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MACROSEISMIC INTENSITY ASSESSMENT METHOD FOR ONLINE QUESTIONNAIRES IN NEW ZEALAND

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Abstract

The Canterbury (New Zealand) earthquake sequence of 2010-2012 caused unexpectedly high levels of damage, and was unparalleled in terms of the quantum of disruption and losses for New Zealand. GeoNet (New Zealand's national geological hazards monitoring service, http://www.geonet.org.nz/) received more than 11,000 online questionnaires from the two most significant earthquakes in the sequence; the main shock (M_w 7.1) and its damaging aftershock (M_w 6.2), challenging the online facility. In addition, four recent moderate sized events (Cook Strait, 21 July 2013, M_L 6.5; Lake Grassmere, 16 August 2013, M_w 6.6; Eketahuna, 20 January 2014, M_L 6.2; Christchurch, 14 February 2016, M_w 5.7) have confirmed the immense public interest in filling in online questionnaires. Although GeoNet automatically calculates Modified Mercalli Intensity (MMI) values for each report, there is currently no method to convert this data into a reliable spatial damage distribution at a community scale. This limits our ability to understand past disasters and help future evacuation and emergency planning. The large number of responses has enabled us to develop a method to calculate community MMI values from the invididual felt reports, based on work carried out overseas and adapted to New Zealand data and macroseismic scale. This paper presents the development of the method, its application to eight recent New Zealand earthquakes and calibration methods currently under progress.

Keywords: macroseismic studies; Modified Mercalli intensity; online felt reports; ShakeMap

1. Introduction

Internet-based macroseismic surveys have been implemented in the last fifteen years by several international seismological institutions, and are becoming a popular way of encouraging citizen science through sharing their experience during an earthquake. Some of the institutions with online macroseismic surveys (or "felt reports") are shown in Table 1.

Automatic intensity evaluations can be made through two different approaches: regression-based or expert-based [1, 2]. A regression-based approach obtains results through a regression between the automatic scores and the traditional intensities (assigned manually by a seismologist) to be in agreement with past datasets. That is the case for the USGS "Did You Feel It" method [3-6]. It involves a thorough review of isoseismal/intensity maps from earthquake catalogues and a transformation into the same intensity scale. The expert-based approach follows the indications of a macroseismic scale and assigns a set of matrix scores using inputs from an expert panel. This method has the advantage that it can be implemented in a short timeframe and other methods can be used to calibrate it, such as the use of Ground Motion to Intensity Conversion Equations (GMICE) [e.g. 7-8], systems like ShakeMap [9] or the recently developed ShakeMapNZ [10], or traditional macroseismic surveys where intensities are assigned to a community by a seismologist. This approach was chosen by a team from INGV to obtain automatic intensities for online surveys in Italy [11-13, 2] and is the one used in this paper. One of the main reasons why the regression-based approach was not followed is that it requires a parallel dataset of traditional MMI values obtained from the felt reports. However, traditional intensity surveys have not been carried out since the implementation of the online questionnaires, and thus a regression-based approach is currently not possible for New Zealand felt reports.

Table 1 – List of some of the international institutions with online macroseismic surveys.

Institution	Website
US Geological Survey (USGS)	http://earthquake.usgs.gov/earthquakes/dyfi (last accessed 24 March 2016
British Geological Survey	http://www.earthquakes.bgs.ac.uk/questionnaire/EqQuestIntro.html (last accessed 24 March 2016
Euro-Mediterranean Seismological Centre	http://www.emsc-csem.org/Earthquake/Contribute/?lang=en (last accessed 24 March 2016
European Seismological Commission	http://seismologist.co.uk/ESC_internet_macroseismology.html (last accessed 24 March 2016
Instituto Nazionale di Geofisica e Vulcanologia (INGV)	http://www.haisentitoilterremoto.it (last accessed 24 March 2016)
Swiss Seismological Service	http://www.seismo.ethz.ch/eq/detected/eq_form/index_EN (last accessed 24 March 2016)
Bureau Central Sismologique Francais	http://www.seisme.prd.fr/english.php (last accessed 24 March 2016
Natural Resources of Canada	http://www.earthquakescanada.nrcan.gc.ca/recent/index-en.php (last accessed 24 March 2016)
Royal Observatory of Belgium	http://www.seismologie.be/index.php?LANG=EN (last accessed 24 March 2016)
New Zealand National Seismic network, GeoNet	www.geonet.org.nz (last accessed April 2016)

