Cybershake NZ v20.8: New Zealand simulation-based probabilistic seismic hazard analysis

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1. Introduction

This poster presents the computational workflow and results of the August 2020 version (v20.8) 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 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 method and the empirical site amplification factors around the transition frequency.

2. Computational overview

A total of 11,875 finite-fault rupture simulations are undertaken and seismic hazard results computed on a spatially-variable grid of 25,948 locations, with distributed seismicity sources considered via conventional empirical ground motion models. 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., 11,875 ruptures versus 25,948 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.

A similar computational workflow is used as in the v19.5 version of Cybershake (Bradley et al, 2020).

3. Advancements in v20.8

One of the major advancements is increasing the transition frequency of the hybrid simulations from f=0.25 Hz to f=0.5 Hz, based on a low frequency (LF) calculation with a 200 m grid, and requiring 16 times more core hours compared to 400 m simulations (doubling the resolution in space and time). This propagates the benefits of LF simulations (explicitly considering directivity, basin-effects, etc.) to an increased range of frequencies.

Additionally, for the first time in Cybershake NZ, the 8 subduction sources were simulated as part of this project (six from the Hikurangi Subduction Zone, and two from the Puysegur Subduction Zone). The magnitude of these ruptures were determined from the Skarlatoudis (2016) Mw-A relation. Improvements made in the Graves and Pitarka (2016) method, based on conclusions from Wirth (2017), for adjusting the slip on subduction interface faults were also incorporated.

