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MODIFIED MERCALLI INTENSITIES FOR THE M7.8 KAIKŌURA (NEW ZEALAND) 14 NOVEMBER 2016 EARTHQUAKE DERIVED FROM 'FELT DETAILED' AND 'FELT RAPID' ONLINE QUESTIONNAIRES

Tatiana Goded[1], Nick Horspool[2], Silvia Canessa[3] and Matt Gerstenberger[4]

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ABSTRACT

This paper describes the shaking intensity levels caused by the M7.8 Kaikōura earthquake of 14/11/2016 according to the information from the two current GeoNet online questionnaires, 'Felt Detailed' and 'Felt RAPID'. A recently developed method to extract intensity levels at a community scale using 'Felt Detailed' data is used. These are compared with individual intensities from 'Felt RAPID' survey, instrumental intensities from two recent ground motion to intensity conversion equations, and traditional intensity assignments. While maximum Modified Mercalli instrumental, traditional, 'Felt RAPID' and individual 'Felt Detailed' intensities go up to 8, community intensities using 'Felt Detailed' mostly only go up to 5, with only four communities with MM 6-7. Reasons for this discrepancy include a) lack of data around the epicentre; b) few reports from this event compared to other smaller recent earthquakes; and c) lack of public awareness of 'Felt Detailed" surveys, released shortly after the earthquake. In addition, only 47% of reports were used to calculate community intensities, based on a minimum requirement for robust calculation of 5 reports. Although 'Felt RAPID' provided a much larger number of reports (more than 15,000) for this earthquake compared to 'Felt Detailed' (3500), the reliability of the former may be compromised by their lack of detail. Results from this paper suggest that, when enough reports are submitted, 'Felt Detailed' can provide good quality data that can be used in tools such as the near-real time shaking intensity maps provided in ShakeMapNZ.

INTRODUCTION

The M7.8 large Kaikōura (New Zealand) earthquake on 14 November 2016 was an unprecedented event: Geodetic and field observations indicate that it caused surface rupture along at least 12 faults in the Northeastern part of New Zealand's South Island. In addition, there is evidence for possible slip in the southern part of the Hikurangi subduction interface [1]. The earthquake caused major disruption, with the main State Highway between Christchurch and Blenheim being blocked by landslides and remaining closed, due to tens of thousands of landslides. The largest event in New Zealand since the M7.8 Dusky Sound earthquake in 2009, this earthquake continues a decade of high impact earthquakes in New Zealand. In addition, major damage was caused in Wellington city, where high levels of shaking were experienced, with damage requiring several buildings in the city centre to be demolished. Spectral accelerations in the city exceeded the current 500-year return period design level spectra (ultimate level state) in the 1-2 s period range at some strong-motion stations [2].

The earthquake occurred when GeoNet was in the process of transitioning its online questionnaires to a new system. Several hours after the earthquake, GeoNet released the new 'Felt Detailed' (FD) online survey, which replaces the previous 'Felt Classic' surveys that had been operative since 2004. In addition, since early 2016 GeoNet had released 'Felt RAPID' (FR), a questionnaire available on the internet and mobile devices where the public chooses a single response from a set of cartoons (each corresponding to a different intensity level) depicting their experience of the earthquake. This paper shows the Modified Mercalli (MM) intensity data for the Kaikōura earthquake derived from both 'Felt Detailed' and 'Felt RAPID' online questionnaires. 'Felt Detailed' results are calculated using two methods: 1) extracting one individual MMI value per report; and 2) calculating intensity values at a "community" level based on multiple responses, providing the first geographical damage distribution of earthquakes derived from online questionnaires in New Zealand [3]. Here a "community" can be a suburb (within a city) or a town (in rural areas). In addition, instrumental MMI extracted from strong-motion data using two recent ground-motion-to-intensity conversion equations (GMICE) have been evaluated for this event. Finally, traditional MMI assignments, where intensities are assigned to a community by a seismologist, were carried out in the epicentral area. The analysis and comparison of these datasets and methods are shown in this paper.

THE COMMUNITY INTENSITY METHOD FOR NEW ZEALAND EARTHQUAKES

Internet-based macroseismic surveys have been implemented in the last fifteen years by several international seismological institutions, and are becoming a very common way for the public to contribute to science through sharing their experiences during an earthquake [3].

Automatic intensity evaluations can be made through two different approaches: regression-based or expert-based [4, 5].

[1] *Corresponding Author, Seismic Hazard Modeller, GNS Science, Lower Hutt, t.goded@gns.cri.nz (Member)*
[2] *Risk Specialist, GNS Science, Lower Hutt (Member)*
[3] *Modelling Technician, GNS Science, Lower Hutt*
[4] *Seismologist, GNS Science, Lower Hutt (Member)*

A regression-based approach obtains results through a regression between the automatic scores (as defined later) and the traditional intensities (assigned manually by a seismologist). The former is the case with the USGS "Did You Feel It" method [6-9]. It involves a thorough review of isoseismal/intensity maps from earthquake catalogues and a transformation of the felt report data into the same intensity scale. In contrast, the expert-based approach follows the descriptions 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 GMICEs, (e.g. for New Zealand data [10,11]), systems like ShakeMap [12] or the recently developed ShakeMapNZ [13], or traditional macroseismic surveys. This approach was chosen by a team from INGV to obtain automatic intensities for online surveys in Italy [5, 14-16] and is one of the methods 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 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 [17] to automatically assign intensity values to each felt report in New Zealand's MMI scale [18-21, 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 [17]. The Canterbury earthquakes of 2010-2012 [22-26] 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, Mw 7.1; Christchurch 22/2/2011, Mw 6.2; Christchurch 13/6/2011, Mw 6.0; Christchurch, 23/12/2011, Mw 5.9). These earthquakes 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 NZ-MMI=8 or above [27, 28].

GeoNet's automatic algorithm assigns intensity to each felt report. However, intensity values applied to single locations are not consistent with the definition of MMI, nor with the way traditional MMI values were estimated; to be consistent with the definition of MMI requires measuring the seismic impact at a community scale. Thus GeoNet's MMI values do not provide information on the geographical damage distribution, essential in seismic hazard and emergency planning. A community estimate has been developed in this study with the use of "community intensities", which estimate the intensity using multiple responses over a community. These community estimates are essential to create intensity maps that could be published in GeoNet's website [29] minutes after an earthquake and be also 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 [13].

