

National Seismic Hazard Model

2022 Revision

Te Taura Matapae Pūmate Rū i Aotearoa
NSHM The New Zealand
 National Seismic
 Hazard Model
 A GNS Science Led Research Programme

E mahi ana me
In collaboration with



Ngā hoa tuku pūtea
Funding partners



MINISTRY OF BUSINESS,
 INNOVATION & EMPLOYMENT
 HIKINA WHAKATUTUKI

Toka
 Tū Ake **EQC**

The science development and review process

NSHM is a large global collaboration

- **Bring in the best knowledge from NZ and around the world**
- **The model needs to represent a broad range of scientific views**
- With something as complex earthquake forecasting it is not reasonable or prudent to develop a single consensus model

More than 50 scientist from around New Zealand and around the world

- University of Canterbury, University of Otago, University of Auckland, NIWA and others
- United States, Canada, Italy, Germany, Australia, England

Key collaborating Institutions: United States Geological Survey, Global Earthquake Model (GEM, Italy), Geoscience Australia, GFZ-Potsdam



The science development and review process

Scientific review is a critical part of any science project

- Particularly challenging for something this large
- On this short of a time-frame

NSHM participatory peer review:

- Technical advice on the development of the NSHM has been provided by a 17-member panel of international scientists, engineers, insurance using a participatory review process.
- Scientifically detailed involvement from panel – weekly input
- Panel included key NSHM end-users

Assurance review:

- International review of processes: science, decision making and peer review, with positive outcomes



The NSHM produces probabilistic forecasts

What is the forecast for?

The NSHM provides a probabilistic forecast of earthquake shaking. The probabilities are determined from the scientifically credible range of shaking we might experience over the next 100 years. Often these probabilities are mapped using the average forecast.

PROBABILISTIC MODEL

Past earthquake events
+
applied statistical and
physical science

Range of future possible
shaking

What is our confidence in the forecast?

The confidence in the forecast is shown by looking at the range of possible futures and how likely they are. Each one of these can be expressed as a different map or different outputs for engineers

Testing the NSHM: The science is internationally peer reviewed by a large panel of experts, and we test the forecasts against past earthquakes, long term data sets and global science.

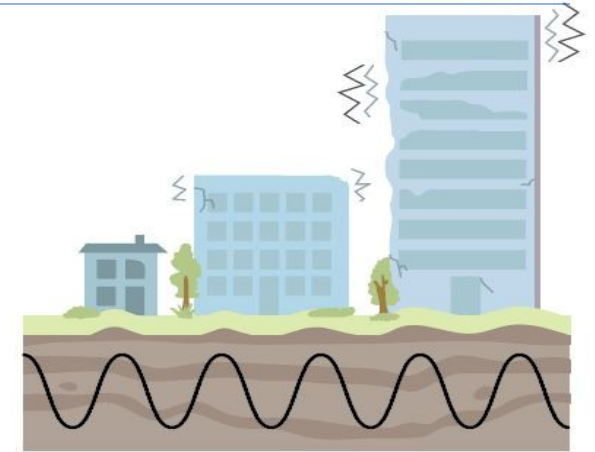
This process and our advanced understanding of how earthquakes work ensures that we are using the *best available science*.

The NSHM produces forecasts of shaking

The NSHM forecasts ground shaking. This is called the hazard.

The NSHM does not forecast the impact on society.

The impact on society is often called the risk.



The NSHM provides important input for making risk based decisions.

Making risk based decisions requires a community to understand their own risk tolerance.

**The NSHM produces a wide range of results that model thousands of future earthquakes
Depending on a communities risk appetite they should look at the relevant results**

How do we make the NSHM?

How do we make the NSHM?

It is a collection of many component models

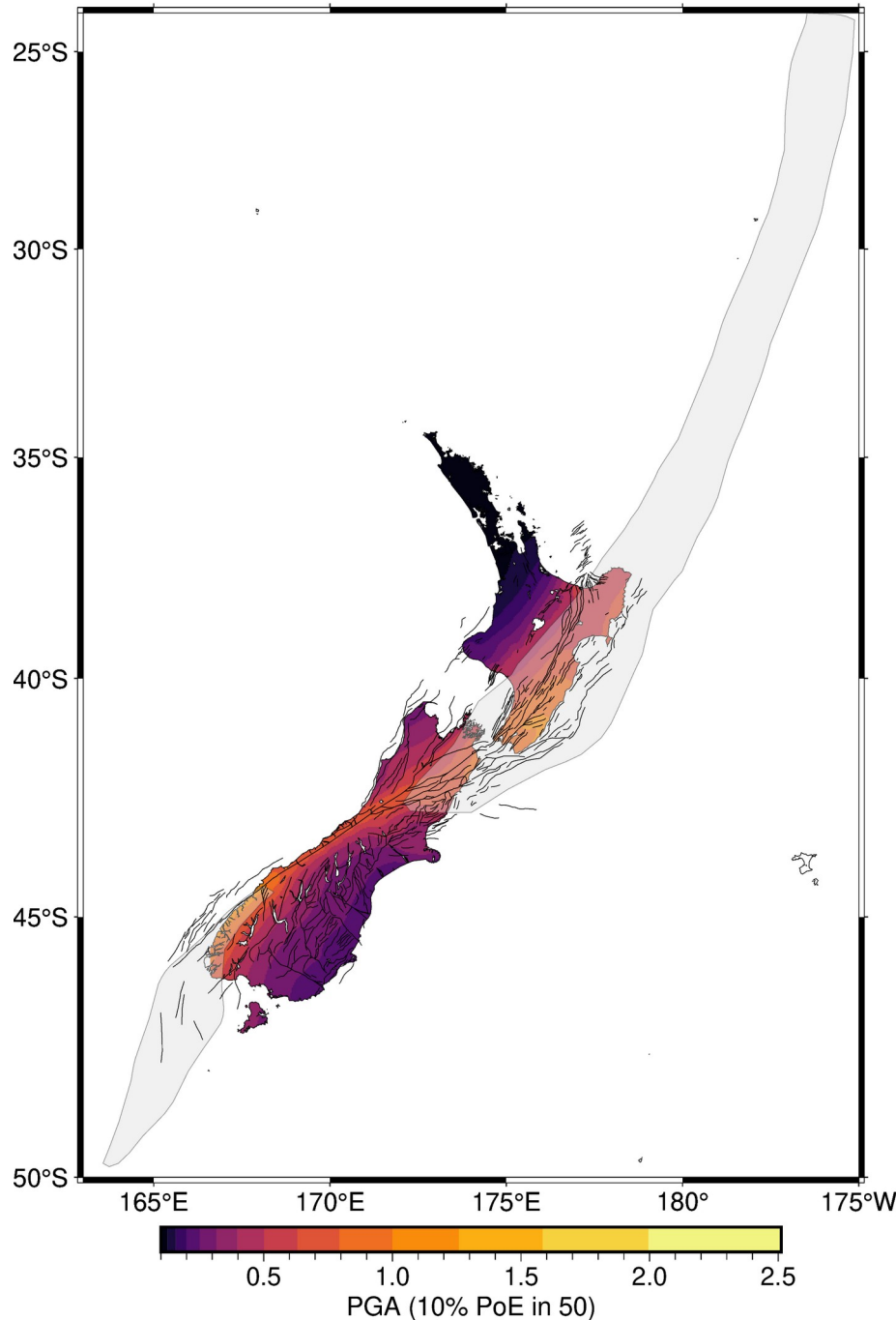
Two Components of the NSHM

1 Earthquake Ruptures

2 Ground Shaking

1. Earthquake Ruptures: where, what frequency and what magnitudes

- Hundreds of thousands of modelled ruptures based on around 1,000 known faults and how they can rupture
- Many hundreds of thousands of random ruptures considered for faults that are unknown



No longer only one Wellington Fault rupture with one magnitude and one rupture length

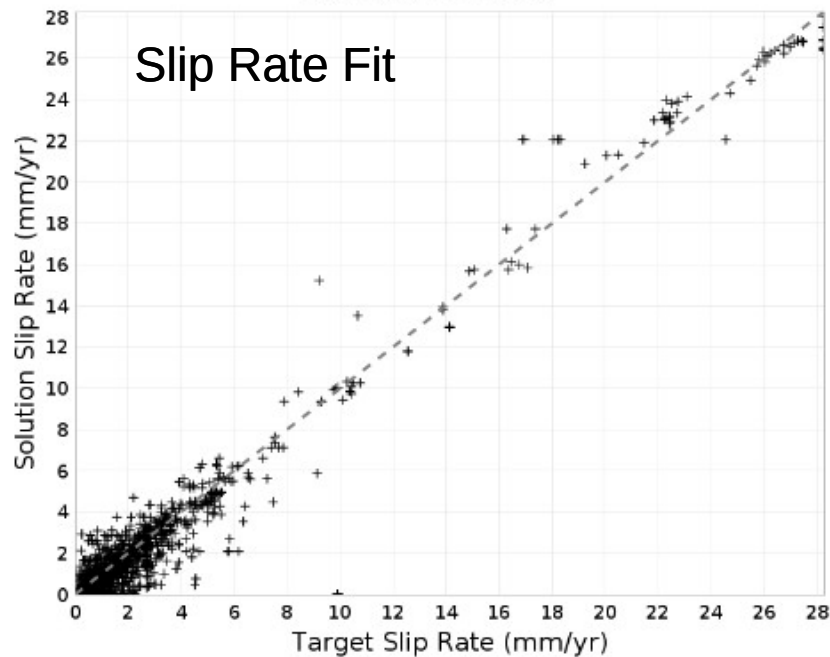
Some modelling key concepts:

- Ruptures can be complex and not just straight linear movement of one fault
- There is uncertainty in magnitude and length
- We have many datasets: each one gives us a slightly different window into the future
- We need many models to represent our range of understanding

