ANNALS OF GEOPHYSICS, VOL. 48, N. 2, April 2005

What is a surprise earthquake? The example of the 2002, San Giuliano (Italy) event

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Abstract
Both in scientific literature and in the mass media, some earthquakes are defined as «surprise earthquakes». Based on his own judgment, probably any geologist, seismologist or engineer may have his own list of past «surprise earthquakes». This paper tries to quantify the underlying individual perception that may lead a scientist to apply such a definition to a seismic event. The meaning is different, depending on the disciplinary approach. For geologists, the Italian database of seismogenic sources is still too incomplete to allow for a quantitative estimate of the subjective degree of belief. For seismologists, quantification is possible defining the distance between an earthquake and its closest previous neighbor. Finally, for engineers, the San Giuliano quake could not be considered a surprise, since probabilistic site hazard estimates reveal that the change before and after the earthquake is just 4%.

Key words *earthquake statistics – Molise earthquake*

1. Introduction

On October 31 and November 1, 2002, two earthquakes of M_w 5.7÷5.9 occurred in the Molise Region in Southern Italy. The sequence caused widespread damage and claimed 28 lives in the town of San Giuliano, with a maximum intensity equal to VII-IX degrees according to the European Macroseismic Scale (Mucciarelli *et al.*, 2003). Just a fraction of the affected area was classified as seismic by the Italian building code (Pinto *et al.*, 2003). In the public debate following the event, some defined it as a «surprise earthquake»; others noticed that the new proposal for Italian seismic zonation (issued before 2002) included all the damaged municipalities, thus the event was expected.

As for any other nation, the seismic history of Italy is full of events that many think of as «surprise earthquakes». Seismologists have been warned to «prepare for the unexpected» (Kanamori, 1995). They share the notion that is now impossible to predict when an earthquake is going to happen. However, even the most skeptic about prediction and forecasts agree that the location of future earthquakes should be known thanks to our knowledge of past seismicity or detailed geological studies. Thus, when an event occurs in an unexpected location it is considered a «surprise earthquake», not only by laymen or the media, but also by specialists. Earthquakes defined as a surprise in the recent literature occurred in various locations around the world: Greece (Stiros, 1996), Turkey (Buckthought, 1999), Taiwan (Lew *et al.*, 2001), Australia (Crone *et al.*,

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2003). On the contrary, sometimes it is remarked that an earthquake occurred precisely where it was expected to happen, like the Loma Prieta, 1989 event (Harris, 1998).

This paper deals with the the concept of «surprise earthquakes» considering two sides of the problem: i) a quantitative, probabilistic definition is needed, and ii) the different meaning of «surprise» that a geologist, a seismologist or an engineer may have in mind. For a geologist, a surprise earthquake is one occurring on a fault that was unknown or considered a non-active one. For a seismologist, the surprise comes when the event happens far from previously mapped historical or instrumental epicenters. For an engineer the surprise is the occurrence of damage in an area not classified as seismic, or that never experienced high macroseismic intensities. In any case, a simplifying definition is that everyone perceives a «surprise earthquake» when it is «distant» from what is known *a priori* (be it faults, epicenters, intensity or expected acceleration maps). The problem is to quantify this distance to transform a subjective perception into a numerical probability. It is not easy to define the meaning of probability attached to earthquakes (see Stark and Freedman, 2003). Here the term«probability» is used according to a subjectivist approach (De Finetti, 1975) expressing probability as confidence in a given result. To put it simply, a probability is small or great according the amount of money one would bet on that outcome.

