ANNALS OF GEOPHYSICS, 59, Fast Track 5, 2016; DOI: 10.4401/ag-7217

Regional macroseismic field and intensity residuals of the August 24, 2016, M_w=6.0 central Italy earthquake

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Abstract

A macroseismic investigation of the August 24, 2016, Mw=6.0 Central Italy earthquake, was carried out through an online web survey. Data were collected through a macroseismic questionnaire available at the website www.haisentitoilterremoto.it, managed by the Istituto Nazionale di Geofisica e Vulcanologia (INGV). Over 12000 questionnaires were compiled soon after the seismic occurrence, coming from over 2600 municipalities. A statistical analysis was applied to the data collected in order to investigate the spatial distribution of intensity of the earthquake. The macroseismic intensity field (I) was described by identifying three main components: an isotropic component (I_I), a regional anisotropic component (I_A) and a local random variations parameter (ε). The anisotropic component highlighted specific and well-defined geographical areas of amplification and attenuation. In general, the area between the Adriatic coast and Apennines Chain was characterized by an amplification of intensity, while the West side of the Apennines showed attenuation, in agreement with the domains found by other works focused on the analysis of instrumental data. Moreover, the regional macroseismic field showed similarities with instrumental PGA data. The results of our analysis confirm the reliability of web questionnaire data.

I. INTRODUCTION

The Amatrice August 24, 2016 earthquake, characterized by the relevant magnitude of $M_{W=}6.0$, was felt over a large area of Central Italy. Since 1997, but only since 2007 in its current aspect and formulation, the *Istituto Nazionale di Geofisica e Vulcanologia* (INGV) manages a crowdsourcing project for the collection of macroseismic information from the population (HSIT, www.haisentitoilterremoto.it). The project is used to assess the intensity of earthquakes as well as to elaborate the results in real time in the form of data, maps and graphs for each seismic event felt by the population [Sbarra et al., 2010; Tosi et al., 2015].

The huge amount of intensity data collected for the described event allowed a detailed regional investigation of spatial distribution of intensity. Although given by non-expert compilers, the over 12000 questionnaires filled in were statistically elaborated to estimate the macroseismic intensity field of the earthquake, separating the isotropic from the anisotropic components. Born as a pre-instrumental discipline mainly oriented to describe the severity of the damage of earthquakes, macroseismic investigation, over the last 20 years, has turned its interest towards new avenues, such as studying areas of lower intensities, real time analysis and in-depth application of spatial statistical analysis, with the aid of the web and of social participation.

II. Data and Methods

Due to the high magnitude of the seismic event, an automatic e-mail was sent to all the users registered to the alert service of HSIT, through a procedure that is routinely activated immediately after the epicenter localization, with the request to compile the HSIT questionnaire. In the first 24 hours from the occurrence of the event we received 9645 questionnaires and have collected 12340 questionnaires since from both registered and unregistered users located throughout Italy (Fig. 1).

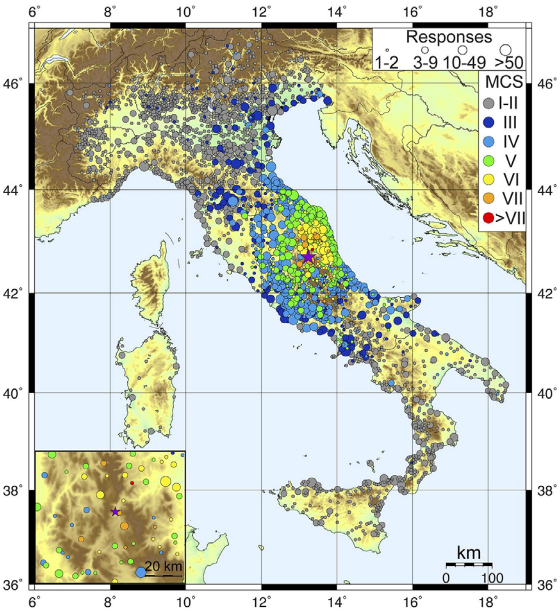

Figure 1. *Municipality macroseismic MCS intensities assessed using 11100 questionnaires, compiled through the HSIT site (www.haisentitoilterremoto.it). The purple star represents the instrumental epicenter. The inset shows an enlargement of the epicentral area.*

A relatively scarce number of responses came from the epicentral area, as commonly occurs in the case of high magnitude events, considering people were too shocked to immediately fill in the questionnaire. For this reason, our paper was mainly focused on the macroseismic intensities observed in the far field. According to the Mercalli–Cancani–Sieberg (MCS) definition, people recognizing the earthquake occurrence in the II MCS degree area are generally so few (about 5%) that they are unlikely to submit questionnaires in the first place. For this reason, I and II MCS were grouped in the same class (see Fig. 1).

