The New Zealand Velocity Model (NZVM) Version 2.0 and ground motion simulations of Hope Fault earthquakes

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1. The New Zealand Velocity Model (NZVM) v2.0

The New Zealand Velocity Model (NZVM) is a crustal velocity model developed for use in physics-based broadband ground motion simulation. The NZVM is based on the concept of embedding high-resolution regional models, in a modular fashion, within a lower-resolution 3D tomography-based velocity model for the shallow crust. This flexible and extensible approach allows new regional models to be incorporated within the NZVM as they become available.

The NZVM Version 2.0 builds on Version 1.0 by incorporating seven recently developed regional sedimentary basin models, distributed throughout New Zealand, to supplement the existing Canterbury region model implemented in Version 1.0. Figure 1 illustrates the locations of the eight explicitly characterised sedimentary basins within NZVM Version 2.0. The modular approach allows for basin models, of varying levels of characterization, to be independently constructed allowing for multiple datasets to be utilised. Table 1 presents the data sources used in the construction of the NZVM Version 2.0 basin models.

Figure 2 presents cross sections of shear wave velocity through the NZVM. Figure 2b highlights the Canterbury region, where one of the numerous modular basin models implemented in NZVM exists, while Figure 2a illustrates the velocity structure in the underlying 3D tomography-based model. Figure 3 presents a velocity cross section through the Waiau basin illustrating the difference in velocity structure between NZVM Version 1.0 and 2.0.

The NZVM Version 2.0 has been implemented within the ground motion simulation framework at the University of Canterbury for use with the Graves and Pitarka (2015) simulation methodology. Previously, the NZVM Version 1.0 has been extensively used to conduct ground motion simulations and hazard analysis in New Zealand.

