UNIVERSITY *of* WASHINGTON

Ground Motion Considerations for the Built Environment in Cascadia

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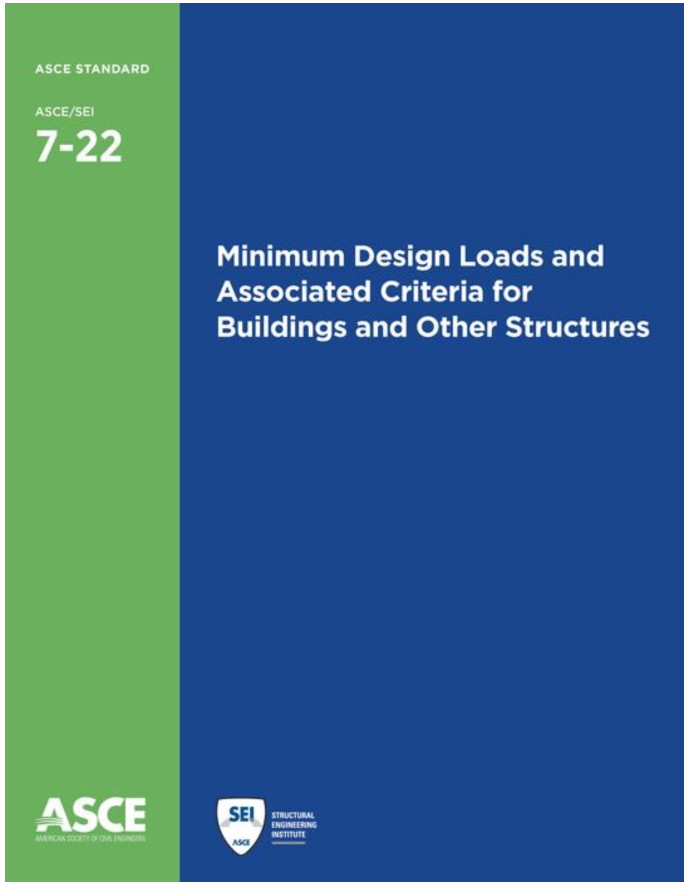
Who Uses Cascadia Ground Motions and GMMs for Infrastructure

- Structural engineering practitioners:
  - New design
  - Evaluation and retrofit
  - Equivalent static analysis or modal analysis using spectral acceleration
  - Dynamic analysis using selected and scaled ground motions
- Researchers
  - Develop improved understanding of infrastructure component and system performance
  - Innovate in building code requirements, special systems, fragility and resilience models, prioritization schemes for retrofit
- Agencies
  - Regional loss estimation for planning
  - Prioritization of limited resources for retrofit

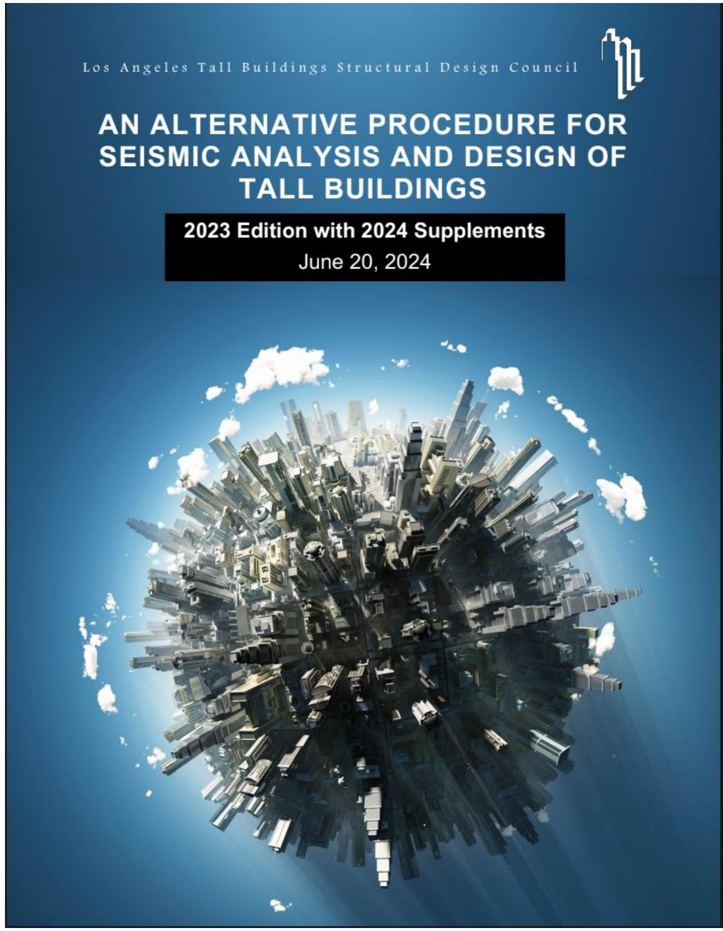
How Structural Engineering Practitioners use Ground Motions

> Conventional Structural Design, New Structures (~85%+):
  - USGS seismic hazard model (map) is used provide a maximum direction acceleration response spectra.
  - For buildings (ASCE 7)
    - Spectra is now defined at 20 structural periods,
    - Each point represents the risk-adjusted MCE (2475-year return period) spectral acceleration
    - Risk-adjustment achieves a uniform collapse risk for an assumed collapse fragility curve.
  - Slightly different for bridges in terms of return period, number of periods defining the spectrum and risk adjustment.
  - Spectra is then interrogated at a single point (the structure's natural period of vibration) that is used to estimate MCE_R and then design level seismic forces (2/3 MCE_R)
  - Spectral shape and ground motion duration are not considered
  - ASCE 7 and associated IBC reference documents are based largely on the CA earthquake experience
  - Both OR and WA are in the process of adopting ASCE 7-22



