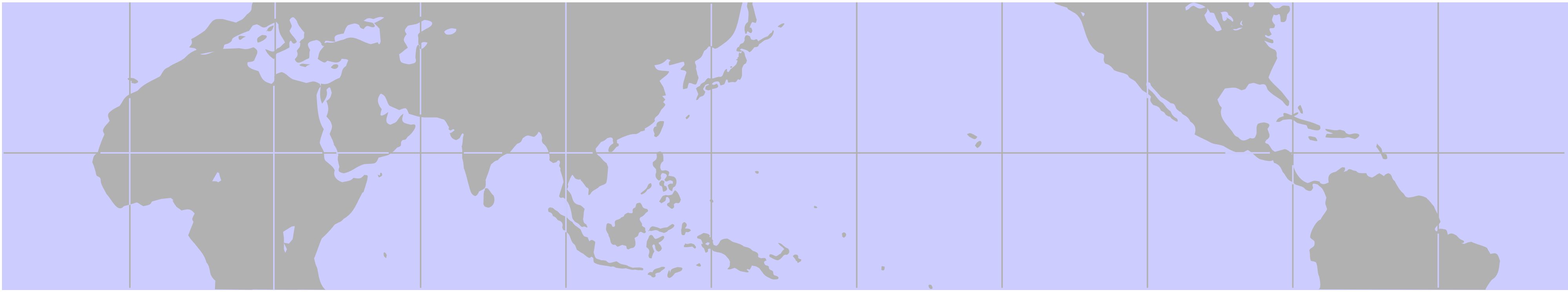
SMR 2333-42

Workshop on Science Applications of GNSS in Developing Countries (11-27 April), followed by the: Seminar on Development and Use of the Ionospheric NeQuick Model (30 April-1 May)

11 April - 1 May, 2012

Ionospheric Effects on the Expanding GNSS Spectrum

GROVES Keith and Carrano C.S., Doherty P.
Institute for Scientific Research Boston College
St. Clement's Hall
140 Commonwealth Avenue
CHESTNUT HILL MA 02467-3862
Massachusetts
U.S.A.



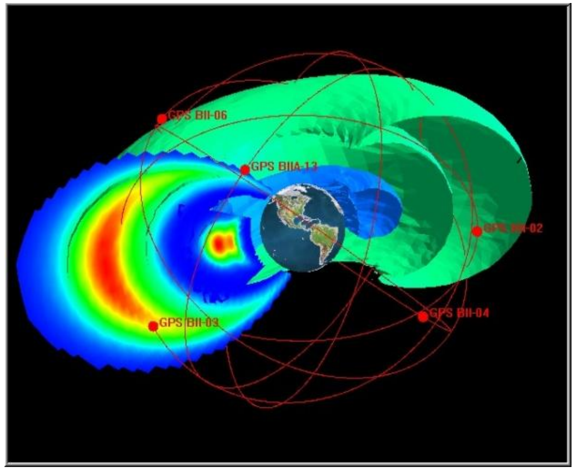
Ionospheric Effects on the Expanding GNSS Spectrum

KEITH M. GROVES

CHARLES S. CARRANO

PATRICIA DOHERTY

Institute for Scientific Research, Boston College

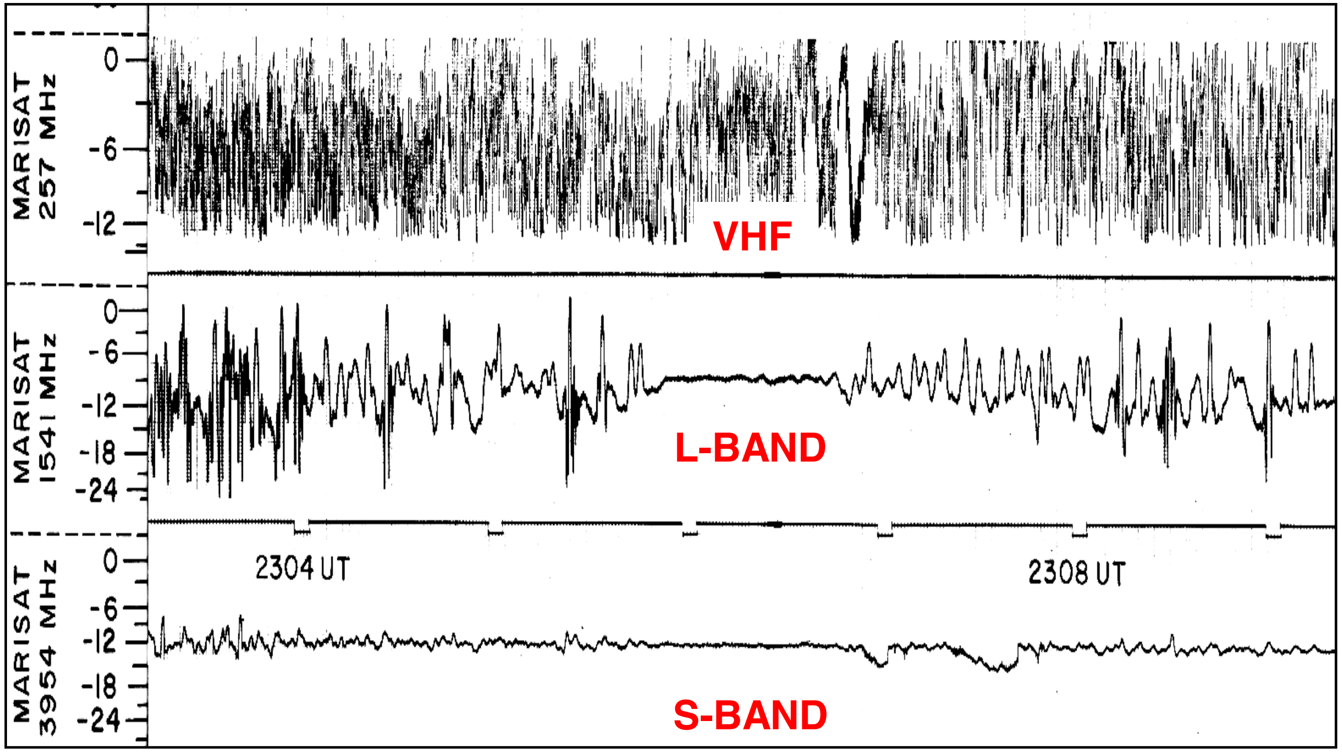


The Expanding GNSS Spectrum

- With the recent introduction of the L5 frequency, the GPS system now utilizes signals from 1176 to 1575 MHz; GLONASS extends the band to 1602 MHz
- Over such a relatively wide frequency span (30%), ionospheric propagation effects may show some variation
- The interest in this study is to understand the scintillation environment across this band
- Specifically we investigate the correlation of signal fading on L1, L2 and L5

Highly correlated fading may result in simultaneous loss of all navigation information for GNSS users

