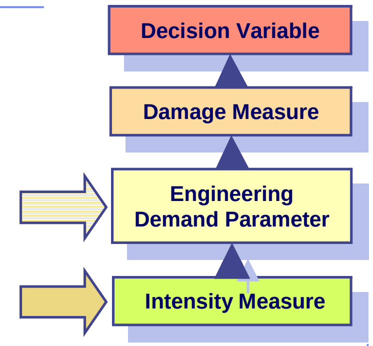
Ground Motion *IM*'s and Record Scaling



Nicolas Luco – U.S. Geological Survey

2006 PEER Annual Meeting

Motivation: PEER PBE Methodology

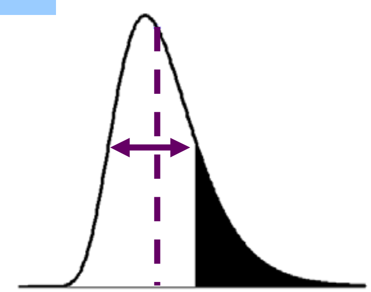
$$v(DV) = \iiint G\langle DV \mid DM \rangle \mid dG\langle DM \mid EDP \rangle \mid dG\langle EDP \mid IM \rangle \mid d\lambda(IM)$$

Impact | **Performance (Loss) Models and Simulation** | **Hazard**

$\lambda(IM)$ is computed via PSHA by seismologists

$G\langle EDP \mid IM \rangle$ is computed via NDA by engineers

$$G\langle EDP \mid IM \rangle = 1 - \Phi\left[\frac{\ln(EDP) - m_{EDP|IM}}{\sigma_{\ln(EDP)|IM}}\right]$$