We have developed a different method of calculating MM intensities from GeoNet's 'Felt Classic' online felt reports, which obtains an intensity value per report together with a community intensity [3, 30]. A 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 expert-based score matrix system developed at INGV [5, 14] for the Italian online questionnaires, and adapted to New Zealand data and the NZ-MM scale. The method has been tested for nine moderate-to-large (Mw 5.7-7.8) earthquakes in the last six years: the four major Canterbury earthquakes, the Cook strait (21/7/2013, Mw 6.5) [31], Lake Grassmere (16/8/2013, Mw 6.6) [29] and Eketahuna (20/1/2014, Mw 6.2) earthquakes. In addition, the method has been applied to the recent 'Valentine's Day' earthquake (14/2/2016, Mw 5.7 [32], in Christchurch and the Kaikōura (14/11/2016, Mw 7.8) earthquake [1].

The community intensity method (also known as "matrix method" throughout this paper), assigns a score to each answer amongst all the intensity values; the score indicates the potential for the answer to indicate each of the different intensity values, thus creating an intensity distribution for each answer to the questionnaire. MM intensities I and II have been grouped together, as it's often difficult to distinguish between these two levels. In addition, all MM intensities of VIII or above have also 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 [e.g. 5, 8, 28, 33], including an evaluation of the building damage grade and building type. As this detailed evaluation is not possible through this method, all the felt reports with MM 8 or above have been grouped together, waiting for an additional analysis carried out separately for the high levels of damage [e.g. 28]. This criterion of grouping all MM8+ together has been followed by the Euro-Mediterranean Seismological Centre [34] and INGV [5, 14].

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 over 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 [19]. 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. Data with insufficient information, inaccurate data or duplicated reports are removed before assigning community MMI values. It should be noted that 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. 5, 6].

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, they 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 2) 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 nine New Zealand earthquakes examined. However, a great number of addresses (up to about 1900 for the Darfield and Christchurch 'Valentine's Day' February 2016 earthquakes) were still not able to be used due to errors in the address names. These have been manually checked for all the earthquakes except for the Kaikōura event. Manual checking considerably increased the number of reports used to calculate the CMMI, adding a further 28% (Darfield September 2010 earthquake) to 68% (Christchurch December 2011 earthquake) felt reports. After the manual checking of addresses, between 82 and 91% of the reports were used [3, 30].

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 assignments (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 [10]; and c) through an improved GMICE using California data [11]. Note [11] also developed equations between MMI and Peak Ground Acceleration (PGA) and pseudospectral accelerations at 0.3, 1.0 and 1.3s periods. Their equation with Peak Ground Velocity (PGV) was selected as the one with the lowest uncertainty (sigma=0.63) of all the equations. When using the GMICE methods, the PGV values assigned to each community corresponds to the closest strong-motion station to the centre of the suburb, following the criterion that both points should be separated less than 1000m. With this criterion the MMI value derived from the equation is assigned to the centre of the suburb without the need to use a ground motion prediction equation (GMPE), which would add an extra uncertainty to the results obtained.

Results from this analysis [3, 30] indicate a good agreement between the matrix and traditional methods. However, the matrix method shows a tendency to overestimate the intensities by one level compared to the traditional method. This tendency should be checked in future earthquakes, as in the 'Valentine's Day' event there were only 33 communities with MMI values derived using the traditional method.

Community MMI results using [10] GMICE from PGV data shows a tendency to overestimate the intensities by about 2-3 intensity levels in comparison to the results from the matrix and traditional methods. CMMI values considerably improve when using [11] GMICE, with an increase of up to 40% in the percentage of communities with the same MMI values as when using the matrix method. However, the comparison using the three methods was only possible for 10 communities when using data from the 'Valentine's Day' earthquake. More reports should be analysed in the future to make final conclusions. The need for more intensity datasets using the traditional method was emphasized in [30], as they enable us to check the reliability of the CMMI method and the MMI values from the different GMICE equations.

A preliminary comparison of 'Felt RAPID' and 'Felt Detailed' MMI values in terms of community and individual intensities for the Kaikōura earthquake was given in [35]. In that paper, no manual correction of addresses was carried out for the felt reports from Kaikōura earthquake, thus only being able to use 17% reports to produce CMMI values (see more details below). That paper then looked into social science differences between the two surveys by comparing specific questions of 'Felt Detailed' against answers in 'Felt RAPID', to analyse the differences between the results in the two surveys. However, no comparison with other methods (GMICEs, traditional assignments) was carried out in [35]. The present paper constitutes a step further than [35], by 1) carrying out a manual correction of addresses (and thus increasing the reports used by 30%, see details below); 2) analysing and comparing the matrix method, the individual intensities, results using the two GMICE equations and traditional assignments using both 'Felt RAPID' and 'Felt Detailed' questionnaires; and 3) analysing the intensities felt in the epicentral area and Wellington city.

NEW ZEALAND ONLINE FELT REPORTS

'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. From November 2016, there are two different surveys on the GeoNet website [29]: 1) 'Felt Detailed' (FD), GeoNet's new questionnaires, very similar to 'Felt Classic' with similar questions and answers plus some additional unrelated questions pertaining to tsunami evacuation and social science related questions (people's reactions after an earthquake, their response, etc.); and 2) 'Felt RAPID' (FR), a questionnaire available on internet 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 FR is to obtain quick and numerous responses from the public using a simplified questionnaire. FR is mainly used by the media and GeoNet as a public communication tool. 'Felt RAPID' has the potential to be used for emergency response management and early damage estimations through tools such as ShakeMapNZ [4]. 'Felt RAPID' consists of six cartoons representing MMI levels from 3 to 8.

It should be noted that currently 'Felt RAPID', although linked to an event on the GeoNet website [29], simply stores the data up to one hour after the earthquake, and does not keep the information on the event ID. Even if respondents keep providing data, it will not be stored if more than an hour has passed since that particular earthquake. Thus, if there are two or more events in a one-hour period, the data will be mixed. In contrast, 'Felt Detailed' surveys are permanently available, and the respondent is asked to provide some earthquake information (at least the earthquake ID) to identify the event they have felt. This survey can be filled in at any time after the event.