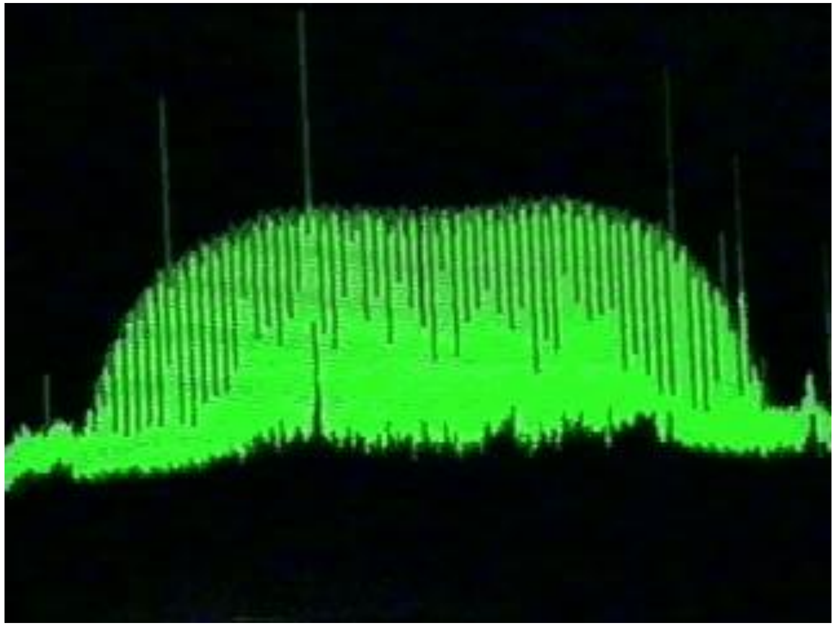
Scintillation: A Series of Squiggly Lines



- We typically present scintillation as shown above, a simple signal fluctuating in time or a series of such signals
- For most real systems that transmit information, however, the characteristics of scintillation over the system bandwidth may be a critical consideration

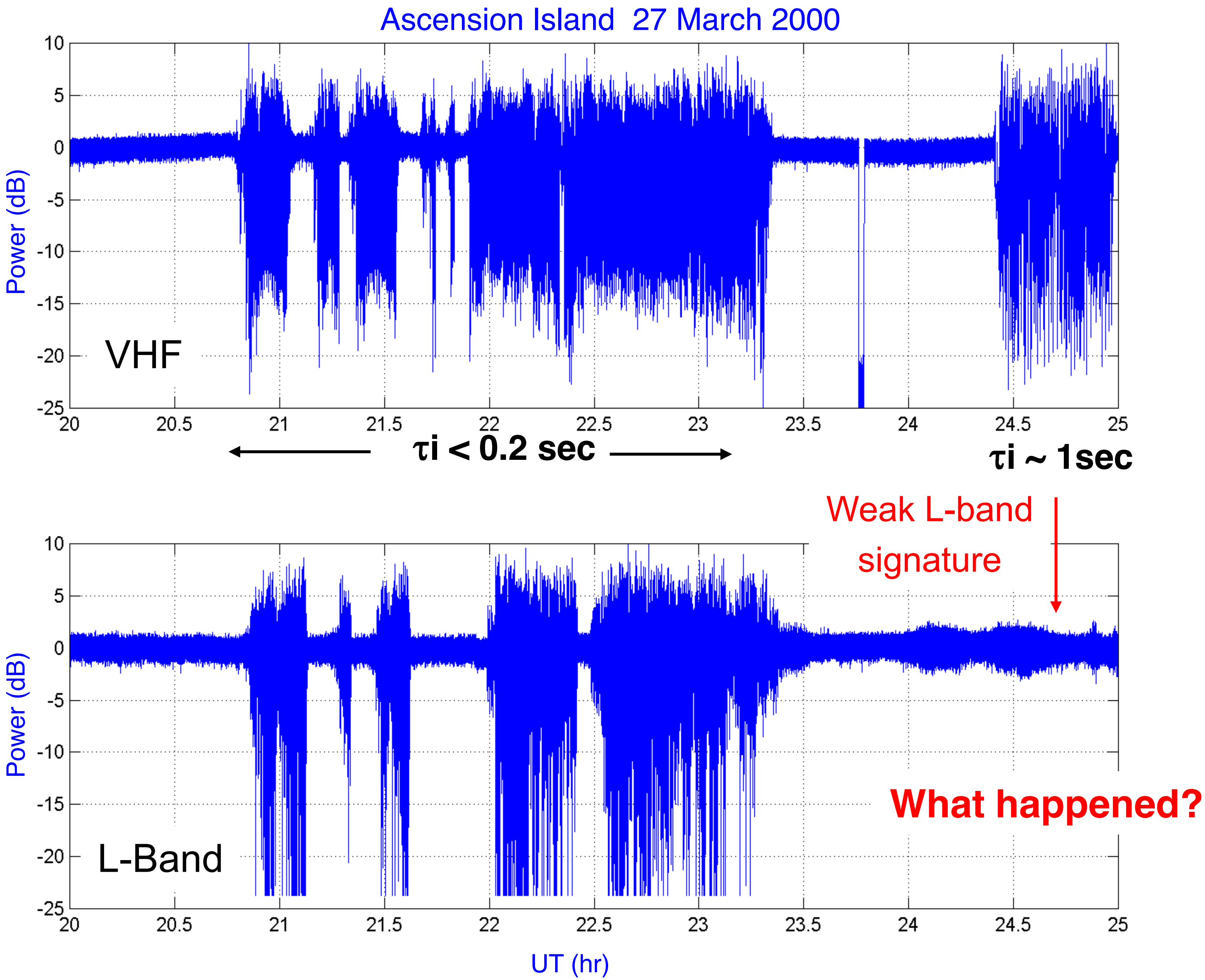
Implications for Systems Example: Mobile User Objective System (MUOS)

- Wideband (5 MHz) UHF SATCOM
- Utilizes code division multiple access (CDMA) waveforms for data & voice
  - "Mobile phone" from space
- Concerns about how scintillation will affect the wideband signals



