

Frequency dependence of effective bottom attenuation due to environmental variability

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Introduction

- Traditionally, ocean sediment attenuation assumes linear frequency dependence such that loss per distance has the form $\mathbf{a} = bf$ (or constant loss per wavelength), where α may have units 1/m or dB/m, and b =constant. Parameterization of sediment attenuation then relies on determination of b .
- More recent inversion studies (e.g., Zhou et al., 1987) have suggested non-linear frequency dependence of attenuation, i.e., $b = cf^x$ such that $\mathbf{a} = cf^{(1+x)}$. Zhou et al. found $x \sim 0.7$, so $\mathbf{a} \propto f^{1.7}$
- Physical models of sediment attenuation mechanism unclear on inherent nonlinear response versus effective nonlinear response due to variable environmental influences.

Model

- Monterey-Miami Parabolic Equation (MMPE) model used to compute propagation. Inputs may include range-dependent sound speed profiles, water-sediment and sediment-basement interfaces, sediment/basement sound speed gradients, sediment/basement sound speed and density fluctuations, and constant sediment/basement attenuation values (linear frequency dependence assumed).
- Sound speed profiles input deterministically.
- Interface roughness based on realizations of spectral model,

$$W_h(K) \propto (1 + L_h^2 K^2)^{-b}$$

- Sound speed/density variability based on realizations of spectral model

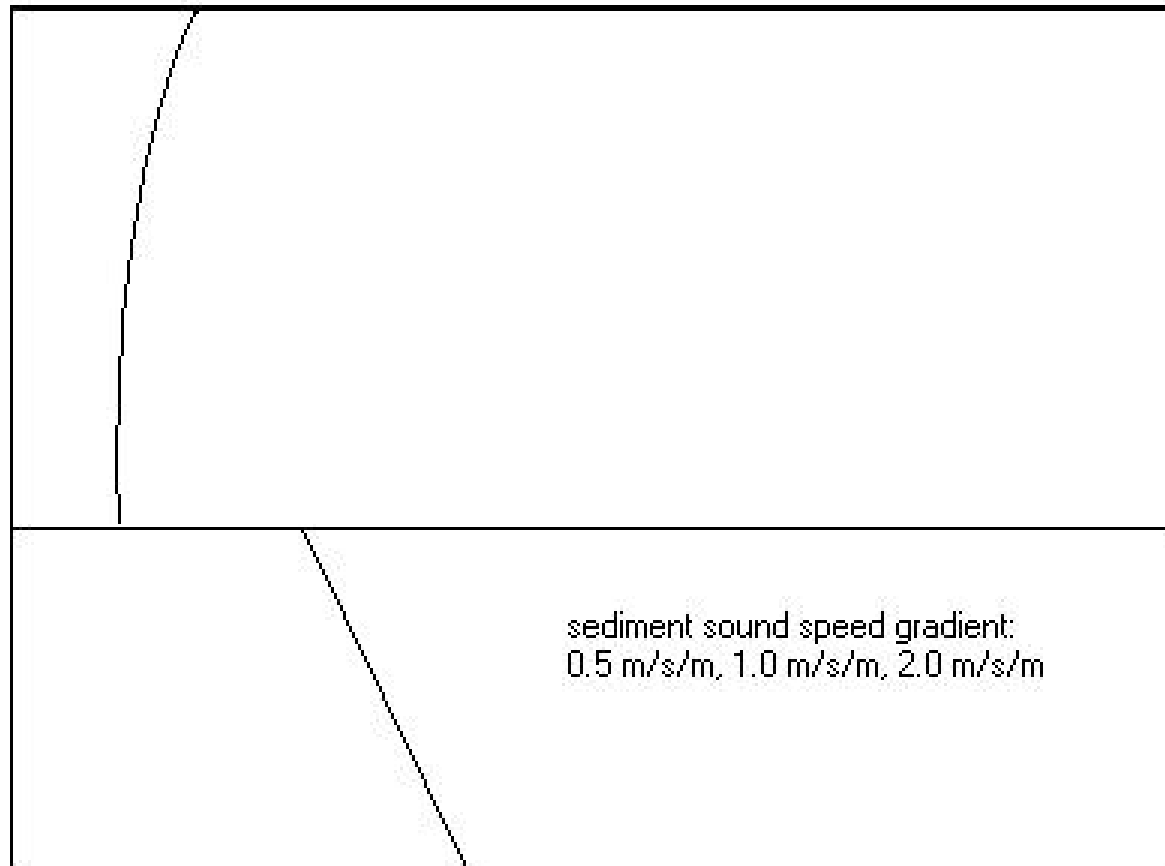
$$W_{dc}(K, M) \propto (\Lambda^2 K^2 + M^2)^{-g}$$

Approach – Part I

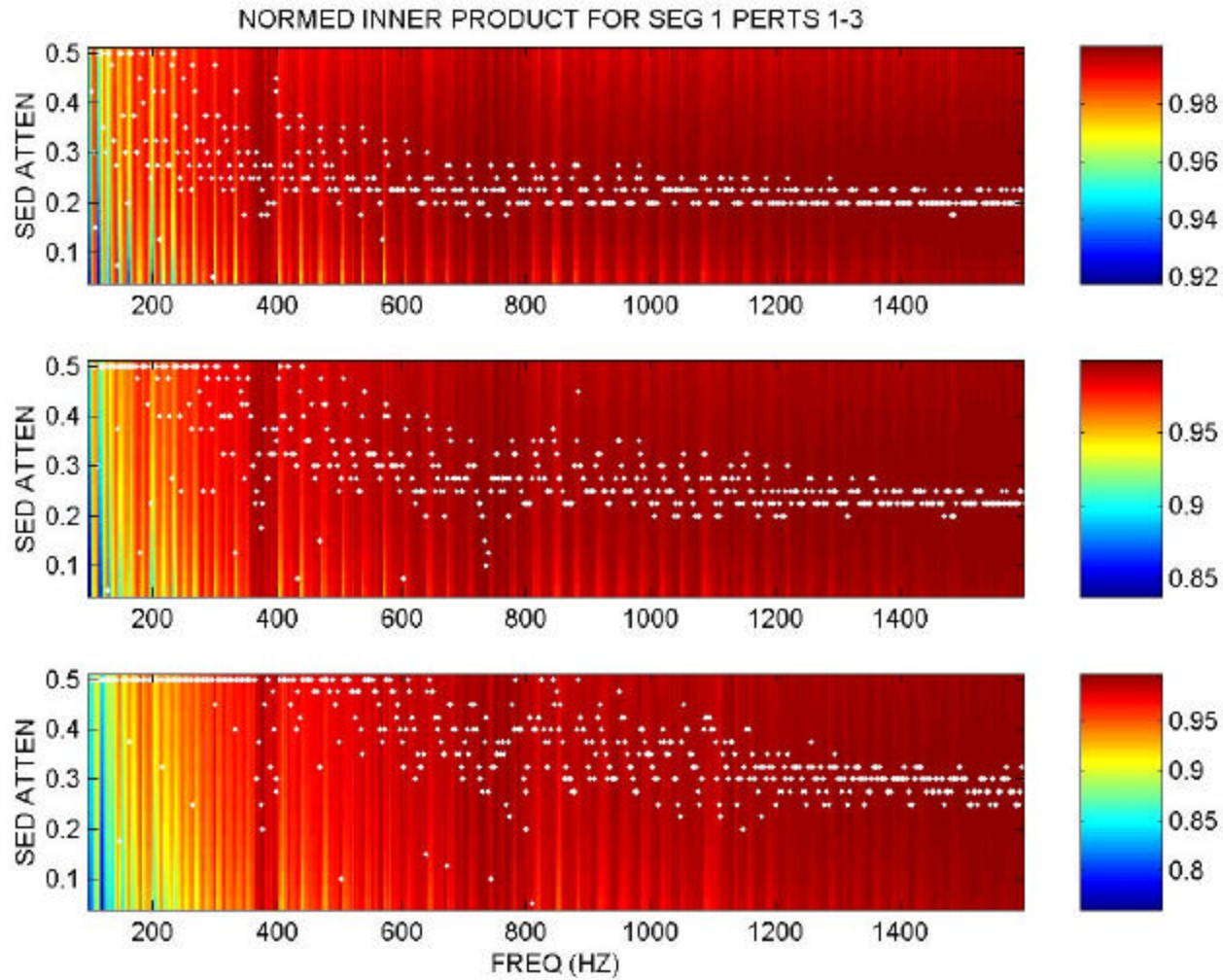
- Direct numerical evaluation of environmental fluctuations influence on effective frequency dependence as measured by simple, linear correlation analysis.
- MMPE model run assuming $b_{\text{sed}} = 0.15$ dB/km/Hz for numerous environments containing perturbations. Results in complex pressure values at multiple depths: $p(r, z_j)$ with $r = 10$ km, and z_j containing 16 depths from 0 to 100 m.
- MMPE model then run for range-independent environment (avg SSP, no sediment gradient, all other values constant). Sediment attenuation then varies from $b_{\text{sed}} = 0.025$ to 0.5 dB/km/Hz. Results in complex pressure replica matrix $p'_b(r, z_j)$.
- Effective attenuation determined by maximizing normalized correlation between pressure magnitudes over band of frequencies,

$$C(r, f, b) = \frac{\sum_j |p(r, z_j)| |p'_b(r, z_j)|}{\sqrt{\sum_j |p(r, z_j)|^2 \sum_j |p'_b(r, z_j)|^2}}$$