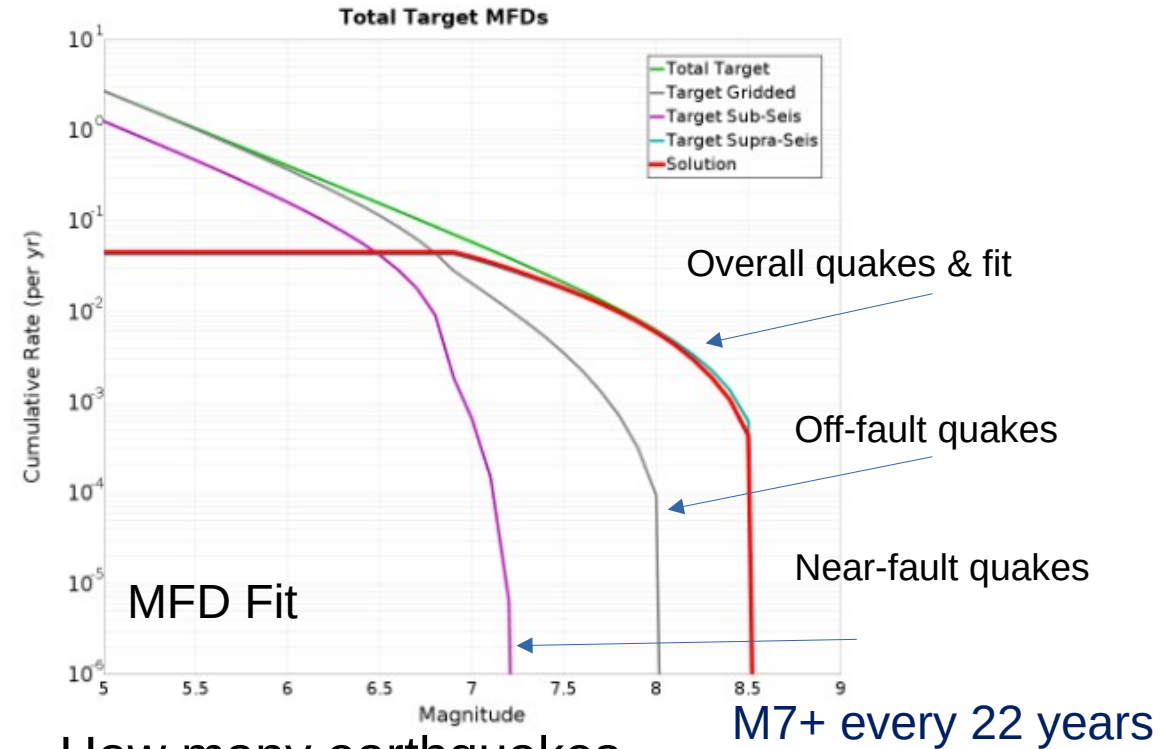


Using multiple data sets to constrain the forecasts

Example highly weighted fit (crustal)



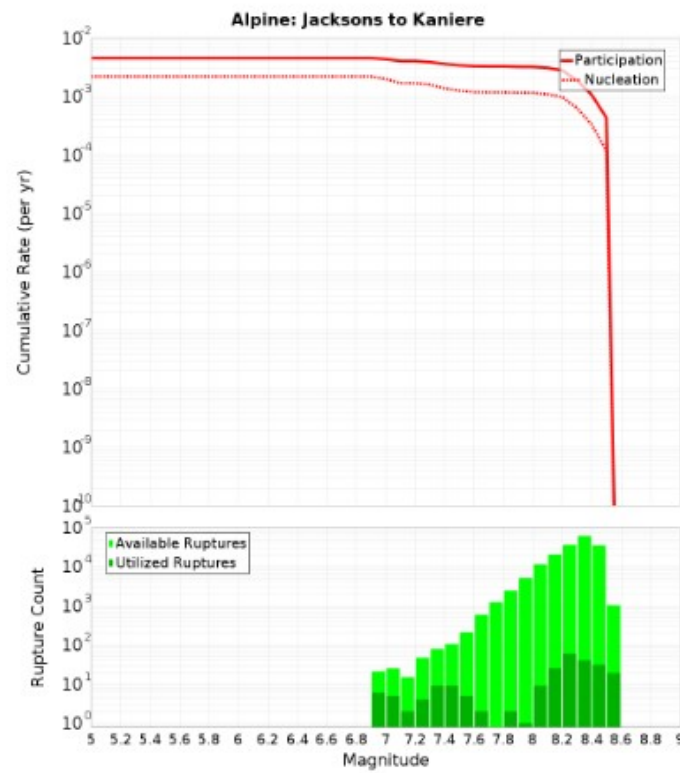
How much slip is expected
On a fault over time



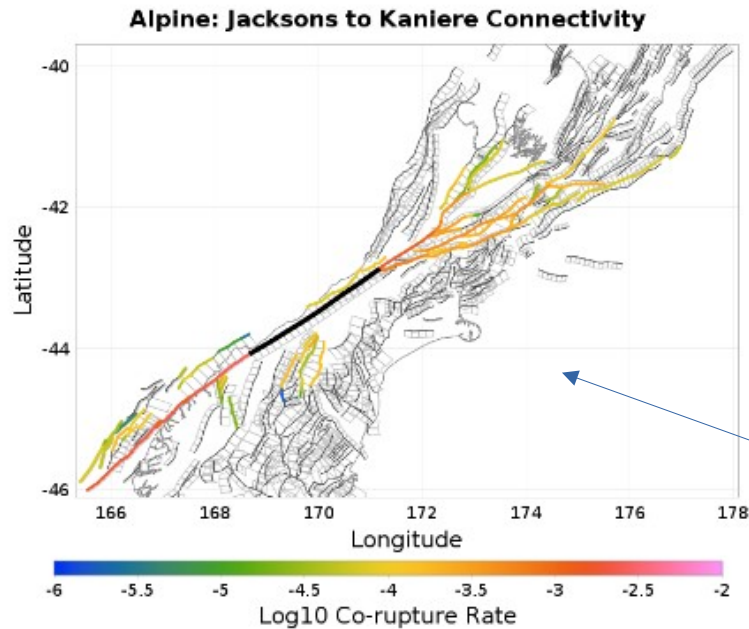
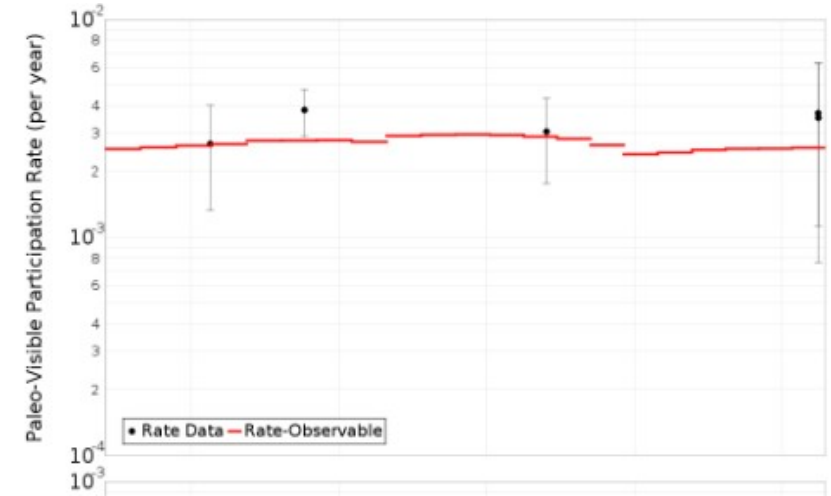
How many earthquakes
over time

Final model: combination of thousands of models – this is just one result

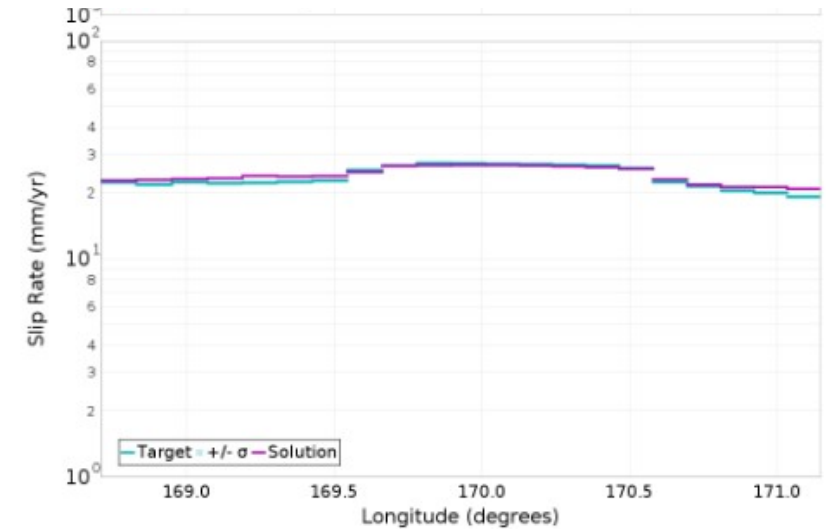
How does the same model fit the Alpine Fault?



Along fault
Fit to past-earthquake
rates



Along fault
Fit to Slip Rate



Connectivity with other faults

Two Components of the NSHM

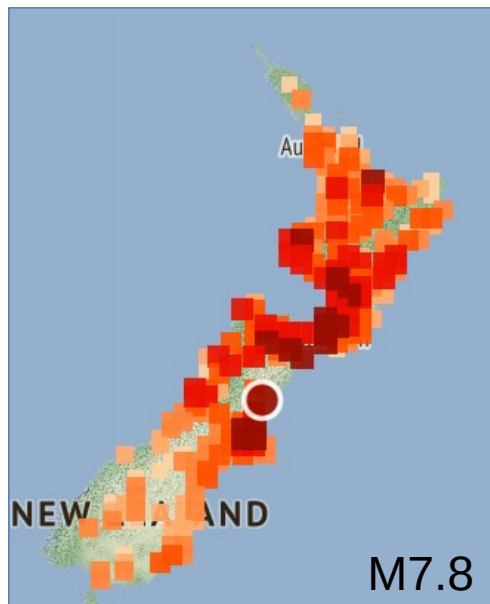
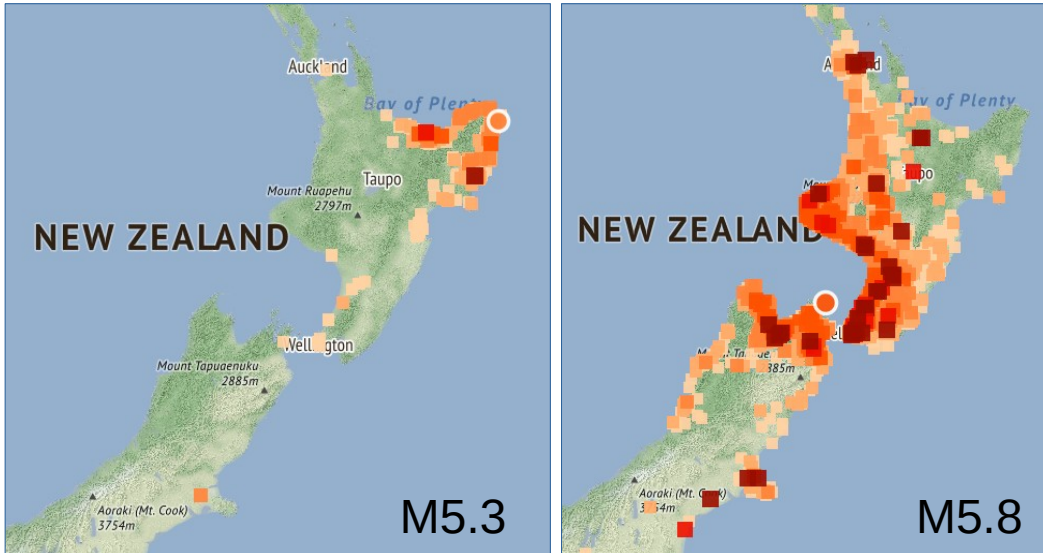
1 Earthquake Ruptures