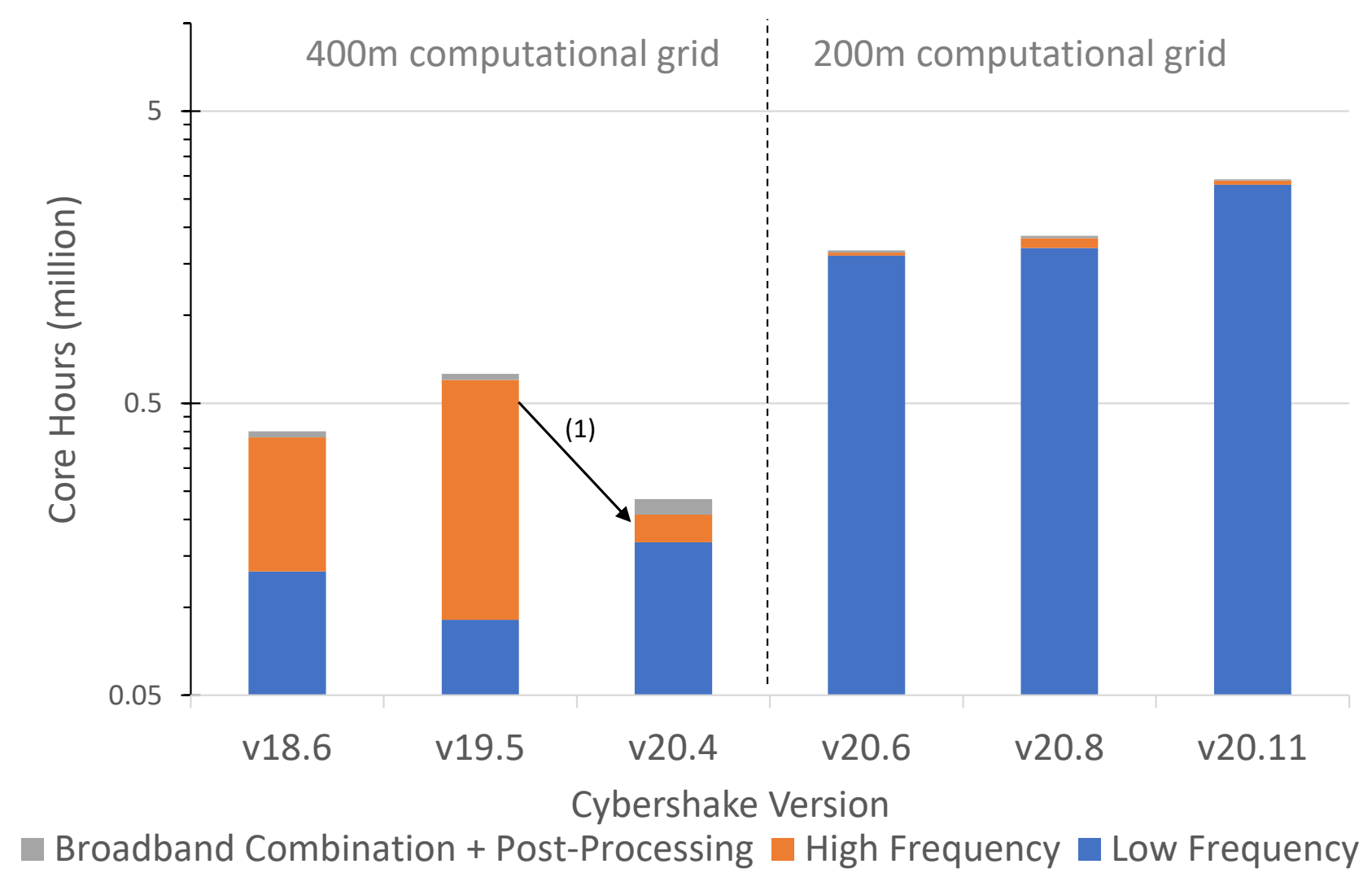

Figure 1 shows that the core hour usage for a full cybershake iteration has roughly increased by 10x since the first production run in 2018. The core hour utilization for the Cybershake project has increased significantly due to 200m simulations and introducing subduction faults. The three Cybershake 200m runs show the computational requirement increase made with the introduction of subduction events. From v20.8 to v20.11 there has been a doubling of the core hour requirements

(1) Due to the large core requirement of HF in v19.5, optimisations to the calculation were made.

Figure 1: Historical core hour usage from Cybershake. v18.6, v19.5, v20.4 were 400m shallow crustal-runs, v20.5 was the 400m run from subduction, v20.6 was the 200m revision of v20.4, v20.8 introduced subduction simulations and v20.11 (currently underway) is the 200m revision of the subduction simulations.

4. Automated kinematic rupture generation

Automated generation of kinematic ruptures (using Graves and Pitarka, 2015) based on the corresponding fault geometry, moment magnitude, rake angle, and hypocenter location is implemented as part of the Cybershake NZ. 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 are represented using empirical models. Considering the optimized scheme for generating simulation domains, 478 faults out of 528 shallow crustal faults and additionally 8 subduction interface 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. This version of Cybershake incorporated the same variability of hypocenter location and slip distribution. Additionally, the sigma values were used from the Leonard (20100 Mw-A relationship to introduce Mw variability; and a correlated change in stress drop was also added. Rake perturbations were added. The total number of rupture realizations for each fault was based on the corresponding rupture magnitude, M_w, this was scaled between 10 and 50 realisations.

