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2 April 2012

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Canterbury Earthquakes Royal Commission
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Dear Justine

RE: Update to GNS Science/University of Canterbury July 2011 Report to the Royal Commission

The following is our response to your request for an update to our July 2011 report to the Commission entitled The Canterbury Earthquake Sequence and Implications for Seismic Design Levels. In this letter we also address the six issues of specific interest to the Commission.

In terms of updated summary information, Figure 1 is a plot of all of the M>3 earthquakes in the Canterbury sequence, with different colours showing the aftershocks following each of the major aftershocks.

Figure 2 shows the latest geodetic source models of the four largest events of the Canterbury sequence showing the locations of the modelled fault ruptures and their slip magnitudes (indicated by the colour scale). These models have been determined using ground-based GPS measurements and, in some cases, InSAR (satellite radar). Such models of how the faults slipped can be non-unique, for example, there are other interpretations that have been published by other research groups.

December 23 earthquakes

A magnitude (Mw) 5.8 earthquake at 1:58 p.m. struck east of Christchurch approximately 6 km off the coast of New Brighton. As with other earthquakes of this shaking intensity, liquefaction occurred in the eastern suburbs of Christchurch. The earthquake was followed by many events throughout the afternoon and overnight with several over magnitude 5. The strongest was a Mw 5.9 earthquake at 3:18 p.m. This new sequence of earthquakes was located east of the June 13th sequence of aftershocks (Figure 3). The two largest earthquakes (Mw 5.8 and 5.9) were not characterised by the very high ground motions of earlier events, except for an isolated high recording at Brighton Beach in the Mw 5.8 event that may be a local site effect (Figure 4, Table 1). Being further from people, and coupled with the slightly lower magnitudes of the biggest shakes, the effects were less damaging to structures than the September 2010 and February 2011 earthquakes.

