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Recent seismicity before the 24 August 2016 M_W 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 M_W 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; Papadoupolous 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 (M_W 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 lines. 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.

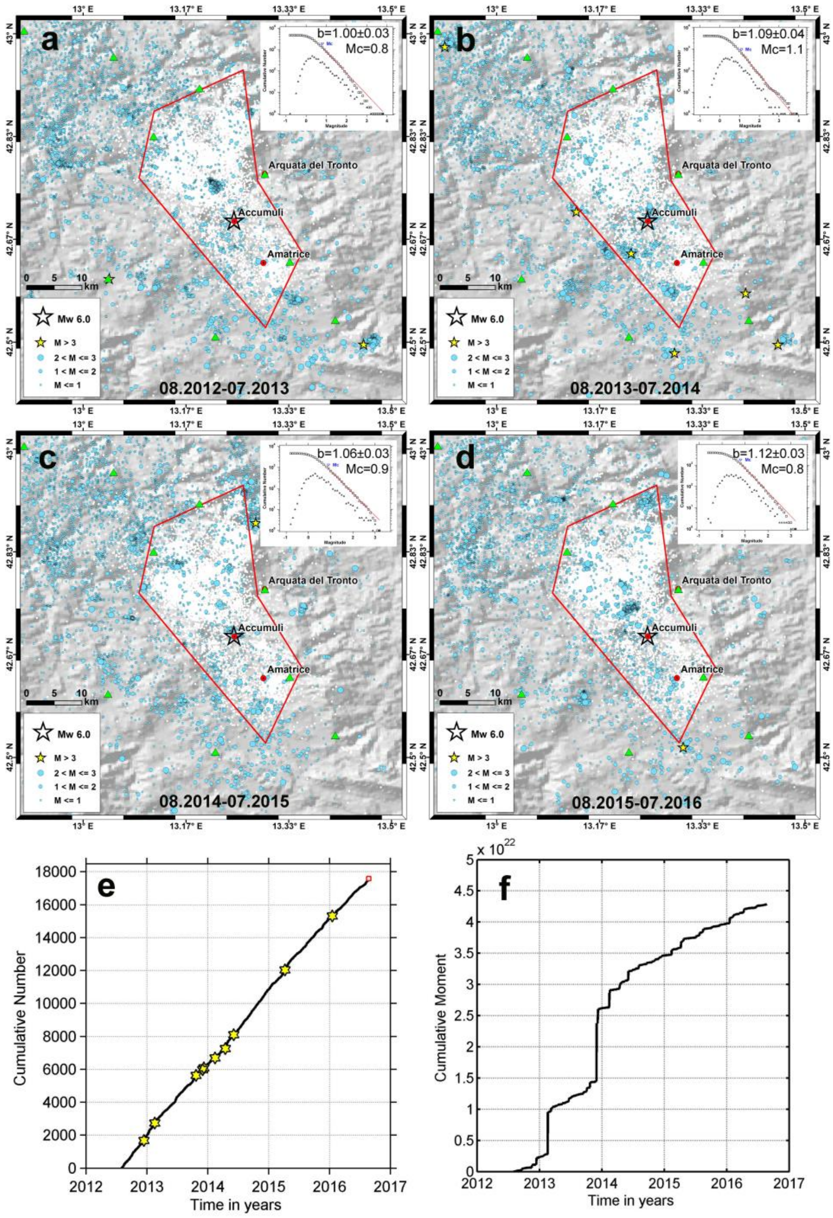

Figure 1. *Seismicity around the Amatrice sequence between August 2012 and July 2016. Red polygon: source area. Black star: epicenter of the August 24, 2016 01:36 UTC M_W 6.0 earthquake. Green triangles: seismic stations. Blue circles: seismic events before the sequence. White circles: seismic events of the sequence; a): seismicity between August 2012 and July 2013; b): seismicity between August 2013 and July 2014; c): seismicity between August 2014 and July 2015; d): seismicity between August 2015 and July 2016; e): cumulative number of earthquakes in the last four years (yellow stars: events $M_L \geq 3.0$); f): cumulative seismic moment released in the last four years.*

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.

