

1. Introduction

Hybrid broadband simulations combine comprehensive physics-based models at low frequencies with simplified physics-based models at high frequencies to reproduce earthquake ground motions. These simulations are widely used in earthquake engineering, but most current implementations rely on ergodic assumptions — globally averaged parameters that neglect site-to-site variability.

A key parameter for the high-frequency decay of these simulations is the attenuation term κ , whose site-specific component κ_0 controls the slope of the Fourier Amplitude Spectrum (FAS) at high frequencies (Figure 1).

Most implementations assume a fixed value (e.g., $\kappa_0 = 0.045$ s; Lee et al., 2022), but observations (Van Houtte, 2014; 2018) show strong spatial variability. Capturing this variability is essential for nonergodic models that improve site-specific predictions.

This work-in-progress presents the first step: computing κ and κ_0 from both observed and simulated New Zealand earthquakes, and evaluating how well the fixed κ_0 assumption represents real data.

2. Methodology & Database

We use the New Zealand small-to-moderate magnitude earthquake database of Lee et al. (2022), which provides both observed and simulated ground motions for:

- 479 shallow-crustal events ($3.5 \leq Mw \leq 5.0$),
- 212 ground-motion stations across a wide range of site conditions,
- A total of 5218 ground motions.

Small-to-moderate events are especially useful for κ_0 studies because they excite the high-frequency band while keeping motions linear, allowing κ and κ_0 to be estimated without contamination from nonlinear site effects

κ was computed for observed and simulated ground motions following the conventional methodology of Anderson and Hough (1984), which estimates the high-frequency attenuation from the slope of the Fourier Amplitude Spectrum in a log-linear scale (see Figure 3a).

3. Results

Figure 3b shows the regression of κ against source-to-site distance for the entire database, comparing observed and simulated records. The overall trends confirm that the ergodic assumption of $\kappa_0 = 0.045$ s, commonly used in simulations, is broadly consistent with the average of the observed data. However, the regression lines also highlight that this fixed value fails to capture the considerable scatter present in the observations, suggesting that site-specific effects and local attenuation conditions strongly influence κ_0 .