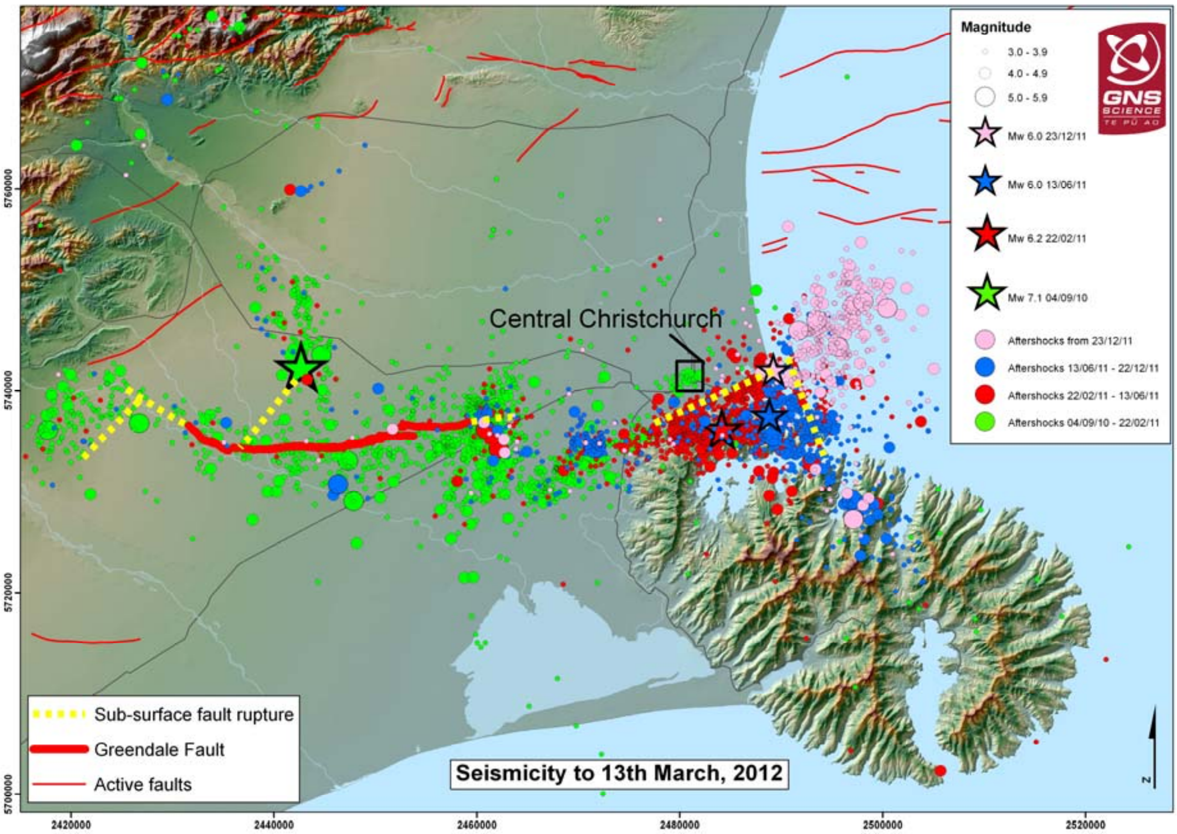
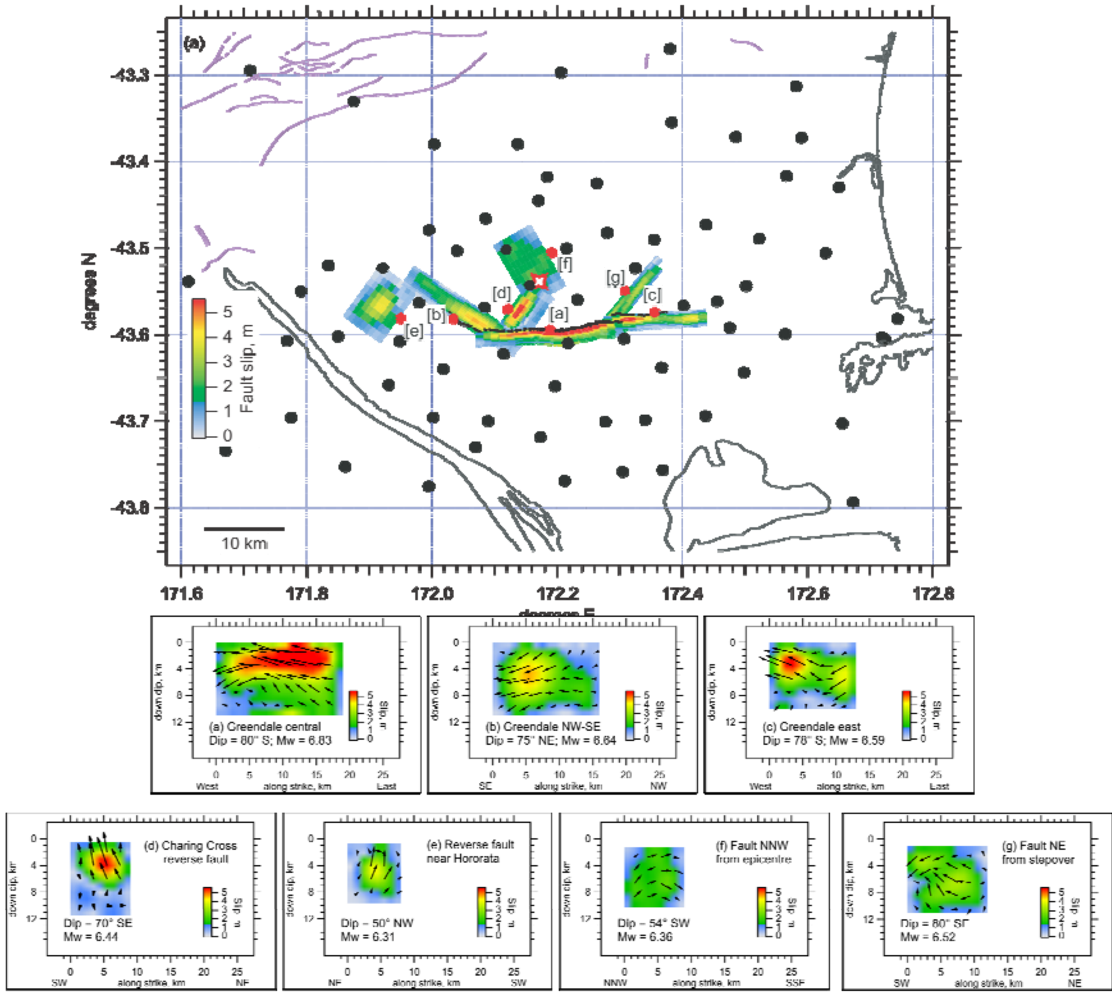
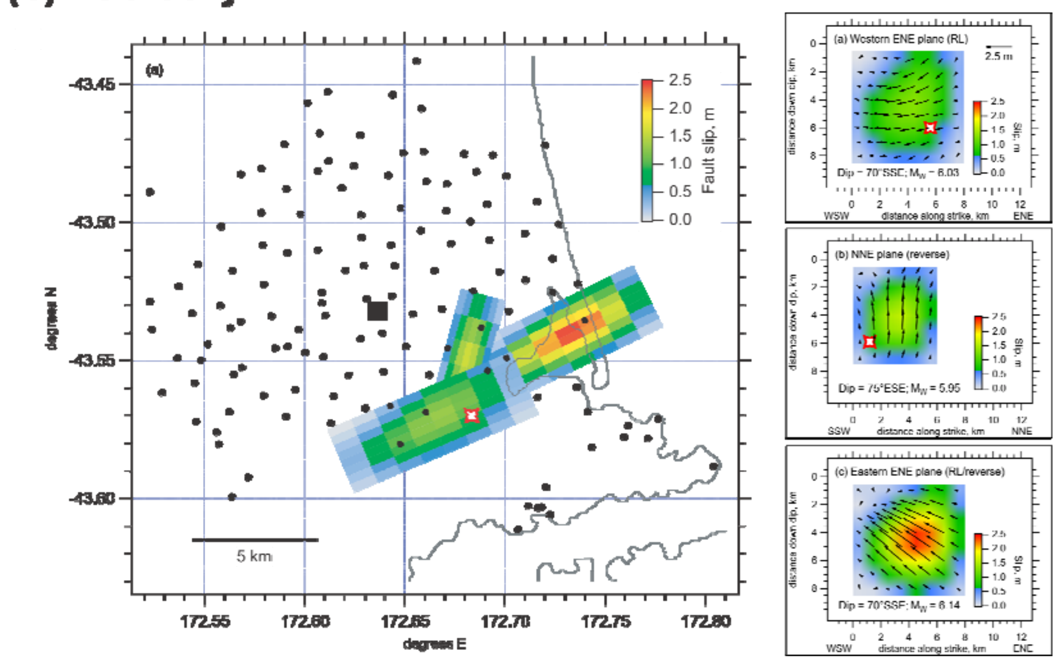


Figure 1. Earthquakes of the Canterbury sequence through to 13 March 2012. The September 4 mainshock and largest aftershocks are shown with stars.

