The final version of this paper is published in:

Tosi, P., P. Sbarra, V. De Rubeis, and C. Ferrari (2015) Macroseismic intensity assessment method for web-questionnaires, Seismological Research Letters, 86, 985-990, doi: 10.1785/0220140229

https://pubs.geoscienceworld.org/ssa/srl/article/86/3/985-990/315804

Macroseismic intensity assessment method for web-questionnaires

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Introduction

Macroseismic investigation with data collected through web based questionnaires is today routinely applied by most important seismological institutions, such as the United States Geological Survey (http://earthquake.usgs.gov/earthquakes/dyfi/, last accessed December 2014), British Geological Survey (http://www.earthquakes.bgs.ac.uk/questionnaire/EqQuestIntro.html, last accessed December 2014), European-Mediterranean Seismological Centre (http://www.emsc-csem.org/Earthquake/Contribute/choose_earthquake.php?lang=en, last accessed December 2014), Schweizerische Erdbebendienst (http://www.seismo.ethz.ch/eq/detected/eq_form/index_EN, last accessed December 2014), Bureau Central Sismologique Français (http://www.seisme.prd.fr/english.php, last accessed December 2014), New Zeeland GeoNet Project (http://www.geonet.org.nz/quakes/, last accessed December 2014). The wide diffusion of Internet and the citizen collaboration (crowdsourcing) allow to record information on the effects and to produce a macroseismic field with low costs and almost in real time. Transformation from qualitative information (as given by questionnaires) to numerical quantification is a crucial issue. In the traditional evaluation of intensity, experts used to work through a complex comparison of effects basically driven by personal experience. The major problem of this approach concerns the difficulty to verify and to reproduce the evaluation process due to the lack of a detailed explanation of the employed workflow and to the large variability of possible cases. On the other hand, an automatic method for the estimation of macroseismic intensities need to be completely well defined and specified in order to be reproducible and verifiable. For these reasons we are going to give in this paper a comprehensive explanation of our intensity assessment method.

A useful automatic method for intensity assessment should be computationally fast and follow strictly the macroseismic scales. To meet these requirements in 2010 we proposed a method that firstly quantified the effects using additive scores associated with each answer of the questionnaire item and then determined an intensity estimate for each questionnaire (Sbarra et al., 2010). After a trial period and having collected more than 500,000 questionnaires, we were able to deeply test the method. As a result of this testing, we describe here a new improved method that takes into account further factors like, among the others, the situation and the location of the observer (Sbarra et al., 2012; Sbarra et al., 2014) in order to obtain a more accurate estimate of the macroseismic intensity degree at the municipality level.

In this paper we show some applications of our method referred to Mercalli, Cancani, Sieberg (MCS) scale, since there is a long experience of its use on Italian earthquakes and to easily compare intensities with traditional ones.

Questionnaire and score matrices

The Istituto Nazionale di Geofisica e Vulcanologia (INGV) collects on-line macroseismic questionnaires (http://www.haisentitoilterremoto.it, last accessed December 2014, in Italian) about events felt in Italy, voluntarily filled in by citizens. Part of these people are registered members (more than 23,000) who are alerted via e-mail after the occurrence of an earthquake near their municipality.

The questionnaire has been online since 2007, it is addressed to a person who is asked to describe personally observed effects (Sbarra et al. 2010). The questionnaire (see Table S1, available in the electronic supplement to this article) consists of simple questions with multiple answers defined following both the MCS scale and the European Macroseismic Scale (EMS).

The questions concern many effects, ranging from transient ones to building damage. The analysis of the questionnaire data for the evaluation of the local macroseismic intensity is performed by a dedicated automatic procedure in order to produce intensity maps which are published in real-time on the website and updated as soon as new data are available.

We do not differentiate macroseismic intensities lower than II, in fact we consider I degree indistinguishable from II in web questionnaire because people recognizing the earthquake occurrence, following the II degree definition, are so few (about 5%) that it is unlikely to receive questionnaires filled by them. Thus we consider the not felt area as characterized by I-II degree. We group in one single class even the higher degrees (>VII), because they need direct evaluations by experts for a correct assessment; the same criterion is followed by the European-Mediterranean Seismological Centre (Musson, 2007). The correspondence between answers and degrees is obtained through a score matrix specifically created for each intensity scale (see Table S2 and S3, available in the electronic supplement to this article respectively for MCS scale and EMS). In the matrix each row represents an answer and the columns refer to the associated macroseismic intensities. A score equal to 1 is given when the considered answer points to a specific intensity, an 0 otherwise. The score matrix represents the formalization of answers in order to properly quantify each effect for intensity assessment. Macroseismic scales use words such as “few”, “many”, and “most” to categorize the percentage of occurrence of effects. Such amounts were converted into percentage ranges for each macroseismic scale (Grünthal, 1998; Molin et al., 2008). When creating the score matrix we assumed that the compiler and the observed building belong to “many,” which is the wider category, and thus the most probable one. Some answers point to a specific intensity degree and assign one to the score of that degree, while other answers are less specific and are associated to a range of intensity degrees to which they assign 1. The answers explicitly excluding an effect add scores to degrees lower than the degree specific of the effect itself; e.g. small object still at higher floors assigns 1 to III and IV, because small objects move at V. The I-II degree is assigned only in case of not felt earthquake. In the questionnaire there is always the answer ‘‘unable to say’’ (which has to be considered as an option different from the absence of the effect) that does not assign any scores. The score matrices take into account all the possible situations and localizations of the observer as well as the building materials, in order to consider all the combinations of the conditions described in the seismic scales. For example the perceived intensity of shaking changes if the compiler is at rest or in motion; at higher floors rather than outdoors; moreover, damage has to be considered differently depending on building materials and typology. To this regard the considered variables are: "situation" of the compiler during the earthquake event (sleeping, at rest, in motion), the "location" where the respondent is (indoor at underground or ground level, indoor at floors from first to tenth, outdoors) and the "building" material of the structure where the observer is (masonry, reinforced concrete, and, only for EMS, wood, steel). The variable "situation" has an influence only on the scores of the question about the felt vibration; "location" modifies the scores of all the transitory effects; finally, "building" influences the scores of damage. Concerning "location", on the basis of the experimental results obtained from the database of *haisentitoilterremoto* used in Sbarra et al., 2010, we consider together the answer "underground" and "ground level", as well as all the levels from the first floor to the tenth, whereas floors higher than tenth are presently discharged as rarely present in Italy and with a poorly studied behavior. According to the description of macroseismic scales, "location" should have more weight than "situation". On the contrary, Sbarra et al. (2014) indicated that the "situation" had the same or more influence on earthquake perception. In particular, people, even if located on the same floor, perceive a stronger vibration if at rest rather than in motion, with a difference of about 0.5 intensity degree; on the other side, there is a difference smaller than 0.5 for observations made outdoors and at lower floors while at rest (Sbarra et al., 2014).

Individual intensity computation

For each questionnaire the intensity distribution is computed by summing, for each intensity degree, the scores of all answered items associated with that degree. The mode of this distribution constitutes the intensity degree most often pointed by the effects reported by the observers. Sometimes the intensity distribution does not show a unique mode, as some local maxima may occur. We define a local maximum as the intensity corresponding to a score value greater than 95% of the modal score value. In this case the individual intensity is computed as the weighted average of the local maxima. In case of not felt response we just assign the I-II degree.

Questionnaires may contain incorrect answers or not enough information; these factors usually modify the score distribution by increasing the variance or decreasing the score value of the mode. Overall the rejection of a bad-quality questionnaire is made using the following criteria.

- Intensity discrepancy: the computed intensity is less than 3 units or more than 2.5 units far from the intensity (*Int*) obtained by using the intensity prediction equation (IPE)

$$Int = -3.15 \log 10R + 1.55ML + 1.51 \qquad (1)$$

which is estimated on a selected subset of data (R is the hypocentral distance in km and ML denotes the local magnitude).

