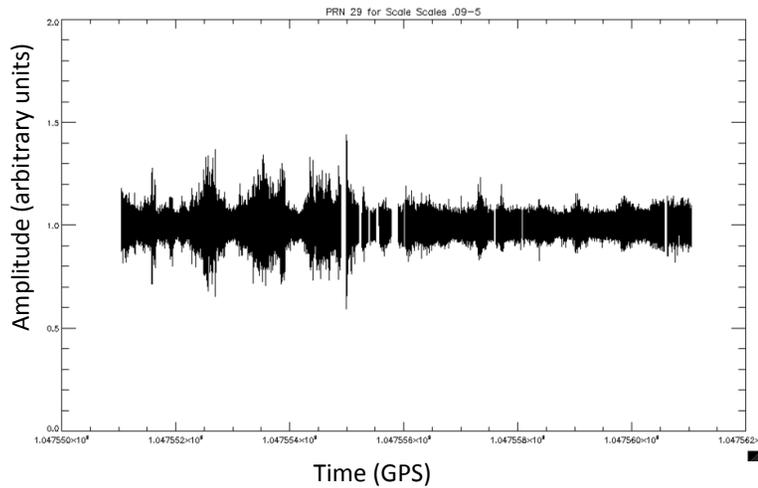
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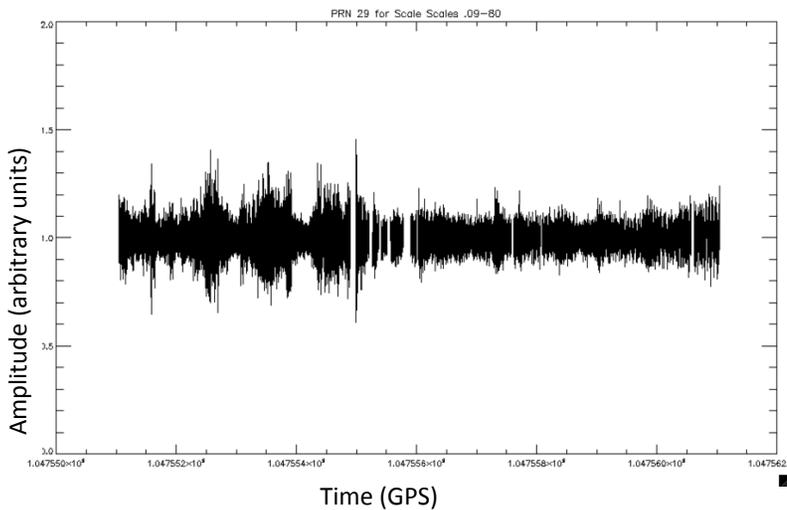
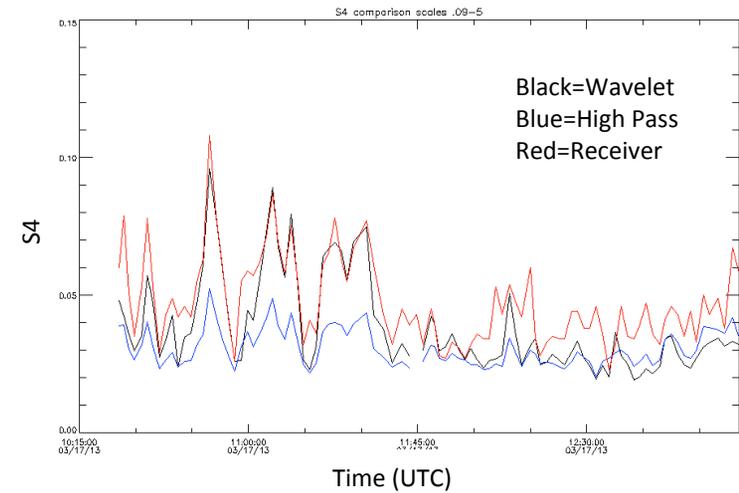


Reconstructed Detrended Signal
Amplitude (arbitrary units)

