# Candidate Ground-Motion Models (GMMs) and Associated Hazard Sensitivities for New Zealand National Seismic Hazard Model (NSHM-2022)

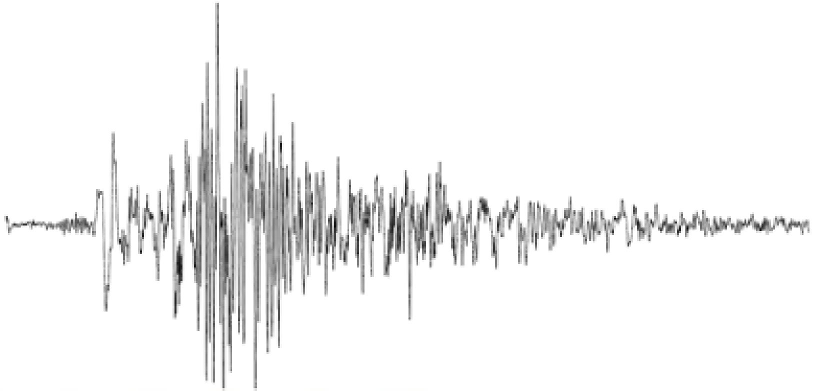
Te Tauira Matapae Pūmate Rū i Aotearoa
NSHM The New Zealand National Seismic Hazard Model
A GNS Science Led Research Programme

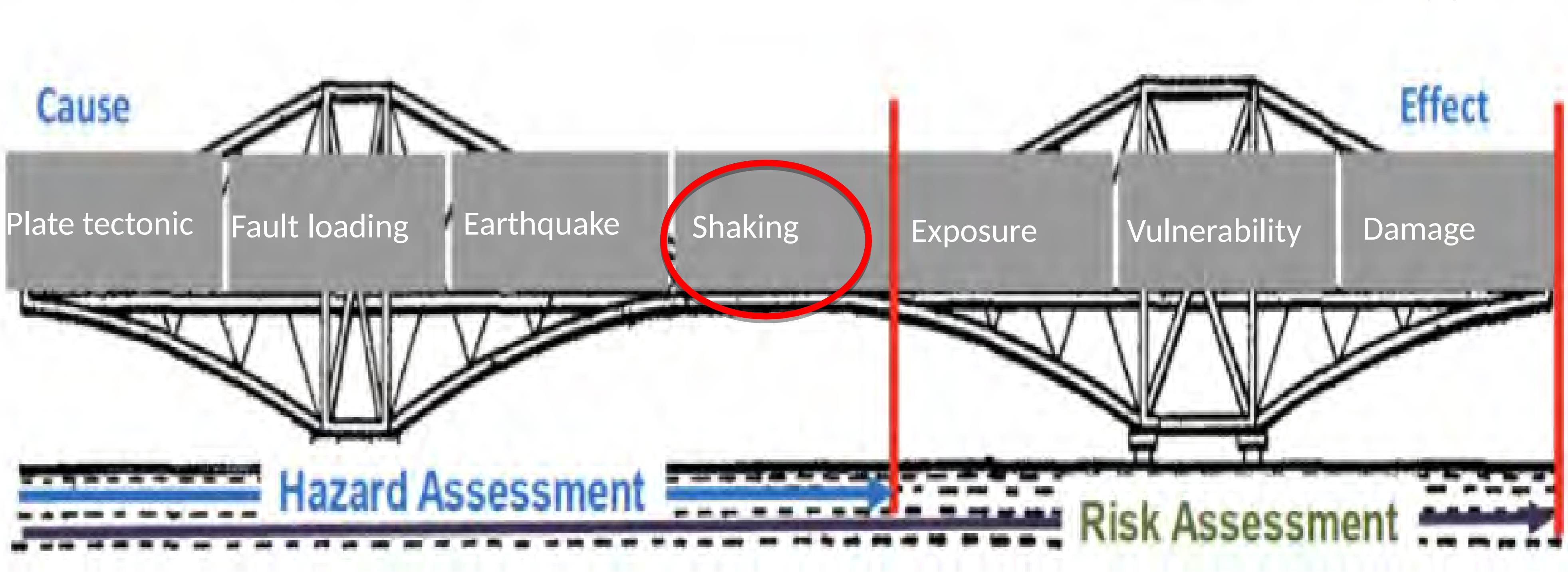
*E mahi ana me*
***In collaboration with***

*Ngā hoa tuku pūtea*
***Funding partners***

# Seismic Hazard Analysis

- **For future earthquakes:**
- How **strong will be the shaking**?
- And How often?

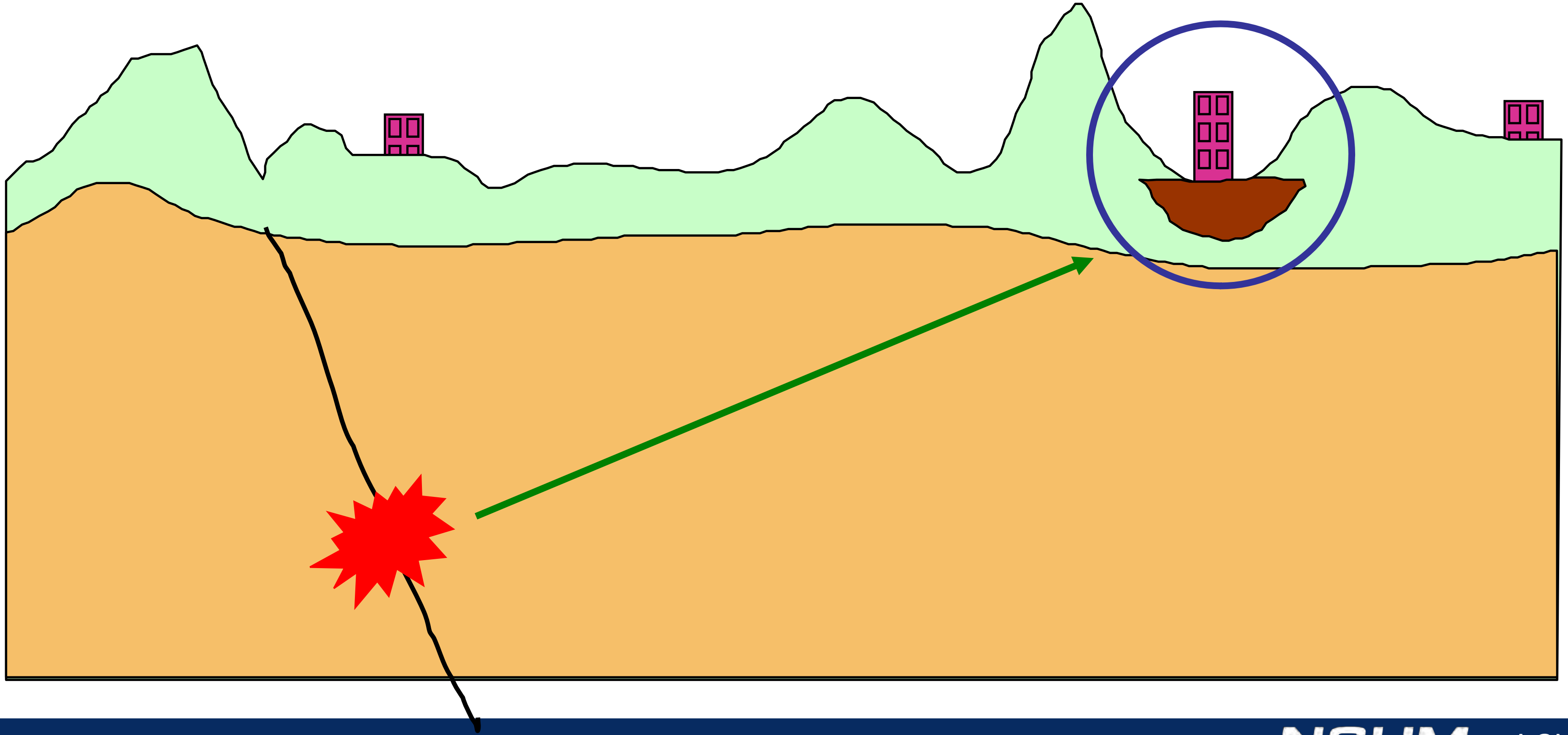




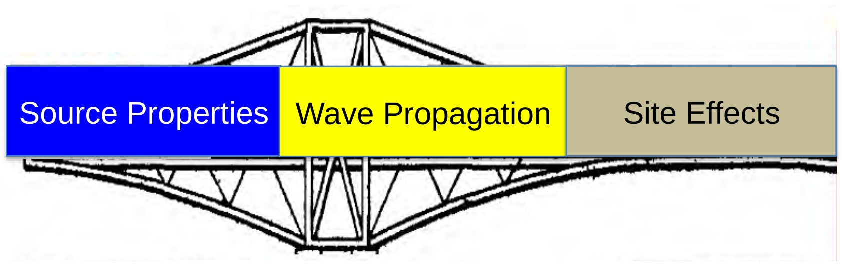
# Ground Motion Models: conceptual framework

Ground motion estimation

**Source + Path + Site**



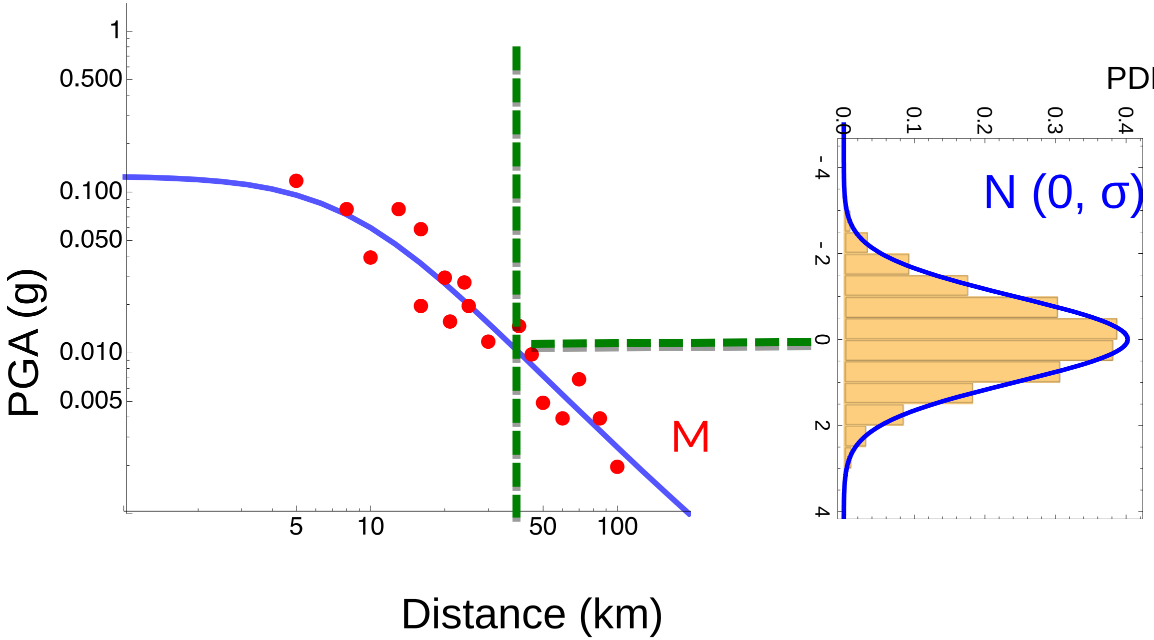
# A typical simple Ground Motion Model




$$lnY \sim a \times f(M) + b \times f(R) + c \times f(S) + \epsilon$$

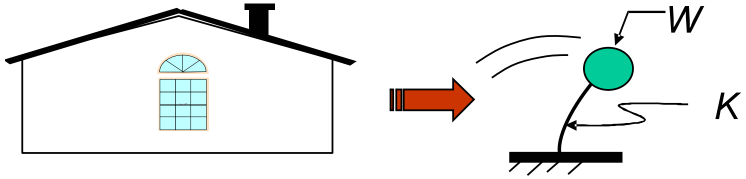
$$lnY \sim \mathcal{N}\left(\mu = f\left(\theta, M, R, S\right), \sigma\right)$$

