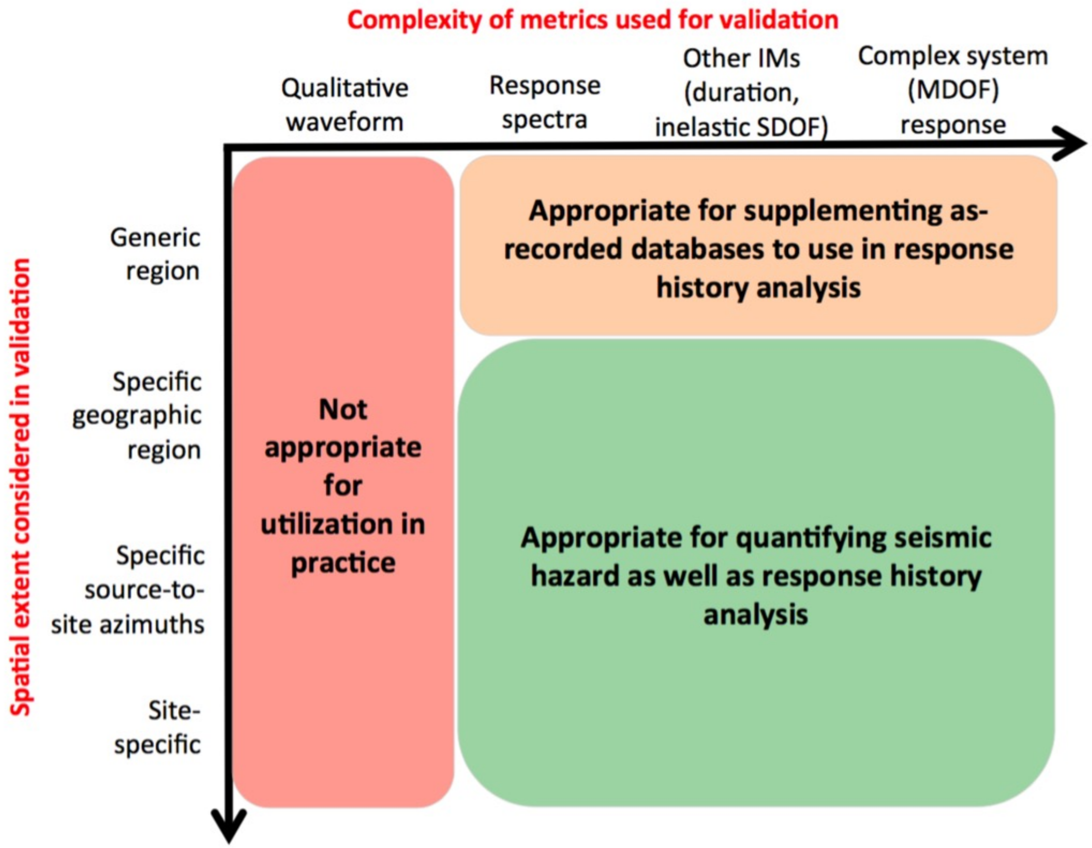
The link between ground motion intended use and necessary validation/acceptance criteria



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Previous sentiments from me about simulation validation in New Zealand in 2021 PEER pacific forum talk:

http://tiny.cc/BradleyValidation2021talk

Motivating statement

Potential user: “Are the simulations a valid representation of reality for me to use?”

Responder: “It depends ….”

Outline

1. Framing: seismic risk using simulated ground motions
2. General simulation use cases
3. Validation and acceptance criteria
4. Considerations for simulated ground motion databases
5. Concluding remarks

