GNS SCIENCE
TE PŪ AO

National Seismic Hazard Model

2022 Revision

Te Tauira Matapae Pūmate Rū i Aotearoa

NSHM The New Zealand National Seismic Hazard Model

A GNS Science Led Research Programme

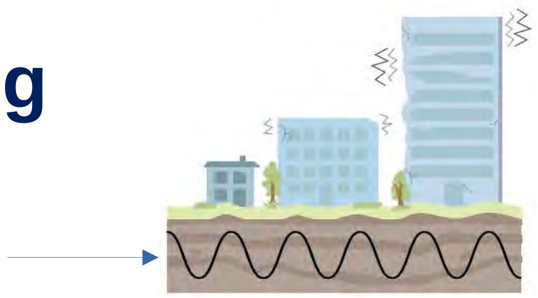
E mahi ana me
In collaboration with

UC University of Canterbury · University of Otago · The University of Auckland · Victoria University of Wellington Te Herenga Waka · USGS · IU · WSP · Australian Government Geoscience Australia · SCEC Southern California Earthquake Center · Missouri S&T · GEM Global Earthquake Model · GFZ Potsdam · UCLA · NIWA · Lamont-Doherty Earth Observatory Columbia University | Earth Institute

Ngā hoa tuku pūtea
Funding partners

Ministry of Business, Innovation & Employment Hīkina Whakatutuki · Toka Tū Ake EQC

The NSHM produces probabilistic forecasts of shaking



What time 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

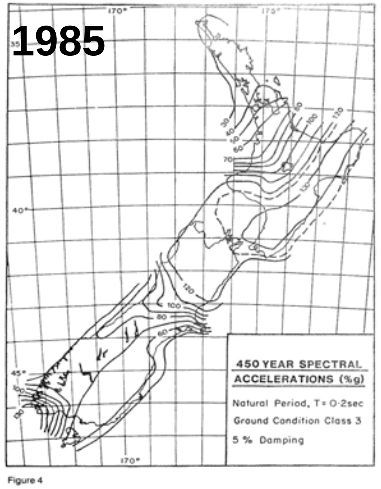
Past earthquake events
+
statistical and
physical science

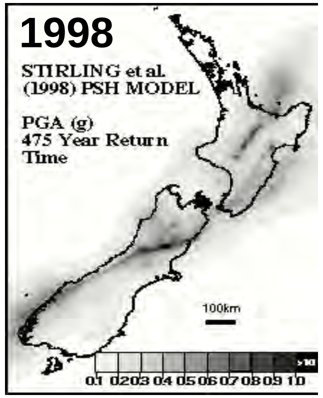
Range of future possible shaking

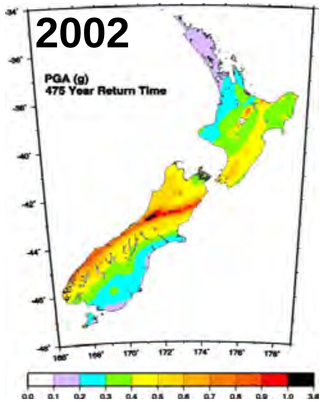
The forecast is a distribution of shaking, not a single number

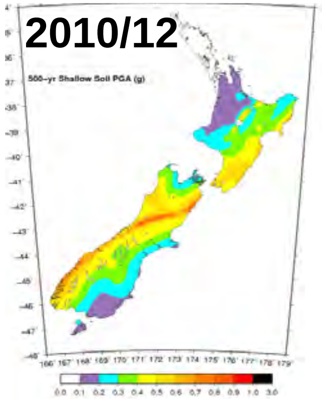
The confidence in the forecast is shown by looking at the range of possible futures and how likely they are. Each one of these can be expressed as a different map or different outputs for engineers

A revision was long overdue









1998: last major methodological revision

2002: minor update to rupture modelling

- Ground shaking models using data up to 1996

2010: data update for rupture modelling (method change for distributed seismicity)

Significant changes in hazard were anticipated based on preliminary work done around the globe on New Zealand hazard

How is the NSHM different to other earthquake forecasts?

Earthquake occurrence and shaking is complicated.

- There are a range of models, data, ideas and expert scientific judgement about how earthquakes work and what the future may look like.

- It is the job of the NSHM team to bring together all of the ideas and models from across the New Zealand and international science community.

- The NSHM forecasts represent the knowledge from across the scientific community and not those from a single research group or organization.

The science development and review process

We aim to represent a broad range of scientific views

- with something as complex as earthquakes it is not realistic or prudent to develop a single consensus model – users need to understand the uncertainty (most want to)
- Expert selection (who is an expert?) and structured elicitation process

NSHM includes scientific understanding from around the world

- Includes a broad range of scientific views
- More than 50 scientists 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

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
- Time consuming and challenging, but very beneficial

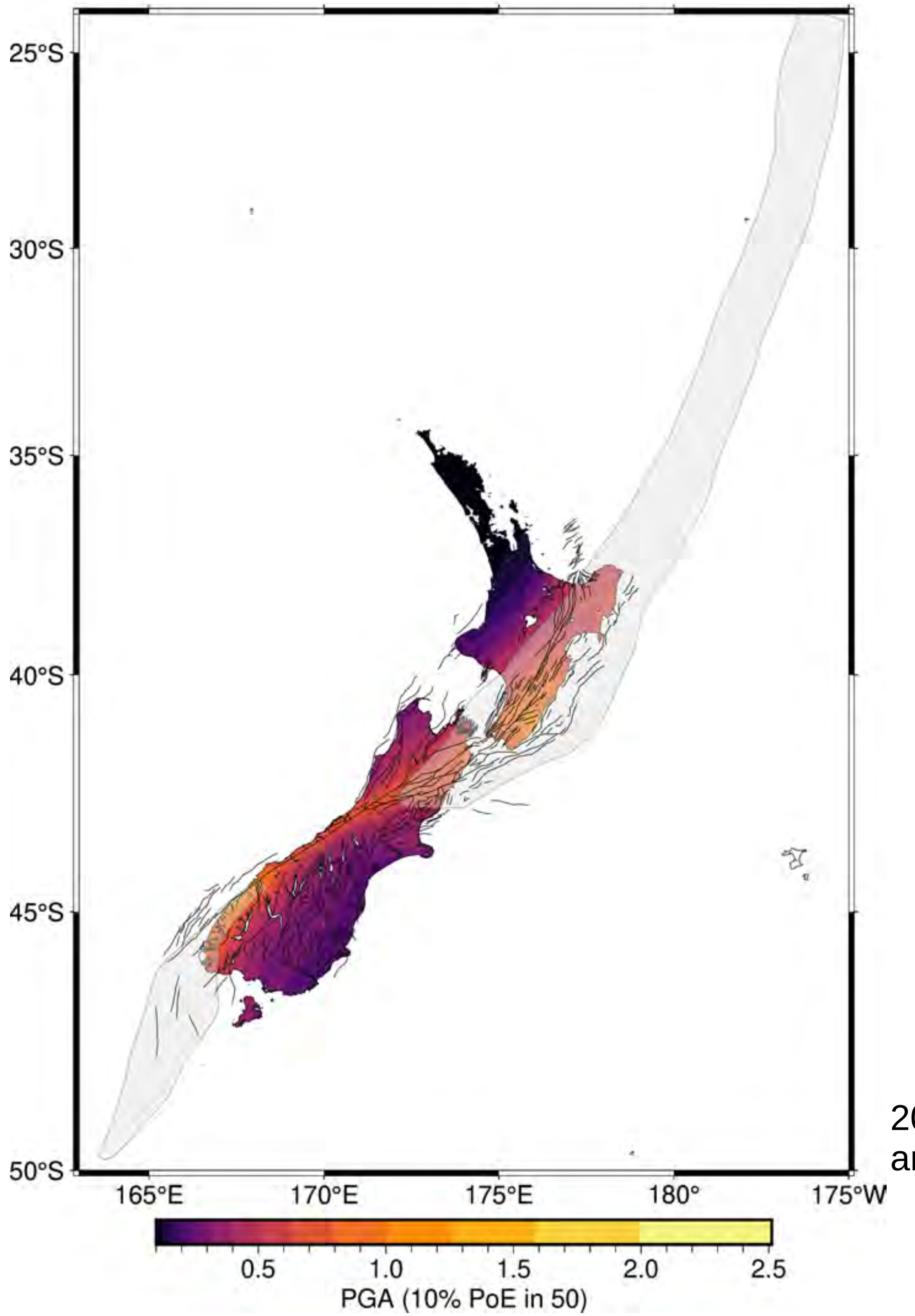
Assurance review:

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

How do we make the NSHM?

