Direct, High-Frequency Simulations of M6.5+ Earthquakes on Washington's Crustal Faults

Ian Stone, USGS Seattle
Jan 10, 2023
USGS Subduction Zone Science Workshop

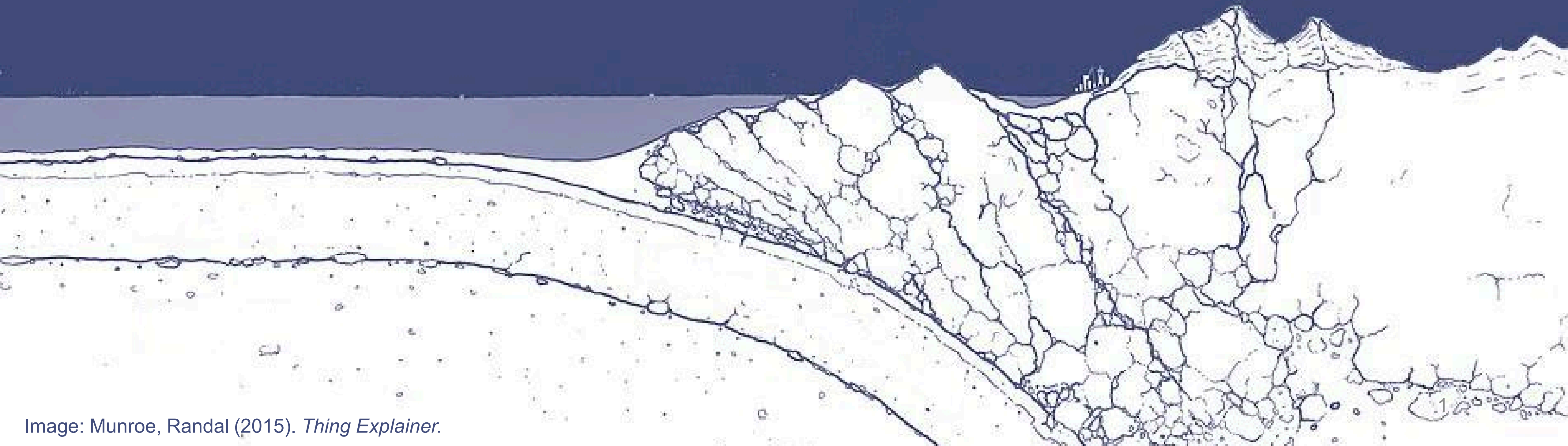


Image: Munroe, Randal (2015). *Thing Explainer.*

Introduction

Subduction in Cascadia influences seismic hazard well inland

- Oblique subduction, along with tectonic forcing from the south, results in deformation of the upper plate
- Crustal faults have produced large (M6.5+) earthquakes in the past

