Community Modified Mercalli intensities derived from GeoNet's online questionnaires

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ABSTRACT: During the damaging and on going Canterbury earthquake sequence, GeoNet (http://www.geonet.org.nz/) received tens of thousands of online questionnaires from the public, with more than 11,000 reports only from the Darfield main shock (M_w 7.1, 4 September 2010) and its main aftershock (M_w 6.2, 22 February 2011). 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), with a total of 26,849 reports received, have confirmed the immense public interest in filling in online questionnaires for research purposes. 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 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, the calibration processes used and its application to eight recent New Zealand earthquakes. The community MMI data will be able to help local authorities for loss estimation and evacuation purposes. In addition, the community MMI data will be included in the recently developed ShakeMapNZ software, providing Rapid damage estimations following an earthquake.

1 INTRODUCTION

Internet-based macroseismic surveys have been implemented in the last fifteen years by several international seismological institutions, and are becoming a very popular way of the public contributing to science through sharing their experience during an earthquake. Automatic intensity evaluations can be made through two different approaches: regression-based or expert-based. 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 of the USGS "Did You Feel It" method (Wald *et al.*, 1999a). 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. for New Zealand data Gerstenberger *et al.*, 2007), systems like ShakeMap (Wald *et al.*, 1999b) or the recently developed ShakeMapNZ (Horspool *et al.*, 2015), or traditional macroseismic surveys where intensities are assigned to a community by a seismologist. This approach was chosen by a team from the 'Instituto Nazionale de Geofisica e Vulcanologia' (INGV) to obtain automatic intensities for online surveys in Italy (Sbarra *et al.*, 2010; Tosi *et al.*, 2015) 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 Modified Mercalli Intensity (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.

In 2004, GeoNet (New Zealand's national geological hazards monitoring service, http://www.geonet.org.nz/) implemented an internet-based questionnaire (‘Felt Classic’) together with an algorithm (Coppola *et al.*, 2010) to automatically assign intensity values to each felt report in New Zealand’s MMI (Modified Mercalli Intensity, called MMI throughout this paper for simplification) scale (Dowrick, 1996; Dowrick *et al*., 2008), based on felt information captured from the questionnaire. 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 (Coppola *et al.*, 2010). The Canterbury earthquakes of 2010-2012 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).

GeoNet’s automatic algorithm assigns an 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 GeoNet’s 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 (Goded *et al*., 2017a). 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 (Horspool *et al*., 2015).

‘Felt Classic’ questionnaires were operative between October 2004 and August 2016. During this period, GeoNet received more than 914,000 felt reports from 27,688 different earthquakes. After that, they have been divided into two: 1) ‘Felt Detailed’ are GeoNet’s new questionnaires, very similar to ‘Felt Classic’ with similar questions and answers plus some additional questions related to tsunami evacuation and social science related questions (people’s reactions after an earthquake, their response, etc.); and 2) ‘Felt RAPID’, a tool for computers and mobile devices where the public chooses from a set of cartoons (each corresponding to a different MMI level) depicting their experience of the earthquake. The purpose for ‘Felt RAPID’ is to obtain quick and numerous responses from the public to be used for emergency planning and early damage estimations. However, its simplicity makes it very difficult to capture all the aspects of the earthquake, as the respondent only chooses from a set of cartoons. Thus, its value as a tool to provide accurate intensity values to be used by emergency planners, local authorities and scientists is being questioned (Goded *et al*., 2017b). The results from this paper refer to ‘Felt Classic’ data. In addition, the recent M7.8 Kaikoura earthquake has been used to produce MM intensity maps using GeoNet’s recent ‘Felt Detailed’ surveys.

In this paper we have developed a different method that obtains an MM intensity value from each ‘Felt Classic’ online 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 (referred to as “community” throughout this paper). The method has been created following the above-mentioned expert-based approach score matrix system developed at INGV (Sbarra *et al*., 2010; Tosi *et al*., 2015) and adapted to New Zealand data and the NZ-MM scale. The method has been tested for nine major (M_w 5.7+) earthquakes in the last six years: the four major Canterbury earthquakes (see above), as well as the Cook strait (21/7/2013, M_w 6.5), Lake Grassmere (16/8/2013, M_w 6.6, Holden *et al*., 2013) and Eketahuna (20/1/2014, M_w 6.2) earthquakes. In addition, the method has been applied to the recent “Valentine’s Day” Christchurch earthquake (14/2/2016, M_w 5.7) and, using ‘Felt Detailed’ questionnaires, to the M7.8 Kaikoura earthquake on 14/11/2016.

