06 Dec ‘21

NSHM: Wellington Basin ground motions & Site/Basin Directions

Anna Kaiser, Elena Manea, Robin Lee, Chris De La Torre, Matt Hill, Liam Wotherspoon, Andrew Stolte, Brendon Bradley, Sanjay Bora, Anne Hulsey, Matt Gerstenberger, and the NSHM Team

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

Ngā hoa tuku pūtea
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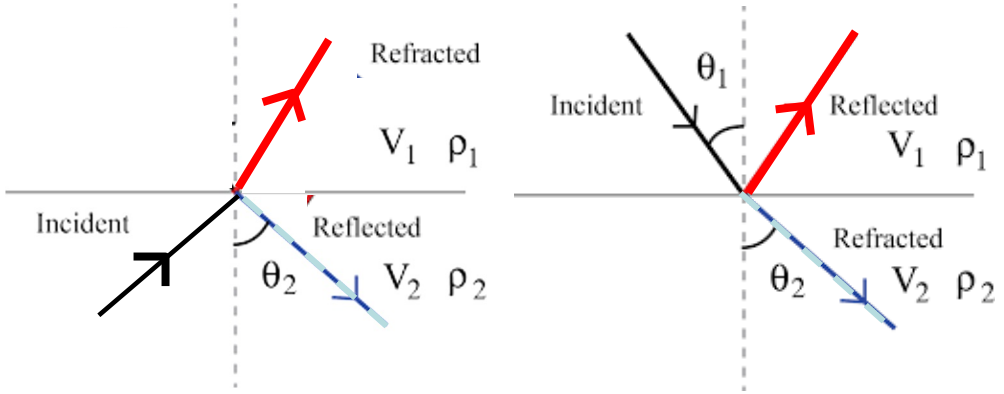
MINISTRY OF BUSINESS, INNOVATION & EMPLOYMENT
HĪKINA WHAKATUTUKI
EQC EARTHQUAKE COMMISSION

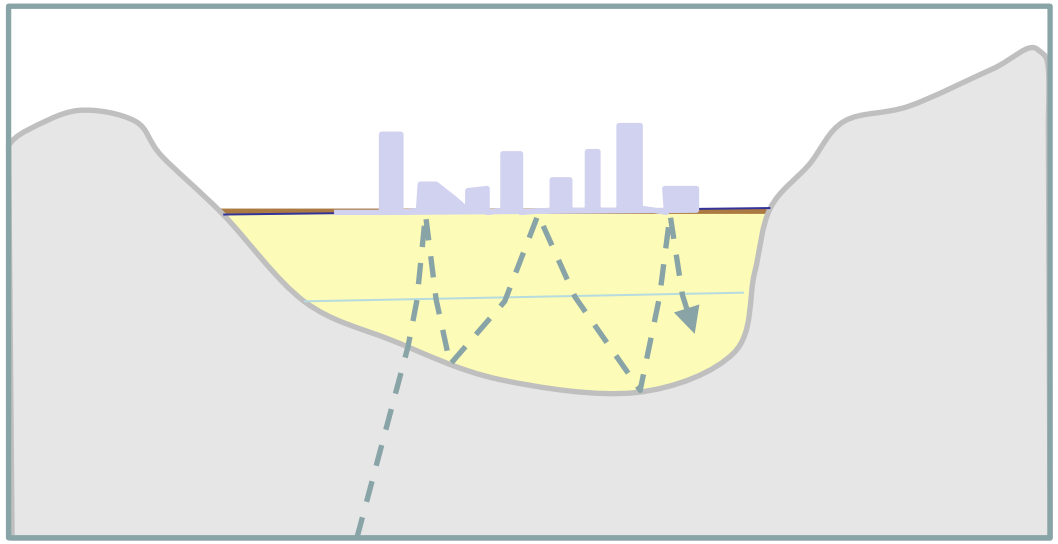
What are basin amplification effects?

Sedimentary basins amplify earthquake ground motion by reflecting, refracting and focusing seismic waves.

- **Amplification depends on:**
  - properties of the soil
  - 3D geometry of the basin and its geological features
  - particular earthquake scenario

- **Amplification in each basin has unique characteristics, in terms of:**
  - period, spectral amplitude and their spatial variation





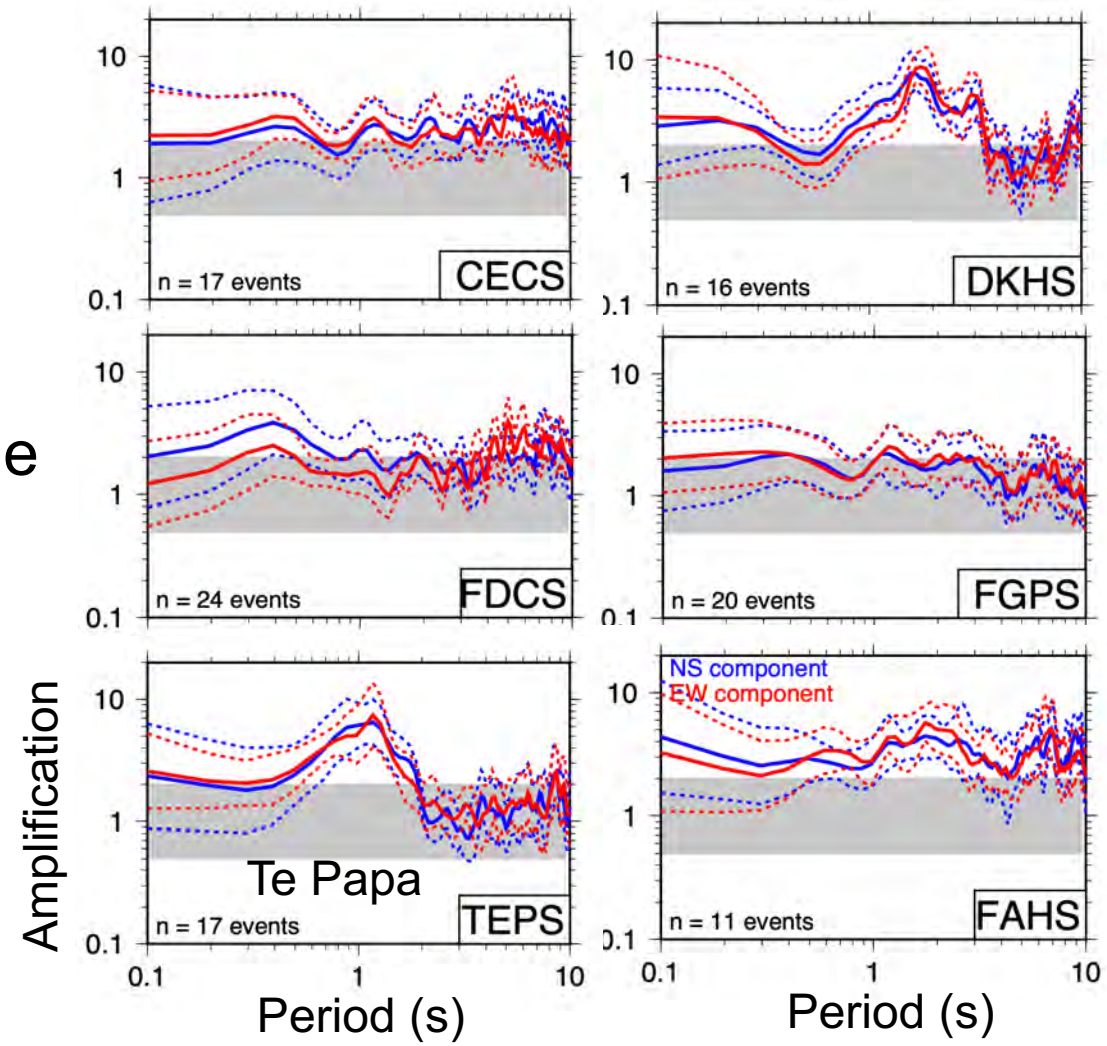
How have we previously treated basin effects in seismic hazard?

- **2002, 2012 NSHM**
  - NZS1170.5 Site Classes A – E

    (McVerry et al. 2006 Ground Motion Model)

  - ➢ Treats all sites in a given site class the same way, though there is a large range of site/basin amplification at different sites

Examples of Class D amplification effects



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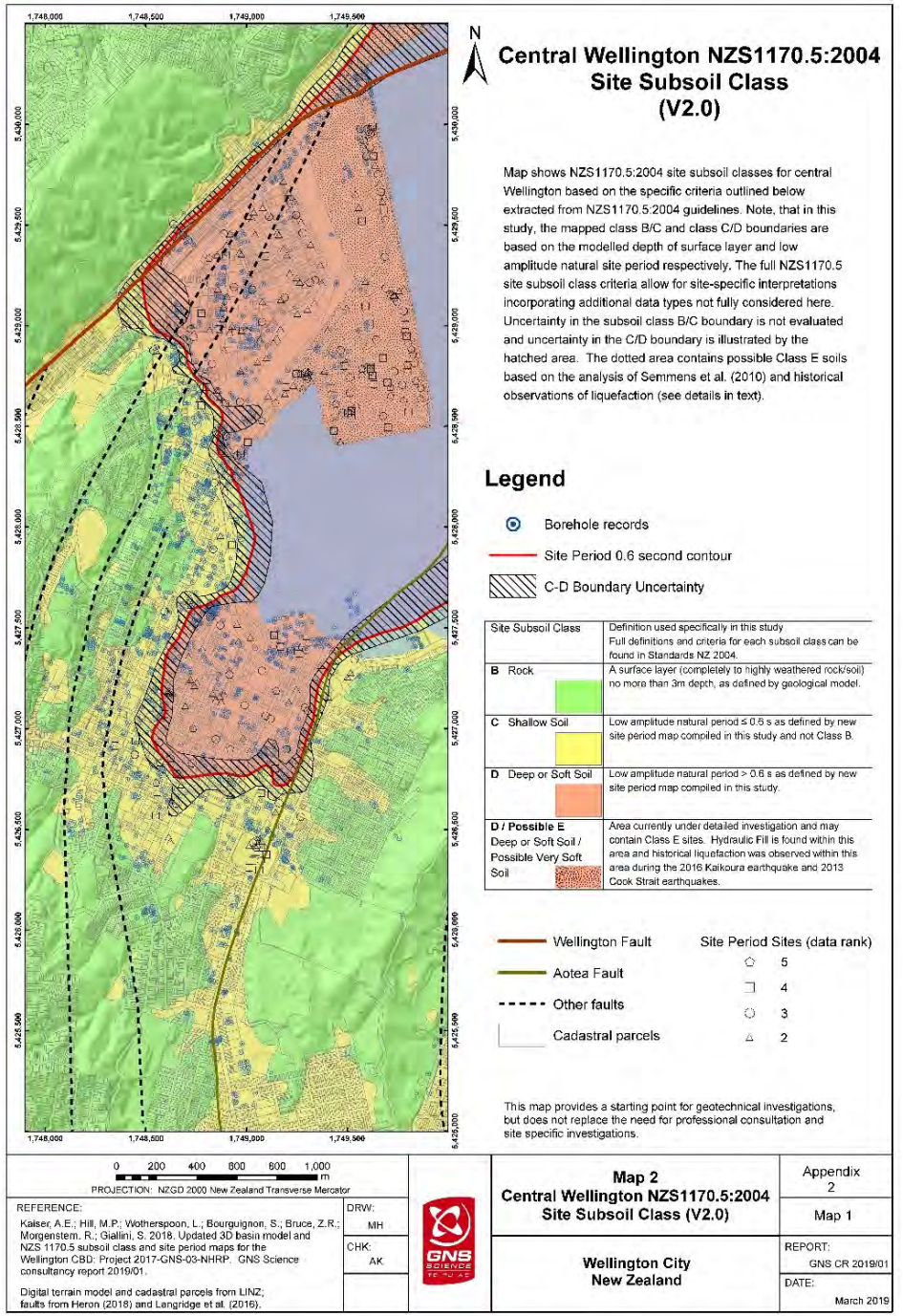
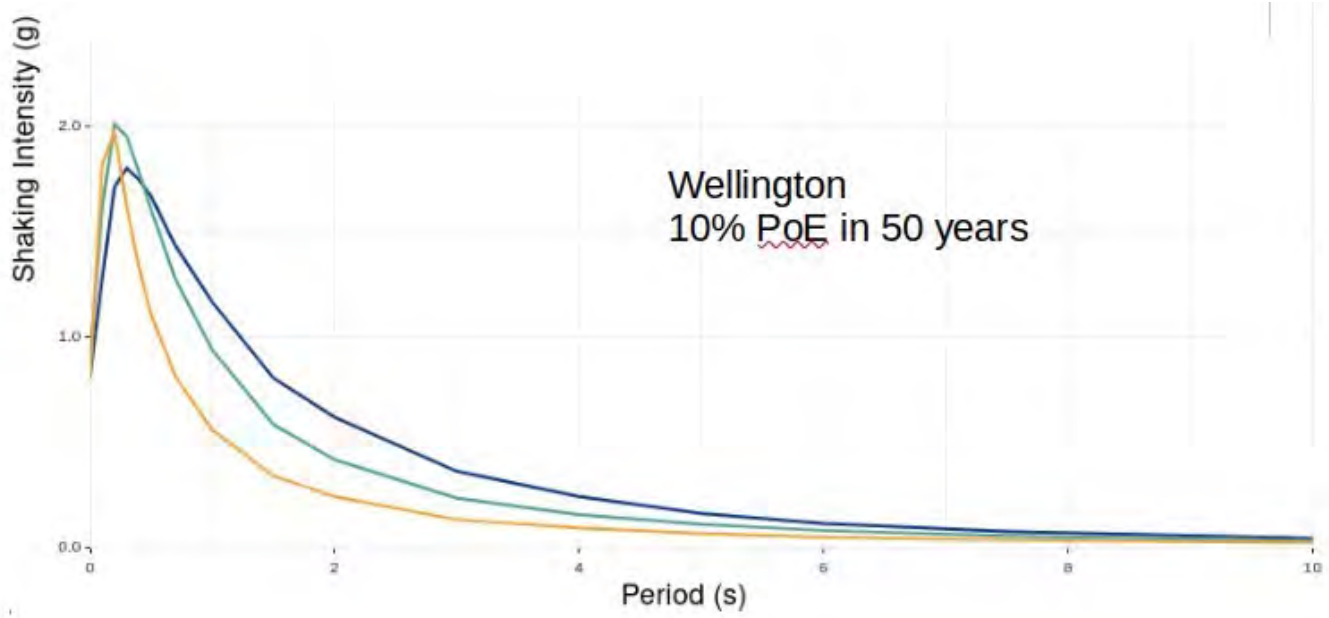
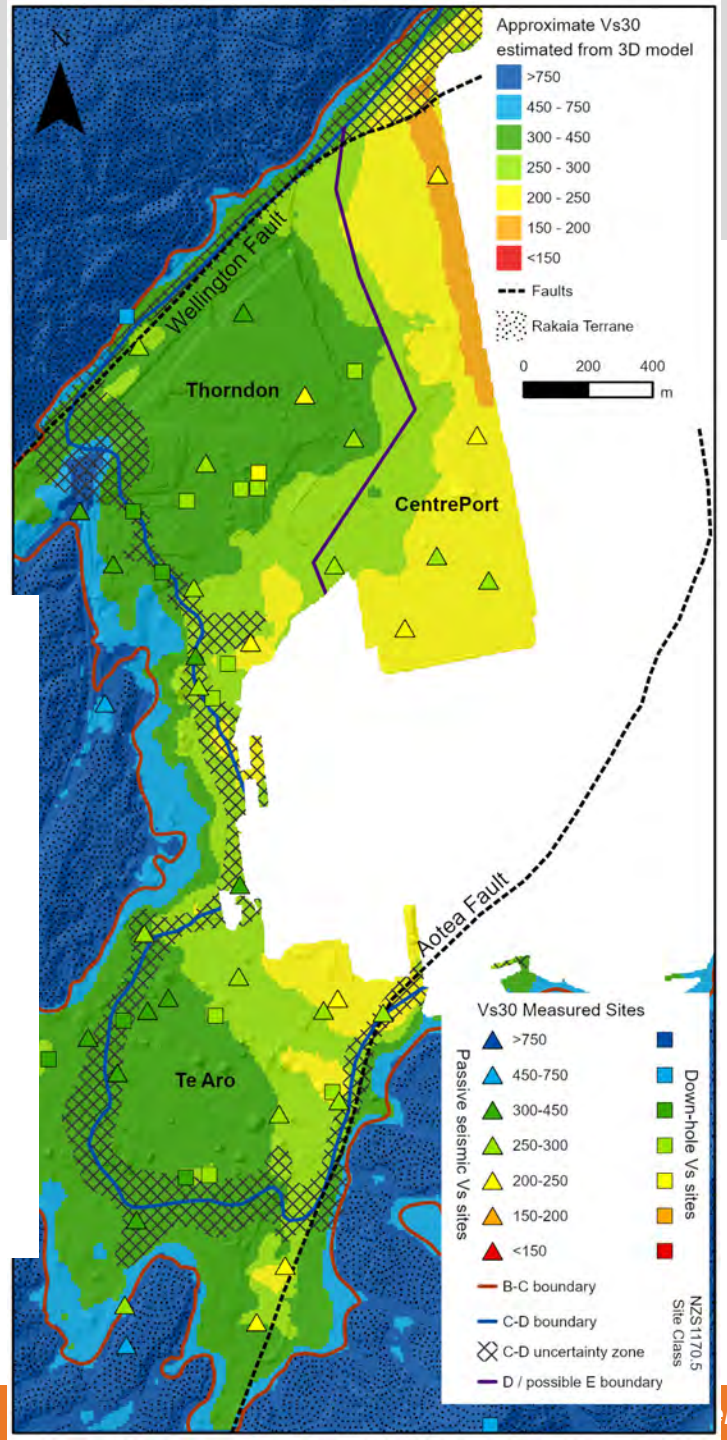
➢ In Wellington, a sharp ‘jump’ in design across the C to D boundary running through the CBD.