1. Framing: seismic risk using simulated ground motions

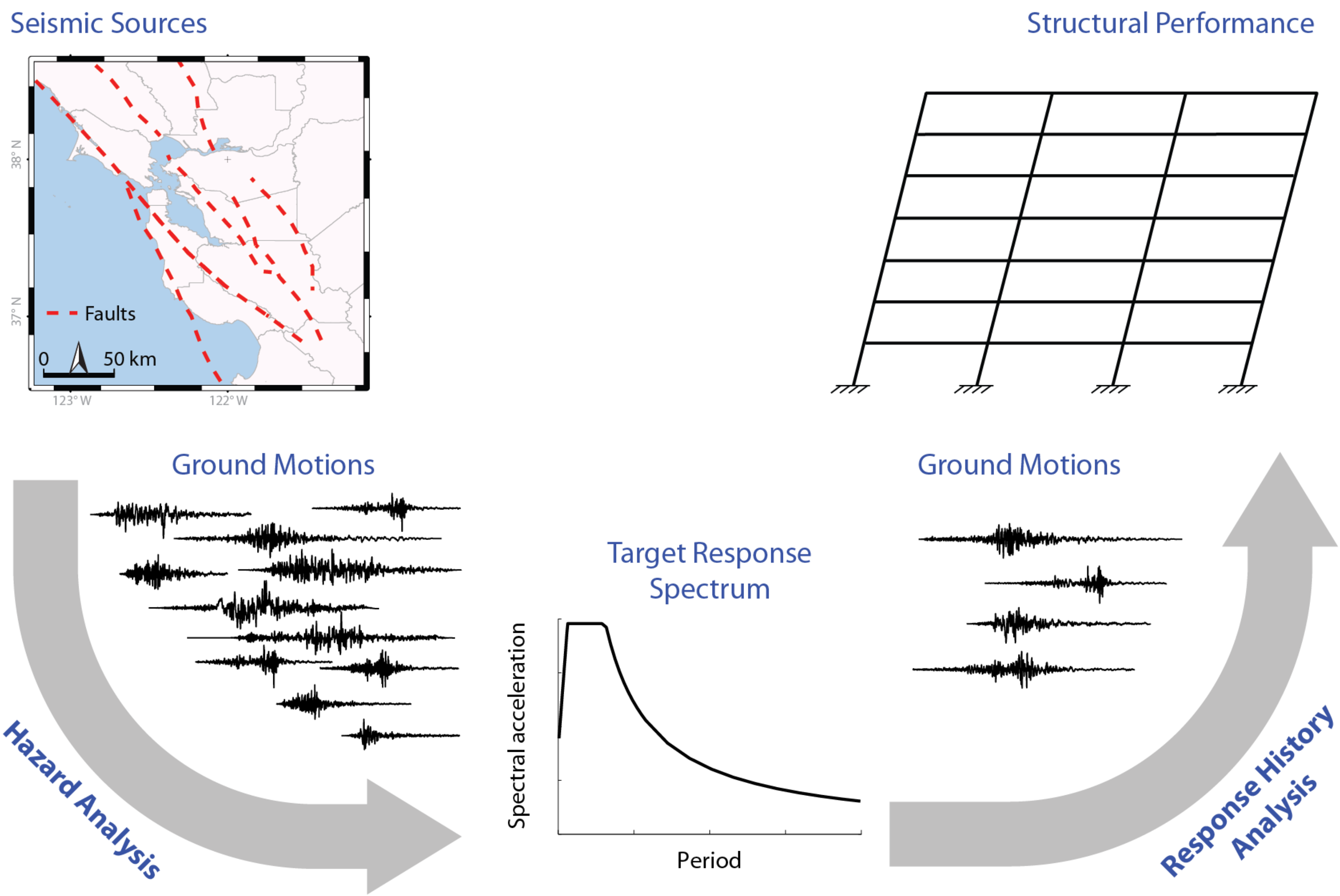
Seismic risk calculation

$$\lambda(\widetilde{EDP}) = \sum_{Rup} \int_{\widetilde{IM}} G(\widetilde{EDP}|\widetilde{IM})\, f(\widetilde{IM}|Rup)\lambda_{Rup}$$

- $\widetilde{EDP}$: Vector of EDPs reflects multiple demands in a single structure and/or multiple structures at different locations
- $\widetilde{IM}$: Vector of IMs reflects multiple attributes of the GM at a site and/or multiple site locations
- Summation over all potential ruptures that pose a hazard to the region; and integration over resulting ground motion intensity
- *lambda* = rate of exceedance; *f* is distribution PDF, *G* is exceedance probability
- Here I use EDP as a measure to refer to ‘risk’, but could also be damage metric (DM) or loss measures (‘decision variables’, DV) in PEER framework notation.

