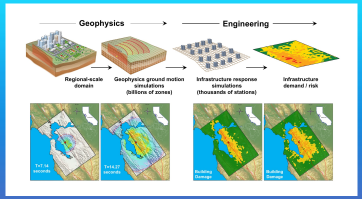

PEER International Pacific Rim Forum
June 16-17, 2021

Significance and validation of the inter-period correlation of simulations

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AECOM, UCB

June 17, 2021

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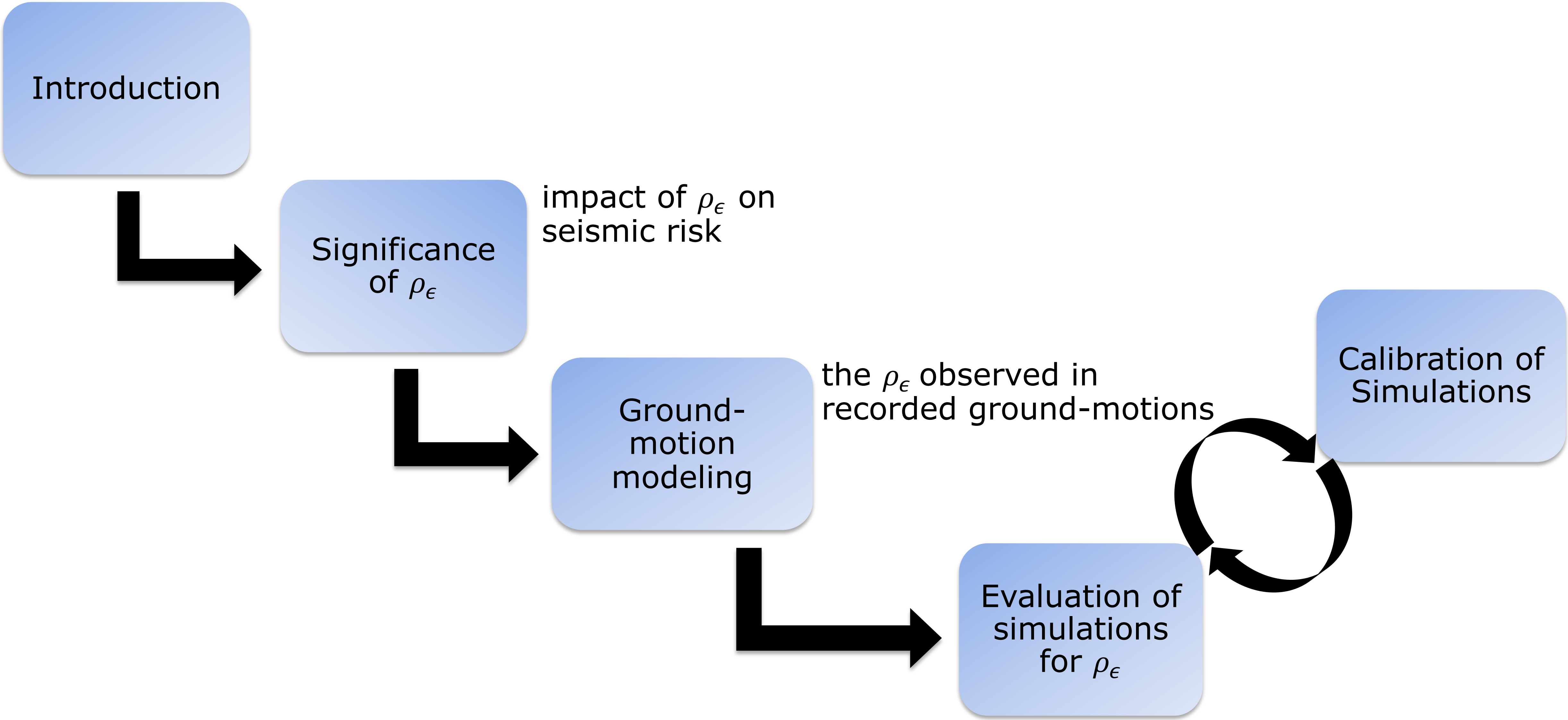
The purpose of this presentation is to…

- illustrate that the inter-period correlation of ground-motions (ρ_{ϵ}) is a critical feature that influences variability of structural response.

  Therefore, it should be considered as a validation parameter in physics-based earthquake simulations.
- Provide example validations and calibrations.