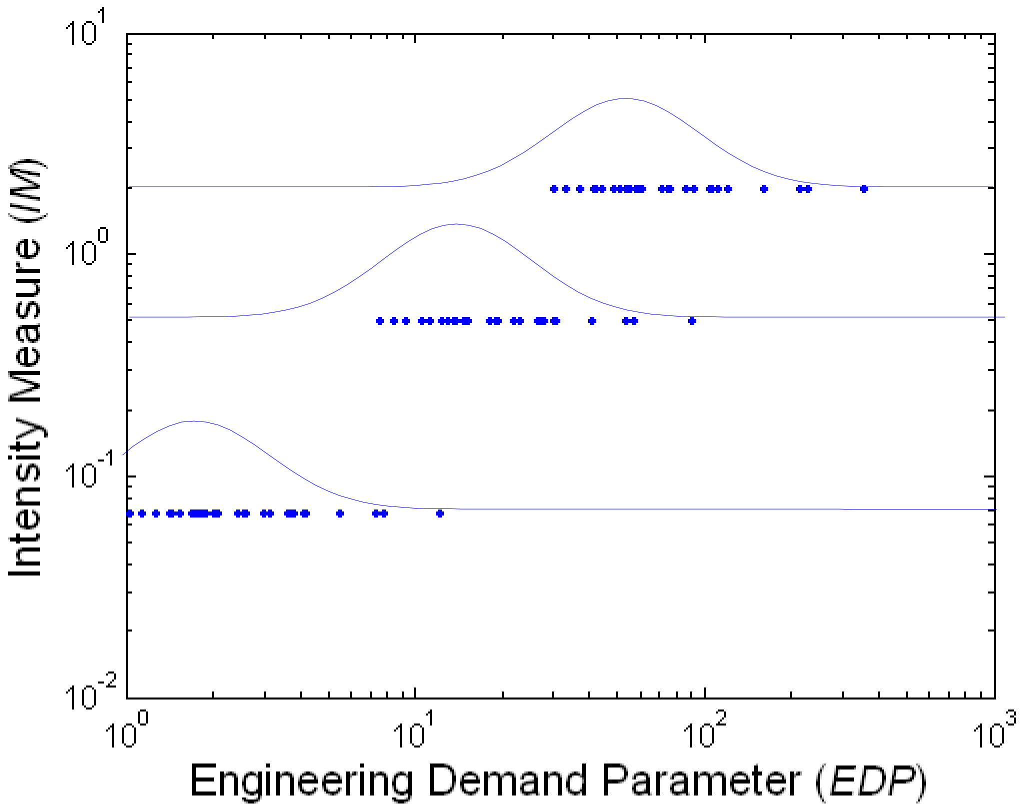


$m_{EDP\,|\,IM}$ = median *EDP* for a given *IM* value

$\sigma_{\ln(EDP)\,|\,IM}$ = variability of *EDP* for a given *IM* value

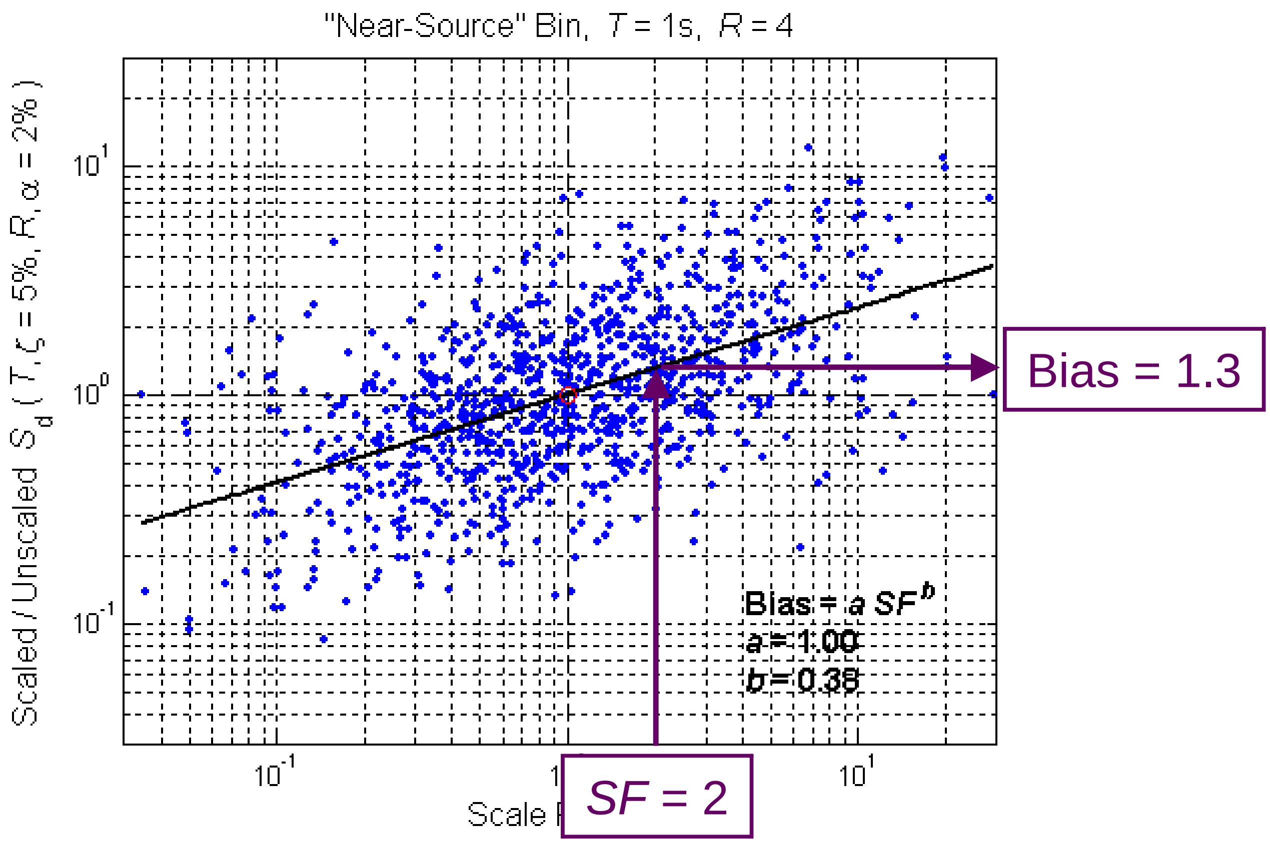
Objective: Establishing $G\langle EDP \mid IM \rangle$

- PEER has employed ground motion scaling (in amplitude) to estimate $m_{EDP|IM}$ & $\sigma_{\ln(EDP)|IM}$

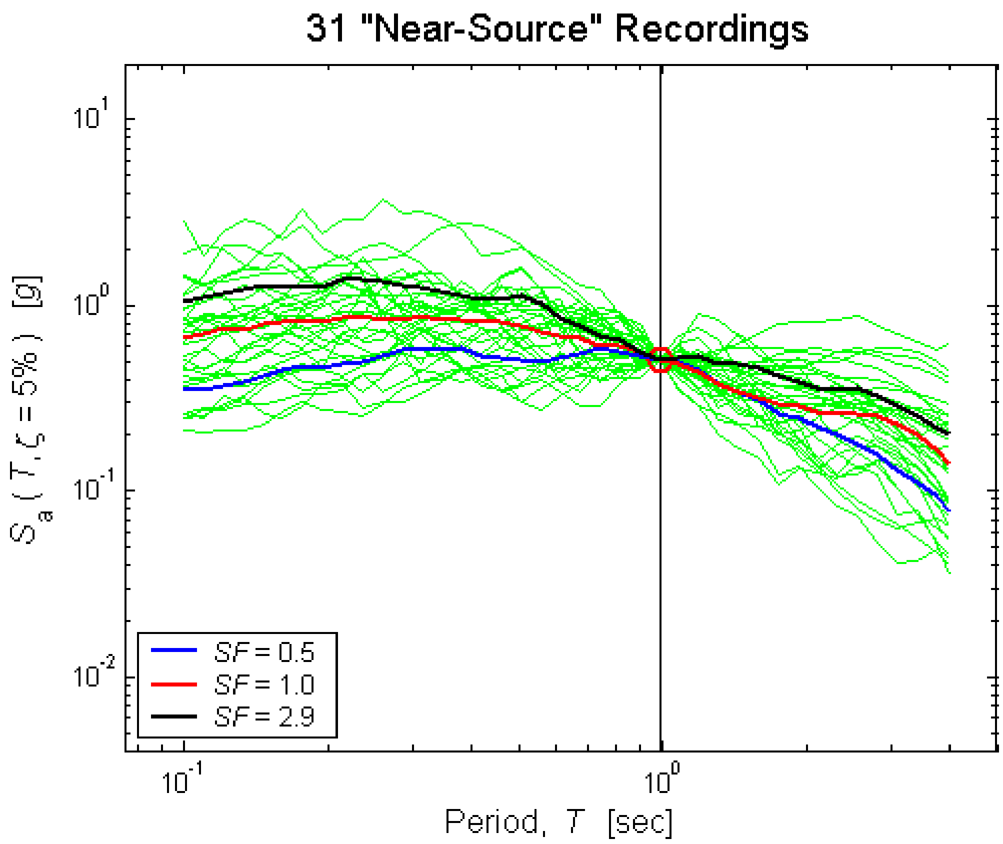


Problem: Scaling can induce bias

- If $IM = S_a(T_1)$, as is typical, scaling can lead to biased estimates of $m_{EDP|IM}$ (not to mention σ)



