Interim results from empirical ground motion model evaluation for the NZ National Seismic Hazard Model Update

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ABSTRACT

As a part of the ongoing 2022 NZ National Seismic Hazard Model (NSHM) Update, the predictive capabilities of candidate empirical ground motion models are evaluated to ascertain models which provide good prediction for NZ conditions and adequately capture epistemic uncertainty. This study utilizes a recent ground motion database, also developed as a part of the project. A high-quality subset of the database appropriate for ground motion model validation was adopted comprising over 16000 ground motion records from over 800 earthquakes recorded at 340 strong motion stations. Prediction of ground motions from shallow crustal, subduction interface and subduction slab earthquakes are considered. Numerous candidate models are considered from Next Generation Attenuation studies (e.g., NGA-West2 and NGA-Sub), as well as other recent international and NZ-specific studies. Assessment of model prediction bias and standard deviations are presented to provide a summary of model performance. Analyses of source, path and site parameter dependence and an examination of prediction for scenarios beyond the validation data range (e.g., large M_w subduction interface), including a comparison between models for such scenarios, are also summarised. Results from this study are used to inform ground motion modelling decisions in seismic hazard analyses, such as logic tree weights, metamodel development, and non-ergodic backbone modelling efforts.

1 INTRODUCTION

Ground-motion characterisation modelling, conventionally through empirical ground motion models (GMMs), is an important component of seismic hazard analysis. While New Zealand (NZ) has a long history of empirical GMM development, efforts have generally been sparse and intermittent because of data paucity limitations at large magnitudes (Mw) and short source-to-site distances (R_{rup}). Therefore, international models (e.g., from the NGA-West2 and NGA-Sub projects) need to be considered to adequately represent epistemic uncertainty of ground motion prediction in NZ. Van Houtte (2017) was the latest study to provide an evaluation of empirical GMM in a NZ context. However, several advances in ground motion data and modelling have occurred since that study. This study provides interim results on the evaluation of predictive performance of candidate empirical GMMs as a part of the 2022 NZ National Seismic Hazard Model (NSHM) Update project which will inform hazard modelling efforts.

2 DATA

This study adopts the ground motion database (GMDB) version 1.0 of Hutchinson et al. (2022), also developed as a part of the 2022 NZ NSHM Update project. Specifically, a subset of high-quality records following the enforcement of several quality and GMM applicability range criteria is adopted as the validation dataset. Table 1 provides details of the GMM applicability range criteria and final quantities of earthquakes, stations, and records. Figure 2 presents the spatial distribution of the earthquakes considered, categorised by tectonic class.

Table 1: Ground-motion database adopted parameter ranges and quantities for each tectonic class.

Tectonic Class	Minimum Magnitude	Maximum R_{rup} (km)	Number of Earthquakes	Number of Stations	Number of Records
Crustal	3.5	300	655	306	12,432
Interface	4.5	500	83	221	1800
Slab	4.5	500	115	226	2432
Total	-	-	853	340	16,664

3 MODELS

The suite of models evaluated comprises a recent NZ model, and credible international models developed by experienced modelling teams using large ground motion databases. Consideration was also given to models which robustly model ground motion phenomena which may be outside of the validation dataset parameter range (e.g., nonlinear site effects). Figure 1 presents tables which list the considered models for each tectonic class.

Crustal

Model	Abbreviation
Bradley (2013)	-
Abrahamson et al. (2014)	ASK (2014)
Boore et al. (2014)	BSSA (2014)
Campbell and Bozorgnia (2014)	CB (2014)
Chiou and Youngs (2014)	CY (2014)

NGA-West2

Interface

Model	Abbreviation
Zhao et al. (2006)	Zhao SI (2006)
Abrahamson et al. (2016)	BCH SI (2016)
Abrahamson et al. (2018)	BCHU SI (2018)
Abrahamson and Gülerce (2020) Global	AG Global SI (2020)
Abrahamson and Gülerce (2020) NZ	AG NZ SI (2020)
Kuehn et al. (2020) Global	KBCG Global SI (2020)
Kuehn et al. (2020) NZ	KBCG NZ SI (2020)
Parker et al. (2020) Global	PSBAH Global SI (2020)