- Contradictory answers: there are more than 3 local maxima, or the local maxima are separated by more than one degree, or the mean value of local maxima divided by the mean of the other values (a sort of signal to noise ratio) is smaller than a threshold, experimentally set to 1.4.
- Scarcity of information: any degree receives less than 3 answers.
- Duplicate entries: the questionnaire was sent more than once by mistake, thus is identical to a previous one received shortly before.

The percentages of rejected questionnaires are quite low, in detail they are 0.9% due to intensity discrepancy and 2.6% for both contradictory answers and scarcity of information.

Municipality intensity assessment

With the term municipality we mean the territory that is inside one of the 8092 administrative boundaries in which Italy is subdivided. A municipality can enclose more than one small town and the average of its size is 37 km^2. The answers of all questionnaires from a municipality are taken into account for computing its macroseismic intensity. In particular, the score distribution of each questionnaire is normalized such that the highest score value (the one corresponding to the modal intensity) is set to 1; then all the individual scores are summed up and a new intensity distribution is obtained at the municipality level. Using this distribution the municipality intensity is computed as the average of local maxima (as before they are defined as the values bigger than 95% of modal score) weighted with the relative frequencies. In Fig. 1 examples of MCS score distribution for three municipalities are shown. In particular Fig. 1A refers to Poggio Renatico for the Emilia earthquake of 20 May 2012, M_L 5.9. The score distribution is wide (including scores from III to >VII) with mode VI and a local maxima VII, the computed weighted average is 6.49 thus the assigned intensity is VI-VII MCS.

Another important issue for a correct evaluation of the municipality intensity regards the estimation of the percentage of "not felt". As established by intensity scales, low intensity degrees are assessed taking into account both the effects and the percentage of people who felt the shaking. As generally occurs using on-line surveys, "not felt" reports are undersampled (Boatwright and Phillips, 2012). This is basically due to the propensity of people to fill the questionnaire only in case of felt earthquake. To increase the "not felt" participation, since 2009, we invite people to become registered users in order to inform them on all the events occurred near their municipality. In this way they are invited to reply through the questionnaire even when they did not feel the quake. In spite of the presence of registered observers, the "not felt" reports remain undersampled. This behavior is conditioned by many factors, among them magnitude, felt intensity, media consideration, Internet diffusion, geographic area. We thus analyzed the responses of a sample of municipalities in the case of an earthquake felt by all (MCS≥VI) and of another one not felt (MCS=I-II), finding that in the first case the responses were on average ten times greater than the not felt responses referred to the second case, so the mean underestimation extent was quantified as a factor of 10. By using this factor, we obtained the corrected felt percentages comparable to the quantifications given by Molin et al., 2008 for MCS scale and Grünthal, 1998 for EMS. If the degree pointed out by the corrected felt percentage is less than the modal score value, then the final macroseismic intensity assigned to a municipality is calculated by averaging the first intensity with the second one, respectively weighted with the number of "not felt" and "felt" responses. Fig. 1B refers to Perugia for the Tevere Valley earthquake of 15 December 2009, M_L 4.2; it shows the case in which the corrected felt percentage is 65% pointing to V MCS, a value greater than the modal value (IV). We think that in this case, the correction factor was not sufficient to reach the felt percentage relative to the modal value, that is based on a greater amount of information, thus we assess the intensity considering only the modal value. Fig. 1C shows the score distribution of Rome for the earthquake occurred in Central Italy on 13 July 2011, M_L 3.6: in this case, by applying the aforementioned correction factor of "not felt" responses, we obtain a felt percentage of 4%, corresponding to the II degree. The average among the modal value (III) and felt percentage degree, respectively weighted by the real number of questionnaires (115 and 302), is 2.28 confirming the II MCS assigned to the city.

We consider the macroseismic intensity of a municipality sufficiently reliable if it is calculated using at least five responses (the same criterion is followed by Mazet-Roux and Bossu, 2010). The intensities calculated with less than five responses are anyhow showed on the online map using a very small dot (see Figure S1, available in the electronic supplement to this article), in order to compare them with other spatially close intensities.

Comparisons with traditional method

In this section we compare the MCS intensities estimated with our automatic method with all the available ones obtained by on-site surveys by INGV team of experts (QUEST Working Group, http://quest.ingv.it/, last accessed December 2014, in Italian; Camassi et al., 2008; D'Amico et al., 2009; Galli et al, 2009; Arcoraci et al., 2012; Arcoraci et al., 2013). In this regard, the bubble plot in Fig. 2 represents the intensities of 106 municipalities pertaining to 5 earthquakes, the strongest one (M_L 5.8) occurred on April, 6 2009 in Central Italy. The intensities reported on the *x*-axis (QUEST-MCS) are assessed by the expert team, while the ones on the *y*-

axis (web-MCS) are obtained through our web-based method for the same municipalities and earthquakes (note that intermediate half degree intensities represent uncertain attributions that occur in case of bimodal intensity distribution). The straight and dot lines in the plot represent the bisector ($y=x$) and the functions $y=x\pm1$, respectively. In particular, the region defined by the dot lines represents the range of intensities $\Delta Int=\pm1$. It can be noted that for all but three municipality intensities fall inside this range meaning that the two methods provide similar results. In particular, most of the cases (99 over 106) are located on or under the bisector, making it possible to conclude that the results are in agreement, with a slight underestimation made by our web evaluation. It is worth to note that the comparison with the traditionally assessed values is not always straightforward; this happens because the INGV team of experts sometimes assigns intensity to suburbs or to the historical center of towns and not to the whole municipality. Such historical centers have older buildings which are more vulnerable to the shaking action of earthquakes. For example, as for the M_L 5.8 Central Italy event, the QUEST report specifies that historical centers showed intensity 3 degrees higher with respect to other zones of the towns.

IPE regression

Our database counts more than 23000 municipality MCS intensities data points, computed by using at least 5 questionnaires. In order to express intensity as a function of magnitude and distance, we simplified the analysis assuming intensity as a continuous variable and plotting in Fig. 3 the MCS averages calculated inside windows 0.02 log$R$ wide for each 0.1 magnitude step. The high intensity values are a few located in the upper left portion of the plot, while most of data refer to low intensities. A least squares regression surface of averaged intensities, excluding the flat II degree region (shaded squares), was obtained,

$$Int = -2.15 \log 10R + 1.03 ML + 2.31 \quad (2).$$

It is drawn with contour lines in Fig. 3, and well represents the overall behavior of the data, even if it fails to reproduce the steep increase of intensity approaching to the epicenter of strongest earthquakes. The proposed regression mainly applies to III and IV MCS, which are the cases most represented by our data. This form of IPE, like the generic $Int=a+bM+c\log R$ with $c=0$, gathered from studies on PGA (Musson, 2005), is particularly simple and can be used to calculate the mean felt area.

In Fig. 4 an overview of several IPEs, drawn on the same plot using colored contour lines, is given. The values expressed in different macroseismic scales - MCS, EMS, Modified Mercalli Intensity (MMI) - can be compared considering their similarity (Musson et al., 2010). The relations come from different assessment method, different dataset (traditional, web questionnaires), and different geographic regions (Italy, UK, USA), but, for low magnitudes and long distances, the values given are quite similar. For low intensities ($Int \leq VI$) Eq. (2) is in good agreement with the relation referred to California by Atkinson and Wald (2007) computed, like our relation, with data from online responses, while for higher intensities it reaches a difference of one degree probably due to scarcity of intensities $Int>V$ in our database.