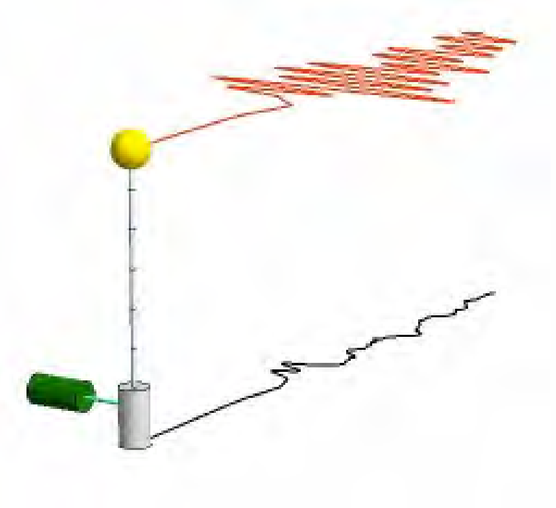
- Y = PGA, PGV, PGD or a **response spectral ordinate**
- M = Earthquake magnitude
- R = Any source-to-site distance measure
- S = Site condition
- ε = Residual




GMPEs are often derived for response spectral amplitudes, e.g. spectral acceleration.

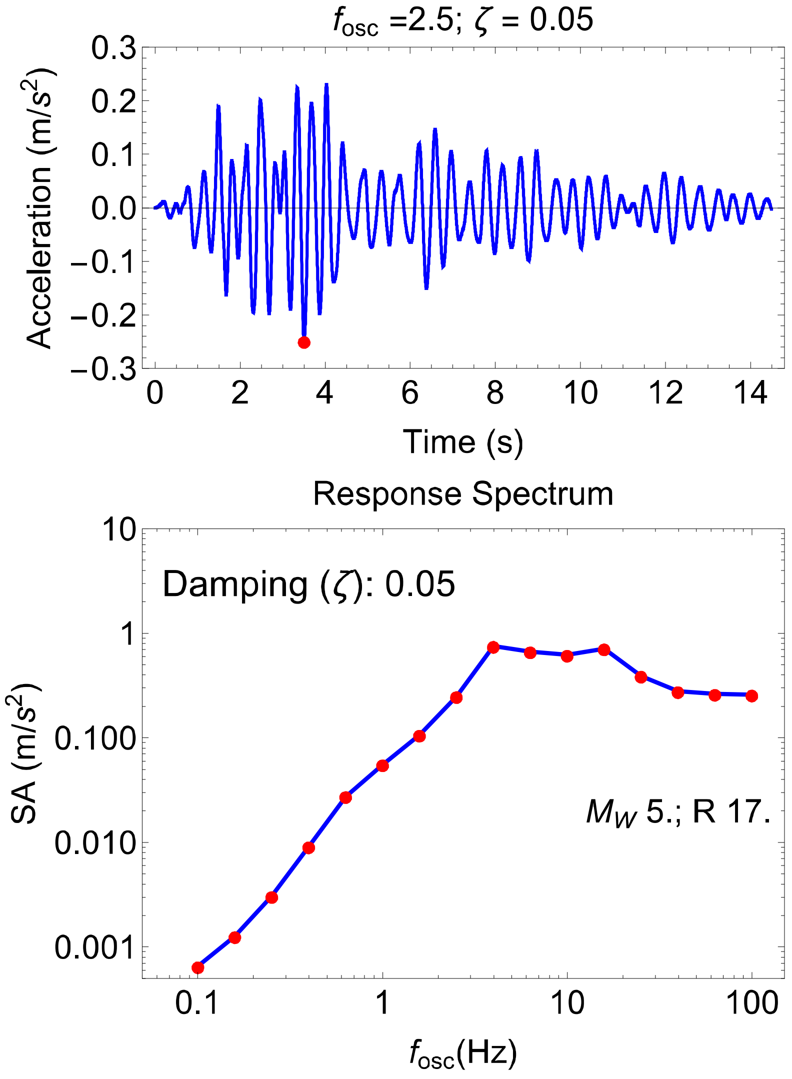
# Response Spectrum: Spectral Acceleration



SDOF (Single Degree of Freedom) Oscillator
Undamped natural frequency:

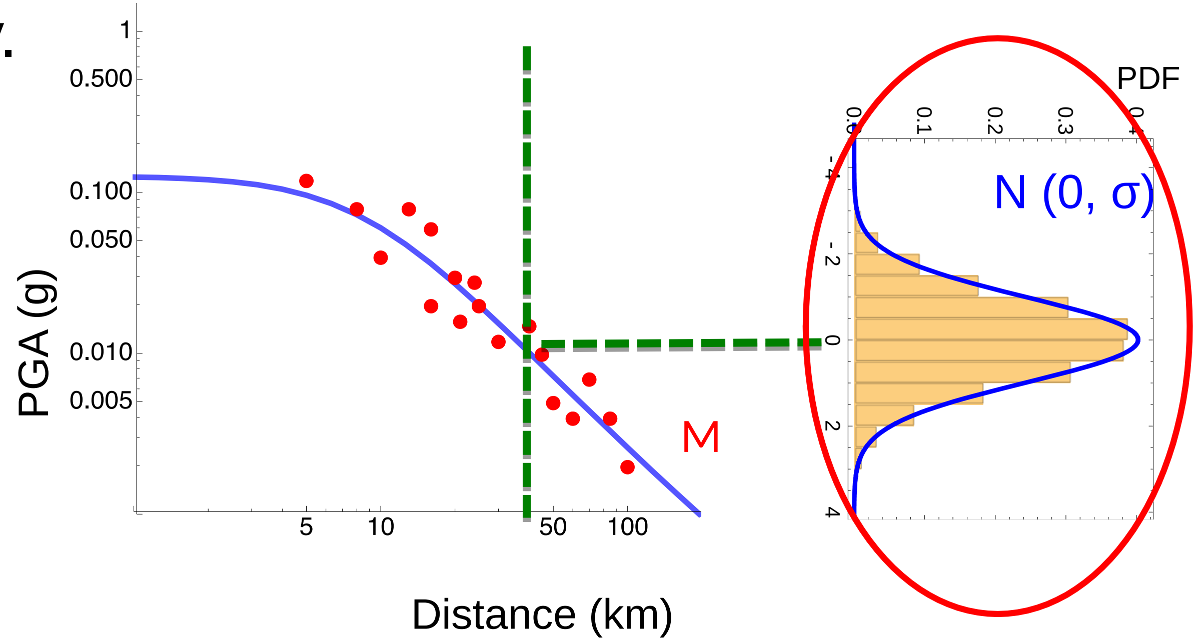
$$f_{osc} = \frac{1}{2\pi}\sqrt{\frac{k}{W/g}}$$




**NSHM-22 provides UHS forecasts for 5% of critical damping.**

# Uncertainty in hazard analysis

- Uncertainty is a key element of PSHA (NSHM)
- We usually dissect it in two components:
  - **Aleatory Uncertainty (Inherent randomness)**
  - **Epistemic Uncertainty (The error due to our ignorance!)**
- These two types of uncertainties are dealt differently hence affect hazard results differently.




**Aleatory Uncertainty**

# Uncertainty: Aleatory & Epistemic

- In practice it is difficult to separate these two types of uncertainties in **absolute sense**. It depends upon the context.
- For a model with simple parametrization the aleatory uncertainty can be large using a dataset.
- For a model with more complex parametrization the aleatory uncertainty will be reduced.
- However, for a more **complex model** the **epistemic uncertainty increases**.
  - As we add more (features) predictor variables in the model it may become difficult to fit the model. The estimated parameter becomes more uncertain.

# Candidate ground-motion models: Epistemic uncertainty

We try to capture this component of uncertainty by using multiple models in **Logic-Tree Framework keeping consistency with probability rules**.

## Crustal

| Model | Abbreviation |
| --- | --- |
| Atkinson (2022)-Backbone | |
| Stafford (2022)-Backbone | |
| Bradley (2013) | - |
| Abrahamson et al. (2014) | ASK (2014) |
| Boore et al. (2014) | BSSA (2014) |
| Campbell and Bozorgnia (2014) | CB (2014) |
| Chiou and Youngs (2014) | CY (2014) |

## Interface/Intraslab

| Model | Abbreviation |
| --- | --- |
| Atkinson (2022)-Backbone | |
| Abrahamson and Guelerce (2020) Global | AG20-GLO |
| Abrahamson and Guelerce (202) NZ | AG20-NZ |
| Kuehn et al. (2020) Global | KBCG20-GLO |
| Kuehn et al. (2020) NZ | KBCG20-NZ |
| Parker et al. (2021) Global | PSBAH21-GLO |

# Applicability of the Models: Crustal

| Model | Abbreviation | IM Period Range | Magnitude | Distance (km) | VS30 (m/s) |
|---|---|---|---|---|---|
| **Atkinson (2022)** | | **PGA-10s** | **~4.5– 8.0** | **0 – 400** | **180 – 1000** |
| **Stafford (2022)** | | **PGA-10s** | **~4.5– 8.0** | **0 – 300** | **180 – 1500** |
| Abrahamson et al. (2014) | **ASK14** | PGA-10s, PGV | 3.0 – 8.5 | 0 – 300 | 180 – 1500 |
| Boore et al. (2014) | **BSSA14** | PGA-10s, PGV | 3.0 – 8.5 | 0 – 400 | 150 – 1500 |
| Campbell and Bozorgnia (2014) | **CB14** | PGA-10s, PGV | 3.3 – 8.5 | 0 – 300 | 150 – 1500 |
| Chiou and Youngs (2014) | **CY14** | PGA-10s, PGV | 3.5 – 8.5 | 0 – 300 | 180 – 1500 |
| Bradley (2013) | | PGA-10s, PGV | 3.9 –7.6 | 0 – 400 | 180 – 1500 |

