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Northern Sicily, September 6, 2002 earthquake: investigation on peculiar macroseismic effects

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Abstract
The Northern Sicily, September 6, 2002 earthquake ($M_l = 5.6$, $M_W = 5.9$) is investigated under macroseismic aspect: peculiar effects are collected besides standard effects normally used to define Mercalli-Cancani-Sieberg (MCS) intensity. They include sound heard during the quake, fear felt and a simple qualitative description of ground movement felt. Spatial coverage of such information is dense enough to be statistically processed, to give an interpolated, smoothed field for each data type. Sound heard is compared with theoretical sound field produced considering source geometry and transmission of waves to air, it also confirms the Southern Sicily amplification disclosed by macroseismic intensity values. Fear felt is also in agreement with macroseismic intensity field while type of ground motion is a partly independent aspect.

Key words *macroseismic intensity – Sicily – earthquake sound – macroseismic effects*

1. Introduction

The principal aim of a macroseismic investigation is to define an intensity field following a specific intensity scale. The definition of a particular scale reflects the effort to mediate heterogeneous damage information into a systematic and structured description. The functionality of an intensity scale resides in its proper effects and damage subdivision. Specific damage should fulfill certain requirements: it must be easily recognizable, it must be specific of as narrow as possible a range of energy released, it must be often associated with other effects of the same degree but must maintain a sufficient independence from them (this can be defined as the power of representation of a specific intensity degree). A particular macroseismic intensity scale is the set of all damage and effects organized in a hierarchical order. Other effects are considered not particularly useful, if not confusing, and they are marginally treated.

Within this paper some not-standard effects are presented because they received a sufficient spatial completeness of data. These effects are:

– hearing of earthquake sound shortly before or during the shaking;

– kind of ground movement felt by people during the event;

– percentage of people feeling fear.

The main shock occurred on September 6, 2002, 01:21 TU, localized by the National Earthquake Center on the Southern Tyrrhenian Sea (latitude 38.45 N, longitude 13.70 E) at a distance of approximately 40 km from the Sicilian town of Palermo, with a magnitude $M_l = 5.6$. Aftershock events are distributed on an ENE-WSW direction in agreement with the focal mechanism (thrust type strike = 255, dip = 49, slip = 121; Pondrelli *et al.*, 2003).

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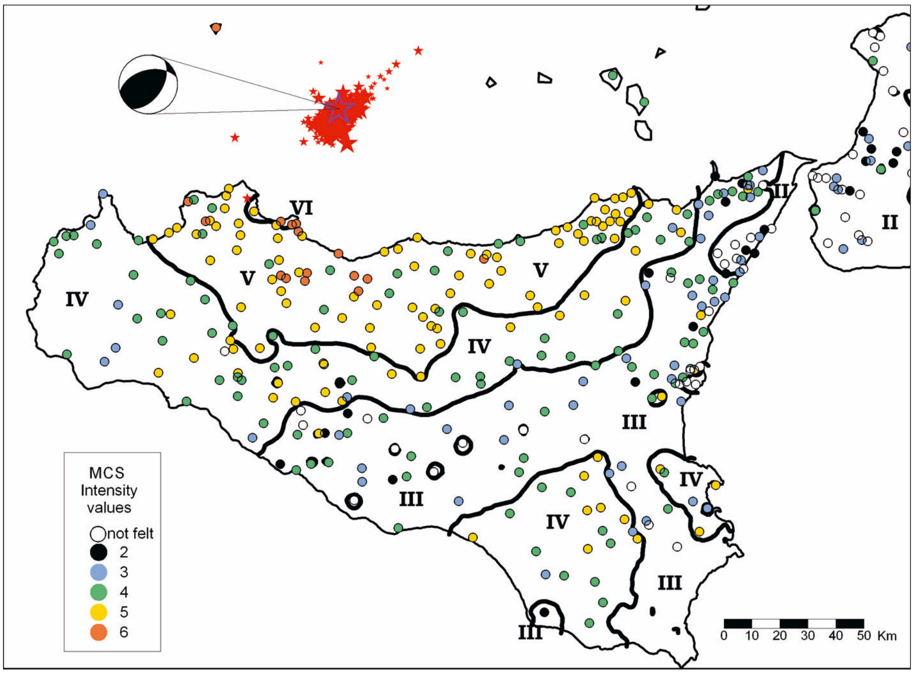

Fig. 1. Macroseismic data of September 6, 2002 event with smoothed and interpolated field reconstruction (black isoseismals). Original intensity values are represented by color dots, while epicenters of the sequence are identified by red stars.