2 Ground Shaking

2. Ground shaking: what is the range of possible shaking when all ruptures are considered

- Use of many models, some internationally developed, some specifically optimised to New Zealand earthquakes
- Each model can give a different forecast for the same rupture
- Final shaking estimate includes all possible ruptures, and the range of shaking possible for each one of those

The shaking people felt in the Kaikoura M7.8 and two recent earthquakes



Conceptual differences from previous NSHMs

Quantifying and modelling uncertainty is a critical part of the model	<ul style="list-style-type: none">• Better includes our understanding of earthquakes• Communicates our confidence in the model results• Final result is a range of shaking, not a single estimate
Results include the influence of multiple data sets and scientific hypotheses	<ul style="list-style-type: none">• A broader range of scientific understanding is included• Earthquake geology, seismology, geodesy, engineering seismology
Modelling of thousand of potential ruptures, rather than a few hundred	<ul style="list-style-type: none">• Complex and multi-fault ruptures – more realistic hazard estimates• Variability in magnitude and rupture length• More high-impact low-probability earthquakes
Specific models for low-seismicity regions	<ul style="list-style-type: none">• Statistical model of greater uncertainty in spatial and temporal mean• Alternative distribution with more variability
100 year forecast	<ul style="list-style-type: none">• Other shorter-term forecasts can be investigated
Use of many ground motions models rather than just one	<ul style="list-style-type: none">• Internationally developed models• Models tuned to NZ data
Much more data is available	<ul style="list-style-type: none">• Particularly for ground motion modelling• More realistic hazard estimates
How many earthquakes will occur?	<ul style="list-style-type: none">• Improved range of future possible shaking included

Sample Example Hazard Results (full results available online)

Parameters used for displaying hazard

- Probability of Exceedance (PoE):

How likely are we to experience this amount of shaking, *or more*, in a particular time period.

For example: 10% Probability of Exceedance in 50 years or 2% Probability of Exceedance in 50 years.

Lower probability means less likely, but higher shaking levels.

Risk Tolerance

- Site conditions:

The behaviour of the near ground surface (e.g., stiff or soft soils) can significantly impact shaking. How we measure this is very different than it was in the previous models, so we are not comparing apples to apples from previous models to now.

- Ground acceleration

A single earthquake contains many frequencies of ground shaking. Land and structures respond differently to different frequencies of shaking

The NSHM produces thousands of results so its important to know what particular information is being shown. For example locations that are near each other but have different site conditions will have different shaking forecasts, and there are many different shaking forecasts for every location.

Earthquake is a mix of shaking frequencies, and each frequency has a different impact

Land and shorter buildings are affected by high frequency shaking and taller buildings by lower frequency shaking



↑
Land responds more to very high frequency (rapid) shaking, which can cause liquefaction



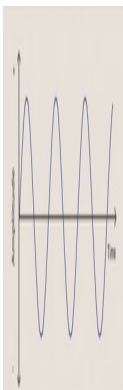
↑
Low-rise (short) buildings respond more to high frequency (rapid) shaking



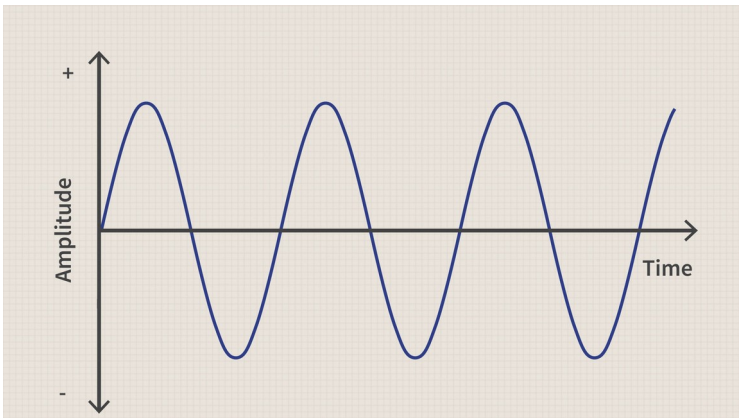
↑
Mid-rise (medium height) buildings respond more to lower frequency (slower) shaking



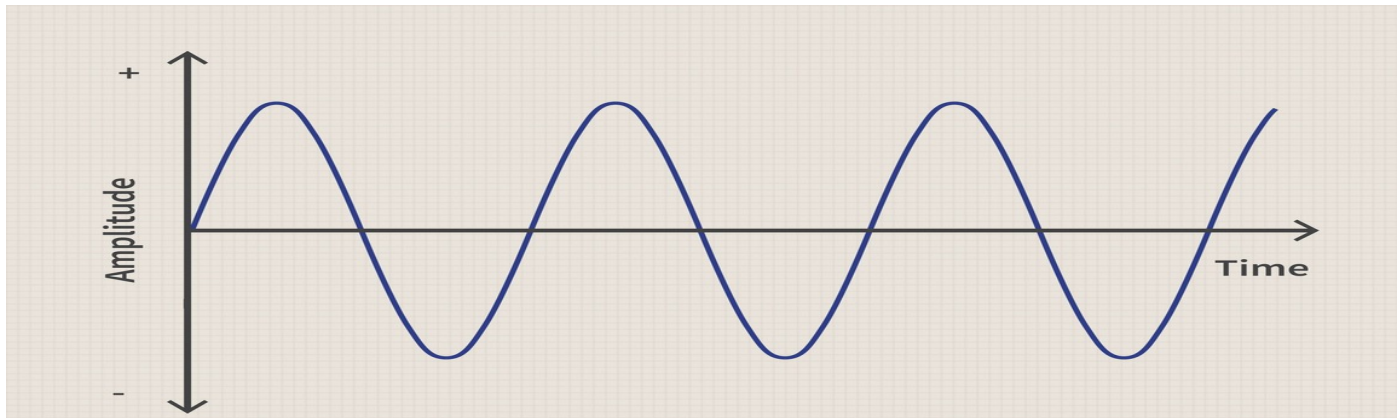
↑
High-rise (tall) buildings respond more to ever lower frequency (slow) shaking



+



+



PGA

SA(0.5 seconds)

SA(1.5 seconds)

SA(3 seconds)

High Frequency/Short Period

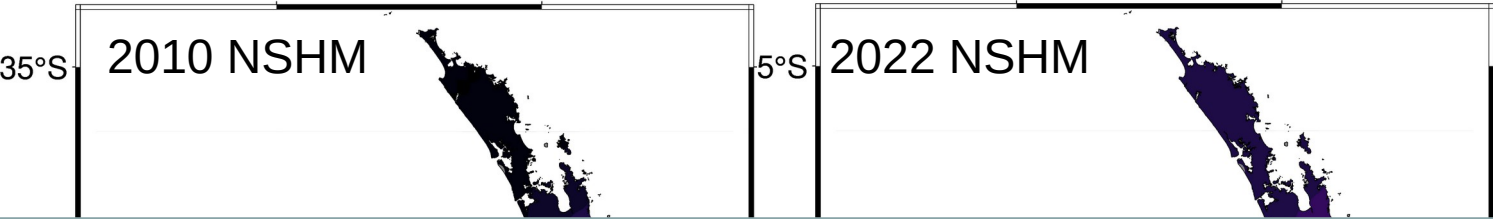
Low Frequency/Long Period

Hazard estimates and changes for different frequencies are different

Comparison of 2010 and 2022 PGA Hazard Maps

PGA: 10% Probability of Exceedance in 50 years
One of many possible comparisons – does not illustrate range of results.

Across all hazard parameters a range from no increase to more than double is seen. When considering site condition/Vs30 differences, the average increase is about 50% or more



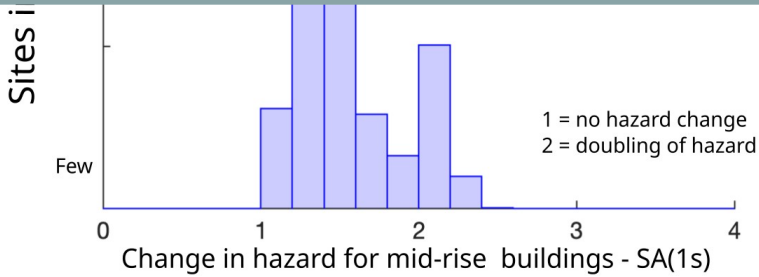
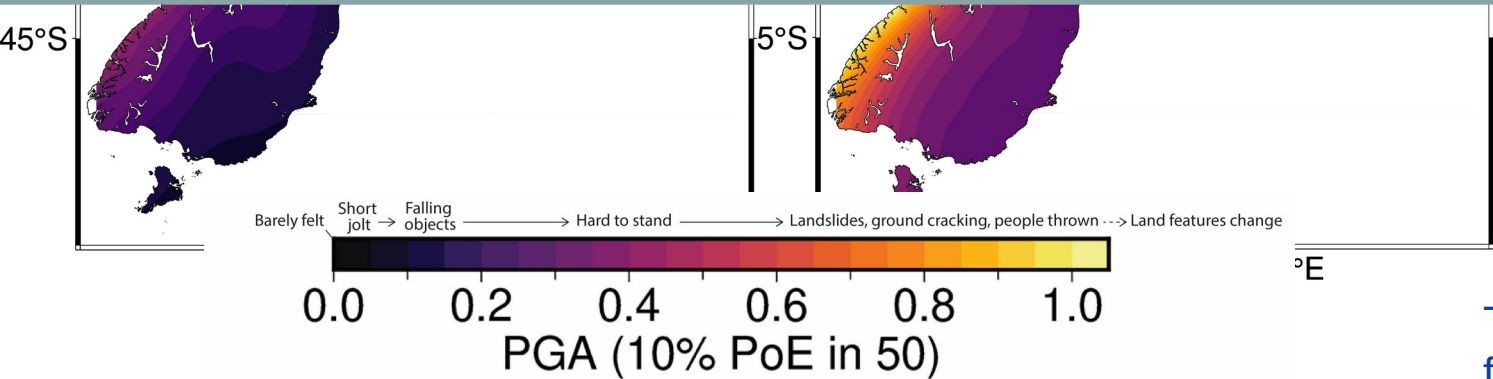
Example shaking for Vs30=250m/s

Location	2010 PGA(g)	2022 PGA(g)
Auckland	0.05	0.13

Increasing hazard does not necessarily translate to an

Shaking hazard increase across New Zealand ranges from approximately *no change*, to more than doubling. The average is an increase of about 50% or more.

