Cybershake NZ v19.5: New Zealand simulation-based probabilistic seismic hazard analysis

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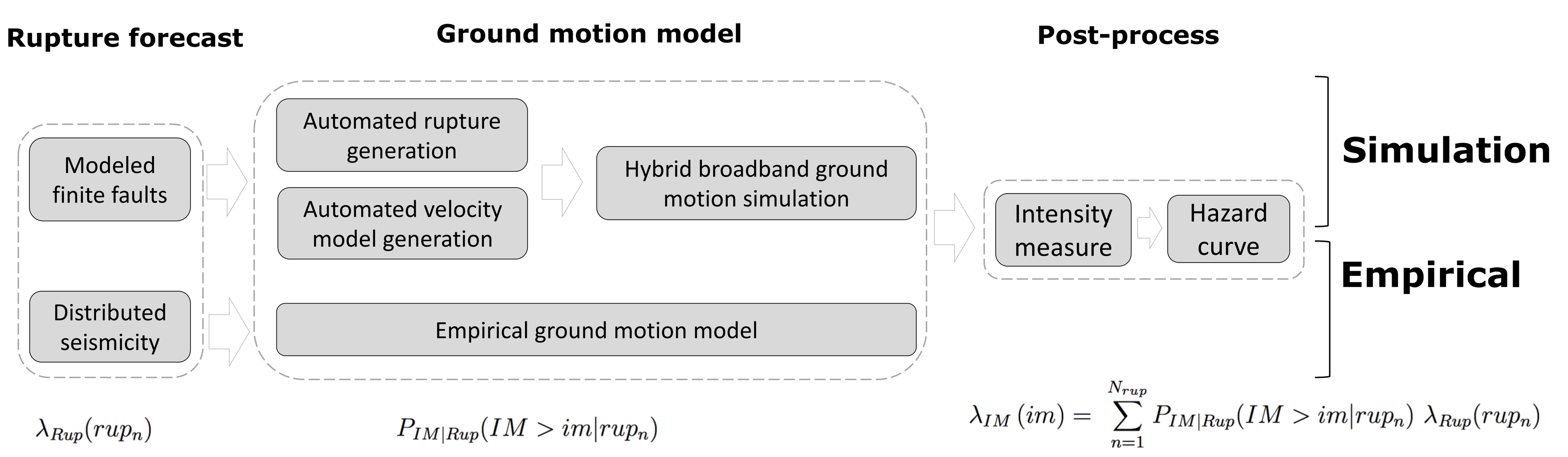
1. Introduction

This poster presents the computational workflow and results of the May 2019 version (v19.5) of probabilistic seismic hazard analysis (PSHA) in New Zealand (NZ) based on physics-based ground motion simulations ('Cybershake NZ'). This version includes several notable advancements resulting from an improved velocity model (NZVM2.03) which now includes nine sedimentary basins across NZ (vs. 1 in v18.6), a NZ-wide Vs30 model, and revisions to the hybrid broadband ground motion simulation method of Graves and Pitarka (2010, 2015, 2016) based on simulation validation in Lee et al. (2019) which results in changes to the high-frequency path duration parametrization and removal of empirical site amplification in the low-frequency calculation.

2. Computational overview

A total of 11,362 finite fault rupture simulations are undertaken and seismic hazard results computed on a spatially-variable grid of 27,481 locations, with distributed seismicity sources considered via conventional empirical ground motion models (as shown in Figure 1). We adopt a 'forward' simulation approach (as opposed to using reciprocity) because of:

a) Large number of output locations relative to rupture realizations considered (i.e., 11,362 ruptures versus 27,481 stations).
b) Computational grid that is determined specific to each rupture in order to optimize the domain size for a targeted minimum ground motion amplitude.
c) Near-term intention to include plasticity.



$\lambda_{Rup}(rup_n)$ $\qquad P_{IM|Rup}(IM > im|rup_n)$ $\qquad \lambda_{IM}(im) = \sum_{n=1}^{N_{rup}} P_{IM|Rup}(IM > im|rup_n)\,\lambda_{Rup}(rup_n)$

Figure 1: Computational workflow of Cybershake NZ v19.5.