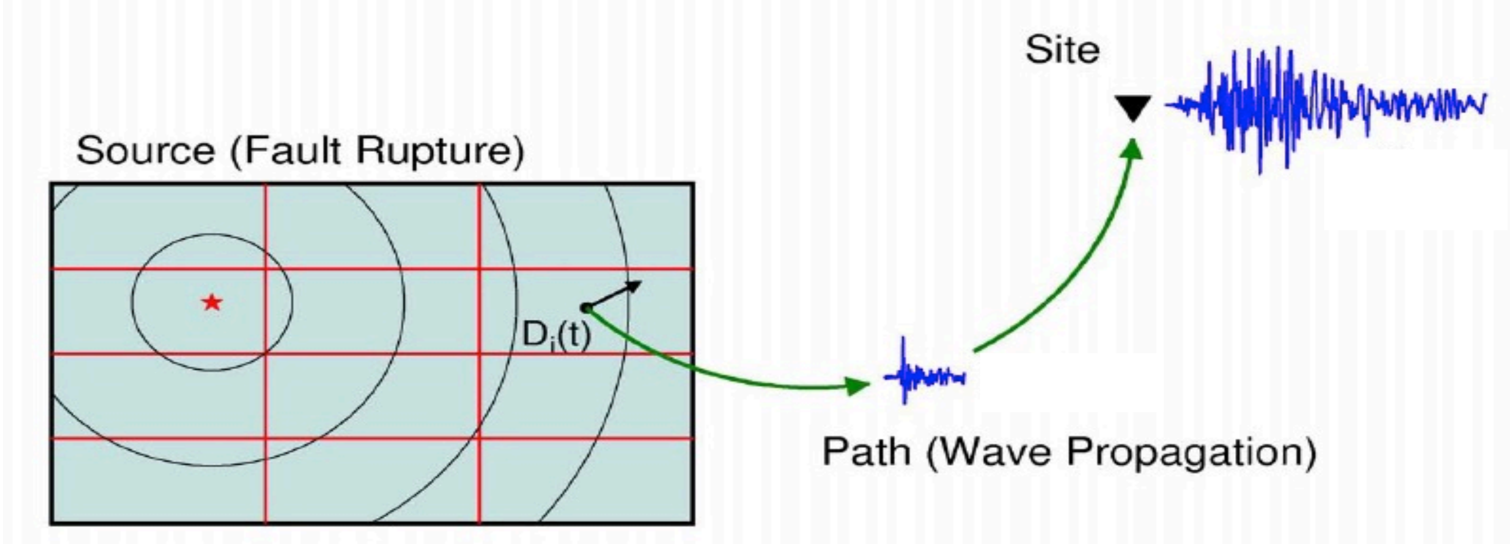

Introduction
Significance of ρ_ϵ
impact of ρ_ϵ on seismic risk
Ground-motion modeling
the ρ_ϵ observed in recorded ground-motions
Evaluation of simulations for ρ_ϵ
Calibration of Simulations

Introduction

Physics-based earthquake ground-motion simulations:

In practice, simulations will be used by engineers increasingly in the next decades.

To use them, we need to **validate** that they contain the ground-motion properties found in recordings.



(image from Graves 2014)

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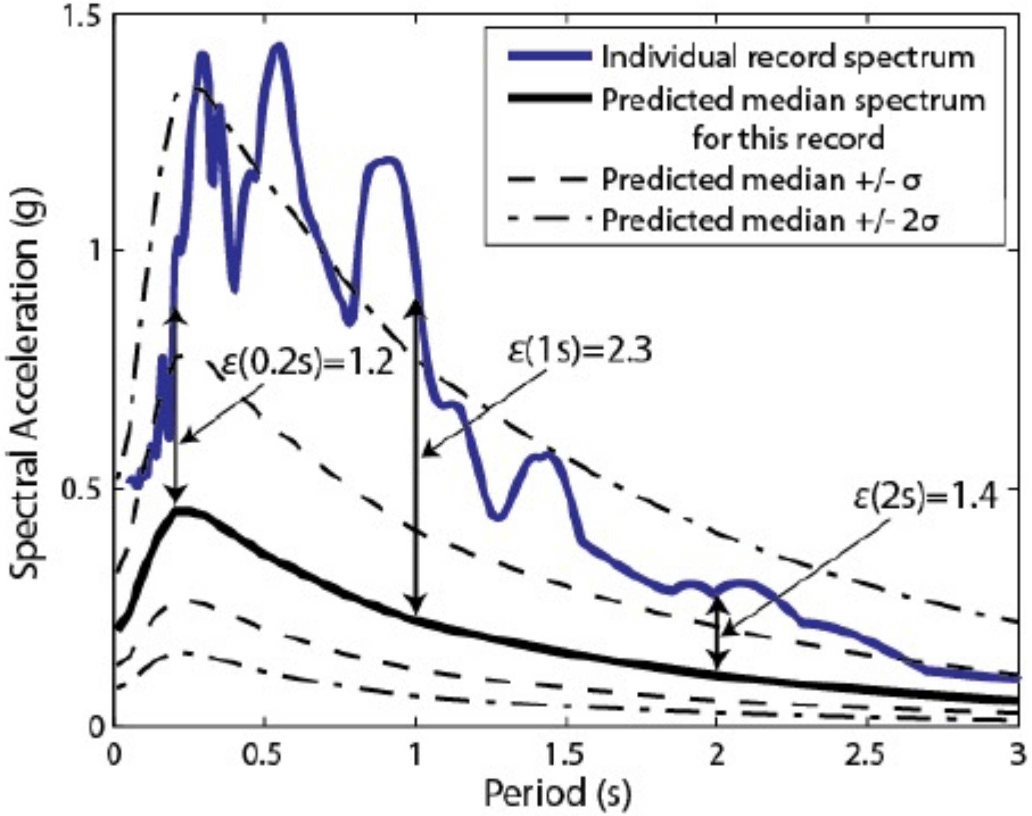
Epsilon (ϵ) is the number of standard deviations difference between the observed GM and the median model prediction (ln units)

observed — model median — model sigma

$$\varepsilon(T) = \frac{\ln Sa(T) - \mu_{\ln Sa}(M,R,T)}{\sigma_{\ln Sa(T)}}$$

ϵ is a "normalized residual"

ϵ is **correlated** between spectral periods



(image from Baker 2010)

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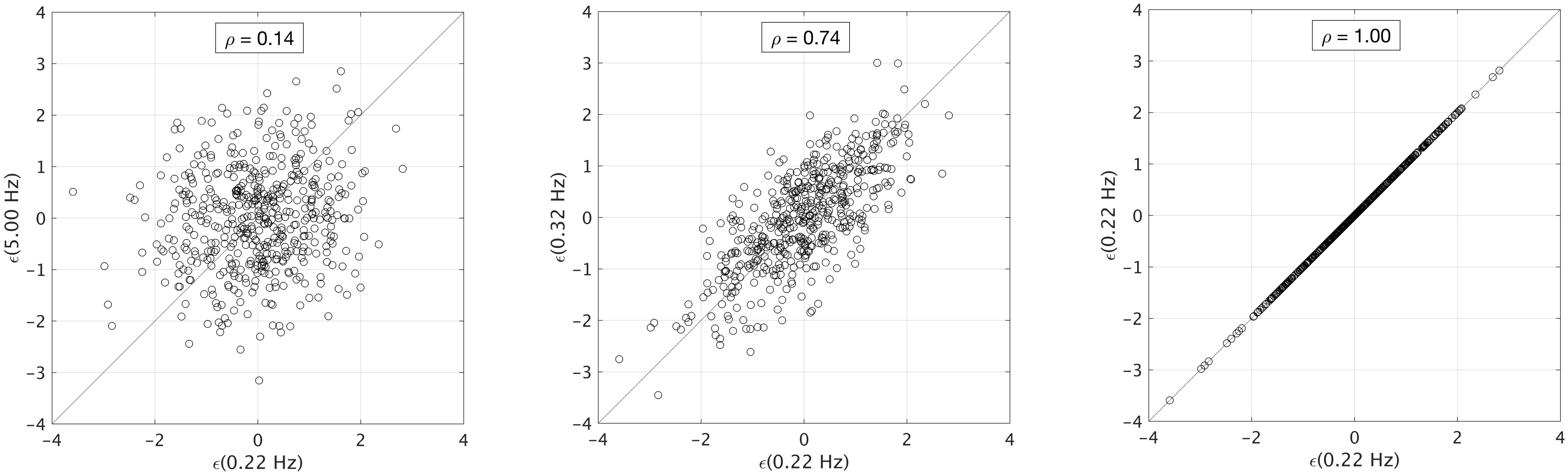
For an entire database:

