Equatorial Amplitude Scintillation Spectrum Analysis and Fading Characteristics on GPS Signals

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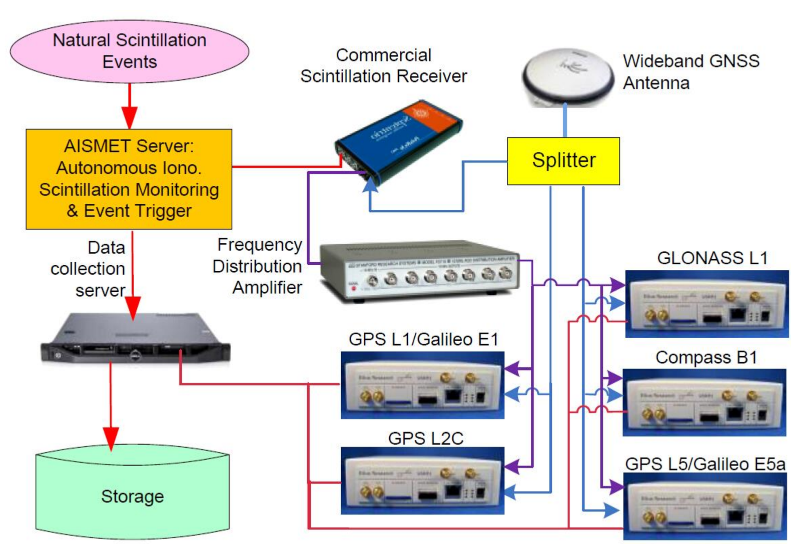
Summary: Deep signal fading during ionospheric scintillation poses a threat to GNSS signal tracking and degrades positioning solution accuracy. Understanding the physics and the characteristics of the signal fading is a pre-requisite to develop robust scintillation mitigation techniques for assured navigation and to utilize GNSS signals for ionosphere and space weather studies. In this study, intermediate frequency GPS data collected on Ascension Island in March 2013 are processed to theoretically analyze and statistically characterize signal fading across all three GPS bands. Spectral and coherence analysis of the strong scintillation signals is presented to partly confirm the theoretical predictions. In addition, probability distributions of amplitude fading are analyzed across the three GPS bands.

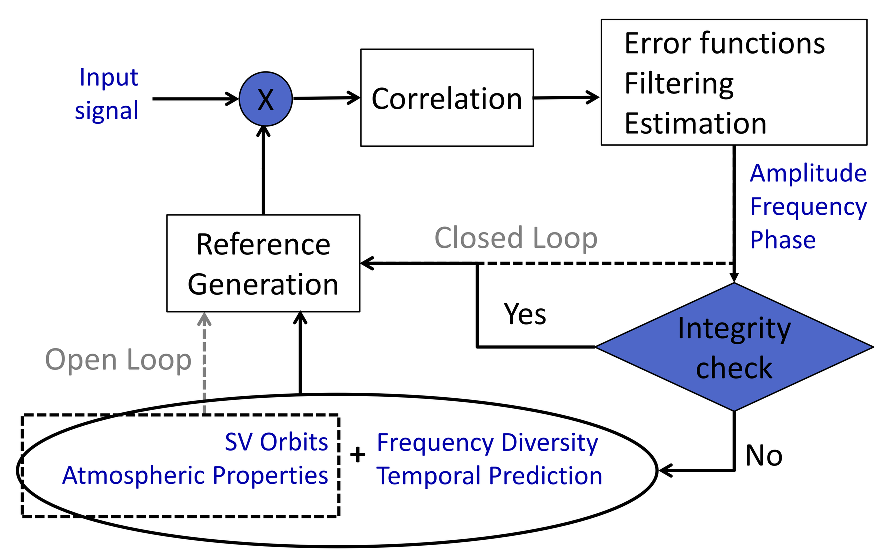
Introduction & Data Set

2-D Phase Screen Theory:

- **Forward Propagation Analytical Equations:**
  - Field in the space $$\psi(x,y) = \int \tilde{\psi}(x_0;\kappa_y)\exp\{ik_x(\kappa_y)(x-x_0)\}\exp\{i\kappa_y y\}\frac{d\kappa_y}{2\pi}$$
  - Field spectrum in the space $$\tilde{\psi}(x_0;\kappa_y) = \int \psi(x_0,y)\exp\{-i\kappa_y y\}dy$$
- **Spectrum Statistical Models:**
  - One-component power law $$\Phi_{\delta n}(q) \approx C_S(q_L^2+q^2)^{-(\nu+\frac{1}{2})} \approx C_S q^{-(2\nu+1)}$$
  - Two-component power law $$\Phi_{\delta\phi}(q) = \begin{cases} C_p q^{-p_1}, & q \le q_0 \\ C_p q_0^{p_2-p_1} q^{-p_2}, & q > q_0 \end{cases}$$

