Regional Adjustments to Ground Motion Models for the Santa Barbara Region, CA

Ken Hudson[1]

[1]Hudson Geotechnics (ken@hudsongeotechnics.com)

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1. Abstract

This study develops region specific adjustments to ground motion model source, path, and site terms for the Santa Barbara region of California, a tectonically active area characterized by unique geological features within the broader context of California's geology. The Santa Barbara region features coastal marine terraces and plains, fault-bounded structures, and shallow alluvial deposits overlying complex basement rock.

A dataset of recent earthquake records within and near the region are used to examine trends of the ground motion intensity measure residuals and propose modification to model terms dependent on the regional bias, azimuthal path effects, and local site effects.

2. Introduction

Seismic Hazard in Santa Barbara

Santa Barbara, California, lies in a seismically active region, where the complex interplay of faults generates significant earthquake hazards. Understanding ground motions— the shaking intensity caused by earthquakes— is critical for designing resilient infrastructure. The National Seismic Hazard Model (NSHM), developed by the U.S. Geological Survey, provides the basis for building code design ground motions. In Santa Barbara, these design ground motions are notably high due to the region's proximity to local faults (**Figure 1**).

Variations in Recorded Ground Motions

Stations CE.25392 and CI.USB that recorded peak ground accelerations (PGA) differing by a factor of 3 (0.08g and 0.26g, respectively) during the 29 May 2013 M4.8 Isla Vista earthquake. The stations are separated by approximately 350 m and their azimuths vary (w.r.t. epicenter) by approximately 2°. Both sites are located on the same uplifted marine terrace (Minor et al. 2007, 2009) overlying Sisquoc formation siltstone with time-averaged shear-wave velocity (V_S) of the upper 30 m (V_{S30}) values of 323 and 313 m/s, respectively. The source for these two records is the same, the path is almost identical, and from conventional metrics, the site effects should be very similar. Therefore, there must be another local site effect not characterized by V_{S30} influencing the large difference in recorded PGA. This observation is what initiated this study.

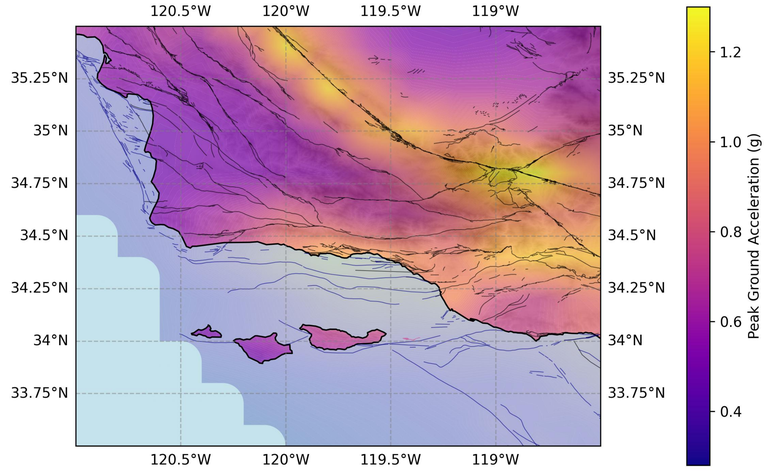

Figure 1: NSHM23 (Petersen et al. 2023) Site Class D Probabilistic Seismic Hazard PGA for 2% probability of exceedance in 50 years (2,475-year return period)

3. Dataset and Methodology

ObsPy (Beyreuther et al. 2010) and gmprocess are used to identify events in the region from 2011 to the present and download/process records, respectively. 5,302 records are successfully downloaded and processed for 42 events (**Figure 2**). A second dataset obtained from the ground motion database (Buckreis et al. 2023, 2025) included 6,826 records from 16 events that were recorded on CE.25392, CI.USB, or CE.25901.