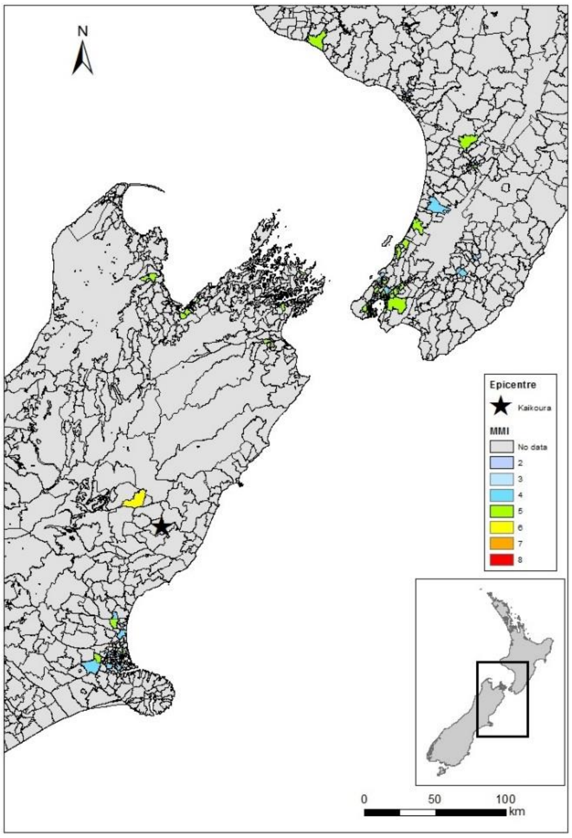

Figure 1: Community MM intensity distribution corresponding to the 14 November 2016 Mw 7.8 Kaikōura earthquake using 'Felt Detailed' surveys.

The major M7.8 Kaikōura earthquake (14/11/2016) occurred when our team was adapting the matrix method to the new 'Felt Detailed' surveys. 'Felt Detailed' was created as a faster and easier-to-fill-in questionnaire than 'Felt Classic'. The survey was sent to several institutions to test and provide feedback before its final release. Currently, 'Felt Detailed' survey asks the respondent to provide the earthquake ID. In the near future, it will be linked to individual earthquakes and thus avoid the respondent needing to include the earthquake data. It should be noted that between August and November 2016 there was only 'Felt RAPID' questionnaires in GeoNet's website, during which the major East Cape (2/9/2016, M7.2) and Kaikōura earthquakes occurred. The public were disappointed about the missing "long reports" in GeoNet's website, showing their willingness to fill in seismic surveys and collaborating in science research. 'Felt Detailed' reports were released in GeoNet's website shortly after the two events to collect this data, and since a few days after the Kaikōura event, 'Felt Detailed' is permanently on GeoNet's website.

It should be noted the much lower number of felt reports received for the Kaikōura event (just above 3,500) compared to previous earthquakes such as the M6.5 Cook Strait (21/7/13) and M6.2 Eketahuna (20/1/14) events, with around 5,500 and 11,000 reports, respectively, for much lower magnitude earthquakes. A reason for this decreased number of reports for a much larger event could be due to the switch in the online questionnaire just before the Kaikōura earthquake, and the lack of awareness from the public of the new survey when the earthquake occurred. In addition, 'Felt Detailed' questionnaires are not (unlike 'Felt Classic' previously and 'Felt RAPID' currently) linked to the earthquake in GeoNet's website. When the earthquake occurred, it only appeared in GeoNet news website. At present, it can be filled in after 'Felt RAPID' if the respondent is willing to fill in a longer survey. For these reasons, this major event has the lowest number of reports of the nine events used to test the matrix method.

'Felt RAPID' data is publicly available using GeoNet's API website. Results for Kaikōura earthquake can be downloaded from [36]. For other earthquakes, the last 11 digits in the URL link should be replaced by the corresponding earthquake ID, which can be obtained from [29]. 'Felt Detailed' data is not publicly available at the moment. Work towards making these data publicly available is under progress.

COMMUNITY INTENSITIES FOR THE KAIKŌURA EARTHQUAKE

A total of 3,507 'Felt Detailed' reports were received from the Kaikōura earthquake. Using the matrix method, a total of 74 community intensities were assigned for the Kaikōura event, using 623 reports. This corresponds to only 17% of the total number of reports being used to assign CMMI values. After manually correcting the addresses, the number of reports being used has increased to 1647, corresponding to 47% of the reports, thus increasing the number of reports used by 30%. With these, CMMI values have been assigned in 164 communities. These numbers are in high contrast to other much smaller events, such as the M6.5 Cook Strait and M6.2 Eketahuna earthquakes, where 328 and 331 communities were assigned MMI values, respectively, with 91% of the reports received being used in both events to obtain CMMI. However, despite the large number of reports received after the Kaikōura earthquake, these were widely distributed across the country. In addition, as the event occurred in a rural area, a large number of reports belonged to communities with fewer than 5 reports, thus CMM intensities were not assigned in those regions. Community intensities for this event are shown in Figure 1, creating quite a sparsely sampled intensity map. Community intensities for the Kaikōura earthquake from 'Felt Detailed' are mostly only up to level 5, with only two communities with an assigned MM6 (one in the epicentral area) and two with MM7. This emphasizes the lack of data for this event, particularly around the epicentre. Higher intensities were very likely felt given the magnitude of the earthquake and the shallow depth (15 km) [2]. Figure 2 shows the number of communities with each assigned CMMI. As it can be seen, 80 out of the 164 communities were assigned a CMMI of 5, followed by 66 communities with CMMI 4 and 14 with CMMI 2. As mentioned above, there were two communities with MM6 and another two with MM7. There were no communities with CMMI of 3 or 8. The reason for this is still unclear. When analysing the individual reports, a total of 48 (1.4%) have the maximum MMI score of 8, 191 reports (5%) have MMI 7 and 137 (4%) have an MMI of 6. It seems clear that these percentages are low enough to not be representative for the CMMI in that community. There is no deficiency in the matrix method to be able to provide high MMI levels, as it was proven with other events, such as the M7.1 Darfield earthquake on 4/9/2010, with 16% communities with CMMI 7-8; or the M6.2 Christchurch earthquake on 22/2/2011, with 33% communities with CMMI of 7 or 8. Other sources of intensity data (ShakeMap and 'Felt RAPID') provided MMI values up to 8, as expected from this event. These sources have also been analysed and are discussed below.

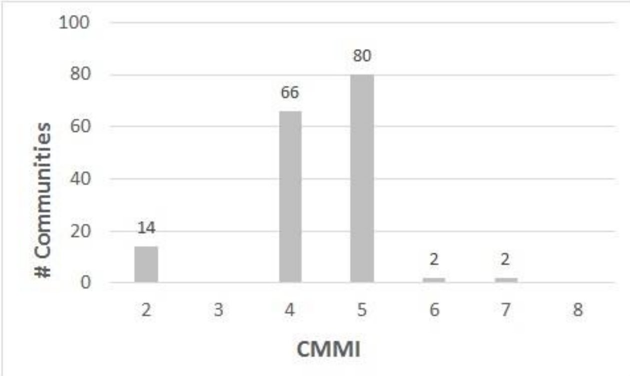

Figure 2: Number of communities with each CMMI level corresponding to the Kaikōura earthquake, using 'Felt Detailed' data.

