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Evaluation of the inter-frequency correlation of CyberShake NZ crustal eqk sims

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Outline

1. Background
2. Simulations Database
3. Residual Analysis
4. Inter-frequency Correlations
5. Conclusions, Next Steps

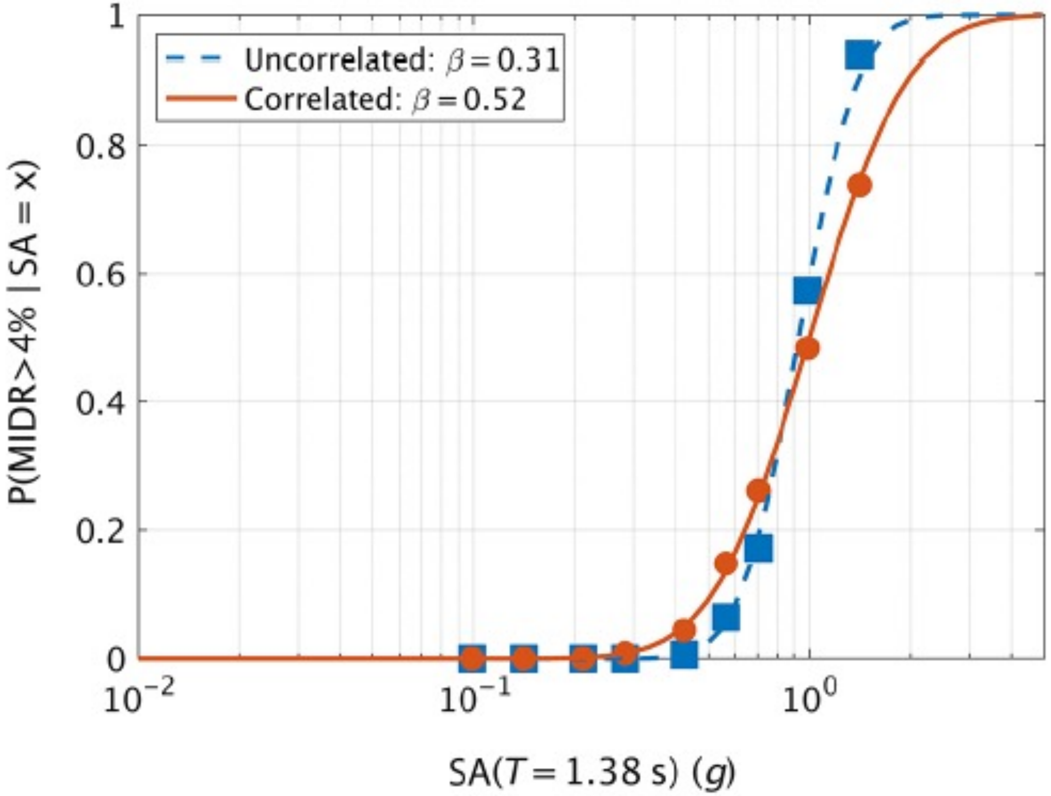
(1) Background

– The inter-frequency (or inter-period) correlation of spectral values is an important parameter for validation in earthquake simulations

- This correlation is related to the width of peaks and troughs in a spectrum (either a Fourier or response spectrum), and therefore impacts the structural response variability and seismic risk estimates developed using the simulations.

- At right, Fragility functions developed from dynamic nonlinear structural analyses in OpenSees using simulations with low correlation (blue) and with realistic correlation (red).

- The standard deviation of the structural response is much larger for the higher correlated simulations, leading to a larger CDF dispersion parameter, β, and in turn larger risk (which is sensitive to the moderate ground motion levels because this is where the hazard is higher)



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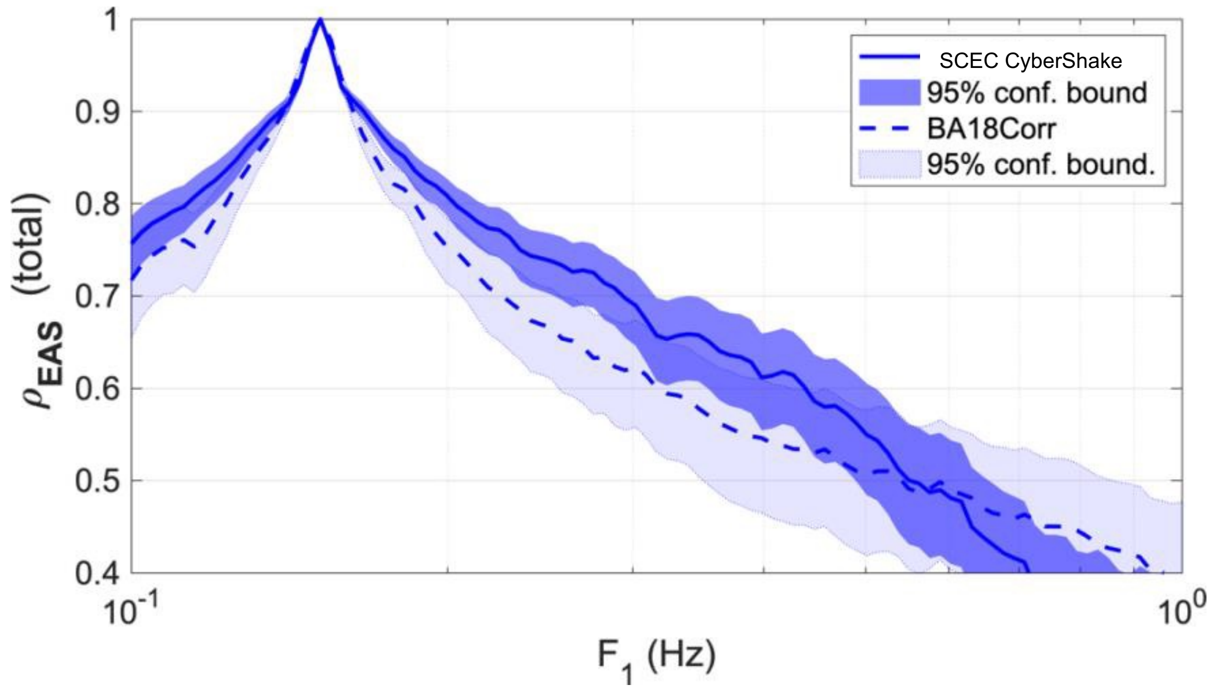
(1) Background

- Bayless and Abrahamson (2018a) evaluated six SCEC BBP simulation methods and compared the inter-frequency correlations (ρ_ϵ) with the NGA-West2 correlations
  - Generally, the simulations are not correlated enough, especially at high frequencies.
  - At low frequencies, the difference between simulation methods is more significant, and the correlations are generally more promising.
- More recently, the evaluation exercise was repeated using SCEC CyberShake (f<1 Hz) simulations
  - A great improvement. Between f = 0.1 – 0.5 Hz, a satisfactory match to the empirical correlations.
  - The between-site component is higher than in the data



Total ρ_ϵ cross section at conditioning frequency 0.15 Hz.
The solid line is the total ρ_ϵ from SCEC CyberShake and the dashed line is from BA18Corr. The darker and lighter shaded regions represent the 95% confidence intervals of ρ_ϵ from these studies, respectively. When the 95% confidence intervals don't overlap, there is a statistically significant difference between the ρ_ϵ at the 0.05 level of significance.