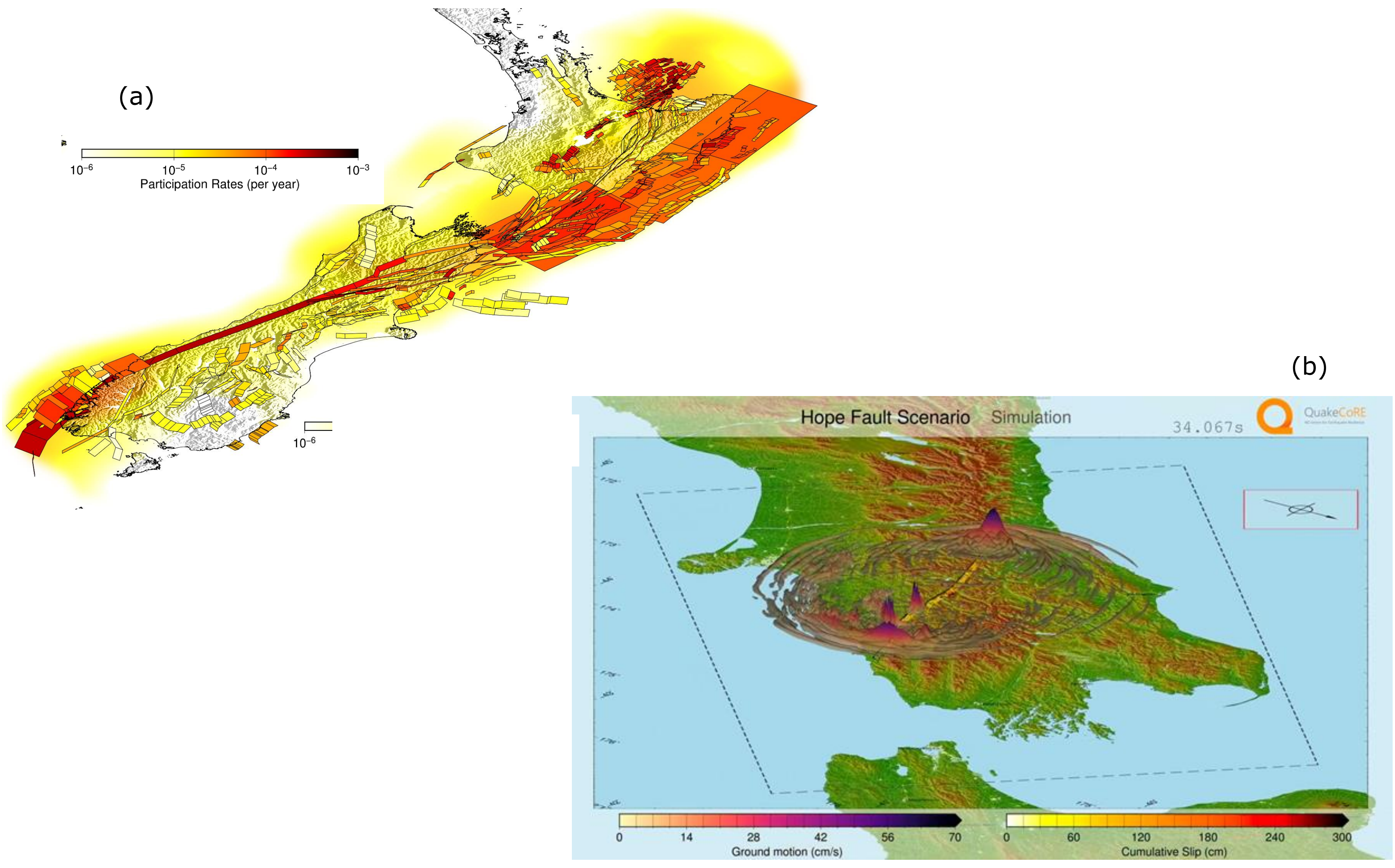

Figure 2: (a) Source rupture geometries and rates; and (b) illustrative ground motion simulation that form the two basic ingredients for PSHA.

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 25,948 locations has a non-uniform spatial density which is a function of population density and sub-surface soil condition. This was revised in v20.8 to have a smaller minimum distance between locations. Previously this value was 2 km and this was increased to 200 m. This increased the proportion of stations in areas of interest. 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 v20.8 we also iteratively improved the representation of near-surface Vs30 based on Foster et al. (2019), as shown in Figure 3. The revised model for this version decreased the vs30 values in general – trending towards the expected values. This model includes consideration for surface geology, topographic terrain, and direct Vs30 measurements including their uncertainty.