Example of scintillation on a 5 MHz UHF waveform

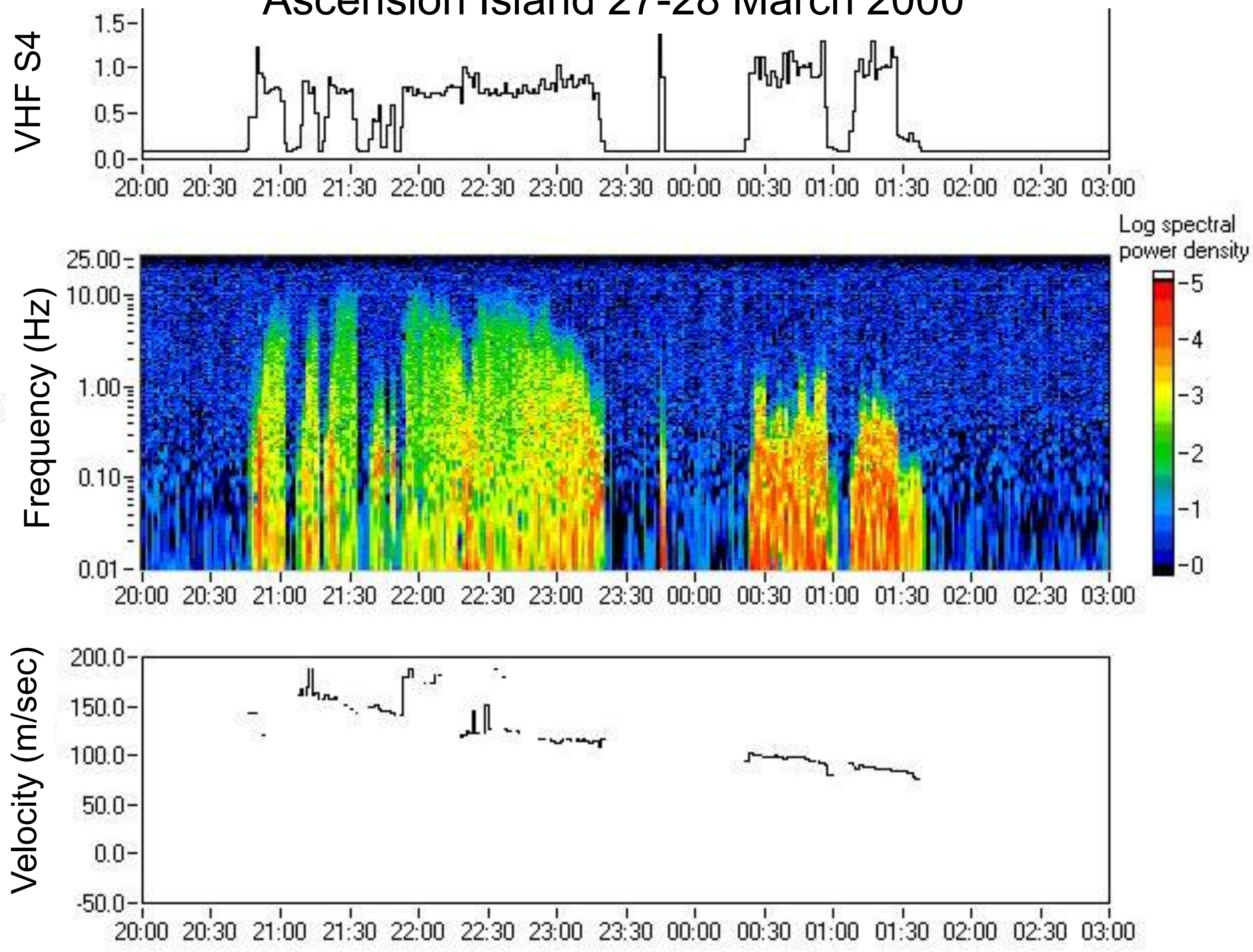
Solar Maximum Conditions at Ascension Island: VHF and L-Band



S4 and Scattering Strength

- S4 near unity; actually increases after midnight
- High frequency component decreases beginning about 22:30; markedly after midnight
- Drift velocity decreases throughout the evening

Ascension Island 27-28 March 2000

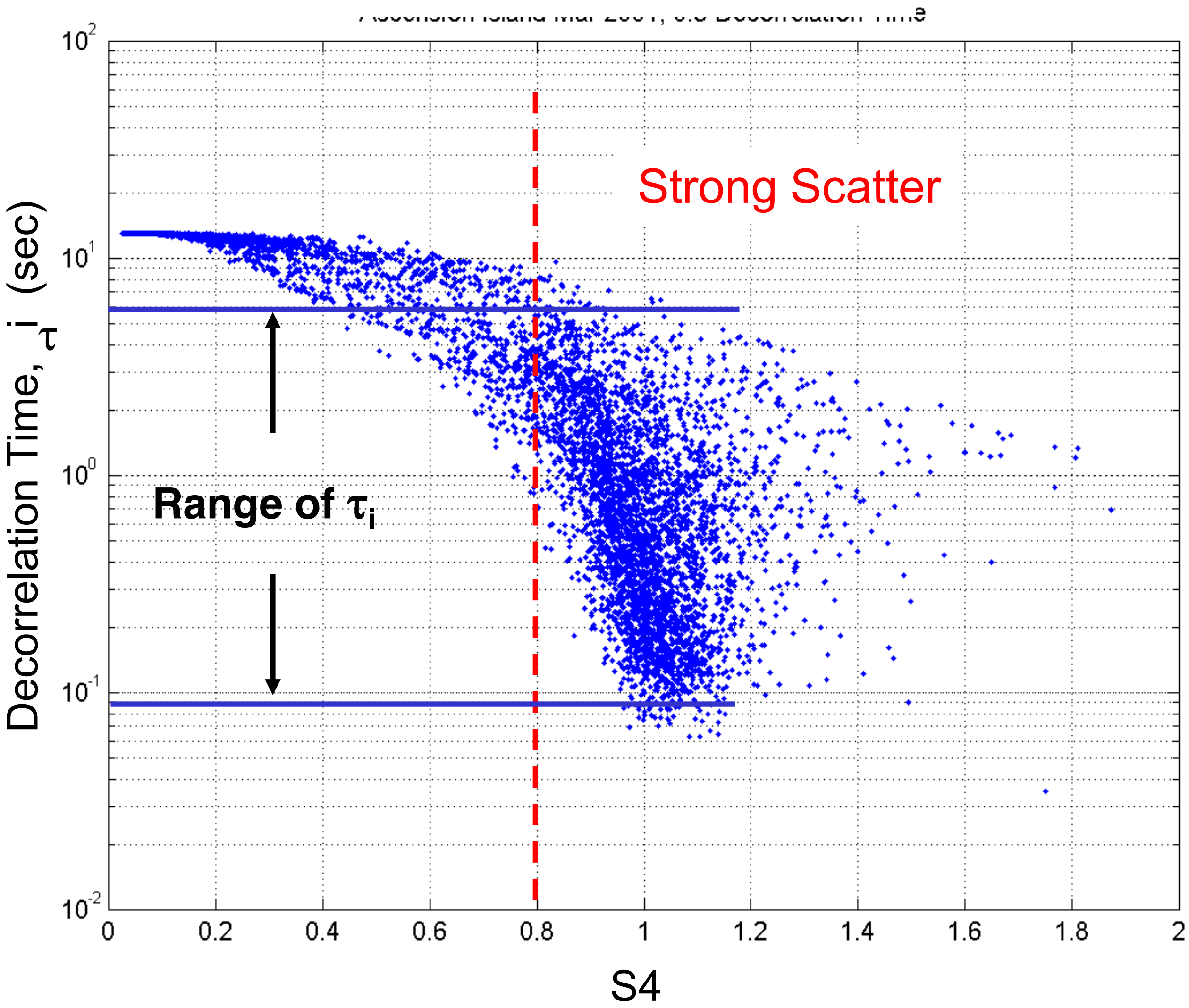


Rate of scintillation decreases with time as velocity slows and density decays

Additional Parameters to Characterize Scintillation: τ_i

- Traditional scintillation index, S4, tracks gross magnitude of satellite signal fluctuations
- Signal decorrelation time τi , determined by lag at which autocorrelation function = 0.5, tracks temporal fluctuations
- A better indicator of strength of scatter (actua propagation conditions) than S4