(1) Background

- The study this presentation summarizes the results of the same analysis applied to the CyberShake NZ simulations:

  - Using CyberShake NZ crustal earthquake broadband simulations, which have a transition frequency of 0.5 Hz between semi-deterministic (LF) and semi-stochastic (HF) components

  - A wide range of simulation sources, sites, and site conditions are utilized to mimic the distribution of recorded data in NGA-W2

  - The inter-frequency correlation is calculated for normalized and smoothed EAS residuals (ρ_{ϵ}) after partitioning the residuals into between-event, between-site, and within-site components.

    - EAS: Effective Amplitude Spectra (Goulet et al., 2018)

  - The correlations calculated from the CyberShake NZ crustal simulations are compared with those calculated from the NGA-West2 database (I call this BA18Corr in some places)

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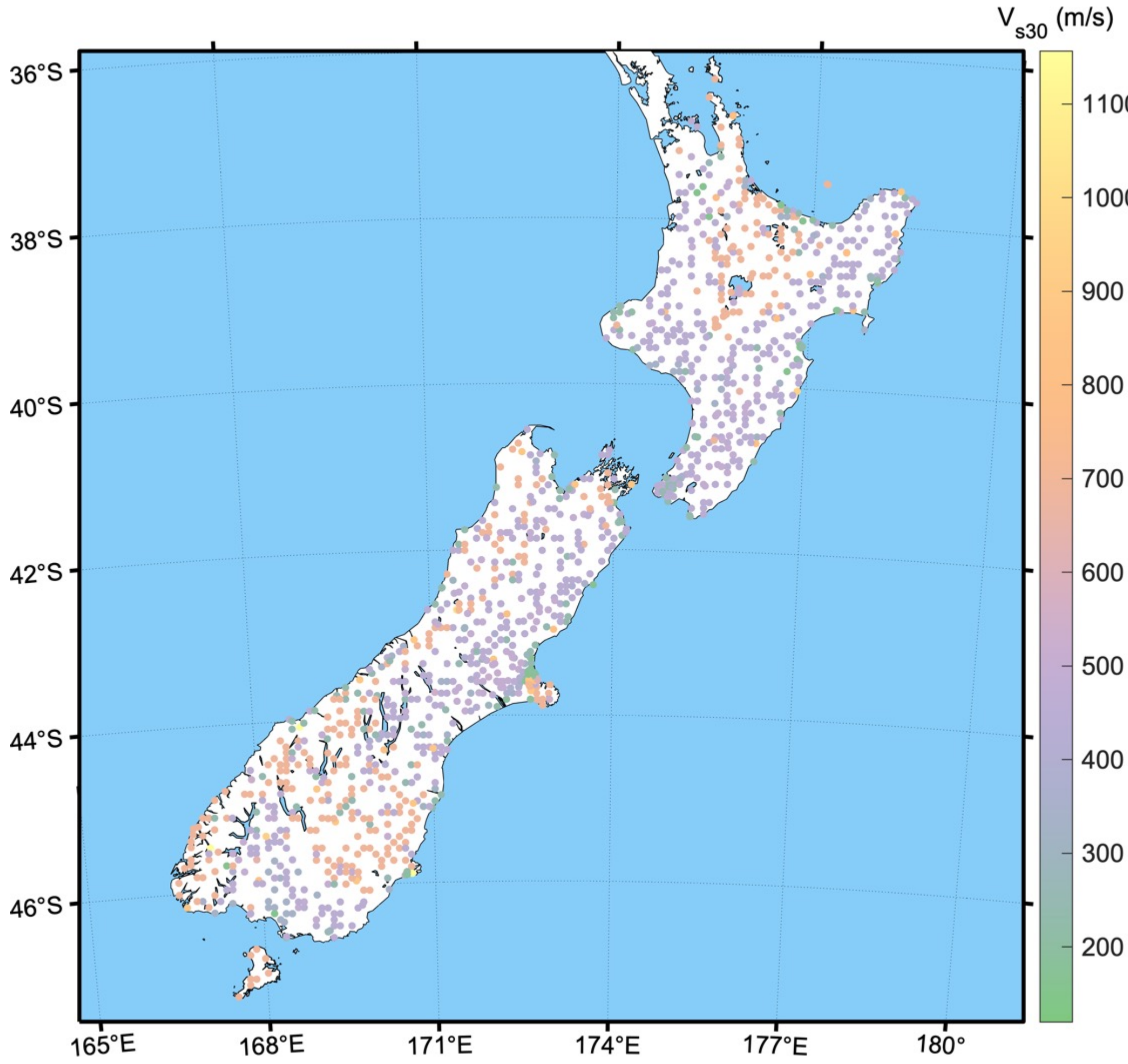
(2) CyberShake NZ Database

– Thanks to Jason Motha for help with the database.

– Utilized dataset
  - A total of 25,785 simulated time series from 161 unique earthquakes and 1,233 unique sites.
  - simulation stations and earthquake scenarios span the northern and southern NZ islands.
  - The scenarios span M5.4 – M8.0.
  - For each earthquake source, one of the available rupture realizations (of source slip distribution and hypocentre) has been selected.
  - Each earthquake has between 11 and 424 recording stations with rupture distances ranging from 0-150 km.
  - Each station has simulations from at least 8 scenario earthquakes.
  - All stations have Vs30 between 120 and 1,156 m/s (map at right)



