Are ground motions in Australia different between cratonic and non-cratonic regions, and different from global models?

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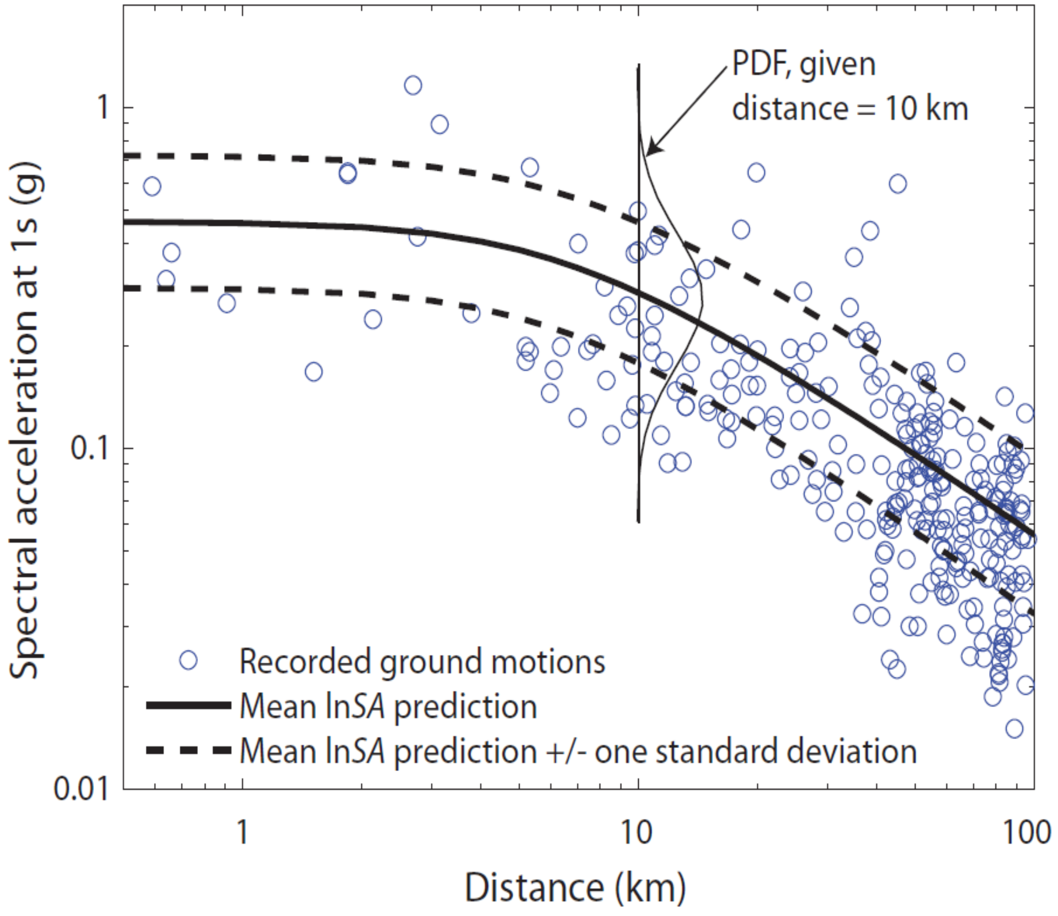
Introduction

- Ground motion models (**GMMs**) estimate the ground motion and its variability as a function of the distance from a causative fault, earthquake magnitude, and other parameters.
- GMMs underpin the seismic hazard results and drive the design ground motions in future engineering guidelines and for infrastructure projects.



Baker, J. W., Bradley, B. A., and Stafford, P. J. (2021).

Introduction

- In Australia, there is a relative paucity of data from which to develop empirical GMMs, and this **contributes significantly to the total uncertainty** in the probabilistic seismic hazard analyses (PSHAs).
    - Including Geoscience Australia's 2023 National Seismic Hazard Assessment (NSHA23; Allen et al, 2023; 2024)
- NSHA23 and others use Australia-specific GMMs, supplemented with GMMs developed for other regions and from simulations.
    - NSHA23 used an expert elicitation workshop with data-driven GMM selection
    - Consultants often use judgment in selecting GMMs

Introduction

With the aim of improving future ground motion studies in Australia, we focused on two questions:

Q1. In what ways, if any, do ground motions from non-cratonic region earthquakes differ from those of cratonic earthquakes in Australia?

