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Impacts of an M9 Cascadia Subduction Zone Earthquake and Deep Sedimentary Basins on Idealized Structures

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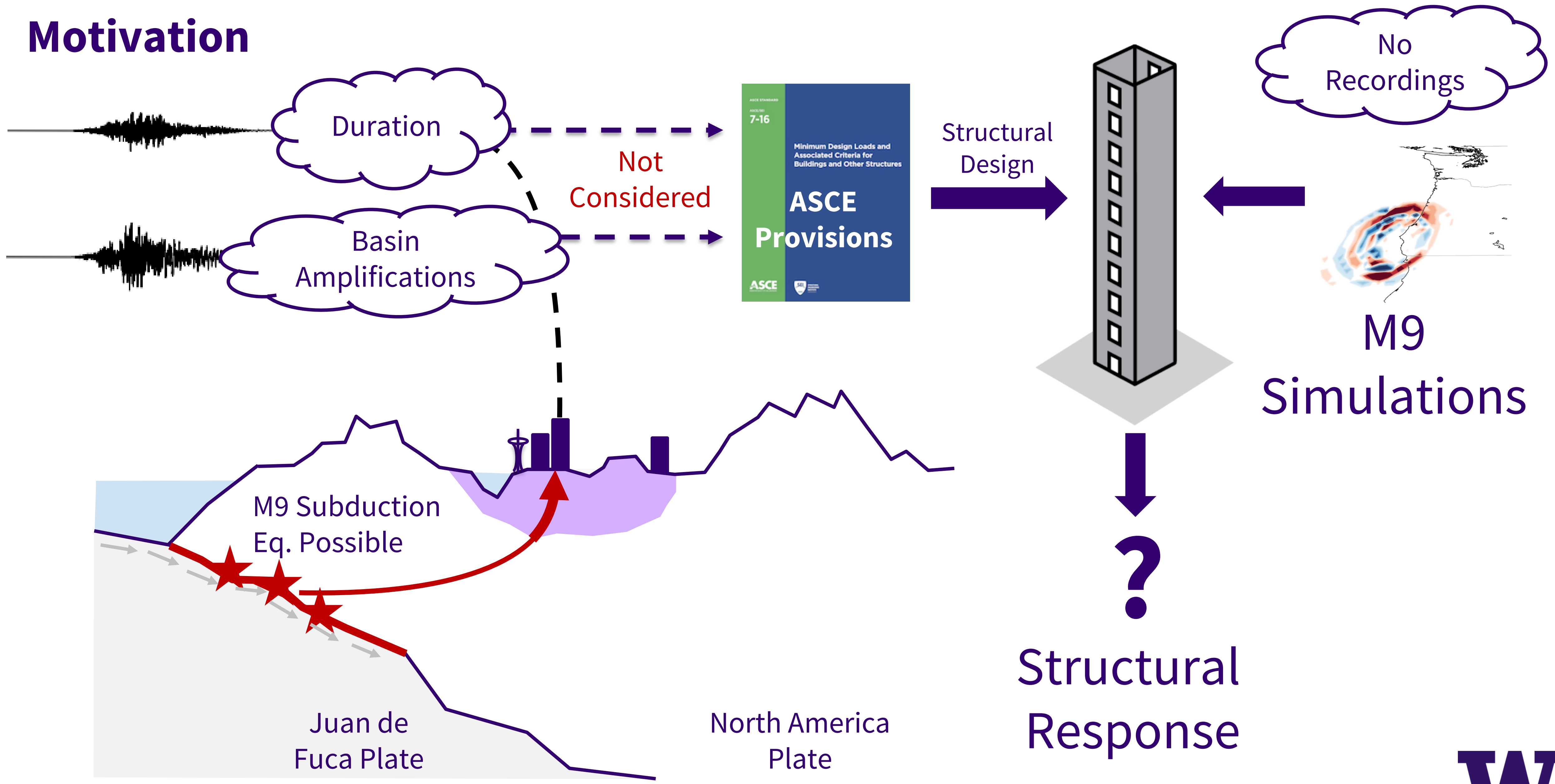
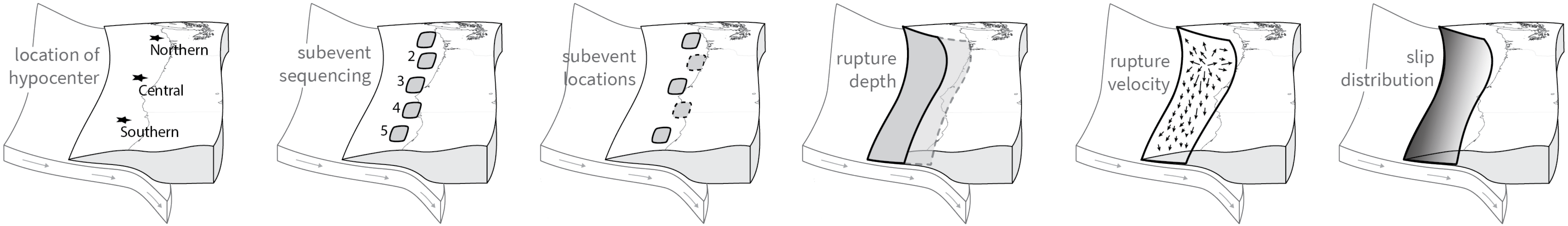
PEER

Motivation



Duration
Basin Amplifications
Not Considered
7-16
Minimum Design Loads and Associated Criteria for Buildings and Other Structures
ASCE Provisions
ASCE
Structural Design
No Recordings
M9 Simulations
?
Structural Response
M9 Subduction Eq. Possible
Juan de Fuca Plate
North America Plate

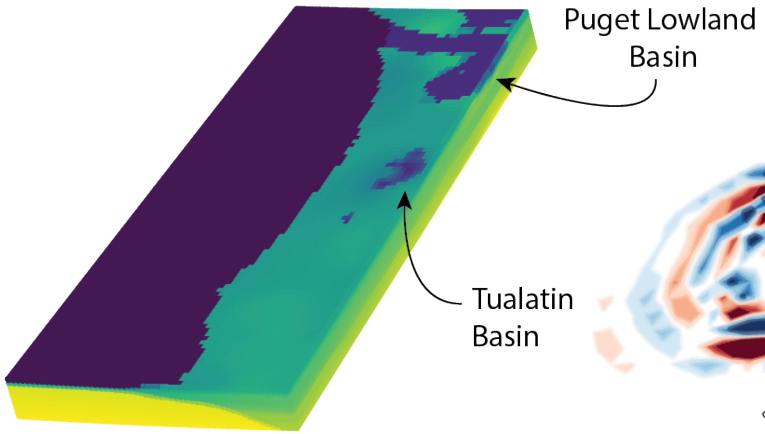
M9 CSZ Simulations

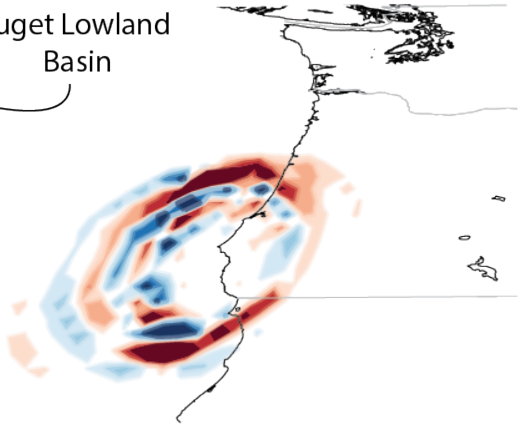


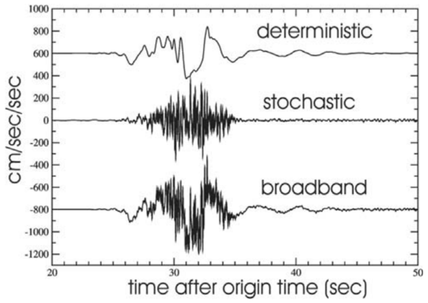
Selecting Rupture Parameters

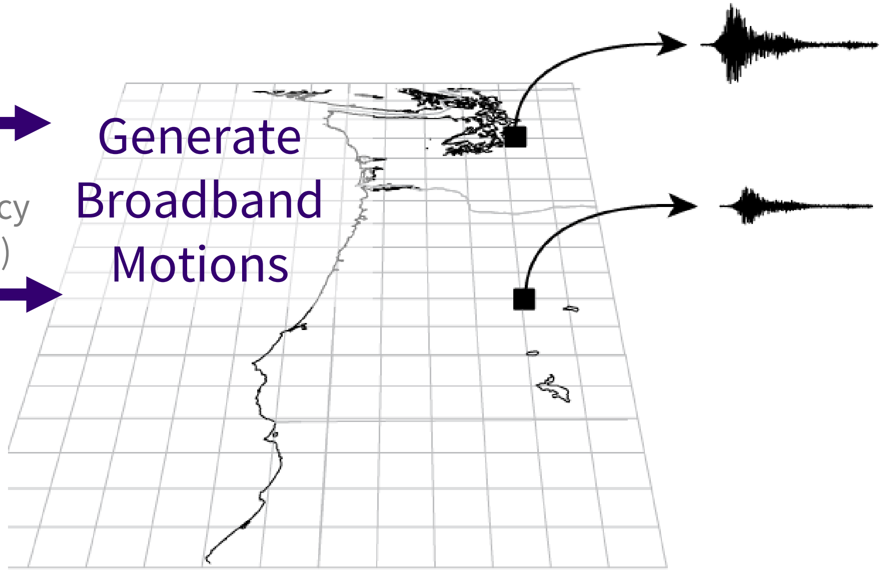
Seismic Wave Velocity Model → **Finite-Difference Simulations** → Low Frequency Motions (>1s) → Generate Broadband Motions

Stochastically Generated Motions → High Frequency Motions (<1s) → Generate Broadband Motions







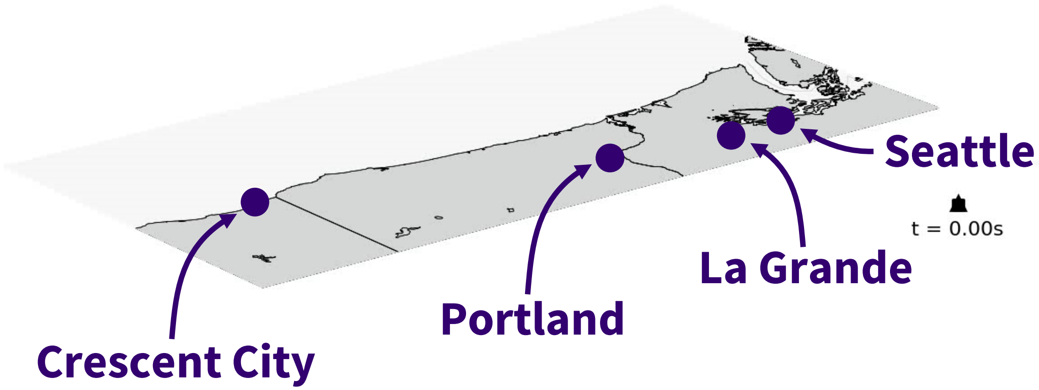


Reference: Frankel, A., Wirth, E., Marafi, N, Vidale, J., Stephenson., W. “Broadband Synthetic Seismograms for Magnitude 9 Earthquakes on the Cascadia Megathrust Based on 3D Simulations and Stochastic Synthetics”, BSSA, 2018

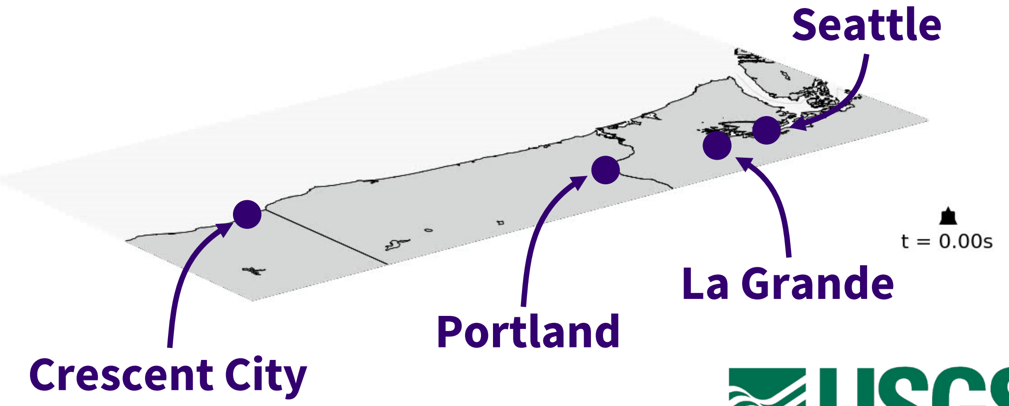
science for a changing world

Two Example Realizations

Realization #1: Rupturing **towards** Seattle



Realization #2: Rupturing **away** from Seattle



Reference: Frankel, A., Wirth, E., Marafi, N, Vidale, J., Stephenson., W. "Broadband Synthetic Seismograms for Magnitude 9 Earthquakes on the Cascadia Megathrust Based on 3D Simulations and Stochastic Synthetics", BSSA, 2018

