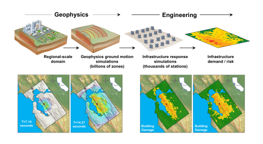


PEER International Pacific Rim Forum

June 16-17, 2021

Kinematic Simulation of Near Fault Ground Motions for the 2019 M7.1 Ridgecrest, CA Earthquake

Robert Graves
U.S. Geological Survey
Arben Pitarka
Lawrence Livermore National Laboratory

June 16, 2021

USGS
science for a changing world

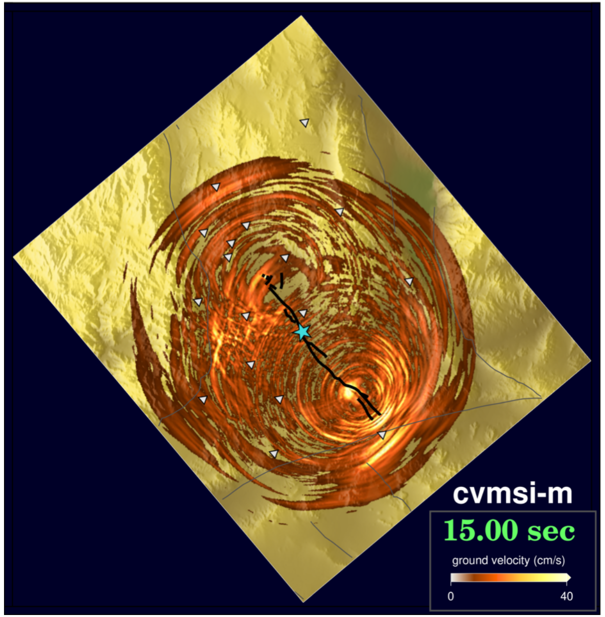
PEER

Objectives

- Examine adequacy of the Graves and Pitarka (2016, GP2016 hereafter) kinematic rupture generator to model near-fault ground motions for the M7.1 Ridgecrest mainshock

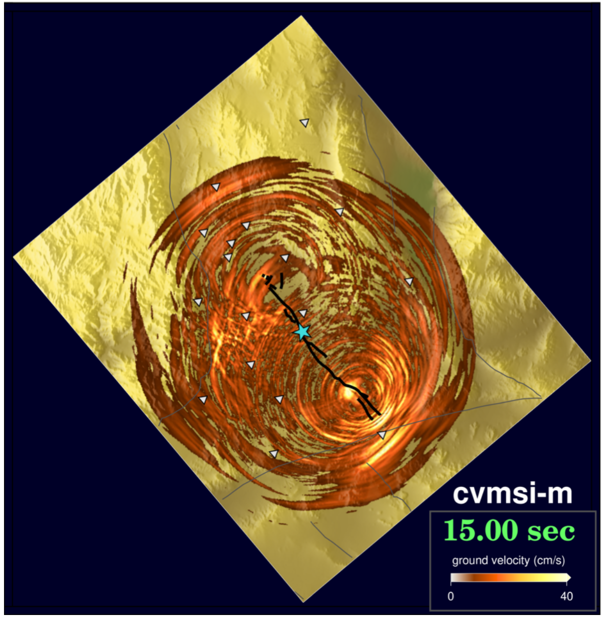
- Explore the upper frequency limit of the GP2016 approach using 3D deterministic modeling

- Investigate impact of change in shape of shallow slip-rate function on ground motion levels

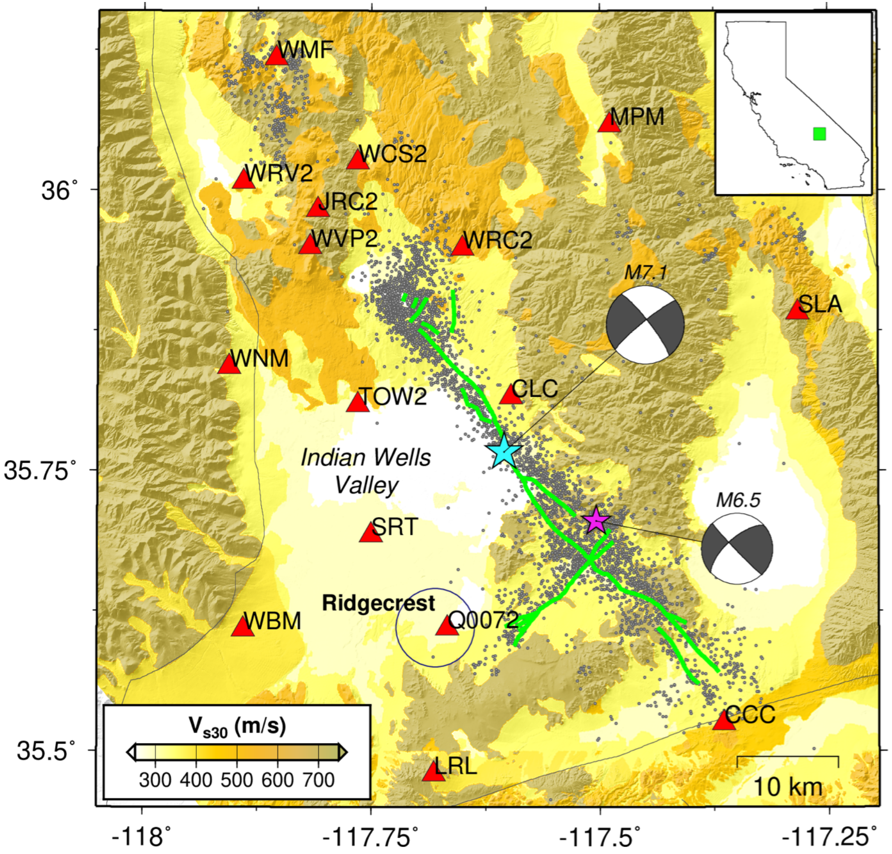


Approach

- Run 3D broadband-deterministic simulations (f < 4 Hz) for suite of randomly generated ruptures using GP2016
- Use forward simulations to test predictive power of GP2016 method; **i.e., not an inversion**
- Simulations use a modified version of SCEC CVMSI that includes a near-surface taper to match site-specific V_{S30}
- Quantify misfit of simulations to observations using Spectral Acceleration Goodness-of-Fit
- Three-component waveforms from lowest misfit model visually compared to observations



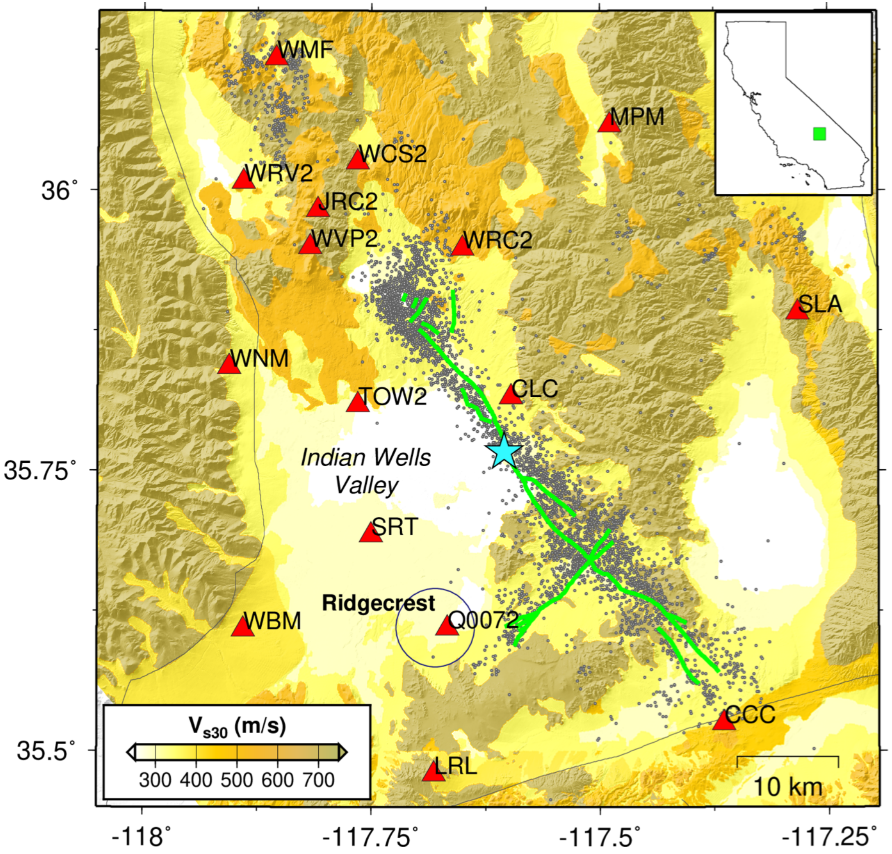
M7.1 Mainshock Setting



- M7.1 Mainshock rupture occurred along multiple subparallel fault segments just east of Ridgecrest, CA
- Predominantly right-lateral slip mechanism
- Left-lateral M6.5 foreshock occurred on conjugate fault about 34 hours before mainshock
- Well recorded by the Southern California Seismic Network (SCSN); 16 strong motion sites within about 30 km of rupture