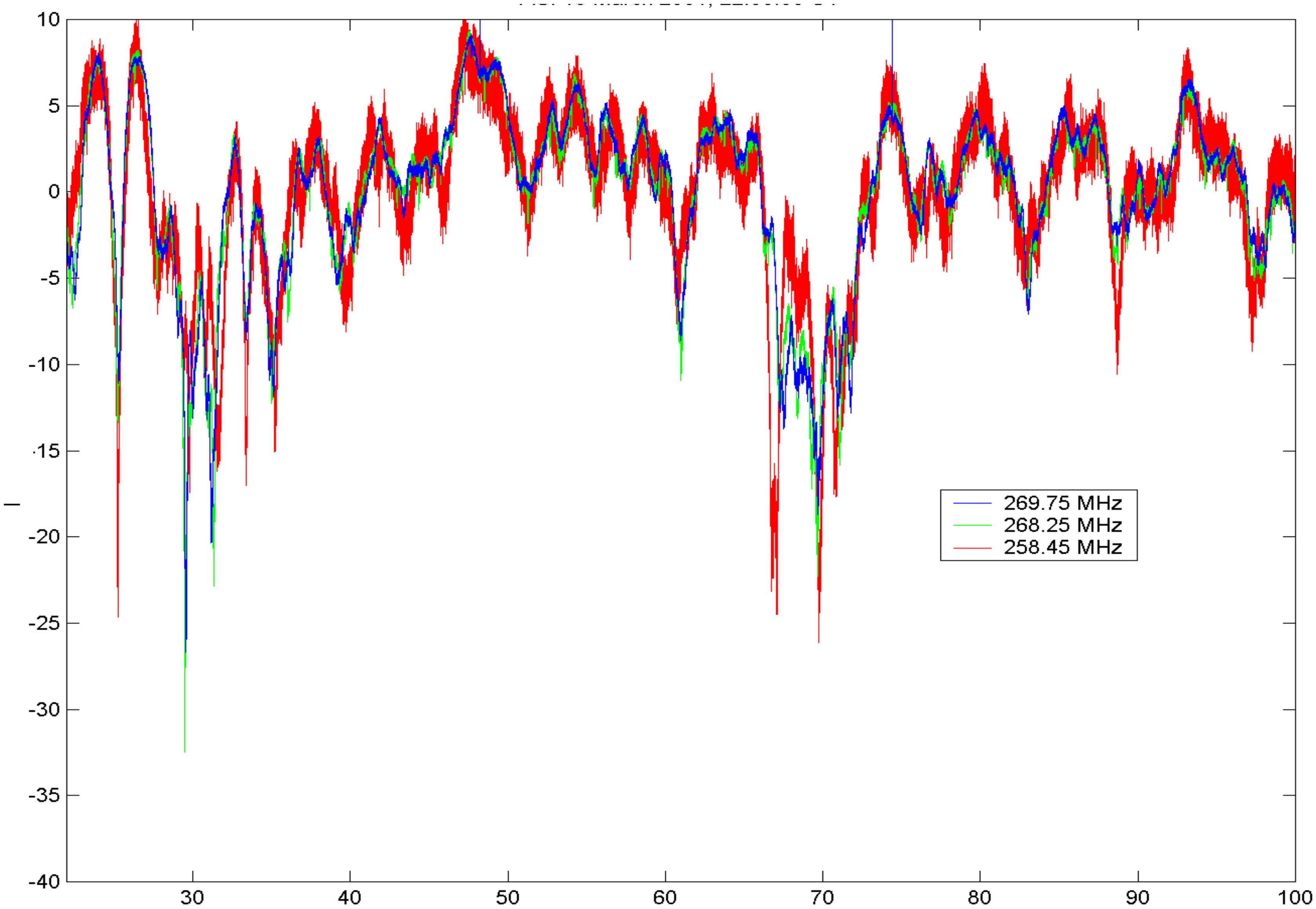
Ascension Island Mar 2001



Variation of τi with S4 depends on effective drift velocity and turbulence

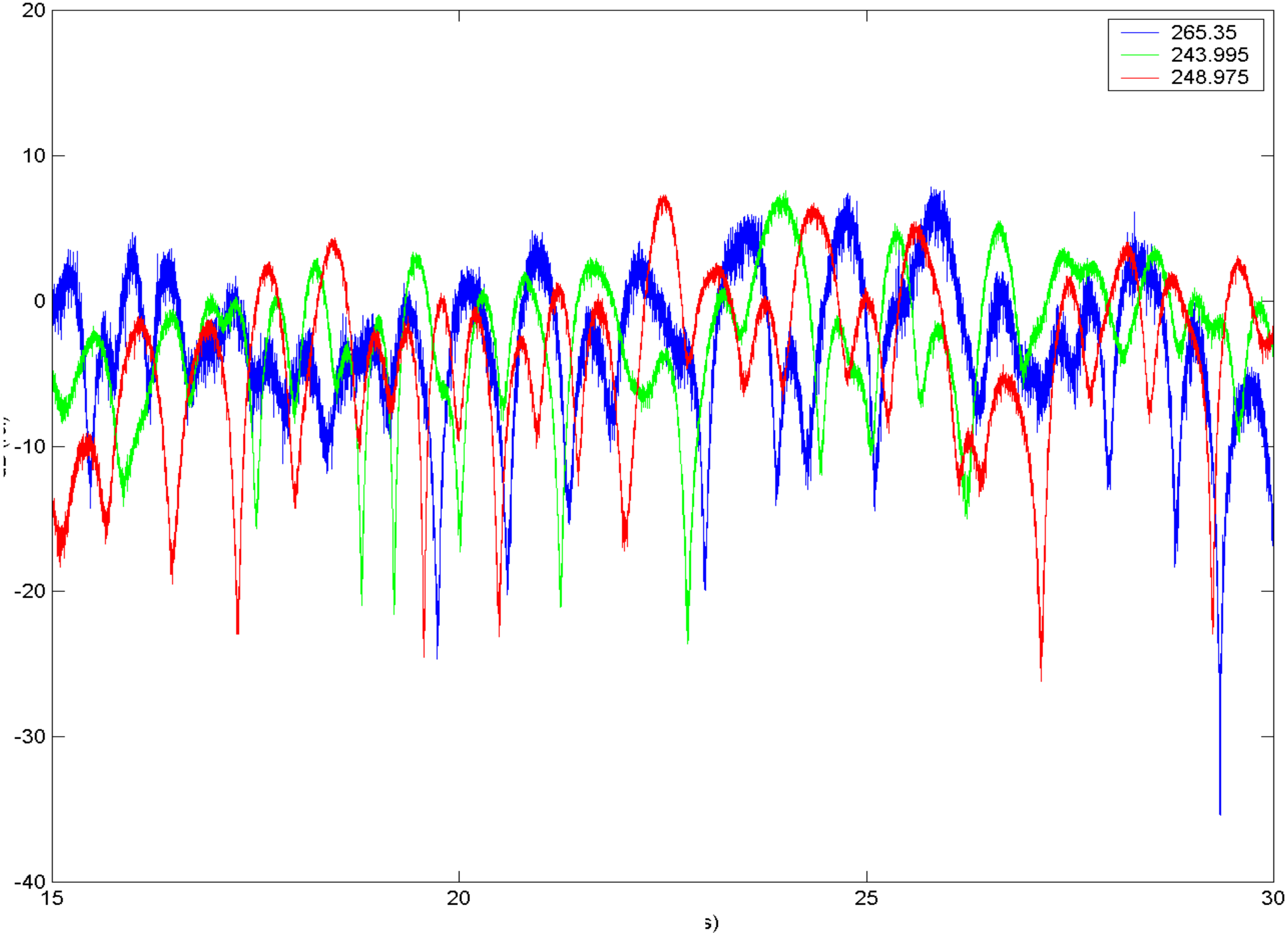
Correlated Scintillation Fluctuations (Large Coherence Bandwidth)

