SIMULATION OF BISTATIC SCATTERING OF DIGITAL SIGNALS OF OPPORTUNITY

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Outline

- Background
- Theory and Model
- Simulator architecture
- Example results
- Conclusion

Background

- Extensive reflected GPS data available from airborne experiments (1997 to present)
  - Empirical evaluation of accuracy for sea roughness, soil moisture, alimetry
  - Almost exclusively GPS C/A (BPSK(1))

Background

- Mission plans/proposals for satellite experiments
  - Specification of antenna gain, integration time, etc
  - Realistic simulation of measurement statistics necessary
- Galileo would ~double number of reflections
  - More complex BOC modulation
- Other signals of opportunity (non-GNSS)
  - Diversity of modulations (QPSK, etc) and frequencies

Background

- Simulated delay-Doppler map (DDM) generator developed during sabbatical at Starlab, Barcelona (2007-08 AY)
- Theory from You's PhD thesis [You, et al, 2004]
- Simulator developed during sabbatical at Starlab, Barcelona (2007-08 academic year)

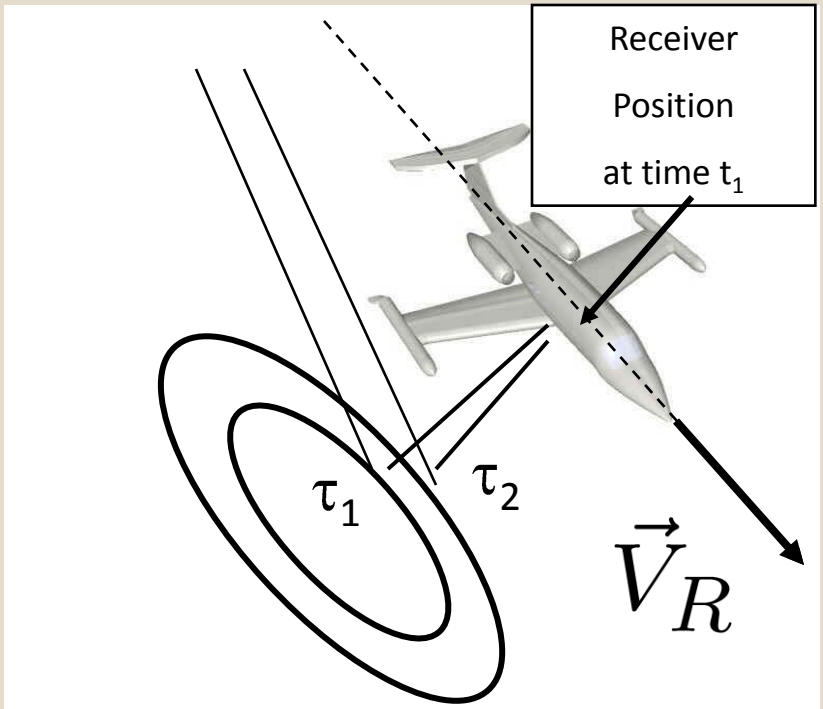
Stochastic Signal Model

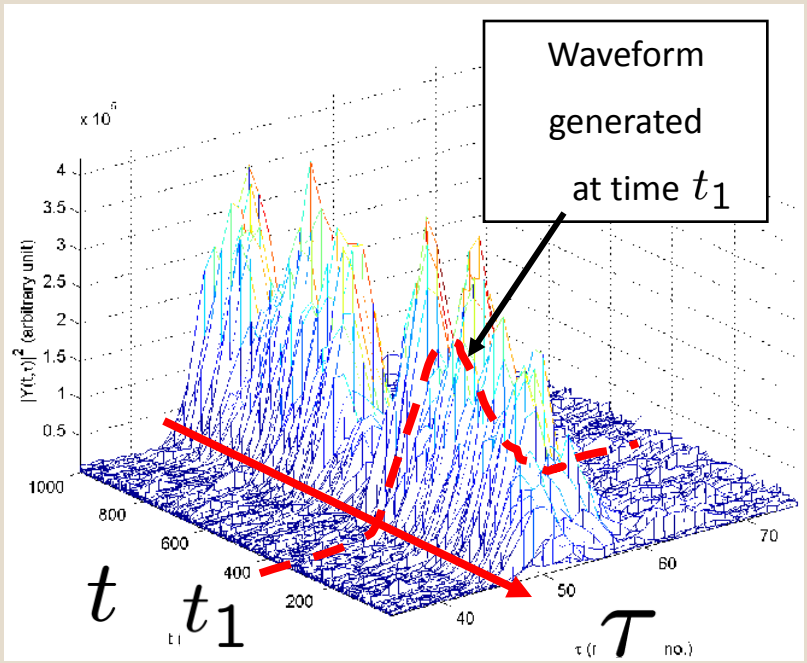
- DDM's are correlated in time ($\tilde{t}$) and between bins
- Statistics must be adequately represented in simulation (ie, separation of independent samples)
- You etal, (2004) model for autocorrelation