2. General simulation use cases

Simulation use cases



(Bradley et al. 2017)

GM simulations for response history analysis

In the context of the seismic risk estimation

$$\lambda(\widetilde{EDP}) = \sum_{Rup} \int_{\widetilde{IM}} \underline{G(\widetilde{EDP}|\widetilde{IM})}\, \underline{f(\widetilde{IM}|Rup)\lambda_{Rup}}$$

Determine this relationship (e.g., building response) using simulation ground motions

From PSHA using empirical GMMs

Variations:

- Conventional code-based GM selection: $\widetilde{IM}$ is simply response spectral ordinates
- General GM selection for PBEE: $\widetilde{IM}$ would consider all relevant GM properties (e.g., SA, Ds595, AI, CAV, etc.)

GMs for seismic hazard analysis

In the context of seismic risk estimation

$$\lambda(\widetilde{EDP}) = \sum_{Rup} \int_{\widetilde{IM}} G(\widetilde{EDP}|\widetilde{IM})\, \underline{f(\widetilde{IM}|Rup)}\, \lambda_{Rup}$$

Simulations used to estimate the GM distribution (either direct use, or indirectly via constraining empirical model functional forms)

Why simulation use case matters?

It will influence:

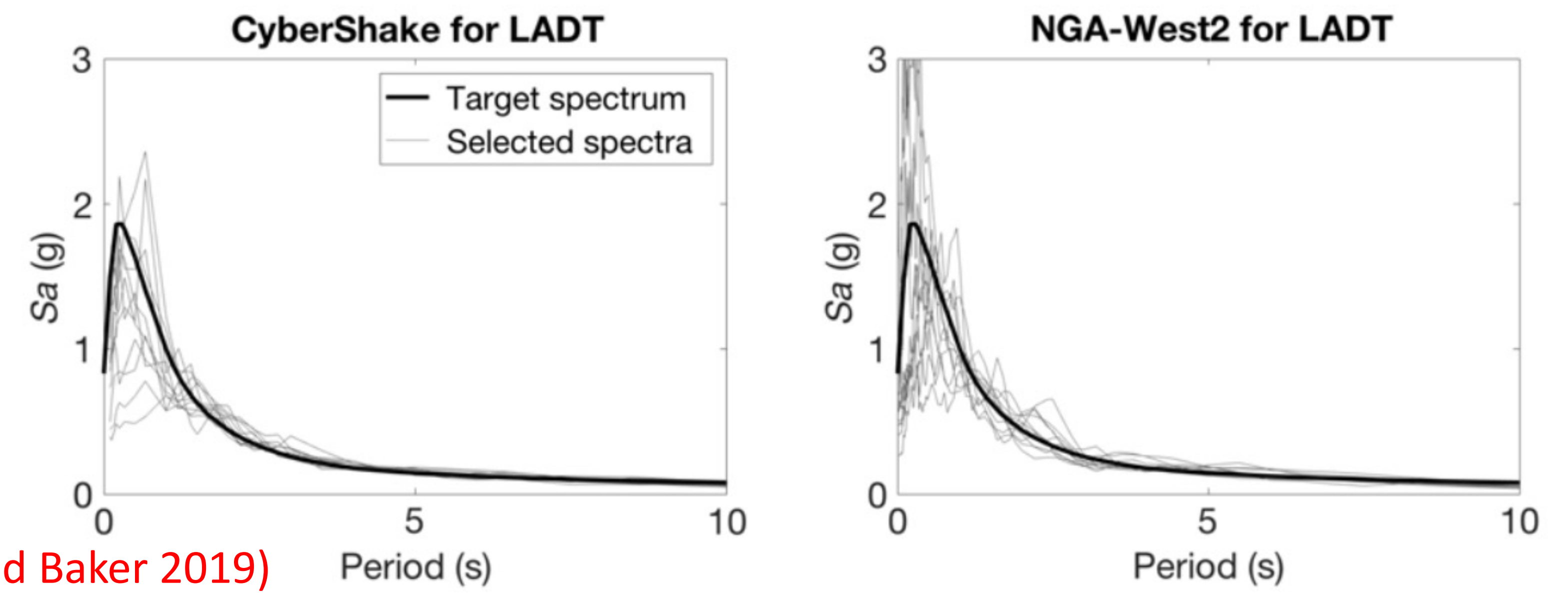
1. ***Input physics vs. output GMs:*** If the underlying simulation physics matters, or just the nature of the resulting waveforms (in terms of their IMs)
2. ***Uncertainty*****:** Whether the simulations consider model and parameter uncertainty
3. ***Site/region-specific*****:** Whether the simulations represent the specific geographic site/region of the structure to be used for
4. ***Complexity of structural model*****:** What ground motion features the numerical models of the structures considered are sensitive to.