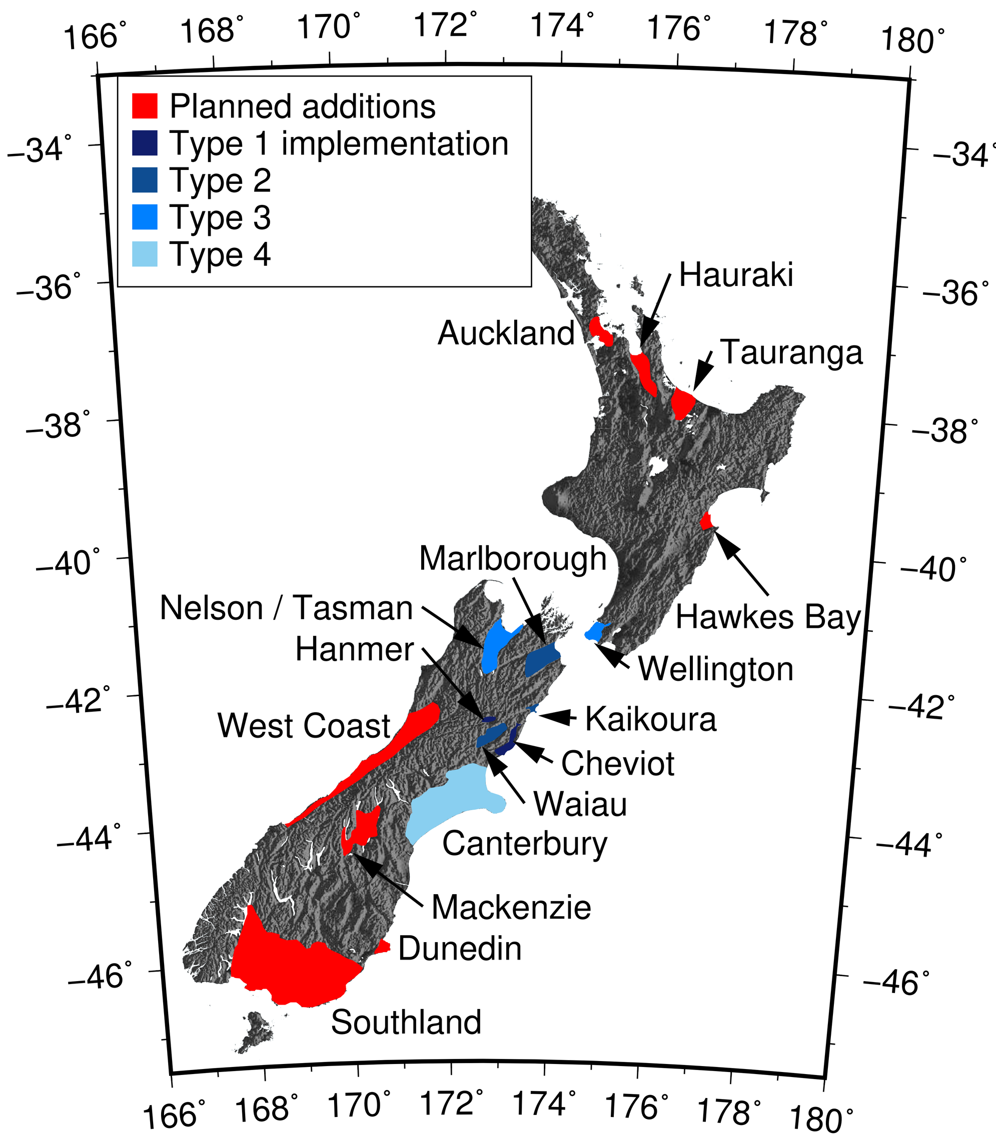

Figure 1: Sedimentary basins characterised in NZVM v2.0 and and planned basin models to be added in a future NZVM version.

Table 1: Data sources used in the construction of NZVM basin models

Type	Data sources used
Type 1	Topographic slope Geologic cross sections Vs_{30}
Type 2	Site periods (HVSR)
Type 3	Surface wave analysis studies
Type 4	Geotechnical and geophysical datasets (seismic reflection lines, boreholes, CPTs, etc)