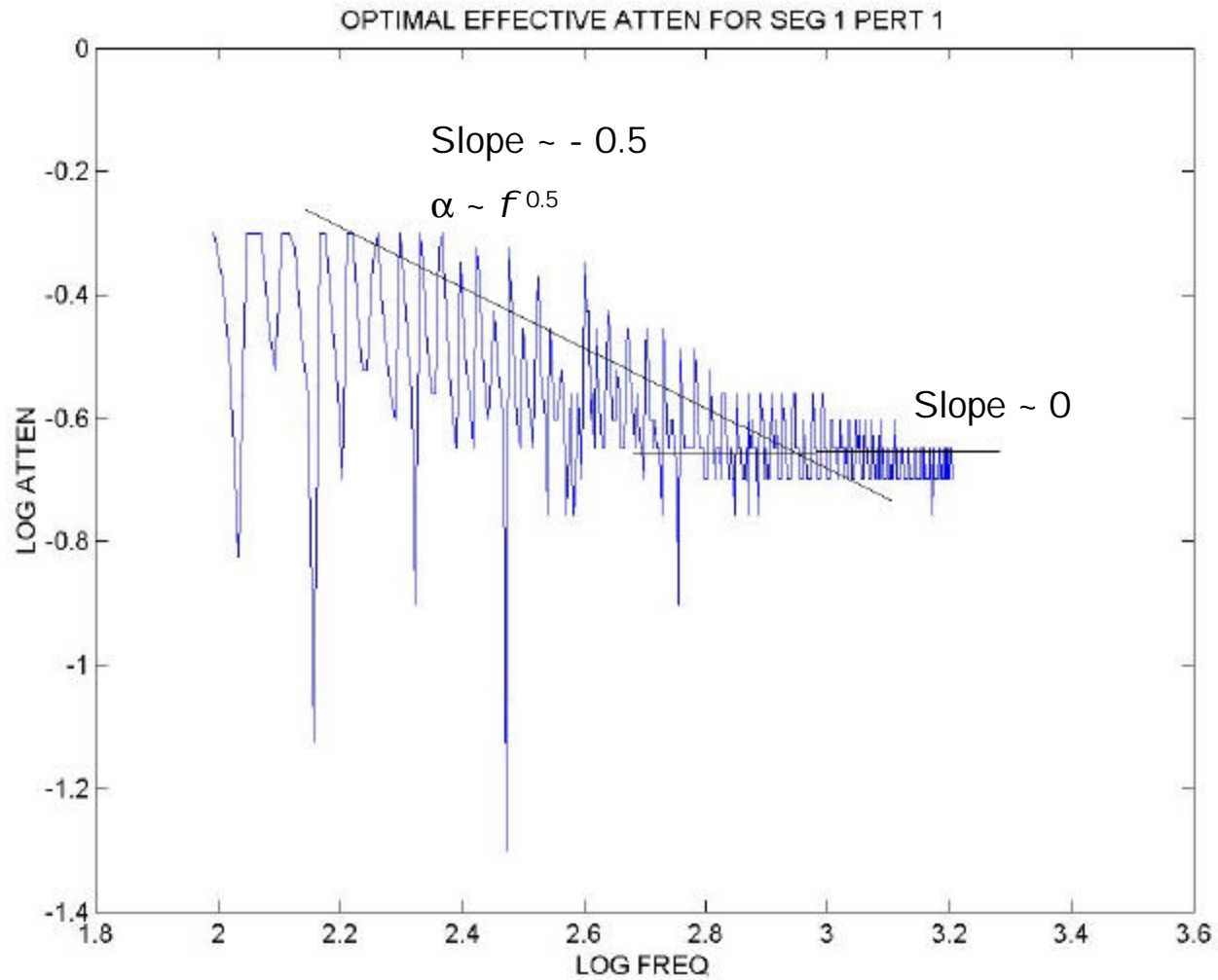
Environment 1



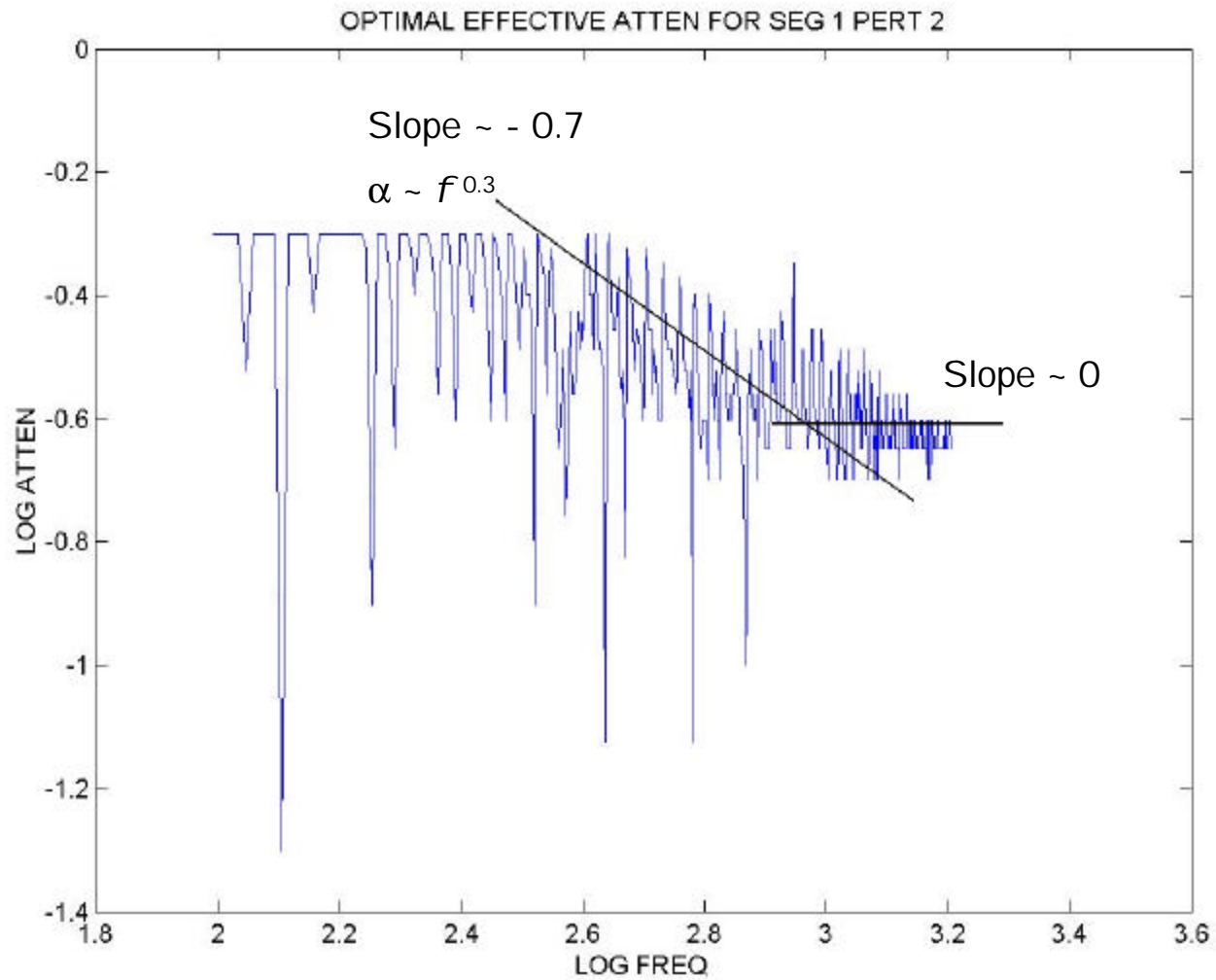
Results, Environment 1



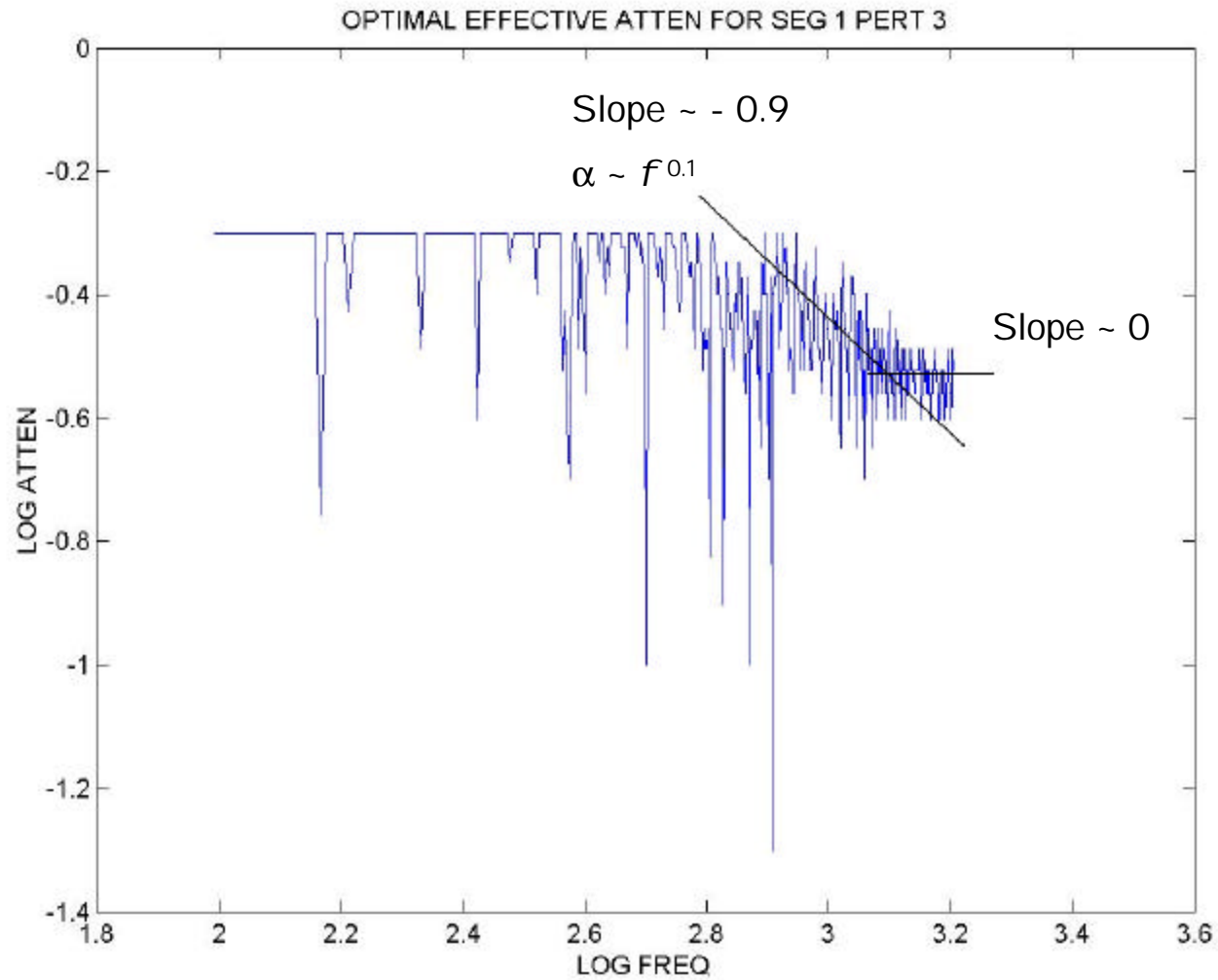
Log-log analysis of Env 1, Pert 1



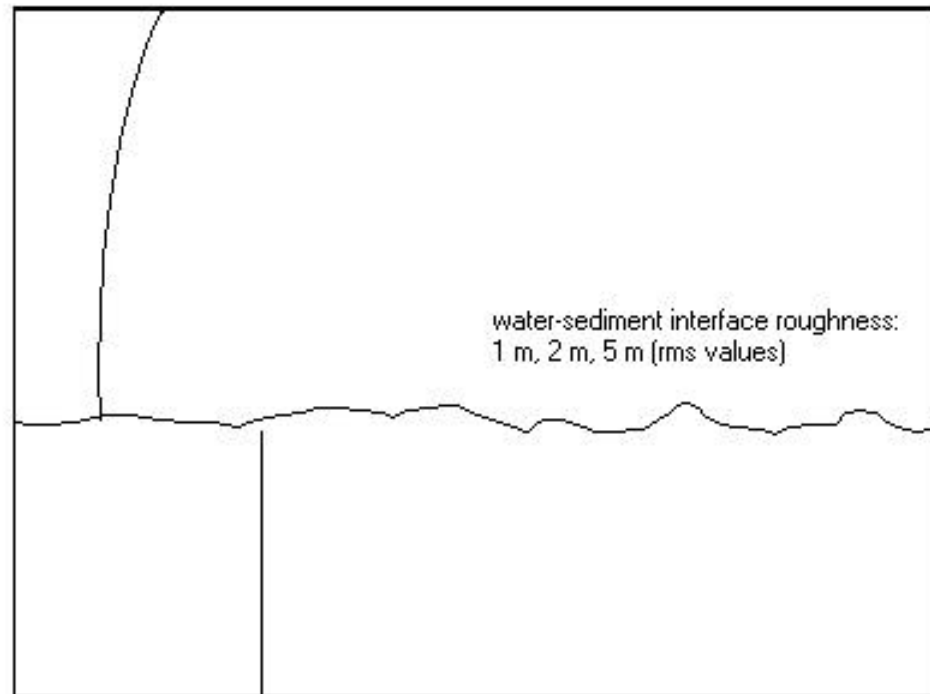
Log-log analysis of Env 1, Pert 2