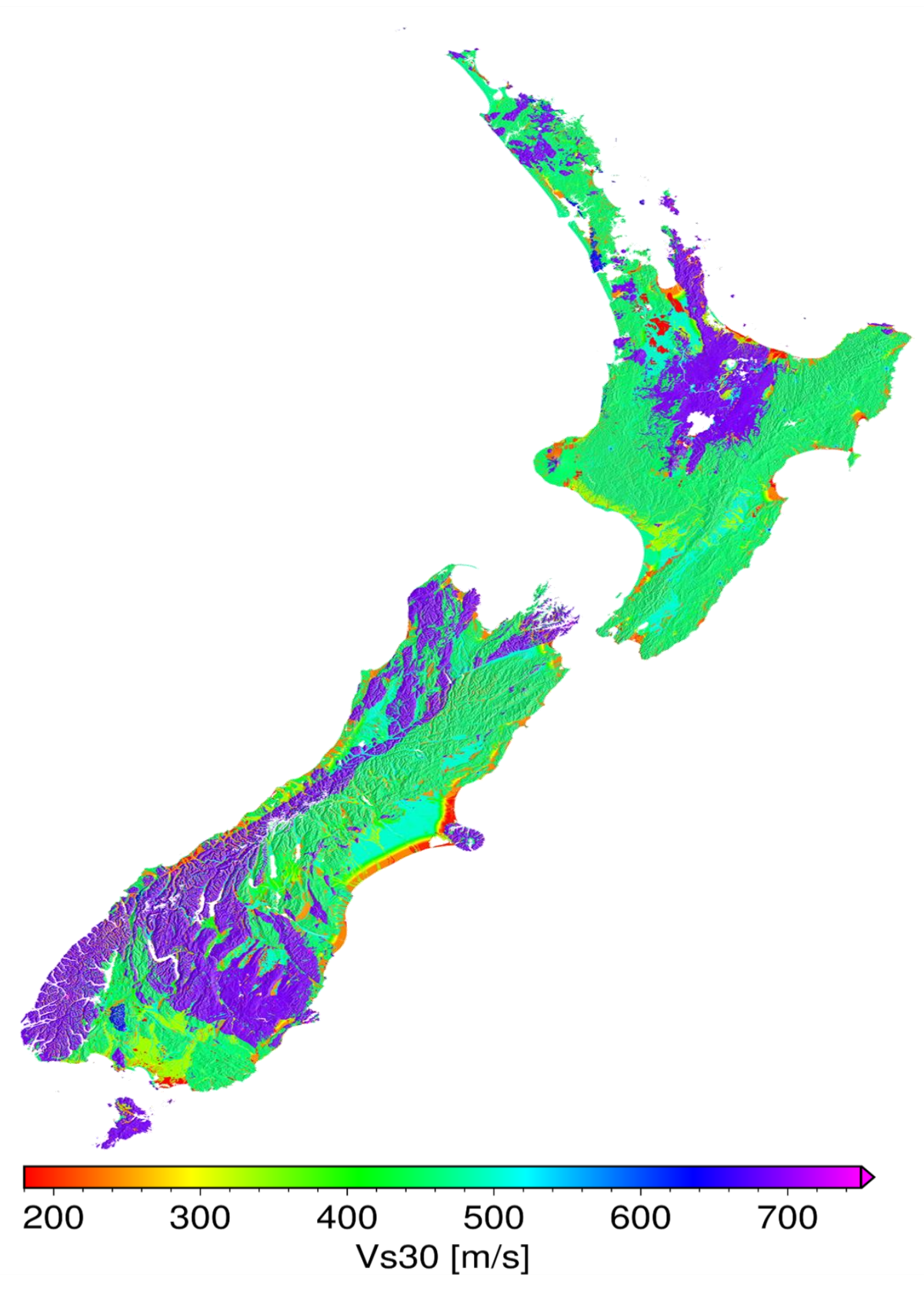

Figure 3: NZ-wide Vs30 model (after Foster et. al. 2019). http://vs30.seistech.nz

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

Figure 4a-b present PGA and pSA(3.0s) hazard curves for a location in the Wellington region from Cybershake NZ and empirical ground-motion models. The 'steepness' of the hazard for $\lambda < 10^{-3}$ indicates lower variability in ground-motion prediction – further scrutiny is needed to ascertain the appropriate variability for simulation-based site-specific hazard (e.g., sampling rare ground-motion levels). Figure 4c-f present the uniform hazard PGA & pSA 3.0s maps (at 10% in 50 years exceedance level), as well as the ratio with maps based on empirical ground-motion models (not shown for brevity).

