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Objective quantification of the seismic source model using the Bayesian Metropolis-Hastings approach

I. Mosca[1] (imosca@nerc.ac.uk)
B. Baptie[1], M. Villani[2], Z. Lubkowski[2], and T. Courtney[3,*]

Introduction

The Bayesian Metropolis-Hastings (BMH) approach is a statistical approach based on the Metropolis-Hastings Algorithm and the Bayesian inference as a fully non-linear method for characterising the seismic source characterisation (SSC) model used for probabilistic seismic hazard assessment (PSHA). This approach allows us to: 1) sample potential models compatible with the data; 2) capture the epistemic uncertainties in the SSC model used for the PSHA; and 3) model the key components of the SSC model jointly rather than individually. The development of a robust SSC model for PSHA and a comprehensive characterisation of its uncertainties can be used to define a transparent and objective weighting scheme for the source model logic tree for PSHA.

We apply this approach to the Wylfa Newydd nuclear site (North Wales, UK), one of the proposed sites for new nuclear power plants in the UK, and benchmark our results using the PSHA developed for this site by Arup for Horizon Nuclear Power (Villani et al., Submitted).

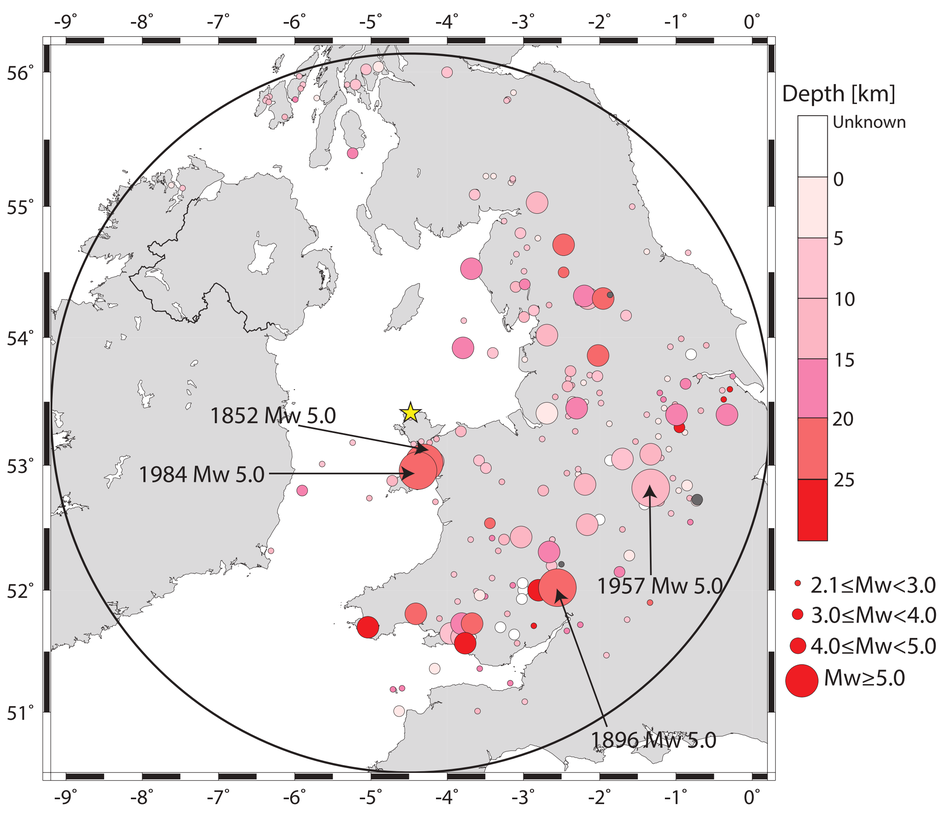
Conclusions

This work presents the first application of the BMH approach for the objective assessment of the quality of the SSC model and a way to better capture its epistemic uncertainties in PSHA. It allows quantitative comparison of various seismic source zone models (SZMs) against the observed seismicity in the study area in a transparent and reproducible way.

