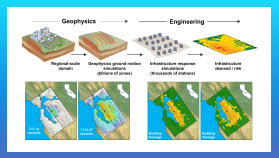

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A Phased Strategy for Transition to Using Synthetic Ground Motions in Seismic Hazard Practice

N. Abrahamson
University of California, Berkeley

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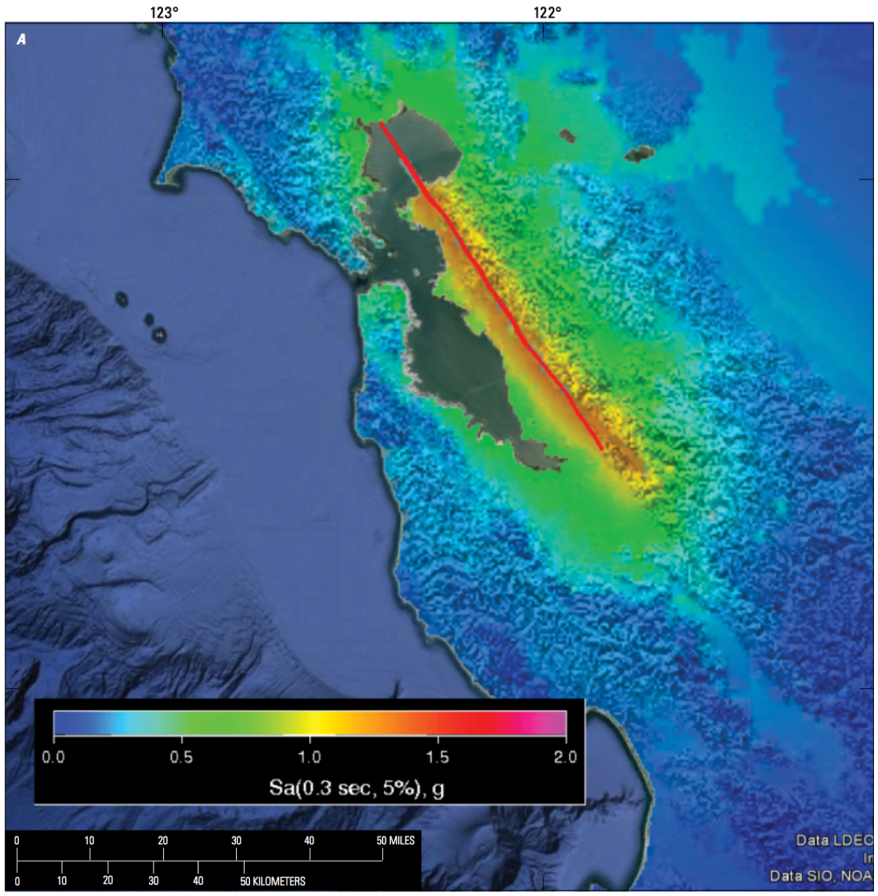
PEER