Increases do not necessarily translate to an equivalent impact for buildings and other structures



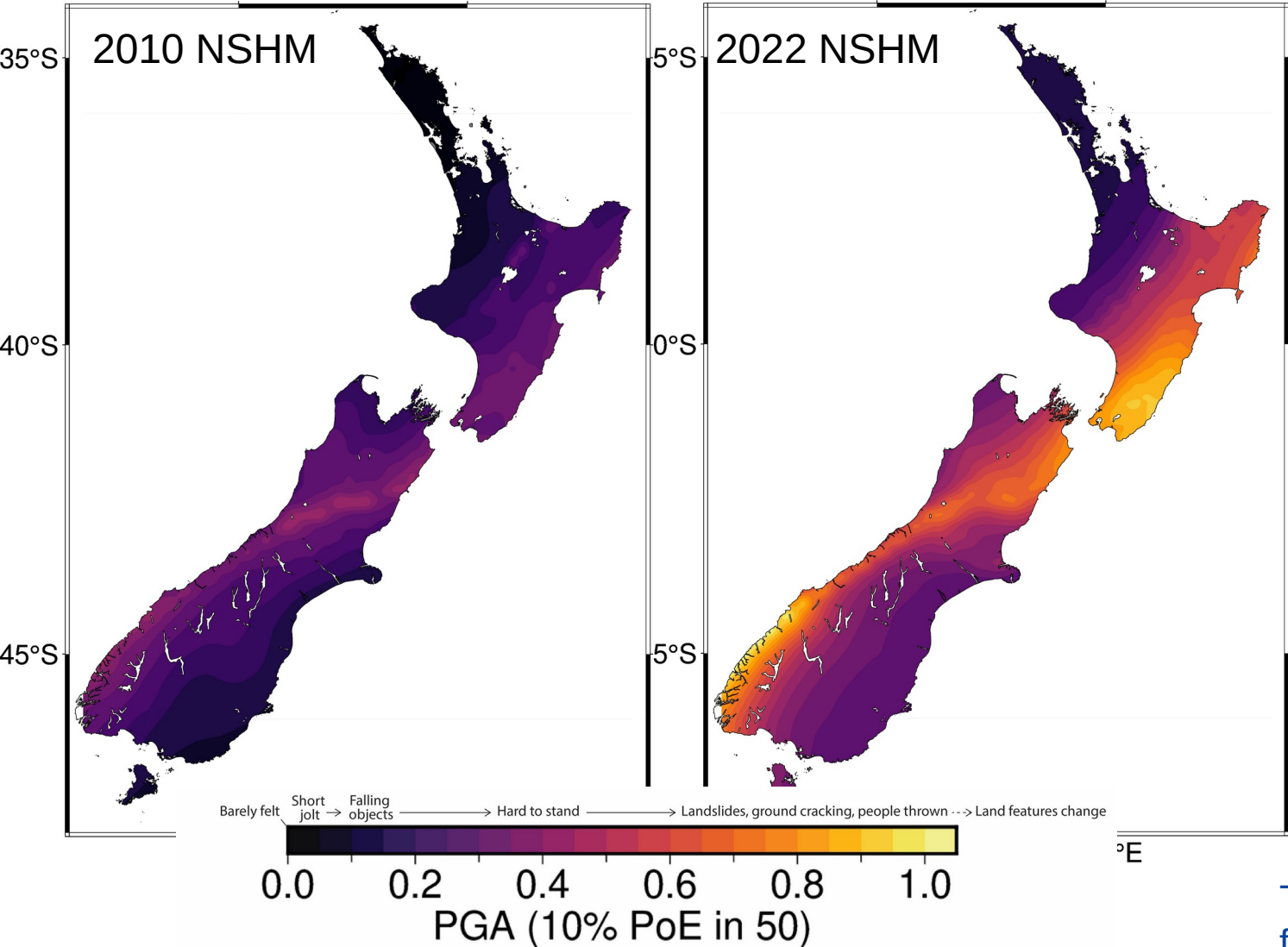
The variability in hazard forecast for mid-rise buildings for an extensive range of sites across Wellington

Comparison of 2010 and 2022 PGA Hazard Maps

PGA: 10% Probability of Exceedance in 50 years

One of many possible comparisons – does not illustrate range of results.

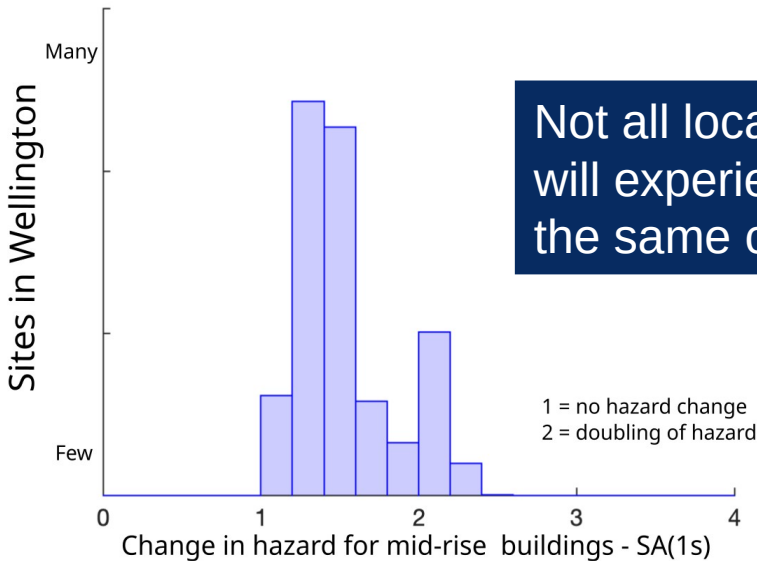
Across all hazard parameters a range from no increase to more than double is seen. When considering site condition/Vs30 differences, the average increase is about 50% or more



Example shaking for Vs30=250m/s

Location	2010 PGA(g)	2022 PGA(g)
Auckland	0.05	0.13
Wellington	0.32	0.82
Christchurch	0.17	0.42
Dunedin	0.1	0.26

Increasing hazard does not necessarily translate to an equivalent increase in impact, as impact does not always increase proportionally to the hazard.

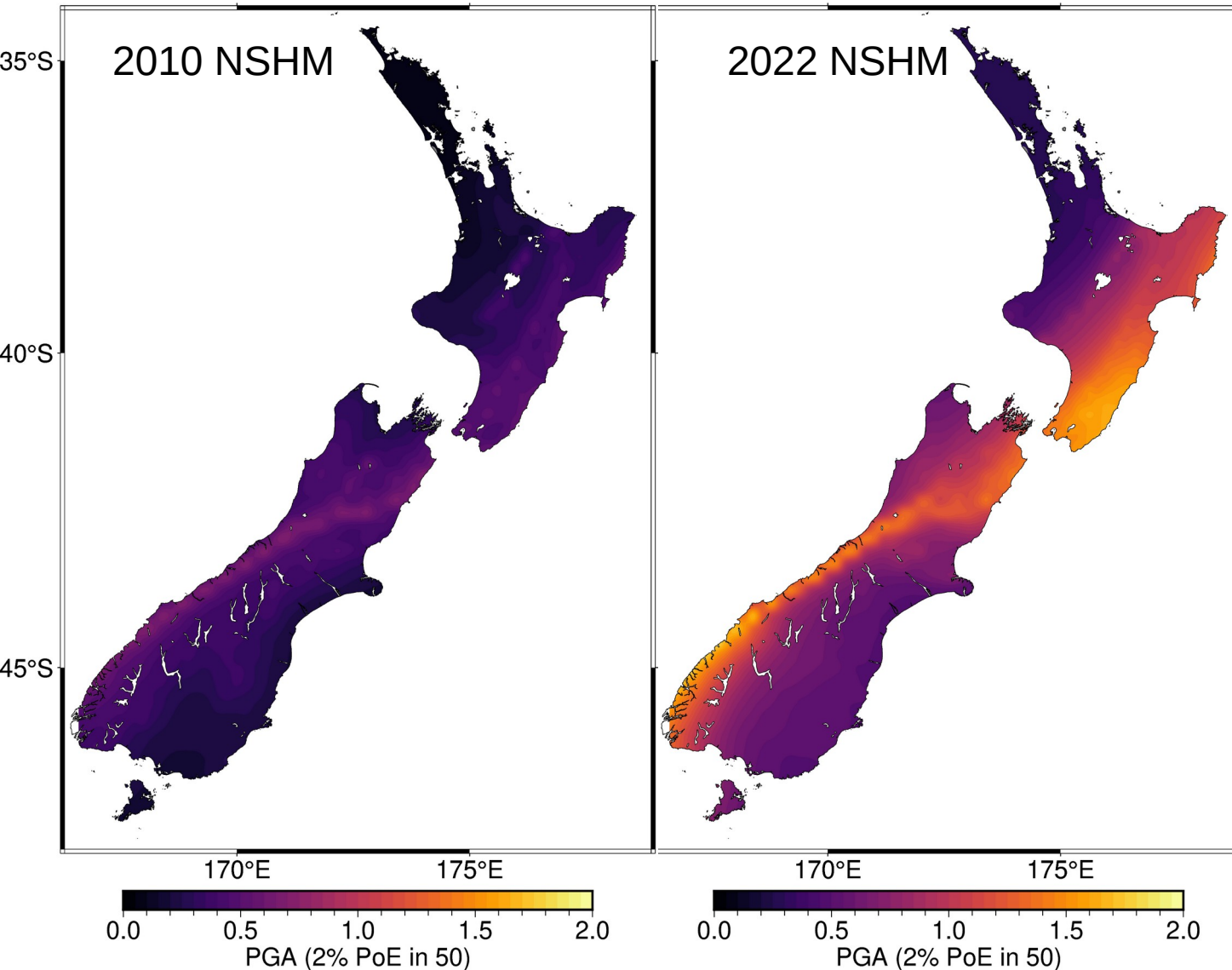


Not all locations will experience the same change

The variability in hazard forecast for mid-rise buildings for an extensive range of sites across Wellington

Comparison of 2010 and 2022 PGA Hazard Maps

PGA: 2% Probability of Exceedance in 50 years: lower risk tolerance



This set of maps shows the shaking with a 2% Probability of being exceeded in 50 years.