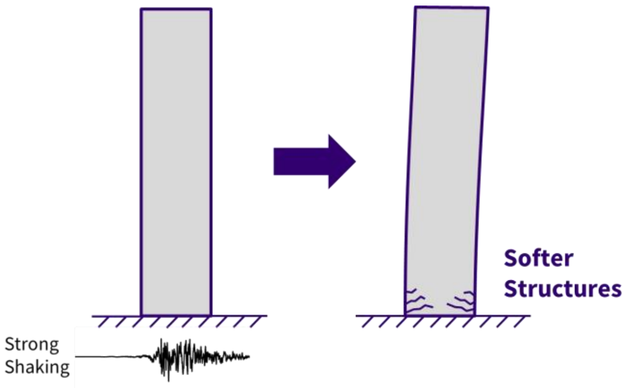
How Structural Engineering Designers use Ground Motions

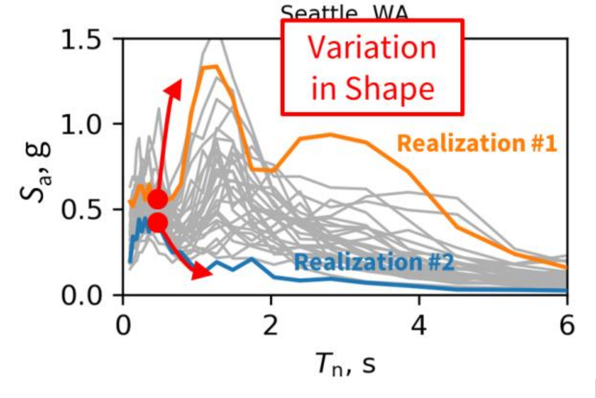
- Performance-Based or Code-Alternative Design, New Structures:
  - Tall buildings, long-span bridges, critical facilities, SDC E (ASCE 7-22 and LA Tall Buildings Guide)
  - Site specific response spectra are developed using site characteristics and available GMMs. Two approaches:
    - Risk-adjusted uniform hazard (similar to USGS)
    - Scenario-based (conditional mean spectra, sometimes developed at multiple structural periods and enveloped)
  - Spectra used for preliminary design using elastic structural analysis
  - For design validation and performance evaluation, nonlinear response history analysis is used, and ground motions are selected from available databases and scaled to the site-specific spectra
  - ASCE 7-22 has rules on record selection and scaling (minimum 11 pairs of records, must exceed 90% of target spectrum over period range of $0.2T$ to $1.5T$)
  - GM selection must consider the source characteristics weighted by their contribution to the hazard (found through deaggregation)
  - NRHA then accounts for spectral shape and duration



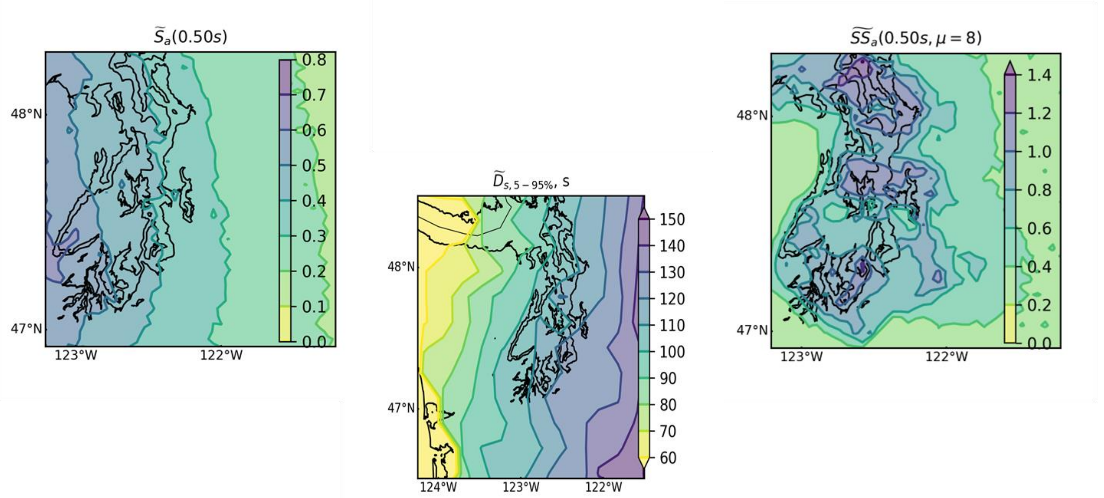
Spectral Shape and Ground Motion Duration

> Many recent studies (e.g., Eads et al. 2015, Chandramohan et al. 2016, Marafi et al. 2016) have shown that ground motion duration and spectral shape influence structural performance





> Alternative IM's that account for one or both (e.g., $S_{a,eff}$) have been developed