The BMH approach tends to favour SZMs based on the past seismicity and penalize those based on the regional geology and tectonics because the acceptance and rejection criteria used by the Metropolis-Hastings Algorithm is based on the ability of the seismic source models to replicate the observed seismicity. However, in the case study of the Wylfa Newydd site, the key output of the BMH approach is stable. This means that the 1-D posterior probability density functions (*pdf*s) are largely independent of the relative role that the seismicity has had in the delineation of the SZMs.

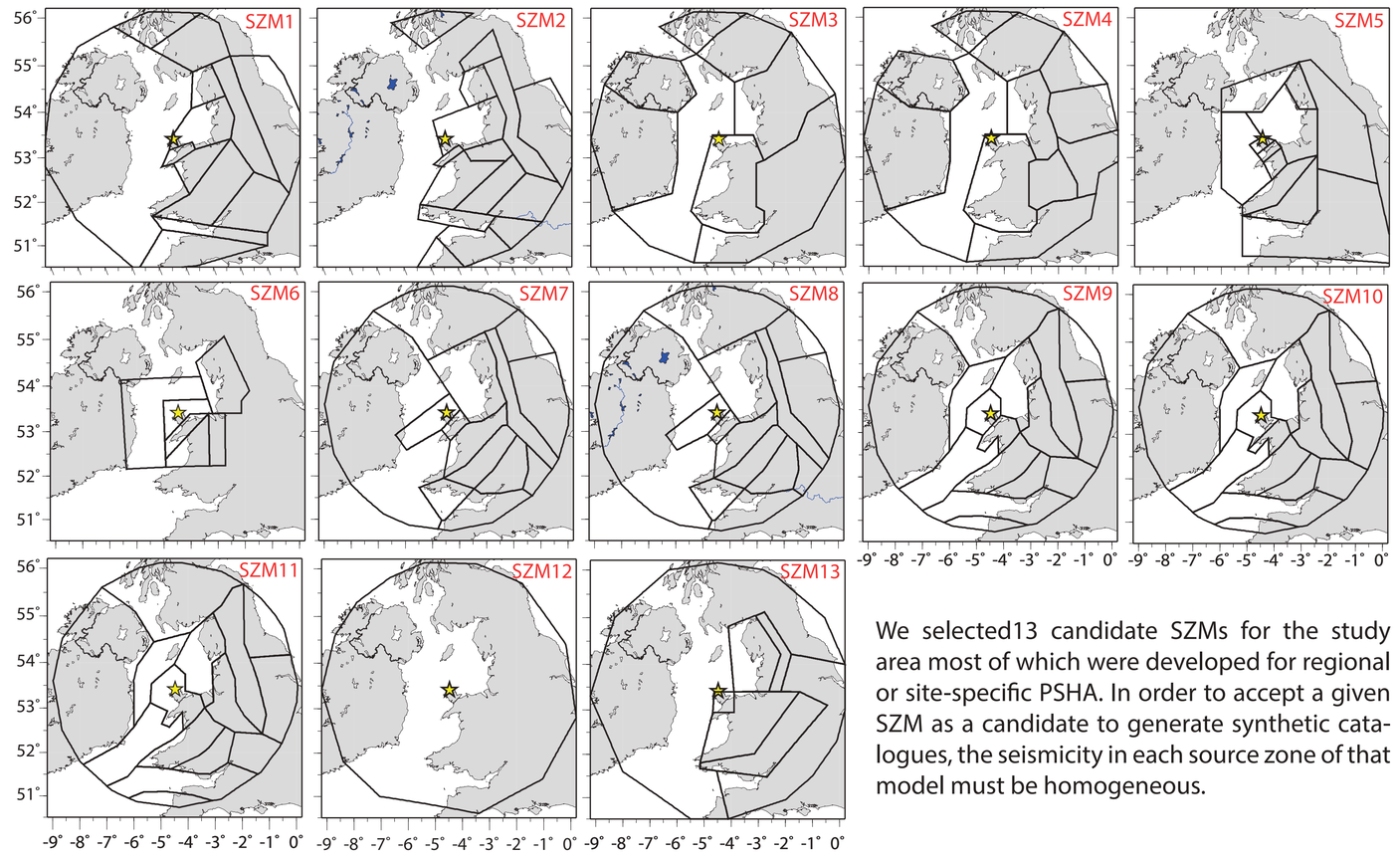
Case study of Wylfa Newydd

STEP 1: PREPARATION OF THE OBSERVED DATA



Distribution of the mainshocks in the study area within the completeness threshold. The yellow star describes the site of Wylfa Newydd and the black circle describes the area within 300 km from the site.