As a way to validate the method, community MM intensities were obtained independently through three other methods for the “Valentine’s Day earthquake: a) obtaining “traditional” MM values (assigned manually by a seismologist) from surveys sent by post to a random distribution of addresses in Christchurch; b) through the most recent New Zealand GMICE, (Gerstenberger *et al*., 2007); and c) through an improved GMICE using California data (Worden *et al*., 2012). The method, once validated, has been applied to the whole set of felt reports from the ‘Felt Classic’ survey, a total of more 914,000 reports from 272,082 different earthquakes. This paper presents the method, validation and main results obtained.

2 INTENSITY ASSESSMENT METHOD

2.1 Individual felt report intensities

A selection of the most relevant survey 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 1) 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". 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.

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 2). The scores have been normalised. MMI values I and II are grouped together, because 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 (eg Goded *et al*., 2014), and an evaluation of the building damage grade and building type needs to be carried out before an MM intensity is assigned. The score matrix has been created in such a way that if an answer indicates that the intensity is below a certain 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 (Dowrick, 1996). From the point when the MMI level is triggered, the scores distribution has been chosen through an expert panel with long experience in using the New Zealand MM scale. The scores gradually increase towards higher levels of intensity when the answers imply higher damage levels.

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

- Reports with insufficient information (<50% answers to questions from Tables 1 and 2) to appropriately assign a score have been eliminated.
- 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.
- 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),; and 2) the remaining addresses have been manually checked for the 8 'Felt Classic' earthquakes. With these two steps, between 82% and 91% of the reports have been used to obtain community MMI values.

2.2 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 Tosi *et al*. (2015), 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. Wald *et al*., 1999a; Tosi *et al*., 2015).

Table 1. Sets of questions used to obtain CMMI values, from GeoNet's 'Felt Classic' 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 (combined with FR4-7)	AO-No damage AP-Hairline cracks AQ-Wide cracks AR-Segments of walls bulged, distorted or partially collapsed 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:

Table 2. 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 1.

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

3 COMMUNITY INTENSITIES FOR NEW ZEALAND EARTHQUAKES

3.1 Community MM intensities for nine M5.7+ earthquakes

The method to obtain community MMI values for New Zealand online felt reports has been tested for nine major (M_w 5.7+) earthquakes described in Section 1. Figure 1 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 VIII for the Darfield and Christchurch 2011 earthquakes, VII for Eketahuna and V-VII for Christchurch 2016 event. For the Darfield event, there are several suburbs with MMI VII and ≥VIII within Christchurch city, at about 20-25 km from the epicenter. The Christchurch 2011 earthquake produced MM ≥VIII intensities not only within the city, but also further North, indicating the amount of damage caused. It should be noted that, despite the large number of felt reports received, there are still many suburbs with no information or less than five reports received, and thus with no CMMI values calculated. This is the case of the recent Kaikoura earthquake: even though more than 3500 reports were received, as the event occurred in a rural area, the reports were widely distributed across the country. As a consequence of this, only 18% of the reports were being used to calculate CMMI.