Slab

Model	Abbreviation
Zhao et al. (2006)	Zhao SS (2006)
Abrahamson et al. (2016)	BCH SS (2016)
Abrahamson et al. (2018)	BCHU SS (2018)
Abrahamson and Gülerce (2020) Global	AG Global SS (2020)
Abrahamson and Gülerce (2020) NZ	AG NZ SS (2020)
Kuehn et al. (2020) Global	KBCG Global SS (2020)
Kuehn et al. (2020) NZ	KBCG NZ SS (2020)
Parker et al. (2020) Global	PSBAH Global SS (2020)

NGA-Sub

Figure 2: Empirical ground motion models considered in the evaluation for each tectonic class.

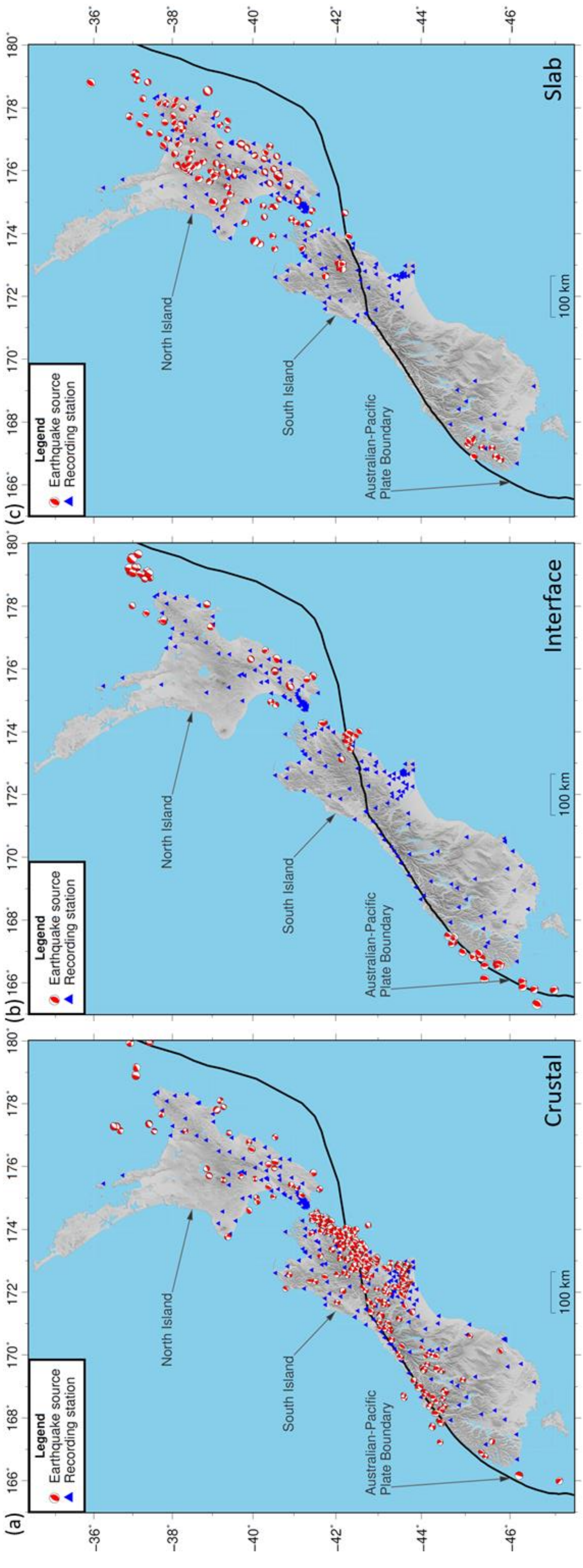

Figure 2: Maps showing location of earthquake sources and ground-motion recording stations considered across New Zealand for (a) crustal, (b) interface and (c) slab earthquakes. The Australian-Pacific tectonic plate boundary is shown by the thick black line.