Two Components of the NSHM

1 **Earthquake Ruptures**   2 Ground Shaking



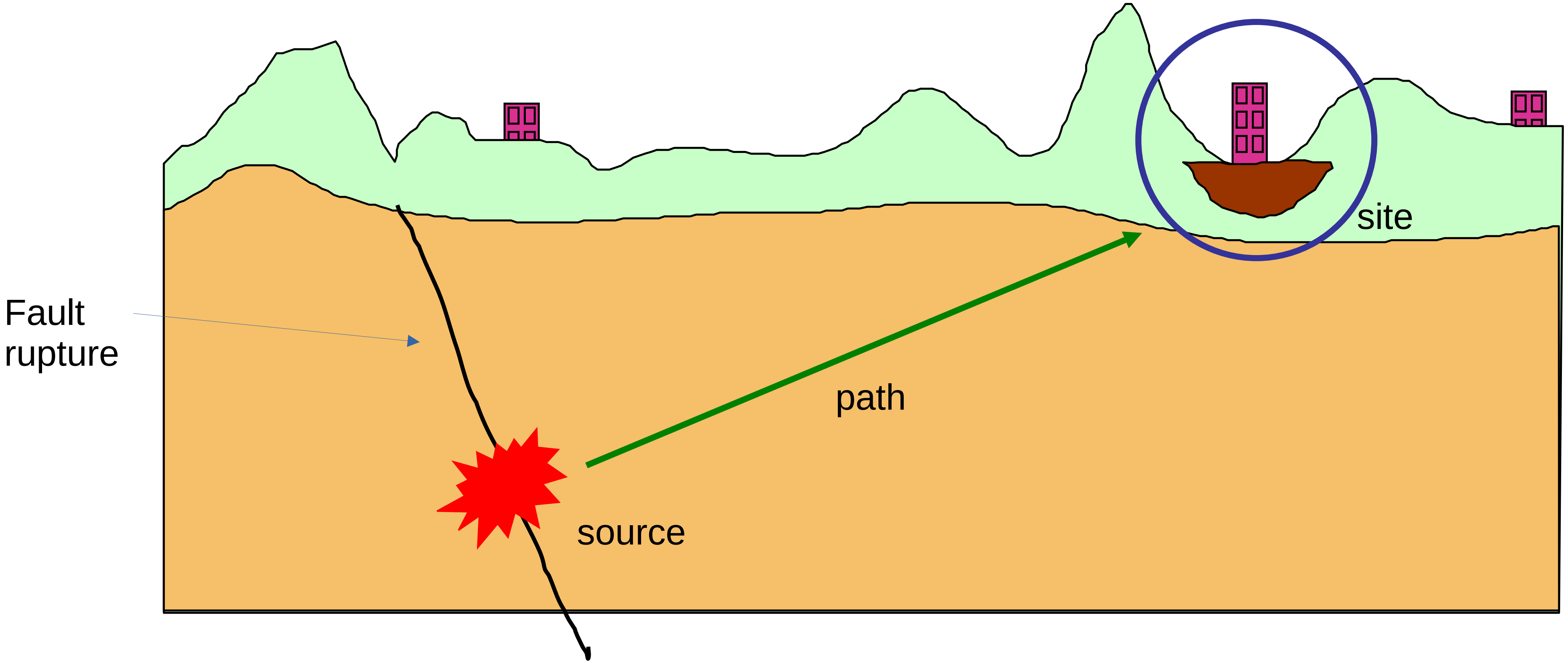
2022 NSHM faults including Hikurangi-Kermadec and Puysegur Subduction Interfaces

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

Main Model Components

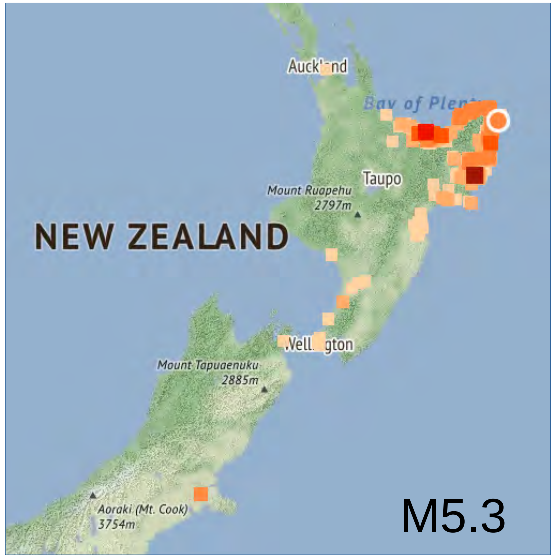
Ground shaking = source effects + path effects + site effects

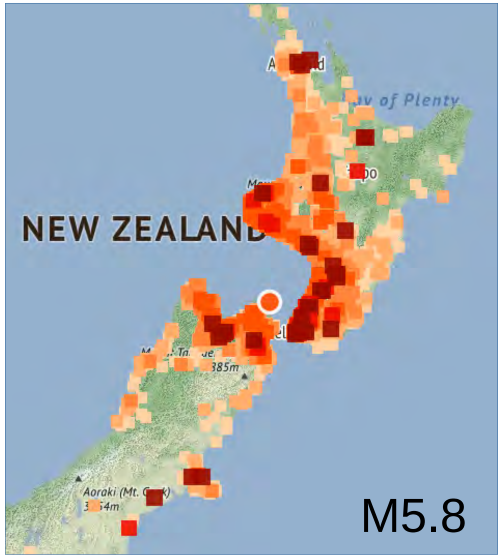


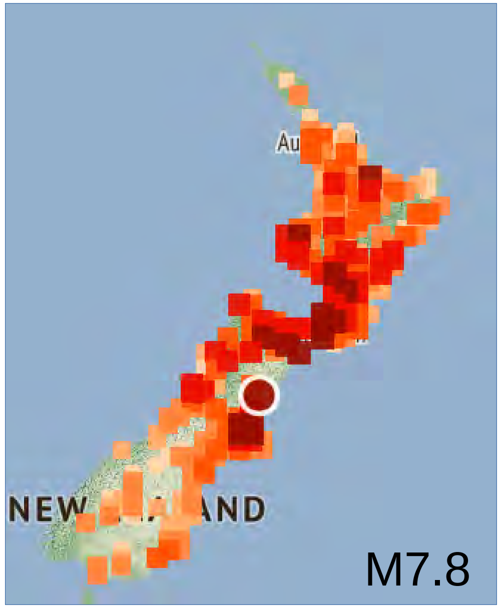
Two Components of the NSHM

1 Earthquake Ruptures

2 **Ground Shaking**



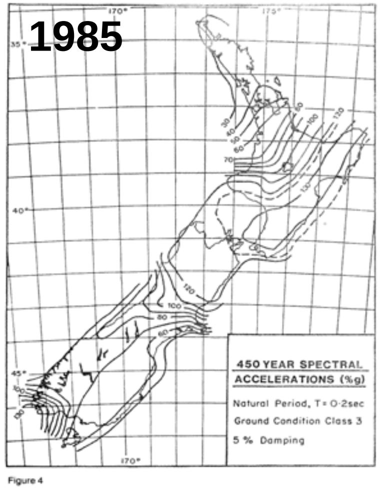


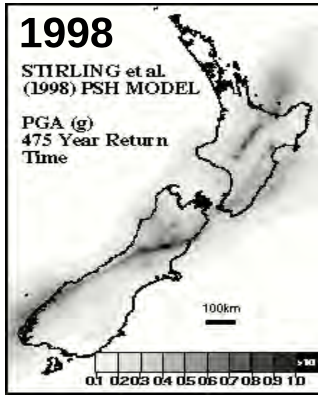


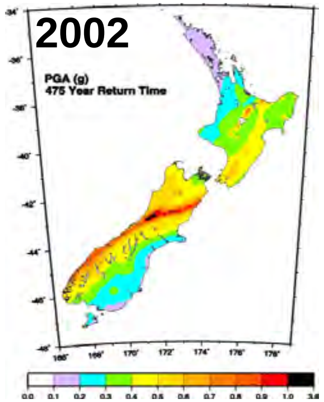
The shaking people felt in the Kaikoura M7.8 and two recent earthquakes