In 2004, GeoNet (New Zealand's national geological hazards monitoring service), implemented an internet-based questionnaire together with an algorithm [14] to automatically assign intensity values to each felt report in New Zealand's MMI (Modified Mercalli Intensity, called MMI scale throughout this paper for simplification) scale [15-17], based on felt information captured from the questionnaire. The questionnaire was similar to the traditional version that had been used for the decades prior to 2004. Three years after the implementation, the success of the online questionnaire project was seen following earthquakes such as the magnitude 6.8 Gisborne event in December 2007, when more than 3,400 felt reports were received [14]. The Canterbury earthquakes of 2010-2012 [18-22] challenged the facility, which needed to deal with more than 15,000 felt reports for the four major events (Darfield main shock, 4/9/2010, M_w 7.1; Christchurch 22/2/2011, M_w 6.2; Christchurch 13/6/2011, M_w 6.0; Christchurch, 23/12/2011, M_w 5.9). They produced by far the largest number of reports received by GeoNet since the implementation of the online questionnaires, with a total of 598 reports being assigned MMI=8 or above [23-24].which is the upper MMI limit of the online questionnaire. It should be noted that the New Zealand MMI scale was designed to have appropriate consistency with the European EMS-92 scale [25] and thus there is a high level of agreement for each intensity level in both scales. This is further emphasized in the conversion table between the Modified Mercalli scale of 1956 and EMS-98 given in [26]. However, conversions between intensity scales are not recommended. It is preferable to reassign intensities in the new scale [26].

GeoNet's automatic algorithm assigns intensity to each felt report. However, intensity values applied to single locations are not consistent with the way traditional MMI values were estimated, by measuring the seismic impact at a regional scale. Thus the current MMI values do not provide information on the geographical damage distribution, essential in seismic hazard and emergency planning. This is being carried out with the use of "community intensities", which estimate the intensity using multiple responses over a region. These are essential to create intensity maps that could be included in GeoNet's website minutes after an earthquake occurs and be used to inform local authorities, emergency planning agencies and the general public. In addition, the implementation of community intensities could be used to generate intensity maps for the recently developed ShakeMapNZ [10].

In this paper we have developed a different method of calculating MMI values from GeoNet's online felt reports, that gives an intensity value per report together with a community intensity. Community intensity (CMMI) is defined by town for regions with a low number of inhabitants, and by suburb for the major cities in

New Zealand. The method has been created following the above-mentioned expert-based score matrix system developed at INGV [2, 11] for the Italian online questionnaires, and adapted to New Zealand data and the MMI scale. The method has been tested for eight major (M_w 5.7+) earthquakes in the last six years (Fig. 1): the four major Canterbury earthquakes (see details above), and the Cook strait (21/7/2013, M_w 6.5, 5,627 felt reports) [27], Lake Grassmere (16/8/2013, M_w 6.6, 5,537 felt reports) [25], and Eketahuna (20/1/2014, M_w 6.2, 10,885 felt reports) earthquakes. In addition, the method has been applied to the recent 'Valentine's Day" earthquake (14/2/2016, M_w 5.7, 3,897 felt reports) [28] which occurred in Christchurch four years after the last M>5 event in the area (23/12/2011, M_w 5.9). This paper presents the method and its application to the eight New Zealand events mentioned above, and describes how efforts are being undertaken to calibrate the method.

