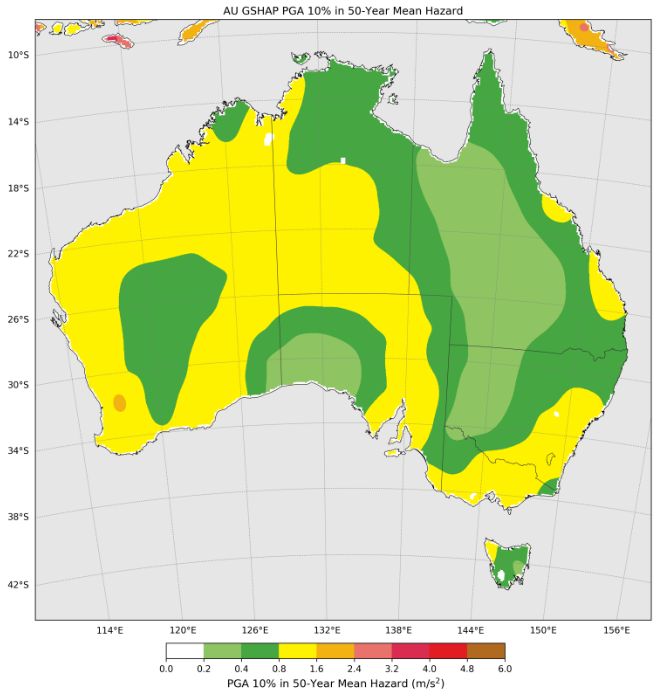
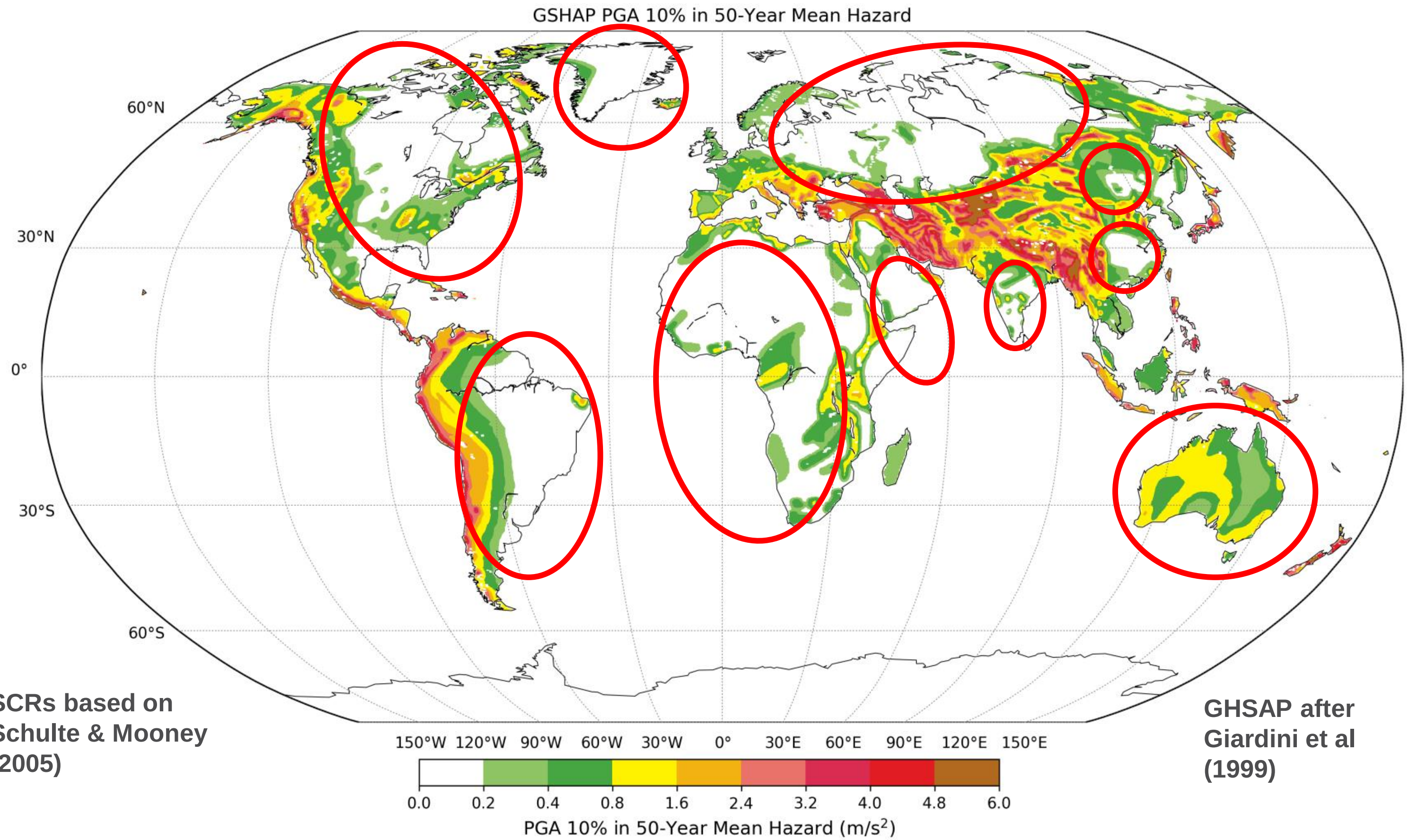
Recolouring GSHAP: Challenging the *status quo* of Australian earthquake hazard

Trevor Allen, Jonathan Griffin, Dan Clark, Hadi Ghasemi, Mark Leonard & Theodora Volti