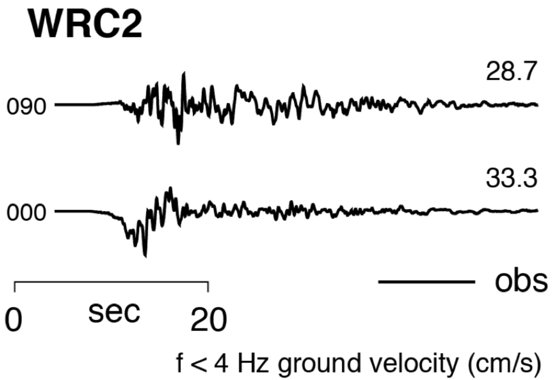
M>2.5 seismicity and focal mechanisms from SCSN
Fault traces from Ponti et al. (2020)
V_{S30} from Wills et al. (2015)

Near Surface Geology



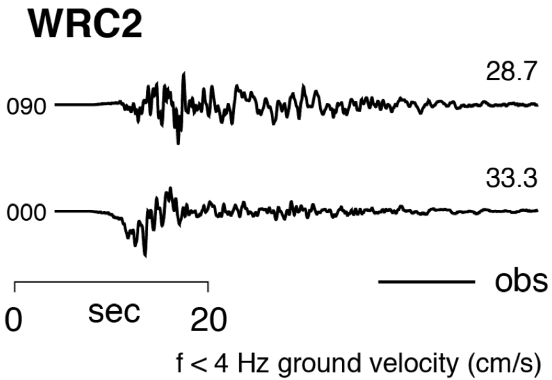
- V_{S30} from Wills et al (2015) range from about 230 m/s to 710 m/s in near fault region
- Most recording sites on V_{S30} > 350 m/s
- Indian Wells Valley (sediment filled basin) lies just west of the mainshock rupture
- Generally harder rock / mountainous regions to the east of rupture
- Coso volcanic region to the northwest of rupture

Comparing GMPEs and Observations

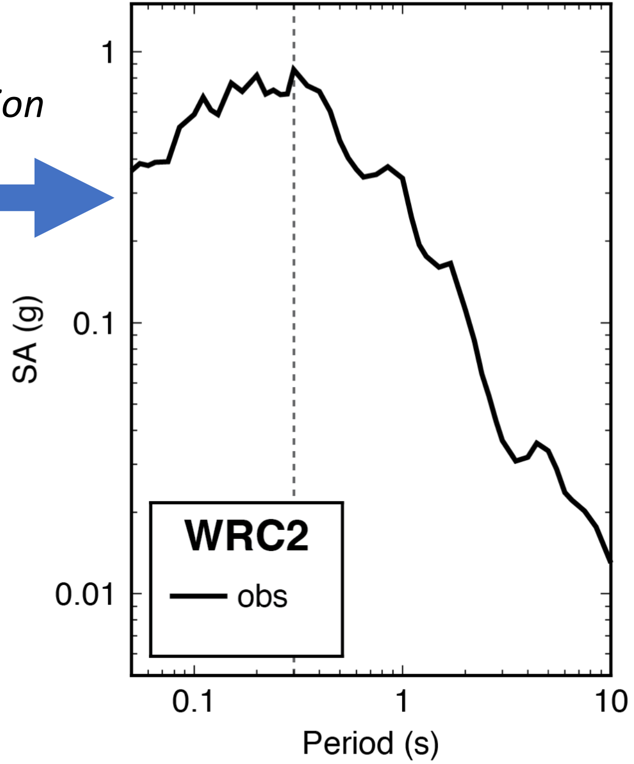


Ground motion data provided by Caltech/USGS Southern California Seismic Network (SCSN), doi:10.7914/SN/CI, archived at the Southern California Earthquake Data Center (SCEDC), doi:10.7909/C3WD3xH1

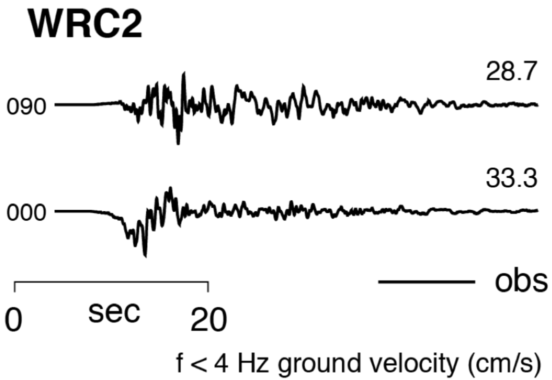
Comparing GMPEs and Observations



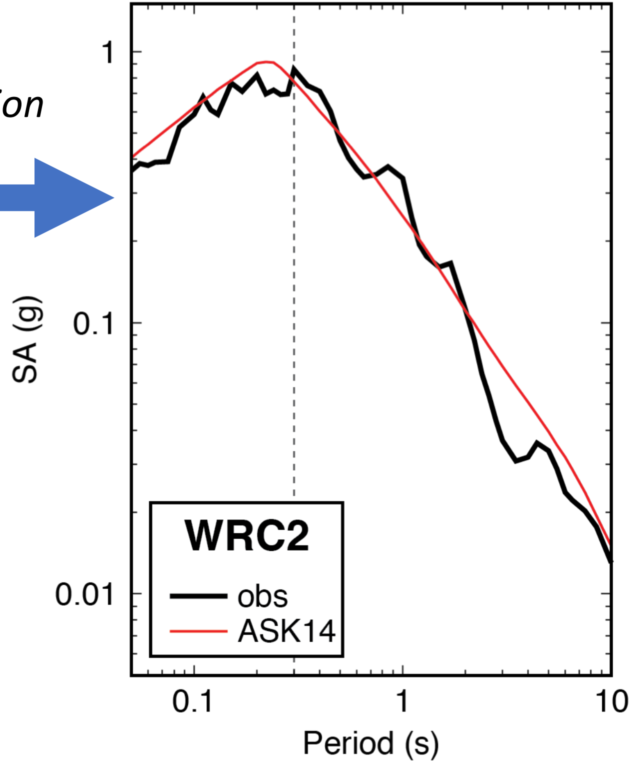
Compute spectral acceleration (RotD50)



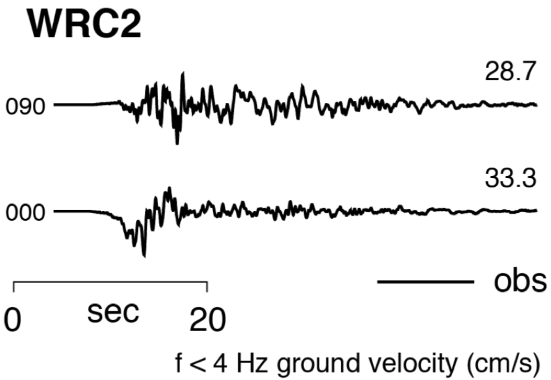
Comparing GMPEs and Observations



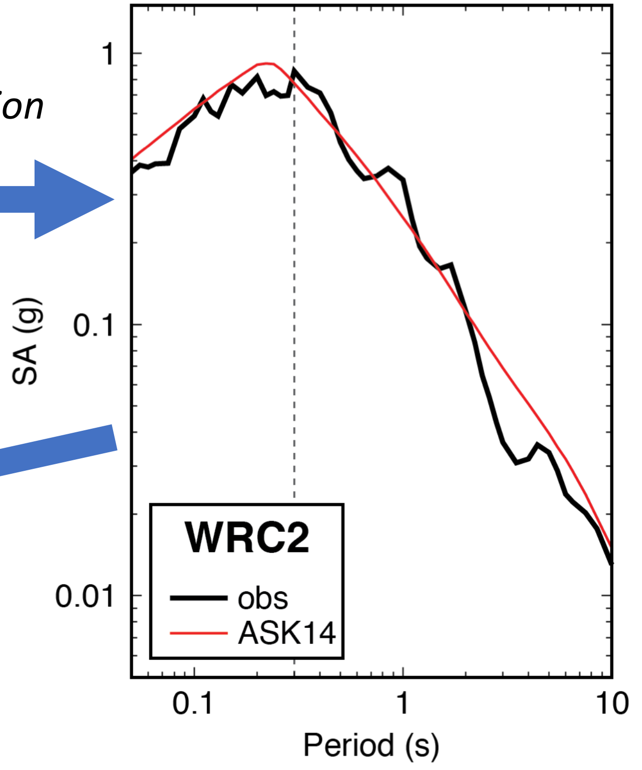
Compute spectral acceleration (RotD50)