Considerations and conclusions

According to Musson and Cecić (2012), the automatic intensity evaluation can be made following one of two approaches: regression-based and expert-like. The first produces results in agreement with past datasets through a regression between automatic scores and human-assigned traditional intensities. We instead adopt the expert-like approach that closely follows the indications of a macroseismic scale. However we constantly test the intrinsic coherence of the macroseismic scale using our experimental data, in search of possible improvements. For example, in Sbarra et al., 2012 and Sbarra et al., 2014 we assess the great influence of “situation” and “location” on the perception of shaking intensity.

The score distributions at the municipality level (e.g. Fig. 1) usually cover a wide range of intensities. This result mirrors reality of villages where macroseismic intensity is the result of the sum of a lot of different effects. For this reason the use of an automatic algorithm is useful for achieving an unbiased intensity assessment. The evaluation of the results over time suggests that the mode of the distribution gives a better estimate with respect to the average of individual intensity used in the previous version of our method (Sbarra et al., 2010). In fact, the average based method had a tendency to favor central values. The comparison of the results estimated with our automatic method with the ones traditionally assigned through on-site survey showed a general agreement in the variability range of ±*1* intensity (Fig. 2), with a tendency of our estimates to be lower than the traditional values.

The proposed method has a modular structure created to include different macroseismic scales just adding new score matrices and to allow future developments. In fact we believe that macroseismic scales are not static objects, but they should rather be updated on the base of new experimental observations as in the case of a recent study (Sbarra et al., 2015) that suggests the existence of non trivial building height effects on felt intensity. This result could influence the score matrices construction. Moreover, in our questionnaire there are some questions about effects (e.g. earthquake sound, earthquake lights) which are not currently used for intensity assessment but could be useful for further evaluations (Tosi et al., 2012).

Acknowledgments

We thank M. Cameletti for careful reading and helpful advices. We are grateful to C. Cauzzi and to an anonymous reviewer for their accurate suggestions. We acknowledge D. Sorrentino for system administration of the entire ICT architecture of http://www.haisentitoilterremoto.it.

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Captions

Figure 1. Examples of MCS score distributions. (A) Poggio Renatico municipality (about 10,000 inhabitants) for the Emilia earthquake of 20 May 2012, M_L5.9 (epicentral distance 24 km), the assigned intensity is VI MCS, corresponding with the modal value. (B) Perugia municipality (about 166,000 inhabitants) for the Tevere Valley earthquake of 15 December 2009, M_L4.2 (epicentral distance 13 km), the assigned intensity is IV MCS, corresponding with the modal value. (C) Roma municipality (about 2,870,000 inhabitants) for the Rieti earthquake of 13 July 2011, M_L 3.6 (epicentral distance 68 km), the assigned intensity, based on both modal value and felt percentage, is I-II MCS.

Figure 2. Comparison between QUEST and web MCS intensities for the following events: 21 June 2013 10:33 UTC M_L5.2; 25 January 2012 8:06 UTC M_L4.9; 6 April 2009 1:32 UTC M_L5.8; 14 March 2009 9:26 UTC M_L3.3; 23 December 2008 15:24 UTC M_L5.1. Circle diameters are proportional to the number of municipalities.

Figure 3. Mean municipality MCS intensity values (colored squares) as a function of magnitude and hypocentral distance. The least squares regression of Eq. (2), drawn in black contour lines, has been calculated on full color squares.

Figure 4. Comparison of some IPEs expressed in different intensity scales, showing the overall similar behavior with respect to magnitude and hypocentral distance.

