THESSALONIKI
16TH EUROPEAN CONFERENCE ON
EARTHQUAKE ENGINEERING
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University of Strathclyde Engineering

Capturing geographically-varying uncertainty in earthquake ground motion models

or

What we think we know may change

Have your phones, tablets or laptops handy!

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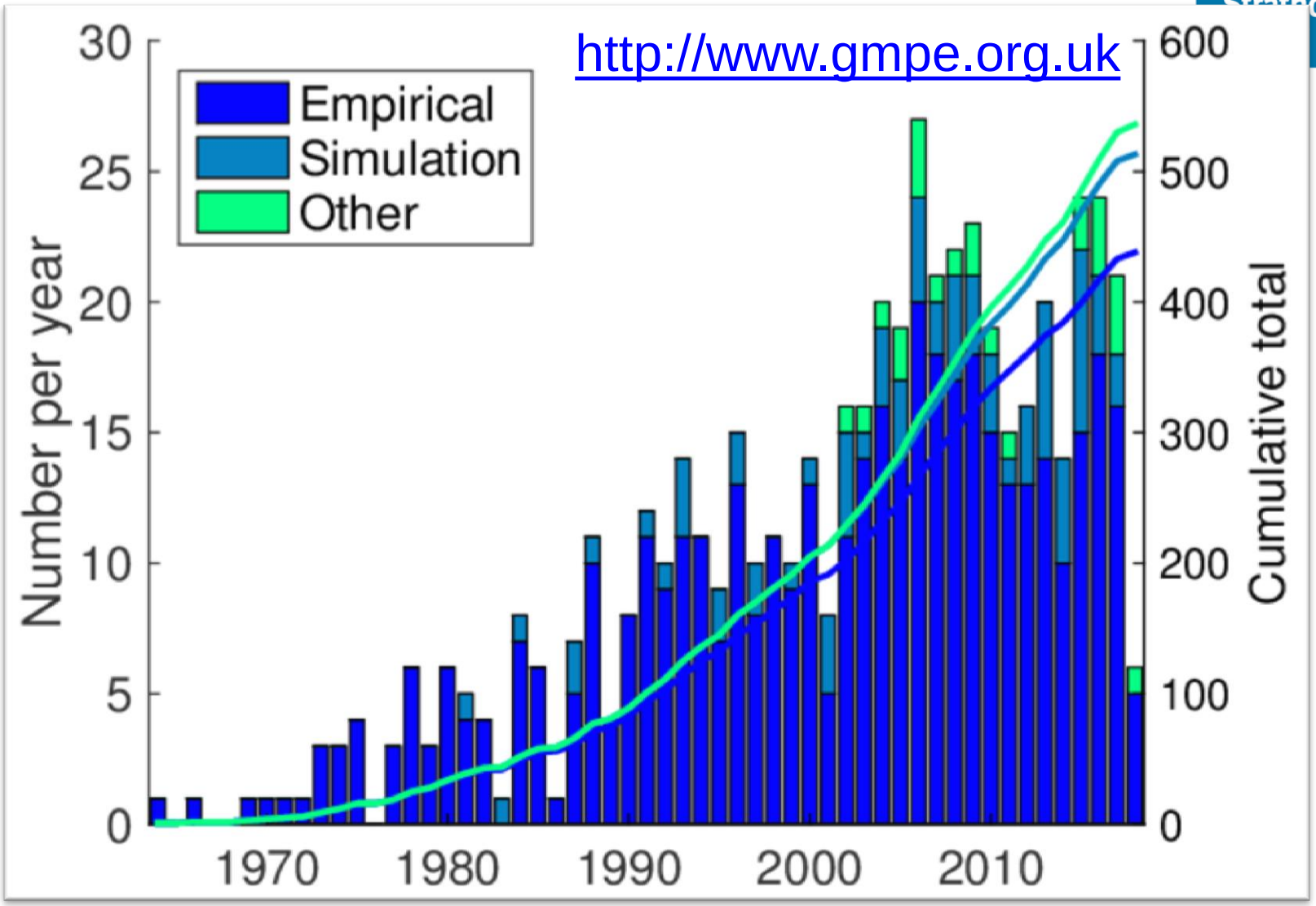
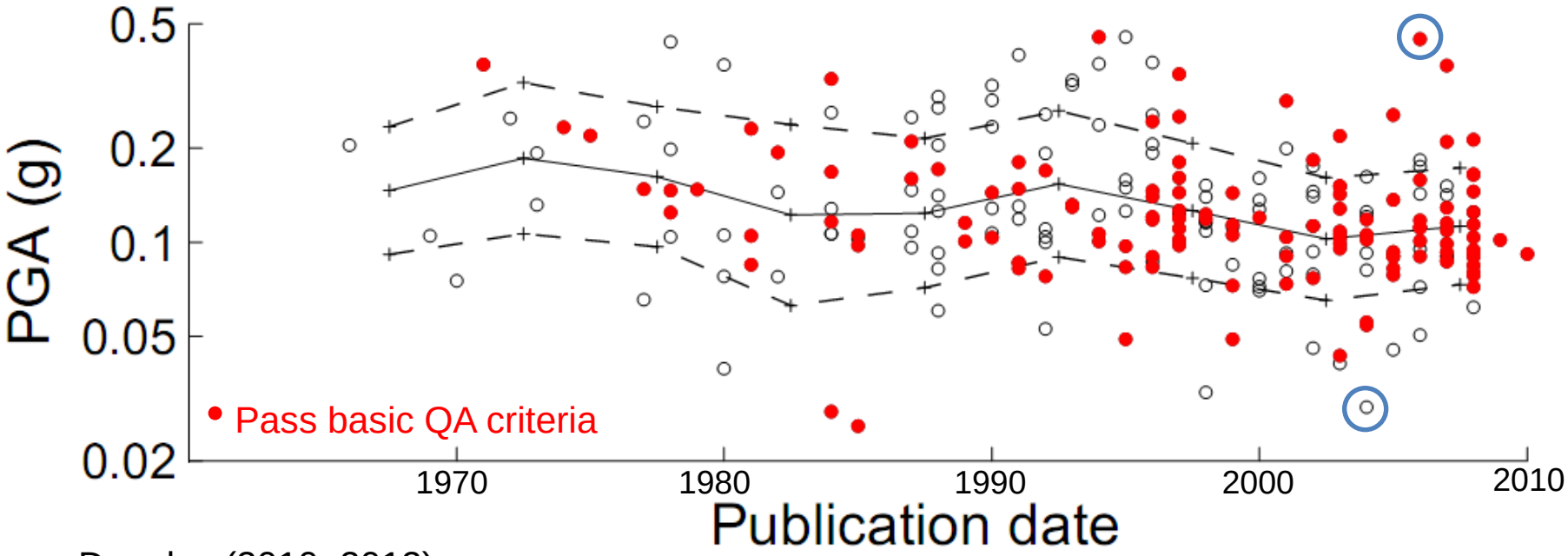
Rapidly increasing number of GMPEs



M_w 6 strike-slip earthquake at r_{jb}=20km on stiff soil

Factor ~ 20

Great engineering implications



Douglas (2010, 2012)

Which dot is the correct estimate of the median PGA?