STEP 2: DEVELOPMENT OF THE SEISMIC SOURCE ZONE MODELS (SZMS)

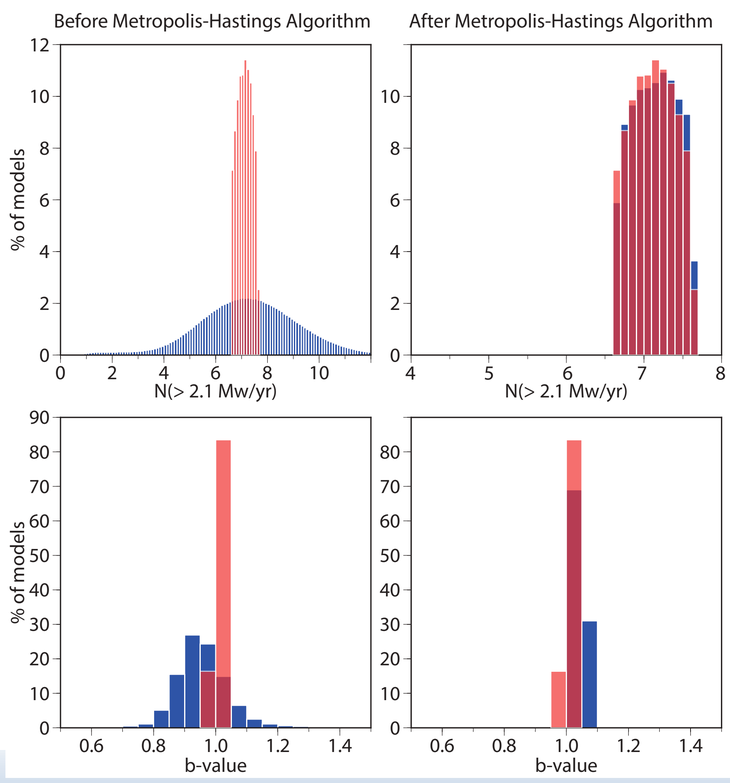


We selected13 candidate SZMs for the study area most of which were developed for regional or site-specific PSHA. In order to accept a given SZM as a candidate to generate synthetic catalogues, the seismicity in each source zone of that model must be homogeneous.

STEP 3: GENERATE SYNTHETIC CATALOGUES

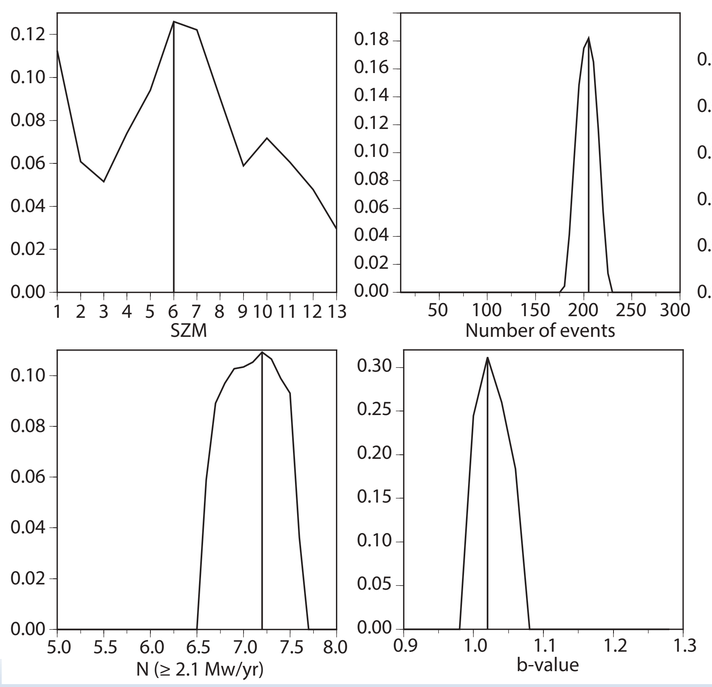
We generated 6,000,000 synthetic catalogues from the 13 candidate SZMs using Monte Carlo simulations. The synthetic catalogues are obtained by choosing the catalogue parameters, including maximum magnitude, the *b*-value, the activity rate, the earthquake magnitude, and the hypocentral depth, at random within their range.