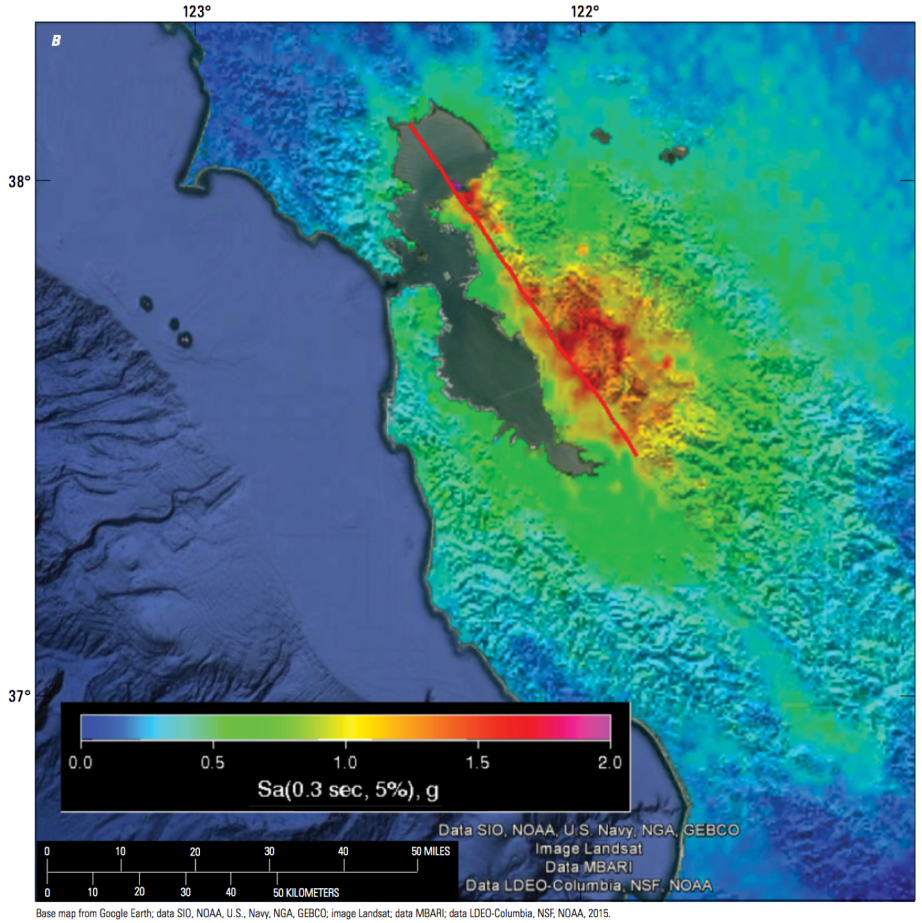
Example – Hayward Scenario T=3 sec
(2018 Haywired Project)

GMPE



Base map from Google Earth; image Landsat/Copernicus; data LDEO-Columbia, NSF, NOAA; data SIO, NOAA, U.S., Navy, NGA, GEBCO, 2015.

3-D Simulatino



Base map from Google Earth; data SIO, NOAA, U.S., Navy, NGA, GEBCO; image Landsat; data MBARI; data LDEO-Columbia, NSF, NOAA, 2015.

Use of 3-D simulation for Seismic Hazard

- A small number of realistic 3-D simulations is not enough for use in hazard analyses
- Ground motions from 3-D simulations should be mean centered with uncertainty
  - Median and epistemic uncertainty in the median
  - Aleatory variability and epistemic uncertainty in the size of the aleatory term

Current Practice for Ground Motions using GMMs

- Median (Centered)
  - Weighted average of the medians from the alternative GMMs
- Aleatory Variability
  - Variability of PSA at a single site and a single period from observations
  - Empirical correlation models
    - Spatial correlation of variability (between sites)
    - Period-to-period correlation of variability at a site
- Epistemic Uncertainty
  - Use alternative GMMs to capture the epistemic range
  - May separate epistemic uncertainty in the median from the epistemic uncertainty in the aleatory variability

Why Not Just Use 3-D Simulations Directly?

- 3-D simulations provide PSA(T) over entire region
  - Is this ready to replace GMMs?
- Issues
  - Need adequate validation of 3-D simulations
    - Current SCEC validations limited to median from 1-D simulations
    - Require quantitative validation of 3-D simulations for both median and variability
  - For hazard, need to separate systematic path effects from variability of source effects for a given source/site pair
    - What is the median and what is the aleatory variability?
    - Requires enough realizations of the source to average out the source variability
  - Need to capture epistemic uncertainty in the base source scaling
    - Requires alternative rupture model generators
    - Comparison of medians from different 3-D simulation methods
  - Shallow 3-D velocity model may be truncated at a minimum VS
    - Correct for the truncated part of the VS profile

Initial Step

- Demonstrate that the 3-D simulations perform no worse than the empirical models in the validation with ground-motion data from past earthquakes
  - Having physics-based simulations is not enough.
  - Need comparison with observations to demonstrate that it works as well as empirical models
- Comparisons with GMMs
  - Ergodic GMMs
  - Non-Ergodic GMMs
    - Uses small magnitude data to constrain linear path and site effects for specific source/site pairs