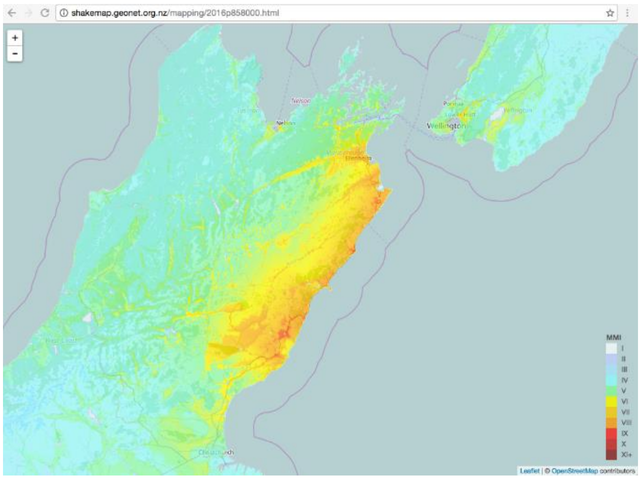

Figure 3: MM intensities using ShakeMapNZ corresponding to the Kaikōura earthquake. (http://shakemap.geonet.org.nz/mapping/2016p858000.html)

Community intensities obtained with the matrix method have been compared to results from ShakeMapNZ [13]. ShakeMapNZ map corresponding to the Kaikōura earthquake is shown in Figure 3. As can be seen, maximum intensities correspond to MMI 7-8 along the East Coast of the South

Island. The Wellington region and Kapiti coast have predominant MM intensities of 4-5, in agreement with CMMI values obtained (Figure 1). Some small areas in the Wellington region also have MM7-8.

The CMMI values have been compared for the Kaikōura earthquake with instrumental intensities using [10] GMICE for New Zealand and [11] GMICE using California data. Results are shown in Figure 4. A total of 252 (7% of the total) felt reports in 24 communities (16 in Wellington region, 5 in Canterbury, 2 in Nelson and 1 on the West Coast of the South Island) were used to calculate CMMI values using both GMICE equations, *versus* 1647 reports (47%) from 164 communities used in the matrix method. The reason for this low number of reports used compared to the matrix method is that, as explained above, only strong-motion stations at less than 1000m from the centre of each community are used to obtain MMI derived from strong-motion data. As it can be seen, 12 out of the 24 communities show a CMMI value two levels higher when using [10] GMICE equation compared to the matrix method, and 8 communities have three levels higher. Results improve when using [11] GMICE, with six communities with only one MM difference with respect to the matrix method. The results using both GMICEs are similar to the ones observed for the Valentine's Day Christchurch earthquake [3,30], where results using [10] were two levels above CMMI values; and better matching was obtained when using [11] GMICE [30]. There are three suburbs that constitute an exception: Korokoro in Lower Hutt (Wellington region), Hokitika and Christchurch Central. All of them have a large difference between the CMMI from the matrix method (2) and the GMICE [10,11] methods, with differences of 4-5 MM intensity levels. Reasons for this discrepancy are unknown and should be further investigated.

None of the 24 communities have matching CMMI and MMIs from the GMICE equations. This is in contrast to the Valentine's Day earthquake [3, 30], where 40% of the suburbs had the same MMI using the matrix and the GMICE [11] method. The fact that [10, 11] GMICE methods are providing MMI of 7 or 8 for the 24 communities, located in different regions, needs further investigation to be fully understood.

Assigning MMI values traditionally is another way to validate the matrix method. So far, traditional assignments using 'Felt Classic' or 'Felt Detailed' data has only been carried out for the 'Valentine's Day' earthquake [2, 30], as explained above. The 'Felt Detailed' dataset for the Kaikōura earthquake will be used in the near future to assign MMI values traditionally. At the present, only seven communities in the epicentral area have had traditional MMI assignments. Results are shown below in a separate section on the epicentral area.

INDIVIDUAL INTENSITIES FOR THE KAIKŌURA EARTHQUAKE FROM 'FELT DETAILED' AND 'FELT RAPID' QUESTIONNAIRES

Due to the low number of community intensities received for the Kaikōura earthquake, the data from 'Felt RAPID' surveys were also checked. Individual FR responses corresponding to the main Kaikōura earthquake were analysed. A total of 15,840 'Felt RAPID' responses were received within one hour of the earthquake, more than 4.5 times the reports received in 'Felt Detailed' [29]. No community MMI values have been extracted from 'Felt RAPID'. The reason for this is that the reliability of FR data might be compromised by the lack of detailed questions. A comparison between 'Felt Detailed' and 'Felt RAPID' data is currently being carried out within our team [35]. The results from this project will indicate if "Felt RAPID' is suitable in the future to obtain reliable intensity values following an event. Given that FR mixes the data for any events within one hour (as explained above) and that there was a great number of aftershocks during the Kaikōura earthquake sequence, including a M6.2 only half an hour after the main eventthe data from 'Felt RAPID' will have a mixture of both earthquakes.

Figure 5b shows the individual 'Felt RAPID' intensities around the macroseismic epicentral area. In Figure 5a, the individual MMI values from 'Felt Detailed' are shown. These correspond to the MMI level with the higher scores in the matrix method, named modal values. This means that in 'Felt Detailed', the MMI chosen is the one with higher probabilities of being the MMI felt at the location of the report, as it is the one with a higher score pointing towards that intensity level. Both 'Felt Detailed' "modal" values and FR data provide MMI up to 8 (Figure 5). A total of 2997 reports had both FD and FR responses, corresponding to 85% of the total number of reports received. The individual MMI values from FD and FR show a majority of MM intensities of 5-6 (both in the Lower North Island and the upper South Island) when using FR v*ersus* 4-5 when using FD, showing a tendency for FR to overestimate the intensity with respect to FD. However, there is a larger number of MM8 values when using FD in regions such as Wairarapa or Marlborough, where FR only goes up to MM7. Thus, for the high levels of intensity, FR seems to be underestimating the intensity by one level compared to FD. A notable difference can be seen in the epicentral area, where there is a considerably larger number of responses from FD. A reason for the larger number of FD responses *vs* FR is that the most affected areas (Kaikōura, Ward, Waiau) did not have electical power shortly after the earthquake, and thus were not able to fill in FR (only available for one hour after the earthquake, as explained above), only FD when the power was back. Results using FD show high MM intensities of 7-8 around the epicentral area.

