

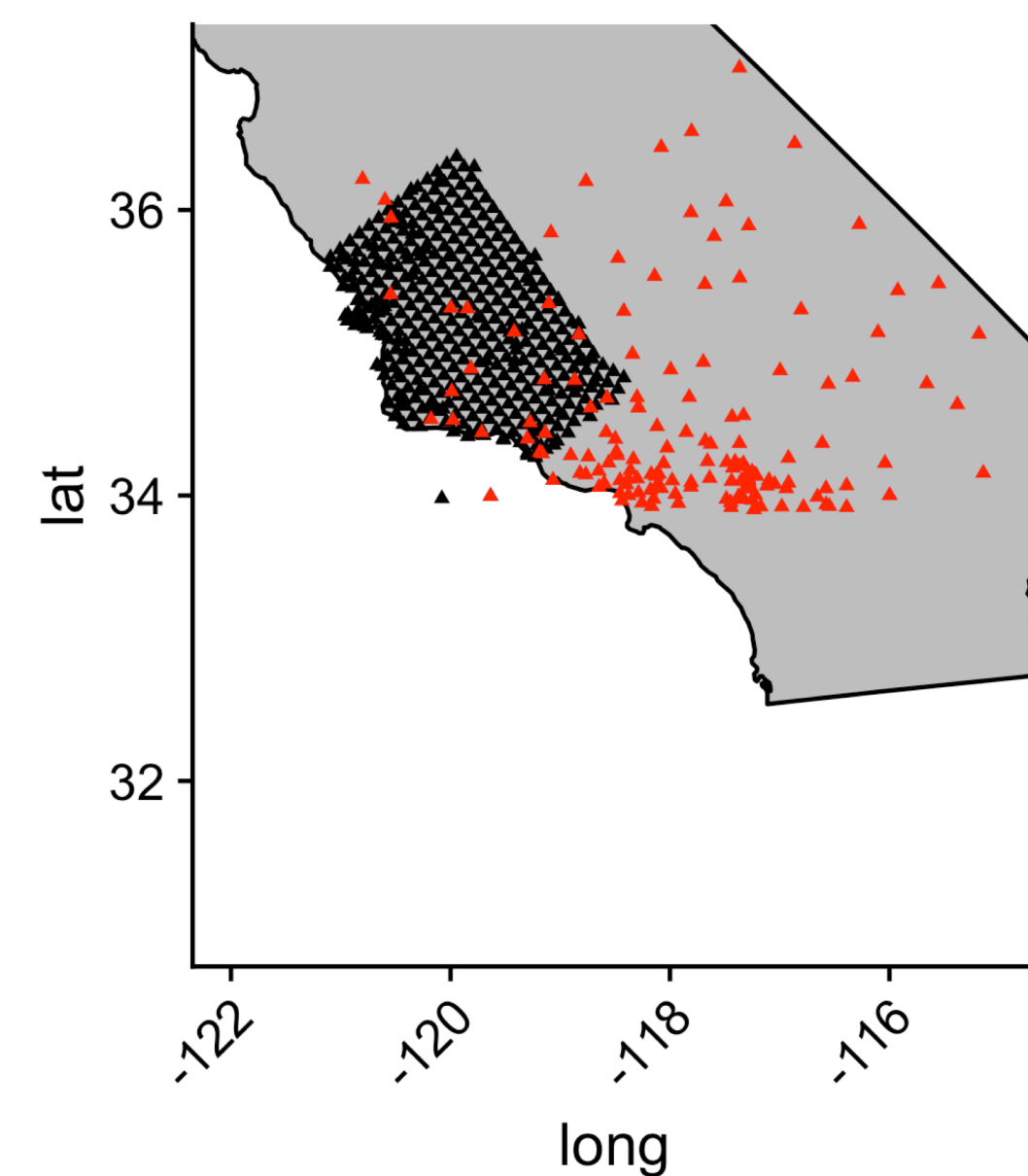
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## Introduction

In the context of probabilistic seismic hazard analysis (PSHA), the standard deviation ( $\sigma$ ) of ground motions drives ground motion estimates at the low probabilities of exceedance used for design. The most promising way to reduce  $\sigma$  is through the removal of the ergodic assumption and transferring of aleatory variability into epistemic uncertainty. Our objective is to better quantify the contributions from repeatable source, site and path variability from ground motions. We use CyberShake as our testbed as it provides a controlled testing environment with large datasets. We also use NGA-West2 dataset, which are more sparse, for comparison and validation. Our analysis procedure builds on work from *Al Atik et al., (2010)* and *Villani and Abrahamson (2015)*. We identify remaining issues and explore innovative solutions.