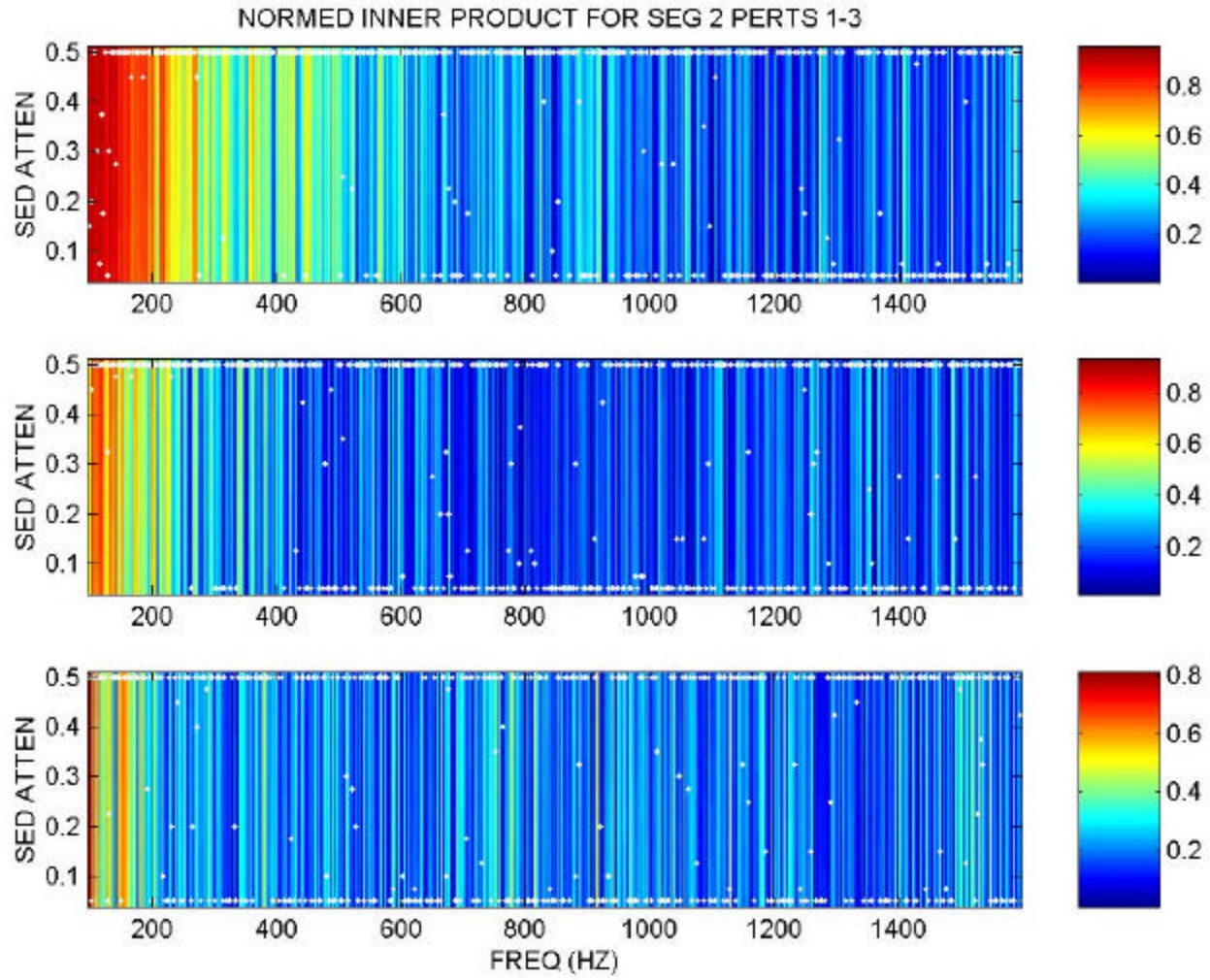
Log-log analysis of Env 1, Pert 3



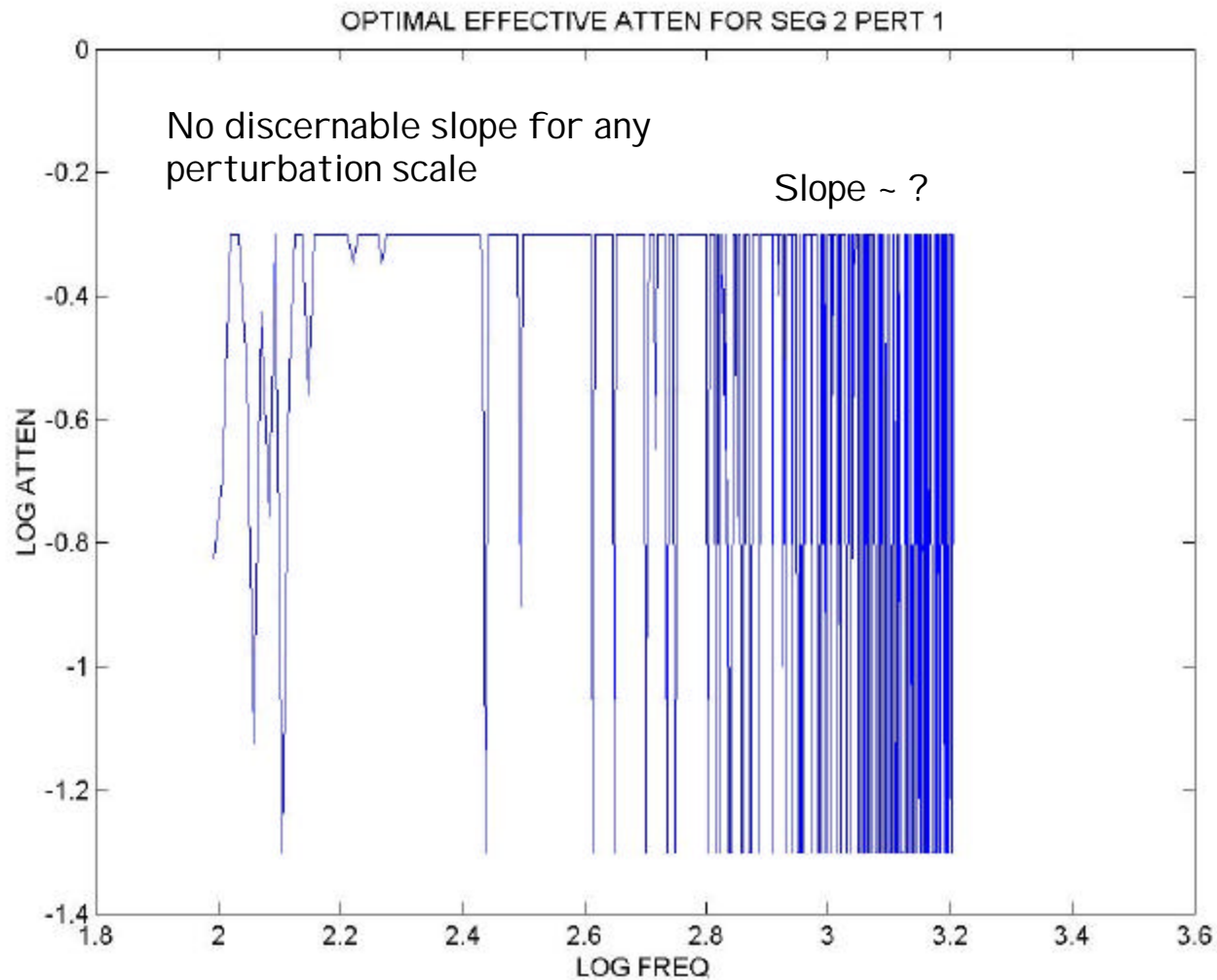
Environment 2



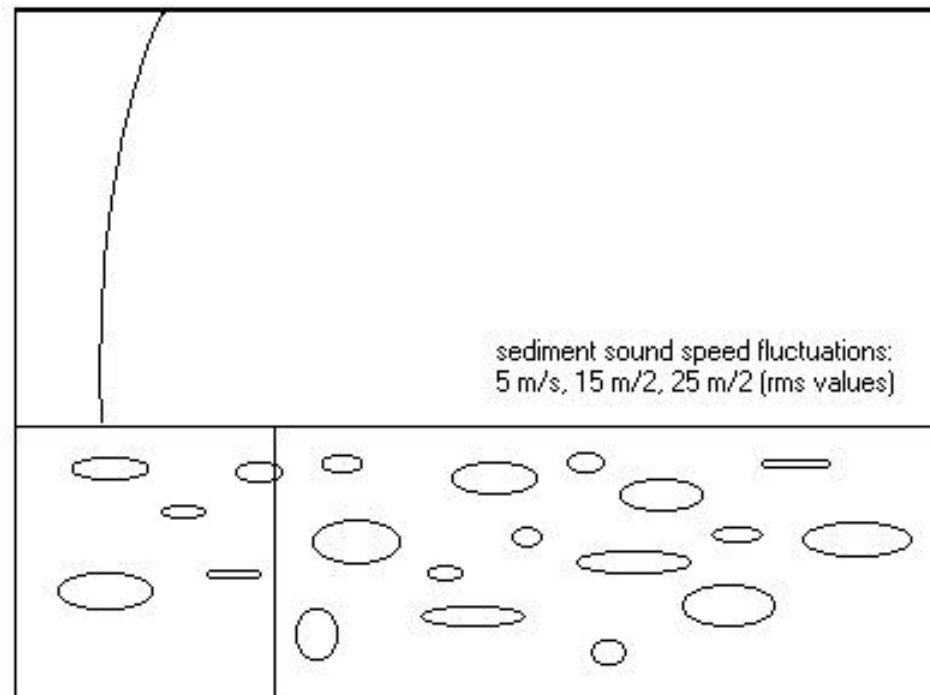
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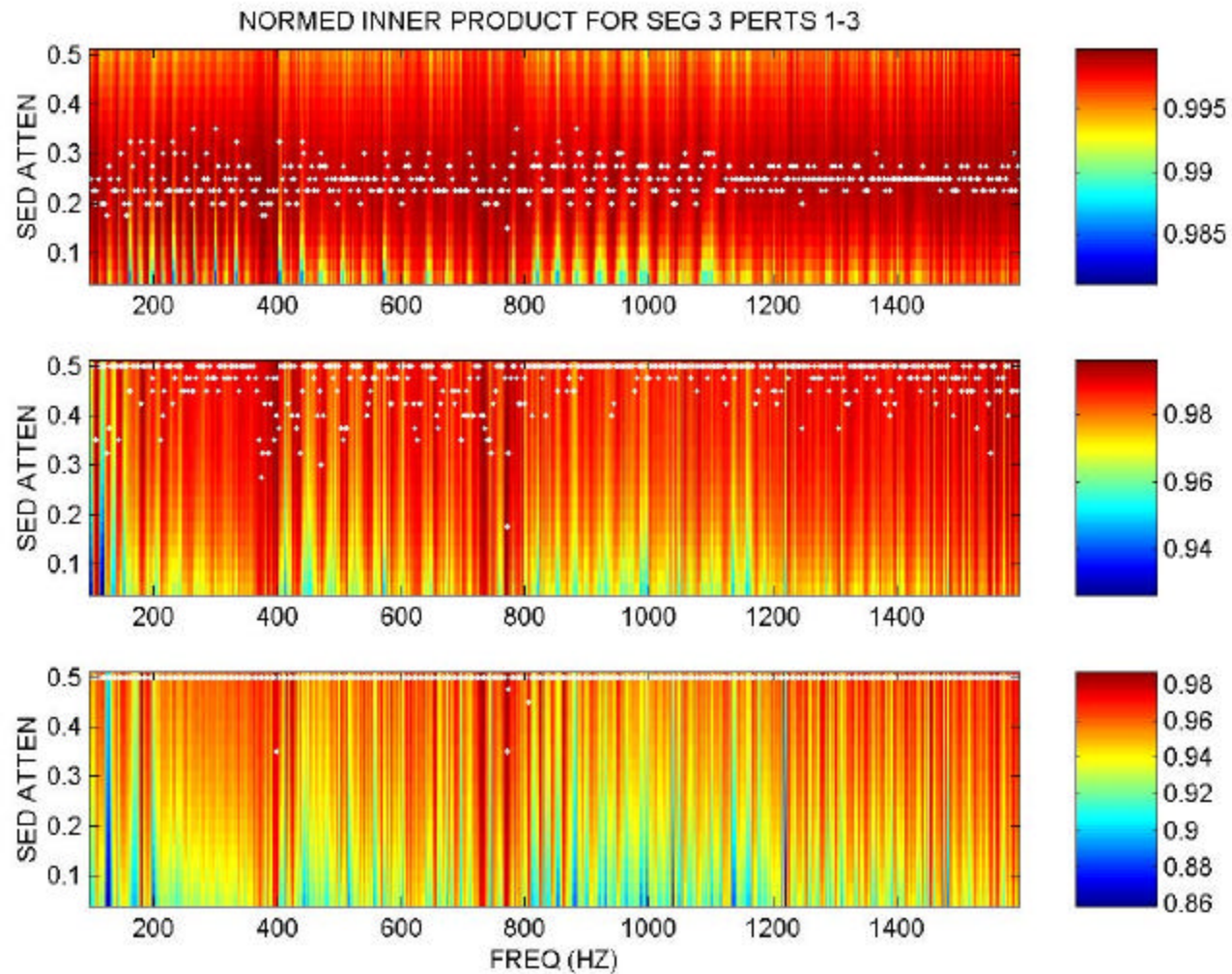
Log-log analysis of Env 2, Pert 1



