Toward a Unified Database of Hybrid Broadband Ground-Motion Simulations for Historical Mw 3.5-7.8 Crustal and Subduction Earthquakes in New Zealand

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1. Introduction

Hybrid broadband ground-motion simulation can be used in seismic hazard and response-history analyses, offering significant potential advantages over empirical models currently used in practice to predict earthquake-induced ground motion. However, validation against observations from historical events is necessary to build confidence in the predictive capabilities of simulations and identify areas for modelling improvements.

2. Recent Validation Studies in New Zealand

Several validation studies have been conducted in New Zealand (NZ), using the Graves and Pitarka (2010, 2015, 2016) hybrid simulation method (GP method) and large datasets of recordings (Figure 1).

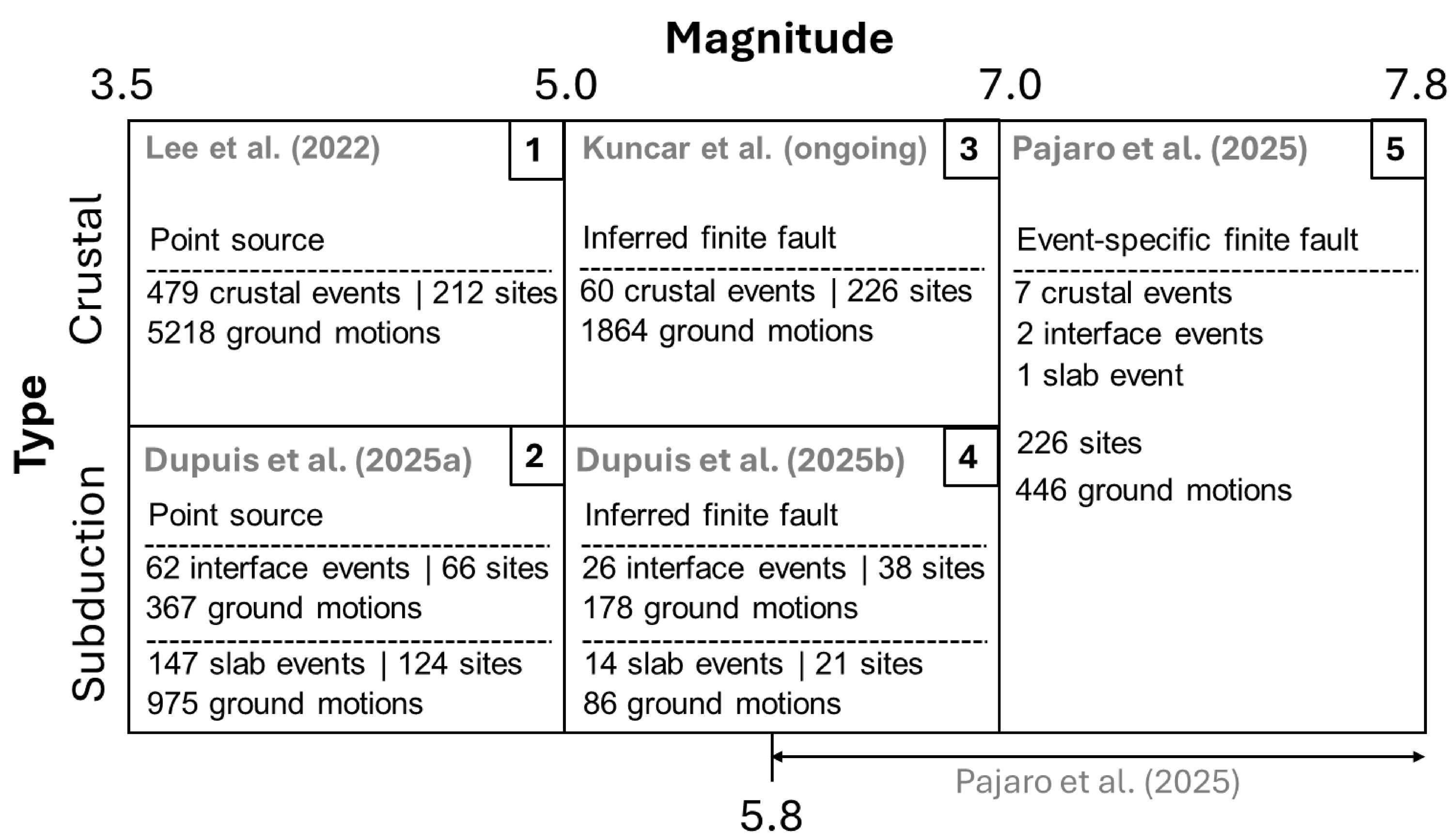

Figure 1: Main validation studies in NZ using large recording datasets, spanning small to large magnitudes and both crustal and subduction events.