Let’s explore these four aspects further

1. Input physics vs. output GMs

Q: Does the underlying physics in the simulation that gives rise to the resulting ground motion matter, or just the resulting motion itself?

- Example: code-based ground-motion selection
  - We are given the target spectrum, and simply want to find time series.
  - We predominantly care about the properties of the resulting GM (reflected via IMs) and less (if anything) about the physics underlying
  - Not sensitive to errors in f(IM|Rup), as amplitude is already set



(Teng and Baker 2019)

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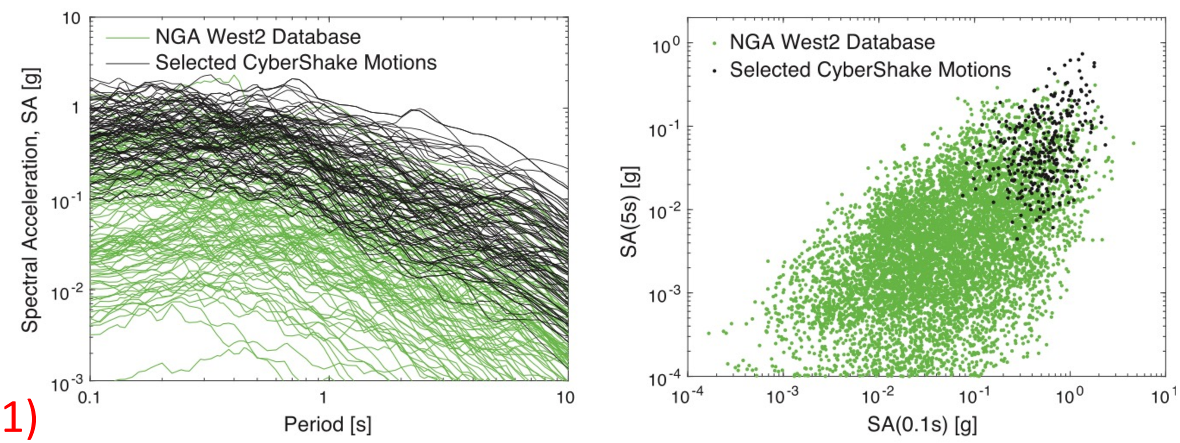
- Example: code-based ground-motion selection
  - We are given the target spectrum, and simply want to find time series.
  - We predominantly care about the properties of the resulting GM (reflected via IMs) and less (if anything) about the physics underlying
- Use of simulations in this context is already widespread in an ergodic framing – i.e., {large M, small Rrup} simulations for general locations to supplement recorded databases
  - but there is no guarantee that these simulations are realistic for the site of interest (i.e., not site-specific)



(Baker et al. 2021)

2. Uncertainty

Q: Do we need to represent f(IM|Rup) comprehensively (via multiple simulation realizations etc.)?