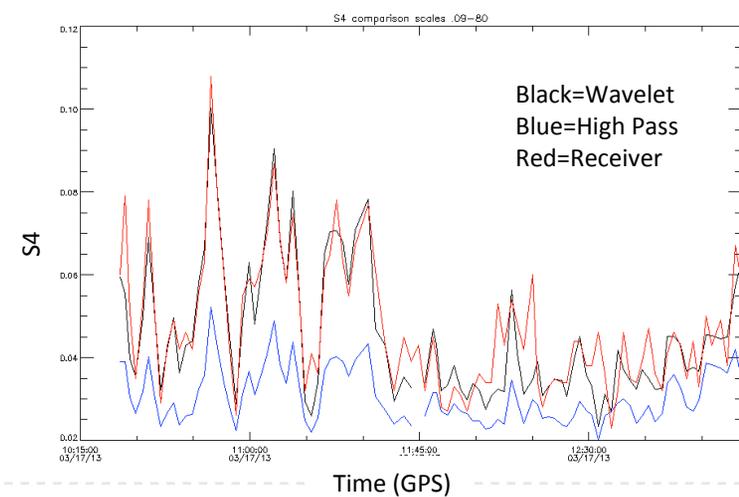


Scales
.09-5

S4 for receiver, high
pass, and wavelet



Scales
.09-80



Correlation

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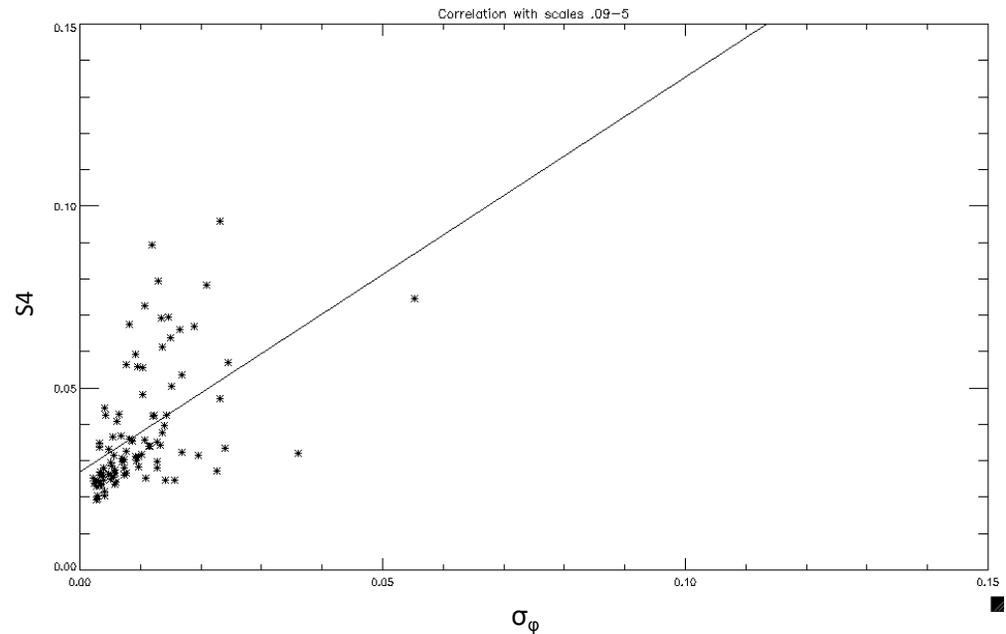
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❖ Applications

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- Receiver values: 0.118967
- Wavelet Scale ranges
 - .09-5: 0.641979 (pictured)
 - .09-15: 0.451540
 - .09-30: 0.414726
 - .09-50: 0.432209
 - .09-80: 0.403695



Conclusions

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❖ Technology

❖ Applications

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- Successful computed S4 and σ_{ϕ} from raw phase and amplitude CASES GPS data
 - Boulder, CO
 - Gakona, AK
- Implemented Wavelet detrending method to analyze CASES GPS data
 - Investigated affects of various scale ranges for S4 and σ_{ϕ}
 - σ_{ϕ} varied more than S4 when increasing scale range
- I was able to find a much higher correlation between S4 and σ_{ϕ} using the scales specified in Mishini et al (2012), but only for smaller scintillation events (less than .3)

Future Work

❖ Science

❖ Technology

❖ Applications

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- Investigate correlation to elevation (correlation may be related to the elevation and not scintillation indices)
- Look into wavelet detrending for smaller scintillation events and investigate correlation
- Apply wavelet analysis for different Alaska locations and geomagnetic conditions



References

❖ Science

❖ Technology

❖ Applications

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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.

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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. Compo, And is available at URL:<http://paos.colorado.edu/research/wavelets/>.

Acknowledgments

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Thank you very much:

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- University of Colorado/LASP



- Questions