# Applicability of the Models: Interface

| Model | Abbreviation | IM Period Range | Magnitude | Distance (km) | VS30 (m/s) |
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| Atkinson (2022) | | PGA-10s | 4.5 – 7.0 | 0 – 400 | 180 – 1000 |
| Abrahamson & Guelerce (2020) Global | **AG20-GLO** | PGA-10s, PGV | 6.0 – 9.5 | 0 – 500 | 150 – 1500 |
| Abrahamson & Guelerce (2020) New Zealand | **AG20-NZ** | PGA-10s, PGV | 6.0 – 9.5 | 0 – 500 | 150 – 1500 |
| Kuehn et al . (2020) Global | **KBCG20-GLO** | PGA-10s, PGV | 5.0 – 9.5 | 10 – 1000 | 180 – 1500 |
| Kuehn et al . (2020) New Zealand | **KBCG20-NZ** | PGA-10s, PGV | 5.0 – 9.5 | 10 – 1000 | 150 – 1500 |
| Parker et al. (2021) | **PSBAH21-GLO** | PGA-10s, PGV | 4.0 – 9.5 | 20 – 400 | 150 – 2000 |

# Applicability of the Models: Intraslab

| Model | Abbreviation | IM Period Range | Magnitude | Distance (km) | VS30 (m/s) |
|---|---|---|---|---|---|
| **Atkinson (2022)** | | **PGA-10s** | **4.5 – 7.0** | **0 – 400** | **180 – 1000** |
| Abrahamson & Guelerce (2020) Global | **AG20-GLO** | PGA-10s, PGV | 5.0 – 8.0 | 10 – 500 | 150 – 1500 |
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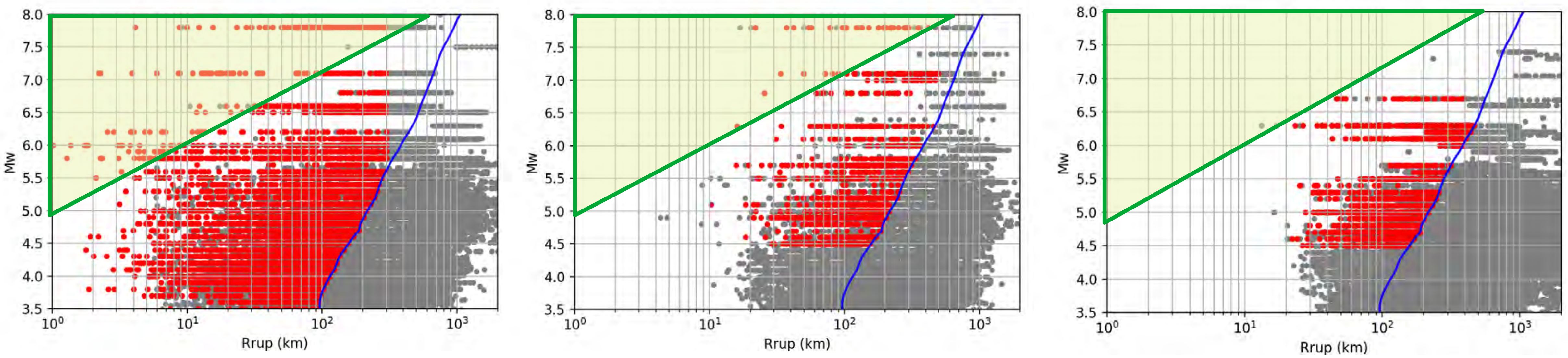
| Parker et al. (2021) | **PSBAH21-GLO** | PGA-10s, PGV | 4.5 – 8.5 | 35 – 1000 | 150 – 2000 |

# Ground-motion model testing and evaluation

Recently compiled NZ strong motion database is considered for testing and evaulation of candidate GMMs.

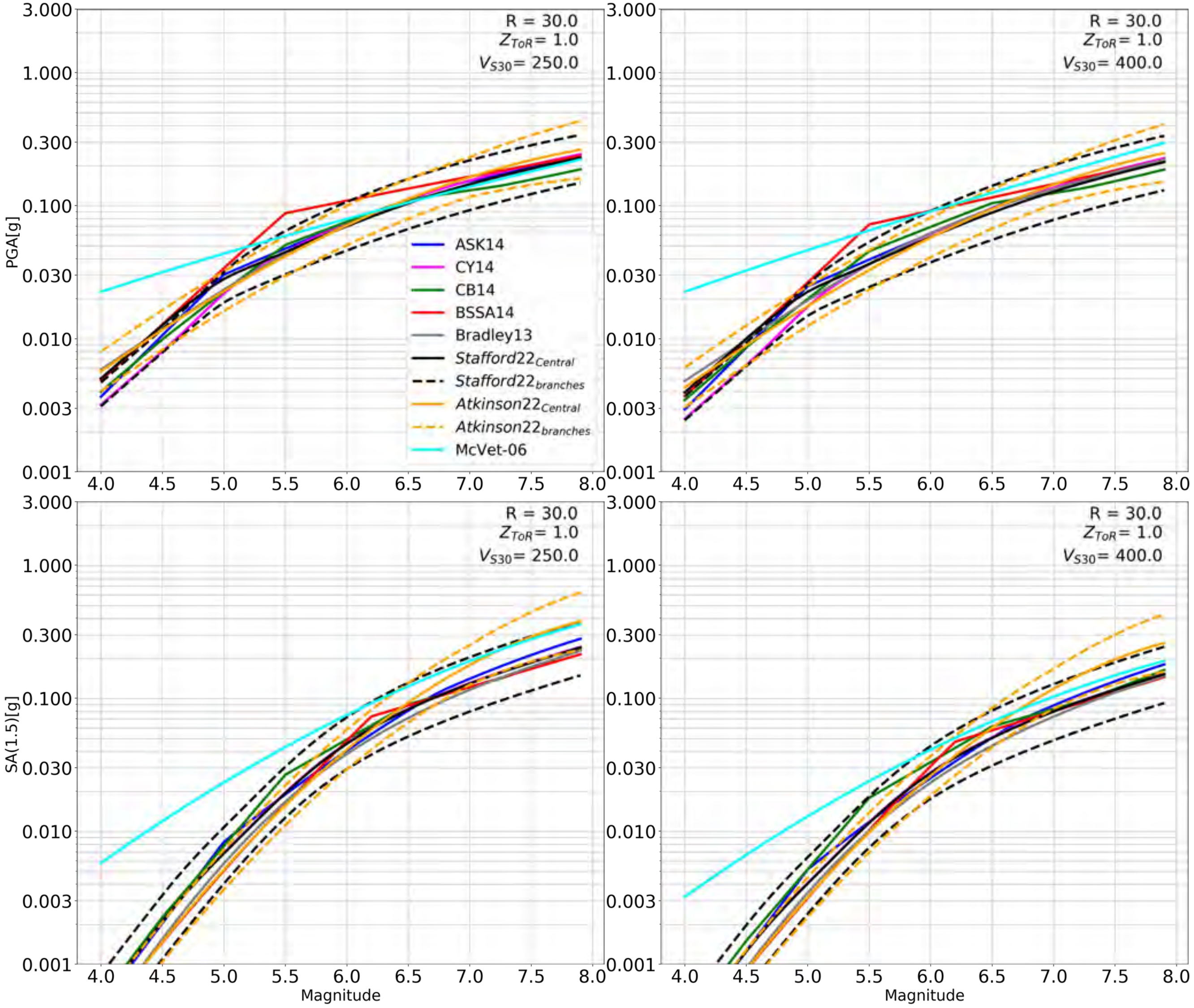
Not enough recorded data in the magnitude and distance range that dominate hazard in New Zealand.