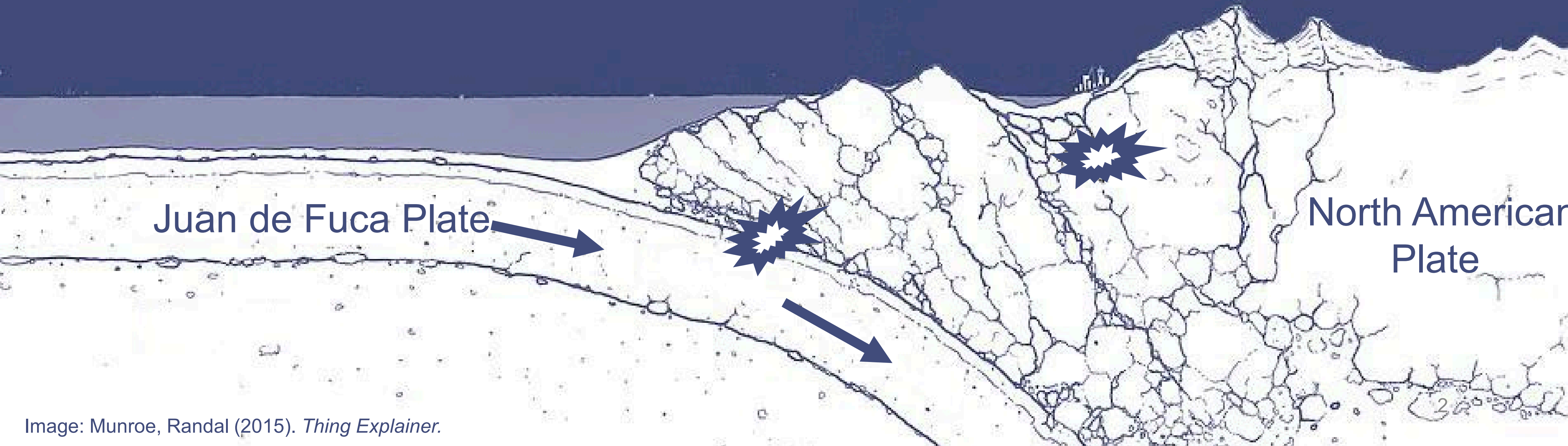


Image: Munroe, Randal (2015). *Thing Explainer.*

Puget Sound Crustal Faults

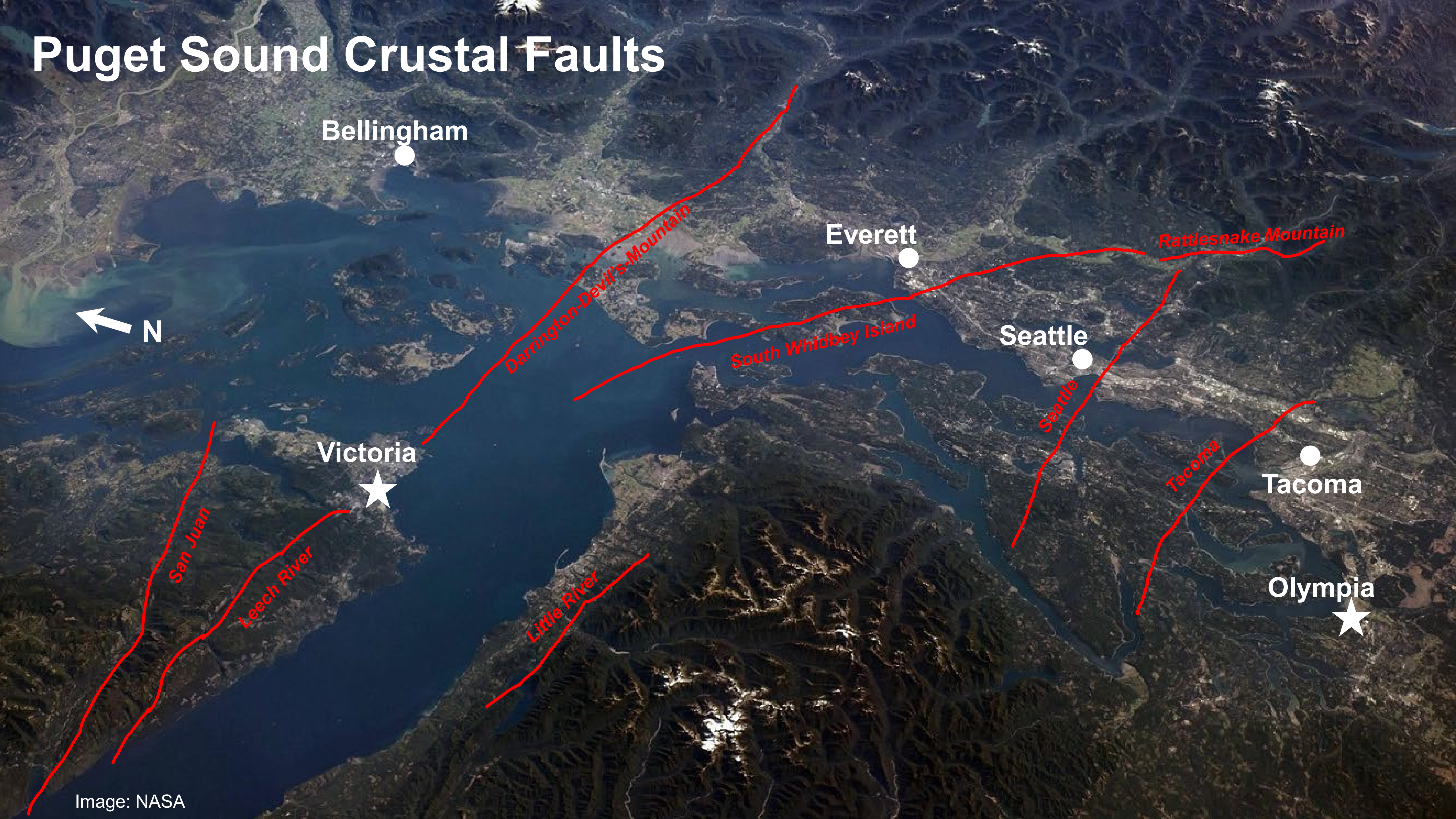
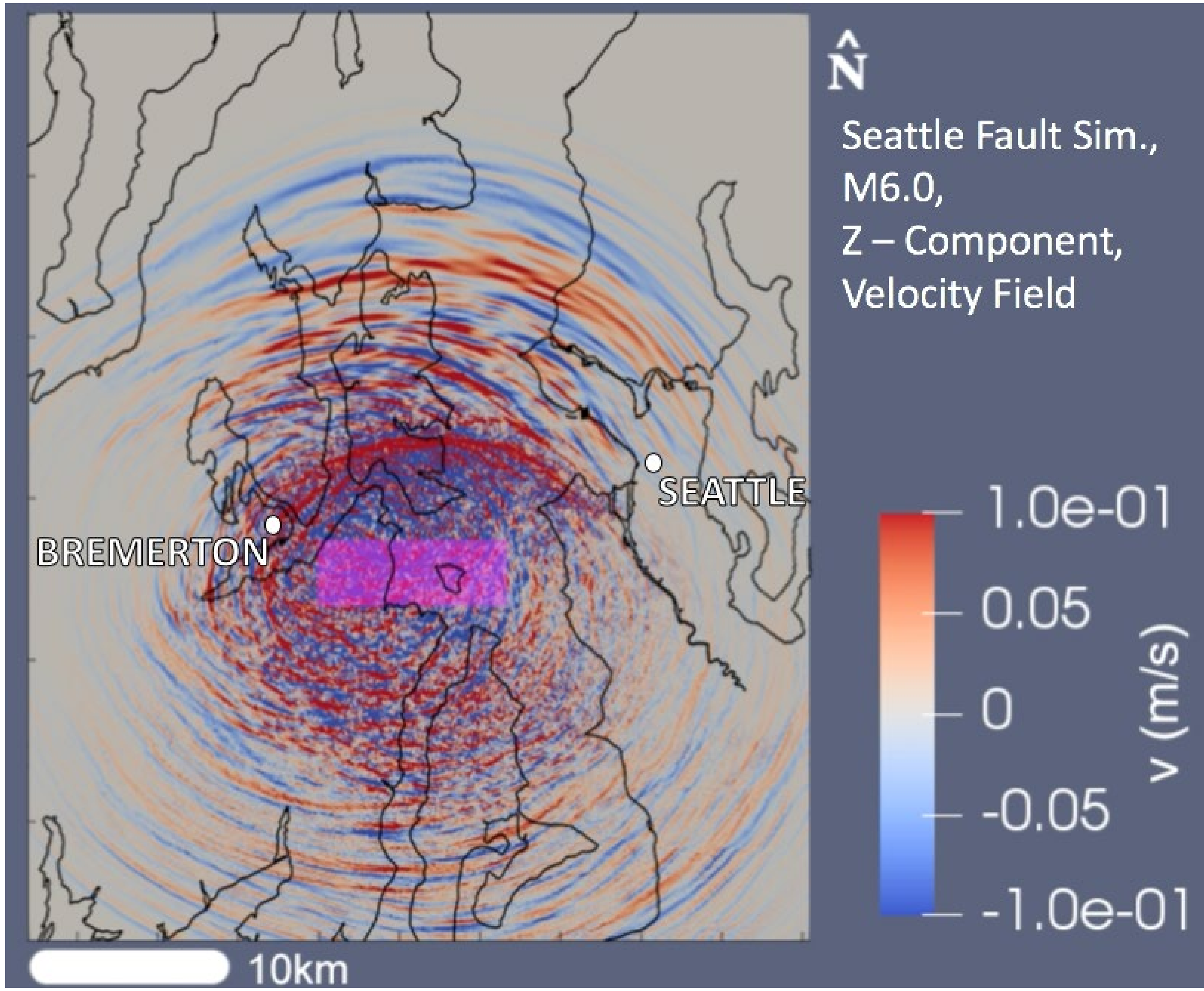


Image: NASA

Crustal Fault Simulations

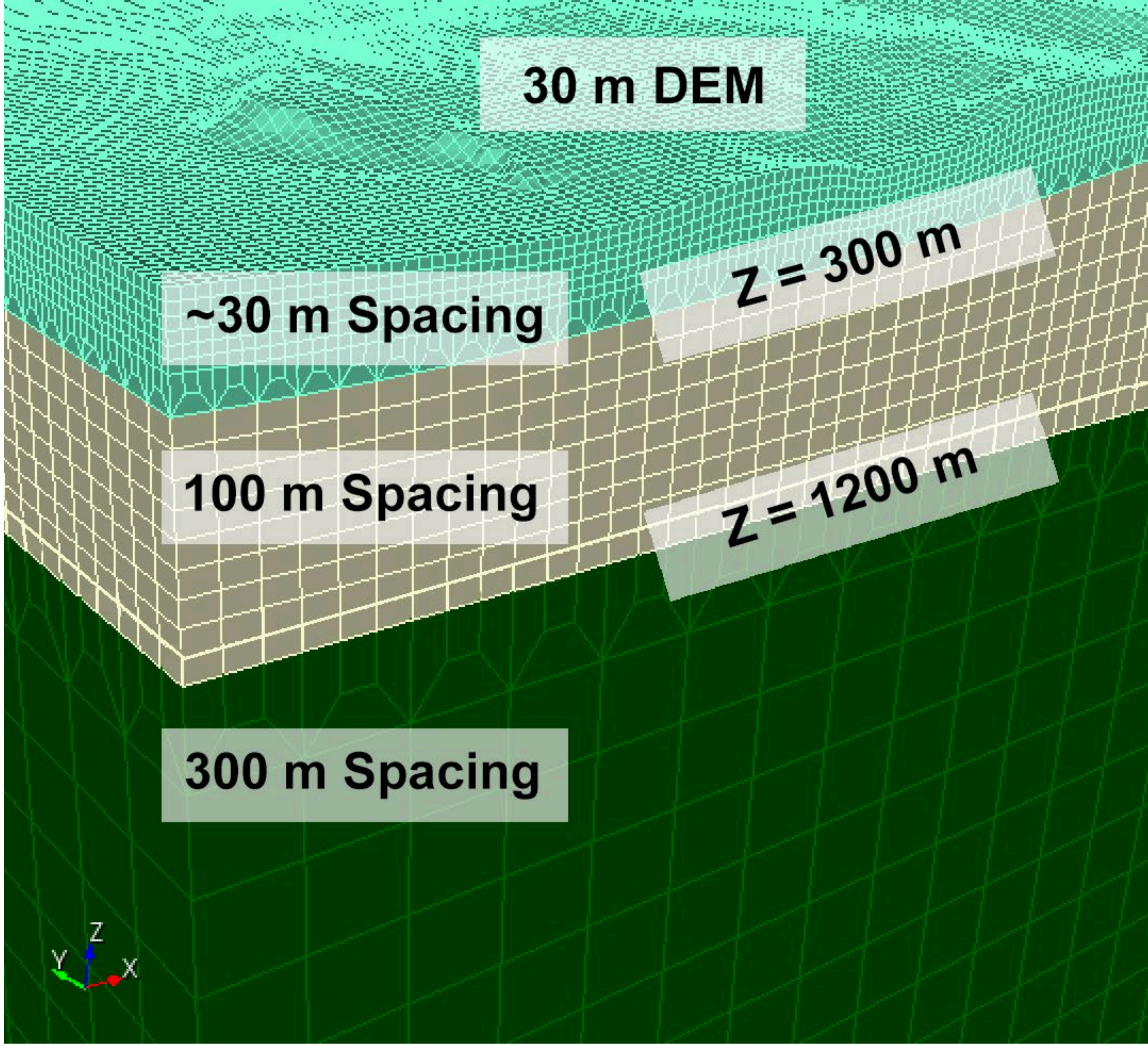
- USGS Seattle is expanding its catalog of directly-simulated ground motions on regional crustal faults
  - Seattle, Tacoma, Southern Whidbey Island Faults