We selected 11100 questionnaires from the original dataset (N=12340), excluding those of poor-quality [Tosi et al., 2015]. Questionnaire data came from 2654 municipalities. For a more reliable estimation of earthquake intensity we excluded all municipalities with less than 3 questionnaires. For each municipality, a specific score distribution, within the spectrum of macroseismic degrees, was given to each answer, relative to the observed effects. The intensity, expressed as a rational number, was then assessed computing the modal value or the average of the local maxima of the distribution [Tosi et al., 2015].

The final dataset was composed of 834 municipality intensity data in the MCS scale derived from 8671 questionnaires. Our aim was to obtain the macroseismic field interpolated in a regular grid. Moreover, the field was distinguished by three main spatial components based on the range of their spatial influence. In more formal terms, we expressed the macroseismic intensity field (I) as:

$$I = I_I + I_A + \varepsilon \qquad (1)$$

where I_I figures as the isotropic intensity component centered at the instrumental epicenter, I_A as the anisotropic intensity component and ε reflects the influence of all local random components. The isotropic component I_I was obtained, as follows. First, we expressed all I intensities as a function of the epicentral distance alone (Fig. 2). Then, we averaged the municipality intensity data within intervals of epicentral distance of 4 km of width:

$$\bar{I}_k = \sum_{j=1}^{m_k} \frac{I_j}{m_k}\,;\, \bar{d}_k = \sum_{j=1}^{m_k} \frac{d_j}{m_k}\,. \qquad (2)$$

Where $\overline{I_k}$ represents the average intensities, I_j is the subset of m_k municipality intensities within k^{th} interval of epicentral distance of 4 *km* of width, $\overline{d_k}$ is the average of epicentral distances d_j in the same subset. The average intensities $\overline{I_k}$ were plotted as orange dots (Fig. 2). The attenuation versus the logarithm of epicentral distance was then fitted with a 3^{rd} degree polynomial function:

$$I_I = 6.91 - 1.14\log d + 0.68\log^2 d - 0.41\log^3 d\,, \quad (3)$$

the fit was calculated up to a distance of 300 km. At longer distances, the intensities were "not felt" so that the macroseismic field became flat.

After having modeled the I_I isotropic component, we proceeded to separate the $I_A + \varepsilon$ components (Eq. 1). This second step was performed by applying the block Kriging interpolation to the $I_A + \varepsilon = I - I_I$. Kriging is an interpolation method tuned through the modeling of the semivariogram, which has already been applied to macroseismic intensity fields [De Rubeis et al., 1992]. The semivariogram is the plot of the variance as a function of interdistance of the measured data points. Two key elements are deduced from the semivariogram: the nugget effect, which is the variance value at 0 distance, i.e. the variance component not dependent by data point interdistance, and the sill, which is the maximum variance. The shortest distance of the sill marks the autocorrelation range, while at longer distances data are no longer spatially autocorrelated. If data are characterized by a relevant ε component (Eq. 1) the semivariogram shows a high nugget variance and the result is strongly smoothed. In our data set we observed the presence of both nugget variance and spatial autocorrelation (Fig. 3). The block Kriging interpolation was set to produce an interpolated and smoothed field of residuals over a regular grid of a 5 km step, thus obtaining the I_A component (Eq. 1). I_A, being the regional anisotropic component, can be defined as the residual after I_I and the random component ε are removed from the original I data. The anisotropic component I_A together with the residual data points, are shown in Fig. 4. Finally, we defined the regional filtered smoothed field I_R as a spatial regular grid of intensities where the random noise component ε was filtered out:

$$I_R = I_I + I_A = I - \varepsilon\,. \quad (4)$$

The final filtered macroseismic field I_R, with the original intensity data points, is depicted in Fig. 5. In this figure we have also drawn the intensity isoseismals, which are the lines separating different macroseismic degrees in the filtered I_R field.