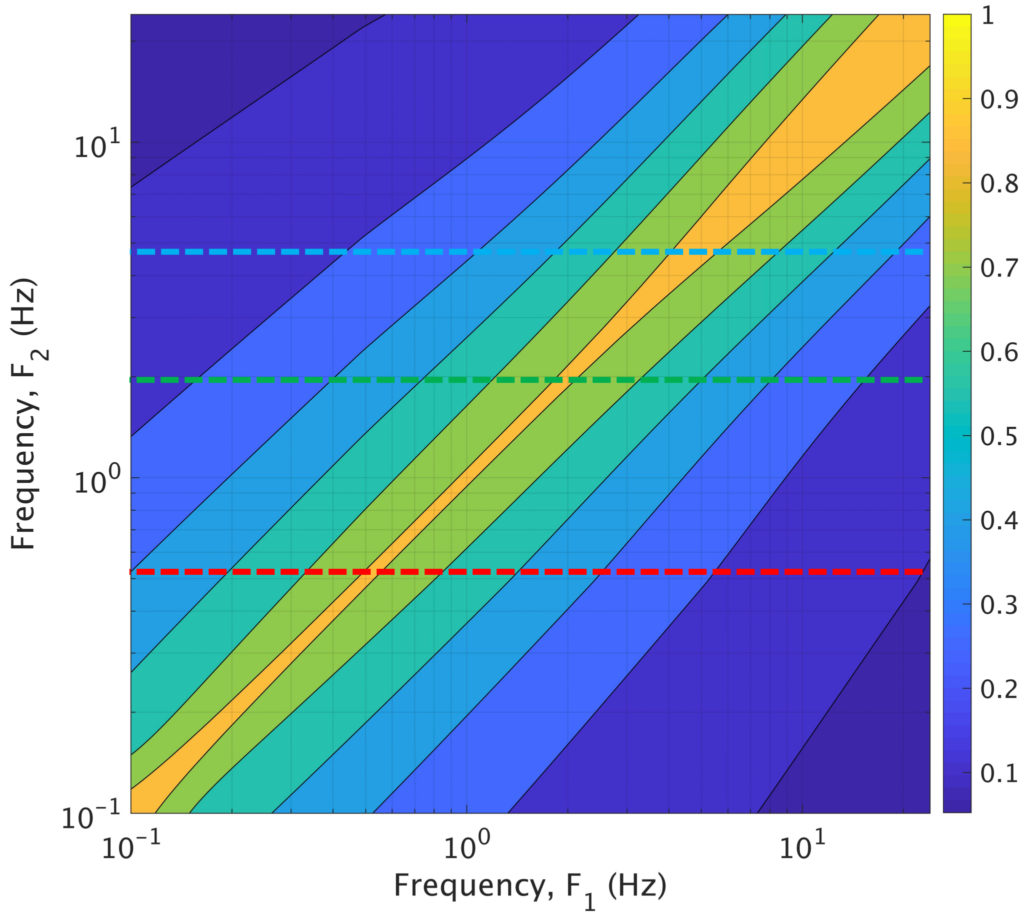
F_1 = 0.2 Hz, F_2 = 5 Hz
ρ = 0.14

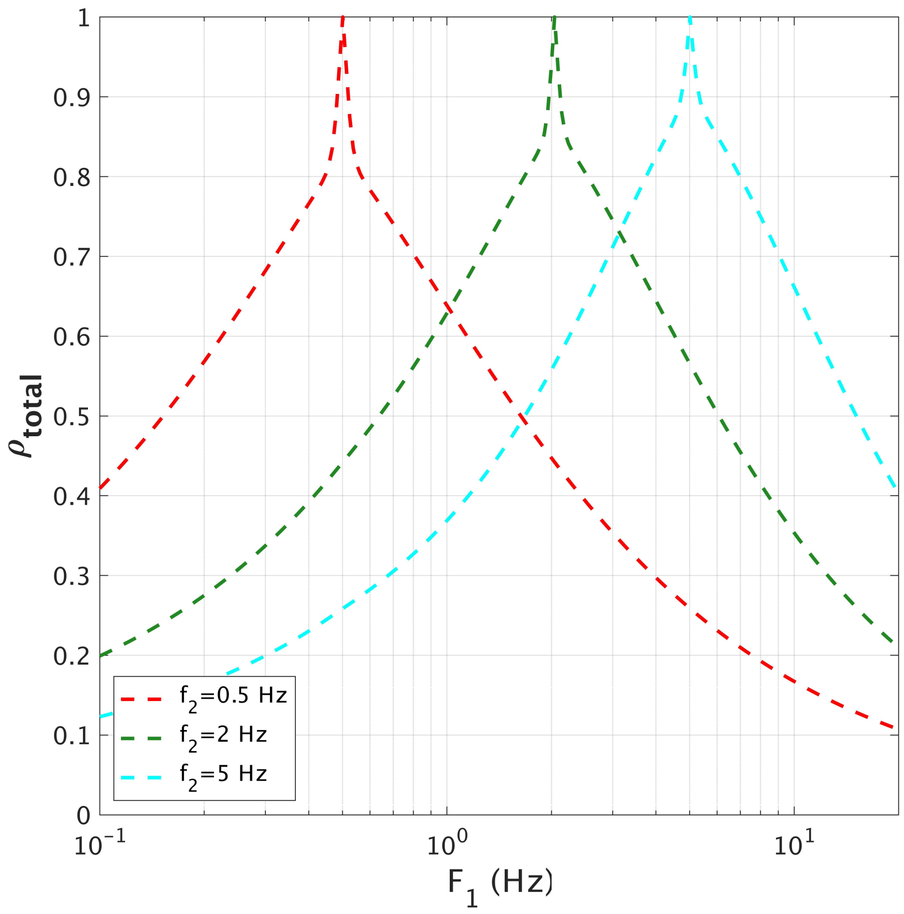
F_1 = 0.2 Hz, F_2 = 0.3 Hz
ρ = 0.74

F_1 = 0.2 Hz, F_2 = 0.2 Hz
ρ = 1.0



Repeat this calculation of ρ for each period (or frequency) pair of interest.