The analyzed data came from macroseismic questionnaires that the Italian INGV (Istituto Nazionale di Geofisica e Vulcanologia) send to every village within a specific distance from the earthquake epicenter. The questionnaire comprises 80 questions mainly based on the effects described by MCS intensity scale.

Macroseismic effects (fig. 1) were noticed across all over Sicily and in part of the Calabria region and they were collected as 549 completed questionnaires from 360 different villages (De Rubeis *et al.*, 2003). Mercalli-Cancani-Sieberg intensity was defined on each location of the territory following methods described in De Rubeis *et al.* (1992). Macroseismic intensities range from not felt to a few data of VII degrees, with the majority of data occurring within IV and V degrees. III, II and not felt degree are shown within an almost horizontal central belt, which introduces a peculiar character to the field: an anomalous increment in intensity in the south of Sicily. Intensity data were filtered and interpolated using a kriging method based on a modeled experimental semivariogram connected to a fractal dimension of intensity data. This choice permitted a separation of regional field from noise (De Rubeis *et al.*, 2003).

2. Data analysis

Many people reported having heard a rumble shortly before or during the earthquake. Information on this effect was collected in two ways: one was a questionnaire aimed at describing the sound heard that people voluntarily compiled on line; the other was the standard macroseismic questionnaire in which a question was pertinent to the hearing of earthquake sounds during the quake. We received 38 compiled questionnaires

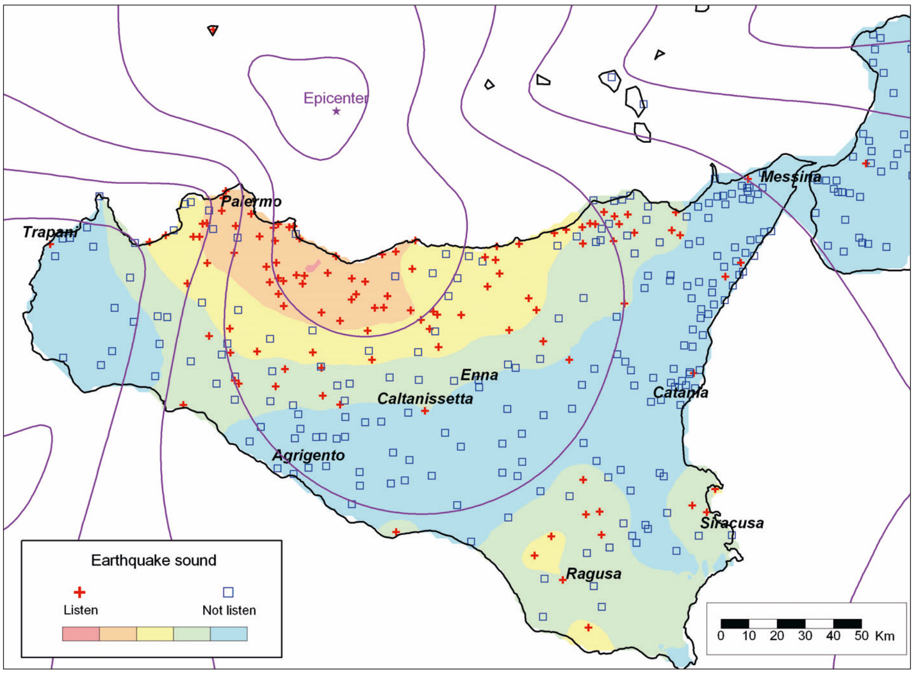

Fig. 2. Earthquake sound heard. Original data with its interpolated and smoothed spatial reconstruction (color shading), compared with the theoretical sound pressure level in relative values (violet contour of equidistance 10 dB) obtained using focal mechanism data.

of the sound oriented kind. The analysis of these shows that many people in Palermo city or nearby were able to identify the source direction, stating that the rumble was coming from the north. In most cases, the sound loudness was compared to that of heavy traffic, often capable to waking people up.