Seattle Fault Earthquake Simulation

Crustal Fault Simulations

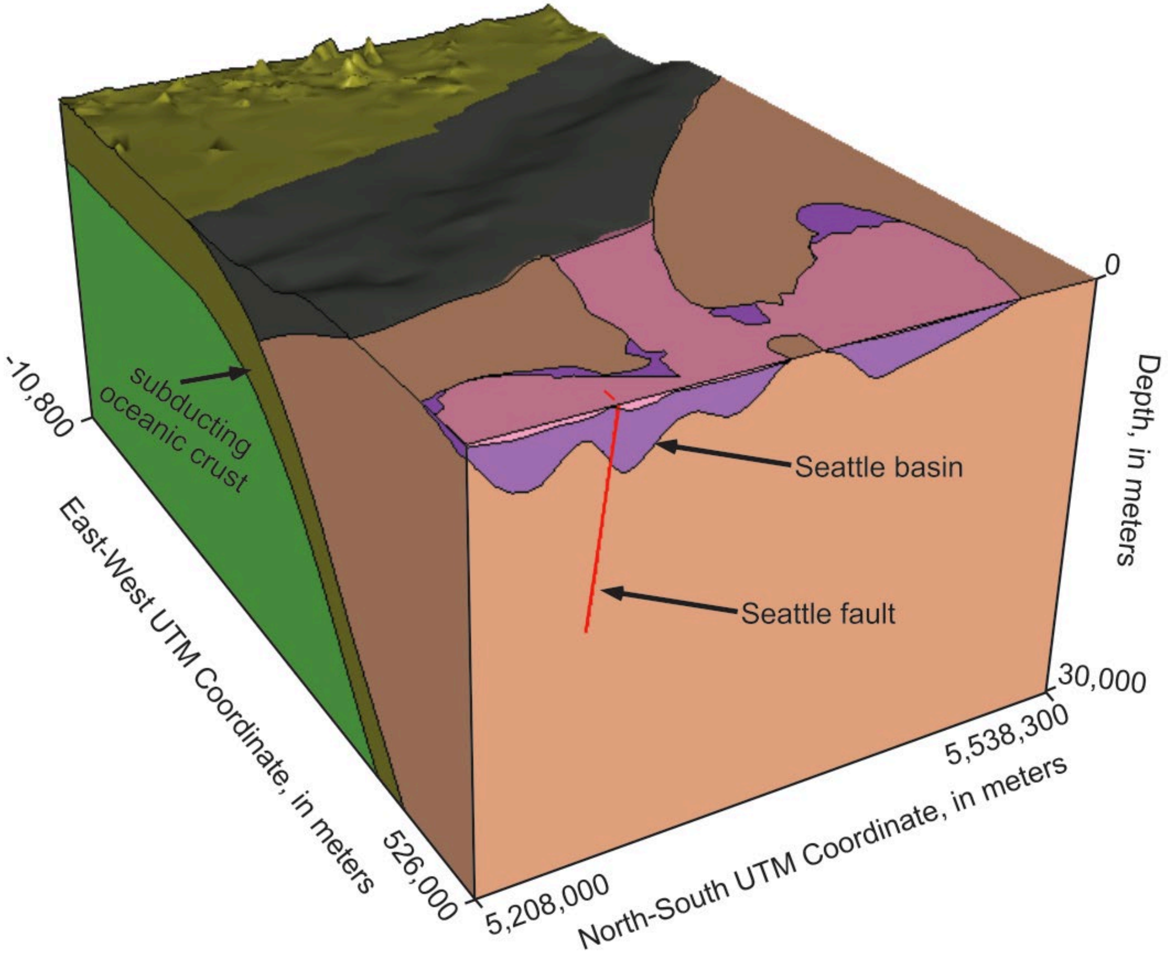
- New simulations can model high frequency ground motions (e.g. 2-3Hz)
  - Allows for modelling effects of shallow velocity structure, topography, etc…
  - … but we must amend seismic velocity model to accurately model high freq. shaking.



Typical mesh spacing for current simulations including topography

Velocity Model Updates

- USGS' Cascadia Velocity Model (CVM) (Stephenson et al., 2017)
  - Considers 3D velocity structure (e.g., sedimentary basins)
  - Accurate for freqs <= 1 Hz
- Lacks near-surface (<100 m) resolution, topography, etc.
- Needed updates to work with higher frequency simulations