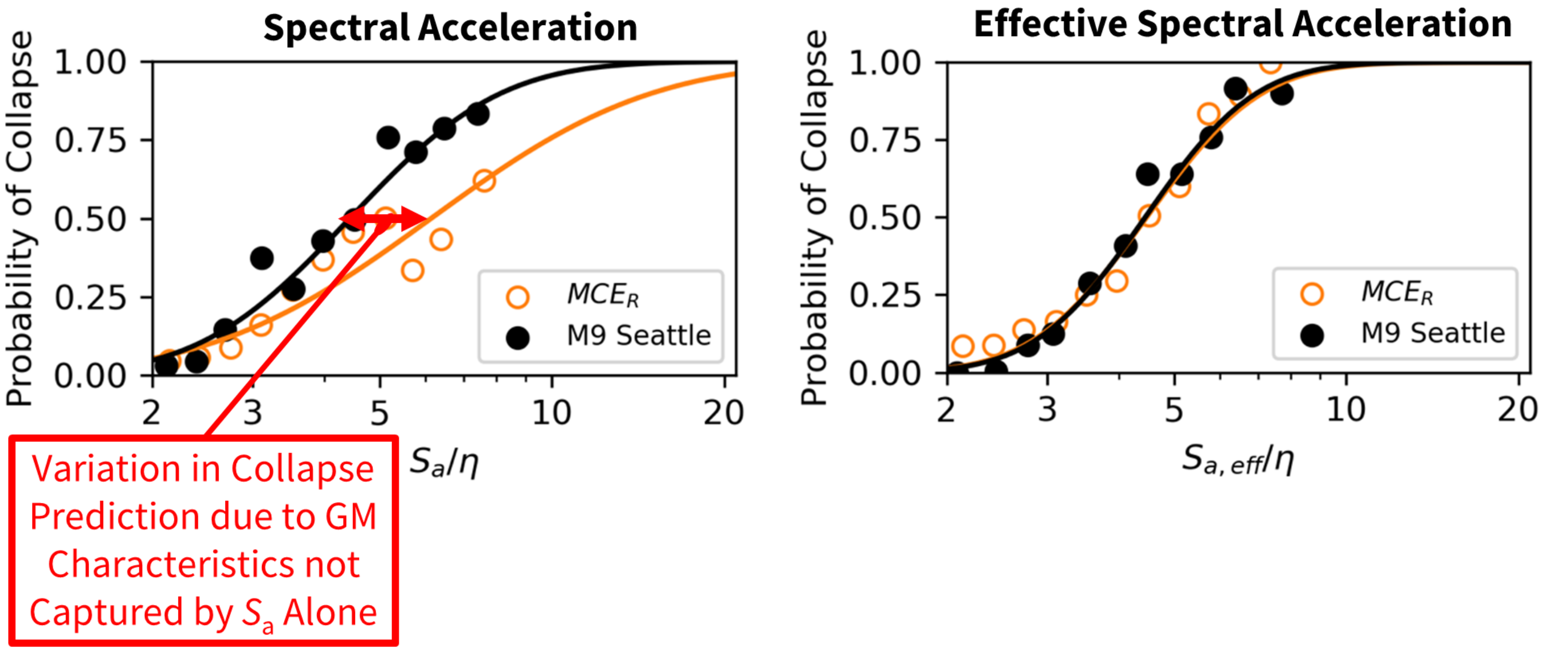


$$S_{a,eff} = S_a \cdot \gamma_{duration} \cdot \gamma_{shape}$$

Spectral Shape and Ground Motion Duration

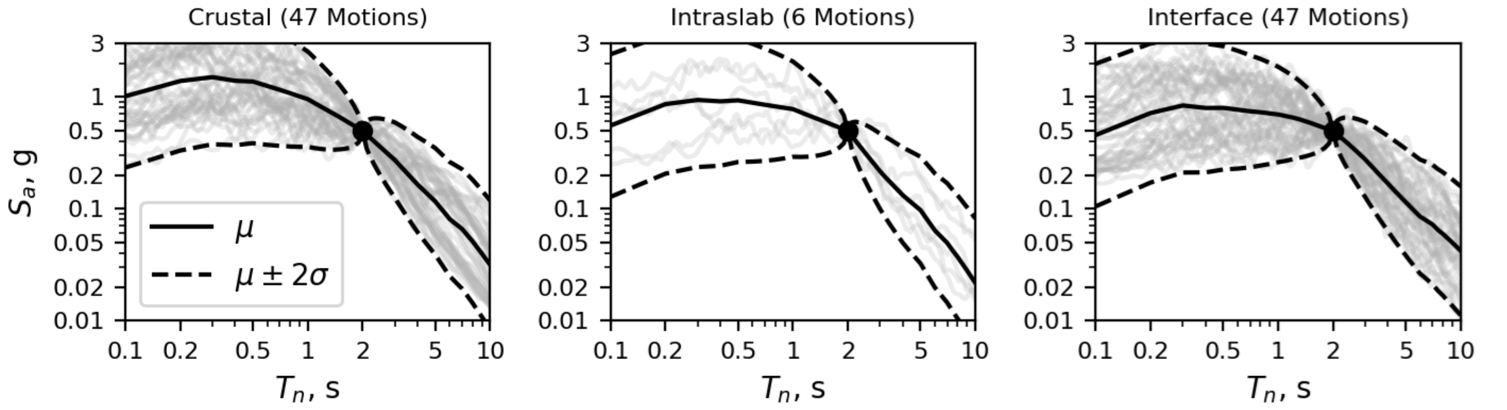
- These alternative IM's reduce uncertainty in estimating structural response (i.e., they correlate better with structural response than S_a alone) so having GMMs that produce the components necessary to produce them is useful, especially for improving regional analysis
- Note that many fragility curves in the literature or in HAZUS were derived using crustal ground motions (different spectral shape and duration) and may be unconservative to apply in Cascadia

Example collapse fragility curves derived from NRHA of tall concrete wall buildings with crustal motions scaled to MCE_R and the M9 ground motions

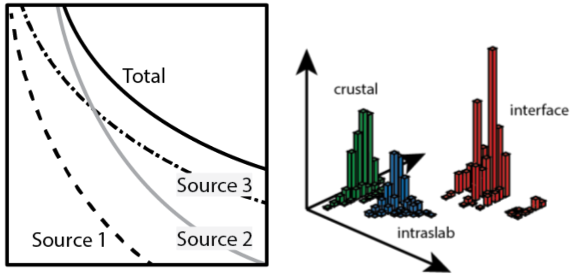


Structural Engineering Research Applications for Ground Motion Models

- Multiple Stripe Analysis:
  - Suites of ground motions are selected and scaled using conditional mean spectra derived for different return periods
  - These are hazard consistent at each return period and rely on hazard specific GMM's and available records
- To generate fragility curves for structures we need stripes to very large return periods so that collapse cases occur
- Integrated with the hazard curve we can then compute 50-year collapse risk (or other performance states)