Changes in 2022 NSHM

- **Vs30 is the new site parameter**
- **Vs30 varies continuously**





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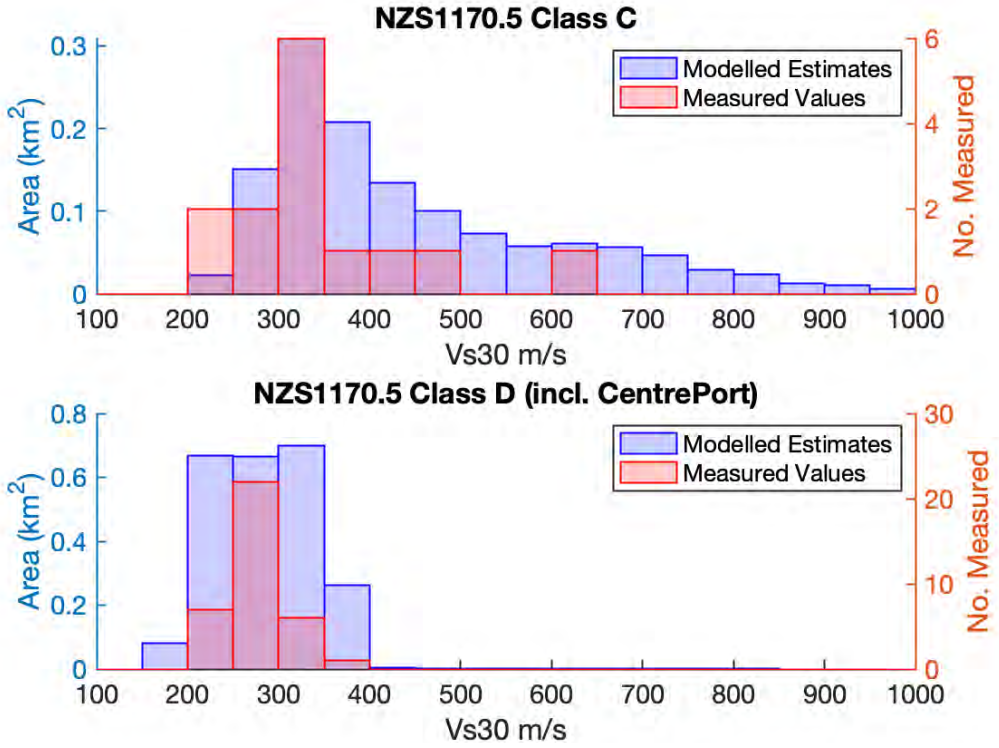
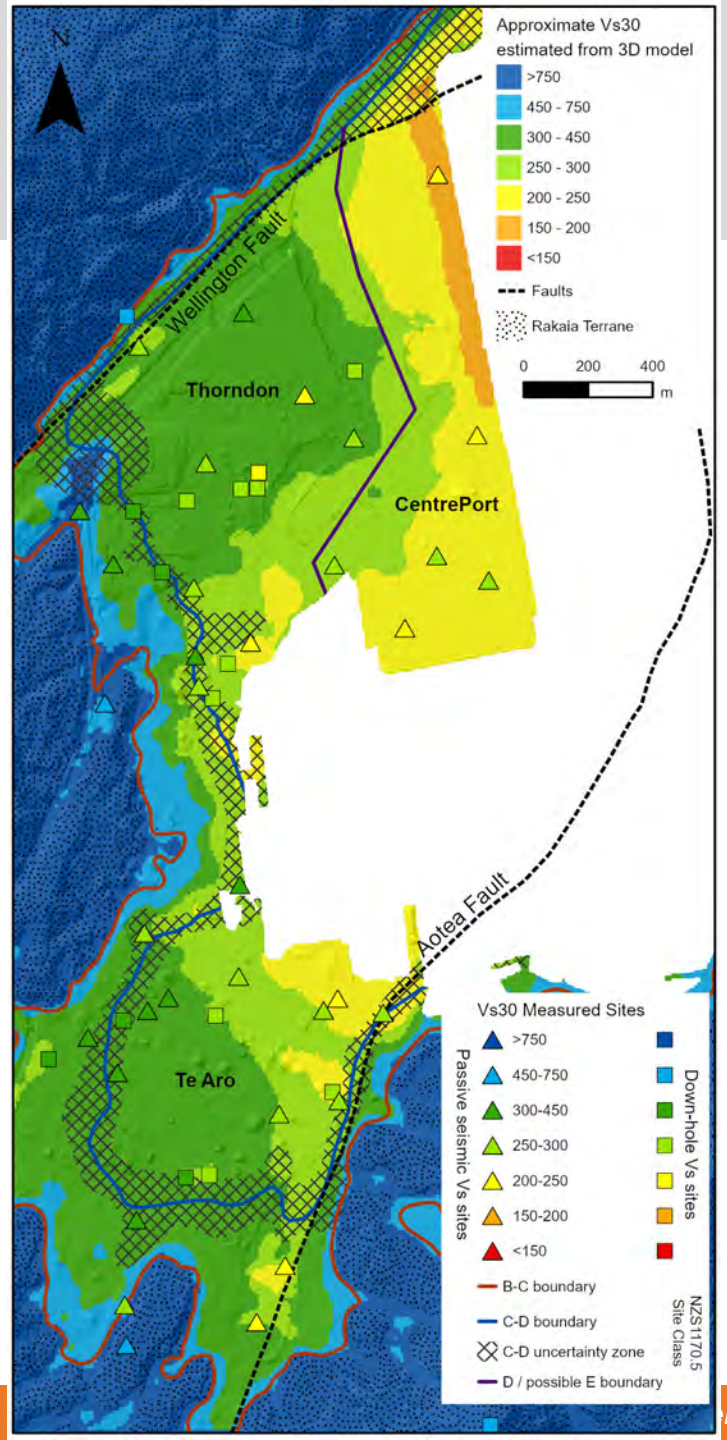
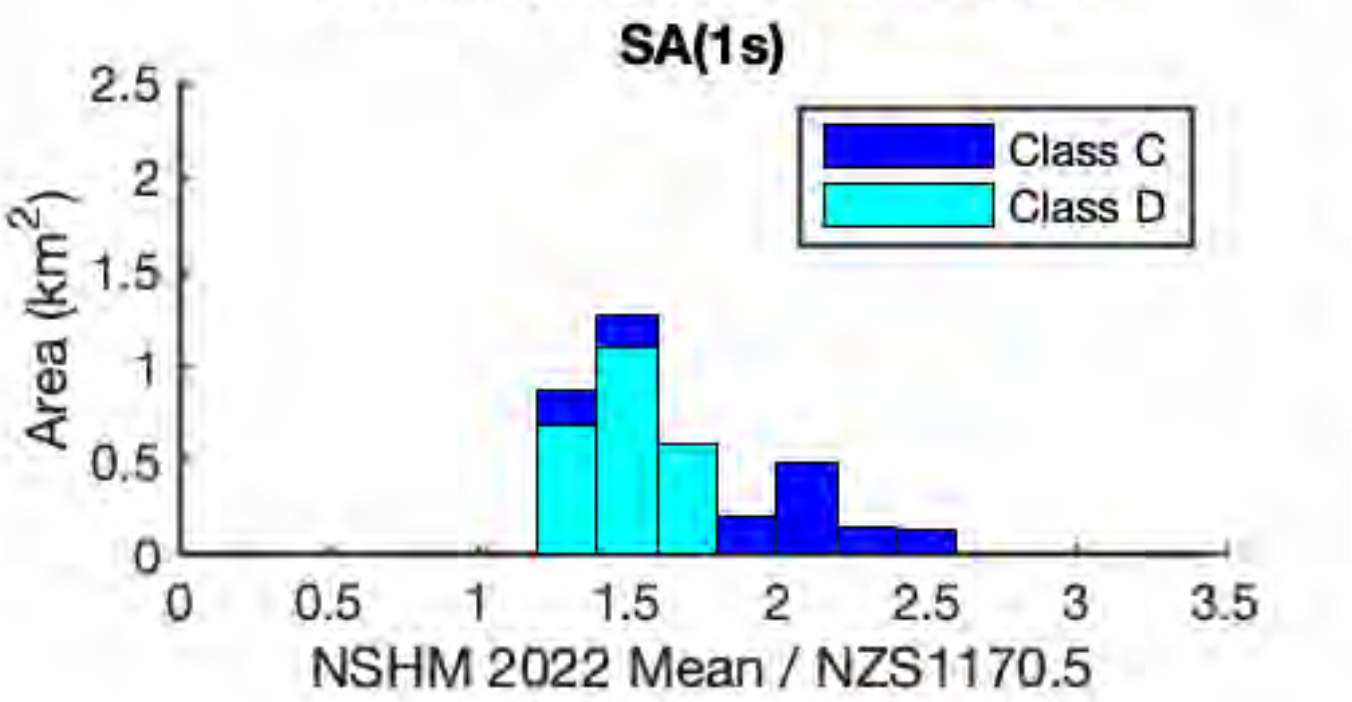
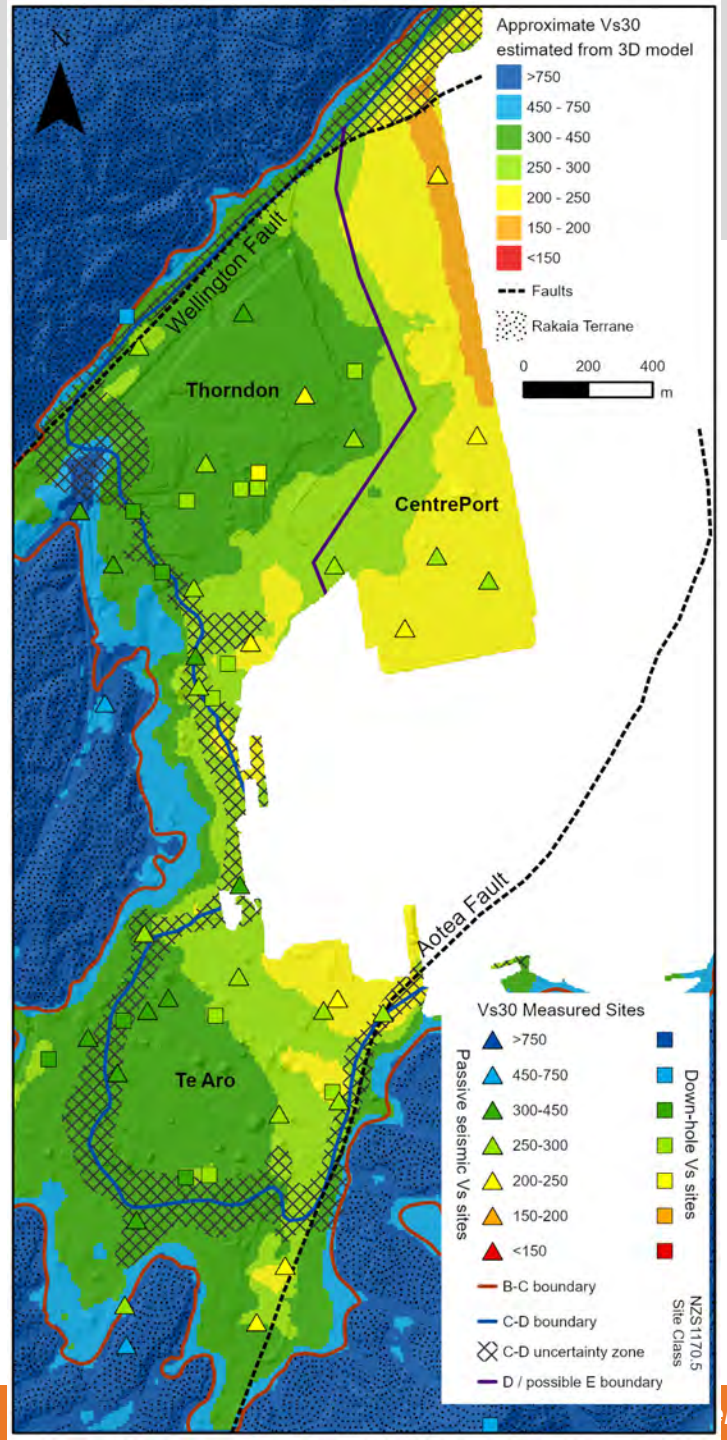




Hazard Changes in 2022 NSHM (including Site Class to Vs30 change)

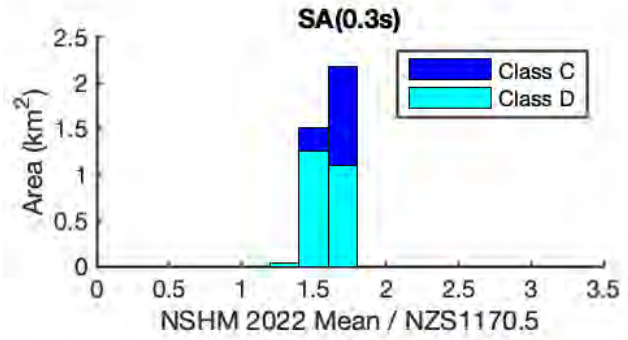


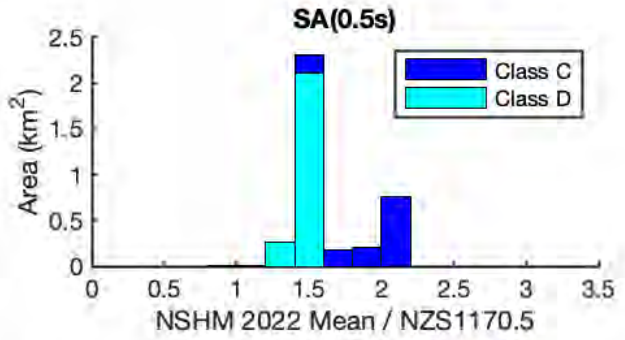


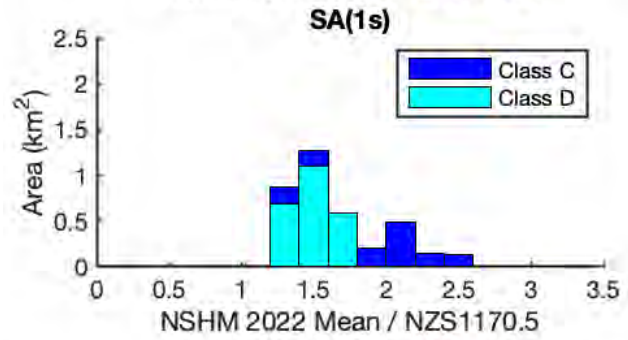
Hazard Changes in 2022 NSHM (including Site Class to Vs30 change)

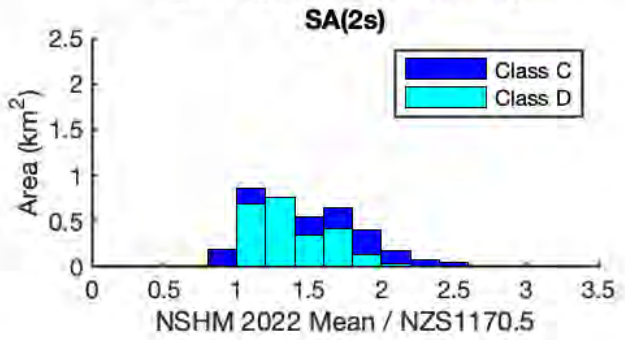
Affects shorter buildings

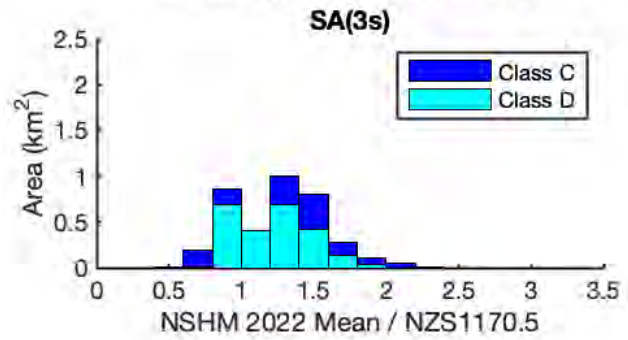
Affects very tall buildings

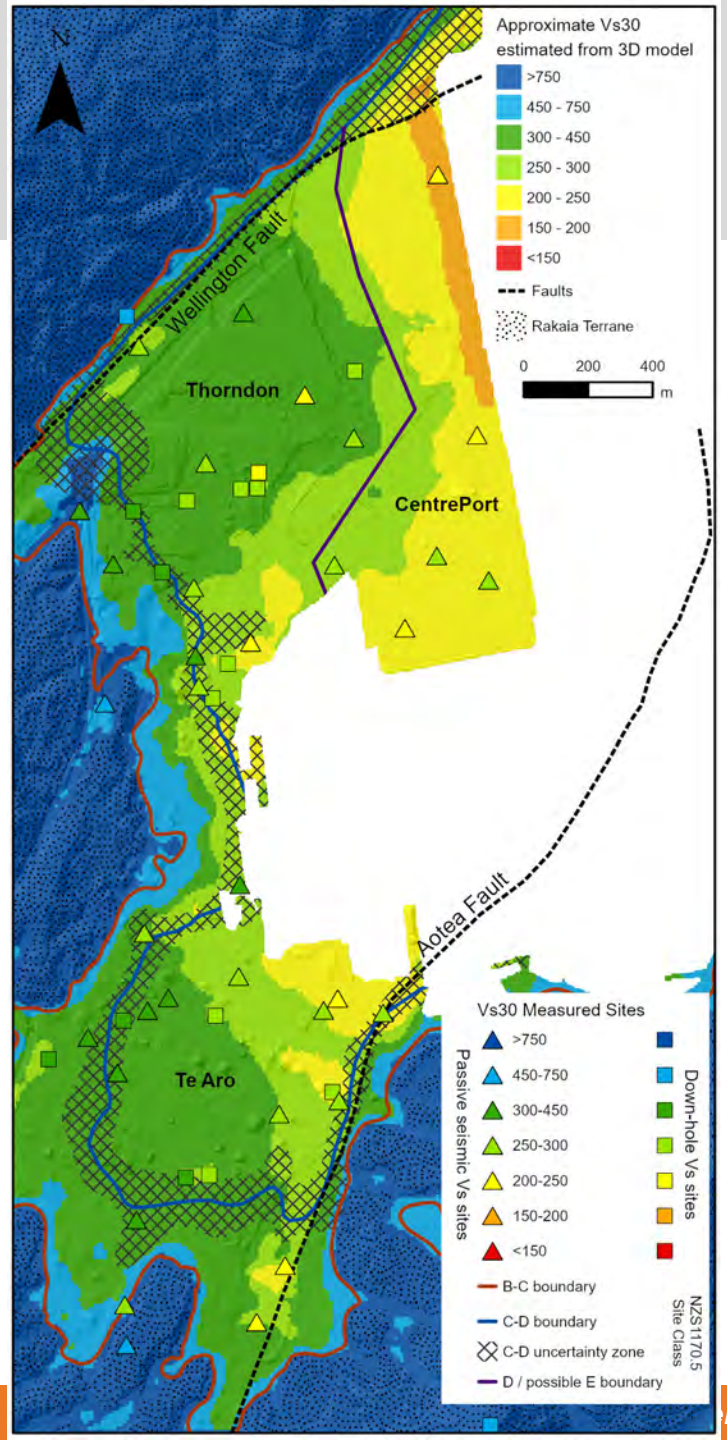












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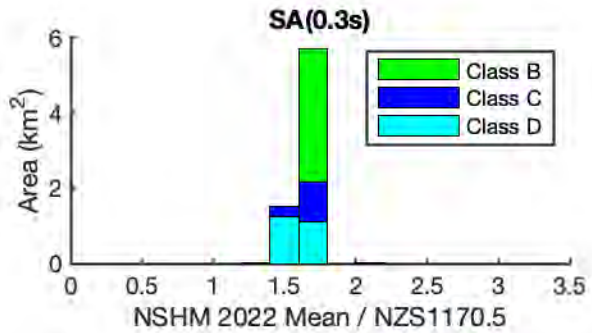
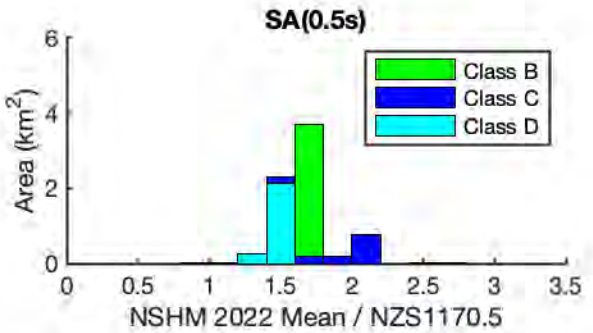
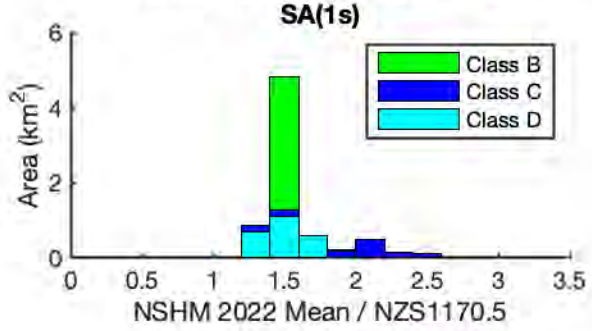
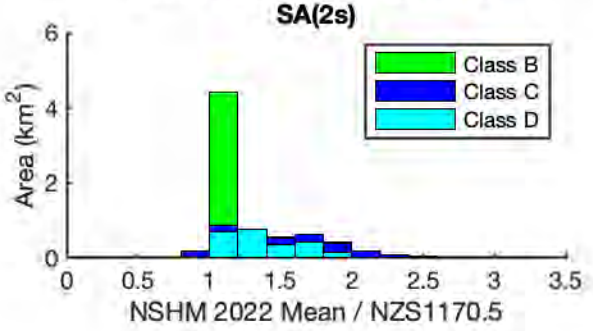
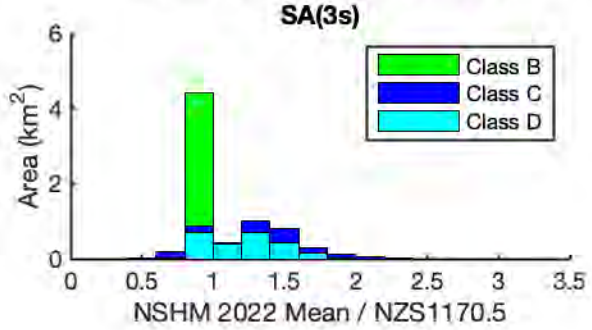




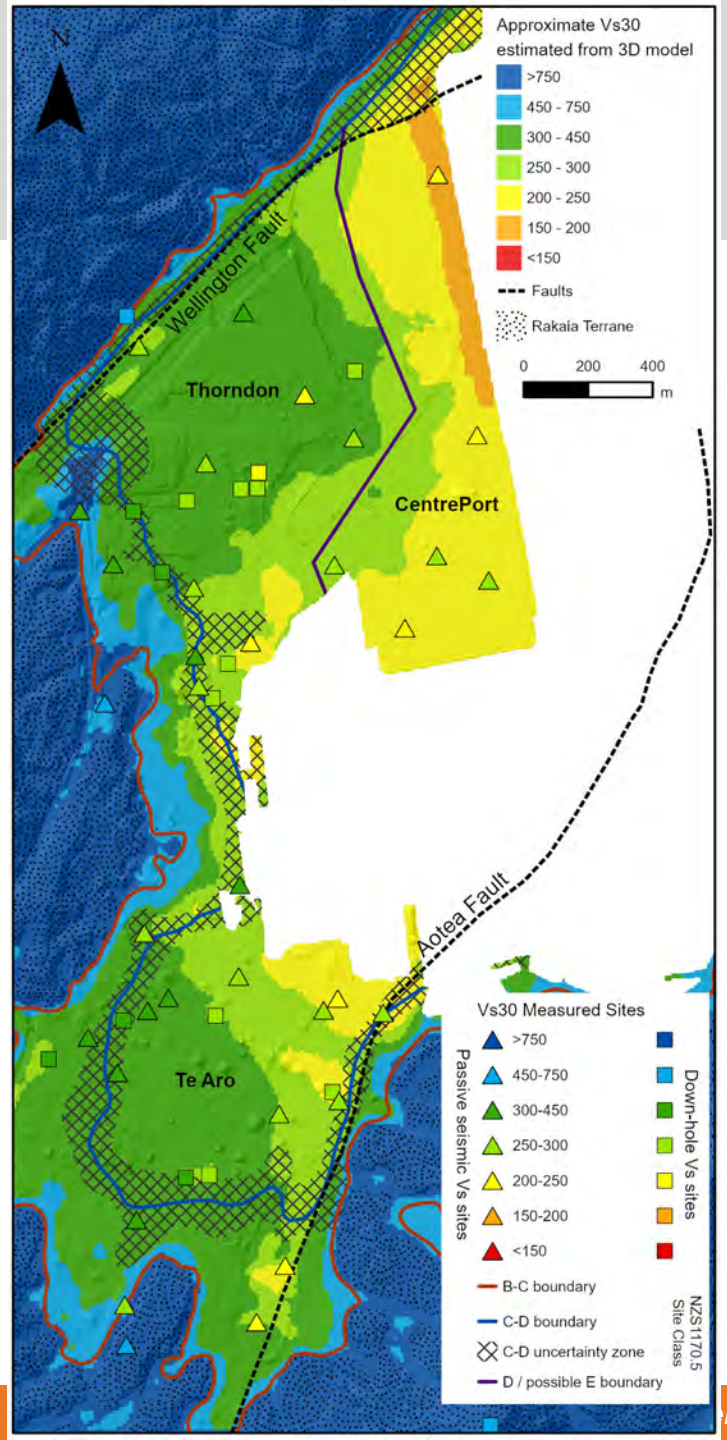






Including rock sites Class B – with an assumption of 750m/s

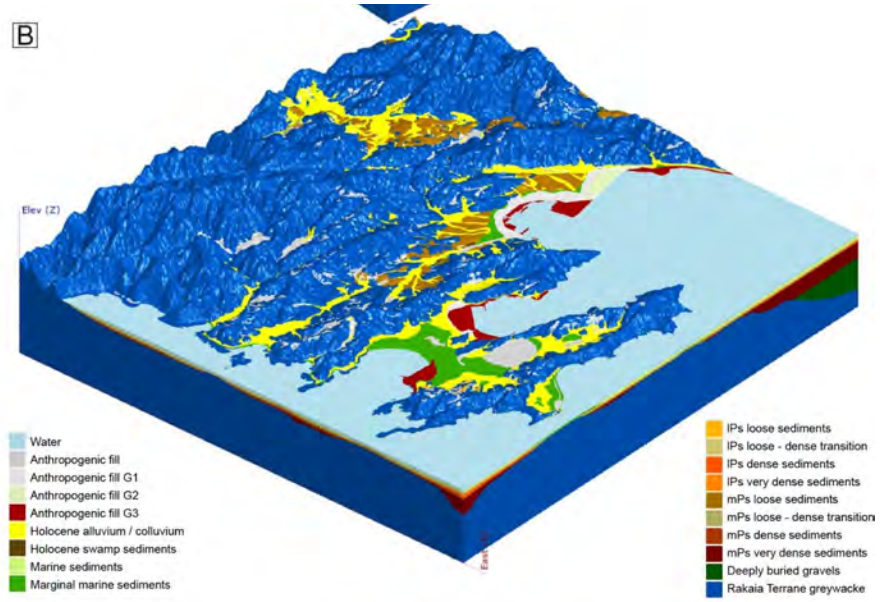
- Vs30 will be variable at Class B sites, which means the true range of changes will be larger

