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Thumbnail-Based Questionnaires for the Rapid and Efficient Collection of Macroseismic Data from Global Earthquakes

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ABSTRACT

The collection of earthquake testimonies (i.e., qualitative descriptions of felt shaking) is essential for macroseismic studies (i.e., studies gathering information on how strongly an earthquake was felt in different places), and when done rapidly and systematically, improves situational awareness and in turn can contribute to efficient emergency response. In this study, we present advances made in the collection of testimonies following earthquakes around the world using a thumbnail-based questionnaire implemented on the European-Mediterranean Seismological Centre (EMSC) smartphone app and its website compatible for mobile devices. In both instances, the questionnaire consists of a selection of thumbnails, each representing an intensity level of the European Macroseismic Scale 1998. We find that testimonies are collected faster, and in larger numbers, by way of thumbnail-based questionnaires than by more traditional online questionnaires. Responses were received from all seismically active regions of our planet, suggesting that thumbnails overcome language barriers. We also observed that the app is not sufficient on its own, because the websites are the main source of testimonies when an earthquake strikes a region for the first time in a while; it is only for subsequent shocks that the app is widely used. Notably though, the speed of the collection of testimonies increases significantly when the app is used. We find that automated EMSC intensities as assigned by user-specified thumbnails are, on average, well correlated with "Did You Feel It?" (DYFI) responses and with the three independently and manually derived macroseismic datasets, but there is a tendency for EMSC to be biased low with respect to DYFI at moderate and large intensities. We address this by proposing a simple adjustment that will be verified in future earthquakes.

Electronic Supplement: Figures of individual intensity assignments and comparison of corrected intensities with other intensity datasets.

INTRODUCTION

"Did You Feel It?" (DYFI; Wald *et al.*, 1999; Dewey *et al.*, 2000) was the first initiative to use the Internet to collect earthquake testimonies through online questionnaires and to rapidly map macroseismic intensities. Since then, many seismological institutes have implemented similar online questionnaires, including the European-Mediterranean Seismological Centre (EMSC; see Data and Resources) where the online questionnaire is available in 32 languages (Bossu, Mazet-Roux, *et al.*, 2015).

In July 2014, the EMSC launched a new smartphone application named LastQuake (Android and iOS platforms) that replaces the traditional online questionnaire with a thumbnail-based questionnaire (Bossu, Mazet-Roux, *et al.*, 2015). This change was implemented simultaneously on its dedicated website for mobile devices, hereafter named mobile website (see Data and Resources). The primary motivations were to eliminate language barriers, and to take into account both the growing prevalence of mobile devices and the difficulty of filling in questionnaires on a small screen (Bossu, Laurin, *et al.*, 2015; Bossu, Mazet-Roux, *et al.*, 2015). The new questionnaire is based on 12 thumbnail-sized images, conceptualized by a professional cartoonist, which aim to be culturally neutral and to depict each level of the European Macroseismic Scale 1998 (EMS-98; Grünthal *et al.*, 1998). To the best of our knowledge, the use of thumbnail-based questionnaires to collect earthquake testimonies with the help of a smartphone application was first attempted by the French Seismological Central Office with its iOS app named SismoCom, launched in 2010 (C. Sira and A. Schlupp, personal comm., 2016). The 12 thumbnails are visible on the mobile website and are also made available in ? Figure S1 (available in the electronic supplement to this article).

We first present the collection tools and the data used in this study and show how the adoption of thumbnail-based questionnaires has increased both the quantity and speed of

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Table 1
Repartition of the Collected Testimonies during the Studied Period as a Function of the Collecting Tool

	Testimonies		*I* > 10		Not Felt	
Thumbnail-based questionnaires						
LastQuake app	36,439	41%	280	77%	4972	62%
Mobile website	25,541	29%	55	15%	2330	29%
Online questionnaires	26,453	30%	31	8%	718	9%
Total of both questionnaires	88,433	100%	366 (0.4%)	100%	8020	9%

In total, 70% were collected through thumbnail-based questionnaires, 41% through the LastQuake smartphone app, and 29% through the mobile website. Intensities greater than 10, which are automatically disregarded, represent 0.4% of the collected testimonies. Not-felt reports represent 9% of the collected testimonies and were mainly collected through the smartphone app.

the collection of testimonies for global earthquakes. We then examine the accuracy of intensity assignments and their reliability by comparing the results from thumbnail-based questionnaires with independent macroseismic studies that utilize EMS-98, as well as comparisons with DYFI results.

WEBSITE AND APP-BASED COLLECTION OF TESTIMONIES

As mentioned above, testimonies are collected by the EMSC through three different channels: an online questionnaire available in 32 languages on its classical website and via thumbnail-based questionnaires on both the mobile website and the LastQuake application. The user's type of device is detected at the start of each Internet request, and mobile-device users are automatically redirected to the mobile website. To be comprehensive, thumbnail-based questionnaires are also optionally collected at the end of the online questionnaire.