4 RESULTS SUMMARY

The adopted evaluation framework follows an in-depth analysis of partitioned residuals (Al Atik et al, 2010) obtained through mixed-effects regression. Intensity measures of interest are pseudo-spectral acceleration (pSA) for 0.01-10.0s and PGA. In this paper, a summary of model prediction bias and total standard deviations are presented. Results of further detailed analyses are only briefly mentioned for conciseness but will be elaborated upon further in subsequent presentations, as well as the final report and paper.

Figures 3, 4 and 5 present the model prediction biases and total standard deviation (σ) for crustal, interface, and slab earthquakes, respectively.

- Figure 3: All crustal models show relatively small biases across all vibration periods with the exception of the Chiou and Youngs (2014) model which tends to underpredict pSA at long periods. The total standard deviation of residuals for each model are generally similar to the expected range from the models when used in forward prediction (i.e., the total standard deviation from the model development).
- Figure 4: The model prediction biases of interface models have more variability than crustal models, varying between roughly 0.5 and -0.5 natural log units, which indicates larger epistemic uncertainty. Like the crustal models, the total standard deviations are generally similar to the expected range from the models when used in forward prediction.
- Figure 5: The range of model prediction biases is largest in the slab models, although the PSBAH (2021) model is the only one systematically underpredicting. Excluding the PSBAH (2021) model, the range of remaining models is similar to the interface models. The total standard deviation of the recent models align well with the expected total standard deviations (based on NGA-Sub models) while the Zhao (2006) model has higher total standard deviations at short periods.

Parameter dependence of partitioned residuals (i.e., between-event, systematic site-to-site, and remaining within-event residuals) were also investigated to identify any trends with source, site and path parameters. While not explicitly included in this paper, the main trends were:

- A slight positive dependence of interface and slab models on M_w.
- Minor localized negative bias for very deep slab earthquakes (i.e., around 200km depth to top of rupture, Z_{TOR}).
- Slight negative bias at large R_{rup}.

Lastly, as the validation dataset of instrumentally-recorded earthquakes has limited magnitude range, the relative prediction of models for unrepresented significant scenarios was examined. This included large M_w, short R_{rup} scenarios for various site conditions (i.e., 30m time-averaged shear wave velocities, V_{s30}). Crustal models were found to be the most similar with one another showing differences that were roughly within a factor of 1.5x, while interface and slab models showed differences that were roughly within factors of 2x and 3x, respectively.

Collectively, the details of the above analyses will inform potential logic trees which may be used in probabilistic seismic hazard analysis calculations. Additionally, a representative suite meta-model can be developed using the existing empirical GMMs to compare with non-ergodic NZ-specific backbone models developed from Fourier amplitude spectra and random vibration theory frameworks, especially a comparison of inter-model uncertainty.

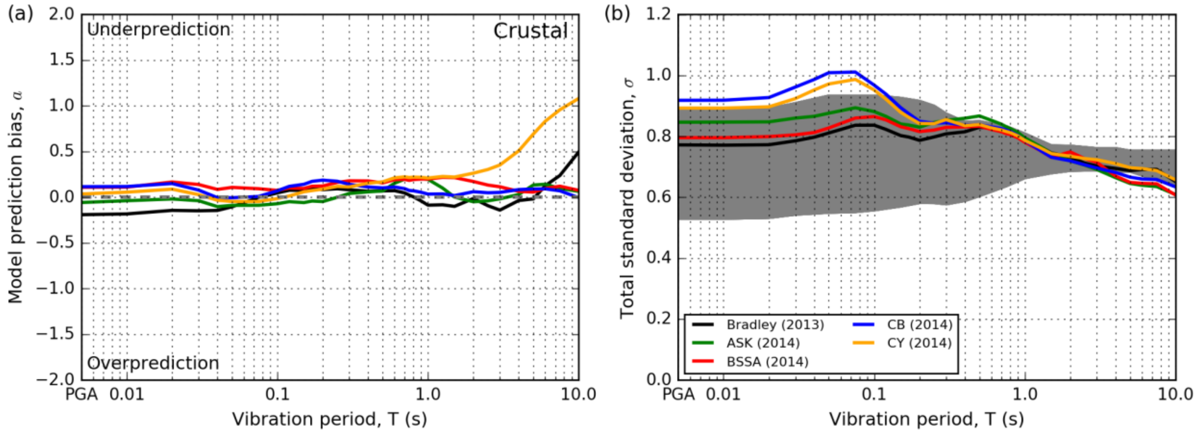

Figure 3: Crustal earthquake (a) model prediction bias, a, and (b) total standard deviation σ. The grey-shaded area indicates an approximate range of model σ when used in forward prediction (based on NGA-West2 models).