Australia in the Global Context

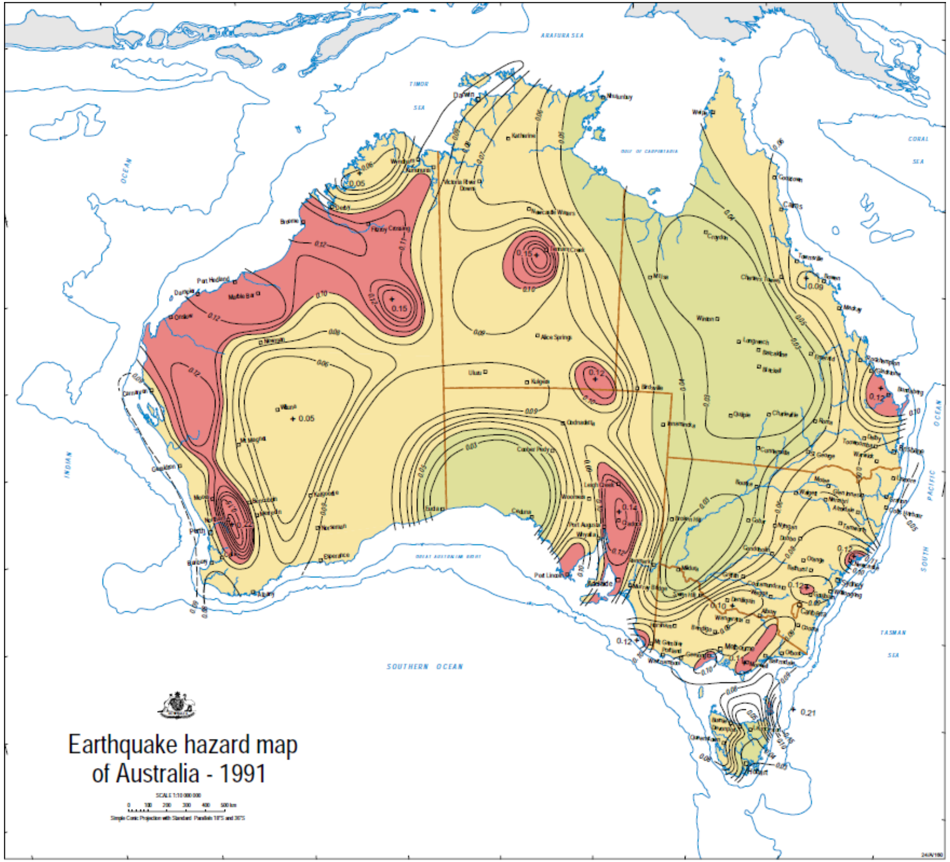


SCRs based on Schulte & Mooney (2005)

GHSAP after Giardini et al (1999)

So, what is the problem?

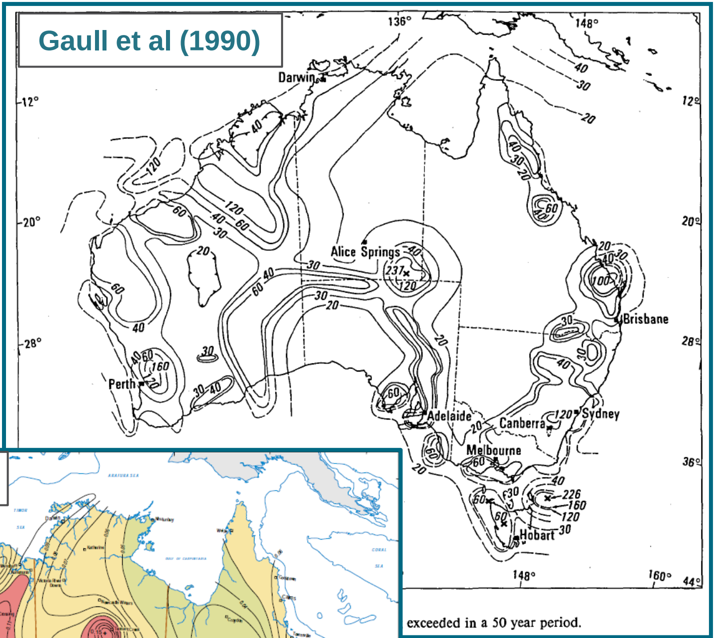
- The Australian contribution to the GSHAP is fundamentally the same map that defines the current *Standards Australia AS1170.4-2007* hazard factors
- These hazard factors trace their lineage to 1990 assessment of Gaull et al.
- The map was updated in 1991 in response to the 1988 Tennant Creek and 1989 Newcastle earthquakes



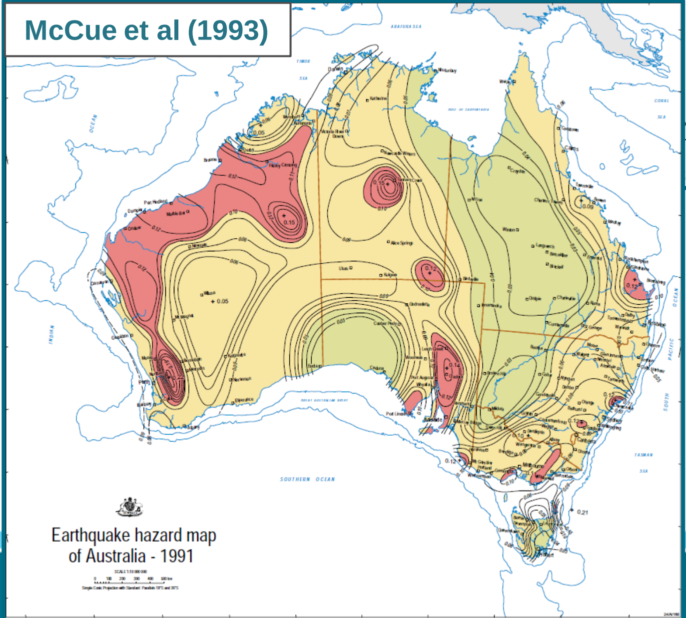
Now for some history…

- The first Australian probabilistic hazard assessment was undertaken by Gaull *et al* (1990):
  - GMMs based on mean isoseismal radii (MMI to PGM conversions from Papua New Guinea data)
- McCue *et al* (1993) *updated and smoothed* the PGV seismic hazard contours of Gaull based on the expert opinion of the authors (McCue, 1993)
  - Gaull PGV contours divided by a factor of 750 to approximate PGA (ATC, 1984)

Gaull et al (1990)