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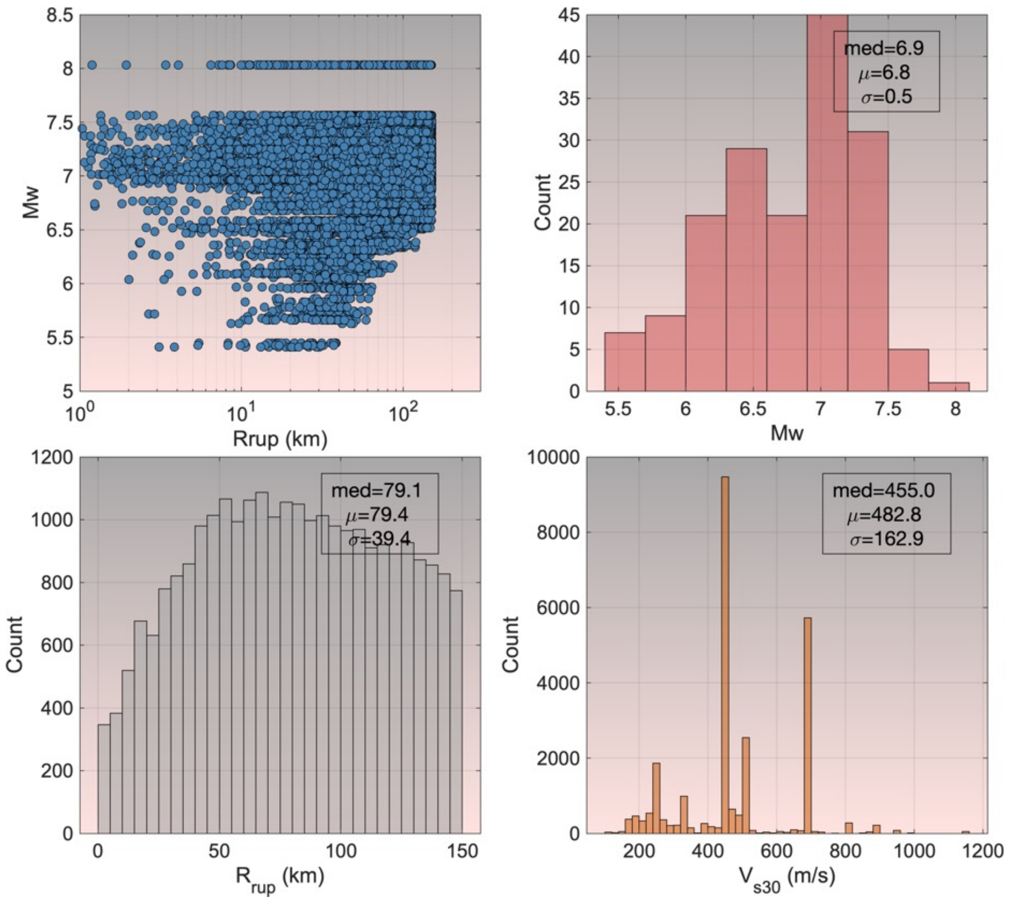
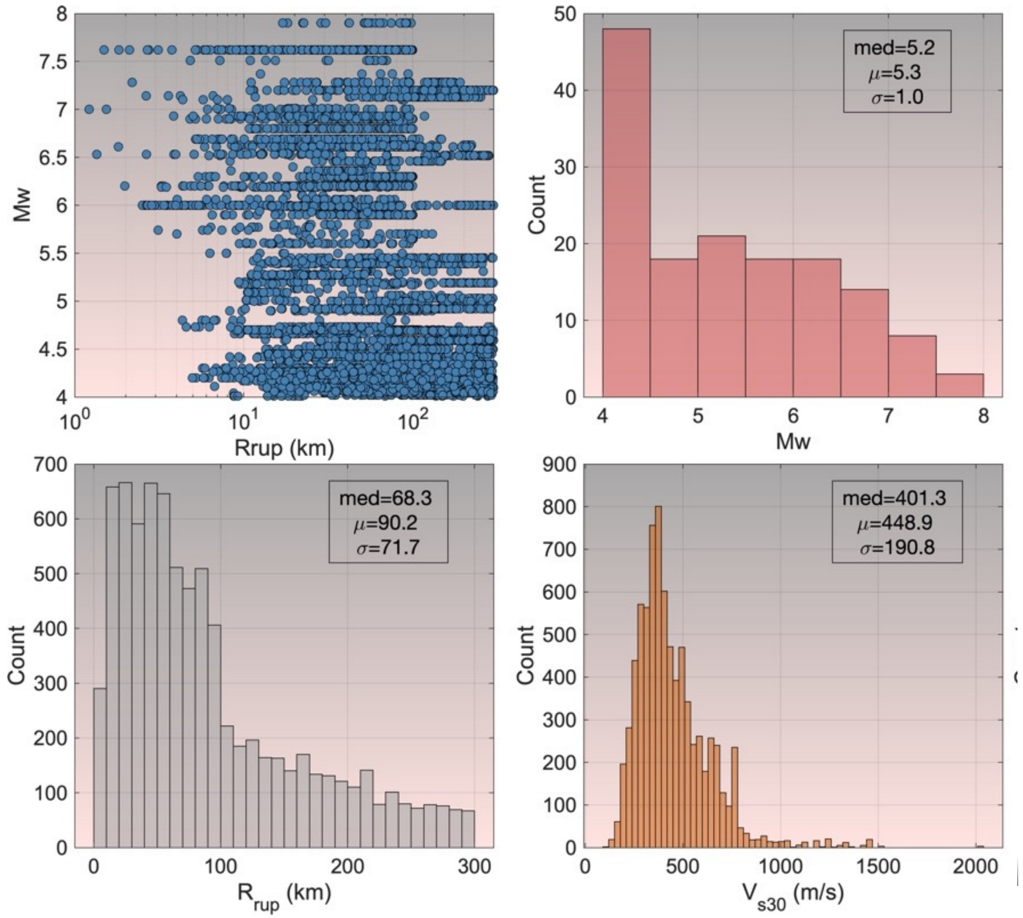
(2) CyberShake NZ Database

- The intention was to create a CyberShake NZ database that has a distribution of earthquake magnitudes, site distances, and site conditions that is comparable to a recorded database like the NGA-W2, so that the partitioning of residuals and subsequent correlation calculations are apples-to-apples

NZ



NGA-W2



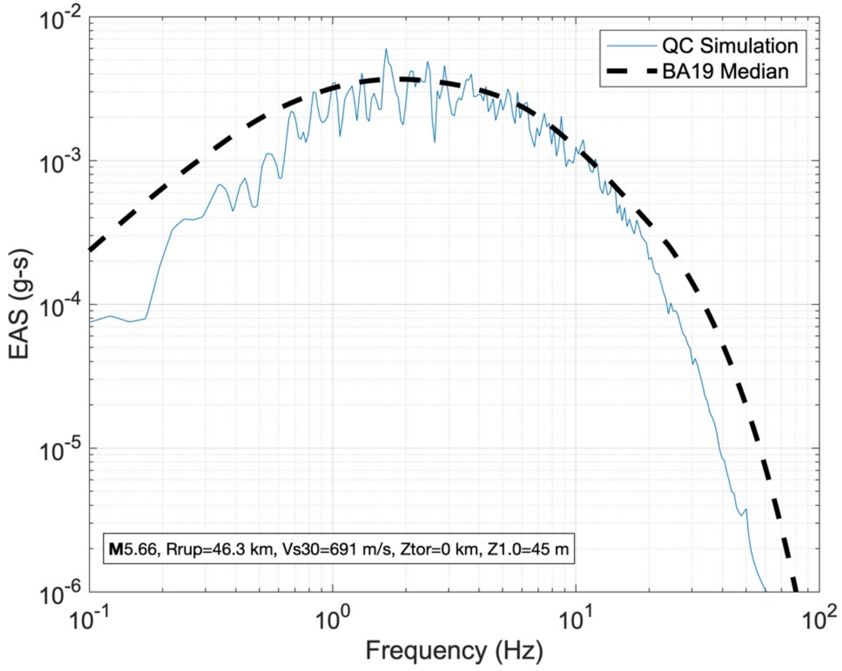
(3) Residual Analysis

– Using the BA19 EAS ground motion model for California, EAS residuals are calculated for the CyberShake NZ database. Following Villani and Abrahamson (2015) and Bayless and Abrahamson (2018a), the residuals take the form:

$$\delta_{total}(f) = Y(f) - g(X_{es}, \theta, f) = \delta B_e(f) + \delta S2S_s(f) + \delta WS_{es} + C(f)$$