## Datasets

Datasets	Number of stations	Number of events	Number of seismograms
NGA-West2 in California	156	73	2013
CyberShake (CS) 17.3	438	~500,000	~10 <sup>8</sup>

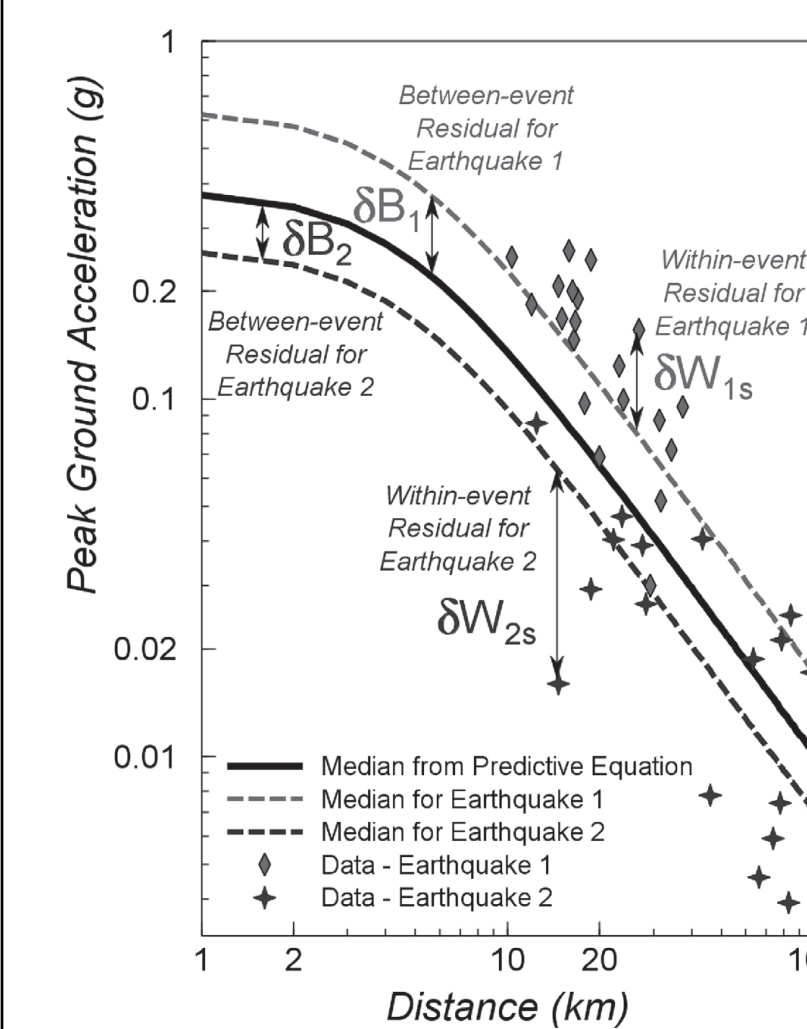
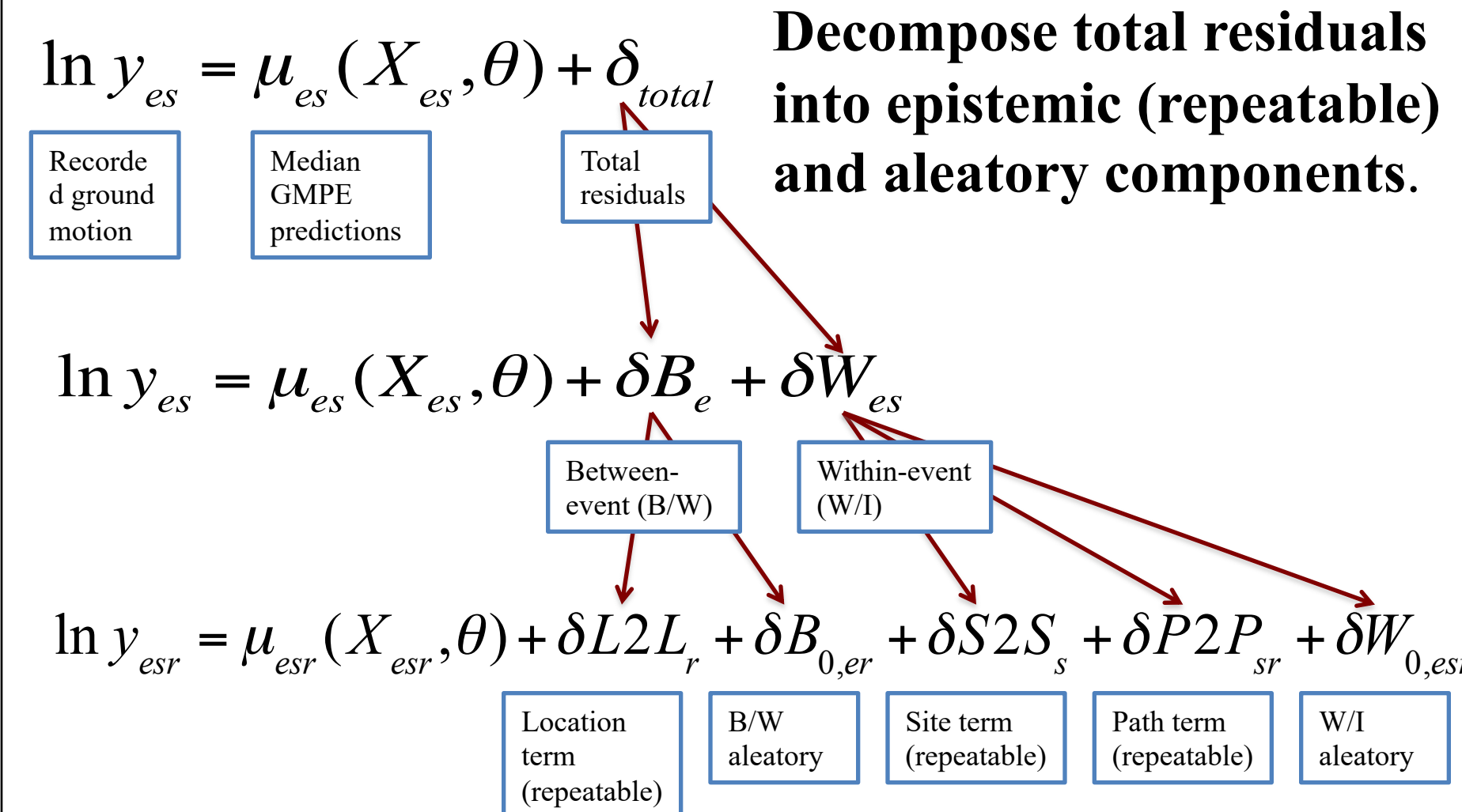