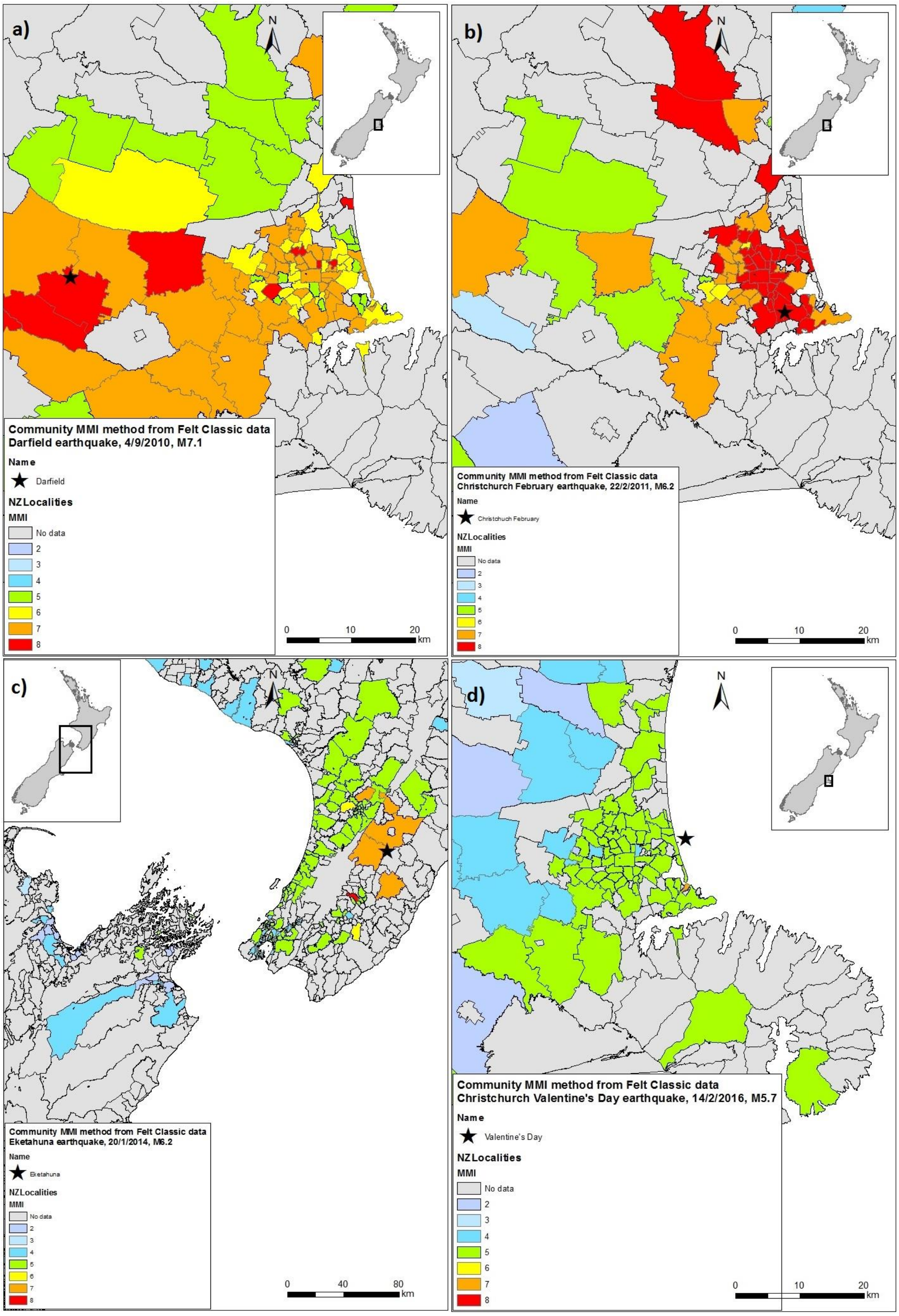

Figure 1. Community MM intensity distribution corresponding to the 4 September 2010 M_w 7.1 Darfield (a), 22 February 2011 M_w 6.2 Christchurch (b), 20 January 2014 M_w 6.2 Eketahuna (c) and 14 February 2016 M_w 5.7 Christchurch (d) earthquakes. The epicentre is indicated with a black star. The inset shows the marked area represented in each map.

3.2 Calibration method using the Christchurch 'Valentine's Day' earthquake (14/2/2016, M5.7)

The "Valentine's Day" earthquake was used to calibrate the method to obtain community MM intensities, as explained above. This earthquake 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 were sent with the same questionnaire as the one provided online. They were 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 were likely to be almost empty of residential properties. A total of 358 surveys were received, both by post and online (using Survey Monkey), and community MMI values were estimated in the traditional way (with one expert assigning the MMI values per suburb/town using all the reports available). A total of 301 reports (84%) were being used for the MMI assignments. Reasons for reports not being used included a) inability to assign a community due to missing addresses (2.2%); b) communities outside Canterbury region (1.4%); and c) communities with less than 5 reports (12%), following the same criterion as for the MMI data using the community MMI matrix method. In total, 33 communities had a traditional MM assignment, compared to the 119 communities from the community MMI method. Thus, the comparison has only been possible for 33 communities in the Canterbury region. A comparison of the results using the community MMI and the traditional methods are shown in Figure 2a. As it can be seen, 48.5% of the communities have been assigned the same MMI value using both methods. A total of 39.4% communities have one level of MM intensity higher, and 9.1% communities one level lower when using the matrix method *vs* the traditional method. In addition, there are 3.0% of communities at two levels of intensity above the traditional assignments. Given the uncertainties derived from both methods (matrix parameters derived from the matrix method, all the uncertainties associated with the manual assignments in the traditional method) these results can be considered satisfactory, with a slight tendency of the matrix method to overestimate the MMI values.