Crustal Interface Slab

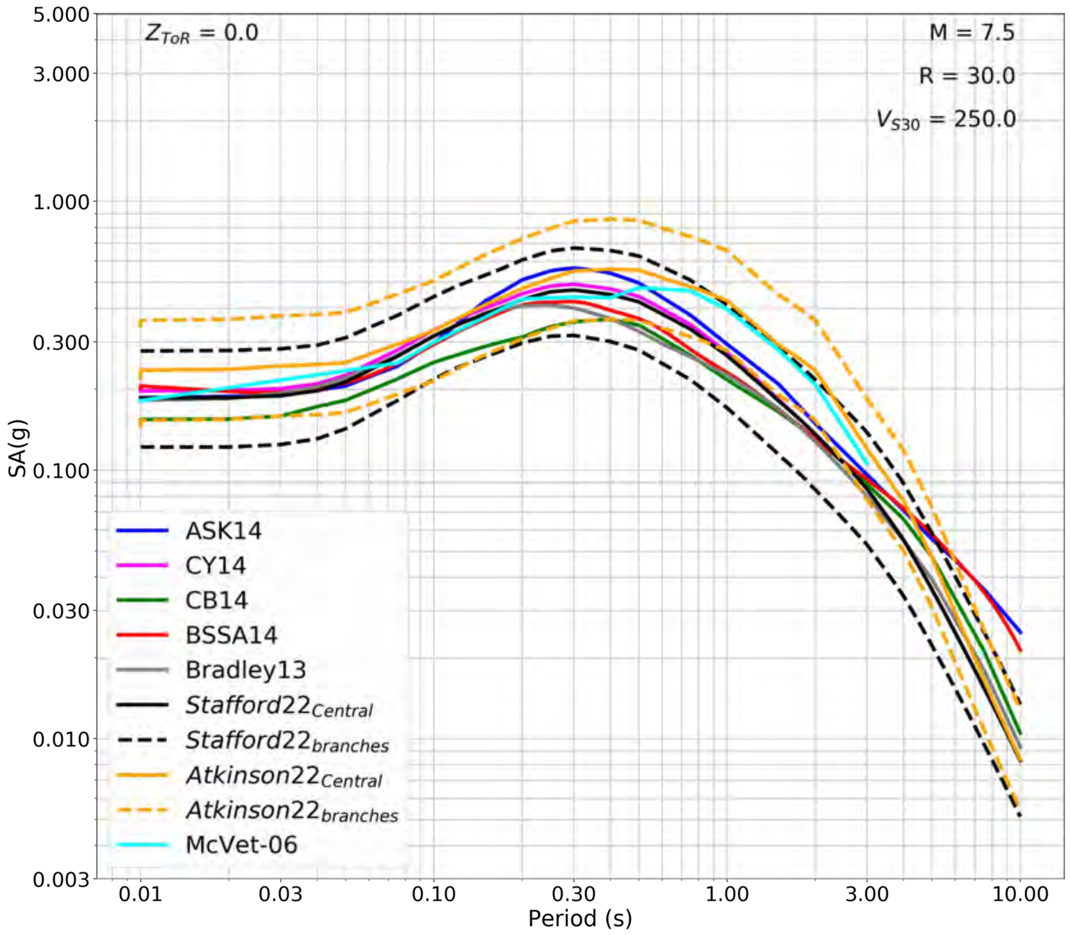



Lee et al. 2022 GNS report

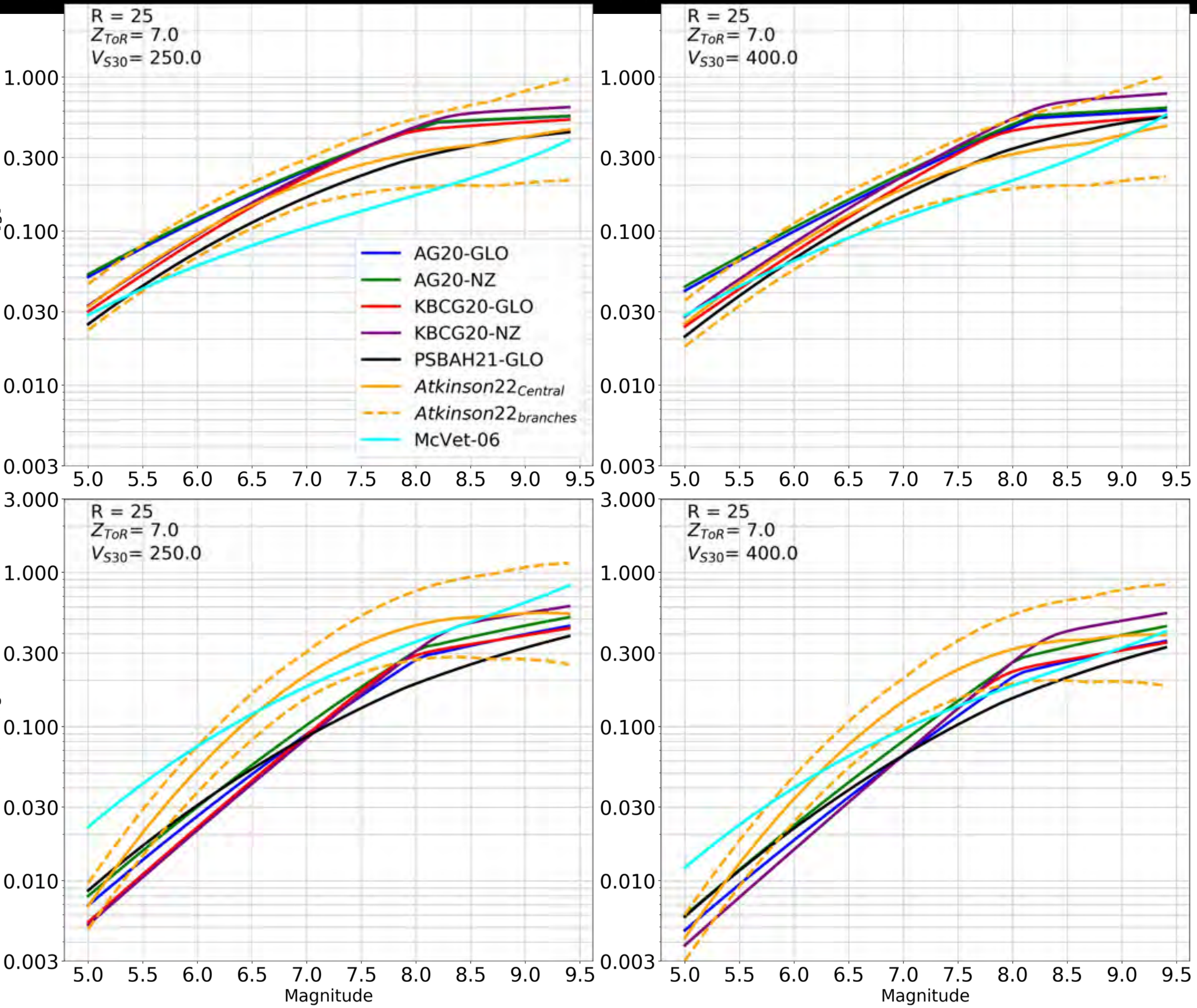
# Candidate Ground-Motion Models Evaluation: Crustal



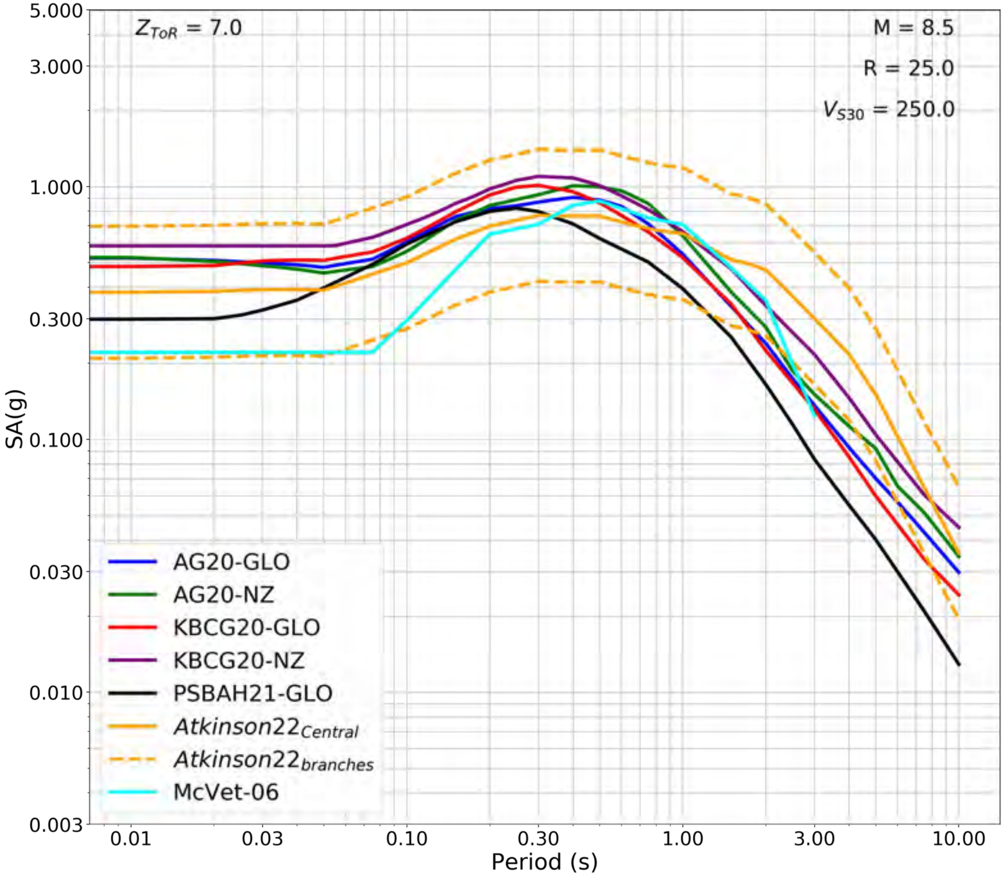

## Relevant for Wellington



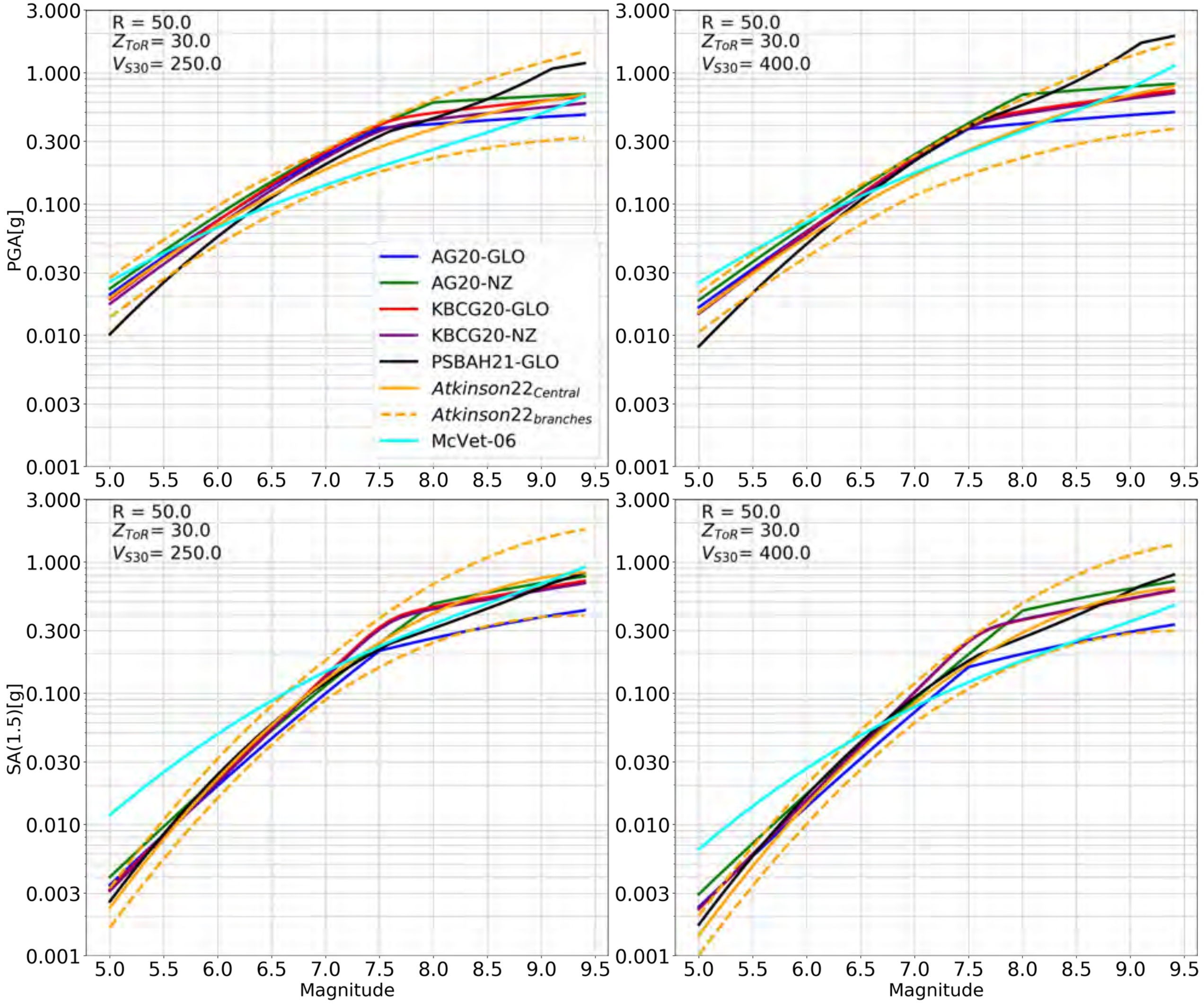
# Candidate Ground-Motion Models Evaluation: Interface