Individual MMI values from FD and FR are shown in Figure 6. As can be seen, 27% of the reports had the same MMI value using both datasets. However, 40% of the reports had an MMI value one level higher when using FR than when using FD, with a total of 66% of the reports with MMI from 'Felt RAPID' higher than those from 'Felt Detailed' (Figure 6a). When analysing these differences by MMI levels (Figure 6b) it seems that there is a tendency for FR data to overestimate the MMI with respect to FD for intensities 5 or below, and to underestimate it for MMI 7 or 8. At MMI 4 and 5, 'Felt RAPID' overestimates with respect to 'Felt Detailed' by mostly one intensity level, and in some cases more than one. At MMI 2, all the reports from FR overestimated the MMI compared FD by more than one intensity unit (500 reports). This could partly be because FR starts at MMI 3 (see above), thus very weakly felt events will be assessed as MMI 3 in that survey, as there is no cartoon for MMI 2. The lack of electrical power around the epicentre after the earthquake (as explained above) can partly explain some of the differences observed [35].

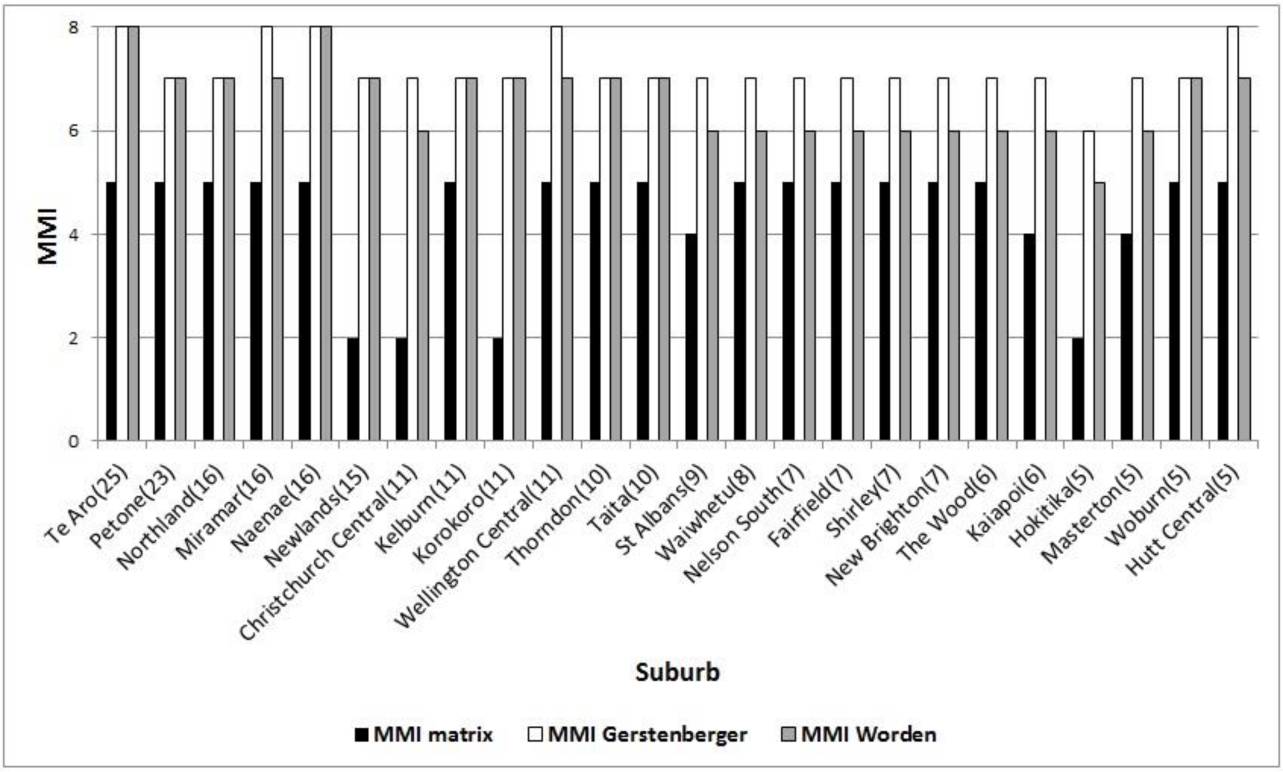

Figure 4: MMI differences using the matrix, Gerstenberger [9] and Worden [10] GMICE methods. Numbers in brackets indicate the number of felt reports used in that community.