**Figure 1.** Map of stations for both datasets. The black and red triangles are stations from CS 17.3 and NGA-West2 in CA, respectively.

## References

1. Al Atik et al (2010). The variability of ground-motion prediction models and its components, *Seismol. Res. Lett.*
2. Villani, M. and N. A. Abrahamson (2015). Repeatable Site and Path Effects on the Ground-Motion Sigma Based on Empirical Data from Southern California and Simulated Waveforms from the CyberShake Platform, *Bulletin of the Seismological Society of America*.
3. Graves et al (2010), CyberShake: A Physics-Based Seismic Hazard Model for Southern California, *Pure and Applied Geophysics*.
4. Ancheta et al (2014). NGA-West 2 Database. *Earthq. Spectra*.

## Mixed Effects Regression



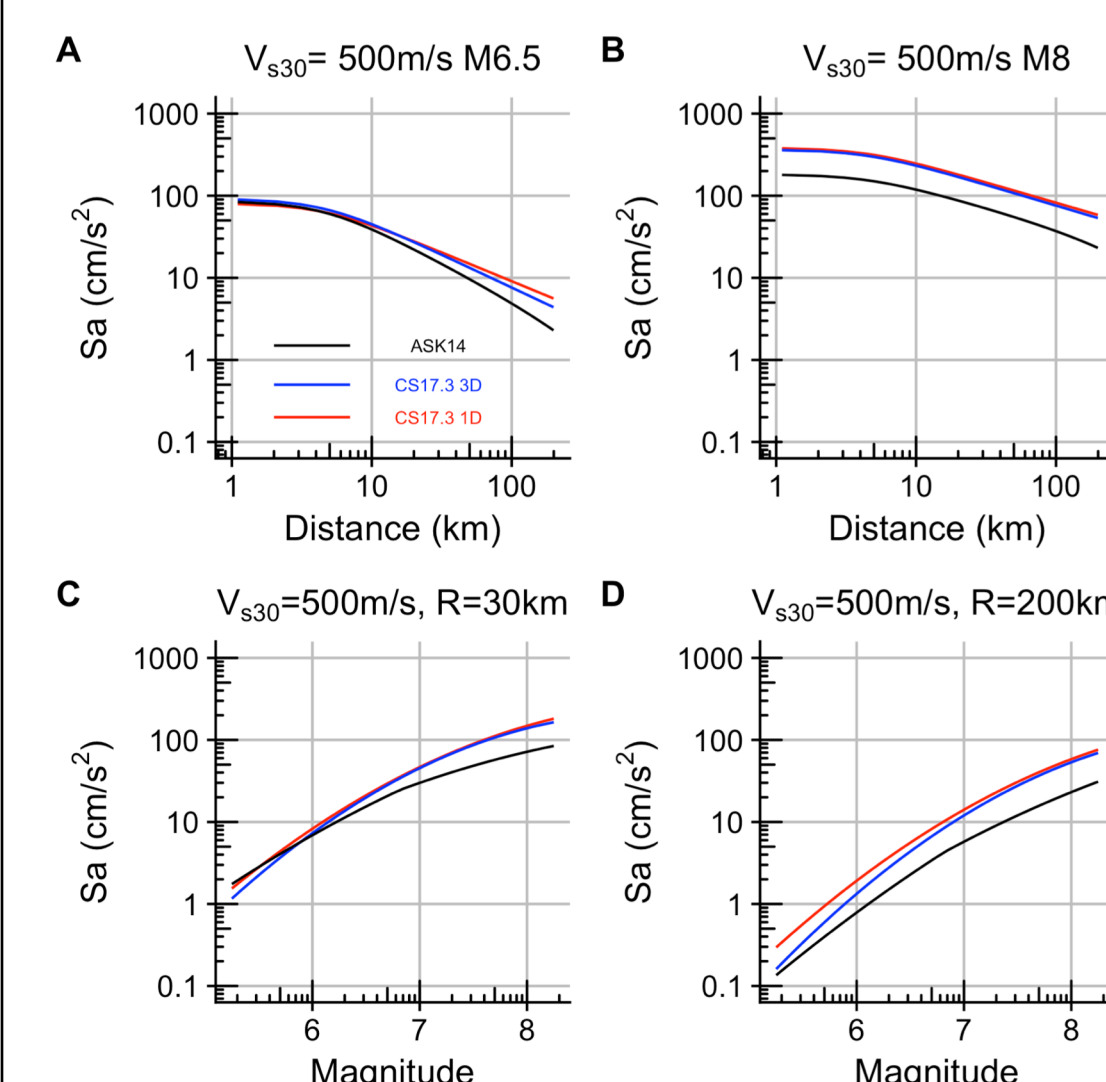
**Figure 2.** Illustration of between-event and within-event components of ground-motion variability (from *Al Atik et al., 2010*).