$Y(f)$ is the natural log of the CyberShake NZ smoothed EAS at frequency f
$g(X_{es}, \theta, f)$ is the median BA19 GMM
X_{es} is the vector of explanatory seismological params (M, R, site cond, etc.)
$\theta(f)$ is the vector of GMM coefficients
$\delta_{total}(f)$ is the total residual for earthquake e and site s and is composed of:

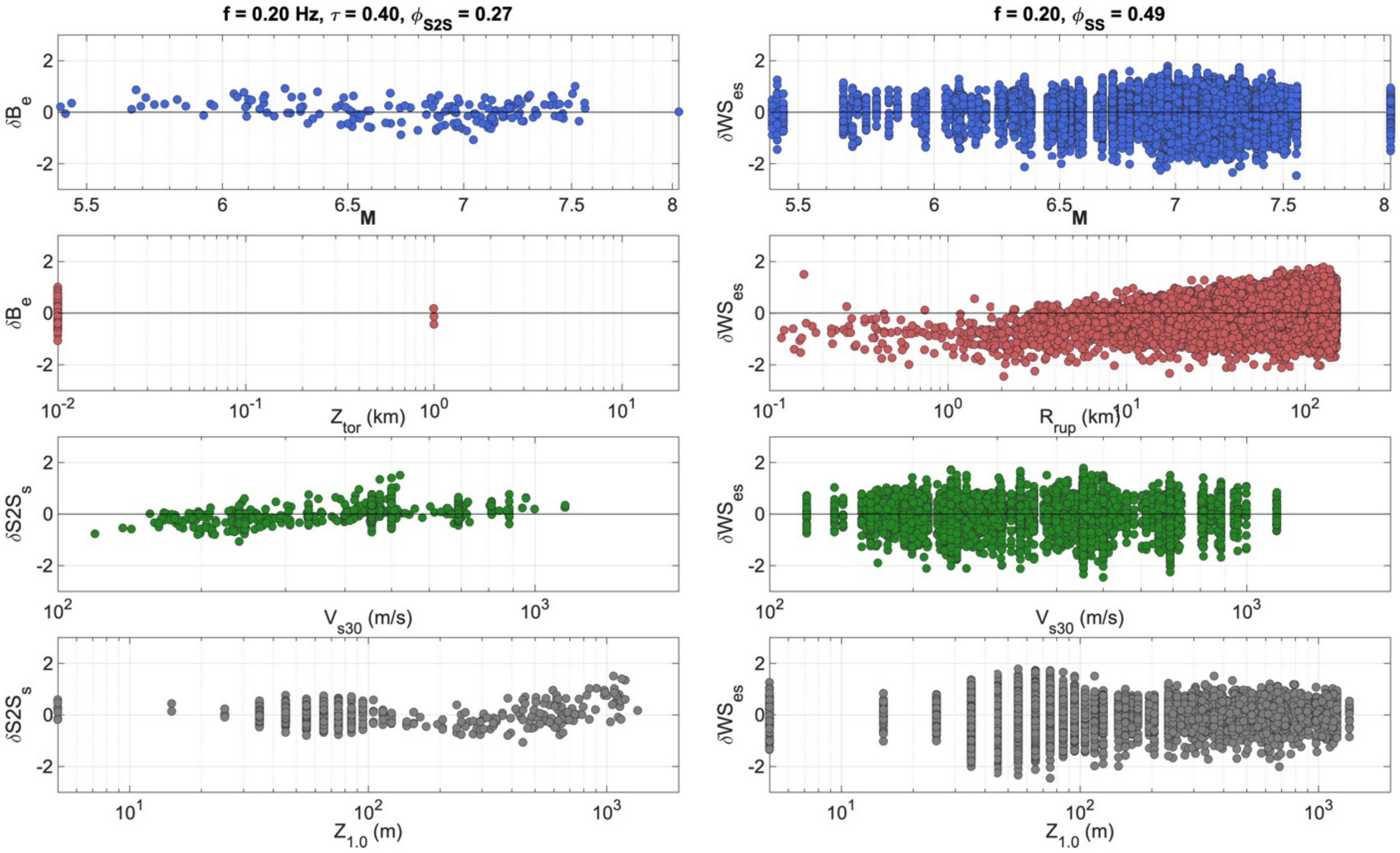
- $\delta B_e(f)$ the between-event residual
- $\delta S2S_s(f)$ the site-to-site residual
- $\delta WS_{es}(f)$ the single station within-site residual
- $C(f)$ the mean total residual, or the mean bias



Example CyberShake NZ spectrum along with BA19 median prediction

(3) Residual Analysis

- Example residual analysis figures for f=0.2 Hz.
- Several interesting observations (excellent topics for a future validation studies) including: differences in Vs30 scaling, distance scaling, and the mean bias (all at low frequencies).
- These residuals, and the similar results at other frequencies in the range 0.1 – 1.0 Hz, are suitable for the purposes of calculating the inter-frequency correlation