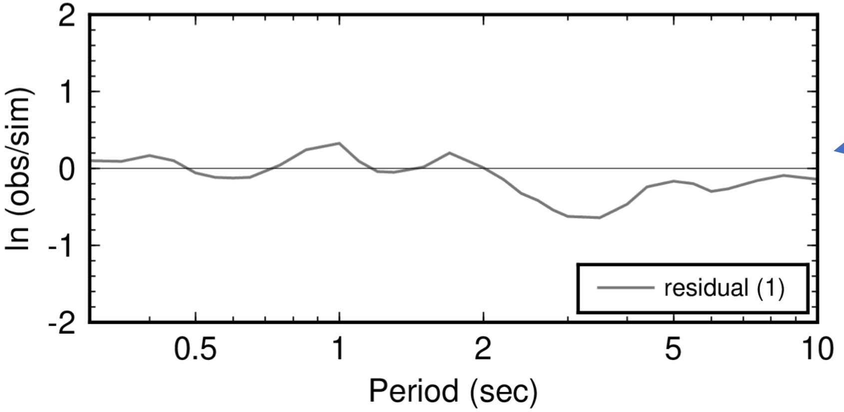
Comparing GMPEs and Observations



Compute spectral acceleration (RotD50)

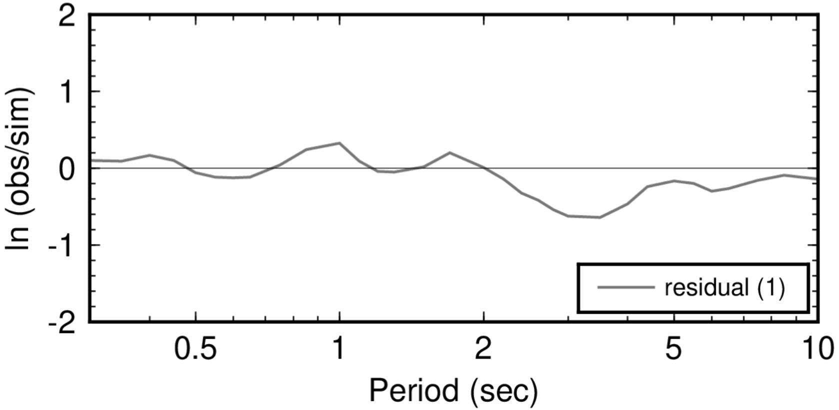


Compute residuals



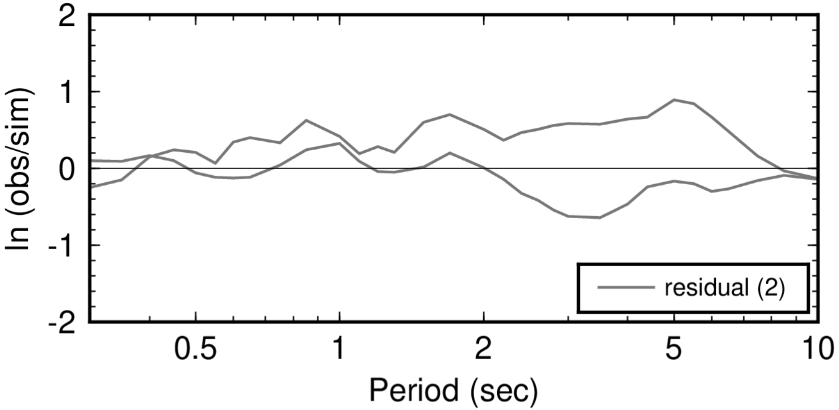
Comparing GMPEs and Observations

- Apply same procedure to all stations



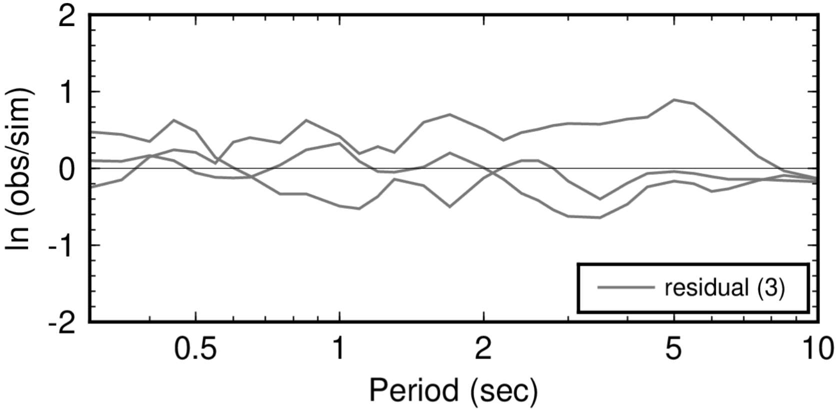
Comparing GMPEs and Observations

- Apply same procedure to all stations



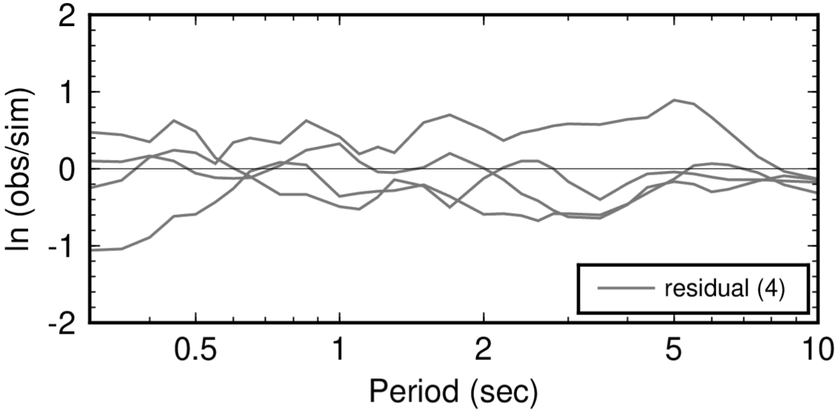
Comparing GMPEs and Observations

- Apply same procedure to all stations



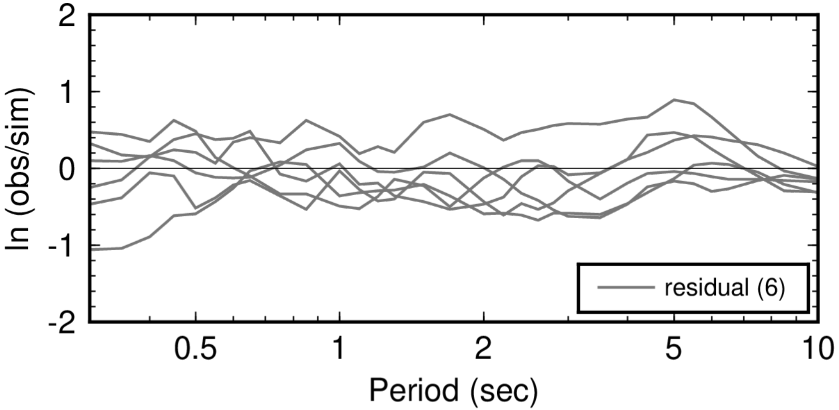
Comparing GMPEs and Observations

- Apply same procedure to all stations



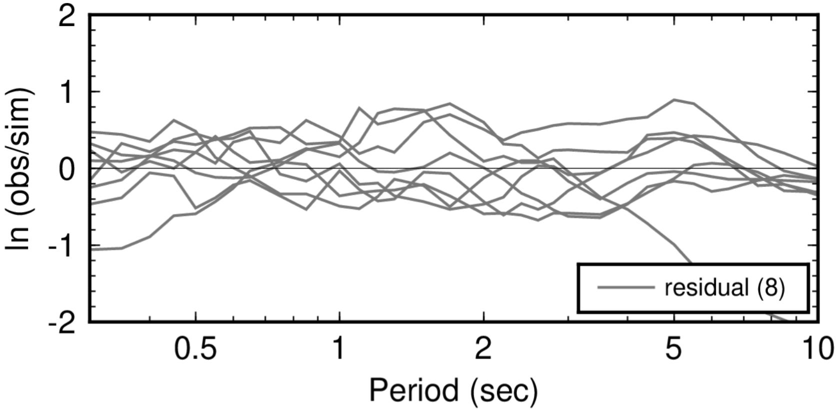
Comparing GMPEs and Observations

- Apply same procedure to all stations



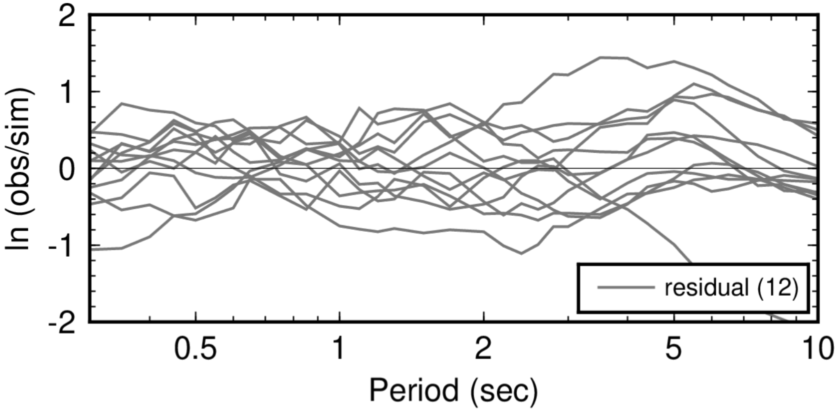
Comparing GMPEs and Observations

