3D 0-5 Hz Wave Propagation Simulations of the 2014 Mw5.1 La Habra Earthquake with Small-scale Heterogeneities, Q(f) and Topography

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Objectives

We perform a suite of 0-5 Hz deterministic simulations of the 2014 Mw 5.1 La Habra, CA, earthquake, with the parallel AWP-ODC-GPU code in a mesh from the Southern California Earthquake Center (SCEC) Community Velocity Model CVM-S4.26-M01. The purpose of this study is to investigate the effects of topography and anelastic attenuation and scattering at high frequencies above 1 Hz. We address these effects through various ground motion metrics.

Model

The size of the simulation domain is 190 km * 140 km * 60 km, with a minimum shear wave velocity clamped at 500 m/s, which can resolve up to 5 Hz with a grid spacing of 20 m and 5 points per minimum shear wavelength.

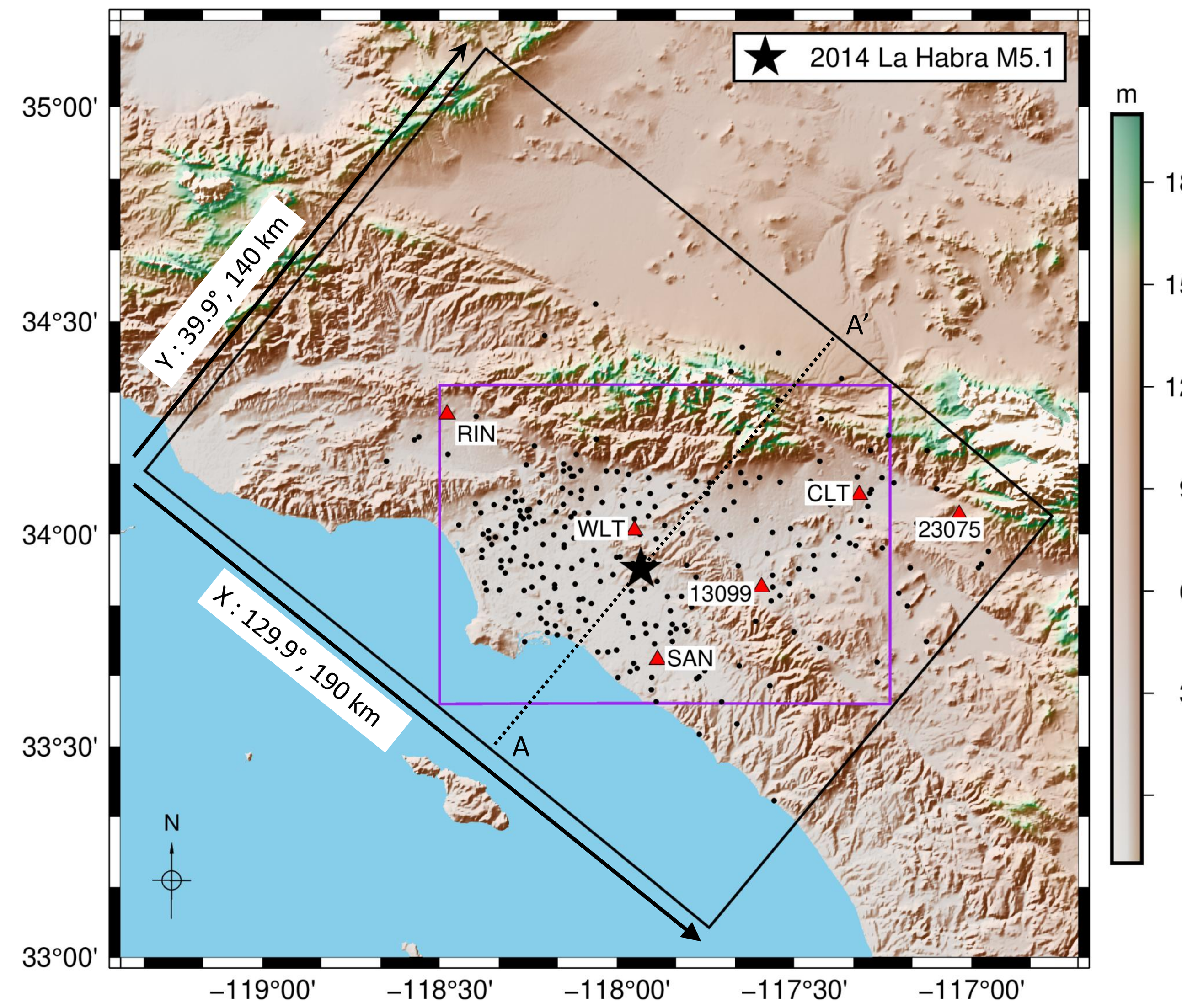

Figure 1. Model domain (black rectangle) used in the simulations. Stations are depicted by circles and the epicenter location of the event is marked by an asterisk. The magenta box is used to show individual comparisons in the following sections.