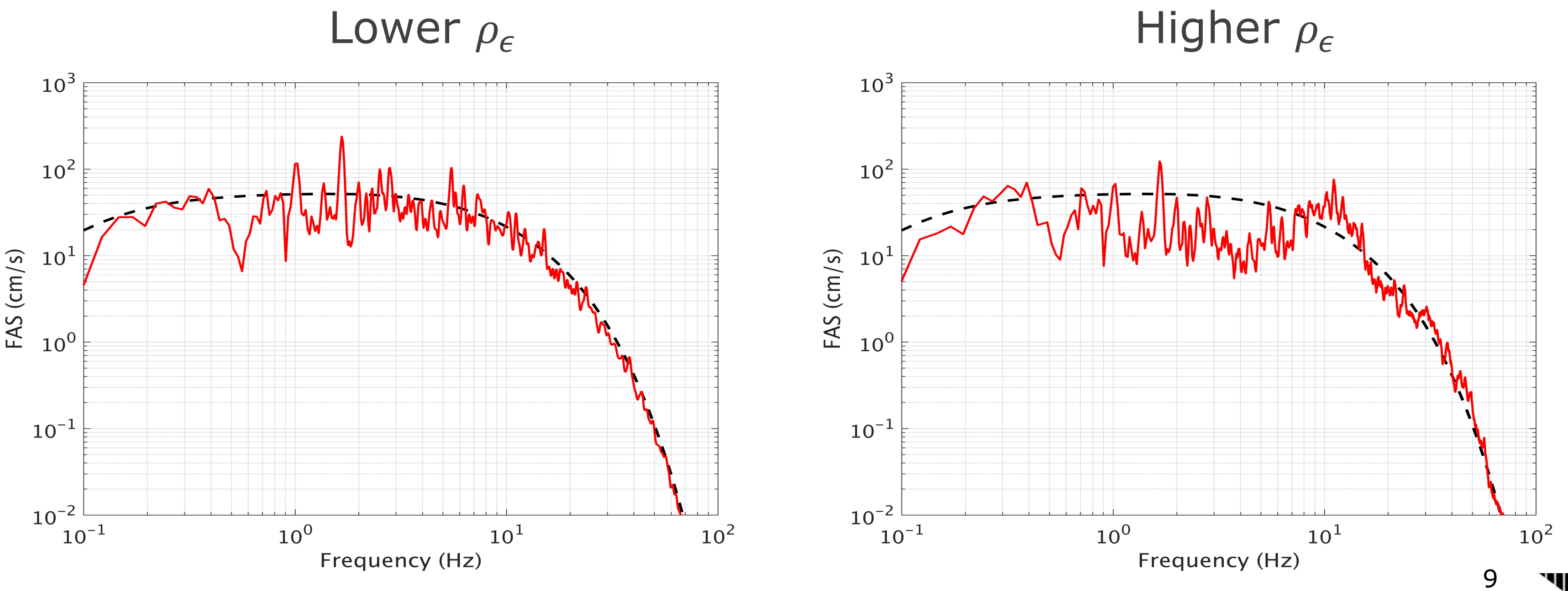
Significance

Why does the **inter-period correlation of ϵ** (ρ_ϵ) matter?

Significance

- ϵ itself is an indicator of the local peaks and troughs at a given frequency in a spectrum
- ρ_ϵ quantifies the relationship of ϵ values between periods
- therefore ρ_ϵ characterizes the relative width of these extrema.

Example Fourier Amplitude Spectra (FAS):



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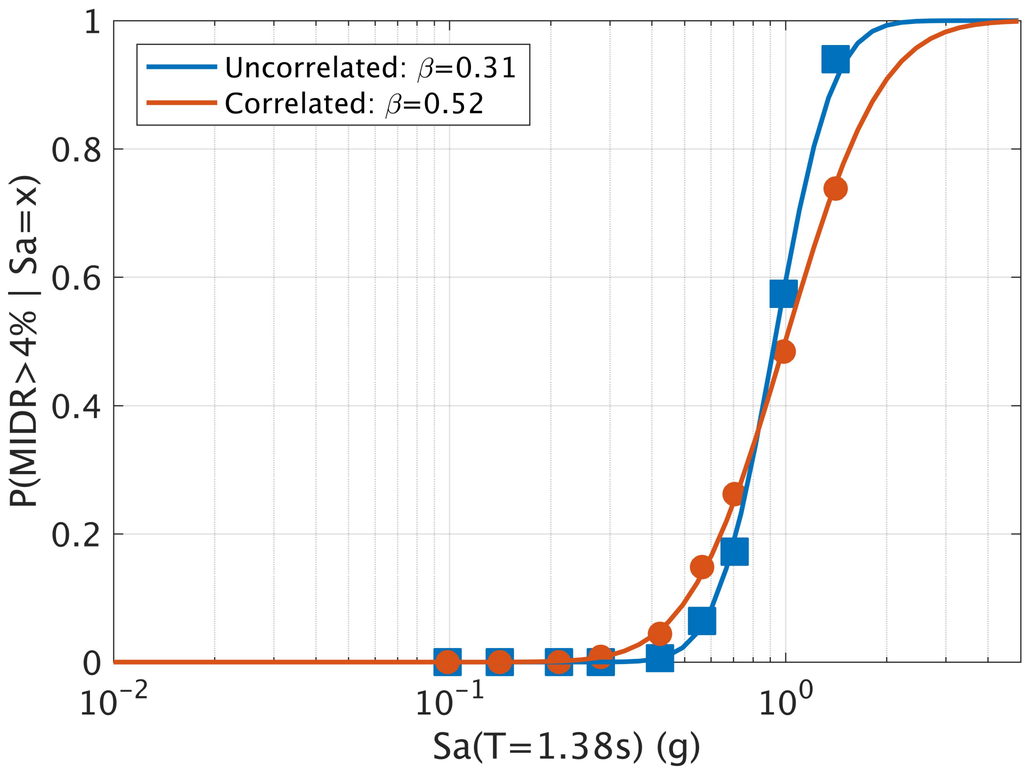
As a measure of the width of spectral peaks, ρ_ϵ is relevant in dynamic structural response