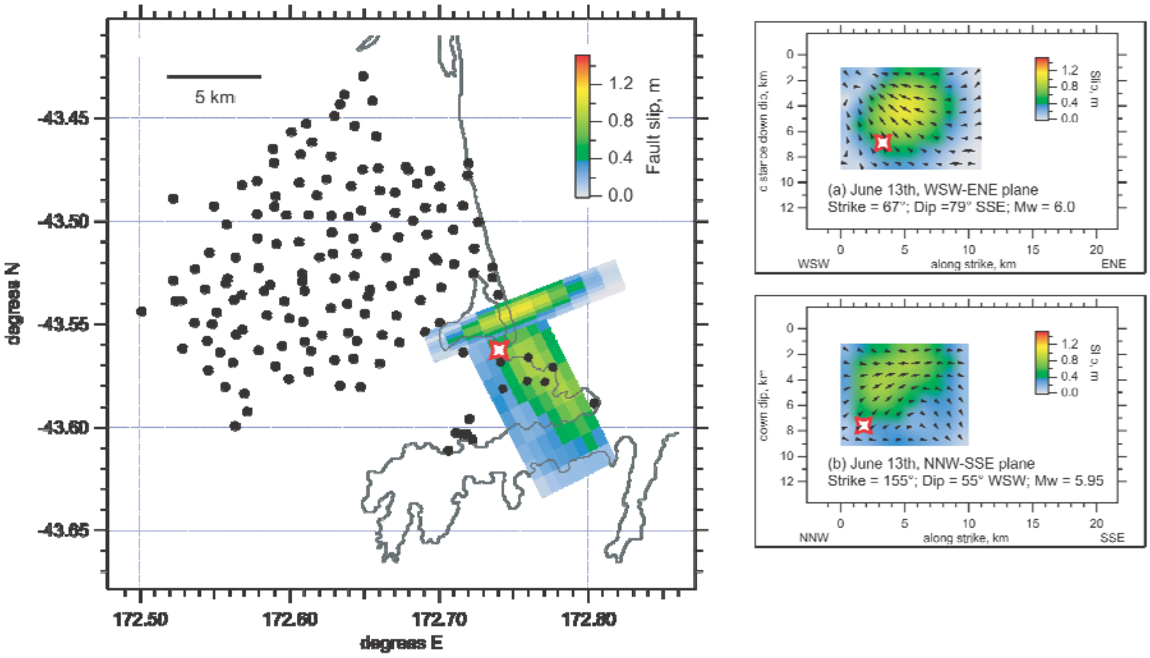
(a) September 4



(b) February 22



(c) June 13



(d) December 23 (larger event)

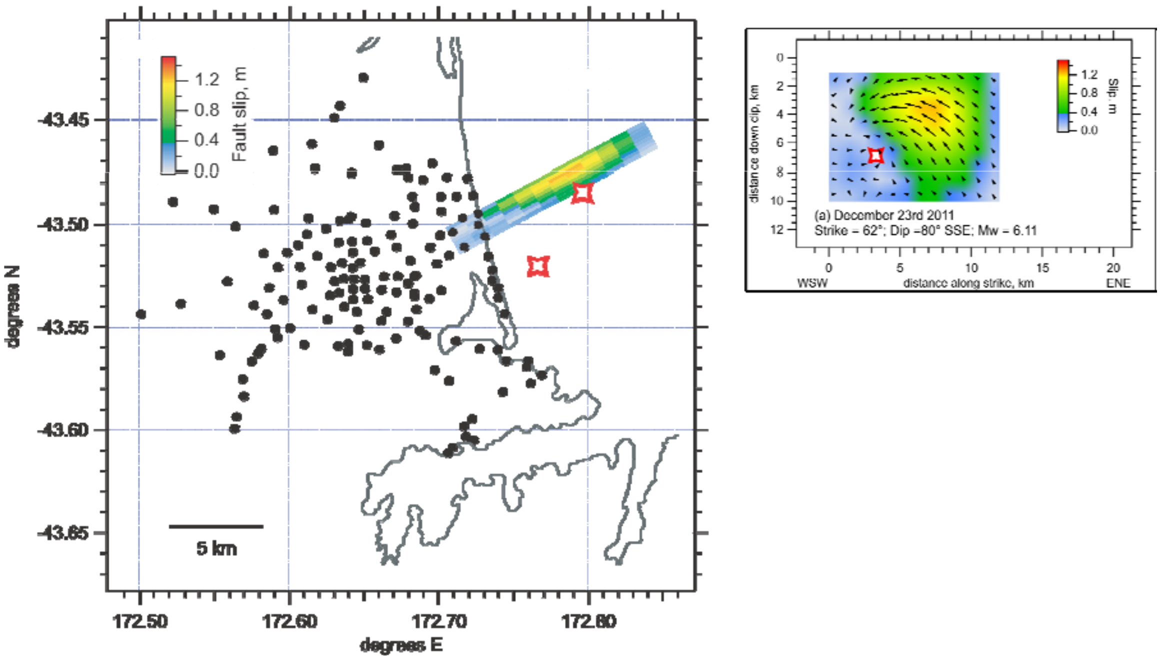


Figure 2. Latest geodetic source models of the four largest events of the Canterbury sequence showing the locations of the modelled fault ruptures and their slip magnitudes (indicated by colour scale). Smaller side-plots show the slip distribution on each modelled fault plane in more detail; arrows indicate the slip direction of the hanging wall relative to the footwall. The earthquake hypocentres are shown by red stars and the black dots indicate locations of GPS sites contributing to the solution. The magnitudes given in the side-plots correspond to the magnitude derived from the geodetic model for each model fault plane and hence will not necessarily match those derived directly from the seismic data in Table 1.