More generally, how can we capture and reduce epistemic uncertainties?

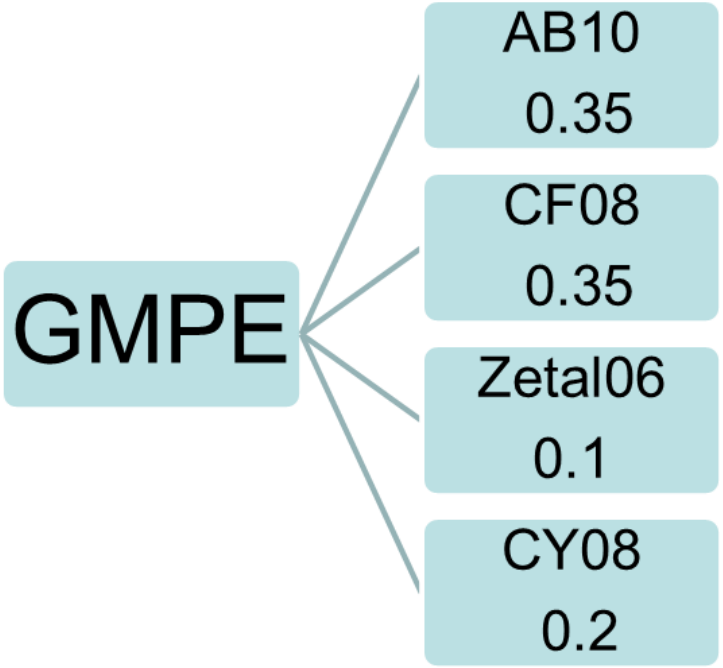
Logic trees to capture uncertainty

Diversification is protection against ignorance.

It makes little sense if you know what you are doing.

Warren Buffet

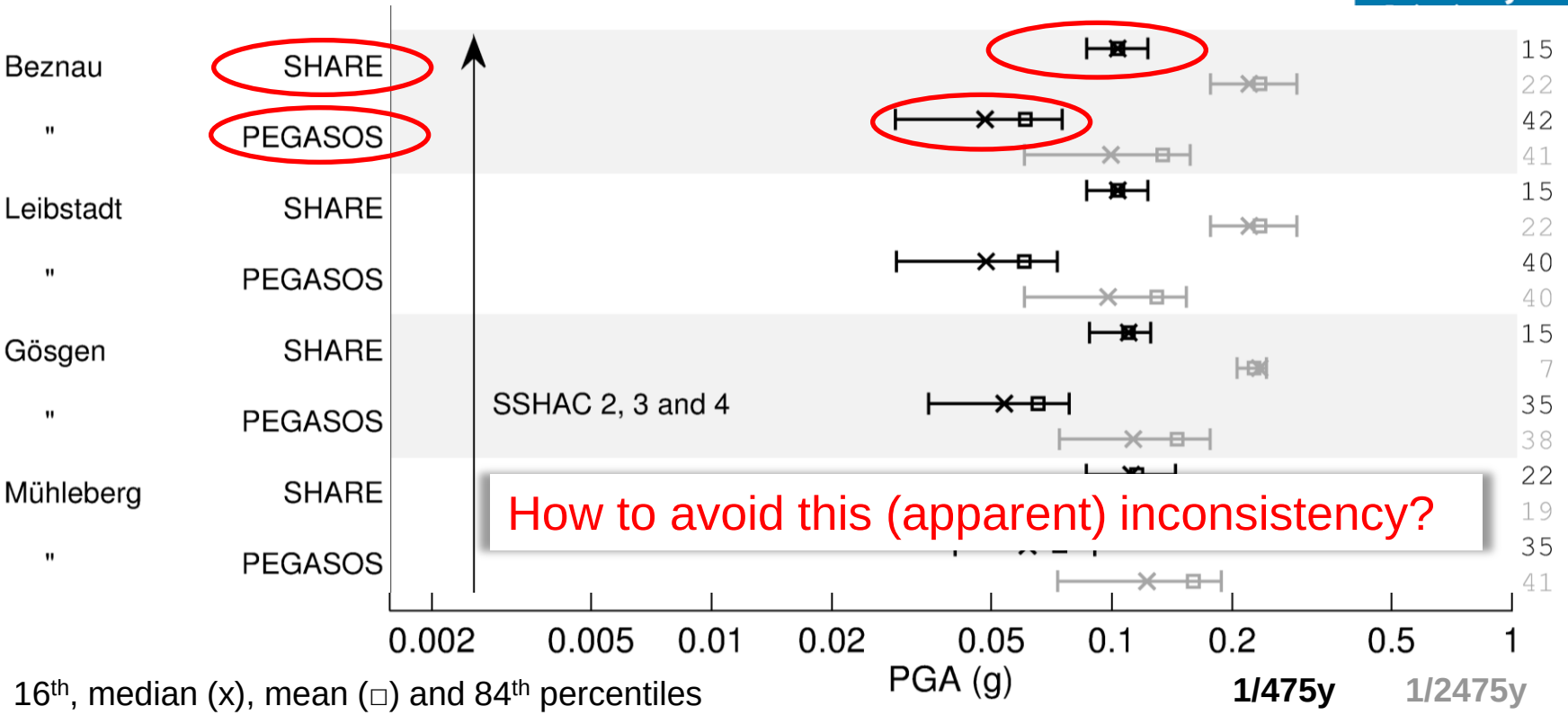
Selection and weights by expert judgement and testing



SHARE FP7 (active crustal)

Delavaud et al. (2012)