We increase the complexity of our model by including (1) frequency-dependent attenuation Q(f) = $Q_0 * f^{\gamma}$; Q(f) = Q_0, if f <= 1 Hz; (γ = 0 generates frequency-independent attenuation).(2) surface topography using a curvilinear grid (O'Reilly et al., 2019), (3) statistical distributions of small-scale crustal heterogeneities (SSHs), with a von Karman autocorrelation to represent the effects of realistic velocity and density perturbations, parameterized by a standard deviation σ, Hurst number $\mathcal{V}$, correlation length L. In the models below, we use Q_0 = 100 * Vs , Vs in km/s, Q_p=2 * Q_s.

- Model-1 : SCEC CVM-S4.26-M01 (γ = 0)
- Model-2 : Model-1 + Q(f) (γ = 0.6)
- Model-3 : Model-1 + topography (γ = 0)
- Model-4 : Model-3 + SSH (σ=5%, $\mathcal{V}$=0.05, L=100m, γ = 0)

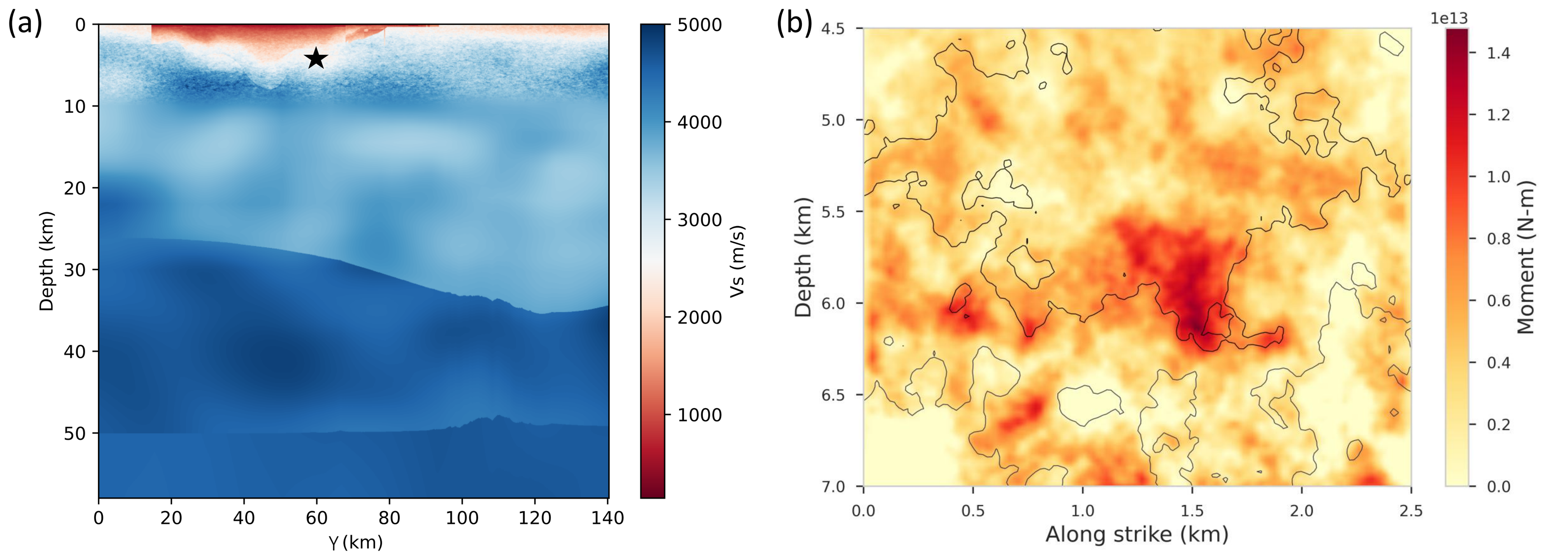

Figure 2. Left: cross section taken at A-A' in Figure 1 showing shear wave velocity (Vs) in Model-4, hypocenter marked by the asterisk; Right: source model with rupture time contoured every 0.5 s.

The finite-fault source (Figure 2b) is obtained from the Graves and Pitarka (2016) kinematic rupture generator, optimized based on goodness-of-fit for near-fault synthetics and data using Model-1.

References

[1] Olsen, K. B., and J. E. Mayhew, 2010, Goodness-of-fit Criteria for Broadband Synthetic Seismograms, with Application to the 2008 Mw 5.4 Chino Hills, California, Earthquake, Seismological Research Letters, 81, no. 5, 715–723.

[2] Graves, R., and A. Pitarka, 2016, Kinematic Ground-Motion Simulations on Rough Faults Including Effects of 3D Stochastic Velocity Perturbations, Bulletin of the Seismological Society of America, 106, no. 5, 2136–2153.