Bayless and Abrahamson (2018):

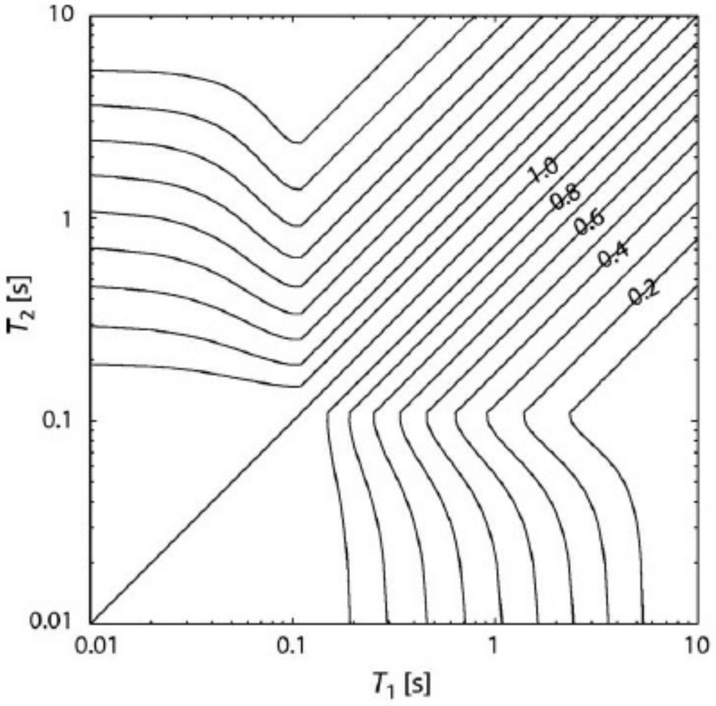
- Structures are sensitive to a range of frequencies about the fundamental one, especially for nonlinear response
- Breadth of spectral peaks influences variability of the response
- Increased ρ_ϵ leads to flatter fragility curves

- Therefore, it influences seismic risk and is an important metric for **validation** of simulations

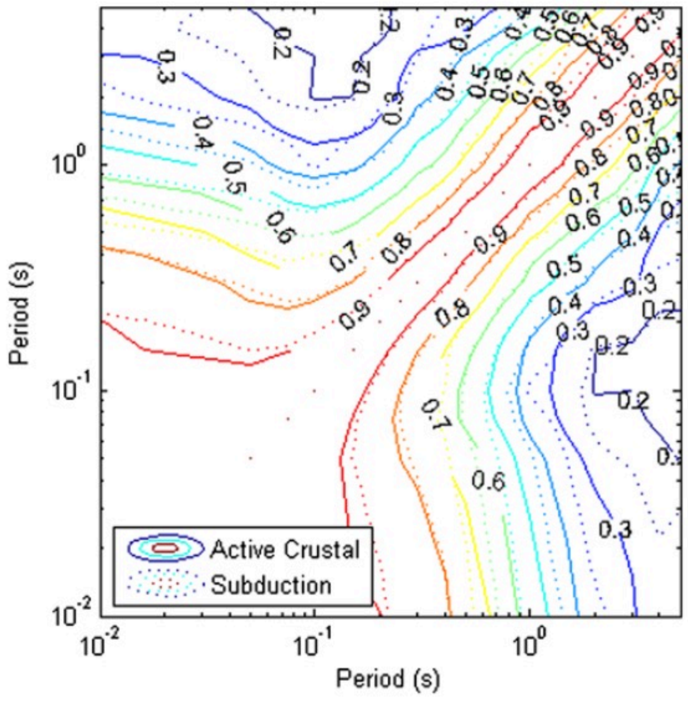


Models for ρ_ϵ - response spectra*

*within-event residual models

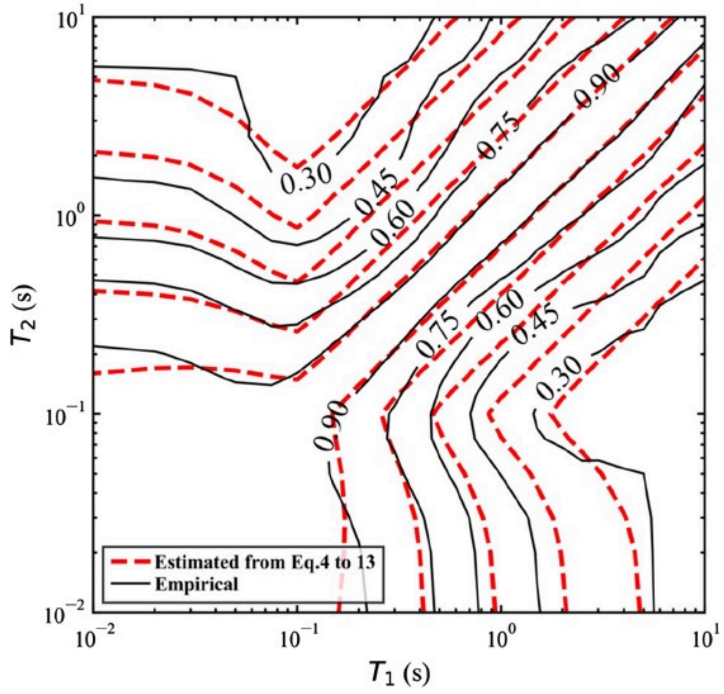


Baker and Jayaram (2008)
Crustal eqks
NGA-West
Updated: Baker and Bradley (2016)