Ascension Island GNSS Data Collection System and Tracking Algorithm:



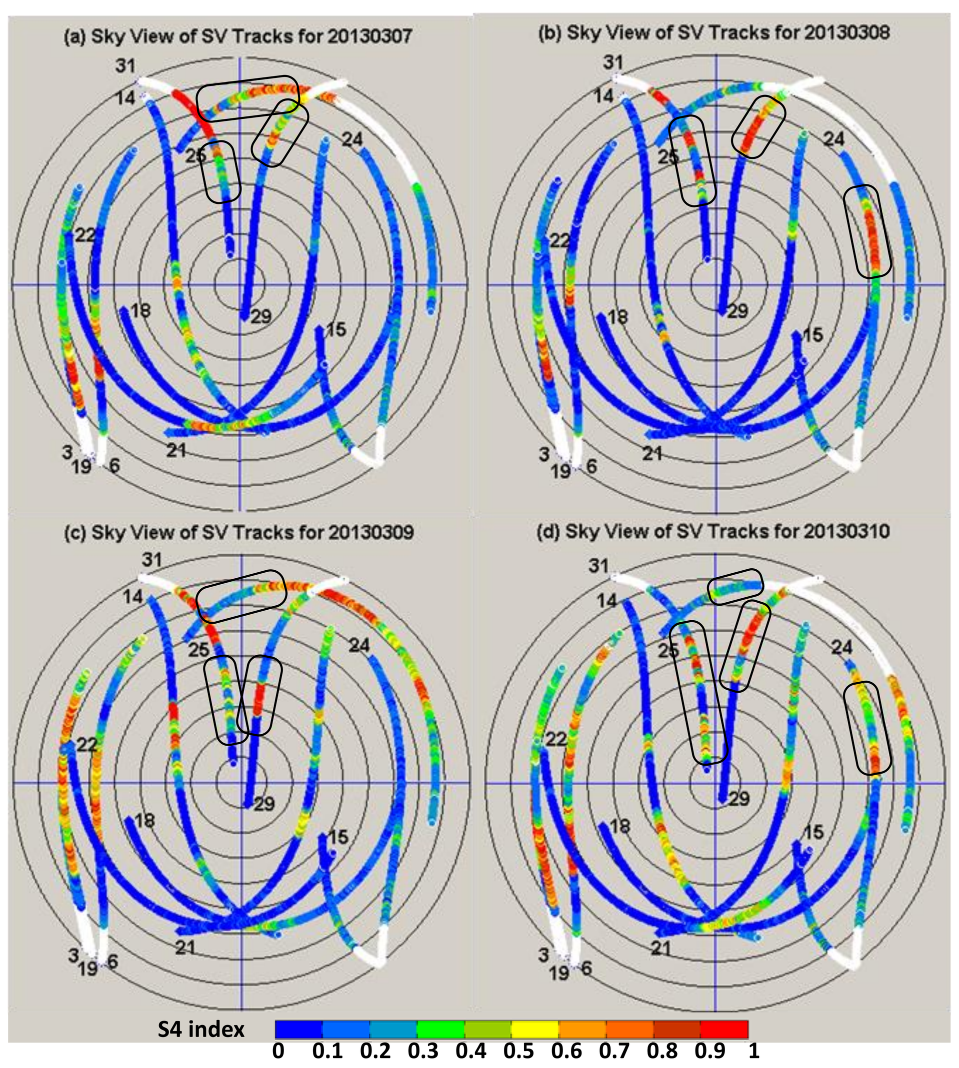


GPS Data Set:

- Data segment length used in this study collected in 2013 on Ascension Island

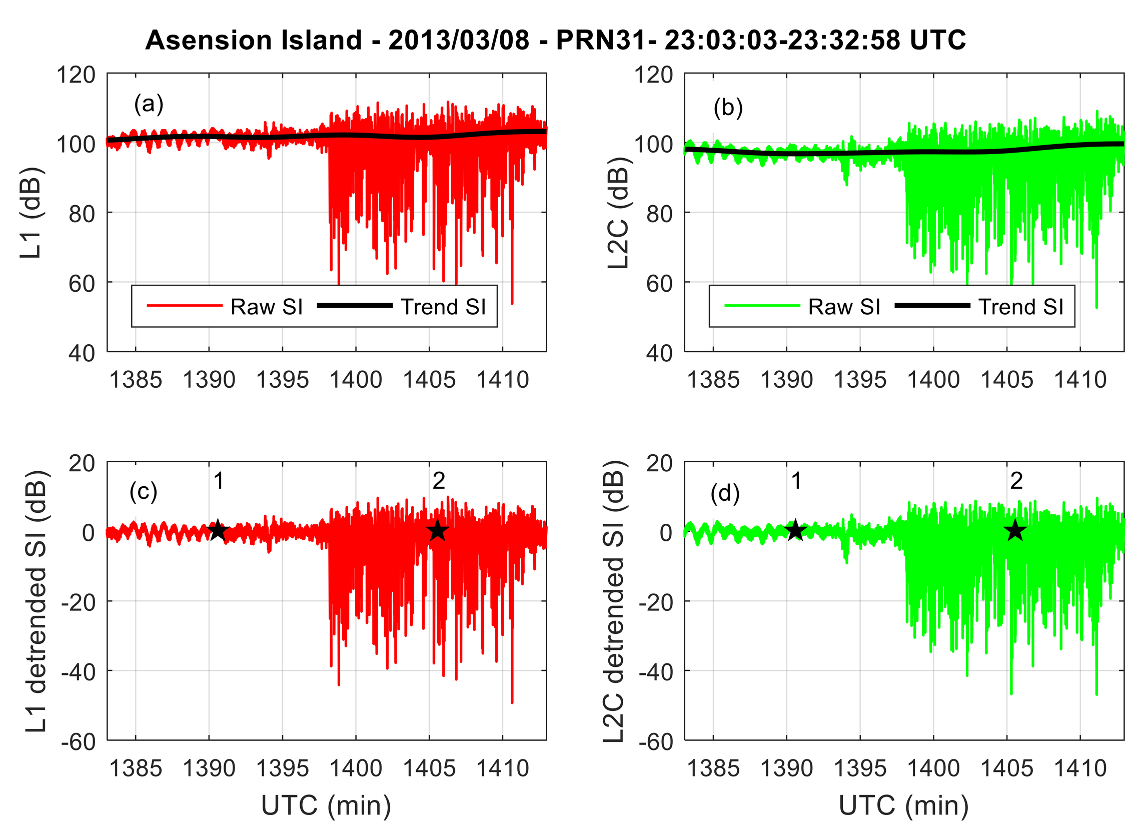
PRN \ Date	3/7	3/8	3/9	3/10	Sum
24	0	1.28	0	1.42	2.70
25	1.21	0	1.07	0.78	3.06
29	1.11	1.00	1.00	1.28	4.39
31	0.83	1.28	1.11	2.00	5.22
Sum	3.15	3.56	3.18	5.48	15.37