Structural Engineering Research Applications for Ground Motion Models



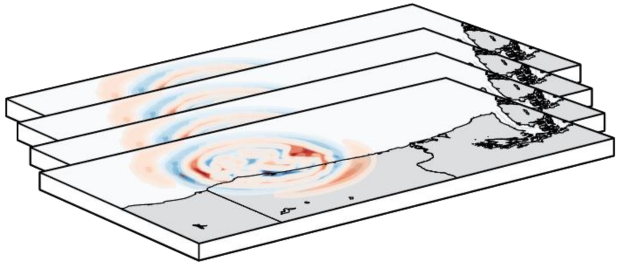
Other Earthquake Sources

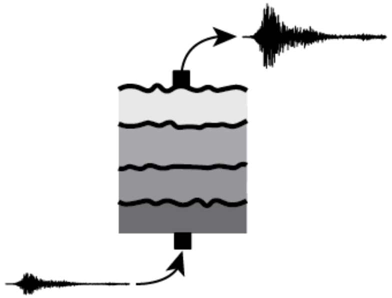
Probabilistic Seismic Hazard Analysis → Multiple Stripe Analysis → Mean Annual Rate of Collapse ($\lambda_{c,other}$) due to Other Earthquakes

Large Interface Earthquakes

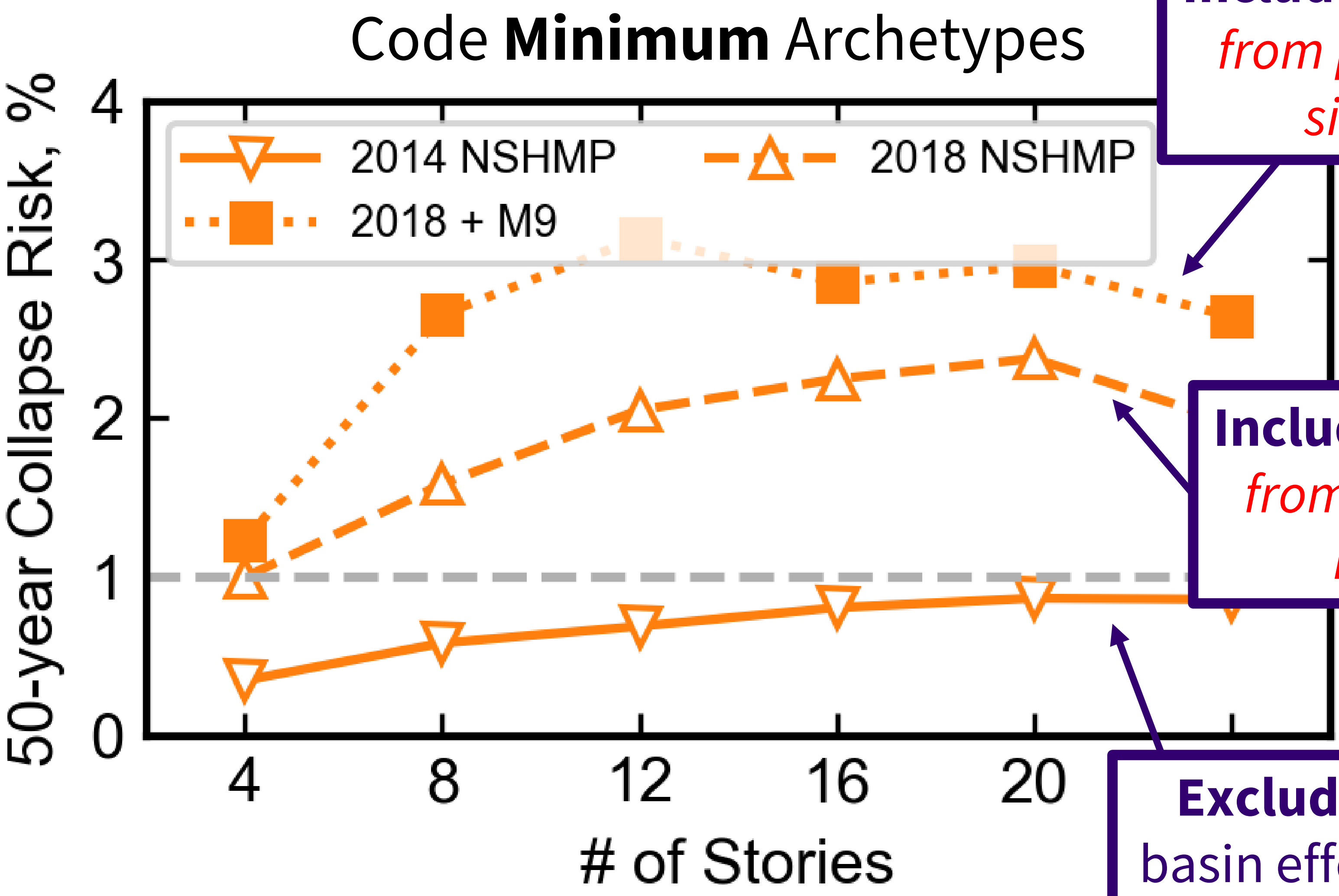
Physics-based Simulations → Local Site Adjustments → Mean Annual Rate of Collapse ($\lambda_{c,CSZ}$) due to Large Interface Earthquakes