Community intensities obtained with this method have also been compared to MM intensities from the most recent GMICE with New Zealand data, from Gerstenberger *et al*. (2007), between Peak Ground Velocity (PGV) and MMI values. The PGV values associated to the suburb will be the ones corresponding to the strong-motion station closest to the centre of the suburb, following the criterion that both points should be separated less than 1000m. This will enable to assign the MMI value to the centre of the suburb using the GMICE equation without the need to use a ground motion prediction equation (GMPE) as that would add an extra uncertainty to the results obtained. Only 22 suburbs have had an MM intensity assigned using Gerstenberger *et al*. (2007) GMICE. In the Christchurch region, all the suburbs have MM intensities 2 or 3 levels higher when using Gerstenberger *et al*. (2007) GMICE than when the traditional method is being used, showing a tendency of the GMICE to overestimate the intensity in comparison with the traditional method. Figure 2b compares the MM intensities using the matrix, Gerstenberger *et al*. (2007) GMICE and the traditional method, for the only 10 suburbs in New Zealand where all 3 values were obtained. A total of 4 out of the 10 suburbs have exactly the same MMI values when using the matrix and traditional methods, with the remaining 6 suburbs having one level difference. However, the MMI values derived from Gerstenberger *et al*. (2007) GMICE are two levels higher than the ones using the traditional method in 9 suburbs, and 3 levels higher in one suburb. Thus, it can be concluded that Gerstenberger *et al*. (2007) GMICE seems to overestimate the MM intensities compared to both the matrix and traditional methods. This indicates that the current New Zealand GMICE might need to be revised in the future. Comparisons of these three methods in future earthquakes using more communities will show if this tendency is being repeated for every event or not.

Future work on this topic includes a quality control method to improve the results by testing other possible scores in the matrix as well as other definitions for the local maximum value.

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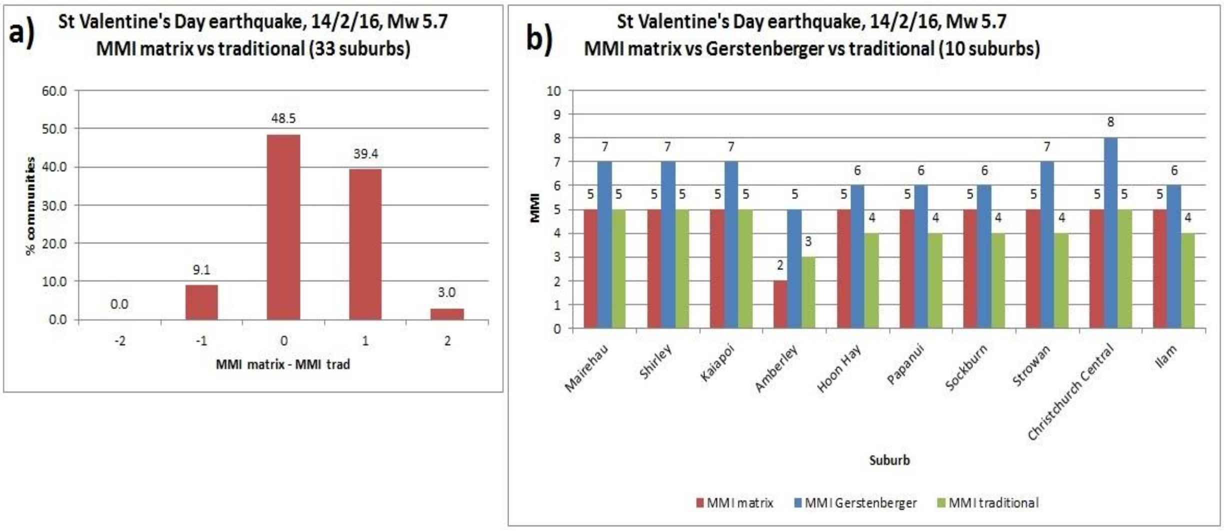

Figure 2. Comparison of Community MM intensities between the matrix and traditional methods (a) and the matrix, traditional and Gertenberger *et al*. (2007) GMICE methods for the 10 suburbs where the 3 MMI values have been possible (b), corresponding to the 14 February 2016 M_w 5.7 Christchurch earthquake.