3. Automated kinematic rupture generation

Automated generation of kinematic ruptures (using Graves and Pitarka 2015 method) based on the corresponding fault geometry, moment magnitude, rake angle, and hypocenter location is implemented as part of the Cybershake NZ workflow (shown in Figure 1). Figure 2a illustrates all of the shallow crustal faults from Stirling et al. (2012) considered in this study. Note that subduction interface ruptures were excluded in v19.5 as the ground motion simulation validation efforts (in New Zealand and elsewhere) have mostly focused on shallow crustal events (e.g., Razafindrakoto 2018, Goulet et al. 2015), and instead represented using empirical models. Considering the optimized scheme for generating simulation domains, 482 faults out of 528 shallow crustal faults in Stirling et al. (2012) model are considered in v19.5 Cybershake NZ.

A Monte Carlo scheme is used to sample variability in the seismic source parametrization by varying the hypocenter location along the strike and dip directions, and slip distribution per each hypocenter realization. The total number of rupture realizations for each fault was based on the corresponding rupture magnitude, M_w, (shown in Figure 3b).

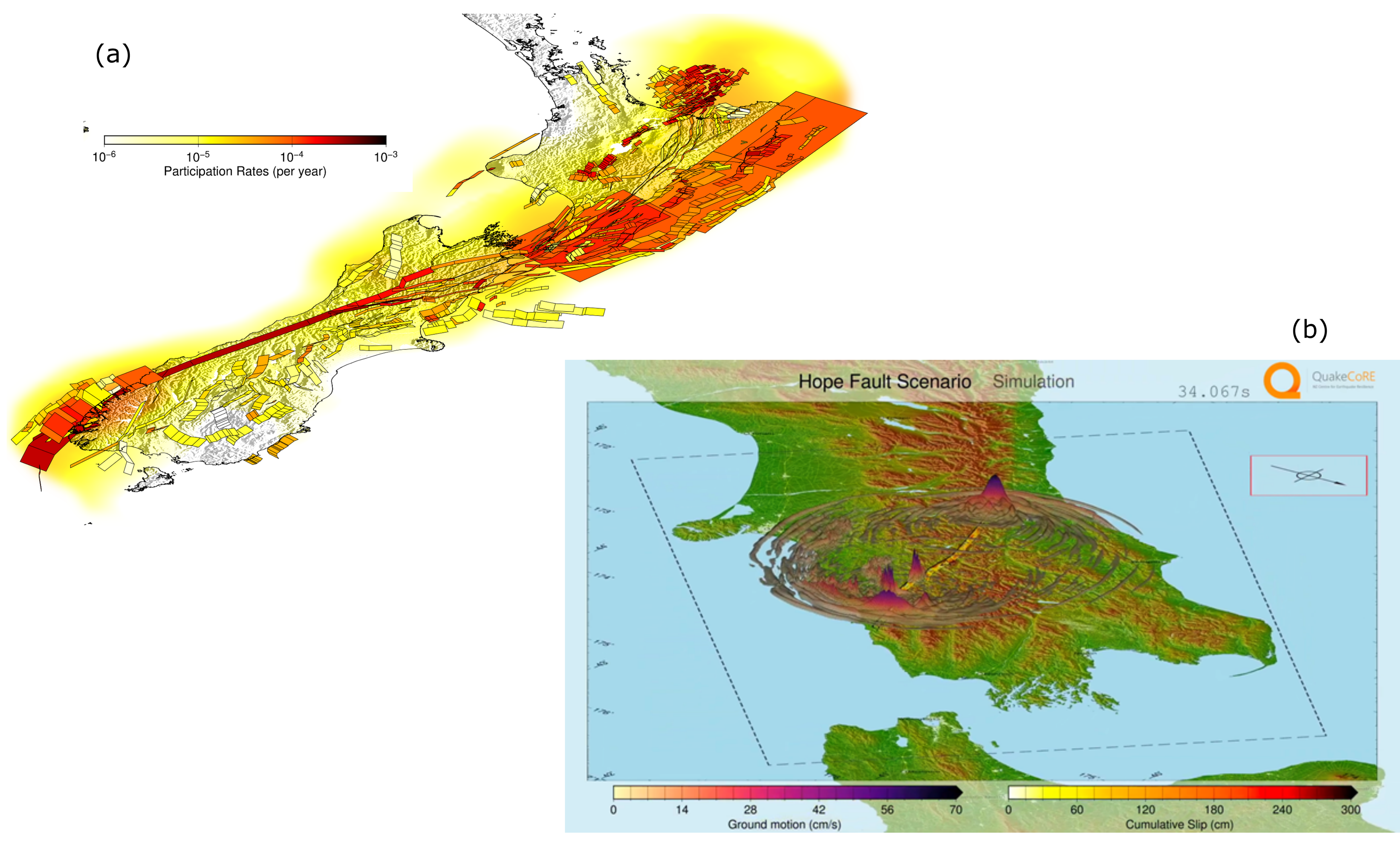


Figure 2: (a) Source rupture geometries and rates; and (b) illustrative ground motion simulation that form the two basic ingredients for PSHA