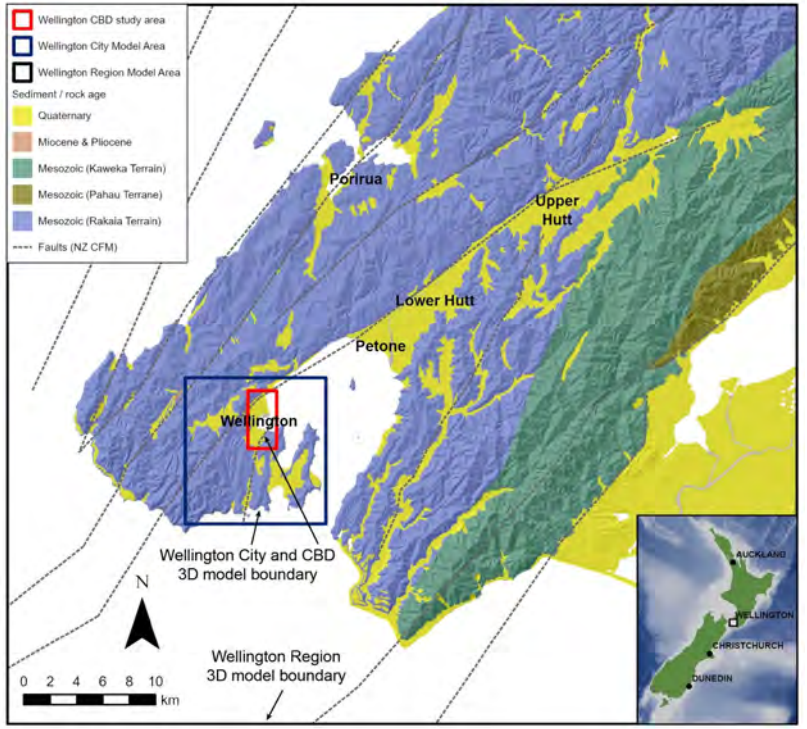


Wider Wellington region

- **Types of hazard changes likely to be similar**
- **3D Model of the Wellington region**

  (currently no regional Vs30 map)





Site/basin effects in New Zealand NSHM

2002, 2012 NSHM

Site model of McVerry et al. (2006)
NZS1170.5 subsoil class

Single model based on global statistical averages

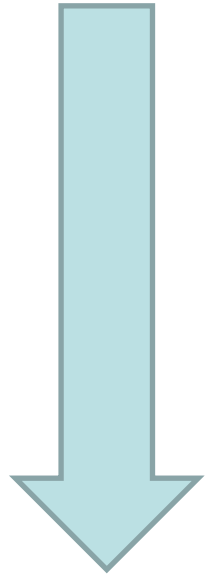
2022 NSHM

Suite of global GMMs
Broad-scale GMM adaptations for NZ
(Regionalised backbone)
Consideration of epistemic uncertainty
Vs30

Wellington Basin case study

Future updates

Finer GM regionalization?
Influence of ground motion simulations?
Additional site parameters?
Basin-specific models?



Increasing ability to capture local ground motion characteristics

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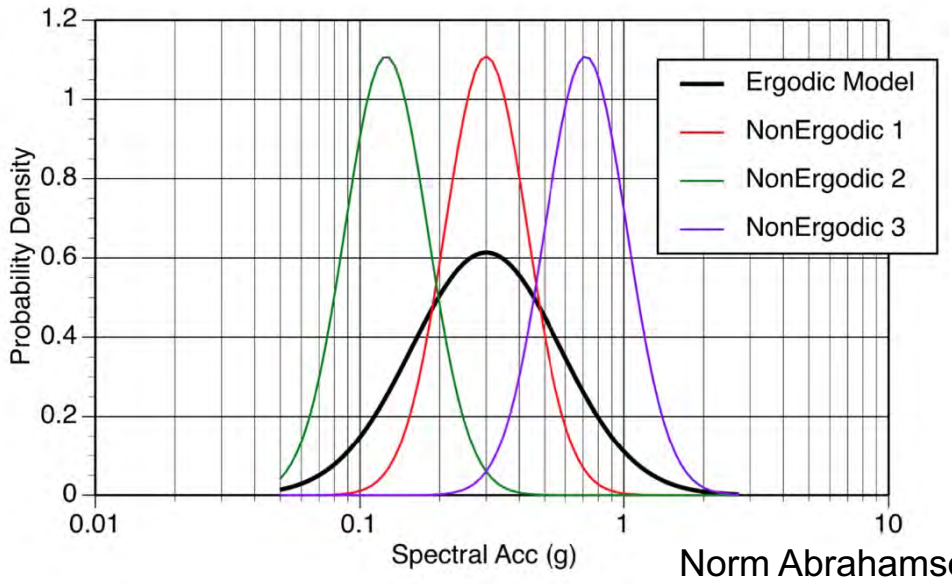
Global models based on statistical averages (ergodic models)



Norm Abrahamson

Increasing complexity and ability to model regional and local ground motions (non-ergodic models)

Next aims of NSHM programme – Wgtn Basin

We know there will (still) be local amplification that will deviate from the mean Vs30-based national model estimate.

Our goal:

To better quantify amplification in central Wellington, its spatial variability and its uncertainty

Key questions:

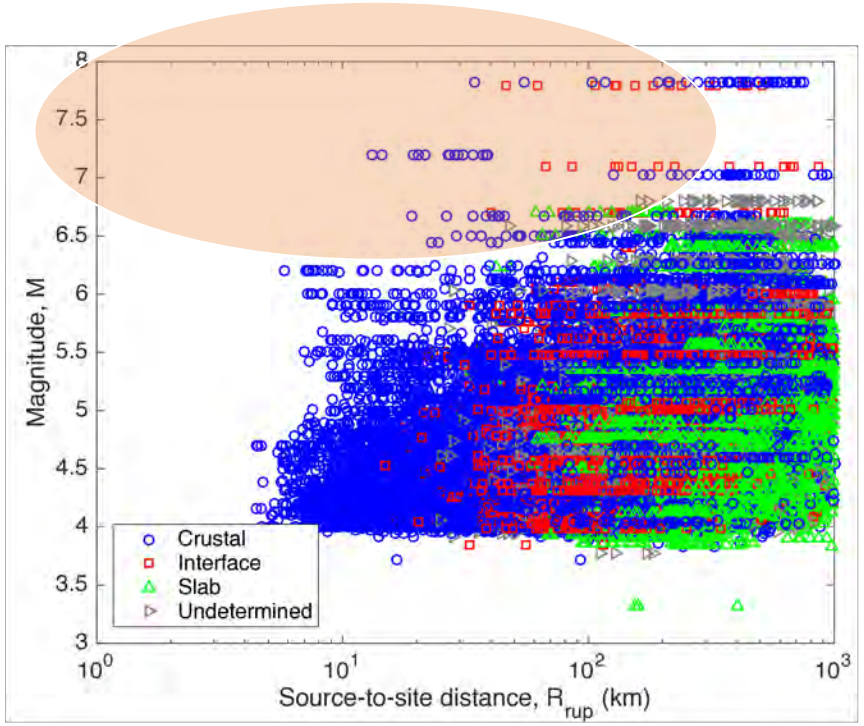
- How does local Wellington Basin amplification differ from the mean 2022 NSHM ground motion predictions?
- Can we refine our mean ground motion predictions or reduce the uncertainty?
- What directions can we take to ultimately improve treatment of site/basin effects in urban seismic hazard?

The challenges of capturing basin-specific effects

- **What happens across the basin and across spectral periods?**
- **What happens in large future earthquakes, not just the small to moderate shaking we have observed in the past?**

This is a challenging problem being advanced in the seismological community

- ➢ Need detailed site and basin-specific characterization
- ➢ Need advanced modelling methods and extensive study (e.g. physics-based simulations)

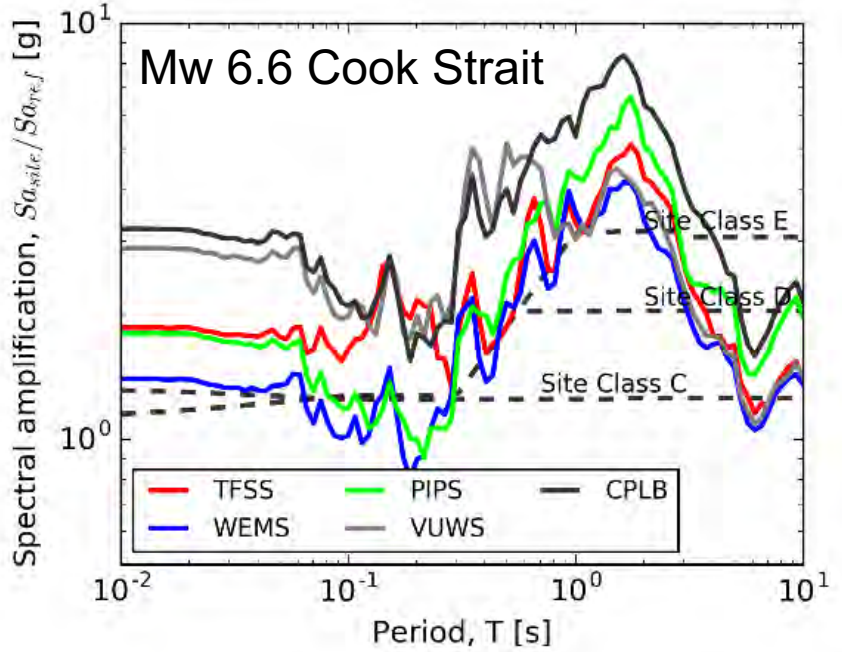


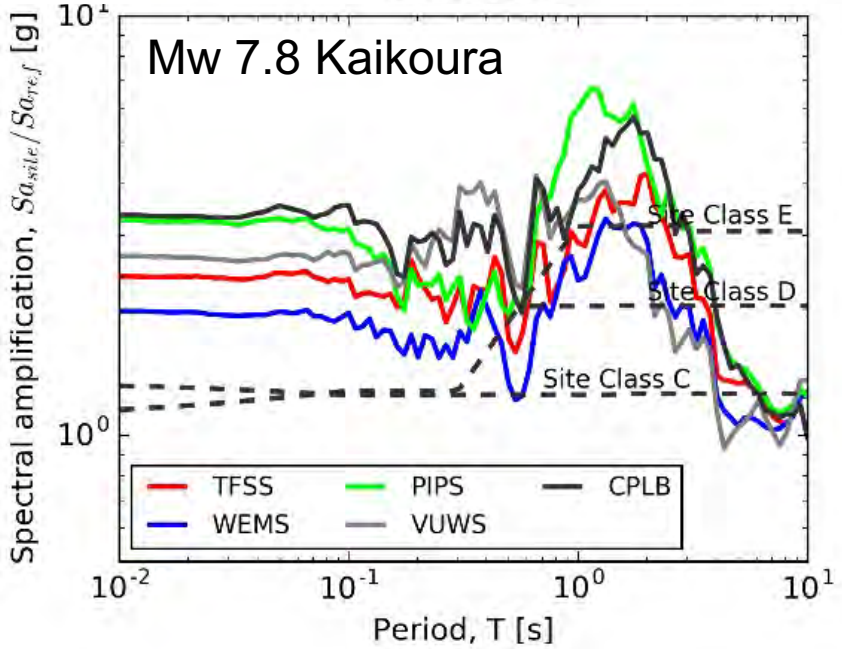
NSHM, Hutchinson et al. 2022

Amplification in the Wellington Basin …

- Past observations show amplification is relatively consistent and repeatable at 1 – 2 s periods within the CBD area at low to moderate accelerations (< 0.2g)

- At these periods amplification trends above the mean predicted by global ground motion models

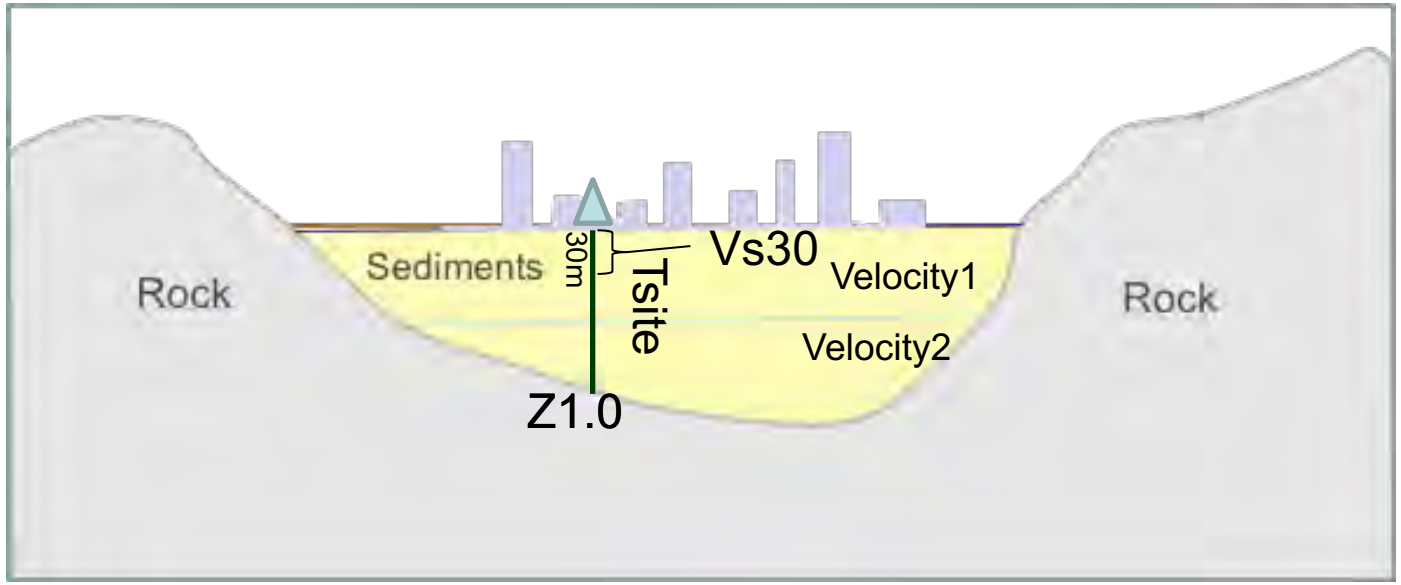




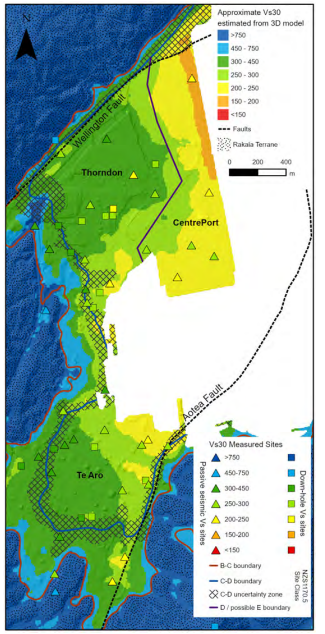
Bradley et al. 2018 BSSA

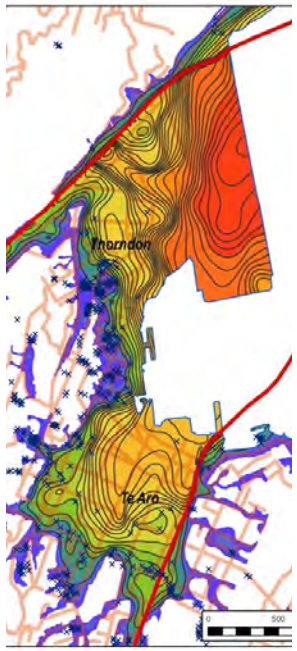
Other site parameters

- **Vs30** (time-averaged shear-wave velocity in the top 30m)
- **Z1.0** (Depth to 1km/s. For Wellington ≈ depth to greywacke basement)
- **Site period (e.g. Tsite/T0)** Fundamental mode resonance



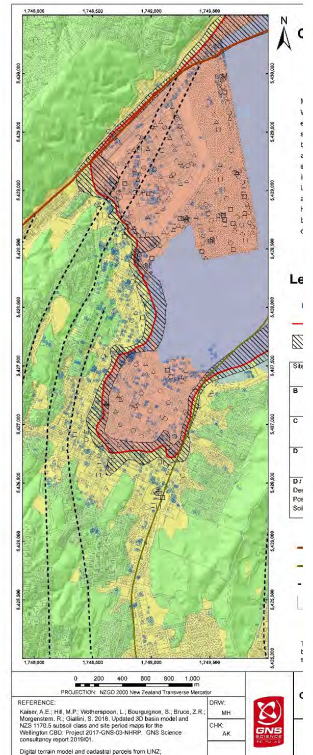
Basement depth & Vs30 (2022 NSHM)

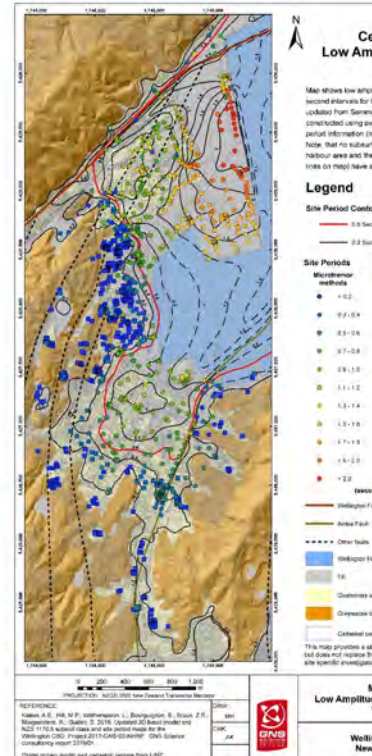




Site subsoil Class
Site period

(Updated in 2019)

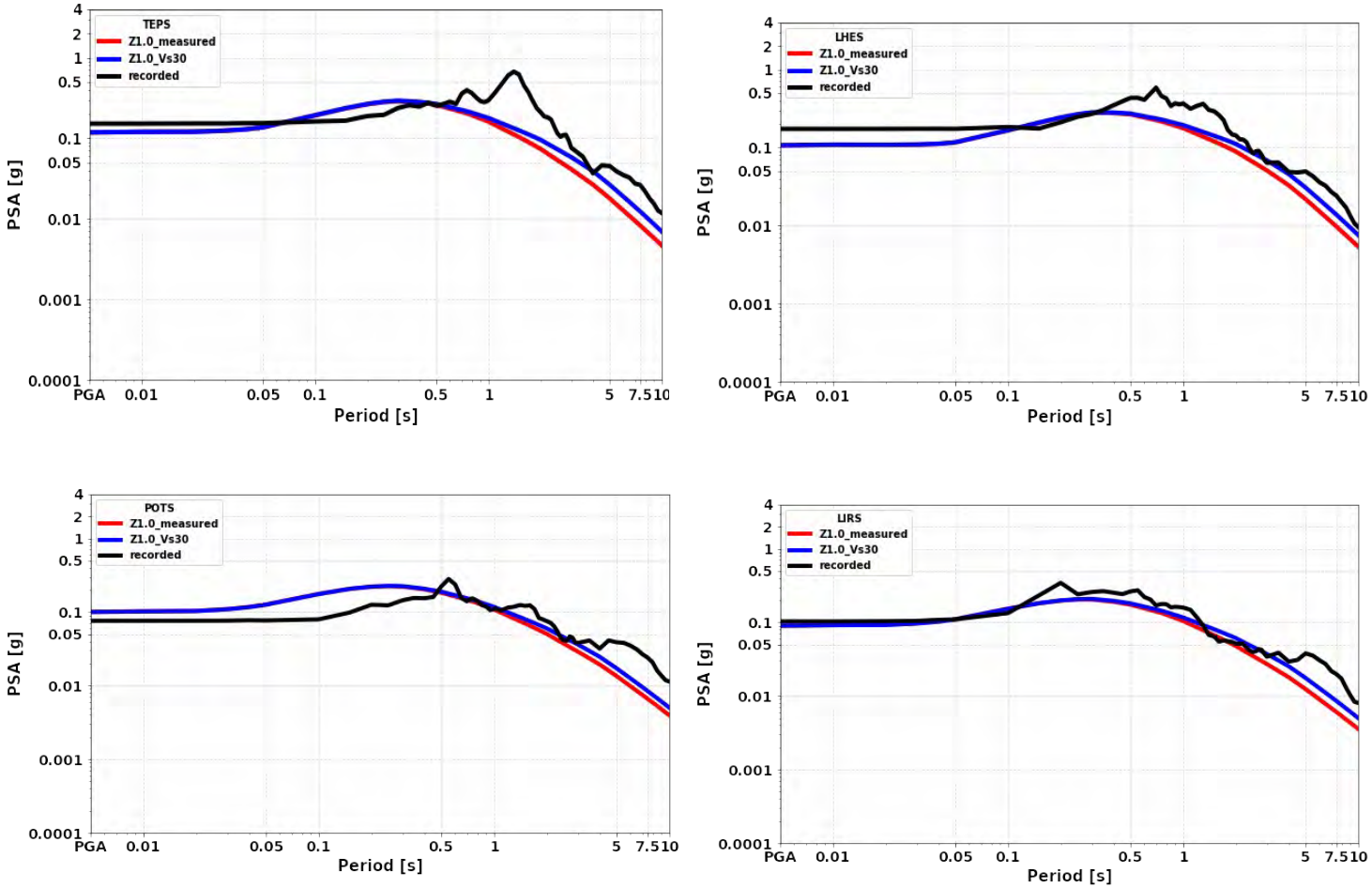




Other site parameters? Wellington Basin – Z1.0

- Many of the underpinning 2022 NSHM ground motion models allow the use of basin-specific Z1.0 (depth to 1km/s).
- In Wellington, this yields no significant improvement (or not yet)….
- Additional ‘basin depth’ parameters (e.g. Z1.0 or Tsite/T0) are potentially useful for the future, particularly when combined with models tuned to NZ site conditions

Example from the Kaikōura Earthquake – just one eartthquake!