→ 50-year Collapse Risk





50- Year Collapse Risk

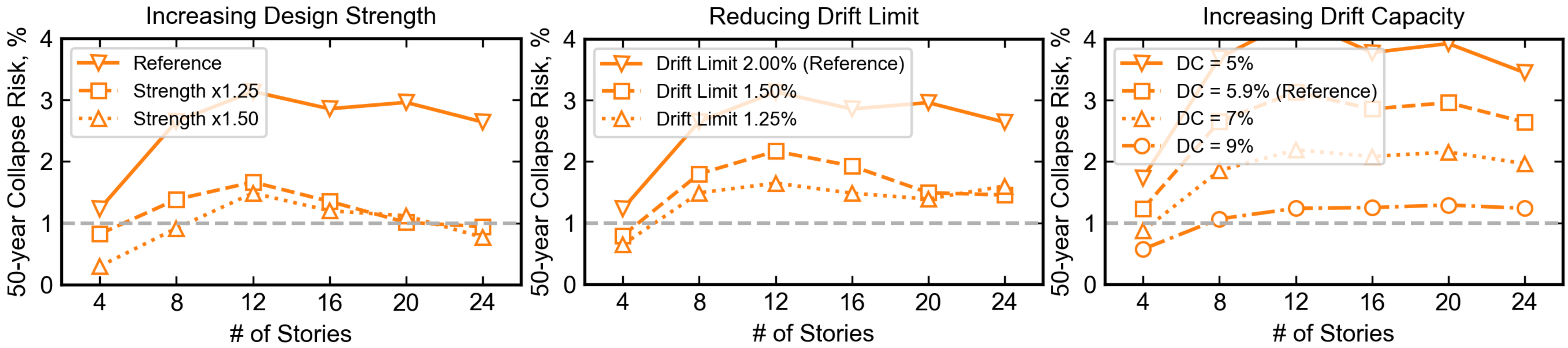


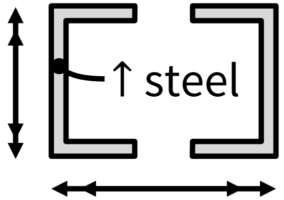
Includes basin effects *from physics-based simulations*

Includes basin effects *from the "California Experience"*

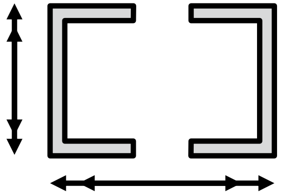
Excludes basin effects

Design Strategies

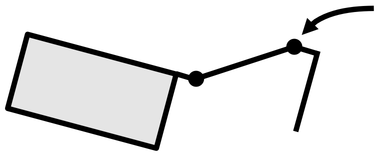




Stronger/
Stiffer
Structure



Stiffer
Structure



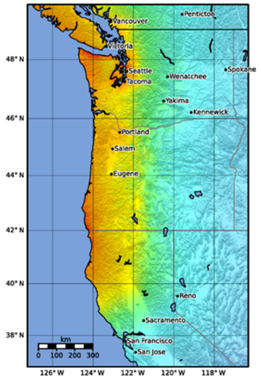
More Ductile
Connections

Improving Regional Scale Simulations

Regional Loss/Resilience Estimation

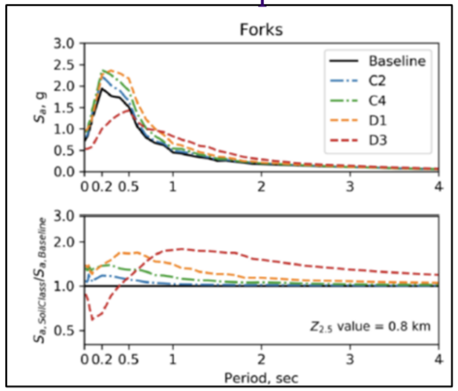
- Each step in the process is improved by quantifying and reducing uncertainties
- UW has developed detailed inventories of bridges to be able to develop detailed structural models and improved fragilities
- Software frameworks such as R2D (NHERI SimCenter) can help integrate detailed models directly into regional simulations

Ground Motion Realizations



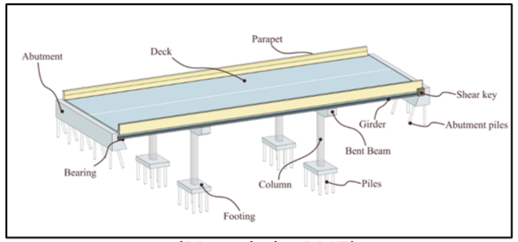
(Frankel et al. 2018)

Site Class Amplification



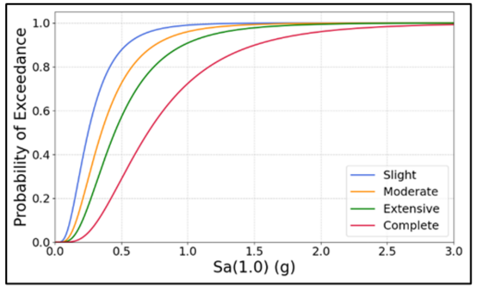
(grant et al. 2020,
de Zamacona Cervantes 2019)

Bridge Type

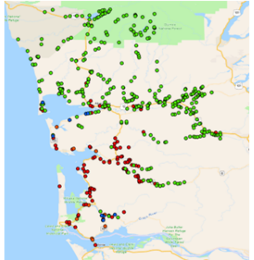


(Mangalathu 2017)