## Ground Motion Prediction Equation

$$\ln y_{es} = b_1 + b_2 * (m - 7) + b_3 * (m - 7)^2 + (b_4 + b_5 * (m - 7)) * (\log(\sqrt{R^2 + 4.5^2}) - 4.73) + b_6 \ln\left(\frac{V_{S30}}{760}\right)$$

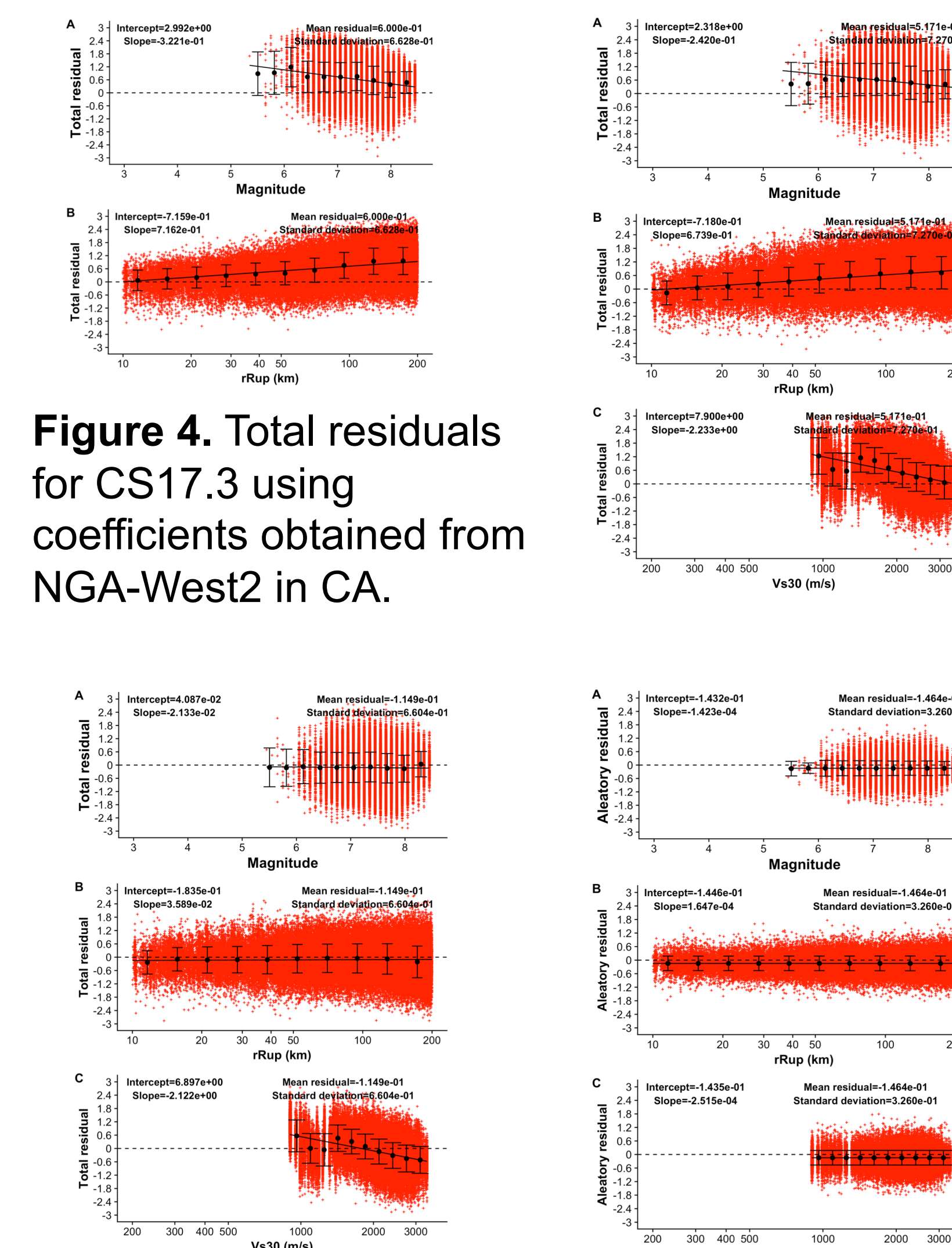
if  $V_{S30} > 760$ ,  $V_{S30}^* = 760$

$m$  is the magnitude of event,  $R$  is rupture distance,  $V_{S30}$  is the time-averaged S-wave velocity to 30 m depth.



**Figure 3.** (A, B) Comparison of distance scaling among ASK14 (black), models derived from CS17.3 3D (blue) and CS17.3 1D (red). (C, D) Comparison of magnitude scaling.