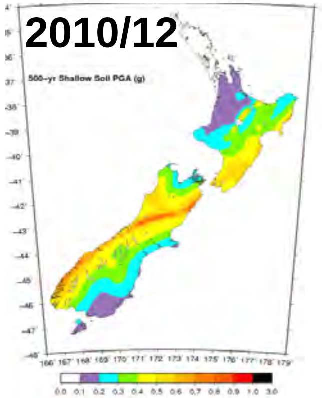
2. Ground shaking: what is the range of possible shaking when all ruptures are considered

- 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









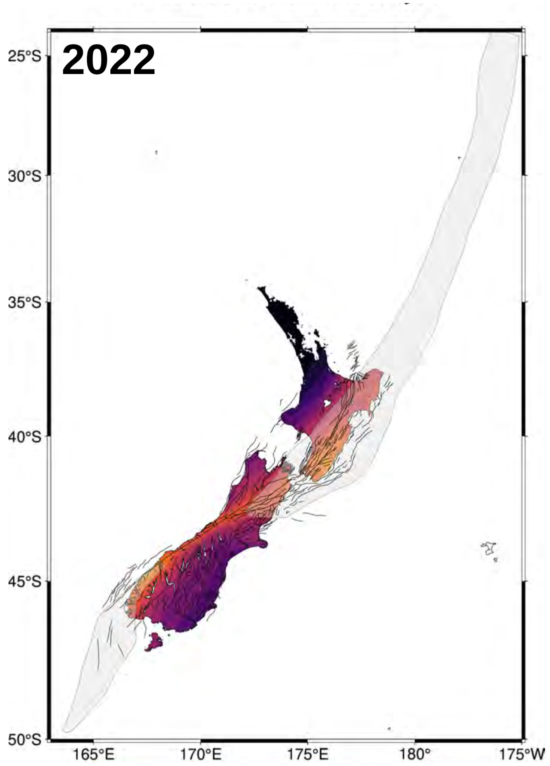
From one model to many

Prior to 2022 (one model)

- One model of possible future earthquake *ruptures*
- One model of possible *ground shaking* from these ruptures
- A <u>single</u> estimate of possible shaking for each location

2022 (a million models)

- Many models of possible future earthquake *ruptures*
- Many models of possible *ground shaking* from these ruptures
- A <u>distribution</u> of possible shaking for each location



Epistemic uncertainty: uncertainty in our knowledge as opposed to randomness in data

Conceptual differences from 2002 and past NSHMs

Quantifying and modelling uncertainty is a critical part of the model	• Better includes our understanding of earthquakes • Communicates our confidence in the model results
Results include the integrated influence of multiple data sets and scientific hypotheses	• Earthquake geology, geodesy, seismology, statistical seismology, engineering seismology • Hybrid models • Joint fitting of data sets
No more strictly characteristic ruptures Modelling of thousand of potential ruptures, rather than a few hundred	• Complex and multi-fault ruptures • Variability in magnitude and rupture length • More high-impact low-probability earthquakes
Specific models for low-seismicity regions	• Statistical model of greater uncertainty in spatial and temporal mean • Order of magnitude more variability than Poisson
Hybrid distributed seismicity model	• Integrated influence of catalogue, earthquake geology and geodesy
100 year forecast with increased variability	• Other shorter-term forecasts can be investigated
Use of many ground motions models rather than just one	• Internationally developed models • Models tuned to NZ data
Much more data is available	• Particularly for ground motion modelling • More realistic hazard estimates

From individual faults to complex ruptures

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, and into what complex ruptures may occur

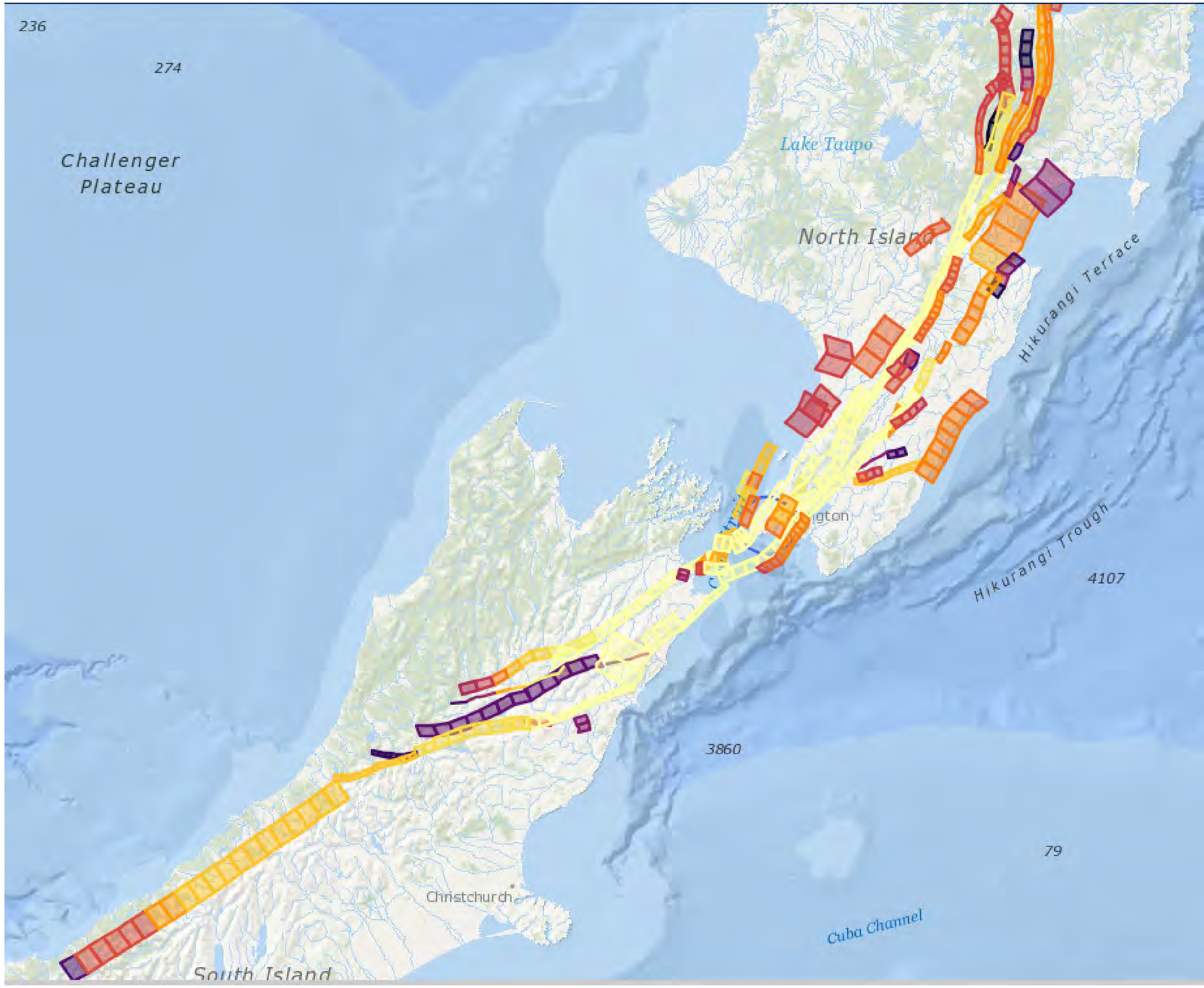
No longer only one fault rupture with one magnitude and one rupture length