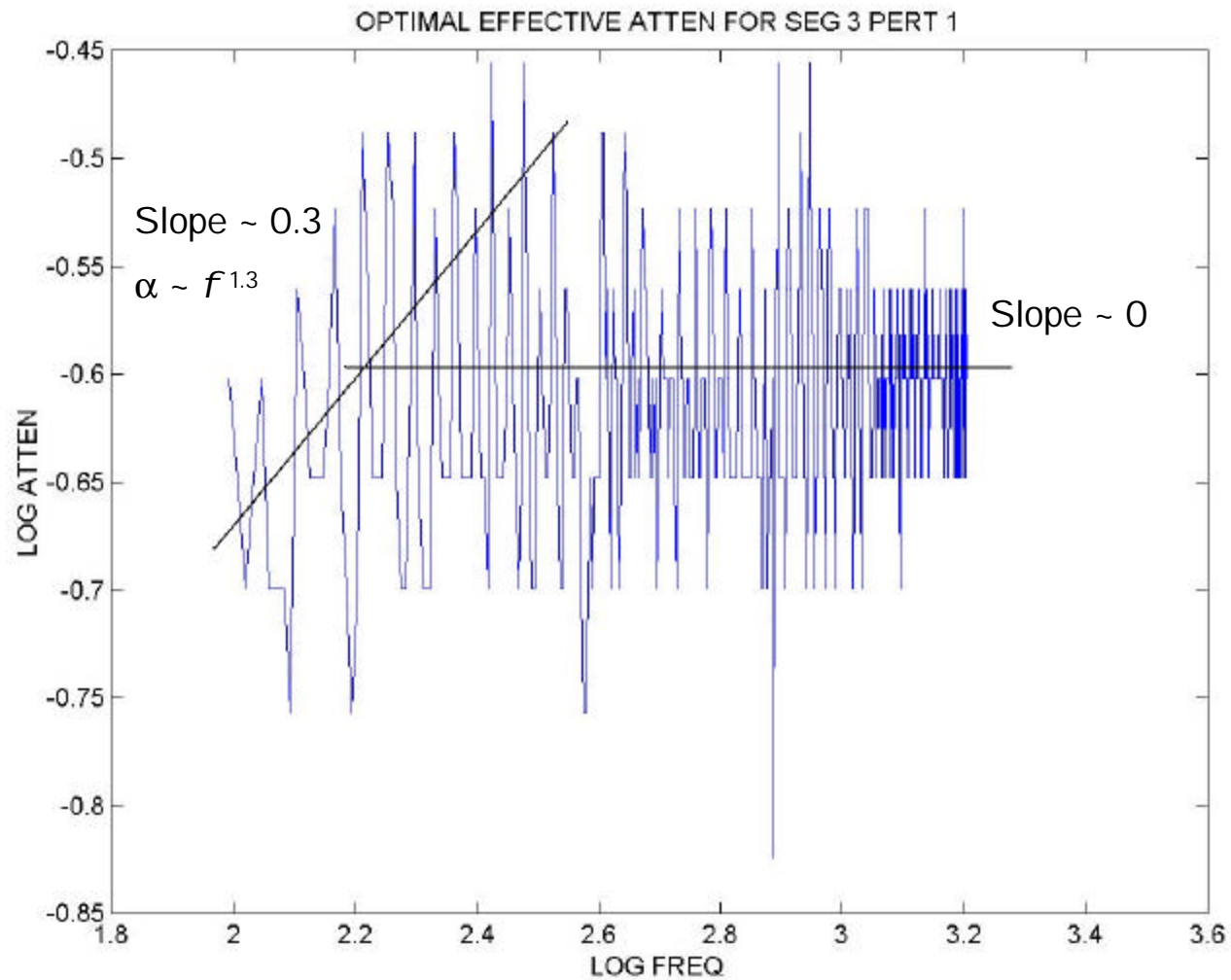
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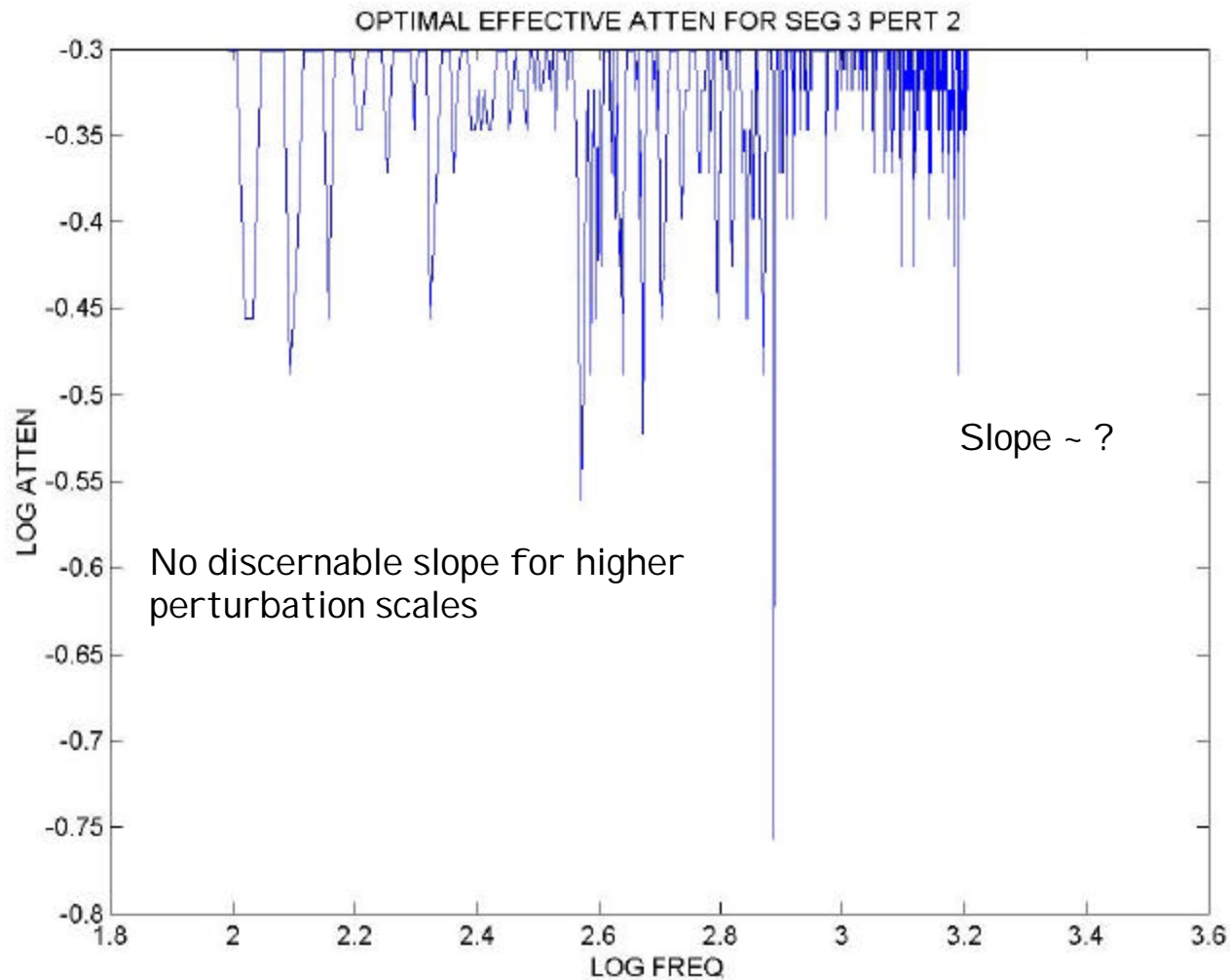
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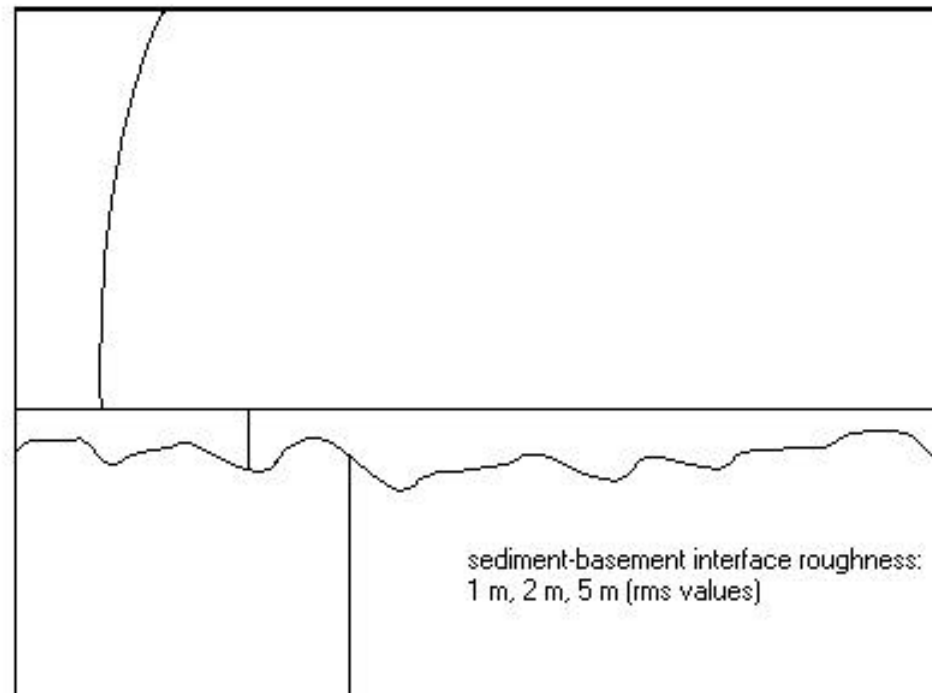
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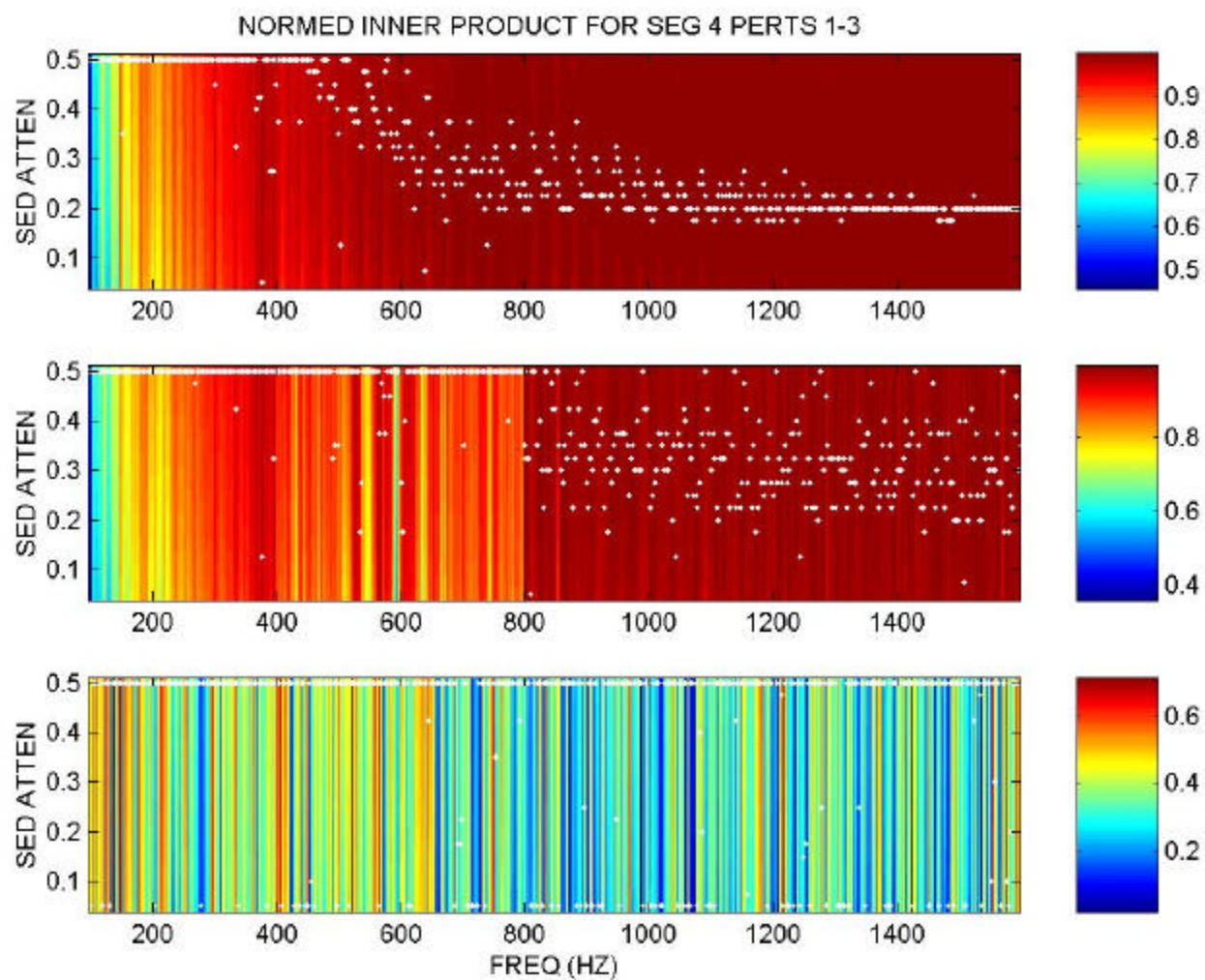
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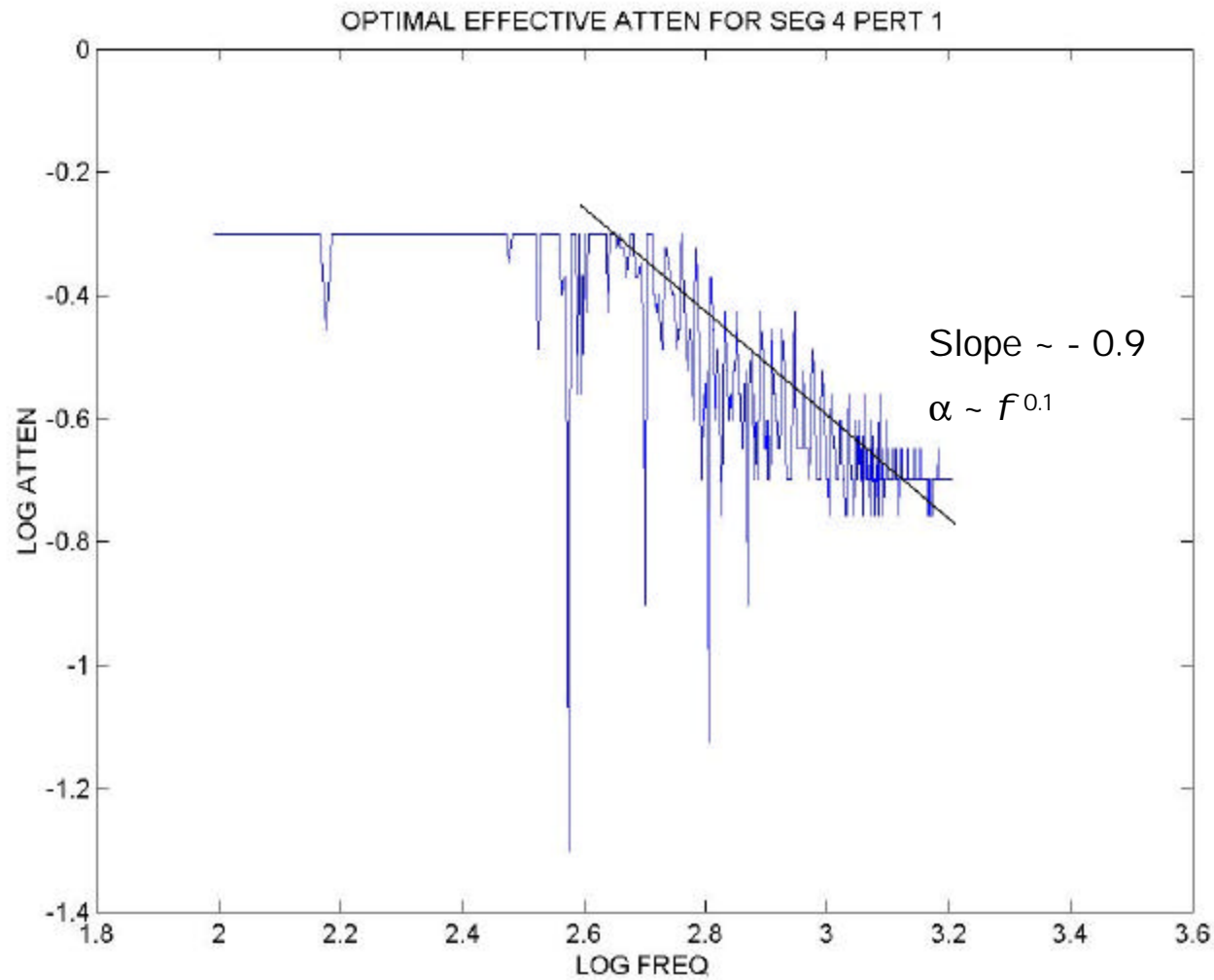
Environment 4