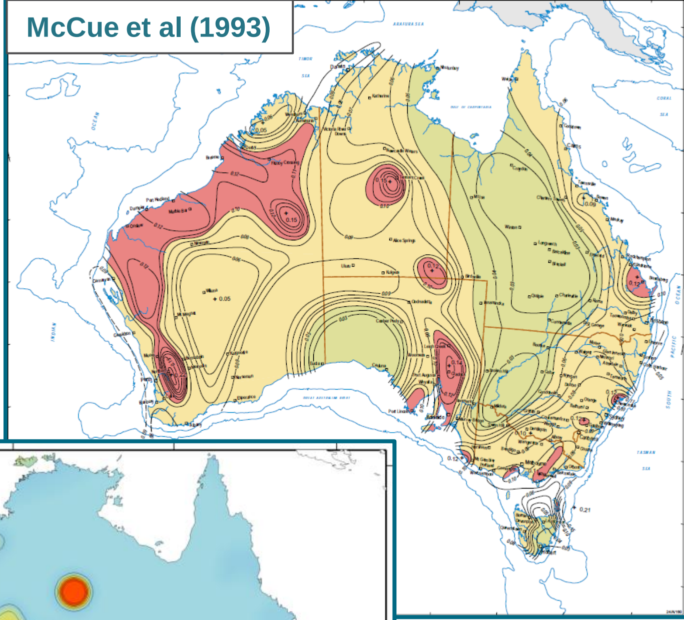


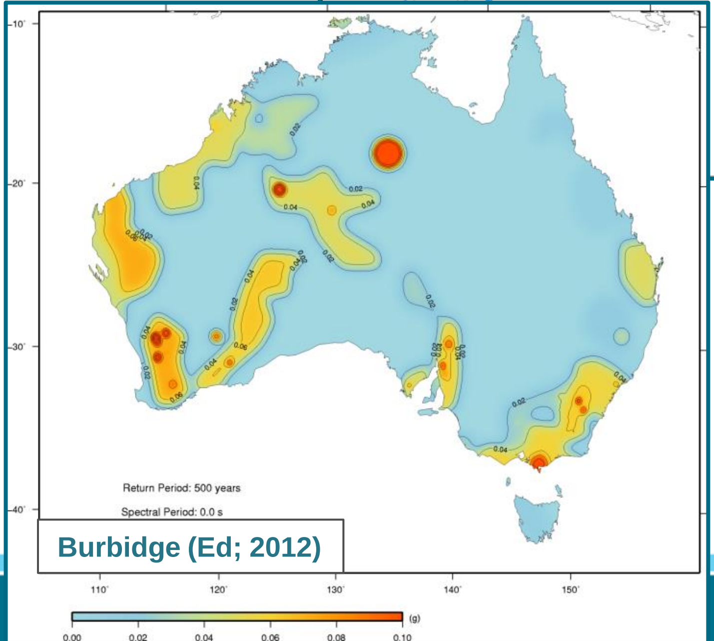
McCue et al (1993)



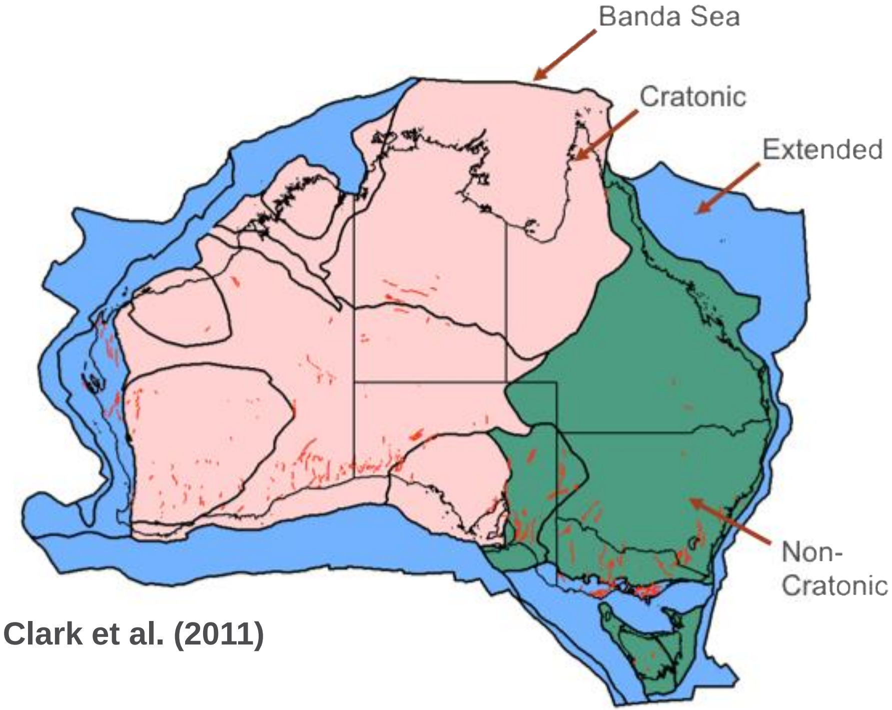
…and some recent history

- An attempt to update the AS1170.4 map was made in 2012 (Burbidge, 2012; Leonard *et al*, 2013):
    - Used modern PSHA software
    - Included multiple source models
    - Used modern GMMs
    - Applied magnitude corrections due to use of inappropriate local magnitude M_L formulae
- The Standards subcommittee elected not to adopt the 2012-13 revision due to the perceived “lack of consensus” amongst Australian seismologists

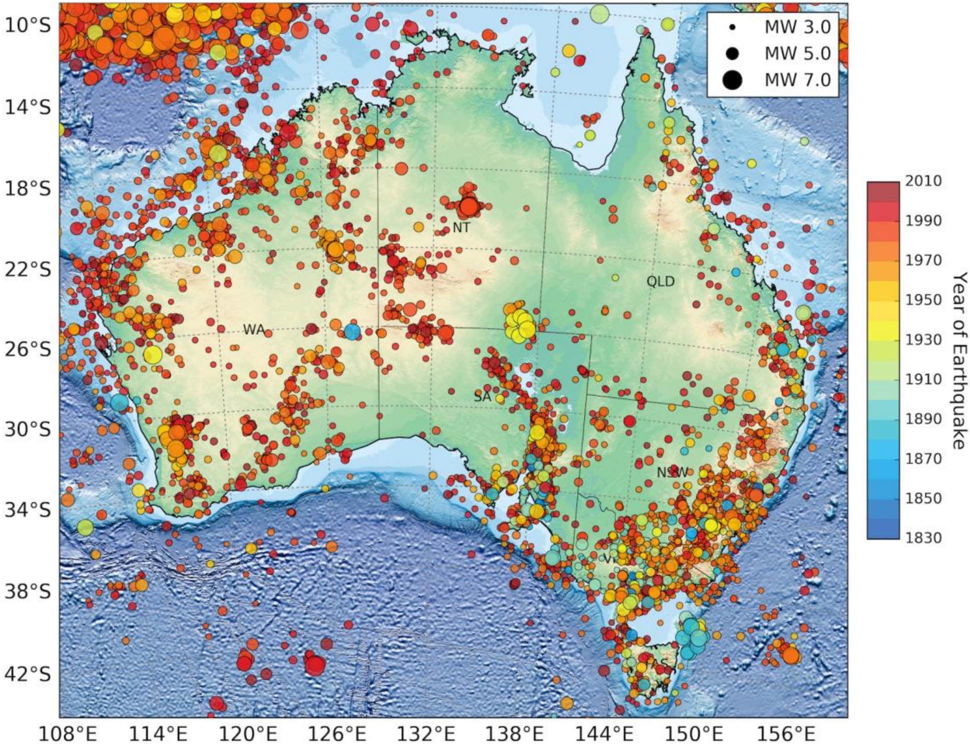




Australian Seismotectonics 101



Clark et al. (2011)



Moving Ahead – The National Seismic Hazard Assessment Project 2018 (NSHA18)

- GA initiated the NSHA18 project to update the national seismic hazard model intended for inclusion into the AS1170.4-2018
- The **Draft NSHA18** update yields many important advances on its predecessors, including:
  - calculation in a full probabilistic framework using the OpenQuake-engine;
  - consistent expression of earthquake magnitudes in terms of moment magnitude, M_W;
  - inclusion of epistemic uncertainty through the use of multiple source models;
  - inclusion of uncertainty on magnitude-frequency distribution (MFD) parameters;
  - inclusion of a national fault-source model;
  - inclusion of epistemic uncertainty on MFD types and earthquake clustering on faults;
  - use of modern ground-motion models