$$R_Y(\tilde{t},\tau,f) = E\left\{Y(t,\tau,f)Y^*(t+\tilde{t},\tau,f)\right\} = \iint I(\vec{\rho},\tau,f)e^{-2\pi\Delta f(\vec{\rho})j}d^2\vec{\rho}$$

$$R_Y(\tilde{t},\tau,f_c) = E\left\{\mathbf{Y}(t,\tau,f_c)\mathbf{Y}^*(t+\tilde{t},\tau,f_c)\right\} = \Lambda^2 * p_1(\tilde{t},\tau,f_c)$$

Stochastic Signal Model





Stochastic Signal Model

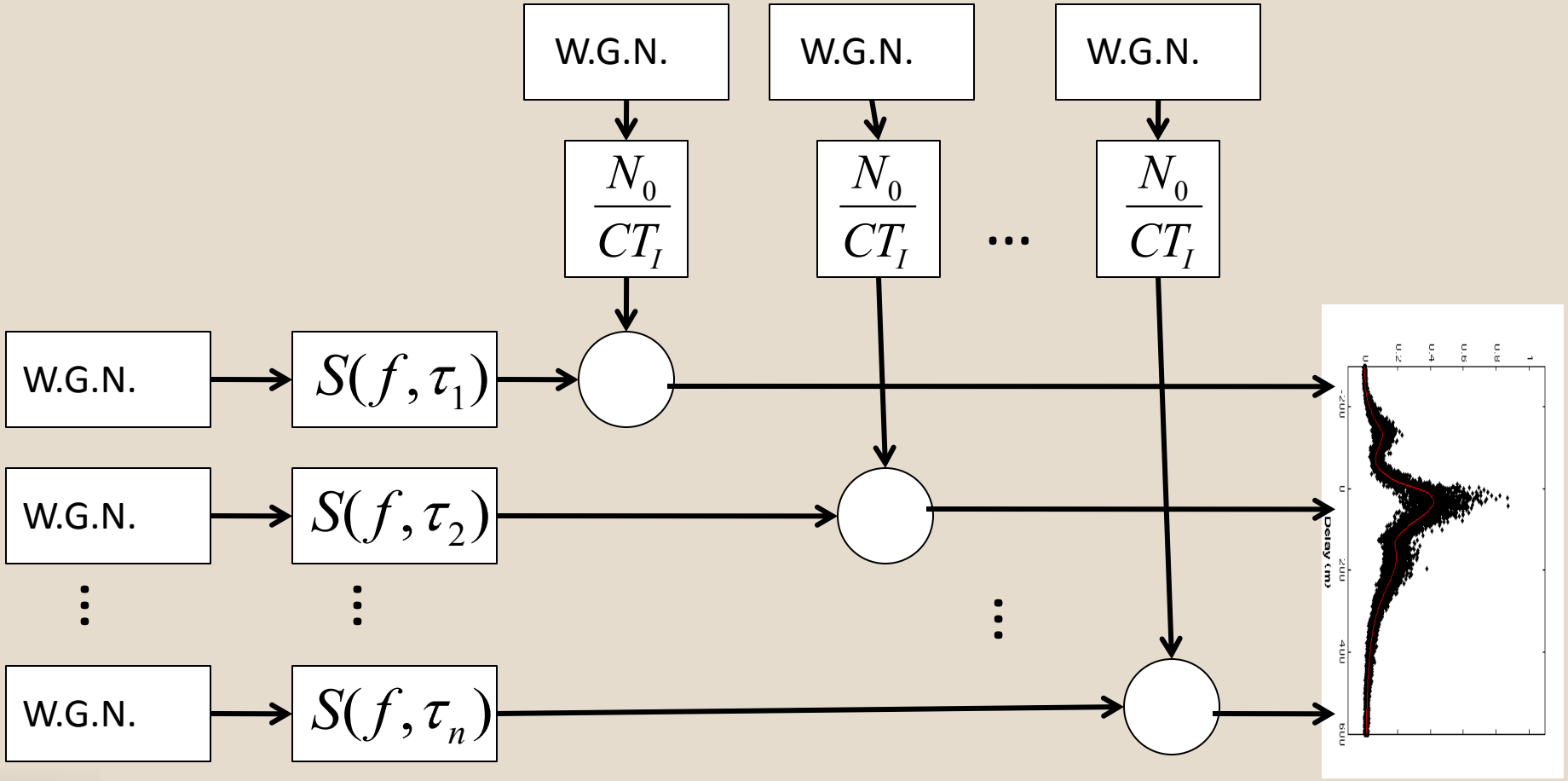
- Spectrum derived earlier by Zuffada and Zavorotny (2001)

$$W_Y(\tilde{f},\tau,f)=\int_{-\infty}^{\infty} R_Y(\tilde{t},\tau,f)e^{-2\pi f\tilde{t}j}d\tilde{t}=\Lambda^2(\tau)*\wp_2(\tau,\tilde{f},f)$$