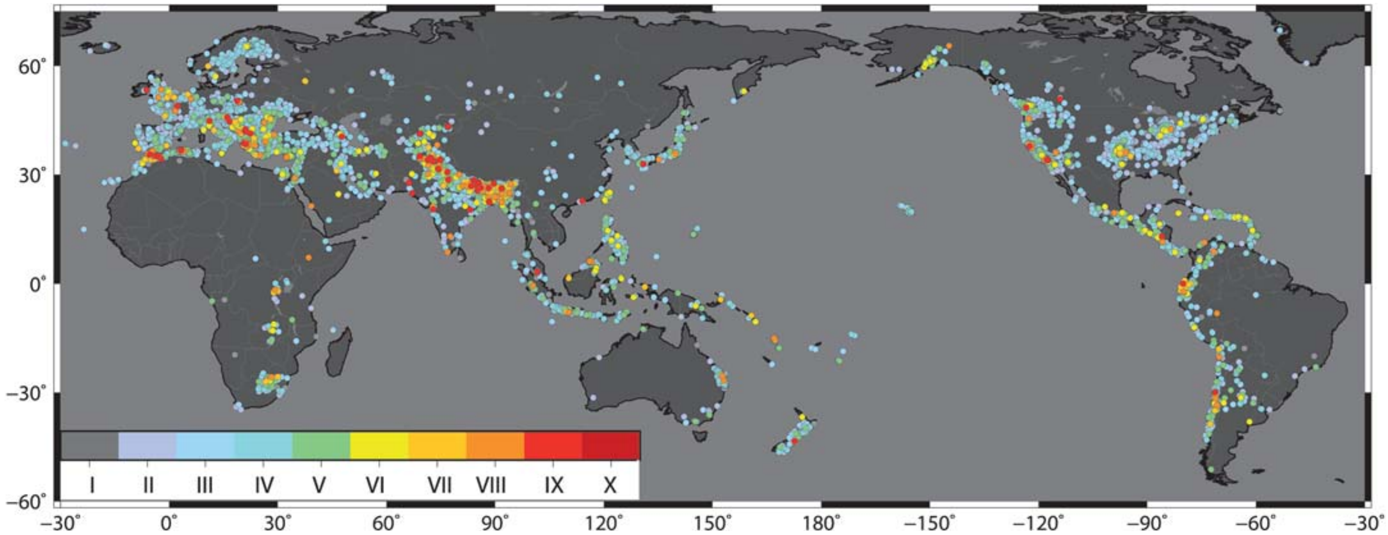
Although it is beyond the scope of this article to provide a detailed description of the websites and the mobile app, some features related to the rapid discrimination of earthquakes widely felt by the population are described because, as presented later, they influence the speed and efficiency of the collection of testimonies. The discrimination of felt earthquakes is an essential element of the EMSC strategy to rapidly engage with eyewitnesses following felt earthquake around the world. This strategy is based on targeted rapid public information on felt earthquakes, regardless of their magnitude, and on the distribution of this information through various channels (websites, Twitter, an app; Bossu, Laurin, *et al.*, 2015; Bossu, Mazet-Roux, *et al.* 2015; Bossu, Steed, *et al.*, 2015). The intention is to meet the eyewitnesses' desire for information in the immediate aftermath of a felt earthquake.

The discrimination of felt earthquakes is performed by two complementary approaches. First, we use Twitter earthquake detection (Earle *et al.*, 2010, 2012) that monitors the publication of Twitter messages (tweets) and applies place, time, and key-word filtering to detect felt earthquakes through surges in published tweets related to shaking experiences; second, we use flashsourcing (Bossu *et al.*, 2008, 2011, 2012) that detects flash crowds, that is, rapid and massive traffic increases (e.g., Jung *et al.*, 2002) generated by the natural convergence of eyewitnesses looking for earthquake information on EMSC websites immediately after a felt earthquake and that identify their geographical origin through their Internet Protocol (IP) address (Bossu *et al.*, 2014). Detections are typically within less than 2 min of an earthquake's occurrence and in the vast majority of cases precede seismographic locations (Bossu *et al.*, 2012; Earle *et al.*, 2012).

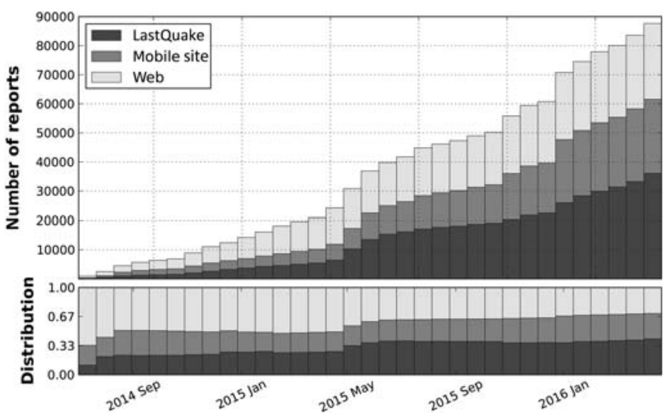
These initial crowd-sourced detections are automatically published as a rolling banner on the classical website; on the mobile website and the app they appear in a pop-up window that invites viewers to confirm the detection by sharing their testimony. It is important to underscore that this information does not generate an alert to the users but is only visible to people who spontaneously, or following a felt earthquake, visit our websites or launch the LastQuake app. App users are only alerted through a notification generally a few minutes later, once these detections have been seismically confirmed. The same rule applies to our email notification service. Therefore, two consecutives phases exist in the collection of testimonies. Prior to the initial seismic location, testimonies are collected from people actively looking for information on the EMSC websites or app following a felt earthquake, a period that, depending on the geographical area and magnitude of the earthquake, lasts from a few minutes to approximately 20 min. After the notification, which is distributed in a geographical area larger than the felt area, additional testimonies are collected as a consequence of the notification itself.

