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Montalvo-Arrieta, Juan C.; Sosa-Ramírez, Rocío L.; Pérez-Campos, Xyoli

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Evaluation of macroseismic intensities in Mexico from recent earthquakes using *¿Sintió un sismo? (Did you feel it?)*

Juan C. Montalvo-Arrieta*, Rocío L. Sosa-Ramírez and Xyoli Pérez-Campos

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Resumen

Las investigaciones macrosísmicas utilizando datos recolectados a partir de encuestas en línea han adquirido un gran auge en los últimos años. Su fácil acceso y bajo costo permiten realizar evaluaciones de la severidad del sismo a partir de los efectos observados por la población. Además es posible generar curvas de atenuación para una región en particular, visualizar el estado de las construcciones y los posibles efectos de sitio. En regiones donde no se tiene una buena cobertura de redes sísmicas, las intensidades macrosísmicas han demostrado ser un gran sustituto de datos instrumentales. En este trabajo se presentan mapas de intensidades macrosísmicas para cuatro sismos en distintos puntos del país. Los datos se obtuvieron de la base de datos del programa ¿Sintió un sismo?, una encuesta en línea implementada en el 2014. Encontramos que la atenuación es menor en zonas consideradas tectónicamente estables que en regiones activas.

Palabras clave: Mapas de distribución de intensidades, curvas de atenuación de la intensidad, intensidad comunitaria de internet, sacudida del terreno, efectos de sitio.

Abstract

Macroseismic investigations with data collected through online surveys has acquired relevance in recent years. Its easy access and low cost allow assessments of the severity of an earthquake from its effects as observed by the population. Furthermore, it is possible to generate attenuation curves for a particular region, visualize the condition of the buildings from a zip code-averaged distribution map, and estimate possible site effects. In regions without a good coverage of seismic networks, macroseismic intensities have proved to be a substitute for instrumental data. In this paper intensity maps for four earthquakes in different regions of Mexico are presented, based on data from the database of *¿Sintió un sismo?* program, an online survey implemented in 2014. Less attenuation was found in areas considered tectonically stable than in those considered as active regions.

Key words: Intensity distributions maps, attenuation intensity curves, community internet intensity, ground shaking, site effects.

J. C. Montalvo-Arrieta*
Facultad de Ciencias de la Tierra
Universidad Autónoma de Nuevo León
Ex-Hacienda de Guadalupe km 8.
Carr. Linares – Cerro Prieto 67700
Linares, N.L., México
Corresponding author: jmontalvoa87@gmail.com

R. L. Sosa-Ramírez
Facultad de Ciencias de la Tierra
Universidad Autónoma de Nuevo León
Ex-Hacienda de Guadalupe km 8.
Carr. Linares – Cerro Prieto 67700
Linares, N.L., México

X. Pérez-Campos
Departamento de Sismología
Instituto de Geofísica
Universidad Nacional Autónoma de México
Ciudad Universitaria
Delegación Coyoacán 04510
CDMX, México

Introduction

An evaluation of ground shaking through macroseismic intensities of four recent earthquakes in Mexico is presented. The intensity data were obtained through the web questionnaire *¿Sintió un sismo?* (last access March 2016), available in Spanish at http://eventos.uanl.mx/sismologia/ which is based on the "Did you feel it?" program (DYFI; Wald *et al*., 1999). The interest in earthquake intensity data is fomented by: (a) the use of internet as a tool to collect very rapidly large amounts of macroseismic data; (b) the recent development of new algorithms to analyze intensity data; and (c) the need to obtain the source parameters of historical earthquakes to improve our understanding of vulnerability, seismic hazard and seismic risk (e. g., Singh *et al*., 1996; Suter *et al*., 1996; Bakun and Wentworth, 1997; Zobin and Ventura-Ramírez, 1998; Suter, 2001; Atkinson and Wald, 2007; Wald *et al*., 2011; Hough, 2012; Hough, 2013; Suter, 2015).

¿Sintió un sismo?, is a web questionnaire that was initially implemented in northeastern Mexico as a tool for the evaluation of ground shaking in a region with few seismological observatories, such as the State of Nuevo León (Montalvo-Arrieta *et al*., 2015). However, after its implementation on the web, several reports of users located in several regions of Mexico were also received. As a result, a link to *¿Sintió un sismo?* was implemented by the Servicio Sismologico Nacional (SSN) on their web page (http://www.ssn.unam.mx), so that internet users could report their experiences and observations for any earthquake felt in Mexico. The macroseismic intensity data collected by *¿Sintió un sismo?* provides information about ground shaking by giving a quick indication of the extent and nature of shaking effects through the generation of intensity distributions maps. These maps are based on citizen input, and allow data collection at rates and quantities not available before. Additionally, it is possible to integrate the macroseismic intensities with instrumental strong-motion recordings to evaluate the ground-motion attenuation relations and seismic site effects.