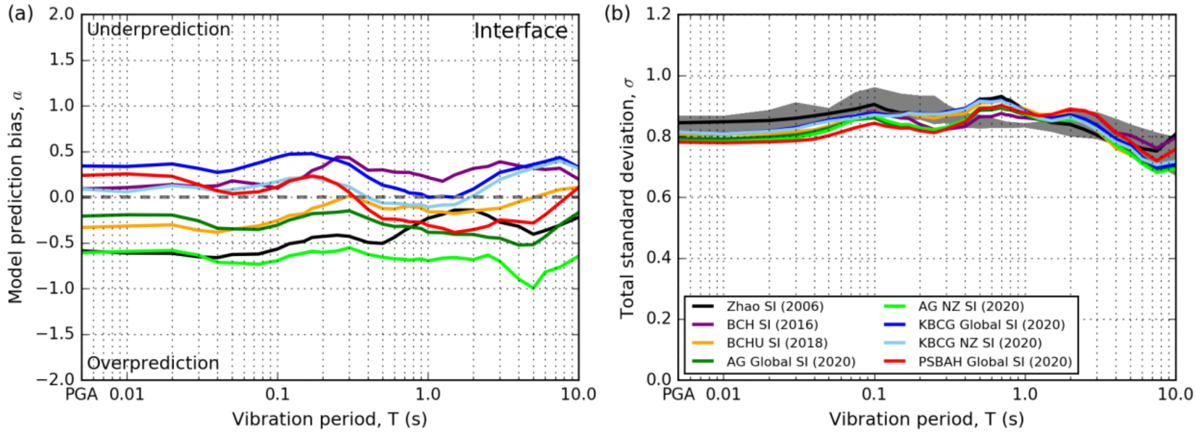

Figure 4: Subduction interface earthquake (a) model prediction bias, a, and (b) total standard deviation σ. The grey-shaded area indicates an approximate range of model σ when used in forward prediction (based on NGA-Sub models).

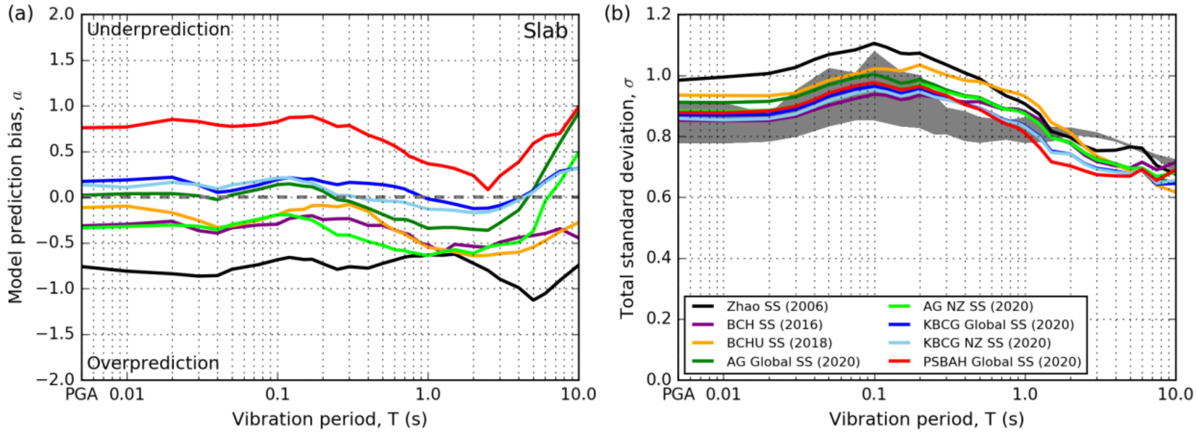

Figure 5: Subduction slab earthquake (a) model prediction bias, a, and (b) total standard deviation σ. The grey-shaded area indicates an approximate range of model σ when used in forward prediction (based on NGA-Sub models).