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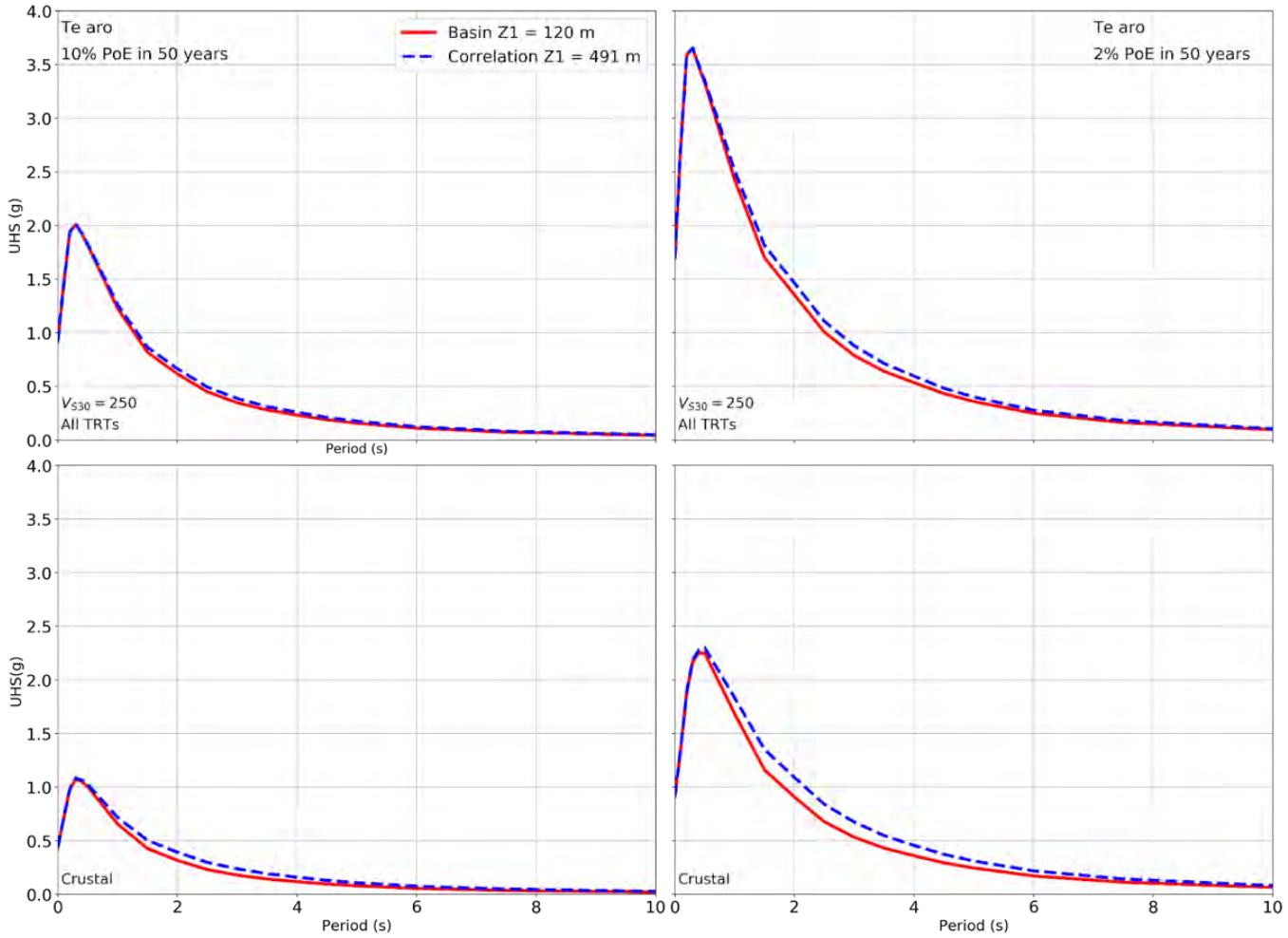
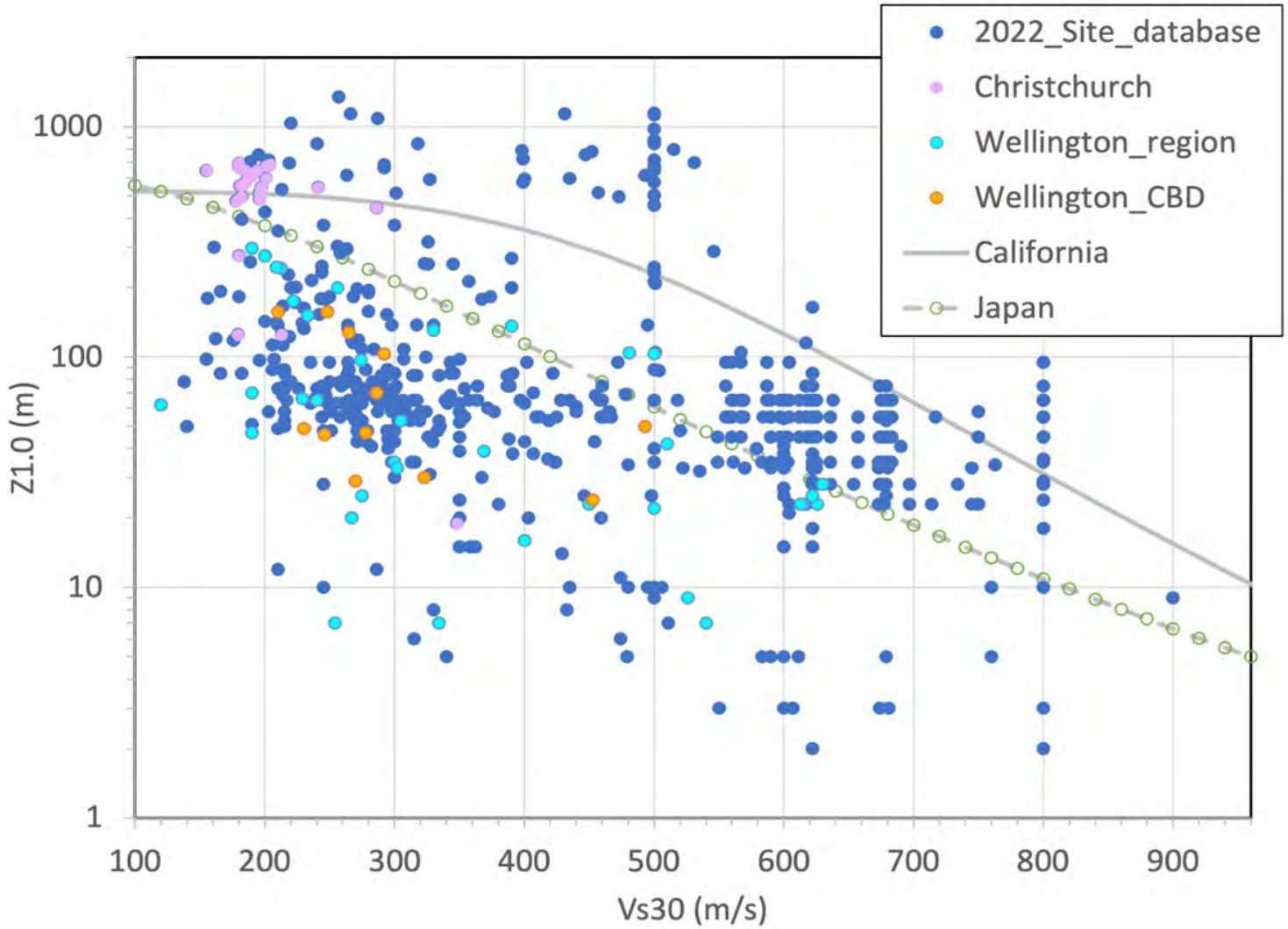
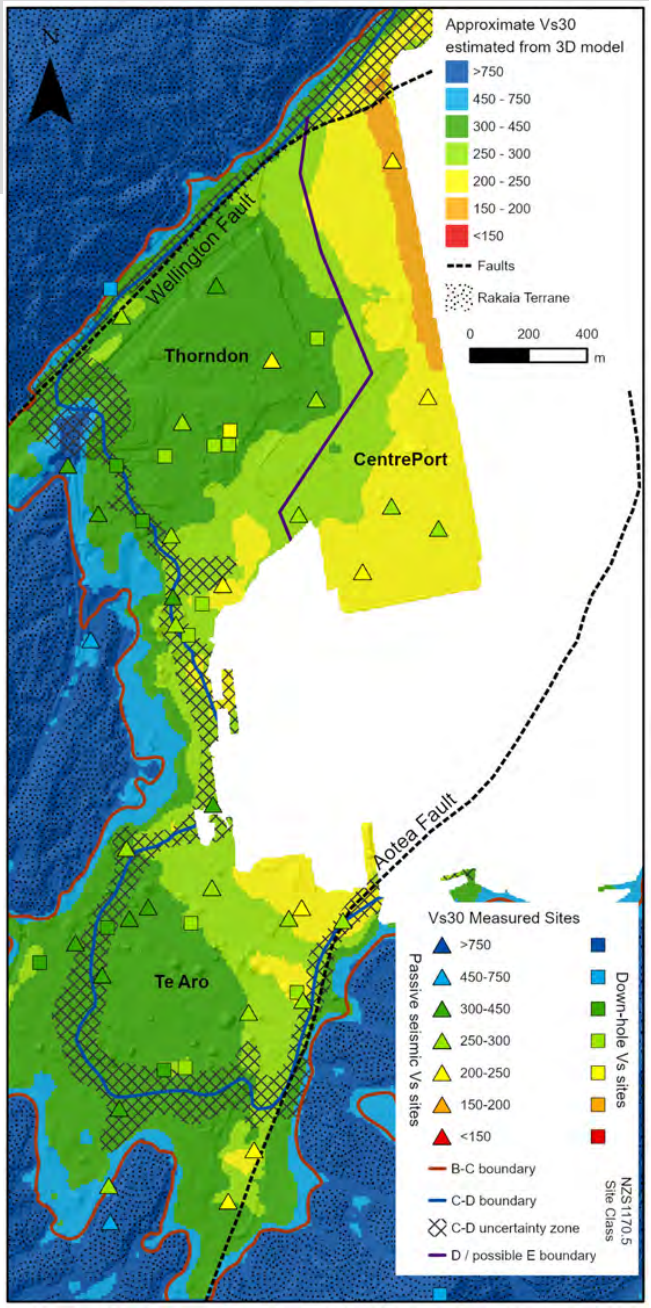


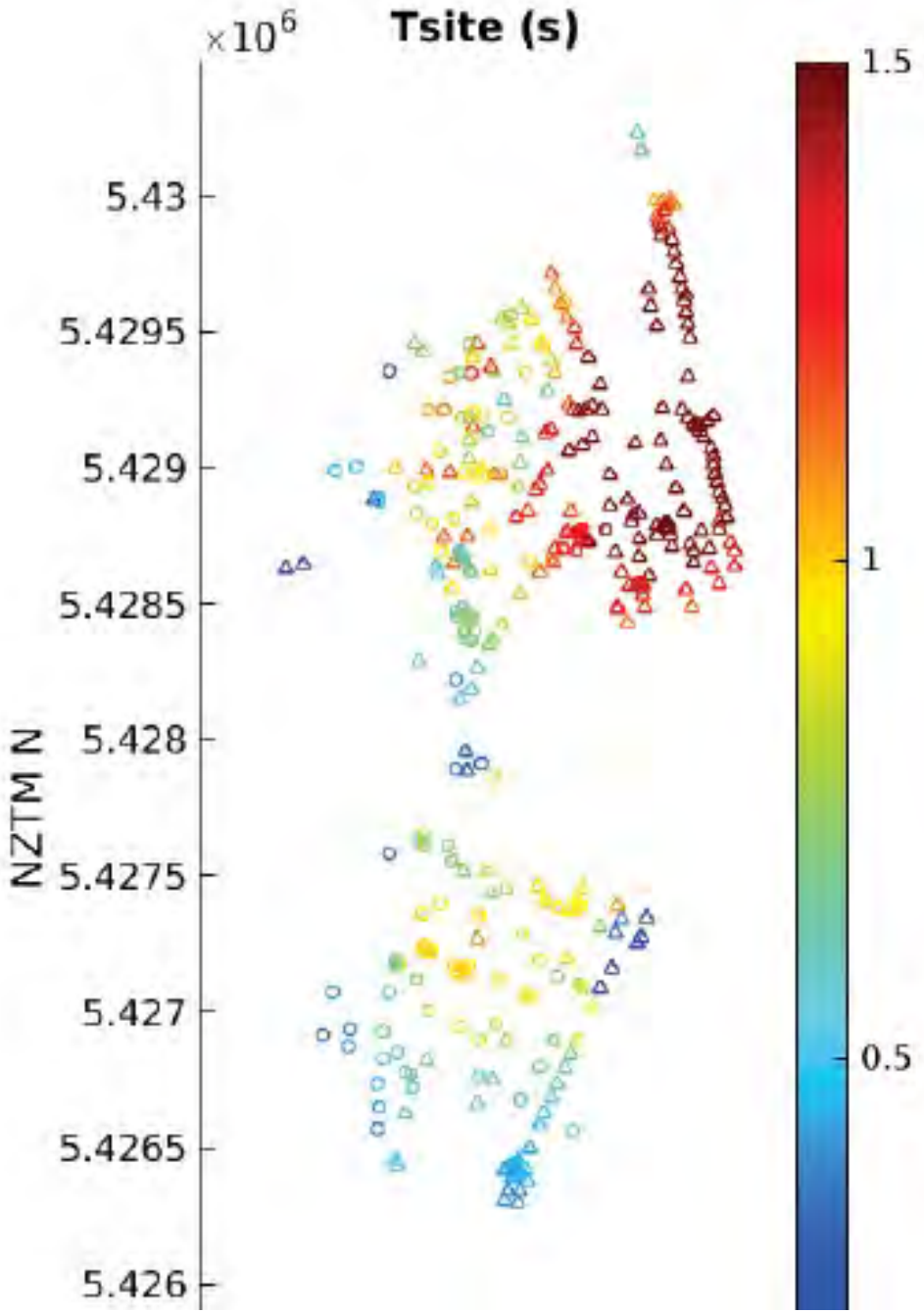
Site Characterisation Database

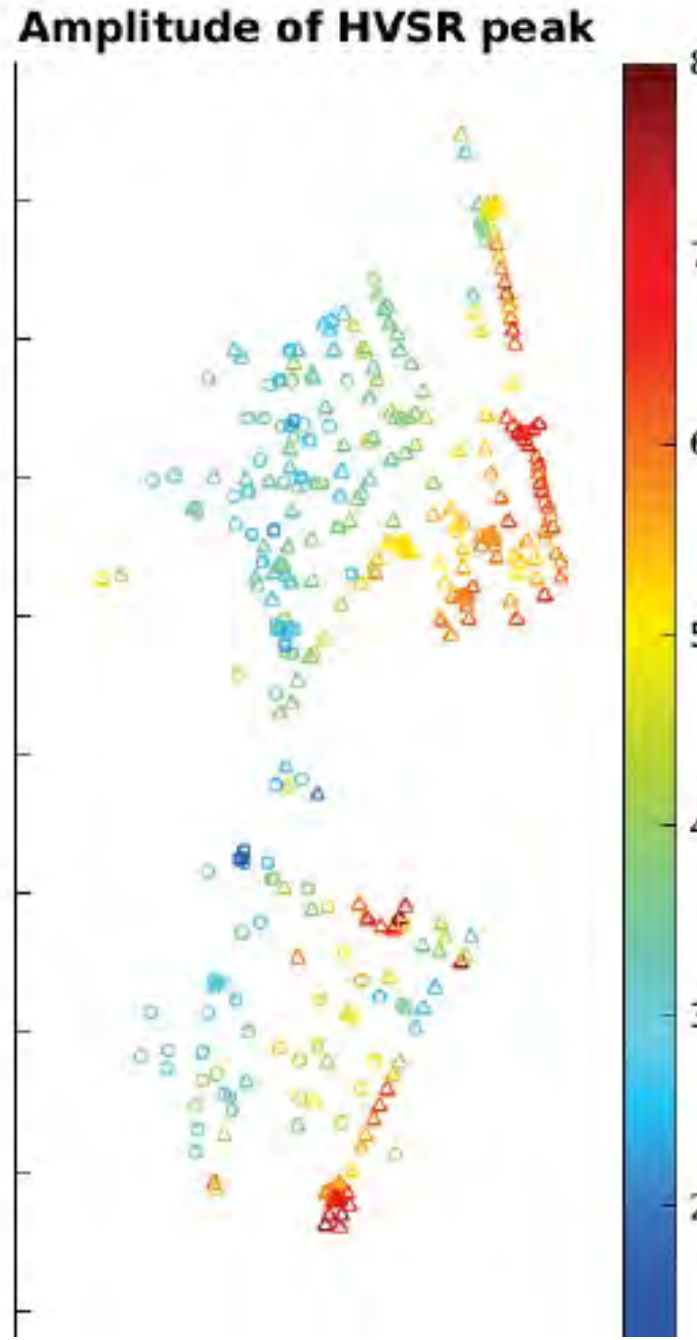
- Wellington Basin (and potentially others in New Zealand) may not look like the ‘average’ basin for which the ground motions models were originally developed.



Database of Wotherspoon et al. 2022)

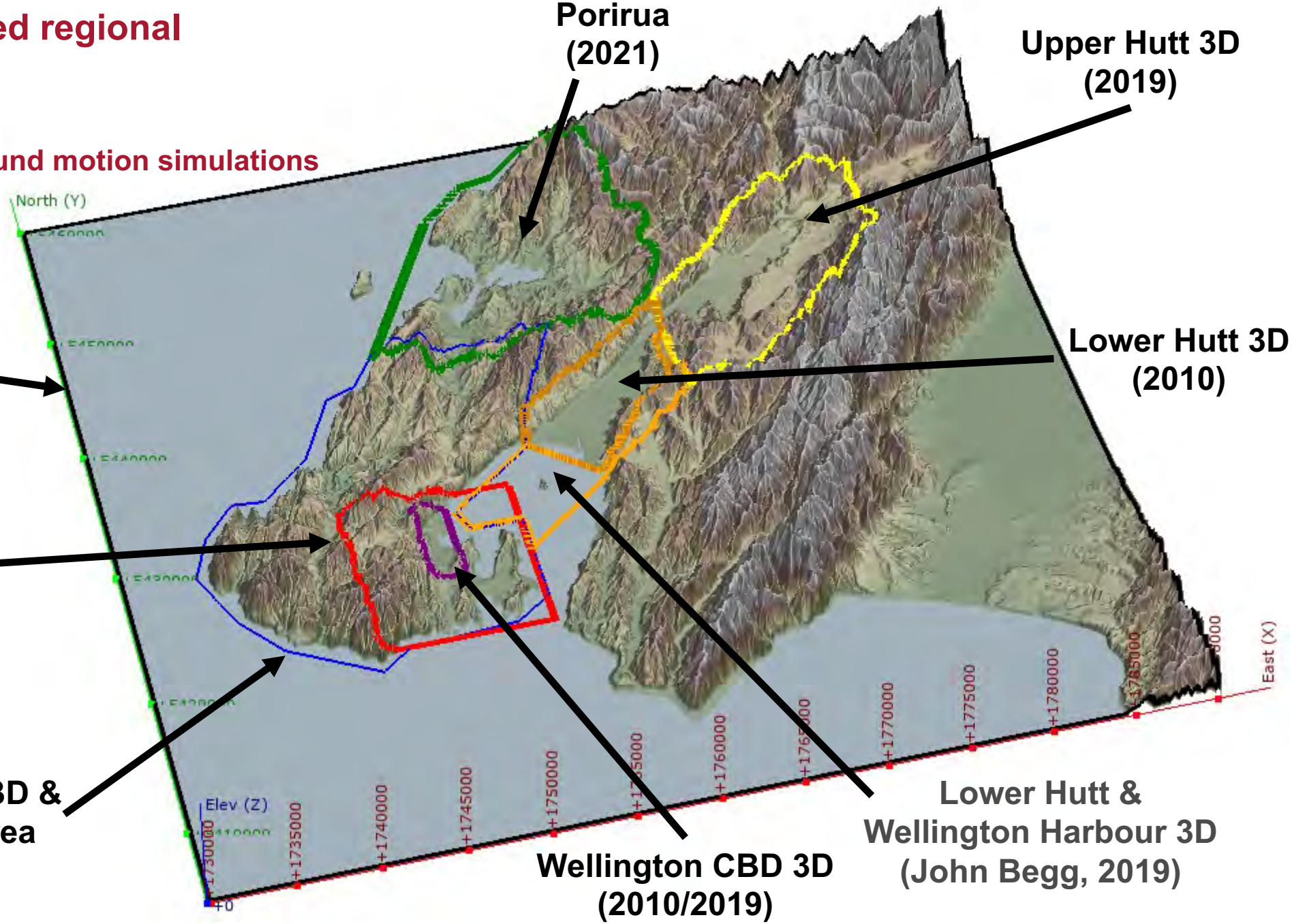

N
Approximate Vs30
estimated from 3D model
>750
450 - 750
300 - 450
250 - 300
200 - 250
150 - 200
<150
Faults
Rakaia Terrane
0
200
400
m
Wellington Fault
Thorndon
CentrePort
Aotea Fault
Te Aro
Vs30 Measured Sites
>750
450-750
300-450
250-300
200-250
150-200
<150
B-C boundary
C-D boundary
C-D uncertainty zone
D / possible E boundary
Passive seismic Vs sites
Down-hole Vs sites
NZS1170.5
Site Class


Tsite (s)
×10^6
5.43
5.4295
5.429
5.4285
5.428
5.4275
5.427
5.4265
5.426
NZTM N
1.5
1
0.5