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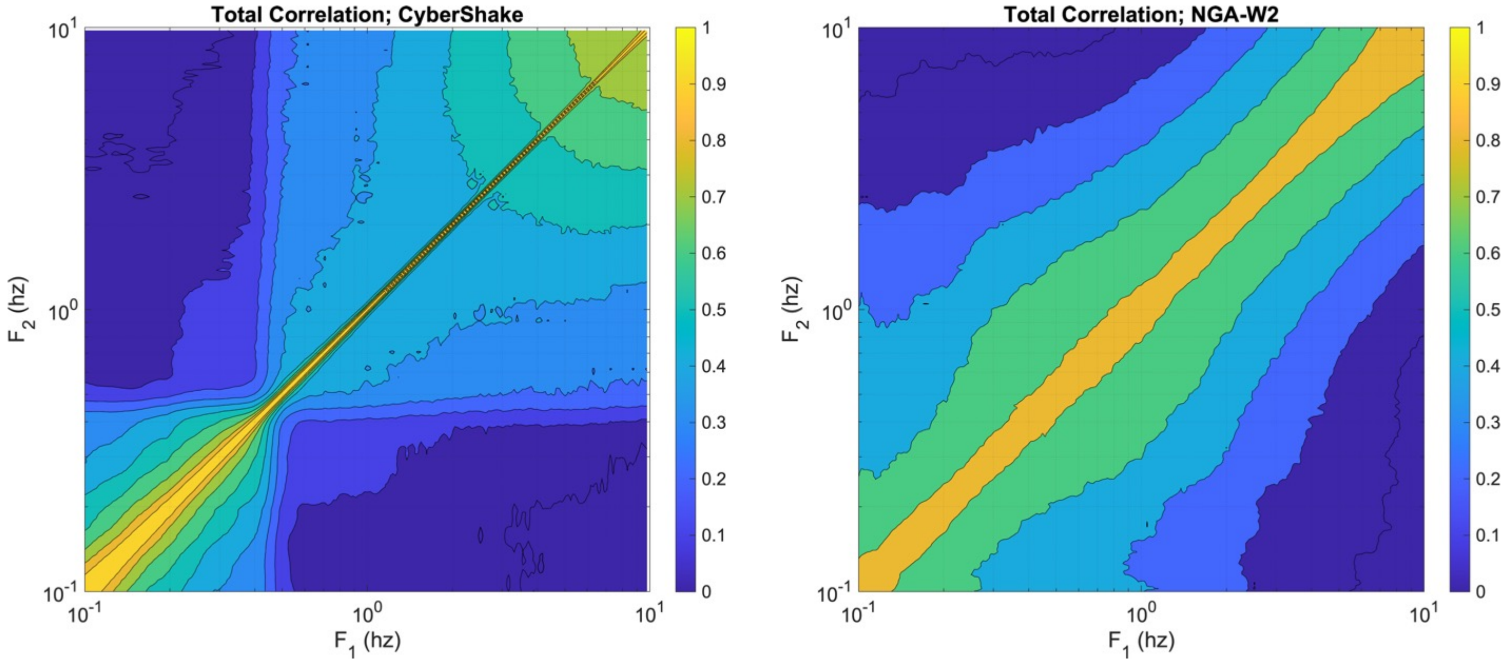
(4) Inter-frequency Correlations

– The EAS residual components are converted to epsilon (ϵ) by normalizing the residuals by their respective standard deviations

– The inter-frequency correlation coefficient (ρ_ϵ) is calculated for each component as well as the total correlation using Equations 3 and 4 of Bayless and Abrahamson (2018b).

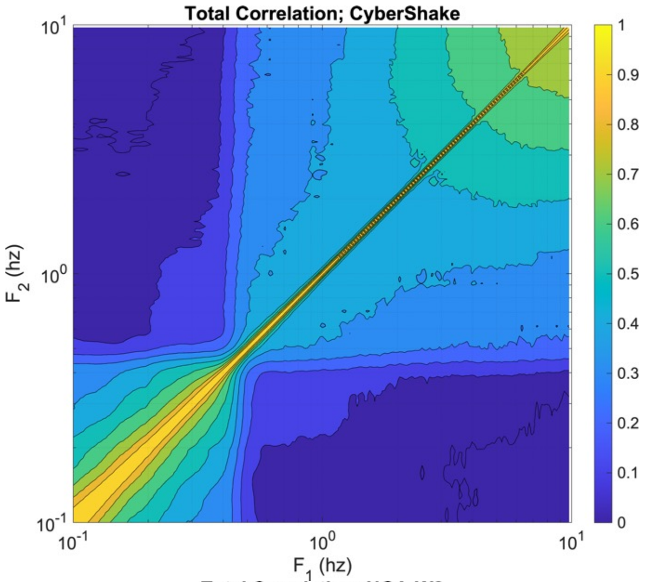
– Repeat at each frequency to create a matrix of ρ_ϵ (shown as contours)

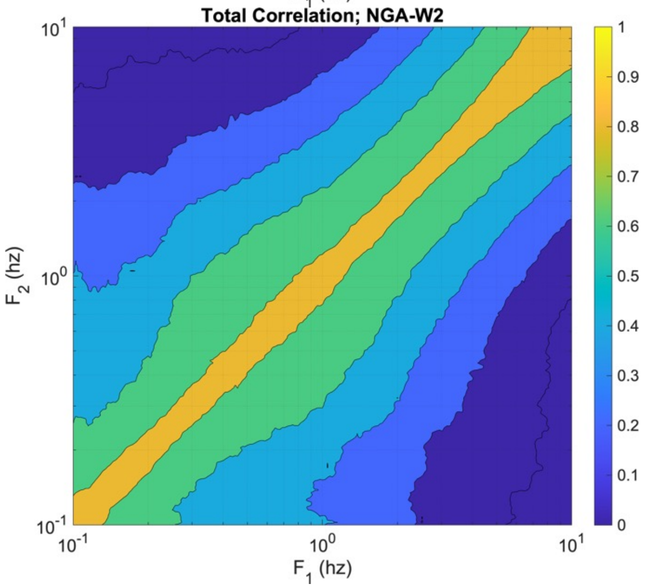
– Total ρ_ϵ contours for CyberShake NZ and NGA-West2 (BA18Corr) at right



(4) Inter-frequency Correlations

- These figures are good for broad comparisons:
  - the total correlation from the CyberShake NZ residuals below the transition frequency (f<0.5 Hz) have contours running roughly parallel to the diagonal, and in this sense compare well with BA18Corr.
  - above 0.5 Hz (semi-stochastic), the total correlation is very different from BA18Corr, with much too steep of decay in the correlation at frequencies very close to the conditioning frequency
    - This is similar to other SCEC simulations at high freq and is a known result of the "stochastic method"