Ascension Island 18 March 2001

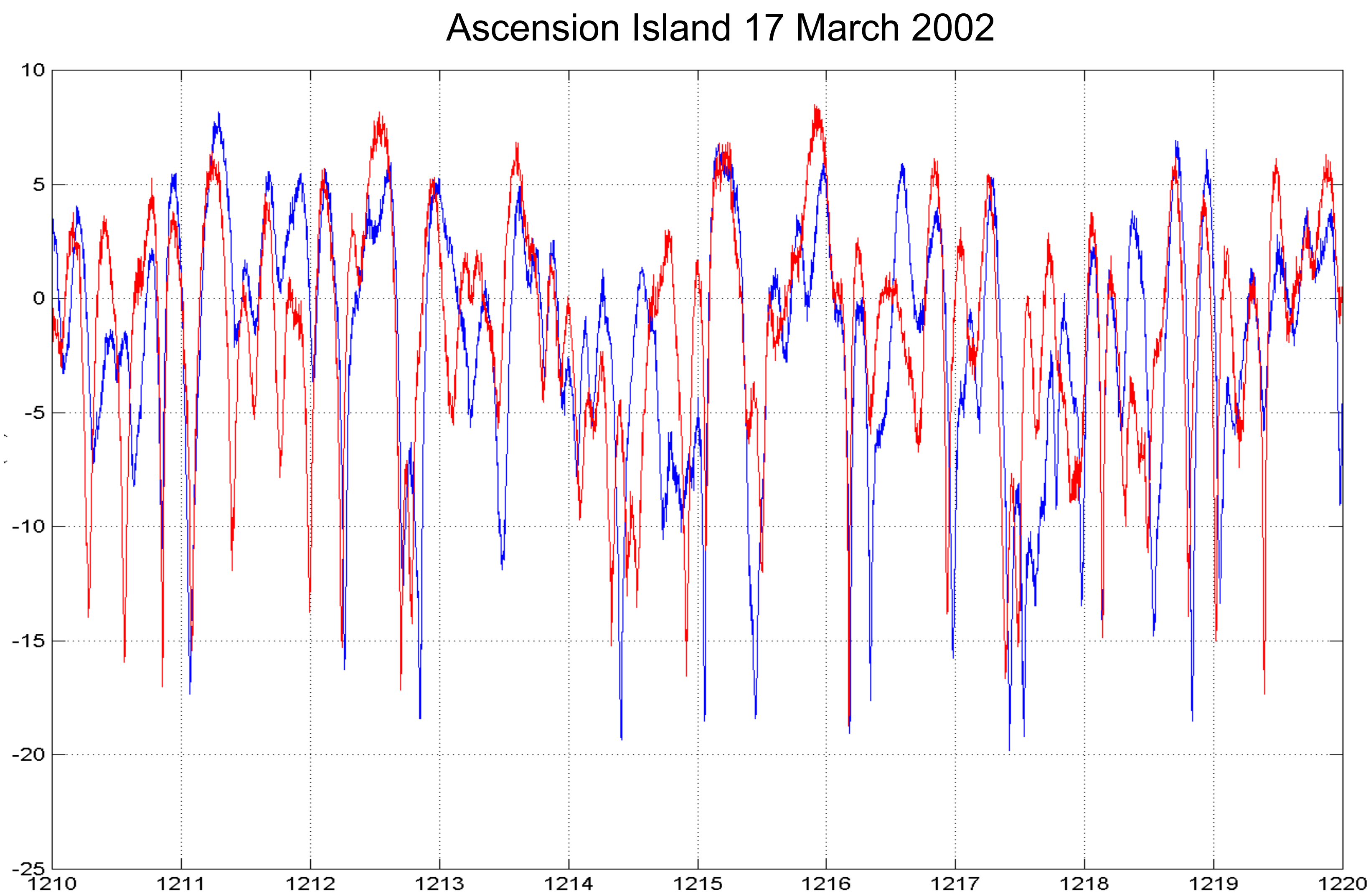


Uncorrelated Amplitude Scintillations (Smaller Coherence BW)

Ascension Island 16 March 2001

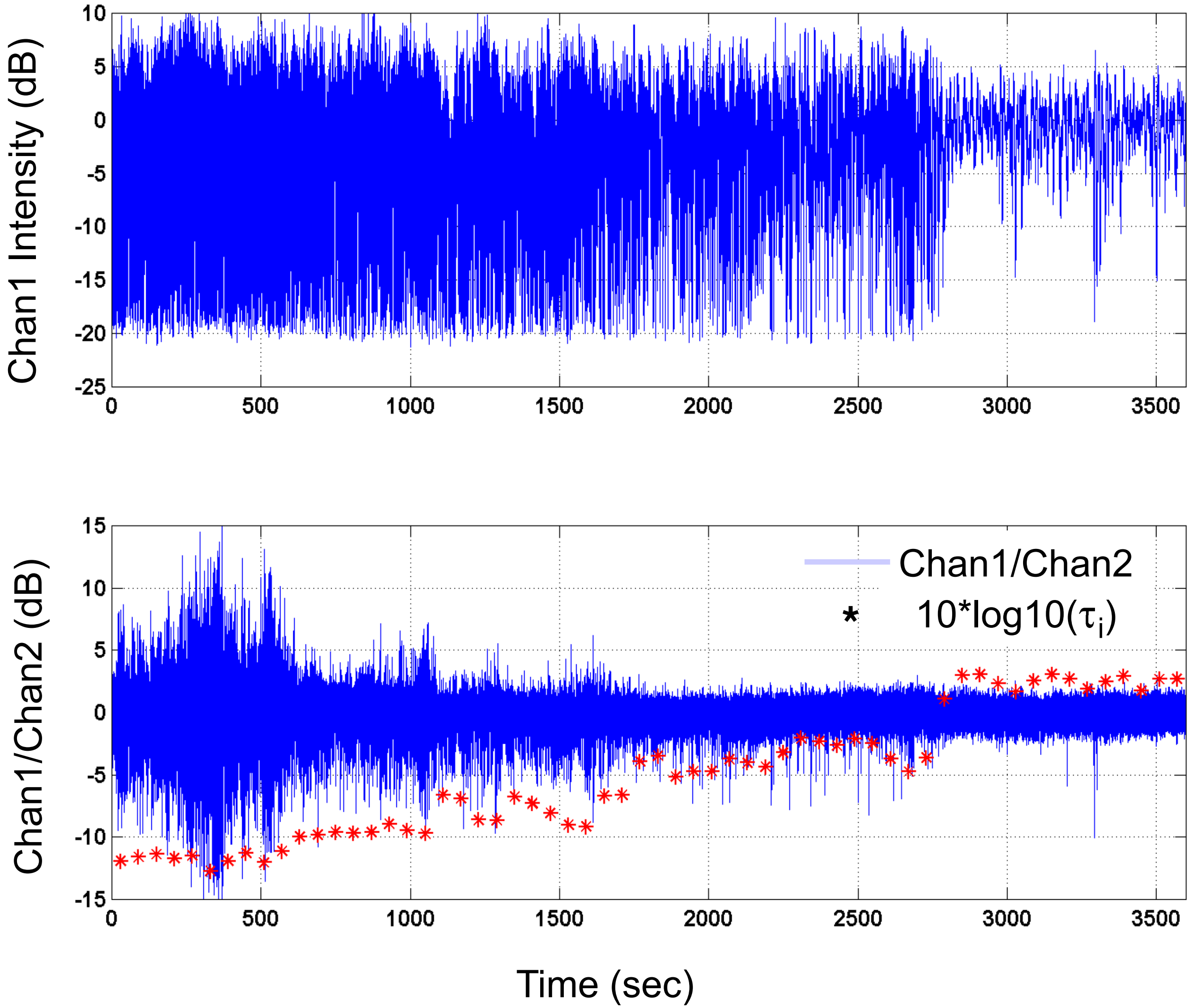


110 kHz Frequency Separation Decorrelation (Very Small Coherence Bandwidth)