Fragility Curve

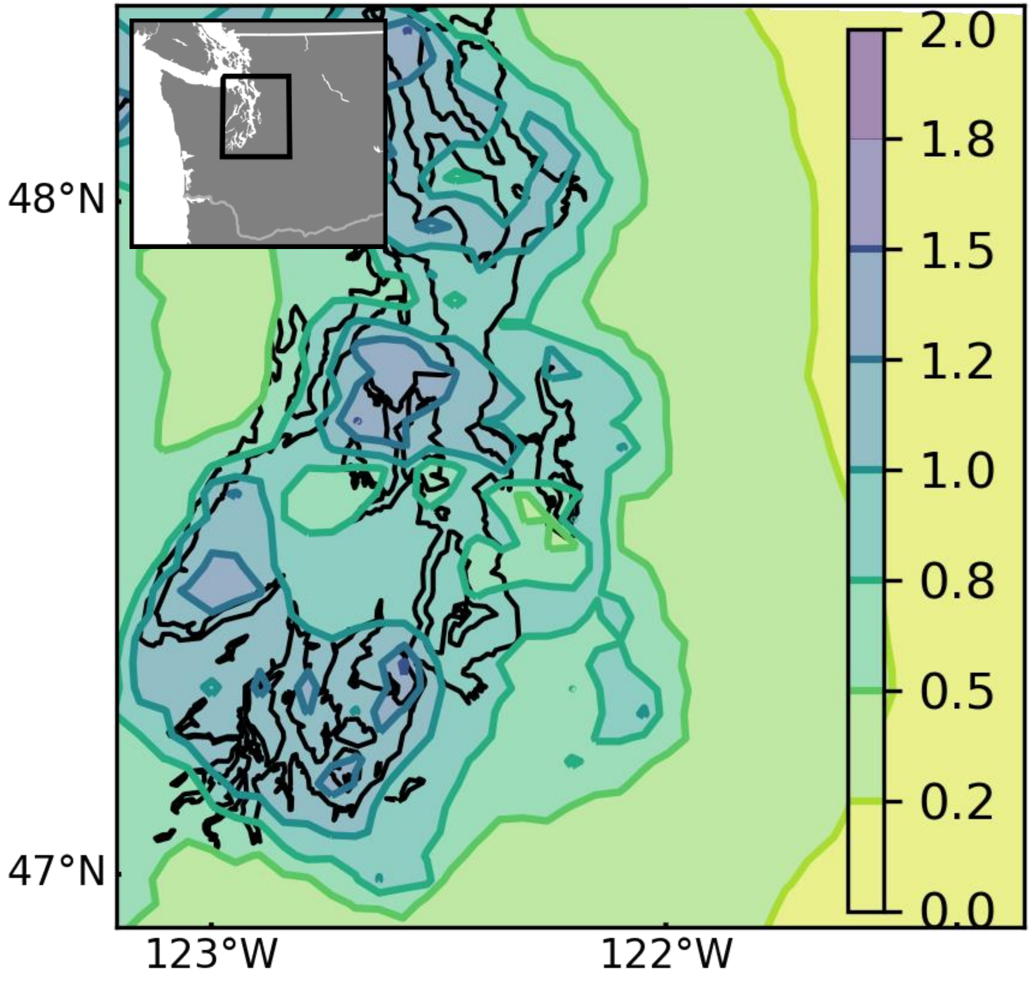


Damage

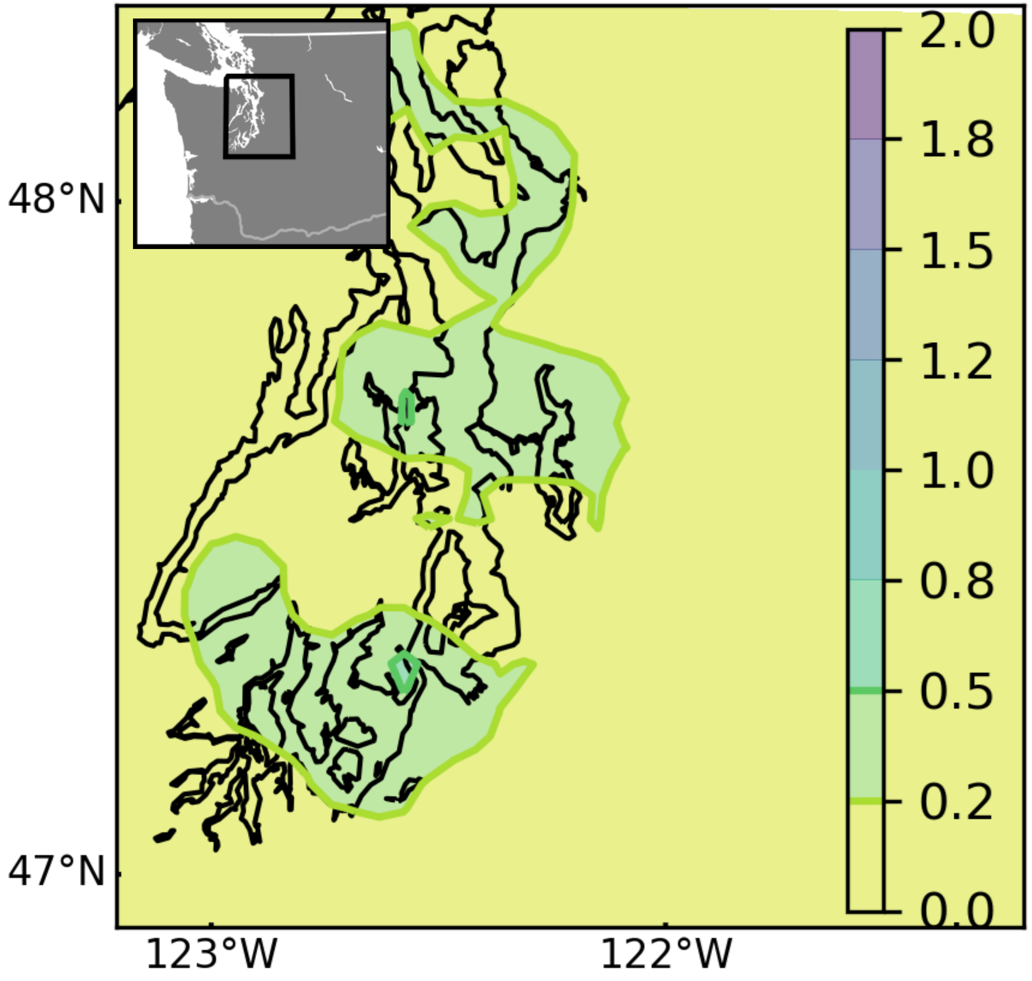


GM Intensity from Physics-based Simulations

$S_{a,eff,col}$
$(T_n = 0.5 \text{ s})$



$S_{a,eff.,col.}$
$(T_n = 2.0 \text{ s})$



Regional Collapse Predictions in an M9