DATA AND DATA COLLECTION PERFORMANCE

Our study period commenced on 1 July 2014, the date of the launch of the LastQuake app, and ended on 1 May 2016, during which 88,433 testimonies were collected and associated with 4723 different earthquakes ranging in magnitude from 2.1 to 8.3. Testimonies reporting intensity greater than 10 EMS (definition of 11 EMS: devastating, most ordinary buildings collapse; Grünthal *et al.*, 1998) are disregarded, as in such extreme circumstances, we consider eyewitnesses to be unlikely to report their experience. Three hundred and sixty-six such testimonies are excluded, that is, 0.4% of the total (Table 1).



▲ **Figure 1.** Map of the 87,521 testimonies reporting intensities up to 10 and collected from 1 July 2014 to 1 May 2016 represented as individual points, higher intensity values overlying lower intensity ones. This map reflects both the seismic activity during this time period and the current European-Mediterranean Seismological Centre (EMSC) visibility in the different regions of the globe.



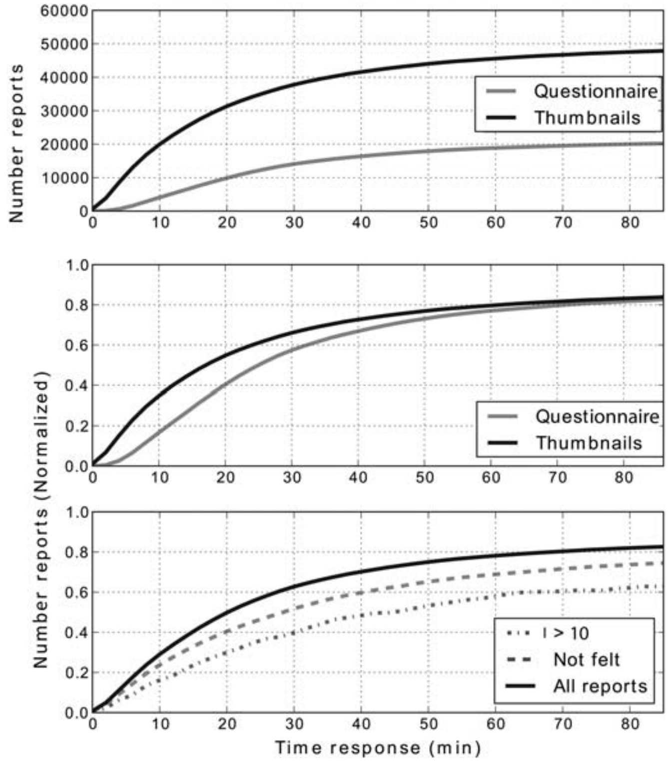
▲ **Figure 2.** Time evolution of testimony collection through the classical website, mobile website, and smartphone app. The rate of collection has been increasing for these three channels over the whole period; the increase is faster for the mobile website and the app, which both use thumbnail-based questionnaires.

"Not-felt" reports (1 EMS) represent 9% of the collected testimonies, which is significantly higher than for DYFI, for which they make up less than 3% of the reports (V. Quitoriano, personal comm., 2016); the vast majority of these (91%) are collected through thumbnail-based questionnaires (Table 1).

Each testimony has an individual geographical location. If the user has accepted our invitation to share it, this is the location provided by the mobile device (for testimonies collected from the app and the mobile website). Otherwise, the user is invited to provide his/her postal address, which is then converted to a point location through an online service. Testimonies are collected from all the continents, with the majority of them coming from Europe, Continental Asia, and North America (Fig. 1).

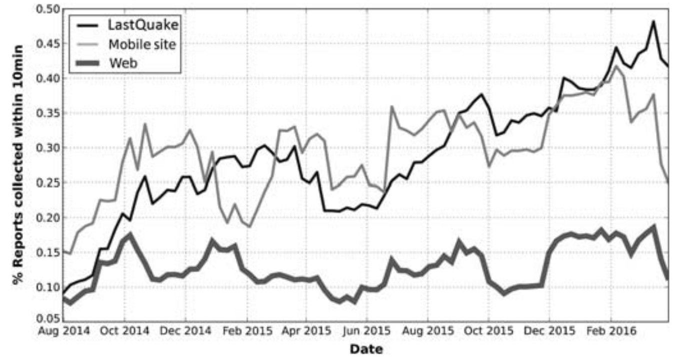
The rate of testimony collection increased over the duration of the studied period for each of the three collection tools, with the mobile website and the app (which use the thumbnail-based questionnaires) exhibiting the most marked increase (Fig. 2). This is particularly true after April 2015, the beginning of the Gorkha, Nepal, earthquake sequence, during which the LastQuake app was used extensively (Bossu, Laurin, *et al.*, 2015). Over the course of the studied period, 70% of the testimonies were collected through thumbnail-based questionnaires with the remaining 30% collected from online questionnaires (Table 1).

The growing proportion of thumbnail-based questionnaire testimonies is partly the consequence of an increasing number of users of the LastQuake app globally, but it also reflects the fact that the app exhibits the highest conversion rate in comparison to the other two available collection tools. The conversion rate is defined by the percentage of eyewitnesses accessing EMSC information through a specific channel and sharing their testimony in a given time window following an earthquake's occurrence (Bossu *et al.*, 2011). For online questionnaires, Bossu *et al.* (2011) found this rate ranges from less than 1% to no more than 10% for different earthquakes between 2008 and 2009 for different time windows, spanning from 2 to 24 hrs. In this study, we find that the composite conversion rates do not change significantly for time windows spanning 10–20 min; the highest conversion rate of 17% is observed for the app, with rates of 3% for the online questionnaires and 2% for the mobile website. This is best illustrated by the results obtained for the 2015 Gorkha earthquake sequence for which the LastQuake app represented one-third of the accesses to EMSC information from Nepal and 70% of the 7000 testimonies collected for the mainshock and its felt aftershocks during the 25-day-long studied period (Bossu, Laurin, *et al.*, 2015).