Fault connectivity

- Many different forecast earthquake ruptures are shown on this map

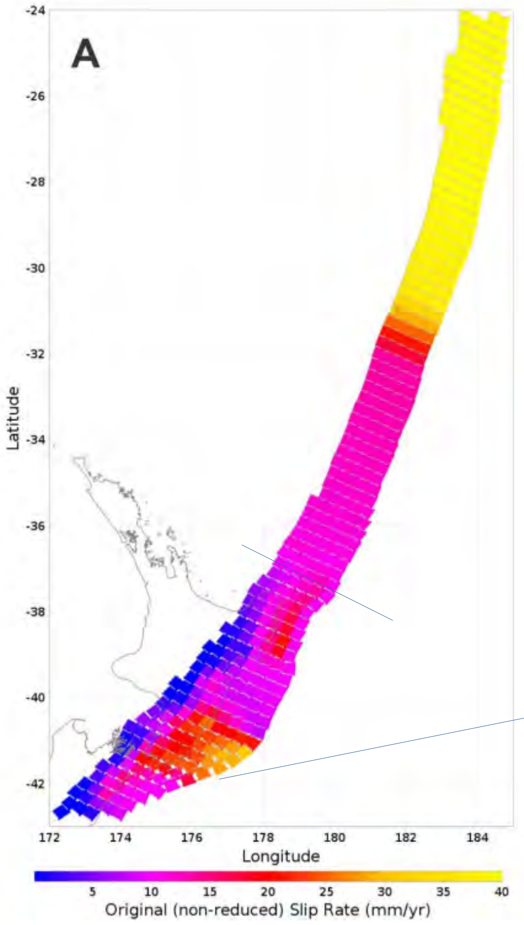
- Each passes within 20km of Wellington

- In the past only a one or two ruptures were considered for Wellington (and other urban faults) now there are hundreds.



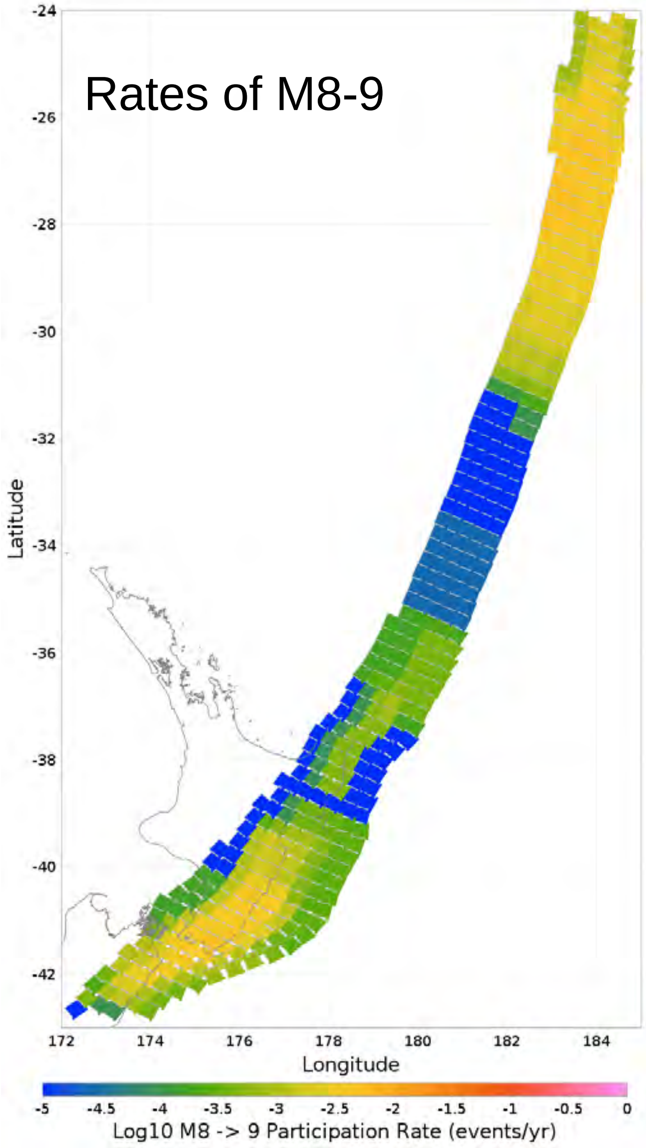
Large Earthquakes on the Hikurangi-Kermadec Subduction Zone

How fast is it moving?

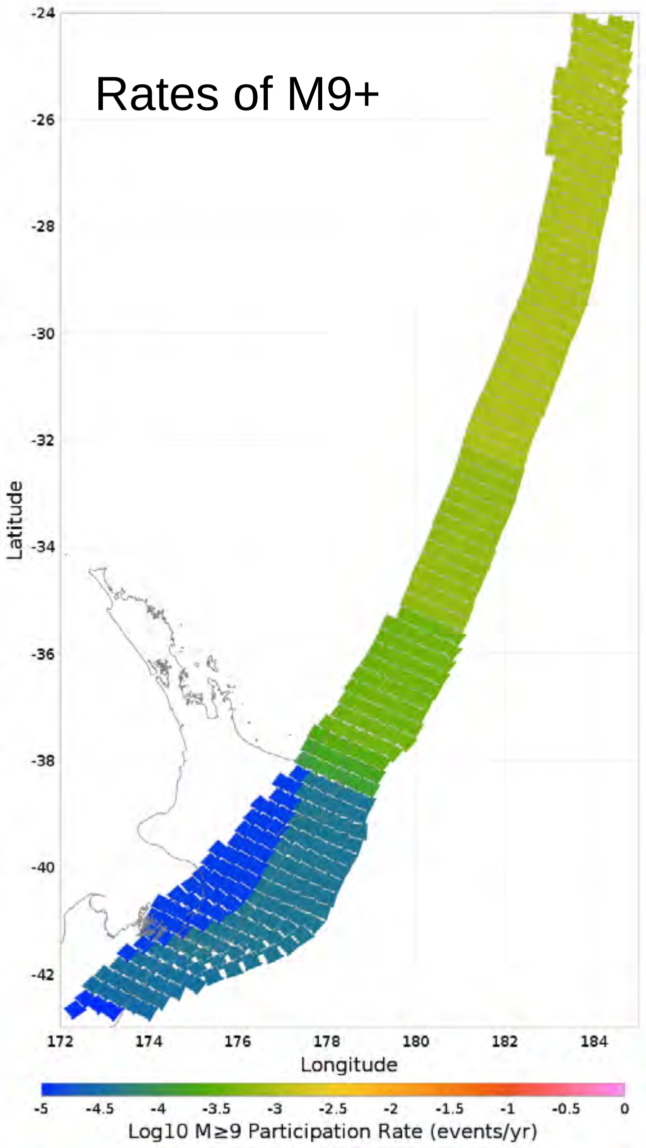


It's stuck!

Rates of M8-9



Rates of M9+



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/Vs30:
  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.

- PGA/SA
  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

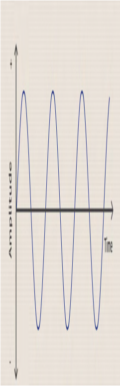
Land and shorter buildings are affected by high frequency shaking and taller buildings by lower frequency shaking

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



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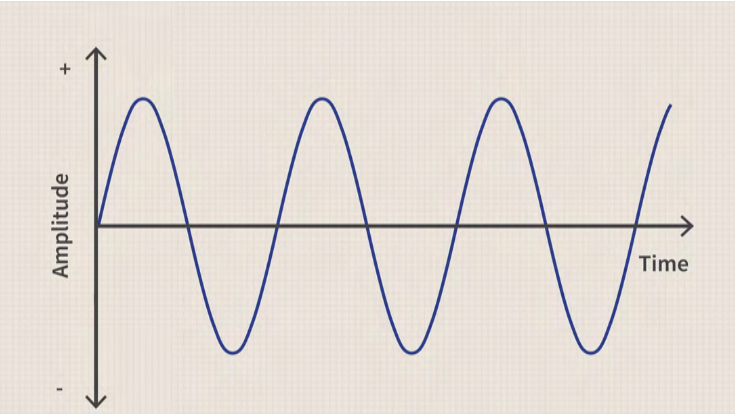