Amplitude of HVSR peak

An updated and combined regional geology/velocity model

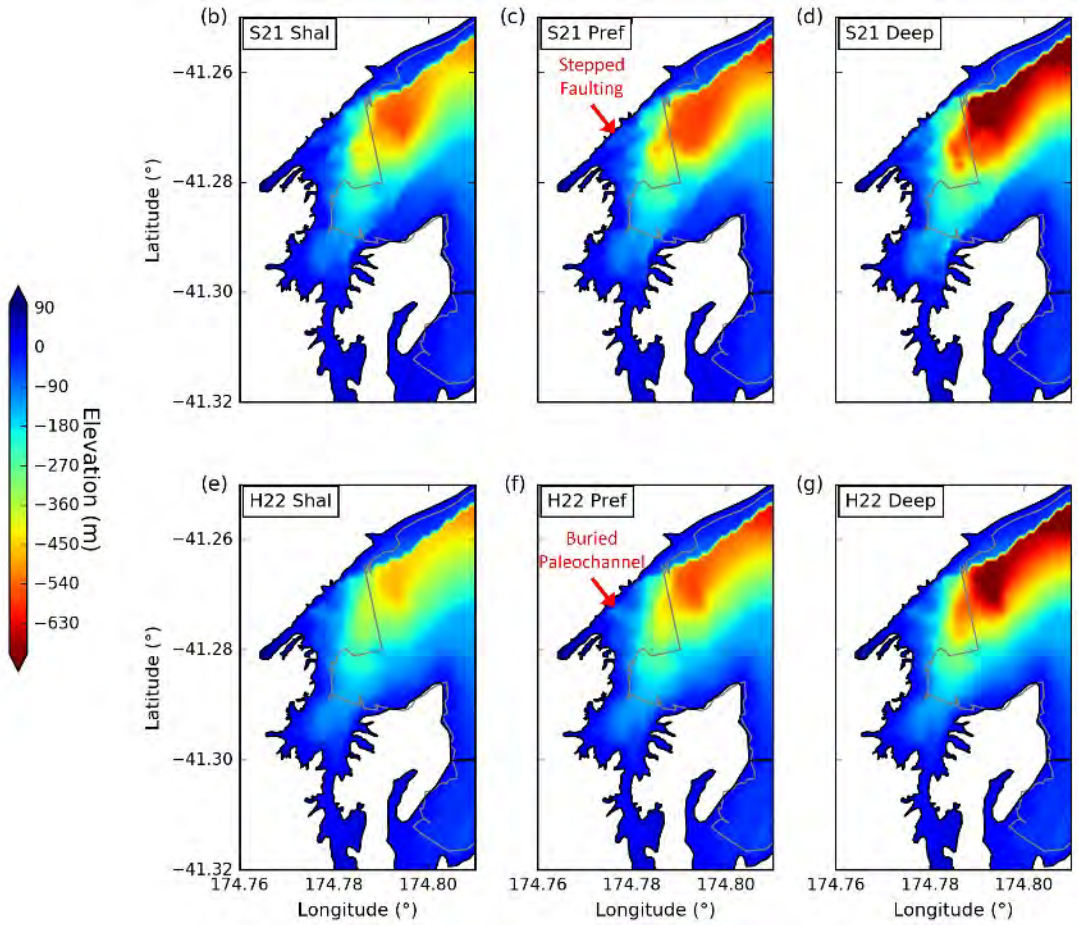
* Allows physics-based 3D ground motion simulations



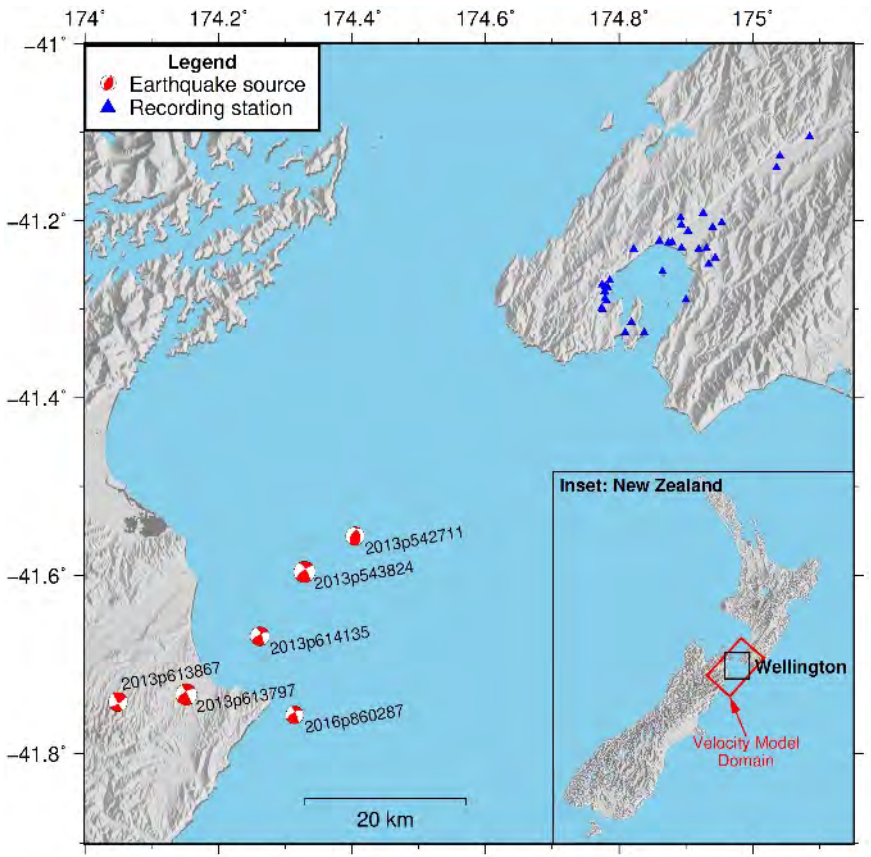
Hill et al.
2022 NSHM

Physics – based modelling methods

- **Lee et al. (2022) Ground motion simulation-based amplification**

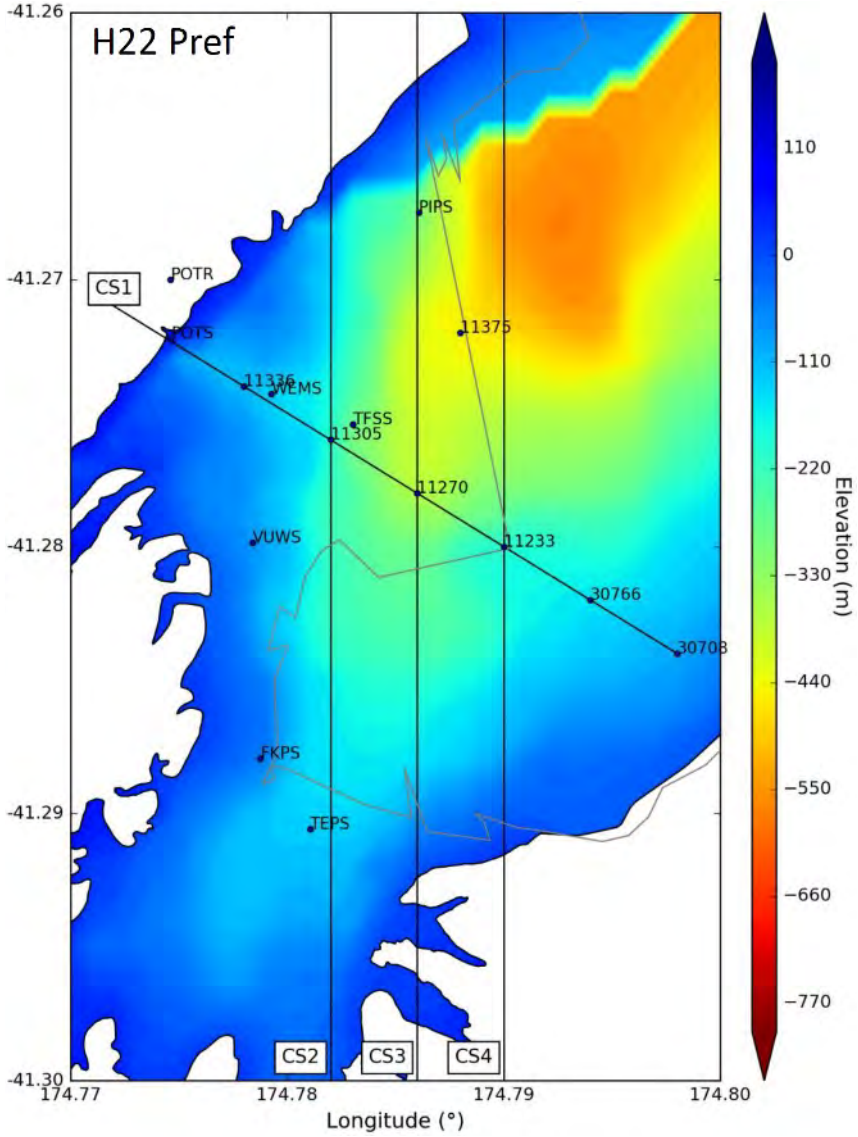


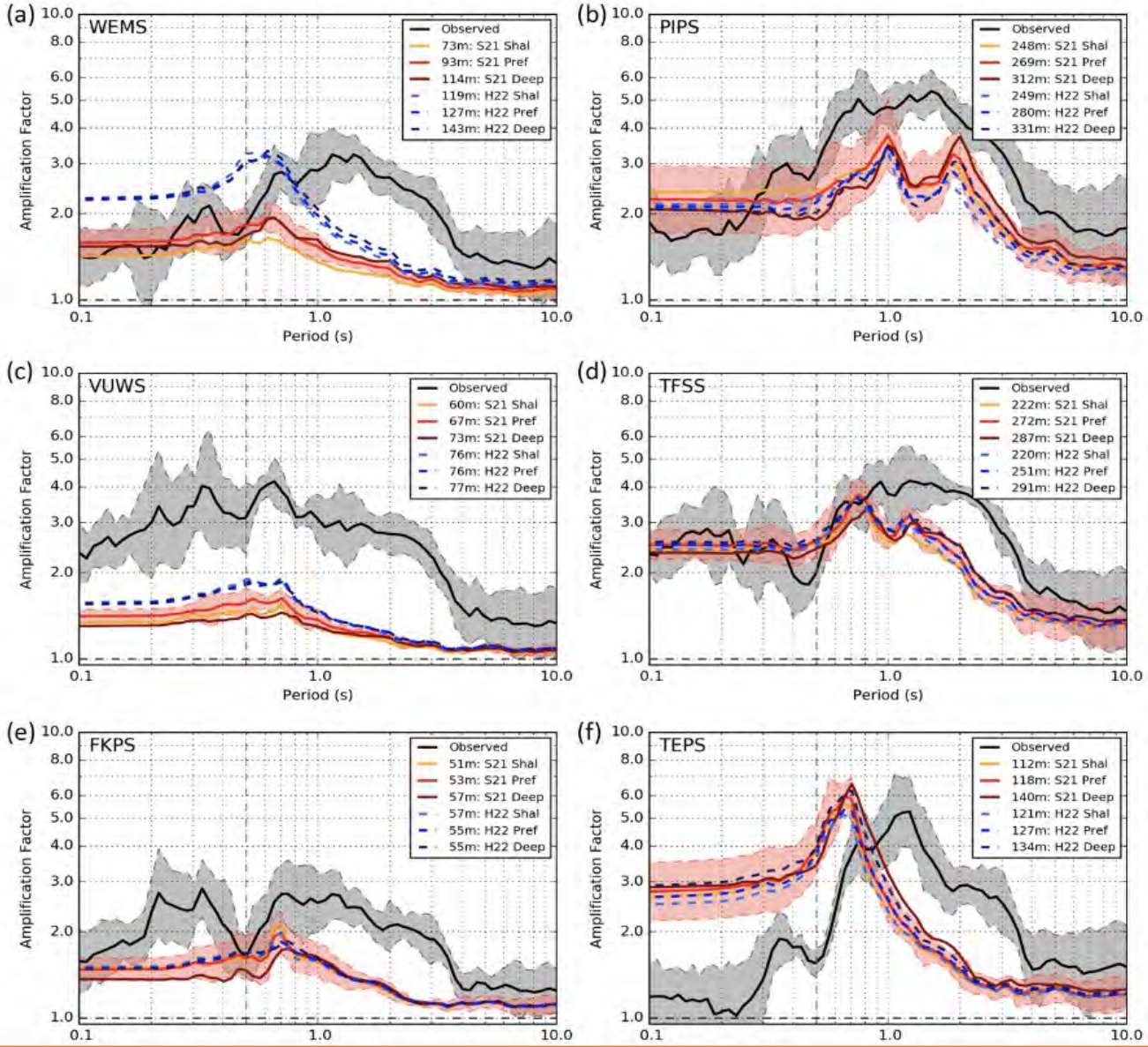
Testing 6 basin geometry models (central Wellington):



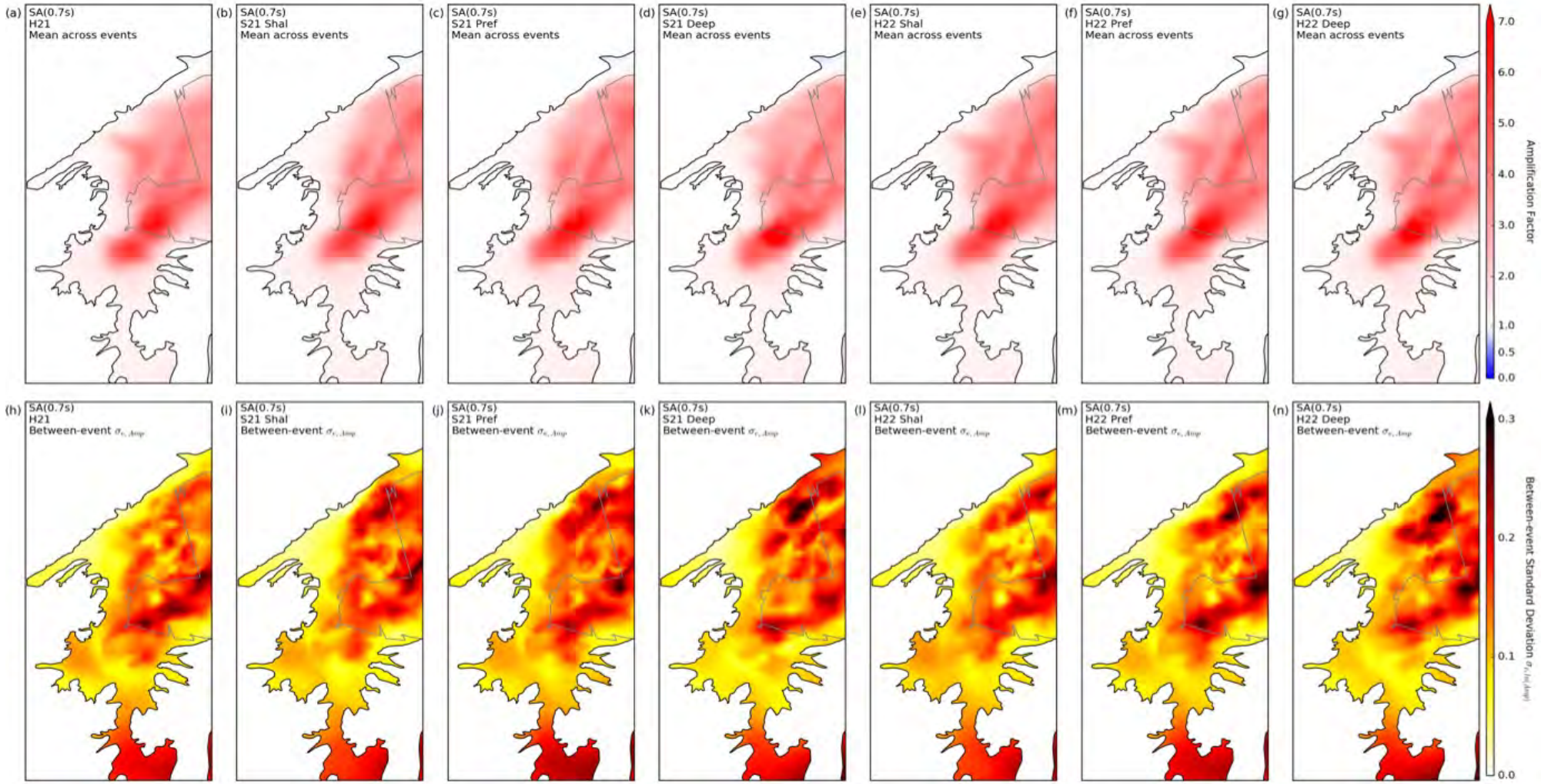
Selected 6 earthquakes:

Physics – based modelling methods (Lee et al. 2022)





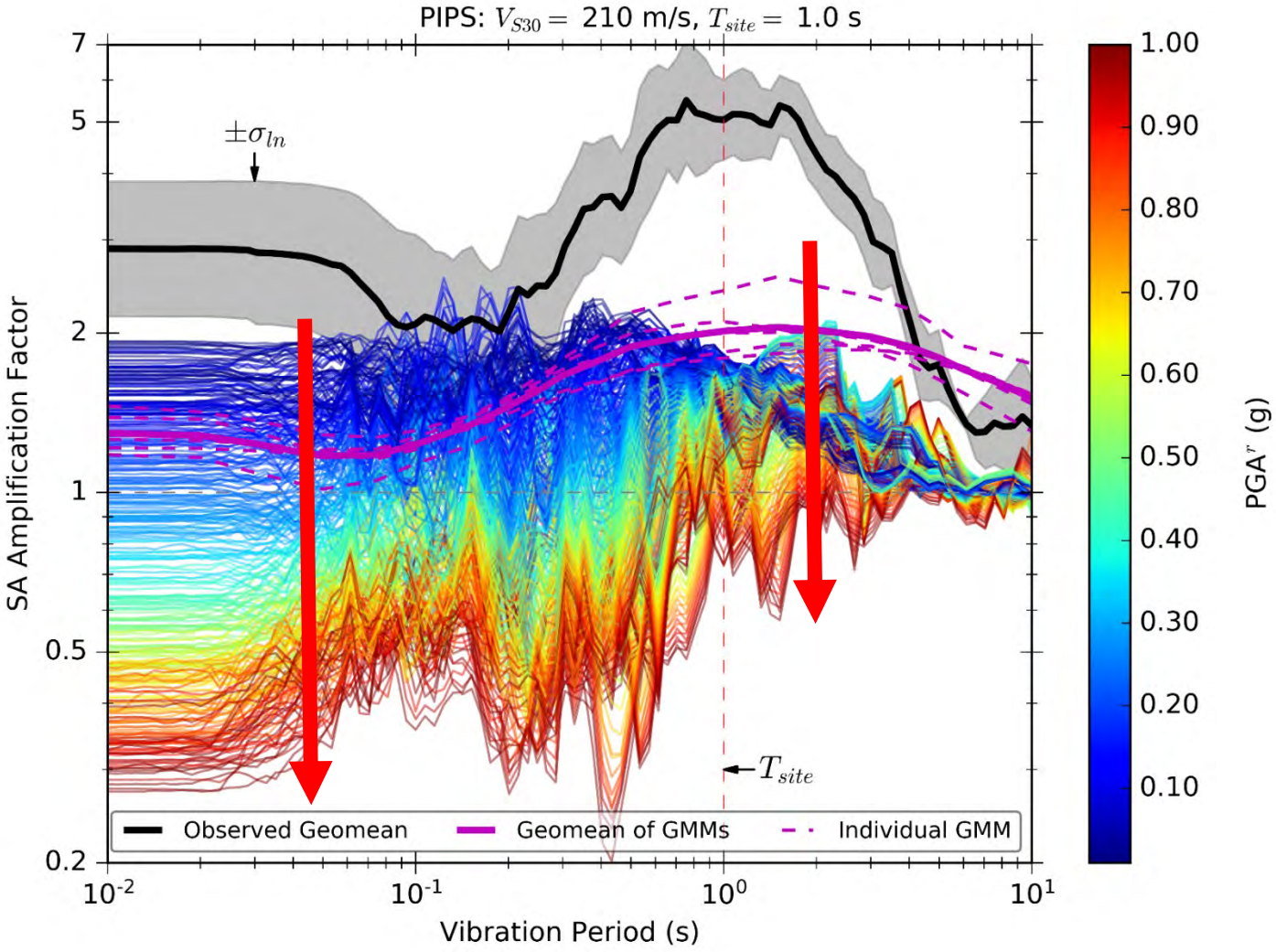
Physics-based modelling methods (Lee et al. 2022)



What happens during strong shaking?

(de la Torre et al. 2022)

Example: Soft Site PIPS – V_{S30} = 210 m/s, T_{site} = 1.0s



- Models the effects of the near-surface at weak to strong shaking (0.01 to 1 g)
- During strong shaking, soils lose strength and 'nonlinear effects' occur
  - Significant deamplification at short periods
  - Some reduction in amplification at long periods.

What happens during strong shaking?

Combining Observations and 1D Nonlinear Simulations

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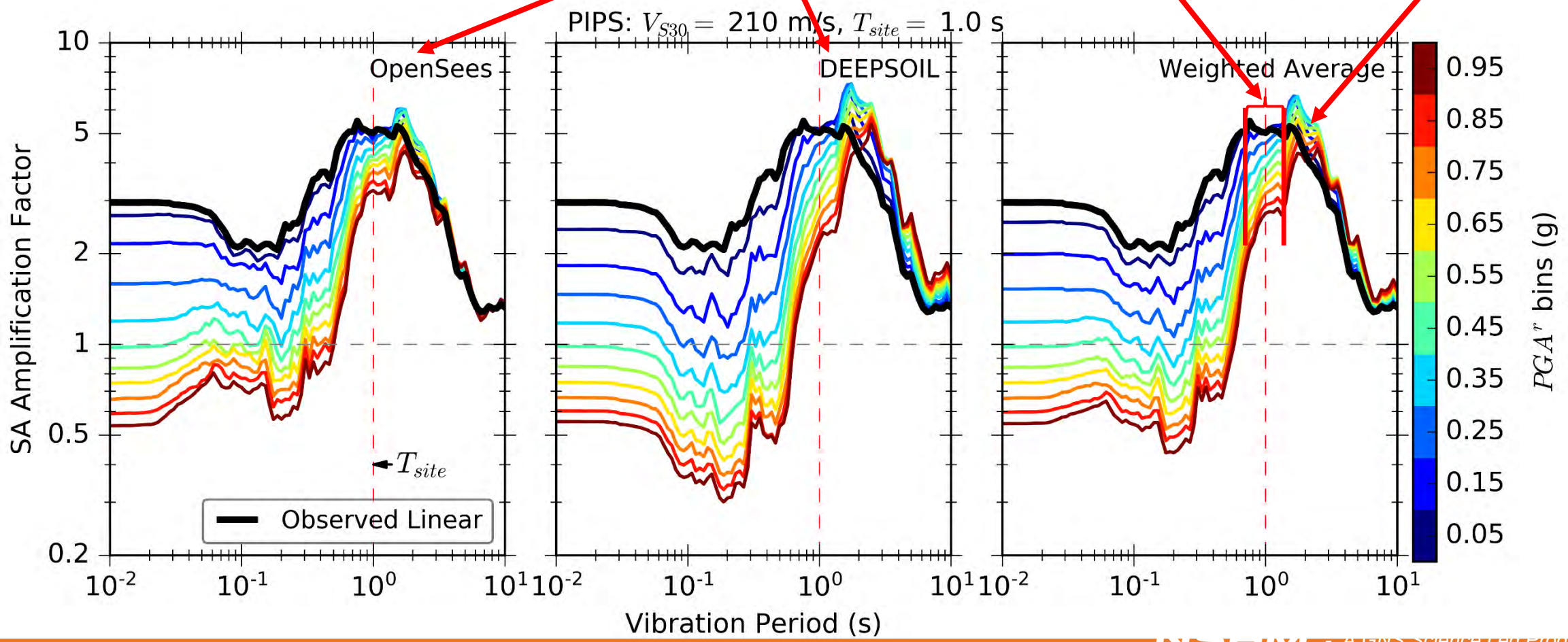
CHRISTCHURCH NEW ZEALAND

Soft Site Example:

Constitutive model uncertanties

Limited reduction
T = 0.7 – 1.5 sec

Slight increase
T > 1.5 sec



What happens during strong shaking?