- Apply same procedure to all stations



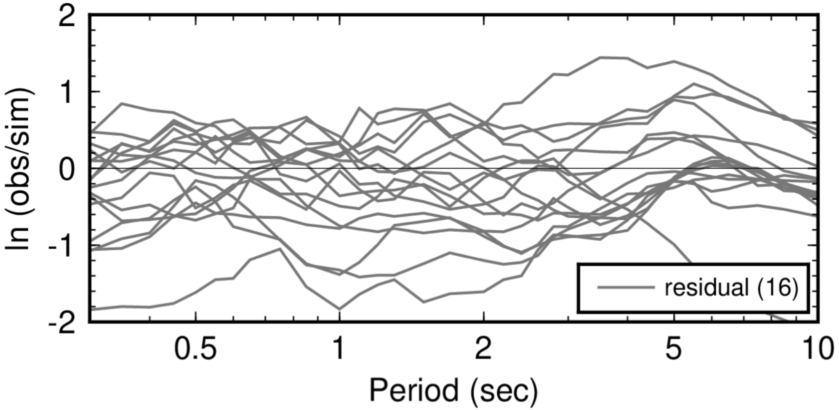
Comparing GMPEs and Observations

- Apply same procedure to all stations



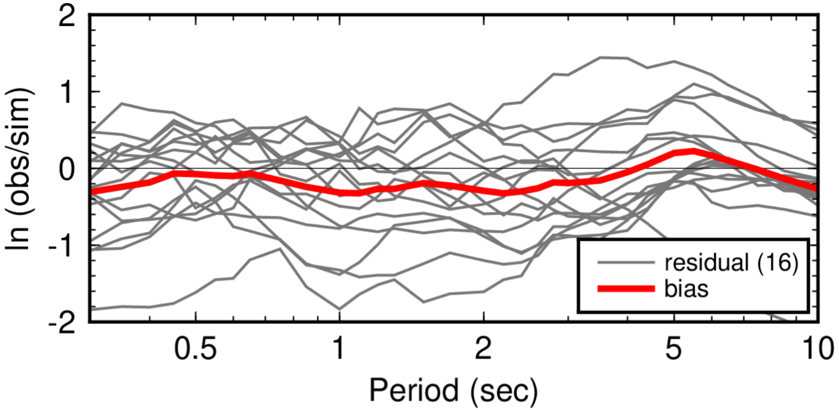
Comparing GMPEs and Observations

- Apply same procedure to all stations



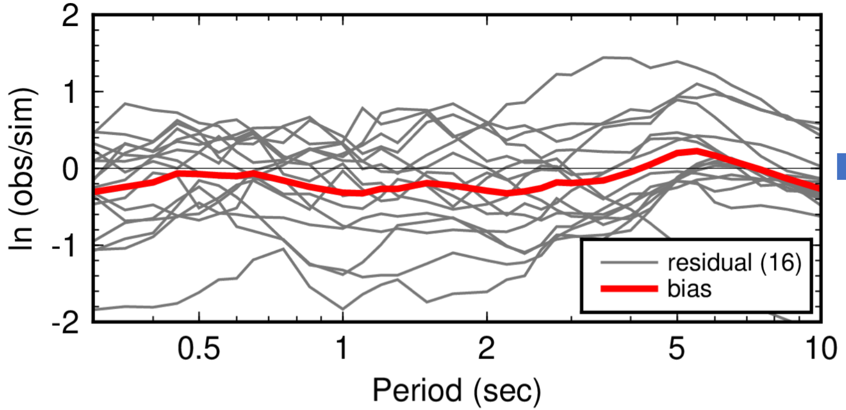
Comparing GMPEs and Observations

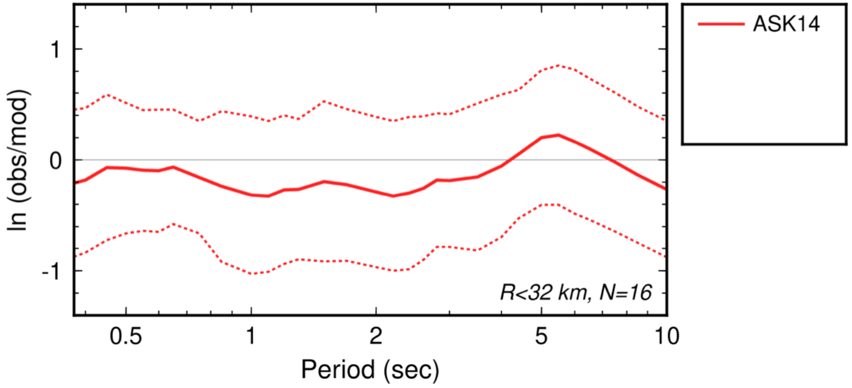
- Apply same procedure to all stations
- Compute average residual at each period: **bias**



Comparing GMPEs and Observations

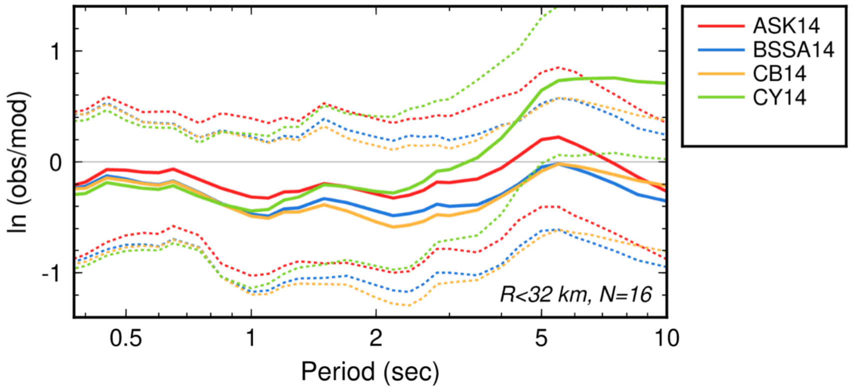
- Apply same procedure to all stations
- Compute average residual at each period: **bias**
- Compute standard deviation





Comparing GMPEs and Observations

- Apply same procedure to all stations
- Compute average residual at each period: **bias**
- Compute standard deviation
- Apply same procedure to other models