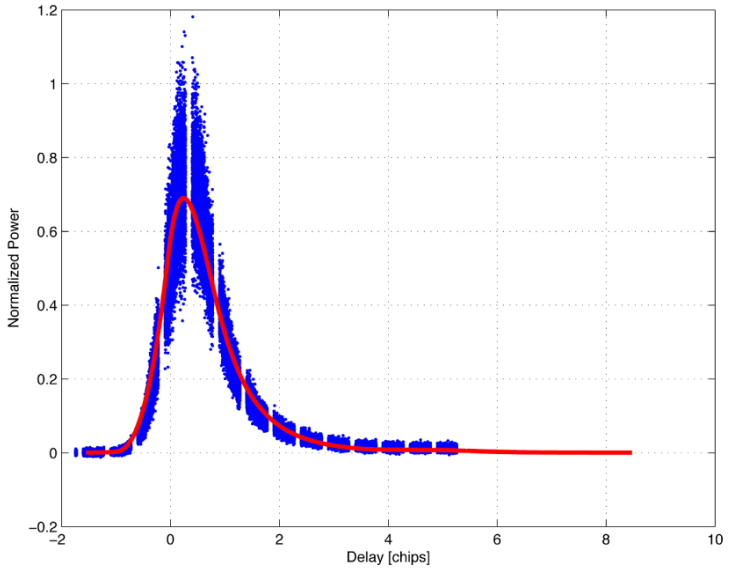
- Bin-Bin correlations take the form

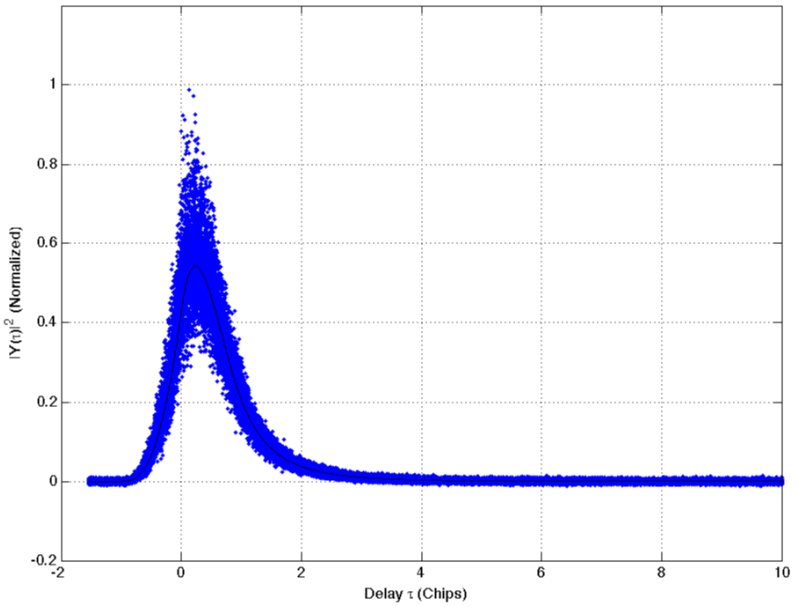
$$\langle Y(\tau_i,f_c;P_{\vec{\nu}})Y^*(\tau_j,f_c;P_{\vec{\nu}})\rangle=\int_{-\infty}^{\infty}\Lambda(\tau_i-\eta)\Lambda(\tau_j-\eta)\mathcal{P}(\eta)d\eta$$

Simulator


W.G.N.
W.G.N.
W.G.N.
$\frac{N_0}{CT_I}$
$\frac{N_0}{CT_I}$
...
$\frac{N_0}{CT_I}$
W.G.N.
$S(f,\tau_1)$
W.G.N.
$S(f,\tau_2)$
W.G.N.
$S(f,\tau_n)$
Delay (m)