Rapidly varying signal fluctuations

110 kHz Frequency Separation
Decorrelation Time and Amplitude Ratio



Good correlation between τ_i and coherent BW

GNSS Study Objectives

- Turning our attention to GNSS, this study will examine data from active scintillation periods at Ascension Island from 2000-2002
- The correlation of fading over the GNSS band will be characterized statistically as a function of scintillation parameters
- The climatology of these parameters is relatively well-established, so ultimately the results will provide global statistics on the correlations of amplitude fading across the GNSS frequency band

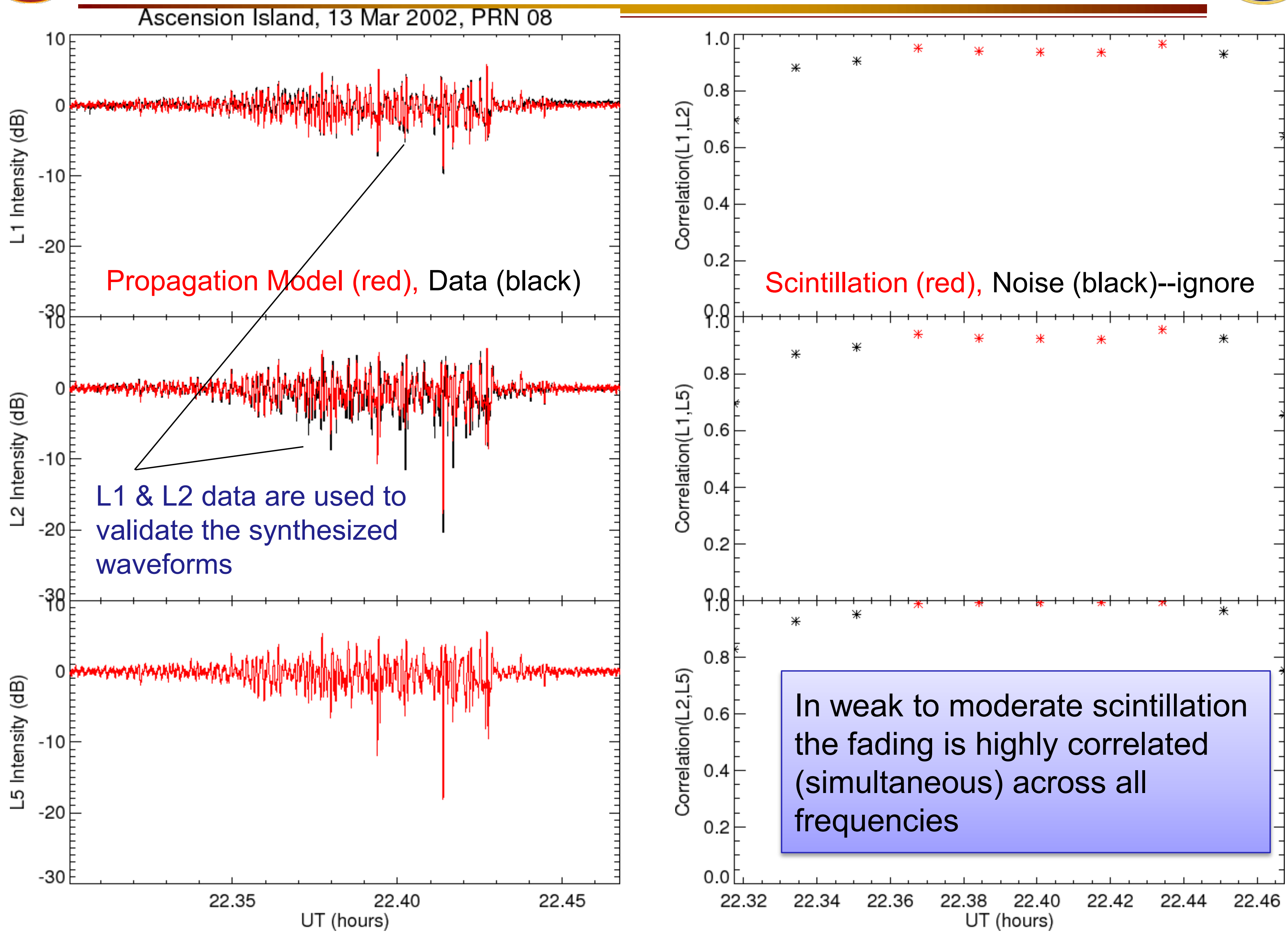
Technical Approach

- One can now perform limited observations of all three frequencies, but because the signals are available on only two satellites and the solar flux is below historical peak levels, it is not possible to explore the full range of scintillation conditions with current measurements
- To understand the frequency-dependence of scintillation effects on GPS signals a phase screen approach is used to simulate ionospheric irregularities
- The phase screen realizations are derived from actual GPS scintillation data collected during the last solar maximum period by AFRL in 2000-2002