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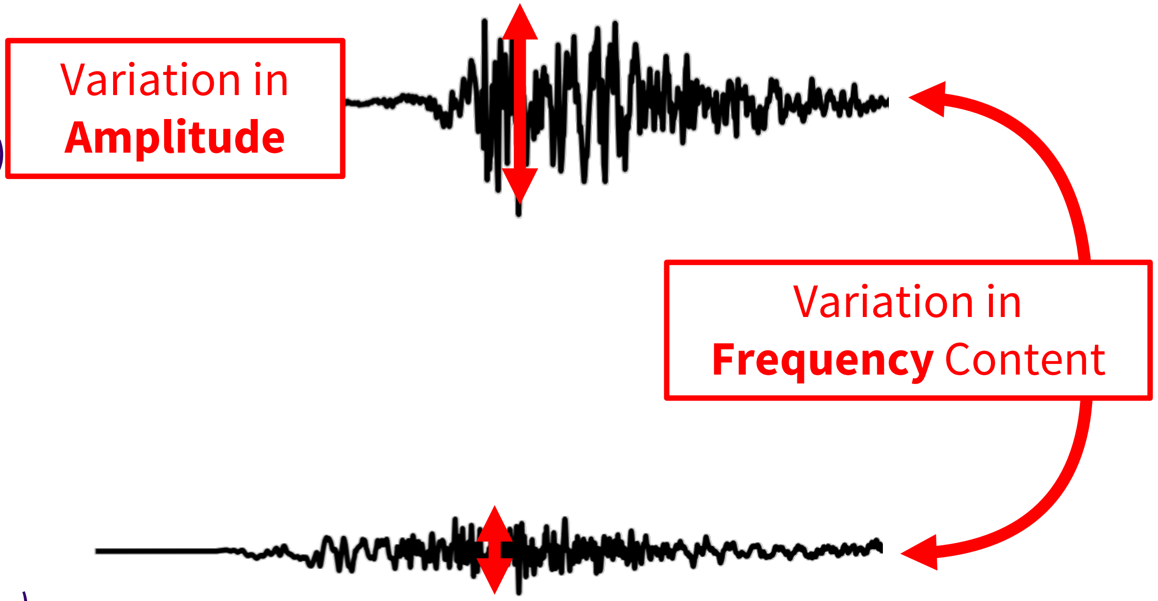
Time Histories

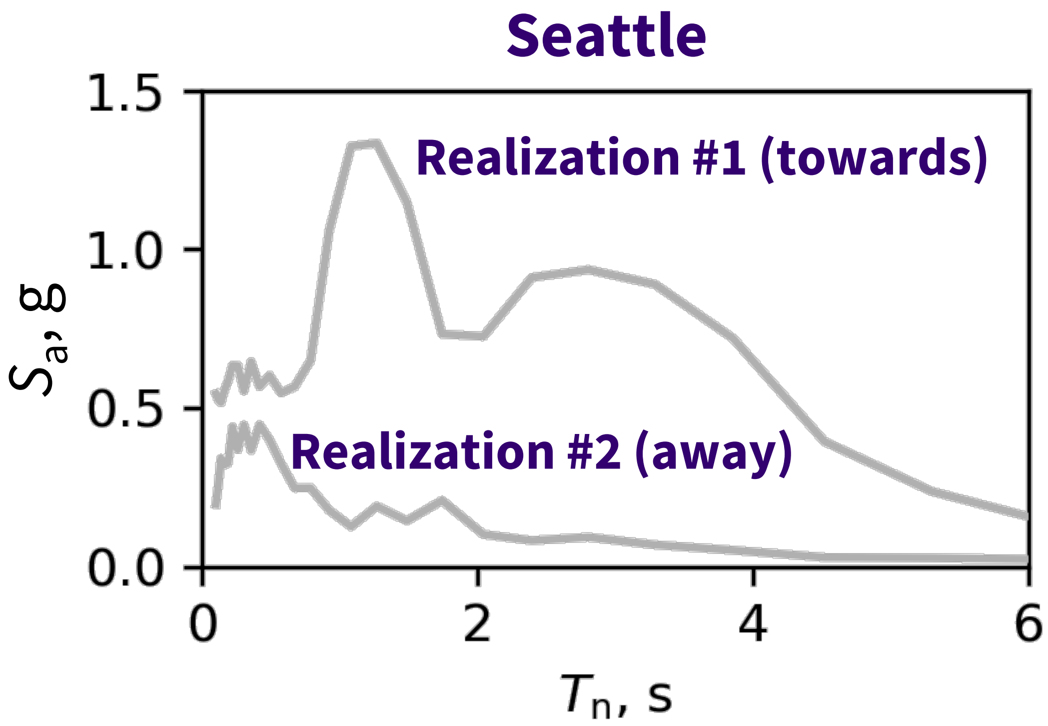
Seattle

Realization #1
(towards Seattle)

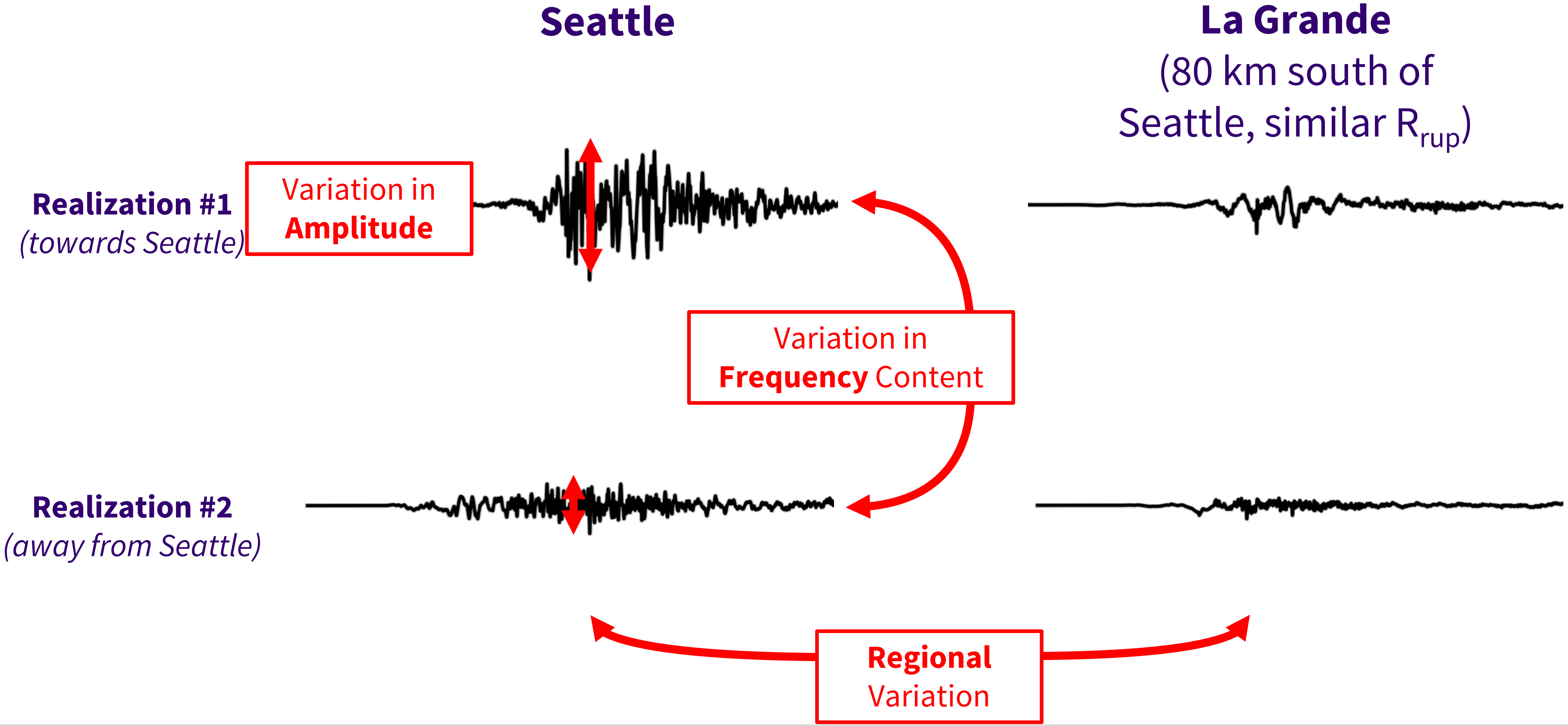


Realization #2
(away from Seattle)