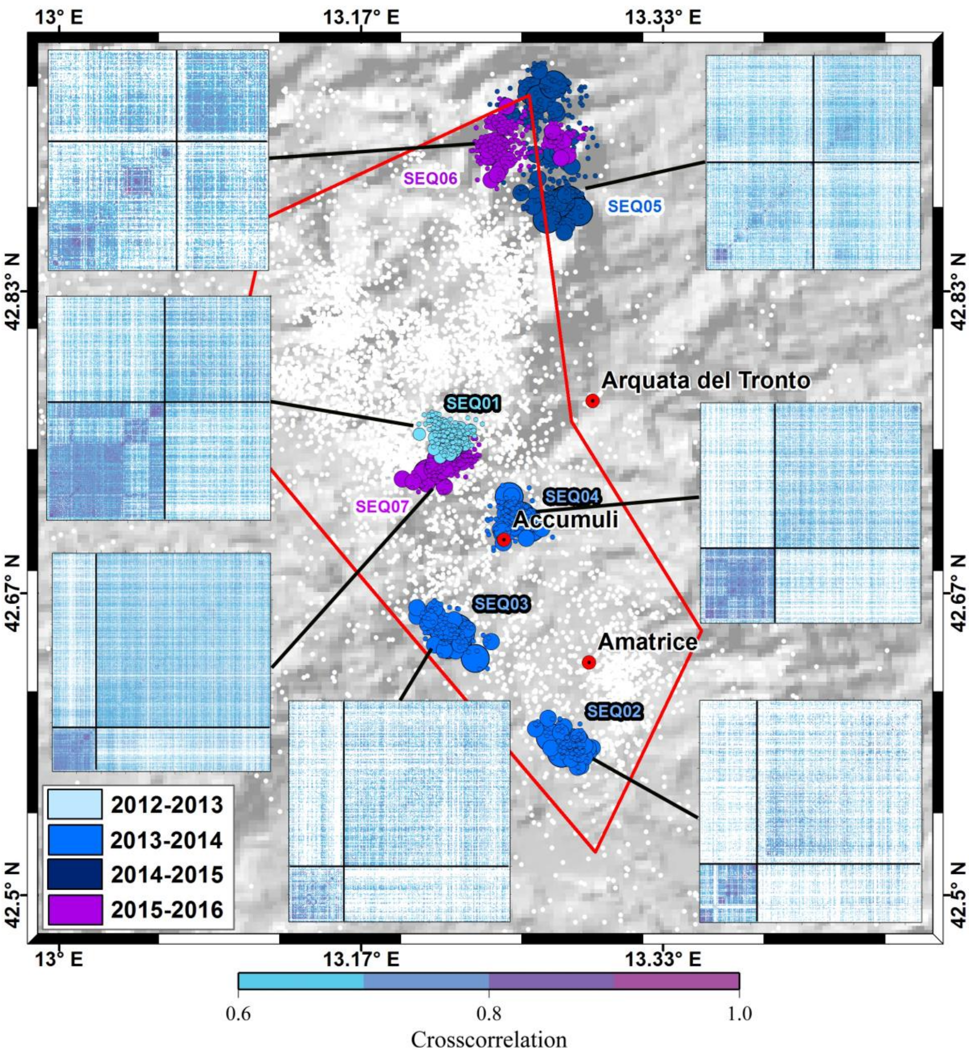

Figure 2. *Clusters of seismicity in the source zone of Amatrice sequence. The cross-correlation coefficient matrix are show in the small panels. The seismicity clusters are colored following an annual time scale.*

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.