Combining Observations and 1D Nonlinear Simulations

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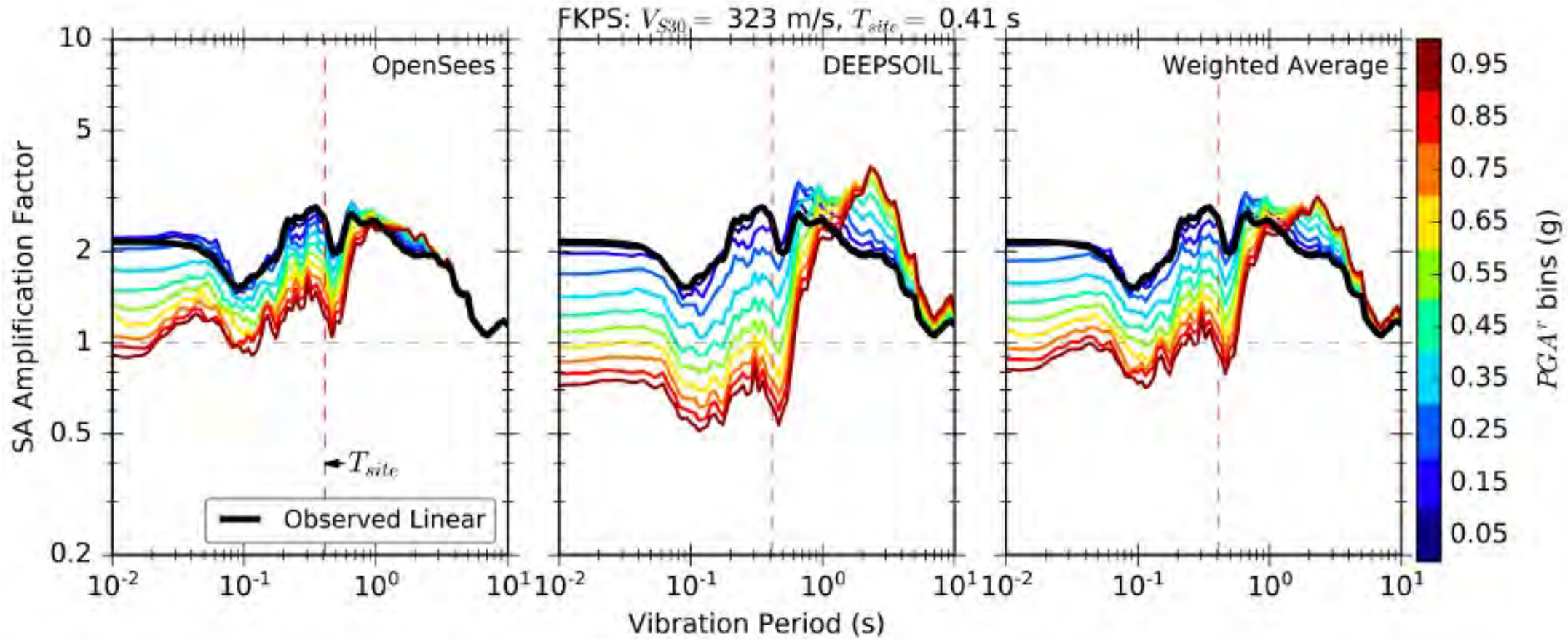
CHRISTCHURCH NEW ZEALAND

- **Stiffer soil site**



Next aims of NSHM programme – Wgtn Basin

- More extensive comparison of amplification models:
  - How does local Wellington Basin amplification differ from the mean 2022 NSHM ground motion predictions?
  - How does it vary spatially and with spectral period?

- What is the uncertainty in the models? Strengths/limitations

- What directions can we take to improve treatment of site/basin effects in urban seismic hazard and future NSHMs?

NSHM22 reports

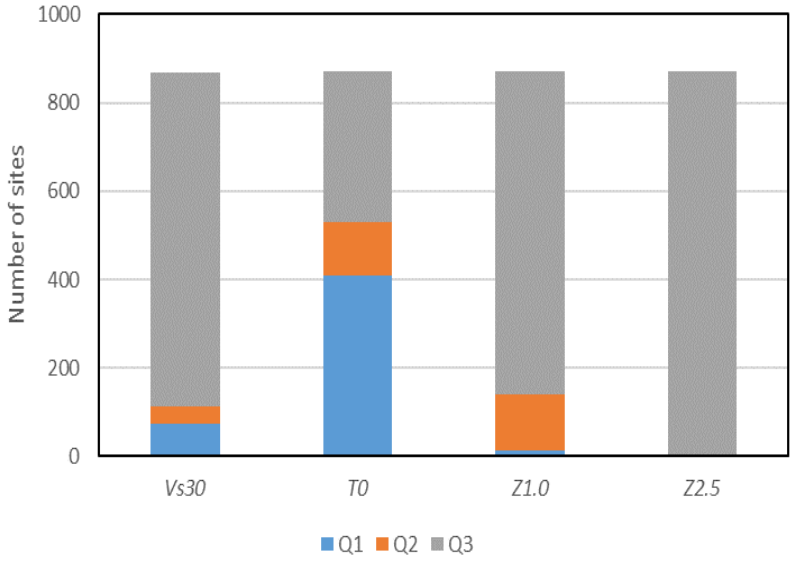
- Kaiser et al. (2022) Site/basin summary report including future directions
- Wotherspoon et al. (2022). NZ site characterisation database
- Hill et al. (2022). Wellington regional 3D geological model
- Lee et al. (2022). Wellington ground motion simulation-based amplification - validation
- De la Torre et al. (2022). Wellington non-linear site amplification models

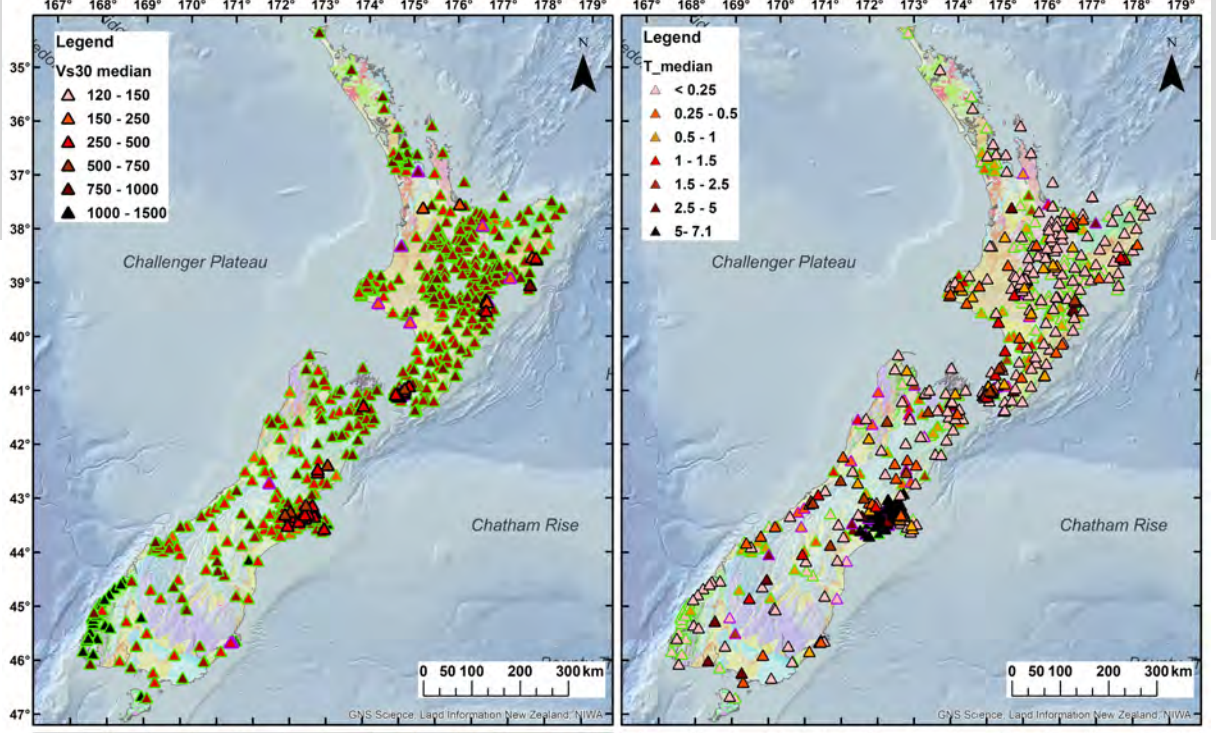
Extra Slides

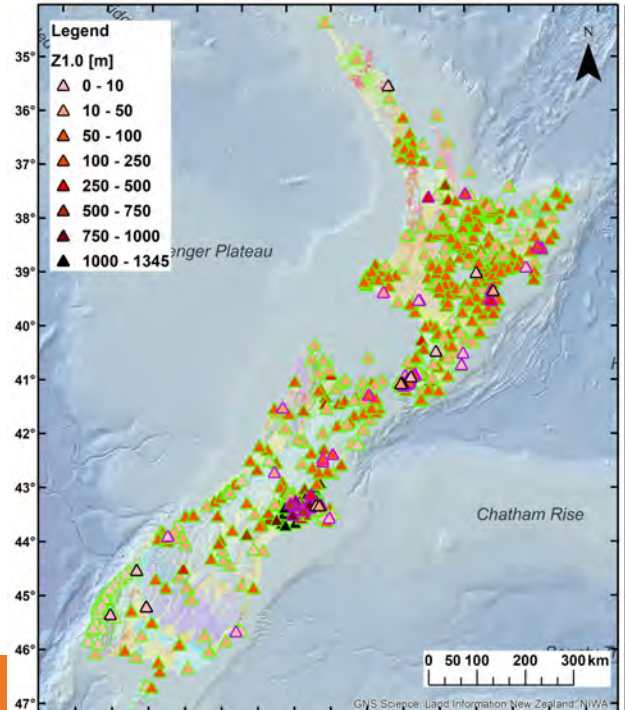
NZ Site and Basin Characterisation

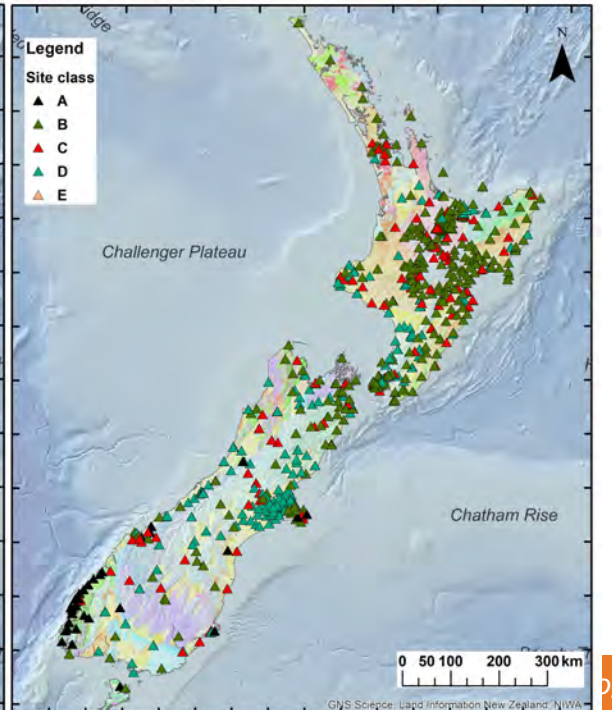
- Improving characterization of Vs30 and other site parameters in New Zealand

- Building and improving regional basin models (only Wellington and Canterbury have well-characterized basin models)

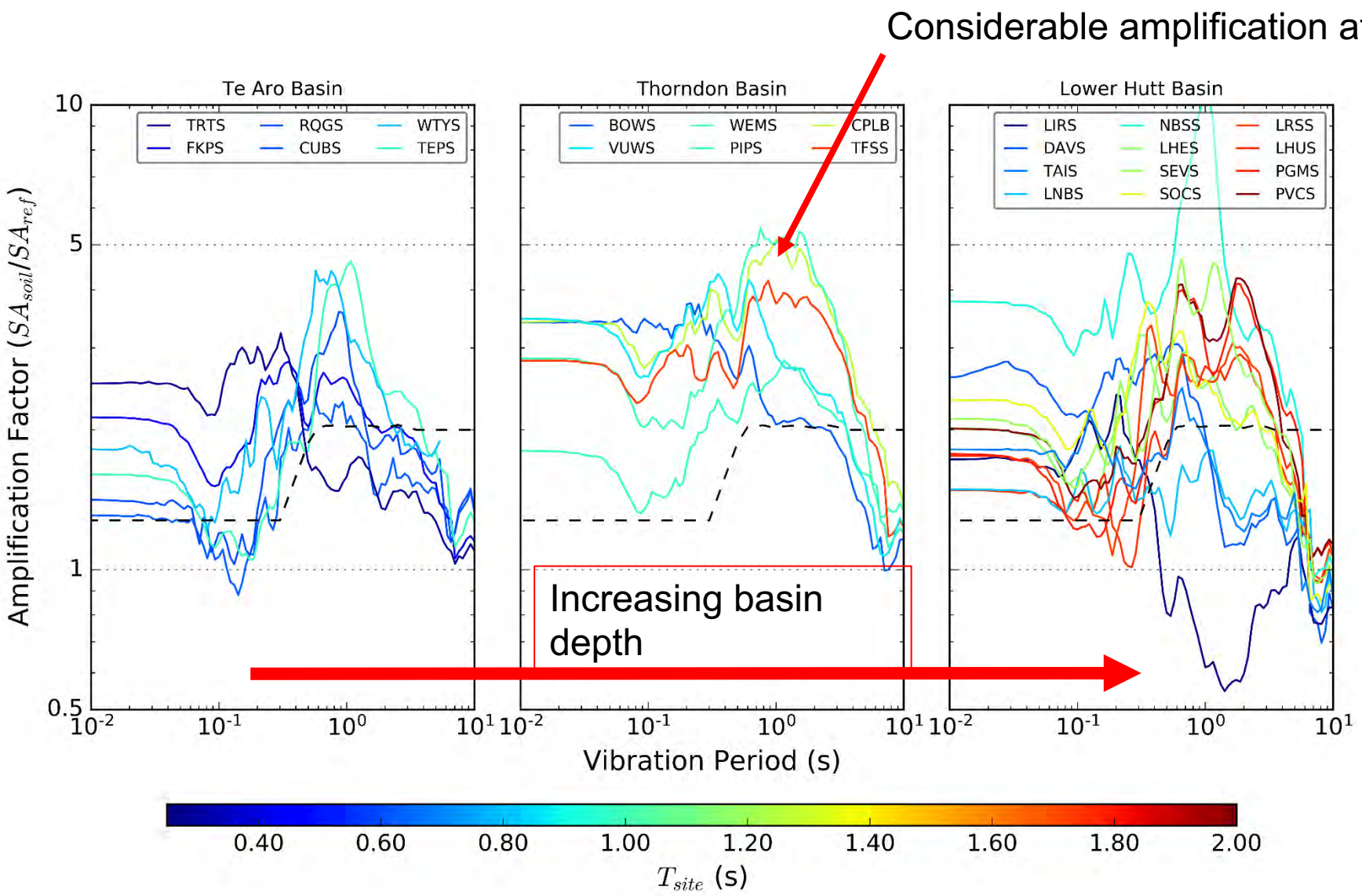








Observed Basin/Site Amplification in Wellington



- Reference station: POTS
- Weak to moderate ground motions
- “Linear” site response
- Higher than NZS1170.5 Site Class D factors

Is relatively consistent and repeatable at 1 – 2 s periods within the CBD area at low to moderate accelerations (< 0.2g)

At these periods is above the mean predicted by global ground motion models

Vs30 information / analysis to support 2022 NSHM release?

Perrin et al. (2015)

Foster et al. (2019)

Foster et al. + 2022 updates (working version)

Update to National Vs30 maps

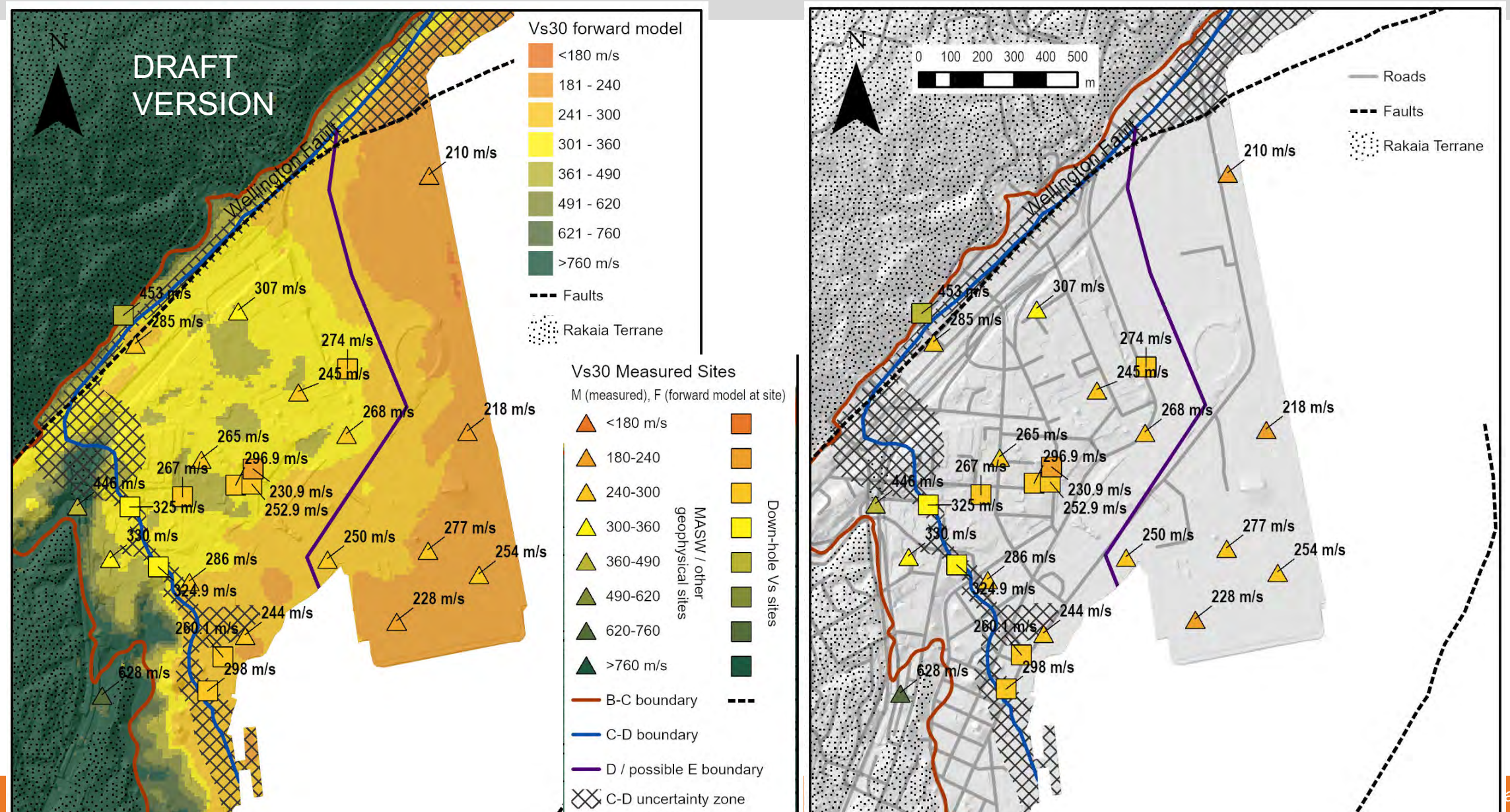
- High-level spatial hazard information for planning / impact assessments etc.