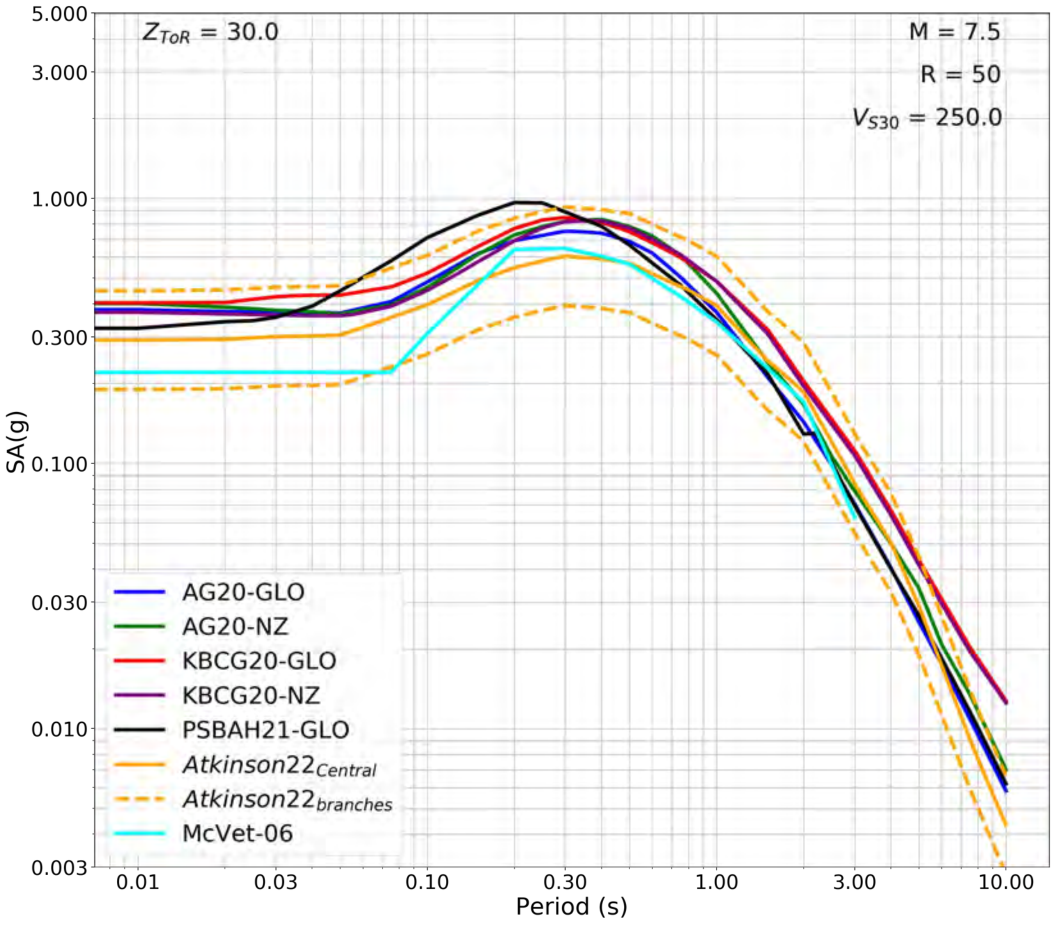



## Relevant for Wellington



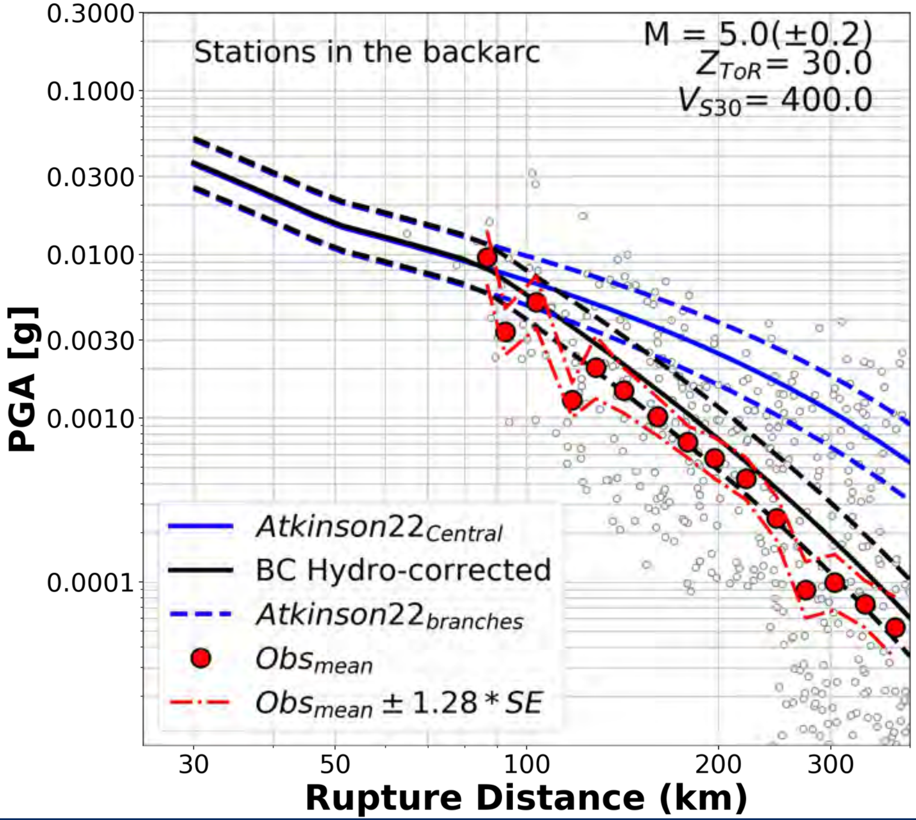
# Candidate Ground-Motion Models Evaluation: Intraslab

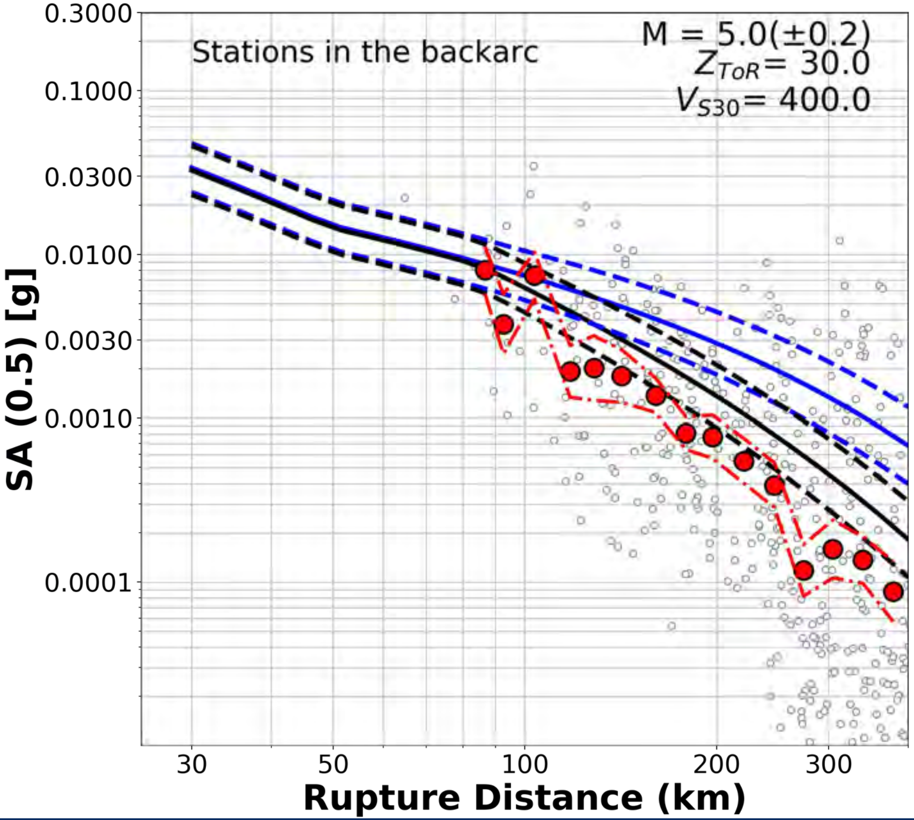


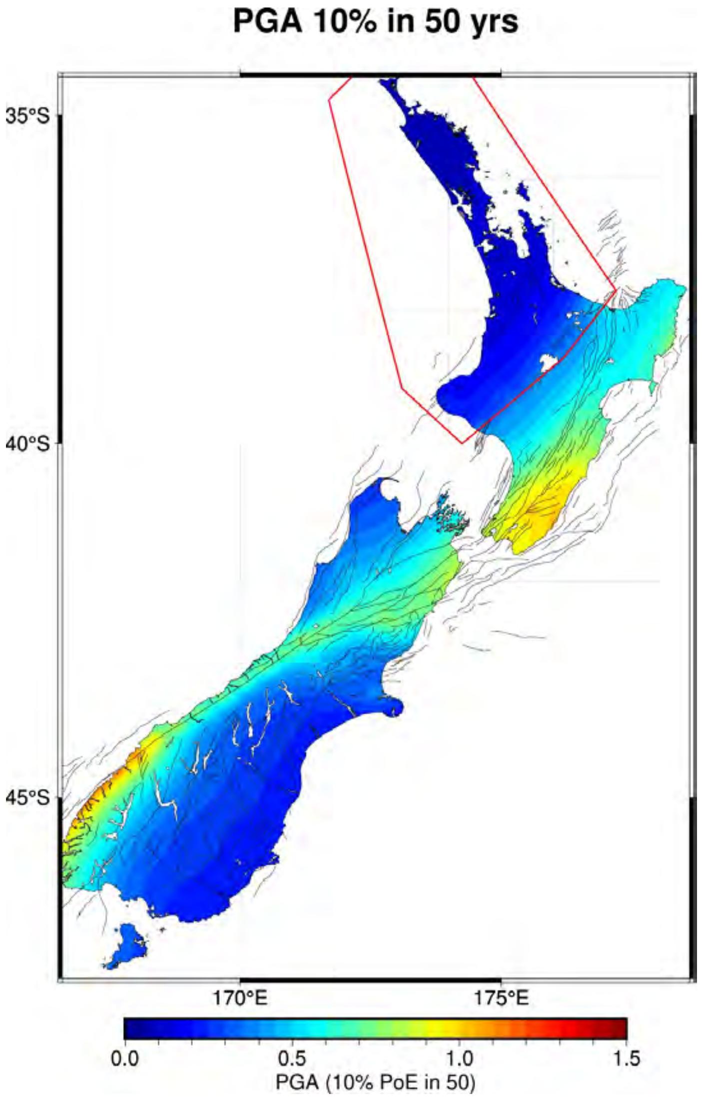



# NZ Specific corrections: backarc attenuation

- The NZ-specific backbone model and none of the NGA-sub models include separate adjustments for backarc attenuation.
- Currently, in NSHM-22 this is achieved by applying **BC Hydro** adjustment factor (Abrahamson et al., 2016).