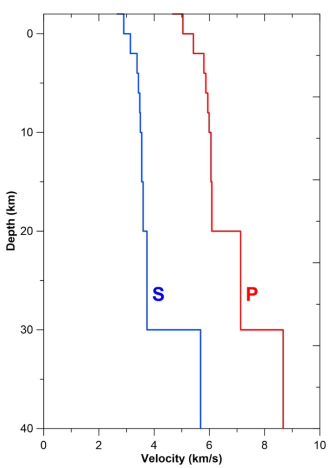
- Code-based GM selection: No, as explained previously.
- Scenario ruptures (e.g., Hayward fault): It depends
  - No: If we are focused on a single ‘reference’ simulation for emerging planning etc. (e.g., HayWired scenario) then rigorous uncertainty is not necessary.
  - Yes: If a range of plausible ruptures is explicitly desired.
- GM simulation-based PSHA (e.g., Cybershake): Yes, it is essential.
- Use of simulations to inform empirical GMMs: As simulations generally used to constrain median model development then would not be required (but would be if wanting to explore variability/uncertainty)

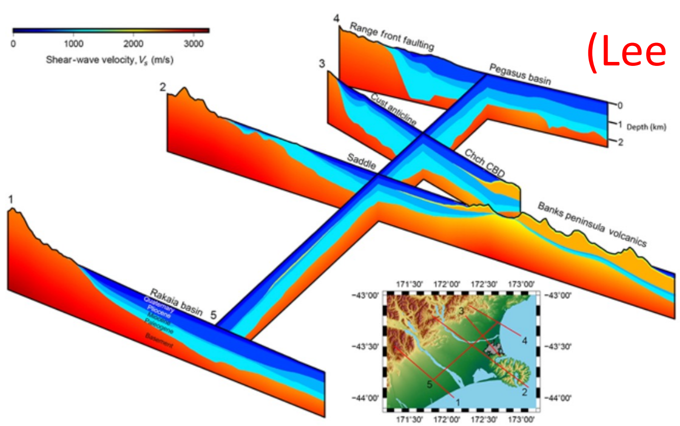
3. Site/region-specific

Q: Does it matter if the simulations are for the specific site of interest or not?

- GM selection:
  - Conventionally not considered (ergodic),
  - However, it would be desirable to be able to select simulations directly at the site of interest (non-ergodic) (e.g., Bradley et al. 2016)
- Seismic hazard:
  - Generally, yes (unless simply for constraining empirical models)

1D, e.g., SCEC BBP ⟶ 3D for the region of interest





(Lee et al. 2017)

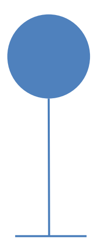
4. Complexity of structural model

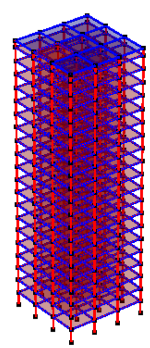
Q: What GM IMs matter for the structural *model* that will be used?

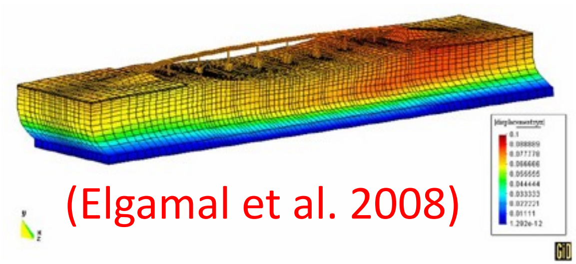
Examples:

- Regional risk using SDOF building models / empirical fragility functions – generally only SA(T_1) matters
- Code-based design checking for new structures – collapse unlikely, SA properties are of primary interest (Chandramohan et al. 2016)
- General PBEE assessment of structures with significant strength/stiffness degradation & geotechnical problems – non-SA IMs important (duration, cumulative measures – AI, CAV etc.)
- 3D numerical models: Tri-component simulated GM realism matters (challenging at high-frequencies)

Increasing model complexity →







(Elgamal et al. 2008)

3. Validation and acceptance criteria

How do we validate simulations with respect to these use case dimensions?