Figure 1

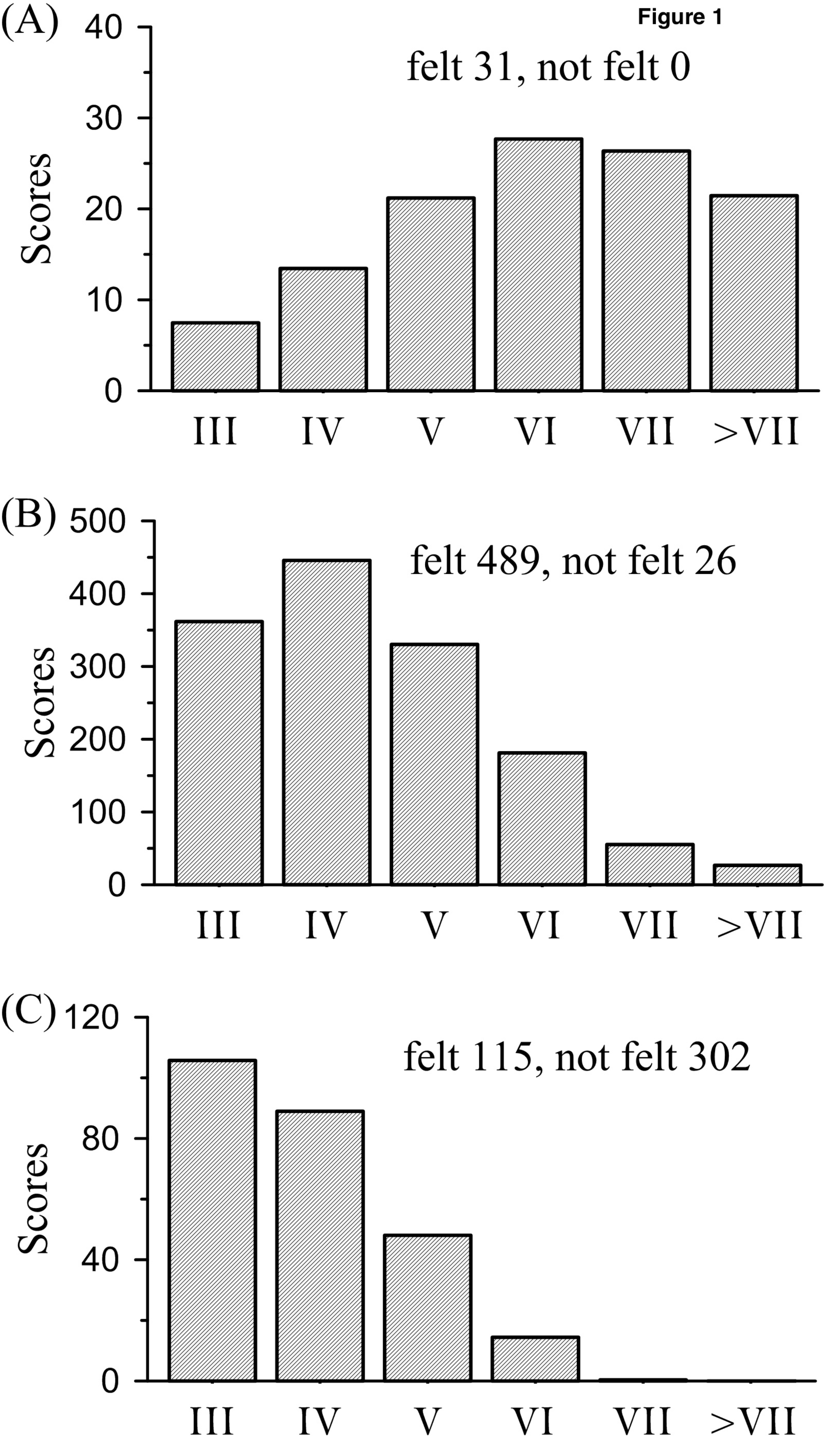
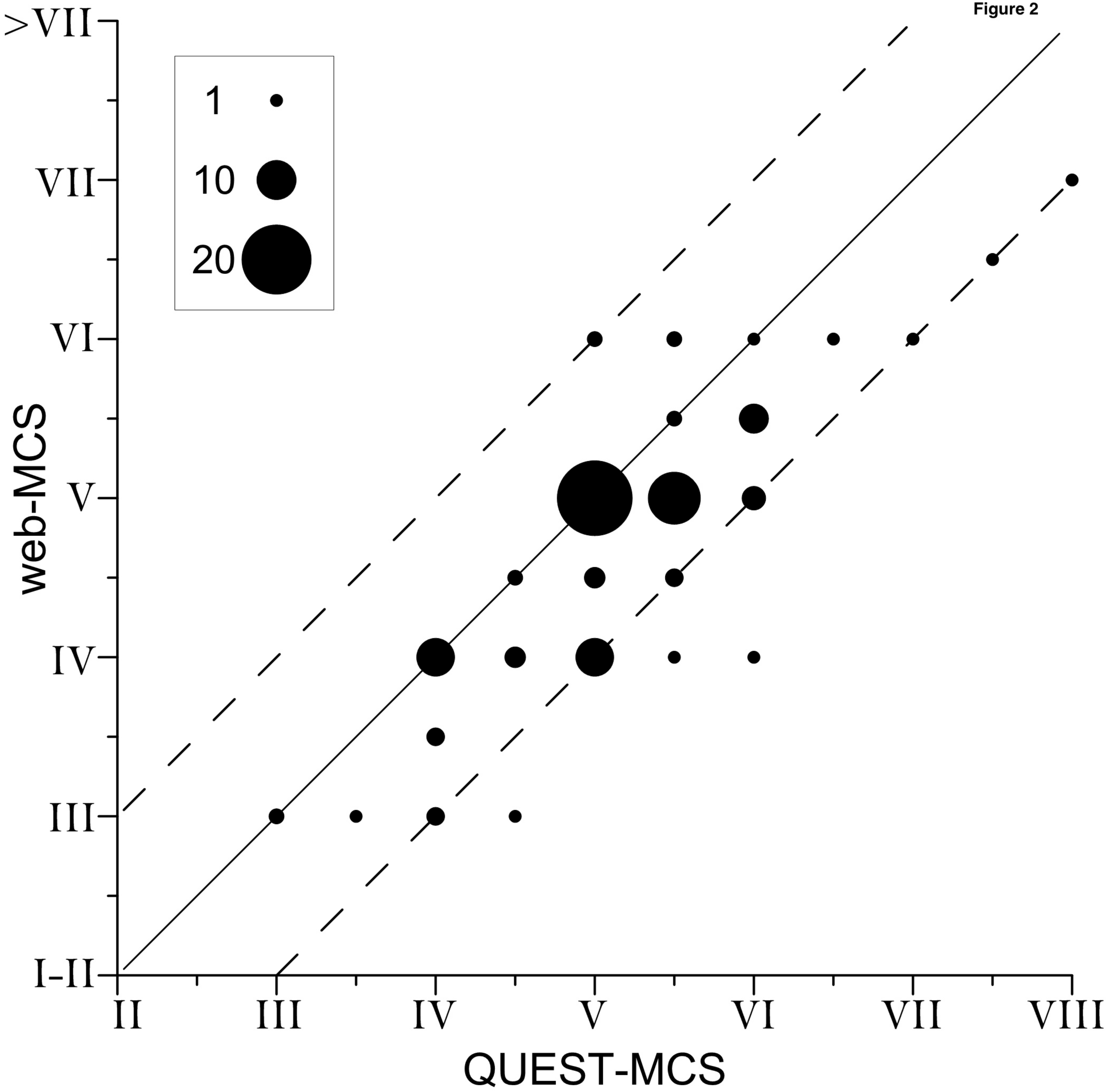
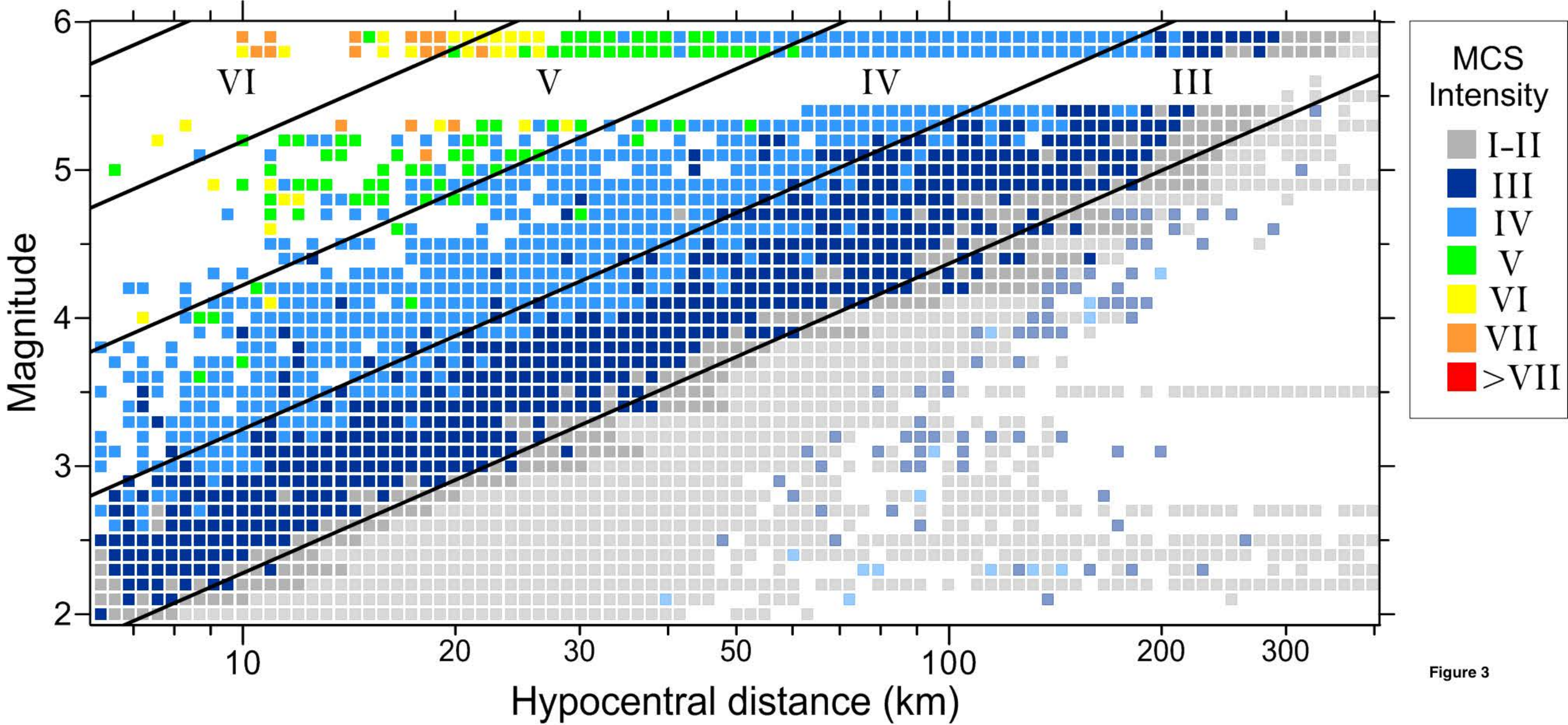

(A)
felt 31, not felt 0
Scores
0
10
20
30
40
III
IV
V
VI
VII
>VII
(B)
felt 489, not felt 26
Scores
0
100
200
300
400
500
III
IV
V
VI
VII
>VII
(C)
felt 115, not felt 302
Scores
0
40
80
120
III
IV
V
VI
VII
>VII

Figure 2



>VII
VII
VI
V
IV
III
I-II
web-MCS
1
10
20
II
III
IV
V
VI
VII
VIII
QUEST-MCS



6
5
4
3
2
Magnitude
10
20
30
50
100
200
300
Hypocentral distance (km)
VI
V
IV
III
MCS Intensity
I-II
III
IV
V
VI
VII
>VII