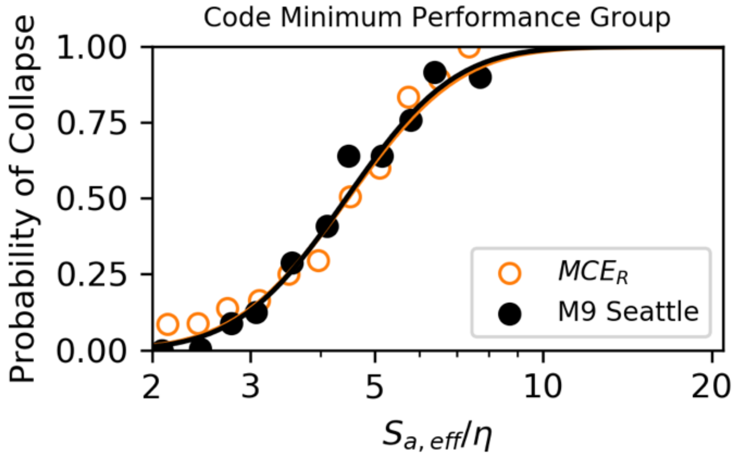
Compute Collapse Probability (for each location)

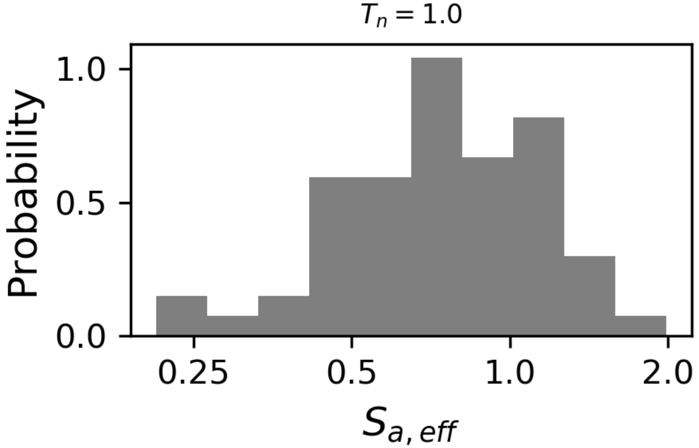
$$P[col.\,|\,M9\,] = \int\int P[\,col.\,|\,S_{a,eff}/\eta\,]\cdot f_{Sa,eff}\,(\,S_{a,eff}\,|\,M9\,)\cdot f_{\eta}(1/\eta)\;d1/\eta\;dS_{a,eff}$$