Uncertainty captured in PSHAs

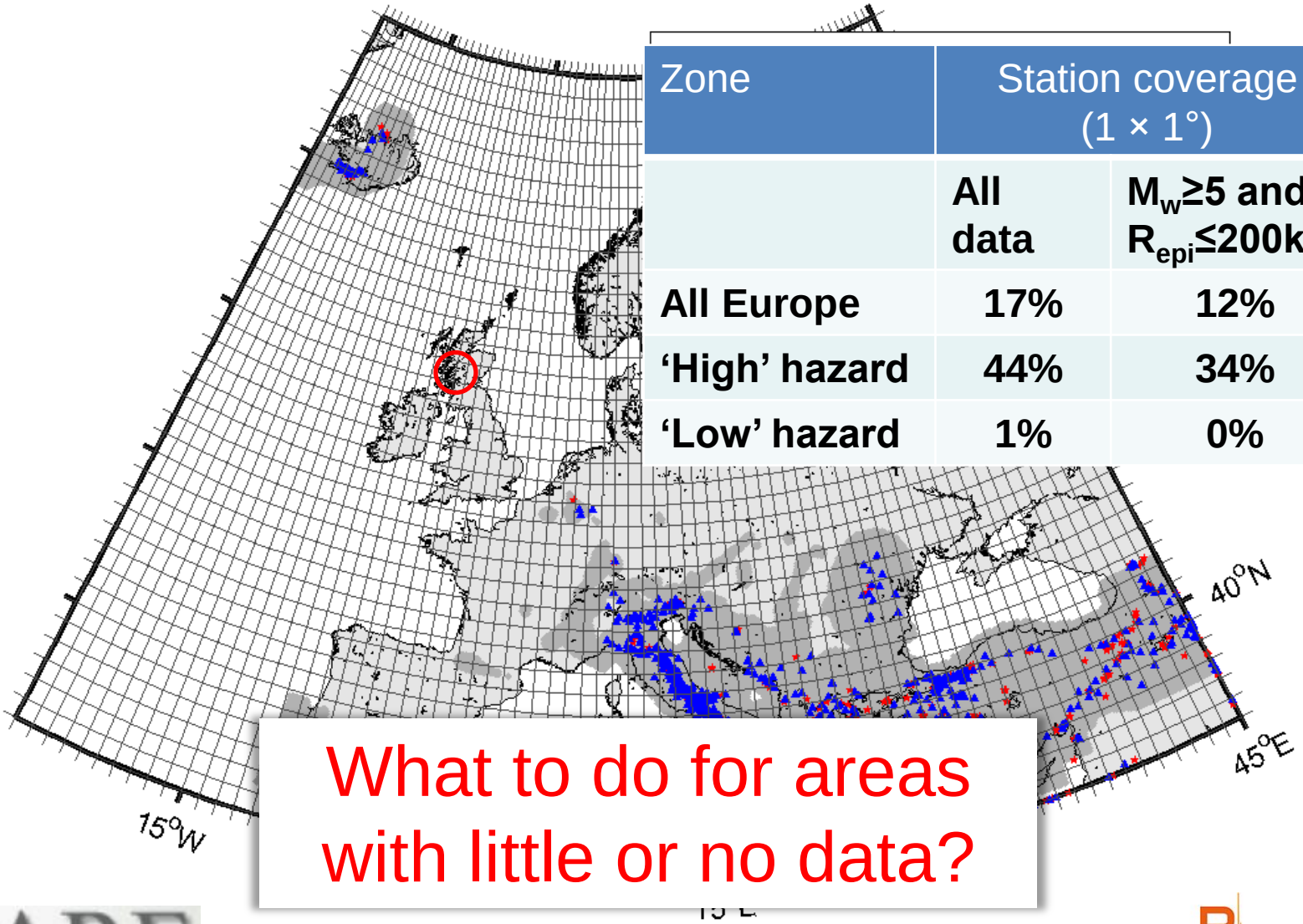


(Extract from Douglas et al., 2014)

Inconsistency in hazard estimates and confidence limits:

- Costly site-specific study (PEGASOS) **appears** to give more uncertain results

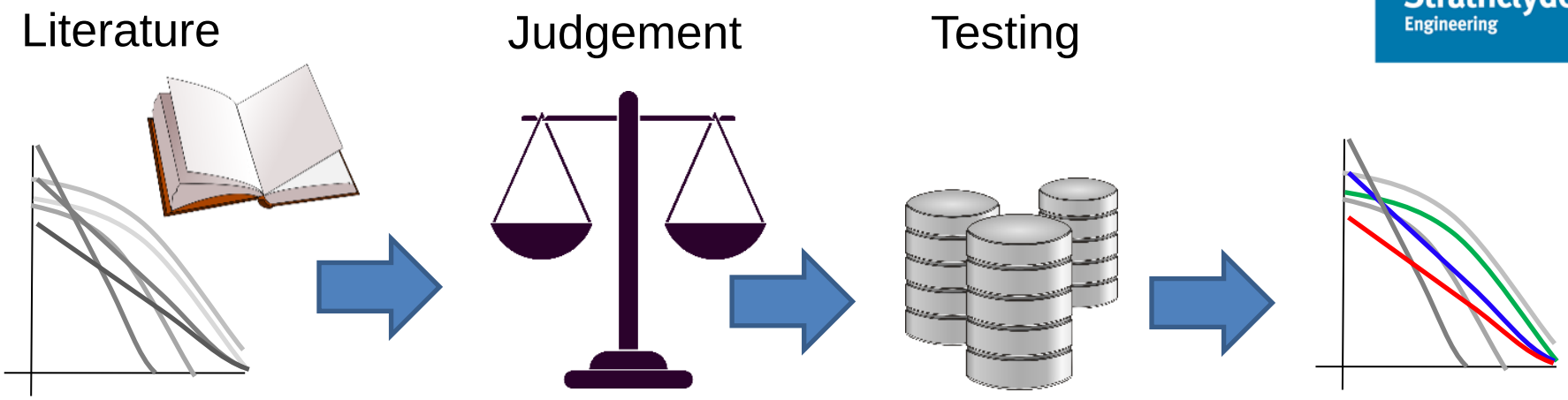
Available data in Europe



Zone	Station coverage (1 × 1°)	
	All data	$M_w \geq 5$ and $R_{epi} \leq 200$km
All Europe	17%	12%
'High' hazard	44%	34%
'Low' hazard	1%	0%