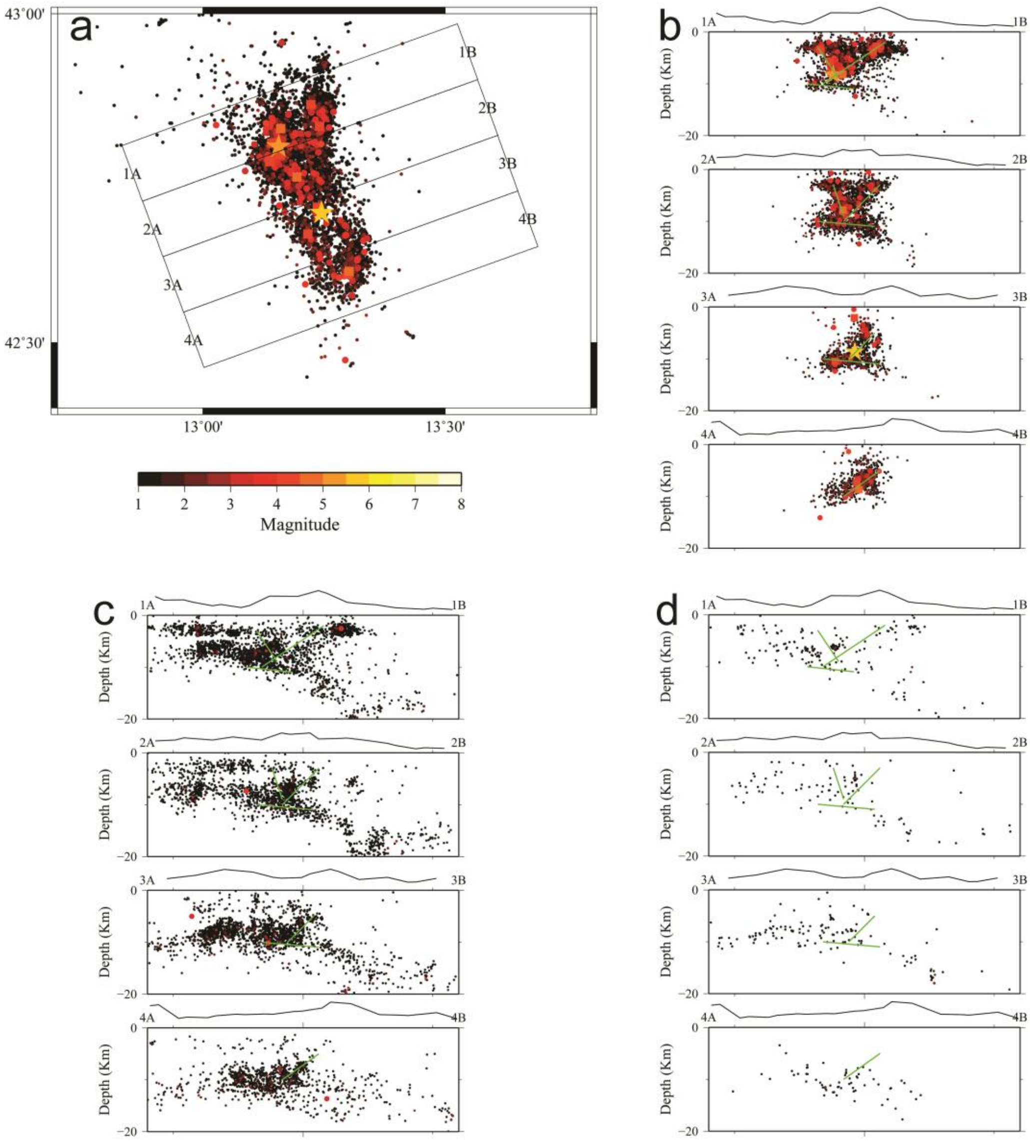

Figure 3. *Sketch of seismicity in depth: a) map of Amatrice sequence; b) sections of Amatrice sequence; c) sections of four years seismicity from 2012 to 2016; d) sections of seismicity of the last 4 months before the Amatrice sequence. Thin green lines: main trends of the seismicity.*

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.

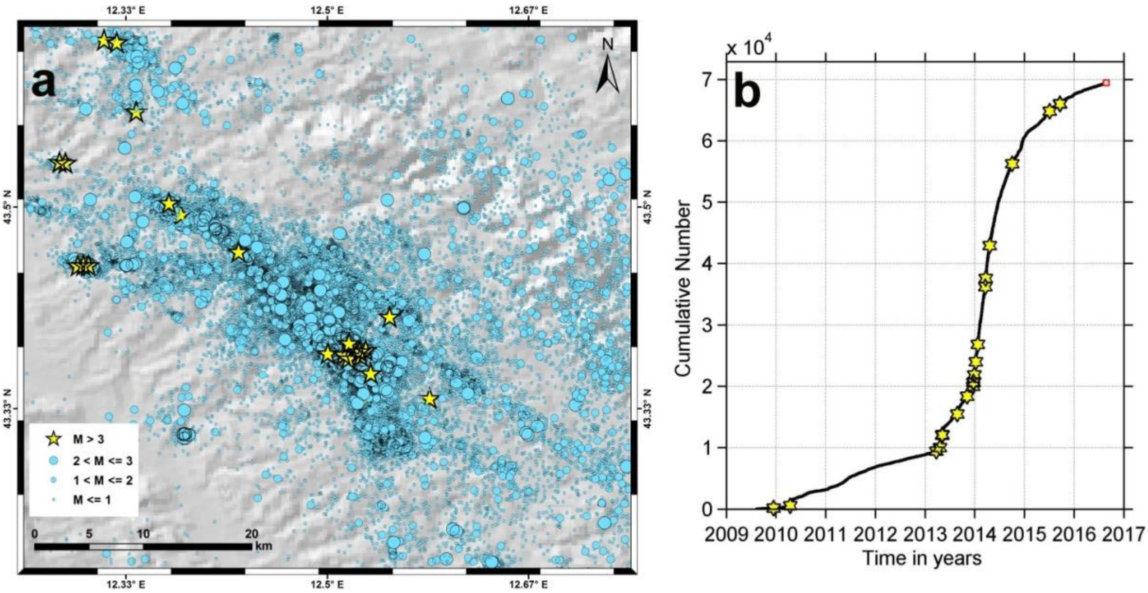

Figure 4. *Seismicity of the Gubbio sequence from August 2009 to August 2016: a) seismicity map; b) cumulative number of earthquakes.*

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REFERENCES

[Aki, 1981] Aki, K., (1981). A probabilistic synthesis of precursory phenomena, in "Earthquake prediction: an international review", Am. Geoph. Un., Washington D.C., 566-574.