The ground motions from the larger December event (spectral acceleration at 0.5 and 1s periods) are plotted in Figure 5 and compared with predictions for the standard New Zealand attenuation model (McVerry 2006) and a new model proposed by Bradley (2010) based on the NGA model of Chiou & Youngs (2008). The McVerry (2006) model incorporates a stress drop scaling factor. This factor is used as a proxy to account for the under-prediction of the near-source (0–10 km) observed ground motions by the McVerry (2006) model for at least the two largest earthquakes of the Canterbury sequence. The under-predictions are believed to result from source features such as higher than normal radiated energy and directivity effects. Following an expert elicitation process undertaken in March 2012, a weighted combination of the McVerry (2006) and Bradley (2010) models will be employed for future earthquake hazard assessments.

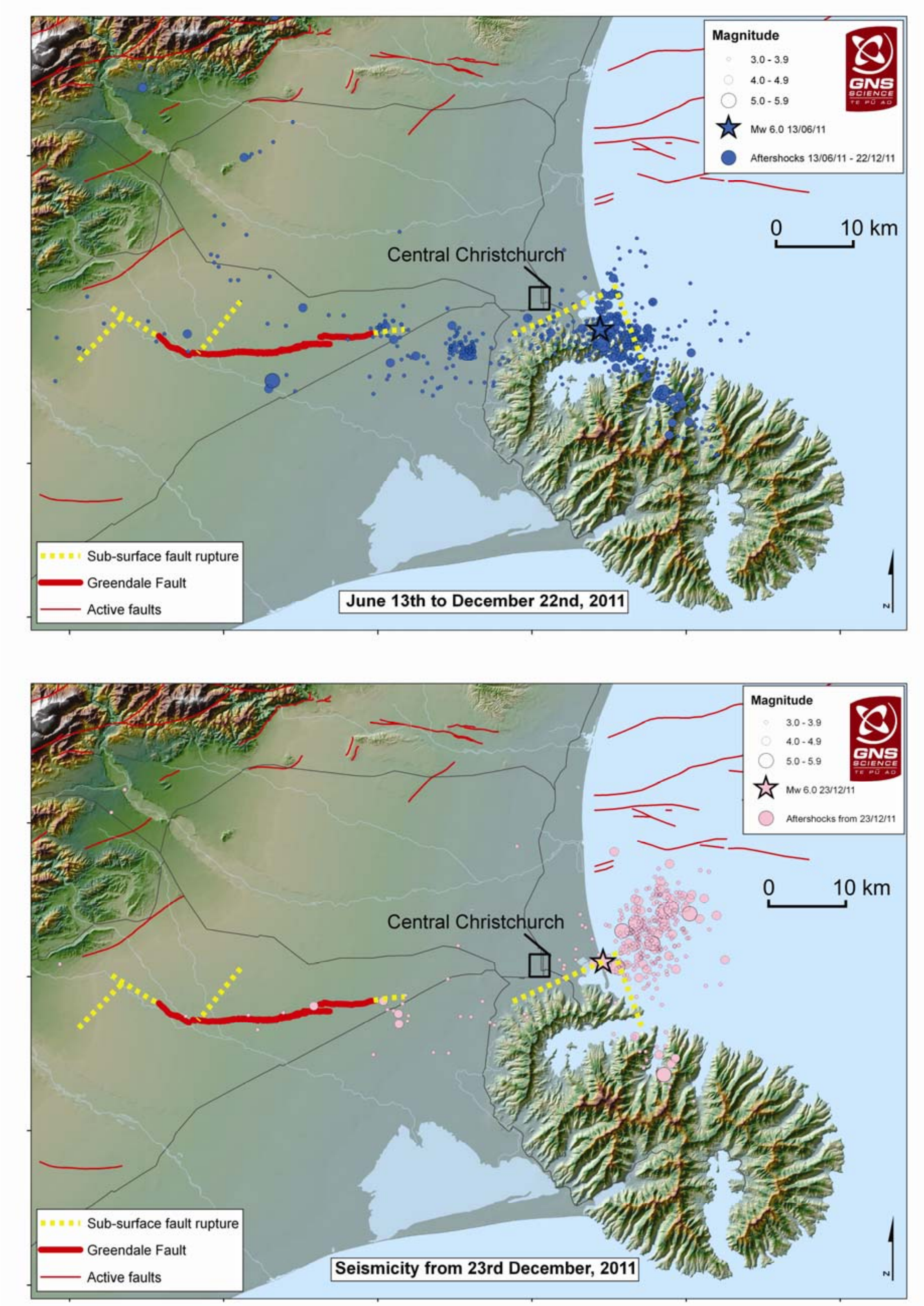


Figure 3. Top: Earthquakes of the Canterbury sequence from June 13 – Dec 22. The June 13 Mw 6.0 earthquake epicentre is shown as the blue star. Bottom: Earthquakes of the Canterbury sequence from Dec 23 until March 20. The Dec 23 Mw 5.9 earthquake epicentre is shown as the pink star.