Many ‘validation’ approaches proposed

Methodology for Validation of Simulated Ground Motions for Seismic Response Assessment: Application to CyberShake Source-Based Ground Motions

Jawad Fayaz[1], Sarah Azar[2], Mayssa Dabaghi[2], and Farzir

EARTHQUAKE ENGINEERING PRACTICE

Guidance on the Utilization of Earthquake-Induced Ground Motion Simulations in Engineering Practice

Brendon A. Bradley,[a),c)] M.EERI, Didier Pettinga,[b)] Jack W. Baker,[c)] M.EERI,

Engineering validation of BB-SPEEDset, a data set of near-source physics-based simulated accelerograms

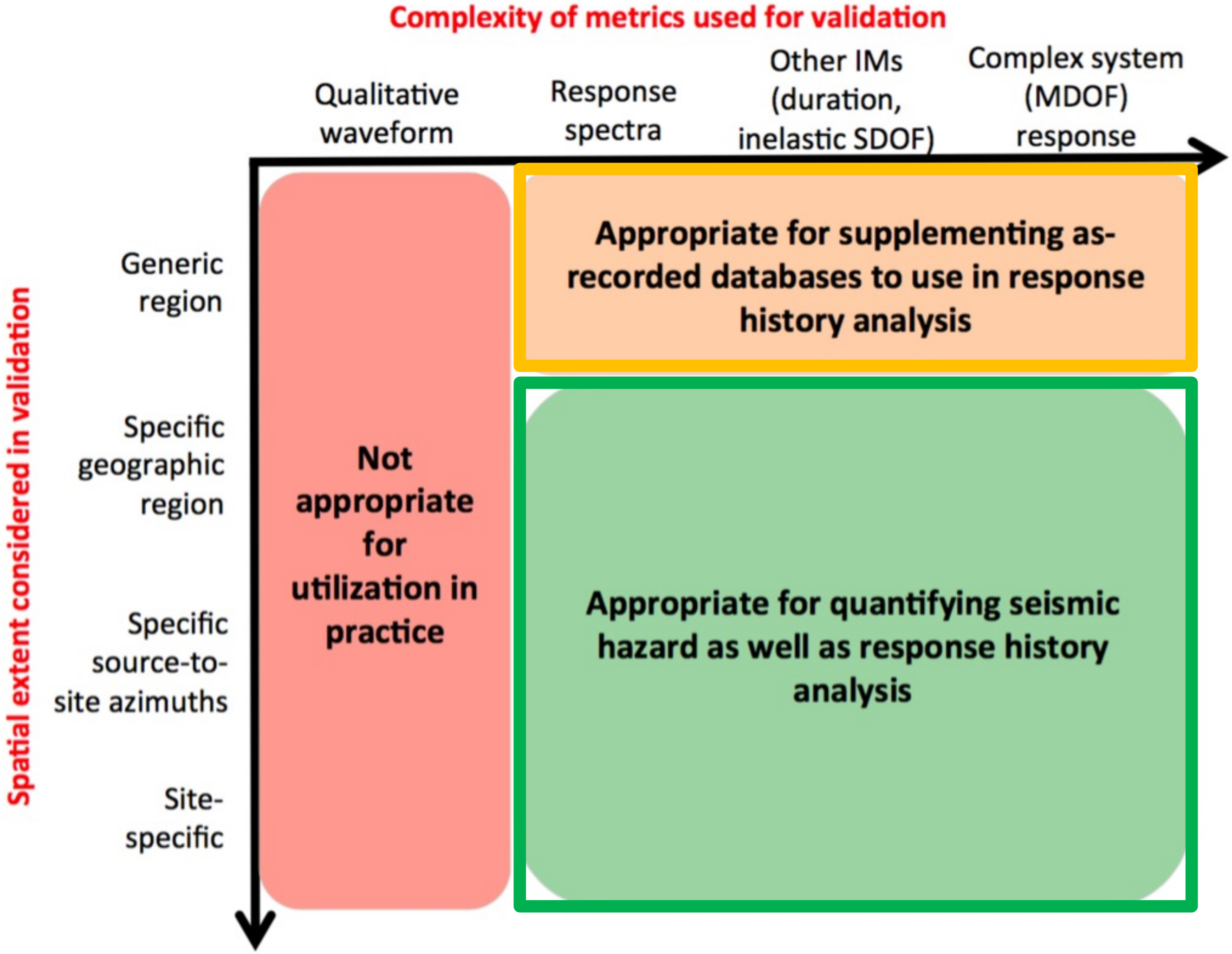
Chiara Smerzini[1], Chiara Amendola[2], R
Arsalan Bazrafshan[3]