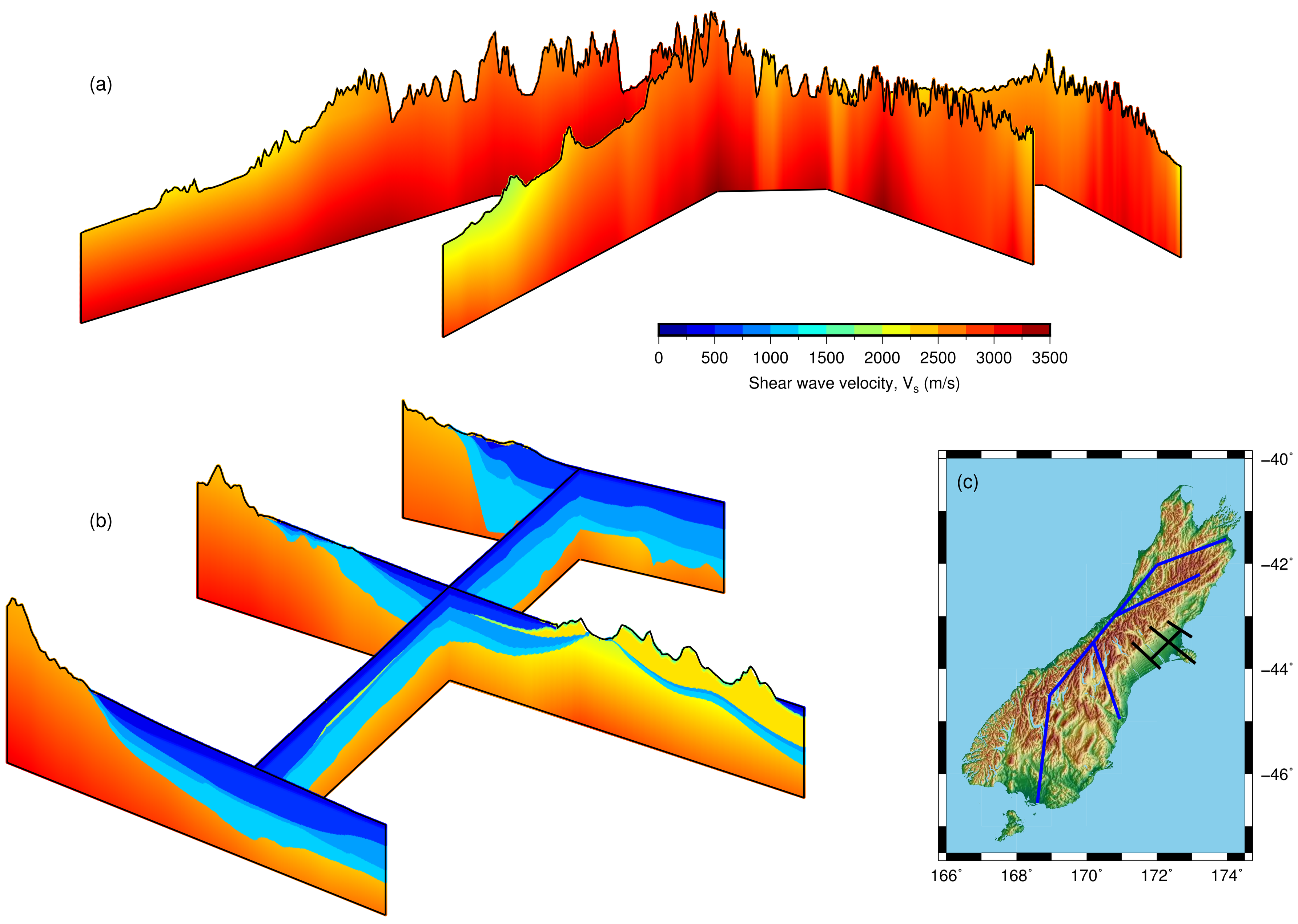

Figure 2: Cross sections of the New Zealand Velocity Model (NZVM) illustrating the modelled variation in seismic velocity over the (a) Canterbury Region, and (b) South Island, and (c) a map of the location of the transects.

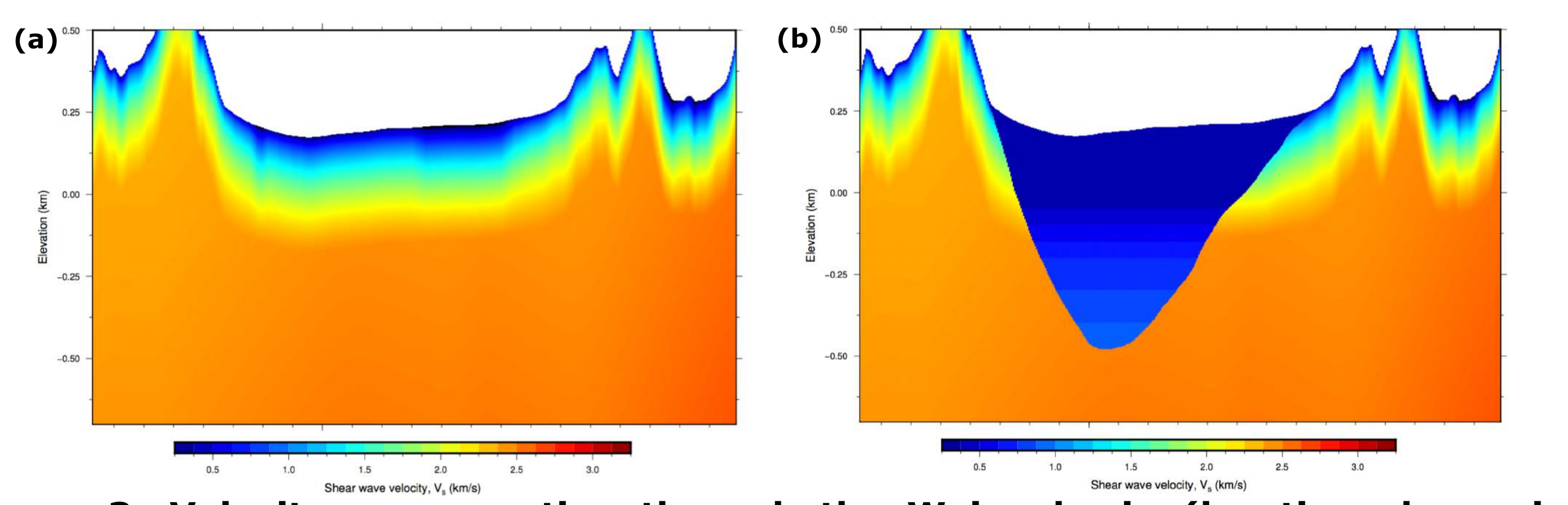

Figure 3: Velocity cross section through the Waiau basin (location shown in Figure 1) for (a) NZVM Version 1.0 without basin characterisation and (b) NZVM Version 2.0 with basin characterisation

Figure 3 illustrates the V_{s30}-based geotechnical layer (GTL) which reduces velocities within the top 350m of the tomographic model used to represent the shallow crust, based on the the Ely (2010) methodology. Additionally an offshore basin-edge smoothing regime has been implemented to reduce the impedance contrast occurring at the tomography-basin interface. This regime smooths this velocity transition over a 10km length to reduce the effect of undesirable offshore reverberations and is designed to occur at a sufficient distance as to not affect onshore motions.