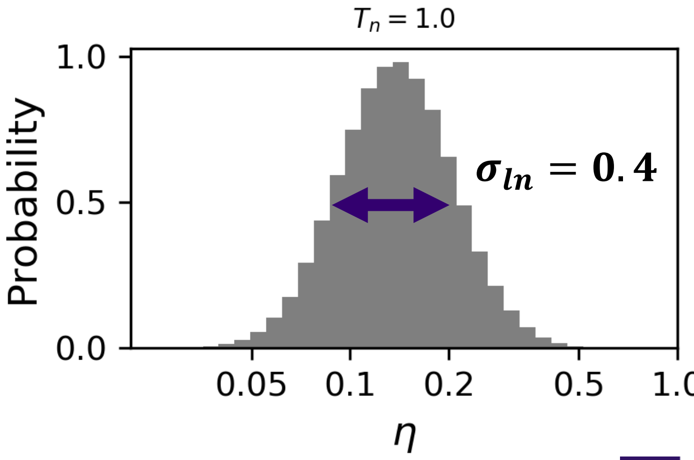
Collapse Fragility

Variation in $S_{a,eff}$ in M9 CSZ

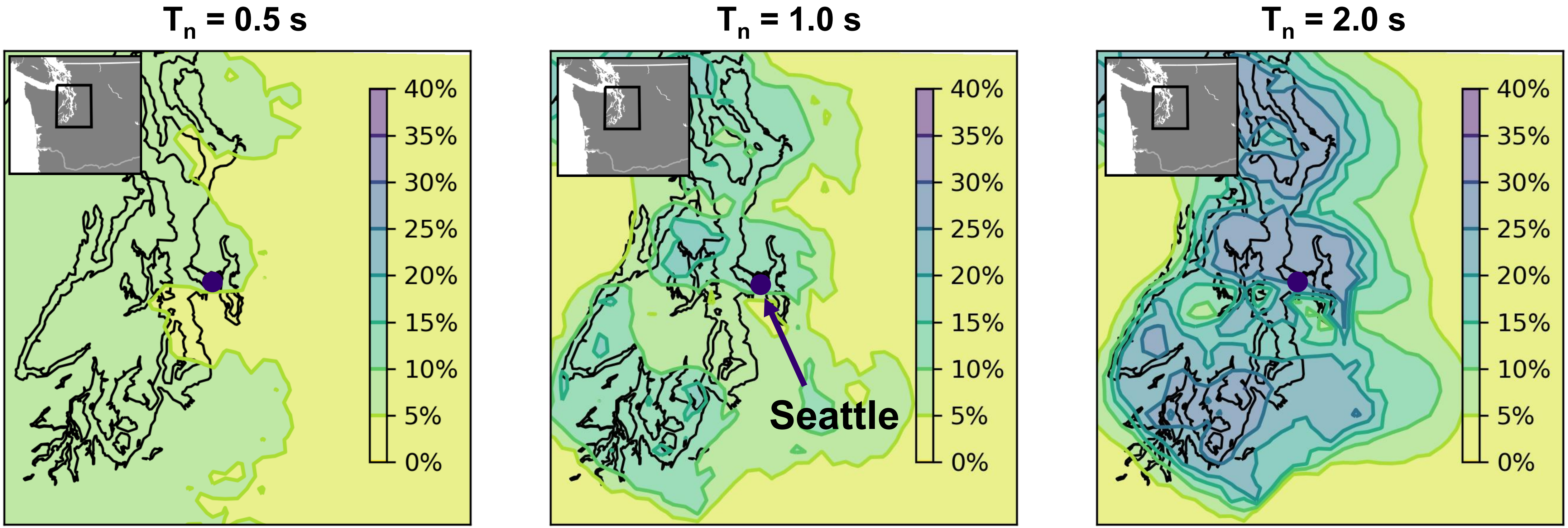
Variation in Strength



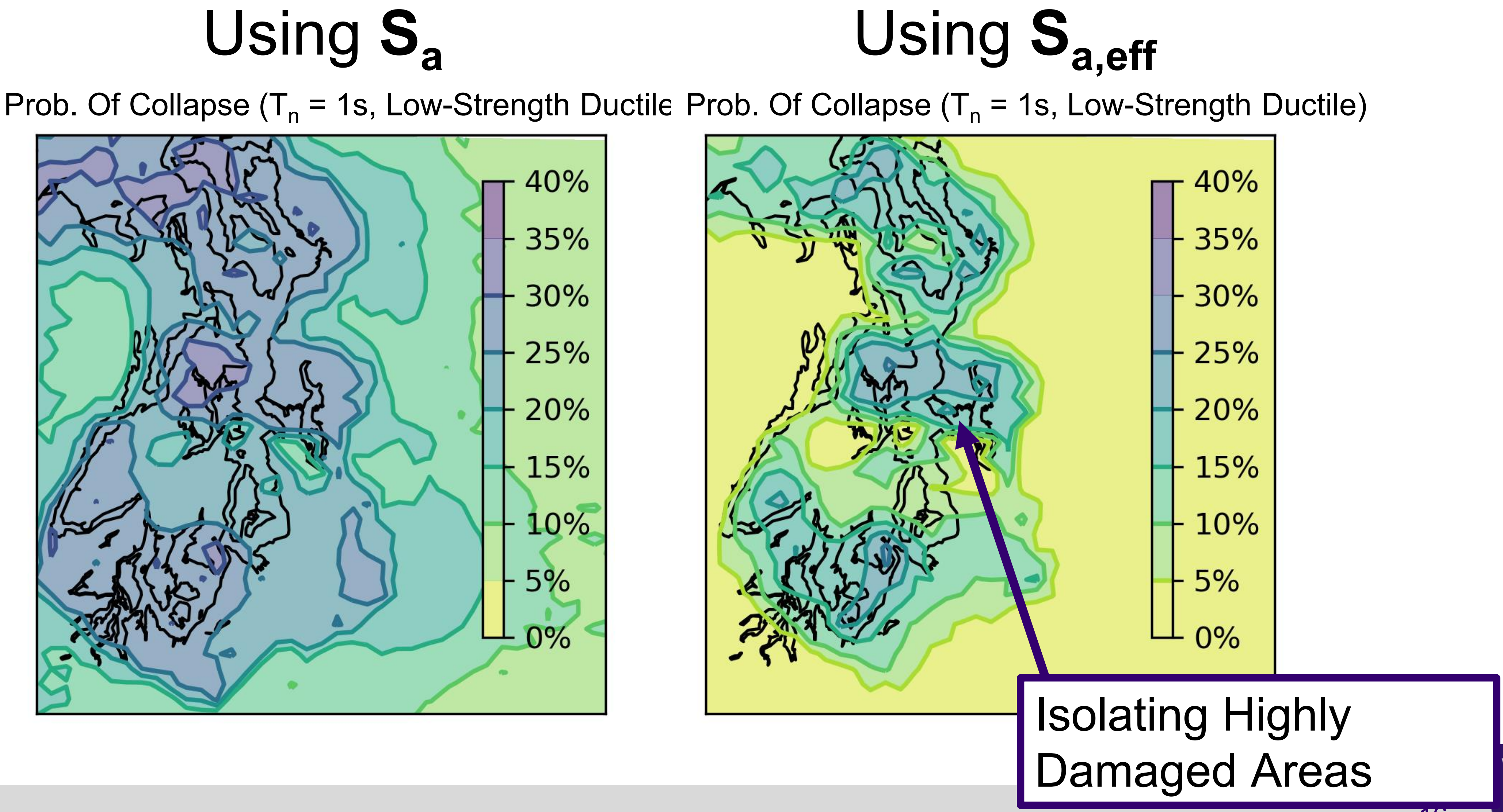




Regional Variation in Collapse Probability



Reducing Uncertainty Results



Thank You!