2. The geologist’s point of view: analysis of a fault database

Italy has a recent database of potential sources for earthquakes with magnitude greater than 5.5. (Valensise and Pantosti, 2001). The lower limit of this database makes the San Giuliano event a suitable subject for our discussion. The database comprises two kinds of seismogenic sources: i) faults known from geological or geophysical studies (that may lack association with known historical earthquakes); ii) sources derived from intensity maps with the methodology proposed by Gasperini *et al.* (1999). The latter is a modern representation of macroseismic historical data, but adds no geological information from what is known from historical seismology (*i.e.* a fault must be there because a large earthquake occurred). The database comprises 60 geological sources and 383 historical sources. Correcting for the geological faults without known earthquakes associated with them, it turns out that 85% of past strong earthquakes are not yet associated with a fault mapped by geologists. This is not a bad result, considering that up to 1984 the ruling paradigm stated that due to morphology, climate and low recurrence rate no geological evidence could be found for Italian events. Figure 1 shows the location of the geological/geophysical faults with the location of the San Giuliano event. The quake did not occur on a previously known fault. The database is a work in progress, which at the moment simply contains too few data to permit a statistical estimate of the probability of «surprise earthquakes» according to the geologist’s point of view.

3. The seismologist’s point of view: analysis of seismic catalogues

The most recent and official catalogue of Italian damaging earthquakes is the CPTI catalogue (Boschi *et al.*, 1999). It contains 243 events with epicentral intensity equal or greater to VII degree MCS from 217 B.C. to 1984 A.D. Figure 2 shows these events with the location of the San Giuliano quake. Was it a «surprise quake»? As said before, a seismologist may define an earthquake as a surprise if it comes outside the previously known locations. It does not necessarily match another epicentral location, since we tend to be a little indulgent about the possible precision of very old quakes. This concept is easy to quantify: it is sufficient to calculate for any earthquake in the catalogue the distance from all the preceding events and then take the minimum (it is the closest neighbor distance, but just for preceding events, hereafter CPND). The plot of CPND *versus* time is expected to be a monotonically decreasing function. As the catalog completeness increases we know about more and more events, thus increasing the probability that after *N* events,

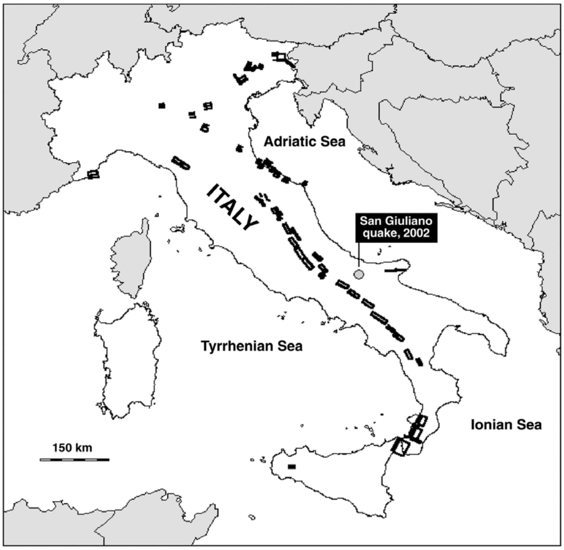

Fig. 1. Location of the geological/geophysical faults from the database of potential sources for earthquakes with magnitude greater than 5.5. (Valensise and Pantosti, 2001) with the location of the San Giuliano event.

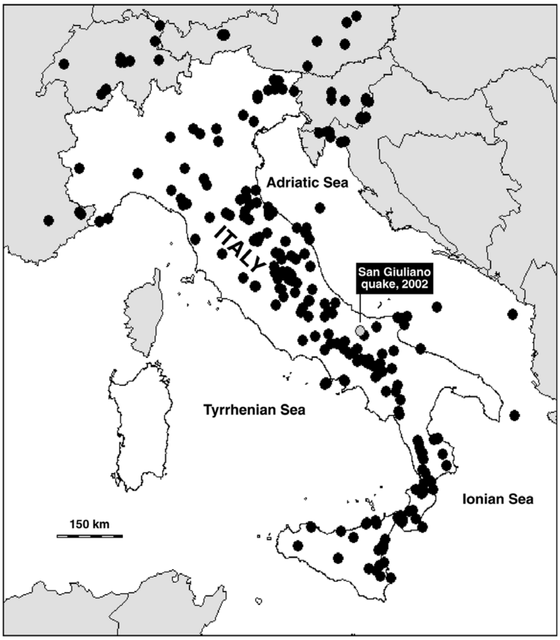

Fig. 2. Events with $I \geq$ VIII MCS from the catalogue of Italian damaging earthquakes (CPTI catalogue, Boschi *et al.*, 1999) with the location of the San Giuliano event. Circle radius is the 75 percentile of the CPND distribution (see text for details).