Reason: Spectral shape is important



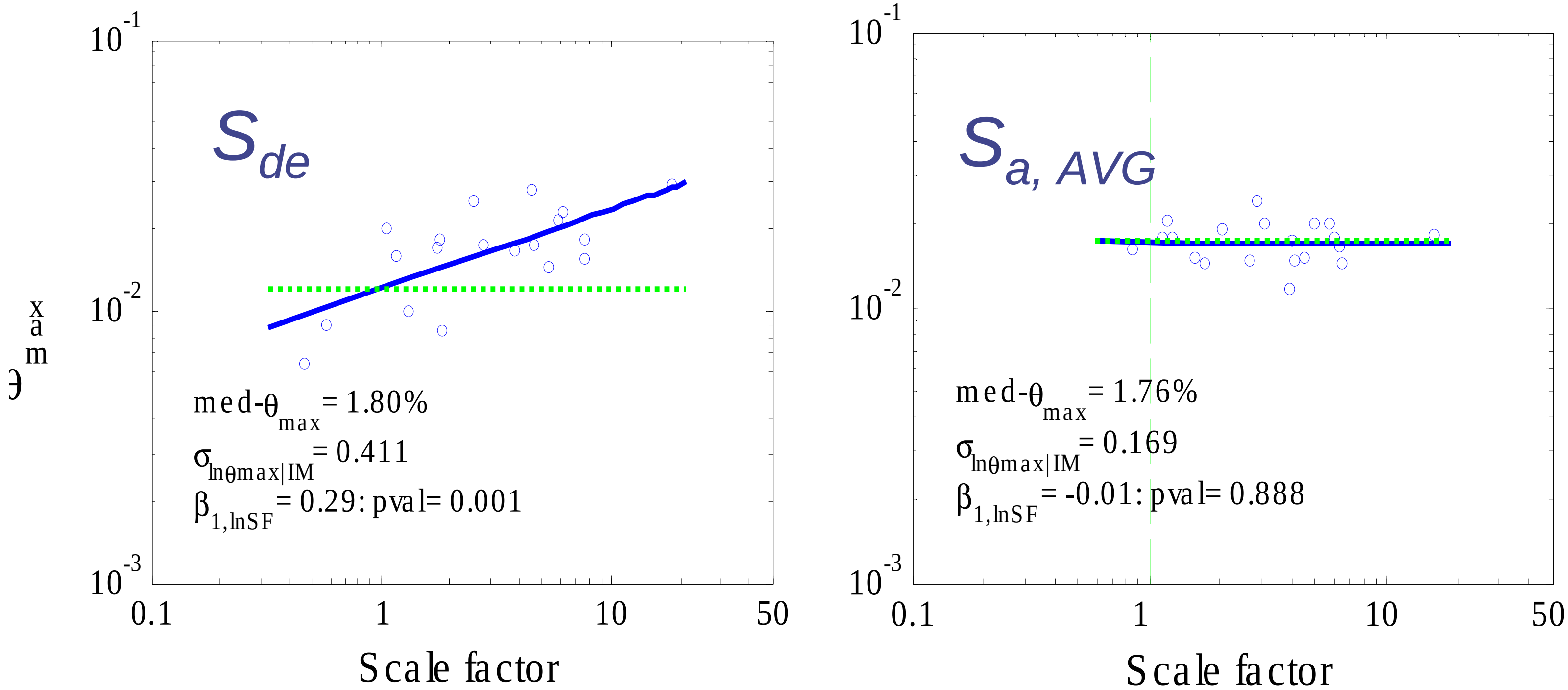
- Scaling to $IM = S_a(T_1)$ alone ignores effect of spectral shape on structural response (*EDP*)

Solution 1: Scaling to Alternative *IM*'s

- Scale to common values of an *IM* that, unlike $S_a(T_1)$, reflects spectral shape, e.g., ...
  - Average Spectral Acceleration over a range of periods (e.g., $0.2T_1$ to $1.5T_1$ from Building Code)
  - Inelastic Spectral Displacement, $S_{di}(T_1, d_y)$
  - Vector composed of $S_a(T_1)$ & Epsilon, ε
  - Other vector and scalar combinations of Spectral Acceleration and Inelastic Spectral Displacement
- Must be able to compute seismic hazard, $\lambda(IM)$, in terms of the alternative *IM*

Solution 1: Scaling to Alternative *IM*'s

- $S_{a,AVG}$ can eliminate scaling-induced bias



- Seismic hazard can be computed using existing attenuation relations & correlations

(Tothong & Cornell, 2006)