NSHA18 – Source Model Summary

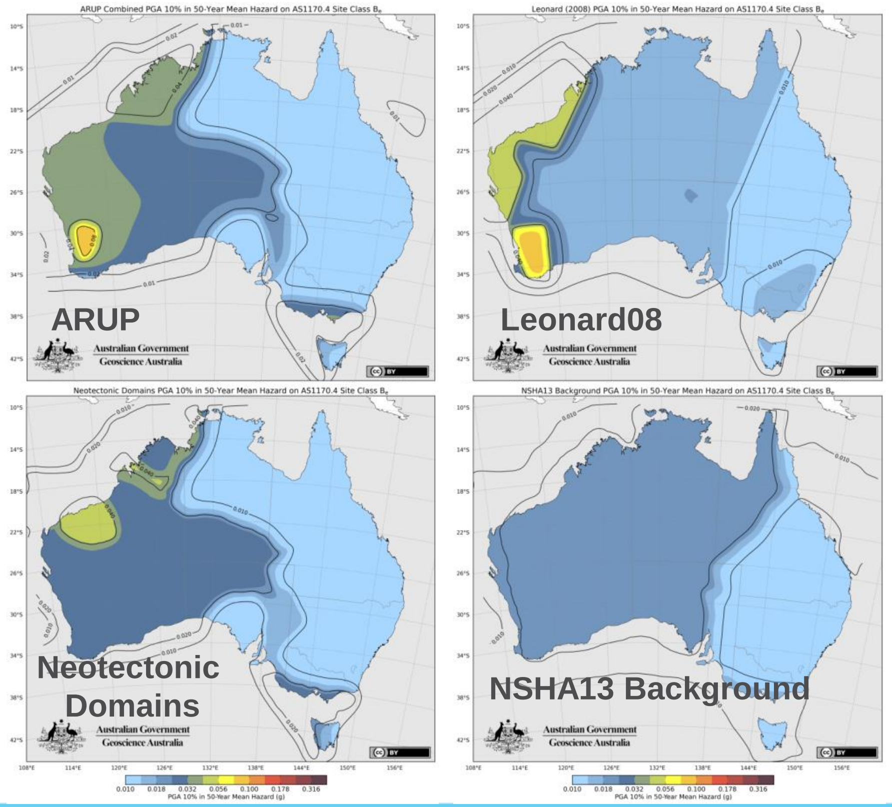
- Solicited the Australian seismological community to contribute seismic source models (SSMs):
  - Samples epistemic uncertainty
  - Provide community with ownership of the final model
- Candidate source models were assessed and weighted through an expert elicitation process
- In total, 20 SSMs models were contributed:
  - 13 SSMs used in the Draft NSHA18
- The process was intended to help gain consensus amongst the seismological community

Model Name	Model Type	Inter-Class Weight	Intra-Class Weight	Reference
AUS6	Regional	0.062	0.254	Dimas *et al.* (2016)
DIM-AUS			0.261	Dimas and Venkatesan (2016)
NSHA13			0.353	Burbidge (2012) and Leonard *et al.* (2014)
NSHA Hotspots			0.132	Burbidge (2012) and Leonard *et al.* (2014)
ARUP	Background	0.201	0.340	Mote *et al.* (2017)
Leonard			0.174	Leonard (2008)
Neotectonic Domains			0.303	Clark *et al.* (2012)
NSHA13 Background			0.119	Burbidge (2012) and Leonard *et al.* (2014)
Sinadinovski & McCue			0.064	Sinadinovski and McCue (2016)
Cuthbertson	Smoothed Seismicity	0.088	0.194	Cuthbertson (2016)
Adaptive Smoothing			0.427	Griffin *et al.* (2016)
Fixed Kernel Smoothing			0.155	Griffin *et al.* (2016)
Risk Frontiers			0.224	Hall *et al.* (2007)
AUS6 with NFSM	Seismotectonic	0.400	0.215	Dimas *et al.* (2016)
DIM-AUS with NFSM			0.273	Dimas and Venkatesan (2016)
NSHA13 with NFSM			0.512	Griffin *et al.* (2016) and Clark *et al.* (2016)
Cuthbertson	Smoothed Seismicity with NFSM	0.249	0.194	Cuthbertson (2016)
Adaptive Smoothing			0.427	Griffin *et al.* (2016)
Fixed Kernel Smoothing			0.155	Griffin *et al.* (2016)
Risk Frontiers			0.224	Hall *et al.* (2007)

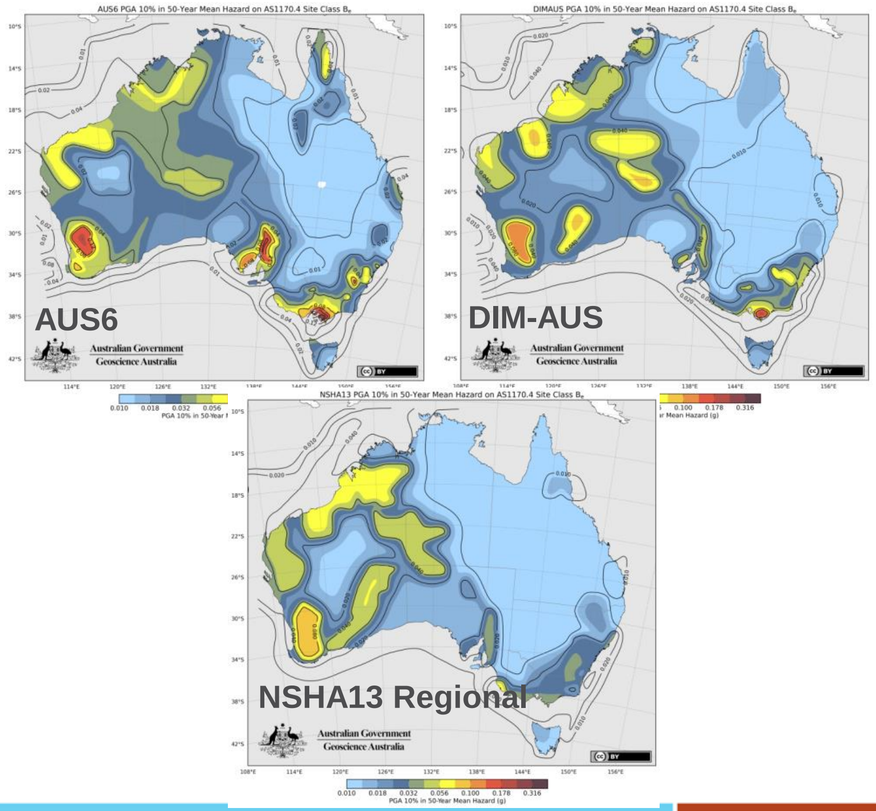
List of Geoscience Australia and third-party source models considered for use in the NSHA18 together with their assigned weights from the Expert Elicitation Workshop.