Residuals for event i at recording station j (R_{ij}) are computed using the natural logarithm of the recorded intensity measure ($\ln IM_{meas}$), typically spectral acceleration (S_a), and the mean predicted intensity measure ($\mu_{\ln IM}$):

$$R_{ij} = \ln IM_{meas} - \mu_{\ln IM}$$

Mixed-effects regression is used to partition R_{ij} into the following variables:

$$R_{ij} = c_0 + \eta_{E,i} + \delta W_{ij}$$

where c_0 is the total bias of the dataset (i.e., if the recordings in the dataset on average are overpredicted, then the c_0 will be negative to correct for this), $\eta_{E,i}$ is the event term for event i (i.e., if event i's records are overpredicted relative to the dataset being examined, then $\eta_{E,i}$ will be negative), and δW_{ij} is the within-event residual for event i at station j (i.e., if a particular record is overpredicted after correcting for the dataset's bias (c_0) and the event's bias ($\eta_{E,i}$), then δW_{ij} will be negative).

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The resulting total bias terms are presented in **Figure 3**. **Figure 4** presents relative misprediction of PGA for the events in the gmprocess dataset and **Figure 5** examines potential path effect biases

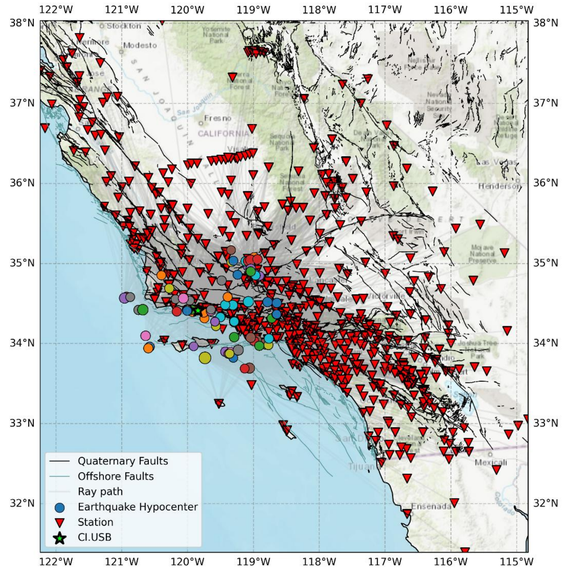

Figure 2: Map showing gmprocess dataset events, recording stations, and processed waveforms' ray paths.

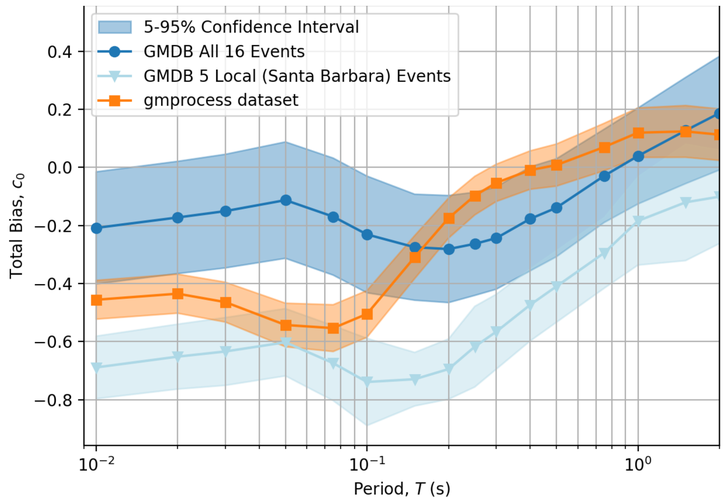

Figure 3: Total bias from the assembled datasets.