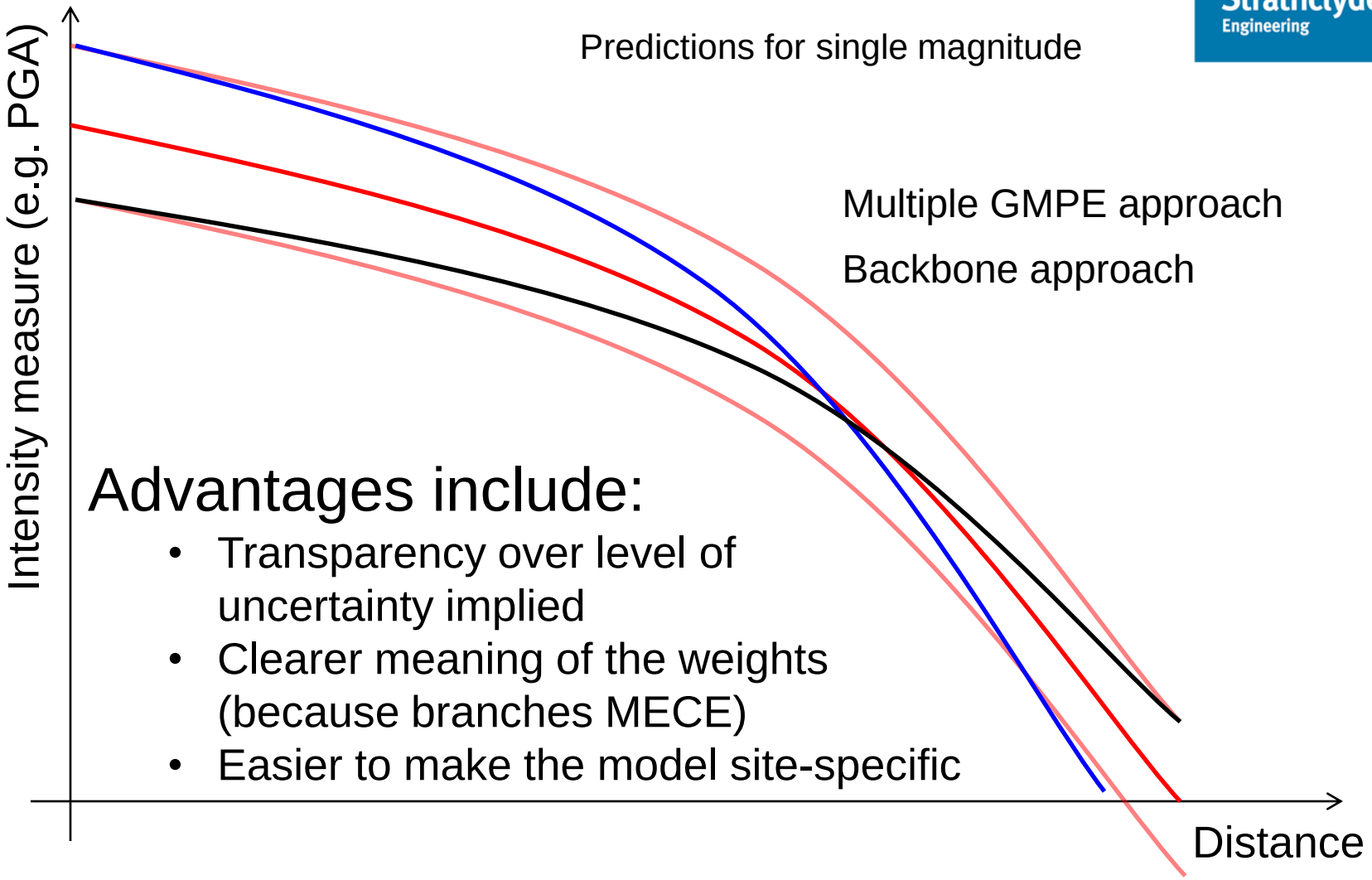
What to do for areas with little or no data?

Problems with multiple GMPEs



- Inconsistent sets of dependent and independent variables
- Testing only strictly useful for regions with lots of data
- Difficult to quantify uncertainties for data-poor regions
- What if no published GMPE is deemed appropriate?
- How many models are enough?
- How to capture what we *do not* know about ground motions?

Backbone approach



Advantages include:

- Transparency over level of uncertainty implied
- Clearer meaning of the weights (because branches MECE)
- Easier to make the model site-specific

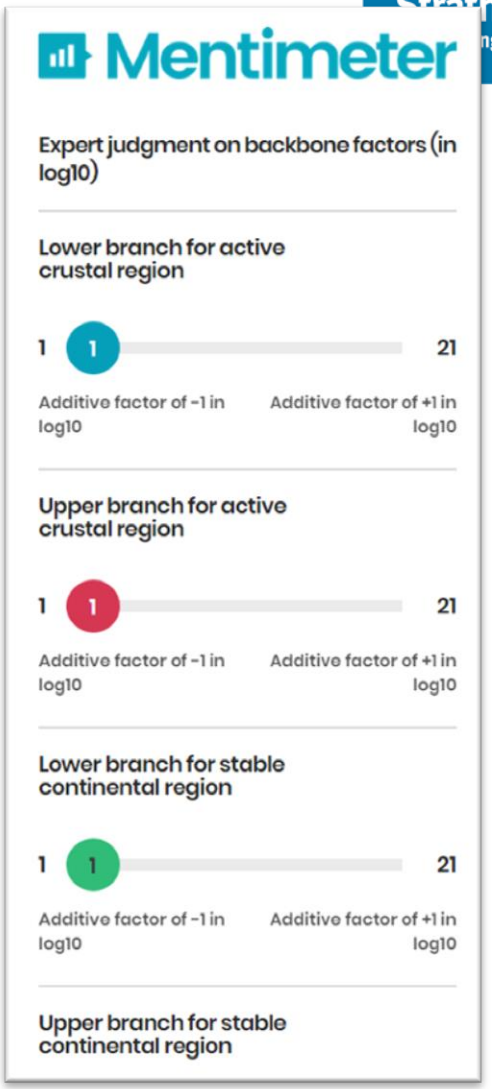
Previous applications

- Increasingly employed in nuclear-related PSHAs
- See convincing “Opinion” paper by Atkinson et al. (2014)

Toro et al. (1997)	Central and eastern North America
Electric Power Research Institute (2004, 2013)	Central and eastern North America
Atkinson (2011)	Canada
Atkinson and Adams (2013)	Various regions of Canada
Al Atik and Youngs (2014)	Western USA
Coppersmith et al. (2014)	Hanford, USA
Petersen et al. (2008, 2014)	Western USA
Bommer et al. (2015)	Thyspunt, South Africa
GeoPentech (2015)	Diablo Canyon and Palo Verde, USA
García-Fernández et al. (2016) & Gehl (2017)	Europe & Middle East
Goulet et al. (2017)	Central and eastern USA
de Almeida et al. (2018)	Angra dos Reis, Brazil