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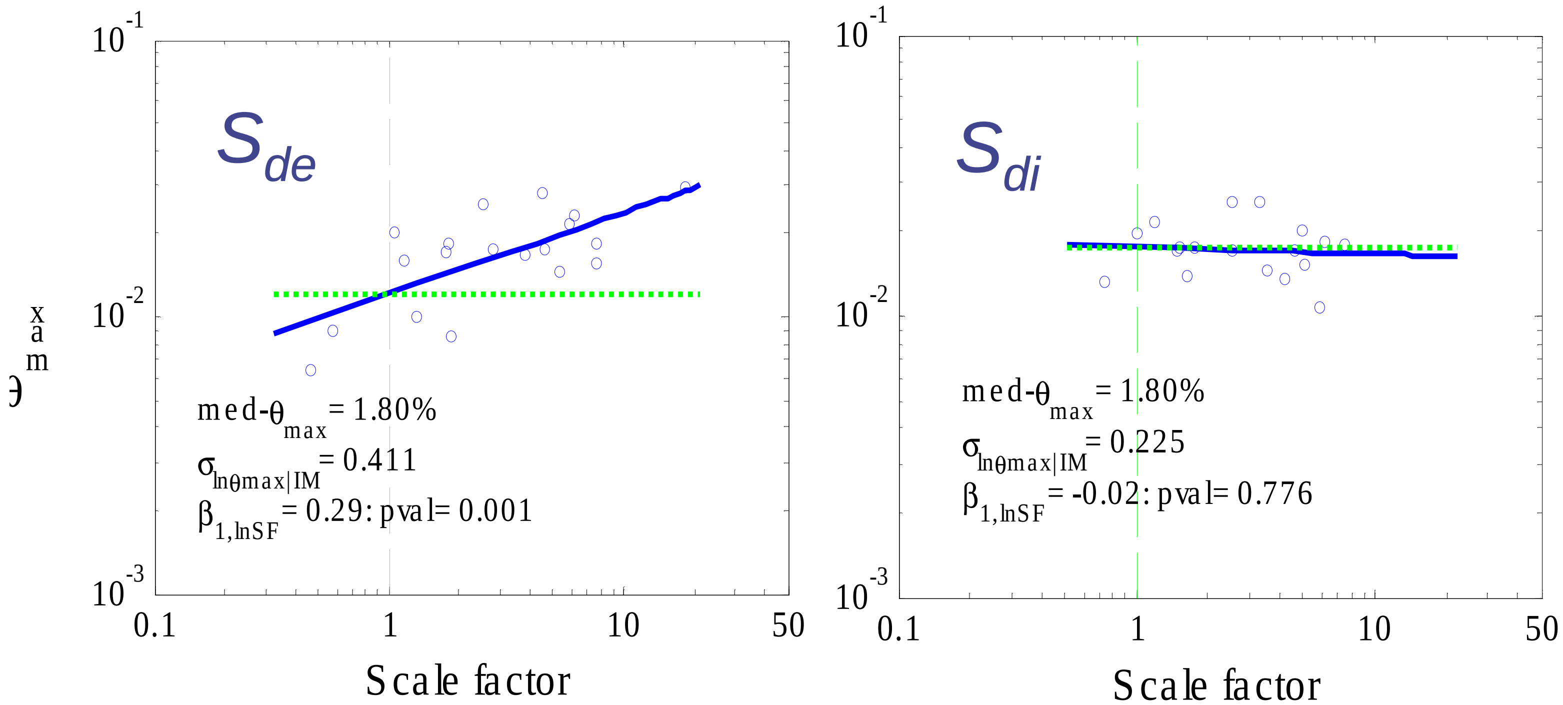
Solution 1: Scaling to Alternative *IM*'s

- $S_{di}(T_1, d_y)$ can eliminate scaling-induced bias

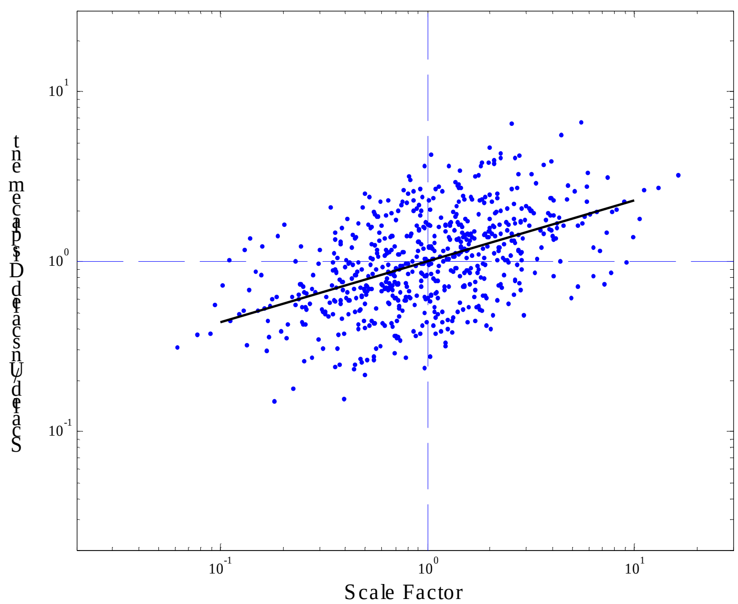


- Attenuation relations for $S_{di}(T_1, d_y)$ are being developed (e.g., by Bozorgnia, Tothong, …)