Figure 3

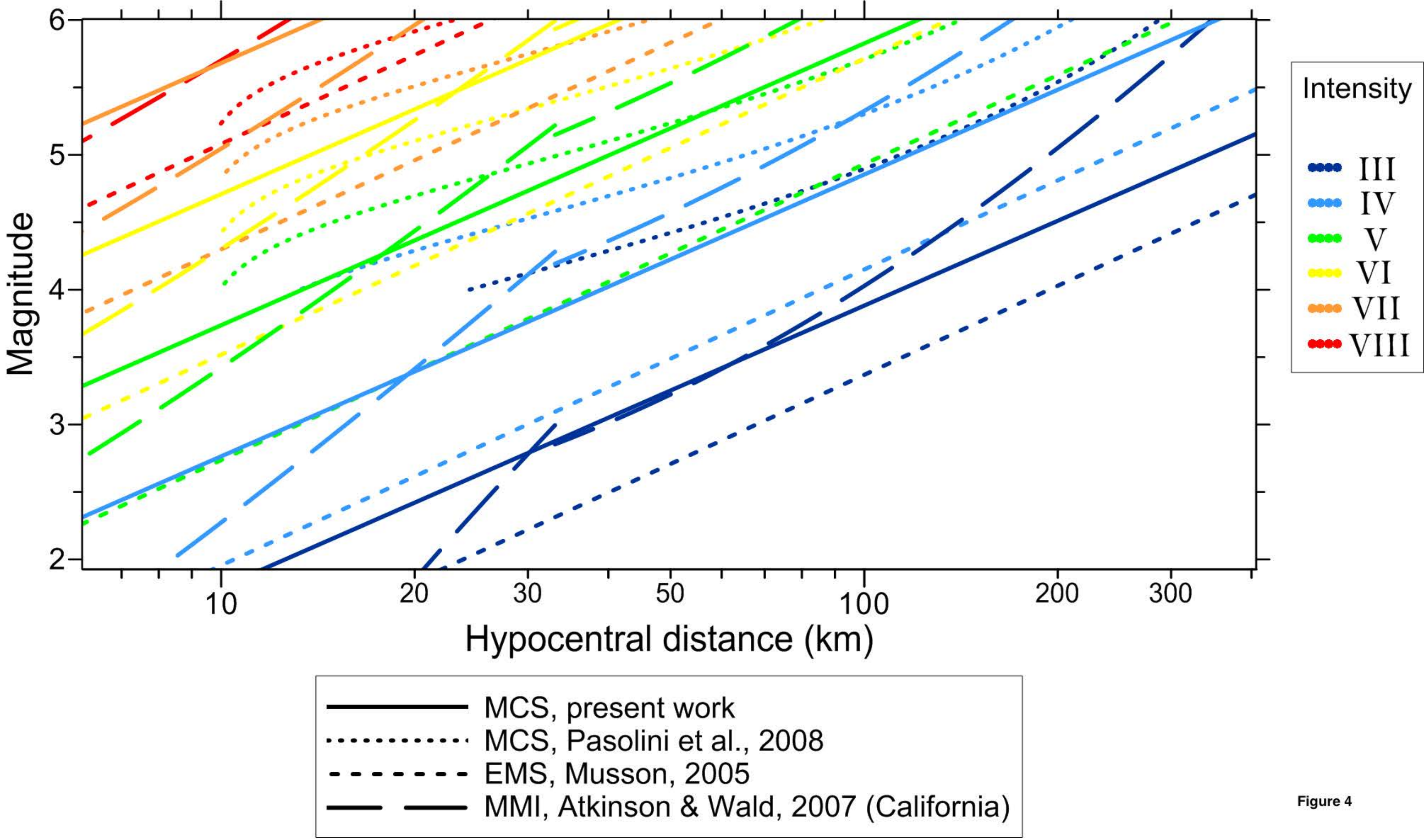

6
5
4
3
2
Magnitude
10
20
30
50
100
200
300
Hypocentral distance (km)
Intensity
III
IV
V
VI
VII
VIII
MCS, present work
MCS, Pasolini et al., 2008
EMS, Musson, 2005
MMI, Atkinson & Wald, 2007 (California)

Figure 4

Electronic Supplement to

Macroseismic intensity assessment method for web-questionnaires

by P. Tosi, P. Sbarra, V. De Rubeis, and C. Ferrari

Questions and answers of the macroseismic questionnaire, score matrices and macroseismic field example

The tables give all the necessary elements to implement the method for the estimation of the macroseismic intensity. [Table S1] show in detail the questionnaire formulation and the corresponding codes used in score matrices [Table S2] and [Table S3], respectively referred to Mercalli Cancani Sieberg (MCS) scale and European Macroseismic Scale (EMS). [Figure S1] shows an example of the MCS macroseismic fields obtained with our method for the event that struck a large area, being felt in the whole North Italy as well as part of central regions and reaching VII MCS in the epicentral area.

Tables

Table S1. Questions and answers of the macroseismic questionnaire of www.haisentitoilterremoto.it, each answer is associated with a numeric code reported in the score matrices ([Table S2] and [Table S3]). The questionnaire is available in two versions according to the location of the observer (indoors and outdoors) and "x" marks the presence of the question in the specified version.

Table S2. MCS score matrix. Each row represents an answer identified by the corresponding numeric code [Table S1] and the columns refer to the associated macroseismic intensities. The matrix do not mention I-II degree, because it is assigned only in case of not felt earthquake. Codes 92-94 (animal upset) are not reported as this effect is mentioned only in EMS macroseismic scale.

Table S3. EMS score matrix. Each row represents an answer identified by the corresponding numeric code [Table S1] and the columns refer to the associated macroseismic intensities. The matrix do not mention I-II degree, because it is assigned only in case of not felt earthquake. Codes 192-195 (effects on plants) are not reported as this effect is mentioned only in MCS macroseismic scale.

Figures

Figure S1. Macroseismic MCS field of the event occurred on May, 20 2012 in Northern Italy (M_L5.9), the epicenter is shown as a violet star and data number is the number of responses for each municipality.