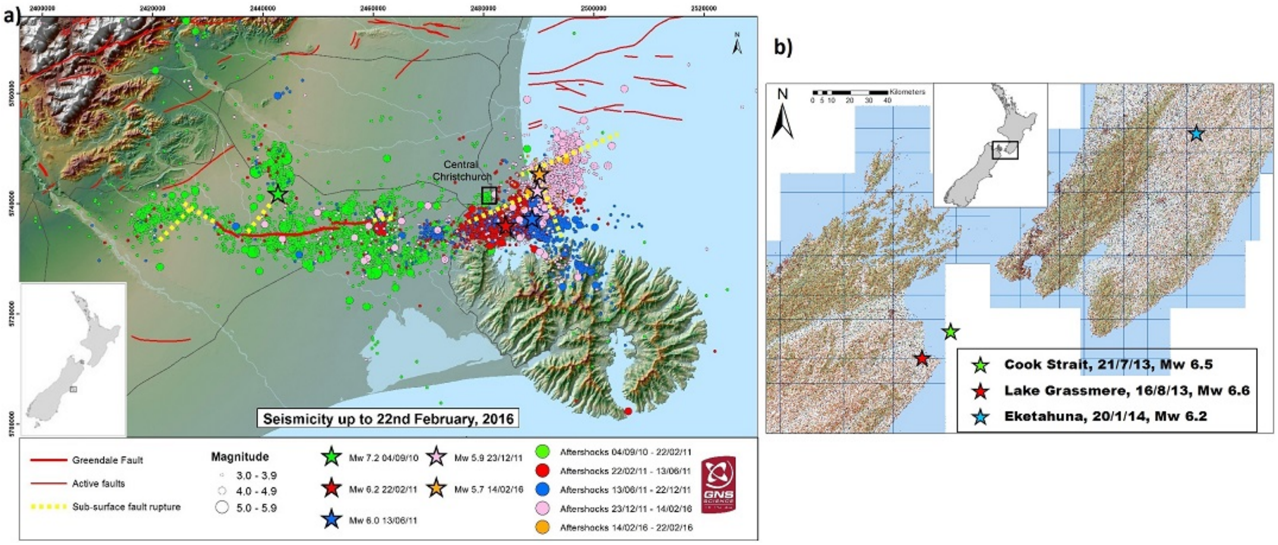

Fig. 1 – a) Canterbury earthquake sequence as of 22 February 2016, showing the major earthquakes and their aftershock sequence: 4 September 2010 (green star), 22 February 2011 (red star), 13 June 2011 (blue star), 23 December 2011 (pink star) and recent 14 February 2016 (orange star) (http://info.geonet.org.nz).; b) Location of the Cook strait (21/7/2013, M_w 6.5), Lake Grassmere (16/8/2013, M_w 6.6) and Eketahuna (20/1/2014, M_w 6.2) earthquakes. Each figure includes an inset showing the marked area in the maps.

2. New Zealand online felt reports

GeoNet's current online questionnaire consists of 32 main questions divided into six stages. The questions from stage four, related to damages to the building, only appear if the respondent answers "yes" to question FR3-8 ("Was there any damage to the building itself, the hot water cylinder, chimneys or exterior water tanks?") in stage 3, thus avoiding unnecessary time spent by respondents who have not observed damage to the building they were in during the earthquake.

Since 2004, GeoNet automatically calculates a MMI value for each felt report, following an inverted pyramid method that requires more and more "positives" to assign the higher levels of intensity [14]. For each earthquake, GeoNet's website provides the number of reports per town/suburb and plots the maximum intensity obtained for each of them. However, until now there has been no attempt to group the intensities into "community" values to be consistent with the definition of MMI values (defined at a regional scale) or to be able to understand the geographical damage distribution caused by earthquakes.

3. Intensity assessment method

3.1 Individual felt report intensities

The method to obtain community intensities developed at INGV [2, 11] for Italian felt reports has been adapted to GeoNet's online questionnaires and to the MMI scale [16]. A selection of the most relevant questions in terms of intensity assignment was carried out. These are the questions used in the method to obtain community intensities. At the present, there are 13 questions from the questionnaire (Table 2) involved in the matrix score system, of which four are combined questions, i.e., questions whose answers need to be used in combination to appropriately assign a score, e.g. "Where were you at the time of the earthquake?" and "How would you best describe the shaking?", being a total of nine questions "combinations". If the respondent was indoors and felt the earthquake, the score system will be different than if the respondent was outdoors, as earthquakes start being felt at MM IV indoors, and MM V outdoors [16]. The questions included in the score system target effects that are clearly described in the New Zealand macroseismic scale, with a clear threshold for the intensity level at which they are triggered.

Table 2 – Sets of questions used to obtain CMMI values, from GeoNet's current online questionnaire

Reference	Question	Answers
FR2-1	Where were you at the time of the earthquake? (combined with FR2-4)	Indoors Outdoors In a stopped vehicle In a moving vehicle
FR2-4	How would you best describe the shaking? (combined with FR2-1)	A-Not felt B-Heard, but not felt C-Gentle, hardly recognised as an earthquake (like light trucks passing) D-A jolt or mild, but unmistakably an earthquake (like heavy traffic passing) E-Moderate F-Strong, powerful G-Violent, severe
FR3-2	Did hanging objects sway?	H-No I-Yes J-Don't Know / Not applicable
FR3-3	Did objects such as glasses, dishes, ornaments or other small shelf items rattle, topple over or fall off shelves?	K-No L-Rattled slightly M-Rattled loudly N-A few toppled or fell off O-A few toppled or fell off P-Nearly everything toppled or fell off Q-No shelves with unrestrained objects R-Don't Know / Not applicable
FR3-5	Did any small items of furniture, appliances (such as TV, computer, microwave) or light machinery slide (not just sway) or topple over?	S-No T-Yes, slid a little (less than 5 cm) U-Yes, slid a lot (more than 5 cm) or toppled over V-Don't Know / Not applicable
FR3-6	Did any large fixtures, appliances (such as fridge, stove or filing cabinet) or heavy machinery slide (not just sway) or topple over?	W-No X-Yes, slid a little (less than 5 cm) Y-Yes, slid a lot (more than 5 cm) Z-Yes, toppled over AA-Don't Know / Not applicable
FR4-1	Was the hot water cylinder (not header tank) damaged? (combined with FR4-2)	No Leaked Fell over Don't Know / Not applicable
FR4-2	The hot water cylinder is... (combined with FR4-1)	AB-Not restrained AC-Restrained AD-Don't Know / Not applicable
FR4-3	Choose the most severe damage that occurred to the brick/concrete chimney where you were: (combined with FR4-4)	AE-No damage AF-Horizontally cracked or loose bricks dislodged AG-Twisted or broken at roofline AH-Fallen from roofline AI-Fallen from base AJ-Don't Know / Not applicable
FR4-4	The brick/concrete chimney is... (combined with FR4-3)	An old chimney (that is, not reinforced) A modern chimney Don't Know / Not applicable
FR4-5	Choose the most severe damage that occurred to exterior elevated water tanks	AK-No damage AL-Shifted/leaking AM-Twisted and/or brought down AN-Don't Know / Not applicable
FR4-6	Choose the most severe damage that occurred to exterior walls	AO-No damage AP-Hairline cracks AQ-Wide cracks AR-Segments of walls bulged, distorted or partially collapsed