Q2. Are the NGA-East and NGA-West2 GMMs, which were developed for use in eastern North America and in tectonically active regions of the world respectively, applicable in Australia, and if so, in which regions of Australia?

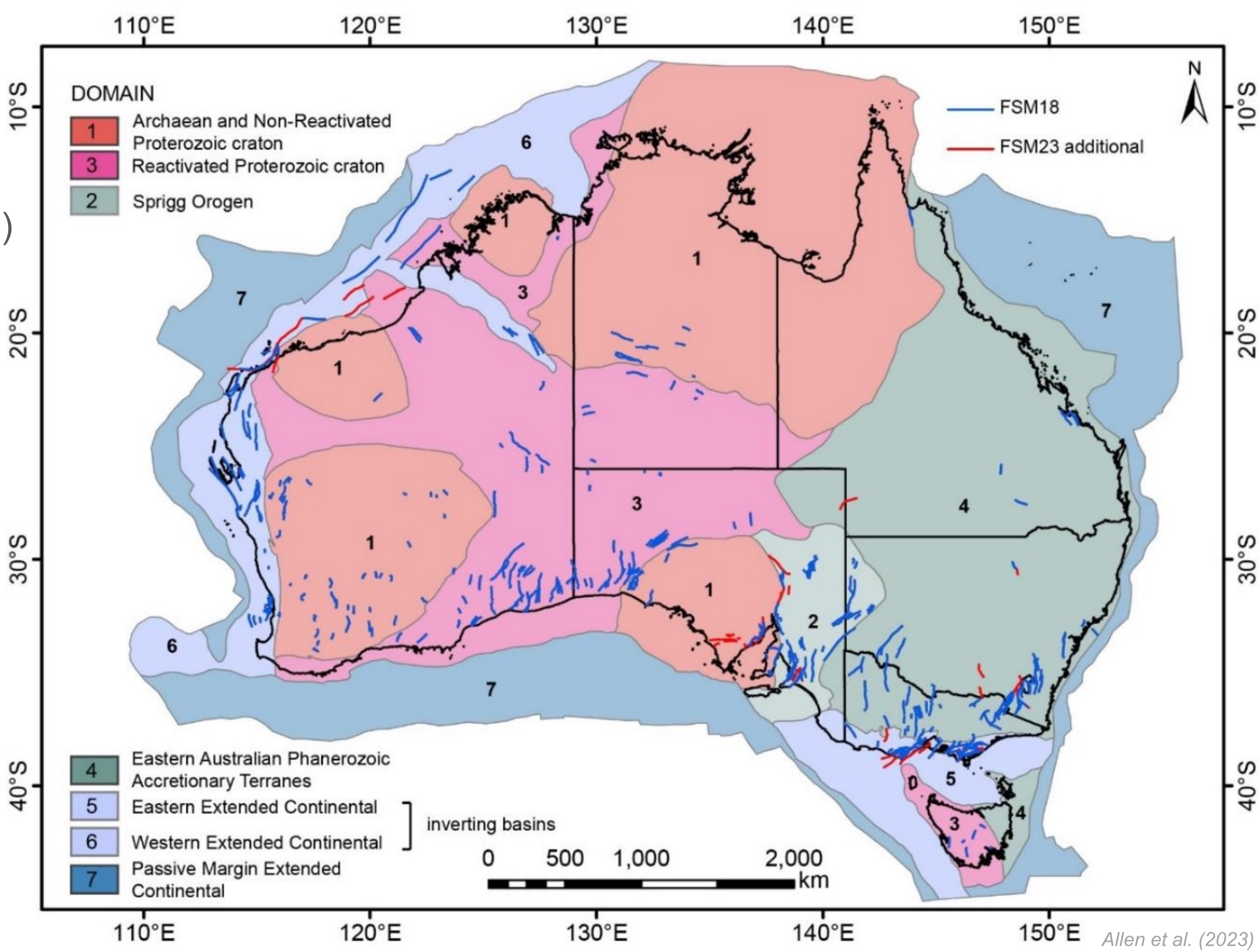
Neotectonic domains

model of Clark et al. (2012)