Figure S1

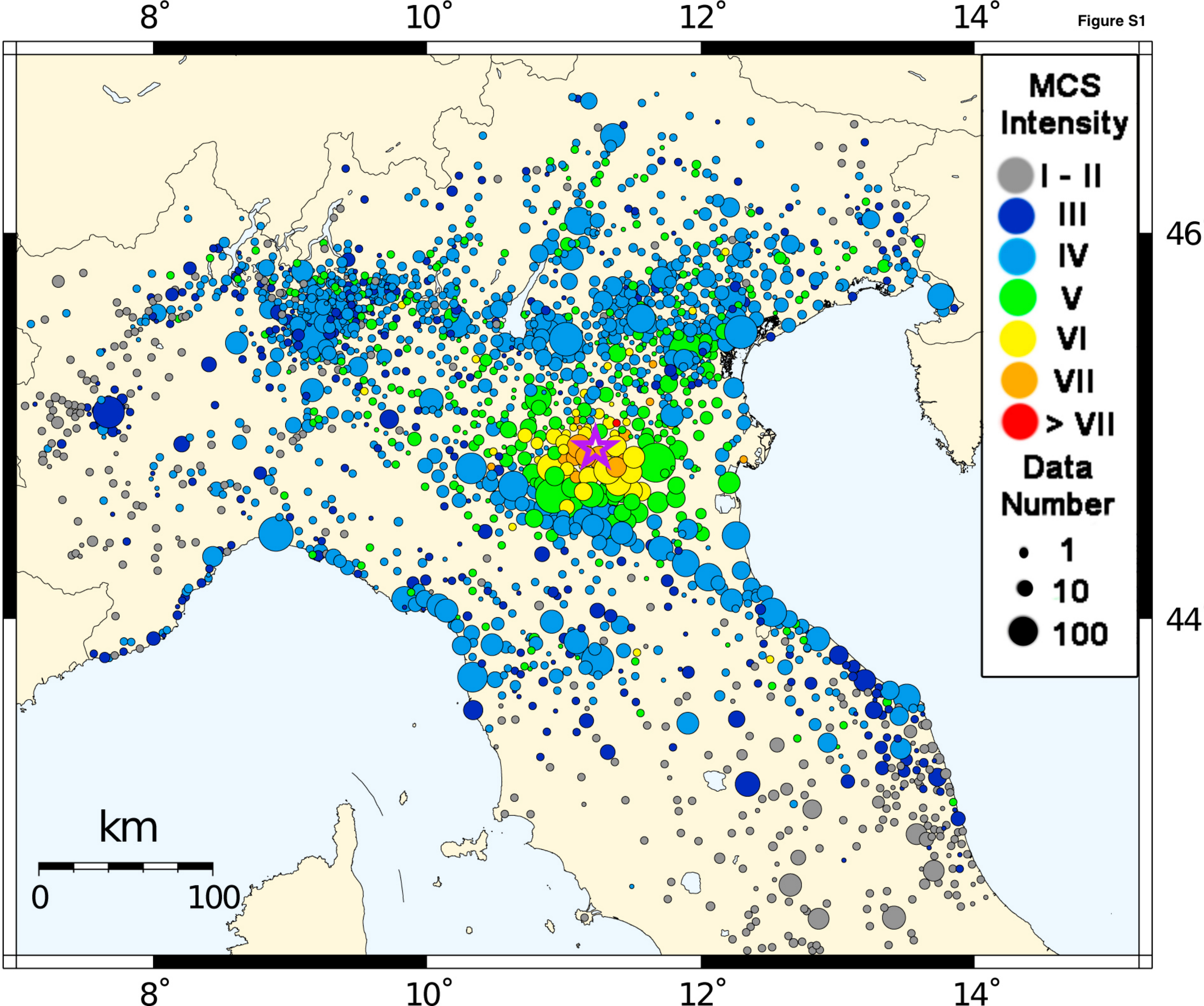

MCS
Intensity
I - II
III
IV
V
VI
VII
> VII
Data
Number
1
10
100
km
0
100
8°
10°
12°
14°
46°
44°

Table S1. Questions and answers.

Question	Answer	Indoors	Outdoors	Code
Earthquake felt	yes	x	x	31
	no	x	x	32
Shaking strength	not felt	x	x	42
	weak	x	x	43
	moderate	x	x	44
	strong	x	x	45
Fear	not at all, very little	x	x	52
	moderately	x	x	53
	a lot, very much	x	x	54
Balance	no problem or dizziness only	x	x	72
	difficulty to keep balance	x	x	73
	fall	x	x	74
Frightened animals	no problem	x	x	92
	animals indoors	x		93
	animals outdoors		x	94
Free-hanging objects	still	x		102
	slight swinging	x		103
	violent swinging	x		104
China and glasses	still	x		112
	rattling	x		113
	clattering together	x		114
	have broken	x		115
Small objects	still	x		122
	moved	x		123
	fell	x		124
Doors and windows	still	x		132
	rattling	x		133
	opening or closing	x		134
	slamming	x		135
Liquids	still	x	x	142
	oscillating slightly	x		143
	oscillating strongly	x		144
	spilling out	x		145
	splashes from pools		x	146
Pictures, vases and books	still	x		152
	shifted	x		153
	few fell	x		154
	many fell	x		155
Furniture	still	x		162
	swinging	x		163
	moved	x		164
	fell or overturned	x		165
Plants and trees	still		x	192
	visibly moving		x	193
	shaking branches		x	194
	branches have broken		x	195

Walls	no damage	x		242
	cracks in plaster only	x		243
	small cracks in walls and/or big pieces of plaster fall	x		244
	large cracks in walls	x		245
	collapse	x		246
Roofs tiles	no damage	x		252
	few sliding	x		253
	many sliding	x		254
Chimneys	no damage	x		262
	cracks	x		264
	fell	x		265
Building damages	no damage	x		272
	slight damage	x		273
	moderate damage	x		274
	partial collapse	x		275
	total collapse	x		276

Table S2. MCS score matrix.

Code	Situation	Location	Building	III	IV	V	VI	VII	>VII
42	unknown	lower floor	any	1	0	0	0	0	0
42	unknown	higher floor	any	1	0	0	0	0	0
42	sleeping	lower floor	any	1	0	0	0	0	0
42	sleeping	higher floor	any	1	0	0	0	0	0
42	sleeping	outdoors	any	1	0	0	0	0	0
42	at rest	lower floor	any	1	0	0	0	0	0
42	at rest	higher floor	any	1	0	0	0	0	0
42	at rest	outdoors	any	1	0	0	0	0	0
42	in motion	lower floor	any	1	1	0	0	0	0
42	in motion	higher floor	any	1	0	0	0	0	0
42	in motion	outdoors	any	1	1	0	0	0	0
43	unknown	lower floor	any	1	1	0	0	0	0
43	unknown	higher floor	any	1	1	0	0	0	0
43	sleeping	lower floor	any	1	1	0	0	0	0
43	sleeping	higher floor	any	1	1	0	0	0	0
43	sleeping	outdoors	any	0	1	0	0	0	0
43	at rest	lower floor	any	1	1	0	0	0	0
43	at rest	higher floor	any	1	0	0	0	0	0
43	at rest	outdoors	any	1	1	0	0	0	0
43	in motion	lower floor	any	0	1	0	0	0	0
43	in motion	higher floor	any	1	1	0	0	0	0
43	in motion	outdoors	any	0	1	1	0	0	0
44	unknown	lower floor	any	0	1	1	0	0	0
44	unknown	higher floor	any	0	1	1	0	0	0
44	sleeping	lower floor	any	0	1	1	0	0	0
44	sleeping	higher floor	any	0	1	1	0	0	0
44	sleeping	outdoors	any	0	0	1	0	0	0
44	at rest	lower floor	any	0	1	0	0	0	0
44	at rest	higher floor	any	0	1	0	0	0	0
44	at rest	outdoors	any	0	1	1	0	0	0
44	in motion	lower floor	any	0	1	1	1	0	0
44	in motion	higher floor	any	0	1	1	0	0	0
44	in motion	outdoors	any	0	1	1	1	0	0
45	unknown	lower floor	any	0	0	0	1	1	1
45	unknown	higher floor	any	0	0	0	1	1	1
45	sleeping	lower floor	any	0	0	0	1	1	1
45	sleeping	higher floor	any	0	0	0	1	1	1
45	sleeping	outdoors	any	0	0	0	0	1	1
45	at rest	lower floor	any	0	0	0	1	1	1
45	at rest	higher floor	any	0	0	0	1	1	0
45	at rest	outdoors	any	0	0	0	1	1	1
45	in motion	lower floor	any	0	0	0	1	1	1