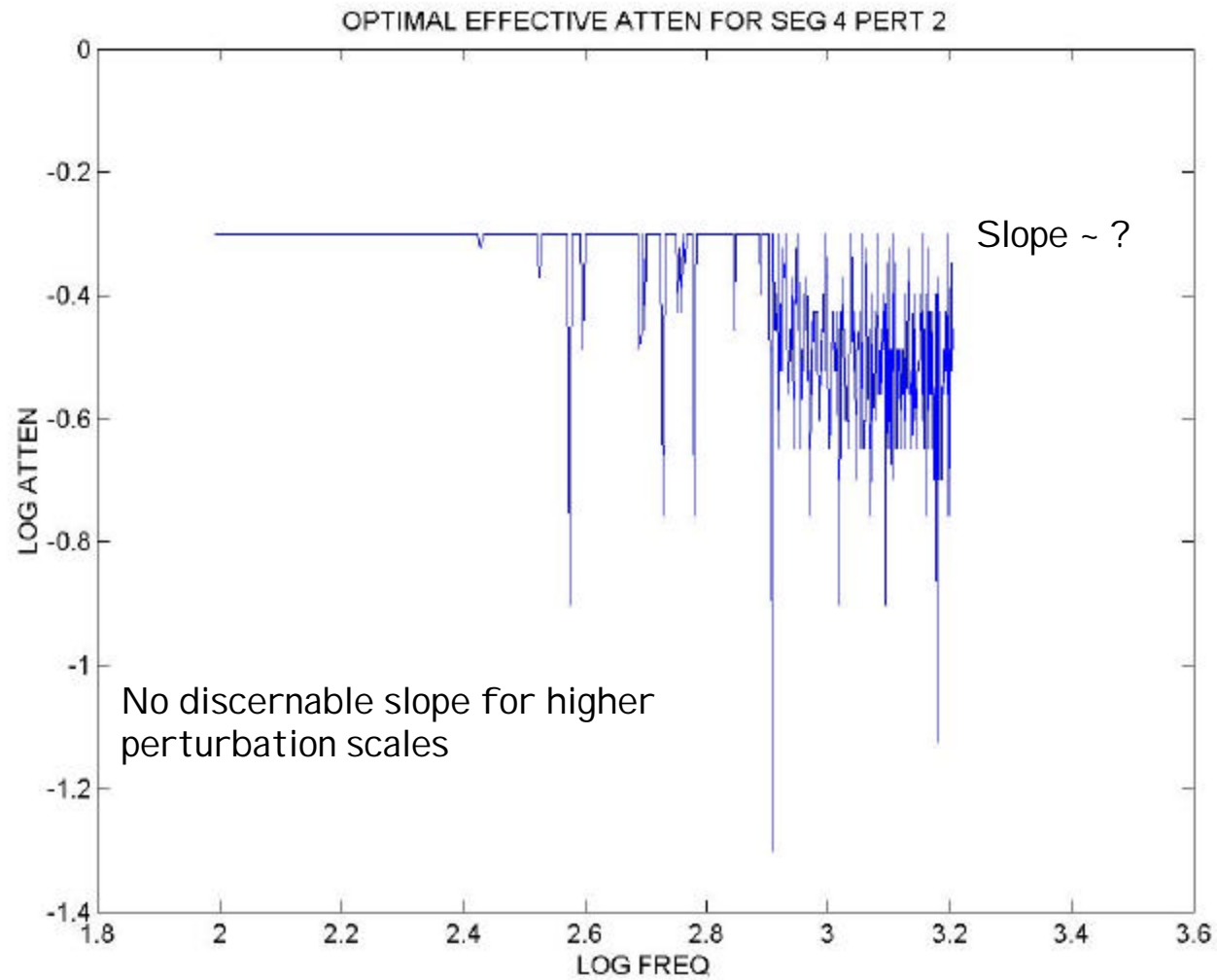
Results, Environment 4



Log-log analysis of Env 4, Pert 1



Log-log analysis of Env 4, Pert 2

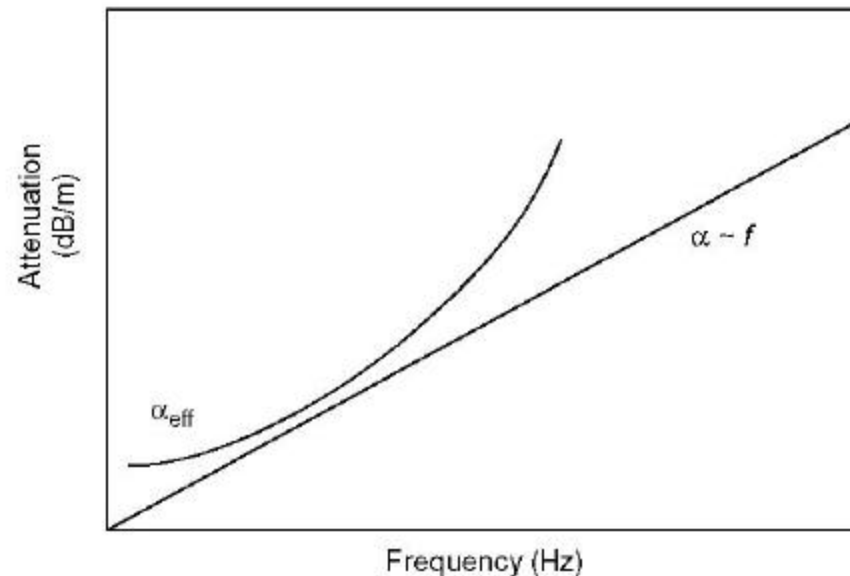


Summary – Part I

- Environmental fluctuations can have significant impact on inversion of sediment attenuation.
- Water-sediment interface roughness seemed to create largest variability in effective attenuation. No trend observed over bandwidth.
- Sediment sound speed gradients and sediment-basement roughness both seemed to introduce noticeable trend in frequency dependence at larger ranges. Specifically, there was enhanced attenuation at the lower frequencies with values of x typically -0.5 to -0.9 (i.e., $\alpha \sim f^{0.1}$ to $\alpha \sim f^{0.5}$) over the band $f = 100 - 500$ Hz.
- These results imply higher loss per wavelength at lower frequencies, or even nearly constant loss per distance over band.

Summary - Part I

- Cause may be primary loss mechanism in these cases due to sub-sediment/basement effects. Thus, lower frequencies interact more readily, thereby increasing the effective attenuation.
- This suggests environments with $x > 1$ may be due to water/sediment interface, or near interface, influences. Potential causes could be small-scale roughness/scattering or even near bottom biologics. Longer range effects could even be related to rough surface scattering.
- If higher frequencies incur enhanced scattering, may expect frequency dependence of attenuation of the form

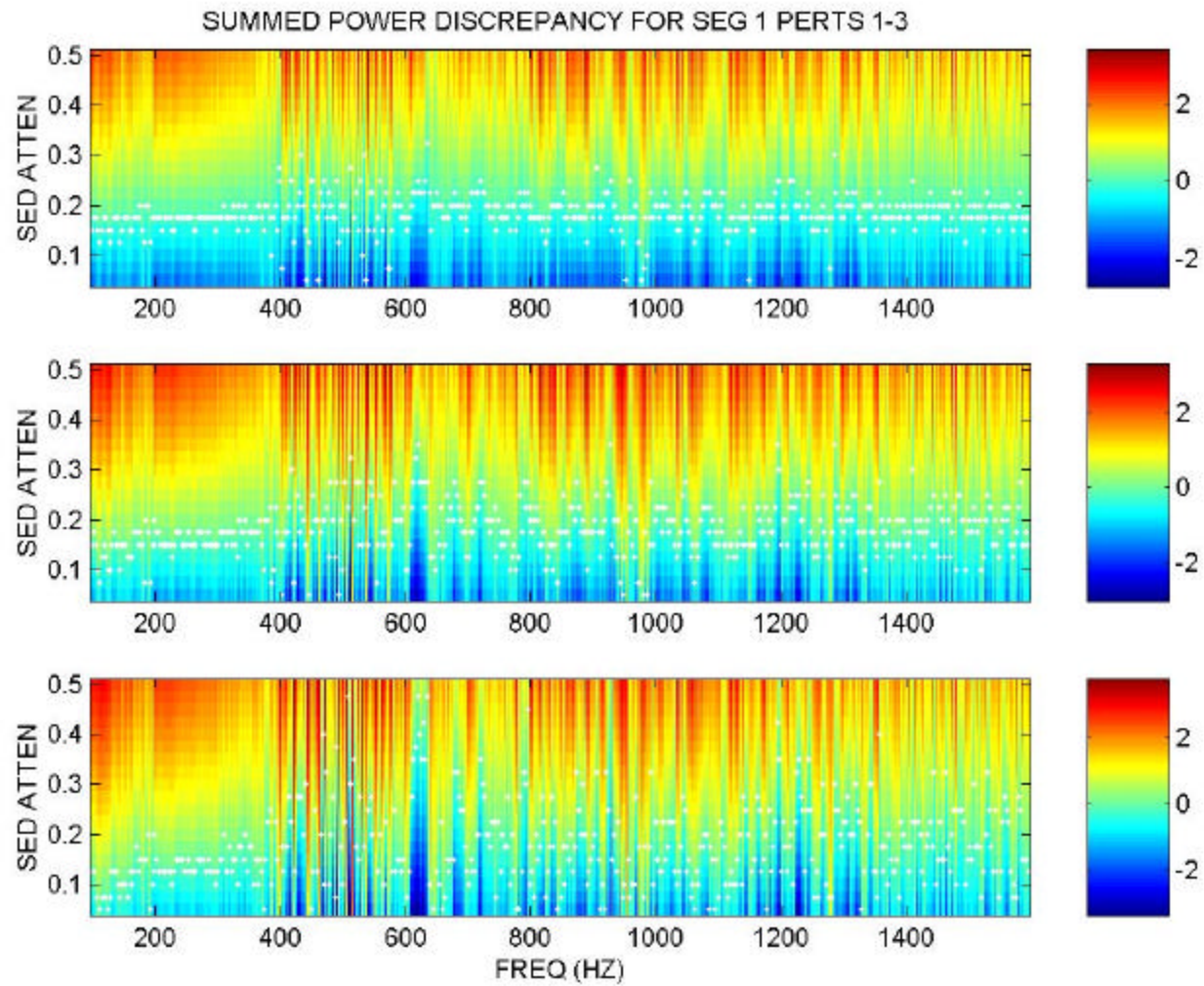


Approach – Part II , New Cost Function

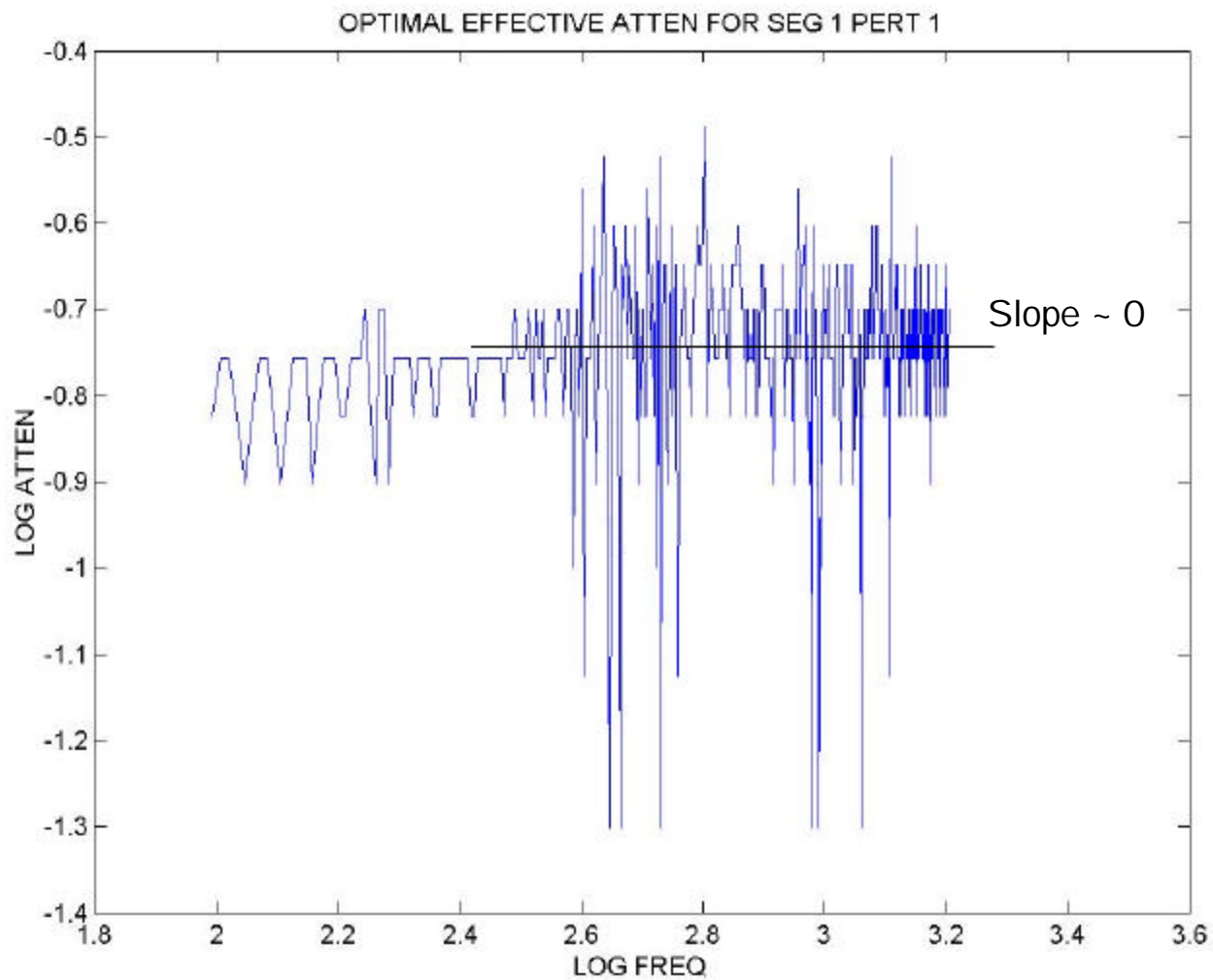
- Previous cost function based on incoherent correlation over depth. However, no reason to expect correlation between scattered field structure (e.g., from rough interface) and range-independent field with effective attenuation.
- Instead, choose simple comparison of total energy integrated over depth, i.e.