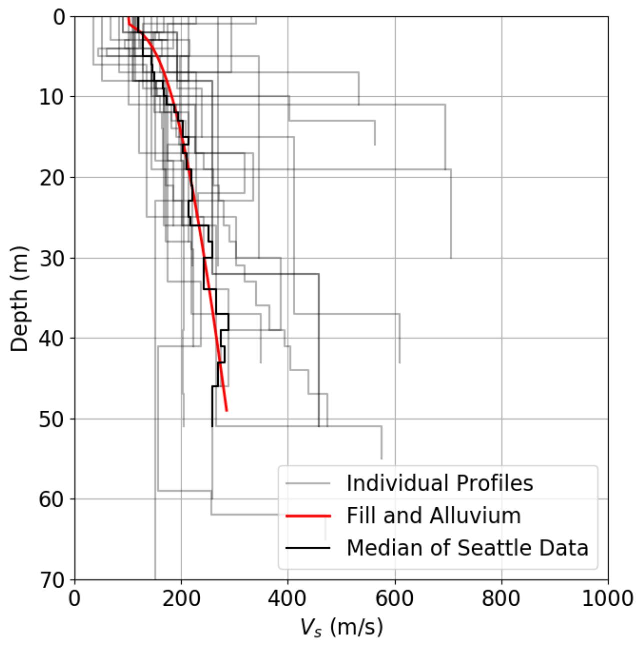


Geologic framework of the Cascadia Velocity Model

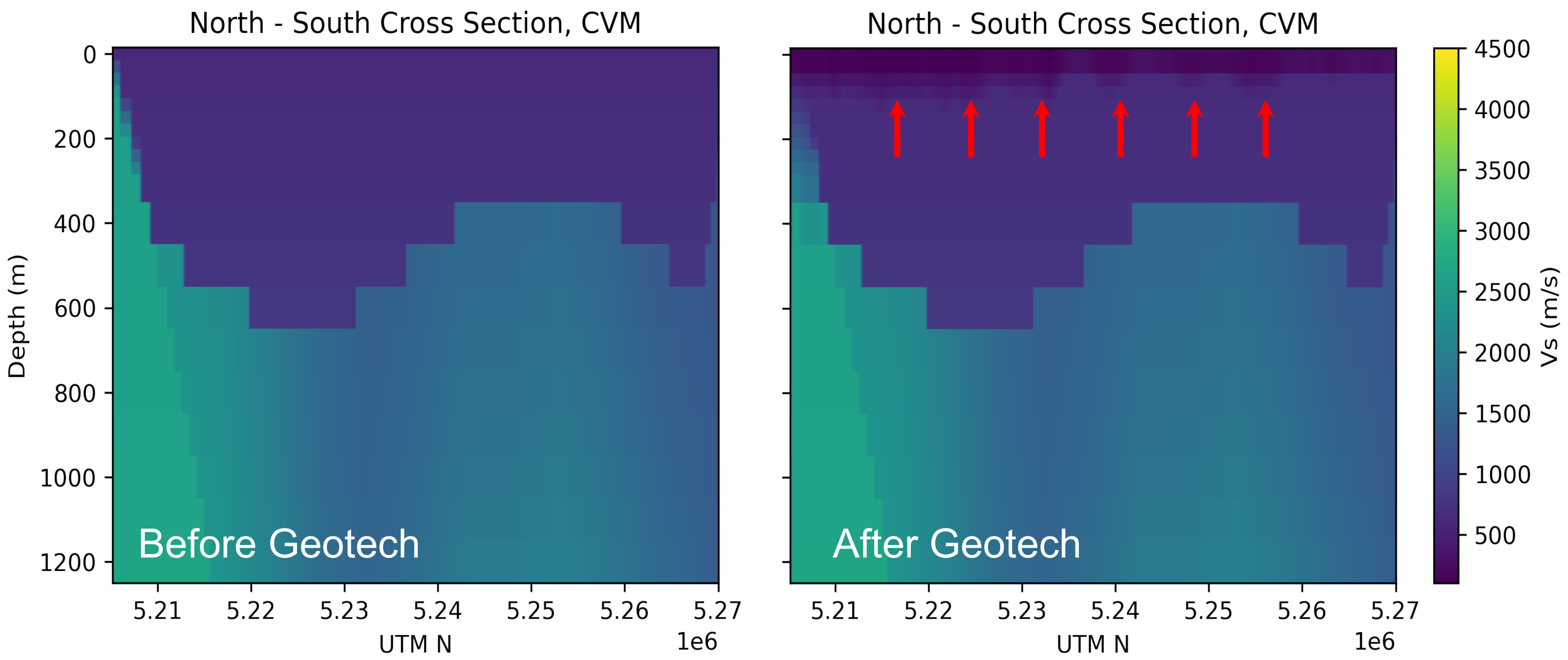
Velocity Model Updates: Geotechnical Gradient

- Amended upper ~100m with a generalized low-velocity gradient derived from regional velocity profiles
    - Profiles vary based on local geology (hard rock, glacial till, fill/alluvium) and site conditions (Vs30)

Example geotech profile for fill/alluvium sites

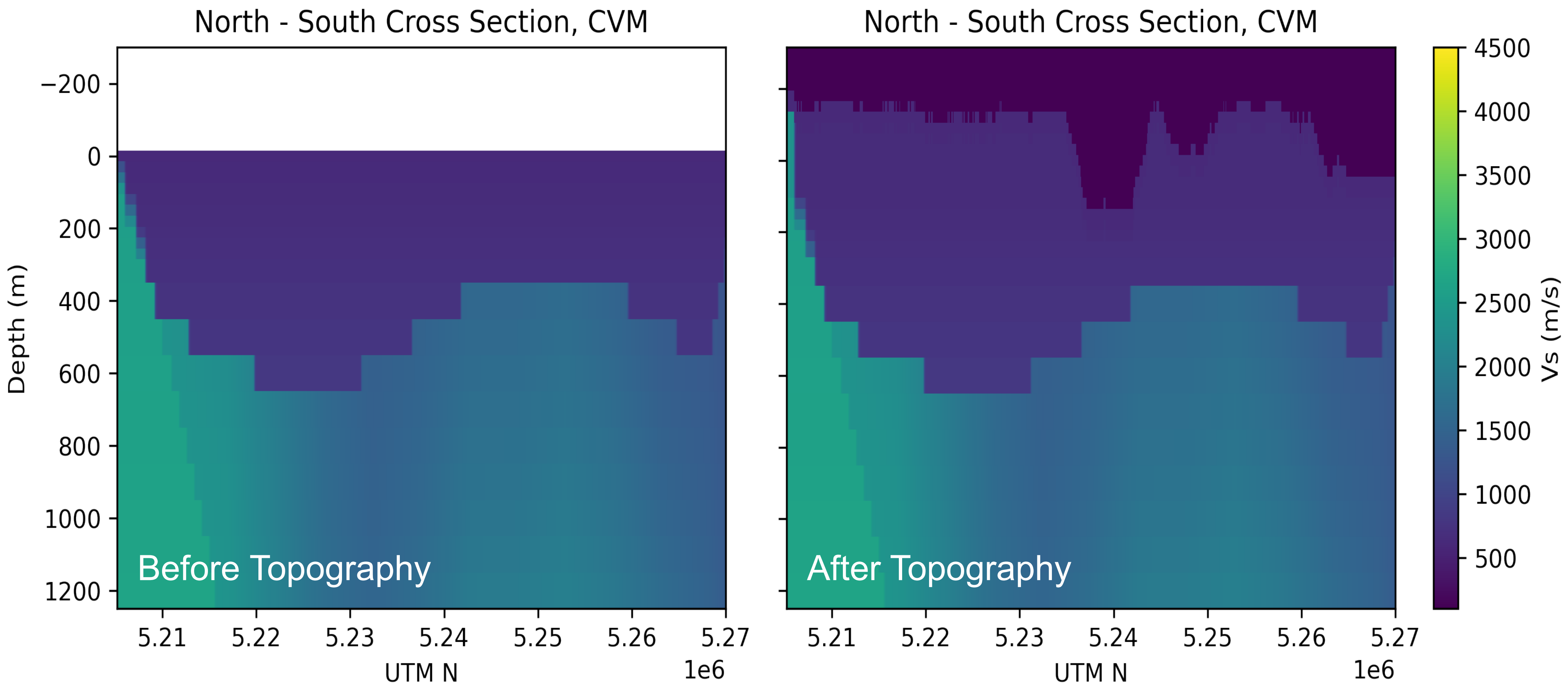


Upper 1.2km of the CVM near Tacoma, before and after adding the geotech gradient



Velocity Model Updates: Topography

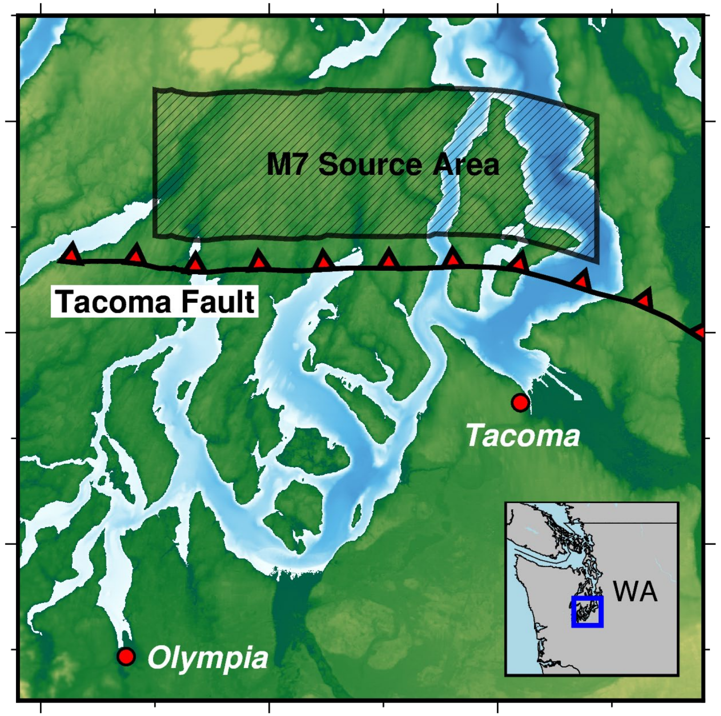
- Topography can significantly alter modeled ground shaking (e.g., Stone et al., 2022)