While these individual studies have provided valuable insights and improvements in simulations based on subsets of the available observational data, a large-scale integrated dataset is needed to fully assess and enhance simulation performance across all earthquake types and site conditions. For example, Table 1 illustrates that different criteria and sources of information were considered in each validation study. An integrated database requires unified considerations.

Table 1: Characteristics of main validation studies in New Zealand.

Study in Fig. 1	Computational features	Site amp. model	NZ velocity model version	Observational database
1	$V_{S,min} = 500\ m/s$ $h_{grid} = 100$ m $f_t = 1\ Hz$	CB14	2.02	Study-specific
2		CB14	2.07	NZ GMDB v3.4
3		BA18	2.09	NZ GMDB v4.3
4		CB14	2.07	NZ GMDB v3.4
5		CB14	2.07	NZ GMDB v4.3

3. Prior validation studies in other regions

Globally, similar efforts have been undertaken, primarily focused on small-to-moderate crustal earthquakes (Table 2). These studies have been conducted considering different simulation methods and frequency ranges.

Table 2: Global validation studies.

Study	Region	Magnitude	No. of events	No. of recordings	f_{max} (Hz)
Goulet et al. (2015); Dreger et al. (2015)	USA (WUS, CENA), JPN	5.4 – 7.2	12	394	Hybrid f_t=1 Hz
Taborda et al. (2016)	Southern California	3.6 – 5.4	30	3071	1
Paolucci et al. (2021); BB-SPEEDset (2025)	ITA, GRC, JPN, TUR, FRA, CHN	4.9 – 7.0	11	~127	Hybrid f_t=0.5-1.3 Hz
Graves (2022)	California	5.9 – 7.3	12	504	Hybrid f_t=1 Hz
Sajan et al. (2024, ongoing)	Southern California	4.0 – 5.5	27	2917	1
Pinilla-Ramos et al. (2025)	San Francisco	3.8 – 4.4	7	943	5
Sajan et al. (2025, ongoing)	Northern California	4.0 – 5.5	59	7416	1
This study (ongoing)	**New Zealand**	**3.5 – 7.8**	**~849**	**~12,751**	**Hybrid f_t=1Hz**

4. Selected ground motions for a unified database

For the proposed database, the following screening criteria are considered (using the latest version of the NZ ground-motion database, NZ GMDB, v4.3):

- Only Crustal, Slab, and Interface earthquakes
- Earthquakes with a CMT solution and $Mw \geq 3.5$
- $R_{rup} \leq 300\ km$ and usable period of at least $T = 2\ s$
- At least 3 recordings per earthquake and station

Based on these criteria, a total of 44,379 ground motions from 1,503 earthquakes, recorded at 369 strong-motion stations, are available. Figure 2 shows the spatial distribution of these events and stations.

Based on the available waveform properties and the planned geographic extent of the simulation domains, we are provisionally considering 12,751 ground motions from 849 events, recorded at 348 stations. This represents a substantially larger validation dataset than those used in previous studies (e.g., Figure 1; Table 2).

5. Simulations and Expected Outputs

Table 3 summarizes the main features of the simulations that will be performed for the integrated database, using the GP method. The observational database to be used will be the NZ GMDB v.4.4, currently under development, which will potentially increase the amount of available validation data.

In addition to paired observed and simulated waveforms, this open-source database will include several intensity measures of engineering interest, computed for the simulations, the corresponding observations, and empirical models. For response spectra, the empirical models used in the 2022 NZ National Seismic Hazard model (Bradley et al., 2024) will be considered. All relevant simulation and empirical input parameters will be provided.