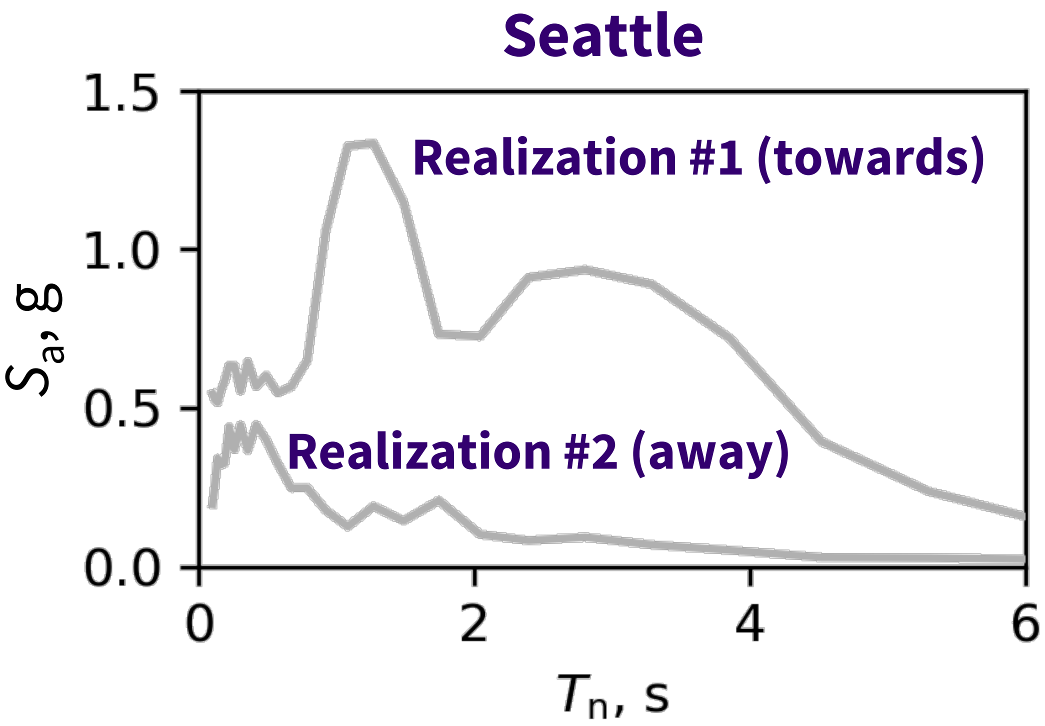
Effect of Basin on S_a

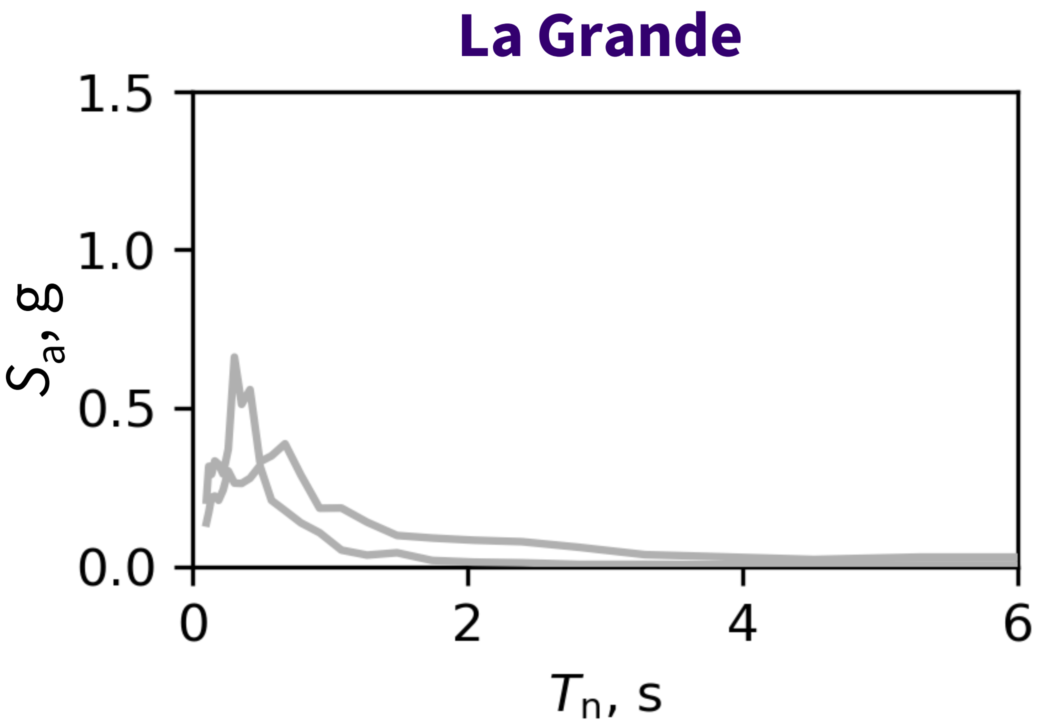


Time Histories

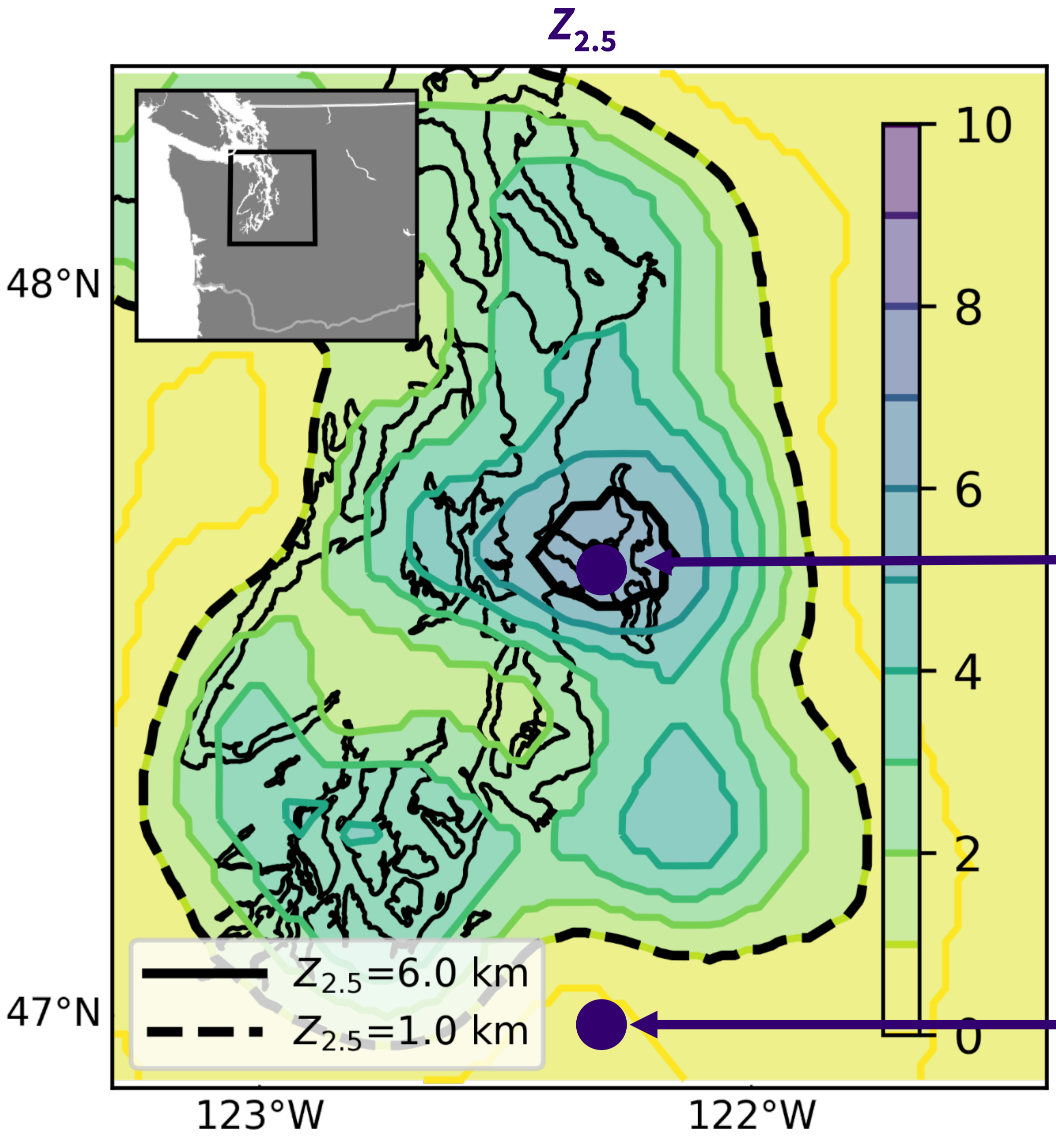


Effect of Basin on S_a





Deep Sedimentary Basin

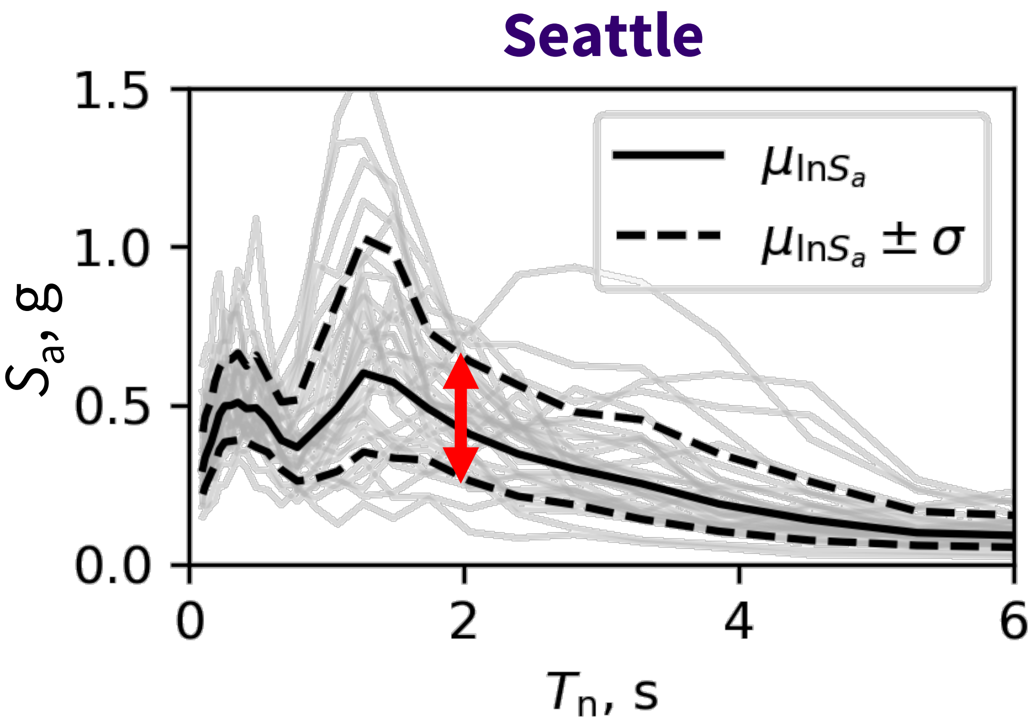


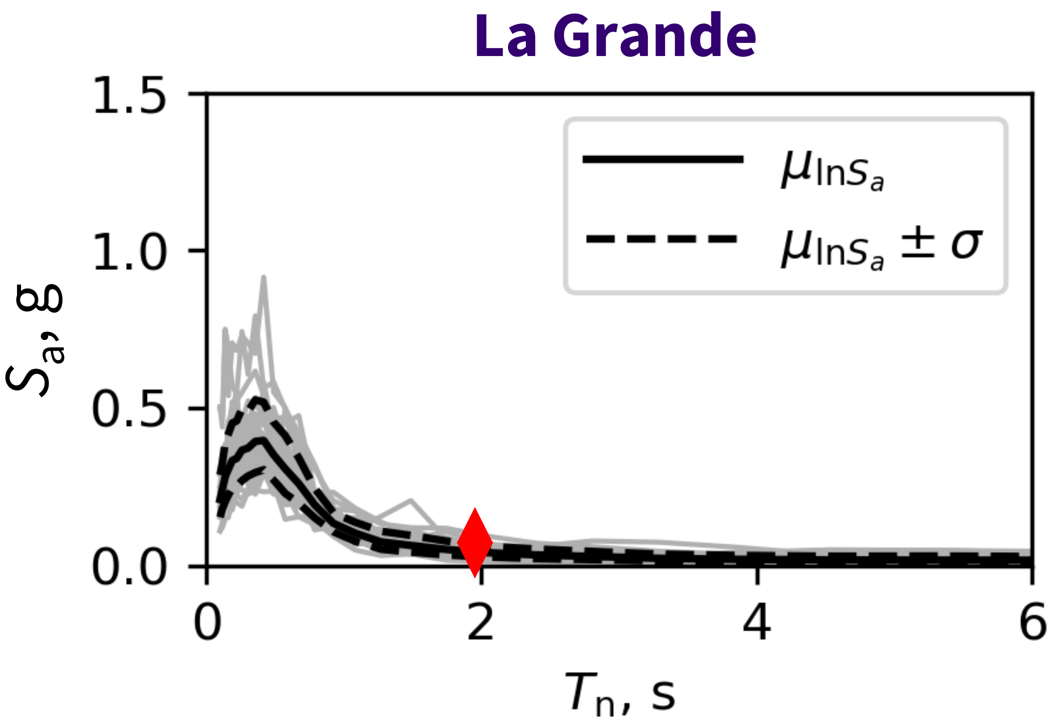
Seattle

Similar **Source-to-Site** Distance

La Grande

Effect of Basin on S_a



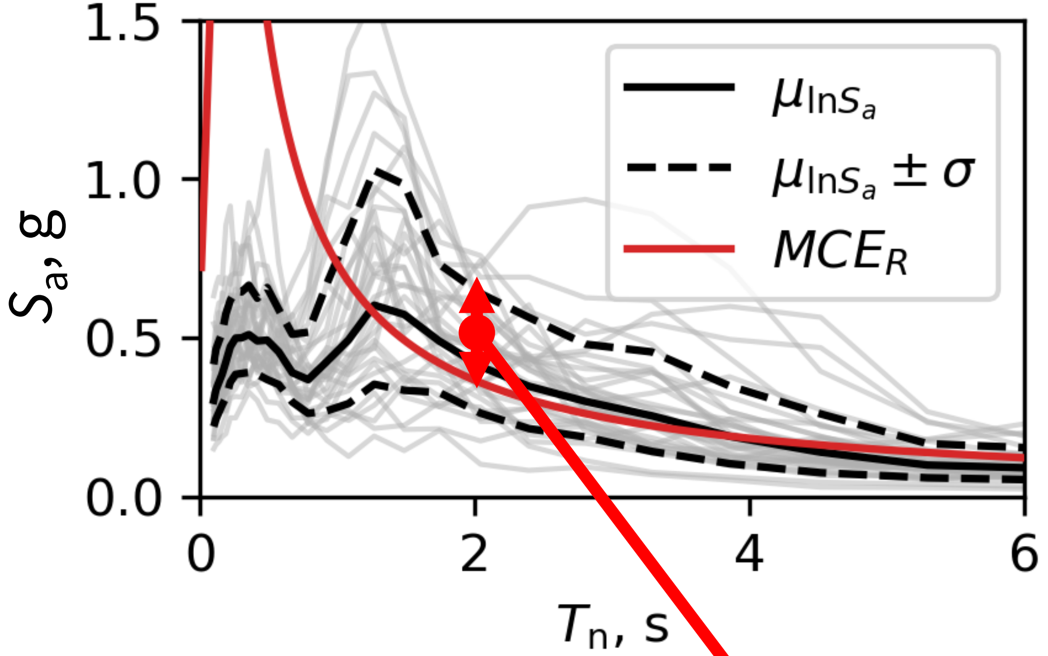


Larger S_a Variation in Seattle

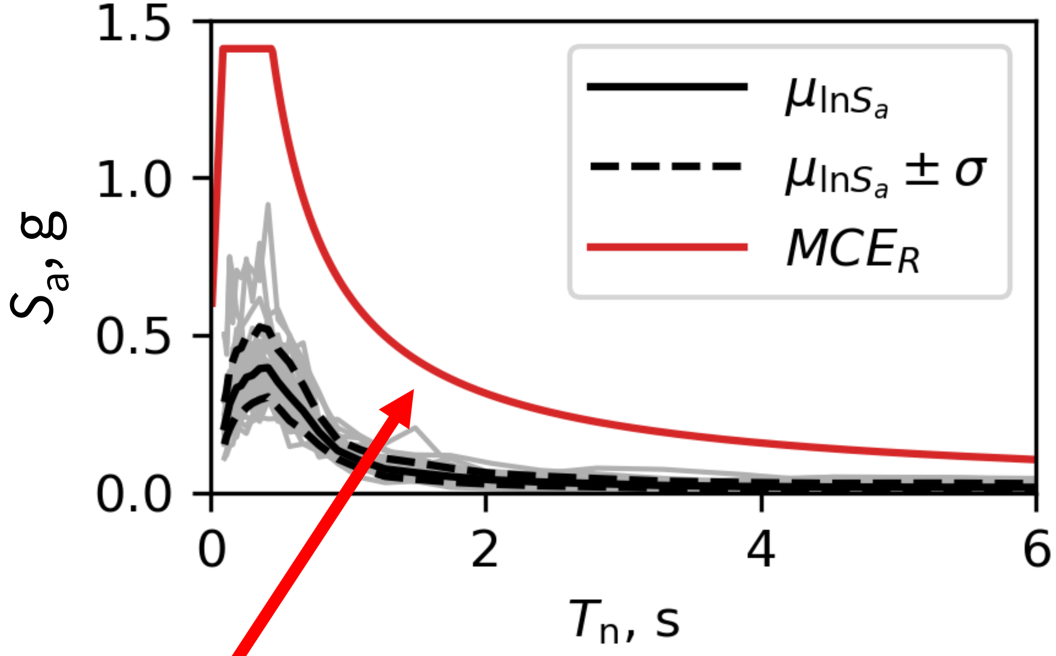
All 30 Realizations