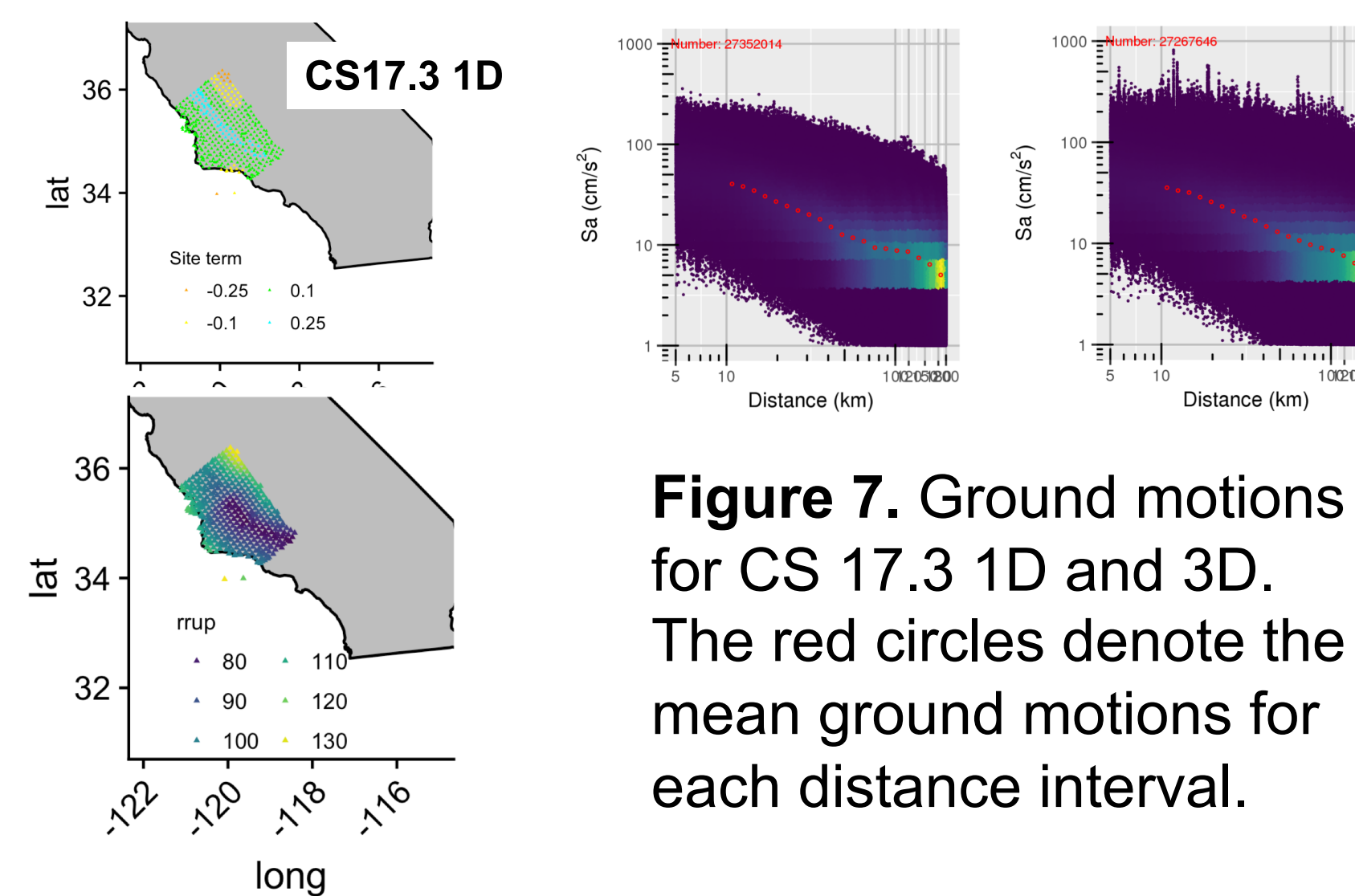
## Residuals



**Figure 4.** Total residuals for CS17.3 using coefficients obtained from NGA-West2 in CA.