NSHA23 GMM logic trees

cratonic: red-pink

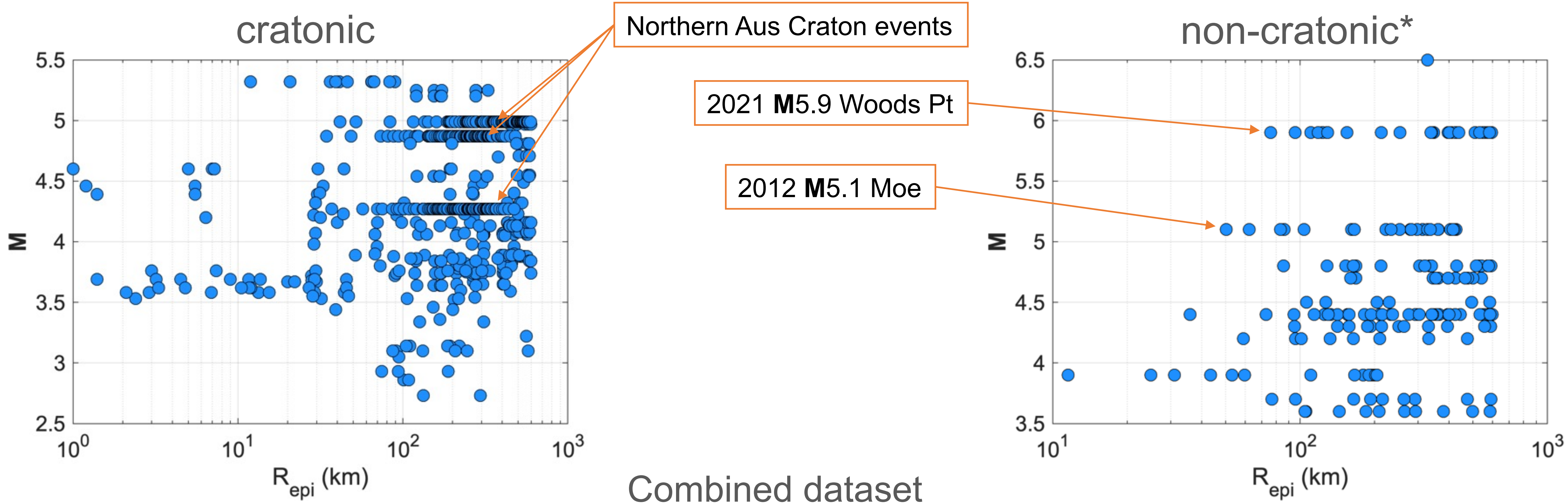
non-cratonic: green-blue



Allen et al. (2023)