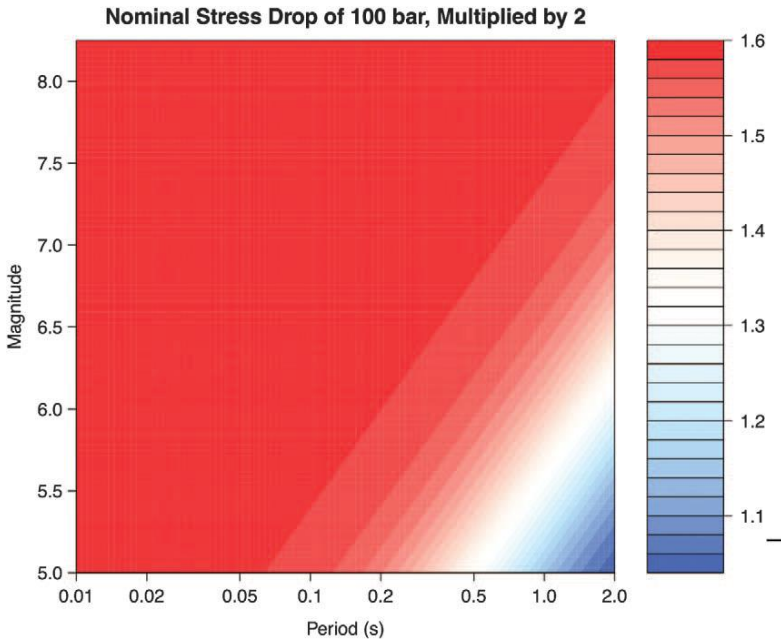
Expert judgement

- On your phone go to **menti.com**
- Enter code **17 78 51**
- Provide your judgement on factors
- Imagine a single central backbone
- 1 implies factor of 10^{-1}=0.1
- 2 implies factor of $10^{-0.9}$=0.13
- 3 implies factor of $10^{-0.8}$=0.16
- …
- 11 implies factor of 10^{0}=1
- …
- 21 implies factor of 10^{1}=10
- For active and stable regions

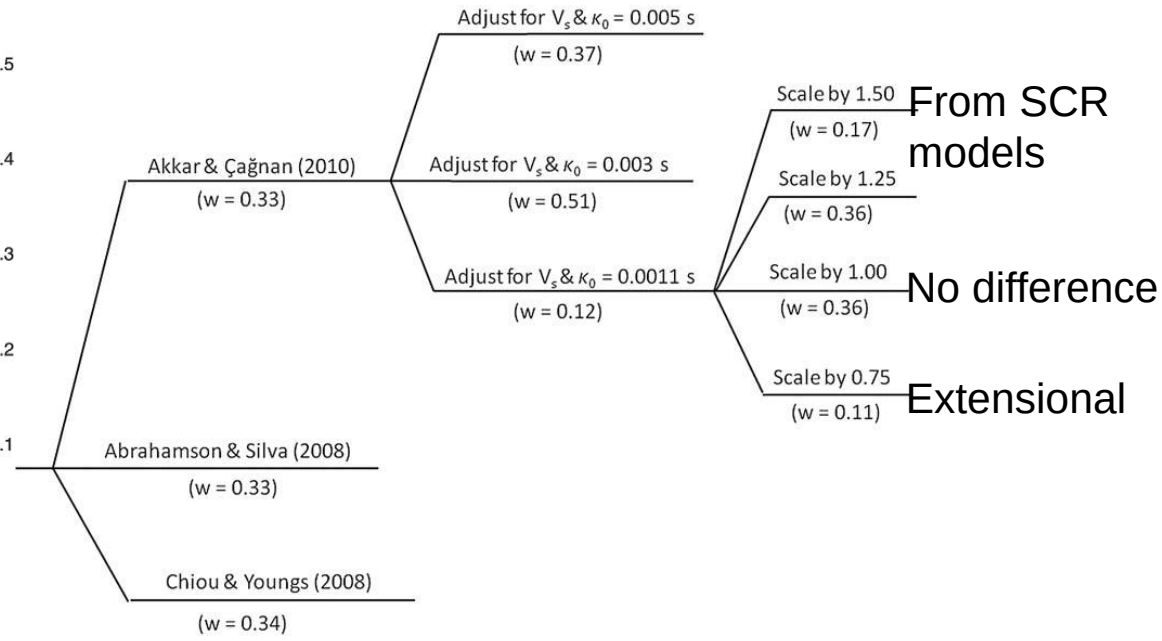


Example from Bommer et al. (2015)

- Three models (Akkar and Cagnan, 2013; Chiou and Youngs, 2008; Abrahamson and Silva, 2008) used as backbones
- Retain models leading to “distinctly separate clusters of hazard curves”
- “The effects of variations in stress drop on spectral accelerations were used to inform the selected scaling factors”