Effect of Basin on S_a

Seattle



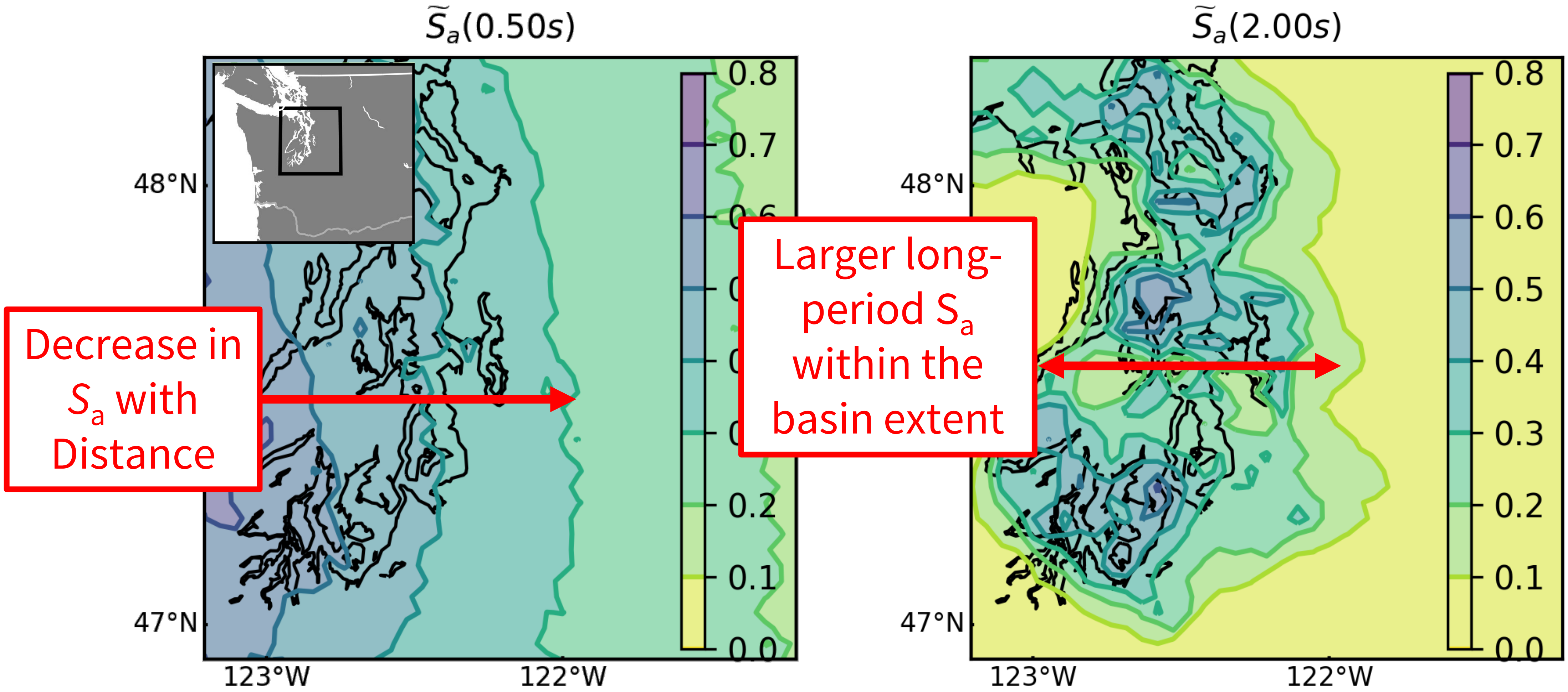
La Grande



20 out 30 **exceed** MCE_R at 2 s

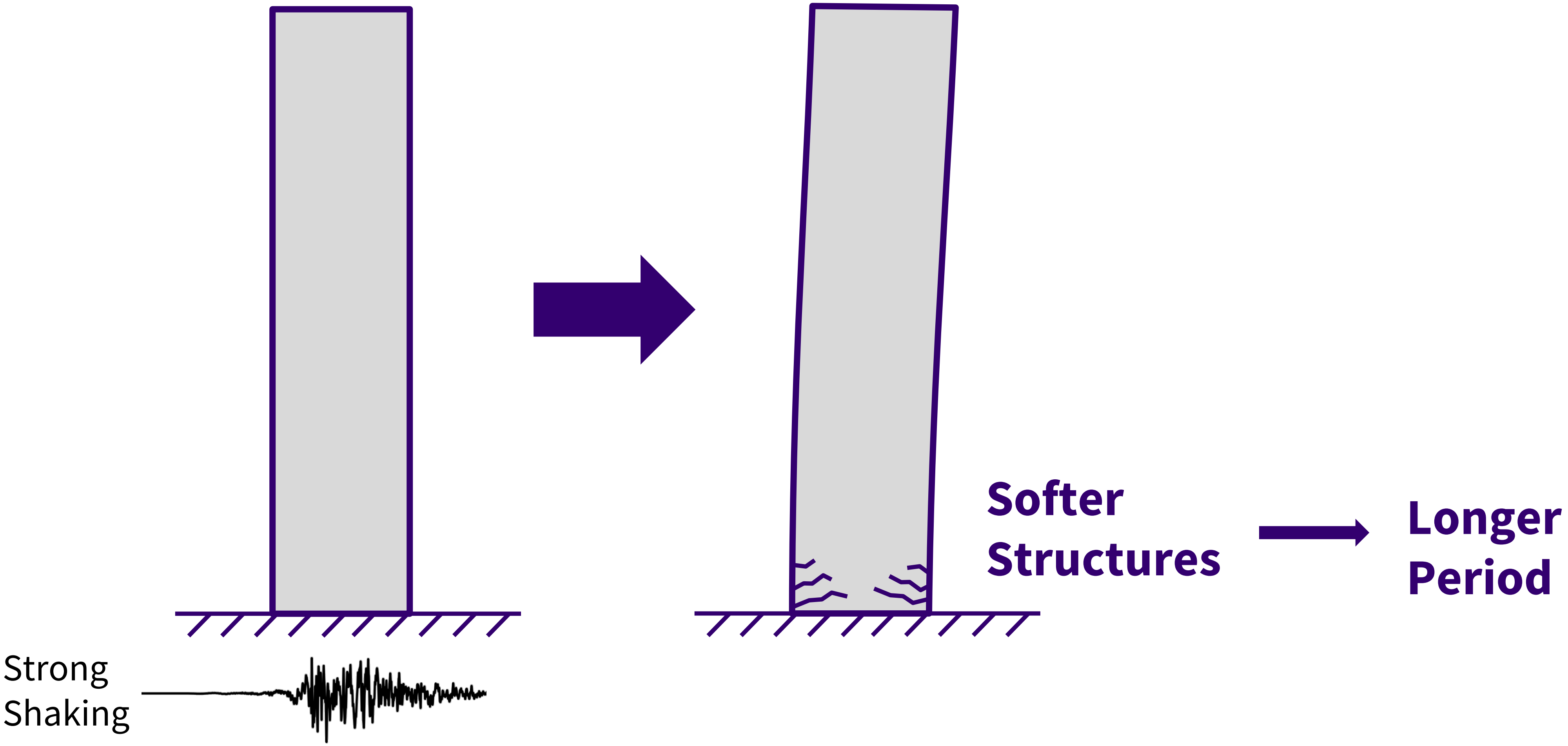
None Exceed MCE_R

Regional Variation of S_a



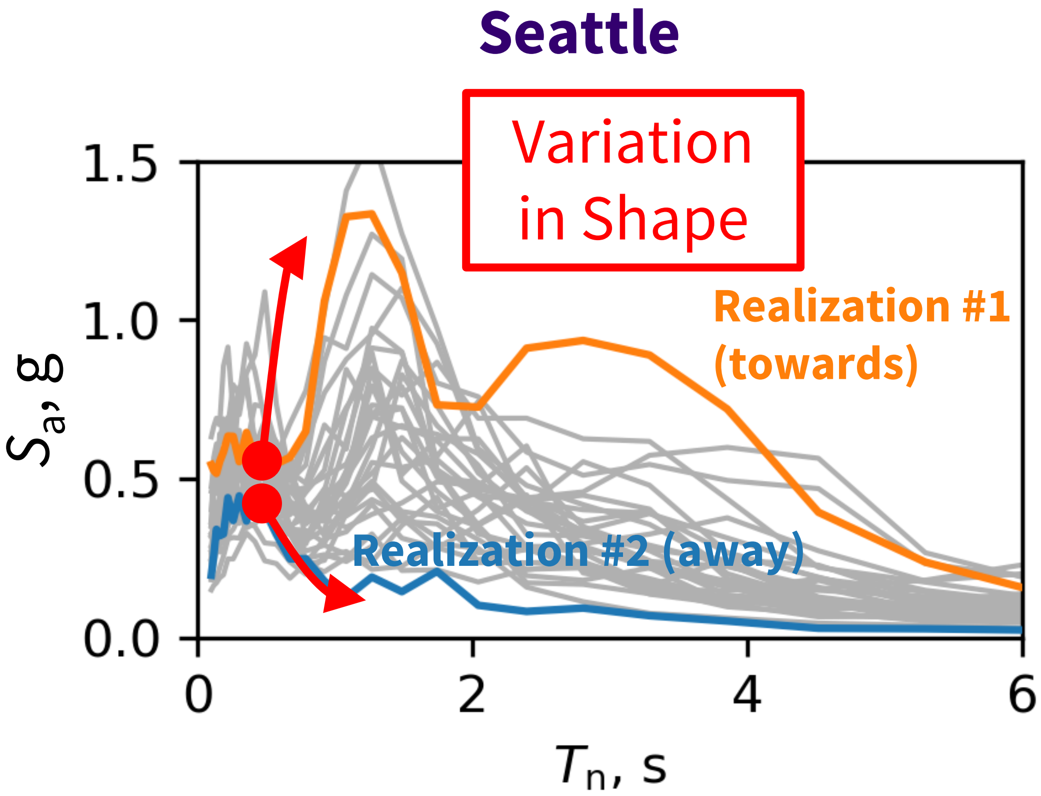
Period Elongation

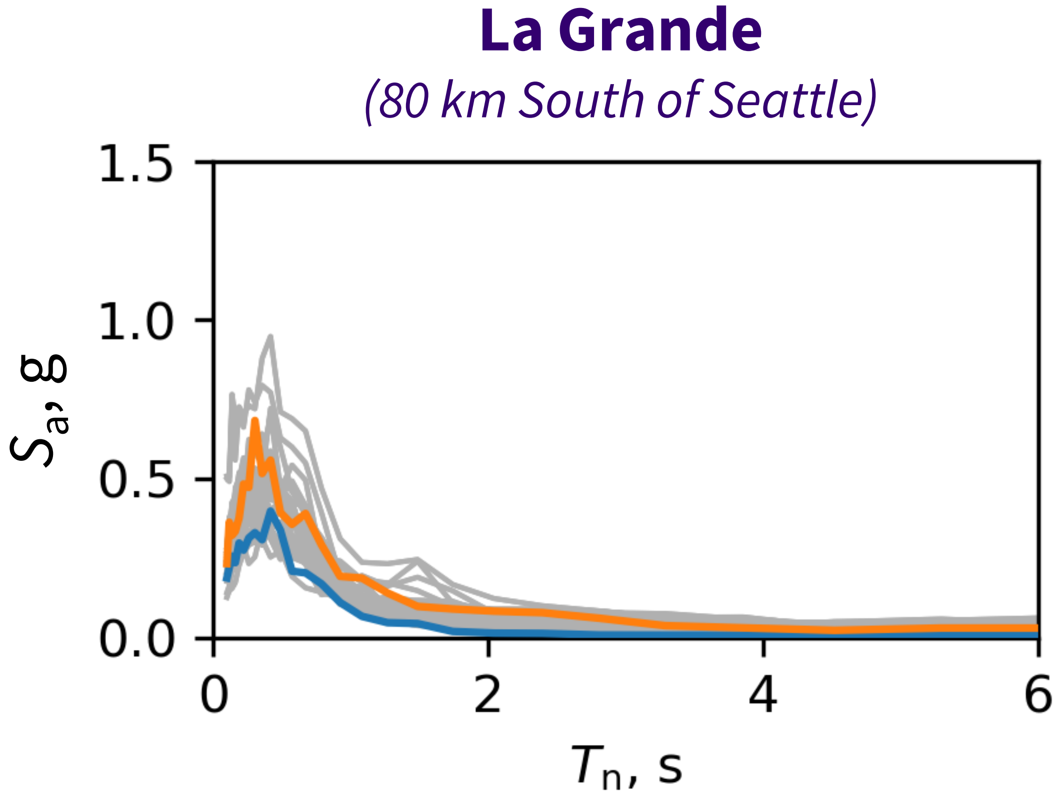
> Structure's period **elongates** under strong shaking



Spectral Shape

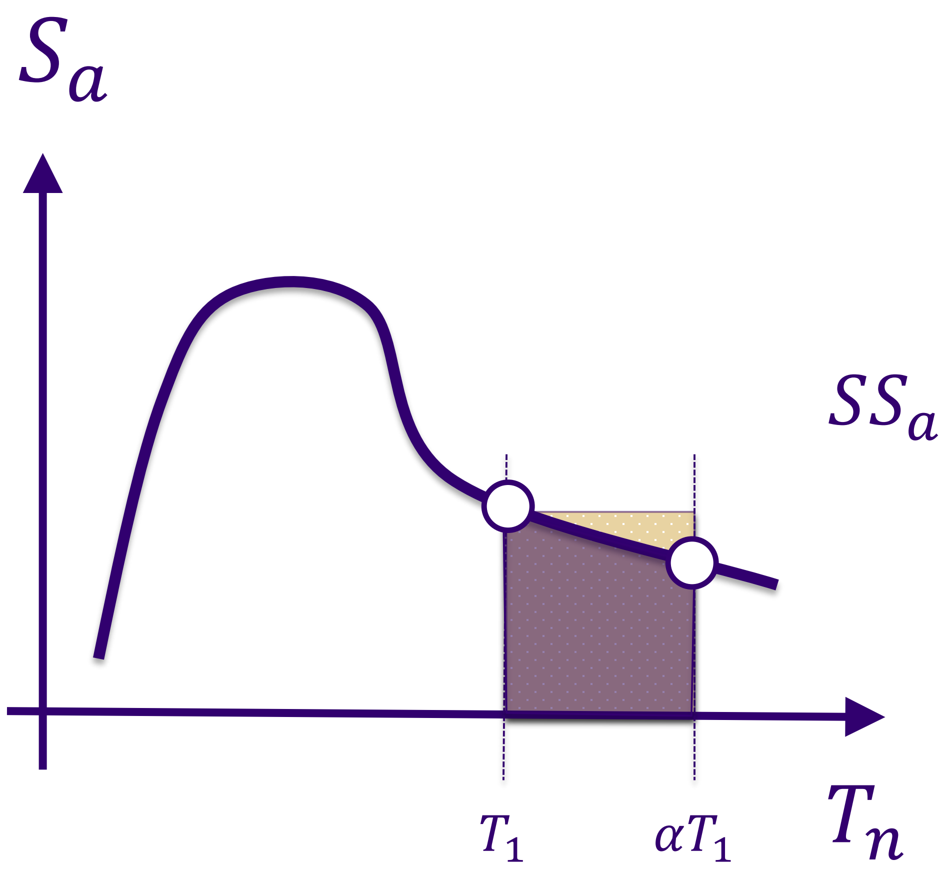
> Frequency content at periods longer than the elastic period **matters**