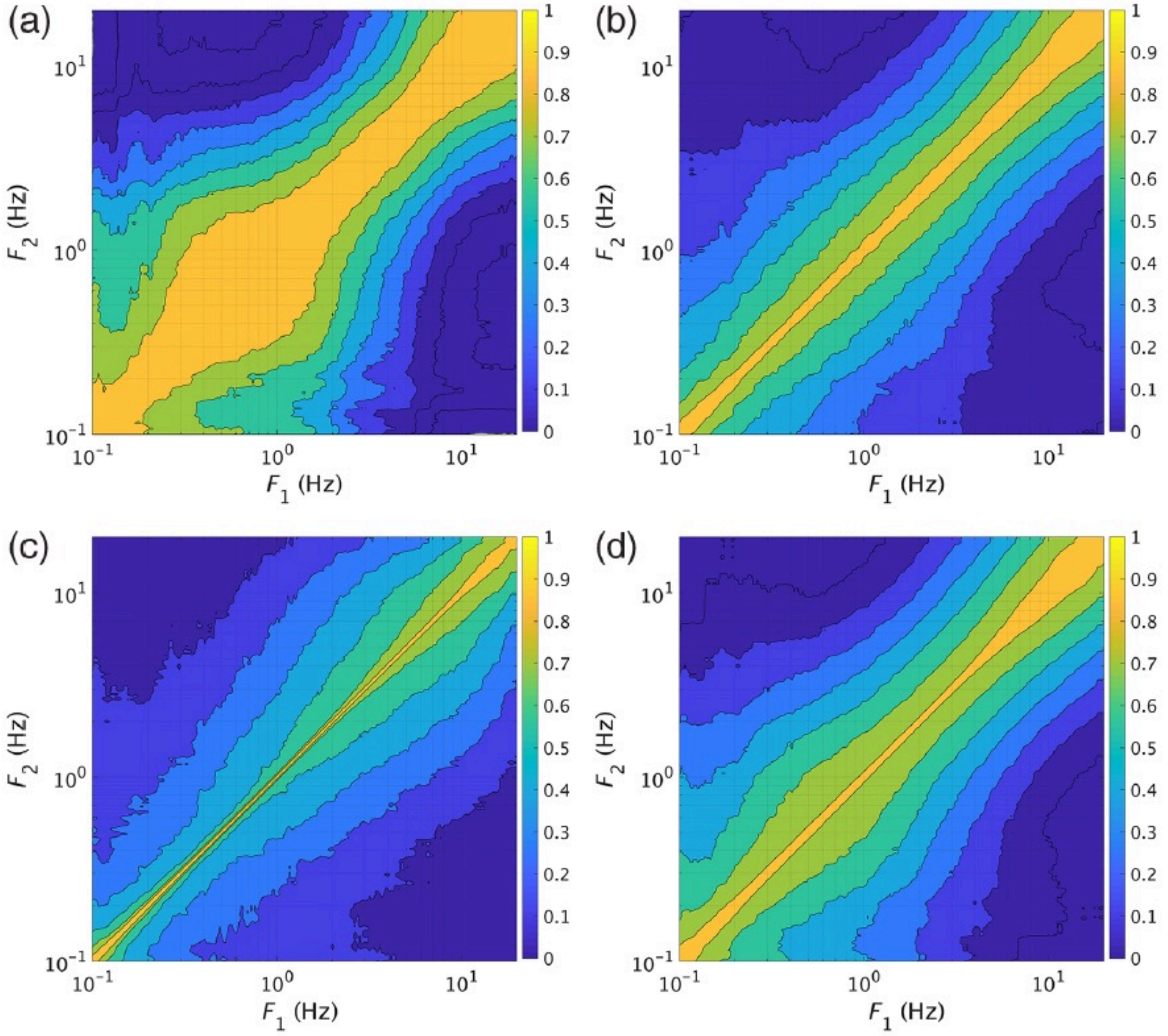
Carlton and Abrahamson (2010)

Crustal vs. Subduction



Macedo and Liu (2021)
Subduction
NGA-Sub

Models for ρ_ϵ - Fourier amplitude spectra



- Stafford (2017)
- At left, Bayless and Abrahamson (2018)

  (a) between-event
  (b) between-site
  (c) within-site
  (d) total

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Evaluation of simulations for ρ_ϵ

Study #1: SCEC Broadband Platform Simulations
Study #2: SCEC Cybershake Simulations

Study #1: SCEC Broadband Platform

- Five simulations methods
- These use 1-D (plane-layered) earth models with no site effects on the SCEC BBP.
- Simulations of 9 crustal earthquakes, each with 50 alternate source realizations
- A sixth (Rodgers et al. 2018) not from the BBP but was evaluated at the same time. M7.0 Hayward fault scenario, with 3-D earth model, f<5 Hz, one realization

Evaluation Procedure

- Calculate residuals from the simulations relative to the FAS model
- Partition the residuals into components: mean bias, between-event, ~~between-site~~, within-site
- Calculate ρ_ϵ for each FAS residual component and the total ρ_ϵ