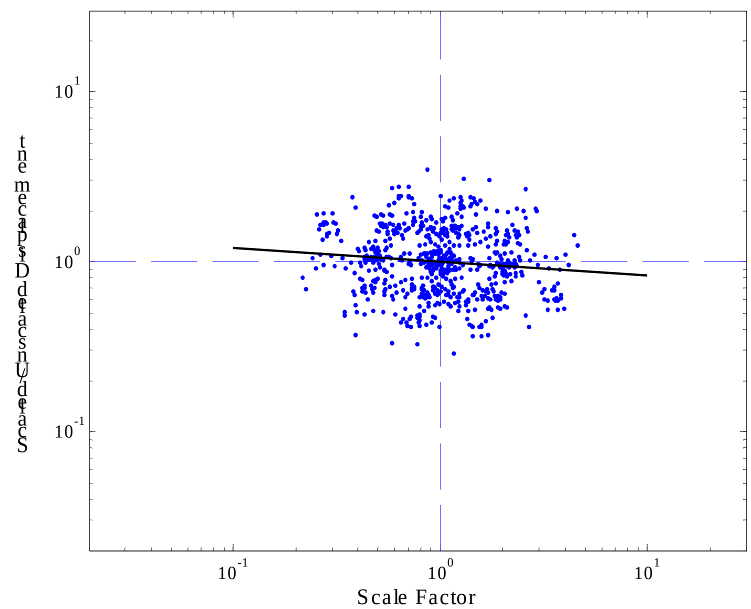
(Tothong & Cornell, 2006)

Solution 1: Scaling to Alternative *IM*'s

- Vector of $S_a(T_1)$ and Epsilon, ε, works too



Magnitude 7+/- Random Set

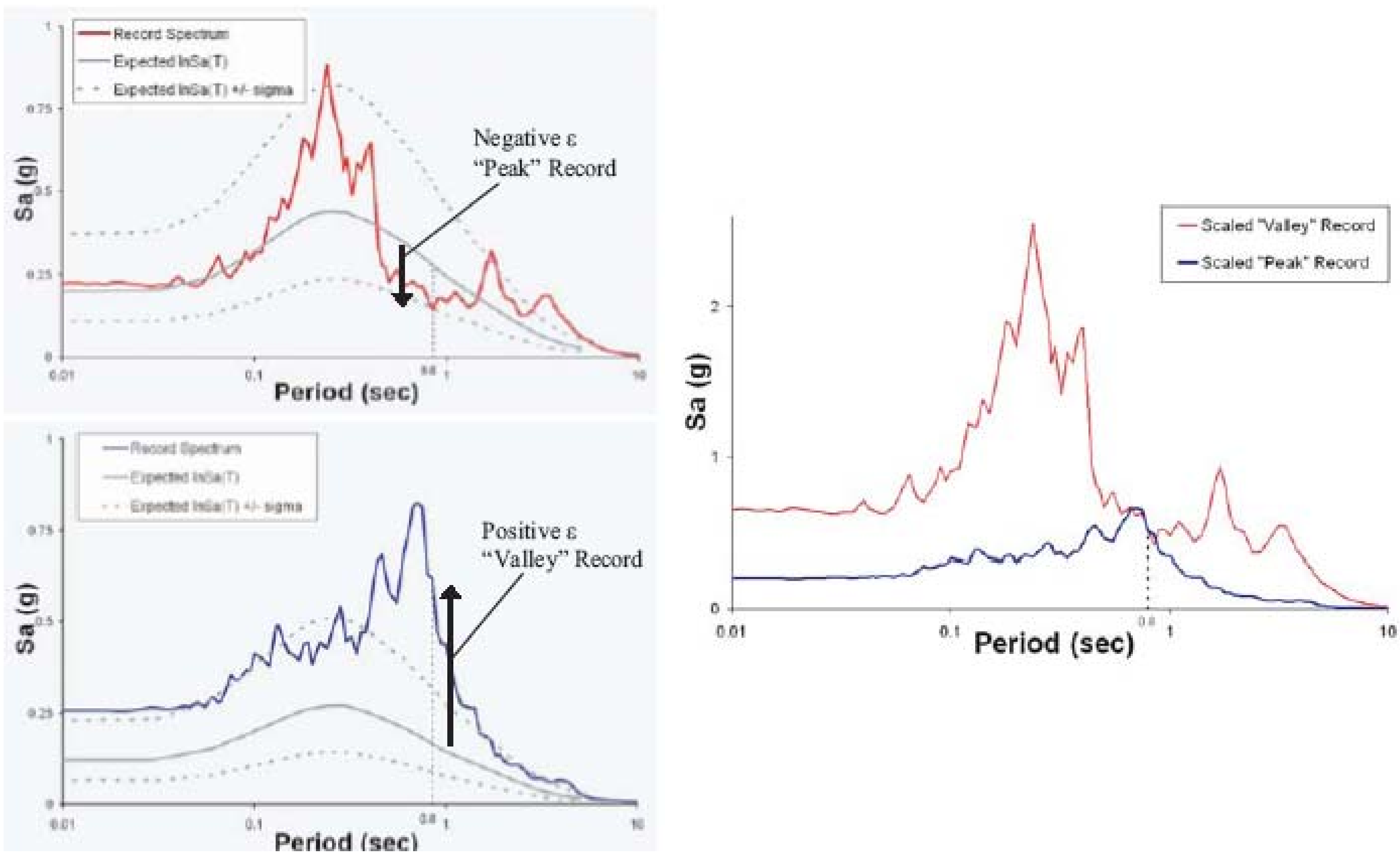


Wide M, R Range Set; Epsilon > 1.5 Only

- Vector Seismic Hazard app. (Bazzurro, 1999)

(Baker & Cornell, 2005)

Aside: Definition of Epsilon, ε



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(Baker & Cornell, 2005)

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Solution 1: Other Benefits

- Fewer ground motions & dynamic analyses, as a result of smaller $\sigma_{\ln(EDP)|IM}$ ("efficiency")