4. Automated simulation domain and computational demand

Simulation domains for the considered ruptures are generated utilizing a detailed velocity model with multiple sedimentary basins, NZVM2.03 (Thomson et al. 2019). The simulation domain for each and every fault is generated using an optimization algorithm which maximizes the land coverage of the simulation domain (in order to remove the unnecessary computational burden of simulating ground motions offshore). Figure 3a illustrates the initial and optimized domains for the AlpineF2K fault as an example among others.

Figure 3b presents the model utilized to determine the number of Monte Carlo realizations for the considered faults, given the their median M_w. The minimum value of 10 realizations are considered for faults with M_w smaller than 6. The core hours on the Nesi Maui (skylake processors) HPC to conduct simulations at the optimized domains with 0.4 km grid size and varying total duration are also presented in Figure 3b. In total, ~600,000 core hours are spent for v19.5 runs.

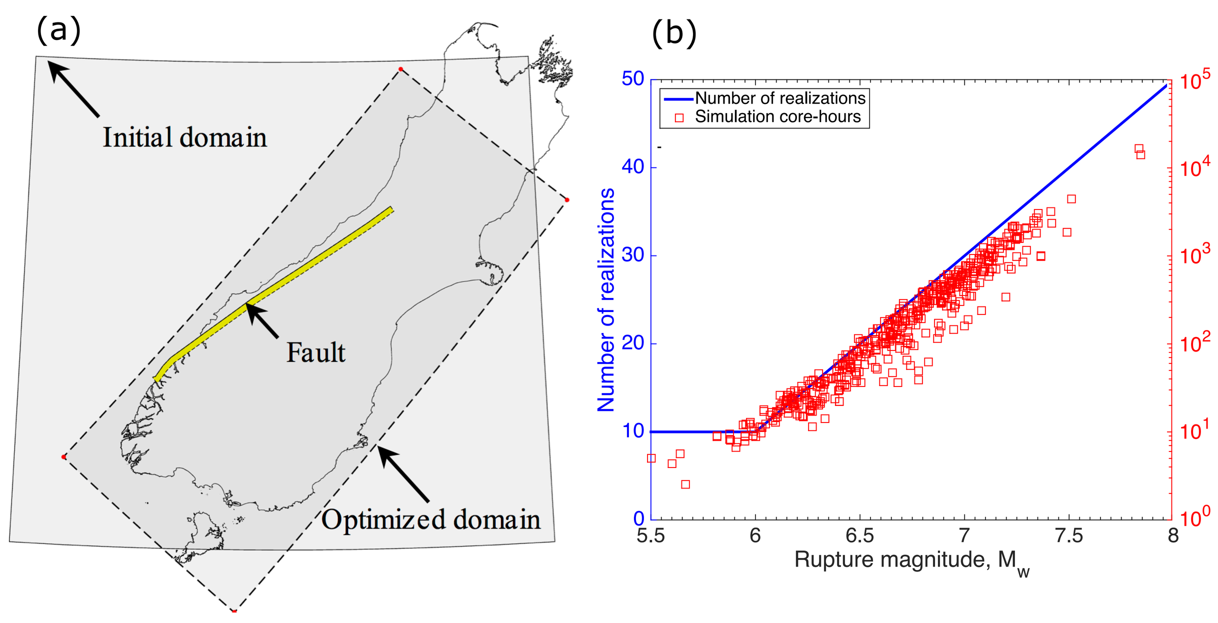


Figure 3: (a) Optimized simulation domain generation; (b) the model utilized to determine the number of realizations per each fault based on rupture magnitude and the corresponding computational demand.