[3] O'Reilly, O., Breuer, A. N., Cui, Y., Goulet, C. A., Olsen, K. B., Roten, D., Thomas-Collignon, G., & Yeh, T. Simulation of elastic waves in the presence of topography using a curvilinear staggered grid finite difference method. Poster Presentation at 2019 SCEC Annual Meeting.

Acknowledgements

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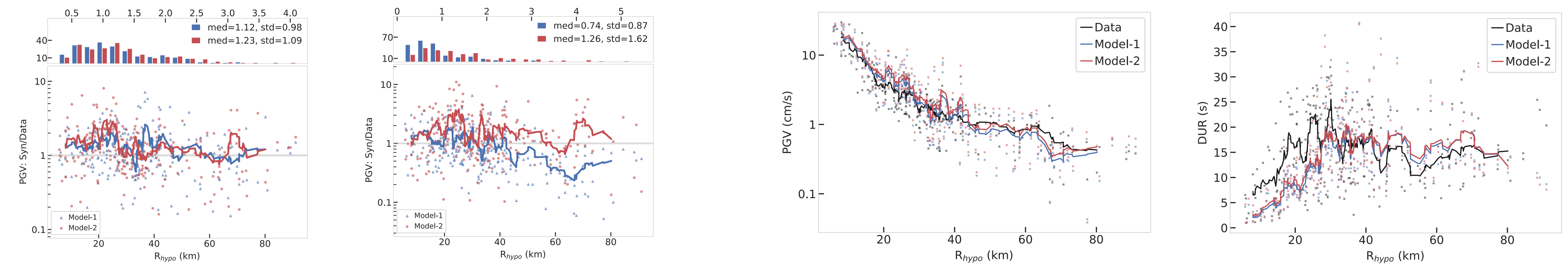
Results

Effects of attenuation : frequency-dependent, γ = 0.6 (Model-2) as compared to frequency-independent (Model-1)

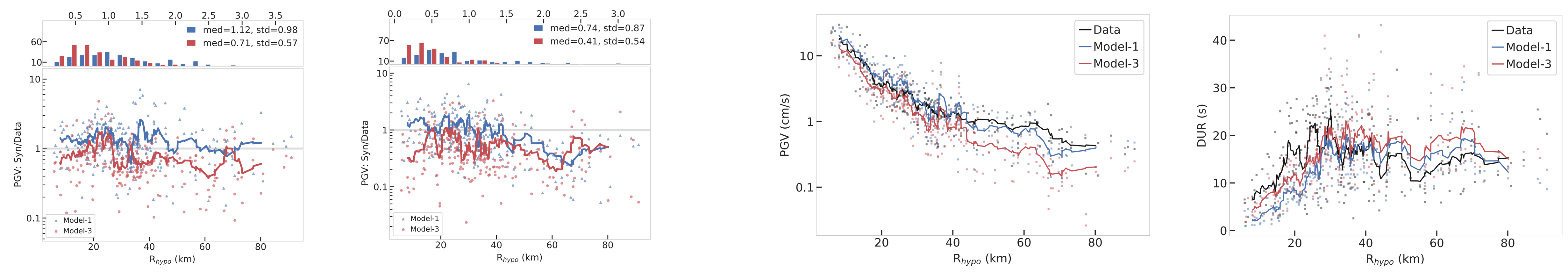
- Q(f) increases the ground motion amplitudes and prolongs the shaking duration
- At high frequencies, the reference model (W/o Q(f)) tends to underpredict amplitudes with increasing distance (R_{hypo}), while Q(f) improves the fit of PGV
- Both models underpredict durations (DUR) at close distances (< 30 km) and overpredict DUR at further distances (> 40 km)



0.15-2.5 Hz | 2.5-5 Hz | 0.15-5 Hz | 0.15-5 Hz

Effects of topography : w/ topography (Model-3) versus w/o topography (Model-1)