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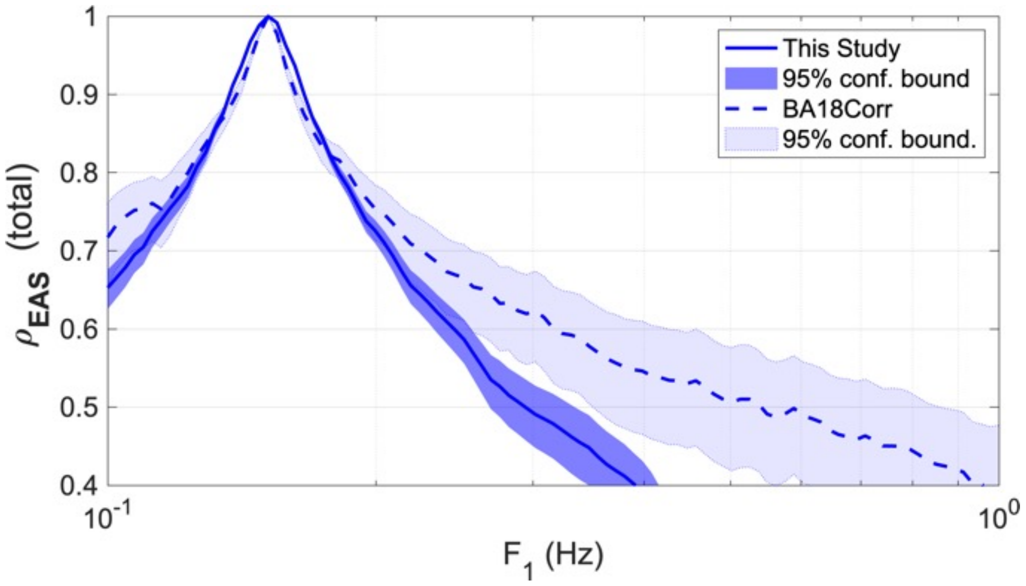
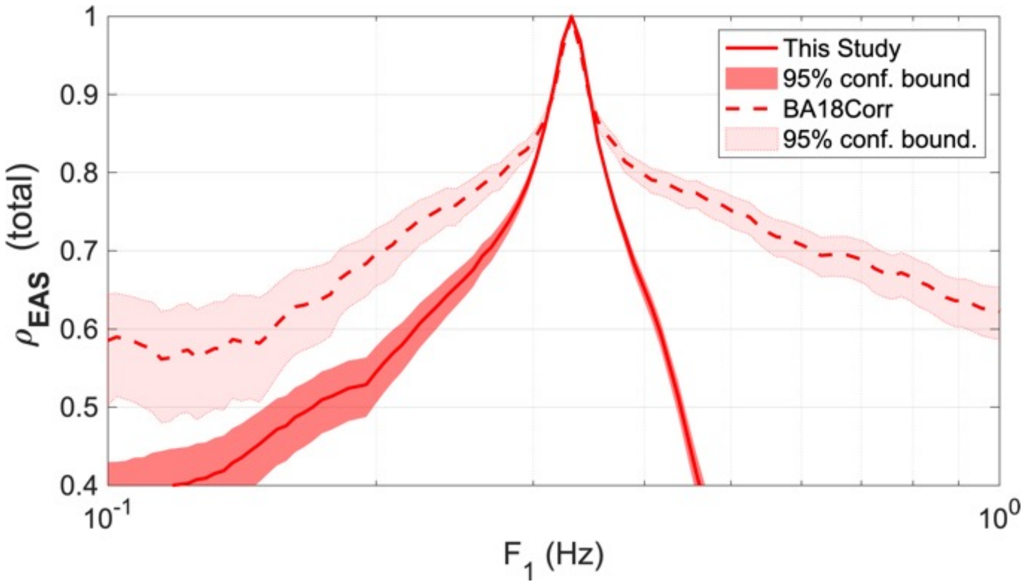
(4) Inter-frequency Correlations

– More useful: cross-sections of the contours and evaluation of the residual components individually

f = 0.15 Hz



f = 0.33 Hz



– solid lines are the total ρ_ϵ from this study, and the dashed lines are from BA18Corr. The darker and lighter shaded regions represent the 95% confidence intervals of ρ_ϵ