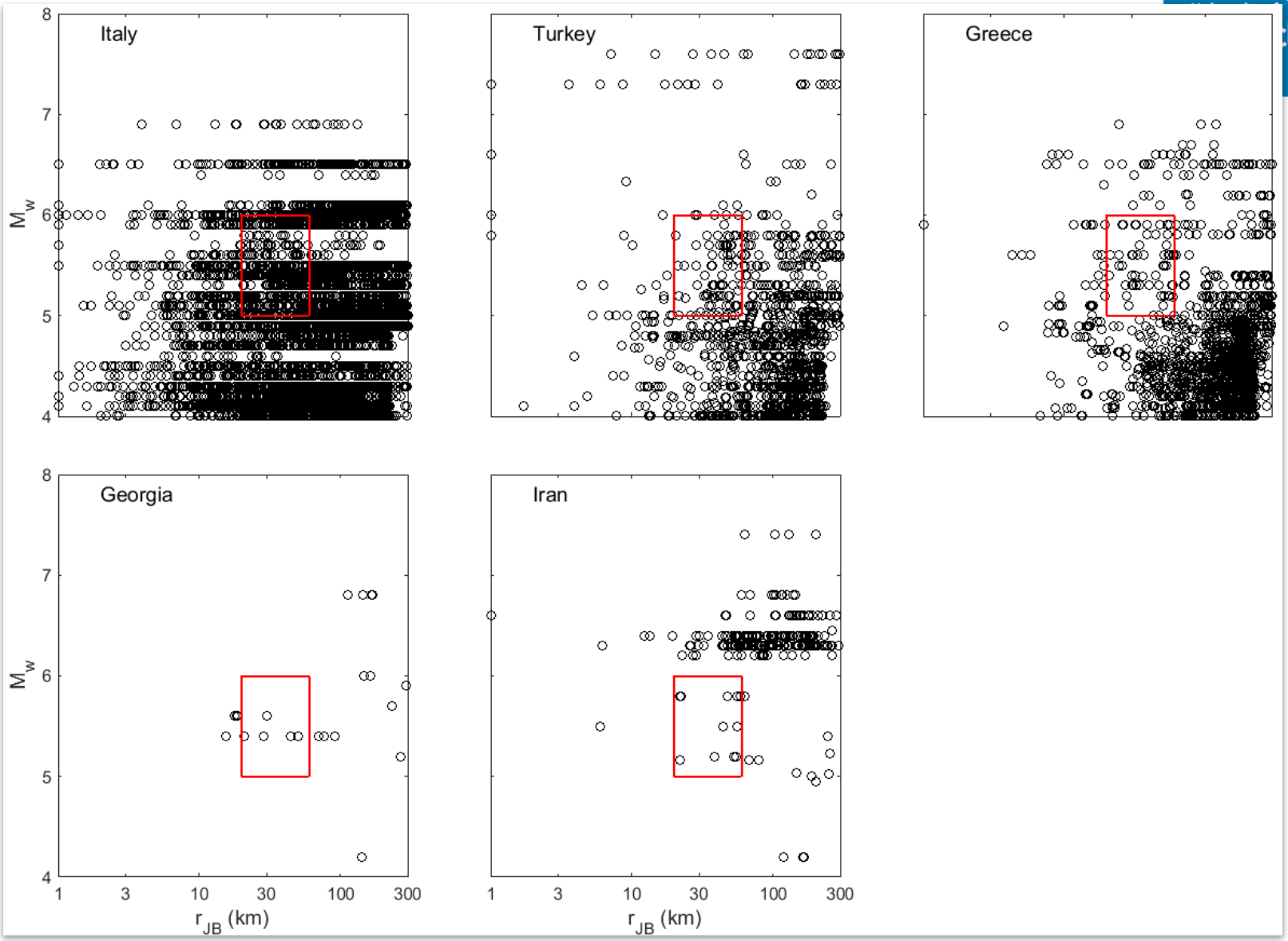
Using Fukushima (1996)



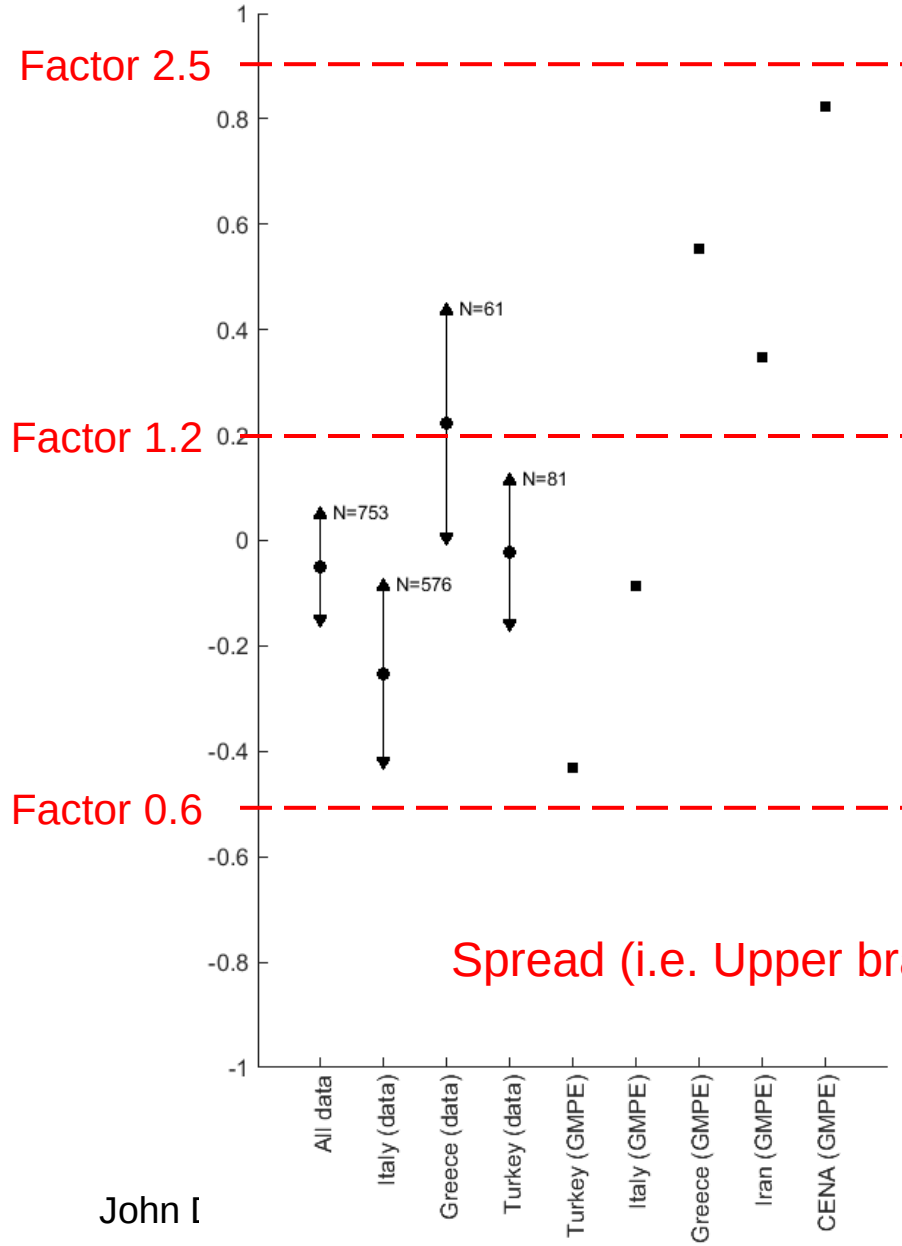
Three main questions

- What GMPE(s) to use for the backbone?
  - Not discussed here
  - See the papers for some suggestions
- How to calibrate the scale factors?
  - Propose empirical approach
  - Also investigate using stochastic models
- How to use local data?
  - Method provides maximum uncertainty
  - Local data reduces this uncertainty

Calibrating backbone approach



Average residuals (ln) for M 5-6 and 20-60km



- Calibrate ‘regional’ uncertainty using data and robust GMPEs
- Apply these factors for all magnitudes and distances to create a generic ground-motion model that can be adjusted based on data
- Similar graph for PSA(1s)

