Recent seismicity before the 24 August 2016 Mw 6.0 central Italy Earthquake as recorded by the ReSIICO seismic network

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Abstract

We present the seismicity of the last four years before the Mw 6.0 earthquake of August 24, 2016, 01:36 UTC in central Italy, with the aim of understanding the preparatory phase of the event. Our preliminary results show that no significant seismic sequence occurred in the months before the mainshock of August 24, 2016 and that there is little similarity between seismicity clusters in the last four years and the aftershocks. We pay attention to differences between the preparatory phase of the Amatrice earthquake and two other seismic sequences: the 2009 L’Aquila earthquake that was preceded by a seismic sequence, and the 2013-2015 Gubbio seismic swarm that, to date, did end without including any strong event.

I. INTRODUCTION

Continuous seismic monitoring near active faults allows to follow and reconstruct the space-time evolution of seismicity, before, during and after a destructive earthquake. It can also be observed that seismicity often tends to cluster, both before and after strong earthquakes, also at great distance both in time and in space [Kagan and Jackson 1991; Mulargia and Geller, 2003; Marzocchi and Lombardi, 2008, 2009; Kagan, 2014; Parsons et al. 2015; Gasperini et al., 2016]. Therefore, seismic sequences that follow Omori’s law [Omori, 1894] and seismic swarms (a subcategory of the sequences characterized by a chaotic trend in magnitude over time) are often observed [De Gori et al., 2015].

In literature there are many examples in which foreshocks are cited as precursors of strong earthquakes [ie.: Aki, 1981; Allen, 1982; Guagenti et al., 1991; Jones, 1985; Vere-Jones et al., 1998; Bakun et al., 2005]. In Italy, the theme vigorously reappeared after the April 6, 2009 L’Aquila earthquake [Grandori and Guagenti, 2009; Sugan et al., 2014; Papadopoulous et al., 2010], characterized by an increase of seismic activity before the mainshock [Chiaraluce et al., 2011; Valoroso et al., 2013].

A detailed investigation of strong earthquakes and sequences in the area around L’Aquila has shown that there is no link between the foreshocks seismic sequences and mainshocks [Amato and Ciaccio, 2012] and that in most cases earthquakes are not preceded by seismic sequences at all. More than twenty seismic sequences occurred in the last two centuries did not result in a strong seismic event [Amato and Ciaccio, 2012; Galadini, 2013]. Out of a total of 127 seismic sequences recorded in Italy between 2008 and 2010, only one was followed by a destructive event [Arcoraci et al., 2011]. Finally, considering the catalog of Italian earthquakes since 1950, only
0.8% of large sequences was followed by a strong earthquake [Marzocchi and Zhuang, 2011]. Gasperini et al. [2016] concluded that about half of all recorded mainshocks are not preceded by any kind of earthquake precursor in a reasonable temporal range.

This work shows the seismicity of four years before the earthquake of August 24, 2016 (Mw 6.0), recorded from the seismic data collected in the eastern central Italy from the ReSIICO network [Monachesi et al., 2013], with the aim of understanding whether any link exists with the seismic sequence. To get a basis for comparison, the long 2013-1015 Gubbio seismic sequence is also analyzed. Up to now this recent sequence has not yet included any strong earthquakes, and it evidences a different style of seismic activity with respect to the patterns attested in the L’Aquila (foreshocks-mainshocks-aftershocks) and Amatrice (mainshocks-aftershocks) earthquakes.

II. SEISMICITY FROM 2012 TO 2016 IN THE EPICENTRAL AREA OF THE AUGUST 24, 2016 EARTHQUAKE

In the last four years, a high resolution seismic monitoring system has been developed in central Italy [Amato and Mele, 2008; Chiaraluce et al., 2014; Monachesi et al., 2013]. Seismic stations belonging to the INGV National Seismic Network, Near Fault Observatory Taboo and to the networks of the Marches and Umbria Regions - centralized in real time at the Ancona INGV headquarters - were brought together to form the ReSIICO network, including a total of 101 stations, 49 of which are equipped with velocimeters, 24 with accelerometers and 28 with both. In some cases, the density and geometry of the monitoring network allow to depict in great detail the geometrical characteristics of seismic patterns, even for limited extension [Valoroso et al., 2013; Marzorati et al., 2014].