Simulator vs. Actual data

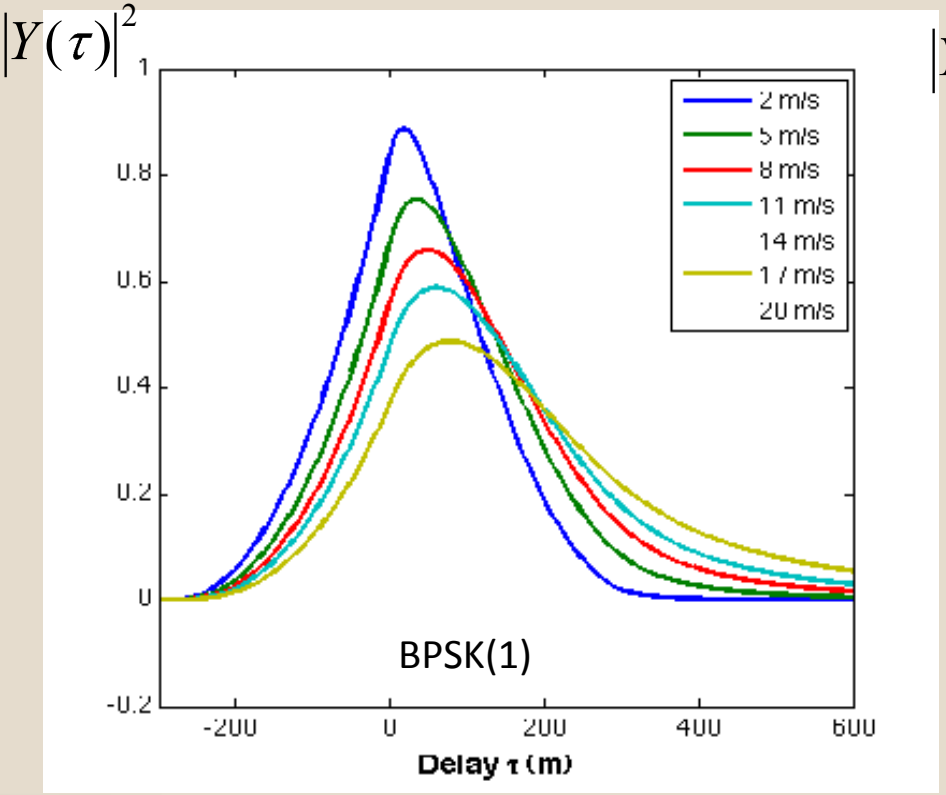


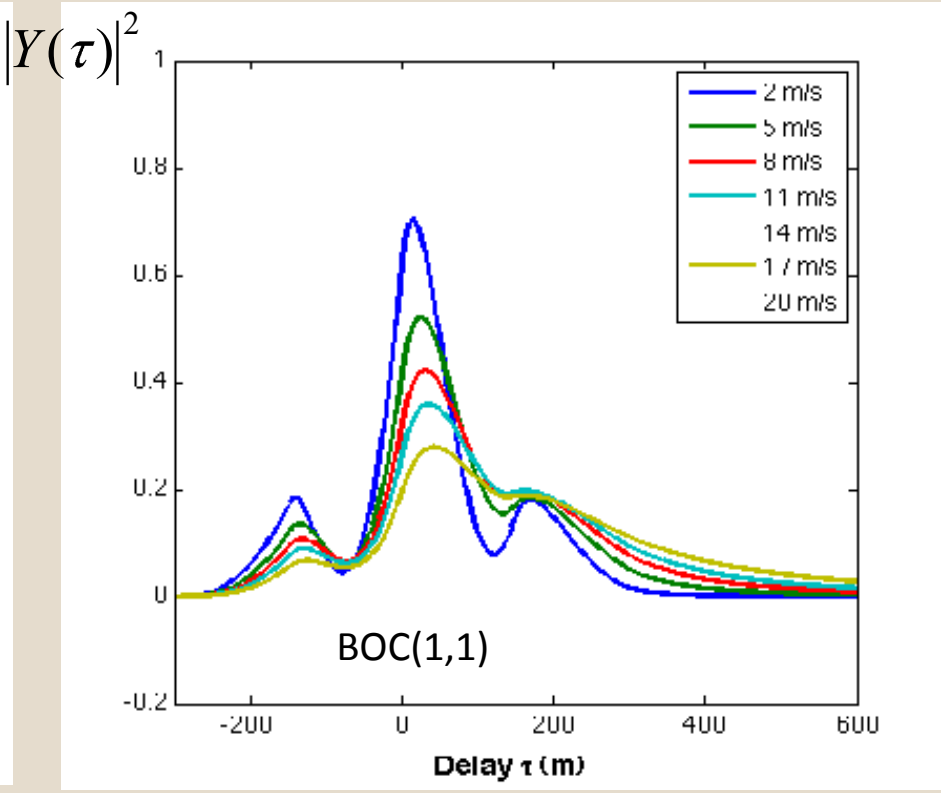


Hi-Winds Experiment

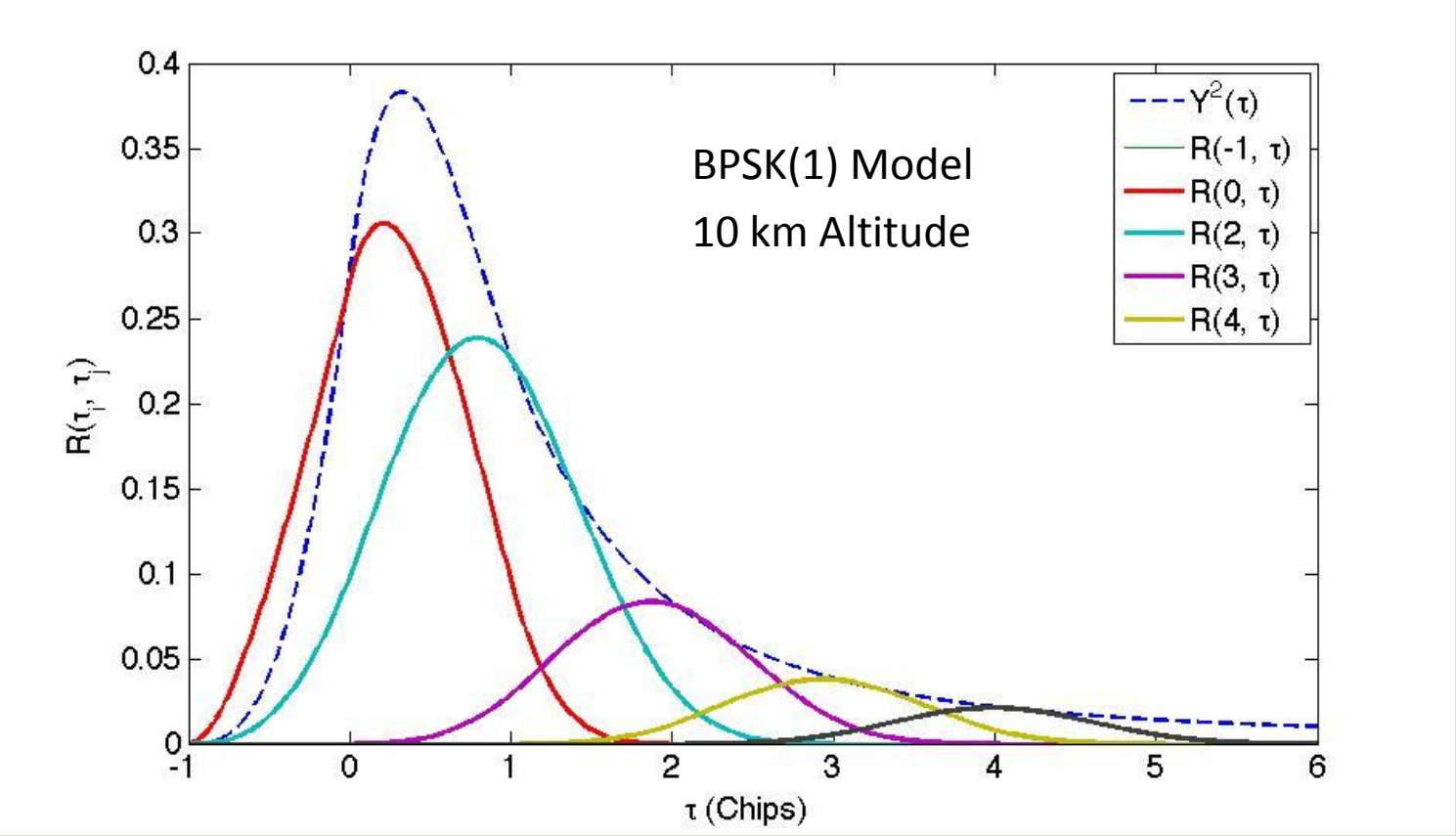
Synthetic Waveform

BOC Modulation



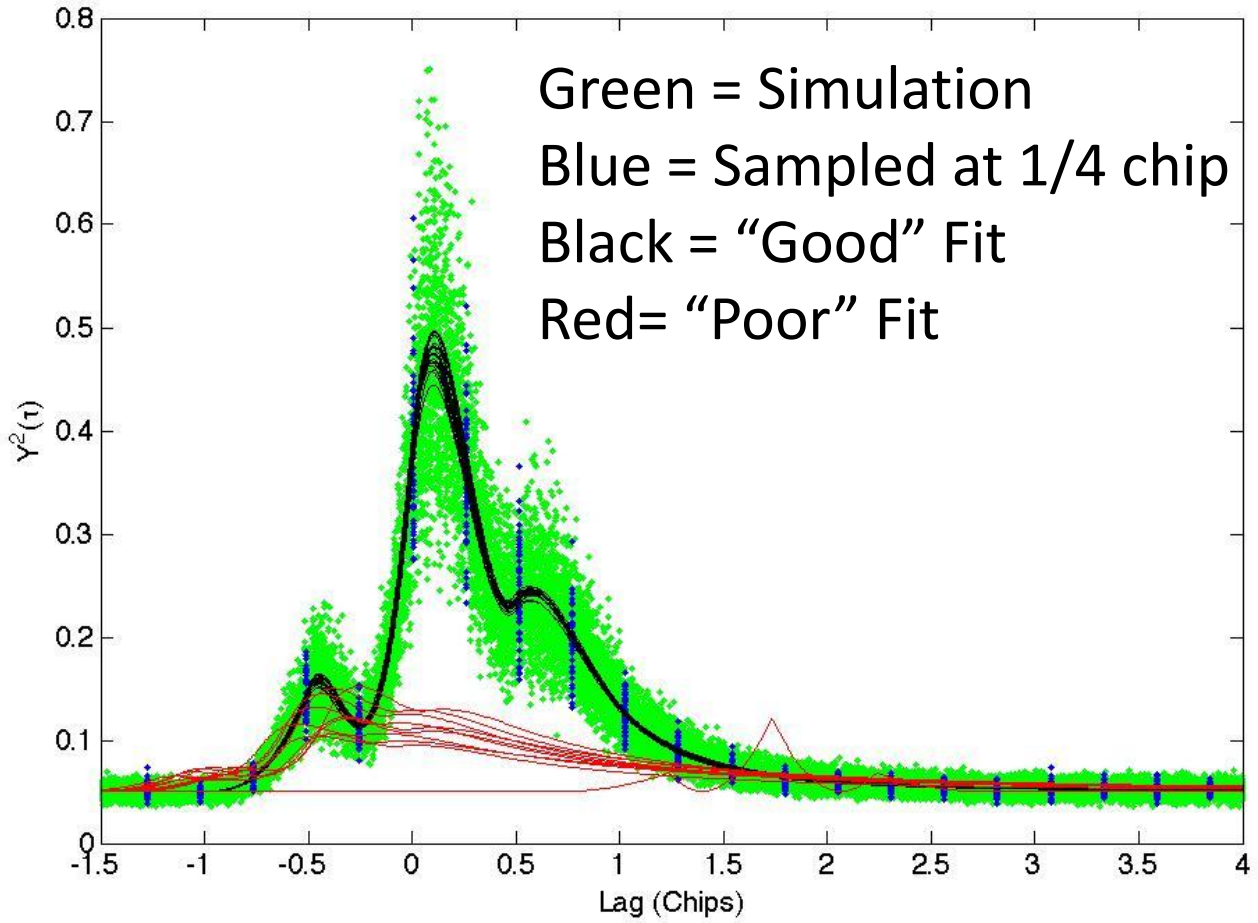


Bin-Bin Correlation

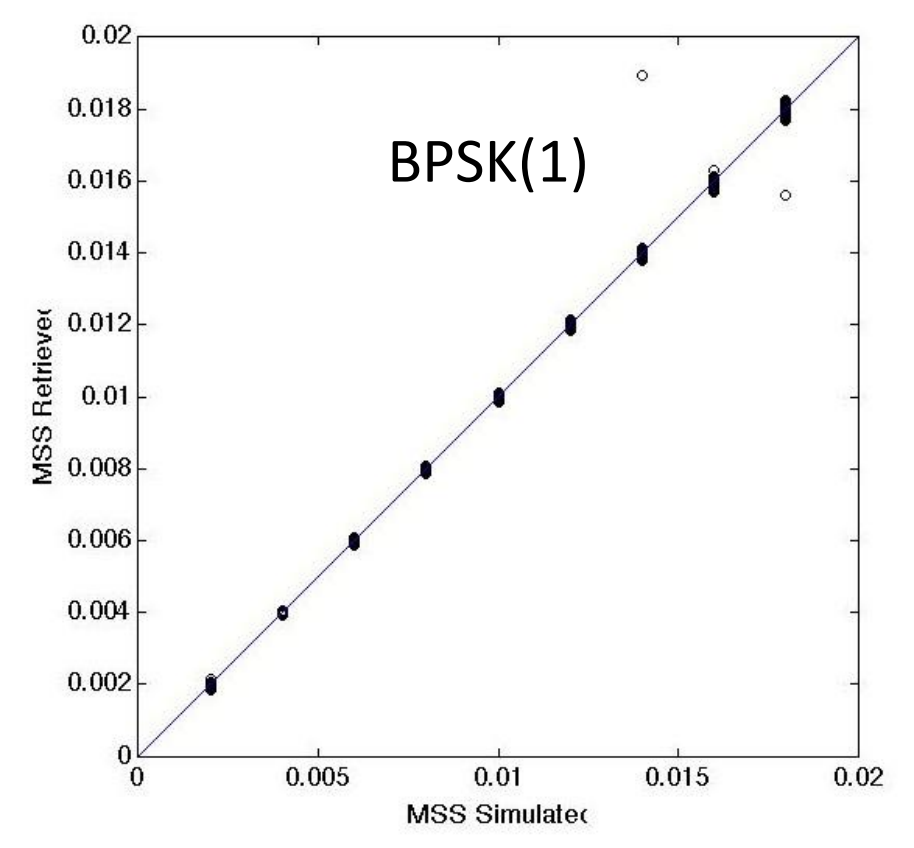


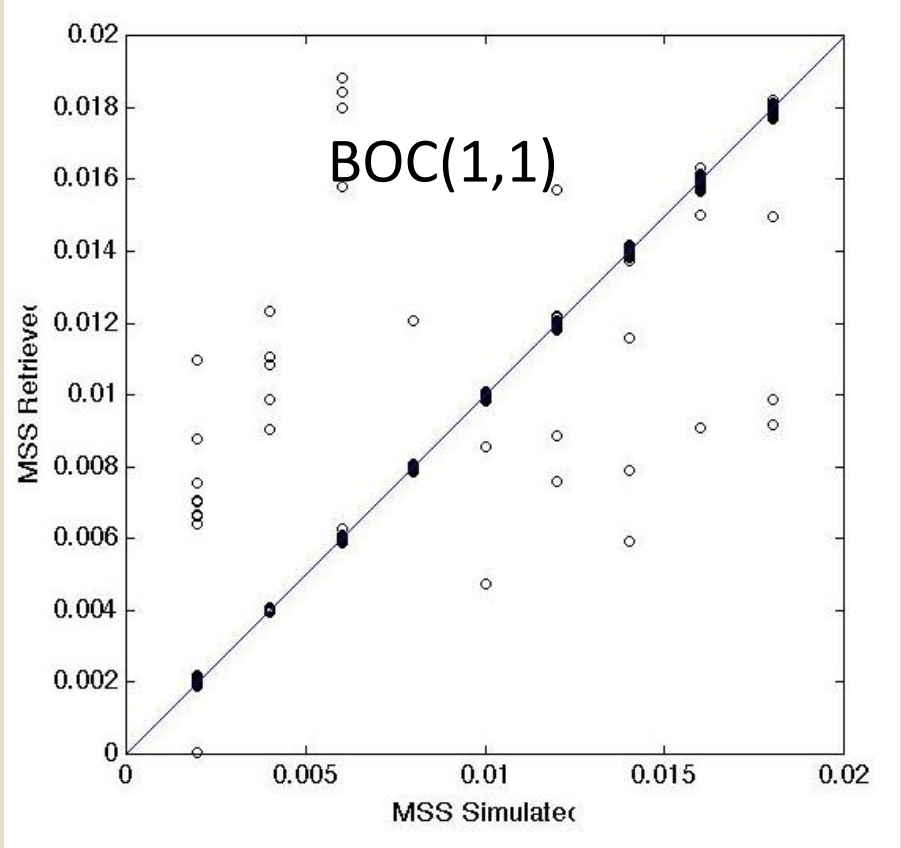
Monte-Carlo Simulation