2. Validation using historic earthquakes

Results of ground motion simulations for historic small-to-moderate magnitude ($4.0<M_w<5.0$) earthquakes are currently being used to validate the velocity structure within NZVM Version 2.0. The validation effort, conducted in parallel with scenario ground motion simulations of the Hope Fault (Section 3), will focus on the Upper South Island as this region houses the majority of the new basin models in NZVM Version 2.0.

Nine events were selected for validation using two criteria:

- Proximity to the Hope Fault. As a large rupture on the Hope Fault is analogous to a number of smaller fault sections rupturing simultaneously, events that mimic these small ruptures can be selected as their characteristics are similar to what is expected in a large magnitude Hope Fault rupture.
- Existence of high-quality ground motion records. Records for historic earthquakes vary in quality and number, especially for older events. Selecting historic events with recorded ground motions located within the new sedimentary basins characterised in NZVM Version 2.0 allows for the effect of these basins to be analysed.

Figure 4 presents the location of the nine historic earthquakes used to validate NZVM Version 2.0 in the context of Hope Fault scenario simulations, and the locations of strong motion stations that recorded these events.

The magnitude limits of the events used in validation allow for events sufficiently large to produce high-quality ground motion recordings at a number of strong motion stations, while still being small enough to ensure the point source modelling assumption is valid. Additionally, the upper magnitude limit reduces the potential for non-linear effects to be present within ground motion records.

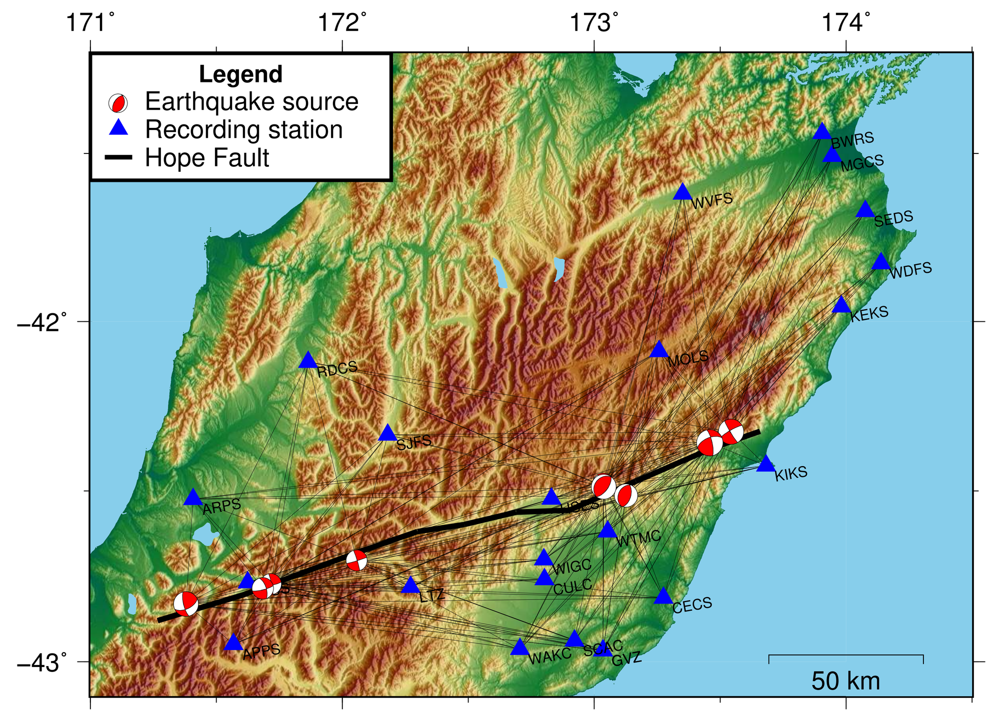

Figure 4: Spatial distribution of historic small-moderate magnitude earthquakes used to validate the velocity structure in NZVM Version 2.0 in the context of Hope Fault scenario simulations

3. Ground motion simulations of Hope Fault scenarios

The Hope Fault is a strike-slip fault in the South Island and a major contributor to the seismic hazard in the region with the second highest slip rate (~20mm/yr) of any South Island fault. The Hope Fault intersects the Hanmer and Kaikoura Basins, which are explicitly modelled in NZVM Version 2.0. Simulations of scenario ruptures on the Hope Fault are being conducted to evaluate its potential impact. Here preliminary results are shown, however, the research is ongoing.