Macroseismic Intensity Data

Macroseismic intensity data of four earthquakes felt by the population, from different regions in Mexico, was analyzed (Table 1). Events 1 and 2 are crustal earthquakes in northeastern Mexico, whereas events 3 and 4 are located in the subduction zone between the Cocos and North America plates. For event 4, we compare our results to those generated by DYFI. Unfortunately, for the other events this comparison was not possible due to a low response from the population, either for our survey (event 3) or DYFI (events 1 and 2). The attenuation of macroseismic intensity curves obtained by *¿Sintió un sismo?*, are compared only with the regression curves obtained by Atkinson and Wald (2007) to DYFI. Hough (2013, 2014) shows that the comparison of historical intensity distributions with those determined using the DYFI system reveals a qualitative difference between them due to the historical intensity distributions, suggesting more widespread damage and other effects revealed by spatially DYFI data.

2 March, 2014, (M4.3) earthquake (Event 1)

On March 2, 2014, at 16:30:16 UTC (11:30:16 local time), a M_c4.3 earthquake was felt in the central portion of the state of Nuevo León (Figure 1). This event is part of the

Table 1. Source Parameters of the Studied Earthquakes.

Reference	Date DD.MM.YYYY	Latitude (km)	Longitude	Depth	*M*
1*	02.03.2014	25.52°	-99.59°	5	4.3
2*	31.05.2015	25.25°	-101.15°	20	4.0
3*	23.11.2015	16.86°	-98.94°	10	5.6
4*	17.12.2015	15.76°	-93.70°	90	6.6
4§	17.12.2015	15.8009°	-93.6294°	85	6.6

Source: *Servicio Sismológico Nacional (SSN). §National Earthquake Information Center. U. S. Geological Survey (USGS).

October, 2013, to March, 2014, ($1.9 \leq M_c \leq 4.5$) seismic sequence in the region. Some of these events resulted in the first internet earthquake intensity reports in northeastern Mexico. Houses damaged were reported in some communities near the epicentral area and in the Monterrey Metropolitan Area (MMA), located approximately 90 km northwest of the epicentral zone, where strong ground shaking was described by the population. Montalvo-Arrieta *et al*. (2015) analyzed intensities from this earthquake; they reported a total of 144 received web questionnaires, 137 of them from the MMA. The descriptions by citizens in the epicentral area correspond to the highest community internet intensity (CII) values, V-VI. In the MMA and other localities of the state, CII values were II–V (Figure 1). The number of responses to the individual questionnaires with respect to time is shown in Figure 2. It is clear that the response of the people took some time, since, as mentioned, this was one of the first attempts to collect information through an online questionnaire.

The averaged MMI values were fit using the standard functional form for the intensity-attenuation relation:

$$MMI = a - br - c\log_{10}(r) \quad (1)$$

where *a*, *b*, and *c* are constants determined by a least-squares fit to the observations and *r* is the epicentral distance (Hauksson *et al*., 2008; Hough, 2012).

Figure 3 shows the comparison of the attenuation of the macroseismic intensity reported for this earthquake with the logarithmic regression model (which is based on the maximum likelihood method of Joyner and Boore, 1993 obtained by Atkinson and Wald (2007) using the database of DYFI for Central and Eastern United States (CEUS), representing a stable continental region, and California (CA) characterizing the ground-motion attenuation to the west of CEUS. The latter region has a higher attenuation than CEUS (Nutli, 1973; Gupta and Nutli, 1976). Kanter (1994) included