*Data courtesy of Geoscience Australia

Ground Motion Data



<u>Combined dataset</u>

733 records from 98 events,

313 unique stations with R < 600 km

Evaluation of GMMs

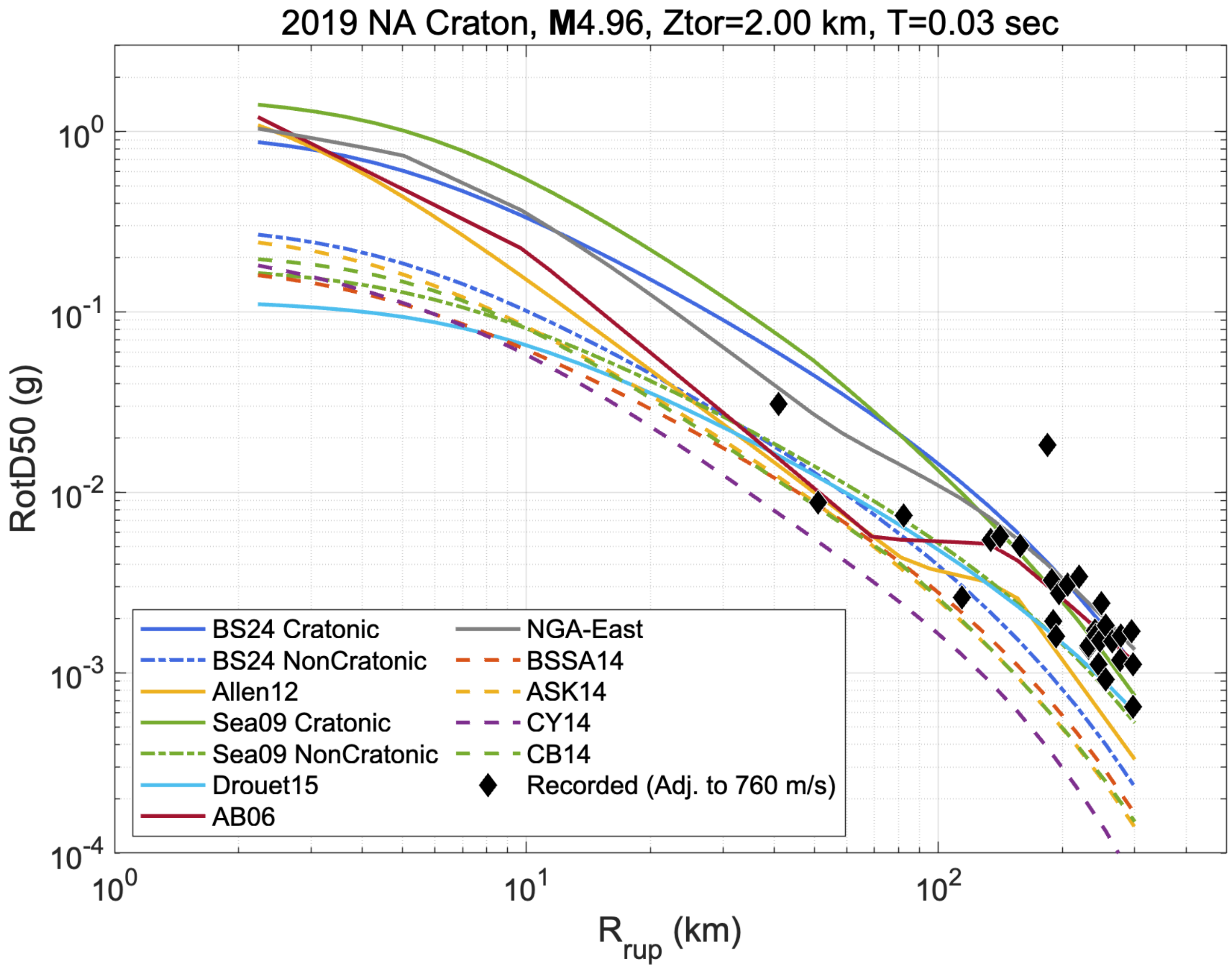
NSHA23 GMMs

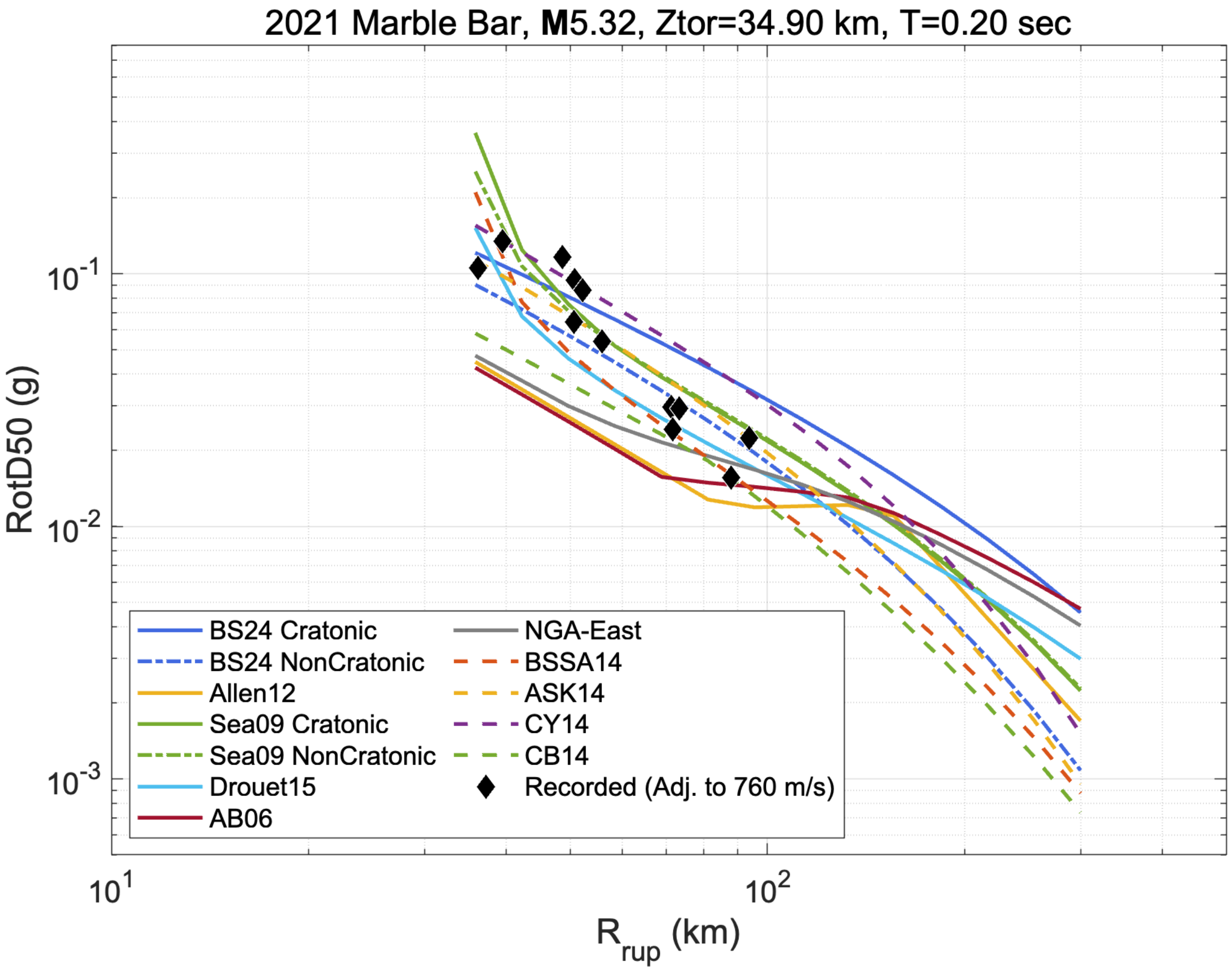
Abbreviation	Reference	NSHA23 Tectonic Region Type
Allen12	Allen (2012)	cratonic, non-cratonic
Sea09 Cratonic	Somerville et al. (2009)	cratonic
Sea09 NonCratonic	Somerville et al. (2009)	cratonic, non-cratonic
Drouet15	Drouet & Cotton (2015)	cratonic, non-cratonic
AB06	Atkinson and Boore (2006)	cratonic, non-cratonic
NGA-East	Goulet et al. (2021)	cratonic, non-cratonic