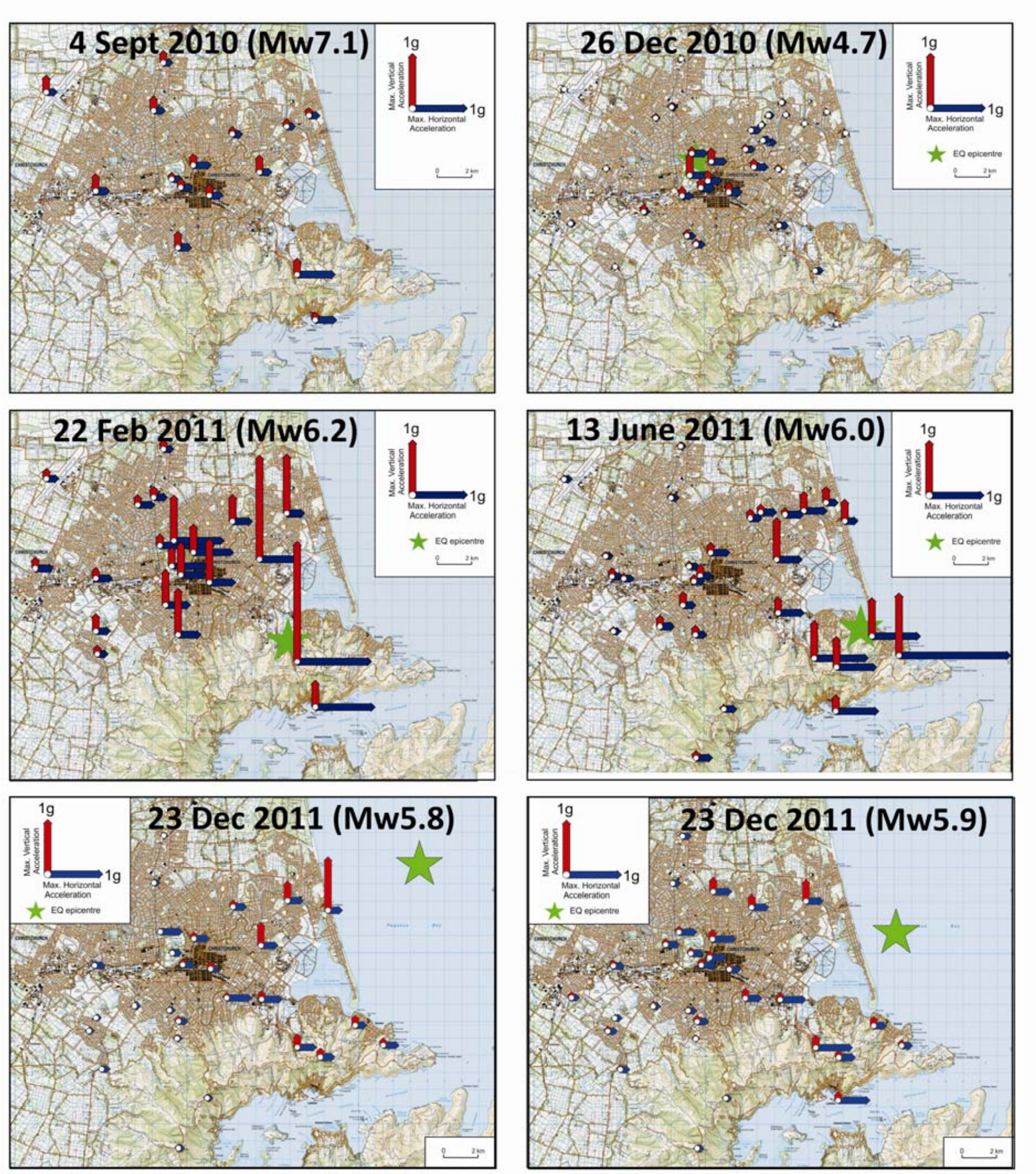


Figure 4. Maximum horizontal and vertical PGAs recorded during the six significant earthquakes of the Canterbury sequence at GeoNet stations and using temporary low-cost accelerometers (Quake-Catcher Network).

Table 1. Summary of the main features of significant earthquakes in the Canterbury sequence. Distances are distance from the fault rupture plane where available, but those marked with an asterisk (*) are taken from the earthquake epicentre. Duration is defined by the approximate length of record containing accelerations over 0.1 g.

Earthquake		**Sep 4 2010**	**Dec 26 2010**	**Feb 22 2011**	**June 13 2011**	**Dec 23 2011**	**Dec 23 2011**
Magnitude	M_w	7.1	4.7	6.2	6.0	5.8	5.9
	M_L	7.1	4.9	6.3	6.3	5.85	6.0
	M_e	8.0	Not known	6.75	6.7	5.6	6.0
Source fault	Rupture	Complex	Strike-slip	Oblique-reverse	Oblique-reverse	Oblique-reverse	Oblique-reverse
	Orientation	E-W surface rupture	E-W	NE-SW	NE-SW N-S	NE-SW	NE-SW
Max. PGA recorded	Horiz.(g)	0.8	0.4	1.7	2.0	0.4	0.7
	Vert. (g)	1.3	0.5	2.2	1.1	1.0	0.4
	Dist. (km)	1.3	~2*	2	3	13* Horiz. 6* Vert.	8* Horiz. 6* Vert.
Max. PGA recorded in CBD	Horiz. (g)	0.3	0.4	0.7	0.4	0.3	0.4
	Vert. (g)	0.2	0.4	0.8	0.2	0.2	0.2
	Dist. (km)	20 – 22	~2 – 3*	5 – 9	9 – 10	13 – 15*	10 – 12*
Duration of shaking >0.1g in CBD (s)		8 – 15	1 – 1.7	8 – 10	6 – 7.5	2 – 4	3 – 4