5. Ground motion output locations and near-surface Vs30

In order to have a consistent grid of points on the surface to store the simulated ground motions and combine the results to obtain seismic hazard, a nation-wide grid of recording stations is generated (Tarbali et al. 2018).

This grid contains 27,481 locations has a non-uniform spatial density which is a function of population density and sub-surface soil condition. The population data provides an appropriate constraint to have a coarser grid size in mountainous regions, and finer grid sizes in highly populated regions (which provides a robust means for site-specific PSHA). Considering the depth corresponding to the time-averaged shear wave velocity of in 30 m depth (Vs30), a denser grid is also placed in regions with soft sub-surface soil. Further details of the non-uniform grid are provided in Tarbali et al. (2018).

In v19.5 we also iteratively improved the representation of near-surface Vs30 based on Foster et al. (2019), as shown in Figure 4. This model includes consideration for surface geology, topographic terrain, and direct Vs30 measurements including their uncertainty.

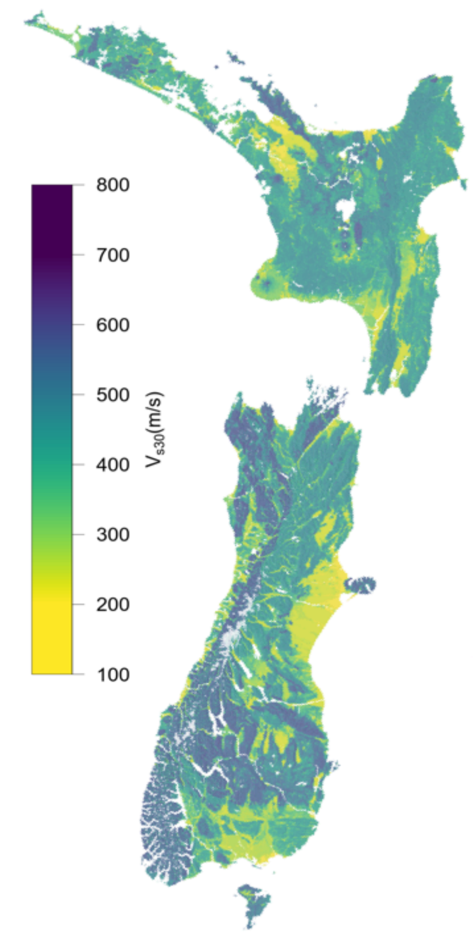
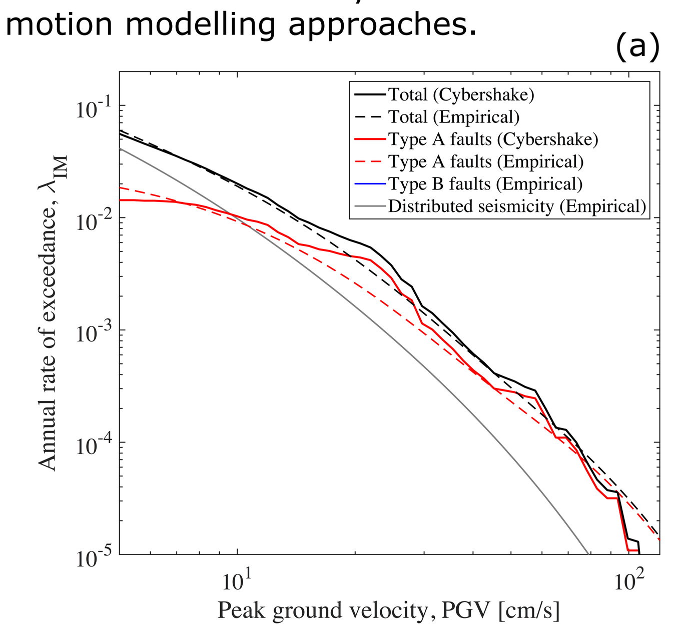
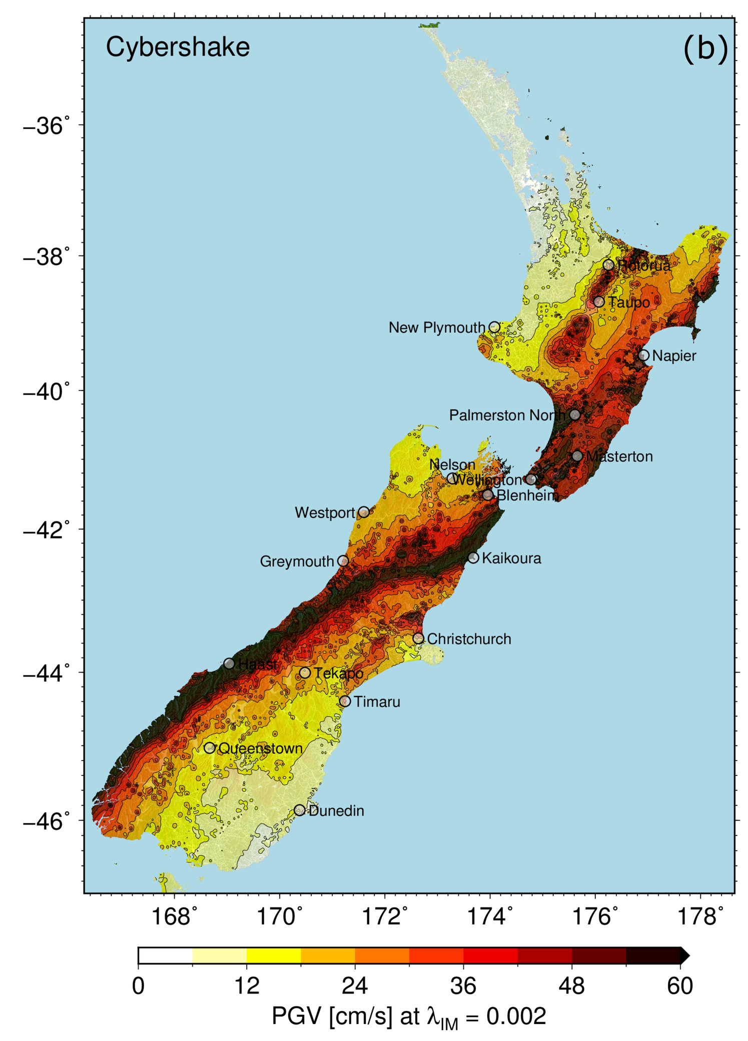