	(combined with FR4-7)	AS-Some walls totally collapsed AT-Don't Know/Not applicable
FR4-7	Choose the main building material for the exterior walls that experienced the damage: (combined with FR4-6)	Wood Stucco (cement) Brick/stone veneer Solid brick Sheet material (fibre cement board, plywood) Concrete block Don't know/Not applicable Other:

The matrix score system assigns a score to each answer amongst all the intensity values, thus creating an intensity distribution for each answer to the questionnaire (Table 3). The scores have been normalised, so that the sum of all scores for each answer equals one. MMI values I and II are grouped together, beacuse it is often difficult to distinguish between these two levels. In addition, all MMI values of VIII or above have been grouped together as one single level. At those levels, an intensity assignment is only possible through a case-by-case analysis of each report by an expert engineer [2, 5, 24, 29], and an evaluation of the building damage grade and building type needs to be carried out before an MM intensity is assigned. This criterion has been followed by the Euro-Mediterranean Seismological Centre [30] and INGV [2, 11].

Table 3 – Score matrix used in this study to assign intensities to New Zealand online felt reports in MM scale. The questions and answers references correspond to Table 2.

Question	Answer	Joint with question-answer	I-II	III	IV	V	VI	VII	>=VIII
FR2-4	A	---	0.5	0.5	0	0	0	0	0
FR2-4	B	---	0.5	0.5	0	0	0	0	0
FR2-4	C	---	0	0	0.5	0.5	0	0	0
FR2-4	D	---	0	0	0	0.5	0.5	0	0
FR2-4	E	---	0	0	0	0	0.5	0.5	0
FR2-4	F	---	0	0	0	0	0	0.5	0.5
FR2-4	G	---	0	0	0	0	0	0.5	0.5
FR3-2	H	---	1	0	0	0	0	0	0
FR3-2	I	---	0	0.167	0.167	0.167	0.167	0.167	0.167
FR3-2	J	---	0	0	0	0	0	0	0
FR3-3	K	---	0.5	0.5	0	0	0	0	0
FR3-3	L	---	0	0	0.65	0.35	0	0	0
FR3-3	M	---	0	0	0.35	0.65	0	0	0
FR3-3	N	---	0	0	0	0.65	0.35	0	0
FR3-3	O	---	0	0	0	0.2	0.6	0.2	0
FR3-3	P	---	0	0	0	0	0.2	0.4	0.4
FR3-3	Q	---	0	0	0	0	0	0	0
FR3-3	R	---	0	0	0	0	0	0	0
FR3-5	S	---	0.333	0.333	0.333	0	0	0	0
FR3-5	T	---	0	0	0	0.65	0.35	0	0
FR3-5	U	---	0	0	0	0	0.333	0.333	0.333
FR3-5	V	---	0	0	0	0	0	0	0
FR3-6	W	---	0.25	0.25	0.25	0.25	0	0	0
FR3-6	X	---	0	0	0	0	0.65	0.35	0
FR3-6	Y	---	0	0	0	0	0.35	0.65	0
FR3-6	Z	---	0	0	0	0	0	0	1
FR3-6	AA	---	0	0	0	0	0	0	0
FR4-2	AB	FR4-1 Leaked or Fell over	0	0	0	0	0	0.5	0.5
FR4-2	AC	FR4-1 Leaked or Fell over	0	0	0	0	0	0	0
FR4-2	AD	FR4-1 Leaked or Fell over	0	0	0	0	0	0	0
FR4-3	AE	FR4-4 An old chimney	0.25	0.25	0.25	0.25	0	0	0
FR4-3	AF	FR4-4 An old chimney	0	0	0	0.2	0.6	0.2	0
FR4-3	AG	FR4-4 An old chimney	0	0	0	0	0.2	0.6	0.2
FR4-3	AH	FR4-4 An old chimney	0	0	0	0	0	0.65	0.35
FR4-3	AI	FR4-4 An old chimney	0	0	0	0	0	0.35	0.65
FR4-3	AJ	FR4-4 An old chimney	0	0	0	0	0	0	0
FR4-5	AK	---	0.2	0.2	0.2	0.2	0.2	0	0
FR4-5	AL	---	0	0	0	0	0	0.35	0.65
FR4-5	AM	---	0	0	0	0	0	0	1
FR4-5	AN	---	0	0	0	0	0	0	0
FR4-6	AO	FR4-7 Solid brick	0.2	0.2	0.2	0.2	0.2	0	0
FR4-6	AP	FR4-7 Solid brick	0.2	0.2	0.2	0.2	0.2	0	0
FR4-6	AQ	FR4-7 Solid brick	0	0	0	0	0	0.65	0.35