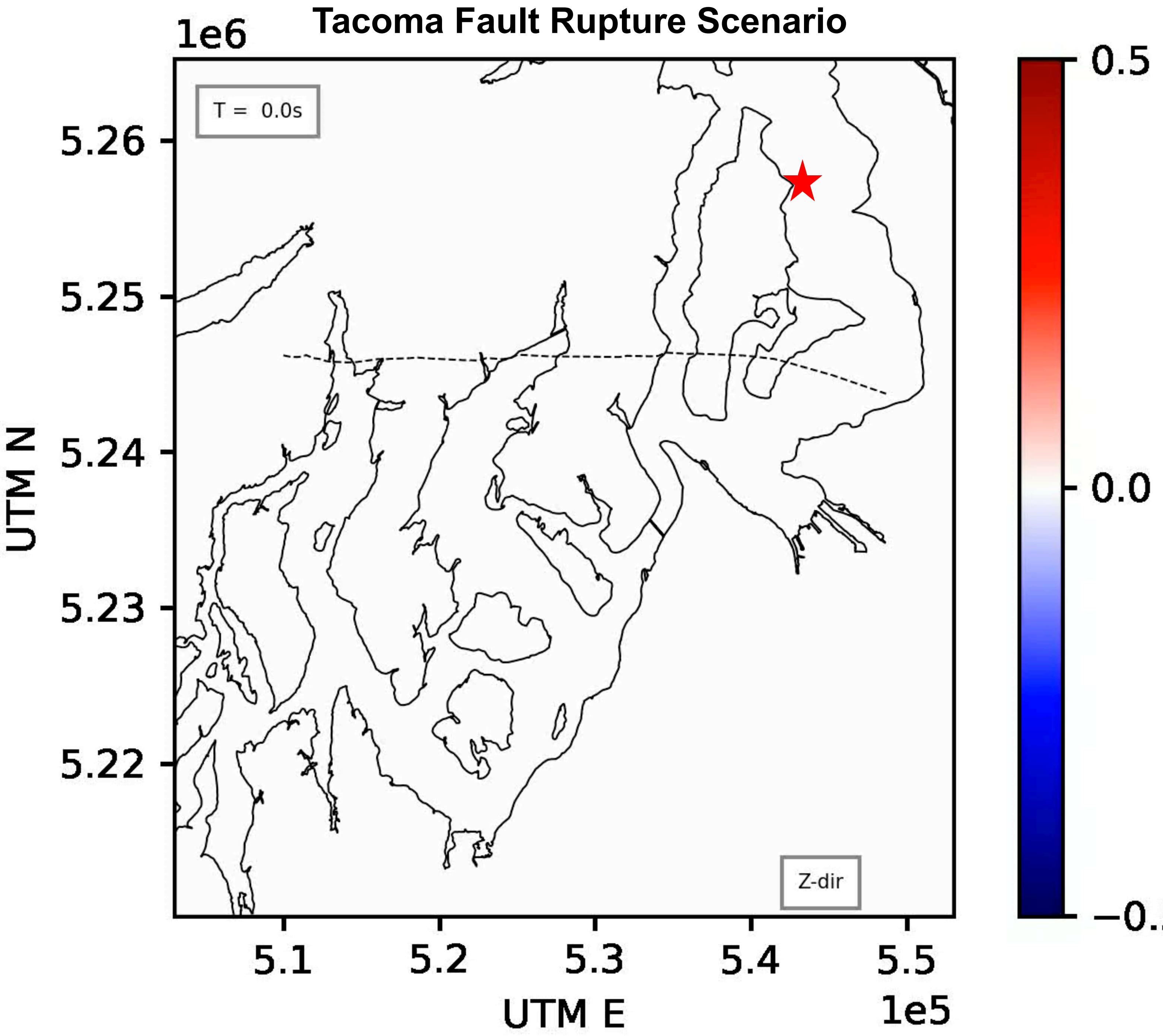


Earthquake Simulations

- SPECFEM3D
- Kinematic, finite fault sources
  - M6.5-7.0
- Geotech profiles, topography, etc.
- Max freq: 2.5 Hz

Tacoma Fault: COMPLETE
South Whidbey Isl. Fault: IN PROGRESS
Seattle Fault: IN PLANNING





Summary

- The USGS in Seattle is producing an updated catalog of **directly simulated ground motions** from M6.5+ crustal earthquakes in the PNW
  - These target high-risk faults, including the **Tacoma (completed), South Whidbey Island (in progress), and Seattle (in planning) Faults**
- We have made updates to the USGS' **Cascadia Velocity Model (CVM)** to accompany these simulations and improve high-frequency (>1 Hz) shaking estimates
  - Updates include addition of a **shallow geotechnical gradient and surface topography**

Results from this work will help improve generalized seismic hazard estimates for the region, and CVM updates will improve future simulations, **both for crustal and megathrust earthquake simulations!**

Photo: Sathish Jothikumar on Flickr

Questions?

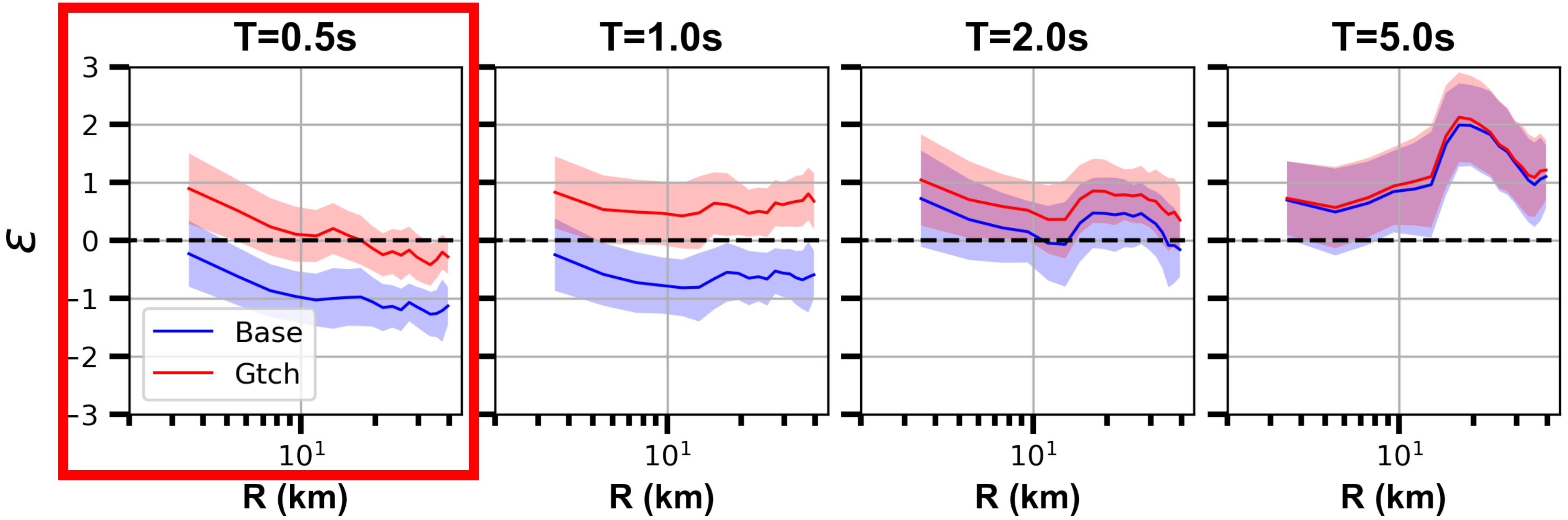
istone@usgs.gov

Photo: Sathish Jothikumar on Flickr

Results

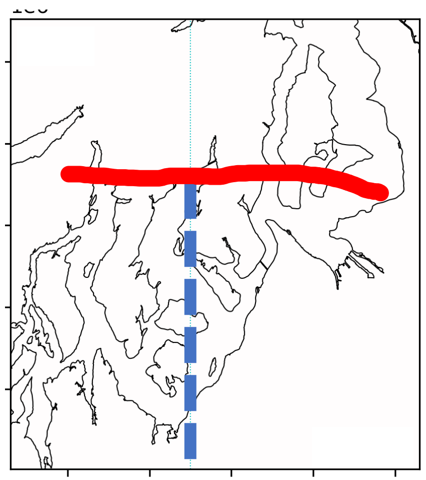
- So far, testing indicates CVM amendments improve high freq. shaking estimates
  - Geotech gradient significantly improves fit of short period shaking (T<1s) to GMM estimates relative to standard CVM