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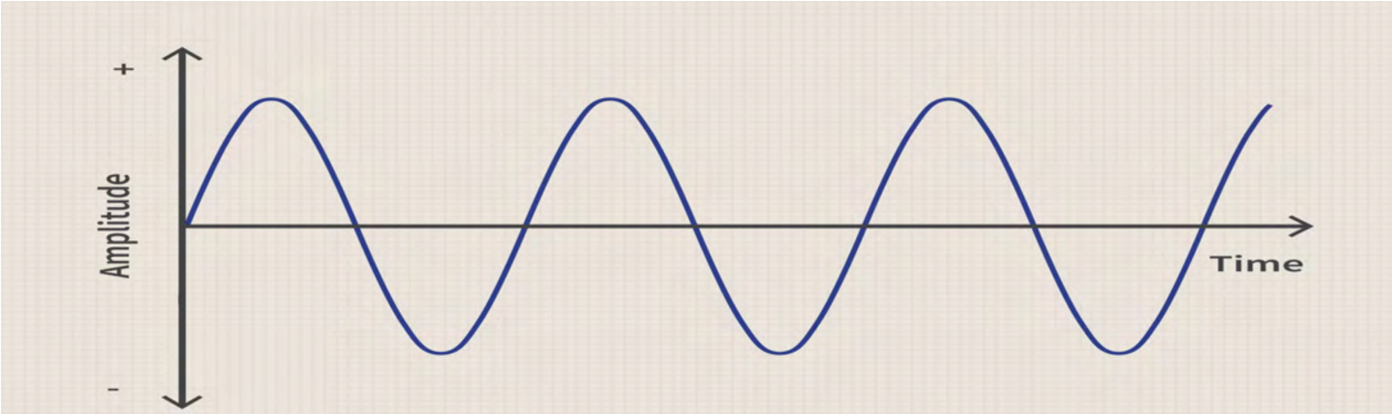


PGA — SA(0.5 seconds) — SA(1.5 seconds) — SA(3 seconds)

High Frequency/Short Period — Low Frequency/Long Period

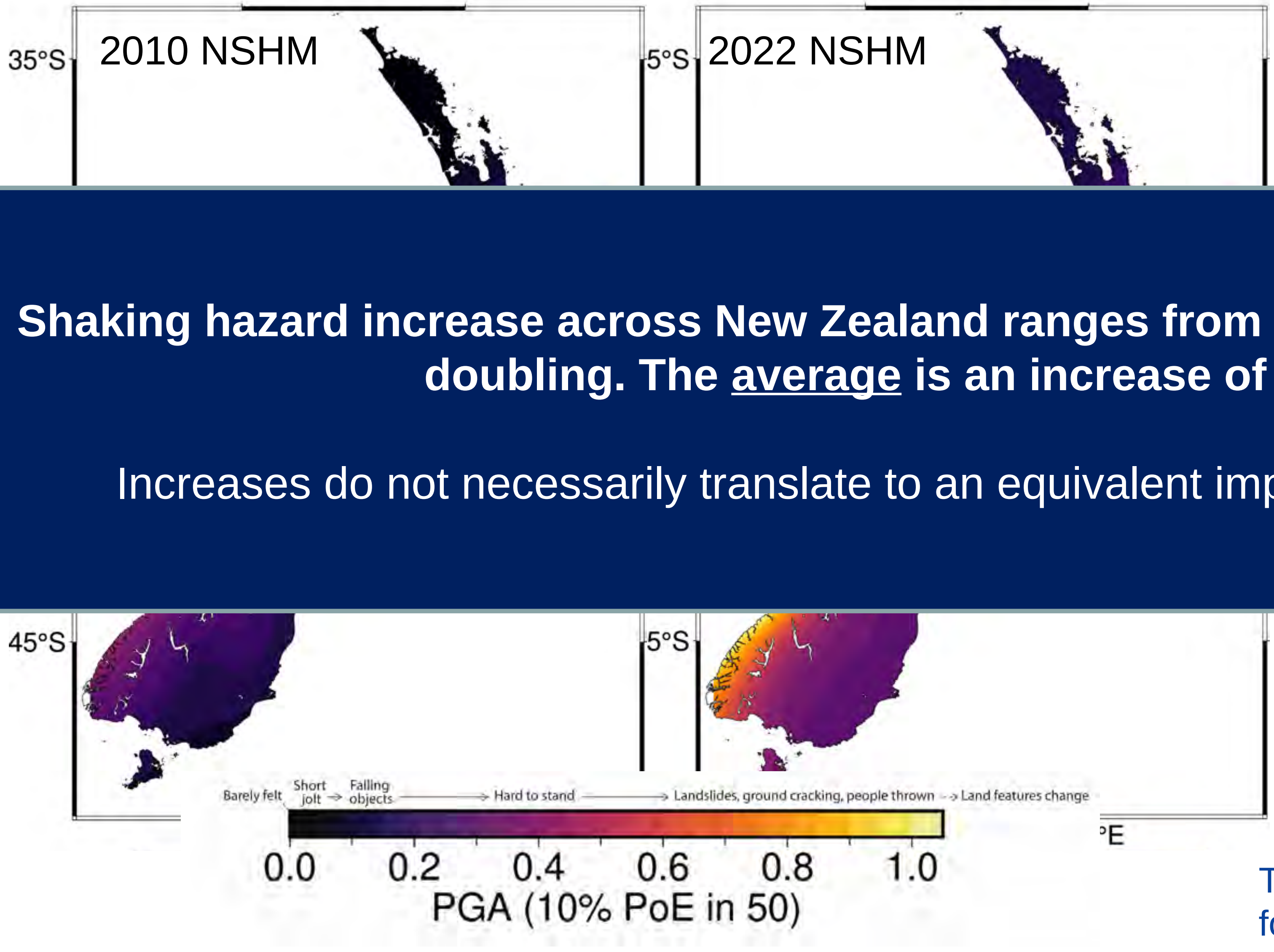
Hazard estimates and changes for different frequencies are different

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



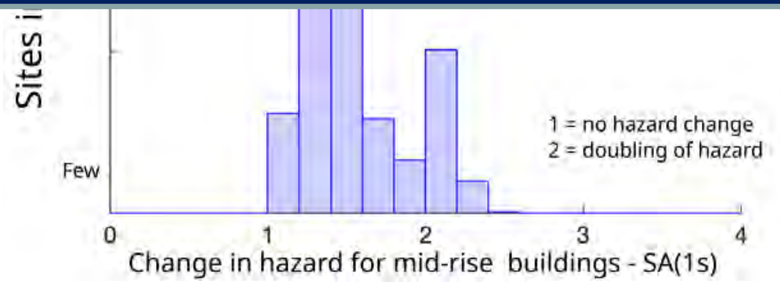
Example shaking for Vs30=250m/s

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 <u>average</u> 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