Phased Implementation

	Median	Epistemic Uncertainty in Median	Aleatory Variability	Epistemic uncertainty in Aleatory
Phase 1	Empirical & Sim Adjust Median: 3-D/1-D ratios + ergodic GMM - Path only from Sim	Empirical: Range from Ergodic GMM	Empirical Non-ergodic GMMs: $\sqrt{\tau^2 + \phi_0^2}$	Empirical: Epistemic uncertainty from non-ergodic GMM
Phase 2	Simulation: Use 3-D simulation from a few scenarios for the median - Path and source	Simulation: Use epistemic uncertainty from 3-D sim	Empirical Non-ergodic GMMs: $\sqrt{\tau^2 + \phi_0^2}$	Empirical: Epistemic uncertainty from non-ergodic GMM
Phase 3	Simulation: Use 3-D simulations for a large number of scenarios for the median	Simulation: Use epistemic uncertainty from 3-D sim	Simulation: $\sigma = \sqrt{\sigma_{mod}^2 + \sigma_{par}^2}$	Simulation: $\sigma_\sigma = \sqrt{\sigma_{\mu\_mod}^2 + \sigma_{\mu\_par}^2}$

Phase 1: Use of 3-D Simulations for Median Path Terms

- Use simulations to adjust median from an ergodic GMM for 3-D path effects
  - Isolate path effects
    - Remove differences between the source used in the simulation and the source scaling in the GMM
  - Account for truncation of the low V_S values in the 3-D velocity model used in the simulations
- Use empirical models for the aleatory variability

Phase 1 – Approach 1a

$$Median = GMM_{erg}(M, R, S)$$

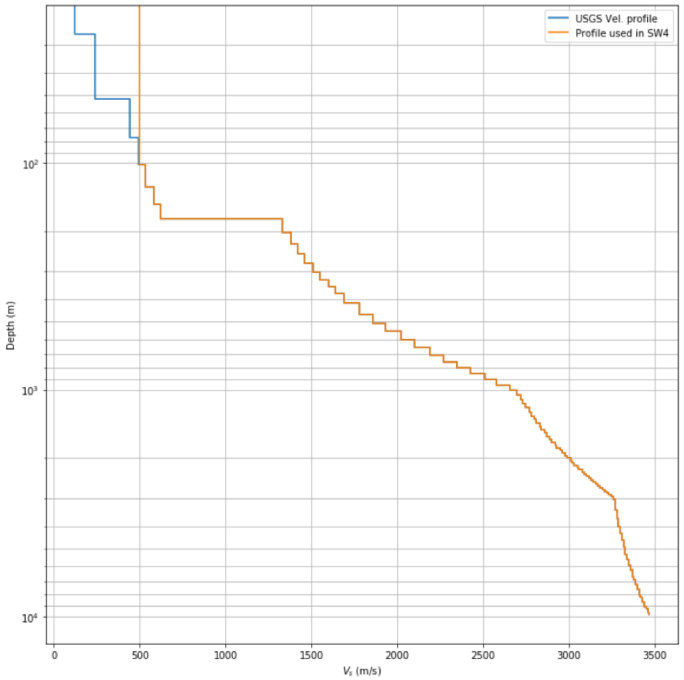
$$+ \frac{SIM_{3D}(Vs\ truncated)}{GMM_{erg}(VS30\ not\ truncated)}$$