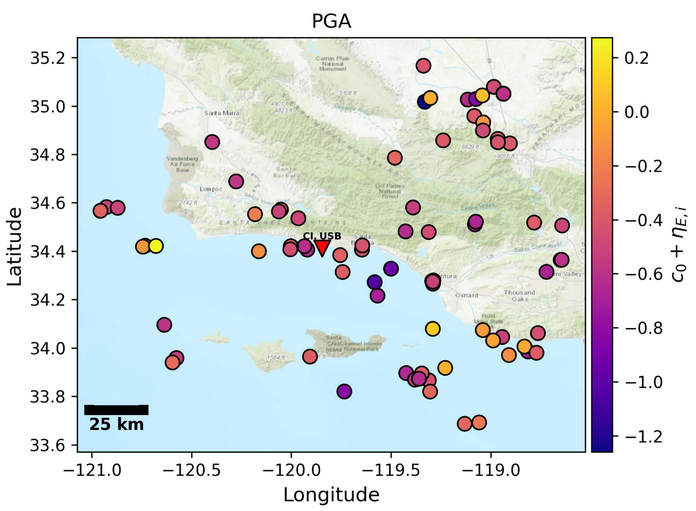

Figure 4: Event misprediction of PGA for gmprocess dataset

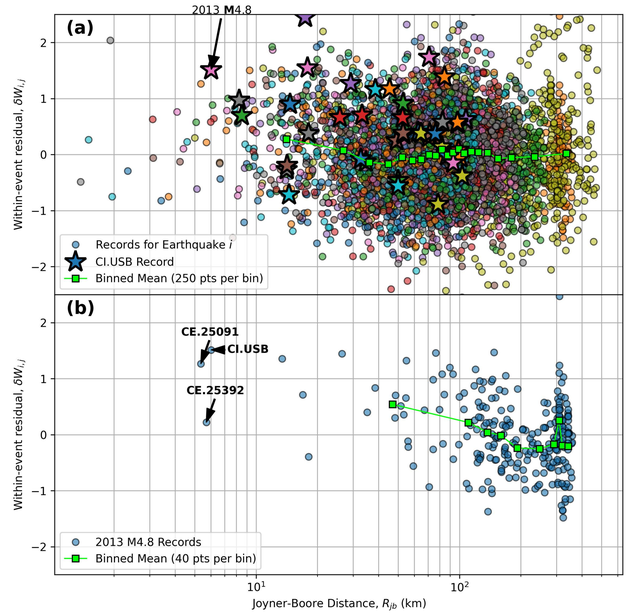

Figure 5: Within-event residuals against Joyner-Boore distance **(a)** for the entire dataset and **(b)** for recordings of the 2013 M4.8 Isla Vista earthquake.

δW_{ij} can be further split using an additional mixed-effects regression into the site term ($\eta_{S,j}$) and the remaining residuals ($\delta W_{ij,0}$). The site term represents the overall misprediction of a station; when it is positive, that means the site typically experiences larger shaking than expected.

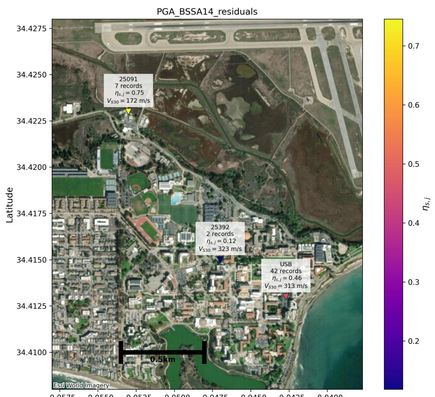

Figure 6: Map of site terms for 3 recording stations at UCSB from the gmprocess dataset.

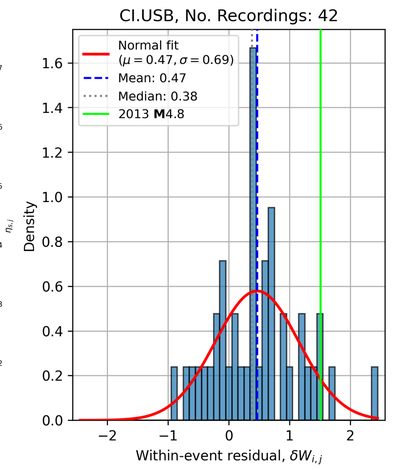

Figure 7: Histogram of within-event residuals at CI.USB from the gmprocess dataset.

4. Conclusions

There seem to be strong biases (relative to ground motion records in California) in source effects for events located within the Santa Barbara region and locally in site effects at stations at UCSB. There are potentially path effects biases as well. Further research is needed on the region to understand mechanisms for these biases.

5. References

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