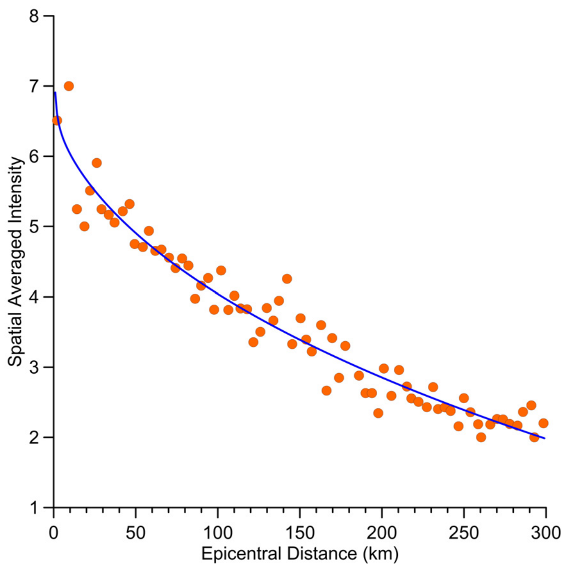

Figure 2. *Macroseismic attenuation as a function of epicentral distance. The orange dots are the spatial averaged intensities within intervals of epicentral distance of 4 km of width, the blue line represents the polynomial fit (Eq. 3).*

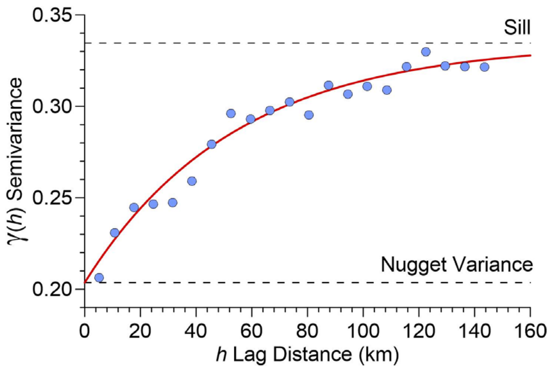

Figure 3. *Semivariogram (blue dots) of the anisotropic component (I_A) of intensities fitted by an exponential model (red line). Nugget and sill variance levels are marked by dashed lines.*

III. Results and Discussion

As results from Fig. 1, the earthquake was felt up to 300 km distance in Northern Italy and up to 250 km distance in Southern Italy. It is worth noting that the data collected from the epicentral area of the earthquake was not highly reliable since it was affected by two main factors. In the first place, this was the area where major damage occurred; thus, a careful survey and evaluation made by expert technicians would be most appropriate for a reliable intensity assessment. For this reason, intensities greater than VII MCS were grouped into a single class, following the same criterion of the European-Mediterranean Seismological Centre [Musson, 2007]. In the second place, municipalities located in the epicentral area submitted a smaller amount of data because people were too shocked to immediately fill in the HSIT questionnaire. For this reason, the maximum intensity point in the map was only VII MCS. Some intensities of VII and greater than VII, shown in Fig. 1, were discarded since they were estimated with less than three questionnaires. Past experience suggests that in the following six-ten months the gap of information from the epicentral area will most probably be filled in, as was observed for the earthquake that occurred in L'Aquila on 6 April 2009.

Two main residual areas were highlighted from our data (Fig. 4). At the North and East sides of the epicenter there was a large positive area, located prevalently on the coast of the Adriatic Sea. The maximum positive residual was found to be located 30 km North from the epicenter. At the West side of the epicenter there was a negative area spanning along the coast of the Tyrrhenian Sea.

Comparing the field of the anisotropic component (Fig. 4) with the Pn and Sn waves attenuation map [Mele et al., 1997] we found agreement between the areas of attenuation, in the uppermost mantle, located on the Italian Tyrrhenian side. The separation of central Italy into two zones of amplification and deamplification is shown also by the spatial pattern of site corrections, showing a high attenuation west of the Apennines as opposed to a low attenuation on the other side due to different crust properties [Di Bona, 2016]. Therefore, regional macroseismic anomalies could be linked to the efficiency of wave propagation inside the crust-upper mantle system.