Expansion of available Vs30 (and Vs) information and analysis

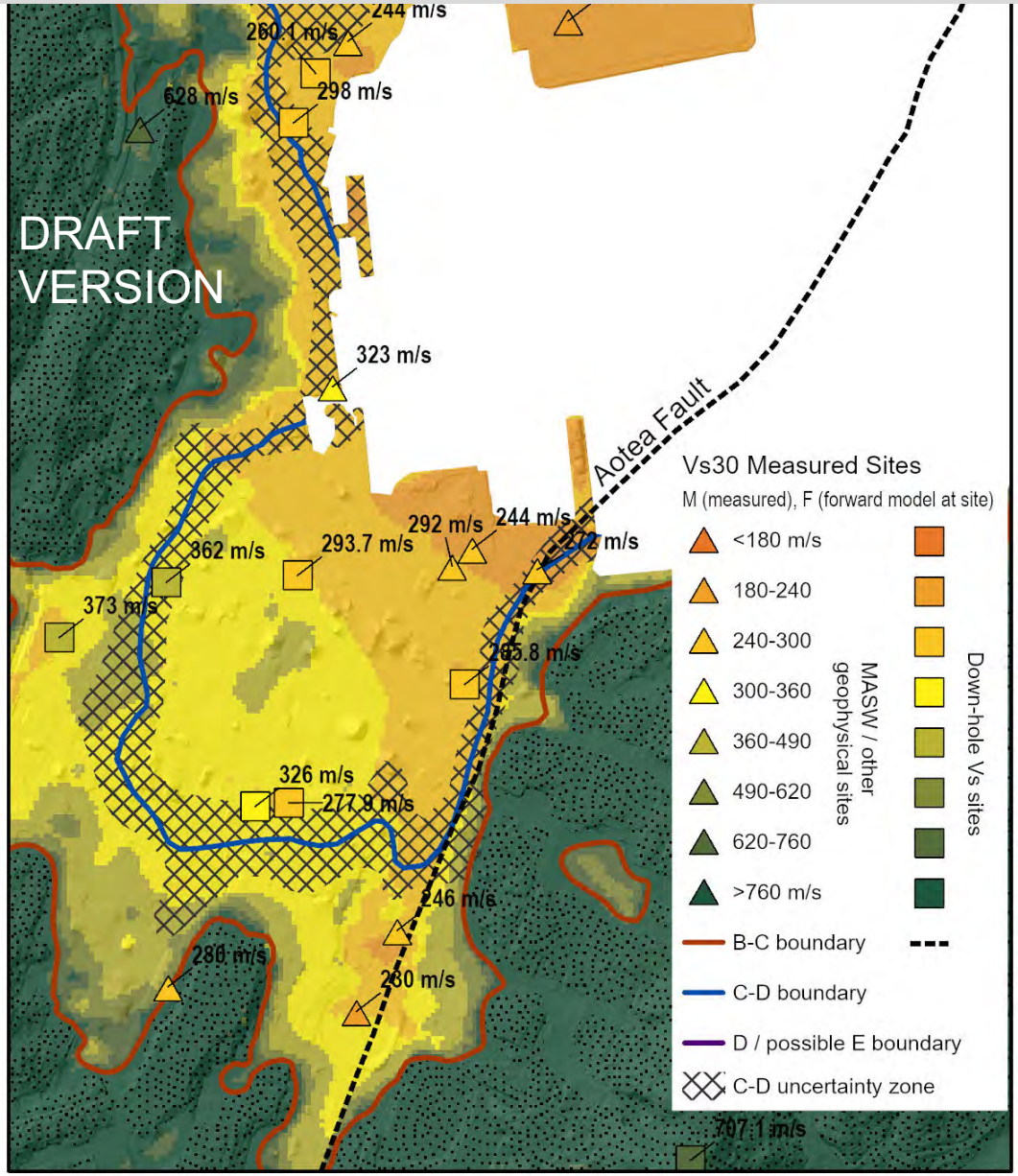
Long-term: Requires significant Vs data compilation/analysis and new data collection

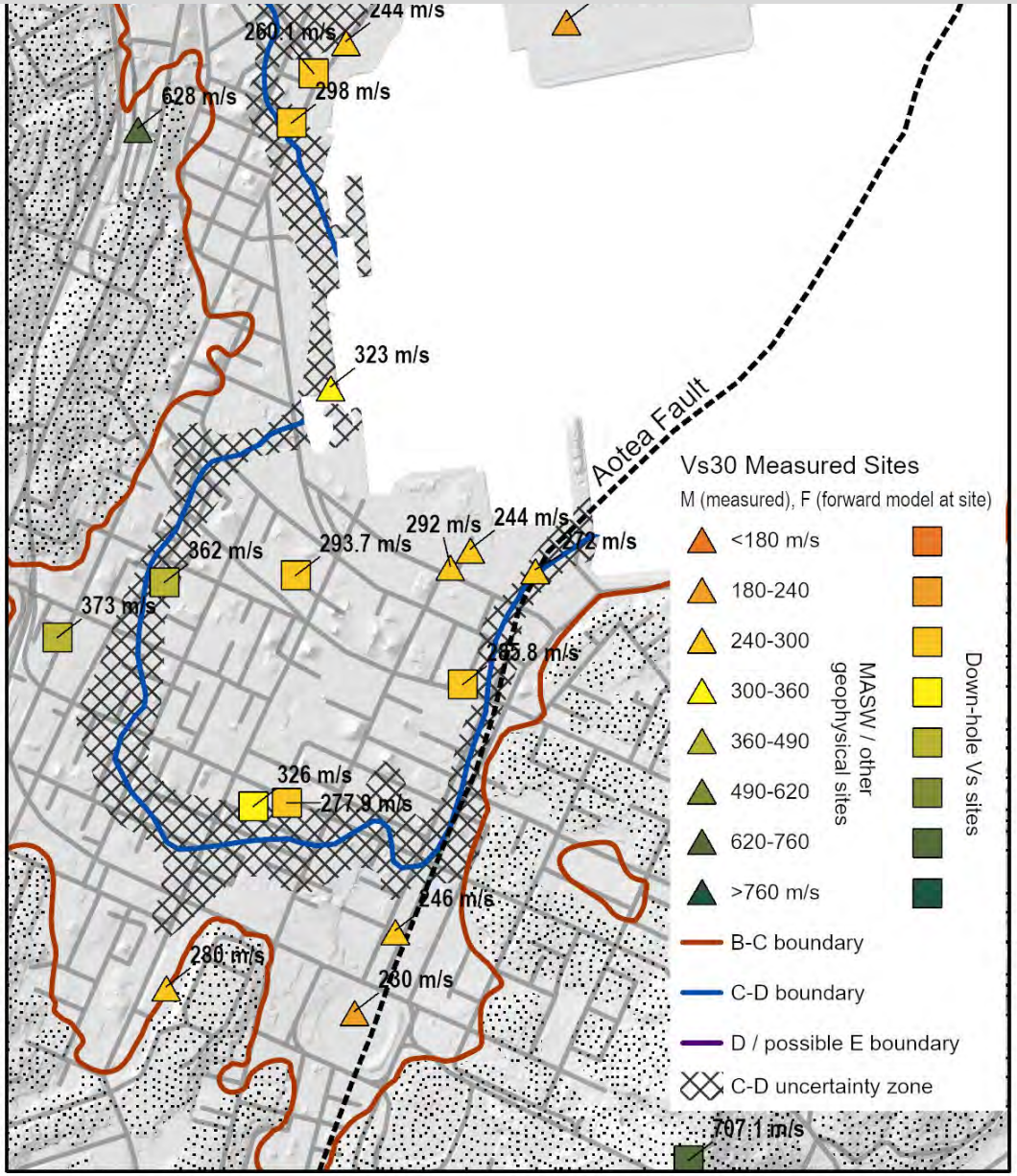
Short-term interim updates / options

Thorndon Basin



Te Aro Basin


DRAFT VERSION
260.1 m/s
244 m/s
628 m/s
298 m/s
323 m/s
Aotea Fault
292 m/s
244 m/s
362 m/s
293.7 m/s
373 m/s
285.8 m/s
326 m/s
277.9 m/s
246 m/s
280 m/s
260 m/s
707.1 m/s
Vs30 Measured Sites
M (measured), F (forward model at site)
<180 m/s
180-240
240-300
300-360
360-490
490-620
620-760
>760 m/s
MASW / other geophysical sites
Down-hole Vs sites
B-C boundary
C-D boundary
D / possible E boundary
C-D uncertainty zone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B-C boundary
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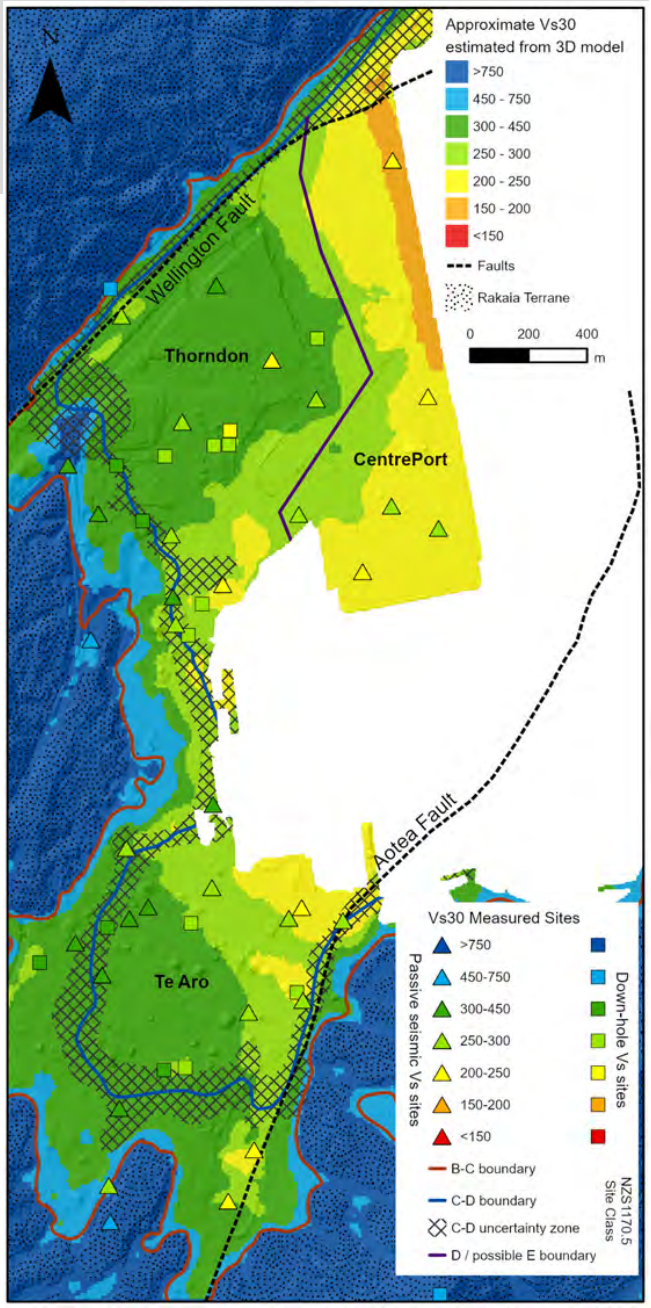
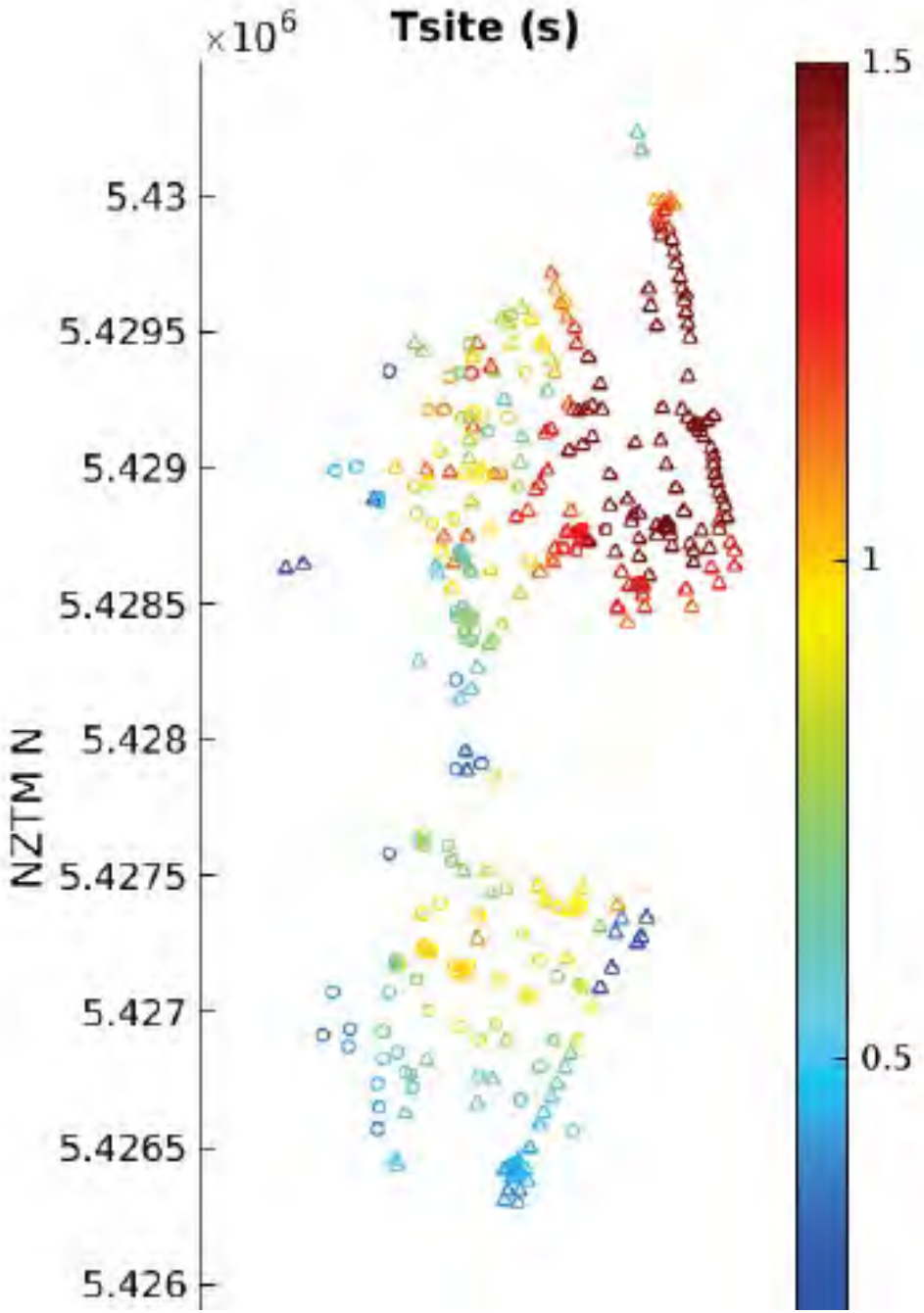
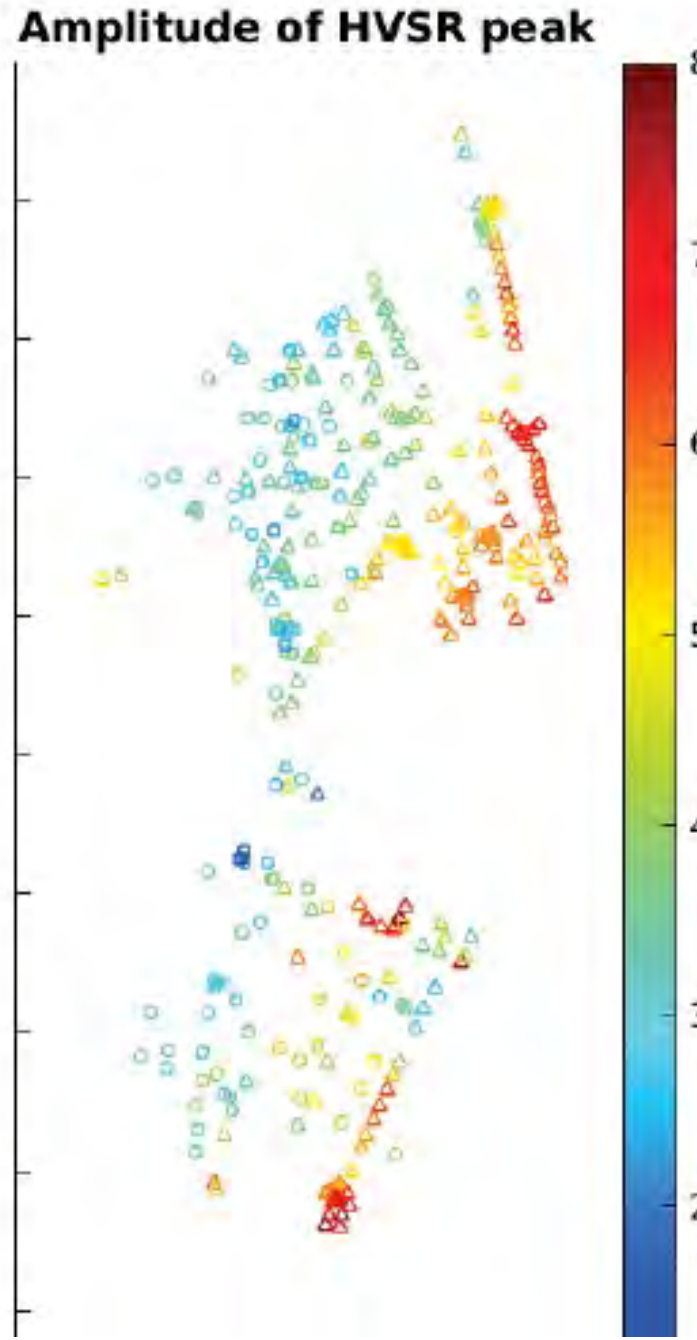
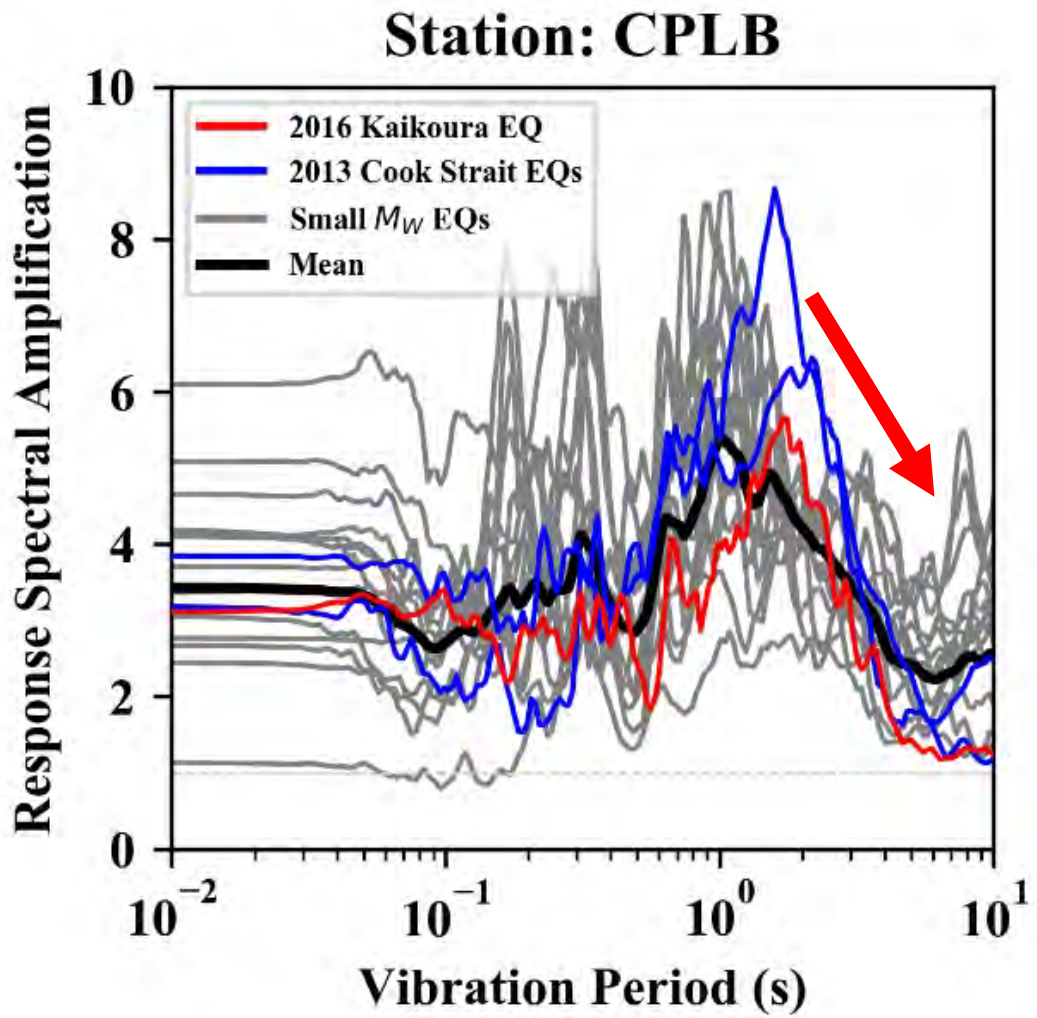

N
Approximate Vs30
estimated from 3D model
>750
450 - 750
300 - 450
250 - 300
200 - 250
150 - 200
<150
Faults
Rakaia Terrane
0
200
400
m
Wellington Fault
Thorndon
CentrePort
Aotea Fault
Te Aro
Vs30 Measured Sites
>750
450-750
300-450
250-300
200-250
150-200
<150
B-C boundary
C-D boundary
C-D uncertainty zone
D / possible E boundary
Passive seismic Vs sites
Down-hole Vs sites
NZS1170.5
Site Class


Tsite (s)
×10^6
5.43
5.4295
5.429
5.4285
5.428
5.4275
5.427
5.4265
5.426
NZTM N
1.5
1
0.5


Amplitude of HVSR peak

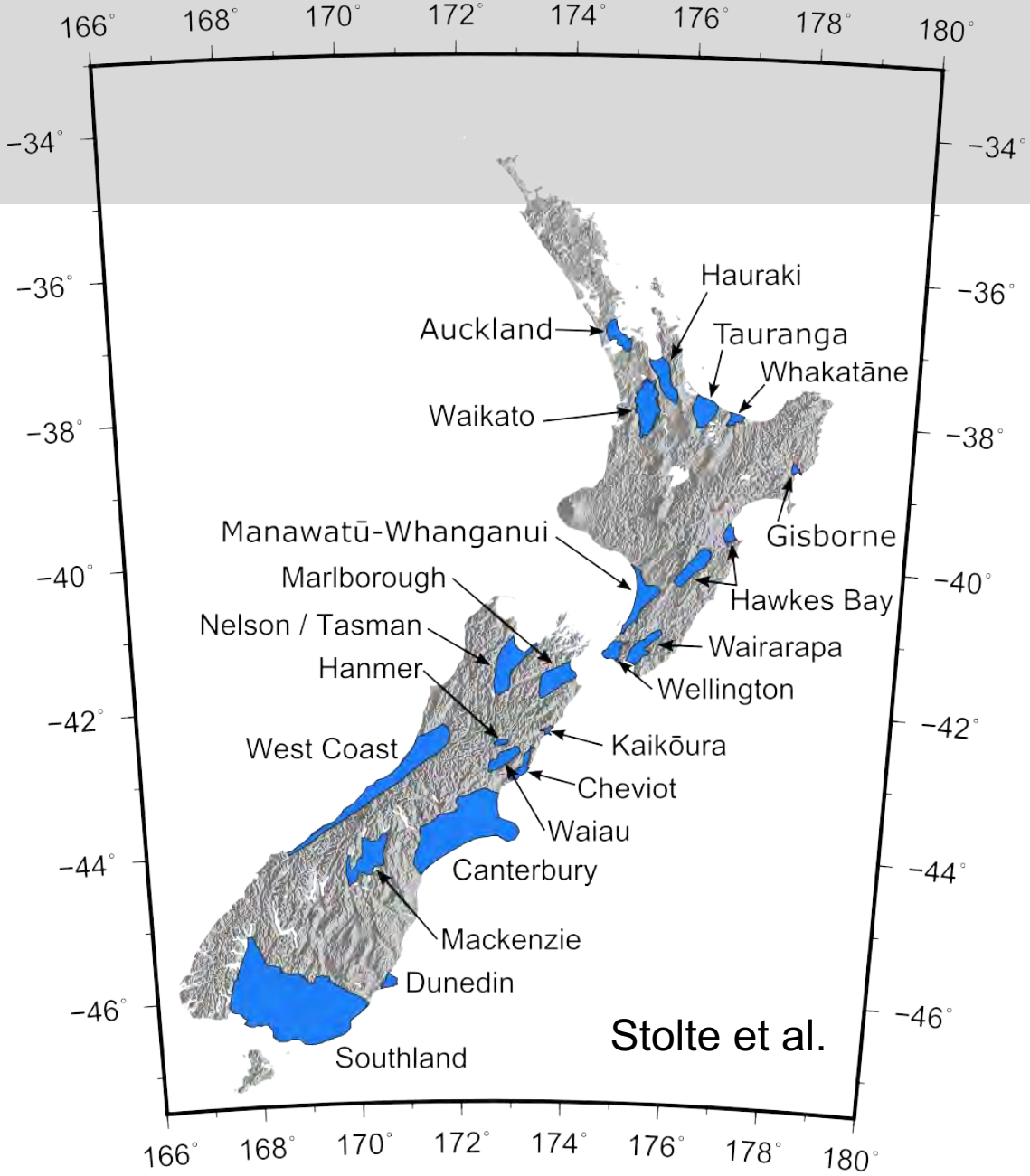
What is the influence of soil nonlinearity when shaking is strong?