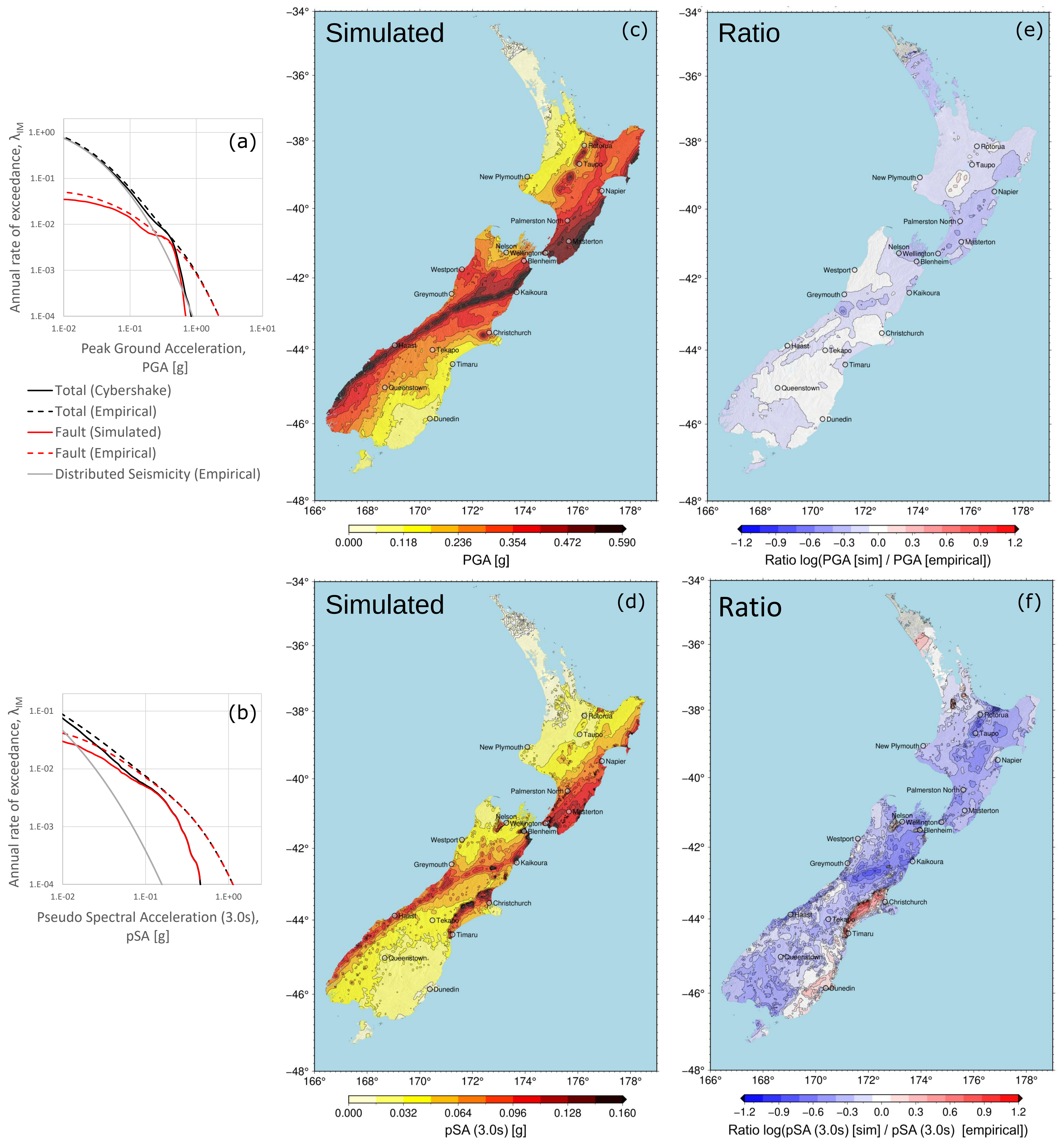

Figure 4: (a-b) PGA, pSA 3.0s seismic hazard curves of a site in the Wellington region; (c-d) PGA and pSA 3.0s maps corresponding to 10% in 50 years exceedance level from Cybershake; (e–f) Ratio maps of Empirical Ground Motion Model & Simulated - log (Cybershake/Empirical).

7. Future work

Cybershake NZ v18.6 was the first version to develop the computational pathway for simulation-based PSHA in New Zealand. In v20.8 we have iteratively advanced the approach through the consideration of 200m LF calculations, inclusion of subduction ruptures, 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) Advancements in the 3D velocity model resulting from the inclusion of additional sedimentary basins as well as full-waveform tomography. Initial models for 10 basins in the south island are currently being implemented.
(2) A new version of the NZ Vs30 model which includes additional site-specific measurements based on direct Vs measurement, and correlations with the extensive CPT and SPT datasets available in NZ.
(3) Explicit consideration of other ground-motion simulation uncertainties. Based on the work of Neill et al. (2019, 2020), considering validation with uncertainties, we plan to incrementally add other uncertainty sources.
(4) Improve the source modelling for subduction events through work from Dupuis et al. (2020) and to incorporate Hikurangi fault curvature in the simulations (Paterson et al. 2020).
(5) Through work with large magnitude validation, our simulation method for large Mw earthquakes will be iteratively improved.