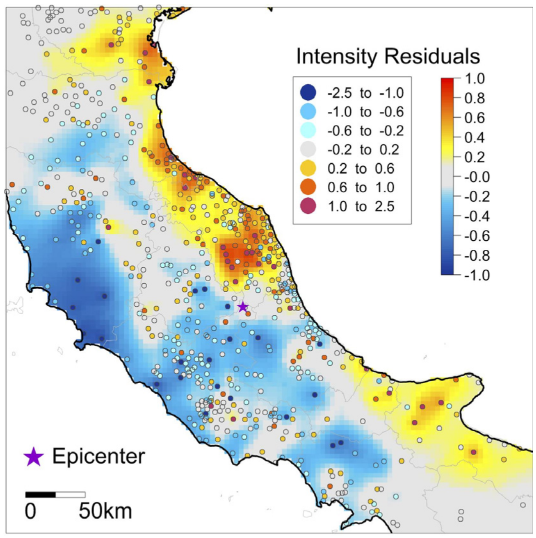

Figure 4. *Intensity residual values (coloured dots) and the anisotropic component field (I_A) (coloured shaded areas) interpolated by using the block Kriging method.*

The filtered macroseismic field (Fig. 5) shows higher intensities on the North and East sides of the epicenter. This main trend was highlighted by the isoseismal separating the IV from V intensity degree and by the isoseismal separating the V from VI intensity degree. The North-East amplification was also showed in the peak ground accelerations (PGA) of the ISMD database (INGV Strong Motion Database; http://ismd.mi.ingv.it/). In order to make a deeper comparison between PGA and macroseismic field, we performed a correlation analysis considering logPGA and macroseismic intensities extracted from the filtered field at seismic station locations. The two sets showed a significant correlation value r=0.74. Data were fitted using the Tukey 3 medians method [Tukey, 1977] (Fig. 6), resulting in the equation:

$$I_R = 2.77 + 1.21 \log PGA\,. \qquad (5)$$

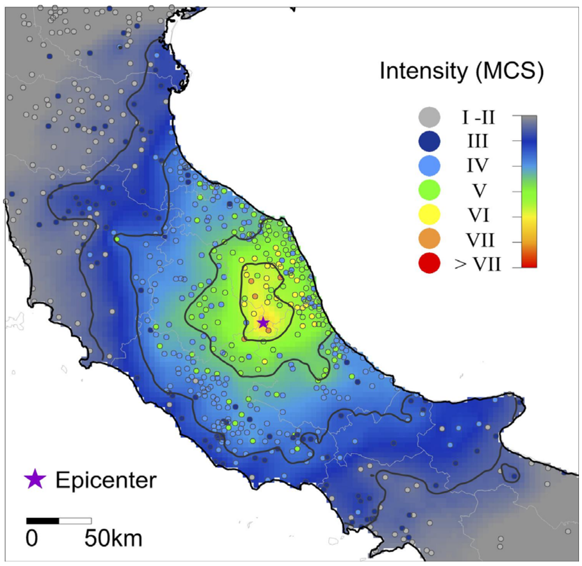

Figure 5. *Municipality intensities (coloured dots) and the regional macroseismic field (I_R) (Eq. 4), the dark lines represent isoseismals separating intensity degrees.*

Our results, thus, show that data obtained through crowdsourcing by simply compiling a web questionnaire was able to define a reliable regional macroseismic field in accordance with instrumental data, and to identify two main areas of amplification and de-amplification of earthquake intensity.

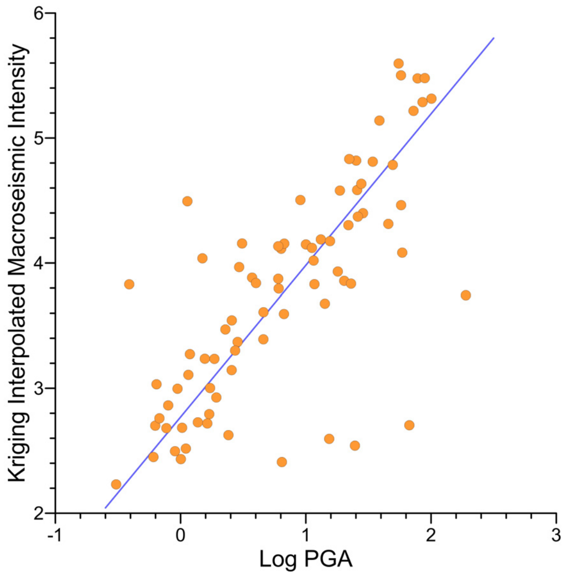

Figure 6. *Scatter plot of logPGA values versus corresponding filtered macroseismic intensities (orange dots). The correlation coefficient is 0.74. The blue line is the Tukey medians fit.*

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