STEP 4: APPLY THE METROPOLIS-HASTINGS ALGORITHM



The distribution of the activity rate N(≥ 2.1 Mw /yr) and *b*-value of the 6,000,000 synthetic catalogues is described by the blue histograms before (left-hand column in the figure) and after (right-hand column in the figure) applying the Metropolis-Hastings Algorithm. The red histograms describe the normalized distributions of N (≥ 2.1 Mw/yr) and b-value of the observed catalogues. Only 173,880 out of 6,000,000 synthetic catalogues fall within the observed *pdf*s and therefore these tend to be accepted by the Metropolis-Hastings Algorithm.

STEP 5: APPLY THE BAYESIAN INFERENCE



In the Bayesian framework, the 173,880 synthetic catalogues accepted by the Metropolis-Hastings Algorithm were converted into 1-D posterior *pdf*s, one for each parameter of the source model.

From the pdfs to the weights

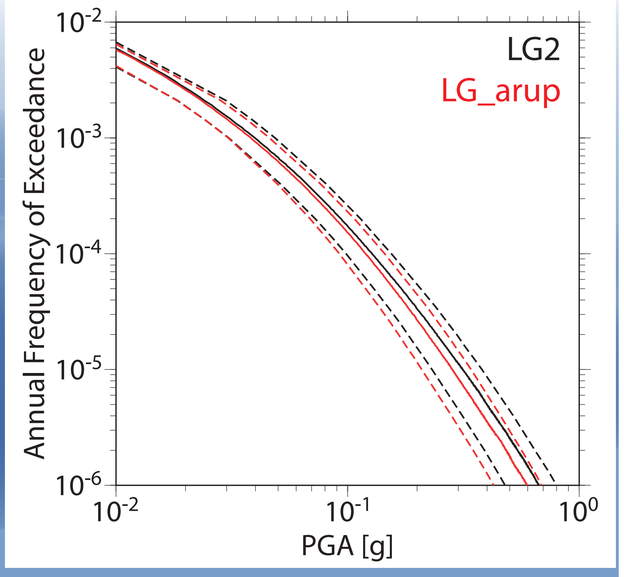
LG		LG_arup	
SZM	Weight	SZM	Weight
SZM1	0.14	SZM7	0.25
SZM2	0.10	SZM8	0.20
SZM4	0.09	SZM9	0.25
SZM5	0.11	SZM10	0.25
SZM7	0.16	SZM11	0.05
SZM8	0.12		
SZM9	0.09		
SZM10	0.10		
SZM11	0.09		

LG is the source model weighting scheme developed from the 1-D posterior *pdf* computed using the BMH approach; and LG_arup is the source model logic tree defined in Villani et al. (Submitted).

PSHA for Wylfa Newydd site

We used the Monte Carlo-based PSHA to compute peak ground acceleration (PGA) hazard curves for the Wylfa Newydd site using the LG and LG_arup weigthing schemes (see table above). The figure in the right-hand side shows the results, together with the standard deviation (dashed lines) around the estimated hazard.

The main finding of this work is that the hazard estimates using the source model logic tree developed by Arup and those developed here are very similar, suggesting that the SSC model for the Wylfa Newydd site is not unique and different weighting schemes for the source model logic tree provide comparable seismic hazard estimates. This is because any SSC model is not strongly constrained by the British earthquake catalogue, which is short in time and does not contain large magnitude (M ≥ 6) earthquakes.



[1] British Geological Survey, the Lyell Centre, Edinburgh, United Kingdom
[2] Arup, London, United Kingdom
[3] Horizon Nuclear Power, Gloucester, United Kingdom
* Now CGN, London, United Kingdom