This shaking is higher than in the 10% PoE map but is less likely to occur.

These hazard maps show only one of many possible comparisons and do not illustrate the range of results

Example values for $V_{s30}=250\text{m/s}$

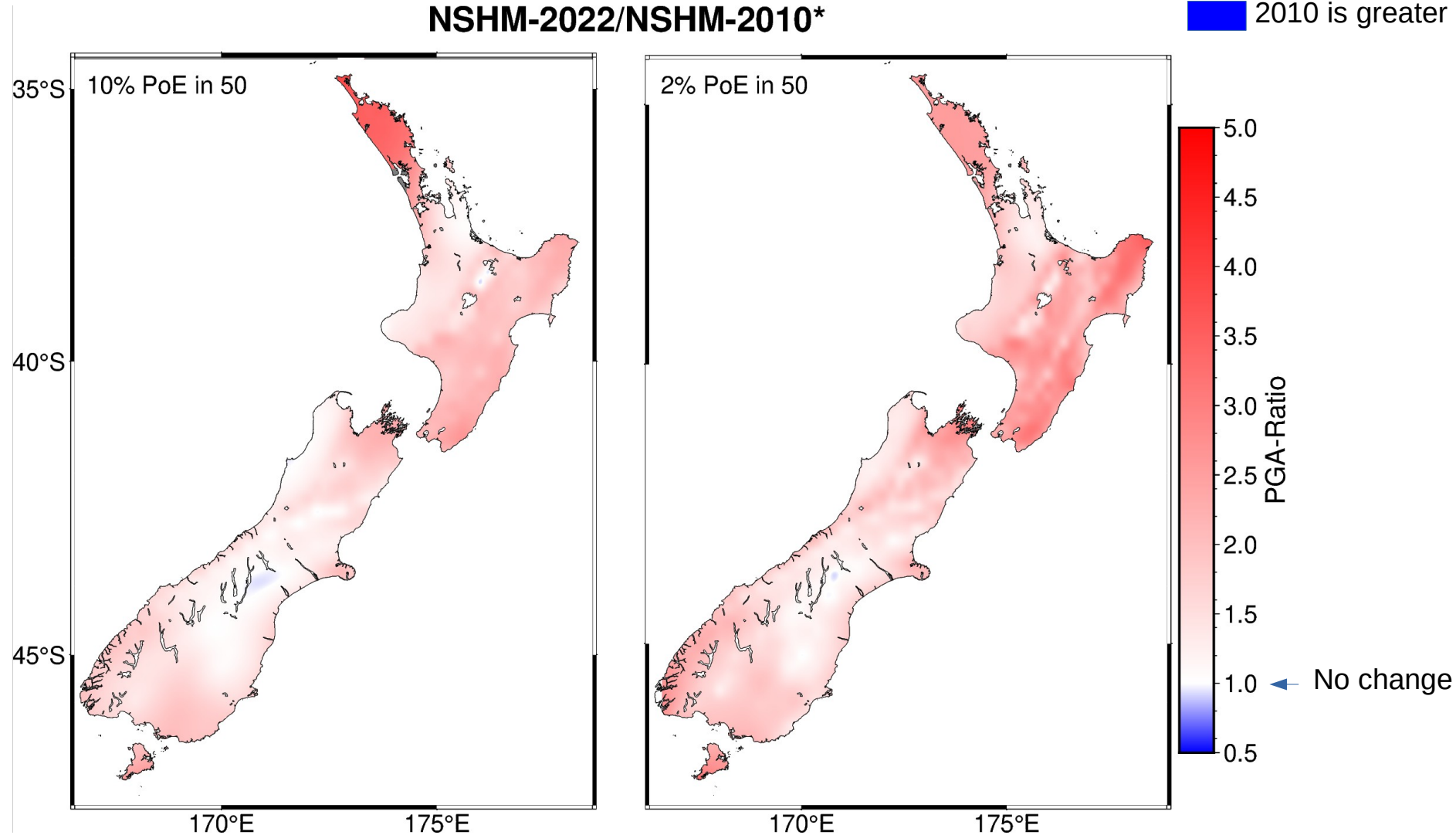
Ratio of change between 2022 NSHM & 2010 NSHM

The maps show the PGA ratio of change between the 2022 NSHM and the 2010 NSHM.

The map on the **left** shows change at 10% probability of exceedance.

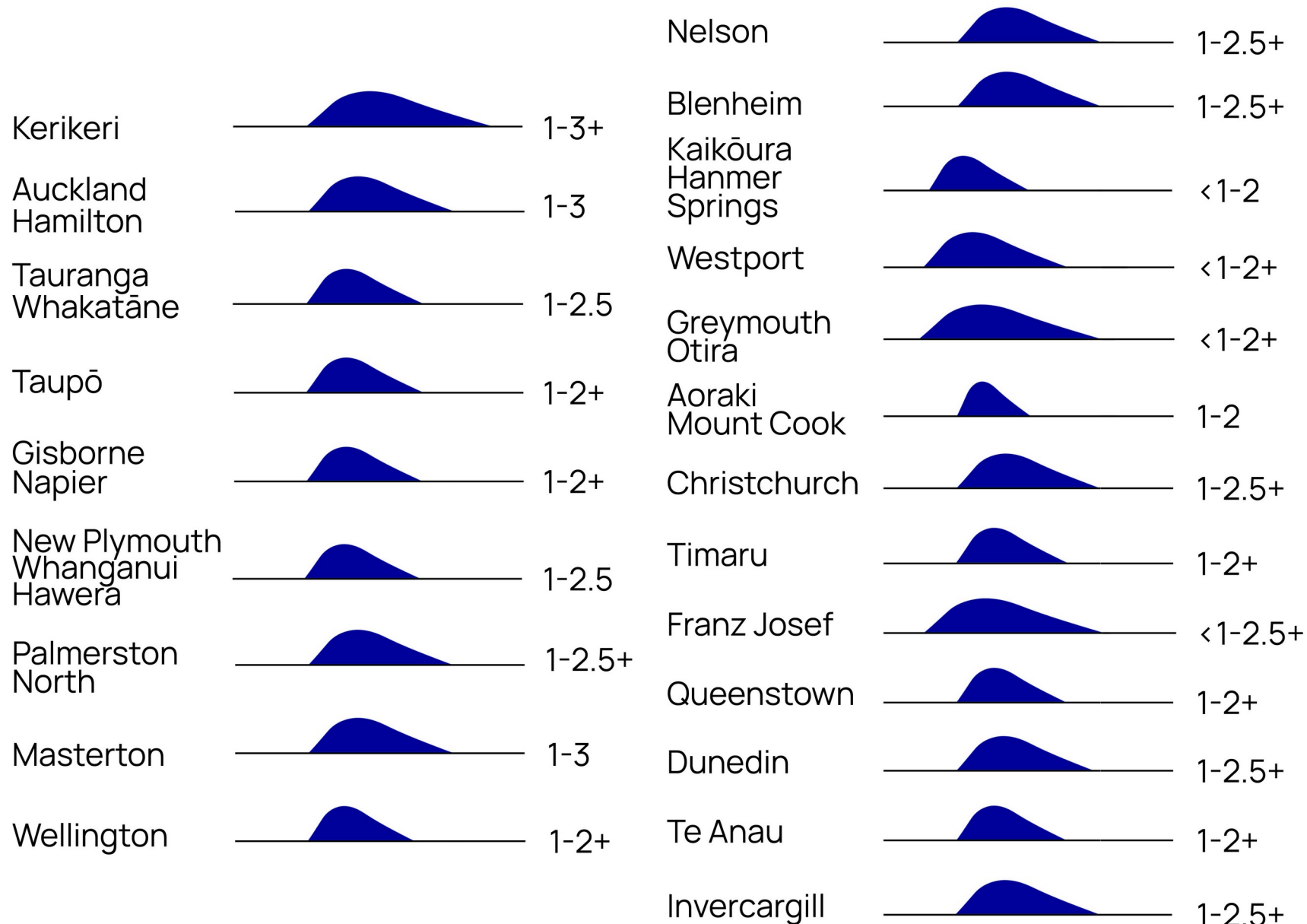
The map on the **right** shows change at 2% probability of exceedance.