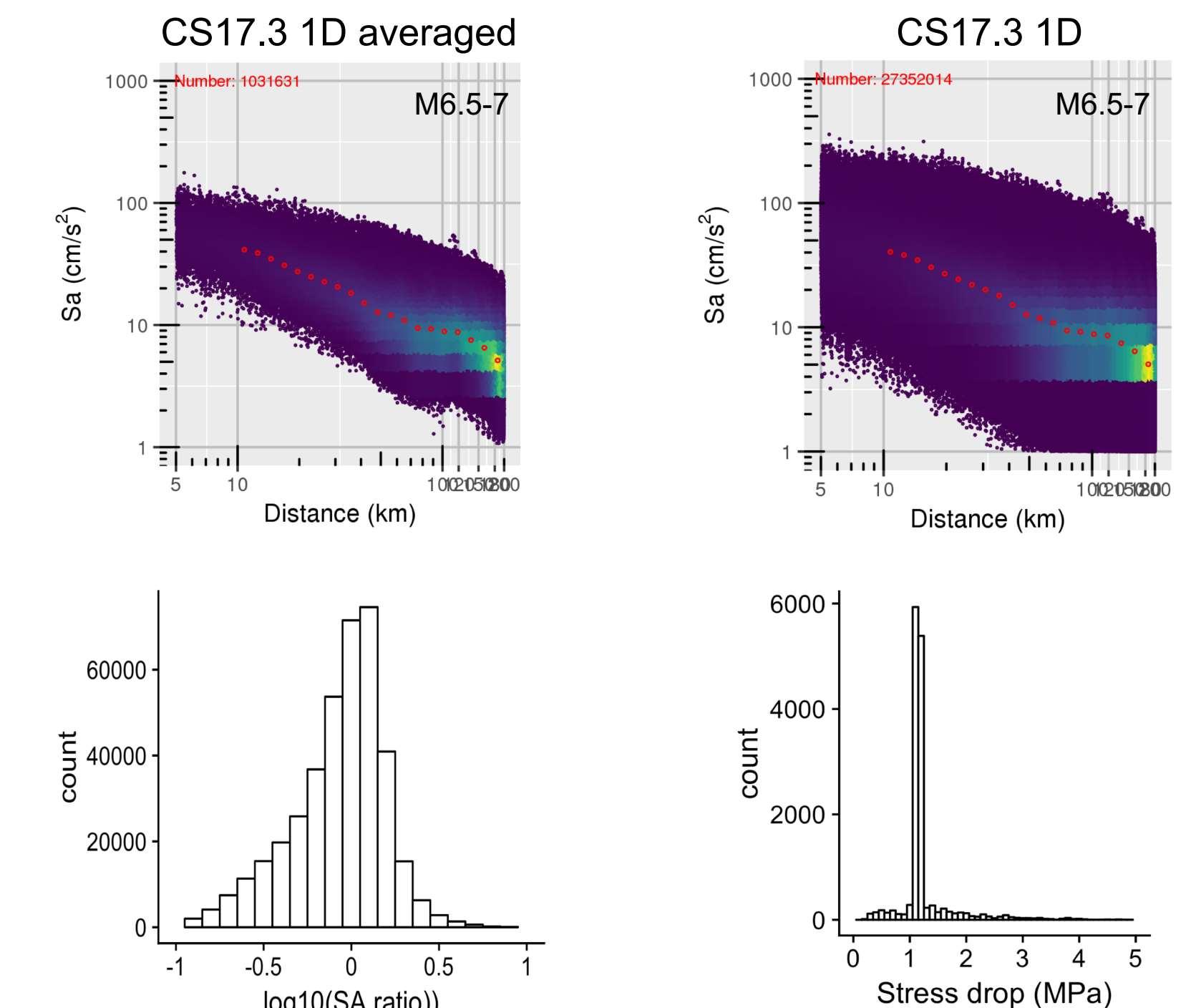
**Figure 5.** Total residuals from the model (left) and aleatory (right) derived with CS17.3 3D dataset.