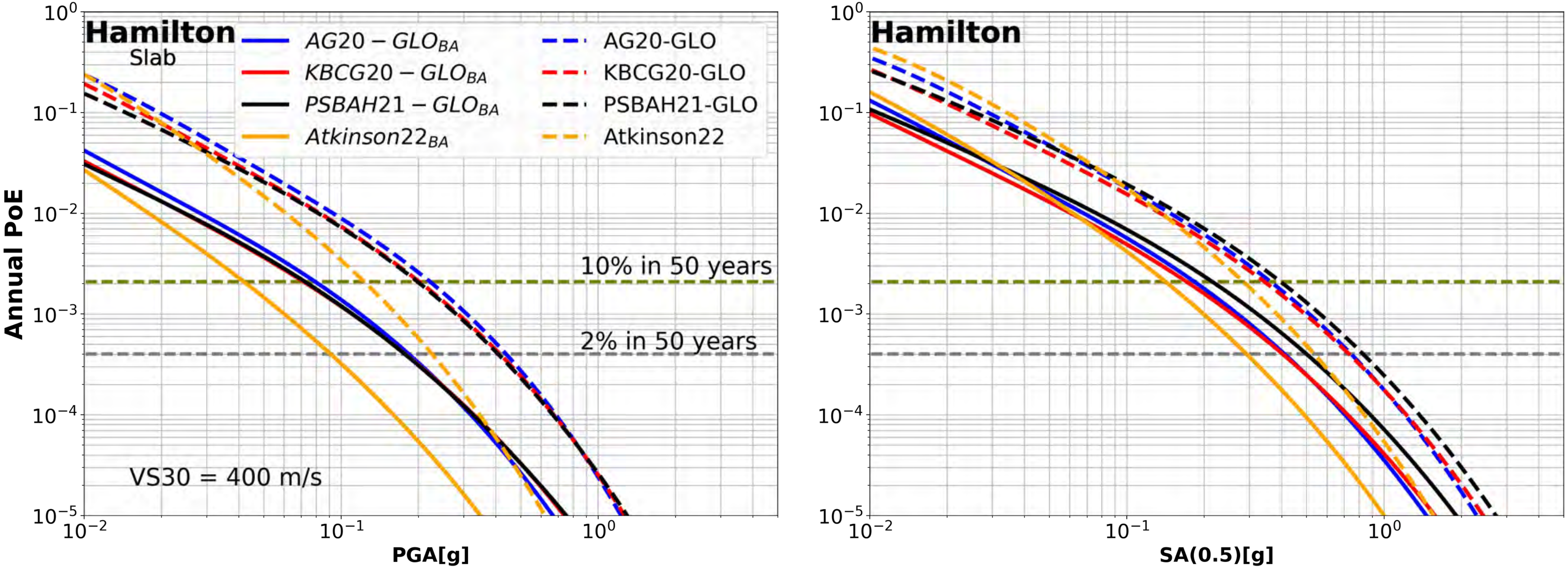


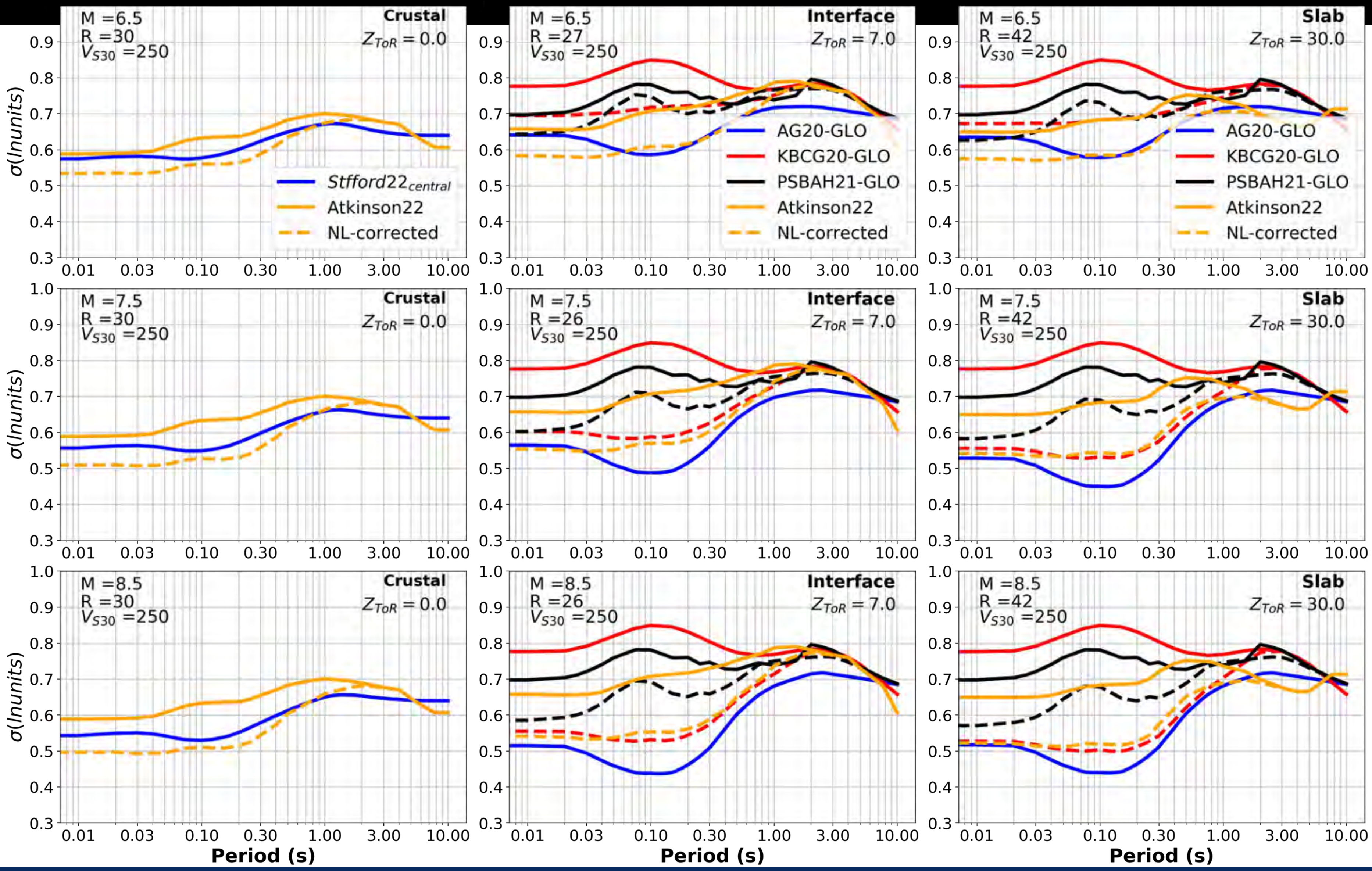



# Backarc attenuation: Hazard Sensitivity

The backarc attenuation correction was applied only in subduction intraslab models which results in significant lowering of hazard in the western part of the north island.



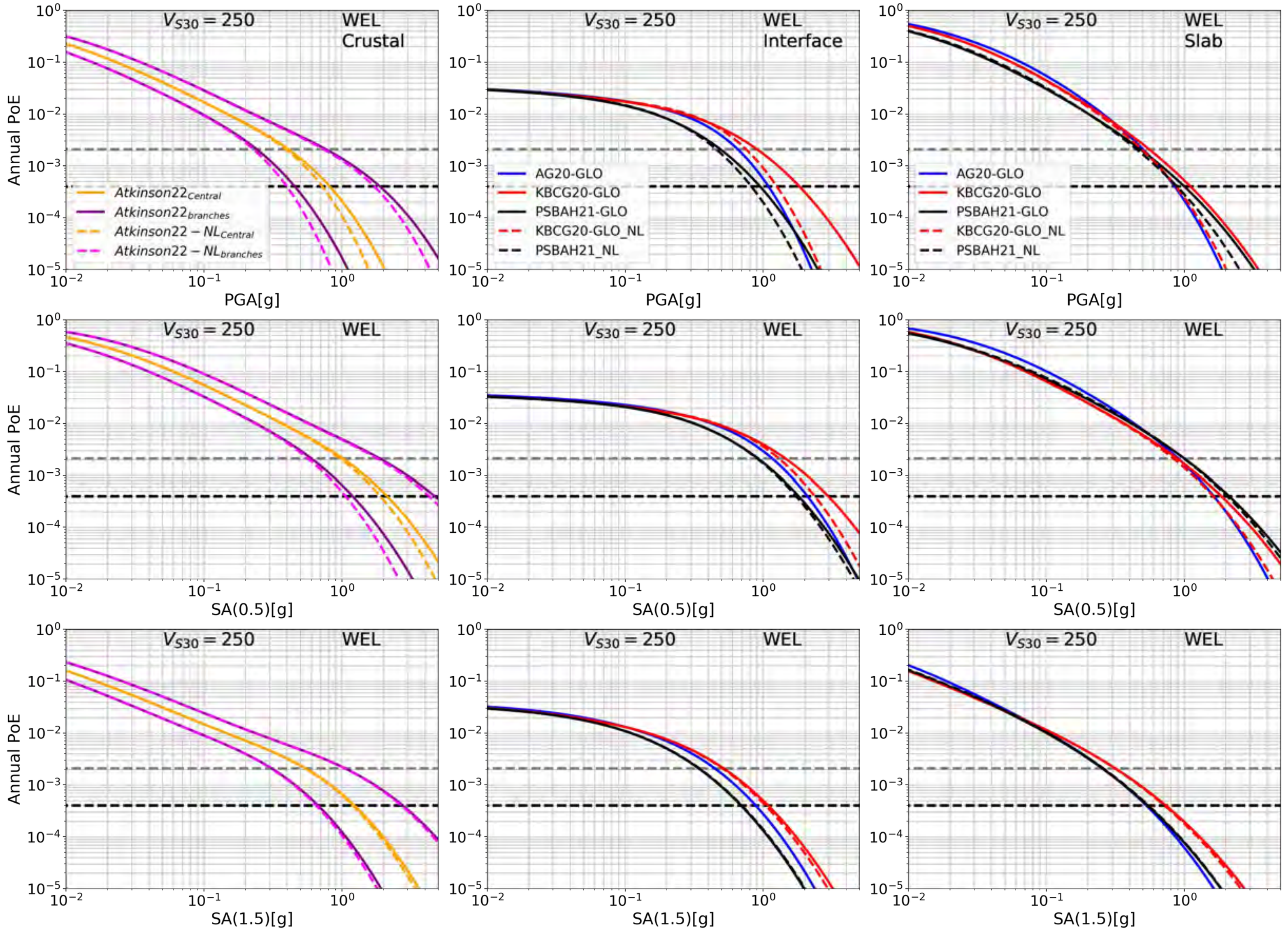
# Correction in Sigma for Nonlinear soil response




It was observed that NGA-sub models KBCG20 and PSBAH21 along with NZ backbone model of Atkinson 2022 do not account for reduction in sigma due to soil nonlineairty.

Hence adopting the **AG20** approach the soil NL correction was applied.

