An Updated Ground Motion Model for Australia Developed Using Broadband Ground-Motion Simulations

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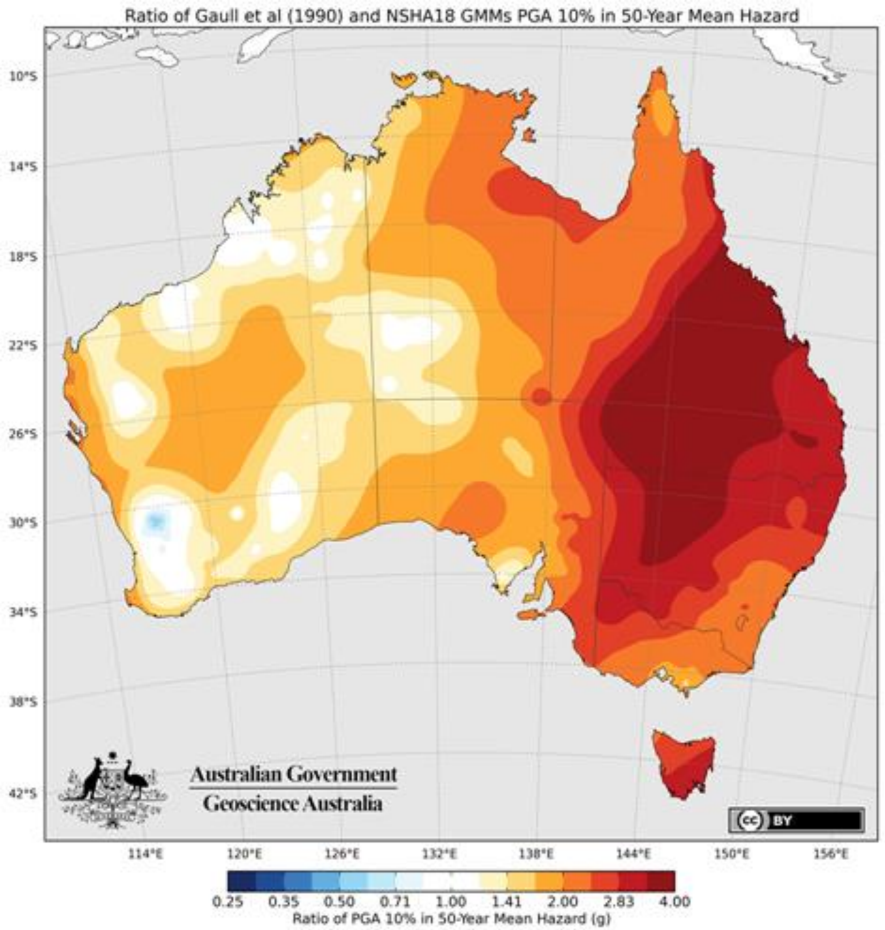
Introduction

– Seismic Hazard results are sensitive to the selection of ground motion models (GMMs).

– Use of modern GMMs, including Somerville et al. (2009; Sea09), was one of the key factors contributing to the reduction of NSHA18 seismic hazard relative to the 1991 national map.

– Sea09 was due for improvement by taking advantage of the ground motions recorded in Australia in the past decade-plus.

– This presentation describes our updated GMM for Australia.



Source: Ghasemi and Allen (2023)

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Overview of GMM Development

- Larger earthquake magnitudes (**M** > 6) typically control design ground motions, but no such Australian earthquake ground motion data are available for developing GMMs.

- We perform large suites of broadband strong motion simulations (Graves and Pitarka, 2015) to account for earthquake source and crustal structure properties of Australia. The simulations constrain the magnitude scaling, depth scaling, near-source saturation, and distance scaling components of the median GMM.

- The simulations are validated with data from smaller magnitude earthquakes (**M** < 6) recorded in Cratonic and non-Cratonic Australia.

GMM Features

- The model is for the median and standard deviation of the horizontal component of response spectral acceleration.

- Two versions: Cratonic and non-Cratonic

  - Common magnitude scaling and geometric spreading models - based on recent observations showing minimal differences between regions.
  - Differ in their anelastic attenuation components (models deviations from the geometric spreading attenuation).
  - Differ in their high frequency source spectra (accounts for the differences in source and crustal structure between regions).

- Two source effects related to earthquake depth are modelled:

  - Effects of surface (Rg) waves from shallow events.
  - Effects of energetic buried ruptures at short periods.

- Other median model components: Hanging Wall, V_{s30}-scaling, $Z_{1.0}$-scaling