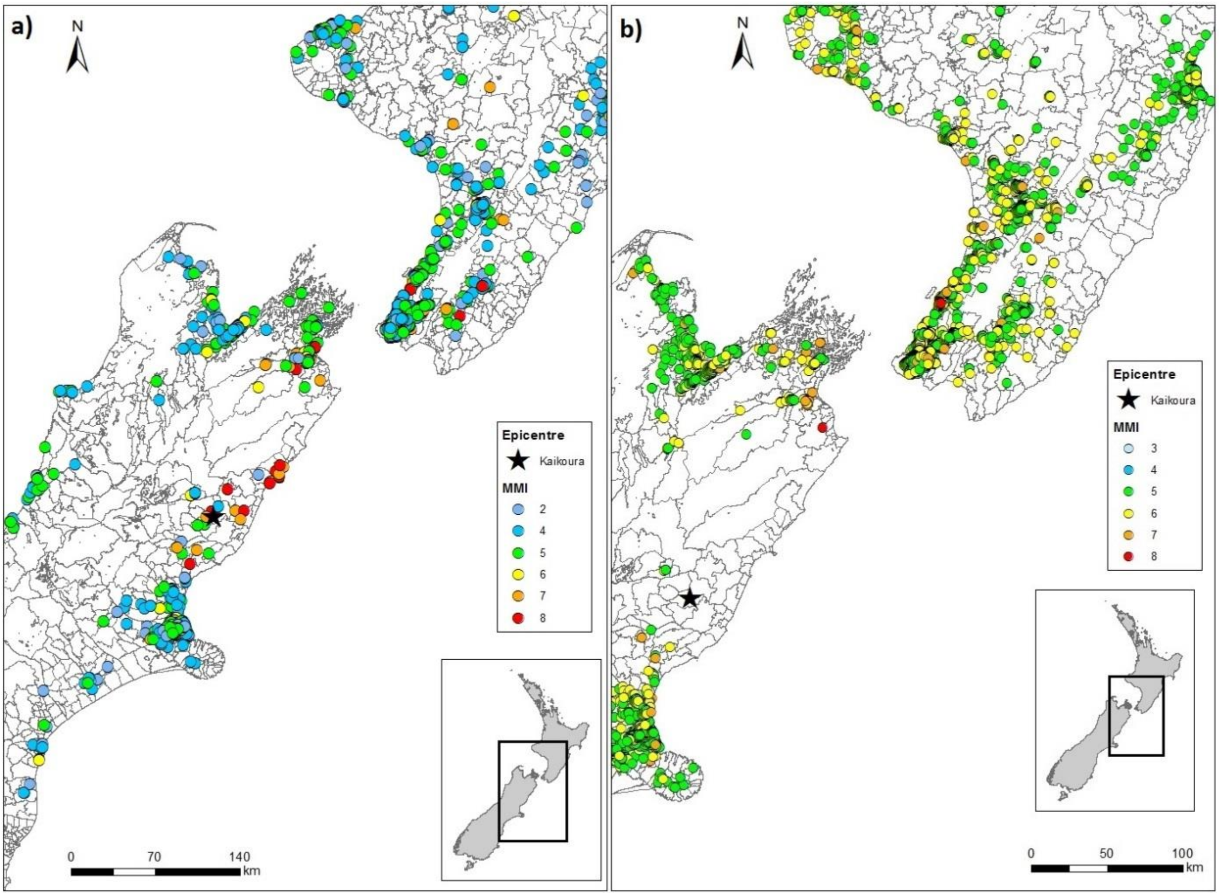

Figure 5: MM intensity distribution corresponding to the 14 November 2016 Mw 7.8 Kaikōura earthquake using (a) 'Felt Detailed' survey individual "modal" values and (b) 'Felt RAPID' individual responses.

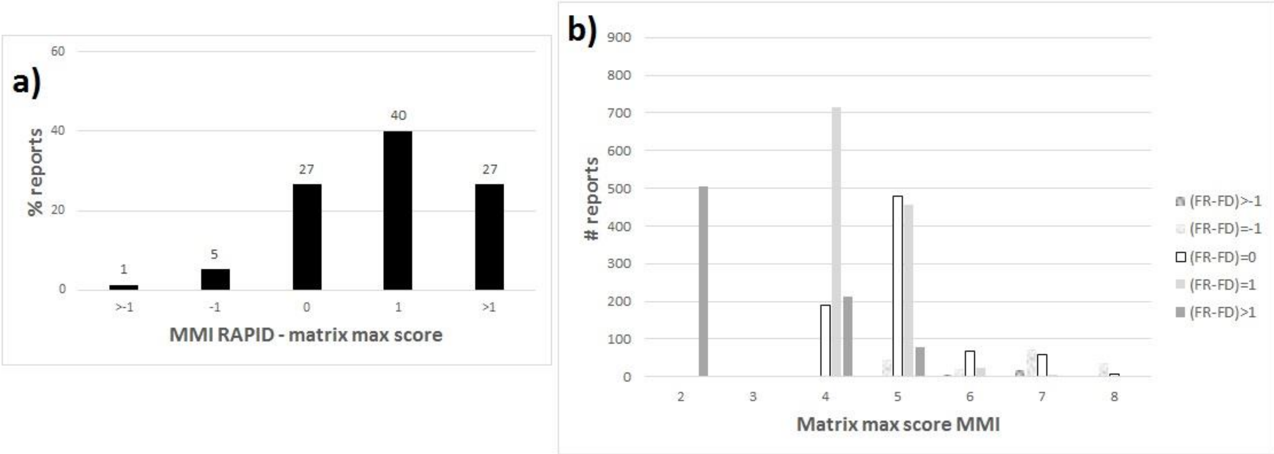

Figure 6: Comparison of MM intensities from 'Felt Detailed' and 'Felt RAPID' datasets from individual reports corresponding to the 14/11/2016 M7.8 Kaikōura earthquake. FD MM intensities correspond to the maximum MMI value (modal) for each report. FR MMI values correspond to the MMI for the cartoon chosen by the respondent. The comparison is shown in terms of: (a) percentage of reports with each MMI level difference between FR and FD; and (b) reports distribution by MMI level, for individual MMI 'Felt RAPID' – 'Felt Detailed' (b).

MM INTENSITIES IN THE EPICENTRAL AREA

The lack of online surveys in the epicentral area makes it difficult to estimate reliable MM intensities. As a first attempt to understand the level of damage that the Kaikōura earthquake caused in the epicentral area, traditional MM intensities (manually assigned by an expert using all the information from each community) have been assigned using 'Felt Detailed' data. Results are shown in Figure 7 and Table 1. There were four communities in the epicentral area with an MM8 intensity, corresponding to Kaikōura, Seddon, Waiau and Ward. These results are in agreement with the ShakeMapNZ intensity maps (Figure 3). Note that MM8 means 8 or above, as this method cannot distinguish between the higher levels of intensity (see above). The town of Cheviot had an MM7, followed by Hamner Springs (MM6) and Culverden (MM5). However, only two out of the seven communities with traditional intensities (Hamner Springs and Kaikōura) had at least five reports, the minimum used in the matrix method. This emphasizes once more the lack of sufficient surveys from this event.

Table 1: Traditional MMI assignmnets in epicentral area for the Kaikōura M7.8 earthquake.

Town	Traditional MMI	# Reports
Cheviot	7	2
Culverden	5	4
Hamner Springs	6	12
Kaikōura	8	8
Seddon	8	2
Waiau	8	1
Ward	8	1

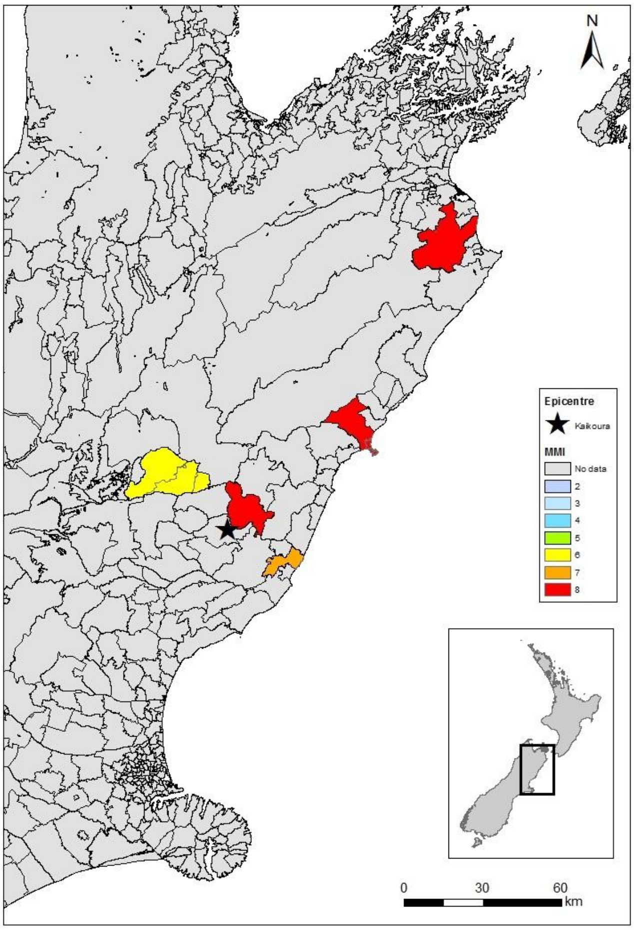

Figure 7: MM intensity distribution in the epicentral area corresponding to the 14 November 2016 Mw 7.8 Kaikōura earthquake using 'Felt Detailed' survey and assigned using the traditional method.