Measuring Spectral Shape

> Developed a Spectral Shape Intensity Measure

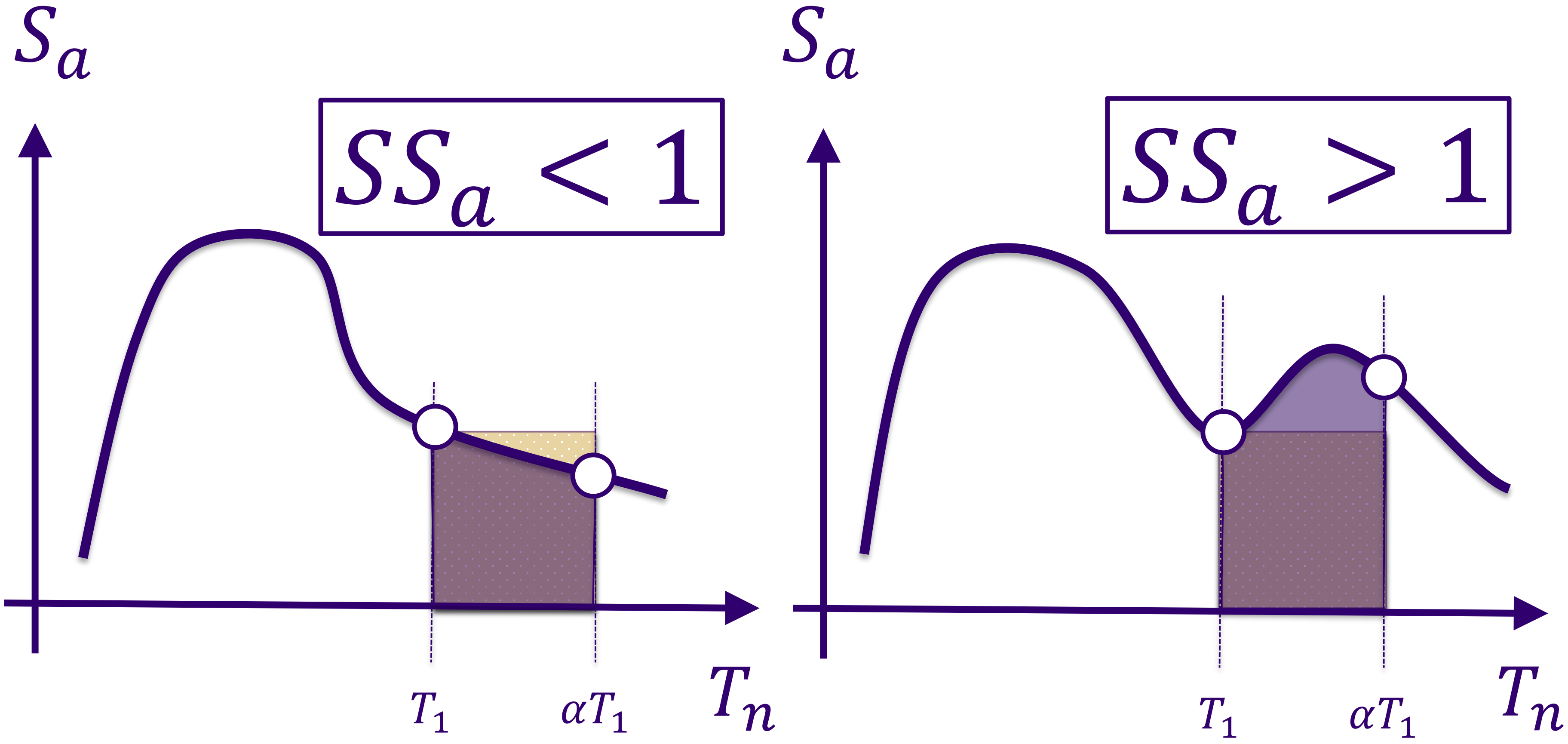


$$SS_a(T_1, \alpha) = \frac{\int_{T_1}^{\alpha T_1} S_a(T_n)\,dT_n}{T_1(\alpha - 1)\, S_a\,(T_1)}$$

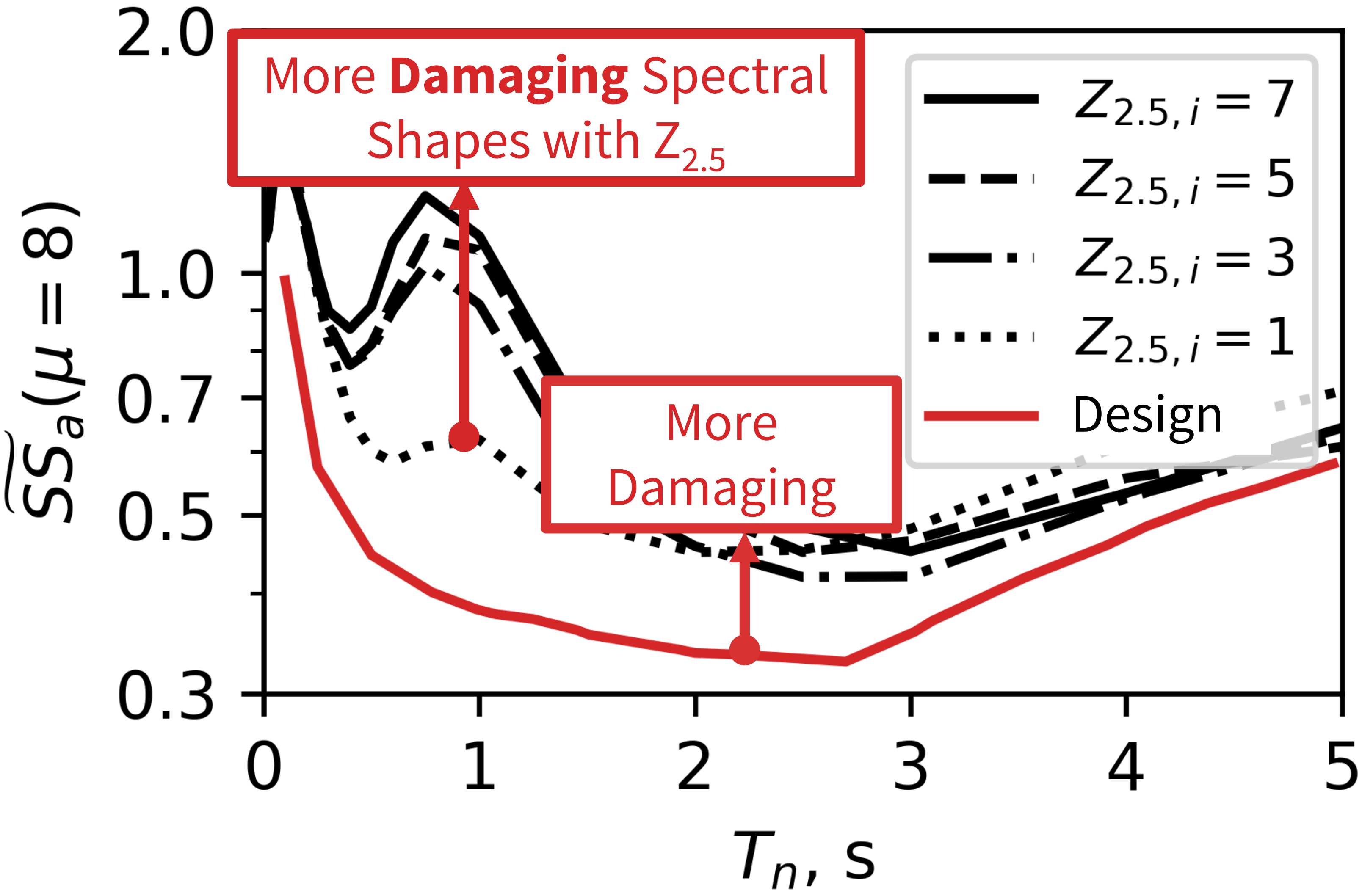
Reference: Marafi, Berman, and Eberhard (2016) Ductility-dependent intensity measure that accounts for ground-motion spectral shape and duration , Earthquake Engineering Structural Dynamics

Measuring Spectral Shape

> Developed a Spectral Shape Intensity Measure



Spectral Shape

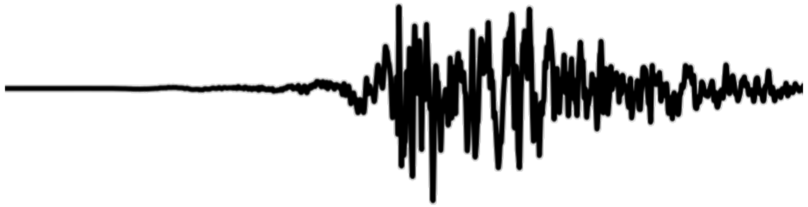


Note: Integrating from T1 to 3.7T_1

Ground Motion Duration

Seattle

Realization #1
(towards Seattle)



~6 minutes long

Realization #2
(away from Seattle)

Longer Durations

↓

More Cycles

↓

More Damage

Reference:
Bommer et al. 2004,
Raghunandan and Liel 2013,
Chandramohan et al. 2015,
Marafi et al. 2016