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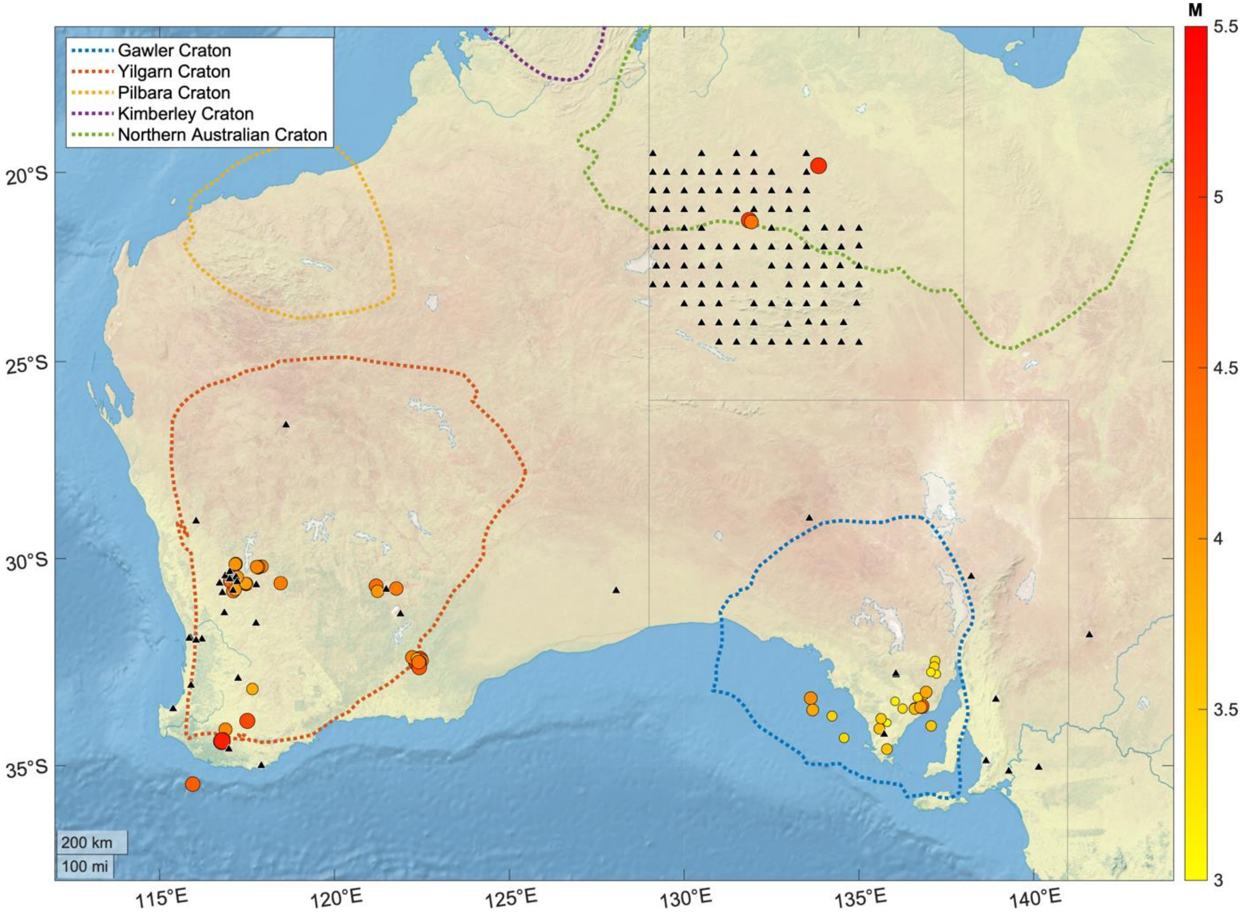
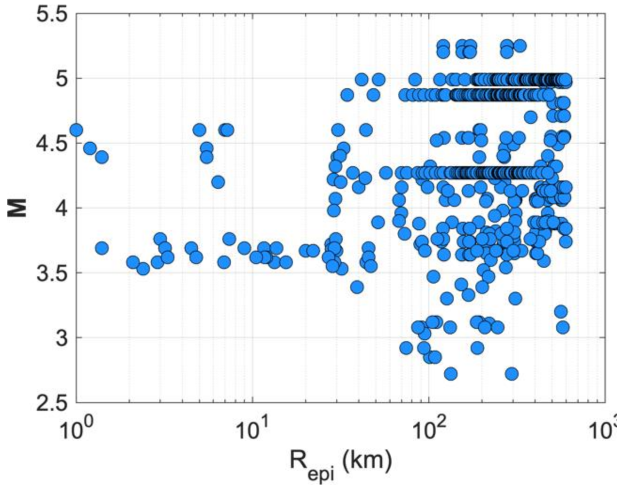
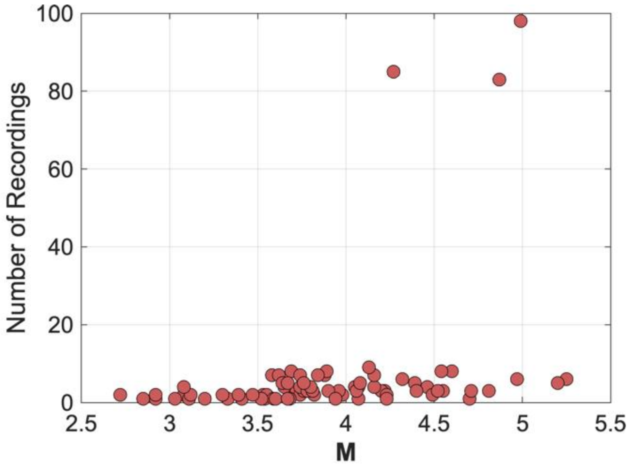
Earthquake Catalogue and Ground Motion Database

– **Cratonic** earthquake ground motion database includes waveform data from Ghasemi and Allen (2021) and from IRIS

- 84 events recorded by 155 unique stations
- Includes three earthquakes with more than 80 recordings
- We use the cut-and-paste method (Zhao and Helmberger, 1994) on nine events to improve our estimates of **M**, focal depth, focal mechanism, and location