$$C(r, f, b) = \sum_j |p(r, z_j)|^2 - \sum_j |p'_b(r, z_j)|^2$$

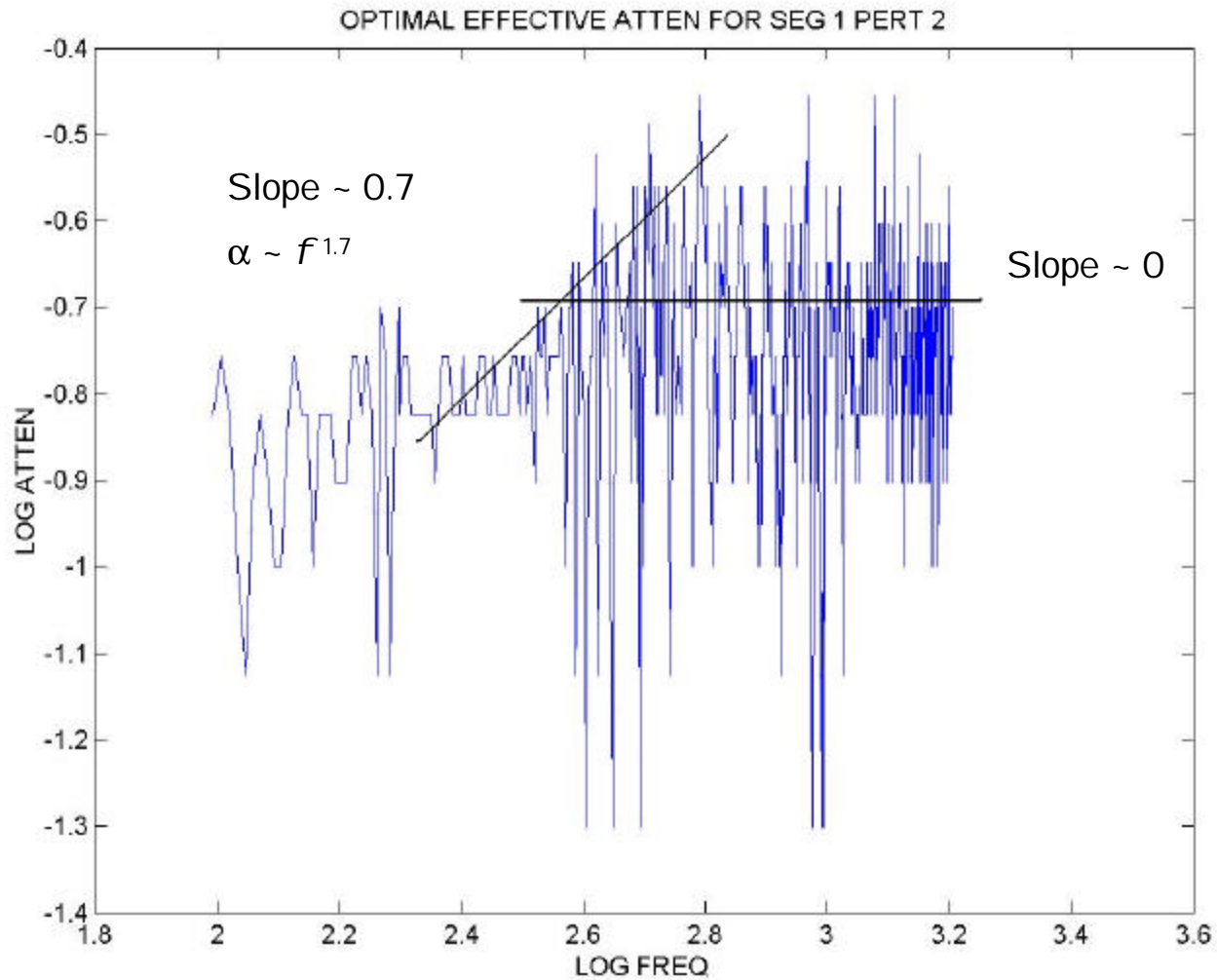
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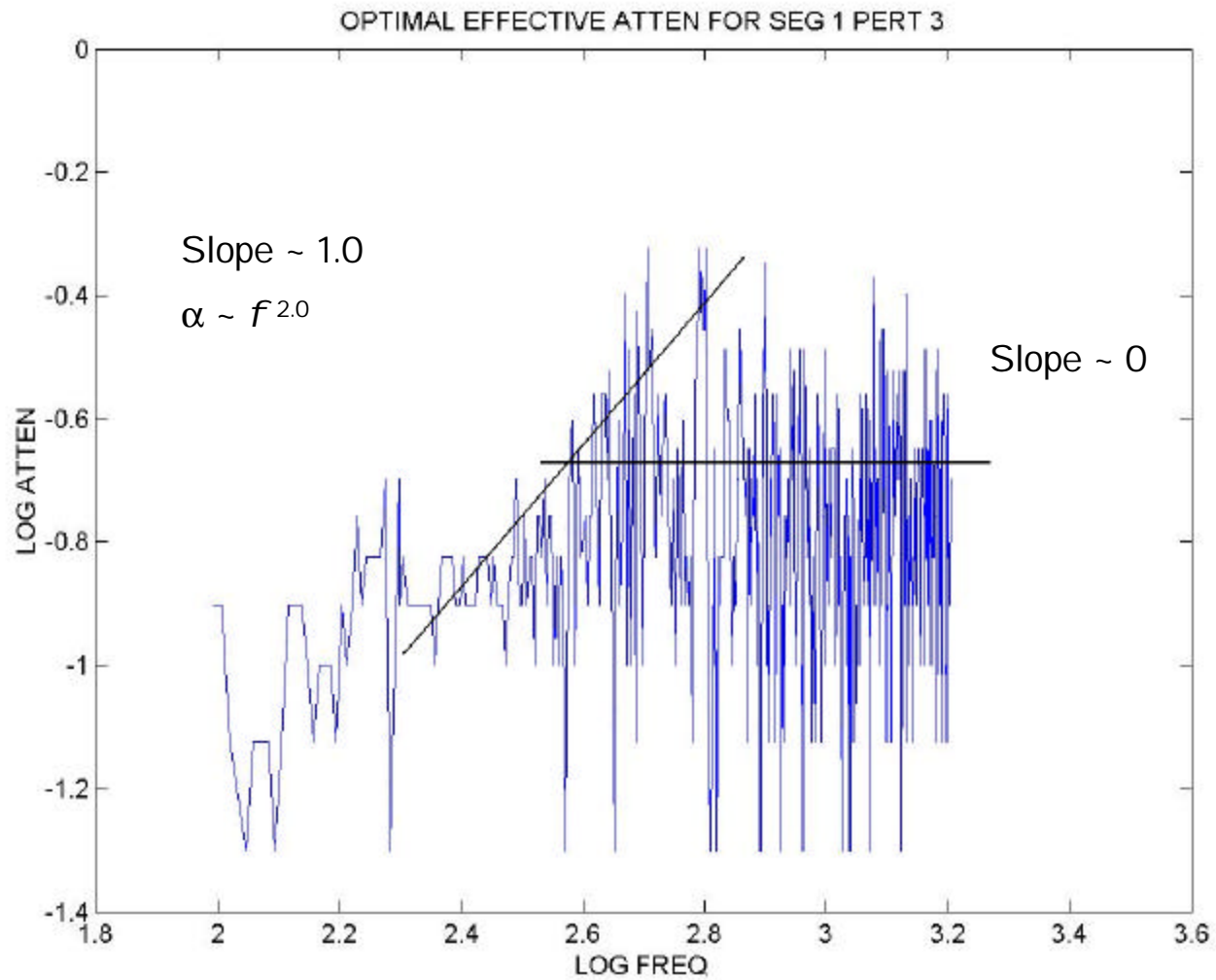
Log-log analysis of Env 1, Pert 1