Summary of M9 Ground Motion Characteristics

high *spectral accelerations*

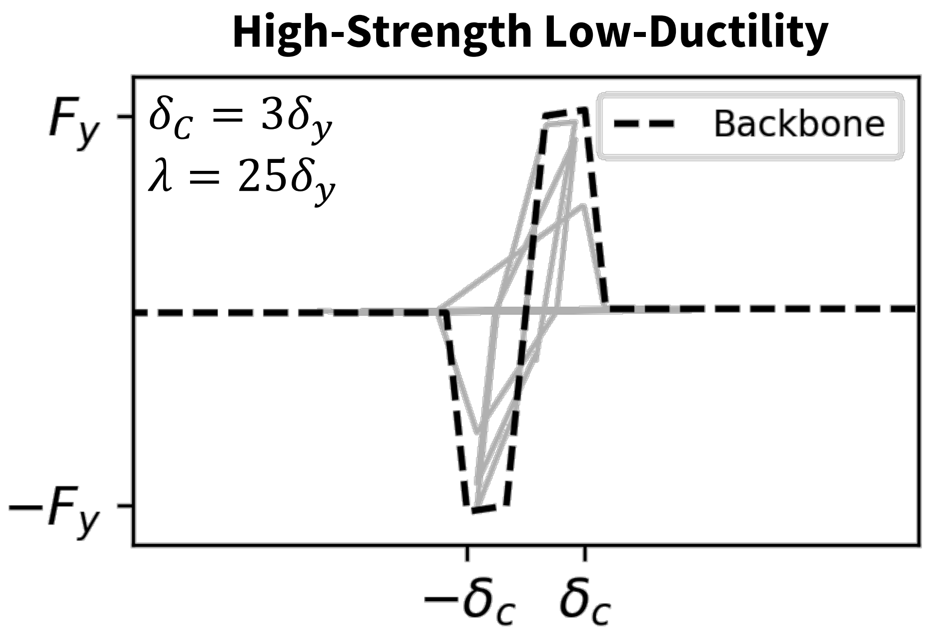
damaging *spectral shapes*

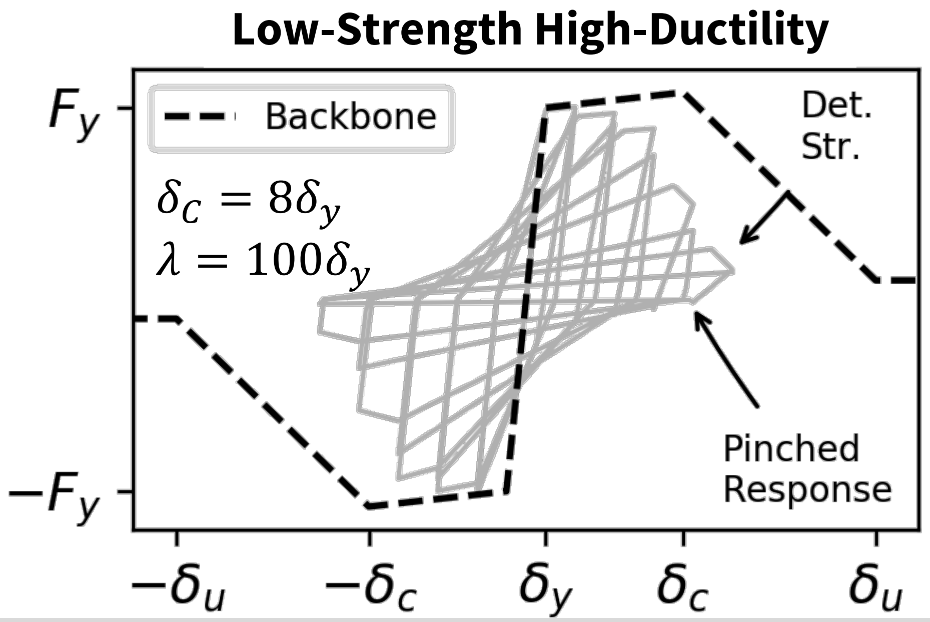
long *durations*

What about structural ***response****?*

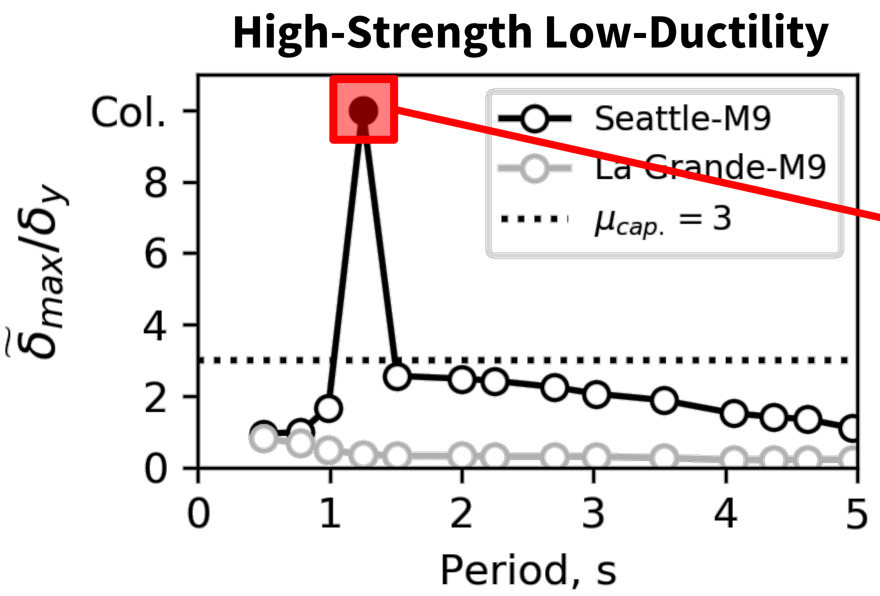
SDOF Properties

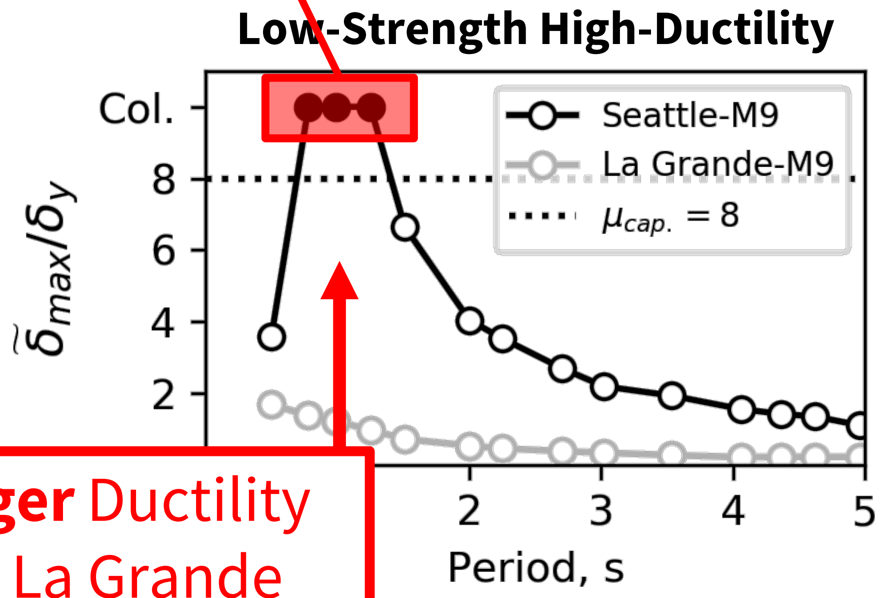
> **Stiffness**
  – Periods: 0.1s to 5s
> **Strength**
  – ASCE 7-16 for Seattle
> **Cyclic Degradation**
  – High-Strength Low-Ductility
    > R = 3, μ_{cap} = 3
  – Low-Strength High-Ductility
    > R = 8 , μ_{cap} = 8
  – Ibarra-Medina-Krawinkler (IMK) Peak-Oriented Material Model



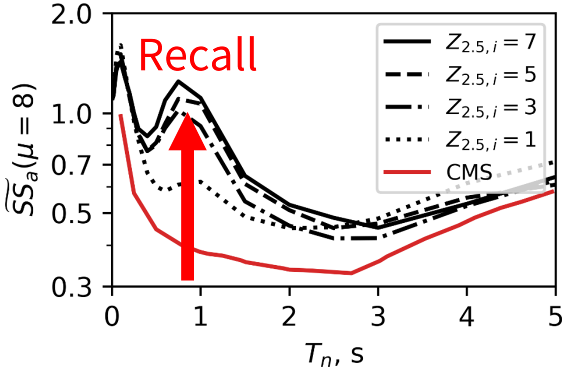


Ductility Demand



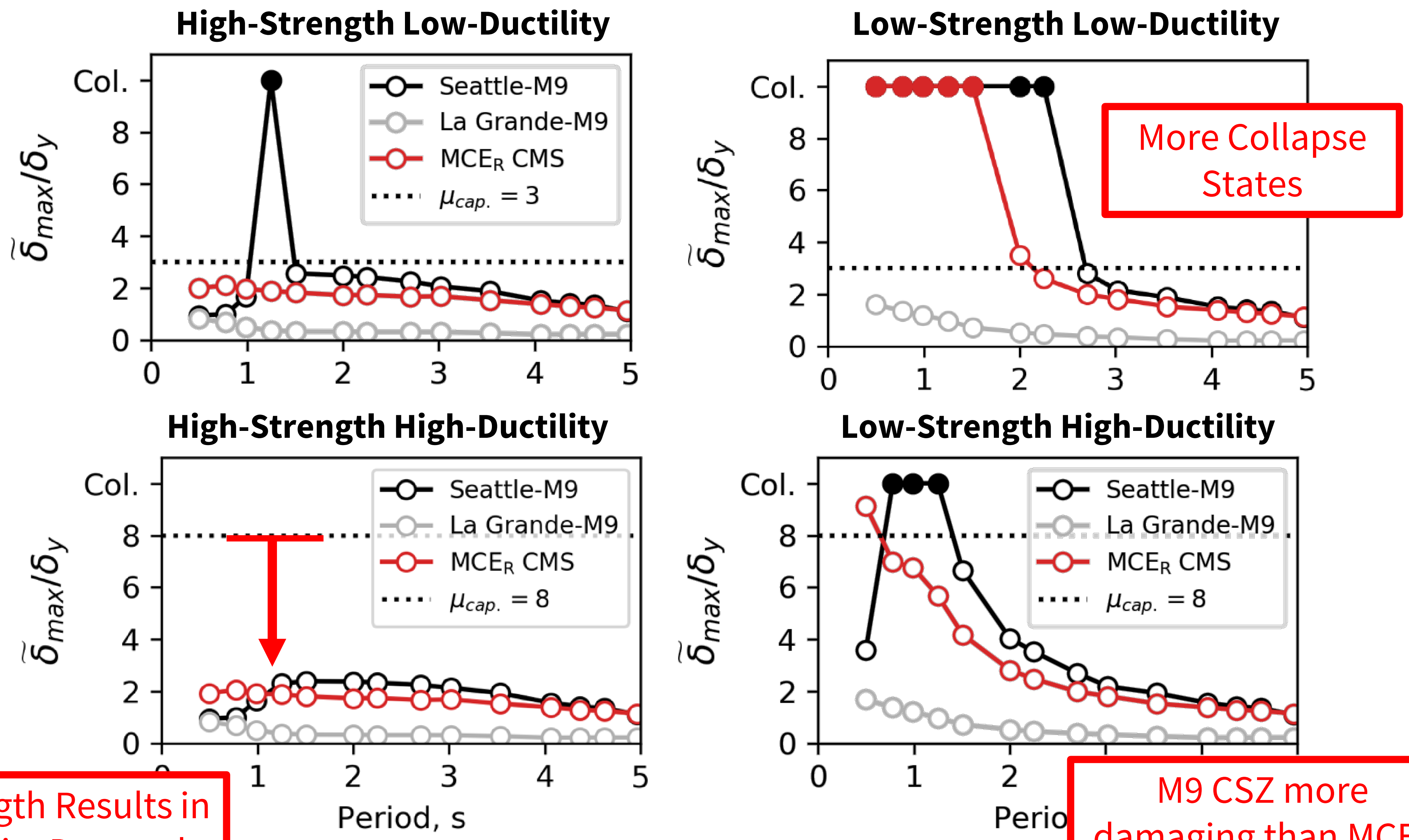


More than 50% of Oscillators **"Collapsed"** at these periods ranges



Seattle has **Larger** Ductility Demands than La Grande

Ductility Demand



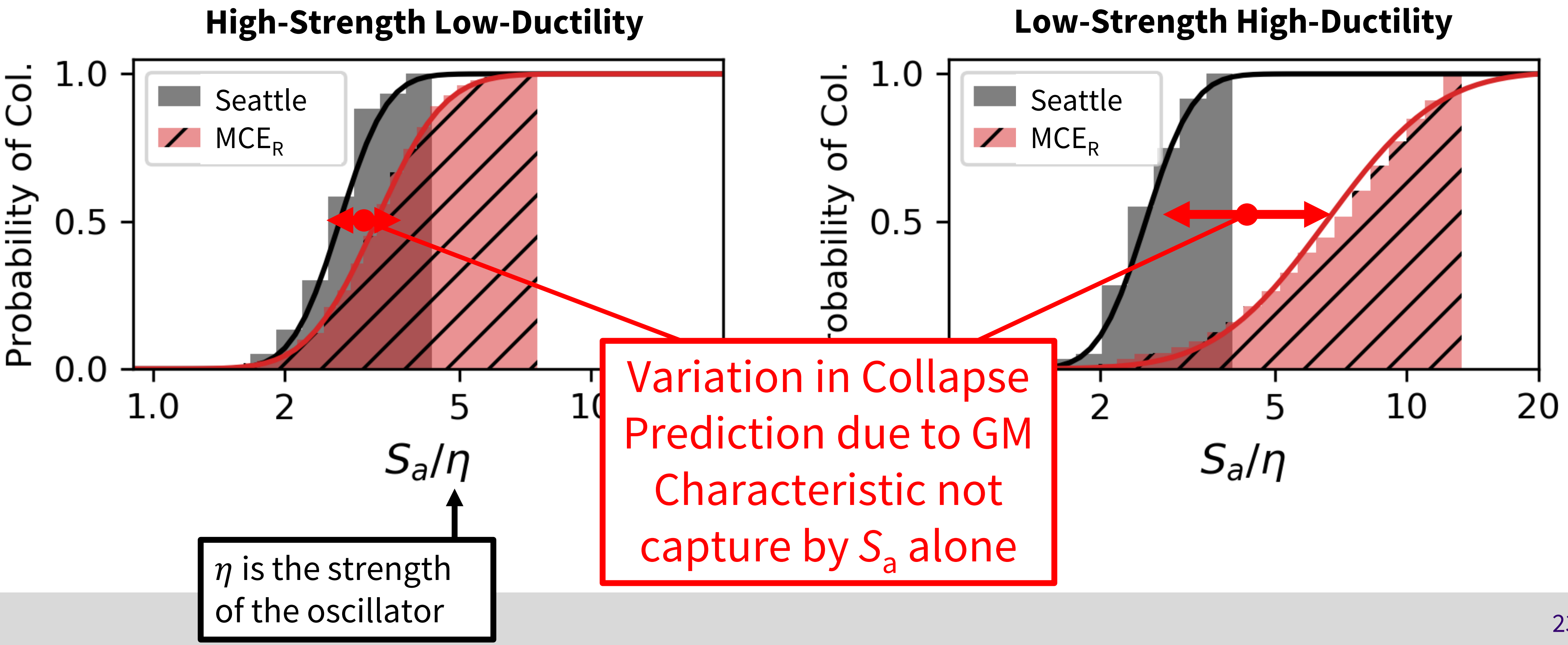
Higher Strength Results in Lower Ductility Demands

M9 CSZ more damaging than MCE_R

Collapse Fragility (S_a)

> Computed using an Incremental Dynamic Analysis

> Normalized $S_{a,c}$ with η and combined all periods within oscillator type



Effective Spectral Acceleration

> Defining Effective S_a

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

> Defining Duration Modifier

$$\gamma_{dur.} = \left(\frac{D_S}{T_n \cdot 12s}\right)^{\boxed{c_{dur}}}$$

For collapse:

$C_{dur} = 0.1$

$C_{shape} = 0.65\sqrt{\mu_{50} - 1} \leq 1.0$

> Defining Shape Modifier

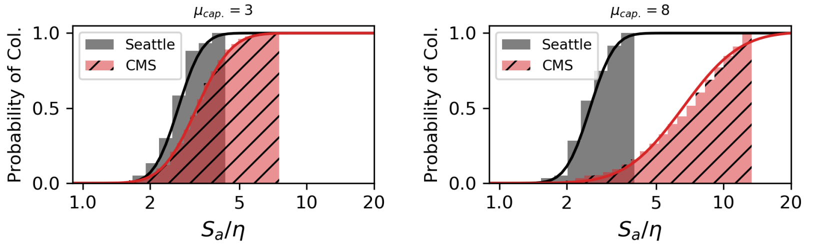
$$\gamma_{shape} = \left(\frac{SS_a}{SS_{a,0}}\right)^{\boxed{c_{shape}}} \quad \text{where } SS_{a,0} = \boxed{\frac{\ln \alpha}{\alpha - 1}}$$

Integral of $1/T_n$

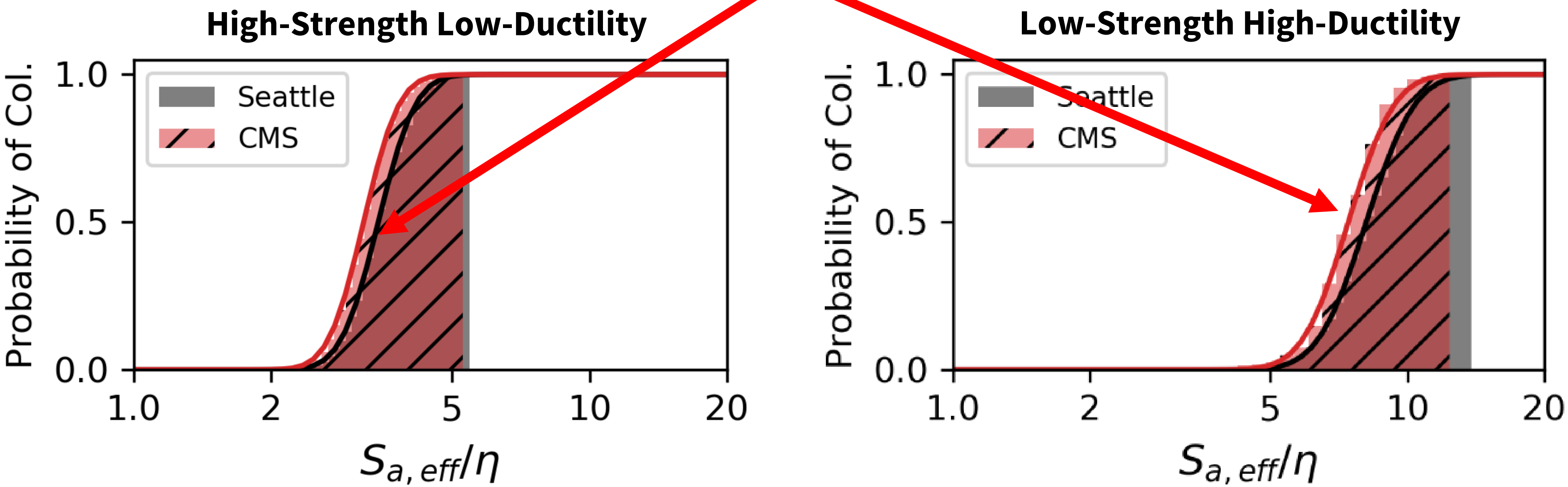
> What do they mean?