FR4-6	AR	FR4-7 Solid brick	0	0	0	0	0	0.35	0.65
FR4-6	AS	FR4-7 Solid brick	0	0	0	0	0	0	1
FR4-6	AT	FR4-7 Solid brick	0	0	0	0	0	0	0

The score matrix has been created in such a way that if an answer is below an intensity level, then the scores are equally distributed in the intensity levels below that level, e.g., if the answer to "Did objects such as glasses, dishes, ornaments or other small shelf items rattle, topple over or fall off shelves?" is "No", then the scores are equally distributed between MMI=I-II (score 0.5) and MMI=III (score 0.5), as objects start to rattle at MMI=IV [16]. From the point when the MMI level is triggered, the scores distribution has been chosen through an expert panel with a long experience using the New Zealand MM scale. The scores gradually increase towards higher levels of intensity when the answers imply higher damage levels.

3.2 Improving the data quality

To assure a good quality dataset, the following steps were carried out to avoid insufficient information, duplication or inaccurate data:

- Reports with insufficient information to appropriately assign a score have been eliminated. These correspond to reports where less tan 50% of the questions used to obtain the scores are answered. Of the nine question combinations used to develop the matrix score system only reports with four or more of these questions answered have been used, eliminating the ones with insufficient information to assign scores.
- Duplicated felt reports have also been eliminated. These correspond to reports with the same address. In these cases, the reports with the earliest dates have been chosen, assuming that the closer in time to the event, the more accurate the information. This criterion has been enforced only for duplicated reports submitted within 3 months of the earthquake.
- Misspelt addresses or suburb names constitute an important challenge in GeoNet's felt reports dataset. Before 2013, respondents were only able to manually enter their address, suburb and town. After 2013, despite a list of suburb names and towns appearing when the submitter starts typing the first letters, he/she can still write it down manually. The consequence of this is that there are many felt reports with erroneous addresses. To assign community intensities at a suburban scale, there is a need to correctly associate a felt report with a suburb. Erroneous addresses are corrected using two steps: 1) felt report addresses are compared to the New Zealand Fire Service Localities GIS database (NZFS: NZL 2016 #1), one of the most complete address databases in New Zealand, and, when an address has been matched with this database, the suburb from the database is assigned to the felt report. With this method, about 64 to 76% of the addresses have been matched for the eight New Zealand earthquakes examined. However, a great number of addresses (up to about 1000 for the Darfield and February 2016 earthquakes) were still not able to be used due to errors in the address names. These need to be manually checked. So far, the manual check has been carried out for the 4/9/2010, M_w 7.1 Darfield and the 22/2/2011 M_w 6.2 and the 14/2/2016 M_w 5.7 Christchurch earthquakes. Manual checking of the addresses for the rest of the earthquakes is in progress.

3.3 Community intensities

Once reports with insufficient information or duplication issues have been eliminated and a score distribution obtained for each felt report, the community MMI value is obtained and assigned to a town or suburb using the boundaries defined in the New Zealand Fire Service Suburb Database. Following the method developed by [2], the community MM intensity is calculated as follows:

- The score distribution of MMI is obtained per community by adding, for each intensity level, all the scores of the reports belonging to that community (town/suburb). Scores are normalised.
- The modal score is calculated as the MMI value with the maximum score.
- Score percentages with respect to the modal score are calculated.
- A local maximum is defined as an MMI with a score value of more than 95% of the modal score.

- The CMMI is obtained as the average of the local maxima weighted by their corresponding normalised scores.
- Only suburbs with five or more responses are used to calculate community intensities; this is considered the minimum number to obtain reliable results. This criterion has been followed by previous studies [e.g. 2, 3].