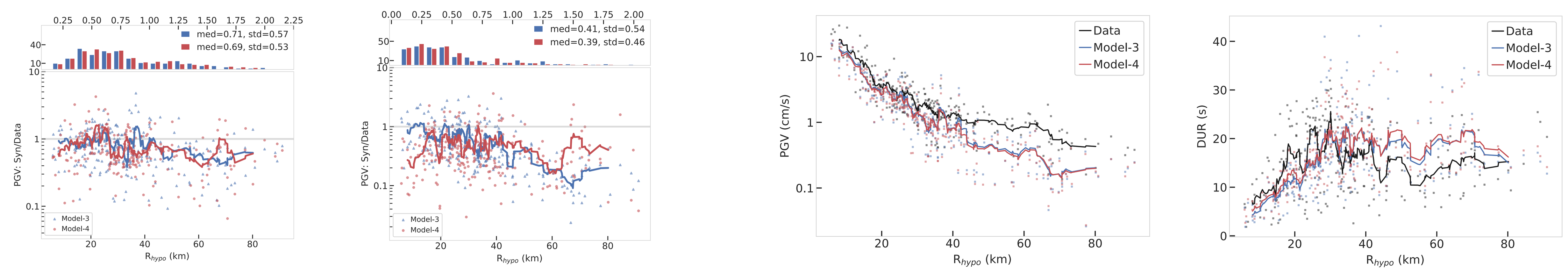
- Topography tends to reduce the ground motion amplitudes and prolongs the shaking duration
- The reduction of PGV from the topography effects is more significant at higher frequencies, with a value of 37% at 0.15-2.5 Hz and 45% at 2.5-5Hz
- The increase of duration is greater than that from Q(f) effects with γ = 0.6



0.15-2.5 Hz | 2.5-5 Hz | 0.15-5 Hz | 0.15-5 Hz

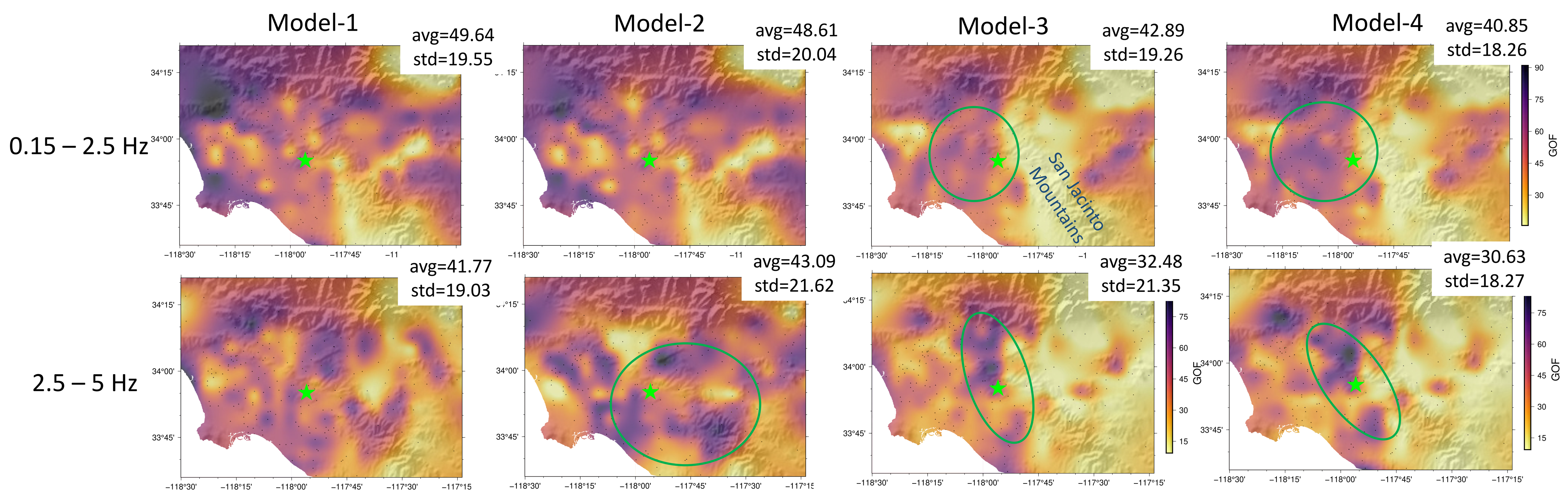
Effects of SSHs : w/ SSHs (Model-4) versus w/o SSHs (Model-3)

- SSHs tends to reduce PGVs and increase DUR



0.15-2.5 Hz | 2.5-5 Hz | 0.15-5 Hz | 0.15-5 Hz

Goodness-of-fit (GOF) : To assess various models, we quantify the GOF between synthetics and data using a suite of ground motion metrics, including PGV, PGA, cumulative energy, Arias Intensity and duration (based on Olsen and Mayhew 2010). Larger GOF values represent better fit, with 100 for perfect fit. The green circles denote areas with better fit compared to the reference model (Model -1)



Conclusions

1. The effects of Q(f), topography, and SSHs play an increasingly important role at higher frequencies, and need to be included to match key metrics of ground motions up to 5 Hz.
2. Frequency dependent attenuation tends to increase durations and PGVs, improving the GOF particularly in basin areas at high frequencies.
3. Topographic scattering and SSHs tend to generate smaller amplitudes and longer durations, improving the GOF in the vicinity of the source to the west, but degrade the GOF east of the San Jacinto Mountains.
4. Future work includes tests with lower minimum S-wave velocities and further tests with SSHs.
5. As the complexity of the models increase with additional features, the variance of the data residual decreases, allowing for smaller GOF values.