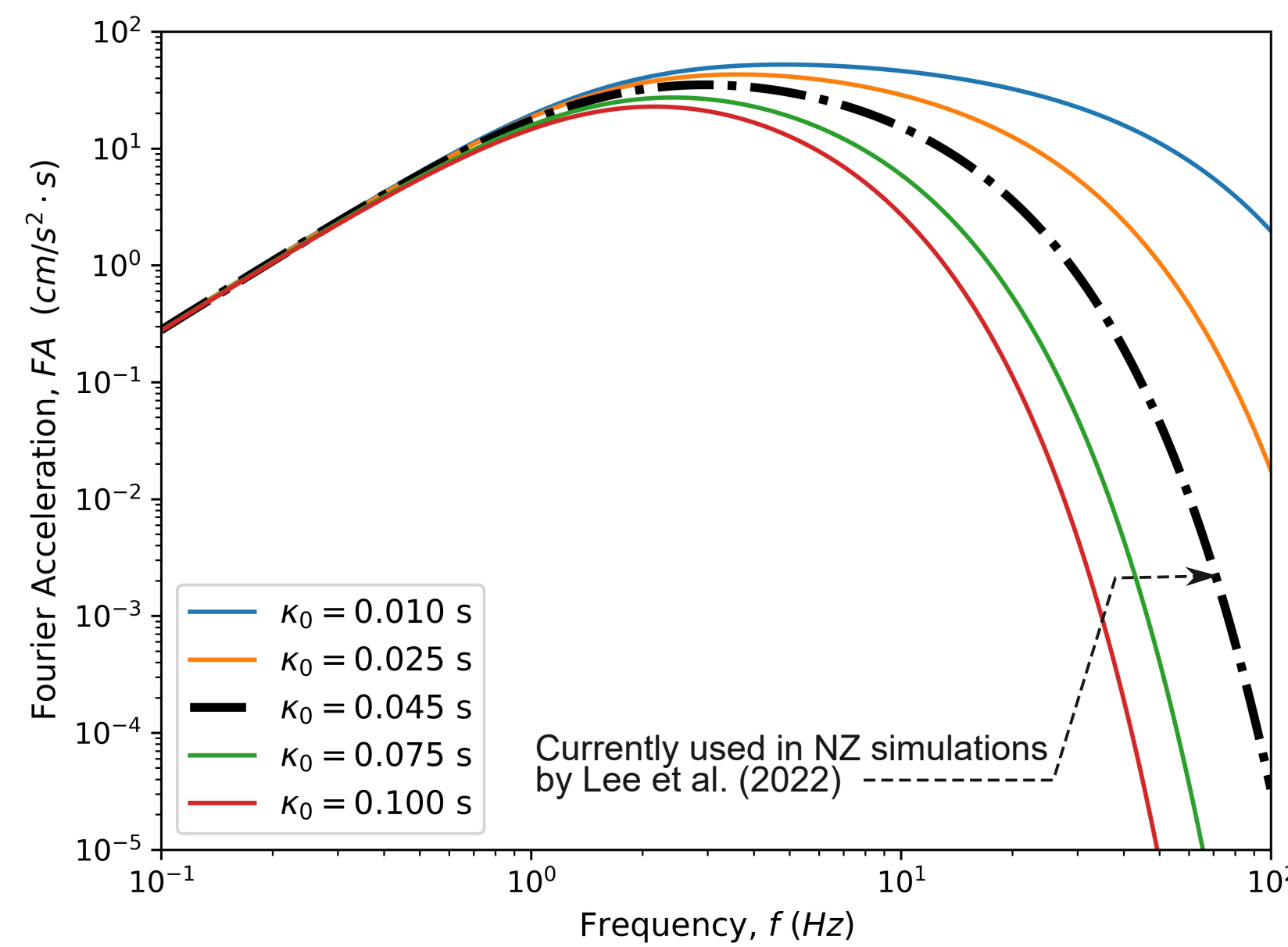


Figure 1. Fourier Amplitude Spectra (FAS) with varying κ_0 values. Increasing κ_0 steepens the high-frequency decay, illustrating its role in controlling site attenuation.