$$+ \frac{SA\_surface(Vs\ not\ truncated)}{SA\_surface(Vs\ truncated)}$$

Accounts for Vs truncation

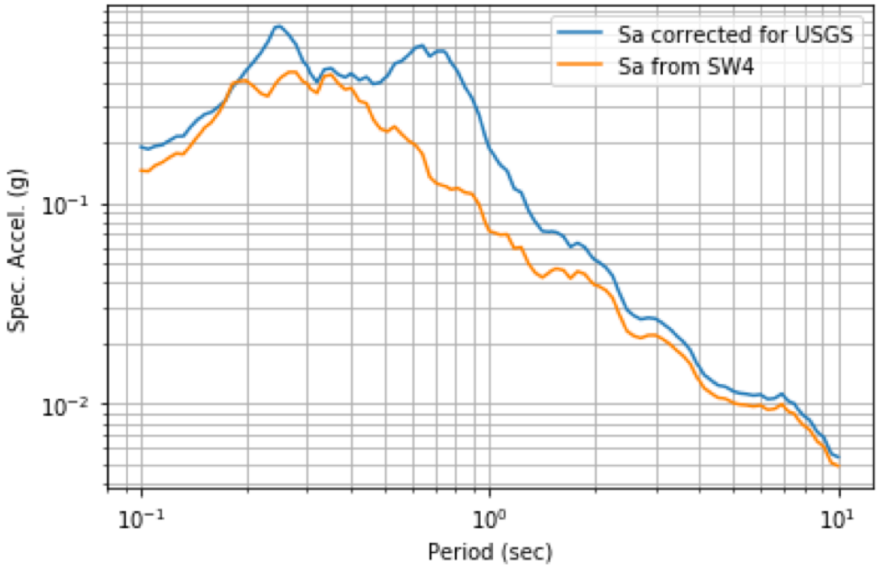
- Does not account for differences in the source between the simulations and GMM
  - Maps source differences into path effects
  - Can remove a constant shift
- Note: GMM uses the VS30 from the untruncated profile because VS30 scaling in the GMM is based on the empirical correlation between VS30 and the deeper VS profile in natural deposits.
  - The empirical correlation between VS30 and Vs(z) in the GMM does not apply to truncated profiles

Correction for Truncation of Shallow V_S profile



Shear wave vel profile, site in Berkeley

Site Correction = $\frac{SA\_surface(Vs\ not\ truncated)}{SA\_surface(Vs\ truncated)}$



(From Lavrentiadis)

Phase 1 – Approach 1b

$$Median = GMM_{erg}(M, R, S)$$

$$+ \frac{SIM_{3D}(Vs\ truncated)}{SIM_{1D}(Vs\_ref)}$$

$$+ \frac{AF_{1D}(Vs\_ref)}{AF_{GMM}(Vs30)}$$

$$+ f_{\Delta path\ 1D,erg}(R_{RUP})$$

$$+ \frac{SA\_surface(Vs\ not\ truncated)}{SA\_surface(Vs\ truncated)}$$

Accounts for differences in the 1-D VS profiles for the 1-D simulation and the GMM

Accounts for differences between GMM distance scaling and 1-D simulation distance scaling

Accounts for Vs truncation

- Removes differences in the source between the simulations and GMM
  - Normalizing by the 1-D simulation based on the same source

Phase 2 Use of 3-D Simulations for Median Source & Path Terms

- Use 3-D simulations for medians for specific key scenarios
  - Following completion of validation of median for the 3-D simulations
  - Includes both source and path effects from the simulations
  - Will need to extrapolate to other scenarios (range of Mag)
    - Use the scaling in the GMM to guide the extrapolation
- Use empirical models for aleatory variability

Phase 2

$$Median = SIM_{3D}(Vs\ truncated)$$

$$+ \frac{SA\_surface(Vs\ not\ truncated)}{SA\_surface(Vs\ truncated)}$$

Accounts for Vs truncation

$$+ f_{GMM\_erg}\ (M)$$

Extrapolation of limited set of simulations to other magnitudes

Phase 3: Use of 3-D Simulations Directly

- Use 3-D simulations for medians for specific key scenarios
  - Will need to extrapolate results from limited scenarios to other scenarios (range of Mag)
    - Use the scaling in the GMM to guide the extrapolation
- Use 3-D simulation results for the aleatory variability
  - Following completion of validation of aleatory variability for the 3-D simulations

Phase 3

$$Median = SIM_{3D}(Vs\ truncated)$$

$$+ \frac{SA\_surface(Vs\ not\ truncated)}{SA\_surface(Vs\ truncated)}$$ Accounts for Vs truncation

Phase 3a:
- Sigma = average aleatory variability from 3-D simulations over all sites