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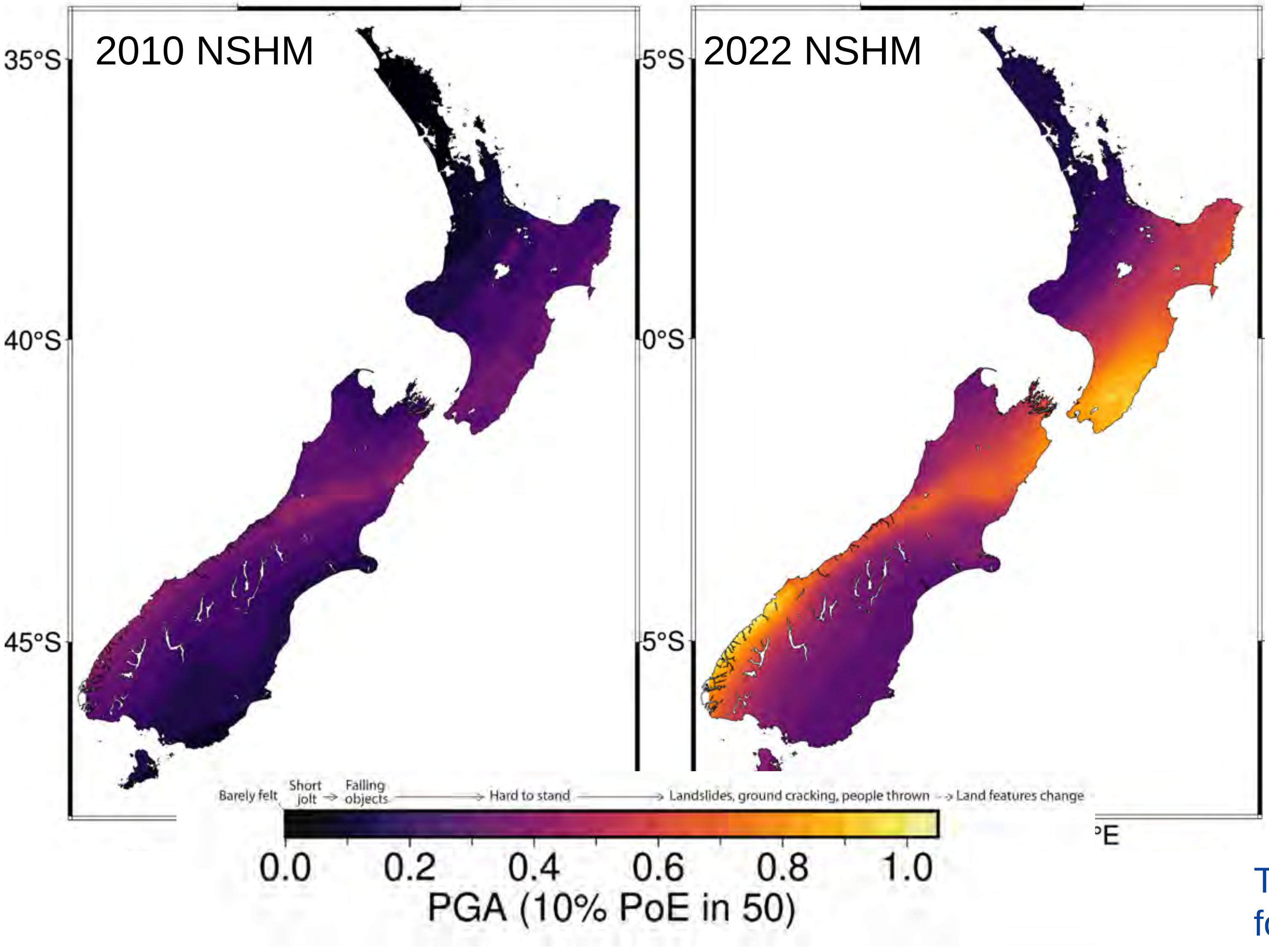
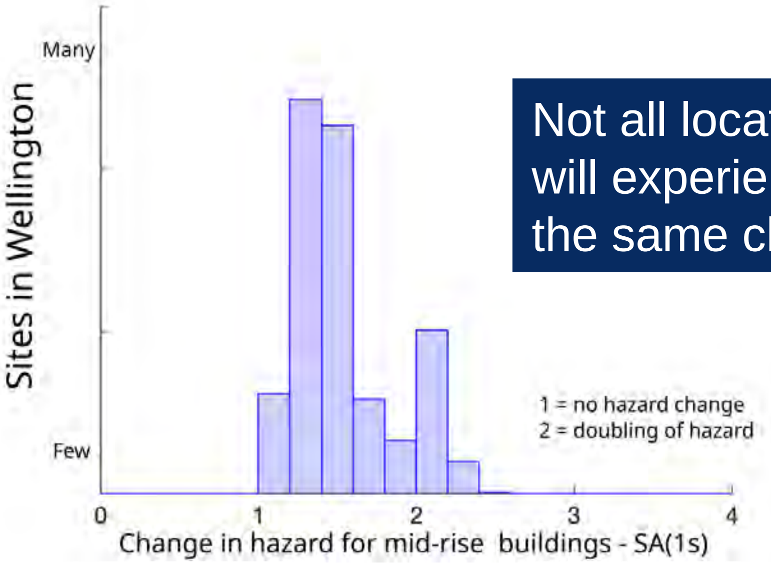


Example shaking for Vs30=250m/s

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

Final thoughts

- 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
- Both rupture model and ground shaking model changes are important everywhere
- Higher hazard: ground motion; Lower hazard: rupture model
- 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.

- All model components, results and data are available, plus 30+ technical reports

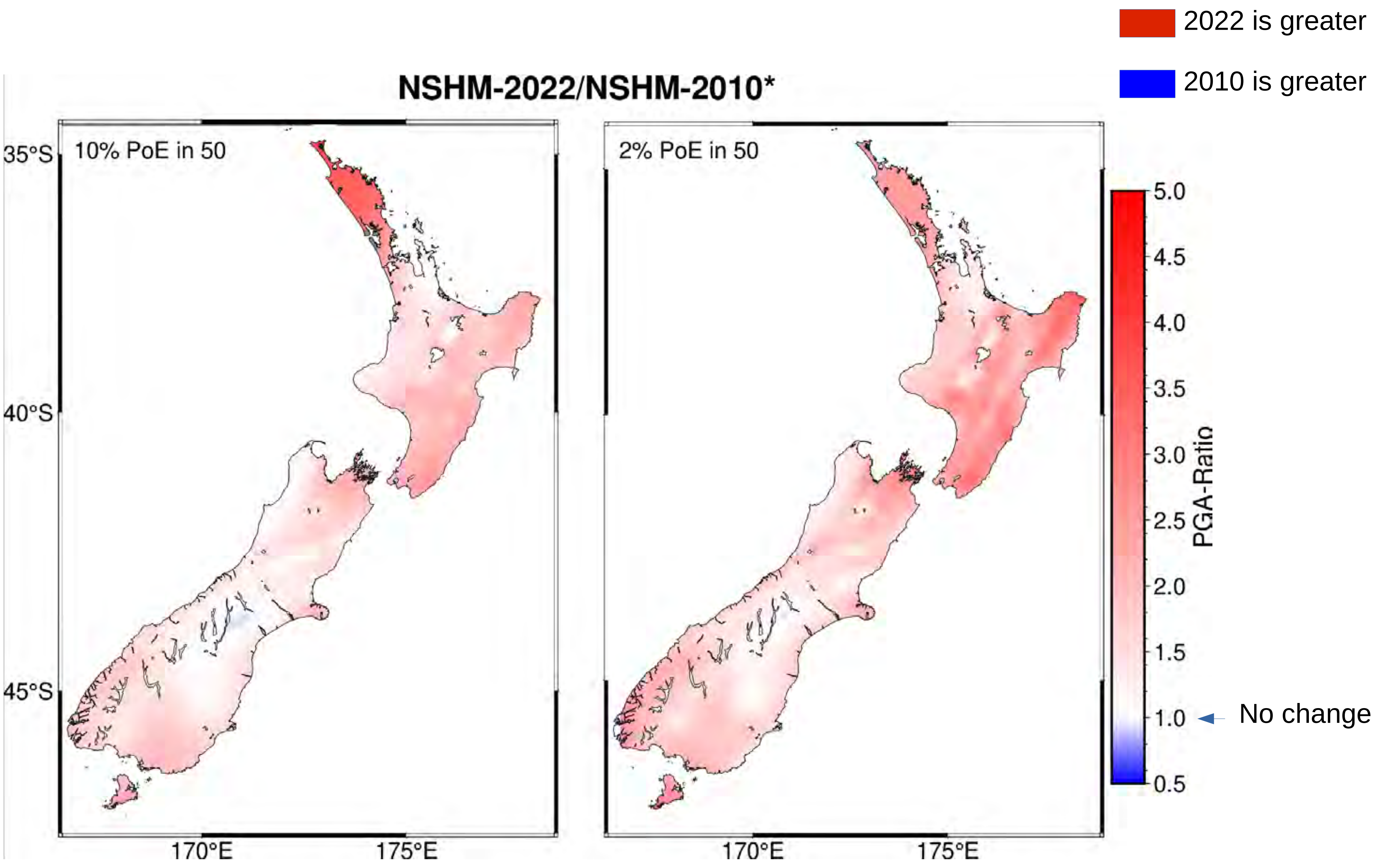
https://nshm.gns.cri.nz

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.

