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The New Zealand National Seismic Hazard Model update: Contributions from the deep south

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ABSTRACT

The New Zealand National Seismic Hazard Model (NSHM) is being updated for the first time since 2010 in a multi-institutional project led by GNS Science (www.gns.cri.nz/NSHM). In the interim, several major well-instrumented and well-studied earthquakes have occurred in the country. These events increased interest and awareness of seismic hazards, and necessitated urgent updates of the NSHM at the regional scale. The current national update is embracing these regional advances, but also incorporating new ideas and state-of-the-art methods in probabilistic seismic hazard analysis (PSHA). This paper is a precis of work being undertaken by our Otago earthquake science group that contributes to the NSHM update. Our work on magnitude-area scaling relations, an important but typically neglected area of PSHA, is highlighted. Efforts to revise earthquake recurrence relations, and to introduce a testing and evaluation step to the overall PSHA method are also discussed.

1 INTRODUCTION

The NSHM is being updated a decade after the last national-scale update (Stirling et al., 2012). Furthermore, the last national-scale update to the Loadings Standard (Standards, 2004) was based on an even earlier version of the model (Stirling et al., 2002). The present update is incorporating many of the lessons learned from recent major earthquakes (Canterbury earthquake sequence and Kaikoura earthquake), and is exploiting the greater interest in seismic hazards among scientists and engineers than what existed during the earlier model developments.

The NSHM update is taking place on several different fronts that collectively incorporate new methods and data, and epistemic uncertainty. The major categories of development are: source model; ground motion model; hazard integration; and software. A project and peer review structure involving a steering committee, technical advisory group, core team, and technical working groups has been developed, and comprises national and international specialists. The project is supported by the Ministry for Business Innovation and Employment (MBIE) and the Earthquake Commission (EQC) for a contracted period of about two years. Consequently, the update will not be able to incorporate all the recent developments in hazard modelling science, but the highest priority developmental needs will be addressed.

In this short paper we precis the contributions to the model developments from our Otago earthquake science group.

2 ACTIVITIES

2.1 Core NSHM Team

Stirling is currently serving in the seven-person Core NSHM team, which has the purpose of providing "big-picture" guidance and decisions on NSHM methods and composition. While some of the core team members are also leaders of the various working groups (Source, Ground Motion Model, Software), Stirling's main role is in providing advice across the board, and particularly to the project leader Gerstenberger. The team typically meets weekly online, with occasional face-to-face meetings at GNS Science in Lower Hutt.

2.2 Magnitude-area scaling relations

This task involves the selection and evaluation of magnitude-area scaling relations for use in the NSHM source model. Magnitude-area scaling relations are empirical regression equations that allow earthquake magnitude to be estimated from the dimensions (e.g. length or area) of a fault source or postulated rupture. The very large differences in fault rupture area between moderate, large and great earthquakes (e.g. Fig. 1) shows that rupture area is an important parameter for estimating the potential magnitudes of future earthquakes. Our preference is to use magnitude-area relations, as the majority of relations are area-based, and area is a better parameter than length for representing the size of dipping faults (especially subduction interfaces). The earlier NSHMs generally incorporated one magnitude-area scaling relation into the model for each seismotectonic region (region of broadly homogenous seismicity and tectonics), with no epistemic uncertainty (i.e., uncertainty in scientific knowledge rather than aleatory parameter variability) in scaling relations within a particular seismotectonic region. The scaling relation used for much of New Zealand in the Stirling et al. (2012) NSHM was the Stirling et al. (2008) relation for oblique slip faults, whereas the Alpine Fault sources utilised the Hanks and Bakun (2002) relation for continental strike-slip faults. The Taupo Volcanic Zone sources used the Villamor et al. (2001) relation for rift zone faults, and the subduction interfaces in Hikurangi and Fiordland utilised the McCaffrey (2008) relation. Magnitude scaling relations have typically been an abbreviated component of source model developments, with past PSH models seldom having more than two or three relations incorporated across the total model (e.g. Field et al., 2013). The present NSHM update uses fault source type rather than seismotectonic region as the primary criterion for application to fault sources. The fault source types are strike-slip, normal, reverse, and subduction interface, and multiple relations are identified for each fault source type.