Spread (i.e. Upper branch/Lower branch) is factor of 4.2

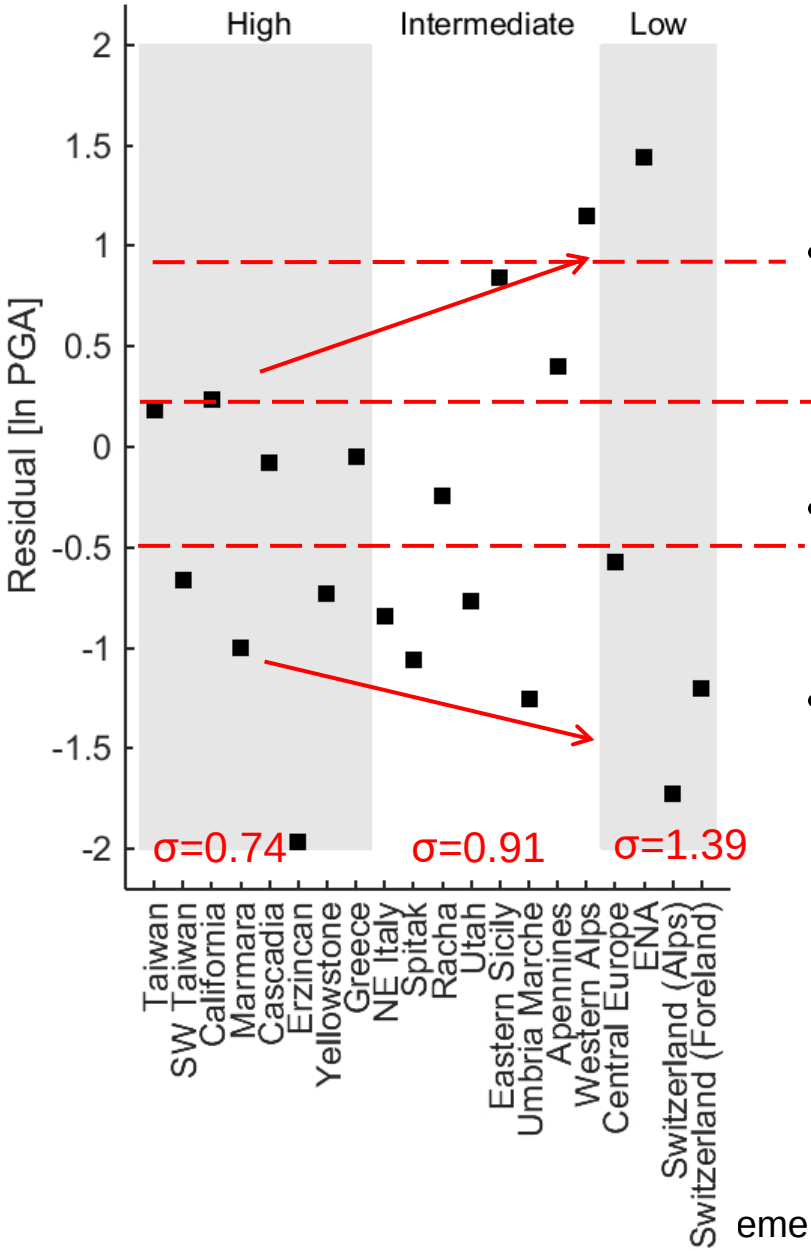
Using stochastic models

- Considered the 20 stochastic models listed by Douglas (2007) as a representative sample
- Classified into three tectonic regimes:
  - Low strain rate (SCR)
  - Intermediate strain rate
  - High strain rate

  Using 2005 Release of the World Stress Map

- Again consider Kotha et al. (2016) as backbone

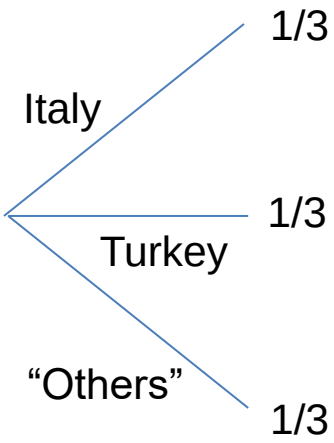
Average residuals (ln) for M 5.5 and 50km



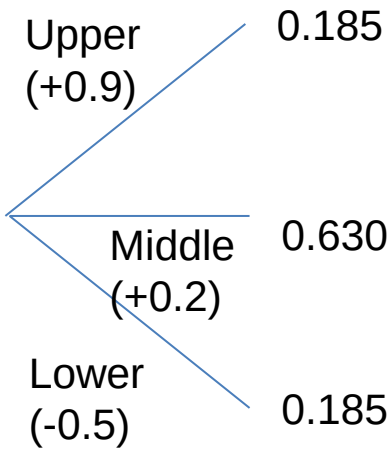
- Stochastic models suggest larger range of scaling factors than empirical (more regions sampled?)
- Larger spread for lower strain regions (less data? regions more different?)
- Similar graph for PSA(1s)

Three-level logic tree

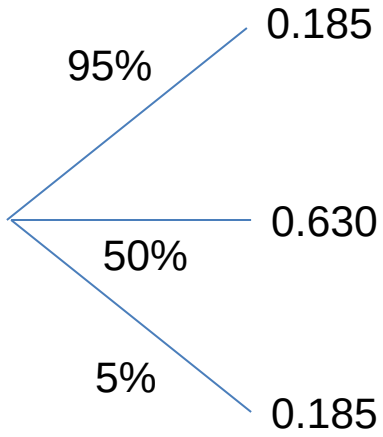
Backbone GMPE: Kotha et al. (2016)