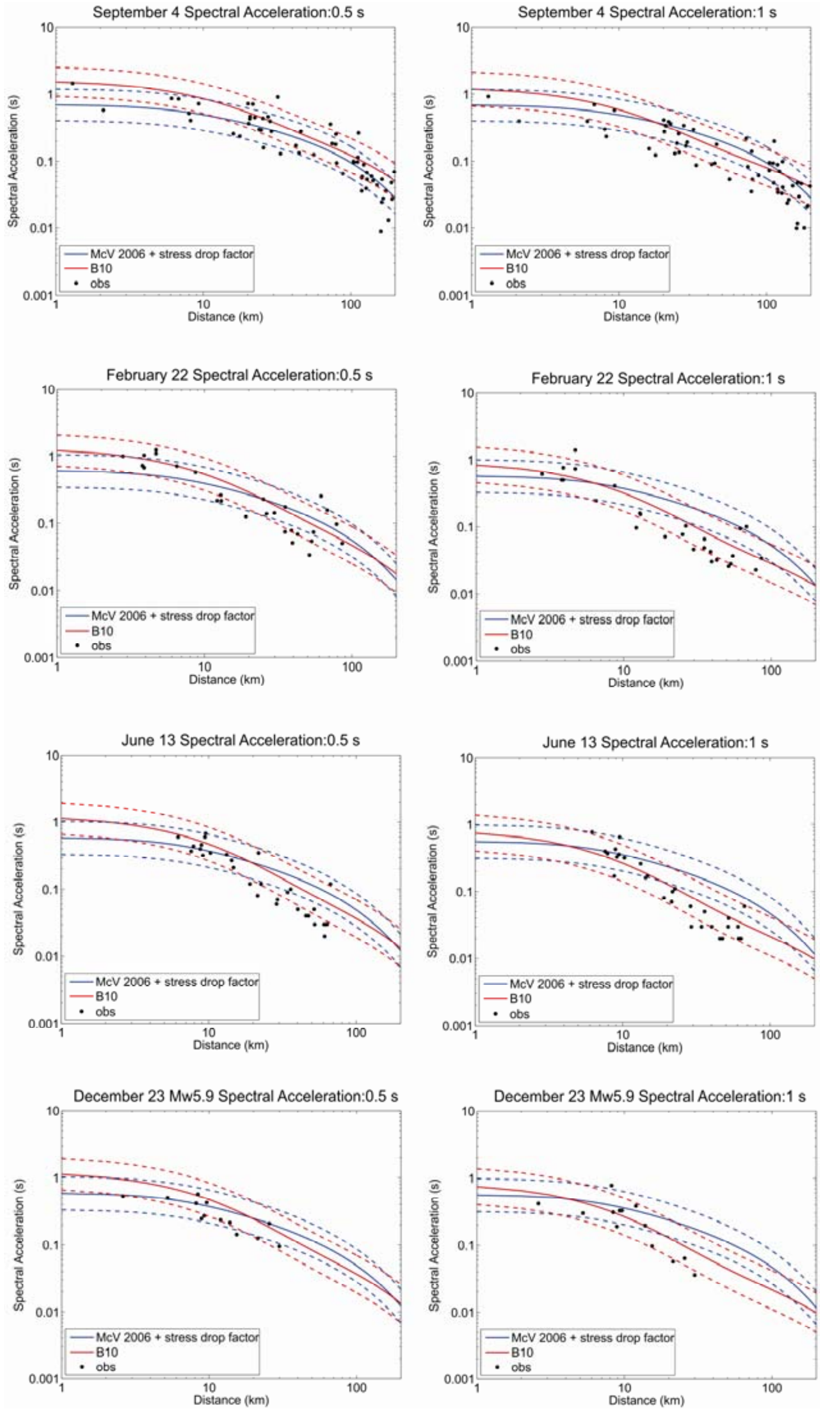


Figure 5. Horizontal spectral accelerations (at 0.5s and 1.0s) for the four largest earthquakes of the Canterbury sequence compared to attenuation models. Plots show geometric mean spectral accelerations compared to the New Zealand national attenuation model (McVerry 2006) and a new model proposed for New Zealand (B10; Bradley 2010). The McVerry (2006) model includes a stress drop scaling factor. Distances are to the earthquake rupture plane where available and epicentral distances elsewhere (for the December 23rd event. Ground motion observations and predictions are for Site Class D (Deep or Soft Soil Sites) that are representative of much of the Canterbury ground conditions, and predictions are based on oblique-reverse earthquake mechanisms.

Specific Issues

Update on progress with reviewing the Z factor and, in particular, explaining how the key drivers of the revised coefficient have been set.

This issue is largely covered off in our letter of 12 March 2012 to Linda Gibb at the Commission. Since then, we have had a further 1-day expert elicitation meeting, the results from which will feed into the calculations of a revised Z factor. By the 18th of April we hope to have a draft GNS Science Report explaining how these calculations have been done.