The selection of scaling relations in the NSHM follows the guidelines of Stirling et al. (2013). These guidelines place the highest importance on recency of development, and a consequence is that the NSHM will not be using scaling relations older than 2010. This criterion is important for the reasons of: (1) incorporating the more recent earthquake data; and (2) the recent developments in earthquake scaling research. An additional criterion for selection is the ability to invert the scaling relations to estimate fault area from magnitude. This ability is required by other aspects of the source model development, in which magnitude is used to estimate source areas for earthquakes on the faults. Methodological and software advances since the Stirling et al. (2012) NSHM allow the rupture areas associated with a range of magnitudes to be distributed along the faults, rather than the limited source dimensions and magnitudes defined for the earlier models. The range of scaling relations are shown in Figs. 2-4, along with proposed associated fault source logic trees in Fig. 5.

A significant aspect of the scaling relation work is the development of an earthquake "flatfile" for evaluating the scaling relations to define weights for the associated source logic trees. The name flatfile was originally coined in the Next Generation Attenuation (NGA) project (e.g. Bozorgnia et al., 2014) for the strong motion database used to develop the various NGA models. In our scaling relations work the flatfile is a database of post-1989 (modern, well-instrumented) earthquakes and associated source parameters, and is being used to evaluate the scaling relations by residual analysis. Specifically, the flatfile data are plotted as magnitude for a given source area, and the scaling relations are then used to estimate magnitude for a given source area. The statistics of the residuals between flatfile-derived and scaling relation-derived magnitudes are then used to weight the scaling relations. In this respect the smallest residual between flatfile and scaling relation would result in the scaling relation being assigned the biggest weight in the logic tree. While this work is in progress, an early example of a residual plot is shown in Fig. 6. We acknowledge that the flatfile will likely have its own uncertainties and data gaps, so our residual analysis will be limited by this uncertainty. Our efforts may eventually include the development of new scaling relations, such as simple "backbone" scaling relations for benchmarking the various scaling relations. The flatfile will be available for these purposes.

Figure 1: Comparison of hypothetical M7 and M8 earthquake rupture areas on the Alpine Fault.