▲ **Figure 3.** Number (top) and percentage (middle) of all testimonies collected with respect to time by thumbnail-based questionnaires and online questionnaires. Comparison of cumulative number of testimonies, not-felt and *I* > 10 reports with respect to time (bottom). Time is elapsed time in minutes since earthquake occurrence. The thumbnail-based questionnaire collects more testimonies and collects them more rapidly than the online questionnaire.

Thumbnail-based questionnaires are not only collected in larger numbers than online questionnaires (Table 1), but they are also collected faster, with, on average, 36% being received within 10 min of an earthquake's occurrence, as compared to 17% for online questionnaires (Fig. 3). Interestingly, the speed of not-felt and EMS > 10 report collections deviate from the average (Fig. 3). Half of EMS > 10 reports are collected more than 60 min after the events, sometimes for low or moderate magnitude earthquakes, strongly suggesting errors or deliberately inflated testimonies. Nonetheless, 15% of EMS > 10 are collected within less than 10 min of an earthquake's occurrence, at a time when few people beyond eyewitnesses and seismic network operators know about the existence of the event, which suggests that many of these early reports come from actual eyewitnesses who simply exaggerate their reports, possibly under strong emotion. Not-felt reports are collected faster, with 28% of them being collected within 10 min (Fig. 3), and this again, supports the validity of early not-felt reports that may be collected as a consequence of earthquake notifications via the app. Although a significant proportion of EMS > 10 reports are likely to be flawed, we have no indication this is the same for the not-reports, and their receipt probably reduce

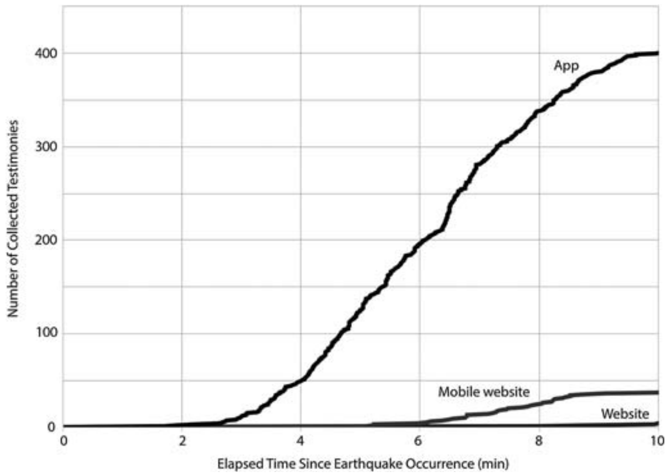


▲ **Figure 4.** Time evolution of the percentage of testimonies collected within 10 min of earthquake occurrence. The percentages are calculated in a centered, 2-month-long sliding time window.

a common sampling bias in macroseismic studies in which not-felt reports are generally underrepresented (Boatwright and Phillips, 2012), the public having poor inclination to report such an "experience."

We also tested whether or not the speed of testimony collection continued to increase during the studied period. An increase in collection rate seems to be the case for those responses collected through the app, whereas no change was observed for the online questionnaire (Fig. 4). This increase in collection rate could reflect a change in the utilization of the EMSC information tools during consecutive felt earthquakes in the same region, with people switching from websites to the app. A comparison of the testimony collection statistics observed for two intermediate depth earthquakes in the Hindu Kush region in October 2015 and April 2016 qualitatively illustrates the evolution in users' behavior. For the *M* 7.5 mainshock in October 2015 (the first earthquake greater than *M* 6 in the Hindu Kush since the launch of the app), 1067 testimonies were collected overall, 700 of them through the websites. Within the first 10 min, 25 testimonies were collected through the mobile website: 19 from the app and 4 from online questionnaires, respectively. Approximately 5 months later, 643 testimonies were collected for the *M* 6.6 aftershock, but the responses were faster: within 10 min, 400 testimonies were collected by the app, 37 through the mobile website, and only 3 through online questionnaires (Fig. 5). Although the mainshock was felt by a larger number of inhabitants, the number of collected testimonies in 10 min through the online questionnaire remained similar, but a 20-fold increase in responses was observed for those collected through the app. The conversion rate (i.e., the proportion of eyewitnesses using EMSC information tools who share a testimony) was also high for the second event, with 28% of the 1132 app users being from Afghanistan, India, Pakistan, and Uzbekistan (the four countries where it was felt) who launched the app before the earthquake notification (7 min 38 s after the earthquake) to share their testimony.

The dynamics of testimony collection is a function of the local visibility of the EMSC information tools. It took longer for the eyewitnesses to identify the tools in October 2015 than



▲ **Figure 5.** Number of collected testimonies with respect to time for the 10 April 2016 *M* 6.6 Hindu Kush earthquake. The LastQuake app played a key role in rapidly crowdsourcing earthquake effects with 400 testimonies collected within 10 min of the earthquake's occurrence.

in April 2016. The comparison also suggests eyewitnesses are likely to use the websites upon first discovery of the online resource, after which a number of them then switch to the app, which speeds up testimony collection for later-felt earthquakes. In a classical mainshock–aftershock sequence, especially in regions where felt earthquakes are rare, the role of the app is likely to increase during an earthquake sequence in association with an increase in the speed of testimony collection.