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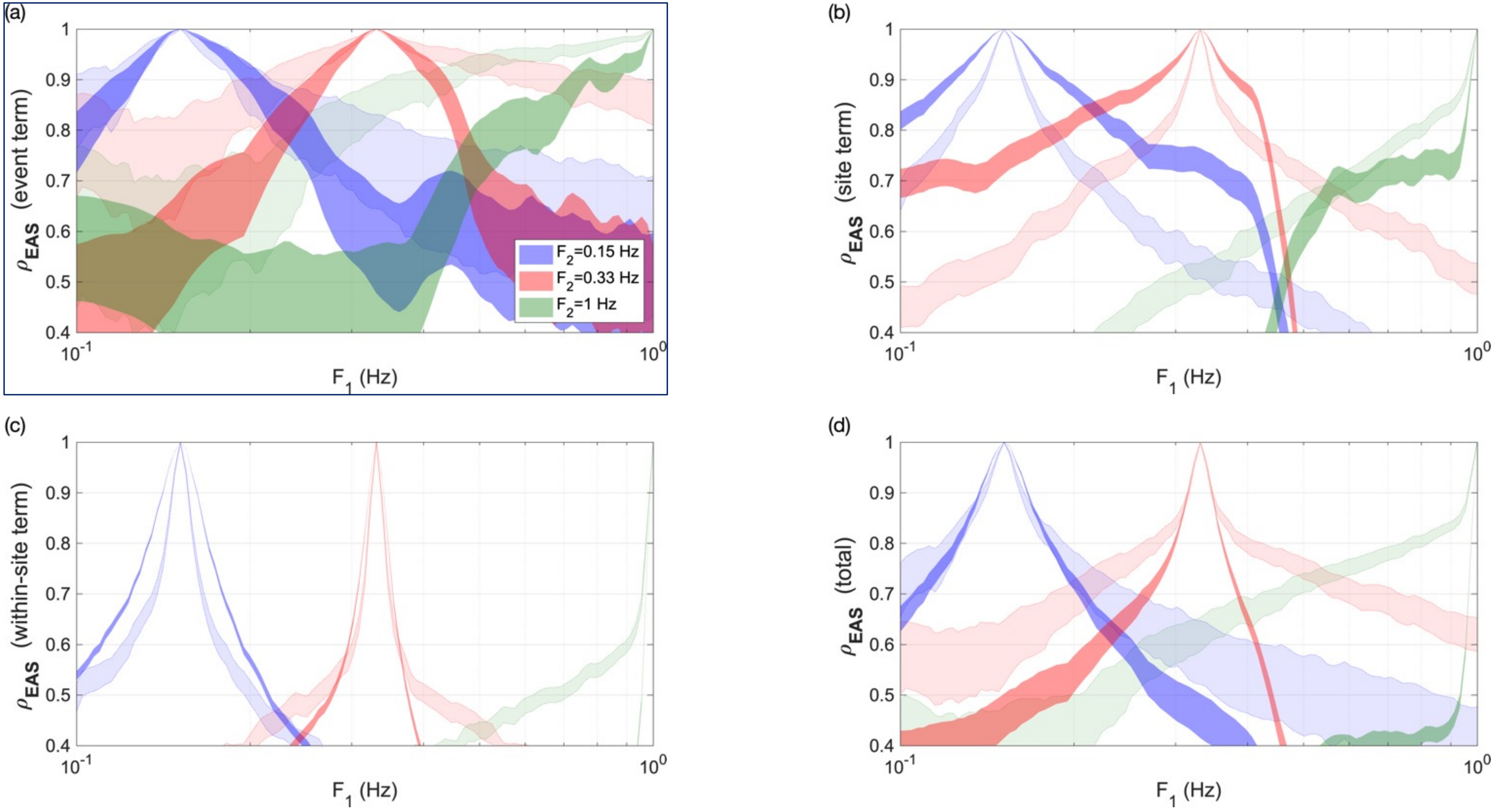
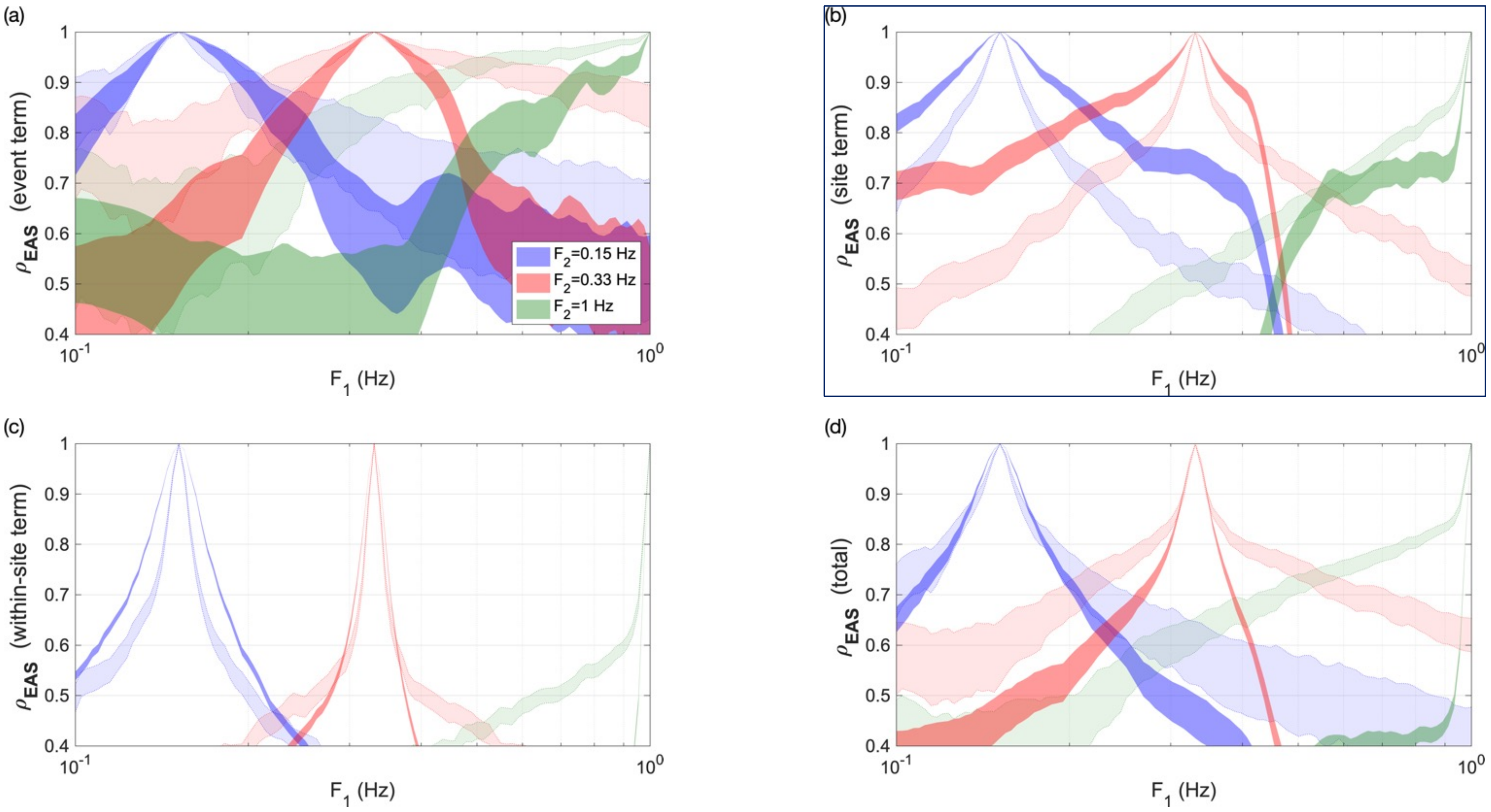
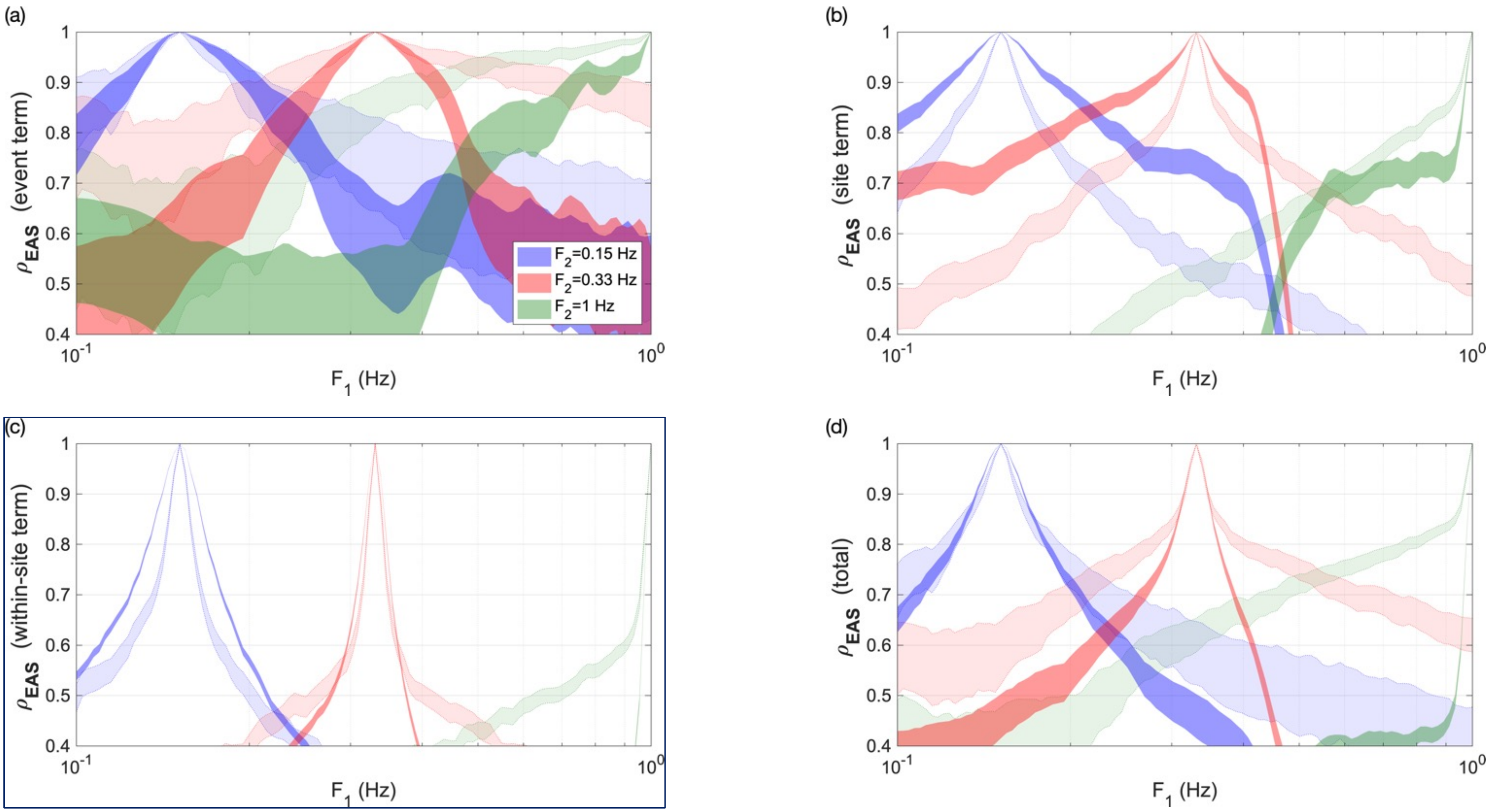