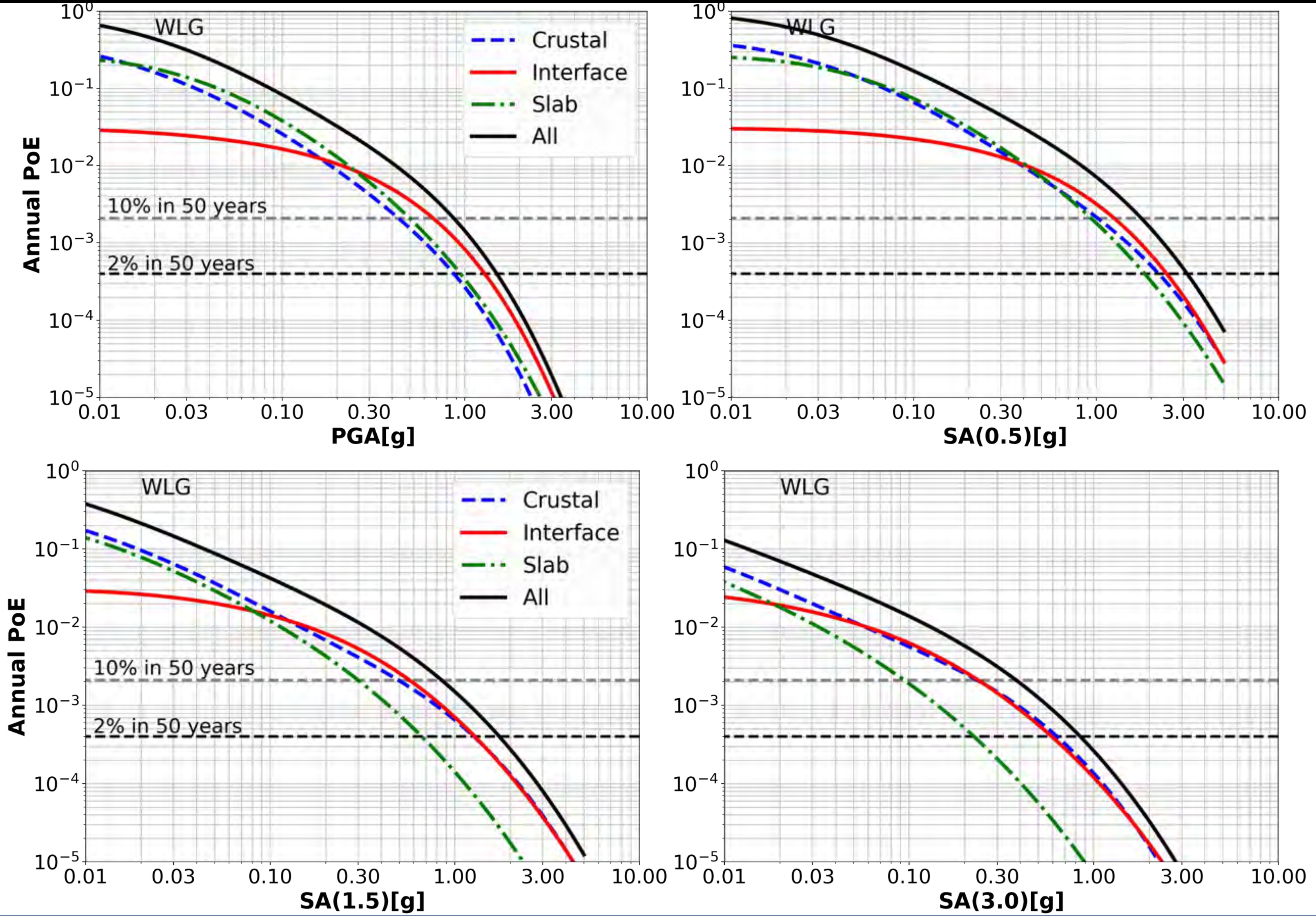
# Sigma for NL soil response: Hazard Sensitivity




## Wellington

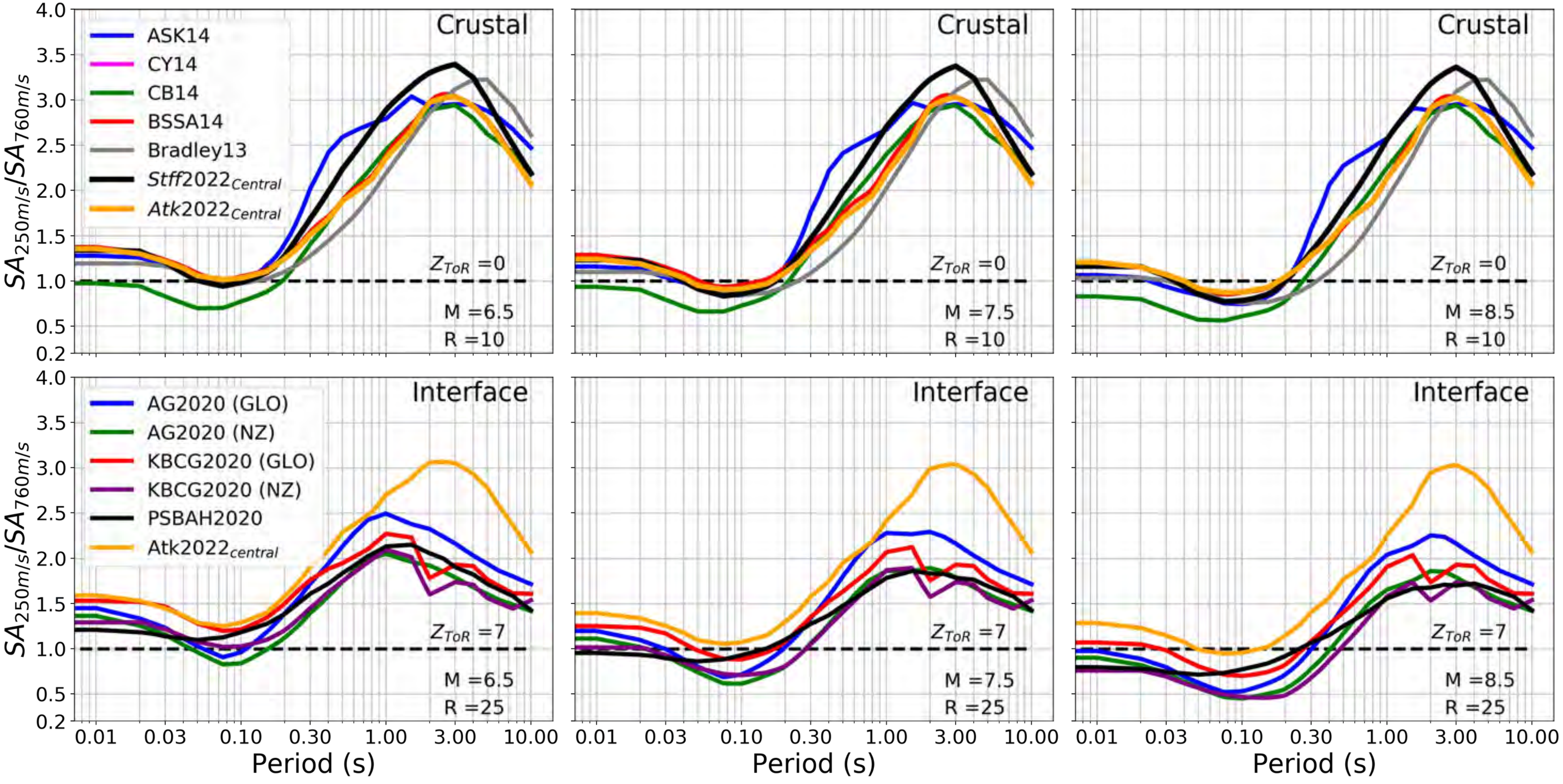
**At shorter periods**: the adjustment for soil nonlinear response in aleatory uncertainty results in lower hazard mainly at low probability ground motions.

# Hazard Sensitivity in terms of Sources: Wellington




- At shorter periods and at lower probabilities major contribution comes from interface sources.
- At longer periods and at lower probabilities major contribution comes from interface sources as well as crustal sources.