Additional GMMs

Abbreviation	Reference	Type
BS24 Cratonic	Bayless and Somerville (2024)	Australia models
BS24 NonCratonic	Bayless and Somerville (2024)	
ASK14	Abrahamson et al. (2014)	NGA-West2 models
BSSA14	Boore et al. (2014)	
CY14	Chiou and Youngs (2014)	
CB14	Campbell and Bozorgnia (2014)	

Evaluation of GMMs





Evaluation of GMMs

$$\ln\left(\frac{Data}{GMM_k}\right) = c_k + \delta B_e + \delta WE_{es}$$

within-event residual

between-event residual

mean bias, c_k

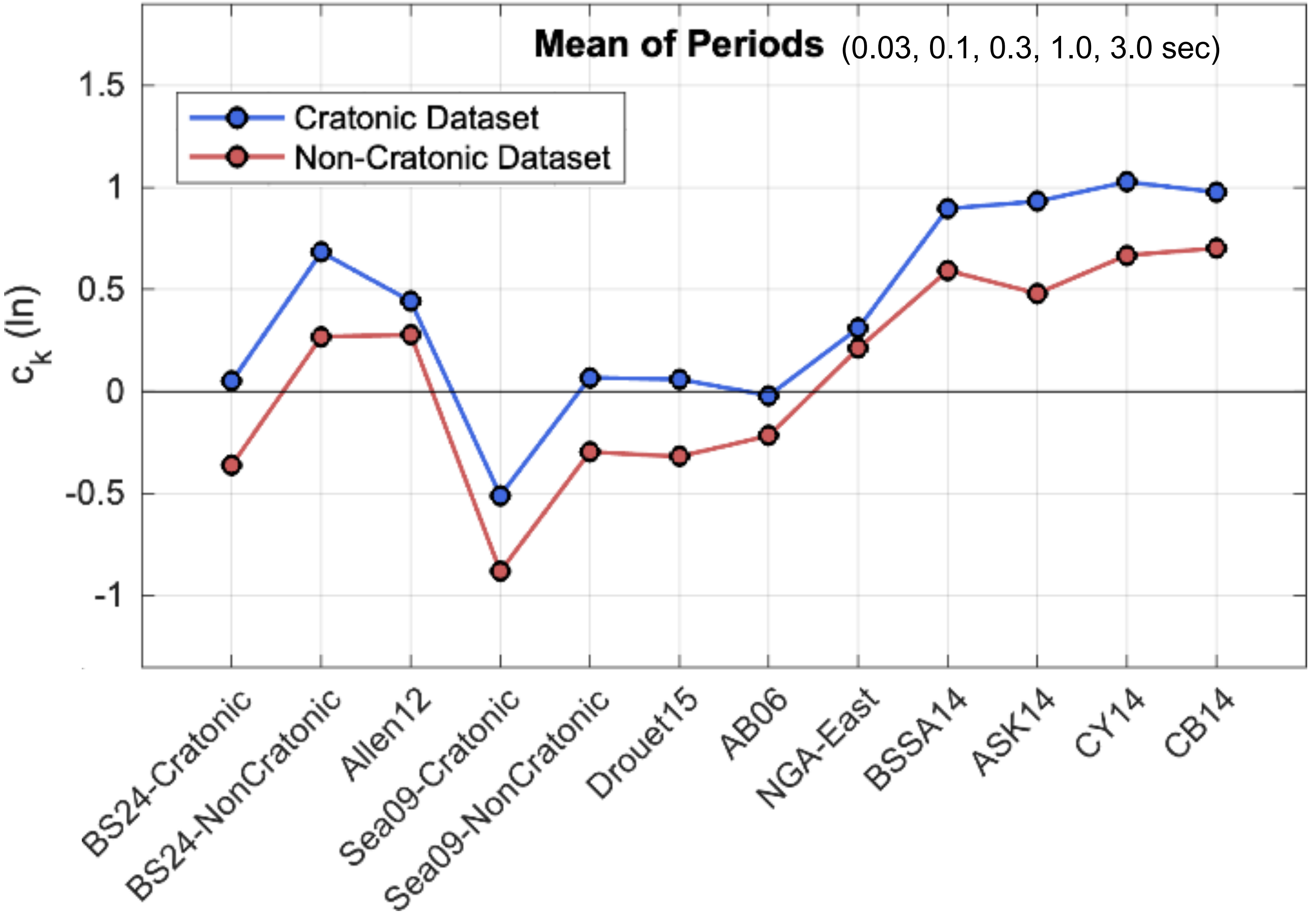
$c_{k,crat}$ $c_{k,noncrat}$

These are the mean biases of the cratonic and non-cratonic datasets for GMM *k*

Evaluation of GMMs

Positive c_k is GMM under-prediction (on avg)

Negative c_k is GMM over-prediction (on avg)