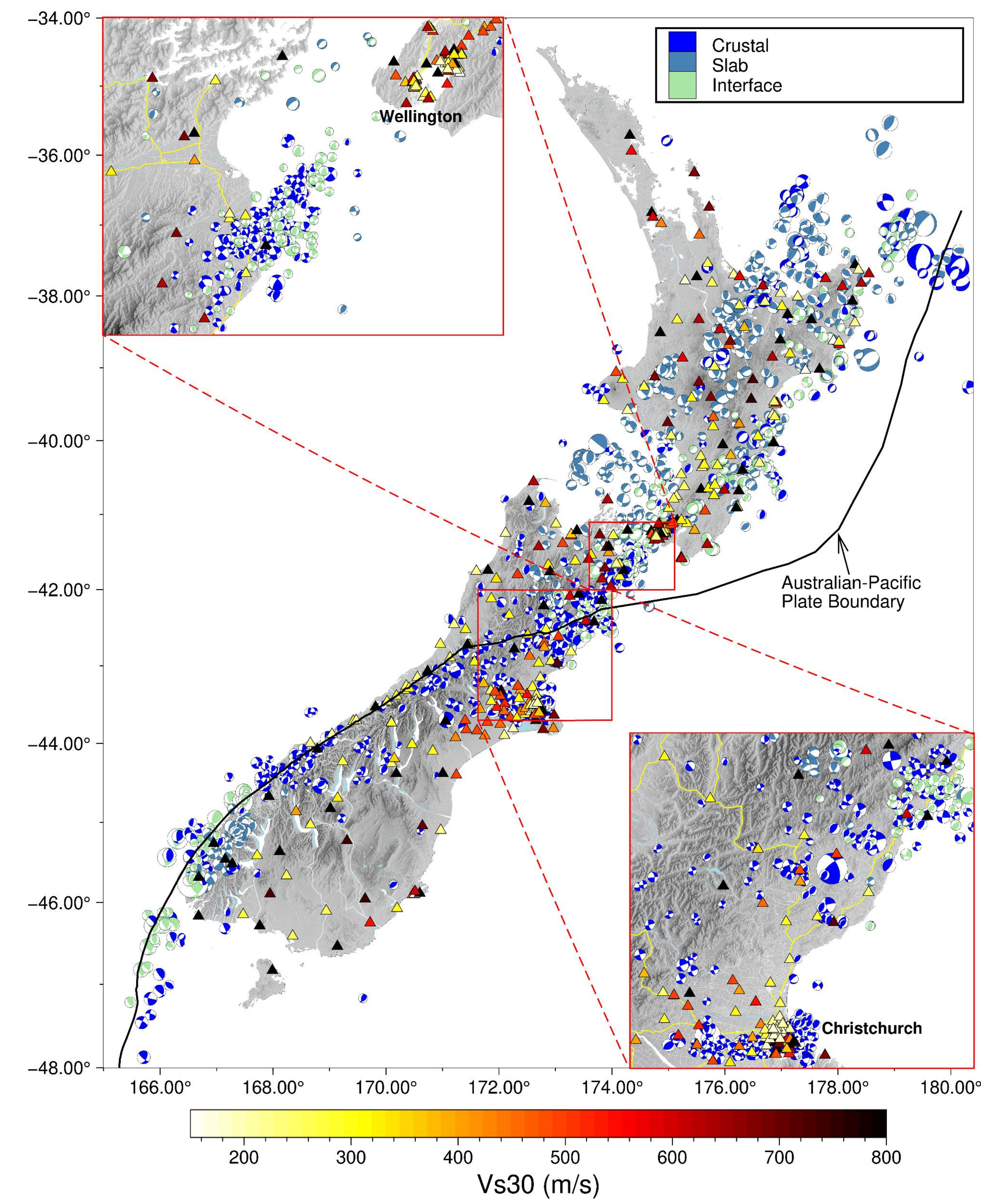

Figure 2: Location of potential stations and earthquake sources to be considered.

Table 3: Features of simulations to be performed.

Minimum shear-wave velocity ($V_{S,min}$)	500 m/s
Grid spacing (h_{grid})	100 m
Transition frequency (f_t)	1 Hz
Site amplification model	BA18
Velocity model	NZVM v2.09
Input parameters (e.g., κ_0, Brune stress parameter, rupture velocity)	Common parametrization for each tectonic class

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