INTENSITY ASSIGNMENT AND COMPARISONS WITH DYFI AND MACROSEISMIC DATASETS

For the thumbnail system, the intensity assignment is based on user-specified thumbnails corresponding to observed effects. All the thumbnail-based questionnaires are included in this intensity assignment study, including the ones collected at the end of the online questionnaire. As stated before, intensities greater than EMS 10 are disregarded and each intensity has an individual location. In this section, we compare our results with DYFI results and with three independent intensity datasets. The comparison is presented with respect to distance from epicenter to dissociate the intensity assignment from any potential effects or artifacts associated with geographical clustering of individual intensity points (e.g., Amorèse *et al.*, 2015), notably the difficulty of comparing intensities between two geographical clusters of different spatial characteristics (e.g., barycenter or surface area).

DYFI employs the modified Mercalli intensity (MMI) scale (Wood and Neumann, 1931), whereas the thumbnails were created following the more recent EMS-98 scale (Grünthal *et al.*, 1998), a scale also employed for the three independently assessed intensity datasets. Following Musson *et al.* (2010), we consider the MMI and EMS-98 macroseismic scales to be equivalent.

The comparison between thumbnail-based questionnaires and DYFI data was performed for 17 earthquakes in Africa, America, Asia, and Europe from July 2014 to April 2016, ranging in magnitude from *M* 4.2 to *M* 8.3, for which both EMSC and DYFI collected a significant number of testimonies (Table 2). Furthermore for these 17 events, DYFI community decimal intensities (CDIs) are available in the geocoded form. These 17 events comprise 20% of the testimonies collected by EMSC in the studied period. For DYFI geocoded data, responses are aggregated in 10 km bins (Wald *et al.*, 2011). For the comparison by distance, mean DYFI data were calculated from the geocoded CDI, weighted by the number of responses.

The three independent macroseismic datasets (Table 2) are for the 2015 *M* 7.8 Gorkha, Nepal, earthquake (Martin *et al.*, 2015); the 2015 *M* 7.3 Dolakha, Nepal, earthquake (Hough *et al.*, 2016); and the 2016 *M* 6.7 Manipur, India, earthquake (Gahalaut *et al.*, 2016). The datasets are based on an exhaustive analysis of accounts from conventional news outlets as well as social media, and they follow the methodology employed by Martin and Szeliga (2010), Martin and Kakar (2012), and Martin and Hough (2016).

We present the comparison of mean automated EMSC intensities, DYFI data, and the independent macroseismic datasets (when available) for the 2015 *M* 7.3 Dolakha, Nepal, earthquake (Fig. 6); the 2016 *M* 6.7 Manipur, India, earthquake (Fig. 7); and the *M* 7.5 Hindu Kush, Afghanistan, earthquake of 26 October 2015 (Fig. 8). The comparison for the *M* 7.8 Gorkha earthquake is presented in detail in a companion paper (Hough *et al.*, 2016) and is available in ? Figures S2–S15) along with the 13 other studied earthquakes (Table 2). For each earthquake, a number of bins for which size is proportional to log distance are defined between the closest and furthest EMSC testimony. The same intervals are then applied to the other datasets concerning the same earthquake; bins with a single observation are disregarded.

As illustrated by Figures 6, 7, and 8, the mean automated EMSC intensities are broadly consistent with independently gathered DYFI and manually derived macroseismic datasets for the 2015 Dolakha and 2016 Manipur earthquakes and show a smooth decay with distance. The main difference between the different datasets is that both DYFI and EMSC are more scattered than the macroseismic dataset derived manually. This is not surprising, especially for the EMSC data that are based on individual accounts (the DYFI data used are already averaged in 10-km geocoded boxes).

We calculate intensity residuals for each distance bin for the 17 studied earthquakes by considering the DYFI intensities as a reference (Fig. 9). The EMSC data are globally consistent with DYFI data and with the three independently and manually derived macroseismic datasets; on average, EMSC intensities are underestimated by 0.25 compared to DYFI results, and residuals present a standard deviation of 0.49. Below DYFI 3, the EMSC intensities are lower than DYFI ones by an average of 0.07 units, which is likely a consequence of the higher proportion of not-felt reports in the EMSC dataset. We believe that below DYFI 3, EMSC intensities are better intensity estimates, because the larger

Table 2
List of Studied Earthquakes with Number of Available Observations for "Did You Feel It?" (DYFI) and European-Mediterranean Seismological Centre (EMSC) Collected Data and the Three Independent Macroseismic Datasets