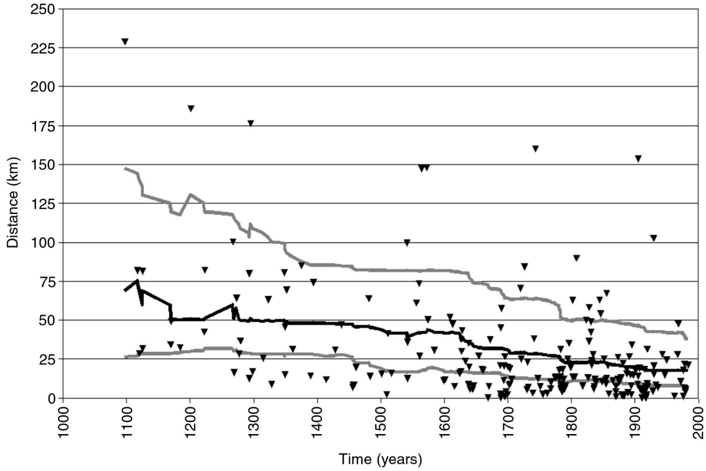

Fig. 3. Individual values of CPND with three percentiles (25%, 50% or median, 75%) calculated from the beginning of the catalogue to the *n*-th quake.

$N+1$ will occur close to a previously known one. If the hypothesis of space stationarity is correct, given a long enough time, CPND should reach the zero limit, *i.e.* all events will occur where at least one was located in the past. Figure 3 shows the CPND function for the CPTI catalog , $I \geq$ VIII MCS. The plot starts from 1100 A.D., because the initial part of the catalog was needed to stabilize the statistics shown in the graph. Along with individual values of CPND, fig. 3 reports three percentiles (25%, 50% or median, 75%) calculated from the beginning of the catalog to the *n*-th quake. As expected, the smoothed CPND is a decreasing function, but does not reach zero and even in this century some events exceed the threshold of the upper quartile. The function decreased at a lower rate in the past 4 centuries. This confirms the findings of Albarello *et al.* (2001) concerning the completeness of the catalog for most of the Italian territory for $I \geq$ VIII MCS after 1600.

If we recalculate the cumulative distribution from 1600 to the present, we obtain a possible key for assigning a probability value to personal beliefs about «surprise earthquakes». It is possible to derive the observed non-exceedance probability for three sample quakes:

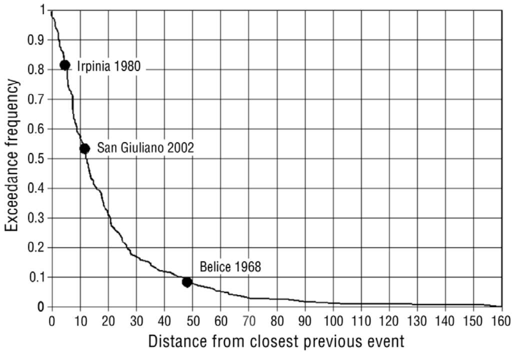

Fig. 4. CPND cumulative exceedance frequency (from 1600 to the present).

i) The Irpina, 1980 earthquake. This event has at least one historical «twin» in 1694, and palaeoseismological observation were able to trace back repetitions on the same fault; for Italy, this is the best known example of an event that occurred where expected.

ii) The Belice, 1968 event. This was a swarm that caused heavy damage in Eastern Sicily. Despite *a posteriori* geological studies, this is still an earthquake that seems to come out of the blue; everybody agrees that it would have been impossible to expect it.

iii) The San Giuliano, 2002 quake, that was a surprise for some but not for all.