## Issues



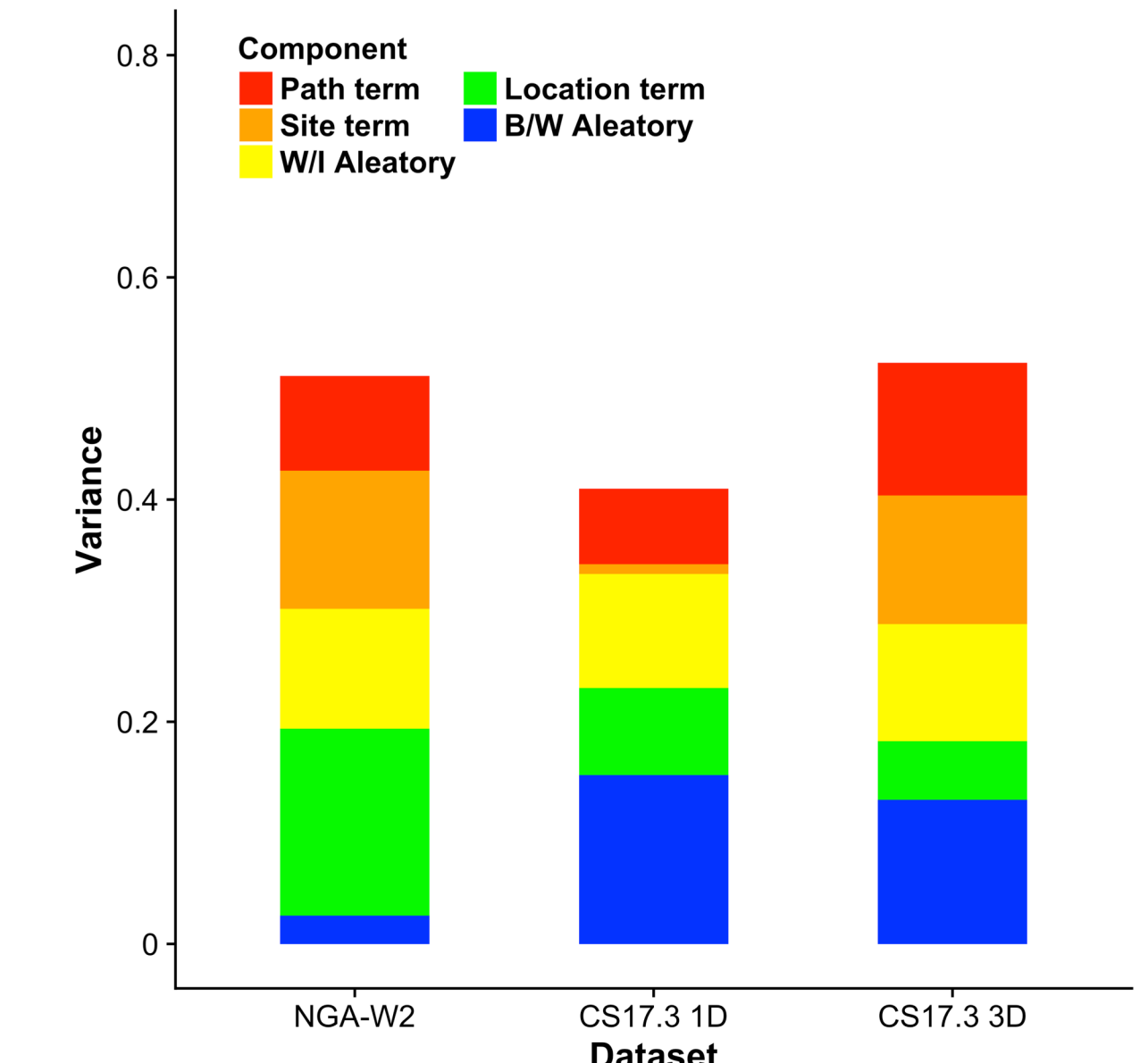
**Figure 6.** Map of site terms and mean rupture distance at each site.

## Issues, continued



**Figure 8.** The variability of ground motions from rupture variations (Top) and stress drop (right).

## Residual Partitioning



**Figure 9.** Partitioning of variance components for three models.

## Conclusions

1. CyberShake generates larger ground motions comparing to existing models;
2. At single site, CyberShake allows us to dig deeper into the source of variability;
3. The correct variance partitioning is not yet captured and more work is still ongoing.