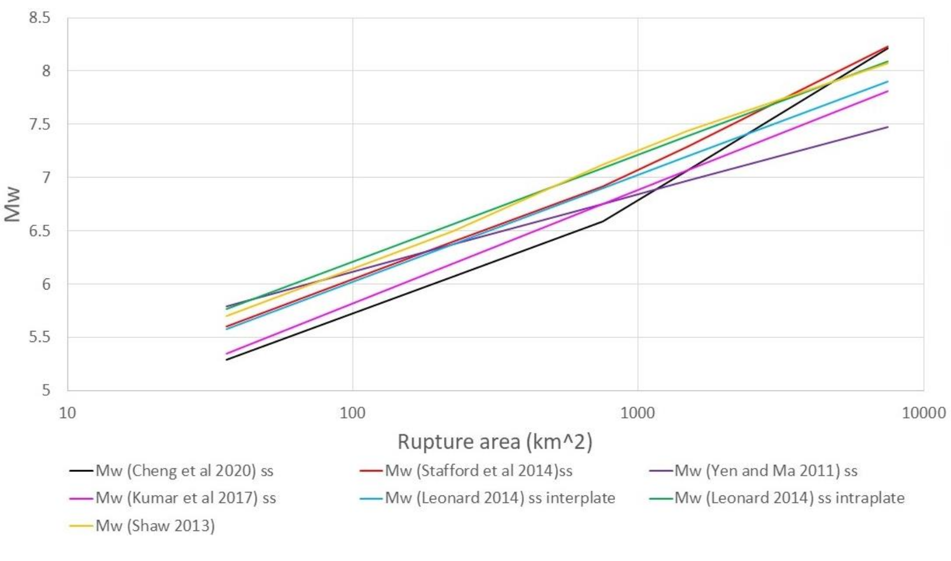

Figure 2: Magnitude-area scaling relations for crustal strike slip earthquakes

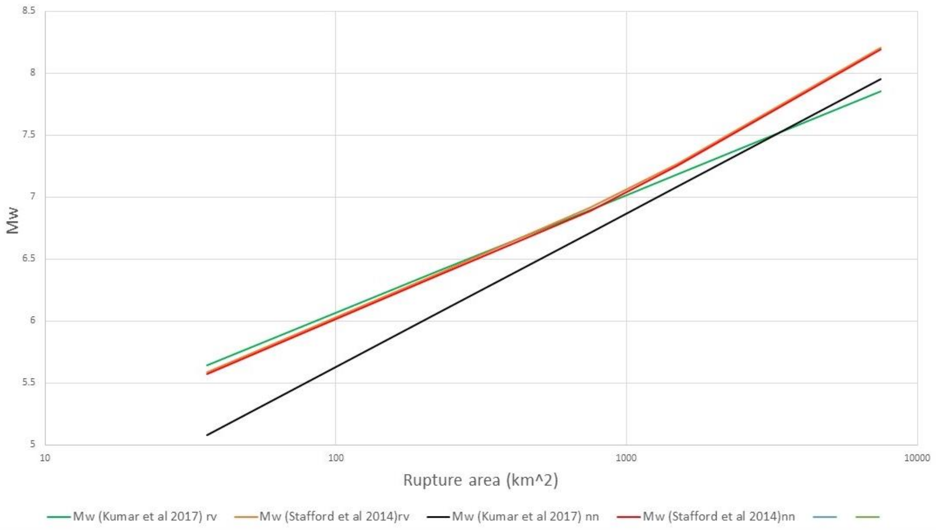

Figure 3: Magnitude-area scaling relations for crustal dip slip earthquakes

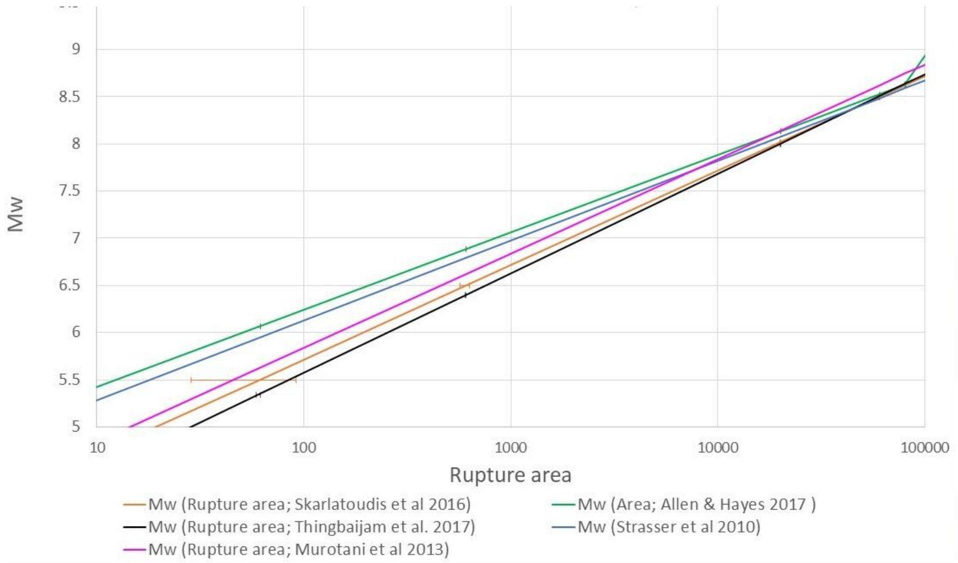

Figure 4: Magnitude-area scaling relations for subduction interface earthquakes

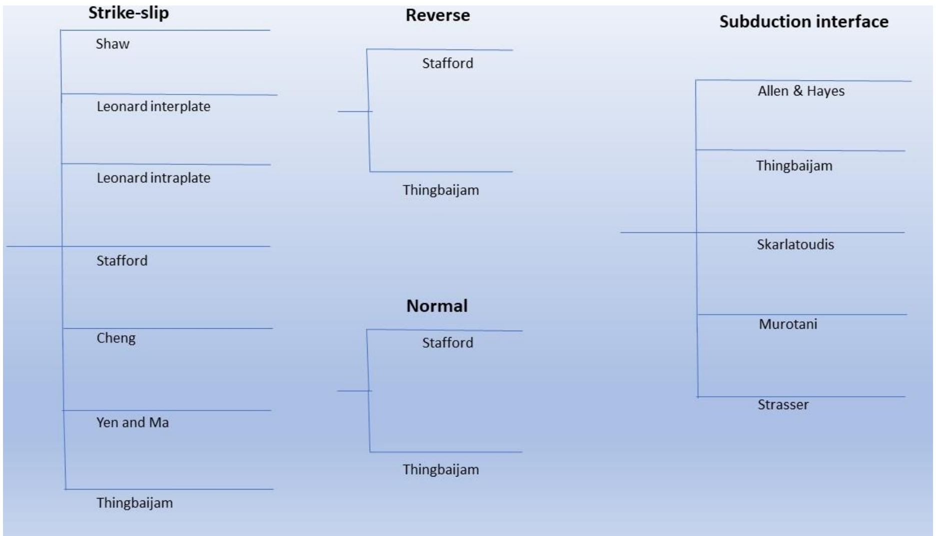

Figure 5: Logic trees for magnitude-area scaling relations

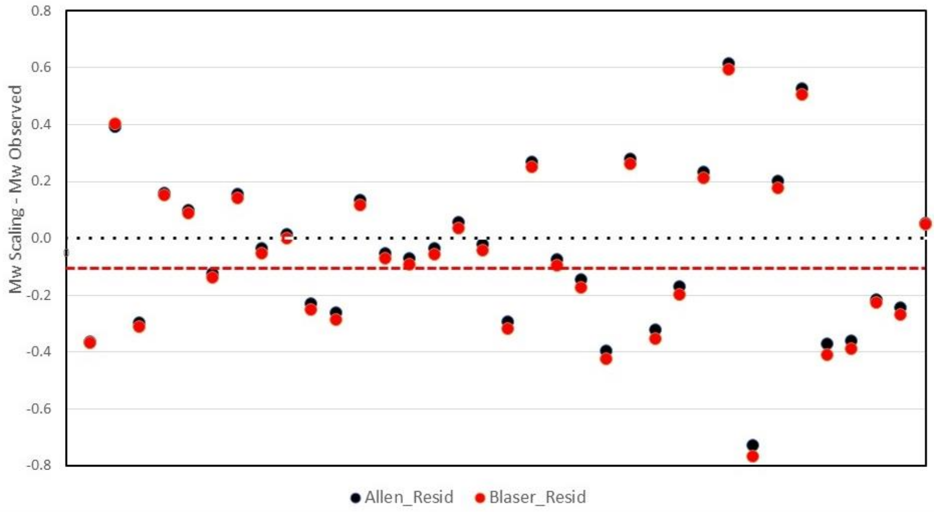

Figure 6: Residual plot for two subduction interface earthquake scaling relations. The dashed lines indicate the average residual for each of the scaling relations.

2.3 Testing and evaluation of hazard results

This task has yet to begin, as it requires the development of draft versions of the NSHM, and has also not yet been fully defined. However, the principles of one component of the task can be outlined. The goal of this component is to compare the outputs of the NSHM (ground motion exceedance rates or ground motions for a given return period) to independent criteria such as site-specific instrumental strong motion records, historical intensity records, and fragile geologic features. These three criteria have been investigated in New Zealand (Stirling and Petersen, 2006; Stirling and Anooshehpoor, 2006; Stirling and Gerstenberger, 2010; Stirling et al., 2019), and collectively will provide independent criteria for comparison to NSHM outputs for time periods ranging from decades to many millenia. Large discrepancies between the NSHM outputs and the independent criteria will then result in focused review of the NSHM parameters that are responsible for the discrepancies. A recent case history is the Clyde Dam seismic hazard re-evaluation (Stirling et al., 2019), in which the recommended mean 10 kyr response spectrum was significantly reduced due to the constraints provided by ancient fragile geologic features near the dam site.