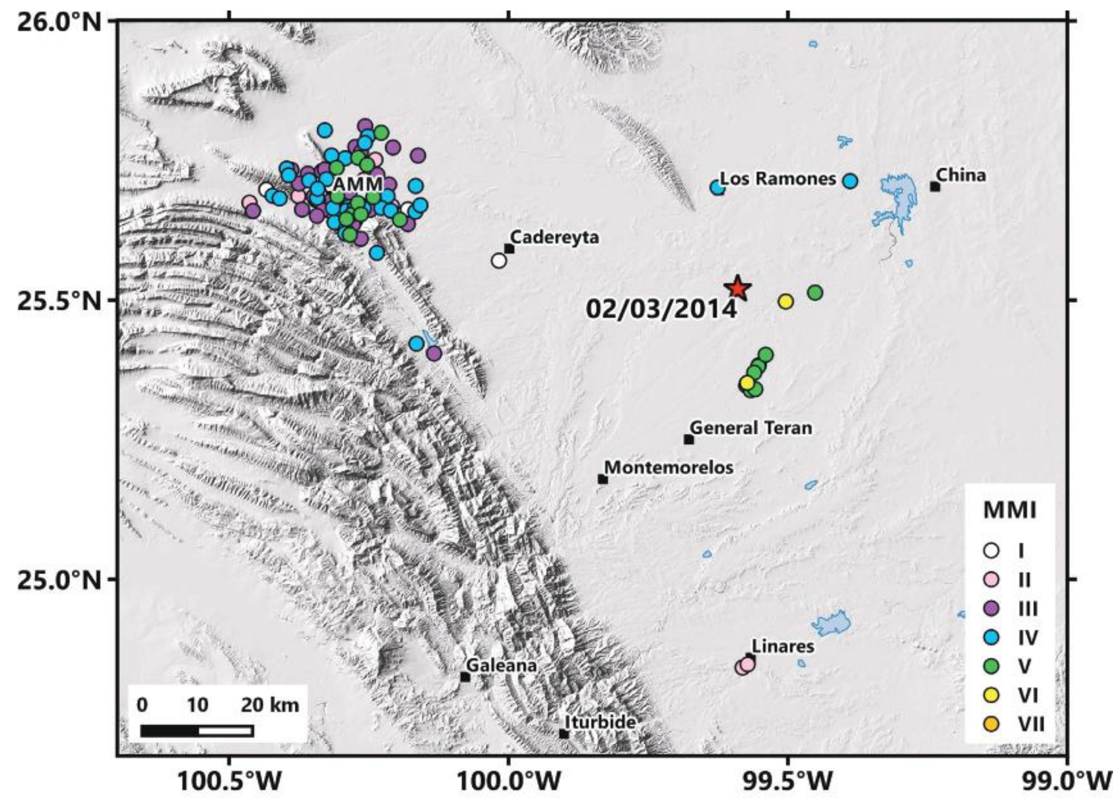


Figure 1. Community Internet Intensity (CII) map showing the distribution of intensities and felt area for the March 2, 2014, earthquake. 144 individual responses from 90 ZIP code areas were received. The red star represents the epicenter.

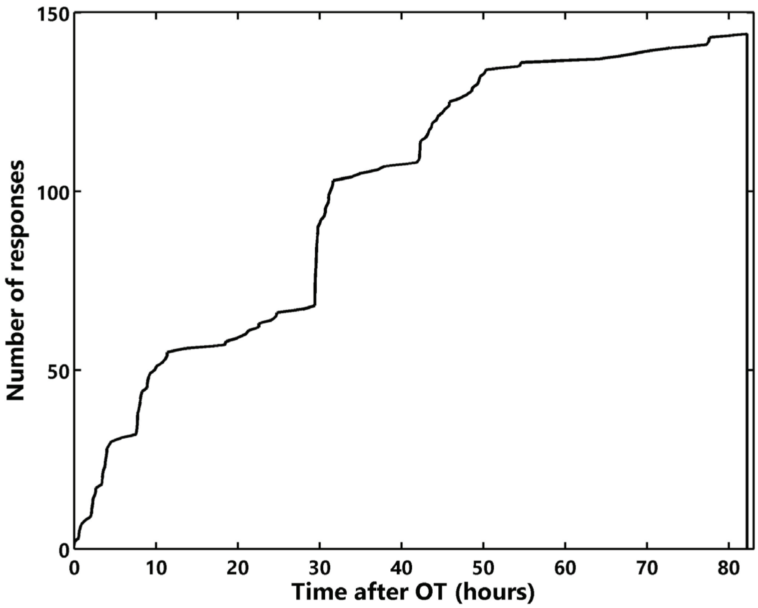


Figure 2. Number of individual questionnaire responses versus time for the March 2, 2014, event. Over 145 entries were received. The earthquake occurred at 11:30:16 local time. The last questionnaire was received 82 hours after the origin time (OT).

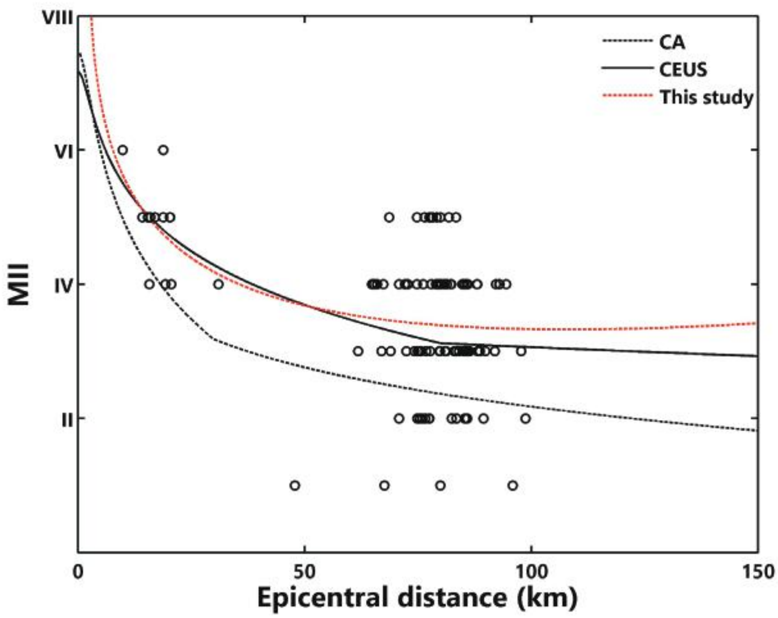


Figure 3. Intensity versus epicentral distance showing the Atkinson and Wald (2007) attenuation models, as well as equation (1) in red for the March 2, 2014, event. Note that the intensity reports show a similar behavior as compared with CEUS model.

the central portion of the state of Nuevo León in the southern limit of CEUS. It is notable the similitude between the intensity-attenuation curve for this event (equation 1) and the attenuation curve proposed by Atkinson and Wald (2007) for CEUS. The attenuation of the seismic intensity reported for event 1 may have a similar behavior to that for the stable continental region of U.S.A.