Progress on the analysis of information that was to be provided by GNS Science to determine the materiality of differences in opinion held by GNS Science and Dr Norm Abrahamson as to the contribution to the severity of shaking in the 22 February 2011 earthquake (directivity versus basin and other effects).

This issue is covered off in our letter to Linda Gibb.

The extent to which GNS Science was aware of risk of an earthquake or aftershock occurring nearer to Christchurch City and suburbs following the 4 September 2010 earthquake.

Immediately after the 4 September 2010 earthquake, GNS Science was very clear in public statements that an aftershock of magnitude 6 could follow the 4 September mainshock. This advice was based on a forecasting model (Gerstenberger *et al.*, 2005; see below) as well, for the first week or so, Bäth's Law, that the largest aftershock is often about one unit of magnitude smaller than the mainshock. These statements were made because of the likelihood of an aftershock, not a larger triggered earthquake further away (which, in comparison, is much less likely). Thus in terms of the location of a magnitude 6 (or any other) aftershock, it would be expected within the existing aftershock zone or adjacent to it (since aftershock zones do tend to expand with time). Figure 6 shows the Canterbury seismicity for September 2010 from the time of the mainshock.

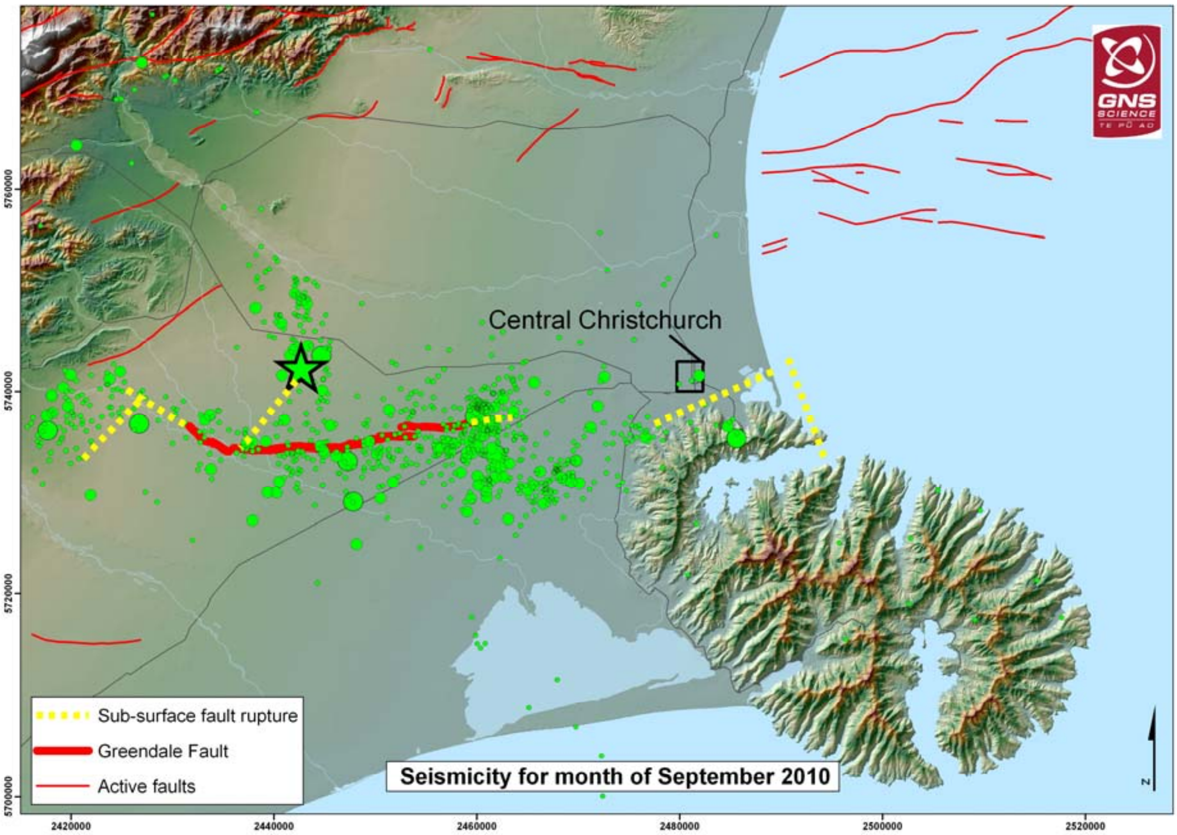


Figure 6. Canterbury seismicity for September 2010 from the time of the magnitude 7.1 mainshock.

While there are a number of ways in which an aftershock zone can be defined, for the purposes of where we could possibly expect a magnitude 6 aftershock to occur, one would normally, for a mainshock of this size, at least consider the area encompassed by the magnitude 4 aftershocks (so excluding the smallest circles in the figure). This then defines an elongated east-west zone that includes central Christchurch and the epicentre of the 22nd February earthquake. Christchurch City, however, consists of a relatively small proportion of the total aftershock zone so the probability of a magnitude 6 occurring in the city is only a small proportion of the overall likelihood.

A more quantitative way of defining the likelihood of future events is to use the Short Term Earthquake Probability (STEP) model (Gerstenberger et al., 2005). Figure 7 shows STEP output for the month of October 2010, based on the aftershock occurrence prior to that. The higher rates of activity forecast by STEP cover a similar area to that described above.