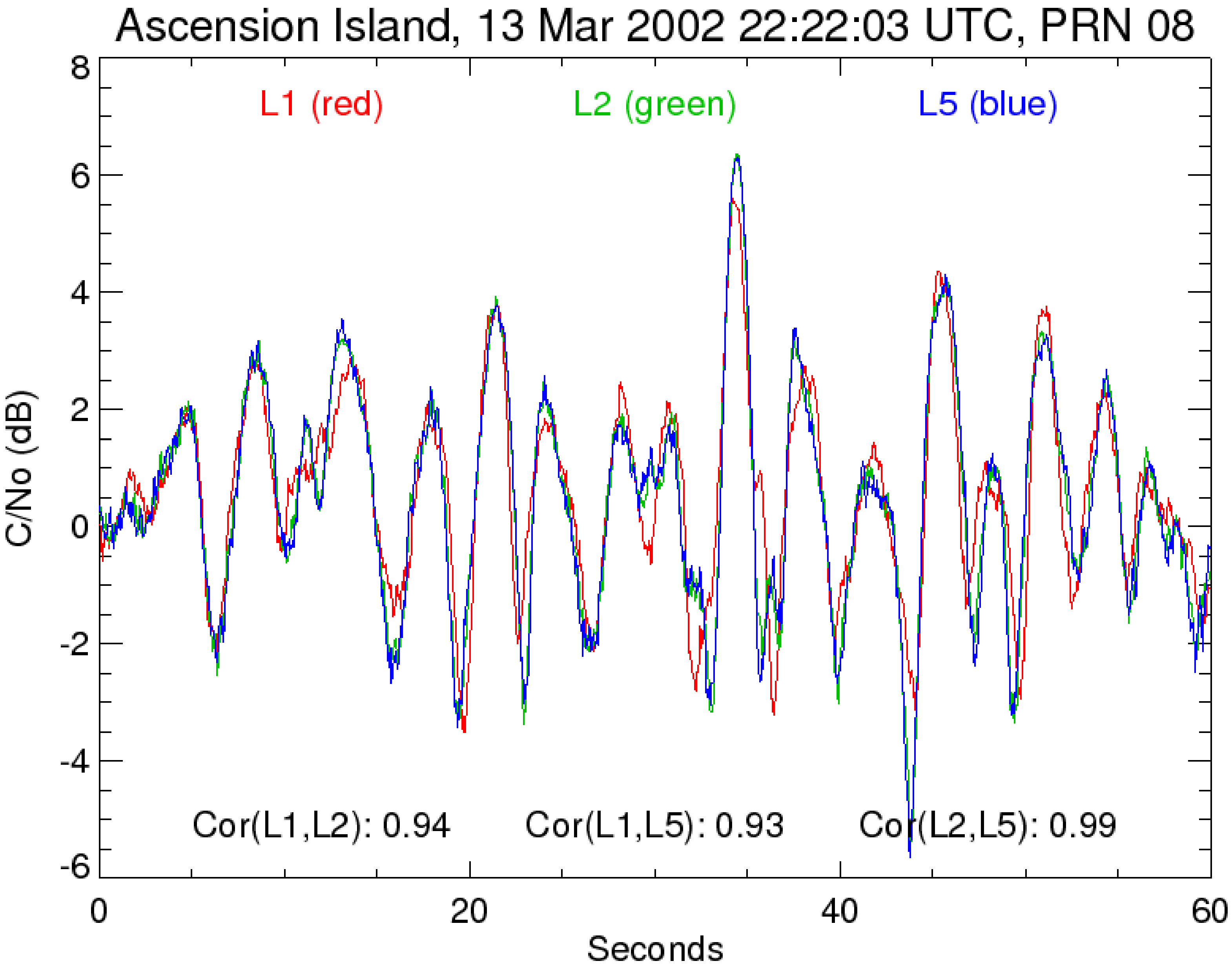
Data-Based Simulation

- A method known as *back-propagation* is used to synthetically propagate the signals observed on the ground upwards until the amplitude fluctuations are minimized, giving an effective phase screen
- Simulated signals at L1, L2 and L5 frequencies are then forward propagated through the data-derived screen to the ground to get consistent propagation effects across the band
- The simulated signals can then be compared with the actual L1 and L2 data to validate the results and provide confidence in the L5 realizations