4. Community intensities for eight recent New Zealand earthquakes

The method to obtain community MMI values for New Zealand online felt reports has been tested for eight major (M_w 5.7+) earthquakes described in Section 1 (Fig. 1). Table 4 shows the main parameters of these earthquakes, including the number of felt reports received and the percentage of reports that have been used to calculate community intensities. As it can be seen in Table 4, in most cases only between 40% and 50% of the reports have been used to estimate community intensities. For two earthquakes, less tan 40% of reports were used (Christchurch June, 33%, and Christchurch December, only 19%) and for the Darfield earthquake the highest proportion of reports were used, around 60%. The reasons for the reports not being include insufficient information, erroneous addresses, duplicated felt reports, reports belonging to suburbs with less than five reports and mismatch in suburb names. However, the number of reports used to calculate the CMMI considerably increase once the addresses are being manually checked, adding a further 28% (Darfield September 2010 earthquake) to 68% (Christchurch December 2011 earthquake) felt reports (Table 4, in brackets). After the manual checking of addresses, between 82 and 91% of the reports have been used for the eight earthquakes considered.

Table 4 – Main parameters from the earthquakes where the community MMI method has been applied. Numbers in brackets in the last two columns correspond to results after manual checking of addresses.

Ref.	Earthquake	Date	M_w	Total reports	# Reports used	% Reports used
1	Darfield	4/9/10	7.1	7564	4610 (6742)	60.9 (89.1)
2	Christchurch February	22/2/11	6.2	4252	1773 (3509)	41.7 (82.5)
3	Christchurch June	13/6/11	6.0	3034	999 (2567)	32.9 (84.6)
4	Christchurch December	23/12/11	5.9	1252	237 (1093)	18.9 (87.3)
5	Cook Strait	21/7/13	6.5	5627	2594 (5142)	46.1 (91.4)
6	Lake Grassmere	16/8/13	6.6	5537	2337 (4886)	42.2 (88.2)
7	Eketahuna	20/1/14	6.2	10885	5472 (9889)	48.0 (90.9)
8	Christchurch St Valentine’s Day	14/2/16	5.7	3897	1721 (3469)	44.2 (89.0)

Fig. 2 shows one example, for each earthquake, of the score distribution for the suburb/town with the highest amount of felt reports. Most of the reports have a CMMI assigned of III-IV, except for the Darfield earthquake, with an MMI of V, and the Christchurch February earthquake, where Christchurch Central was assigned a community MMI of >=VIII. Note that in this case, this method is unable to distinguish the exact intensity, as damage to the buildings involved needs to be analysed case by case by an expert [e.g. 24], as mentioned above.

Fig. 3 shows CMMI maps for the Darfield, Christchurch 22 February 2011, Eketahuna and Christchurch 14 February 2016 earthquakes. Overall, a decrease of intensity is seen for suburbs further away from the epicenter, with higher intensities around the epicentral area of VII for the Darfield, Eketahuna and Christchurch 2016 events, and >=VIII for the Christchurch 2011 earthquake. For the Darfield event, there are several suburbs with MMI VIII or higher within Christchurch city, at about 20-25 km from the epicenter, whereas closer to the epicenter intensities vary from V to VII. Two suburbs are shown with MM II intensities. These inconsistencies need to be further investigated and indicate a need for a calibration of the CMMI method. It should be noted that, despite the large amount of felt reports received, there are stillmany suburbs with no information or less than five reports received, and thus with no CMMI values calculated.

For the 14 February 2016 M_w 5.7 earthquake, results have been compared to intensities derived from the recent ShakeMapNZ [10] (Fig. 4), where Peak Ground Acceleration (PGA) values have been transformed into

MMI values using recent GMICE [8] to be able to make a direct comparison. Results show that intensities derived from ShakeMapNZ are one-two intensities higher around the epicentral area (close to the coastline) than from the community MMI method, but the two methods give similar results further away from the epicenter.