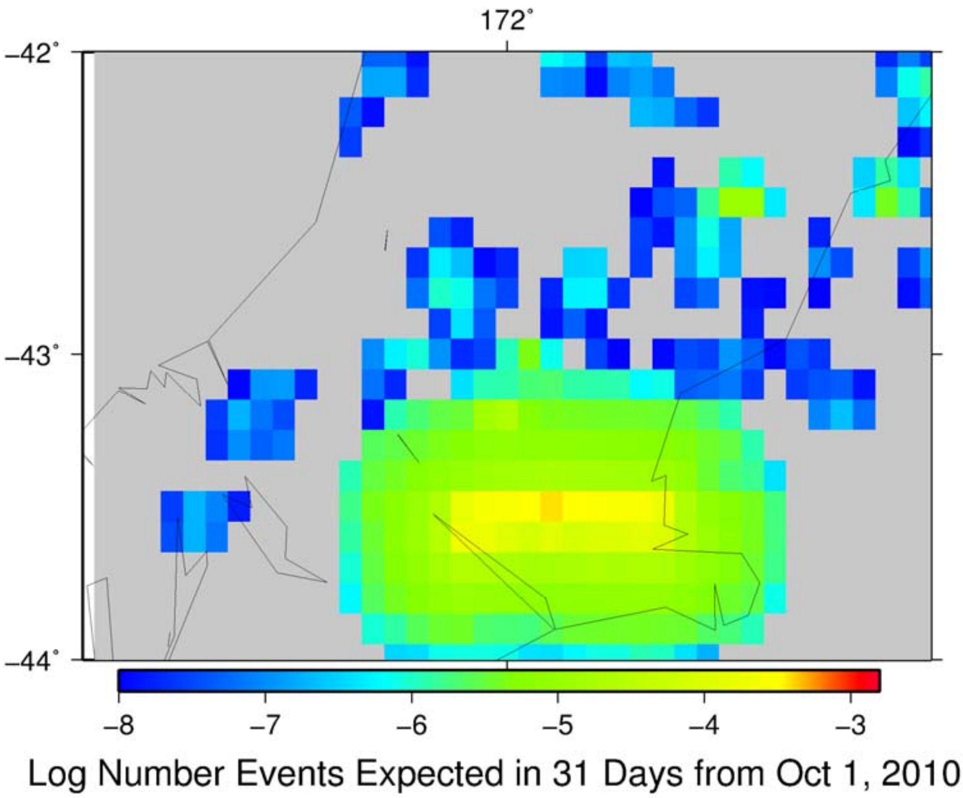


Figure 7. Forecast aftershock rates for the month of October 2010 based on September aftershocks using the STEP model. On the coloured scale, '-3' means 1 chance in 1,000 that a M>5 aftershock occurs in that pixel within that month; in this example the total number of forecast M>5 aftershocks is 2.3.

The extent to which GNS Science has provided advice to third parties on the appropriate ways and means of communicating seismic risk to the general population of either Christchurch or other at risk population centres such as Wellington.

The GNS Social Science team has been active in this area of research for a number of years, over which time they have formed extensive collaborations with other New Zealand and international researchers. A lot of the research output is through scientific publications, but the team also interacts closely with agencies such as MCDEM, EQC and many Regional Councils.

The focus of this research has been to improve risk communication to the public so that they will take individual actions to be better prepared for natural hazard events. No specific attention has been paid to acceptability of seismic risk relating to building standards and potential loss of life.

We enclose some key publications and also include in the Appendix a list of outreach and teaching activities and an extensive list of publications by GNS Science and other collaborators. We also enclose a paper derived from a recently completed PhD thesis by one of the team (Wendy Saunders) about a risk-based approach to land-use planning.

Examples internationally of an earthquake/aftershock sequence such as that experienced in Canterbury since 4 September 2010.

We have sought clarification from Linda Gibb on a tighter definition of this question. As a result we have been undertaking computer searches of a global earthquake catalogue looking for sequences of shallow earthquakes where there have been a significant number of aftershocks of M>6. This work is still underway, but we hope to be able to provide some preliminary results by the end of the week. Once we have identified some likely candidate sequences we could search for more detailed information on ground shaking or impacts on people or buildings, if that would be of use to the Commission.

Any comments that GNS Science may have on the report by Brendon Bradley.

Comments on Brendon's report were contained in our letter to Linda Gibb. Since then, Brendon has participated in our 1-day expert elicitation meeting on GMPE models for New Zealand, and his B10 attenuation model, along with the McVerry 2006 model, are now both being used in calculating a revised Z factor.

Yours sincerely

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Dr Anna Kaiser
Seismic Microzoning Scientist

Dr Stephen Bannister (Reviewer)
Research Seismologist

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APPENDIX

Earthquake risk communication — Outreach and teaching activities

- Short courses – GNS Science Earthquake short course (2003–2009), annual Joint Centre for Disaster Research Summer Institute (since 2008) and workshops at Australasian Natural Hazards Management Conferences (see below)
- Conferences – Biannual Australasian Hazards Management conference (since 2004)
- Newsletters – GNS Science, JCDR Research Updates
- Websites – MCDEM, JCDR, GNS Science
- Input to MCDEM projects – Earthquake section of the MCDEM consistent messages for CDEM
- Teaching – course content via Massey Emergency Management teaching project

Earthquake risk communication research (and related topics) 2010- 2011

Peer-reviewed journal articles (accepted & published)

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