Sampling Epistemic Uncertainty in SSMs

Background SSMs

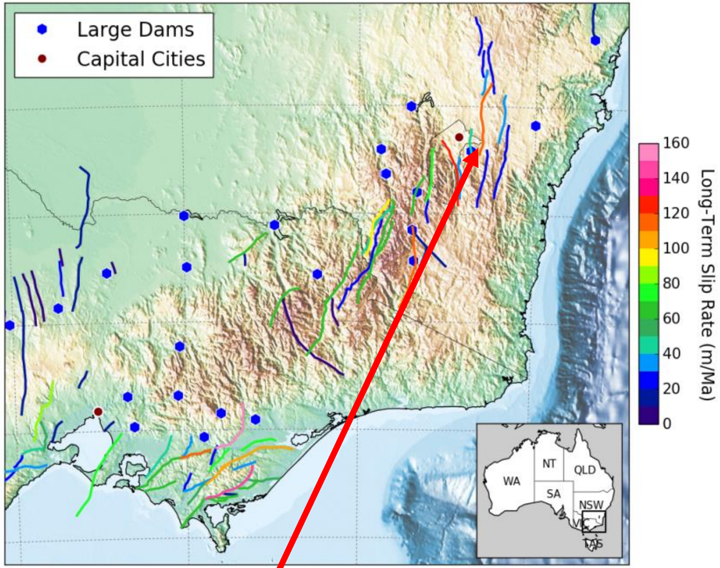


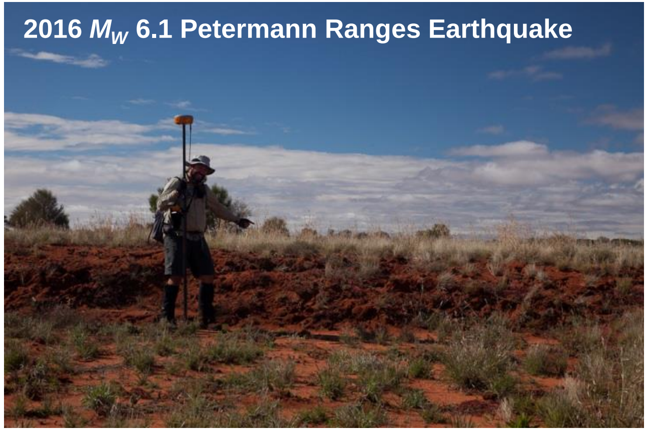
Regional SSMs



National Fault-Source Model

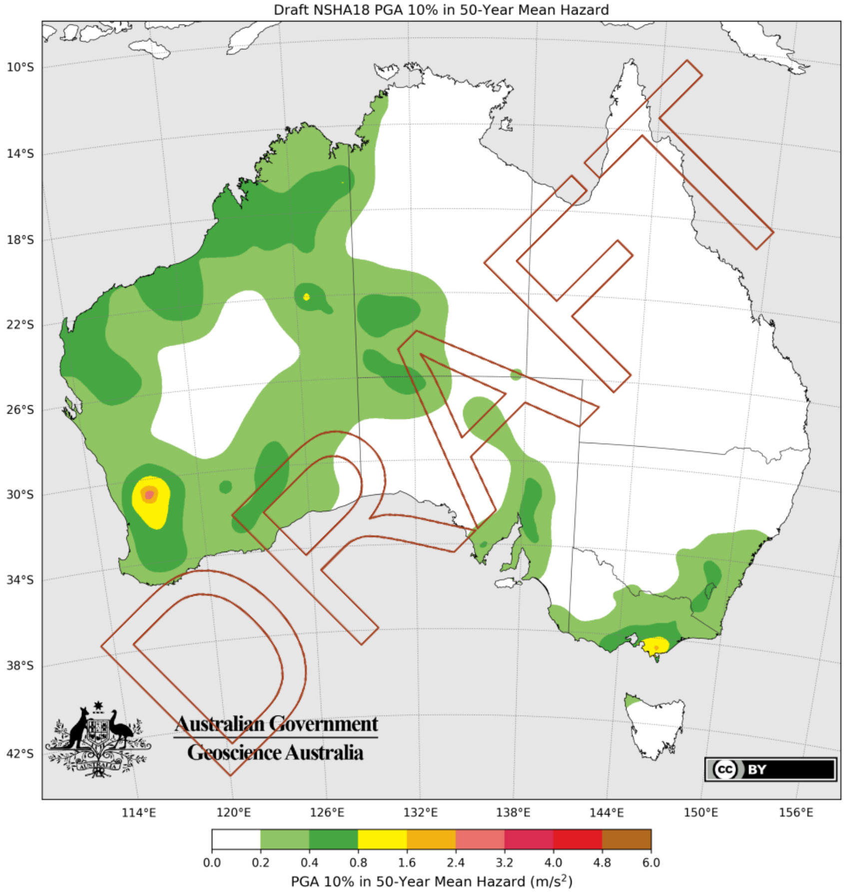
- Australia's Neotectonic Features Database (Clark *et al.*, 2012) was used to build a national fault-source model
- Approximately 350 features incorporated
- Fault hazard was assumed to be additive:
    - Used with Regional & Smoothed Seismicity SSMs





Draft NSHA18 Hazard Map

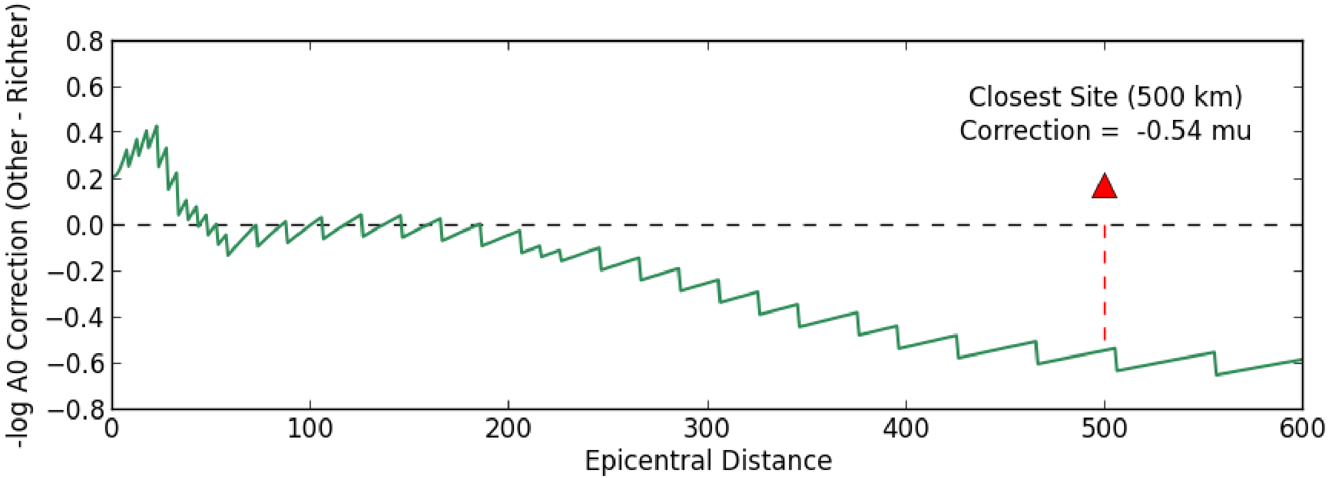
- On average, hazard values are 63% lower than AS1170.4-2007 values at the 1/500-year return period
- The large reduction in seismic hazard at the 1/500-year AEP level has led to concern amongst engineering design professionals:
    - Will the updated values will provide enough structural resilience to potential seismic loads from rare large earthquakes?