31 May, 2015, (M_c4.0) earthquake (Event 2)

The epicenter of the Saltillo earthquake of May 31, 2015, (M_c4.0) was located 26 km to southwest of Saltillo city. It occurred at 23:34:17 (local time). Due to its origin time, the earthquake was widely felt in Saltillo and Ramos Arizpe, Coahuila, in northeastern Mexico. Information about this event was extensively spread through social networks, and caused a big concern among the population in the region. Near the epicentral area the population density is scarce so,questionnaires were only received from the two mentioned cities. More than 250 users responded to *¿Sintió un sismo?,* allowing an evaluation of the macroseismic intensities for this earthquake.

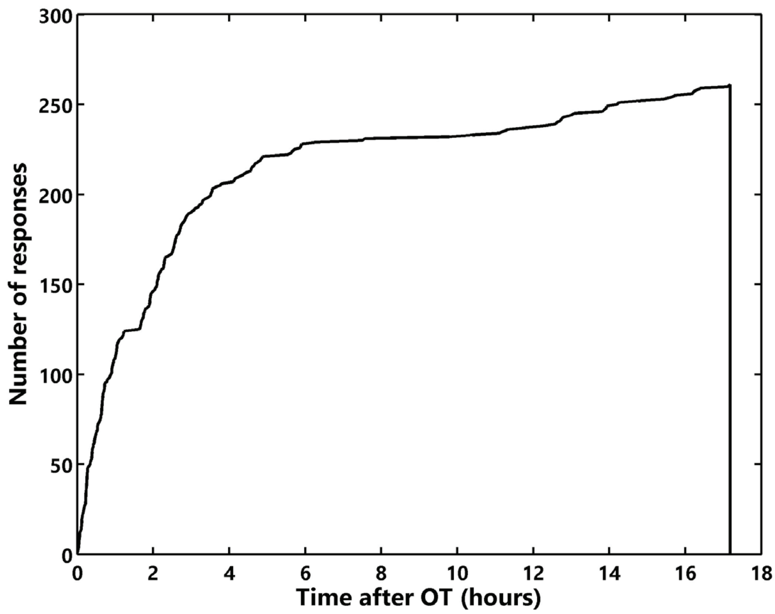


Figure 4. Number of individual questionnaire responses versus time for the May 31, 2015, event. A total of 261 surveys were received. The earthquake occurred at 23:34:17 local time. The last questionnaire was received 17 hours after the origin time (OT).

Responses were received during the first 17 hours after the event. In the first 30 minutes we received 50 questionnaires and 150 during the first two hours. Figure 4 shows the impressive rate of responses and feedback from users for the Saltillo earthquake. This is very noticeable in a region with no recently felt earthquakes. In this case the data quality and quantity depend on the population density and internet access (Mak and Schorlemmer, 2016), but not necessarily on earthquake awareness or overall hazard of the region (Wald *et al*., 2011). This behavior is similar in the MMA for the March 2, 2014, earthquake. As responses are received from a community, their ZIP code area is color-coded according to the computed CII. The map is then updated as we receive more surveys. Figure 5a shows the intensity map for the first 30 minutes after receiving the first questionnaire. Figure 5b depicts the final CII map 17 hours after the origin time. These maps also show that individual communities can change intensity (color) as data from more respondents are processed, and a new consensus is reached. This can be seen in the intensity data of Figures 5a and 5b. Therefore for multiple observations in a community, the intensity value reflects the average effects of shaking reported by that community. Additionally, according to Wald *et al*. (1999), with sufficiently distributed responses it has been shown that even small-scale variations in intensity can be recovered.

Figure 5b shows the final CII map for the Saltillo earthquake, the intensity values vary from II to V. Additionally, the distribution of intensity data shows a northeast trend. The propagation of energy could be affected by the structural orientation of main faults and lineaments in this portion of Mexico, in agreement with the explanation by Horton and Williams (2012) and Hough (2012) for the Mineral Virginia earthquake of 2011. These authors mentioned that axial distribution of intensities can be caused by anisotropic propagation resulting from local tectonics. In Mexico, the same conclusion was reached by Aguilera (1888) for the intensity distribution of the 1887 Sonora earthquake (see Suter, 2006).

23 November, 2015, (M5.6) earthquake (Event 3)

This event was located 48 km East of San Marcos, Guerrero (SSN, 2015), and originated at Cocos-North American subduction zone. This event was felt in Mexico City and some localities of central Mexico. Figure 6a shows the CII map obtained for central Mexico. We received 22 questionnaires in a lapse time of 15 hours (Figure 7), all of them from Mexico City.