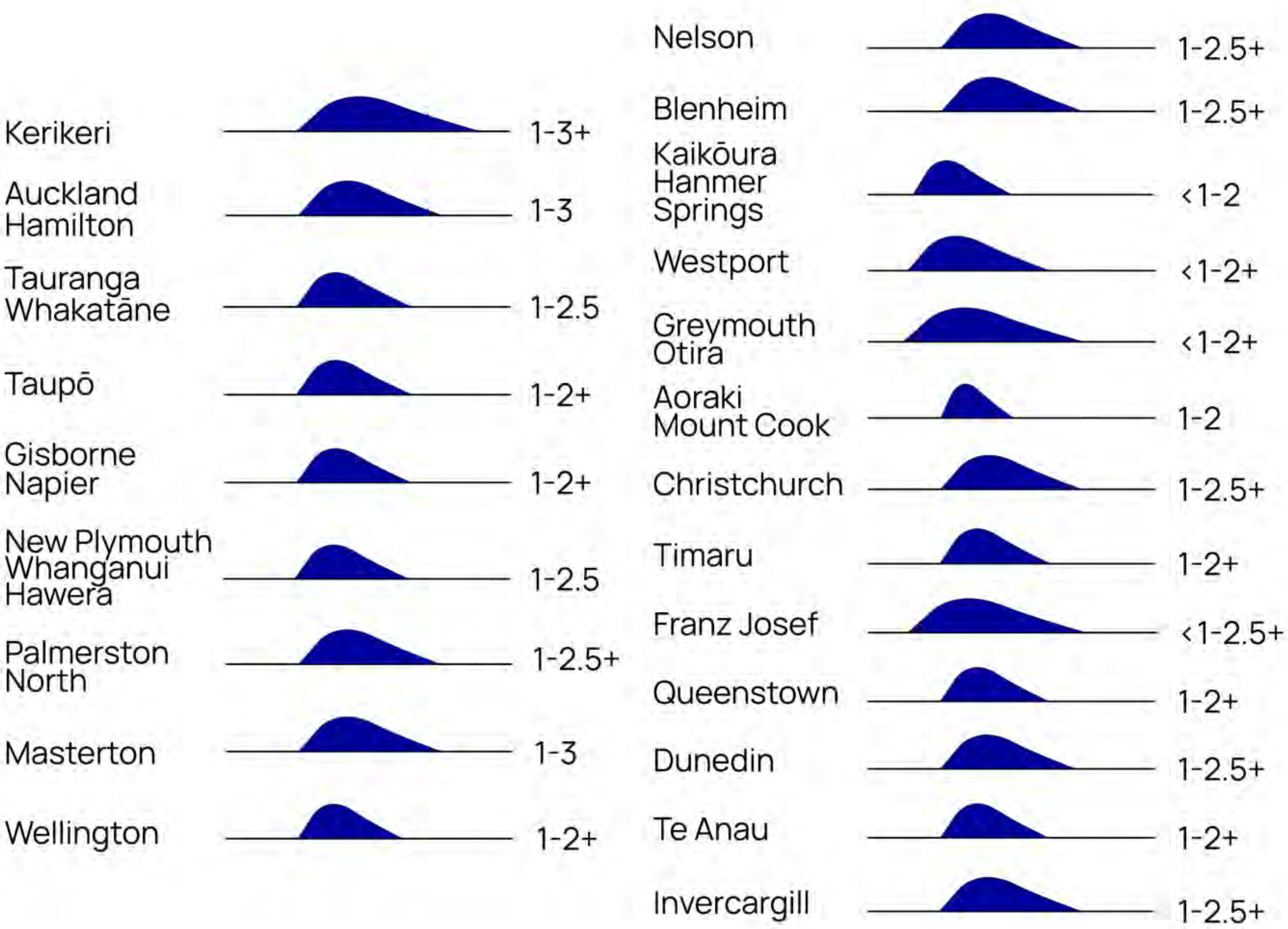
The map on the **right** shows change at 2% probability of exceedance.



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

Schematic of hazard change when compared to previous estimates

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



1 = no change

Uncertainty and Risk Tolerance

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

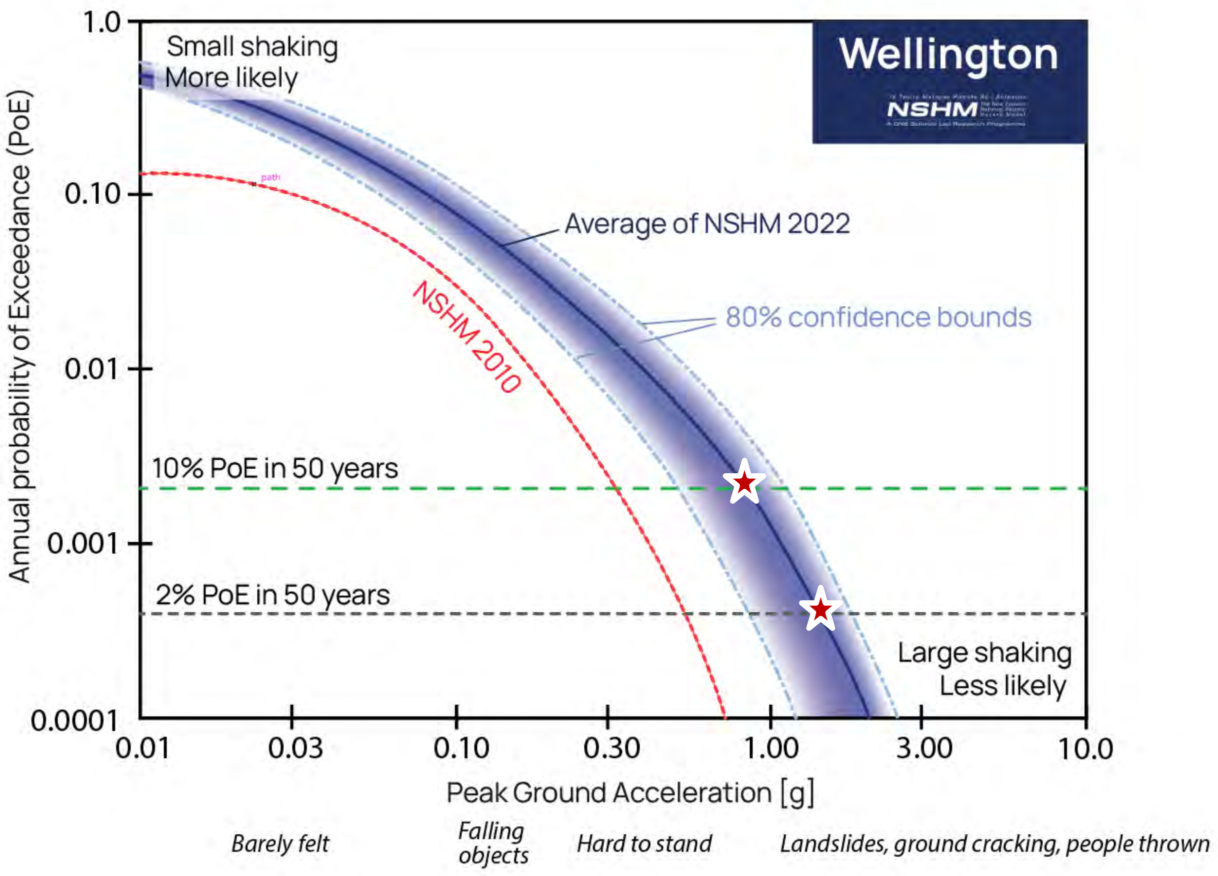
The maps show the average shaking for all locations but only for a single probability of exceedance – 2% or 10% (see ★)