MM INTENSITIES IN WELLINGTON

The Kaikōura earthquake caused great damage in Wellington City, with spectral acceleration exceeding the current 500-year return period design level spectra [2]. A zoomed map of CMMI values in the Wellington region from FD as well as individual FR responses are shown in Figure 8. The great majority of communities had an MM5 assigned. However, results from FR show that higher intensities (MM6-7) were experienced in Wellington city. This predominance of MM5 with smaller contributions of higher MM values is in good agreement with ShakeMapNZ results (Figure 3).

Figure 9 shows the cumulative MM5-or-above values felt in Wellington City, corresponding to the four M6.0+ earthquakes that occurred between 14/11/16 and 17/11/16 at 4pm. 'Felt RAPID' data has been used to produce this figure. It shows that during the Kaikōura main event, almost 1400 FR reports chose MM6 or above as the level of intensity felt in the city, and almost 250 reports indicated a level of MM7 or above. A total of 14 reports with MM8 were sent after the Kaikōura main earthquake. Results for the largest aftershock (M6.3) indicate that 49 reports indicated MM6+, six reports indicated MM7+ and none indicated MM8+. The large difference between the M6.2 results and the M6.3 (579 *versus* 279 reports with MM5+, 248 *versus* 49 reports with MM6+) could be due to the public getting confused between the M6.2 and the main M7.8 event, being only half an hour apart.

CONCLUSIONS AND FUTURE WORK

This paper presents Modified Mercalli intensities for the M7.8 14/11/16 Kaikōura earthquake derived from two GeoNet online questionnaires, 'Felt Detailed' and 'Felt RAPID'. Results from 'Felt Detailed' (3507 reports) have been analysed in four ways: 1) individually for each report; 2) grouped in community intensities for towns/suburbs in New Zealand; 3) using New Zealand's latest GMICE and 4) using an alternative GMICE derived from California data.

The fact that the earthquake occurred in a rural area limited the number of communities with MMI assigned, as only 47% reports corresponded to communities with at least 5 reports, the minimum number required in this method. In addition, the non-existence of a link to 'Felt Detailed' survey in the information page of the earthquake is a reason for the low number of reports received compared to other smaller events in similar locations (e.g., Cook Strait and Lake Grassmere, with around 5500 reports each). Community intensities from the Kaikōura earthquake go up to MM5, with only an additional four communities with CMMI of 6-7, a low level given the magnitude and shallow depth of the event. This also applies to the epicentral area, with a lack of CMMI values above 6. A possible reason for this could be the low percentage of reports with individual MMI 7-8 (only 6%) submitted, that has precluded them from representing a community with a CMMI. This is confirmed when looking at the individual "Felt Detailed" responses, where MM intensities of 7-8 are shown in Marlborough and the lower North Island, showing that "Felt Detailed" surveys have captured the high levels of intensities. However, as indicated above, the number of reports submitted was insufficient to represent the high levels of intensity experienced in certain regions.

Results from this paper indicate the need to manually correct the addresses to be able to use a much larger number of reports to obtain CMMI values. For the Kaikōura earthquake, there was a total of 30% increase in the number of reports used after the addresses were corrected. This increase has resulted in more than double number of communities with CMMI assigned, from 74 to 164. These results emphasize the need to establish a way to avoid misspelt addresses or to improve our geocoding strategy.

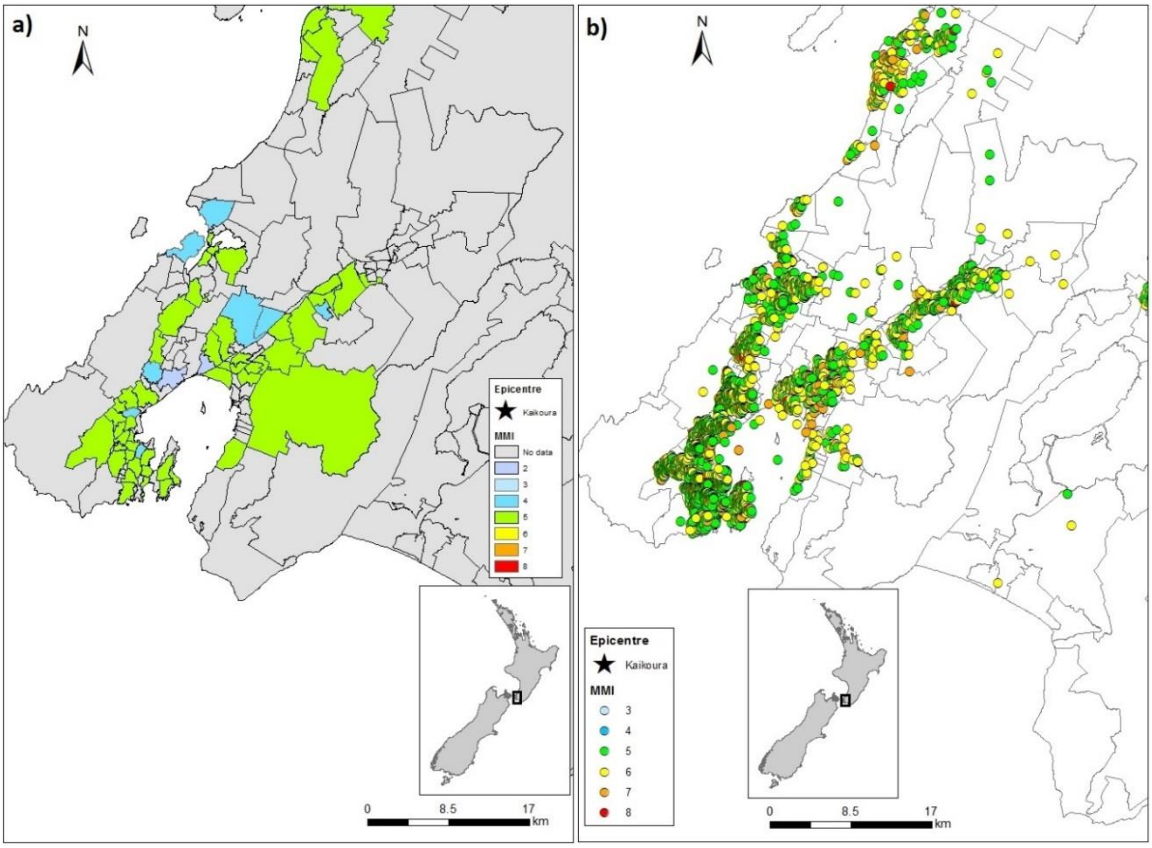

Figure 8: Community MM intensity distribution in Wellington region corresponding to the 14 November 2016 Mw 7.8 Kaikōura earthquake using (a) 'Felt Detailed' survey and (b) individual MM intensities from 'Felt RAPID' survey.