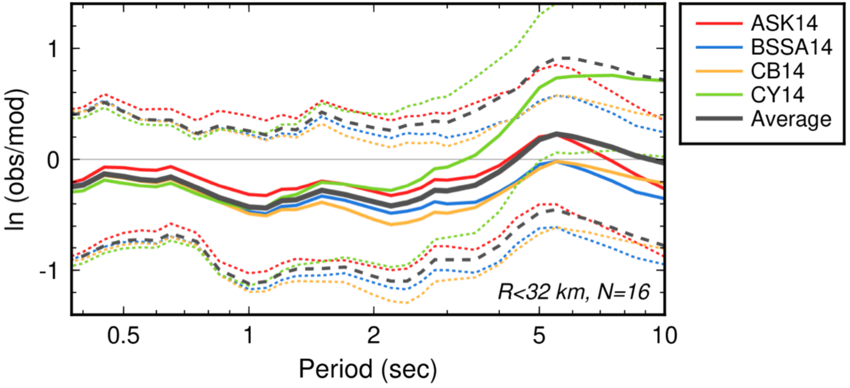


Comparing GMPEs and Observations

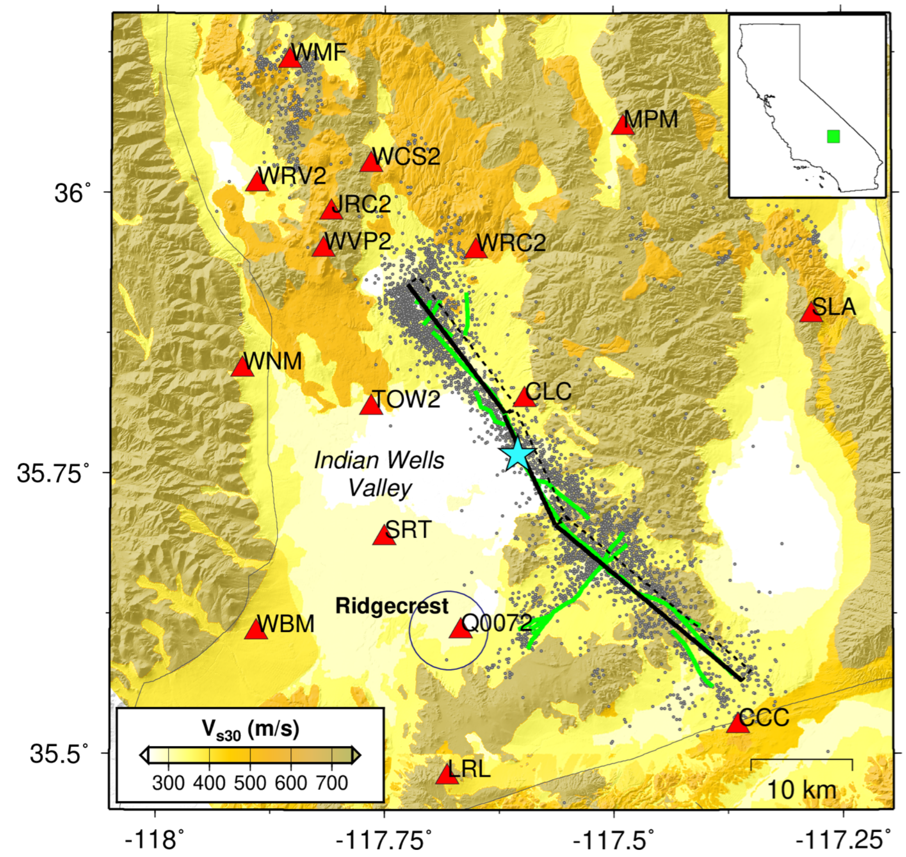
- Apply same procedure to all stations
- Compute average residual at each period: **bias**
- Compute standard deviation
- Apply same procedure to other models
- Average across models

Key GMPE Features:

- *Roughly 20% **under-prediction** at 5-6 sec period (large variation)*
- *Roughly 30-40% **over-prediction** at 1-4 sec period (small variation)*

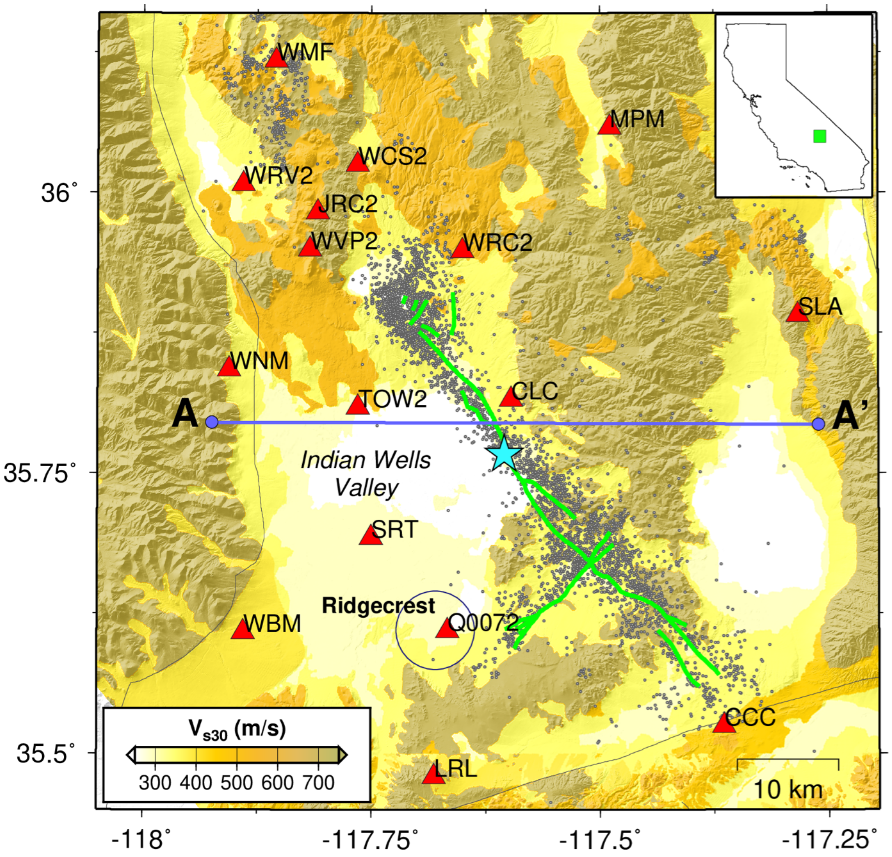


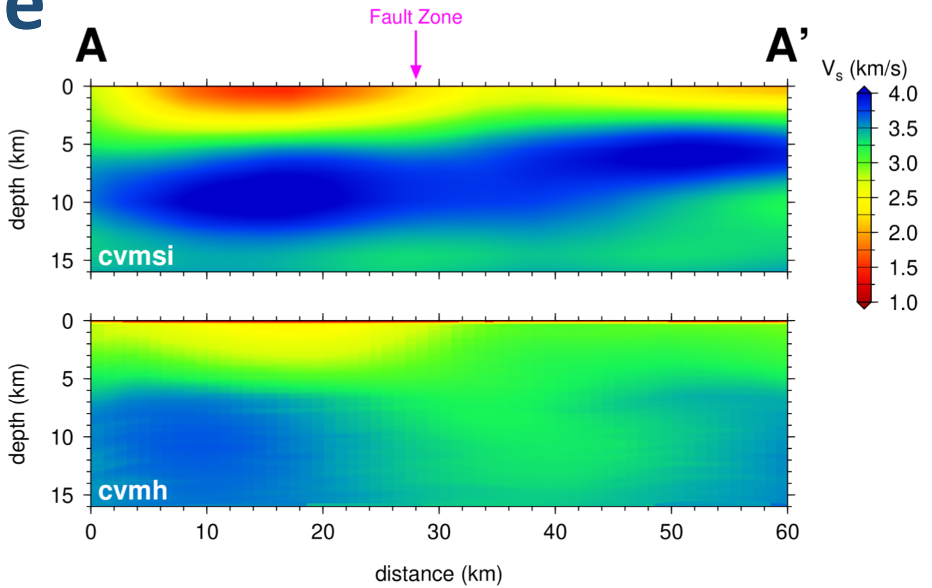
Ground Motion Simulations



- Simulate strong ground motions at 16 near fault sites
- Use SCEC 3D seismic velocity model CVMSI
- 20 m grid spacing and minimum Vs of 400 m/s yields reliable results to maximum frequency of 4 Hz
- Simulations use three-segment fault model of Ji et al (2019)

Seismic Velocity Structure

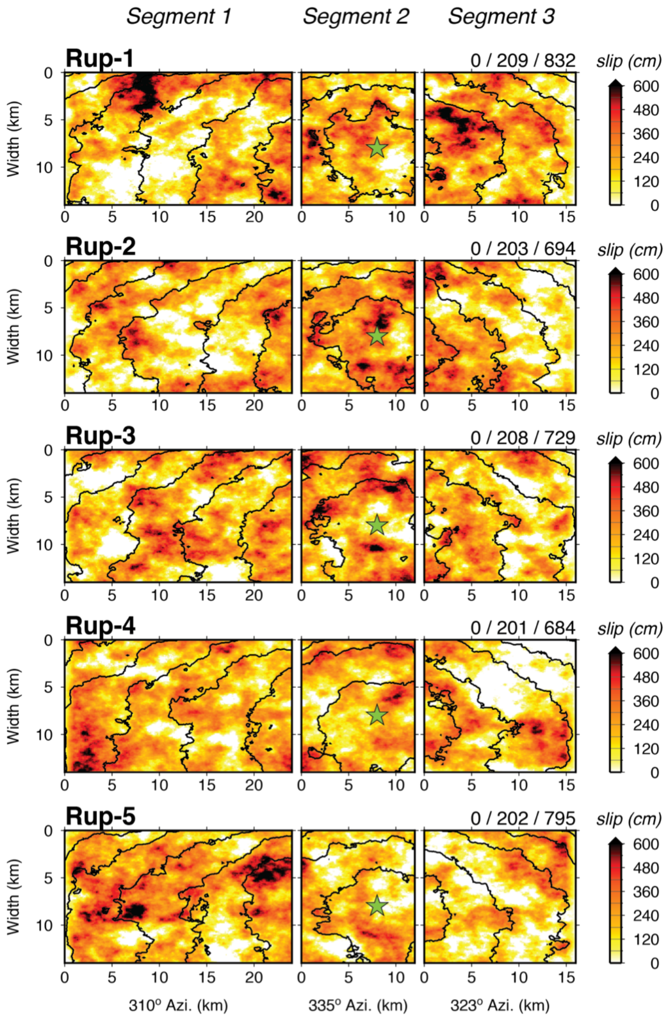




- CVMSI model has better resolution in this region; more events & stations in inversion
- Also consistent with previous refraction (Fliedner et al., 2000) and structural geology (Monastero et al., 2002) studies