Earthquake/Region Name and/or Country	Magnitude	Date (yyyy/mm/dd)	Number of EMSC Testimonies ($I \leq 10$)	Number of Geocoded DYFI Testimonies	Number of DYFI Geocoded Boxes	Macroseismic Intensities (EMS-98)
South Africa	5.5	2014/08/05	608	271	67	—
Napa, U.S.A.	6.1	2014/08/24	505	10,748	623	—
Spain	4.8	2015/02/23	808	130	70	—
Gorkha, Nepal	7.8	2015/04/25	960	1060	294	3413
Michigan, U.S.A.	4.2	2015/05/02	911	10,073	5977	—
Dolakha, Nepal	7.3	2015/05/12	1142	717	222	1005
England, United Kingdom	4.2	2015/05/22	1608	142	42	—
Malaysia	6.0	2015/06/04	278	116	28	—
Greece	5.3	2015/06/09	680	49	15	—
Chile	8.3	2015/09/16	113	591	380	—
Hindu Kush, Afghanistan	7.5	2015/10/26	1055	578	174	—
Arizona, U.S.A.	4.1	2015/11/02	2633	5,101	129	—
Vancouver, Canada	4.9	2015/12/30	2805	10,767	2986	—
Manipur, India	6.7	2016/01/03	2031	647	167	374
California, U.S.A.	4.4	2016/01/06	922	5973	3166	—
Gibraltar	6.3	2016/01/25	518	100	44	—
Myanmar	6.9	2016/04/13	1280	282	98	—

EMS-98, European Macroseismic Scale 1998.

proportion of not-felt reports partially corrects for a sampling bias of online macroseismic data collection (Boatwright and Phillips, 2012). For intensities greater than 3 DYFI, there is a systematic and growing intensity underestimation by the automated EMSC procedure, which reaches 1 at 6 DYFI (Fig. 9). A simple linear adjustment above 3 DYFI (Fig. 9) brings the mean difference for all intensities greater than 3 DYFI to zero. The standard deviation after the adjustment (in the same intensity range) was 0.36. The potential adjustment of average EMSC intensities is given in equation (1), with I_{adj} standing for adjusted intensity, and I_{thumb} for the thumbnail intensity

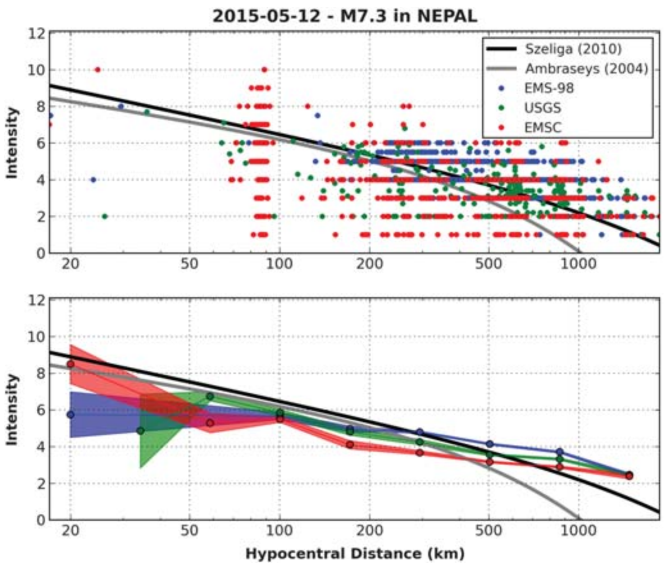
$$I_{\text{adj}} = 1.3 I_{\text{thumb}} - 0.75 \quad \text{for } I_{\text{thumb}} > \text{III}. \tag{1}$$

This potential adjustment will need to be confirmed by future earthquakes. The adjusted curves for the 17 studied earthquakes (Table 1) are presented in ? Figures S16–S32.

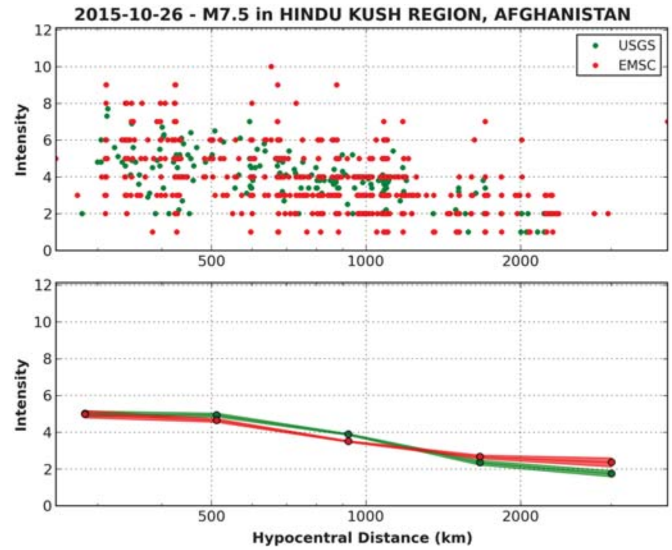
DISCUSSION

Collection of eyewitnesses reports based on thumbnail questionnaires takes advantage of the growing global use of mobile devices, notably smartphones. The increased use of mobile devices also affects the way the general public accesses rapid earthquake information, as illustrated during the Gorkha earthquake sequence (Bossu, Laurin, *et al.*, 2015). Websites and smartphone apps are complementary for both the dissemination of rapid earthquake information and testimony collection, because their usage by the public evolves during an earthquake sequence. Initially, smartphone apps such as LastQuake are used less in regions that have not recently experienced felt earthquakes. When an initial significant felt earthquake occurs, eyewitnesses predominantly access earthquake information through websites; many of them subsequently switch to smartphone app when other earthquakes are felt. This was observed during the Gorkha earthquake sequence (Bossu, Laurin, *et al.*, 2015) and is described in this article for earthquakes in the Hindu Kush region in 2015 and 2016.