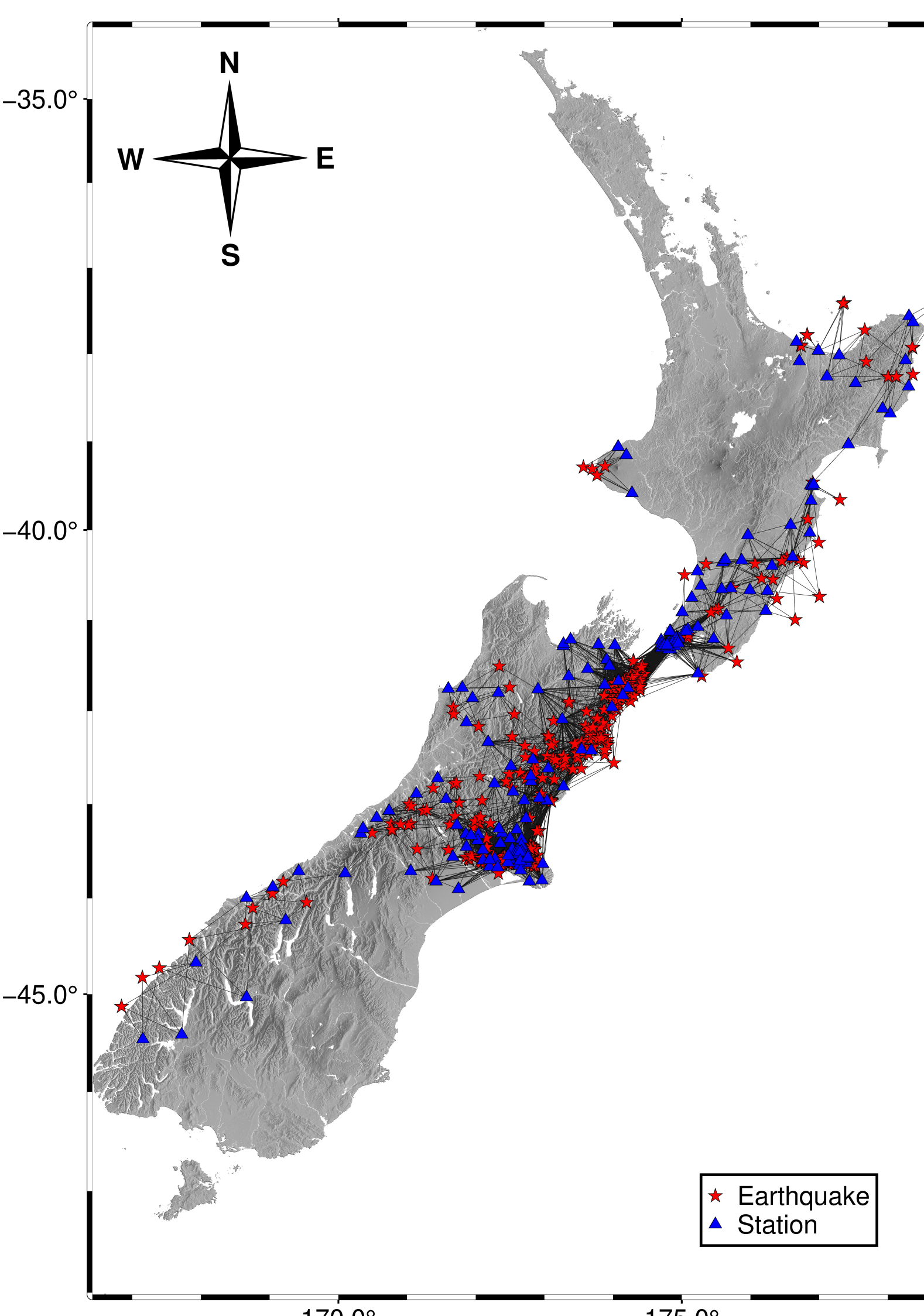


Figure 2: Map of New Zealand showing the distribution of 479 shallow-crustal earthquakes ($3.5 \leq Mw \leq 5.0$) and 212 ground-motion stations from the Lee et al. (2022) database used in this study.