Kinematic Rupture Modeling

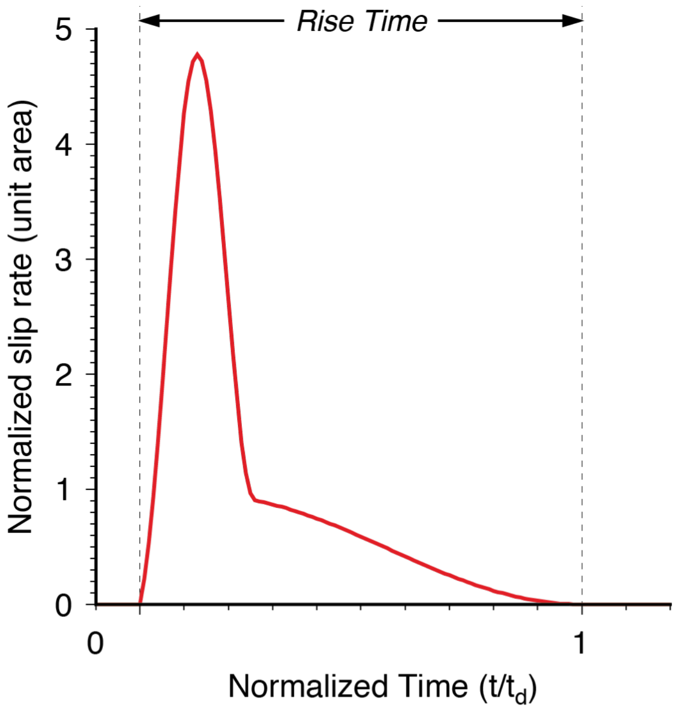
- Three-segment fault model with total fault length = 52 km; fault width = 14 km
- Generate suite of 5 randomized ruptures using GP2016 kinematic rupture generator
- Use average rupture speed of 60% local Vs, consistent with inversions (e.g., Ji et al., 2019; Wang et al., 2020)
- Includes GP2016 depth-dependent effects of rise time lengthening and rupture speed reduction in upper 5 km (*mimics velocity strengthening*)



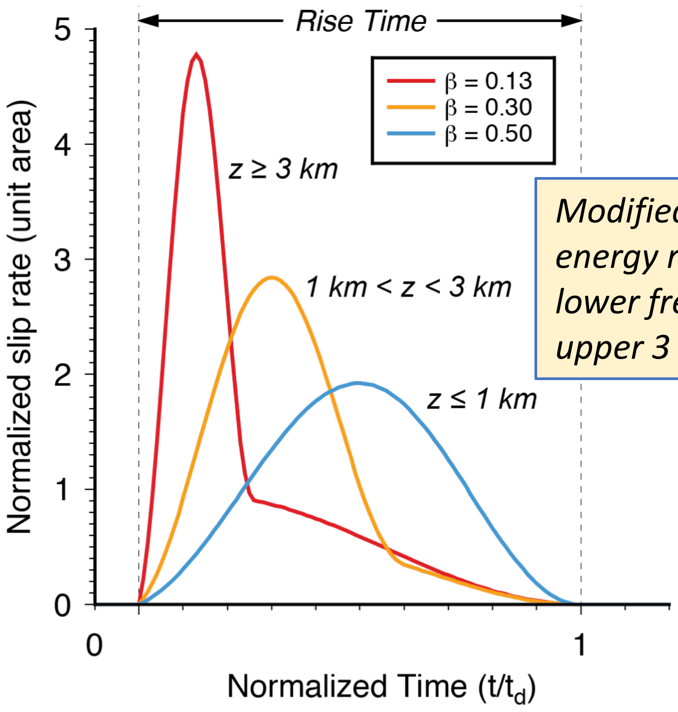
Kinematic Rupture Modeling

- Run 2 slip-rate formulations for each slip model:

Standard GP Slip-rate



Modified GP Slip-rate

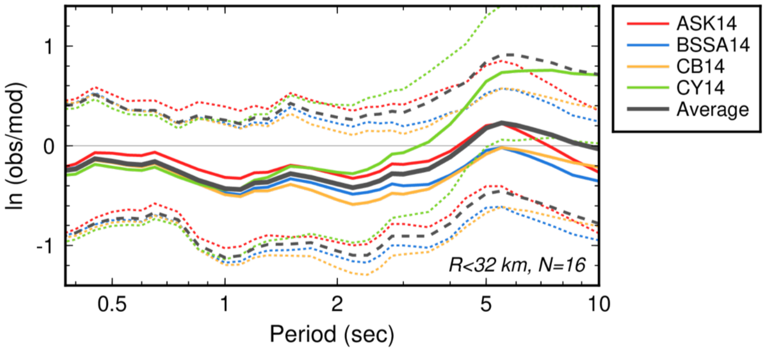


Modified GP shifts energy release to lower frequencies in upper 3 km of rupture

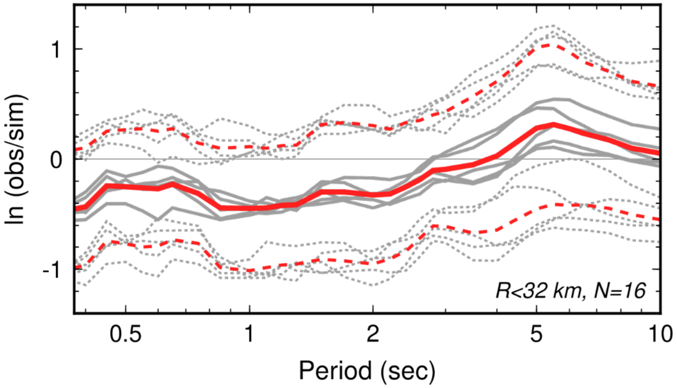
Simulation Goodness-of-Fit (GoF)