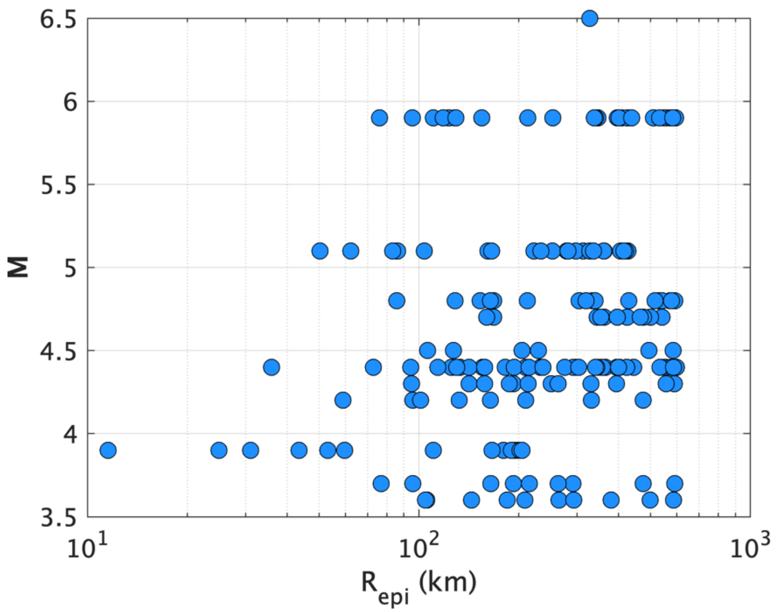


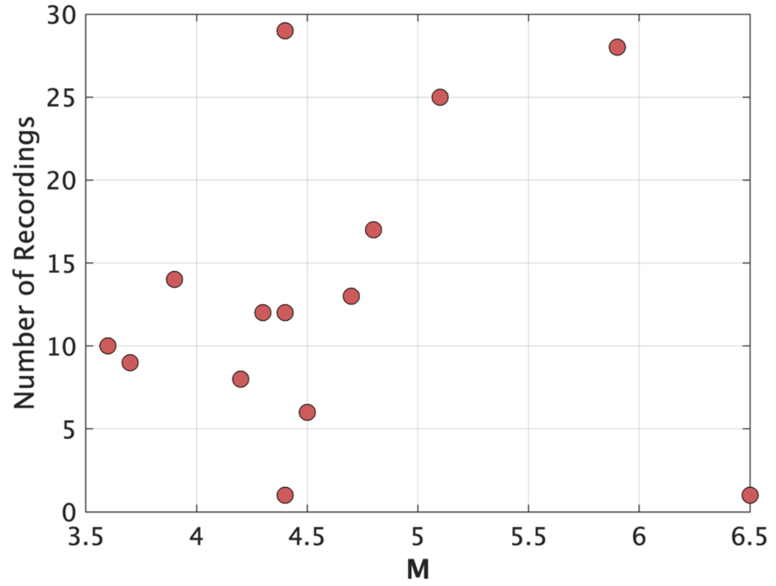
Earthquake Catalogue and Ground Motion Database

– **Non-Cratonic** ground motion database includes response spectra and metadata and was provided by Geoscience Australia (Trevor Allen, personal communication) at our request.

- From the data provided by GA, we identified 13 events to use for the GMM development.

- These include the 2021 **M**5.9 Woods Point and 2012 **M**5.1 Moe earthquakes in Victoria, and one recording of the 2019 **M**6.5 earthquake off the Kimberley coast





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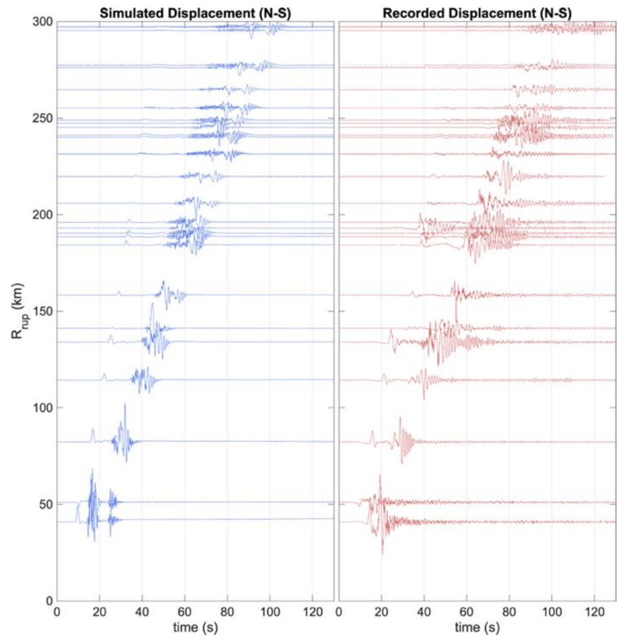
Earthquake Ground Motion Simulations

Phase 1: Validation using data

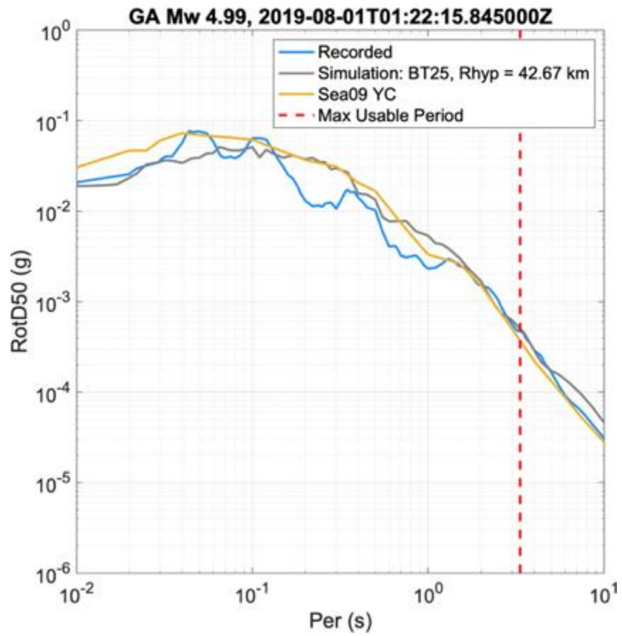
– This phase is critical to establish confidence in the simulations and their input parameters, such as the seismic velocity models used to develop Green's Functions.