Figure 6b shows the CII map for Mexico City, superimposed to the geotectonic zones defined by Marsal and Mazari (1959) as: (1) the hill zone, formed by volcanic tuffs and lava flows; (2) the lake-bed zone, formed by clays with thicknesses varying from 10 to 130 m; and (3) the transition zone, composed of alluvial sandy and silt layers, with scattered clay layers. In Mexico City the CII varied from I to III, in the lake-bed zone the MMI values were III.

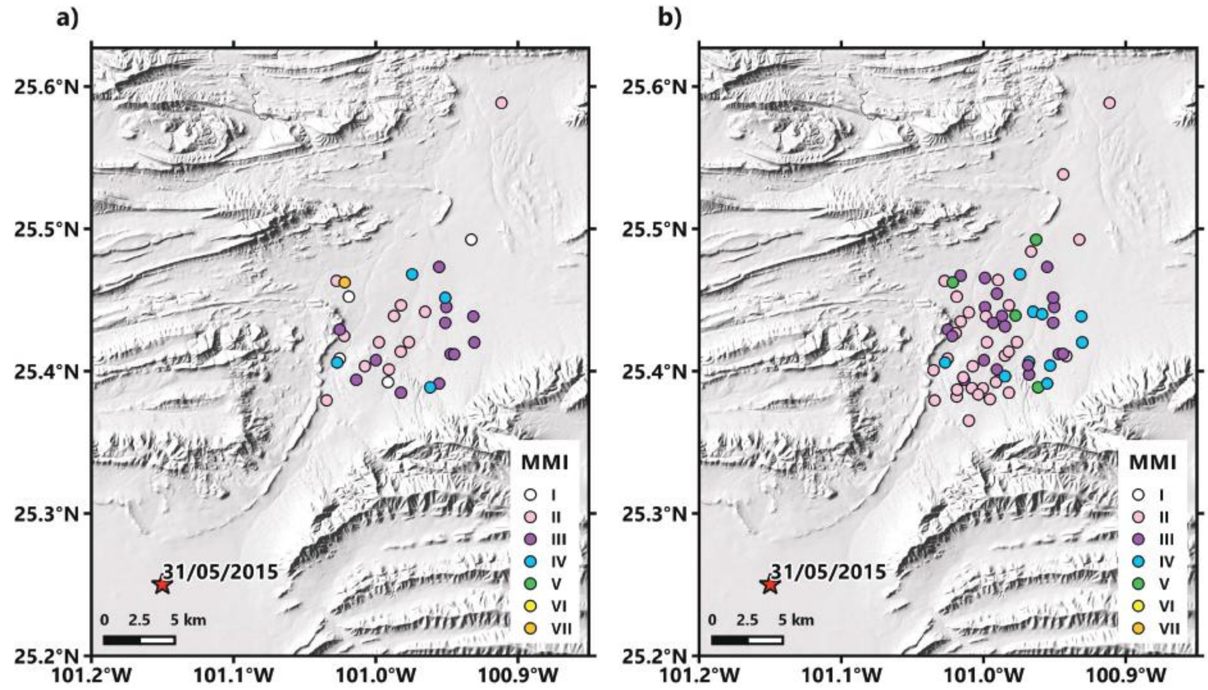


Figure 5. Community Internet Intensity (CII) map showing the distribution intensities and felt area for the May 31, 2015, earthquake after (a) 30 minutes from the origin time, and (b) after 17 hours of the origin time. 261 individual responses from 73 ZIP code areas were received. The red star represents the epicenter.