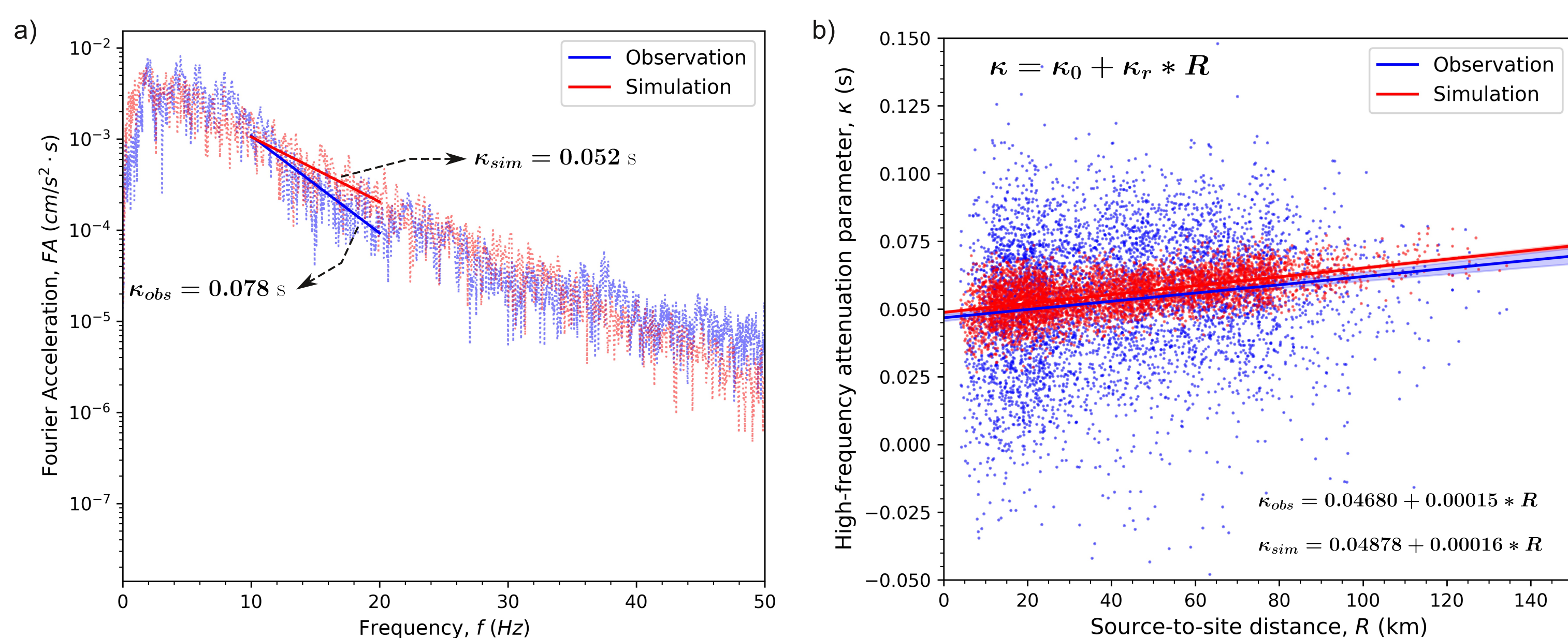


Figure 3: a) RMS Fourier Amplitude Spectrum for event 2012p001403 at station CACS, with regression fit (10–20 Hz). b) κ versus distance: simulations (red) and observations (blue) align with the ergodic $\kappa_0 = 0.045$ s, but observations show larger scatter.

The impact of data availability on κ_0 estimation is illustrated in Figure 4, which presents the regression for two stations. At stations with many recordings, the κ_0 estimates are more stable and associated with narrower uncertainty bounds, while stations with only a few recordings show large variability and uncertain estimates. This result underscores the importance of dense and long-duration station datasets for reliable nonergodic ground-motion modeling.