– Involves comparing
  - (a) waveforms
  - (b) response spectra
  - (c) distance scaling
  - (d) goodness-of-fit

(a)



(b)



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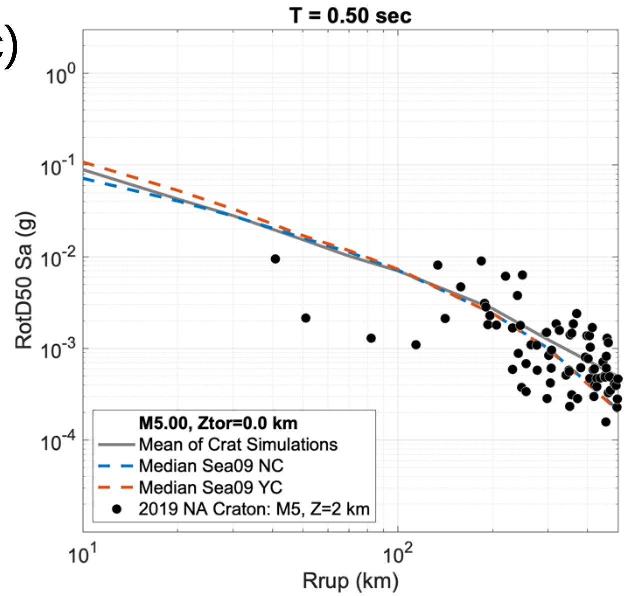
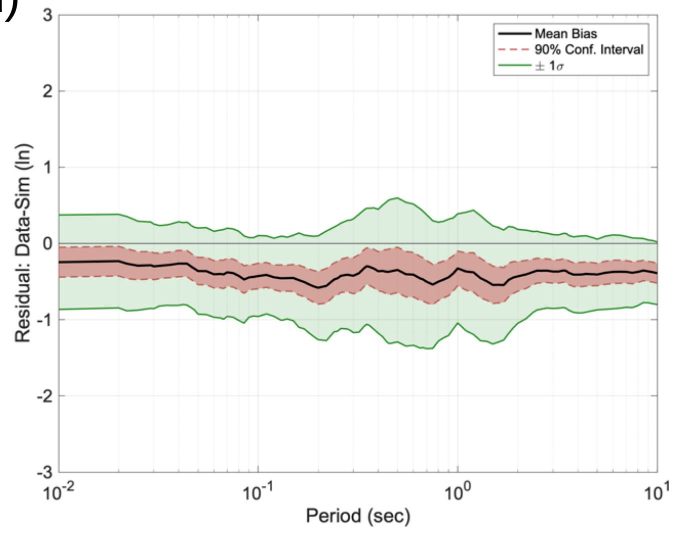


(d)



Earthquake Ground Motion Simulations

Phase 2: Forward Simulations

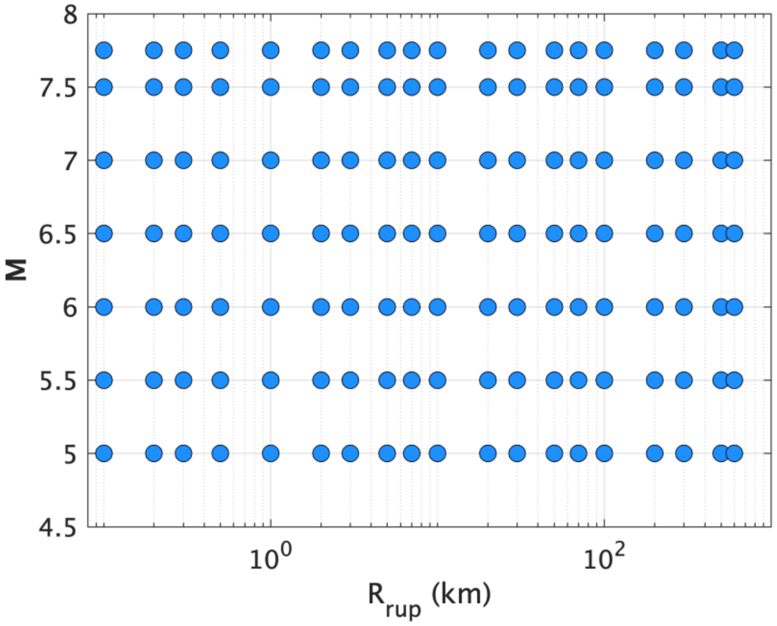
– Suites of scenario events with a range of **M**, source depths, and kinematic source realizations to develop a simulated ground motion database.

– The products of the simulations are ground motion time histories and response spectra.

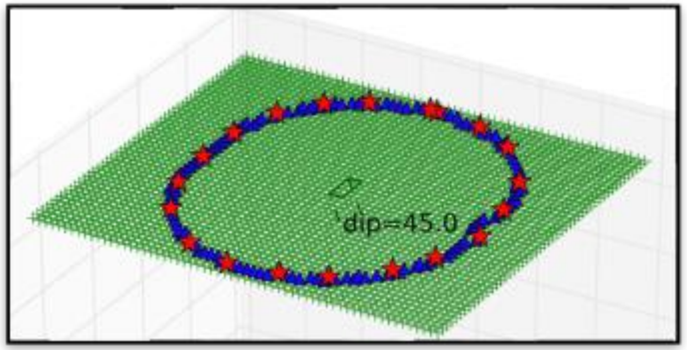
– All the simulations, including input files and output files, are available on DesignSafe:
doi.org/10.17603/ds2-w7qe-mh53
doi.org/10.17603/ds2-5pw1-s719

– In total, there are 104,000 simulated three-component ground motion time histories from 410 simulated earthquakes.