Mean PGA calculated on rock sites (AS1170.4 Site Class Be) for a probability of exceedance of 10% in 50 years (in units of m/s^2)

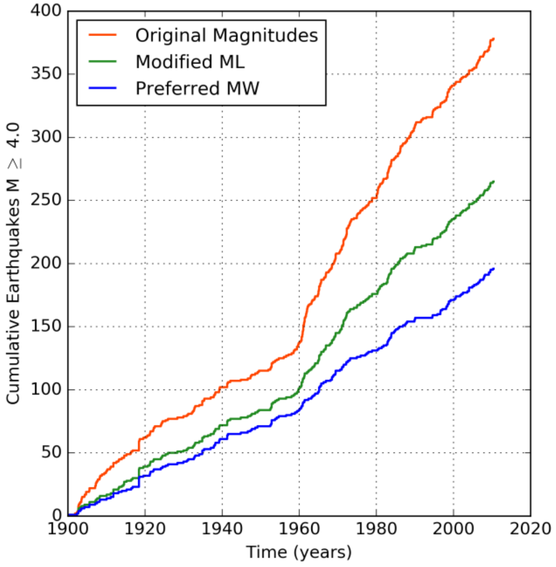
Why has the estimated hazard changed?

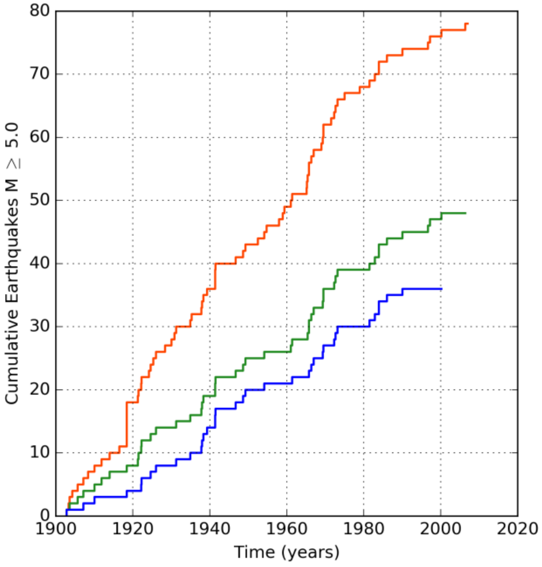
- The reduction in the rates of moderate-to-large earthquakes ($M_W \geq 4.0$):
  - through the correction of pre-1990 local magnitude M_L estimates due to use of inappropriate (i.e. Californian) relationships; and
  - through the conversion local magnitude M_L to moment magnitude M_W
- The increase in *b*-values, particularly in eastern Australia, owing to the M_L to M_W conversions
- The use of modern ground-motion attenuation models

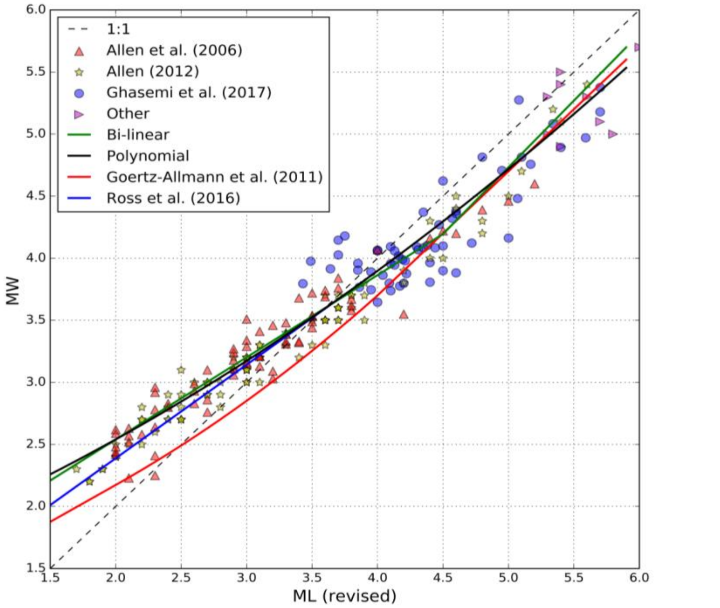


Combined Effects of Magnitude Adjustments

- Rates of moderate-to-large earthquakes have approximately halved relative to original catalogue magnitudes
- *b*-values have increased due to the conversion of M_L-M_W, which decreases rates of large earthquakes