A larger data set came from the macroseismic questionnaire. Such data are treated statistically in a simple way, to assure the mitigation of anomalies and the spatial continuity of answers. Errors may be due to misinterpretation of sounds (buildings or other structures produce sound during the shaking) or, by simply underestimating the process due to attention driven by other more involving effects (shaking, damage, etc.). This binary information is converted by simply counting the percentage of affirmative perception on total answers, weighted by a power 2 of distance, inside a circular area of 30 km. Such filtered and interpolated data are compared with a theoretical model of the acoustic pressure transmitted from the *P*-waves to the air in each point, calculated using the focal mechanism parameters of the event and, consequently, the radiation pattern of *P*-waves (Tosi *et al.*, 2000). Results are depicted in fig. 2 where point data (heard, not heard) are plotted with their smoothed interpolation and theoretical sound pressure level. The theoretical field is represented in the figure with a contouring of decibel relative value, as the absolute sound pressure level can vary widely in relation to the soil properties in each site. Sound was heard by many people until distances of around 150 km in an ESE direction from the epicenter, and until distances of 110 km to the south. Then after a belt of practically total absence, sound was heard again on the Iblei Mountains, within a range of 165 to 220 km from the epicenter.

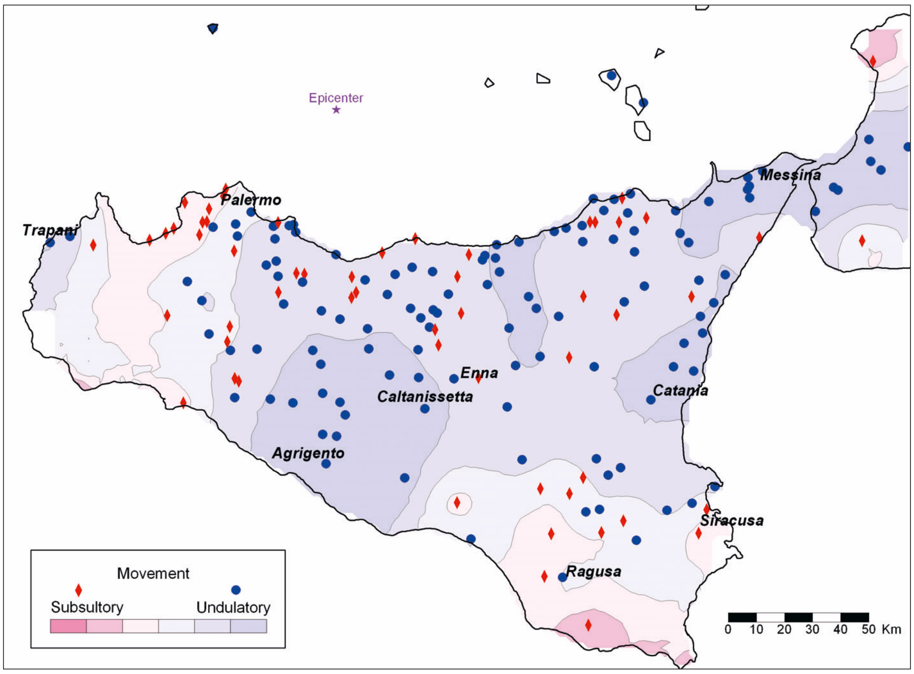

Fig. 3. Prevailing type of ground movement perceived by people during the event (subsultory or undulatory). Original data are represented with their interpolated and smoothed spatial reconstruction (color shading).

The second effect investigated concerns the kind of movement felt: the choice is between subsultory and undulatory. The resulting field is represented with data in fig. 3. There is a prevalence of undulatory response over most of the island of Sicily and the overall pattern is different from that of the other investigated effects. It is interesting to note that in the southern part of the island (Mt. Iblei area), corresponding to a relatively high MCS intensity, the kind of movement in prevalence is subsultory. Also for earthquake sound this zone is particular, in fact, several locations here reported hearing a quake rumble at more than 160 km of distance from the epicenter. Such a coincidence supports the hypothesis of site amplification behavior in the area.

Similar attention was given to another effect not considered for standard intensity evaluation. Complete questionnaires contained information on the degree of fear felt by people: nobody, few, many or all. These categories were ranked and used to build a continuous smoothed and interpolated field. The method followed is similar to that used to build a sound field. Fear can be due to several factors such as the MCS intensity level, earthquake sound, people's excitability and their group influence, etc. Results shown in fig. 4 reveal an overall pattern close to both the filtered intensity field and sound. Thus, all fields collaborate to confirm a general pattern of effects provided by this seismic event.