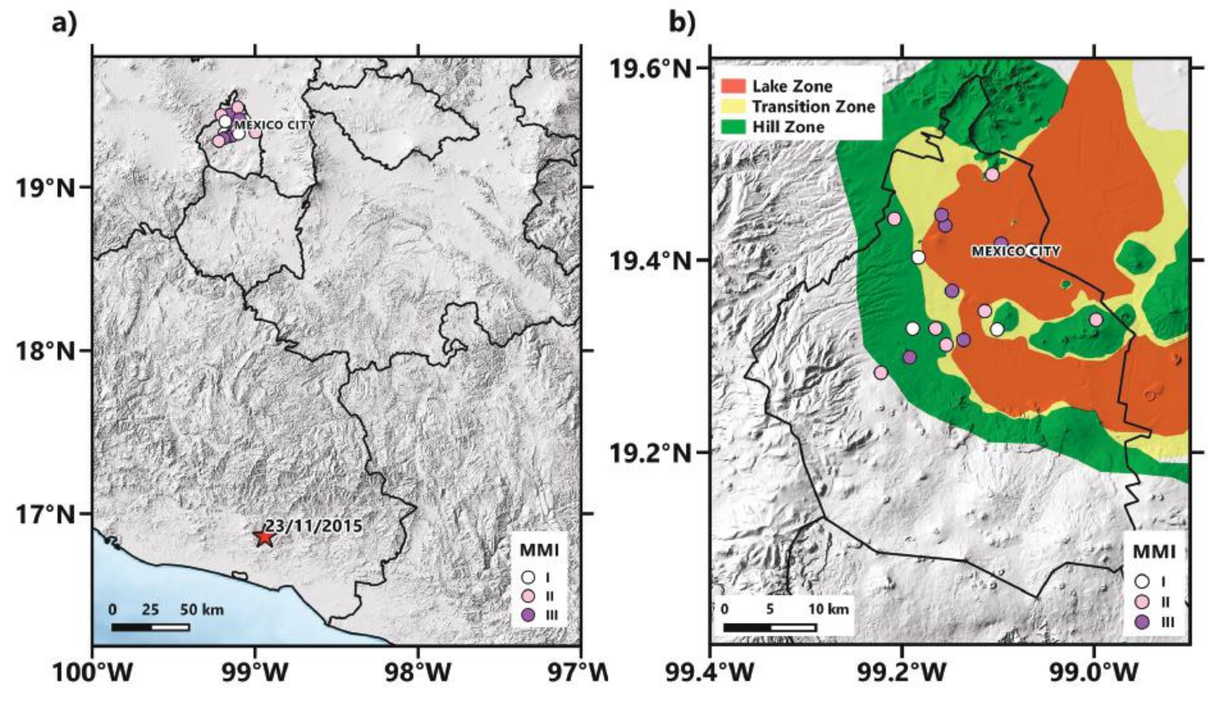
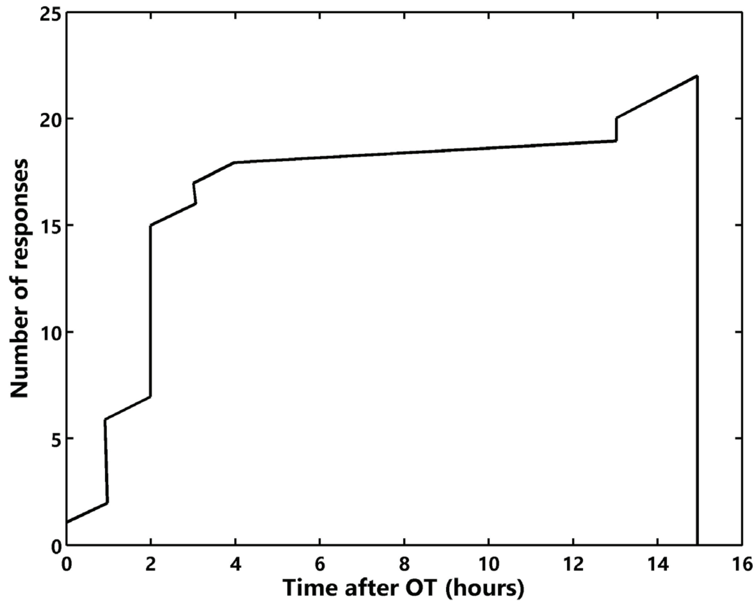


Figure 6. (a) Community Internet Intensity (CII) map showing the distribution intensities and felt area for the November 23, 2015, earthquake. 22 individual responses from 19 ZIP code areas, all of them from Mexico City, were received. The red star represents the epicenter. (b) Comparison of geotectonic zones from the Valley of Mexico (Marsal and Mazari, 1959; Flores-Estrella *et al*., 2007) and CII values.

Figure 7. Individual questionnaire responses versus time for the November 23, 2015, event. Over 20 entries were received. The last one was received 15 hours after the origin time (OT). The earthquake occurred at 14:41:20 local time.



17 December, 2015, (M6.6) earthquake (Event 4)

Event 4 occurred in the subduction zone between Cocos and North American plates, at 90 km depth according to the SSN (Table 1). The epicenter was located near the city of Tonalá in the state of Chiapas (Figure 8). The earthquake was widely felt in southeastern Mexico and some places in Belize and Guatemala (SSN, USGS). During this event we probed the capabilities of *¿Sintió un simo?* in terms of the response of web users located in cities of several states of Mexico. Figure 8 shows the CII map. CII data are mainly focused in the Chiapas and Tabasco states. In the state of Chiapas, including the capital city Tuxtla Gutierrez, the intensities had values between IV - VI. Near the epicentral area the CII reported was IV. The CII reports from Tabasco state come from cities located in the basin of the Grijalva River, such as Villahermosa. This basin is characterized by thick soil deposits from the Quaternary, that amplify the ground motions. Other CII data were from Oaxaca, Veracruz and Estado de México states.