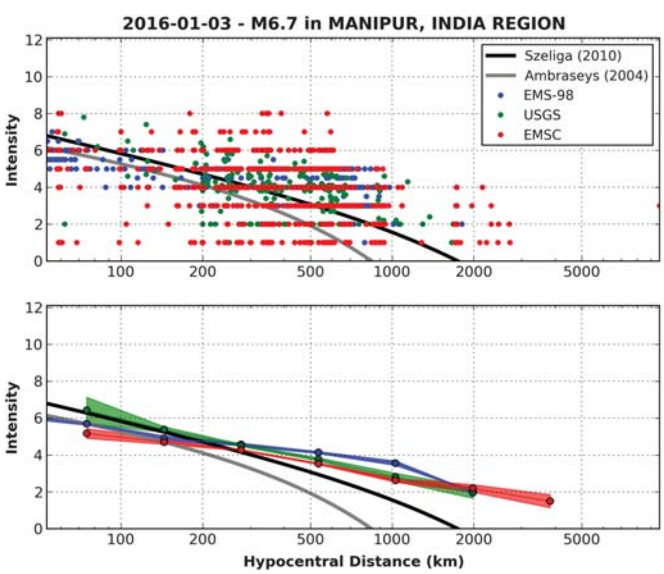
The thumbnail-based questionnaire is an efficient way to collect extensive earthquake testimonies on a global scale: within less than two years of their implementation, they represent 70% of the collected testimonies by the EMSC (Table 1) and are collected from all seismically active regions of the world (Fig. 1). Their introduction has not reduced testimony collection through online questionnaires but has augmented them, thus increasing the total number of collected testimonies (Fig. 2). We surmise that before the introduction of thumbnail-based questionnaires, many users of mobile devices were uncomfortable completing our online questionnaire on a small screen and/or unwilling to spend the couple of minutes required to fill it out and/or were not at ease with any of the 32 available languages.



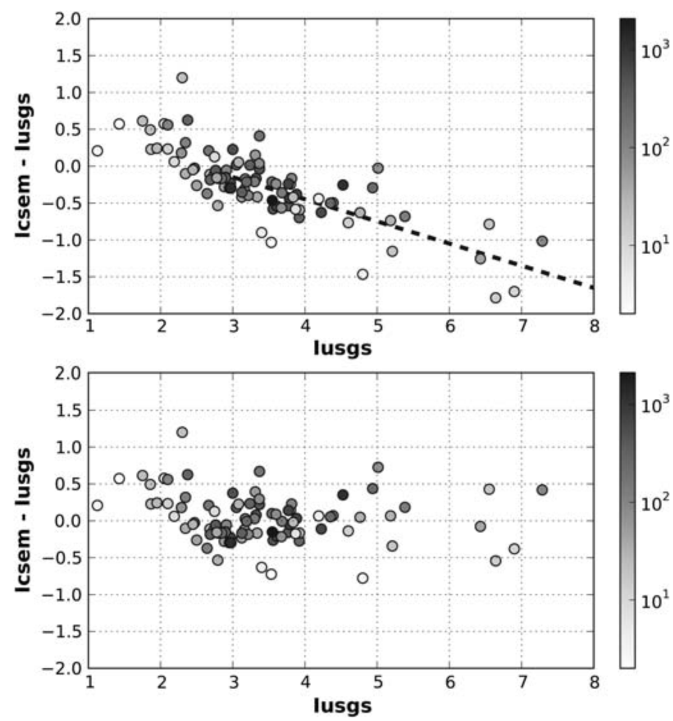
▲ **Figure 6.** (Top) Individual intensity assignments from Hough *et al.* (2016) (blue dots), EMSC individual intensities (red dots), and U.S. Geological Survey (USGS) "Did You Feel It?" (DYFI) geocoded data (Wald *et al.*, 1999, 2011) for the *M* 7.3 Dolakha, Nepal, earthquake. (Bottom) The dot represents the midpoint in distance between the upper and lower bin boundaries. Shading indicates ±1 standard deviation of the mean calculated for each (logarithmic) distance bins. Black and gray lines show the intensity prediction equations from Szeliga *et al.* (2010) and Ambraseys and Douglas (2004), respectively.



▲ **Figure 8.** (Top) Individual intensity assignments from EMSC individual intensities (red dots) and DYFI geocoded data (Wald *et al.*, 1999, 2011) (green dots) for the *M* 7.5 Hindu Kush, Afghanistan, earthquake. (Bottom) Bin-averaged mean values for the same datasets. Shading indicates ±1 standard deviation of the mean calculated for each (logarithmic) distance bins.



▲ **Figure 7.** (Top) Individual intensity assignments from Gahalaut *et al.* (2016) (blue dots), EMSC individual intensities (red dots), and DYFI geocoded data (Wald *et al.*, 1999, 2011) for the *M* 6.7 Manipur, India, earthquake (Bottom) Same as Figure 6.



▲ **Figure 9.** Intensity residuals (above) computed for the 17 studied earthquakes (Table 2) considering the DYFI data as the reference dataset and residuals after a linear adjustment for intensities greater than 3 (dashed line). The shading of the dots is function of the number of EMSC thumbnail-based testimonies, as shown in the bargraphs to the right. Icsem, Intensity from EMSC thumbnails data; Iusgs, Intensity from DYFI data.

The conversion rate (defined as the percentage of eyewitnesses accessing EMSC information through a specific channel and sharing their testimony in a given time window since the earthquake's occurrence) is higher for the app than for the mobile website, although they both collect testimonies through thumbnail-based questionnaires. The reason remains unclear. It could be due to ergonomic differences between the app and the mobile website or due to the time required to download the 12 thumbnails on the mobile website before submitting a testimony, a delay that does not exist for the app, for which the thumbnails are integrated into the application.