Figure 4: NZ-wide Vs30 model (after Foster et. al. 2019).

6. Seismic hazard curve and uniform-hazard ground motion map

Figure 5a presents the hazard curve for a location in the Canterbury region from Cybershake and empirical ground motion models, indicating the need to include more parametric uncertainties in the simulation to appropriately represent the site-specific hazard (e.g., sampling rare ground motion levels). Figure 5b-d present the uniform-hazard PGV maps (at 10% in 50 years exceedance level), indicating region-specific differences between the Cybershake and empirical ground motion modelling approaches.





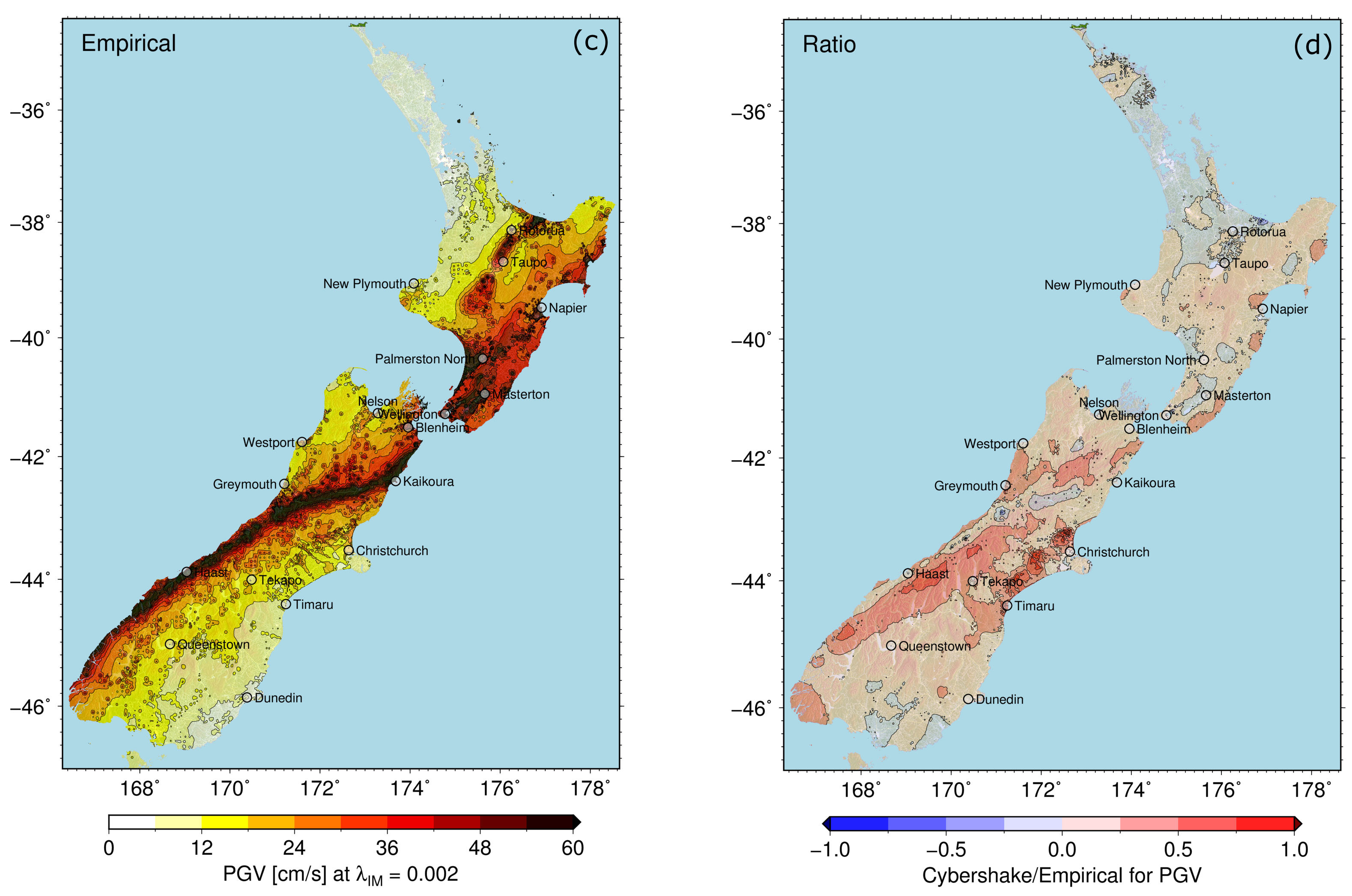


Figure 5: (a) PGV seismic hazard curve of a site in the Canterbury region; (b-c) PGV maps corresponding to 10% in 50 years exceedance level from Cybershake and empirical ground motion models; (d) log (Cybershake/empirical).

7. Future work

Cybershake NZ v18.6 was the first version to develop the computational pathway for simulation-based PSHA in New Zealand. In v19.5 we have iteratively advanced the approach through the consideration of an improved 3D velocity model, Vs30 model, and modifications to the hybrid broadband simulation methodology based on validation insights.

In the immediate future we plan to implement the following advancements into the next iteration:

(1) Reduce the computational grid for the low-frequency calculation to 200m. We have been computationally-constrained in the past, but now have the compute resources to consider 200m (f=0.5Hz transition frequency).
(2) Continue to consider iterative advancements in the 3D velocity and Vs30 models as well as simulation methodology advancements arising from on-going work on simulation validation. Progressing work on full waveform tomography is likely to supplement the deep characterization along with the addition of sedimentary basins more faithfully representing the shallow structure in populated areas of interest.
(3) Consider subduction interface ruptures through physics-based methods. We have made the necessary implementations to source, velocity models, and simulation methods to consider subduction simulations; in parallel with work on subduction rupture simulation validation.
(4) Explicit consideration of other ground motion simulation uncertainties. We have considered only slip and hypocentre uncertainties in v19.5 (similar to SCEC Cybershake efforts). Based on the work of Neill et al. (2019), considering validation with uncertainties, we plan to incrementally add other uncertainty sources.