5 REFERENCES

Coppola, J.M., Cowan, L.X., Downes, G.L., Fenaughty, K.F., Grimwood, P.D., Leach, P. & Robertson, E.J. (2010). Felt earthquake reporting via the internet in New Zealand. *Seismological Research Letters* 81: 984-991.

Dowrick, D.J. (1996). The modified Mercalli earthquake intensity scale; revisions arising from recent studies of New Zealand earthquakes. *Bulletin of the New Zealand National Society for Earthquake Engineering* 29: 92–106.

Dowrick, D.J., Hancox, G.T., Perrin, N.D. & Dellow, G.D. (2008). The Modified Mercalli intensity scale – revisions arising from New Zealand experience. *Bulletin of the New Zealand Society for Earthquake Engineering* 41(3): 193-205.

Gerstenberger, M.C., Worden, C.B. & Wald, D.J. (2007). A probabilistic relationship between ground shaking parameters and MMI based on felt report data. *Proceedings of the New Zealand Society of Earthquake Engineering Technical Conference 2007*, Palmerston North (New Zealand), 2007, Paper 034, 8 pp.

Goded, T., Cousins, W.J. & Fenaughty, K.F. (2014). Analysis of the severe damage online felt reports for the Canterbury (New Zealand) 2011 aftershocks on 22 February Mw6.2, 13 June Mw6.0 and 23 December Mw6.0. *Seismological Research Letters* 85: 678-691.

Goded, T., Horspool, N., Gerstenberger, M., Canessa, S. & Lewis, A. (2017a). Macroseismic intensity assessment method for online questionnaires in New Zealand. *Proceedings of the 16th World Conference on Earthquake Engineering*. Santiago de Chile (Chile), January 2017, Paper 1109, 12 pp.

Goded, T., Horspool, N., Gerstenberger, M., Commer, M.A., Becker, J.S., McBride, S., Canessa, S. & Lewis, A. (2017b). A comparison between Geonet's 'Felt RAPID' and 'Felt Detailed' online questionnaires. *Proceedings of the New Zealand Society of Earthquake Engineering Technical Conference 2017*. Wellington (New Zealand), April 2017, Paper 0181, 8 pp.

Holden, C., Kaiser, A.E., Van Dissen, R.J. & Jury, R. (2013). Sources, ground motion and structural response characteristics in Wellington of the 2013 Cook Strait earthquakes. *Bulletin of the New Zealand Society for Earthquake Engineering*, 46(4): 188-195.

Horspool, N.A., Chadwick, M., Ristau, J., Salichon, J. & Gerstenberger, M.C. (2015). ShakeMapNZ: informing post-event decision making. *Proceedings of the New Zealand Society for Earthquake Engineering Technical Conference 2015*, Rotorua (New Zealand), April 2015, Paper O-40, 369-376.

Sbarra, P., Tosi, P. & De Rubeis, V. (2010). Web-based macroseismic survey in Italy: Method, validation and results, *Natural Hazards* 54: 563-581.

Tosi, P., Sbarra, P., De Rubeis, V. & Ferrari, C. (2015). Macroseismic intensity assessment method for web questionnaires, *Seismological Research Letters* 86: 985-990.

Wald, D.J., Dengler, L.A. and Dewey, J.W. (1999a). Utilization of the internet for Rapid community intensity maps, *Seismological Research Letters* 70: 680-697.

Wald, D.J., Quitoriano, V., Heaton, T.H., Kanamori, H., Scrivner, C.W. & Worden, B.C. (1999b). TriNet "ShakeMaps": Rapid generation of peak ground-motion and intensity maps for earthquakes in Southern California. *Earthquake Spectra* 15(3): 537-556.

Worden, C.B., Gerstenberger, M.C., Rhoades, D.A. & Wald, D.J. (2012). Probabilistic relationships between ground-motion parameters and Modified Mercalli intensity in California. *Bulletin of the Seismological Society of America* 102(1): 204-221.