45	in motion	higher floor	any	0	0	0	1	1	1
45	in motion	outdoors	any	0	0	0	1	1	1
52	any	lower floor	any	1	1	1	0	0	0
52	any	higher floor	any	1	1	0	0	0	0
52	any	outdoors	any	1	1	1	0	0	0
53	any	lower floor	any	0	0	1	1	0	0
53	any	higher floor	any	0	1	1	1	0	0
53	any	outdoors	any	0	0	1	1	0	0
54	any	lower floor	any	0	0	0	0	1	1
54	any	higher floor	any	0	0	0	1	1	1
54	any	outdoors	any	0	0	0	0	0	1
72	any	lower floor	any	1	1	1	1	0	0
72	any	higher floor	any	1	1	1	0	0	0
72	any	outdoors	any	1	1	1	1	0	0
73	any	lower floor	any	0	0	0	0	1	1
73	any	higher floor	any	0	0	0	0	1	0
73	any	outdoors	any	0	0	0	0	1	1
74	any	lower floor	any	0	0	0	0	0	1
74	any	higher floor	any	0	0	0	0	1	1
74	any	outdoors	any	0	0	0	0	0	1
102	any	lower floor	any	1	1	1	0	0	0
102	any	higher floor	any	1	1	0	0	0	0
103	any	lower floor	any	0	0	1	1	0	0
103	any	higher floor	any	0	0	1	0	0	0
104	any	lower floor	any	0	0	0	1	1	1
104	any	higher floor	any	0	0	1	1	1	1
112	any	lower floor	any	1	0	0	0	0	0
112	any	higher floor	any	1	0	0	0	0	0
113	any	lower floor	any	1	1	0	0	0	0
113	any	higher floor	any	1	0	0	0	0	0
114	any	lower floor	any	0	1	1	0	0	0
114	any	higher floor	any	0	1	0	0	0	0
115	any	lower floor	any	0	0	0	1	1	1
115	any	higher floor	any	0	0	1	1	1	1
122	any	lower floor	any	1	1	1	0	0	0
122	any	higher floor	any	1	1	0	0	0	0
123	any	lower floor	any	0	0	1	1	0	0
123	any	higher floor	any	0	0	1	0	0	0
124	any	lower floor	any	0	0	0	1	1	1
124	any	higher floor	any	0	0	1	1	1	1
132	any	lower floor	any	1	1	0	0	0	0
132	any	higher floor	any	1	0	0	0	0	0
133	any	lower floor	any	0	1	1	0	0	0
133	any	higher floor	any	0	1	0	0	0	0
134	any	lower floor	any	0	1	1	1	0	0
134	any	higher floor	any	0	1	1	0	0	0

135	any	lower floor	any	0	0	1	1	1	1
135	any	higher floor	any	0	1	1	1	1	1
142	any	lower floor	any	1	1	0	0	0	0
142	any	higher floor	any	1	0	0	0	0	0
142	any	outdoors	any	1	1	1	1	0	0
143	any	lower floor	any	0	1	1	0	0	0
143	any	higher floor	any	0	1	0	0	0	0
144	any	lower floor	any	0	0	1	1	0	0
144	any	higher floor	any	0	0	1	0	0	0
145	any	lower floor	any	0	0	0	1	1	1
145	any	higher floor	any	0	0	1	1	1	1
146	any	outdoors	any	0	0	0	0	1	1
152	any	lower floor	any	1	1	1	0	0	0
152	any	higher floor	any	1	1	0	0	0	0
153	any	lower floor	any	0	0	1	1	0	0
153	any	higher floor	any	0	0	1	0	0	0
154	any	lower floor	any	0	0	0	1	1	0
154	any	higher floor	any	0	0	0	1	0	0
155	any	lower floor	any	0	0	0	0	1	1
155	any	higher floor	any	0	0	0	1	1	1
162	any	lower floor	any	1	1	0	0	0	0
162	any	higher floor	any	1	0	0	0	0	0
163	any	lower floor	any	0	1	1	1	0	0
163	any	higher floor	any	0	1	1	0	0	0
164	any	lower floor	any	0	0	0	1	1	1
164	any	higher floor	any	0	0	0	1	1	0
165	any	lower floor	any	0	0	0	0	0	1
165	any	higher floor	any	0	0	0	0	1	1
192	any	outdoors	any	1	1	0	0	0	0
193	any	outdoors	any	0	0	1	0	0	0
194	any	outdoors	any	0	0	0	1	1	0
195	any	outdoors	any	0	0	0	0	0	1
242	any	any	masonry	1	1	1	0	0	0
242	any	any	concrete	1	1	1	1	0	0
243	any	any	masonry	0	0	0	1	1	0
243	any	any	concrete	0	0	0	0	1	0
244	any	any	masonry	0	0	0	0	1	0
244	any	any	concrete	0	0	0	0	1	1
245	any	any	masonry	0	0	0	0	0	1
245	any	any	concrete	0	0	0	0	0	1
246	any	any	masonry	0	0	0	0	0	1
246	any	any	concrete	0	0	0	0	0	1
252	any	any	masonry	1	1	1	0	0	0
252	any	any	concrete	1	1	1	0	0	0
253	any	any	masonry	0	0	0	1	0	0
253	any	any	concrete	0	0	0	1	0	0

254	any	any	masonry	0	0	0	0	1	1
254	any	any	concrete	0	0	0	0	1	1
262	any	any	masonry	1	1	1	1	0	0
262	any	any	concrete	1	1	1	1	0	0
264	any	any	masonry	0	0	0	0	1	0
264	any	any	concrete	0	0	0	0	1	0
265	any	any	masonry	0	0	0	0	0	1
265	any	any	concrete	0	0	0	0	0	1
272	any	any	masonry	1	1	1	0	0	0
272	any	any	concrete	1	1	1	1	0	0
273	any	any	masonry	0	0	0	1	1	0
273	any	any	concrete	0	0	0	0	1	0
274	any	any	masonry	0	0	0	0	1	0
274	any	any	concrete	0	0	0	0	0	1
275	any	any	masonry	0	0	0	0	0	1
275	any	any	concrete	0	0	0	0	0	1
276	any	any	masonry	0	0	0	0	0	1
276	any	any	concrete	0	0	0	0	0	1

Table S3. EMS score matrix.

Code	Situation	Location	Building	III	IV	V	VI	VII	>VII
42	unknown	lower floor	any	1	0	0	0	0	0
42	unknown	higher floor	any	1	0	0	0	0	0
42	sleeping	lower floor	any	1	0	0	0	0	0
42	sleeping	higher floor	any	1	0	0	0	0	0
42	sleeping	outdoors	any	1	0	0	0	0	0
42	at rest	lower floor	any	1	0	0	0	0	0
42	at rest	higher floor	any	1	0	0	0	0	0
42	at rest	outdoors	any	1	0	0	0	0	0
42	in motion	lower floor	any	1	1	0	0	0	0
42	in motion	higher floor	any	1	0	0	0	0	0
42	in motion	outdoors	any	1	1	0	0	0	0
43	unknown	lower floor	any	1	1	0	0	0	0
43	unknown	higher floor	any	1	1	0	0	0	0
43	sleeping	lower floor	any	1	1	0	0	0	0
43	sleeping	higher floor	any	1	1	0	0	0	0
43	sleeping	outdoors	any	0	1	0	0	0	0
43	at rest	lower floor	any	1	1	0	0	0	0
43	at rest	higher floor	any	1	0	0	0	0	0
43	at rest	outdoors	any	1	1	0	0	0	0
43	in motion	lower floor	any	0	1	0	0	0	0
43	in motion	higher floor	any	1	1	0	0	0	0
43	in motion	outdoors	any	0	1	1	0	0	0
44	unknown	lower floor	any	0	1	1	0	0	0
44	unknown	higher floor	any	0	1	1	0	0	0
44	sleeping	lower floor	any	0	1	1	0	0	0
44	sleeping	higher floor	any	0	1	1	0	0	0
44	sleeping	outdoors	any	0	0	1	0	0	0
44	at rest	lower floor	any	0	1	0	0	0	0
44	at rest	higher floor	any	0	1	0	0	0	0
44	at rest	outdoors	any	0	1	1	0	0	0
44	in motion	lower floor	any	0	1	1	1	0	0
44	in motion	higher floor	any	0	1	1	0	0	0
44	in motion	outdoors	any	0	1	1	1	0	0
45	unknown	lower floor	any	0	0	0	1	1	1
45	unknown	higher floor	any	0	0	0	1	1	1
45	sleeping	lower floor	any	0	0	0	1	1	1
45	sleeping	higher floor	any	0	0	0	1	1	1
45	sleeping	outdoors	any	0	0	0	0	1	1
45	at rest	lower floor	any	0	0	0	1	1	1
45	at rest	higher floor	any	0	0	0	1	1	0
45	at rest	outdoors	any	0	0	0	1	1	1
45	in motion	lower floor	any	0	0	0	1	1	1
45	in motion	higher floor	any	0	0	0	1	1	1
45	in motion	outdoors	any	0	0	0	1	1	1
52	any	lower floor	any	1	1	1	0	0	0
52	any	higher floor	any	1	1	0	0	0	0