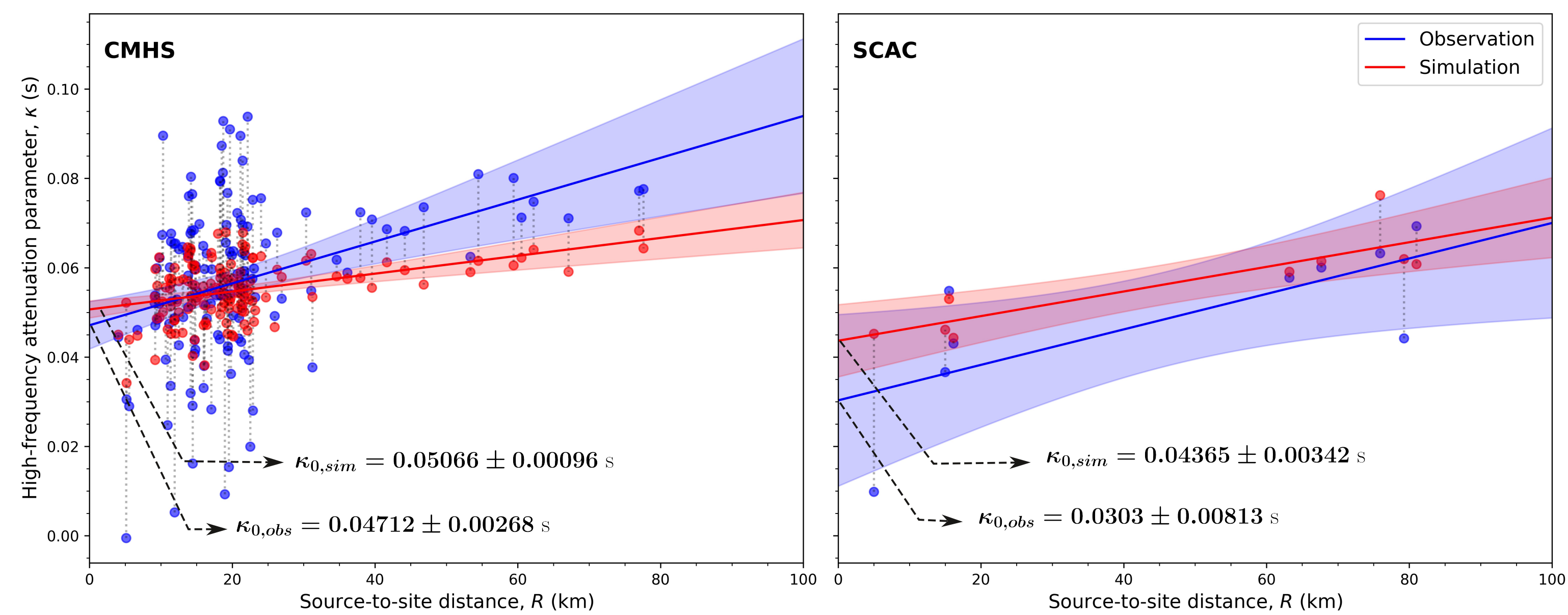


Figure 4: Example of κ_0 regression for two stations. Stations with many recordings yield stable and narrow uncertainty ranges, while sparse data lead to highly variable κ_0 estimates.

Finally, Figure 5 compares histograms of κ_0 derived from observed and simulated ground motions. Both distributions peak near the ergodic value of 0.045 s, supporting its use as a reasonable average parameter. Nevertheless, the observed distribution is notably wider, with some sites exhibiting significantly higher or lower values. This variability, absent in the simulations, emphasizes the need for incorporating spatially varying κ_0 models to better represent high-frequency ground-motion behavior across New Zealand.