# Site-term in the Ground Motion Models: VS30



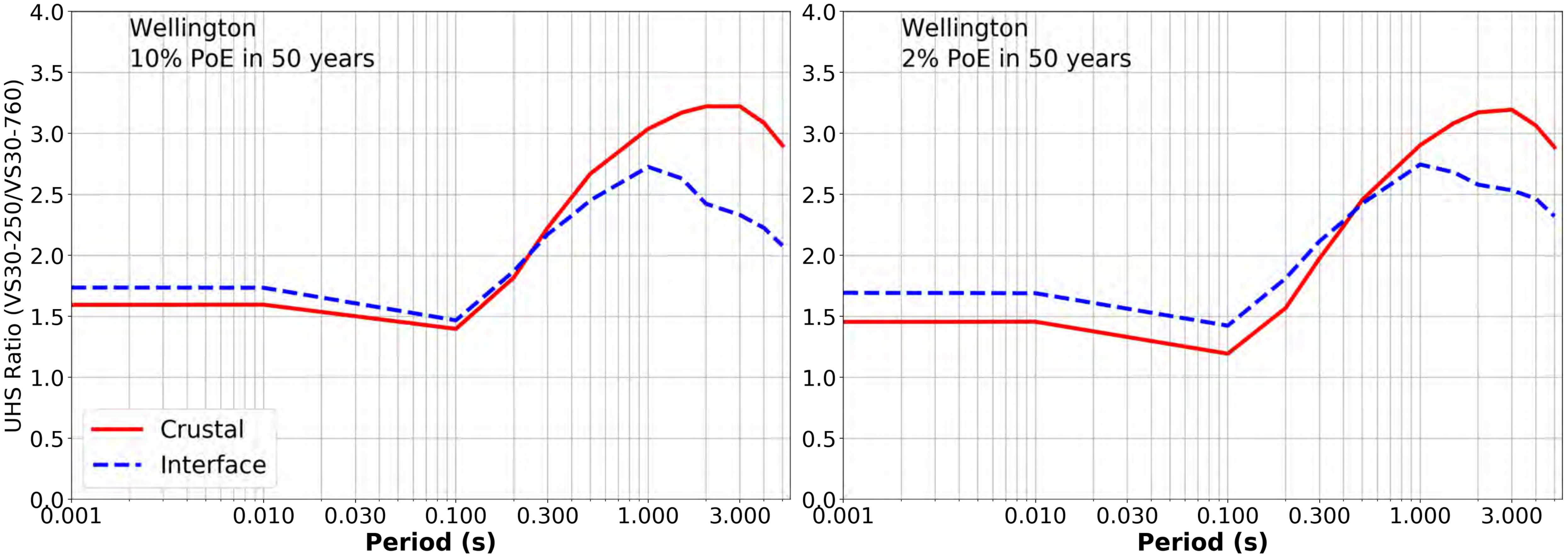

- Differences due to tectonics.
- Databases

Scenario dependence and nonlinearity

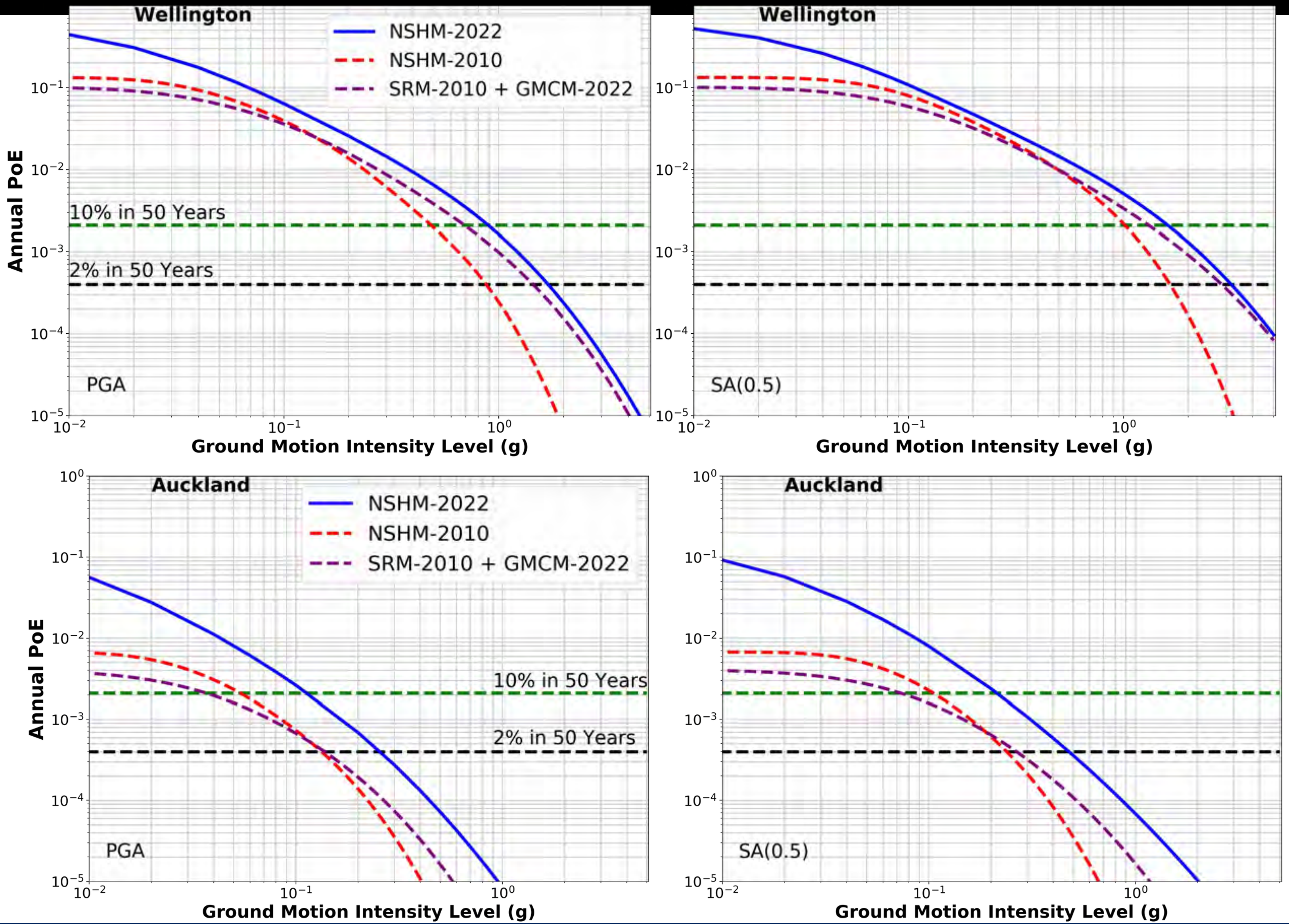
**A VS30 based site-term is used by all the models.**

# Hazard Sensitivity in terms of Site-effects: Wellington

## Ratio of Uniform Hazard Spectra for different types of Sources



# Hazard Sensivity with respect to NSHM-2010 GMCM




In the high seismicity areas such as Wellington the update in ground-motion models is the major driver of the change in seismic hazard.

Whereas at low seismicity areas such as in Auckland the major change comes from update in seismicity rate models (SRM) causes the change.

# Summary

- A hybrid approach that consists backbone models and weights on models approach.
- For **testing and evaluation** of the models **not enough data in the magnitude range that control** hazard in New Zealand. Hence, comparison of median predictions and aleatory uncertainty was performed.
- NZ backbone model and NGA-Sub Models do not differentiate **between fore-arc and backarc attenuation of ground motion with distance**.
- **BC Hydro adjustment factor was applied** which appears to be consistent with the data as a first order approximation.
- In KBCG20 and PSBAH21 models **aleatory uncertainty was adjusted to account for nonlinear soil response**.
- Further **epistemic branches were considered** on NGAWest2 crustal and NGA-Sub models.

# Summary of NGA-Subduction Data

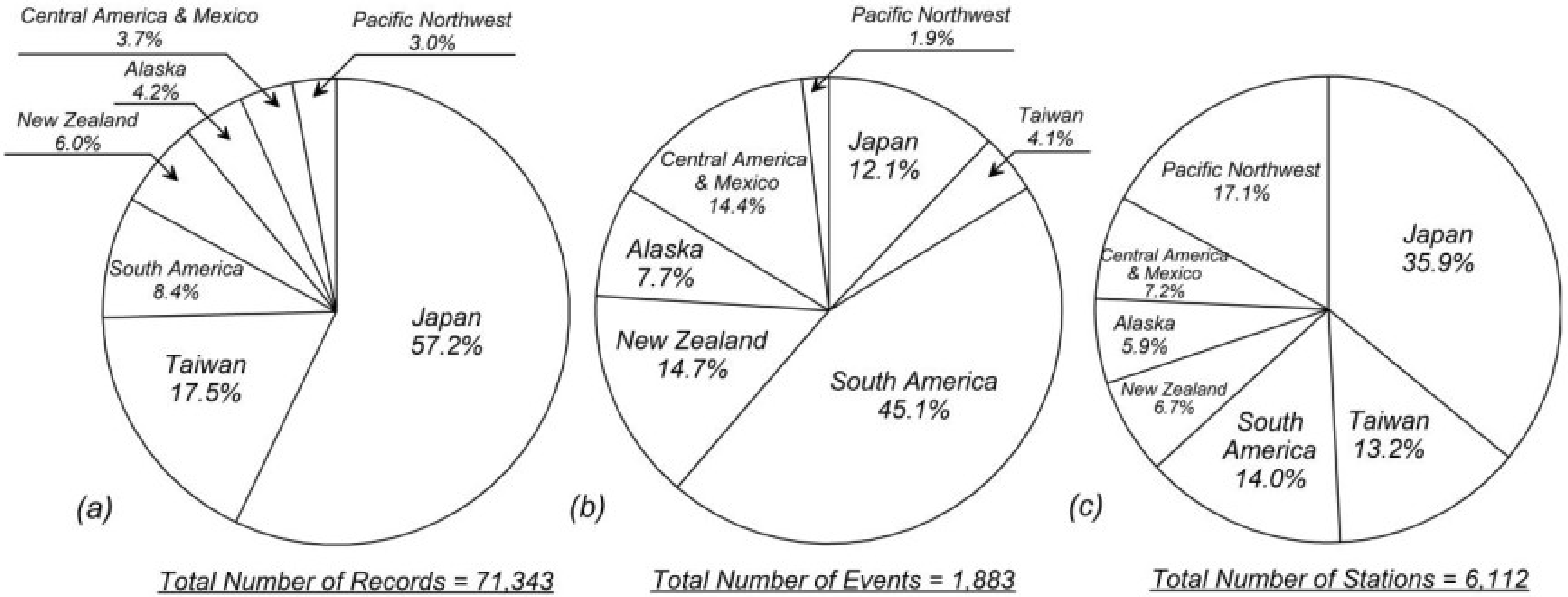
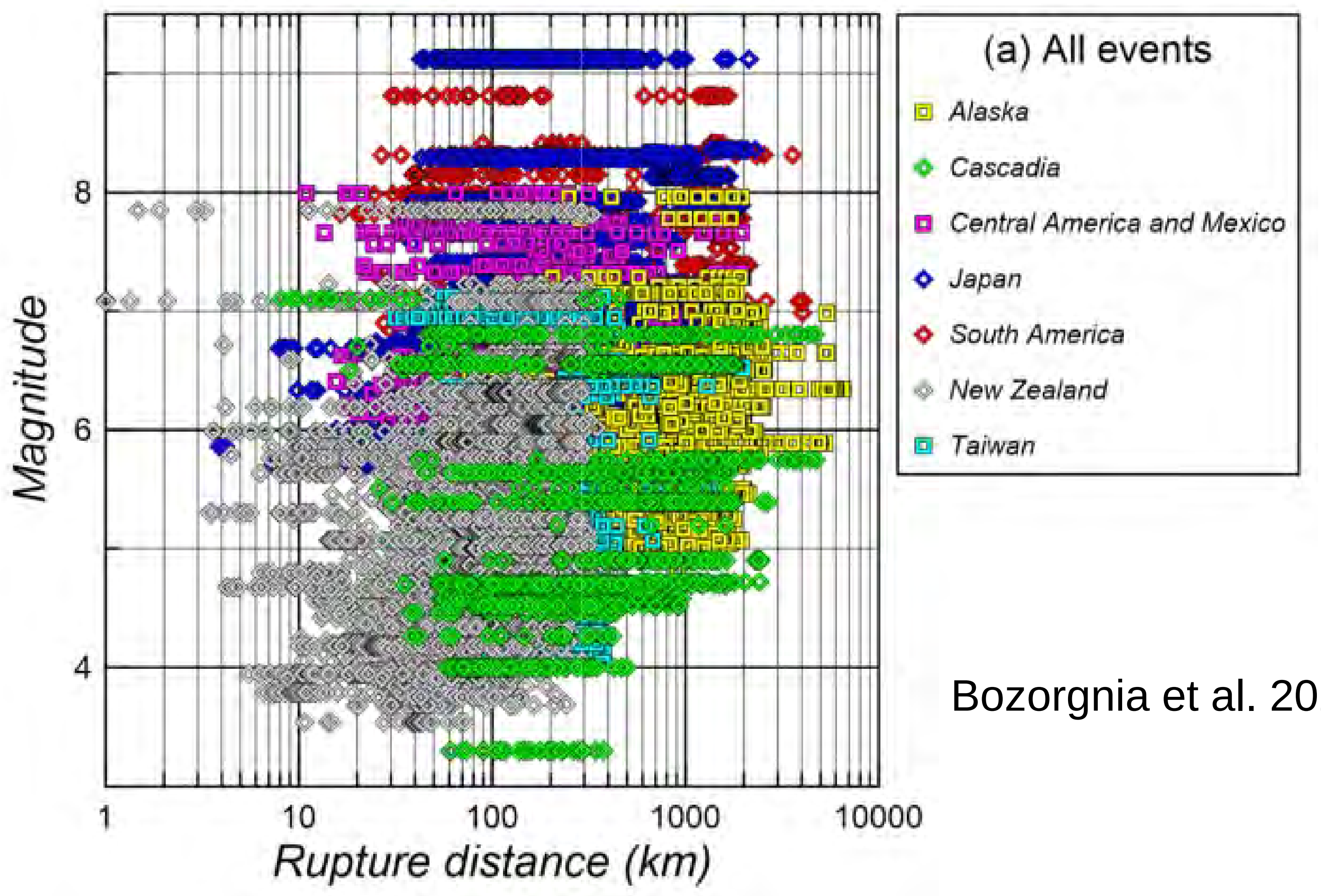



Figure 2. Regional distribution of the NGA-Sub database, (a) number of recordings, (b) number of events, (c) number of stations.

Kishida et al. 2021

# Summary of NGA-Subduction database




Bozorgnia et al. 2020

- The larger magnitude events are mainly from South America and Japan.
- **In terms of measured VS30 and basin depth parameters (Z1.0 and Z2.5)** the database is dominated by data from Japan.

# Basin depth adjustments AG20: Seattle basin