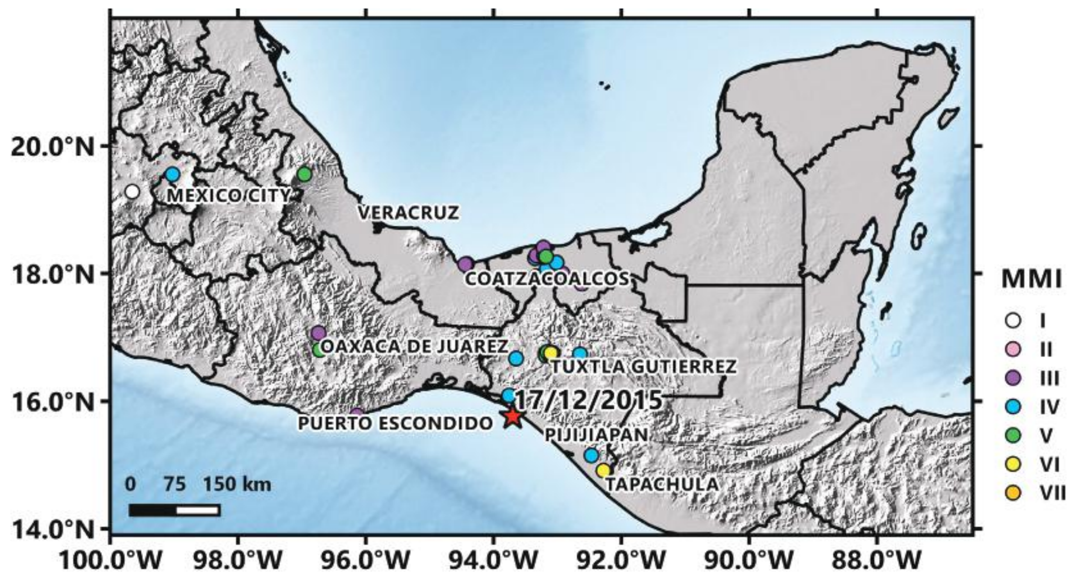


Figure 8. Community Internet Intensity (CII) map showing the distribution intensities and felt area for the December 17, 2015, earthquake. 51 individual responses from 41 ZIP code areas were received. The red star represents the epicenter.

The CII map generated in this study (Figure 9a) was compared with the DYFI intensity map (Figure 9b). In contrast to Figure 8, these maps report the CII averaged by city, similar as DYFI procedures for intensity maps outside U.S.A. DYFI received 122 CII reports from Belize, Guatemala and Mexico, 48 of them were from Mexico. DYFI and *¿Sintió un sismo?*, received reports of almost the same Mexican states; however, DYFI received only one survey from the state of Tabasco, while *¿Sintió un sismo?*, 30. Figure 10 depicts the response time for DYFI and *¿Sintió un sismo?*, DYFI includes the reports from Belize, Guatemala and Mexico. The DYFI intensity map for Mexico shows CII values that vary from III to IV, whereas for *¿Sintió un sismo?,* CII reports vary from III to VI. The differences in CII data could be related to the larger number of surveys received by *¿Sintió un sismo?*

Figure 11 shows the intensity attenuation obtained by DYFI and *¿Sintió un sismo?* (equation (1)) compared with CEUS and CA models. In both curves, the attenuation intensity is correlated with an active province. The intensity attenuation curve of DYFI includes all reports received from Belize, Guatemala and Mexico.

Discussion and Conclusions

In this study we presented the first CII maps for Mexico from *¿Sintió un sismo?*, which is a web questionnaire where citizens report their experiences and observations for any felt earthquake, just by answering a simple multiple-choice questionnaire. Based on the information obtained with our web questionnaire, we have documented the intensity maps of the March 2, 2014, (*M*4.3),

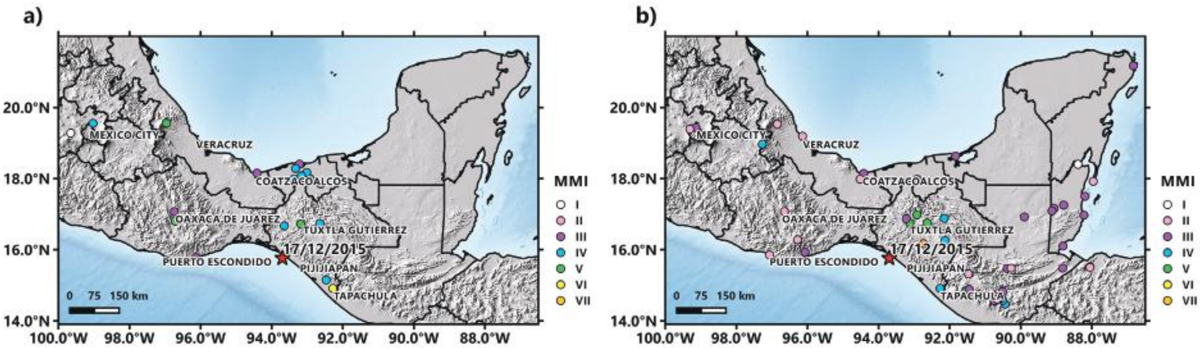


Figure 9. Comparison of felt area for (a) this paper results of the December 17, 2015, earthquake averaged by city, and (b) the DYFI results.