- Observations at soft site (waterfront)
- Max PGA ≈ 0.2-0.25 g
- Some observed nonlinearity
- What about future large events that dominate the hazard?

Other NZ basins

- **Only Canterbury and Wellington basin are considered ‘well-characterised’**
- **Basic basin models exist for several other locations**



Summaries also in Wotherspoon et al. 2020 / Thomson et al. 2020

Wellington Basin – exploration of site models

Ongoing work

- Review of 3D Vs characterization and simulation sensitivity testing
- Combination of 3D simulations and near-surface non-linear adjustments
- Further contrast/comparison of alternative site models and consideration of epistemic (and aleatory) uncertainty

Method	Advantages	Limitations	Status
Global GMM site models (e.g. NGA-West2)	Robust global statistical averages	Not tailored to or directly incorporating regional or local basin characteristics. Uses site parameters as imperfect proxies to capture site effects.	Established. Continued global development.
New Zealand backbone GMM site models (Atkinson 2022 / Stafford 2022)	Robust global statistical averages, guided by New Zealand data.	See above.	Developed in the 2022 NSHM. Continued regional development.
Site-specific empirical site models (de la Torre et al. 2022; Manea et al. 2022b; Bradley et al. 2018, etc.)	Direct measurements of local site/basin amplification.	Usually only applicable to linear site response (weak shaking). Need an interpolation scheme to be applied anywhere in the basin.	Established; further developed in the 2022 NSHM. Interpolatoin scheme?
Site-specific empirical and nonlinear site models (de la Torre et al. 2022)	Considers both local site observations and how site/basin amplification may change in strong earthquake shaking.	Large uncertainties and difficult to validate Needs an interpolation scheme to be applied anywhere in the basin.	Developed in the 2022 NSHM. Further sensitivity analysis. Interpolation scheme?
3D physics-based simulation site models (Lee et al. 2022a)	Models complex 3D basin-specific amplification effects	Needs extensive development and validation. Does not (alone) consider nonlinear effects.	Under development.

What next?

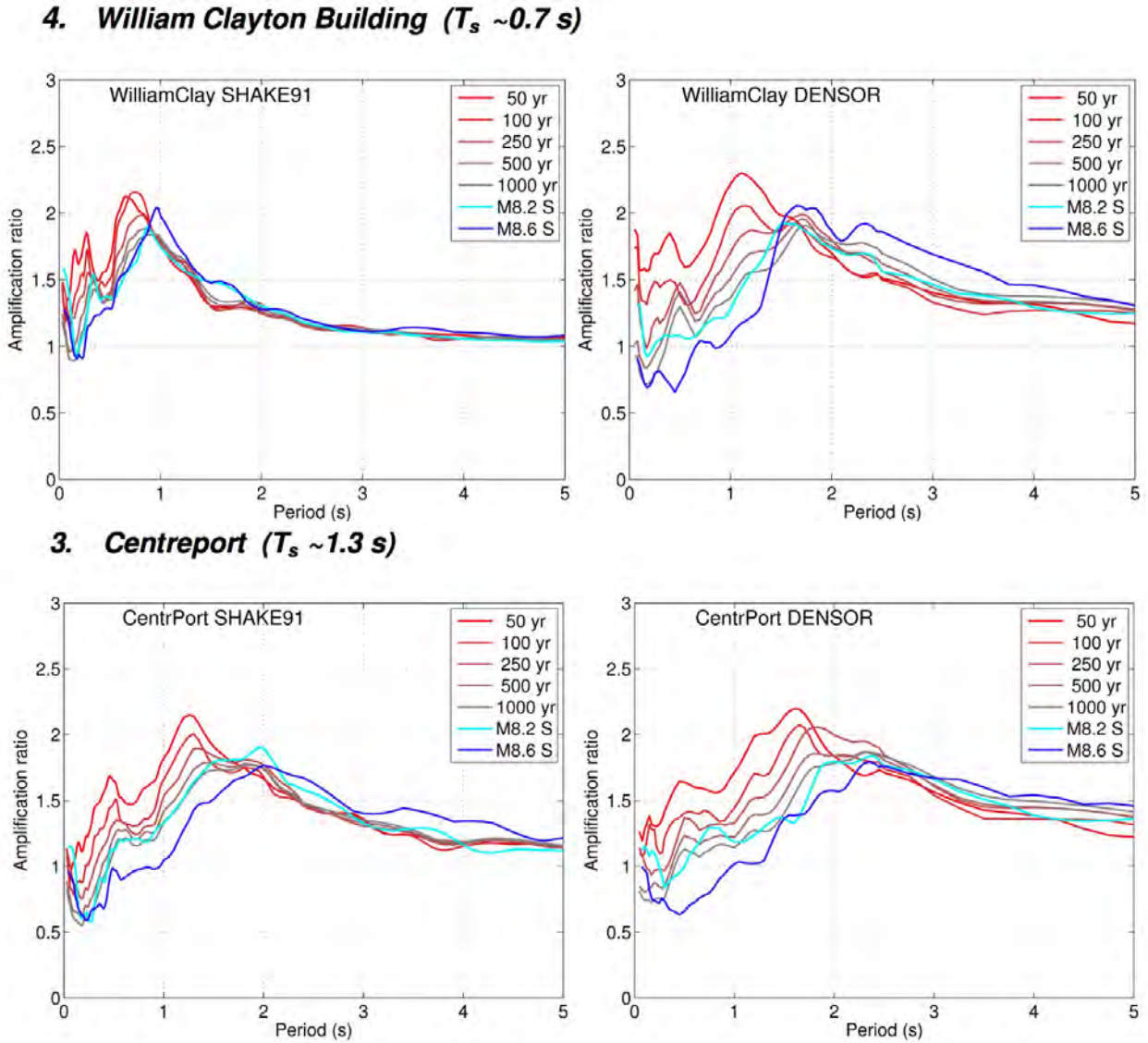
- **Site parameters – improving characterization and testing**
  - Vs30 & Basin depth parameters e.g. Z1.0 / Z2.5 / T0,
  - Full Vs profiles and HVSR curves
  - Testing of suites of site parameters/proxies (incl. related to topographic effects) to identify most useful parameters for future GMM development
  - Longer-term hosting of database – underpinning data and public access
  - What is the scope and priority for new data collection?

- **Vs30 information / analysis to support NSHM release?**
  - National Vs30 map?
  - Urban Vs30 mapping and assessment of changes in hazard (Including effect of Site Class to Vs30, e.g. Wellington)
  - Expanded Vs / Vs30 databases and analysis

- **Wellington basin case study**
  - Review of 3D model Vs characterization (also informs Vs30 map) / new data collection in 'gaps'?
  - Simulation sensitivity testing
  - Combination of 3D simulations and near-surface non-linear adjustments
  - Further contrast/comparison of alternative site models and analysis of epistemic (and aleatory) uncertainty
  - Decisions around how to implement site models in NSHM

- **Other New Zealand basins?**

How repeatable are these amplification effects in large proximal earthquakes ?



We know non-linear soil effects significantly impact amplification, but when and how much?

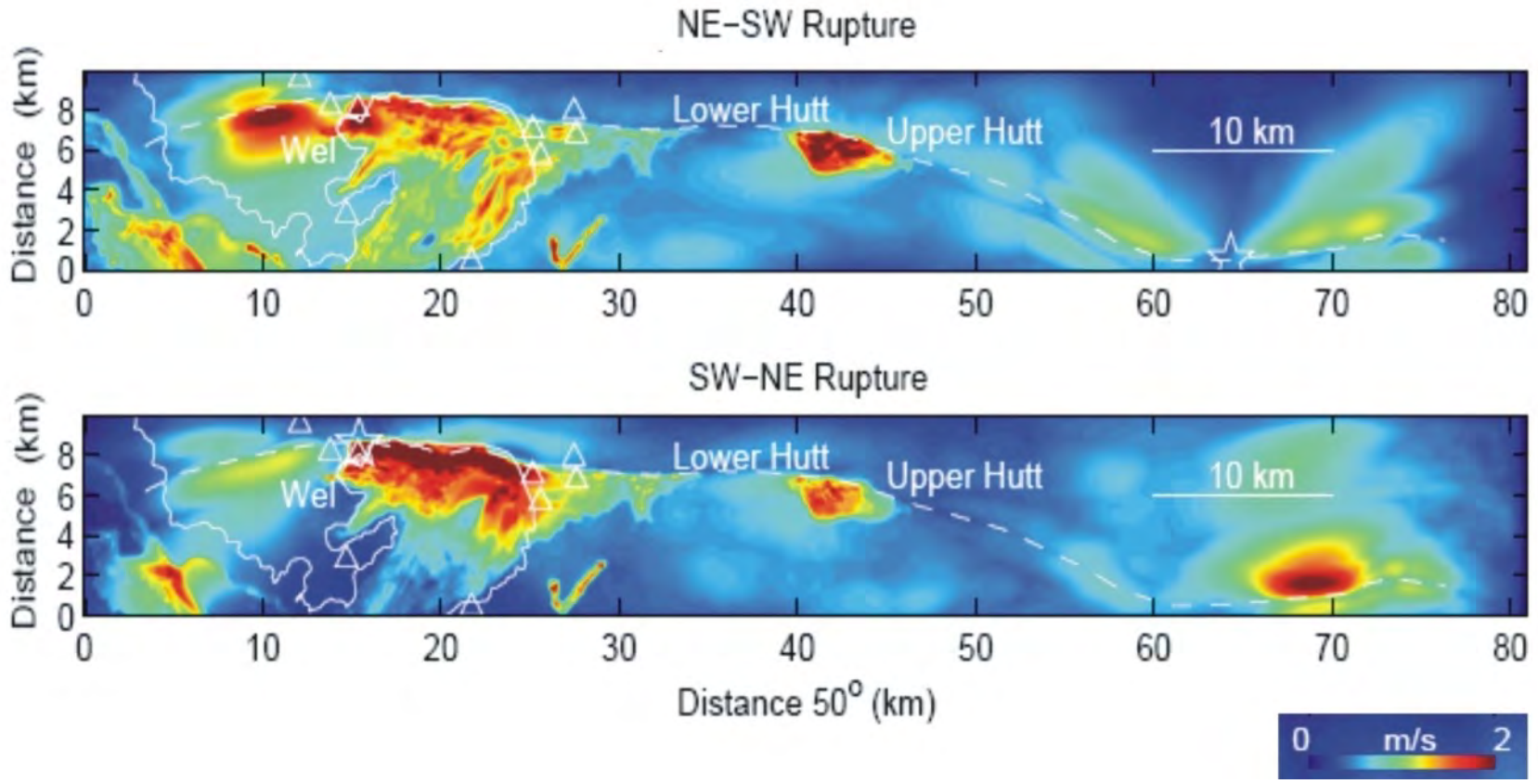
Large earthquake may change the amplification characteristics

- e.g. Hikurangi subduction earthquakes or Wellington Fault scenarios

John Zhao in Kaiser et al. (2012), GNS Science consultancy report

Earthquake simulations capture the influence of earthquake source and sedimentary basin

Wellington Fault scenario – two different ruptures

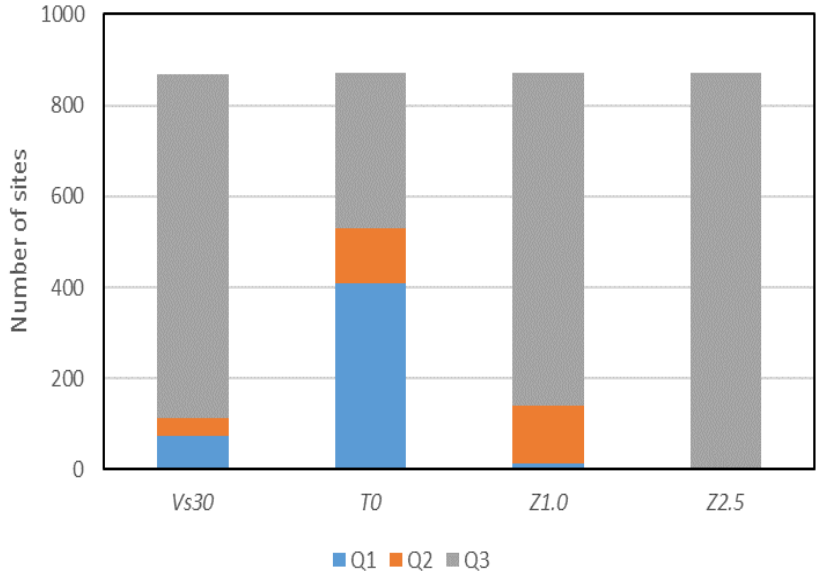


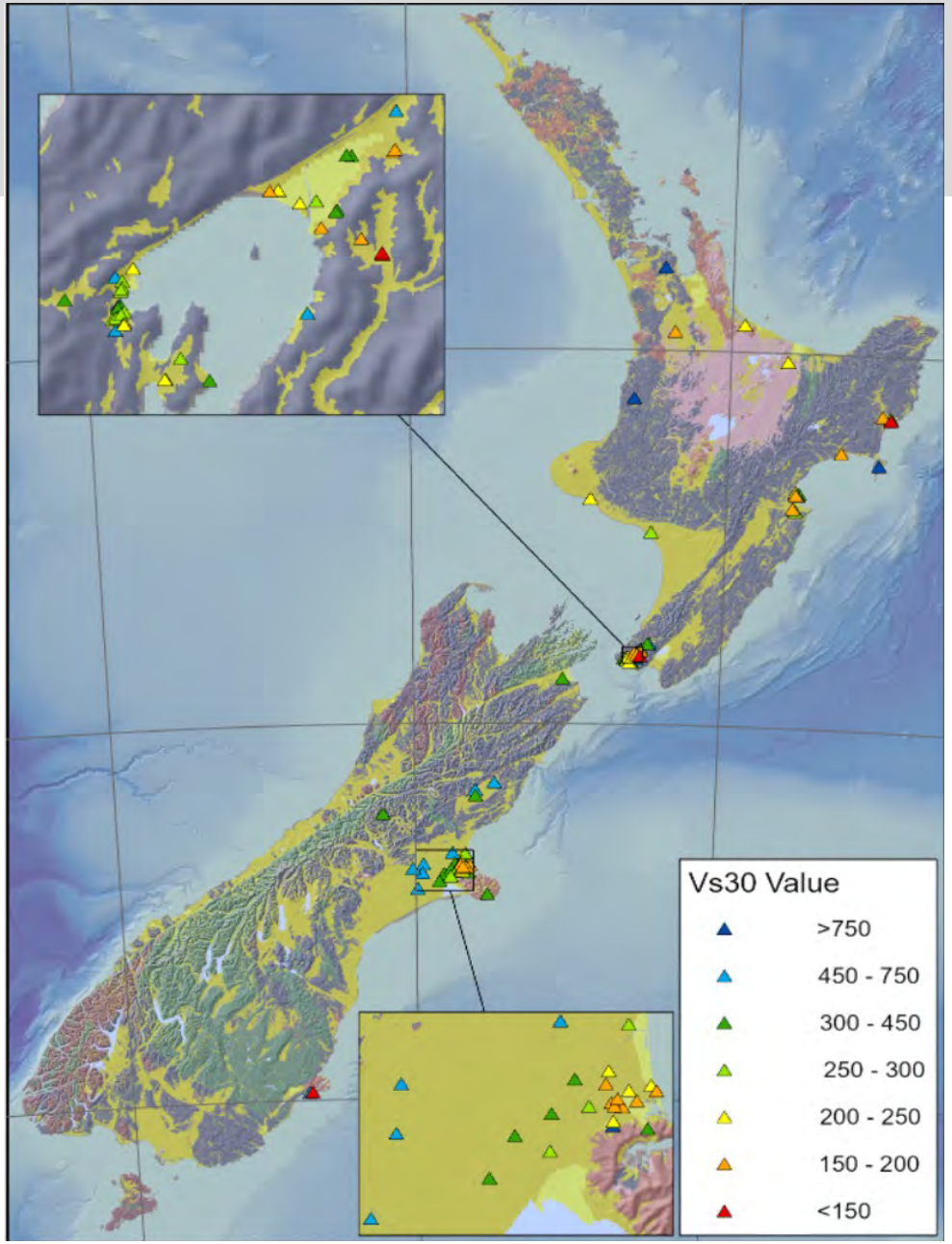
Benites et al. 2010

Site Characterisation Database

- Improving Vs30 characterization
  - Requires new data collection (e.g. Vs), to make significant improvements

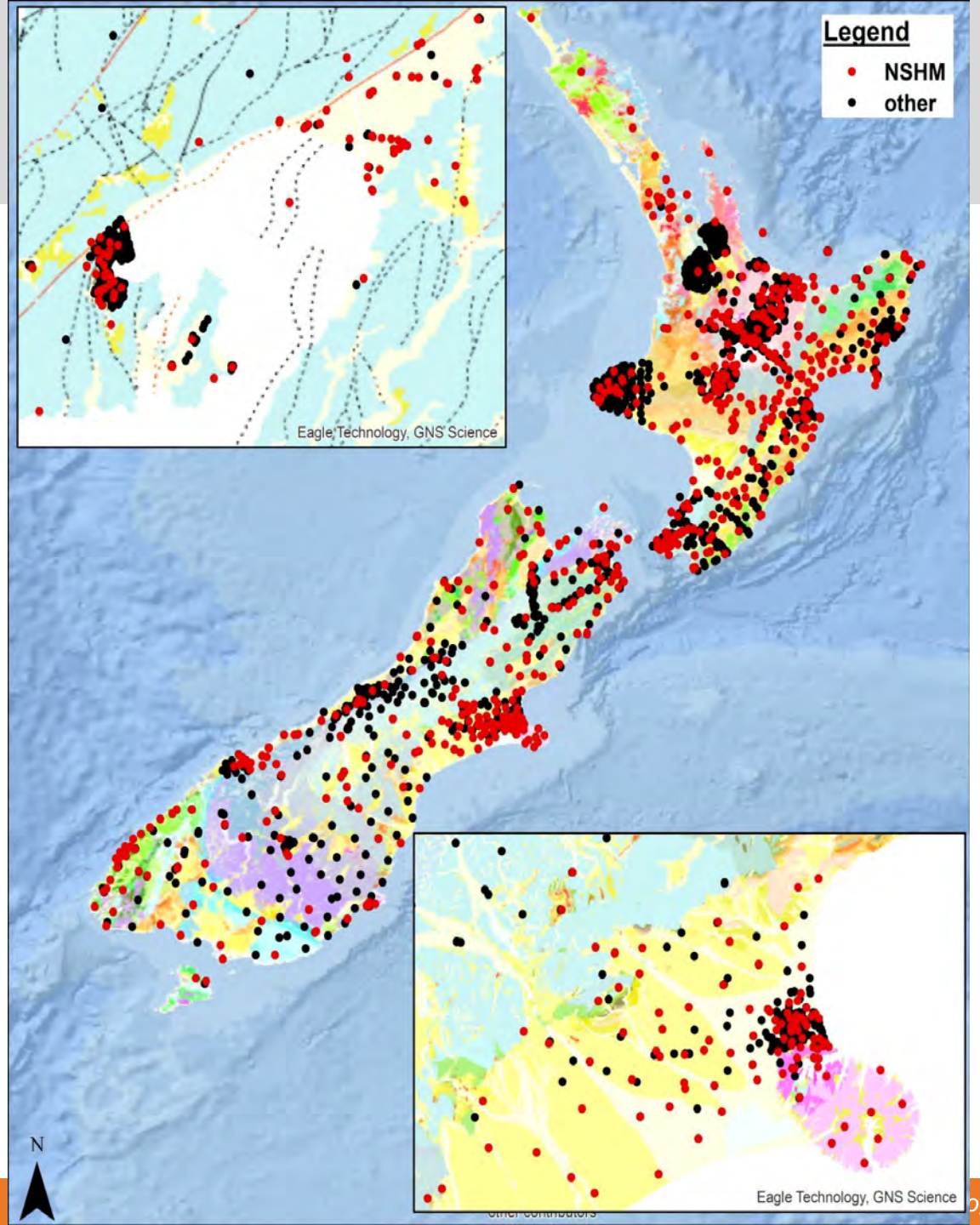
- Vs profiles useful for wider applications & analysis
  - Constrains site parameter estimates (e.g. Vs30, Z1.0) and basin velocity models /





Site Characterisation
T0 (fundamental site period)

- **Potential to significantly expand coverage beyond GeoNet station locations / develop national T0 map**

➢ Useful to constrain basin models & infer other basin depth parameters (e.g. Z1.0)

➢ Site period or related information from HVSR curves could be used directly in future GMMs/regional GMM adaptations considered in New Zealand