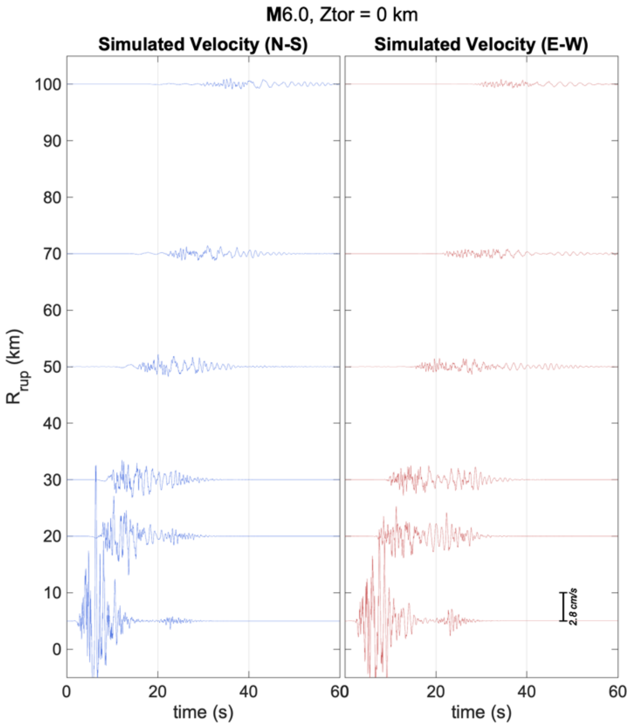
Mag-Distance combinations



Orientation of Stations for one Rrup



Simulated Velocity Time Histories



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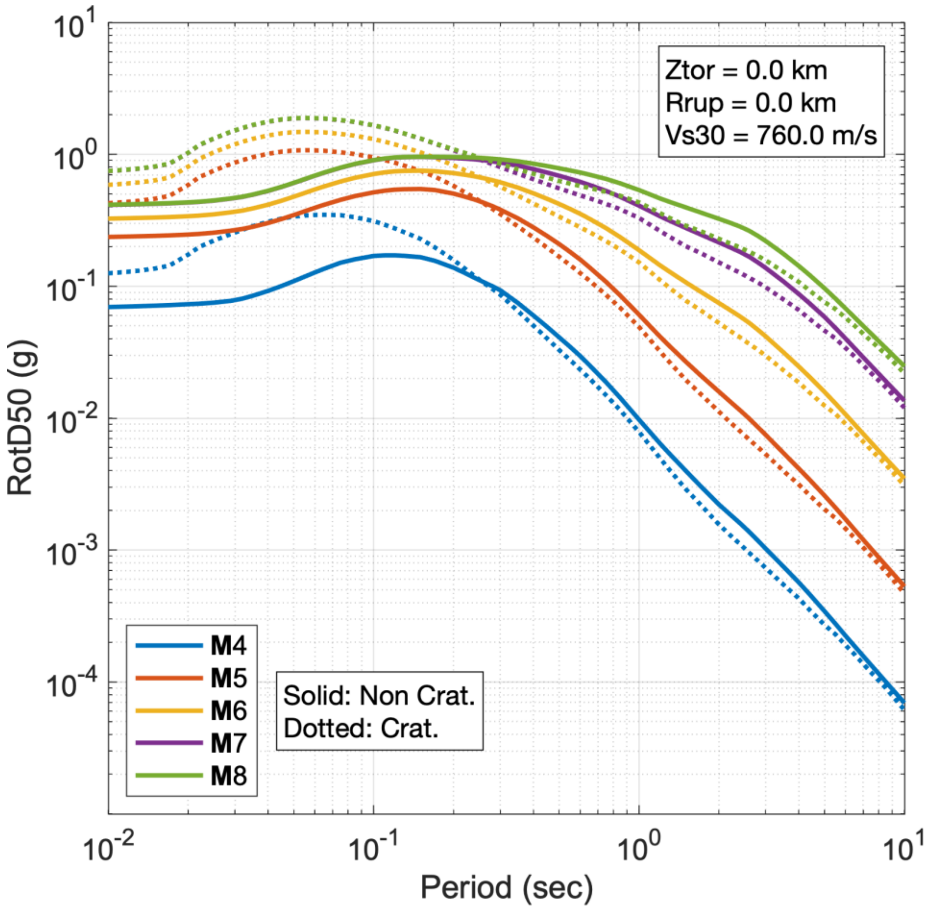
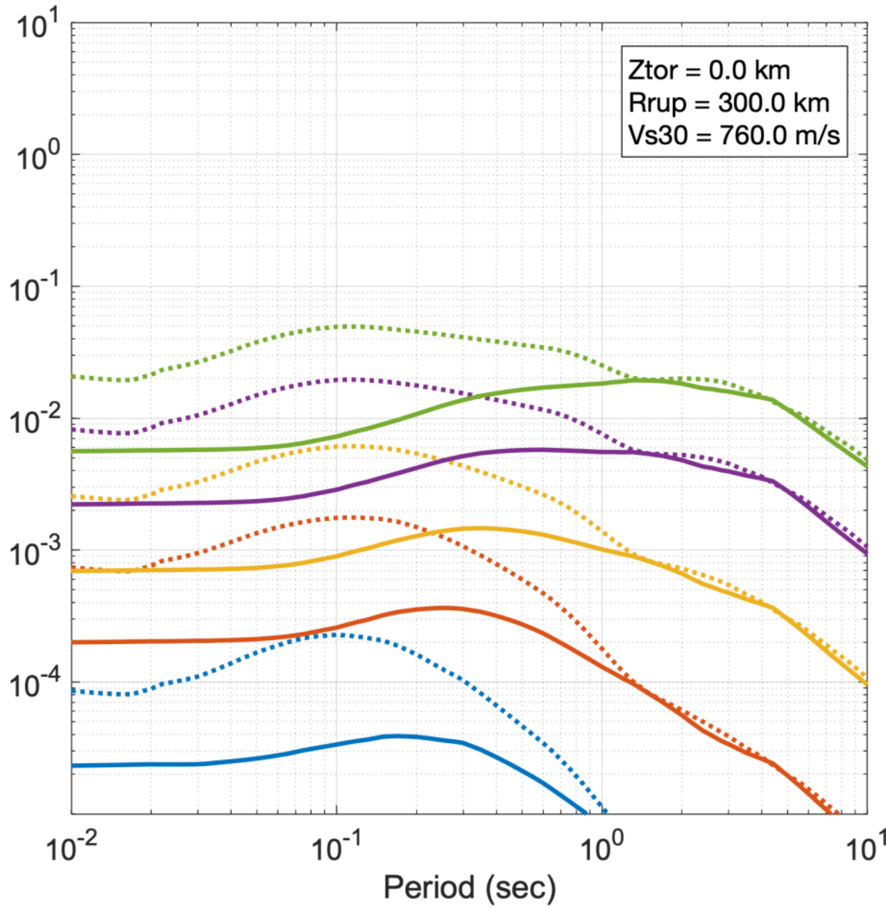
GMM Performance – Effect of Distance