- Example:

IM	$\sigma_{\ln(EDP)\mid IM}$	# Records
S_a	0.4	16
$S_d^{\,I}$	0.35	12
$\vec{S}_a$	0.3	9
$\{\ \vec{S}_a,\ S_d^{\,I}\ \}$	0.2	4

(9-story building, $EDP = \theta_{max}$)

- Insensitivity to the M, R, ε, etc. of selected ground motions ("sufficiency")

(Luco, Manuel, Baldava, & Bazzurro, 2004)

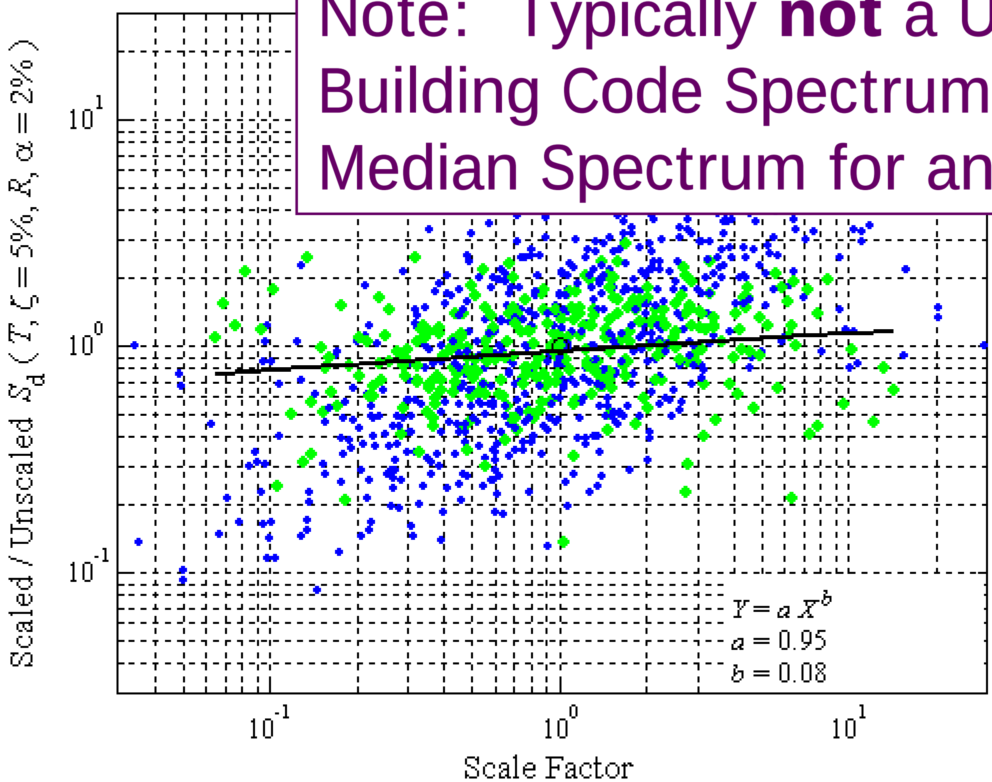
Solution 2: Focus on Median $EDP\,|\,S_a(T_1)$

- Still need $\sigma_{\ln(EDP)|Sa(T1)}$ for PBE, but can settle for generic estimates from researchers
- Focus shifts to efficient ways of obtaining unbiased estimates of $m_{EDP|Sa(T1)}$, e.g., ...
  - Selecting ground motions based on spectral shape (or ε); $S_{di}(T_1, d_y)$; or $S_{a,AVG}$
  - Spectral matching
  - Simulating ground motions
- Same focus as "average response of at least 7 ground motions" in Building Code

Solution 2: Focus on Median $EDP \mid S_a(T_1)$

- Scaling may not induce bias if ground motions are of "appropriate" spectral shape

Note: Typically **not** a UHRS, Building Code Spectrum, or Median Spectrum for an *M* & *R* !



(Luco & Bazzurro, 2005)