The relevant CPND are 6, 12 and 48 km respectively. Figure 4 reports the cumulative non-exceedance observed probability from 1600 to the present. The three earthquakes are plotted at their relevant CPND. The Irpinia, 1980 quake is well within the first quartile of the distribution. An earthquake that fully behaved according to our beliefs occurred closer to a previous neighbor than the 80% of all the events with $I \geq$ VIII MCS. The Belice, 1968 earthquake, on the contrary, falls well above the last quartile, with just about 10% of events occurring at a greater distance from their previously known neighbors. The San Giuliano, 2002 event lies before the median, so it is difficult to call it a surprise when more than half of the catalog has a larger CPND.

4. The engineer's point of view: analysis of ground motion probability

The last point of view about «surprise earthquakes» is the engineer's one. It has been mentioned before that the San Giuliano municipality was not classified as seismic in 2002. However, a proposal for new classification had already been completed by the date of the quake, including San Giuliano among the municipalities where anti-seismic design is mandatory. The new Italian zonation become official law in 2003, assigning to San Giuliano a PGA = 0.25 g. This would have been sufficient for an engineer to expect the San Giuliano quake. Moreover, the highest intensity observed at the San Giuliano was VIII-IX MCS, due to a swarm of earthquakes which occurred in the Southern Apennines in 1456.

To quantify how much the hazard estimate has changed before and after the 2002 quake, a direct site hazard estimate can be performed. Galli *et al.* (2003) provided a detailed seismic history for the San Giuliano municipality. Their site intensity catalog comprises 40 events with $I \geq$ V MCS from 1125 to the present. For 21 earthquakes a direct observation is available, while for the others intensity is estimated from an attenuation relationship or from isoseismal patterns. To estimate probabilistic seismic hazard at a site we used the non-parametric procedure first proposed by Magri *et al.* (1994) and then refined by Albarello and Mucciarelli (2002). The estimate was performed using the catalog up to 2001 and then adding the 2002 event. Figure 5 shows the average return times estimated separately for intensities ranging from V to VIII degree MCS. It is clear that the occurrence of the 2002 quake leaves unchanged the expected average return times for intensities V and VI, while it decreases the estimate for $I =$ VII by a mere 9%. For intensity VIII, the occurrence of the 2002 events increases the return time of just 4%, well within the error limits.

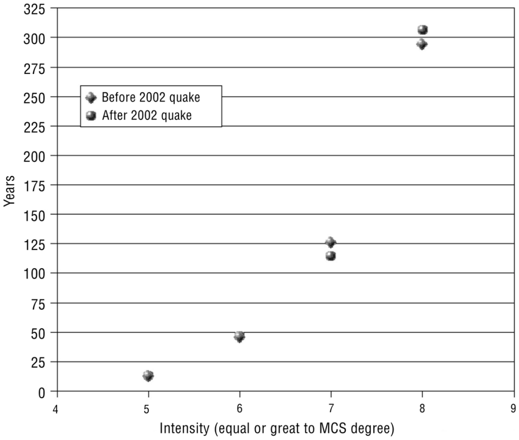

Fig. 5. Average return times estimated separately for intensities ranging from V to VIII degree MCS using the catalogue up to 2001 and then adding the 2002 event, following the procedure proposed by Albarello and Mucciarelli (2002).

5. Conclusions

The San Giuliano, 2002 events gives the opportunity for some thoughts on the meaning of «surprise earthquakes». The meaning is different, depending on the disciplinary approach. For geologists, the Italian database of seismogenic sources is still too incomplete to allow for a quantitative estimate of the subjective degree of belief. For seismologists, quantification is possible defining the distance between an earthquake and its closest previous neighbor. The distribution of CPND is monotonically decreasing, but not yet equal to zero. This may imply that there is a non-null probability that future earthquakes with $I \geq$ VIII MCS may catch Italian seismologists by surprise. The quantification obtained with CPND seems suitable for describing the degree of expectation relevant to two extreme cases (Irpinia, 1980 and Belice, 1968).

Finally, for engineers, the San Giuliano quake could not be considered a surprise, since PSHA maps and maximum observed intensity were not exceeded by this quake. A site hazard estimate reveals that the change before and after the earthquake is just 4%.

Acknowledgements

Thanks to Francesco Mulargia and Maria Rosaria Gallipoli for stimulating discussions and suggestions.

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(received July 15, 2004;
accepted October 05, 2004)