The saturation in magnitude scaling at large **M**, especially at short periods and close distances, is apparent in the large spread in median spectra for small magnitudes, and very little sensitivity at larger **M**.

Rrup = 0 km



Rrup = 300 km



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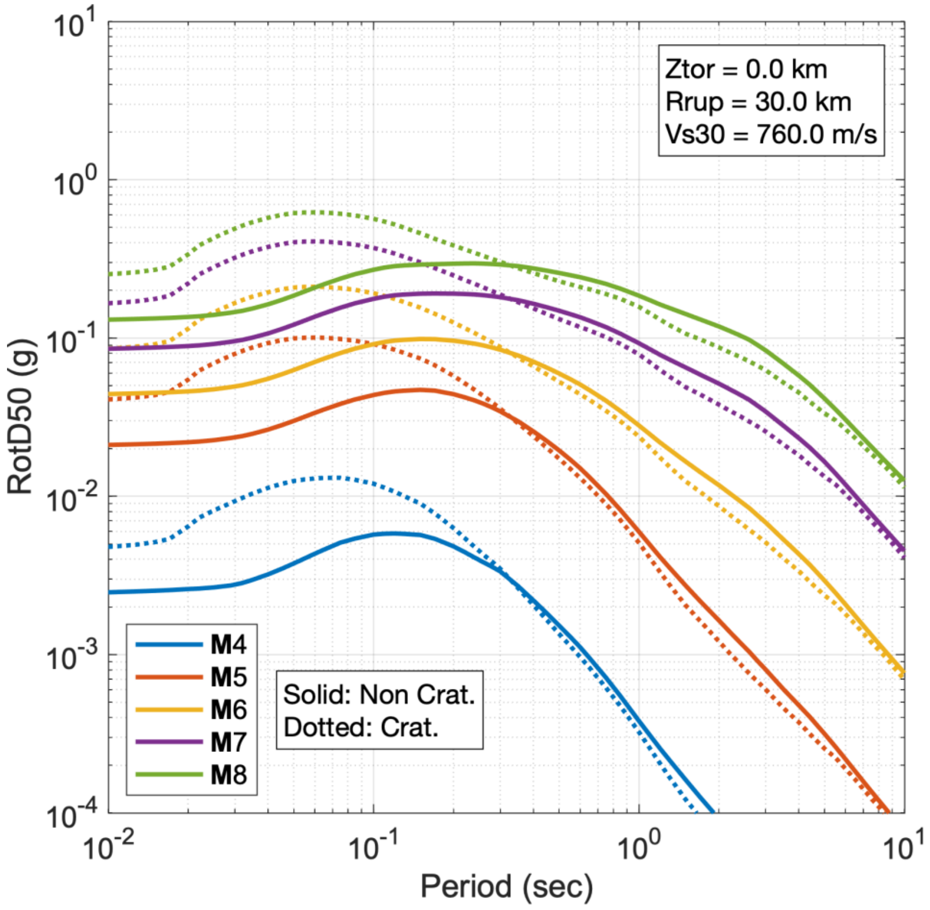
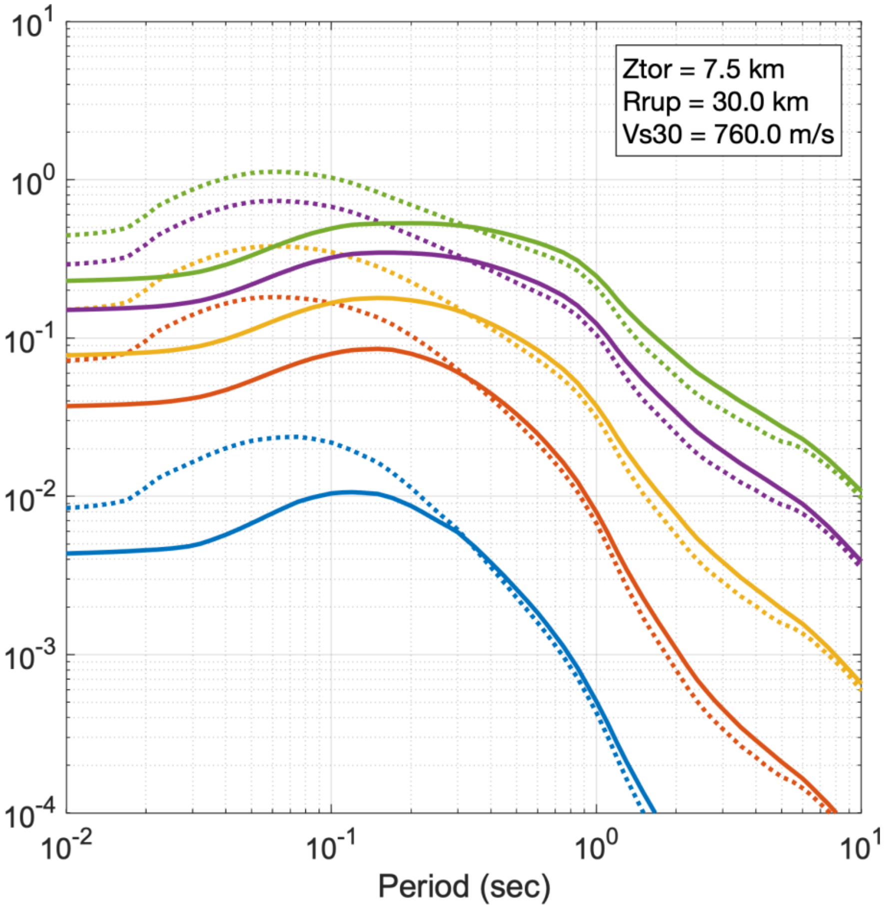
GMM Performance – Effect of Earthquake Depth