(a)
(b)
(c)
(d)
ρ_{EAS} (event term)
ρ_{EAS} (site term)
ρ_{EAS} (within-site term)
ρ_{EAS} (total)
F_1 (Hz)
F_2=0.15 Hz
F_2=0.33 Hz
F_2=1 Hz


(a)
ρ_{EAS} (event term)
F$_1$ (Hz)
F$_2$=0.15 Hz
F$_2$=0.33 Hz
F$_2$=1 Hz
(b)
ρ_{EAS} (site term)
F$_1$ (Hz)
(c)
ρ_{EAS} (within-site term)
F$_1$ (Hz)
(d)
ρ_{EAS} (total)
F$_1$ (Hz)


(a)
(b)
(c)
(d)
ρEAS (event term)
ρEAS (site term)
ρEAS (within-site term)
ρEAS (total)
F2=0.15 Hz
F2=0.33 Hz
F2=1 Hz
F1 (Hz)
1
0.9
0.8
0.7
0.6
0.5
0.4
10-1
100

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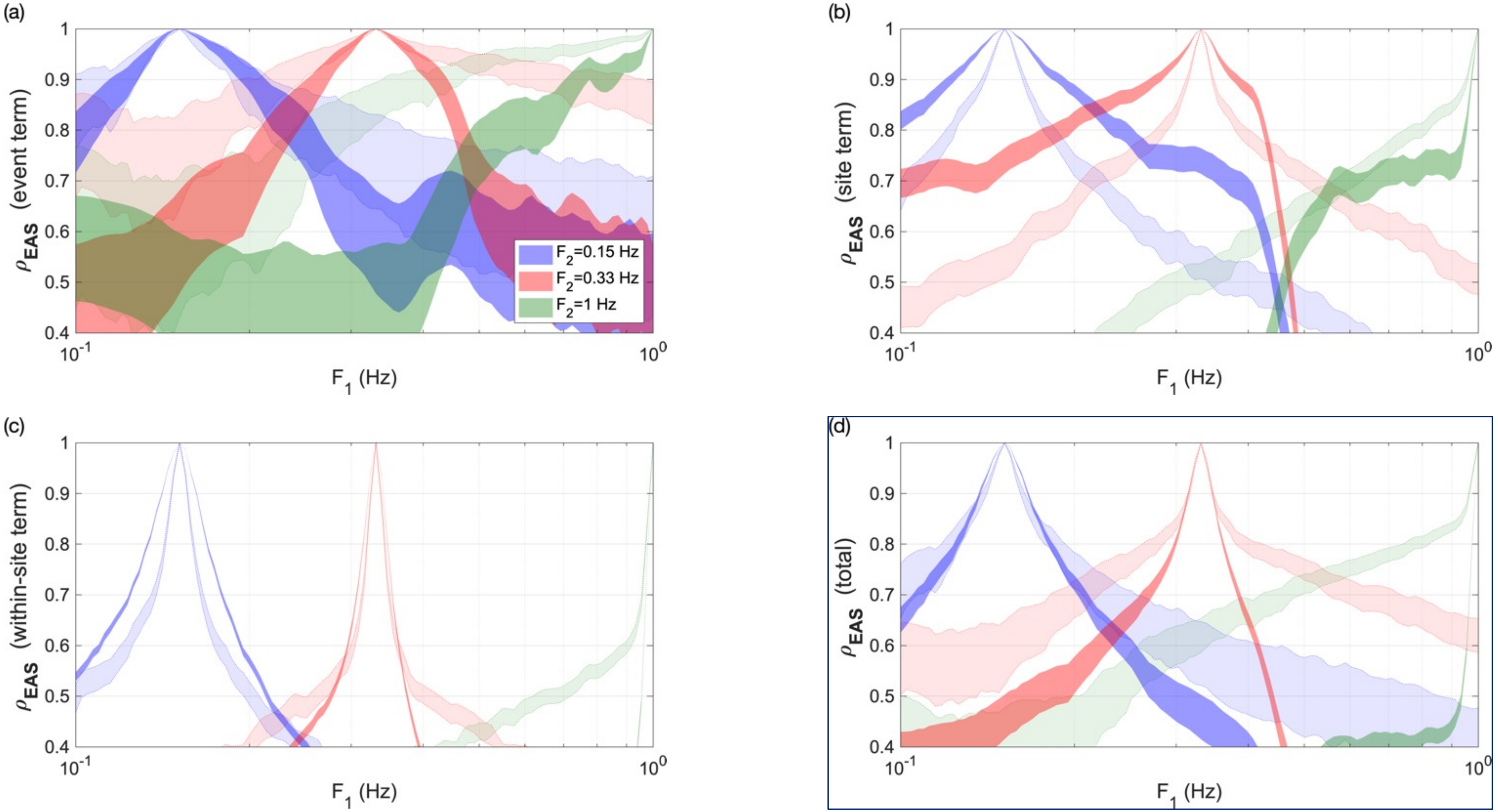
(a)
ρEAS (event term)
F1 (Hz)
F2=0.15 Hz
F2=0.33 Hz
F2=1 Hz
(b)
ρEAS (site term)
F1 (Hz)
(c)
ρEAS (within-site term)
F1 (Hz)
(d)
ρEAS (total)
F1 (Hz)

(5) Conclusions, Future Work

- Compared with BA18Corr, the 0.1 < f < 0.25 Hz CyberShake NZ simulations have a satisfactory level of inter-frequency correlation

  - This is a significant improvement from the conclusions of Bayless and Abrahamson (2018a) about the SCEC BBP simulations.
  - At frequencies above 0.25 Hz, the CyberShake NZ simulations have lower, less agreeable correlation than the empirical model.
  - Above the transition frequency of 0.5 Hz, the low inter-frequency correlation is a known characteristic of the "stochastic method" simulation technique

- The correlation from the between-site residual component requires the most calibration moving forward.

  - CyberShake NZ correlation is significantly higher than the empirical model at frequencies below 0.5 Hz. This may be due to the relative simplicity of the seismic velocity model in the simulations (with less variability in site amplification than the recorded data).
  - It may also be related to the effects of low frequency basin waves mapped into the site terms.

- Future topics

  - The cause of large correlation ρ_ϵ for the between-site component of the residuals could be investigated by evaluating the effect of low frequency basin waves on the analysis, or by utilizing results from refined or alternative seismic velocity models. Repeatable path and basin effects could be evaluated through an in-depth residual analysis.
  - Repeating this analysis with CyberShake NZ simulations using a higher crossover frequency (e.g. 1 Hz or larger) would be informative.

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