>1 ,means 2022 is larger
<1 means 2010 is larger



Schematic of hazard change when compared to previous estimates

This figure is intended to give a general comparison and not precise values



Uncertainty and Risk Tolerance

Hazard curves: a deeper understanding of the hazard for a single location in New Zealand

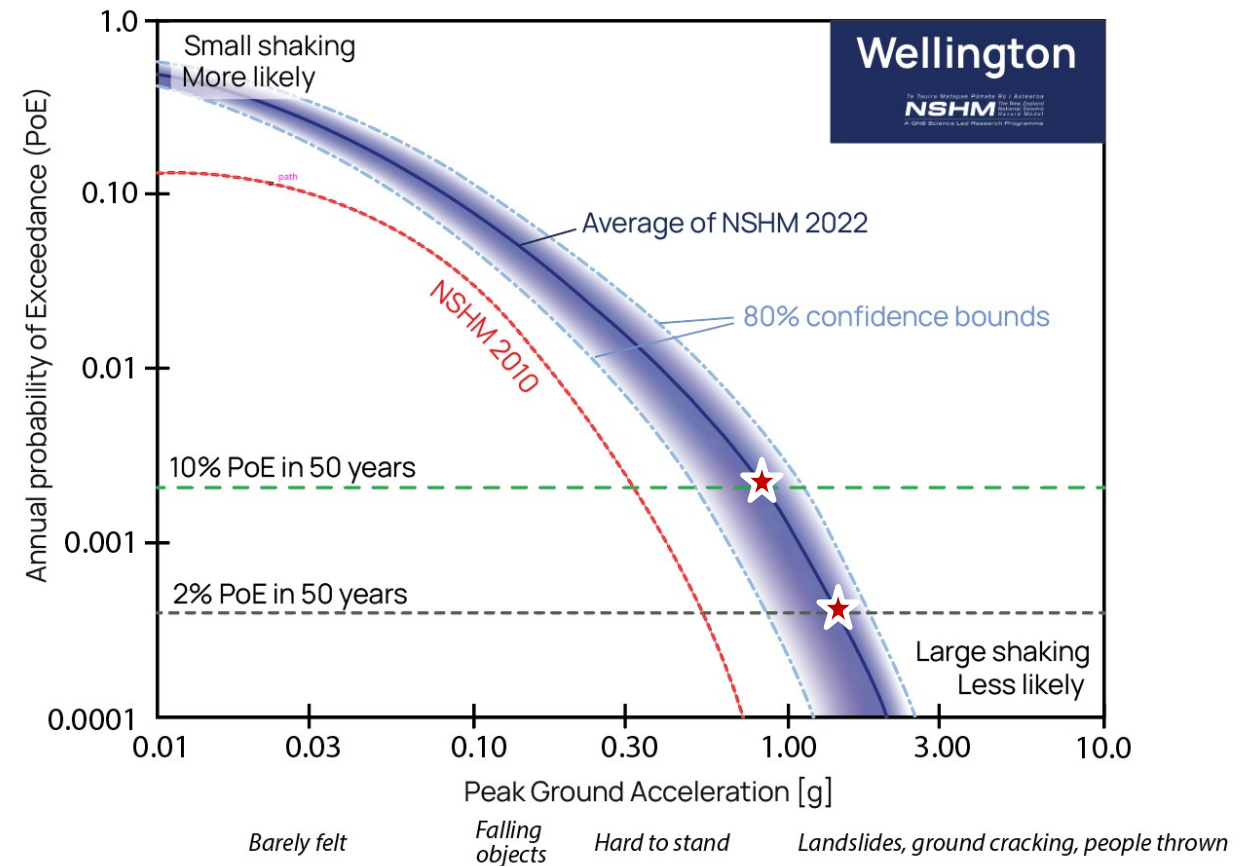
The maps show the average shaking for all locations but only for a single probability of exceedance – 2% or 10% (see ★)

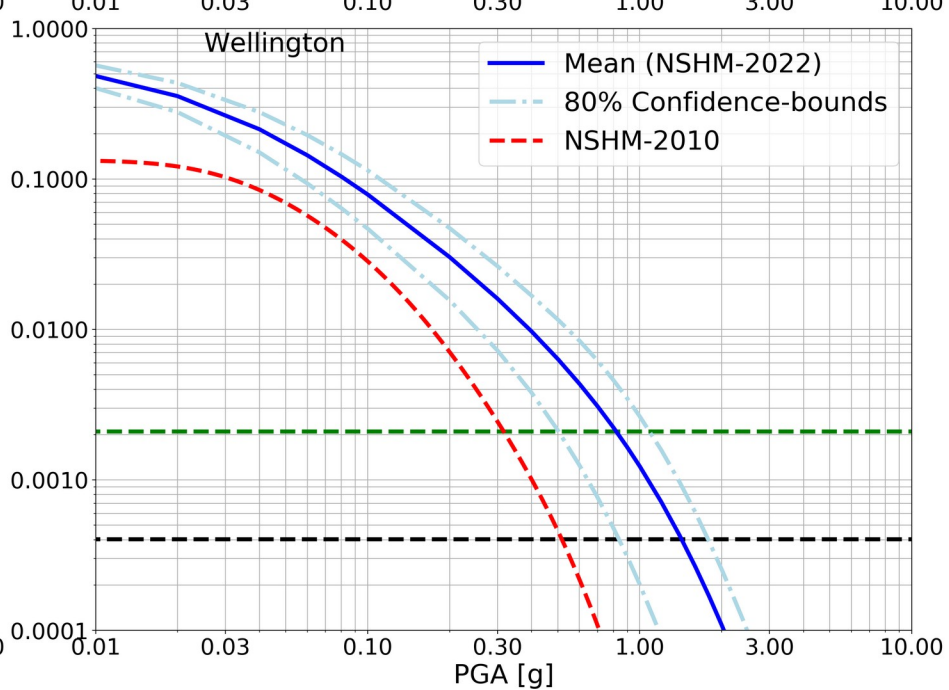
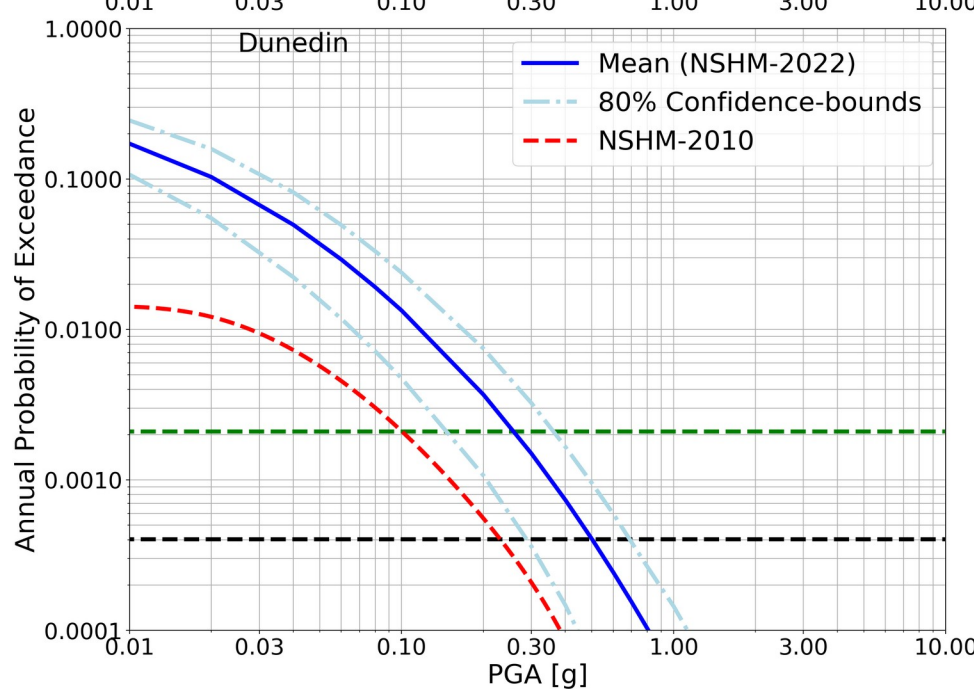
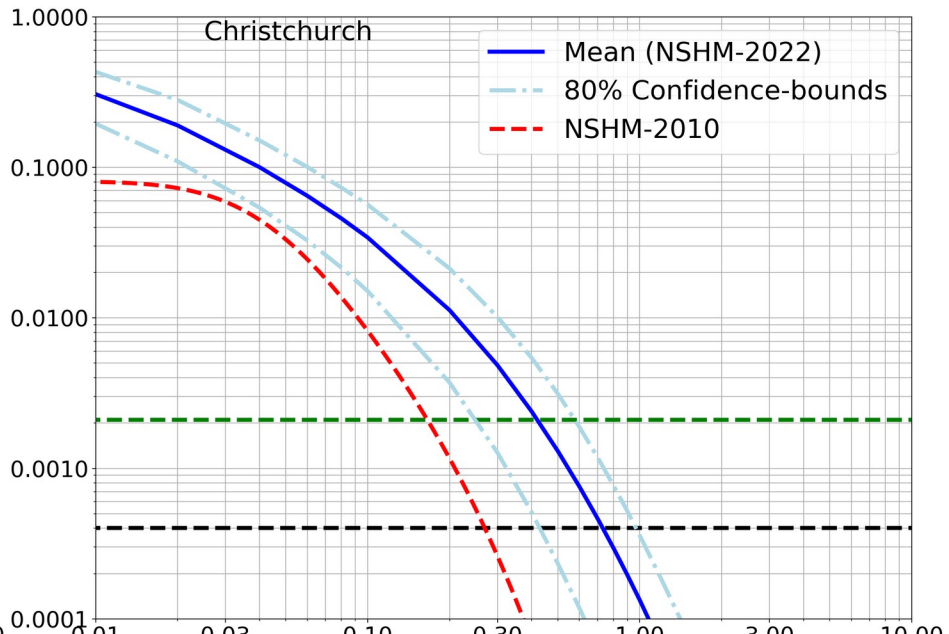
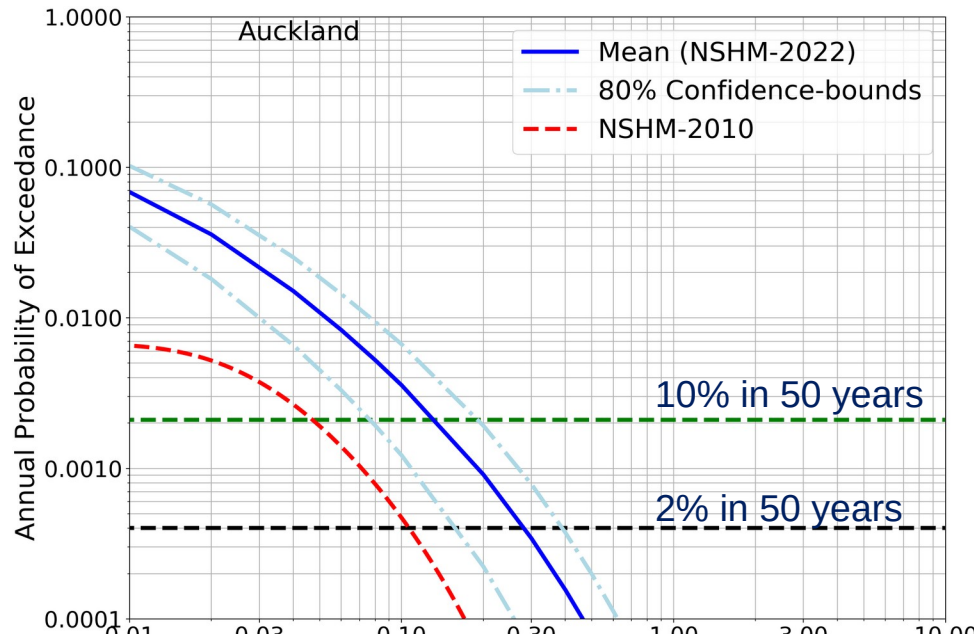
A hazard *curve* shows the shaking for a single location, but for all probabilities of exceedance