REFERENCES

Abrahamson N, Gregor N, Addo K. (2016). BC Hydro ground motion prediction equations for subduction earthquakes. Earthquake Spectra. 32(1):23–44. doi:10.1193/051712eqs188mr.

Abrahamson N, Gülerce Z. (2020). Regionalized ground-motion models for subduction earthquakes based on the NGA-SUB Database. Berkeley (CA): University of California, Pacific Earthquake Engineering Research Center Headquarters. 197 p. PEER Report 2020/25.

Abrahamson N, Kuehn N, Gulerce Z, Gregor N, Bozorgnia Y, Parker G, Stewart J, Chiou B, Idriss IM, Campbell K, et al. (2018). Update of the BC Hydro subduction ground-motion model using the NGA-Subduction Dataset. Berkeley (CA): University of California, Pacific Earthquake Engineering Research Center Headquarters. 80 p. PEER Report 2018/02.

Abrahamson NA, Silva WJ, Kamai R. (2014). Summary of the ASK14 ground motion relation for active crustal regions. Earthquake Spectra. 30(3):1025–1055. doi:10.1193/070913eqs198m.

Al Atik L, Abrahamson N, Bommer JJ, Scherbaum F, Cotton F, Kuehn N. (2010). The variability of ground-motion prediction models and Its components. Seismological Research Letters. 81(5):794–801. doi:10.1785/gssrl.81.5.794.

Boore DM, Stewart JP, Seyhan E, Atkinson GM. (2014). NGA-West 2 equations for predicting PGA, PGV, and 5%-damped PSA for shallow crustal earthquakes. Earthquake Spectra. 30(3):1057–1085. doi:10.1193/070113EQS184M.

Bradley BA. (2013). A New Zealand-specific pseudospectral acceleration ground-motion prediction equation for active shallow crustal earthquakes based on foreign models. The Bulletin of the Seismological Society of America. 103(3):1801–1822. doi:10.1785/0120120021.

Campbell KW, Bozorgnia Y. (2014). NGA-West2 ground motion model for the average horizontal components of PGA, PGV, and 5% damped linear acceleration response spectra. Earthquake Spectra. 30(3):1087–1115. doi:10.1193/062913eqs175m.

Chiou BS-J, Youngs RR. (2014). Update of the Chiou and Youngs NGA model for the average horizontal component of peak ground motion and response spectra. Earthquake Spectra. 30(3):1117–1153. doi:10.1193/072813eqs219m.

Hutchinson J, Bradley BA, Lee R, Wotherspoon L, Dupuis M, Schill C, Motha J, Kaiser AE, Manea E. In press. (2022) New Zealand Strong Ground Motion Database. Lower Hutt (NZ): GNS Science. (GNS Science report; 2021/56).

Kuehn N, Bozorgnia Y, Campbell KW, Gregor N. (2020). Partially non-ergodic ground-motion model for subduction regions using the NGA-Subduction Database. Berkeley (CA): University of California, Pacific Earthquake Engineering Research Center Headquarters. 148 p. PEER Report 2020/04.

Parker GA, Stewart JP, Boore DM, Atkinson GM, Hassani B. (2021). NGA-subduction global ground motion models with regional adjustment factors. Earthquake Spectra. doi:10.1177/87552930211034889.

Van Houtte C. (2017). Performance of response spectral models against New Zealand data. Bulletin of the New Zealand Society for Earthquake Engineering. 50(1):21–38. doi:10.5459/bnzsee.50.1.21-38.

Zhao JX, Zhang J, Asano A, Ohno Y, Oouchi T, Takahashi T, Ogawa H, Irikura K, Thio HK, Somerville PG, et al. (2006). Attenuation relations of strong ground motion in Japan using site classification based on predominant period. Bulletin of the Seismological Society of America. 96(3):898–913. doi:10.1785/0120050122.