2.4 Earthquake recurrence models

Since the genesis of the Otago earthquake science group in 2016, a significant focus has been in the acquisition of paleoearthquake data for Otago active faults, along with efforts to understand the recurrence behaviour of faults in low seismicity regions. Work conducted on the Akatore, Northwest Cardrona, Hyde, and Long Valley faults (e.g. Taylor-Silva et al. 2019), together with rigorous statistical modelling of paleoearthquake data on a global scale (e.g. Griffin et al., 2020) will contribute to improving the earthquake recurrence estimates for the NSHM. Some of the Otago faults show marked aperiodicity of earthquake occurrence, and this seems to be a characteristic of low seismicity regions (Griffin et al., 2020). The aperiodic behaviour is in stark contrast to that of the Alpine Fault, a plate boundary master fault that shows remarkable regularity in earthquake recurrence (Berryman et al., 2012). Ongoing efforts will focus on acquiring more data for Otago faults, along with a major EQC-funded project to initiate fault identification and characterisation work in the unstudied (scientifically neglected) Southland region.

CONCLUSIONS

We have provided a precis of work being undertaken by our Otago earthquake science group that contributes to the NSHM update. Our work on magnitude-area scaling relations has been highlighted, along with a brief summary of other ongoing or planned activities.

ACKNOWLEDGEMENTS

The useful addition of Figure 1 was on the suggestion of the anonymous reviewer.

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