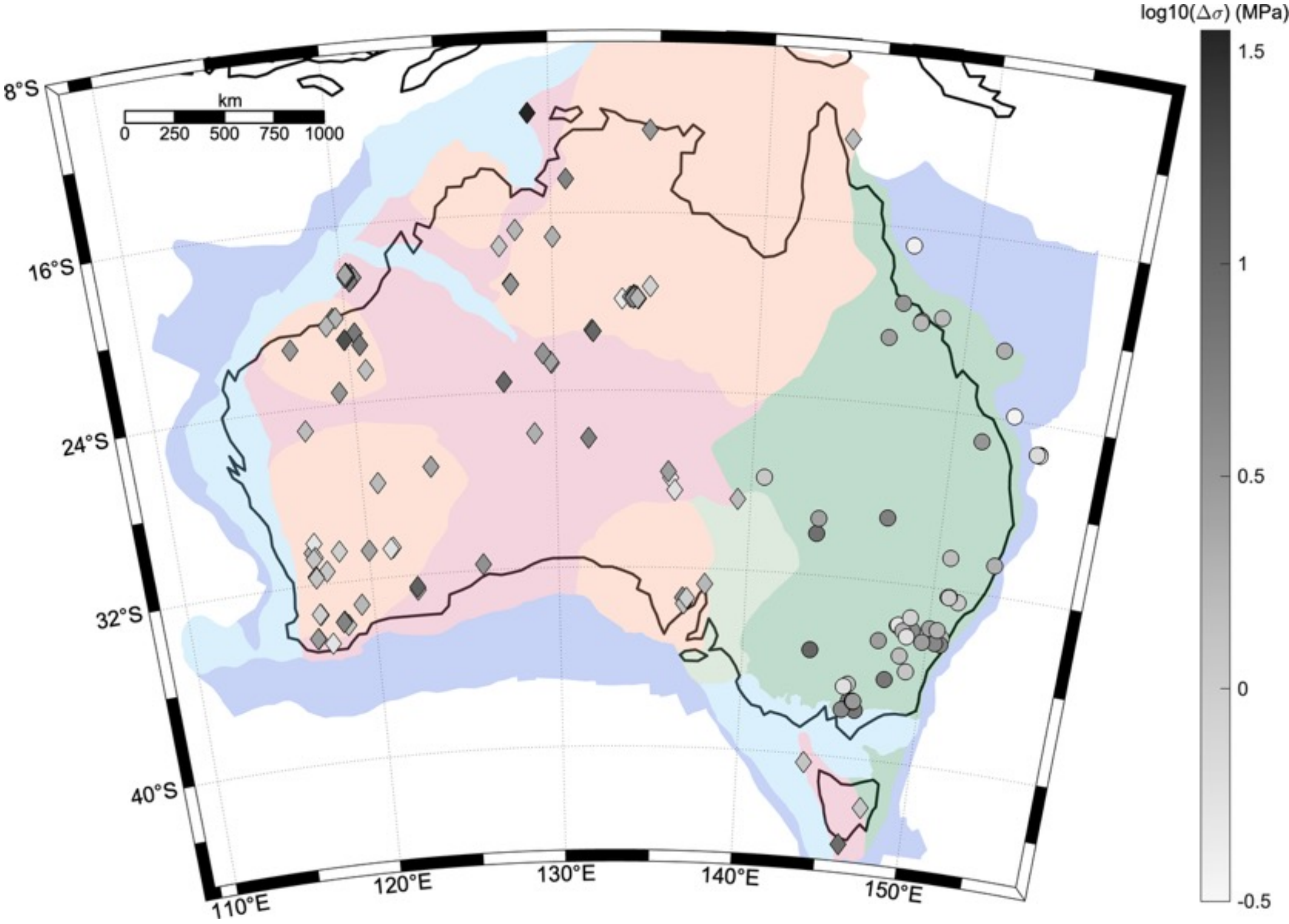


Evaluation of GMMs

- **For the 12 GMMs, we find a range of approximately 10% – 50% higher average ground motions for the cratonic dataset.**
- At T = 0.03, 0.1, and 3 sec, the cratonic ground motions are systematically larger than the non-cratonic ground motions on average.
- At T = 0.3 and T = 1 sec, the differences are relatively small compared with the other spectral periods. At T = 1 sec, there is best GMM performance for all 12 models.
- The four NGA-West2 GMMs all under-estimate the short period ground motions on average by substantial factors of 3-4. This bias reduces with increasing spectral period and is a combination of both (small) magnitude and (large) distance scaling.