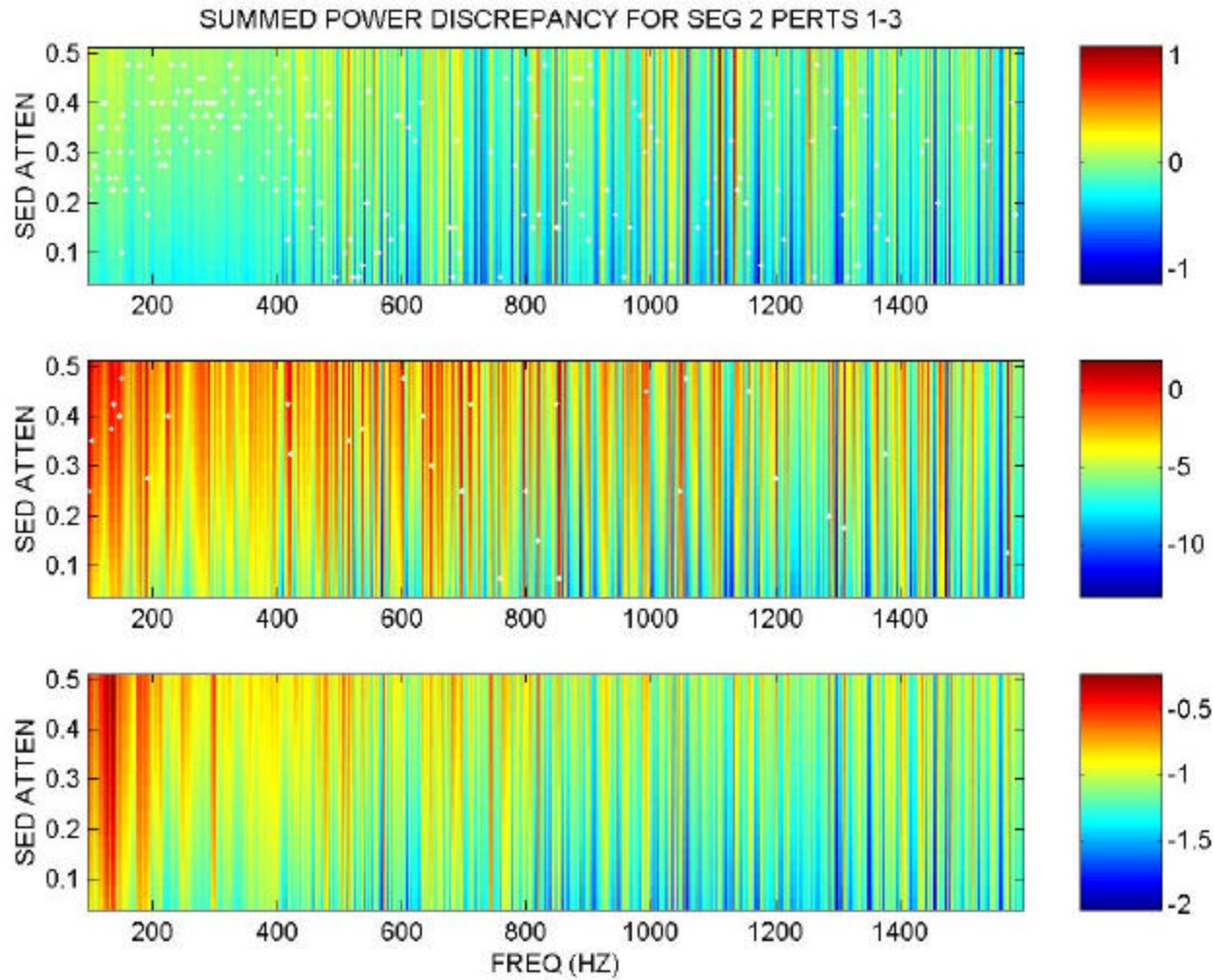
Log-log analysis of Env 1, Pert 2



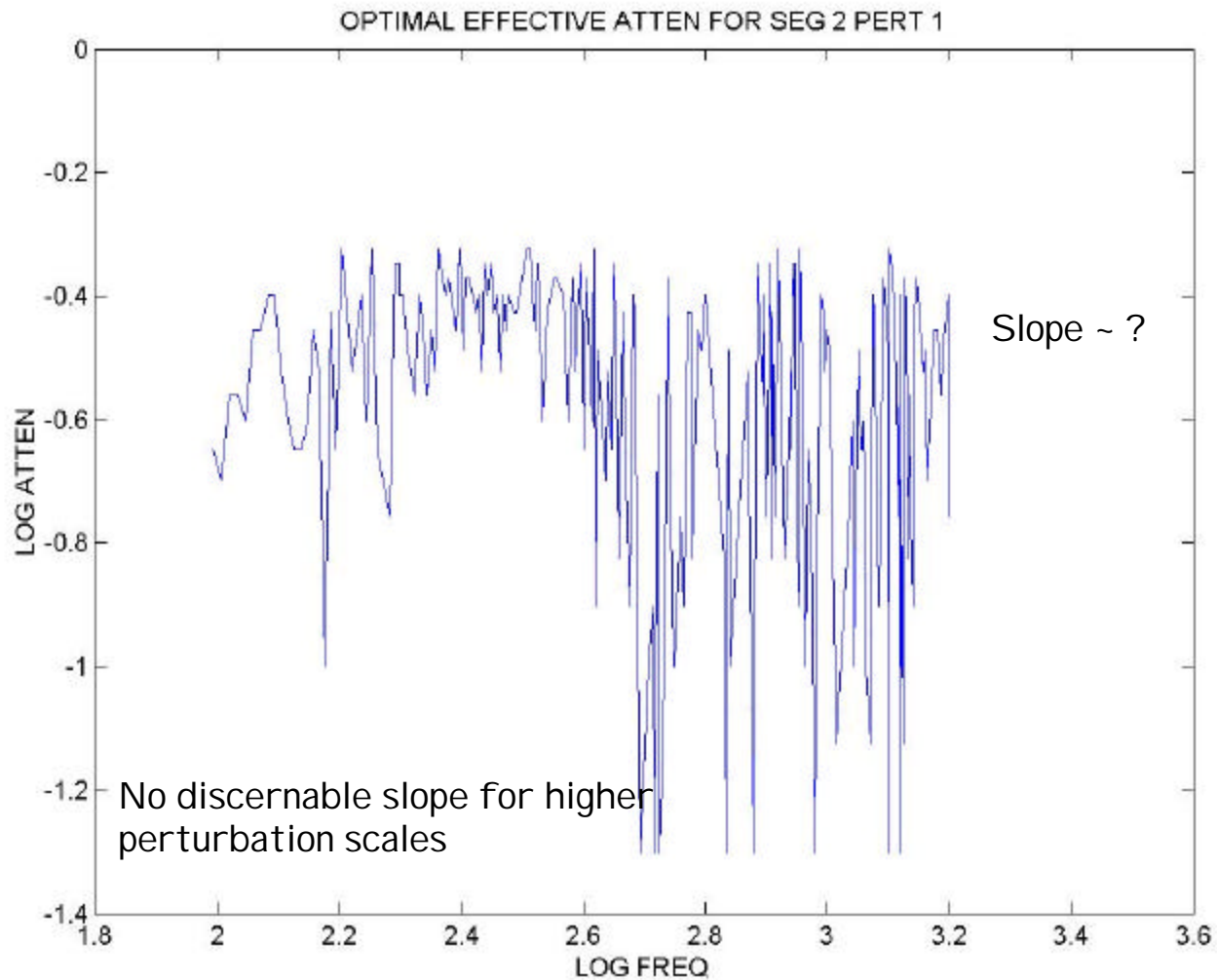
Log-log analysis of Env 1, Pert 3



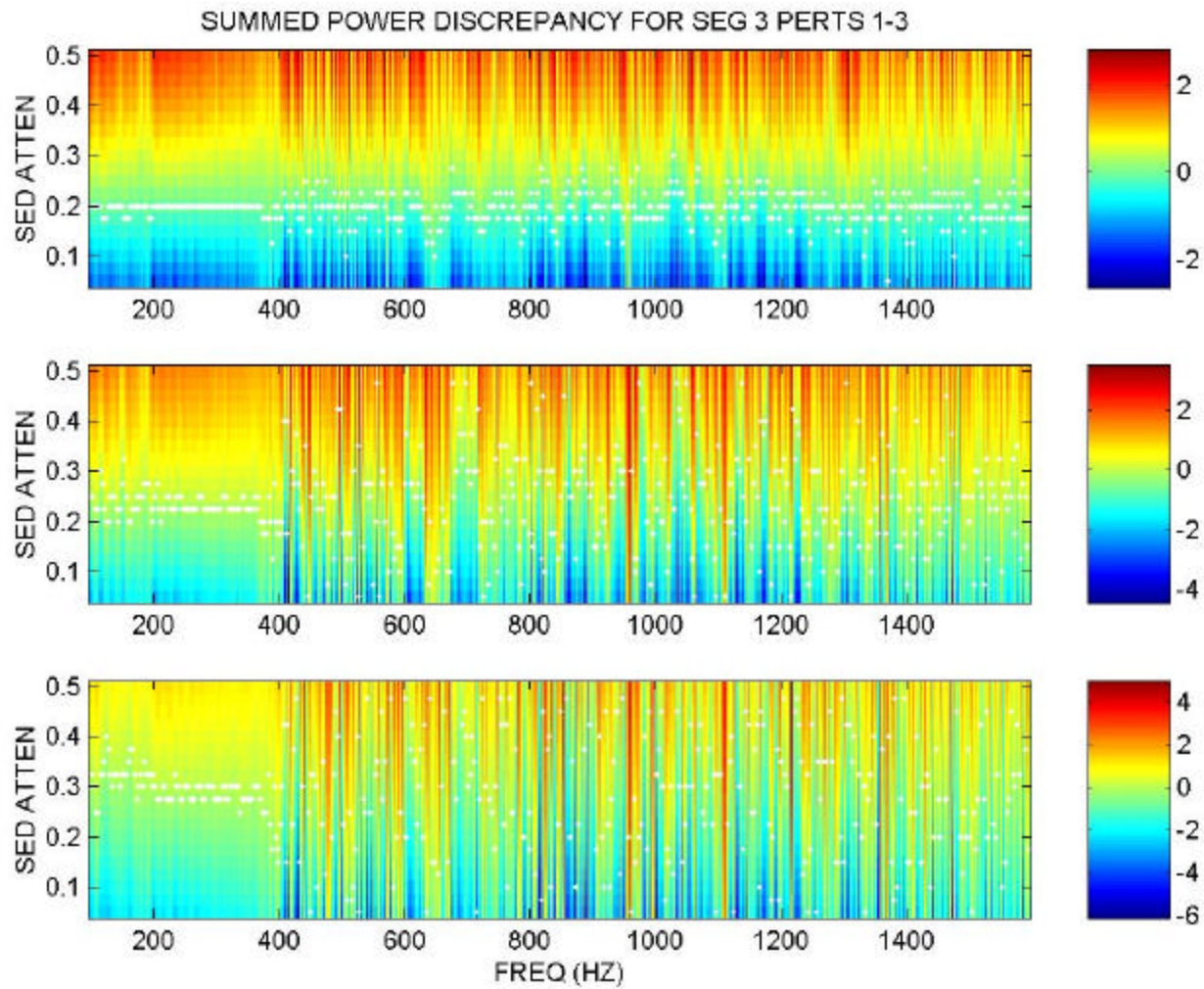
Results, Environment 2



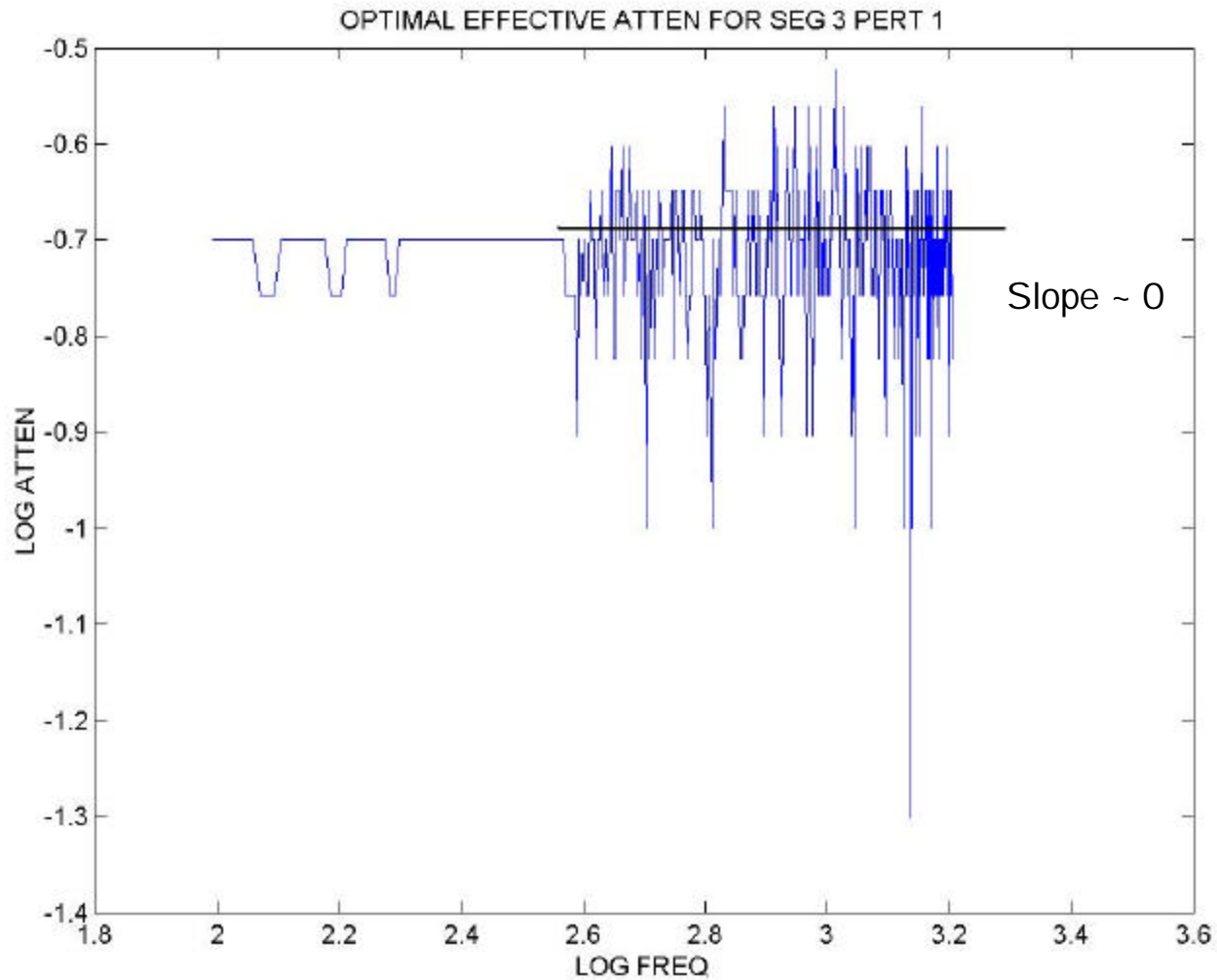
Log-log analysis of Env 2, Pert 1



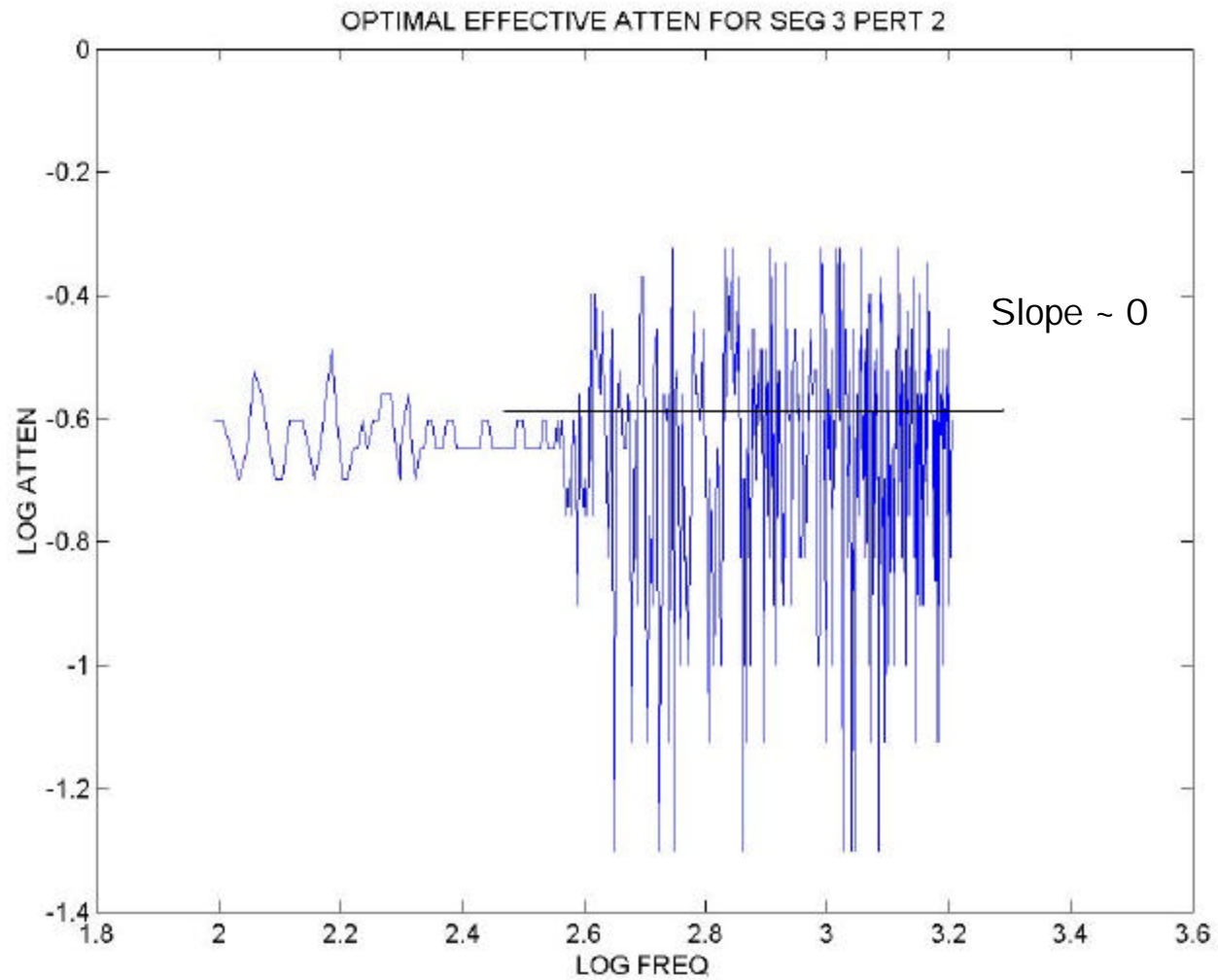
Results, Environment 3



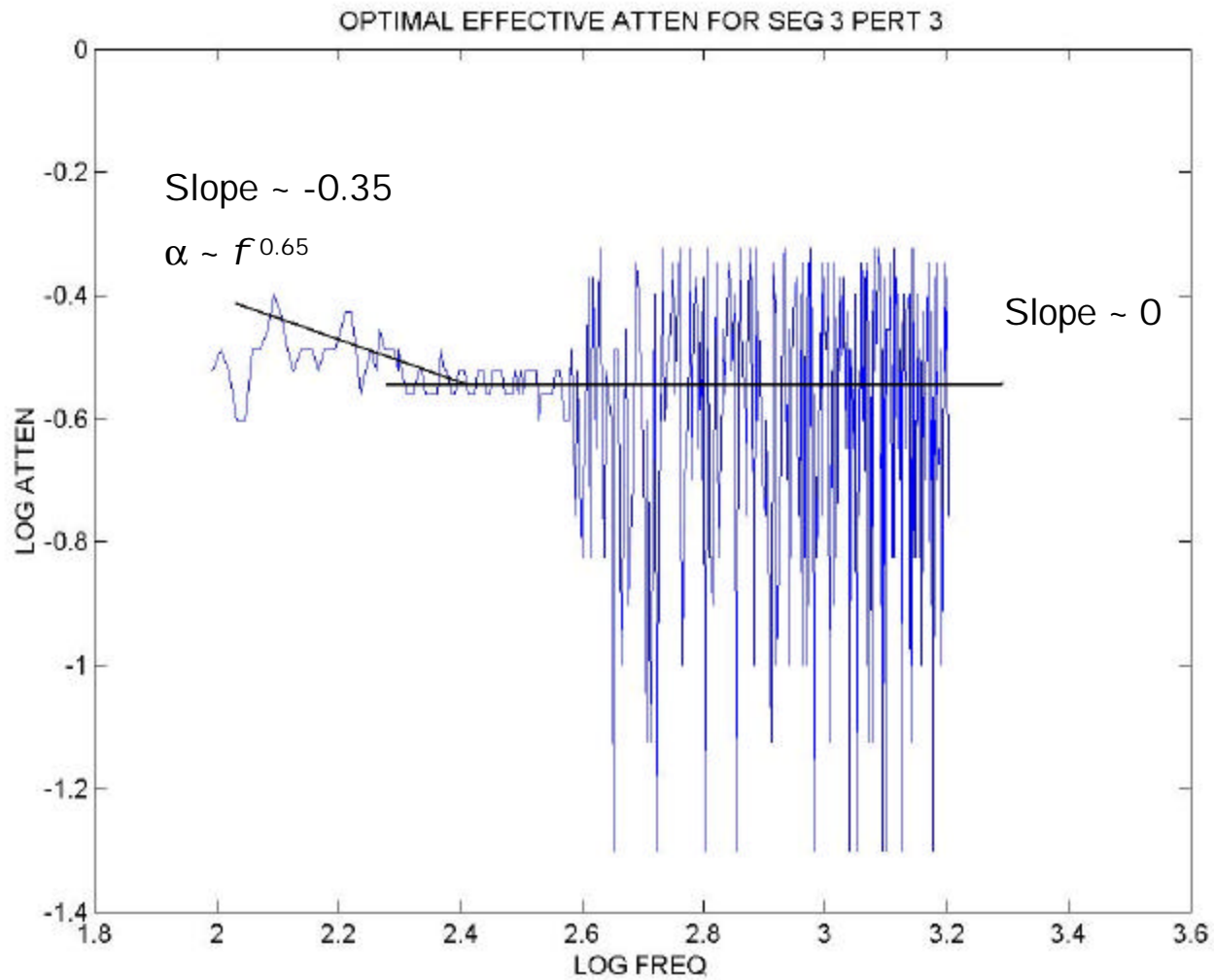
Log-log analysis of Env 3, Pert 1



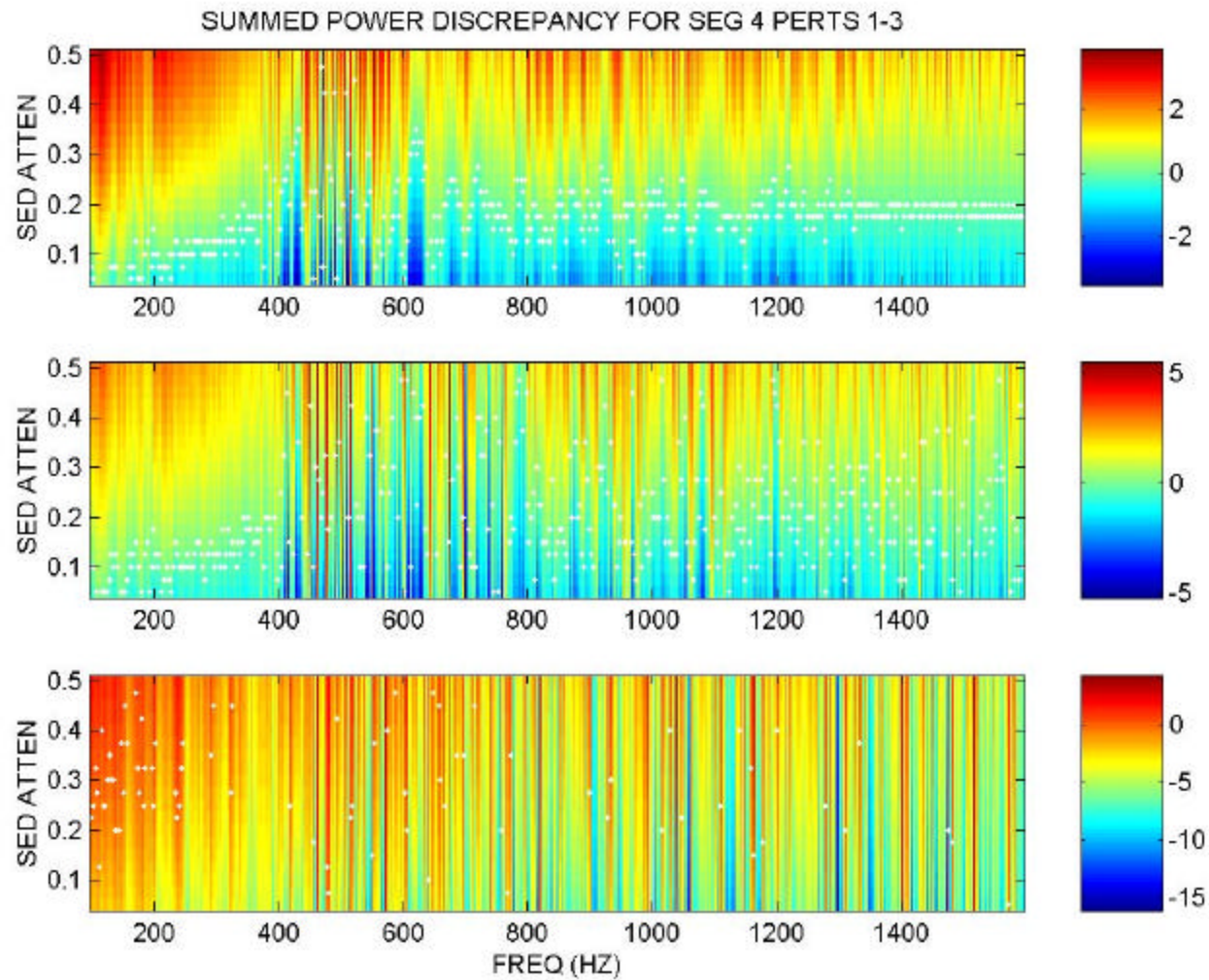
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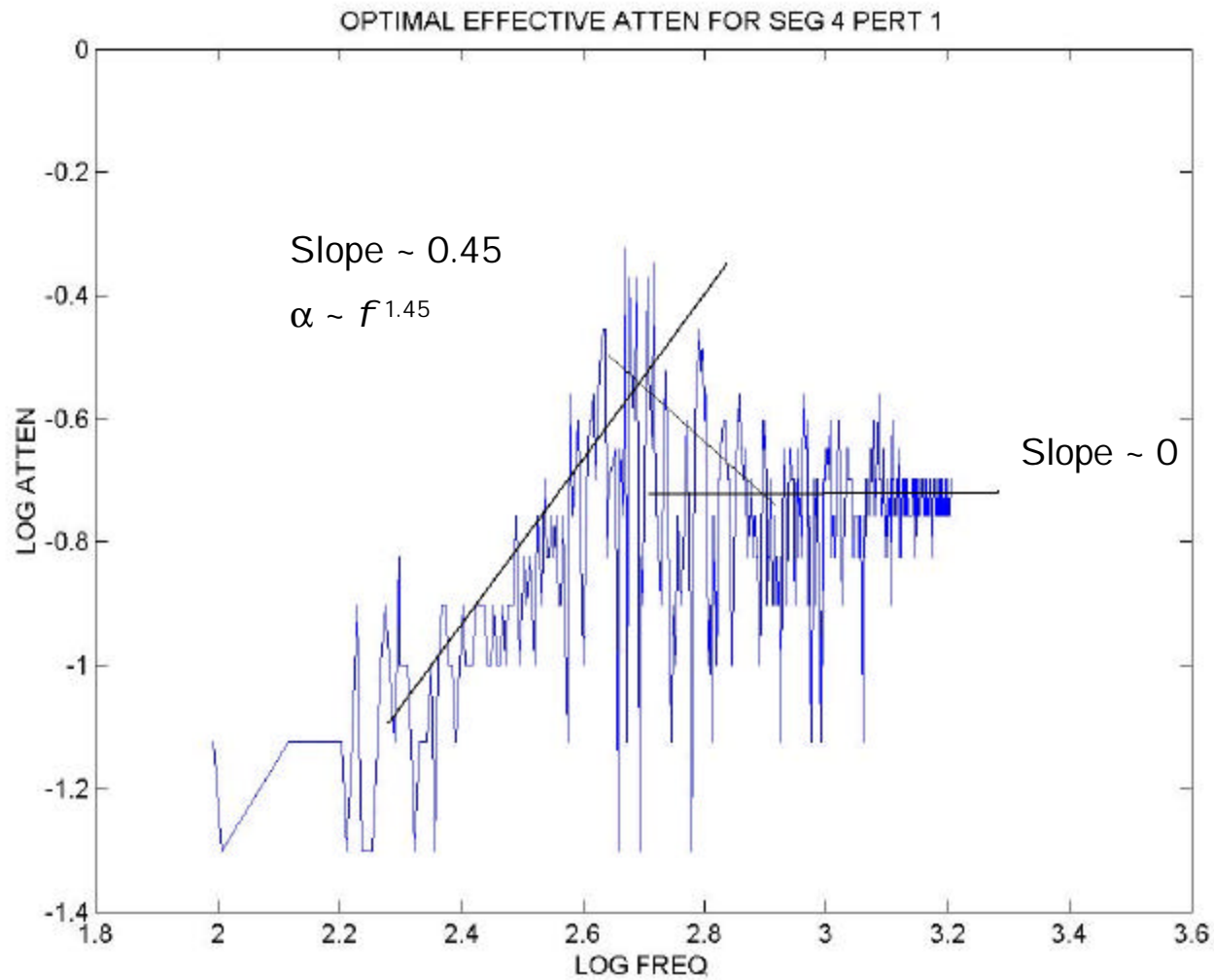
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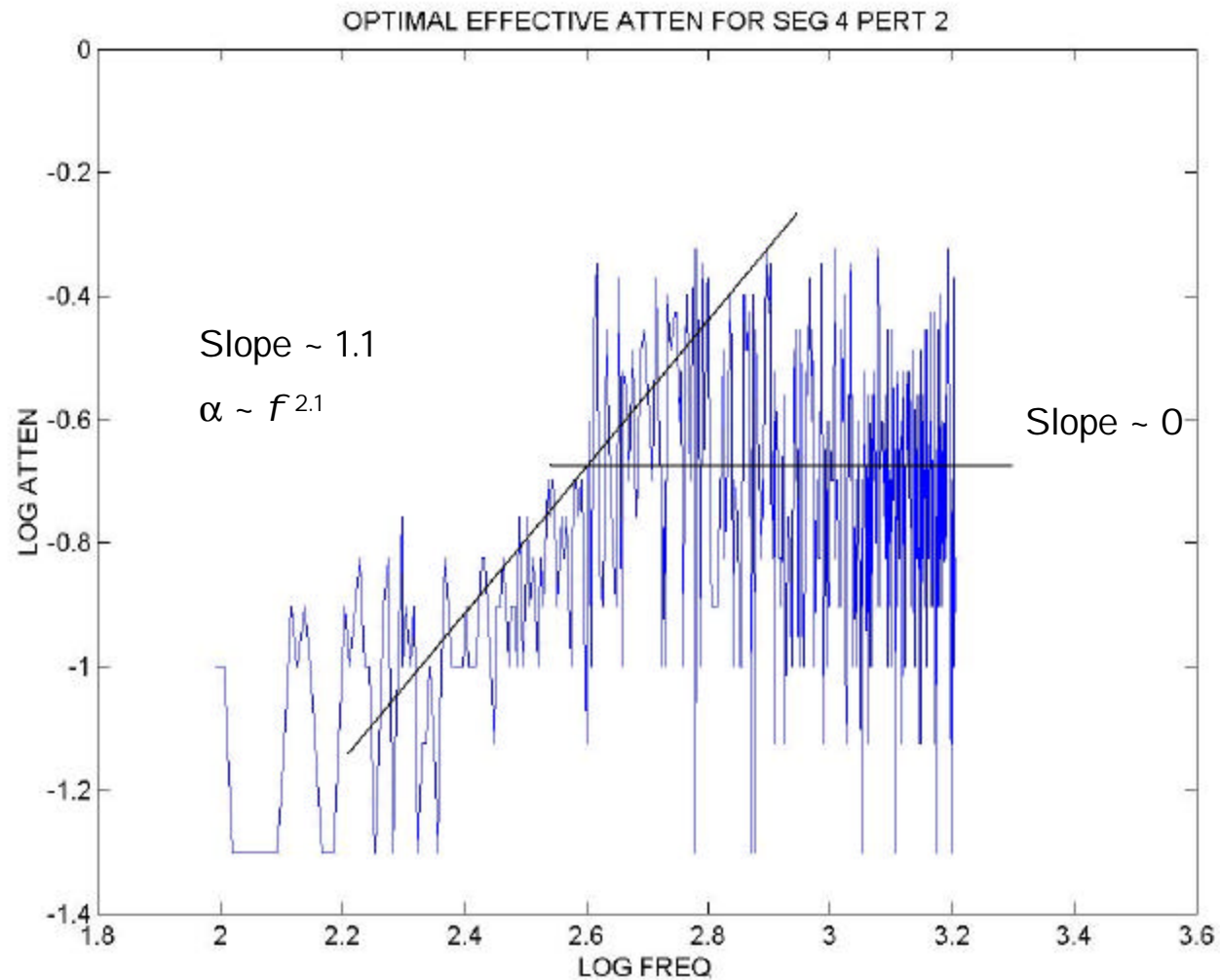
Results, Environment 4



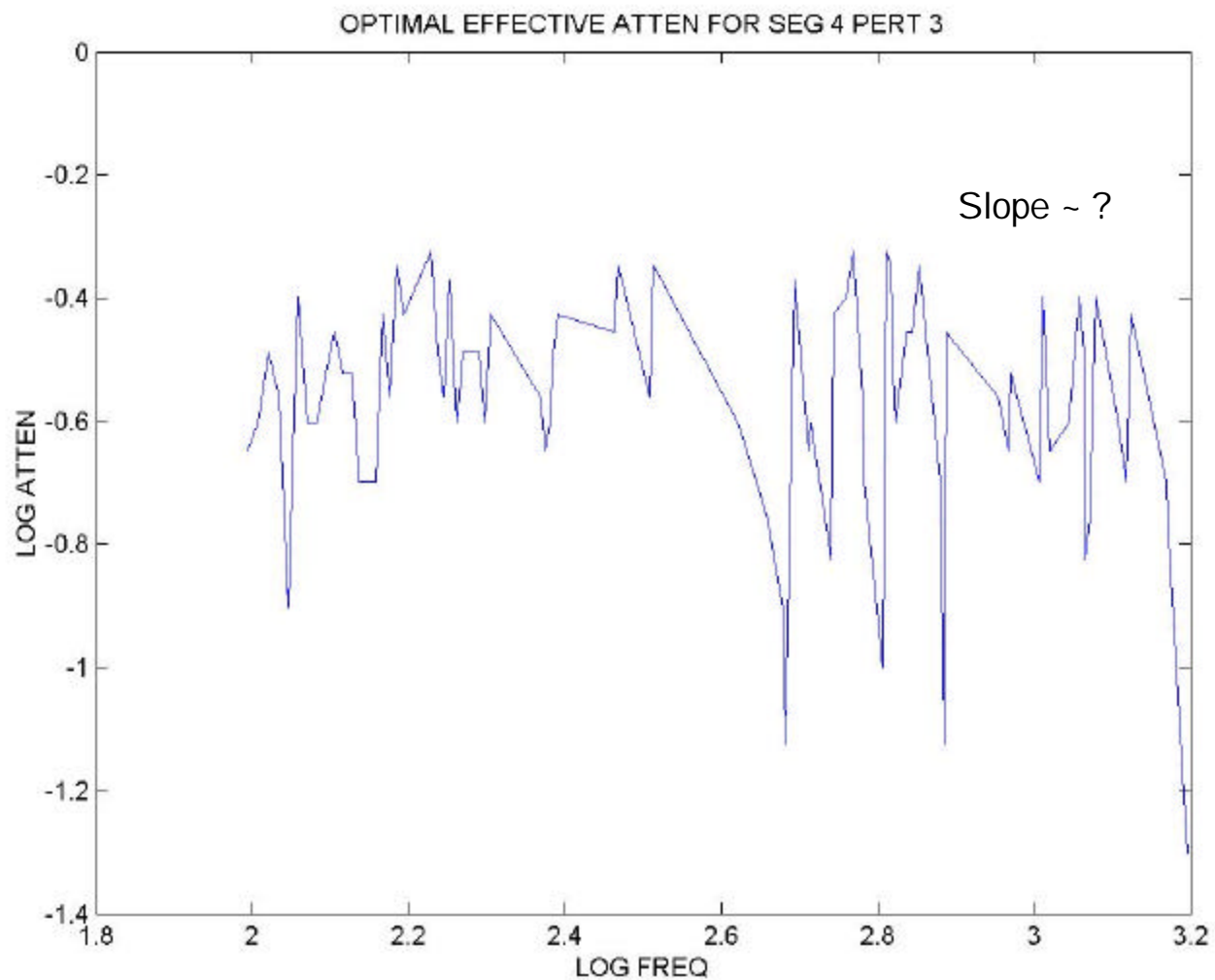
Log-log analysis of Env 4, Pert 1



Log-log analysis of Env 4, Pert 2



Log-log analysis of Env 4, Pert 3



Summary - Part II

- Cost function can be critical to inversion!
- Total energy in field for low (< 100 Hz) and high (> 1 kHz) frequencies do not exhibit nonlinear attenuation effect for these perturbations. Mid-frequency (100 - 1000 Hz) do exhibit nonlinear dependence for some perturbations, $\alpha \sim f^{(1.7 \rightarrow 2.0)}$.
- Gradient in sediment sound speed and basement interface roughness affect total energy the most.
- Subbottom variability still suggests reduction in power law dependence, $\alpha \sim f^{0.6}$, over low frequencies.

Summary - Part II

- Previous conjecture still valid, and may be interpreted physically as indicated below