– $\boldsymbol{\gamma}$ **> 1 more** damaging & $\boldsymbol{\gamma}$ **< 1 less** damaging than those considered in structural evaluations

Collapse Fragility ($S_{a,eff}$)

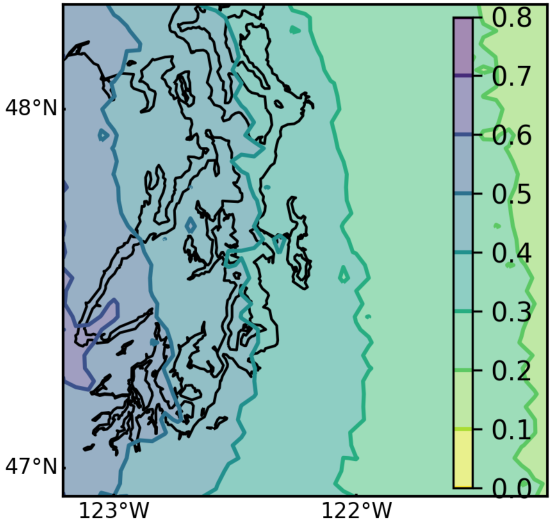


Similar collapse predictions regardless of GMs used



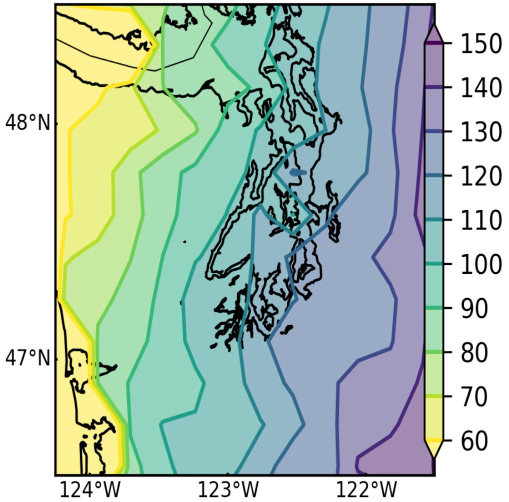
GM Intensity from Physics-based Simulations

$S_a\,(T_n\!=\!0.5s)$



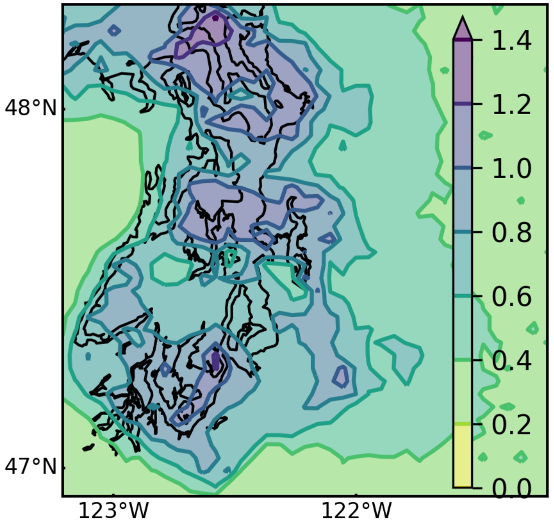
Spectral Acceleration

$D_{S,5\text{-}95\%}$



Ground-Motion Duration

$SS_a(T_n\!=\!0.5s,\mu\!=\!8)$

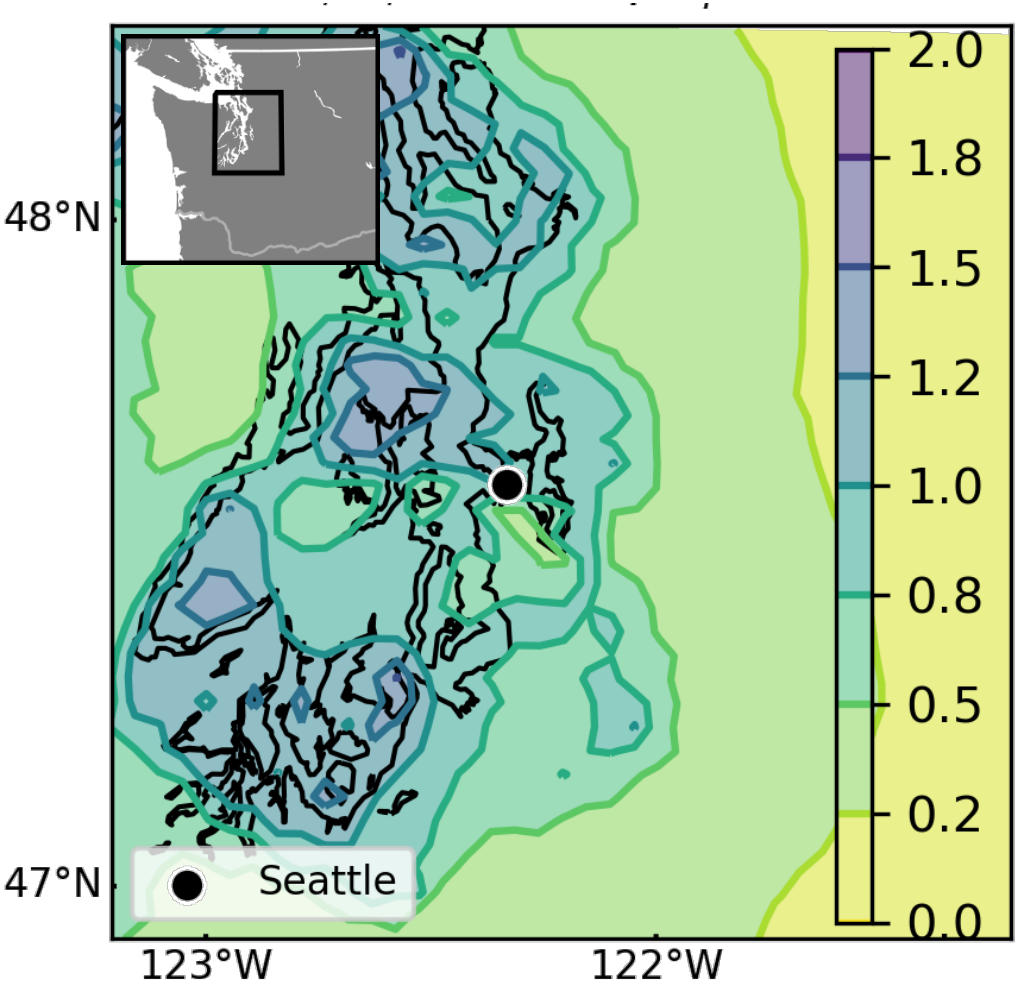


Spectral Shape

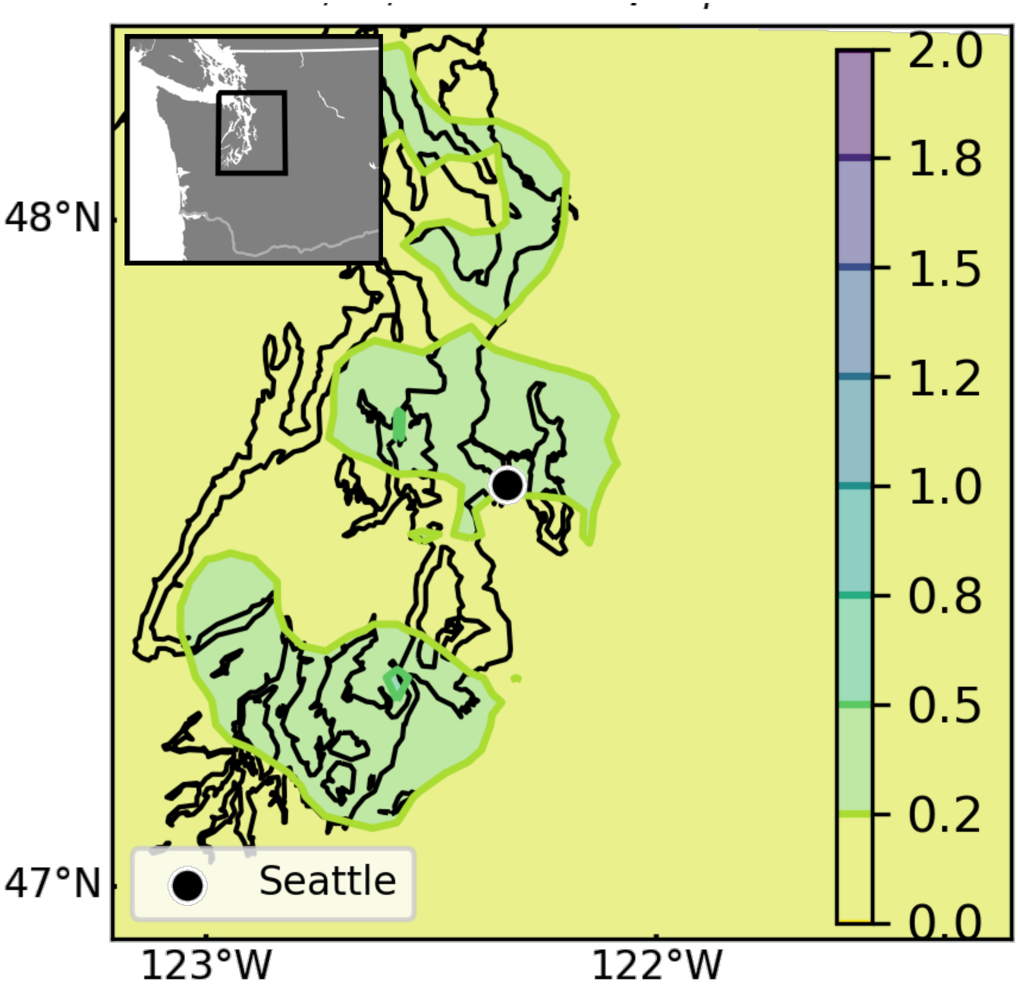
$$S_{a,eff} = S_a \cdot \gamma_{duration} \cdot \gamma_{shape}$$

GM Intensity from Physics-based Simulations

$S_{a,eff.,col}$
(T_n = 0.5 s, Low-Strength High-Ductility)



$S_{a,eff.,col.}$
(T_n = 2.0 s, Low-Strength High-Ductility)

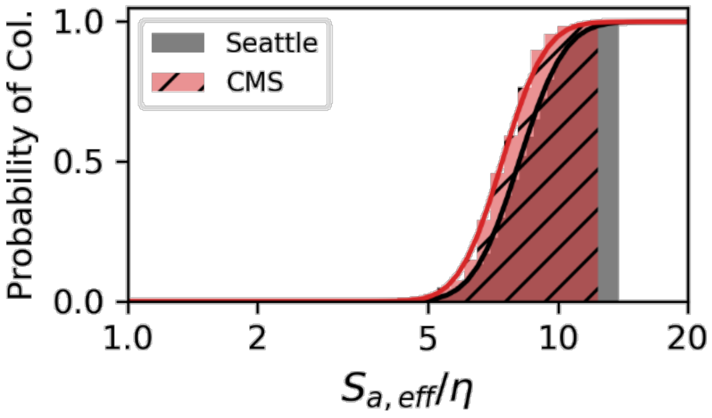


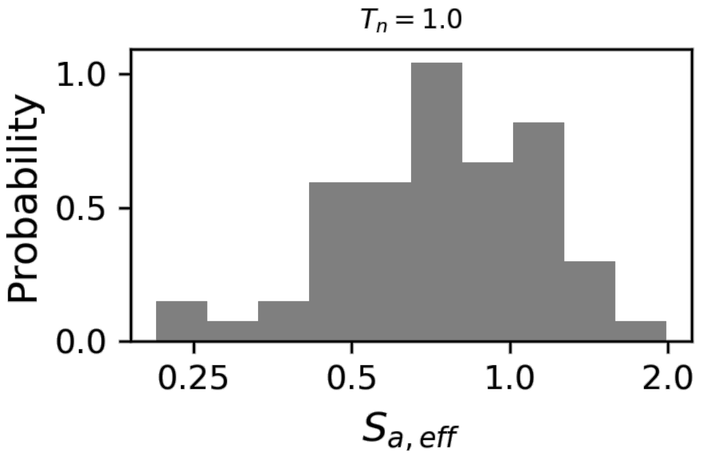
Regional Collapse Predictions in an M9

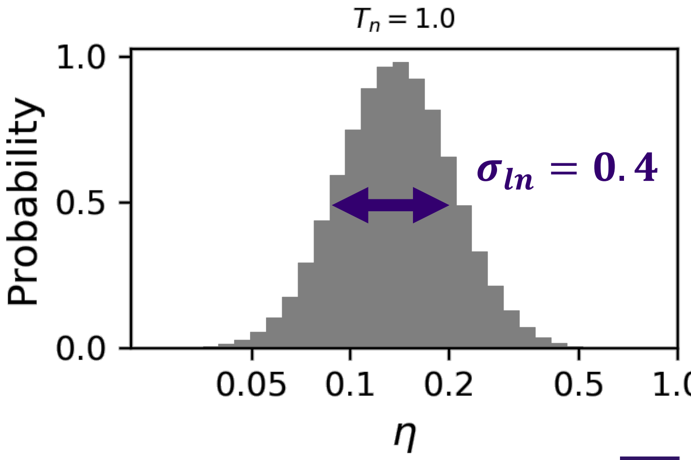
> Compute Collapse Probability (for each location)

$$P[col. \mid M9] = \int\int \underbrace{P[col. \mid S_{a,eff}/\eta]}_{\text{Collapse Fragility}} \cdot \underbrace{f_{Sa,eff}(S_{a,eff} \mid M9)}_{\text{Variation in } S_{a,eff} \text{ in M9 CSZ}} \cdot \underbrace{f_{\eta}(1/\eta)}_{\text{Variation in Strength}} \, d1/\eta \, dS_{a,eff}$$