The effects of R_g waves are represented in the depth scaling term which amplifies the long period ground motions for shallow earthquakes and de-amplifies them for deep earthquakes.

Ztor = 0 km



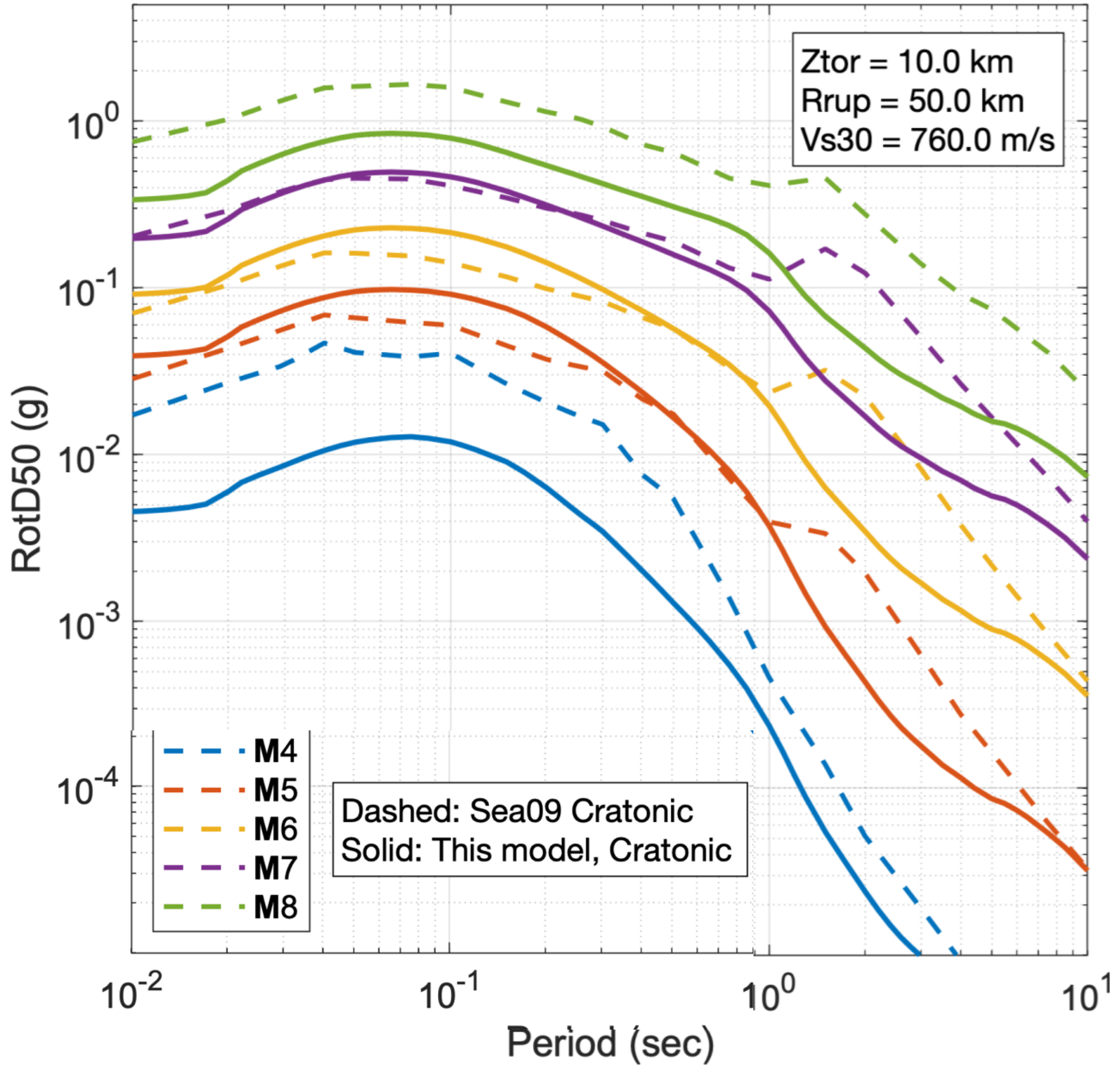
Ztor = 7.5 km



GMM Performance – Comparison with Sea09

Sea09 observed and modelled a localised peak around 1.5-2.0 seconds in the response spectra due to the R_g waves caused by a shallow low velocity layer in the Yilgarn Craton crust.