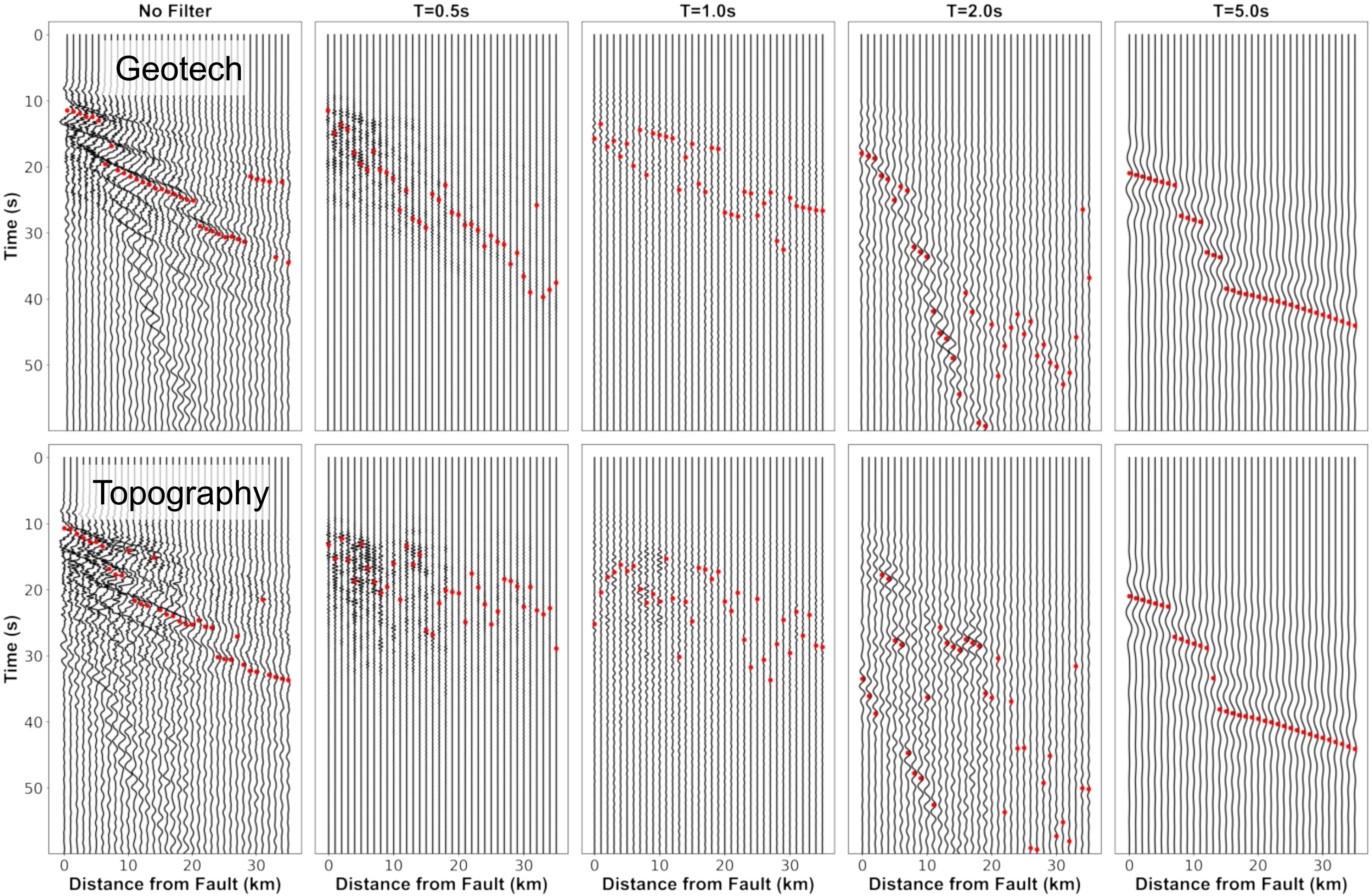
Epsilon (ε) versus distance from the rupture. ε measures misfit with respect to GMMs.
+1ε → ground motion is 1 standard deviation higher than GMMs
-1ε → ground motion is 1 standard deviation higher than GMMs



Comparison: Geotechnical Gradient vs Topography

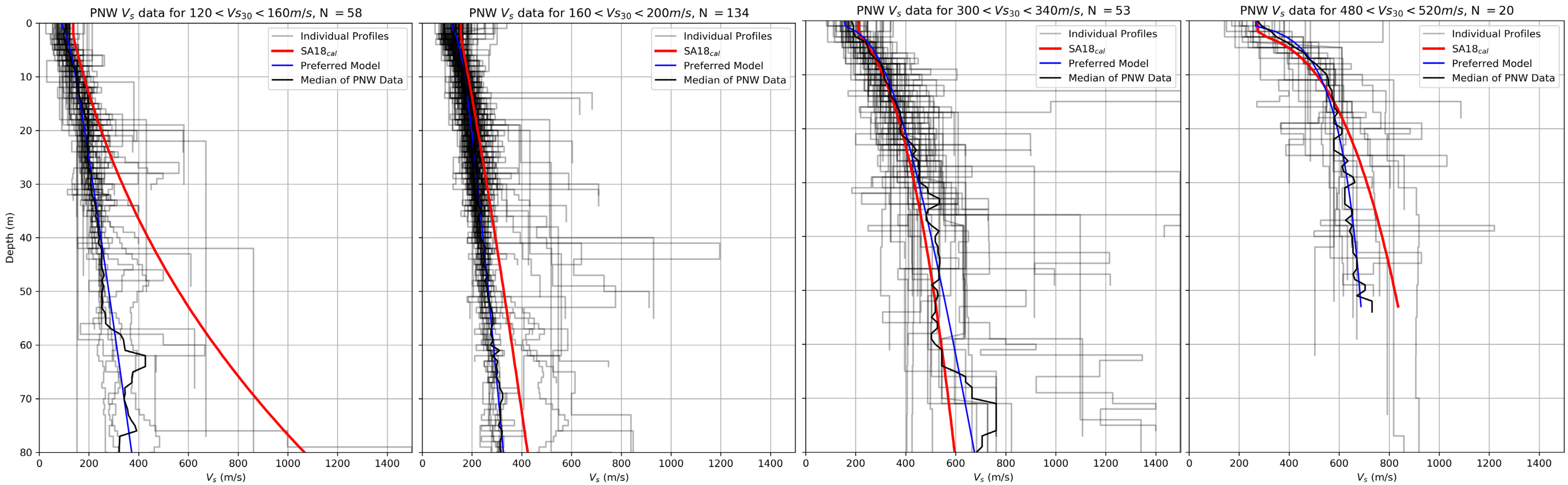
- Topography scatters wavefield at shorter periods relative to Geotech model





Velocity Model: Geotechnical Updates

- Amends CVM with shallow, region-specific velocity profiles (work by Alex Grant and Erin Wirth)



Example fits to PNW Shallow Velocity Data

BLUE: This Study, RED: California (Shi and Asimaki)