The data collected by the ReSIICO dense network allowed to develop accurate propagation models [1D – De Luca et al., 2009, and 3D – Carannante et al., 2013] with whose help a better constrain of the location of recorded earthquakes has become possible. In this work, we will analyze the seismic events of the last four years, starting from August 1, 2012, as derived by the routine location analysis procedure of the INGV-Ancona working group, that integrates the results of an automatic P and S picking procedure [Spallarossa et al., 2014; Scafidi et al., 2016] with the human expert analysis for the most critical cases and M ≥ 2.5 events. Both the automatic and human revision procedures use the Hypoellipse location code [Lahr, 1999], the 1-D model derived by De Luca et al. [2009] and relevant station corrections, updated for the new stations. The same procedures are used also for the analysis of the 2016 sequence. A comparison of automatic and human-revised locations pointed out that, for the automatically well-located events, more than 90% of the automatic locations presented a distance from the human-revised one lesser than the estimated formal error [Cattaneo et al., 2016]. From 2012 onwards the network geometry in this area was quite stable and the detection and location procedures were well established: the obtained catalog can thus be considered homogeneous [Cattaneo et al., 2016; Marzorati and Cattaneo, 2016].

Fig. 1 shows the recorded seismicity in the investigated area, subdivided in four 1-year panels, going from August 1 to July 31 of the next year. The whole dataset is composed by 17758 events, whose magnitude ranges from -0.8 to 3.9. The area interested by the August 24, 2016 mainshock and by the following sequence (“source area” in the following) is depicted in thin
Seismicity appears rather uniformly distributed, in space and in time, both within the source area and in the surrounding zones. Small clusters of seismicity, often not related to any event with magnitude larger than 3.0, can be recognized in the source area. Some events with $M_L \geq 3.0$ are present in all panels, with a relatively higher rate of occurrence in the 2013-2014 period. The $b$-value, computed on the whole analyzed area for the different time-periods, does not show significant deviations with respect to the mean term of 1.0, above a threshold of completeness magnitude ranging between 0.8 and 1.1. The seismicity rate does not show significant variations in the last four years, as depicted by the cumulative number of events (Fig. 1e). Also the moment release rate (Fig. 1f), after two step in 2013, linked to two events of magnitude 3.8 and 3.9 respectively, seems to depict a steady state for the last two years and a half. In order to investigate if the previous seismicity within the source area affected the same structures activated with and after the mainshock, we applied a cross-correlation technique to evaluate the similarity between the waveforms of the events before the sequence and the aftershocks. In particular 7 clusters of events were selected, concentrated in areas between 2 and 10 km of extension and in a time frame smaller than one year (Fig. 2). Cluster SEQ01 occurred in the 2012-2013 time frame, clusters SEQ02, SEQ03 and SEQ04 in 2013-2014 and are the closest to the mainshock epicenter, SEQ05 occurred in 2014-2015, SEQ06 and SEQ07 in 2015-2016. Thus SEQ02, SEQ03 and SEQ04 are rather close in time, but clearly distinct in space; SEQ05 and SEQ06 are partially overlapping in space, but separated in time by more than one year; SEQ01 and SEQ07 are more closely linked in space, but are 3 years apart in time. It seems that the space-time evolution of these clusters does not show any particular relationship.
The events of each cluster were cross-correlated with the aftershocks of the 2016 sequence, selecting just the events located in an area slightly larger than that depicted by the cluster, in order to take into account possible location errors. It is well known that a high similarity of waveforms among different events allows to hypothesize a common mechanism and closely spaced sources [Waldhauser and Ellsworth, 2000]. Fig. 2 shows a synthetic view of the results: for each cluster, the correlation matrix is presented. Each matrix is subdivided by thin gray lines in four quadrants: the lower left one represents the correlation of the events of the clusters, the upper right the correlation of the aftershocks and the other two the mixed correlations.

*Figure 2.* Clusters of seismicity in the source zone of Amatrice sequence. The cross-correlation coefficient matrix are show in the small panels. The seismicity clusters are colored following an annual time scale.
Looking at the lower left quadrants, it is quite evident that, as a general trend, each cluster presents a rather high level of similarity, sometimes subdivided in more sub-clusters (as in the case of SEQ01, where a clear sub-family subdivides the sequence). The upper right quadrants show significant levels of correlation, but in general lower values with respect to the previous case: this can be due to the larger extension of the selected events, but also to the larger magnitude span of these data with respect to the clusters. On the contrary, the mixed correlations (clusters vs aftershocks) show, as a mean term, lower values. This is particularly true for SEQ02, SEQ03 and SEQ04, the 3 clusters surrounding the mainshock epicenter: here the correlation values are marginal, with few exceptions, leading to hypothesize that the clusters activated structures well distinct from the structures responsible of the 2016 sequence. Also SEQ07 shows very low values, while SEQ01, and in particular SEQ05 and SEQ06 present higher degrees of similarity. Preliminary results show that the nucleation of the sequence affected structures different from those responsible for the previous seismicity and re-activated some shallow secondary structures of the northernmost sector of the sequence.