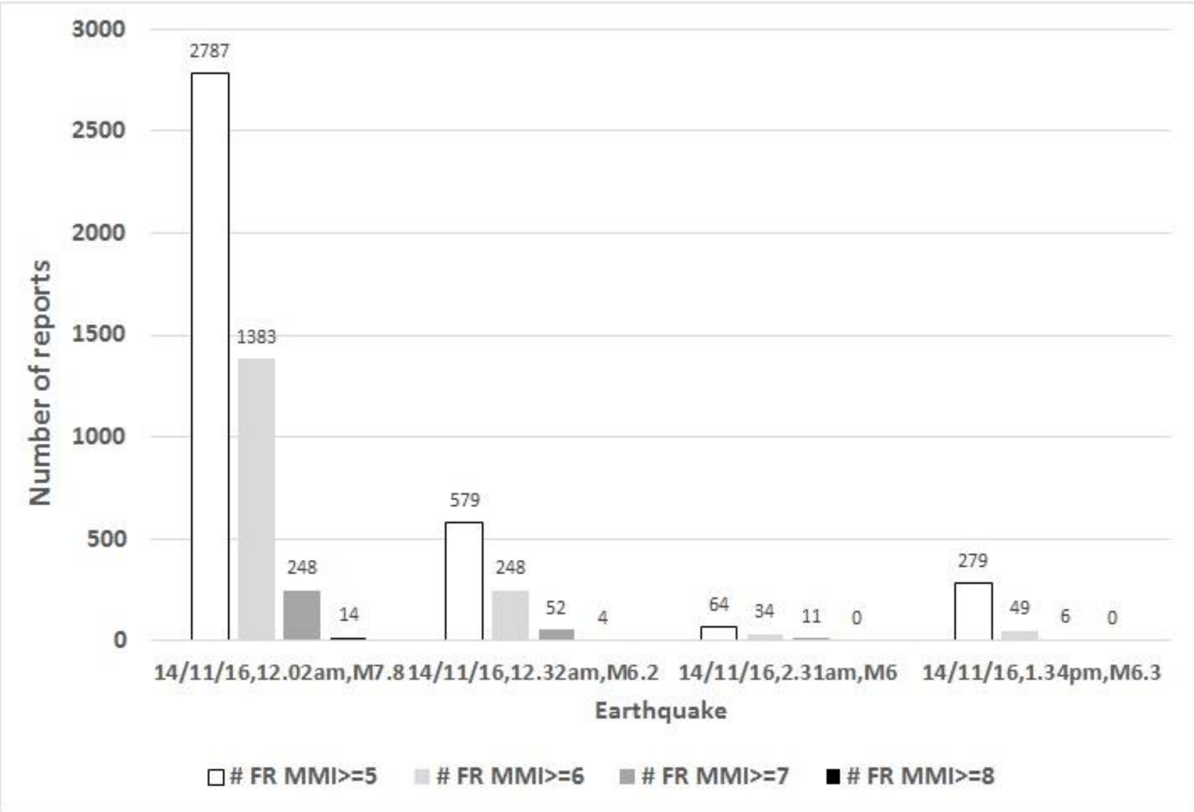

Figure 9: Cumulative MM5+ intensities felt in Wellington City during the Kaikōura earthquake sequence, corresponding to all M6.0+ events between 14/11/16 and 17/11/16 at 4pm. The 'Felt RAPID' dataset has been used to produce this figure.

Individual MM intensities from 'Felt RAPID' go up to 8. However, 'Felt RAPID' data lacks information in the epicentral area, mainly due to the lack of power after the event, as this survey is only stored for up to 1 hour after. In addition, the lack of detail from 'Felt RAPID' may produce inaccurate MMI estimations. Our team is currently analysing the accuracy of 'Felt RAPID' *versus* 'Felt Detailed'.

In addition, traditional MMI assignments have been carried out for seven communities in the epicentral area. Results show that four of them had MM8 or above. Traditional assignments for the rest of the country (which are quite time consuming) will be carried out in the near future. Results from it will help improve calibration of the matrix method system.

Comparisons to ShakeMapNZ results indicate a good agreement with community MM intensities using the matrix method. Despite the few communities with MMI values assigned, the matrix method has captured the overall shaking intensity felt during the Kaikōura earthquake. The very small areas with higher intensities seen in ShakeMap (along the East coast of the South Island, in certain areas in the Wellington region) have not been captured with CMMI. However, these small areas have been assigned higher MMI values when using the traditional method (for the epicentral area) or by analysing individual FD or FR data.

Results using the two GMICEs are around two levels of intensity above the CMMI from the matrix method. Better results are obtained when using Worden et al. [11] GMICE, in agreement with previous research using data from the M5.7 Christchurch Valentine's Day 14/2/16 earthquake. However, both GMICES provide MM7 and MM8 for almost all of the communities, in Wellington, Nelson and Canterbury regions, which might be overestimated. More earthquakes need to be analysed to understand the differences between the matrix and GMICEs methods.

Results from this earthquake have shown that a large number of reports is needed to be able to provide sufficient quality and quantity of community MM intensities. There are two main reasons for the low number of CMMI values in the Kaikōura earthquake. First, the epicentre being in a rural area precluded a large amount of data being received in the epicentral area, in contrast to the Darfield and Christchurch earthquakes in 2010-2011, which occurred in or near a highly populated city. Second, the switch to the long 'Felt Detailed' surveys just after the earthquake has made it difficult for the public to be aware of this new questionnaire, affecting the number of reports received. Although 'Felt RAPID' data produced 4.5 times more reports than 'Felt Detailed', its reliability might be compromised by the lack of detailed questions. Further investigation on the intensity results from FD and FR surveys in future earthquakes will indicate whether FR data can be used in near-real-time tools such as ShakeMapNZ. At present, FD reports are strongly recommended as the best dataset to provide reliable MM intensities that appropriately represent the shaking level felt during an earthquake in New Zealand.

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