- Shaking shown in the upper left is smaller, but more frequent
- Shaking shown in the lower right is larger but much less frequent

The bold blue line is the average forecast. This is more likely to occur than any other forecast in the shaded region

Also shown is the NSHM's 80% confidence bounds for what the shaking may be (less or more than the average)

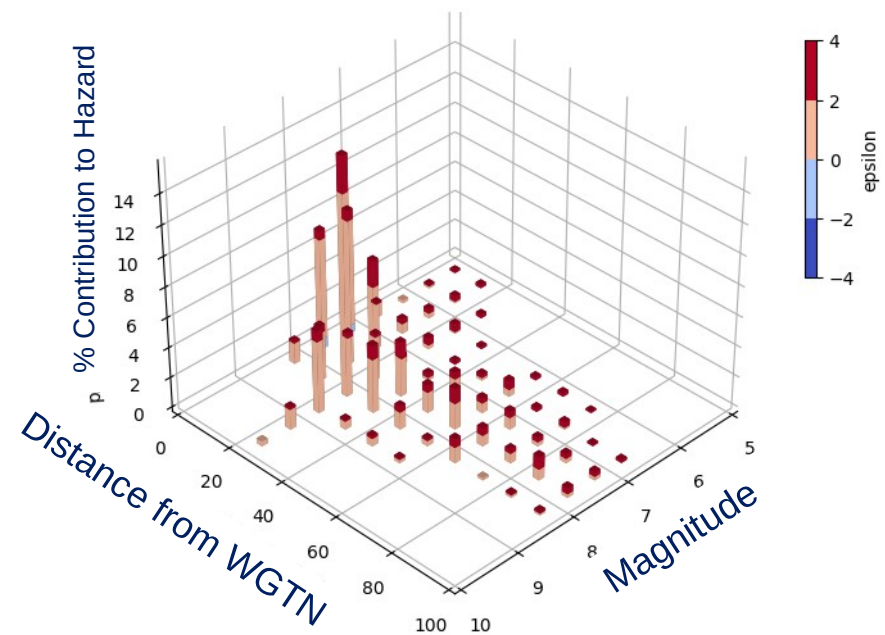
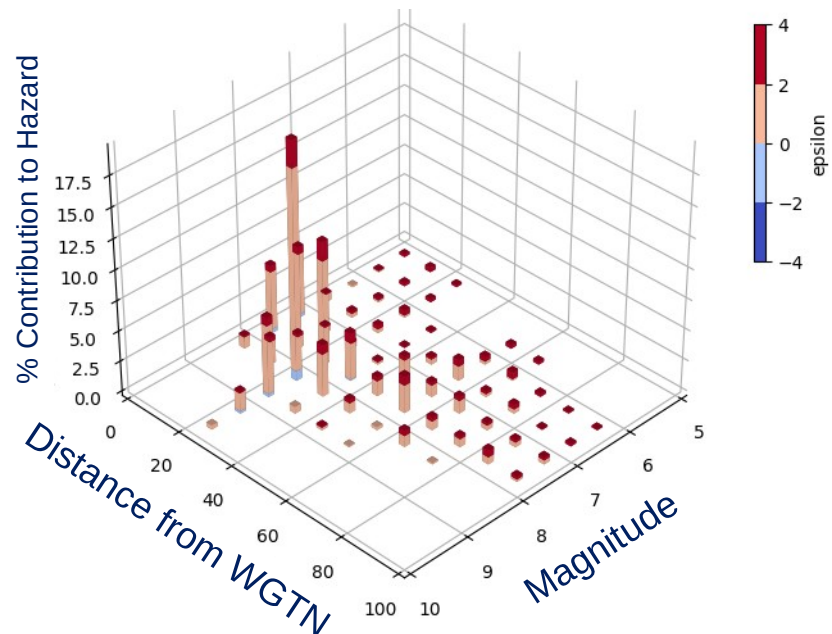
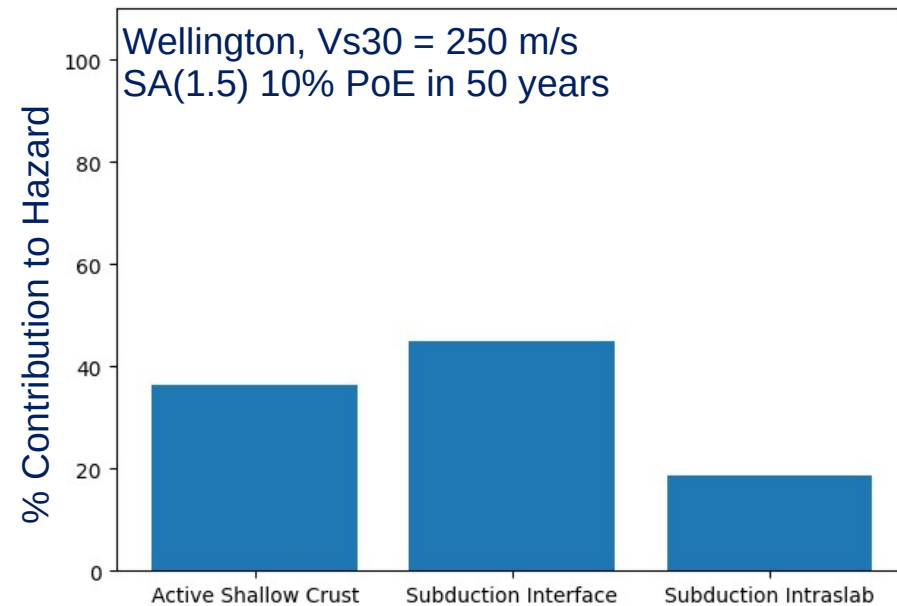
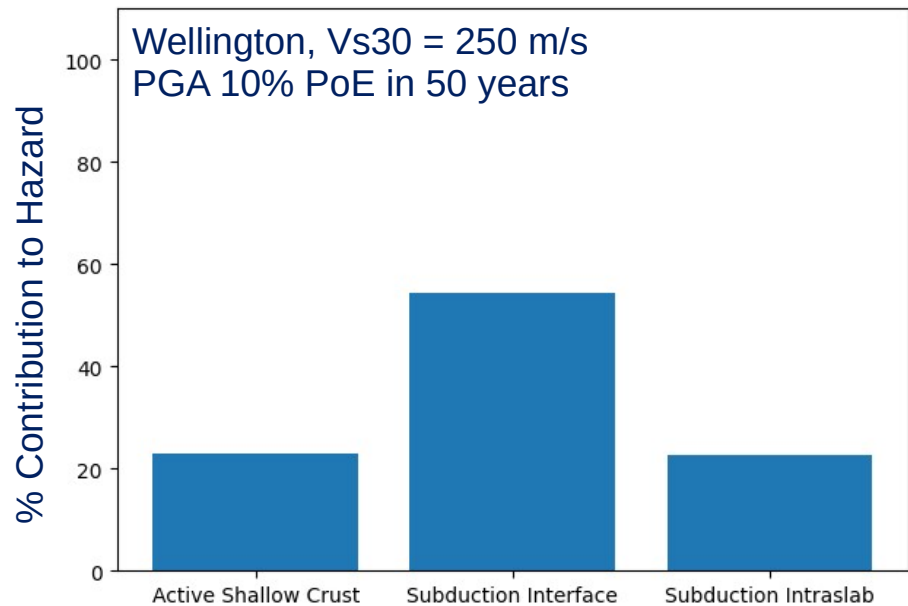




PGA Vs30 = 250 m/s

What earthquakes are causing the hazard?

Understanding what ruptures matter for a region: disaggregation



High Impact Low Probability Events

The 2016 M7.8 Kaikoura earthquake, which ruptured more than 20 faults, demonstrated that many faults can rupture in a single earthquake affecting multiple regions.

This has been difficult to model in the past, but we are now able to model such complex ruptures. Now we have:

- More realistic hazard estimates
- Modelling of very low probability, but potentially high impact ruptures.