52	any	outdoors	any	1	1	1	0	0	0
53	any	lower floor	any	0	0	1	1	0	0
53	any	higher floor	any	0	1	1	1	0	0
53	any	outdoors	any	0	0	1	1	0	0
54	any	lower floor	any	0	0	0	0	1	1
54	any	higher floor	any	0	0	0	1	1	1
54	any	outdoors	any	0	0	0	0	0	1
72	any	lower floor	any	1	1	1	1	0	0
72	any	higher floor	any	1	1	1	0	0	0
72	any	outdoors	any	1	1	1	1	0	0
73	any	lower floor	any	0	0	0	0	1	1
73	any	higher floor	any	0	0	0	0	1	0
73	any	outdoors	any	0	0	0	0	1	1
74	any	lower floor	any	0	0	0	0	0	1
74	any	higher floor	any	0	0	0	0	1	1
74	any	outdoors	any	0	0	0	0	0	1
92	any	lower floor	any	1	1	1	0	0	0
92	any	higher floor	any	1	1	0	0	0	0
93	any	lower floor	any	0	0	0	1	1	1
93	any	higher floor	any	0	0	1	1	1	1
94	any	outdoors	any	0	0	0	0	1	1
102	any	lower floor	any	1	0	0	0	0	0
102	any	higher floor	any	1	0	0	0	0	0
103	any	lower floor	any	0	1	0	0	0	0
103	any	higher floor	any	1	1	0	0	0	0
104	any	lower floor	any	0	0	1	1	1	1
104	any	higher floor	any	0	1	1	1	1	1
112	any	lower floor	any	1	0	0	0	0	0
112	any	higher floor	any	1	0	0	0	0	0
113	any	lower floor	any	0	1	0	0	0	0
113	any	higher floor	any	1	1	0	0	0	0
114	any	lower floor	any	0	0	1	0	0	0
114	any	higher floor	any	0	1	1	0	0	0
115	any	lower floor	any	0	0	0	1	1	1
115	any	higher floor	any	0	0	1	1	1	1
122	any	lower floor	any	1	1	1	0	0	0
122	any	higher floor	any	1	1	0	0	0	0
123	any	lower floor	any	0	0	0	1	0	0
123	any	higher floor	any	0	0	1	1	0	0
124	any	lower floor	any	0	0	0	0	1	1
124	any	higher floor	any	0	0	0	1	1	1
132	any	lower floor	any	1	0	0	0	0	0
132	any	higher floor	any	1	0	0	0	0	0
133	any	lower floor	any	0	1	0	0	0	0
133	any	higher floor	any	1	1	0	0	0	0
134	any	lower floor	any	0	0	1	0	0	0
134	any	higher floor	any	0	1	1	0	0	0
135	any	lower floor	any	0	0	0	1	1	1
135	any	higher floor	any	0	0	1	1	1	1

142	any	lower floor	any	1	0	0	0	0	0
142	any	higher floor	any	1	0	0	0	0	0
142	any	outdoors	any	1	1	1	1	0	0
143	any	lower floor	any	0	1	0	0	0	0
143	any	higher floor	any	1	1	0	0	0	0
144	any	lower floor	any	0	0	1	1	0	0
144	any	higher floor	any	0	0	1	0	0	0
145	any	lower floor	any	0	0	0	1	1	1
145	any	higher floor	any	0	0	1	1	1	1
146	any	outdoors	any	0	0	0	0	1	1
152	any	lower floor	any	1	1	0	0	0	0
152	any	higher floor	any	1	0	0	0	0	0
153	any	lower floor	any	0	0	1	1	0	0
153	any	higher floor	any	0	0	1	0	0	0
154	any	lower floor	any	0	0	0	1	0	0
154	any	higher floor	any	0	0	1	1	0	0
155	any	lower floor	any	0	0	0	0	1	1
155	any	higher floor	any	0	0	0	1	1	1
162	any	lower floor	any	1	1	0	0	0	0
162	any	higher floor	any	1	0	0	0	0	0
163	any	lower floor	any	0	0	1	0	0	0
163	any	higher floor	any	0	1	1	0	0	0
164	any	lower floor	any	0	0	0	1	1	0
164	any	higher floor	any	0	0	1	1	1	0
165	any	lower floor	any	0	0	0	0	0	1
165	any	higher floor	any	0	0	0	0	1	1
242	any	any	masonry	1	1	1	0	0	0
242	any	any	concrete	1	1	1	1	0	0
242	any	any	wood	1	1	1	1	1	0
242	any	any	steel	1	1	1	1	1	1
243	any	any	masonry	0	0	0	1	0	0
243	any	any	concrete	0	0	0	0	1	0
243	any	any	wood	0	0	0	0	0	1
243	any	any	steel	0	0	0	0	0	1
244	any	any	masonry	0	0	0	0	1	0
244	any	any	concrete	0	0	0	0	0	1
244	any	any	wood	0	0	0	0	0	1
244	any	any	steel	0	0	0	0	0	1
245	any	any	masonry	0	0	0	0	0	1
245	any	any	concrete	0	0	0	0	0	1
245	any	any	wood	0	0	0	0	0	1
245	any	any	steel	0	0	0	0	0	1
246	any	any	masonry	0	0	0	0	0	1
246	any	any	concrete	0	0	0	0	0	1
246	any	any	wood	0	0	0	0	0	1
246	any	any	steel	0	0	0	0	0	1
252	any	any	masonry	1	1	1	1	0	0
252	any	any	concrete	1	1	1	1	0	0
253	any	any	masonry	0	0	0	0	1	1

253	any	any	concrete	0	0	0	0	1	1
254	any	any	masonry	0	0	0	0	0	1
254	any	any	concrete	0	0	0	0	0	1
262	any	any	masonry	1	1	1	1	0	0
262	any	any	concrete	1	1	1	1	0	0
264	any	any	masonry	0	0	0	0	1	1
264	any	any	concrete	0	0	0	0	1	1
265	any	any	masonry	0	0	0	0	0	1
265	any	any	concrete	0	0	0	0	0	1
272	any	any	masonry	1	1	1	0	0	0
272	any	any	concrete	1	1	1	1	0	0
272	any	any	wood	1	1	1	1	1	0
272	any	any	steel	1	1	1	1	1	1
273	any	any	masonry	0	0	0	1	0	0
273	any	any	concrete	0	0	0	0	1	0
273	any	any	wood	0	0	0	0	0	1
273	any	any	steel	0	0	0	0	0	1
274	any	any	masonry	0	0	0	0	1	1
274	any	any	concrete	0	0	0	0	0	1
274	any	any	wood	0	0	0	0	0	1
274	any	any	steel	0	0	0	0	0	1
275	any	any	masonry	0	0	0	0	0	1
275	any	any	concrete	0	0	0	0	0	1
275	any	any	wood	0	0	0	0	0	1
275	any	any	steel	0	0	0	0	0	1
276	any	any	masonry	0	0	0	0	0	1
276	any	any	concrete	0	0	0	0	0	1
276	any	any	wood	0	0	0	0	0	1
276	any	any	steel	0	0	0	0	0	1