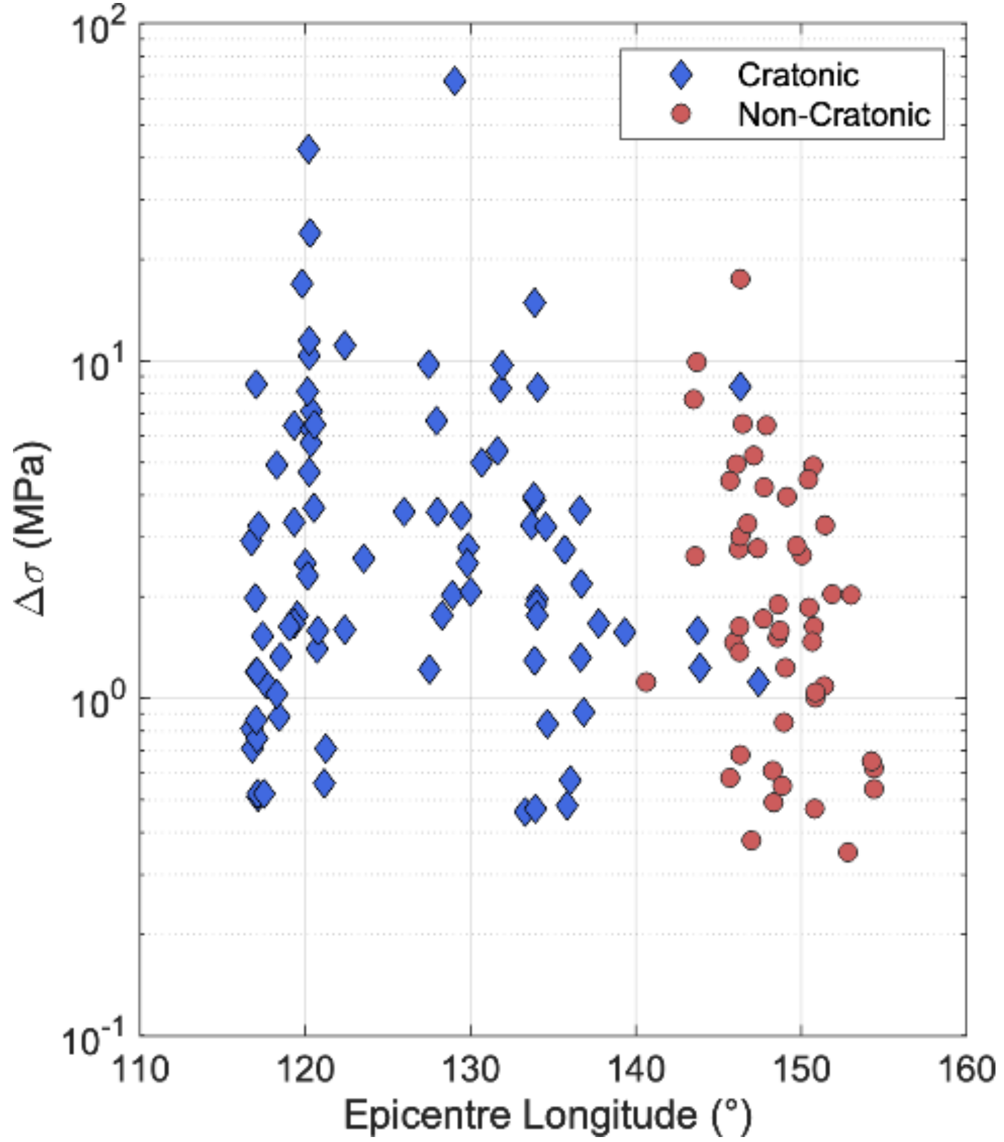
Evaluation of Stress Drops

- Allen (2025) analysed stress drops for over 290 earthquakes in Australia in the magnitude range of 3.1 to 6.6.
- We investigated whether there is a systematic difference in stress drops between the NSHA23 cratonic regions (diamonds) and non-cratonic regions (circles) using the stress drops from Allen (2025)



Evaluation of Stress Drops

- Excluding shallow (< 3km depth) and low stress drop (< 0.33 MPa) events, which are associated with known source effects in cratons,
- We found that the average stress drops for the cratonic and non-cratonic regions are 2.6 and 1.9 MPa



Conclusions

Q1. In what ways do non-cratonic and cratonic GMs differ?

- We found approximately 10% – 50% higher ground motions on average for the cratonic dataset; with the strongest difference at periods T = 0.03, 0.1, and 3 sec.
- At intermediate spectral periods (T = 0.3 and 1 sec), the difference between regions was smaller and may not be statistically significant.
- By excluding very shallow events, we found that the average stress drops for the cratonic and non-cratonic regions are 2.6 and 1.9 MPa, respectively, a difference of a factor of 1.4.

Conclusions

Q2. Are the NGA-East and NGA-West2 GMMs applicable in Australia?

- The four NGA-West2 median GMMs significantly under-estimate the short period non-cratonic Australian ground motions on average (for this small to moderate mag dataset). This bias reduces with increasing spectral period.
    - In larger magnitude and shorter distance ranges, where we do not have data in Australia, the NGA models are constrained by global earthquake data and by finite-fault earthquake simulations.
    - These mag/distance ranges are often critical for seismic hazard, so we consider these models applicable in Australia to capture the epistemic uncertainty.
- The NGA-East model performs similarly to the two Australian models (BS24-Cratonic and Allen12), suggesting it is appropriate to use for cratonic regions of Australia.

Conclusions

Disclaimer:

These conclusions are subject to the limitations of the data, including:

- uncertainties in site parameters (V_{S30} values and site amplification),
- uncertainties in source metadata (moment magnitudes, depths, and locations), and
- the overall limited quantity of data.

Empirical evaluations of the GMM performance only apply within the distance and magnitude ranges of the available dataset; in this case for small to moderate magnitudes.

Thank you.

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