Anelastic attenuation uncertainty

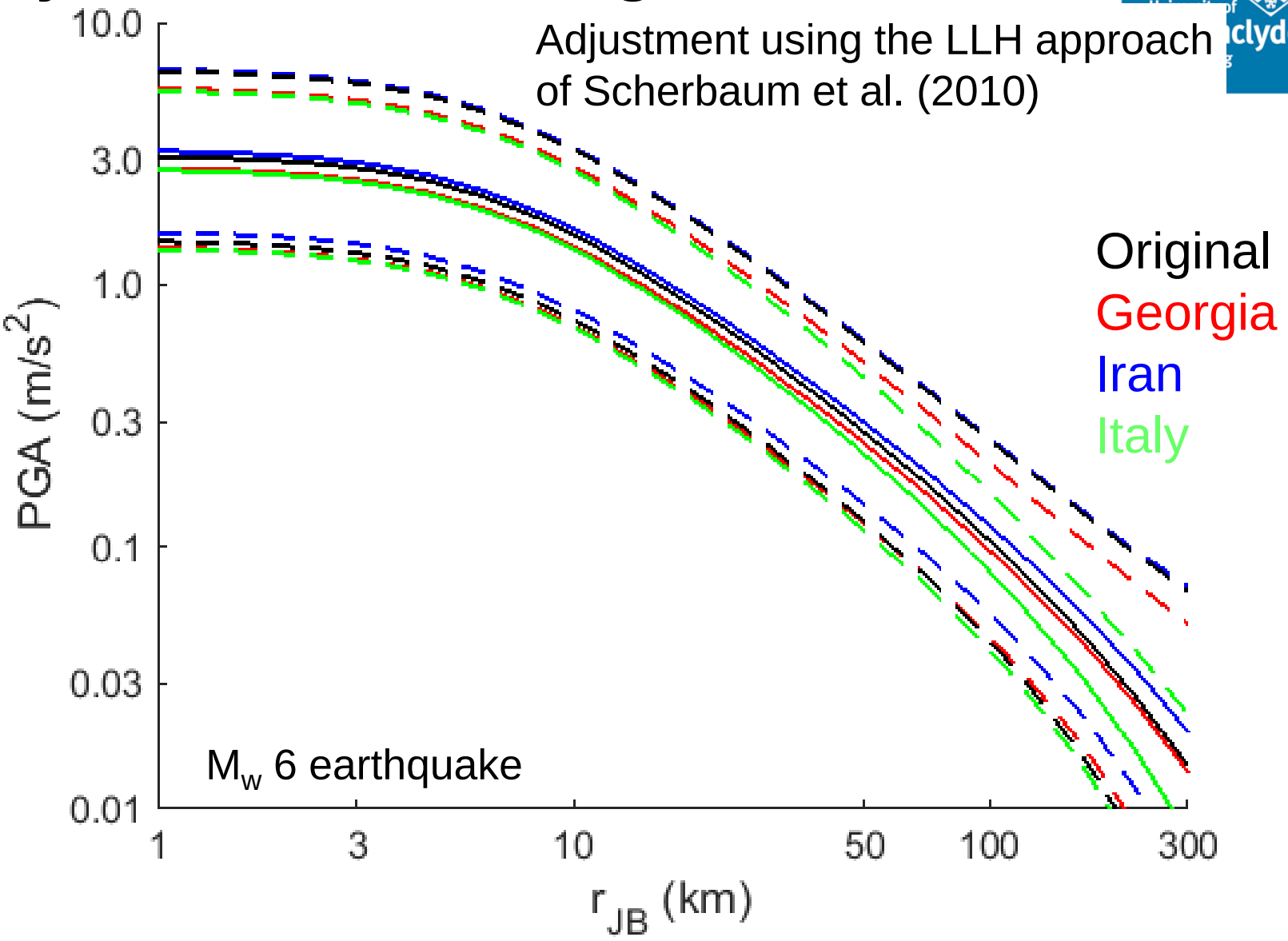


Average "stress drop" uncertainty



Statistical uncertainty from confidence limits of regression (e.g. Al Atik and Youngs, 2014)

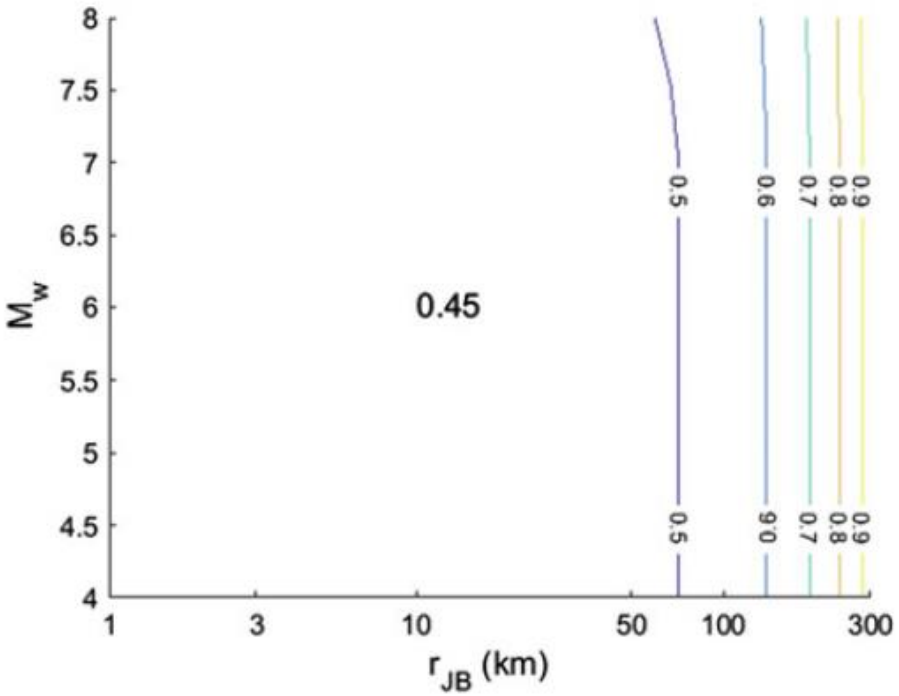
Adjustment of weights



Uncertainty implied

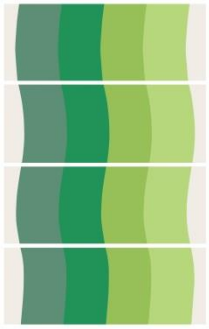
Site	References	k	σ_{μ} (ln)
Edinburgh, UK	ESHM (Woessner et al. 2015)	1.68	0.23
Berlin, Germany	ESHM (Woessner et al. 2015)	1.55	0.34
Istanbul, Turkey	ESHM (Woessner et al. 2015)	2.51	0.13
Mühleberg, Switzerland	ESHM (Woessner et al. 2015)	2.09	0.18
"	**PEGASOS (Nagra 2004)**	**2.15**	**0.41**
Bruce, Canada	**AMEC Geomatrix Inc. (2011)**	**1.94**	**0.49**
Thyspunt	**Bommer et al. (2015)**	**1.19**	**0.51**
Yucca Mountain	**CRWMS M&O (Stepp et al. 2001)**	**1.80**	**0.45**

Using Toro (2006)



Conclusions

- Backbone approach is being increasingly employed
- It has clear advantages over multi-GMPE approach
- Appears simple but …
- … care is required when applying it for a specific site
- Empirical and stochastic models are useful for calibration
- Proposal provides maximum uncertainty in absence of data
- Local data allows this uncertainty to be reduced
- But we should be humble about *what we do not know*



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Also see: "Calibrating the backbone approach for the development of earthquake ground motion models" in 2nd Best PSHANI, Cadarache, 14-16 May (on my website)

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