Low-Strength High-Ductility



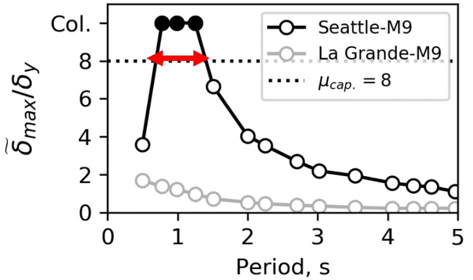




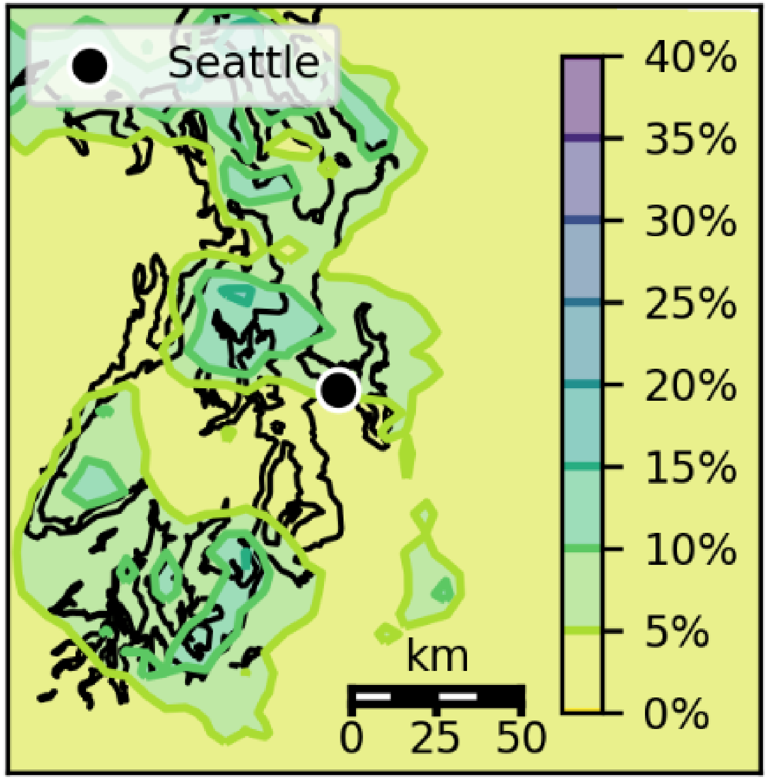
Regional Variation in Collapse Probability

> Collapse Probability for a Low-Strength High-Ductility System

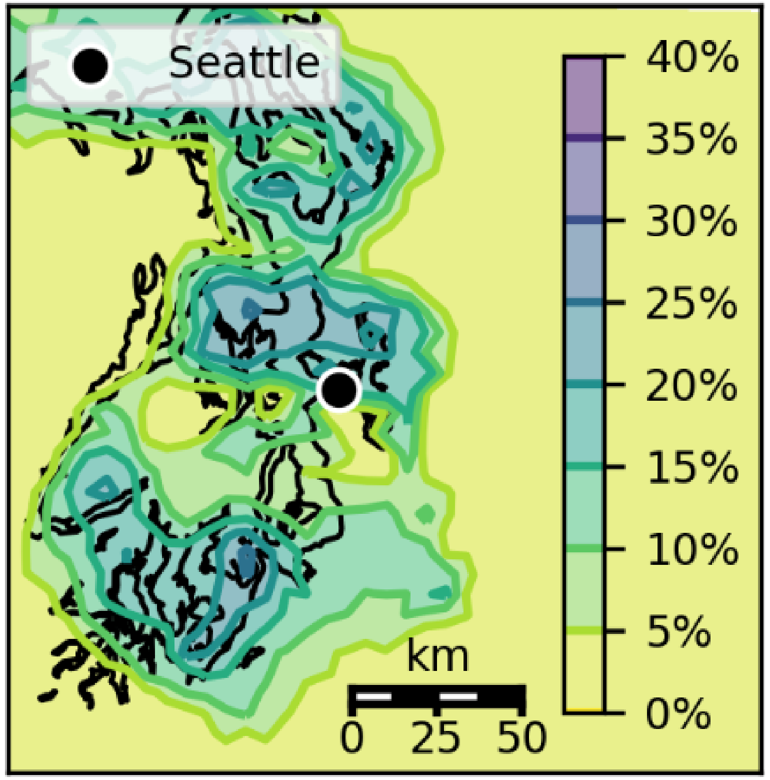
Recall



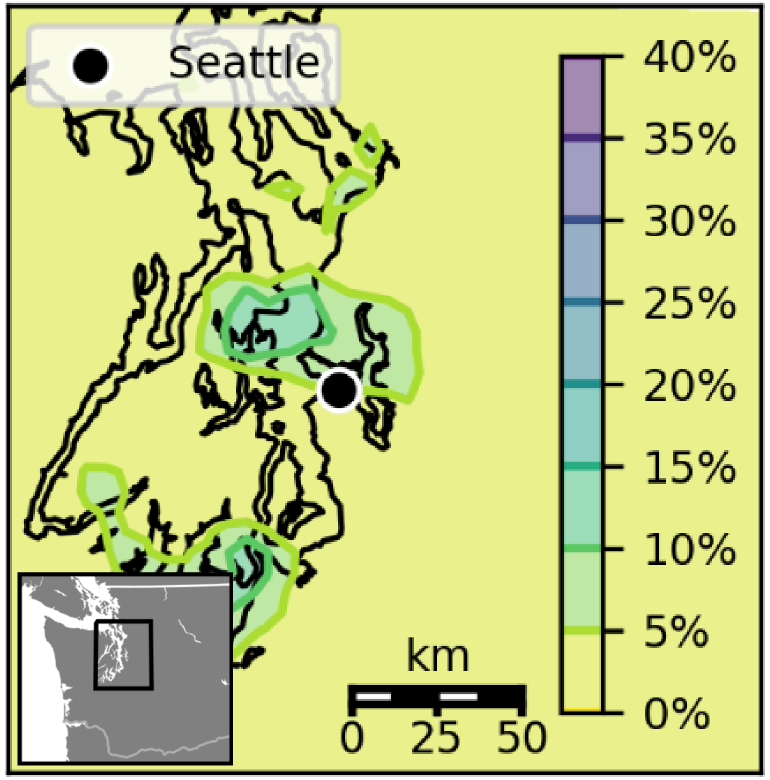
$T_n = 0.5$ s



$T_n = 1.0$ s



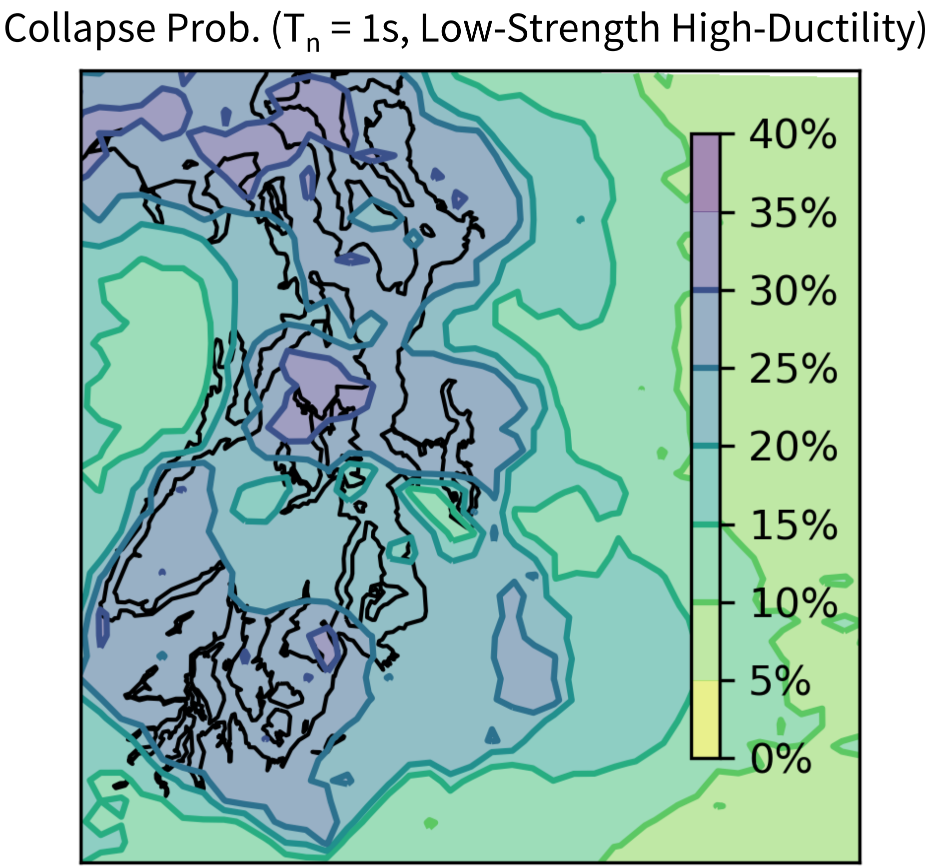
$T_n = 2.0$ s



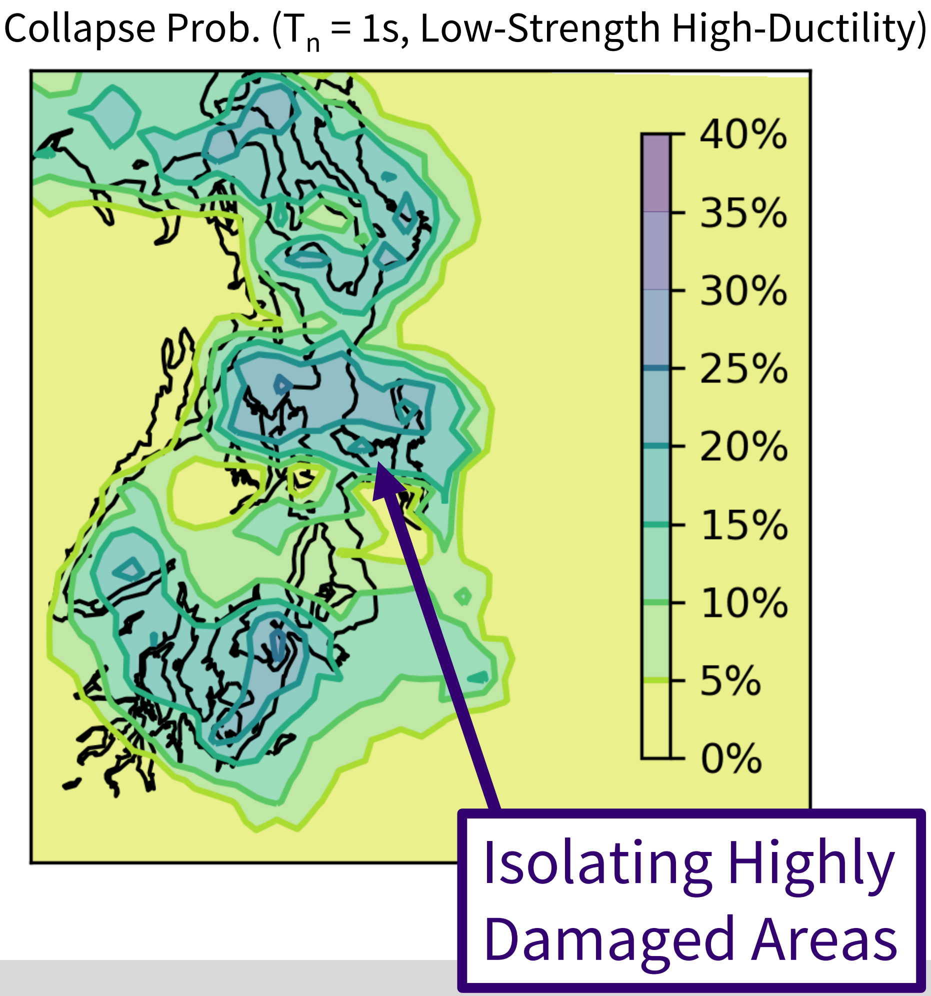
Period with most damage

$S_{a,eff}$ More Efficient than S_a

Using S_a



Using $S_{a,eff}$



Conclusions

> The simulated M9 CSZ motions in Seattle are damaging
  - Large spectral accelerations
  - Damaging spectral shapes
  - Long durations

> Structural Performance
  - Ductility demands in M9 CSZ exceed MCE_R CMS
  - Basin Effects result in large ductility demands at periods between 0.5s to 1.5s.
  - Increasing strength and ductility reduced collapse susceptibility

> Effective Spectral Acceleration ($S_{a,eff}$)
  - Accounts for the effects of spectral acceleration, shape, and duration
  - Better isolates areas of high collapse probability than S_a

Acknowledgments

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  - National Science Foundation
    - Hazards SEES: Award #1331412
  - United States Geological Survey
  - Earthquake Engineering Research Institute
    - Graduate Student Fellowship

> *Hazards SEES (M9 Project) Team:* Arthur Frankel, Erin Wirth, John Vidale, Steve Kramer, Andrew Makdisi, Alex Grant, Mike Greenfield, and others

Award #: EAR-1331412

Thank You!