- Sky view of the data

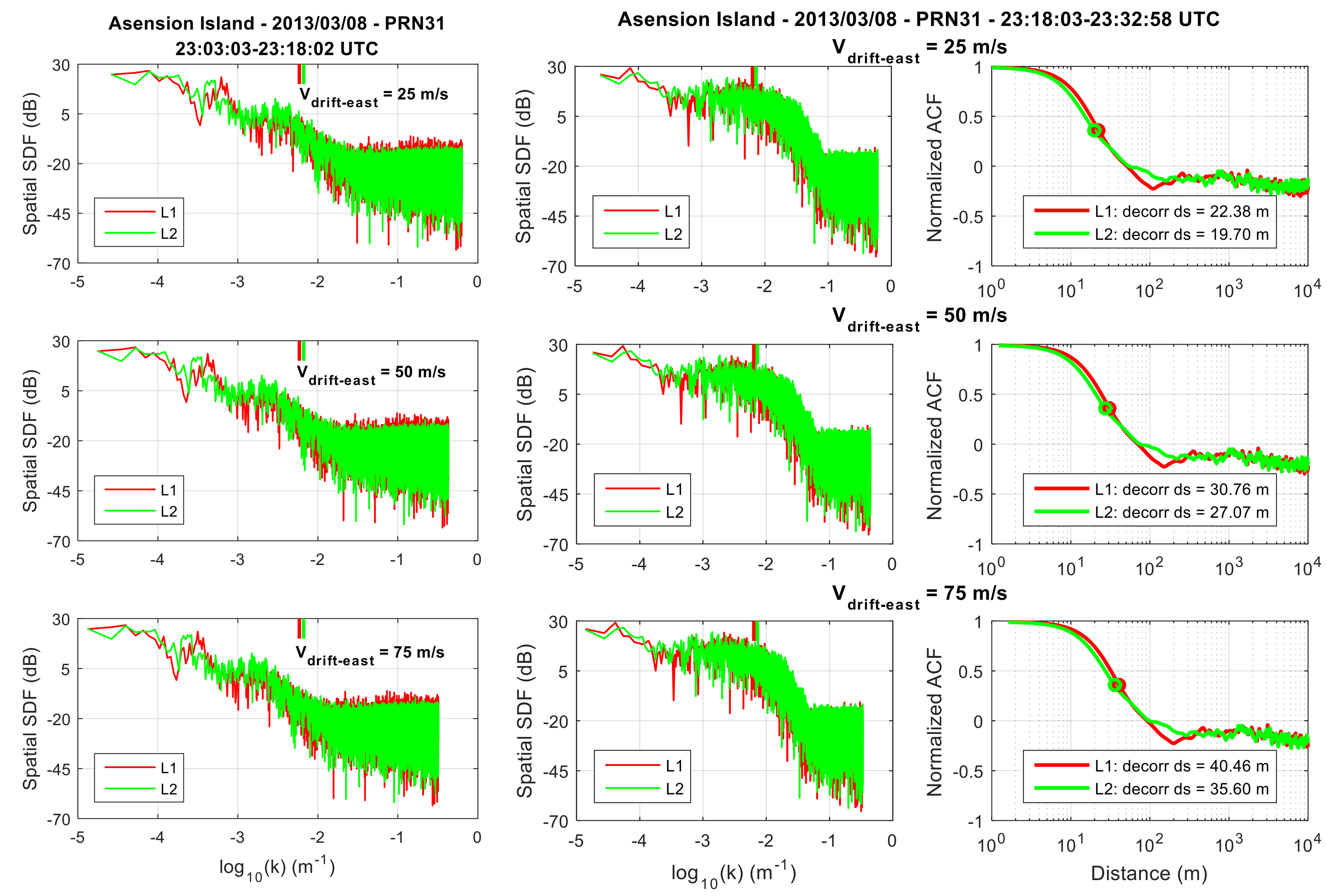


Results

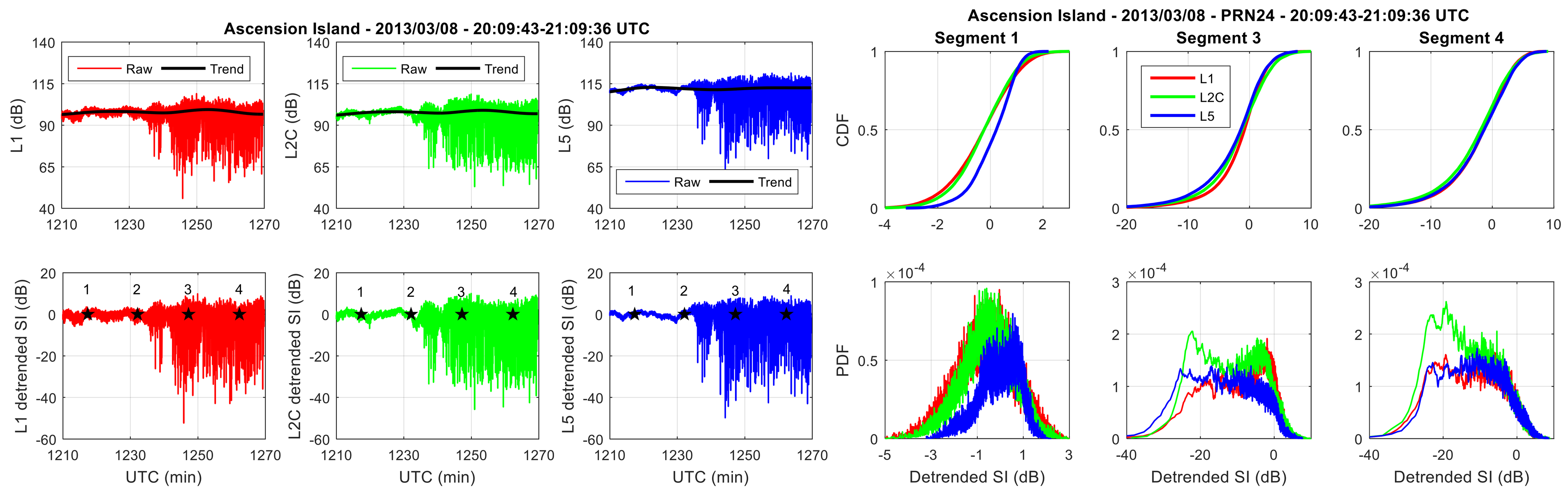
Spatial Spectrum and coherence analysis:



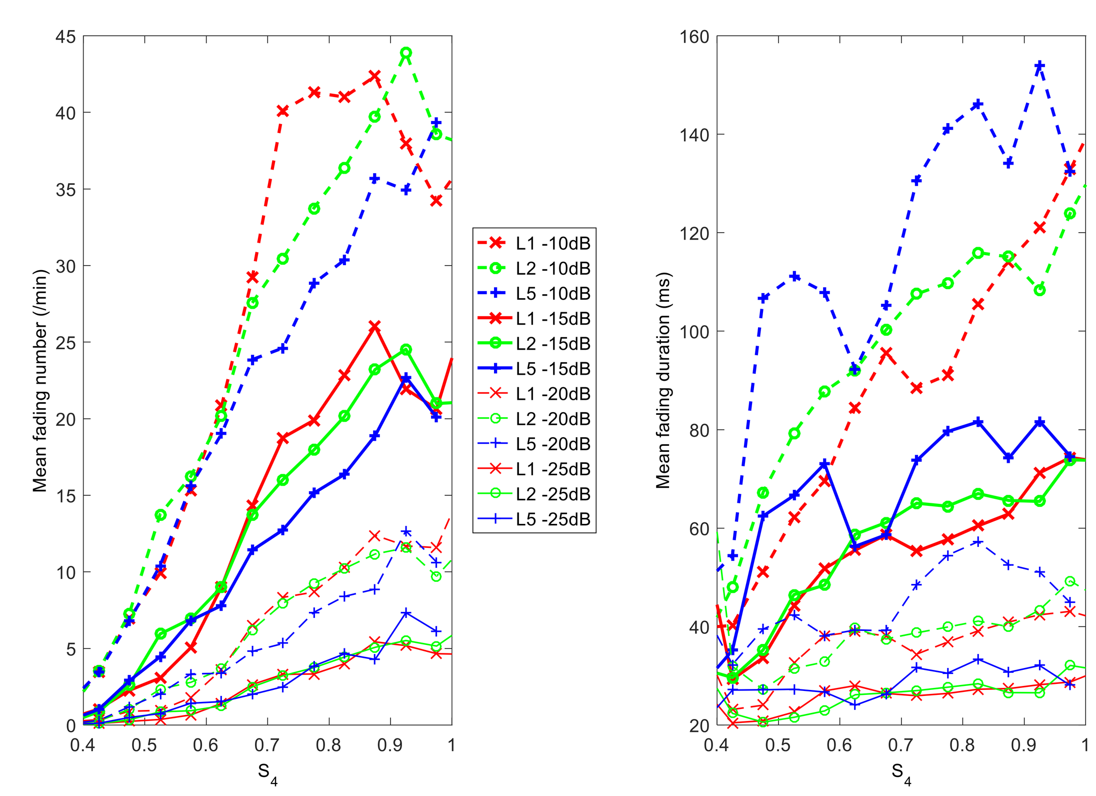
- Segment 1 is quiet; segment 2 is plagued with strong scintillation
- The effective scan velocity shifts the spectra
- Scintillation spectrum is enhanced at the low frequency part
- The spectra support power-law theory
- The auto-correlation function is the inverse Fourier Transform of the spectrum density function
- De-correlation distance reflects the scale of the irregularity



Signal Intensity Statistics:



Signal Intensity Fading vs S_4 Index:



- The numbers of fades increases when amplitude scintillation becomes stronger
- The mean duration of fades increases as scintillation gets stronger, but not as dramatically, especially for deeper fading cases
- L5 tends to have a smaller number of fades, yet are of longer duration than those on L1 and L2C at a given S_4 level

Conclusion

- The spectra of real scintillation data support phase screen theory and power-law statistical models.
- The drift velocity plays an important role in determining the spatial spectra, and further the scale of irregularities.
- For quiet signals, the detrended signal intensity is close to log-normal distributions for all three frequencies.
- The distribution of the log10 of the detrended signal intensity appears to be near uniform within a certain range and exponential outside the range, although the shape varies in very strong scatter cases.
- When amplitude scintillation becomes stronger, the number and the duration of fades increase.

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