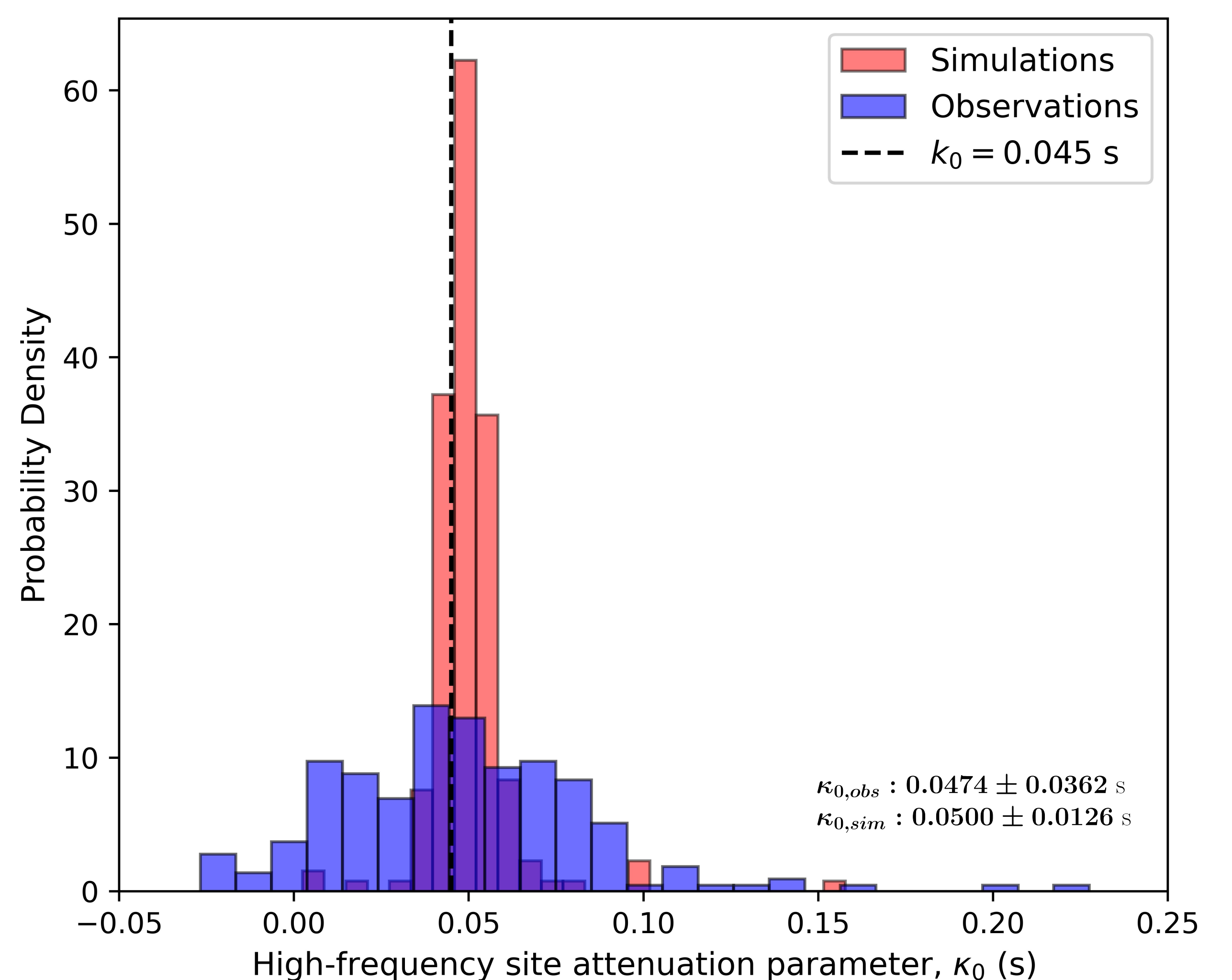


Figure 5: Histograms of κ_0 from observations and simulations. Both distributions peak near the ergodic value (0.045 s), but the observed values are more dispersed, highlighting site-specific variability absent in the simulations.

4. Future work

Future work will focus on advancing the treatment of κ_0 in hybrid broadband simulations. While the ergodic assumption ($\kappa_0 = 0.045$ s) matches overall trends, it neglects site-to-site variability. Next steps include:

- Testing the Van Houtte (2018) κ_0 map as a baseline in simulations.
- Developing an extended, simulation-based κ_0 map tailored to broadband modeling.
- Improving uncertainty quantification with more robust error estimates.
- Validating κ_0 maps through simulations against observations, with focus on high frequencies.

Expected Results: A simulation-oriented κ_0 map for New Zealand, improved realism in simulations, and more reliable site-specific predictions to support nonergodic models.

Key takeaways

- The high-frequency site attenuation parameter, κ_0 , is highly site-dependent — using a fixed ergodic value (e.g., 0.045 s) in hybrid broadband ground motion simulations fails to capture observed variability.
- Small-to-moderate magnitude events are valuable for κ_0 estimation since nonlinear effects can be neglected.
- Simulations currently reproduce the mean κ_0 but underestimate its scatter, highlighting the need for spatially varying models.
- Incorporating nonergodic κ_0 maps into hybrid simulations will reduce epistemic uncertainty and improve site-specific high-frequency ground motion predictions.

References

- Anderson, J. G., & Hough, S. E. (1984). A model for the shape of the Fourier amplitude spectrum of acceleration at high frequencies. *Bulletin of the Seismological Society of America*, 74(5), 1969-1993.
- Lee, R. L., Bradley, B. A., Stafford, P. J., Graves, R. W., & Rodriguez-Marek, A. (2022). Hybrid broadband ground-motion simulation validation of small magnitude active shallow crustal earthquakes in New Zealand. *Earthquake Spectra*, 38(4), 2548-2579.
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