Phase 3b:
- Sigma = site-specific aleatory variability from 3-D simulations

- Assumes simulations for a range of scenarios to capture the magnitude scaling

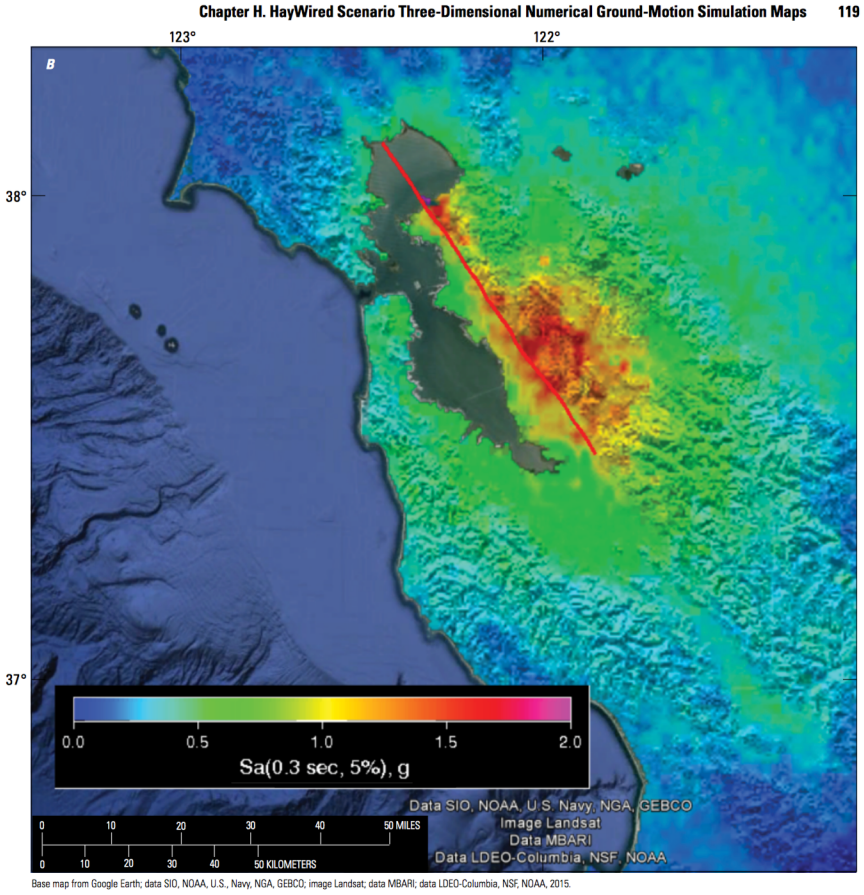
Summary of Phased Approach

	Median	Epistemic Uncertainty in Median	Aleatory Variability	Epistemic uncertainty in Aleatory
Phase 1	Simulations for Path only	Empirical (ergodic)	Empirical (non-ergodic)	Empirical (non-ergodic)
Phase 2	Simulations for path and source for limited scenarios	Empirical (ergodic)	Empirical (non-ergodic)	Empirical (non-ergodic)
Phase 3	Simulations for path and source for large number of scenarios	Simulations:	Simulations:	Simulations:

Steps for the Phased Implementation

	Prior to Implementation	Simulations needed
Phase 1	Initial validation of 3-D simulations for median path effects (allows for constant scale factor from data)	1-D and 3-D simulations for a limited set of scenarios
Phase 2	Complete validation of 3-D simulations for median (source and path)	1-D and 3-D simulations for a limited set of scenarios
Phase 3a	Complete validation of the aleatory variability for the region	Larger number of simulations - more scenarios
Phase 3b	Complete validation of the aleatory variability for the individual sites - do the 3-D simulations capture site-specific variability?	Larger number of simulations - More realizations for sigma at each site

How Many Realizations per Scenario?



Spectral Period (sec)	GMM Sigma after Removing Systematic Site and Path (ln units)	N for 10% uncertainty in mean
PGA	0.39	15
0.1	0.41	17
0.3	0.42	18
0.5	0.46	21
1.0	0.50	25
3.0	0.54	29

Conclusions

- Phase 1 is can be implemented soon
  - Need initial validation to demonstrate that this is an improvement
- Phase 2 requires additional validation and more scenarios
- Phase 3 requires a much larger number of scenarios and realizations
  - More efficient methods or faster computers