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

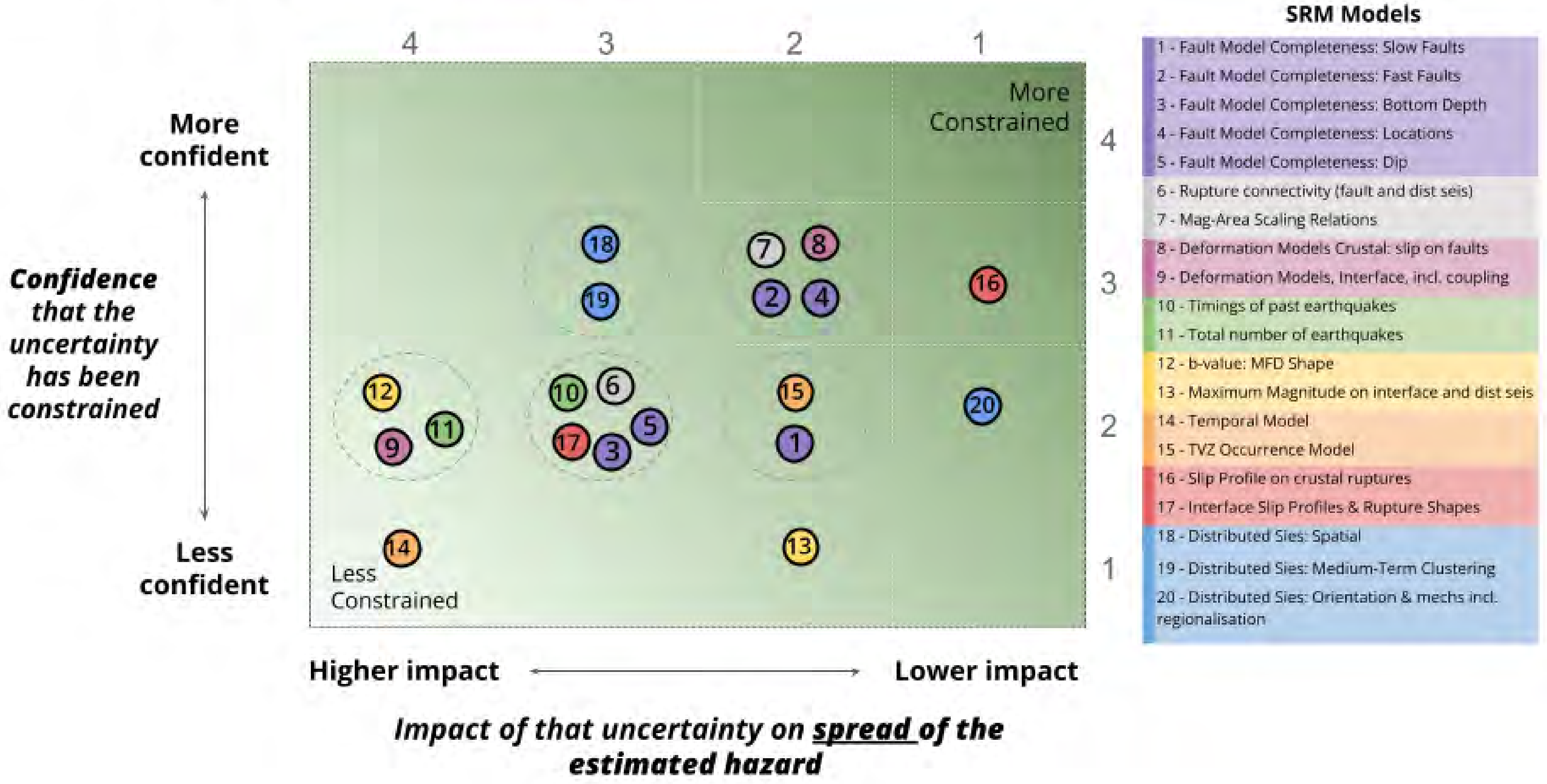
- Shaking shown in the upper left is smaller, but more frequent
- Shaking shown in the lower right is larger but much less frequent

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)



Confidence versus impact on spread of hazard

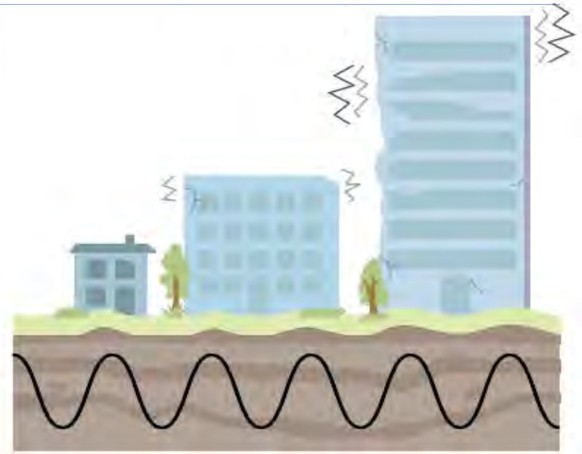


The NSHM produces forecasts of shaking

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.

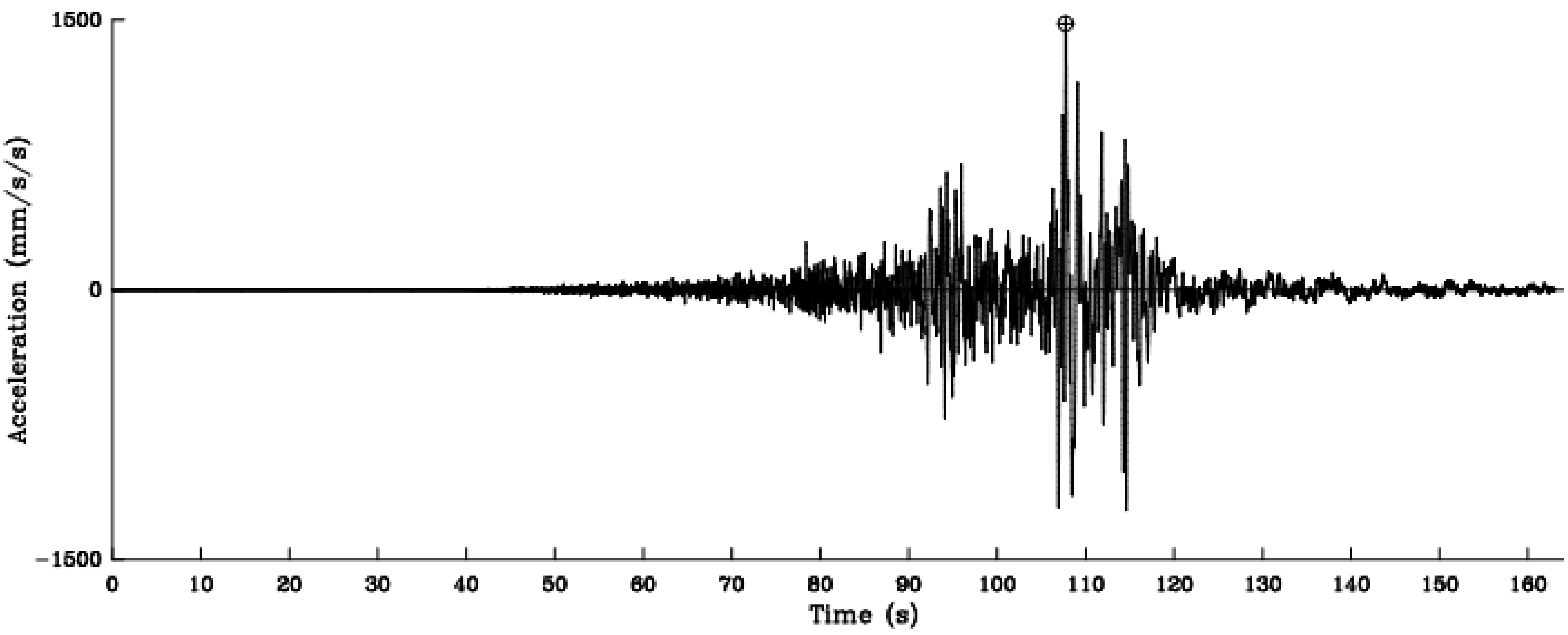


The NSHM provides important input for making risk based decisions.

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

2016 M7.8 Kaikoura Earthquake in Wellington: every earthquake has many shaking frequencies



Kaikoura earthquake ground shaking recorded in Wellington