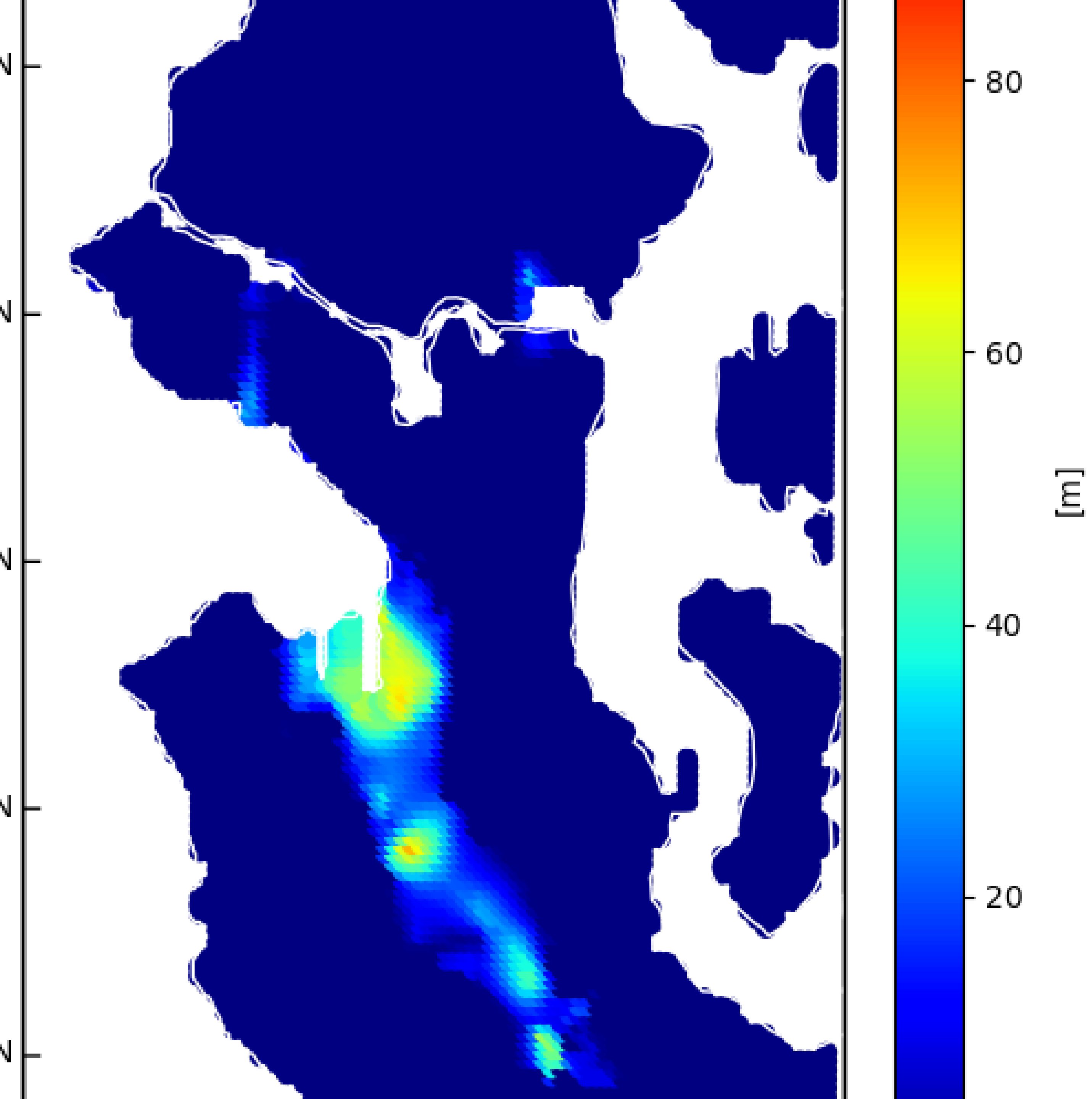
$$Vs(z) = Vs_0 + Az + B\ln(z)$$

$Vs_0 = 13.903 + 0.546\,Vs30$ — Vs at z = 0

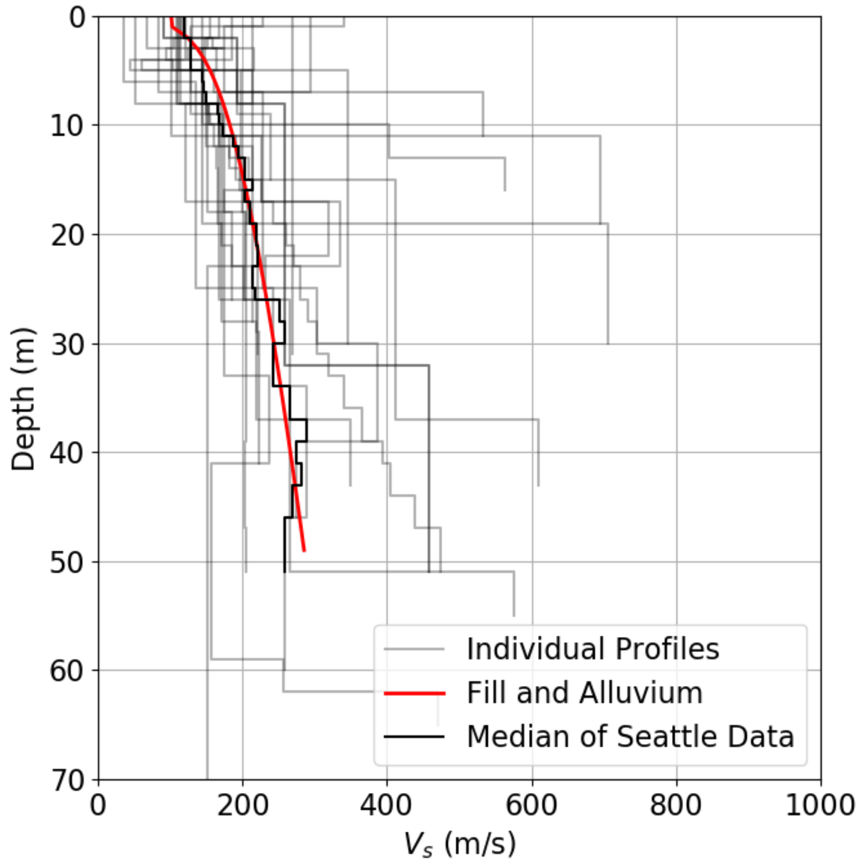
$A = 1.437 + 0.002\,Vs30$ — Linear increase with depth

$B = 0.0004\,Vs30^2$ — Shallow curvature

(Slide stolen from Alex Grant)