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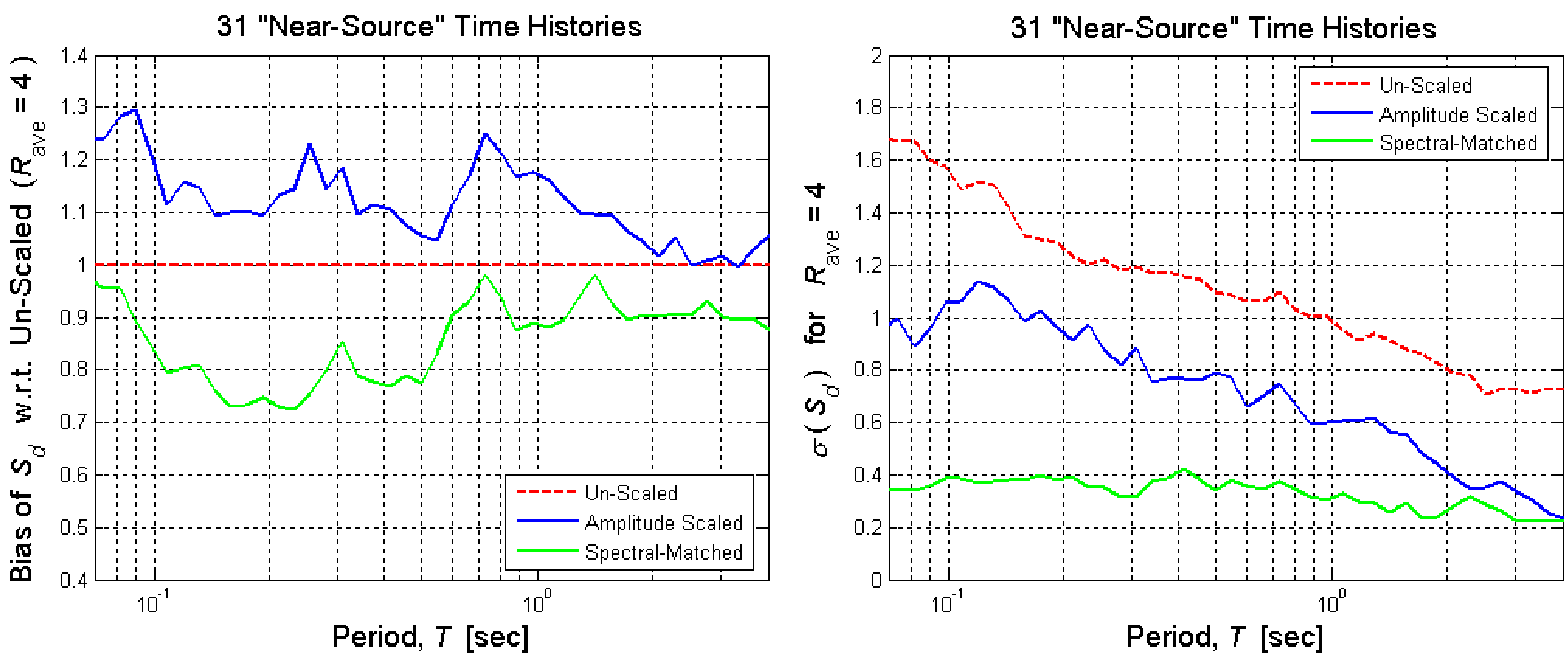
Solution 2: Focus on Median $EDP \mid S_a(T_1)$

- Spectral matching *has been observed* to result in biased low estimates of $m_{EDP|Sa(T1)}$



- But can significantly reduce the # of ground motions needed relative to $S_a(T_1)$ scaling

(Bazzurro & Luco, 2003)

Summary

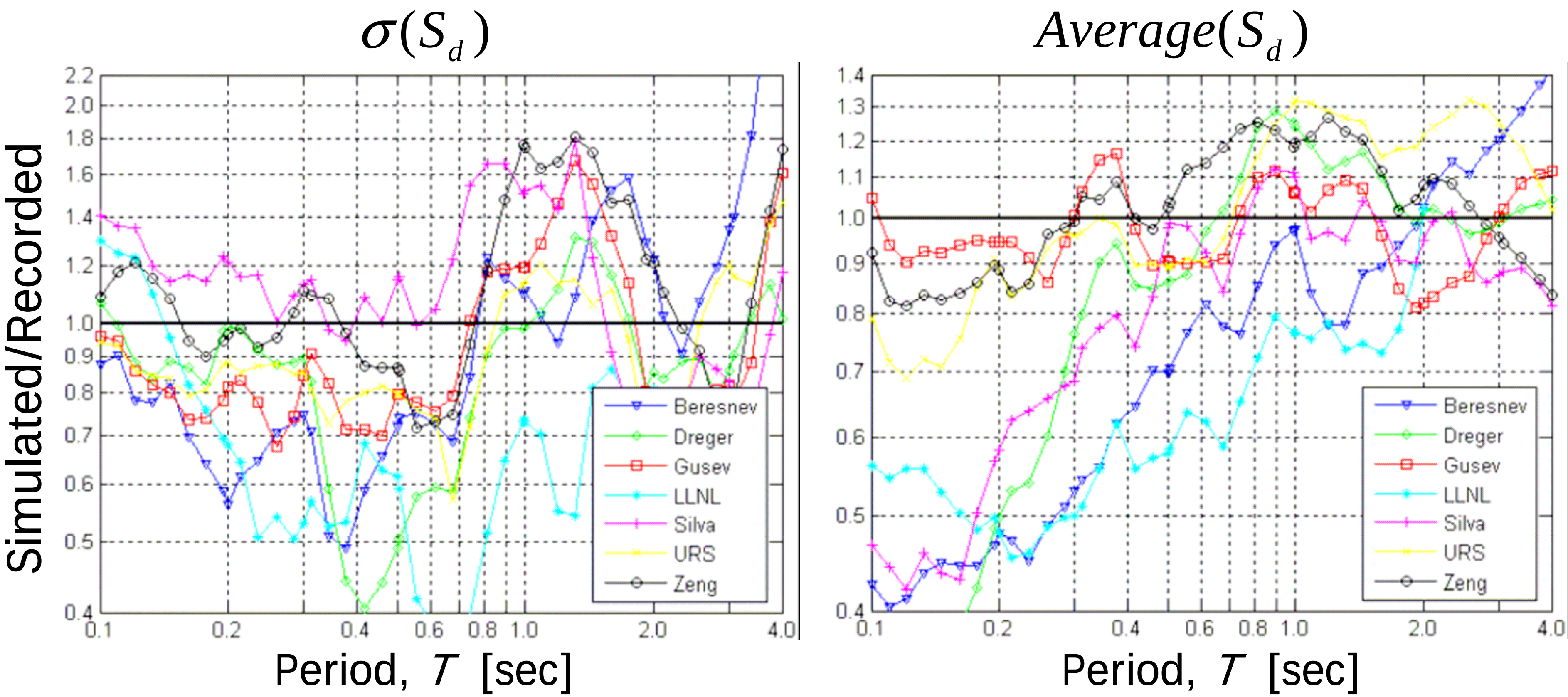
- PEER has explored alternatives to $IM = S_a(T_1)$ in PBE that can ...
  - reduce the number of ground motions needed to accurately estimate median $EDP\,|\,IM$
  - aid in selecting ground motions that lead to unbiased estimates of $m_{EDP|IM}$, even with scaling

  e.g., $S_{a,AVG}$; $S_{di}(T_1, d_y)$; and $\{S_a(T_1), \varepsilon\}$, etc.