10 km altitude
45 dB-Hz C/N0
0.63 Reflectivity



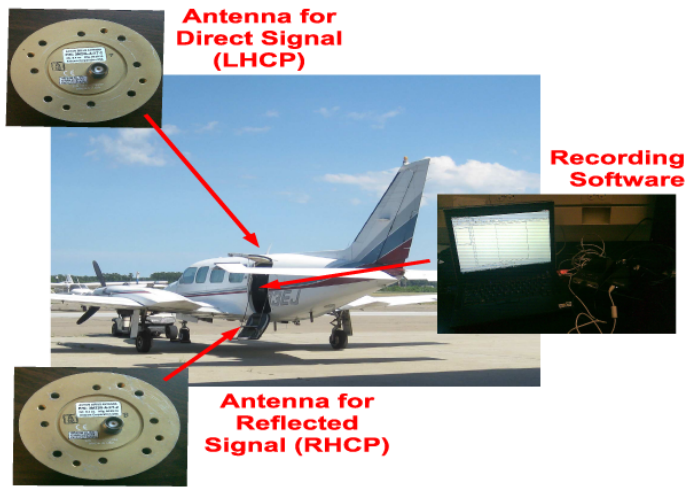
Simulation Results



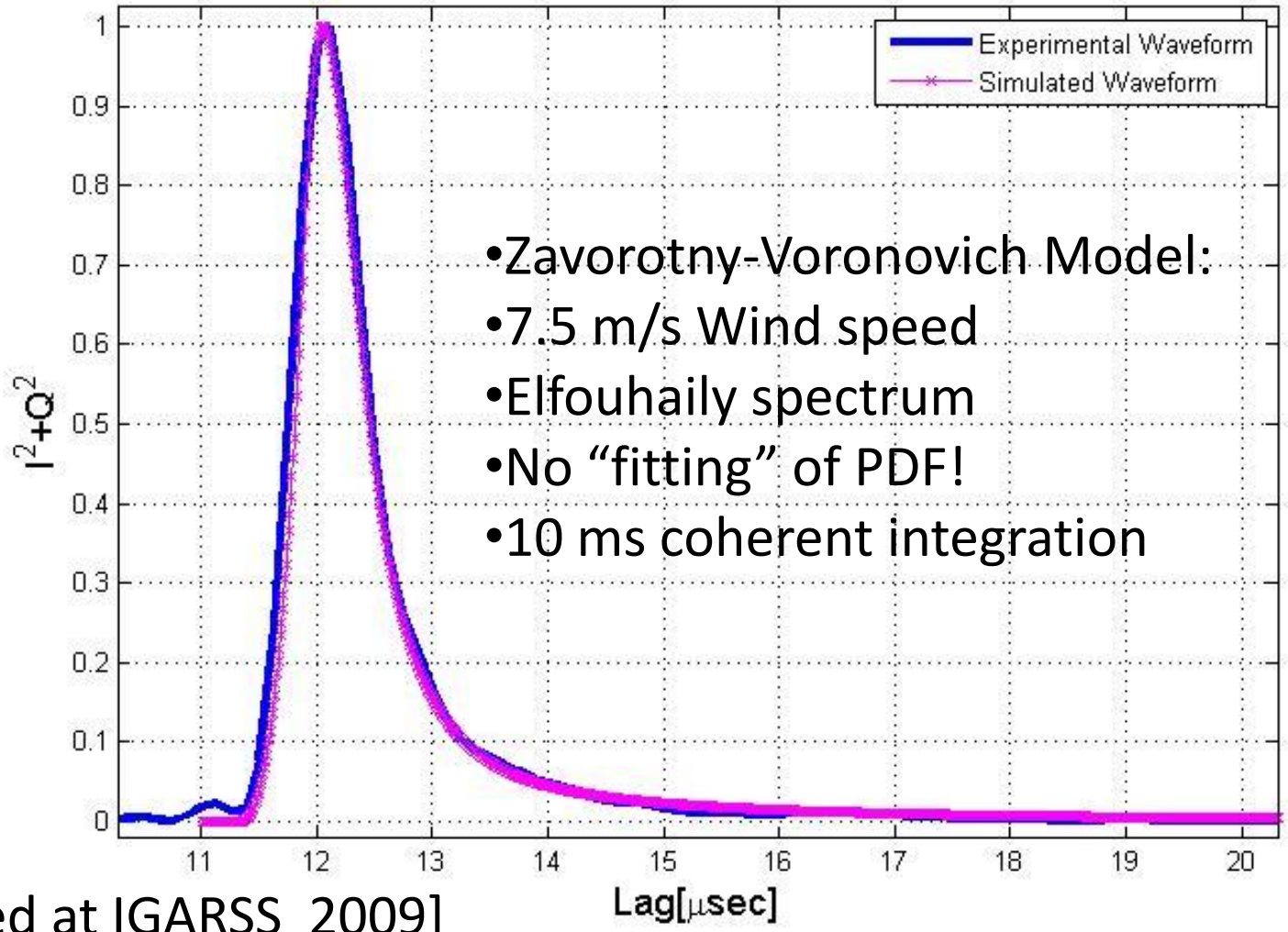


[Presented at IGARSS 2009]

Digital Satellite Signals of Opportunity (DSSO)



- First airborne experiment: Summer 2010 ~3100m
- XM Radio: 2342.205 MHz, QPSK. 8MHz/8bit sampling
- Model link budget matches experiment (direct signal) within 0.2 dB - for T_I=1 to 35 ms



- Zavorotny-Voronovich Model:
- 7.5 m/s Wind speed
- Elfouhaily spectrum
- No "fitting" of PDF!
- 10 ms coherent integration

[Presented at IGARSS 2009]

Conclusions

- Numerical simulator for GNSS-R waveforms developed
- Temporal correlation shaped by model
- Bin to bin correlation not yet implemented
- “Poor” fits to BOC waveforms were common
  - More frequent at low roughness values
  - Easily detection by residual test
  - “Good” fits had acceptable statistics

Acknowledgements

Starlab®

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References

You, et al, “Stochastic Voltage Model and Experimental Measurement of Ocean-Scattered GPS Signal Statistics,” IEEE TGARS, V42, N10, Oct. 2004, pp 2160-2169.

C. Zuffada and V. U. Zavorotny, “Coherence time and statistical properties of the GPS signal scattered off the ocean surface and their impact on the accuracy of remote sensing of sea surface topography and winds,” in *Proc. IGARSS, 2001, pp. 3332–3334.*

Betz, “Binary Offset Carrier Modulations for Radionavigation,” Navigation, V48, N4,Winter 2001–2002, pp 227-246