- Apply same procedure as done with GMPEs to compute bias and standard deviation

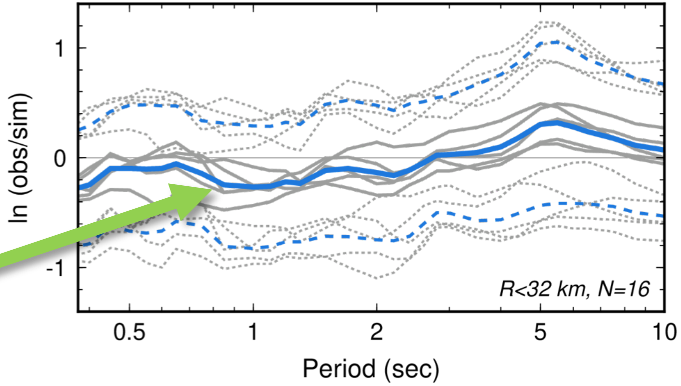
GMPE



Standard GP



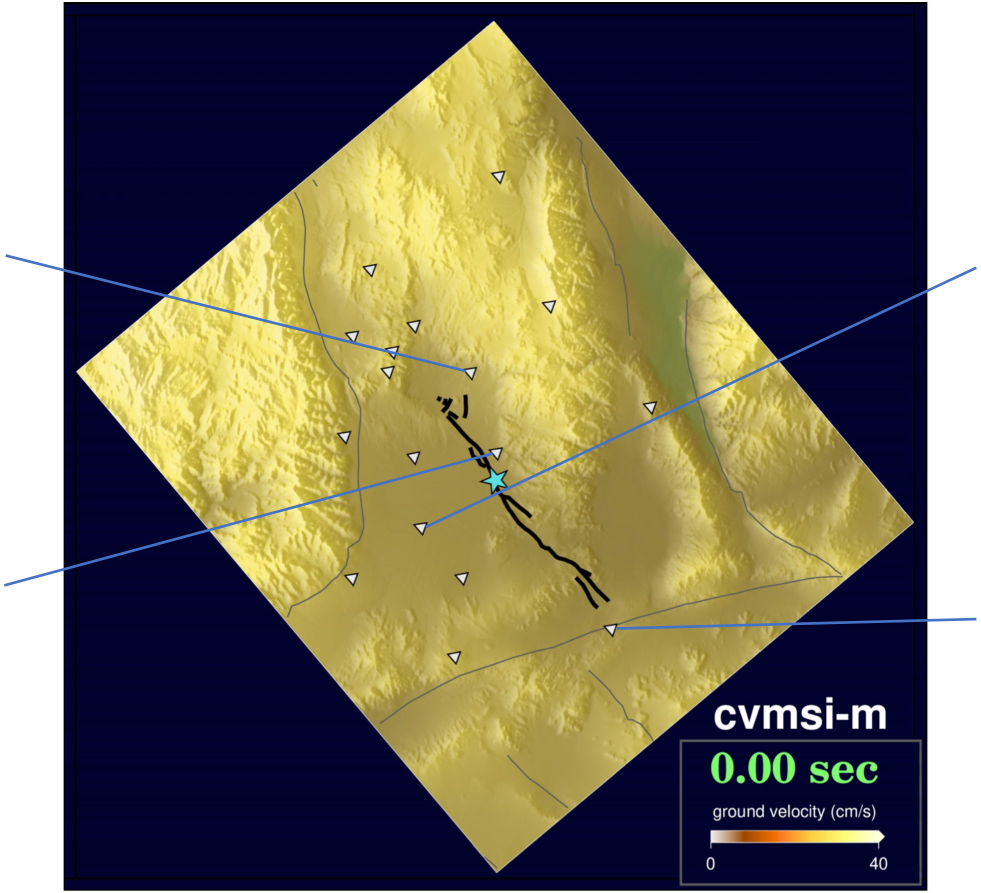
Modified GP



Modified GP improves fit at periods less than 4 sec

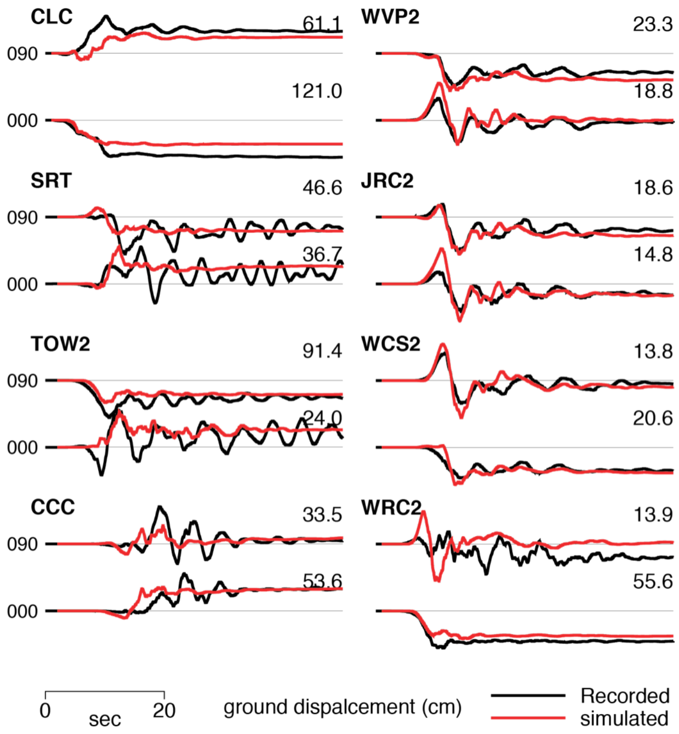
Waveforms for Lowest Misfit Case

Ground Velocity (f < 4 Hz)



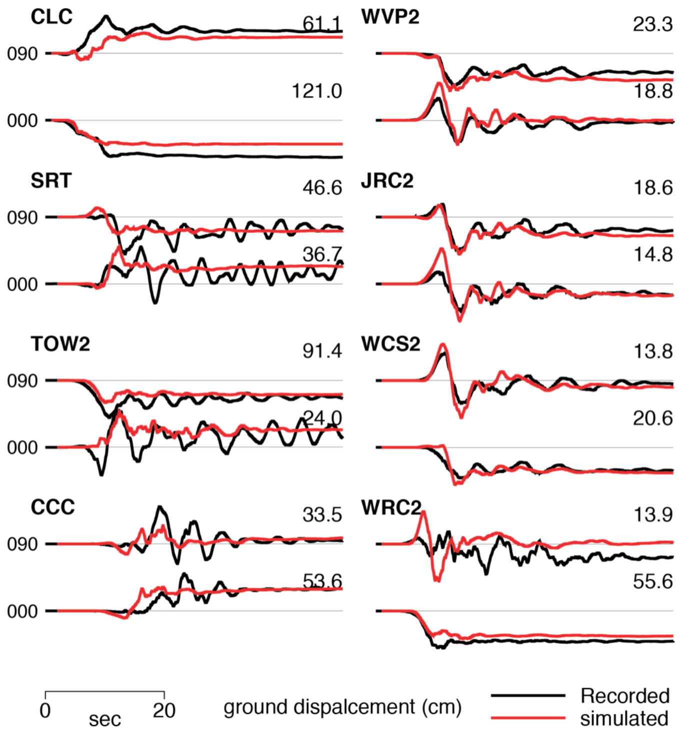
Ground Displacements and Slip Distribution

- Horizontal displacements for lowest misfit case in good agreement with near fault observations

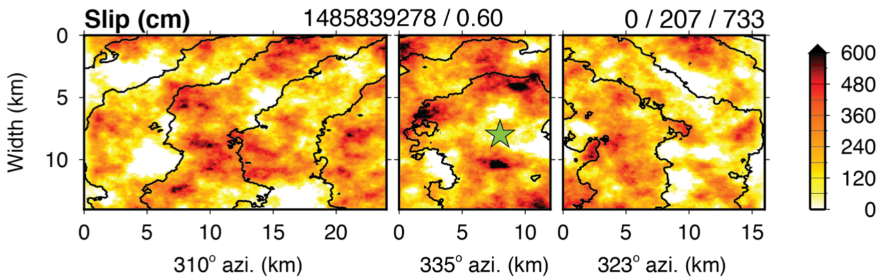


Ground Displacements and Slip Distribution

- Horizontal displacements for lowest misfit case in good agreement with near fault observations

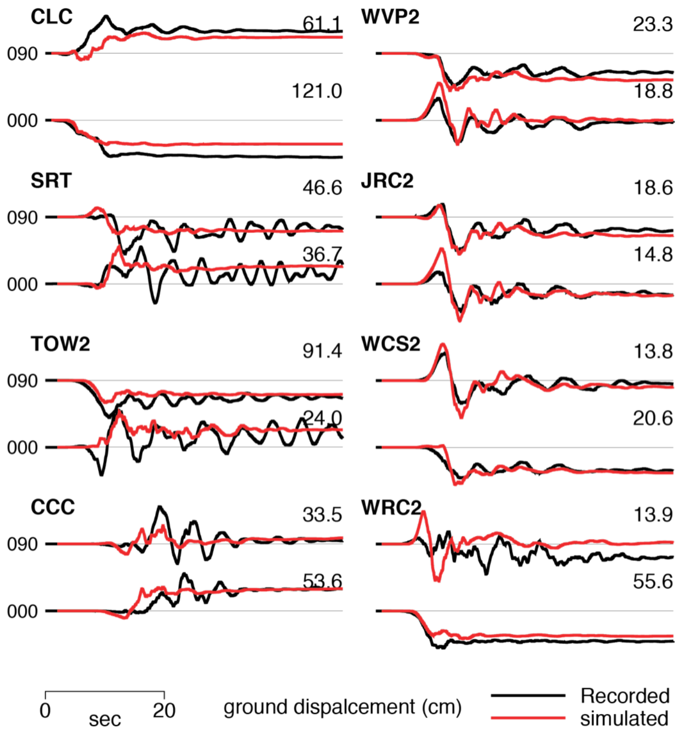


- Rupture for lowest misfit case has largest slip in middle portion of fault

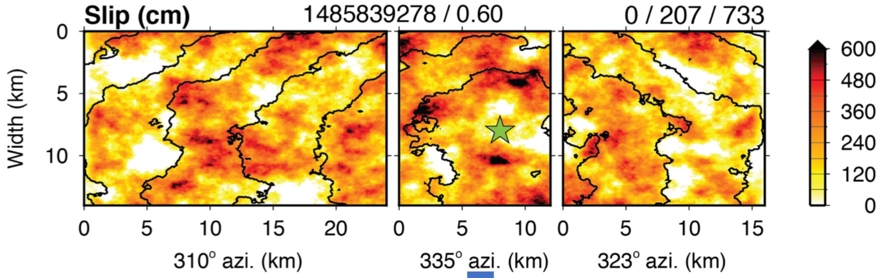


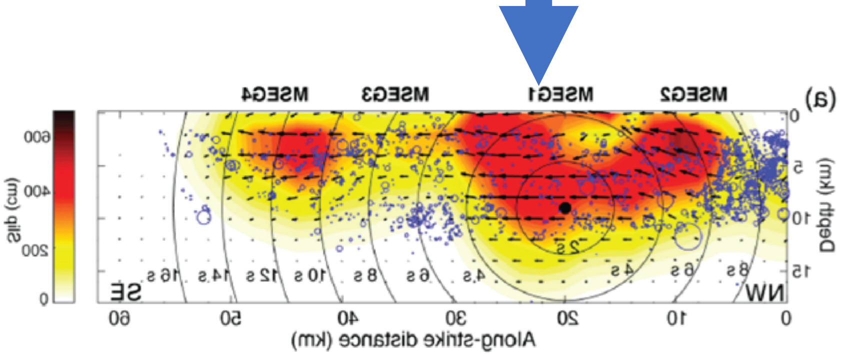
Ground Displacements and Slip Distribution

- Horizontal displacements for lowest misfit case in good agreement with near fault observations



- Rupture for lowest misfit case has largest slip in middle portion of fault
- Similar to rupture models determined from ground motion inversion