- PEER has also investigated other efficient ways of obtaining estimates of $m_{EDP|Sa(T1)}$, including spectral matching and simulation

Extra Slides ...

Simulated vs. Recorded Inelastic Response



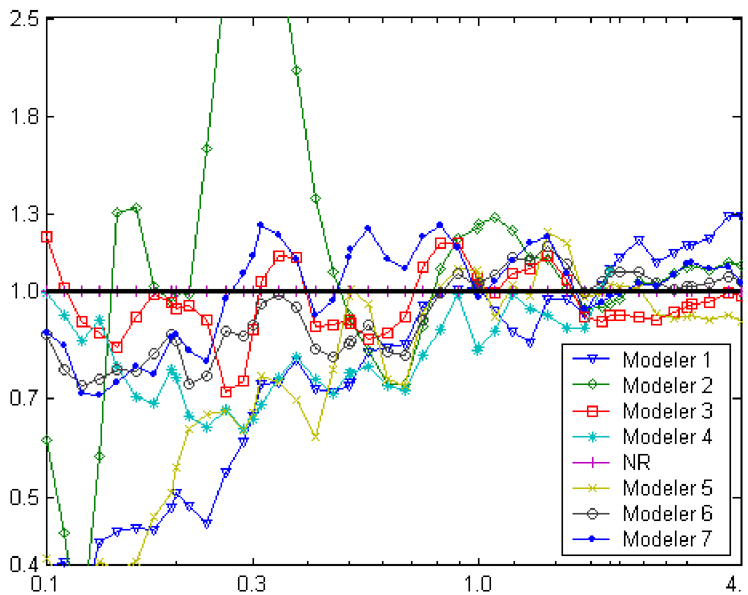
- ➢ Variability of inelastic response to simulated time histories can be smaller, but it can also be larger – i.e., you can't count on it (yet).
- ➢ More importantly, inelastic response to simulated time histories can be biased w.r.t. un-scaled time histories – need validation.

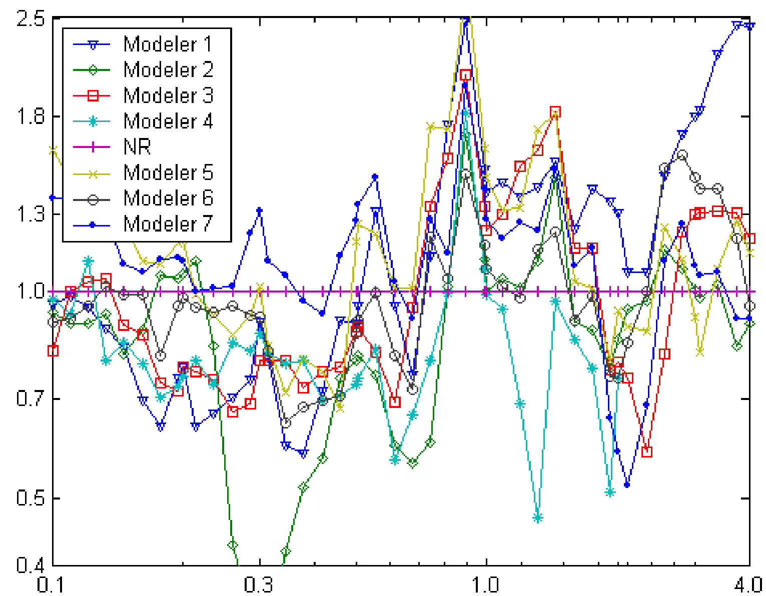
May Simulated Records be used?

- PEER is investigating how $EDP \mid IM = S_a$ from simulated records compares with that from recorded ground motions
- Example: (SDOF oscillators, $EPD = \delta$)

$m_{EDP|IM}$ $\sigma_{\ln(EDP)|IM}$

Simulated/Recorded





Period Period

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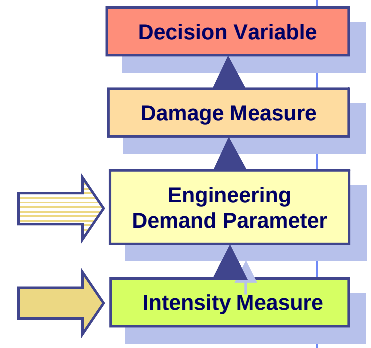
Summary of PEER Achievements



- New *IM* 's and attenuation relations, and vector-valued hazard analysis
- Criteria for selecting among alternative *IM* 's, considering *EDP*|*IM* (efficiency, sufficiency)
- Evaluation of alternative *IM* 's via case-studies (e.g., PEER Testbeds)
- Guidance for selecting and scaling (or spectrum-matching) ground motion records
- Comparison of *EDP*|*IM* for simulated vs. recorded ground motions, and improvements in simulations techniques