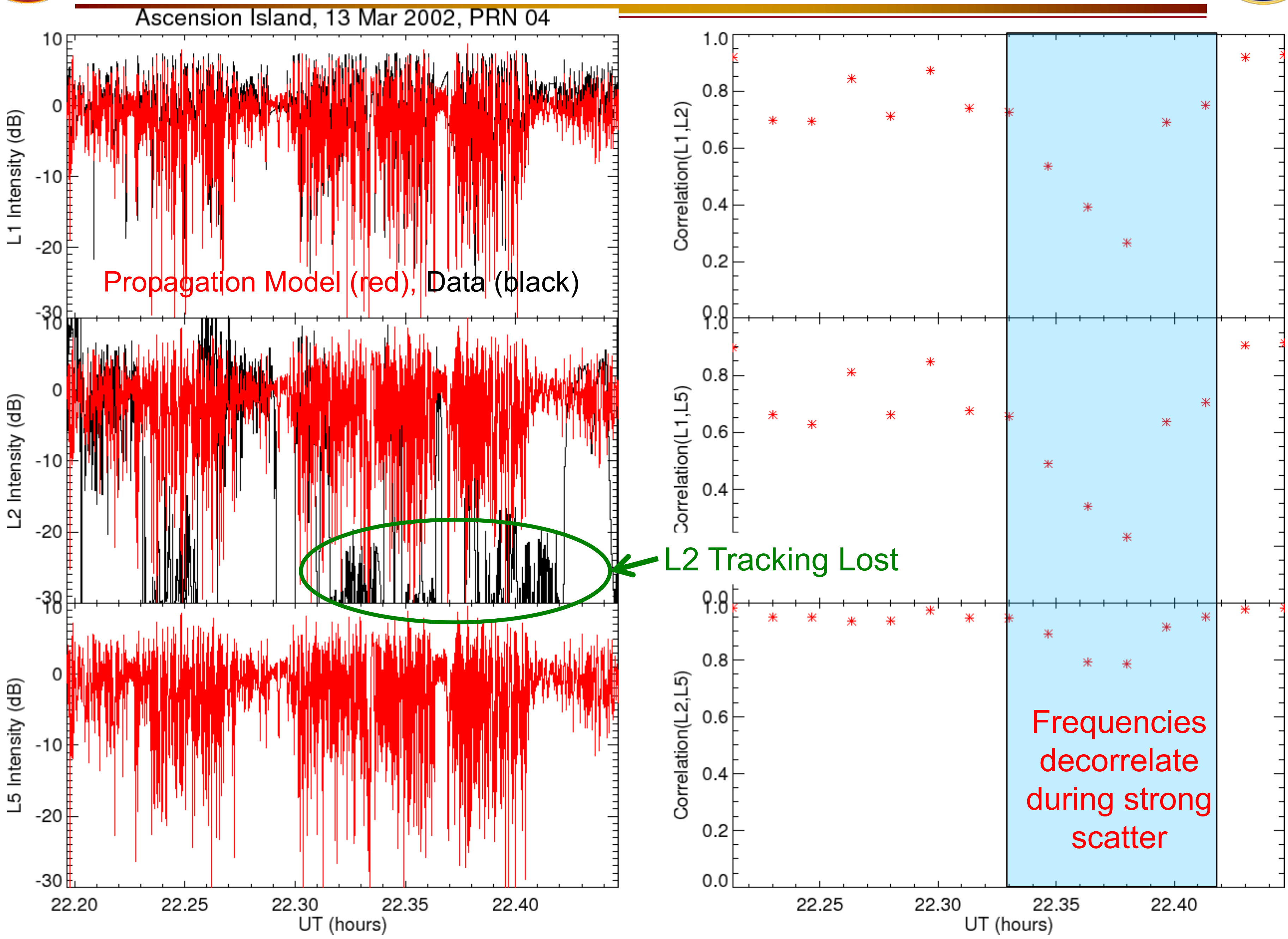
Weak Scatter Example



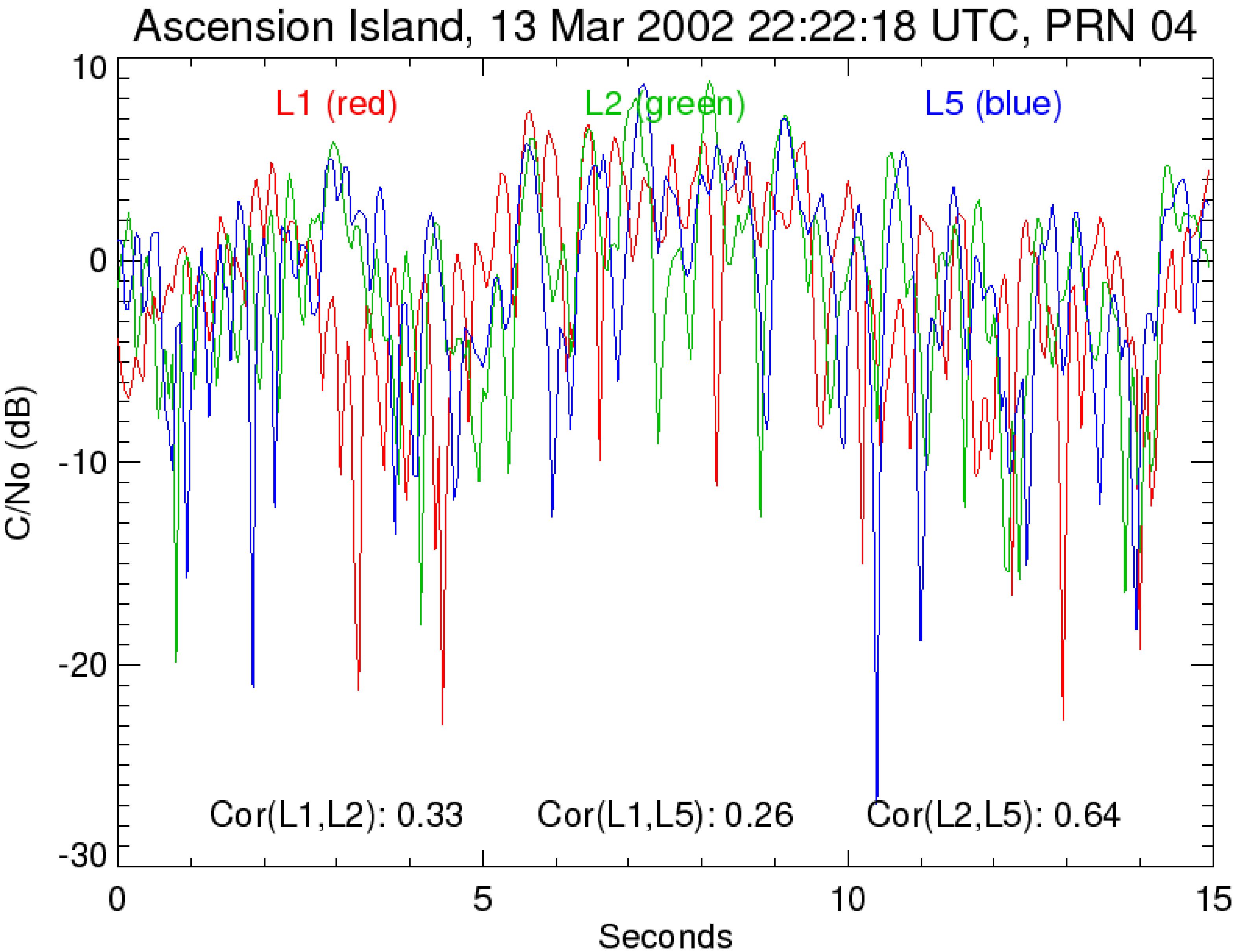
Weak Scatter Example – Zoom (L1 S_4=0.4)



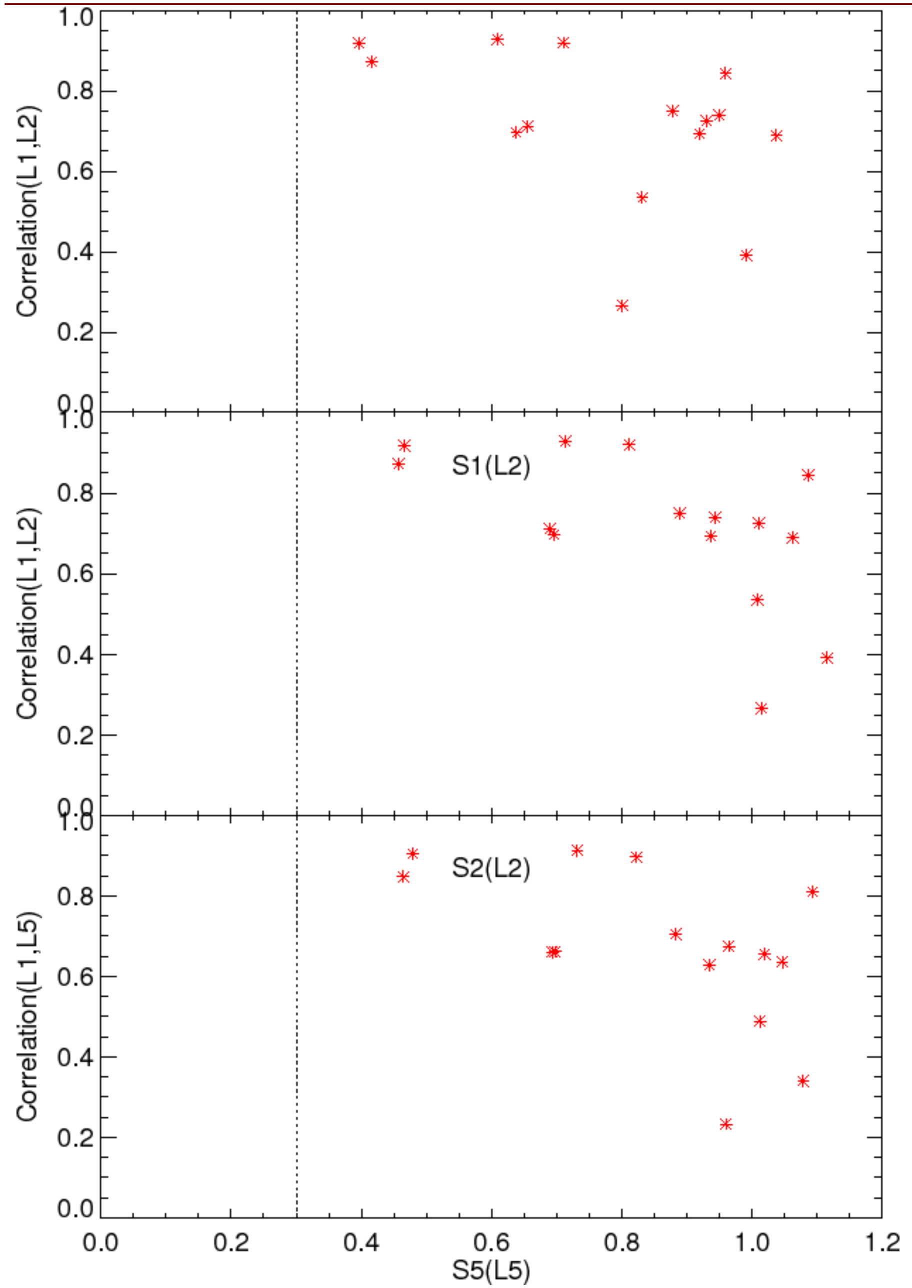
Strong Scatter Example



Strong Scatter Example - Zoom (L1 S_4=0.9)



Frequency Correlation vs. Scintillation Intensity (PRN4)



- These results for a single satellite pass show expected behavior—i.e. the correlation between frequencies will decrease with increasing scattering strength
- We will process the extensive database collected during the previous solar maximum to better characterize the statistical behavior
- Results will be presented in terms of the ionosphere's coherence bandwidth at L-band frequencies

$$\omega_{coh} = \frac{2\pi\omega_o L_o^2}{\ln\left(\frac{L_o}{l_i}\right)\lambda z_r \sigma_\varphi^2}$$

Summary

- The coherence bandwidth of the ionospheric medium is an important parameter for assessing impacts on real space-based radio frequency systems
- For GNSS systems frequency-dependent scintillation effects may be important determinants of performance
- Preliminary results indicate that the real world will frequently produce both correlated and uncorrelated fading, but when the fading is strongest it will tend to be uncorrelated, particularly between L1 and lower GNSS frequencies
- Ironically, the strongest scatter events may provide improved performance for multi-band GNSS systems due to the decorrelation of scintillation effects across the band