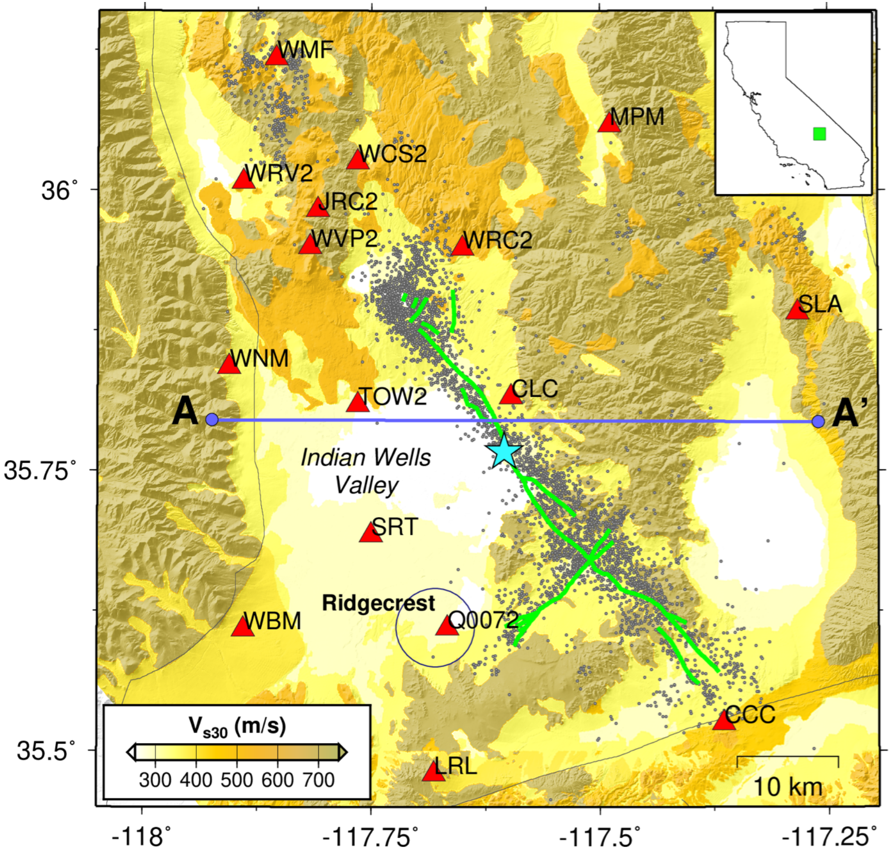
Inverted rupture from Wang et al. (2020)

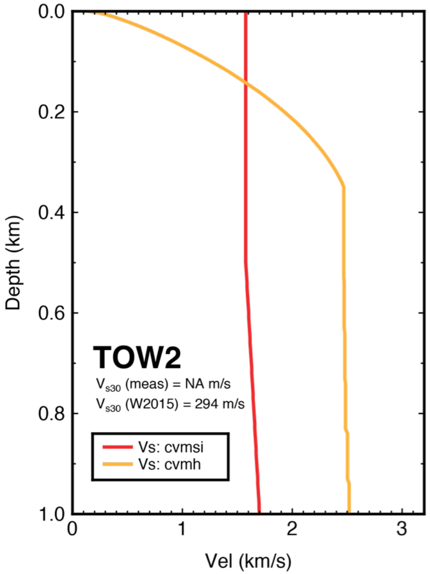
Results

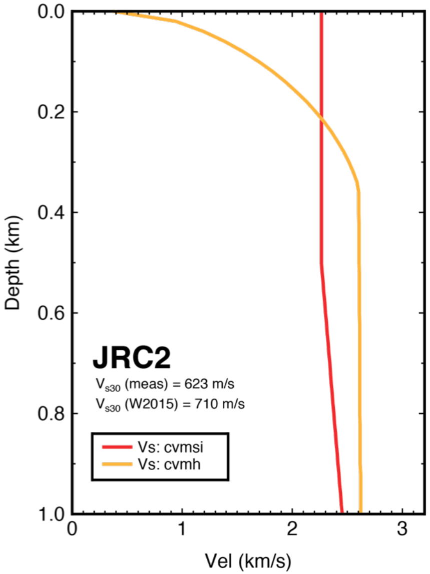
- Simulations incorporating change in shape of shallow slip-rate improve fit to observed motions at 1-4 sec period range
- Lowest misfit case has average rupture speed of 60% local Vs with large slip near middle of rupture, similar to other studies
- Simulations reproduce many features of observed waveforms; however, later arriving phases at Indian Wells Valley sites not well matched
- Demonstrates ability of GP2016 to produce realistic ground motions over broad frequency range (0-4 Hz), boosting confidence in predictive power of this method

END

Seismic Velocity Structure

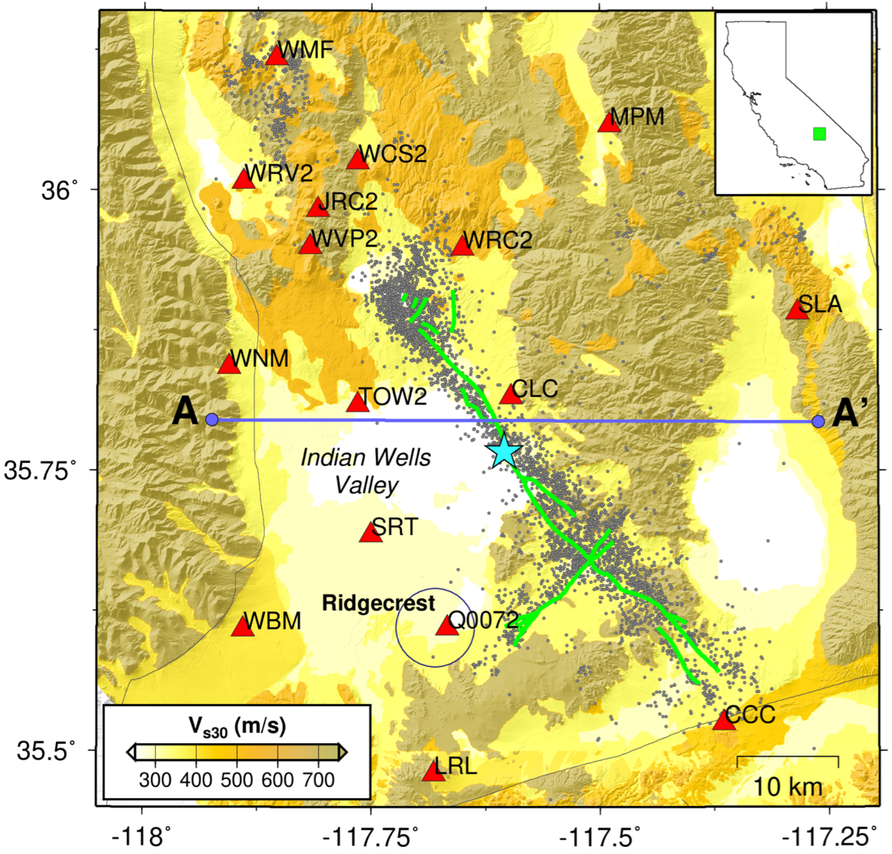


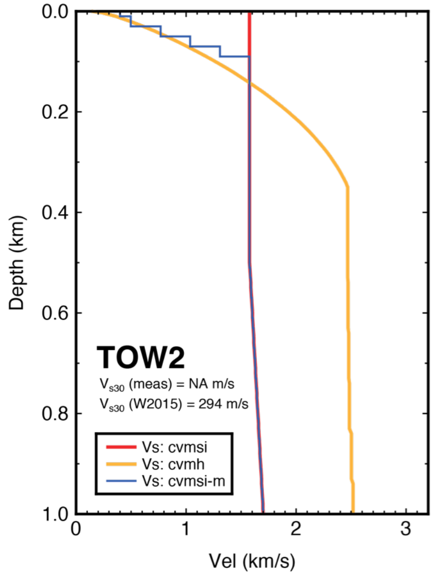


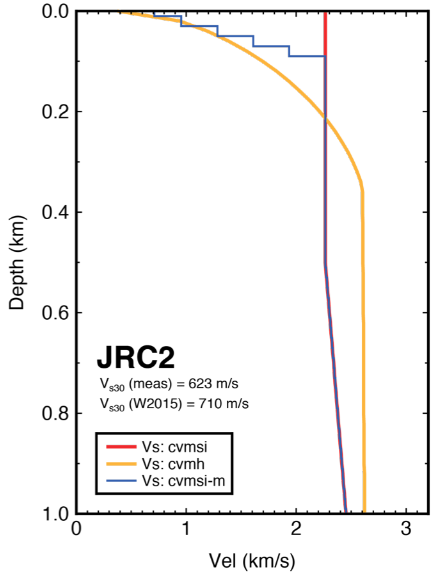


- CVMSI model has unrealistically high Vs in near surface (about 2 km/s)

Seismic Velocity Structure







- CVMSI model has unrealistically high Vs in near surface (about 2 km/s)
- Add taper to upper 100 m to match V_{S30} values from Wills et al (2015)