In order to add further information, we can compare the depth distribution of the previous seismicity with those of the sequence. For this comparison we use the preliminary locations (mainly provided by the automatic procedure run in Ancona), that are rather homogeneous with the previous catalog, also for what regards the 1D propagation model used for locations, and thus focal depths are more directly comparable.

Fig. 3a shows the epicentral locations of the best-located events of the first month of the sequence (9353 events), and the trace of 4 cross-sections, approximately perpendicular to the main trend of the sequence. The color scale and the symbol size represent the local magnitude. Fig. 3b shows the cross-sections of the sequence: thin green lines are depicted just to highlight the main trends of the seismicity, mainly the most energetic one, without any presumption of structural interpretation but just to simplify the comparison with the previous seismicity. Indeed the same lines are reported in Fig. 3c, that show the seismicity from 2012 to 2016. It is quite evident that, even if some events of the previous seismicity fall in the areas activated by the sequence, the general trend of the depth distribution is rather different, mainly for the southernmost section. This observation is still more evident if we limit the analysis to the last 4 months before August 24, 2016 (Fig. 3d): none of the geometries recognizable in the sequence are evident in these data; the seismicity is always present (1179 events) but of low energetic level (maximum magnitude 2.8) and without any clear cluster, in particular in the area of nucleation of the mainshock between the urban centres of Accumoli and Amatrice.
Figure 3. Sketch of seismicity in depth: a) map of Amatrice sequence; b) sections of Amatrice sequence; c) sections of four years seismicity from 2012 to 2016; d) sections of seismicity of the last 4 months before the Amatrice sequence. Thin green lines: main trends of the seismicity.
III. THE 2013-2015 GUBBIO SWARM

While the sequence of L’Aquila in 2009 was preceded by foreshocks [Chiaraluce et al., 2011], the preliminary results of the previous section show that the seismicity recorded for months prior to the 2016 Amatrice sequence had the same characteristics as in the previous four years. With the aim to add examples to stress the idea that seismicity can represent foreshocks of a greater earthquake only in some cases and not always, we show another type of sequence, similar to a swarm, which hit the area of Gubbio (Umbria) over a period of at least a year and a half. Although most of the events were small (only two reached the maximum magnitude 3.9), they were perceived by the population over a lengthy period of time, and put local authorities on the alert. Fig.4a depicts 69574 events in a magnitude range from -2.2 to 3.9 recorded from August 2009 to August 2016. This unique data set was collected thanks to the presence, in addition to the INGV National Seismic Network, of the Near Fault Observatory Taboo [Chiaraluce et al., 2014]. The high-resolution network started recording 3 years before the beginning of the swarm, so the background seismic rate of the area is visible (Fig.4b). In the early months of 2013, the rate increased and a few earthquakes of magnitude 3 started appearing. The rate remained very high over the whole of 2013-2014, starting to fall down only in the first half of 2015. At the end of 2015, the rate of seismicity returned to levels similar to those observed before the start of the sequence, no event of magnitude greater than 3 being recorded anymore. Therefore, this prolonged seismicity cluster does not represent aftershocks or foreshocks of a destructive earthquake near in space and reasonable time.

IV. CONCLUSIONS

On August 24, 2016 at 01:36 UTC a Mw 6.0 earthquake struck central Italy, starting a sequence that is still ongoing while we are preparing this report. The seismicity recorded in this area during the past four years was analyzed in order to preliminarily investigate the preparatory phase of the earthquake. Our preliminary results indicate a steady rate of seismicity up to the destructive event. Within the four previous months, seismic sequences did not take place in the vicinity of the source and no magnitude ≥ 3 event was recorded. Through cross-correlation techniques, we verified the low similarity between the clusters of seismicity between 2012 and 2016 and the aftershocks following the event on August 24. In addition, the different distribution in depth of the previous seismicity and the aftershocks shows, at a first glance, that the nucleation of the mainshock falls on a structure different from those concerned in the previous seismicity and the following sequence re-activate only some shallow structures in the northermost part. A more precise and reliable feature of these preliminary results will be obtained from future analysis on revised locations of the seismic sequence with all seismic data available and a 3D velocity model to study the presence of repeating earthquakes. The comparison between the Amatrice sequence, the 2013-2015 Gubbio swarm, that apparently ended in 2016 without producing a strong earthquake, and April 6, 2009 L’Aquila earthquake introduces a further example of different behaviors of the seismicity in the preparatory phases of earthquakes in central Italy.
Figure 4. Seismicity of the Gubbio sequence from August 2009 to August 2016: a) seismicity map; b) cumulative number of earthquakes.

ACKNOWLEDGEMENTS

We thank Viviana Castelli that help us to improve text form.

Some of the figures were created using the GMT software package [Wessel et al., 2013], ZMAP [Wiemer 2001] and ArcGis®.

REFERENCES