Numerous scenario source geometries involving multiple fault segments spanning from the Kelly Fault (a splay fault off the Alpine fault) through to the Jordan Thrust are being considered. The scenarios vary from M_w 7.1 to a maximum magnitude of 7.7. The effect of fault geometry, hypocentre location, slip distribution and magnitude scaling relations will be investigated to determine the effect of the source model on the resulting ground motions.

Figure 5 presents ground motion simulation results for a Hope Fault scenario (Mw=7.57 South-West hypocentre, Length=247km, Area=3826km²) conducted using the Graves and Pitarka (2015) methodology and comparisons with a ground motion simulation of the November 2016 Kaikoura earthquake (Mw=7.8, Length=290km, Area=5510km²). The PGV for the Kaikoura event is significantly larger than the Hope Fault scenario due to the relative magnitudes and large asperities on the Kaikoura source model. (See Bradley et al. (2017) for source details and simulations of the Kaikoura 2016 earthquake).

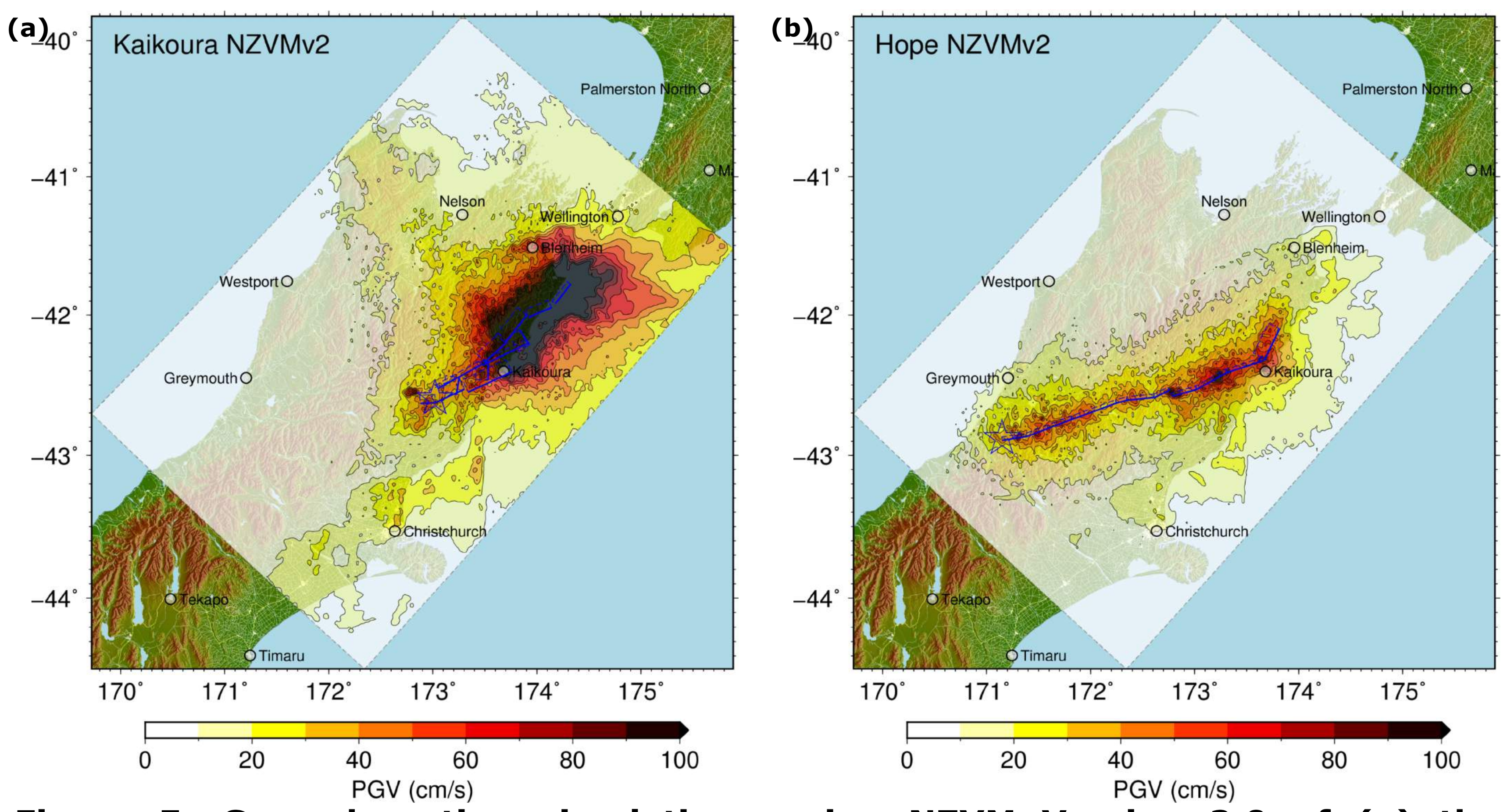

Figure 5: Ground motion simulations using NZVM Version 2.0 of (a) the November 2016 Kaikoura and (b) a scenario rupture of the Hope Fault.

Figure 6 presents comparisons of the Kaikoura and Hope fault simulations with the Bradley (2013) empirical ground motion model (GMM) for PGV versus source-to-site distance. A moving geometric mean of each simulation is shown. This illustrates that for all source-to-site distances the Hope Fault simulation produces median PGVs that are less than those predicted by the Bradley (2013) GMM. On the other hand, the Kaikoura simulation appears to predict PGVs larger than the GMM for the majority of source-to-site distances.

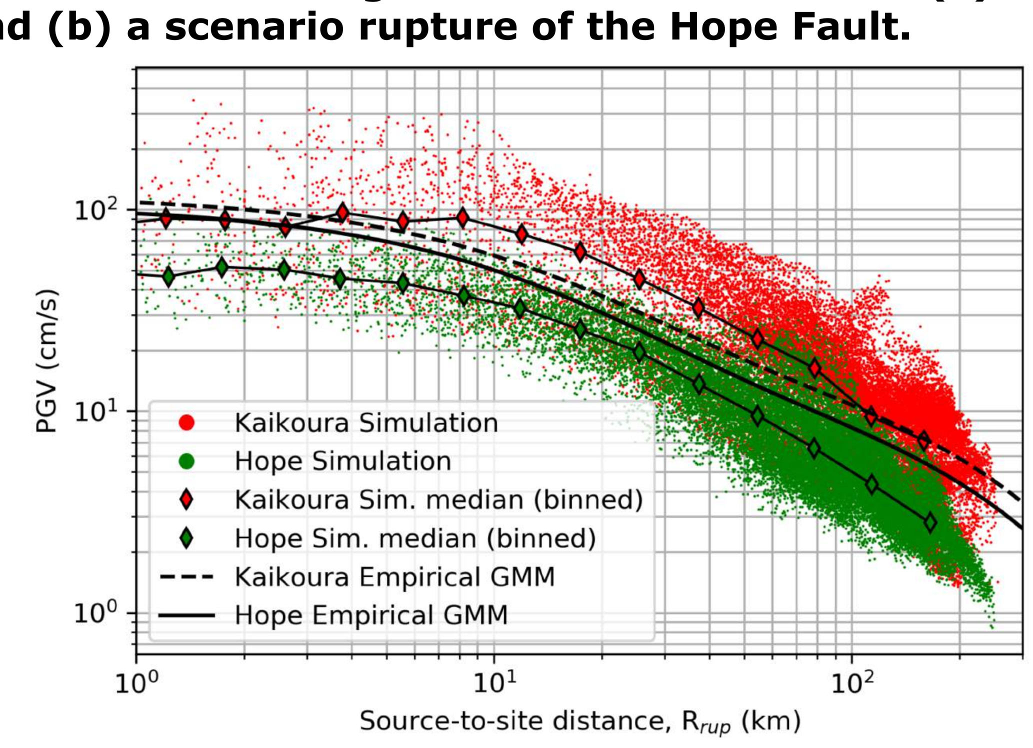

Figure 6: Comparisons of simulations and empirical GMM predictions of the Kaikoura November 2016 and a scenario rupture of the Hope Fault.