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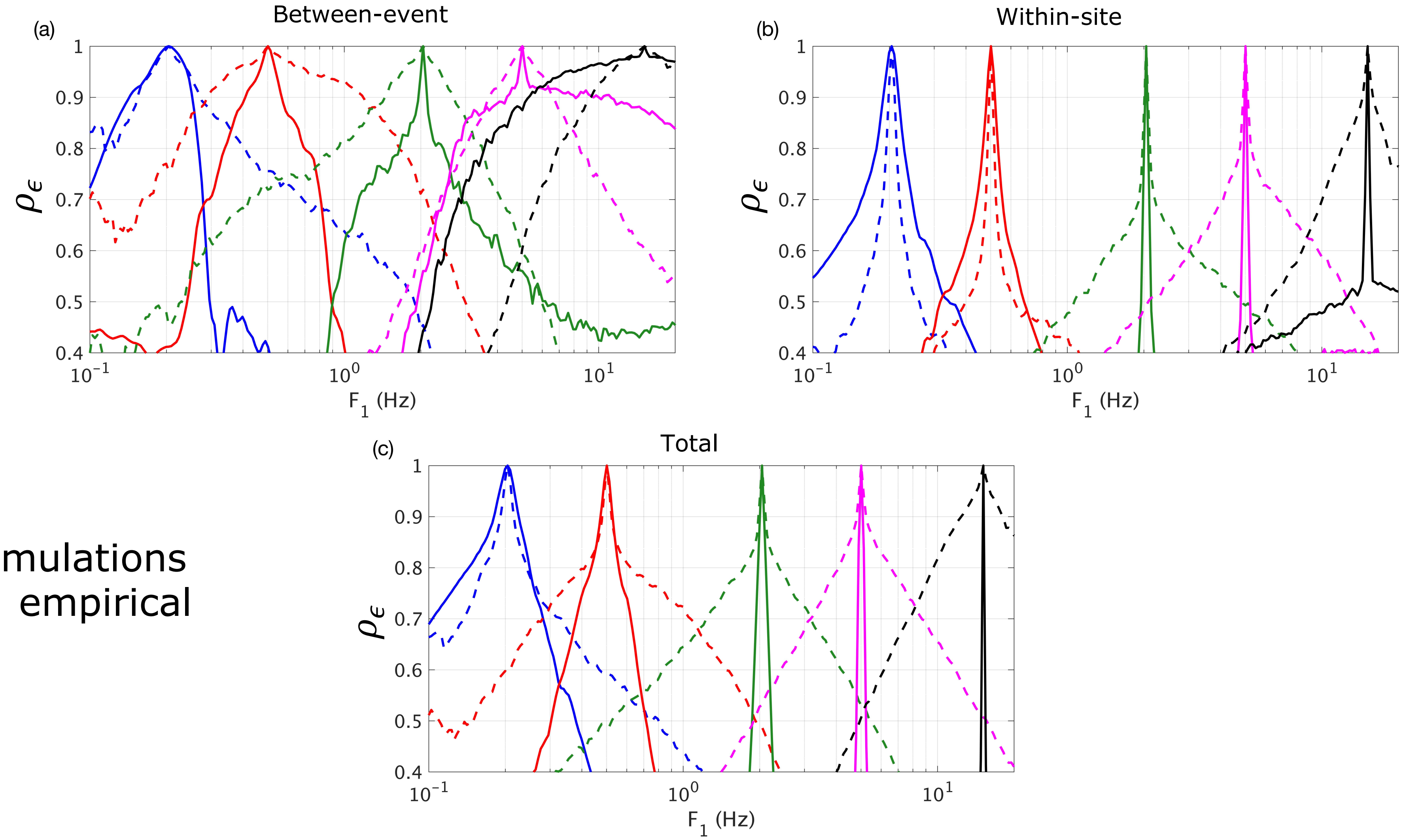
Study #1: SCEC Broadband Platform



Solid: simulations
Dashed: empirical

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Study #1: SCEC Broadband Platform

Conclusions from Bayless and Abrahamson (2018)

- None of the six finite-fault simulation methods tested adequately capture ρ_ϵ over the entire frequency range evaluated
- Several show promise, especially at low frequencies.
- changes to the rupture generator may be the most promising approach to modifying the long period ρ_ϵ
- Using the correlation of the FAS provides the developers of the simulation methods better feedback in terms of how they can modify their methods that is not clear when using response spectra
- More calibration is required

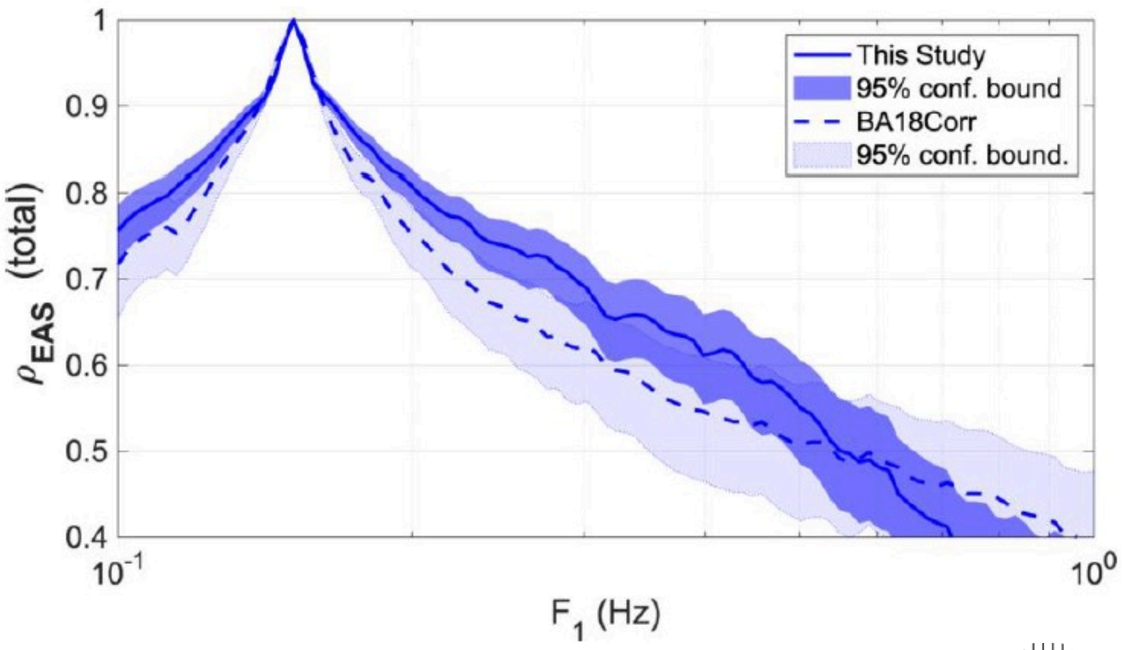
Study #2: SCEC Cybershake

Evaluation Procedure

- The same as for the BBP simulations with the additional advantages:
  - Much wider range of Mw, paths, rupture distances, site conditions, etc - better mimics NGA-W2
  - 3D crustal model