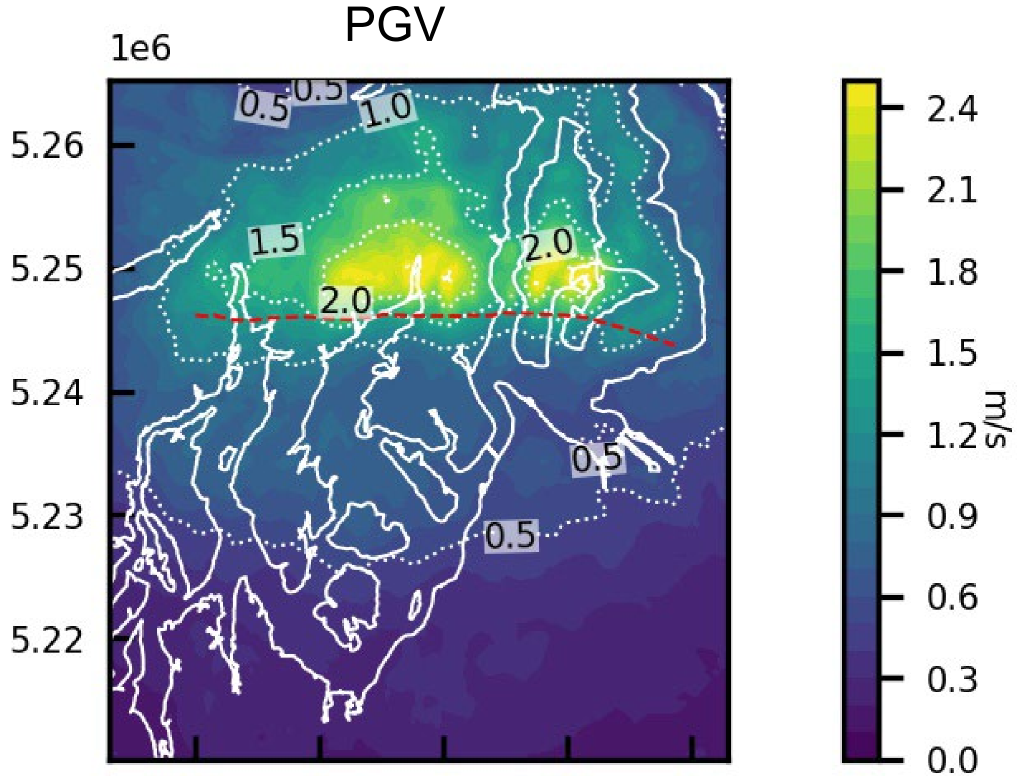
Fill and Alluvium

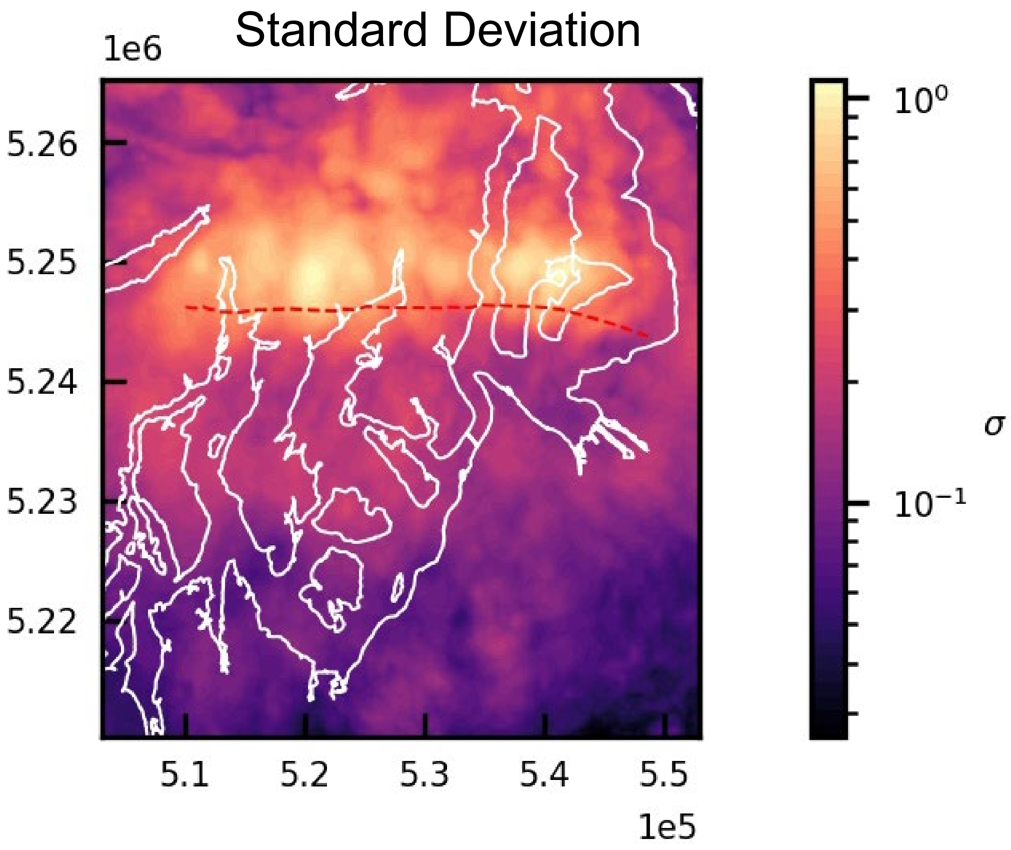


Average Peak Ground Velocity (PGV): Geotechical Gradient

- Strongest shaking manifests just north of fault (hanging wall)
- 0.5 m/s shaking extends as far south as Tacoma

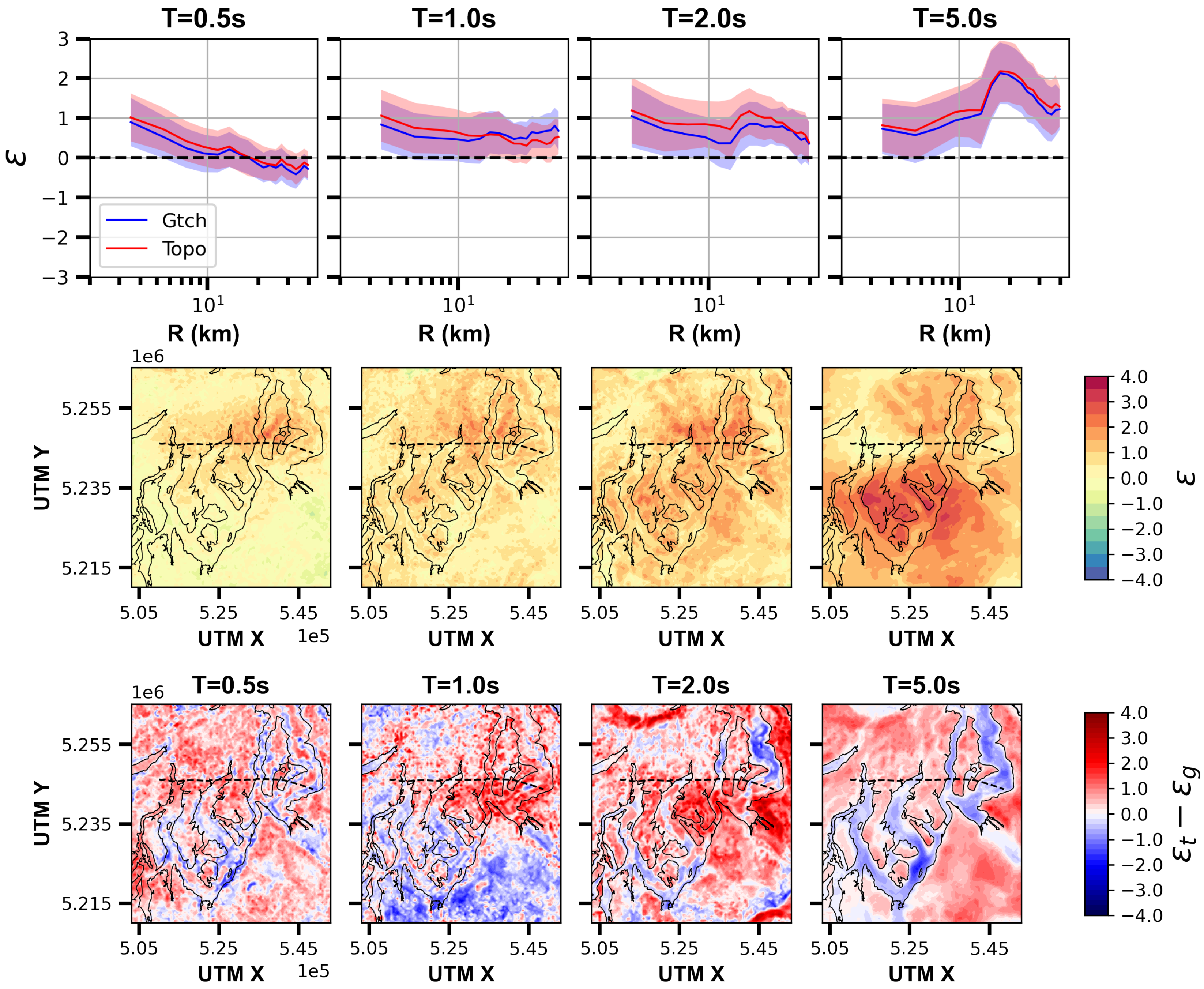
- Greatest variability is in the same region





Benchmark: Topography

- Average ground motions aren't hugely different from the geotech simulations
- Amplification patterns appear dependent on scale of topography



Simulation Parameters

- Simulations run using SPECFEM3D
- Model mesh has variable spacing with depth to accommodate surface topography and shallow low Vs
- Accurate up to ~2.5Hz