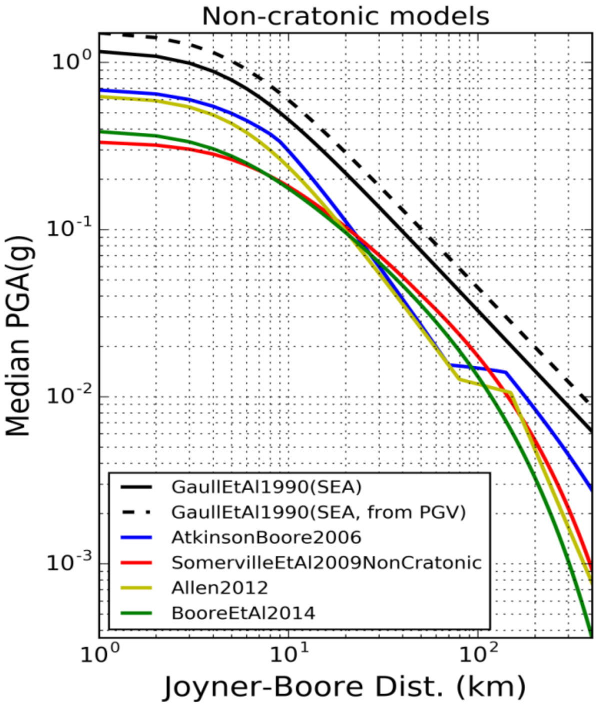


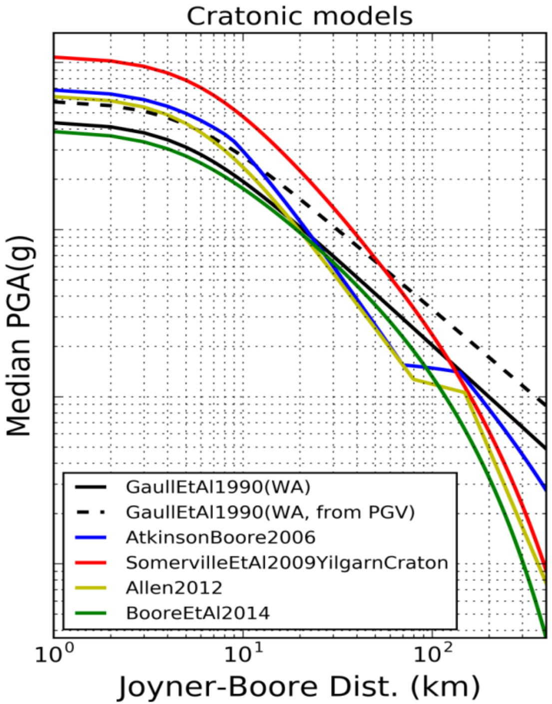




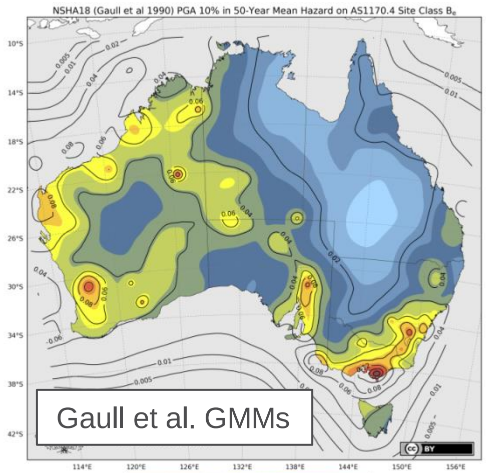
Modern Ground-Motion Models

- Ground-motion levels in the AS1170.4-2007 map were based on PGV hazard of Gaull et al. (1990) divided by a factor of 750 (ATC, 1984)
- The 1990 GMMs are more slowly attenuating than modern models:
    - The 1990-era non-cratonic (eastern) models estimate significantly higher ground motions than modern GMMs





NSHA18 Calculated Using Gaull et al. (1990) GMMs



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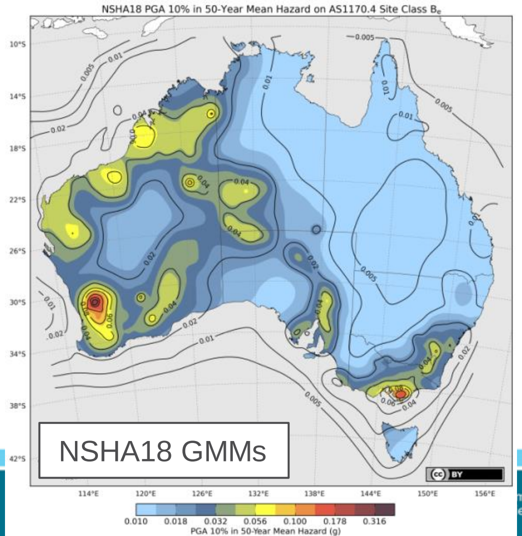

- Applied Gaull et al. (1990) GMMs as used in AS1170.4-1993 maps to the NSHA18 seismic source model:
  - AS1170.4-1993 PGA hazard based on PGV / 750 (ATC, 1984)
- Calculated ratio of Gaull GMMs / NSHA18 GMMs

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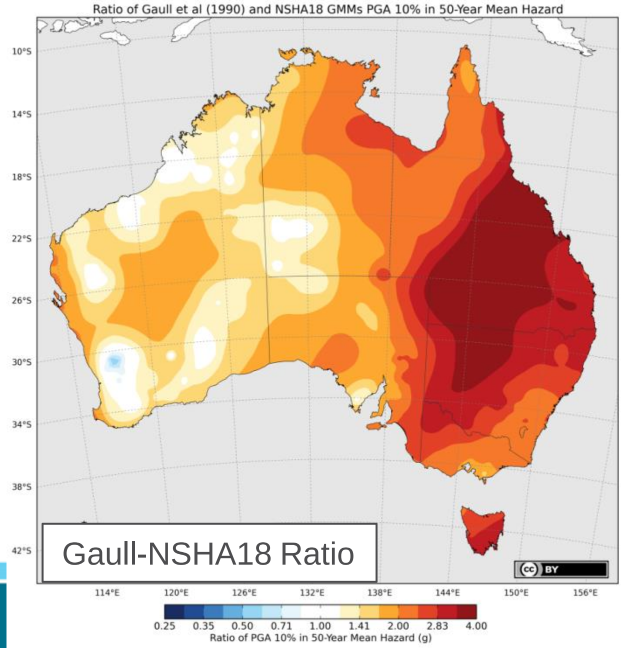
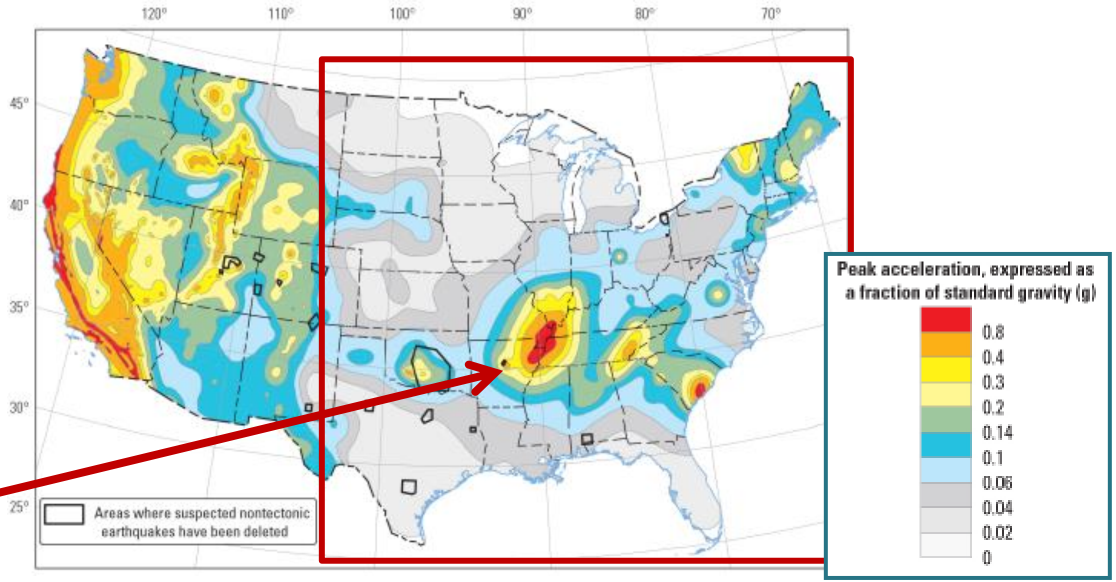