Conclusions

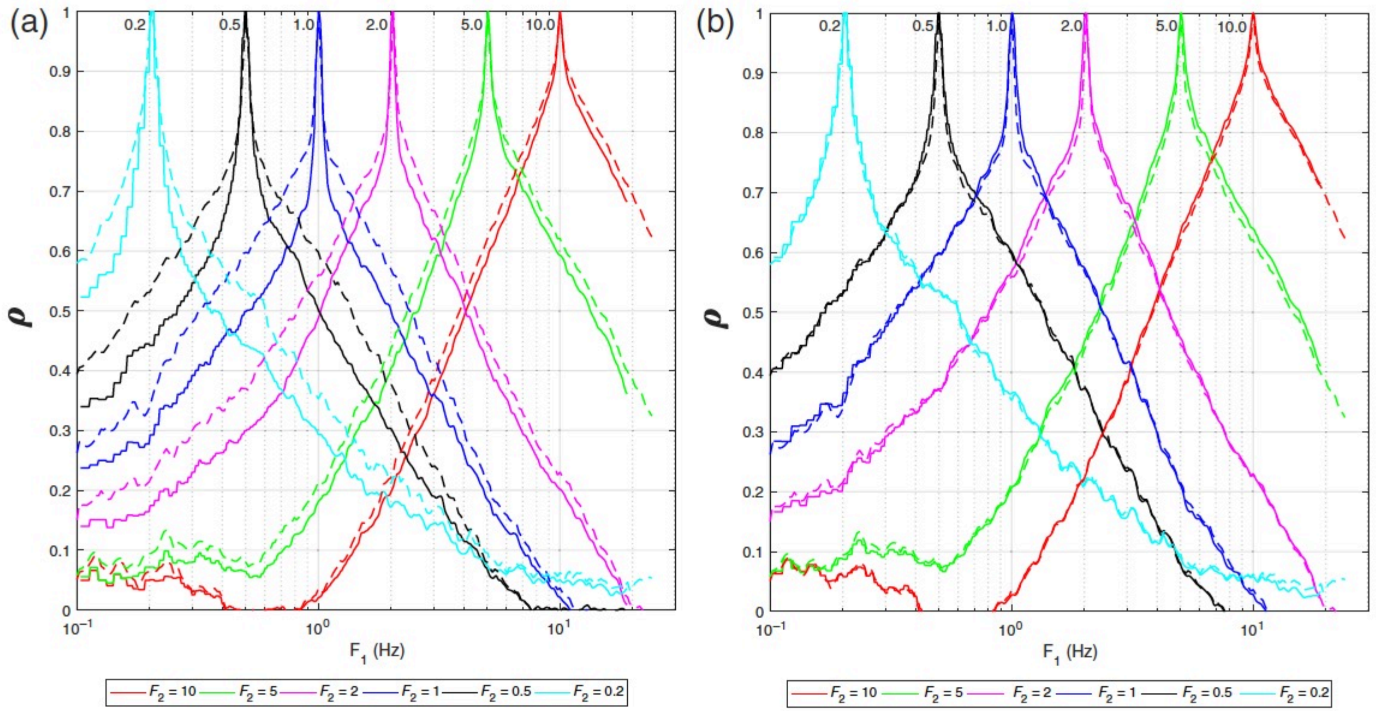
- the 0.1 < f < 0.5 Hz CyberShake 15.4 simulations have a satisfactory level of total inter-frequency correlation
- The between-site component could be improved
  - this may be due to the relative simplicity of the seismic velocity model in the GTL, or to the effects of low frequency basin waves mapped into the site terms



Calibration of simulations for ρ_ϵ

Wang et al (2019): Applied a post-processing method to SDSU simulations

before after



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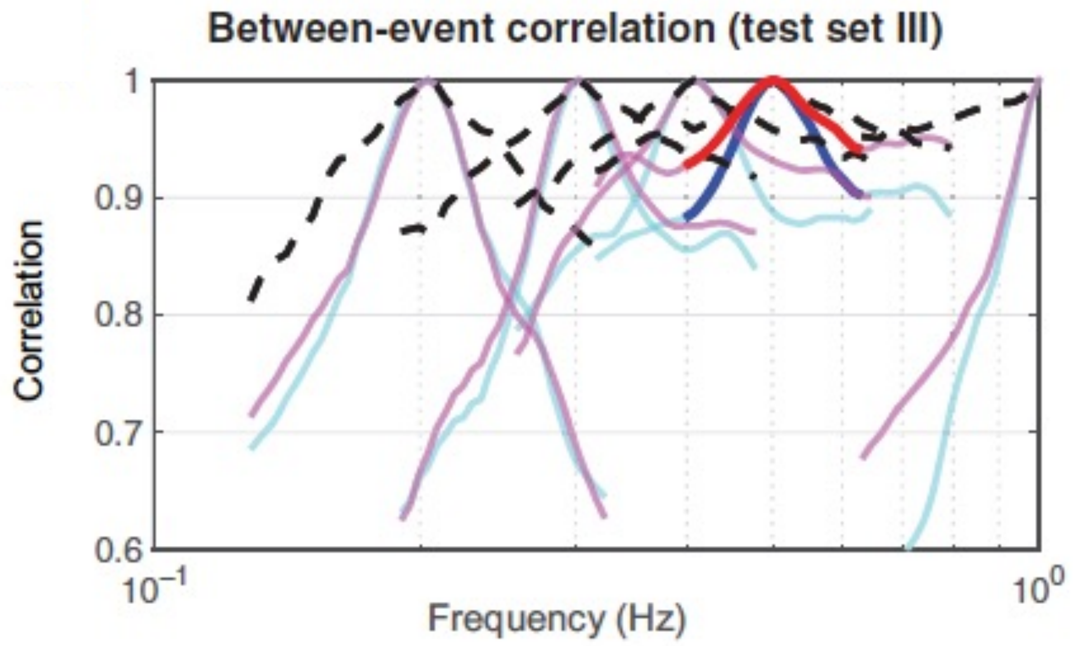
Calibration of simulations for ρ_ϵ

Song et al. (2020): investigate the effect of pseudodynamic source models on the correlation using the SCEC BBP with the Song et al. (2014) source model approach

- The cross-correlation in source parameters (slip, rupture velocity, and peak slip velocity) improves the between-event ground-motion correlation around 0.5 Hz (red and blue)
- Minimal effect at other frequencies



Dashed: empirical
Magenta: correlated source parameters
Cyan: uncorrelated source parameters

Summary

Importance of ρ_ϵ as a validation parameter

- Low FAS ρ_ϵ in simulations under-estimates the variability in structural response.
- This leads to structural fragilities which are too steep (under-estimated dispersion parameter β) and to non-conservative estimates of seismic risk.

Evaluation of Simulations

- SCEC BBP: None of the methods evaluated are adequate for the full frequency range evaluated; some are acceptable at low frequencies.
- SCEC Cybershake: adequate total ρ_ϵ between 0.1-0.5 Hz. Between-site component could be improved

Calibration of Simulations

- Can incorporate the observed ρ_ϵ into simulations by post-processing (e.g. Wang et al, 2019)
- Ongoing; needs more work to get a solution which does not ignore the physical process
  - e.g. correlation of source parameters (Song et al. 2020)
  - Others?

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Thank you

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