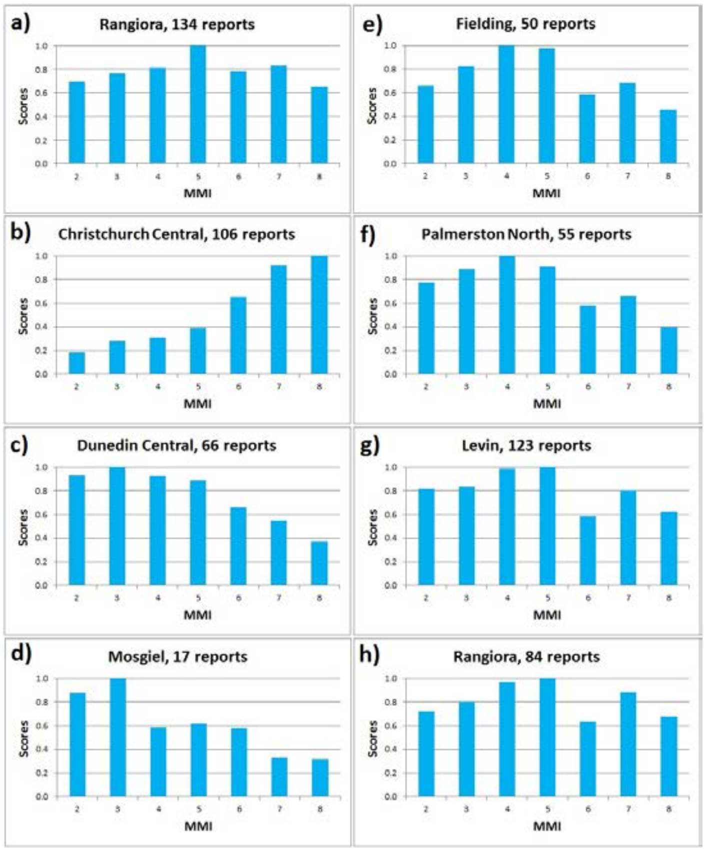

Fig. 2 – Examples of normalised MMI score distributions for New Zealand earthquakes. The suburbs/town with the highest amount of felt reports have been chosen for each earthquake. a) Rangiora (15,000 inhabitants) for the 4 September 2010 M_w 7.1 Darfield earthquake, with a CMMI of V; b) Christchurch Central (about 10,100 inhabitants in 2006) for the 22 February 2011 M_w 6.2 Christchurch earthquake, with a CMMI of >=VIII; c) Dunedin Central (about 120,000 inhabitants) for the 13 June 2011 M_w 6.0 Christchurch earthquake, with a community MM intensity of III; d) Mosgiel (about 6,700 inhabitants) for the 23 December 2011 M_w 5.9 Christchurch earthquake, with a CMMI of III; e) Fielding (about 15,000 inhabitants) for the 21 July 2013 M_w 6.5 Cook strait earthquake, with a CMMI of IV; f) Palmerston North (about 80,000 inhabitants) for the 16 August 2013 M_w 6.6 Lake Grassmere earthquake, with a CMMI of IV; g) Levin (about 20,000 inhabitants) for the 20 January 2014 M_w 6.2 Eketahuna earthquake, with a CMMI of IV; h) Rangiora (15,000 inhabitants) for the 14 February 2016 M_w 5.7 Christchurch earthquake, with a CMMI of IV.

5. Conclusions and future work

A method has been developed to calculate community MMI values for New Zealand earthquakes, using GeoNet's online felt reports. The method has been fashioned on one developed by INGV using Italian online felt reports, and adapted to New Zealand MM scale and questionnaires. It is an expert-based approach that follows the guidelines of the macroseismic scale to calculate MMI values at a community (suburb/town) scale, through a matrix score system that provides weights to each of the relevant questions in the online survey. The method has been implemented and tested for c. 43,000 felt reports corresponding to eight recent moderate to large (M_w 5.7 to 7.1) New Zealand earthquakes.

Currently, we are focusing on the calibration of the method. To achieve this, two different approaches are being carried out. First, the community MM values will be compared to those obtained with recent GMICEs [7,8]. Second, the recent M_w 5.7 Christchurch earthquake on 14 February 2016 gave us the opportunity of carrying out the first traditional survey since GeoNet implemented the online felt reports in 2004. A total of 3800 postal surveys have been sent with the same questionnaire as the one provided online. These have been sent to target suburbs where the community MMI method had enough reports to give confidence in the quality of the data. Addresses were randomly chosen in these suburbs. Care was taken to avoid red-zone suburbs from the 2010-2011 earthquake sequence, as these are likely to be almost empty of residential properties. About 300 surveys have been received so far, and evaluation of community MMI values estimated the traditional way (with one expert assigning the MMI values per suburb/town using all the reports available) is in progress.

The comparison of the MMI values with the three methods will serve to summarise the main differences and calibrate the new community intensity method.

Once the method is calibrated and updated, it will be used for the whole set of online felt reports since 2004. In addition, the results will be used to obtain ShakeMaps for New Zealand earthquakes directly using community MM intensity values.