Comparison Against the USGS 2014 NSHM

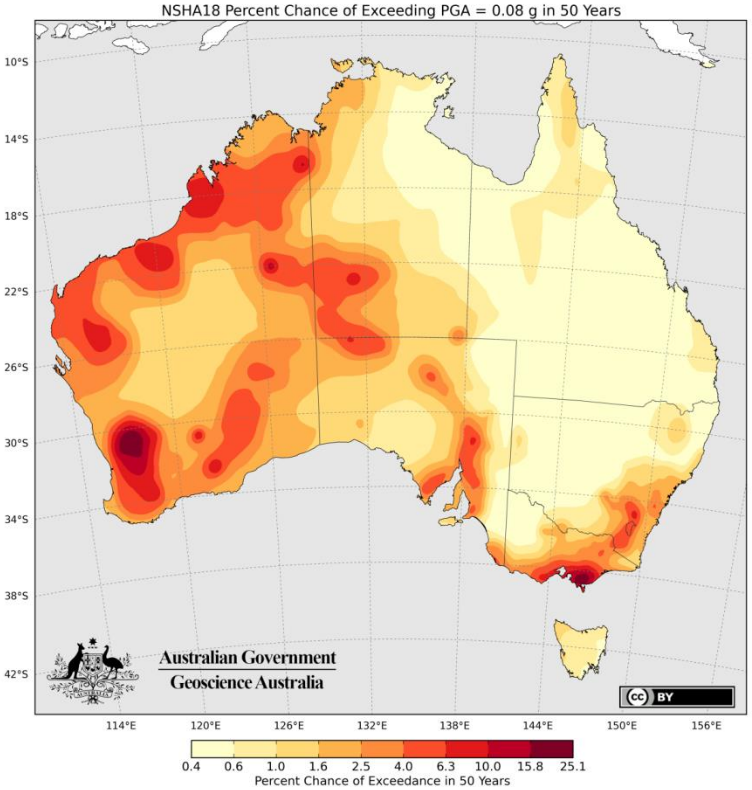
- Calculated the percentage of land area exceeded by different PGA thresholds with a 2% AEP in 50 years for the U.S. National Seismic Hazard Maps east of 105°W (Petersen et al., 2014) and the draft NSHA18
- Percentage of areas very consistent between the two SCRs
- The New Madrid Seismic Zone contributes to higher areas of exceedance at high PGA thresholds

PGA Levels (g)	Australia % Land Area Exceedance	CEUS % Land Area Exceedance
0.02	88.3	96.1
0.04	63.7	65.0
0.06	45.7	43.8
0.08	30.2	30.5
0.1	21.6	22.7
0.14	11.6	13.2
0.2	2.5	6.8
0.3	0.6	3.4
0.4	0.3	1.7



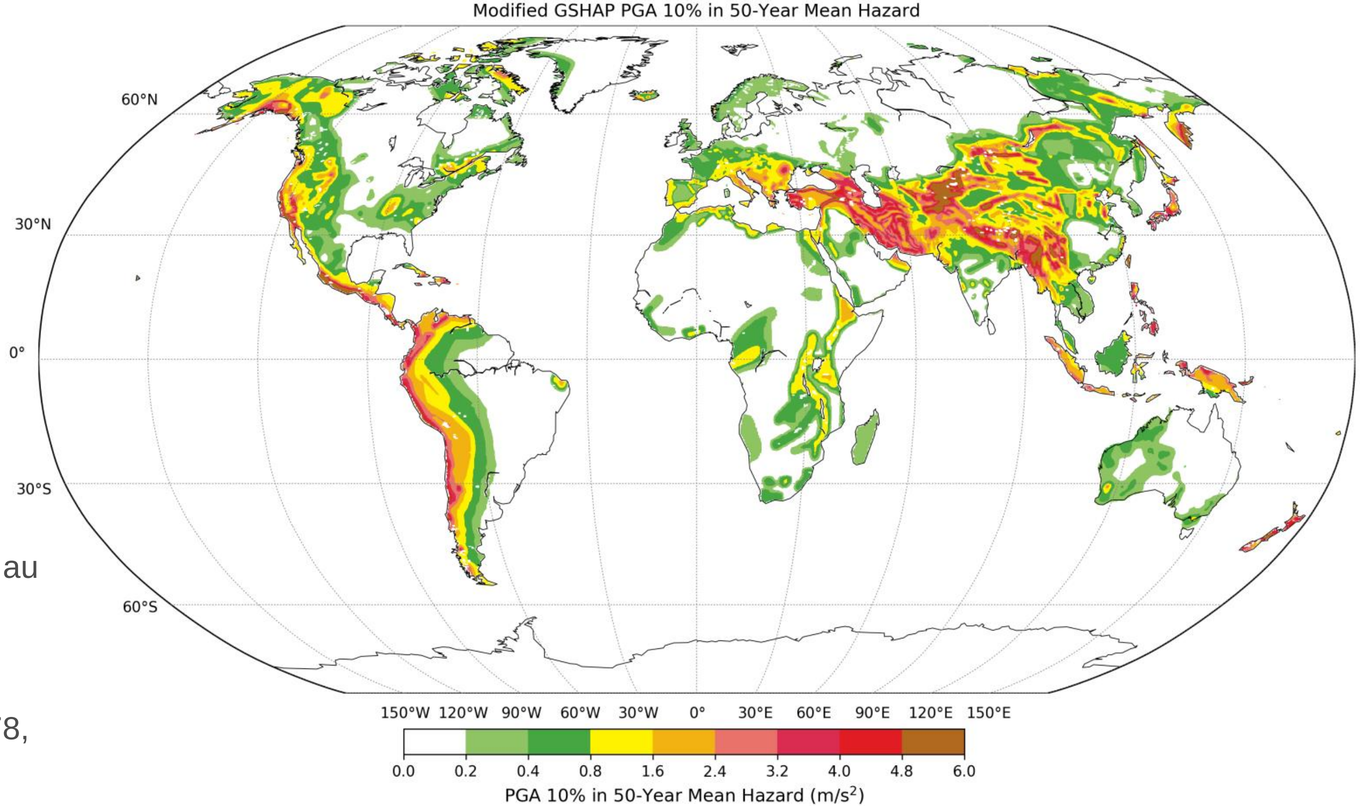
The Challenge Ahead

- It is clear that modern estimates of the 10% in 50-year hazard is significantly lower than the 1991-era AS1170.4 values:
  - Do the new values offer enough seismic protection?
- Australian seismologists and engineers value the seismic protection the 1991-era hazard estimates offer:
  - The new AS1170.4 will maintain the 1991 values, with a 0.08 g hazard floor
  - In regions of low strain, is PSHA even necessary?
- Should the AS1170.4 consider moving towards a 2% in 50-year probability level?
  - Fault sources do not contribute significant hazard at the 10% in 50-year probability level
  - This cannot be achieved without substantial change to the over-arching National Construction Code that references the AS1170.4
- It would seem sensible to move to ground-motion periods other than PGA
- Should we consider risk- or performance-based objectives to define design ground-motions?



Probability of exceeding 0.08 g in 50 years

Questions?



Phone: +61 2 6249 9111

Web: www.ga.gov.au

Email: clientservices@ga.gov.au

Address: Cnr Jerrabomberra Avenue and Hindmarsh Drive, Symonston ACT 2609

Postal Address: GPO Box 378, Canberra ACT 2601