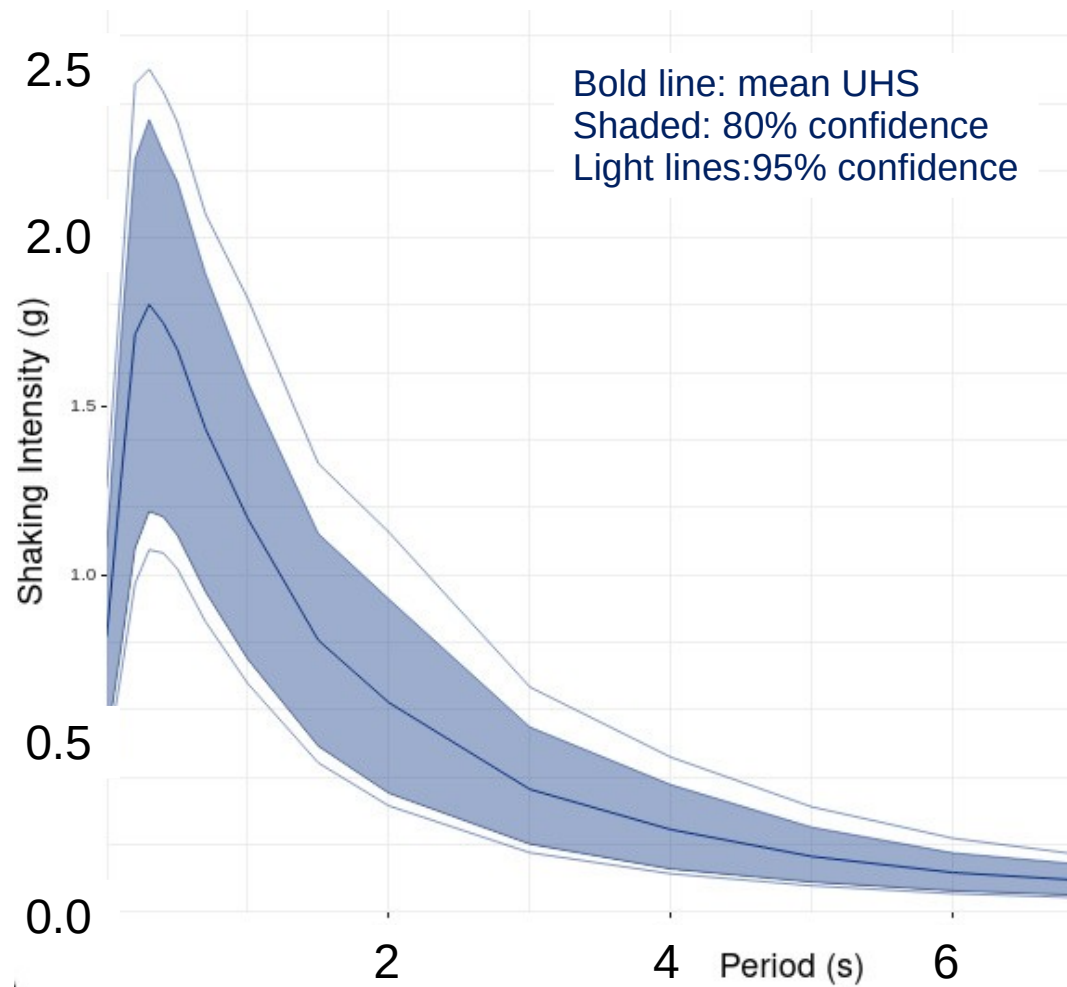
Large earthquakes can happen anywhere in New Zealand
The map here shows one example of a very low probability but high impact rupture.
This is an M8.3 event with a rate of about 1-in-1 million years.
We expect around two M8.3+ crustal earthquakes every 1,000 years.

Summary

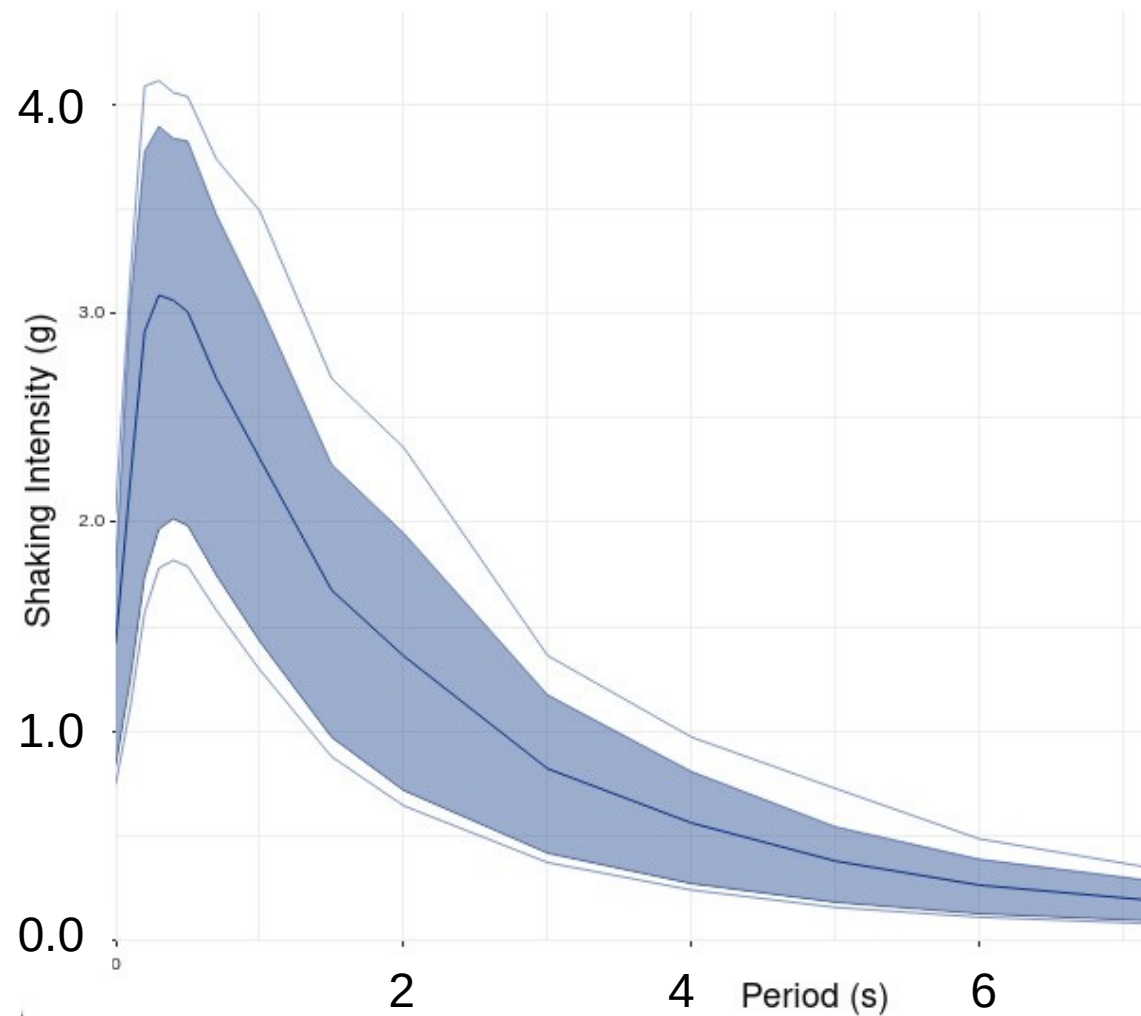
- Forecast ground shaking hazard has increased across New Zealand with an average increase of about 50% or more.
 - In general the range is from no change to more than doubling
 - The NSHM forecasts shaking hazard it does not forecast impact (risk).
 - Increases in hazard do not necessarily correspond to equivalent increase in impact.
-
- The Hikurangi-Kermadec Subduction Zone represents a significant source of hazard for New Zealand and can affect much of the country.
 - Our other well-known faults continue to be significant, such as the Wellington Fault, the Alpine Fault, and the faults that they connect with.
 - Many other larger faults are also important to New Zealand's hazard landscape, and for each region there are smaller local faults that may cause significant shaking.
 - The potential for events on unknown faults is also included in the model.
-
- What parts contribute the most to the hazard changes: ground motion modelling and total expected number of forecast earthquakes

Changes in spectral shape

Wellington UHS



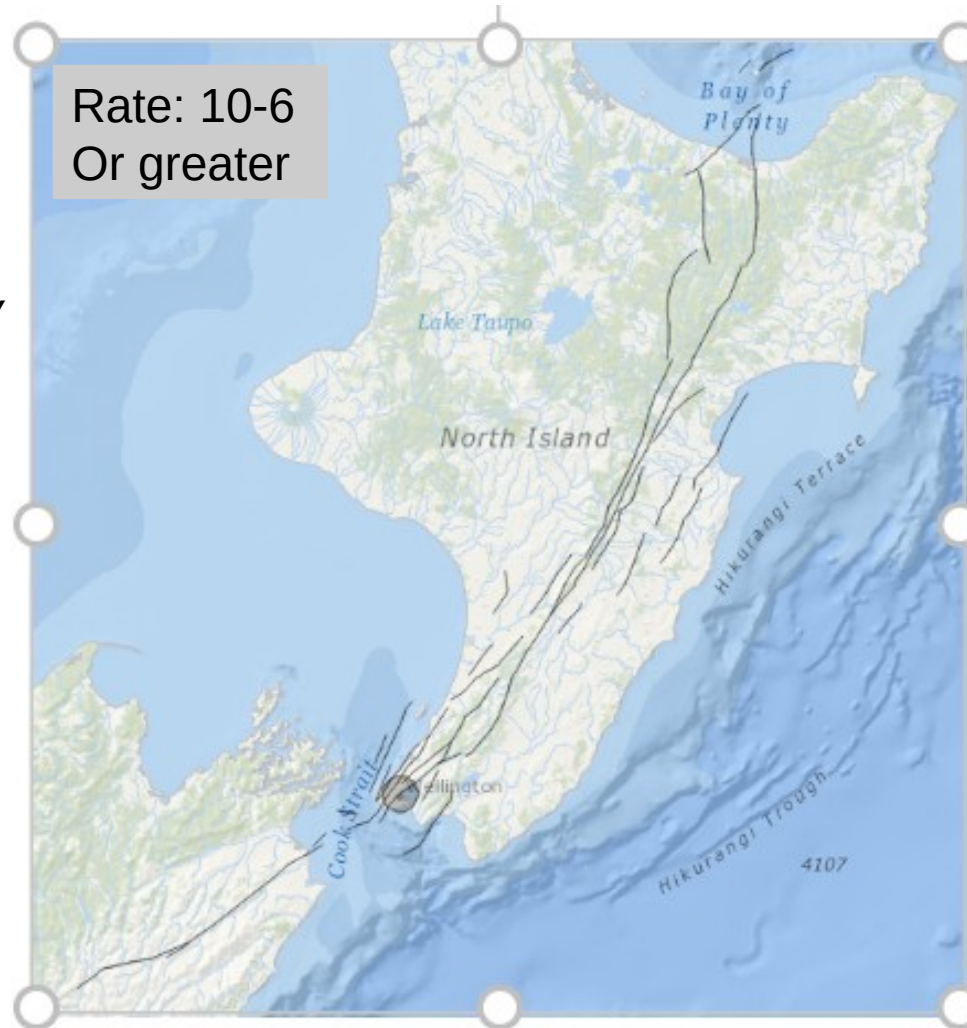
10% PoE in 50 years, Vs30 = 250 m/s



2% PoE in 50 years, Vs30 = 250 m/s

High Impact Low Probability Events: Wellington Region Events

Each panel shows *many* earthquake ruptures



All including very low probability



less low probability

All ruptures pass within 10km of Wellington

Large Earthquakes on the Hikurangi-Kermadec Subduction Zone