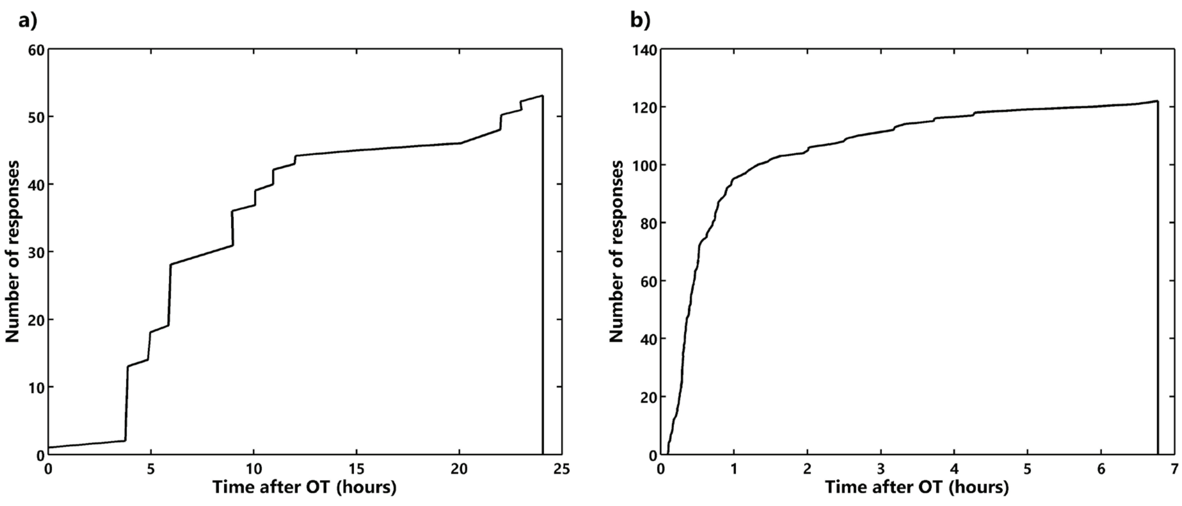


Figure 10. Comparison of individual questionnaire responses versus origin time (OT) for (a) this paper results of the December 17, 2015, earthquake, and (b) the DYFI results.

May 31, 2015, (*M*4.0), November 23, 2015, (*M*5.6), and December 17, 2015, (*M*6.6) earthquakes that were originated in different seismotectonic settings of Mexico reflected in the obtained CII maps.

Although *¿Sintió un sismo?* was launched in 2014 as a web questionnaire to assess the ground shaking in northeastern Mexico, it was until 2015 that it started being used throughout the country. The number of questionnaires is expected to increase over time, in order to improve the evaluation of effects caused by earthquakes across the country. In addition, in the future we can: (a) test the correlation between the macroseismic intensities obtained by *¿Sintió un sismo?*, and the instrumental ground-motion recordings such as peak ground acceleration and peak ground velocity to create Shake Maps (Wald *et al*., 1999a, b; Wald *et al*., 2005), (b) to obtain an empirical regression to determine the dependence of MMI on M and the distance from the fault, for the seismotectonic provinces in Mexico.

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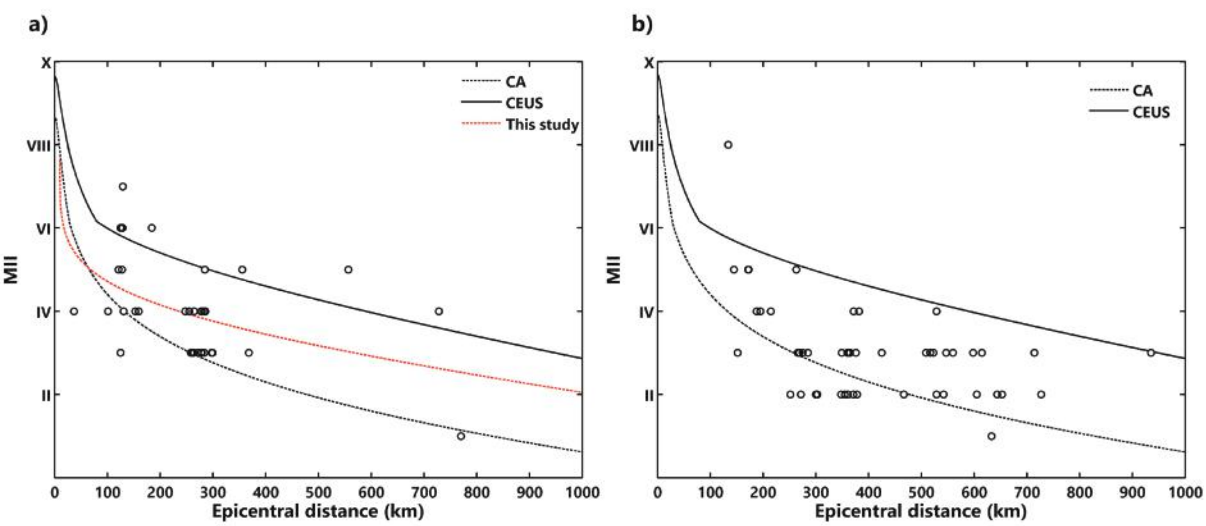

Figure 11. Comparison of intensity-distance attenuation for (a) this paper results of the December 17 , 2015, earthquake, and (b) the DYFI results. Dotted red line is the fit using equation (1).

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