There is no indication that thumbnail-based reports are generally unreliable: testimonies reporting intensity greater than 10 EMS, which are likely to be errors or exaggerated reports, represent only 0.4% of the collected testimonies (Table 1). Not-felt reports, which are useful to map the felt area and improve the resolution of the lowest intensities, represent 9% of the total, which is significantly higher than the 3% observed with DYFI (V. Quitoriano, personal comm., 2016). This could be due to the app notifications and the "earthquake around me" list shown both in the LastQuake app and by the mobile website. This could be the motivating factor for individuals who have not felt any shaking to submit a not-felt report when informed about the existence of a seismic event in their surroundings. Although the proportion and spatial distribution of not-felt reports remains too low to precisely map the felt area, increasing their collection potentially improves the resolution of lowest intensities and the consistency with intensity-predictive equations for the low intensities, as well as the drop-off of intensities with distance (Boatwright and Phillips, 2012).

Thumbnail-based questionnaires not only efficiently collect testimonies of global earthquakes, they also collect them rapidly with 36% of the responses collected within 10 min of an earthquake's occurrence (compared to 17% for online questionnaires; Fig. 3). For earthquakes in the period 2008–2009, it took two hours to collect the same percentage of responses (Bossu *et al.*, 2011). The speed of testimony collection at EMSC has therefore improved by an order of magnitude over the last seven years. Furthermore, our analysis over the last two years suggests that the process is still on-going (Fig. 4). We believe that the replacement of the online questionnaire by the thumbnail-based questionnaire is not the only reason for the success but that the very rapid dissemination of earthquake information also contributes to this improvement in performance.

The second part of this work compared the collected testimonies by the EMSC for 17 earthquakes (Table 2) with DYFI data (Wald *et al.*, 1999) and three independent humanly derived macroseismic datasets (Martin *et al.*, 2015; Gahalaut *et al.*, 2016, Hough *et al.*, 2016). The comparison was performed by distance to exclude potential effects of spatial clustering. The EMSC data collected through thumbnail-based questionnaires are consistent with the other datasets, but it seems to underestimate higher intensities (Fig. 9). This underestimation could reflect a potential limitation in the use of thumbnails, which show only the most significant effect of the considered intensity level. For example at 6 EMS, many, but not all, buildings suffer nonstructural damage (Grünthal *et al.*, 1998); the inclusion of reports at the same location where no damage was observed will irremediably reduce the average intensity below 6 EMS, despite the reports being fully compatible with the definition of this intensity level. Questionnaire-based testimonies are less affected, because answers to the different questions provide more details and provide the possibility to cross-check information and describe different effects. Still the impact remains limited, and although this needs to be confirmed in future earthquakes, a simple linear adjustment seems to offer an appropriate solution.

More generally, neither online questionnaires nor thumbnail-based questionnaires can provide fully reliable macroseismic data at high intensity (EMS > 7), because they do not collect any information about building vulnerability. Even if they did, a layperson does not have the expertise to provide reliable vulnerability information, a conclusion also reached by Coppola *et al.* (2010). One of the main advantages of rapid testimony collection is to improve situational awareness, to contribute to a more efficient emergency response, and to provide *in situ* constraints to earthquake damage scenarios (Bossu, Mazet-Roux, *et al.*, 2015). In addition, the EMSC also collects testimonies that cover cross-border earthquakes, and thumbnail usage eases the fusion of these with macroseismic datasets collected at national scale, especially in the European-Mediterranean region. A service for data distribution is being currently developed within the framework of the European Plate Observing System (EPOS) initiative to ease and extend the use of testimonies collected by the EMSC.

CONCLUSION

Smartphones are playing a role in the daily life of an ever-growing proportion of the world's population. The use of a thumbnail-based questionnaire to collect earthquake testimonies takes advantage of this technological evolution. Collection of macroseismic data with thumbnails is more efficient and rapid than with online questionnaires, because it reduces language hurdles and works on a global scale. The EMSC data are, on average, well correlated with DYFI (Wald *et al.*, 1999) and with the three independently and manually derived macroseismic datasets, but there is a tendency for EMSC to be biased low with respect to DYFI at moderate and large intensities. We propose a simple linear adjustment, to be verified on future earthquakes, to remedy this discrepancy. The main advantage of thumbnail-based questionnaires, as implemented at EMSC, is that a large number of testimonies can be collected within 10 min of an earthquake's occurrence, which is essential to improve rapid situation awareness and in turn to contribute to an efficient earthquake response.

DATA AND RESOURCES

European-Mediterranean Seismological Centre (EMSC) macroseismic data are available upon request (www.emsc-csem.org, last accessed May 2016). The mobile website can be accessed at m.emsc.eu (last accessed May 2016). The U.S. Geological Survey (USGS) "Did You Feel It?" (DYFI) data are free to download in various formats at http://earthquake.usgs.gov/ (last accessed September 2016). The macroseismic dataset for the M 7.3 Dolakha, Nepal, earthquake (Fig. 6) is presented in an electronic supplement to Hough *et al.* (2016). The macroseismic dataset for the M 6.7 Manipur, India, earthquake (Fig. 7) is presented in an electronic supplement to Gahalaut *et al.* (2016). Some plots were made using the Generic Mapping Tools (www.soest.hawaii.edu/gmt, last accessed September 2016).

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