Relative to the Sea09 model, the revised long-period amplification model is over a broader period range and so the spectral shape does not have a localised peak around 1.5-2.0 seconds.



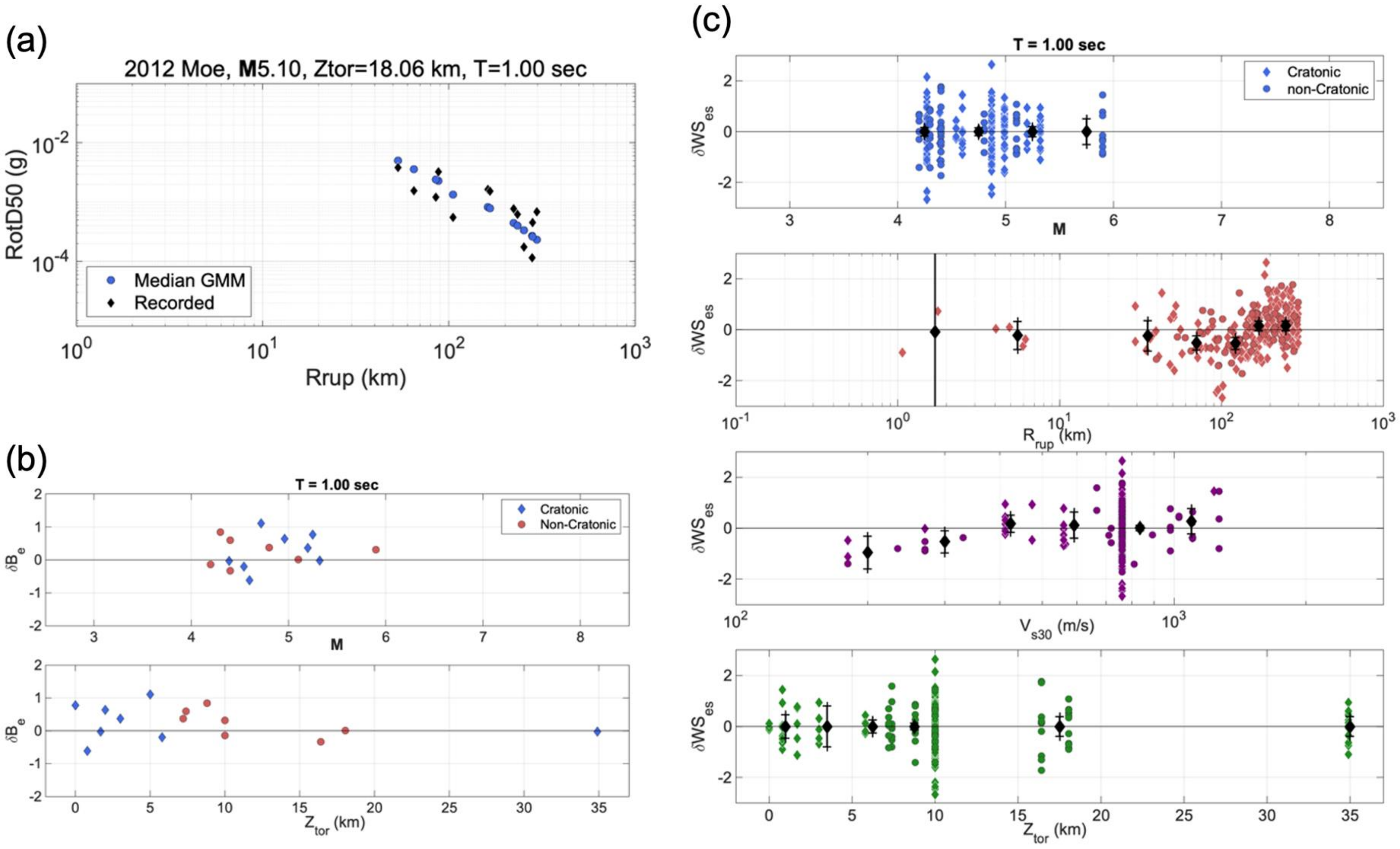
GMM Performance – Comparisons with Data

We used the recorded data to check that the median GMM developed from the simulations is not biased with respect to magnitude, depth, and distance

(a) Comparisons between the model and data recorded in the 2012 Moe earthquake.

(b) Between-event residuals versus **M** and depth

(c) Within-event residuals versus **M**, Rrup, Vs30, and Ztor



Summary

- We updated the Sea09 GMM for the median and standard deviation of the horizontal component of response spectral acceleration for **Cratonic** and **non-Cratonic** regions of Australia.

- Suites of forward simulations are used to extrapolate the model to larger earthquake magnitudes that typically control design ground motions but for which no Australian data are available.

- The **M**-scaling and geometric spreading terms are the same for the Cratonic and non-Cratonic models.

- The models differ in their anelastic attenuation components and in their high frequency source spectra derived from the simulations and validated by the data; these account for the differences in source and crustal structure between regions.

- The models provide adequate representations of the data and embody the differences in ground motions observed between Cratonic and non-Cratonic regions of Australia.

- This model has been enabled by the high quality and volume of the seismograms and geological information made available by Geoscience Australia and University of Melbourne.

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