3. Discussion

From the analysis of the earthquake sounds it can be seen that the area where the rumble was heard by most people is in good accordance with the modeled acoustic pressure given by the *P*-waves. On the contrary, the comparison with the S_v radiation pattern showed a minimum in

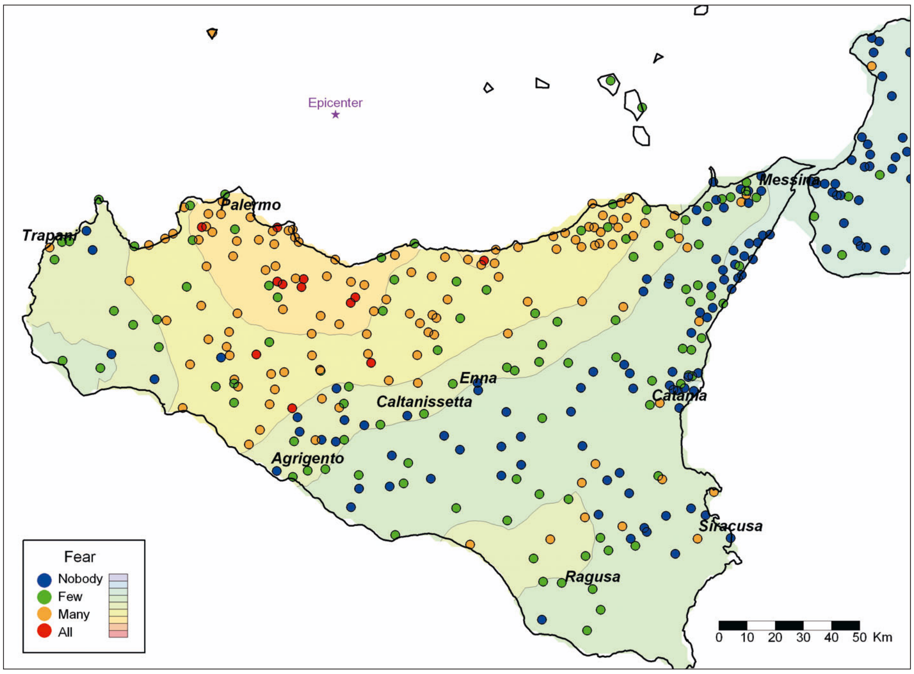

Fig. 4. Fear felt by people during the event with its interpolated and smoothed spatial reconstruction: compare these results with the macroseismic intensity field (fig. 1).

the same zone. It is interesting to note that in the central belt of the island, where the sound was not heard, there is a prevalence of undulatory movement. The explanation can be that here the distance from the epicenter is 100 km. According to Suhadolc and Chiaruttini (1987) at these distances the largest component of motion is the horizontal one, due to the L_g-wave group. In the Mt. Iblei area, beyond 150 km, people reported having heard the earthquake sound and the ground movement is again, as near the source, subsultory. Using the event focal mechanism it was possible to calculate that in the SE direction there was a minimum in the radiation pattern of the *S*-wave, thus L_g phase (resulting from the interference of multiple *S*-wave reflections at the Moho discontinuity) was no longer dominant. The sound here could have been due to the critically refracted *P*-wave traveling in a low attenuation basement, probably in association with site effect.

4. Conclusions

Peculiar macroseismic effects, not strictly related to a particular intensity degree or to a specific energy release, can be of interest if sufficiently collected and interpreted. Answers on simple perception of sound heard during the quake, fear felt and description of felt ground movement were systematically collected for the event that struck Sicily on September 6, 2002 (magnitude $M_l = 5.6$, $M_W = 5.9$). Original data were composed basically of qualitative information: heard sound and ground movement are divided into two categories (heard, not heard and subsultory, undulatory respectively), felt fear was ranked into four levels (nobody, few, many or all). Spatial distribution of all this information followed village locations and a simple averaging statistics was implemented to give continuity to data. Smoothed and interpolated sound fields showed a correlation with both fear felt and macroseismic intensity field: the southern amplification of effects was confirmed. The general theoretical behavior of sound sufficiently agreed with experimental data. Ground movement was generally undulatory except for the western side of Sicily and southern side where it had a remarkable amplification character for most macroseismic effects. Finally, the spatial distribution of the fear effect showed that the overall pattern of the MCS intensity field can be reconstructed even using very simple transient effects.

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