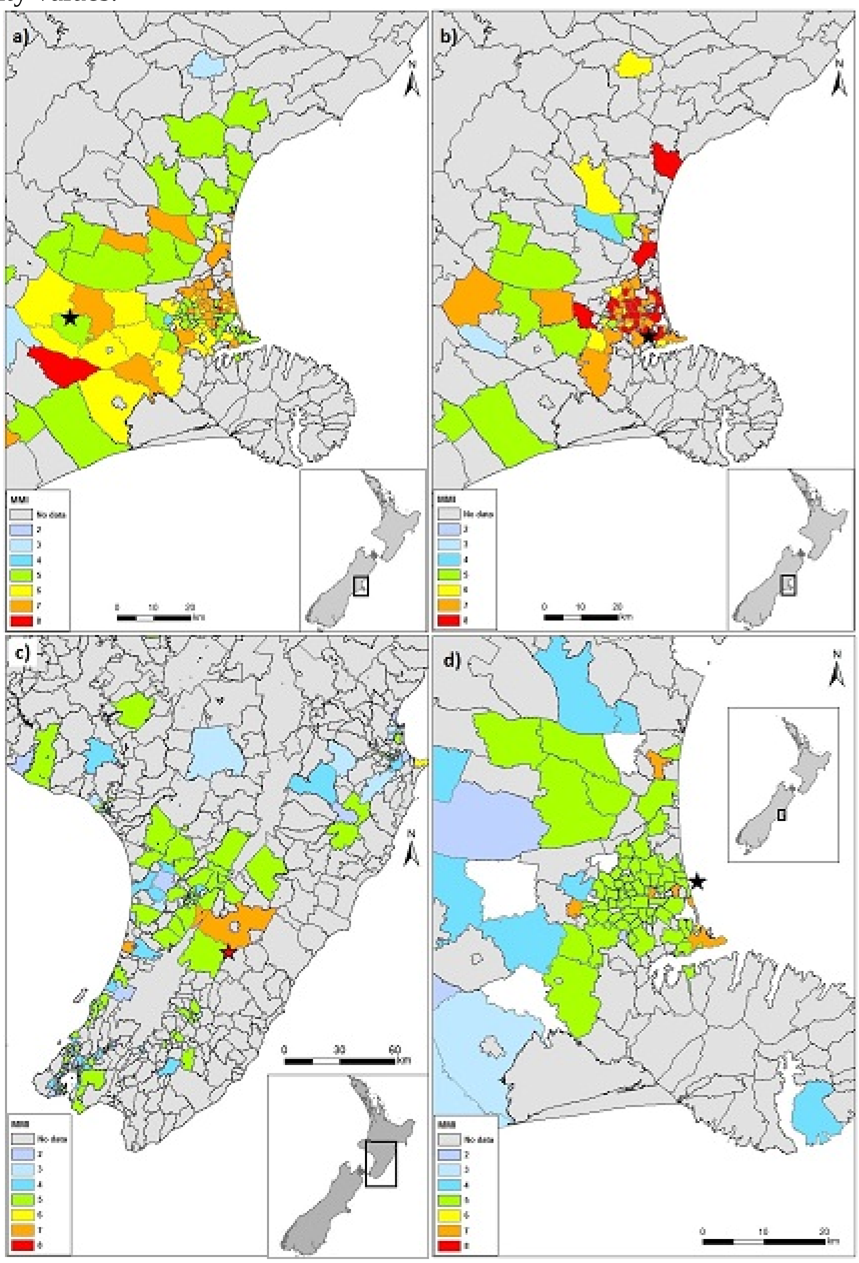

Fig. 3 – Community MM intensity distribution corresponding to the 4 September 2010 M_w 7.1 Darfield (a), 22 February 2011 M_w 6.2 Christchurch (b), 20 January 2014 M_w 6.2 Eketahuna (c) and 14 February 2016 M_w 5.7

Christchurch (d) earthquakes. The epicentre is indicated with a red or a black star. The inset shows the marked area represented in each map.

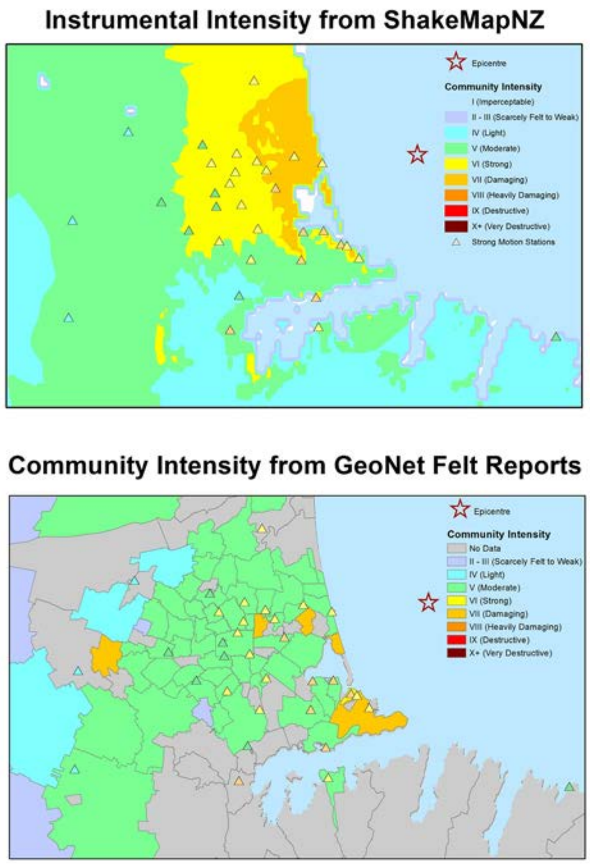

Fig. 4– Comparison of the MMI distribution between ShakeMapNZ and the community MM intensity method, for the 14 February 2016 M_w 5.7 Christchurch earthquake.

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