Findings from a decade of ground motion simulation validation research and a path forward

Sanaz Rezaeian[1], Jonathan P Stewart, M.EERI[2], Nicolas Luco, M.EERI[1], and Christine A Goulet, M.EERI[3]

Validation and utilization guidance

'Validation matrix' for simulation utilization



Bradley et al. (2017)

Acceptance criteria

Q: Is using a specific simulation method (incl. velocity and rupture models) better than empirical GMMs (hazard) and recorded ground motions (GM selection)?

A: Assess via multiple test metrics that allow comparison of model performance of simulation-based prediction with conventional approach.

- Hazard: Analysis of prediction residuals for historical events from sim vs. empirical GMMs at site/region of interest; general performance/scaling against global data; scaling extrapolation beyond data
- GM selection: Examine if distribution of seismic demand statistically the same using simulated vs. recorded ground motions

Aside: Goodness-of-fit (GOF) scores (e.g., Anderson 2004) are suitable for comparing two or more simulations against each other, but they don't allow for comparison against the conventional prediction using empirical GMMs.

4. Considerations for simulated ground-motion databases

Considerations for simulated ground-motion databases

- Attention here focused on the general problem of databases that federate simulations from different groups, different methods, and/or different regions
- In contrast, a ‘database’ for a single set of simulations, for a specific region, simulation method etc. can be thought of as simply supplementary material to an associated journal paper
- Unlike databases of observed ground motions, which are measurements of reality (having removed ‘low-quality records’), all simulations are model approximations, with the approximation accuracy being a function of many features:
  - Simulation method
  - Rupture model, velocity model
  - Treatment of parameter uncertainties (if any), etc.
- Having metadata attributes that would seek to classify all of these features would be onerous/prohibitive (and changing with time as simulations advance)

Considerations for simulated ground-motion databases

An alternative may be to simply focus on whether specific simulated ground motions (based on the underlying parameters, models, methods) are suitable for the different typical use cases:

1. ***Code-based GM selection:*** Primarily emphasizing SA match with consideration of M,R, Vs30 etc. (ergodic wrt site of interest)
2. ***Regional risk applications:*** SA-based IMs of importance over the specific region of interest; may or may not consider simulation uncertainty
3. ***Site-specific GM selection:*** multi-IM match of ground motions to target distribution (CS/GCIM concepts), but no need for simulation uncertainty
4. ***Site-specific hazard*** (PSHA): These are 'general-purpose simulations' for any application. We are generally not here yet, with existing projects (SCEC Cybershake, Cybershake NZ etc.) in a research-mode. However, learnings here have carry-over benefits to all other applications.

5. Concluding remarks

Concluding remarks

- The link between ground motion intended use and necessary validation/acceptance criteria
- The use case dictates the importance of:
  1. *Input physics vs. output GMs:* If the underlying simulation physics matters, or just the nature of the resulting waveforms
  2. *Uncertainty*: Whether the simulations consider model and parameter uncertainty or not
  3. *Site/region-specific*: Whether the simulations represent the specific geographic site/region of the structure to be used for
  4. *Complexity of structural model*: What ground motion features the numerical models of the structures considered are sensitive to.

  and what validation metrics are necessary.
- Acceptance criteria should be based on superior performance compared with conventional alternatives (hazard: empirical GMMs; GM selection: recorded GMs)
- Considering the development of federated databases of simulated GMs from heterogeneous groups/methods/regions could focus on the intended use case as simple database metadata attributes

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Thank you for your attention

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