[Allen, 1982] Allen, C.R., (1982). Earthquake prediction – 1982 overview, Bull. Seism. Soc. Am, 72, 6, 331-335.

[Amato and Ciaccio, 2012] Amato, A., and Ciaccio M. G., (2012). Earthquake sequences of the last millennium in L'Aquila and surrounding regions (central Italy), Terra Nova, 24, 52-61.

[Amato and Mele, 2008] Amato, A., and Mele F.M., (2008). Performance of the INGV National Seismic Network from 1997 to 2007, Annals of Geophysics, 51, 2/3, 417-431.

[Arcoraci et al., 2011] Arcoraci, L., Battelli P., Castellano C., Marchetti A., Mele F., Nardi A., and Rossi A., (2011). Bollettino Sismico Italiano 2008-2010, 30° Convegno Nazionale, Gruppo Nazionale di Geofisica della Terra Solida, novembre 2011, Trieste (poster).

[Bakun et al., 2005] Bakun, W. H., Aagaard B., Dost B., Ellsworth W. L., Hardebeck J. L., Harris R. A., Ji C., Johnston M. J. S., Langbein J., Lienkaemper J. J., Michael A. J., Murray J. R., Nadeau R. M., Reasenberg P. A., Reichle M. S., Roeloffs E. A., Shakal A., Simpson R. W., and Waldhauser F., (2005). Implications for prediction and hazard assessment from the 2004 Parkfield earthquake, Nature, 437, 969-974.

[Carannante et al., 2013] Carannante, S., Monachesi G., Cattaneo M., Amato A., and Chiarabba C., (2013). Deep structure and tectonics of the northern-central Apennines as seen by regional-scale tomography and 3-D located earthquakes, J. Geophys. Res. Solid Earth, 118, doi:10.1002/jgrb.50371.

[Cattaneo et al., 2016] Cattaneo, M., Frapiccini M., Ladina C., Marzorati S., and Monachesi G., (2016), A mixed automatic-manual seismic catalog for Central-Eastern Italy: analysis of homogeneity (under review to Annals of Geophysics).

[Chiaraluce et al., 2011] Chiaraluce, L., Valoroso L., Piccinini D., Di Stefano R., and De Gori P., (2011). The anatomy of the 2009 L'Aquila normal fault system (central Italy) imaged by high resolution foreshock and aftershock locations, J. Geophys. Res., 116, B12311, doi:10.1029/2011JB008352.

[Chiaraluce et al., 2014] Chiaraluce, L., Amato A., Carannante S., Castelli V., Cattaneo M., Cocco M., Collettini C., D'Alema E., Di Stefano R., Latorre D., Marzorati S., Mirabella F., Monachesi G., Piccinini D., Nardi A., Piersanti A., Stramondo S., and Valoroso L., (2014). The Alto Tiberina Near Fault Observatory (northern Apennines, Italy), Annals of Geophysics, 57, 3, 2014, S0327, doi:10.4401/ag-6426.

[De Gori et al., 2015] De Gori P., Lucente F.P., and Chiarabba C. (2015). Stressing of fault patch during seismic swarms in central Apennines, Italy, Geophys. Res. Lett., 42, 2157-2163, doi:10.1002/2015GL063297.

[De Luca et al., 2009] De Luca G., M. Cattaneo, G. Monachesi and A. Amato, (2009). Seismicity in the Umbria-Marche region from the integration of national and regional seismic networks. Tectonophysics, 476(1), 219-231. doi: 10.1016/j.tecto.2008.11.032.

[Galadini, 2013] Galadini, F., (2013). I terremoti in Abruzzo e la cultura sismologica tra la fine dell'Ottocento e i primi del Novecento. In: "… pareva quel giorno dell'Universal Giuditio. Il terremoto aquilano del 1703 tra indagine storica e sviluppo della sismologia moderna", Edizioni Kirke, Cerchio, XVII-CIV.

[Gasperini et al., 2016] Gasperini, P., Lolli B., and Vannucci G., (2016). Relative frequencies of seismic main shocks after strong shocks, Geophys. J. Int., 207, 150-159.

[Grandori and Guagenti., 2009] Grandori, G, and Guagenti E., (2009). Earthquake Prediction: Lesson from L'Aquila Earthquake, ingegneria sismica, Anno XXVI, 3, 56-62.

[Guagenti et al., 1991] Guagenti, E., Grandori G., and Tagliani A., (1991). Probabilistic interpretation of short-term earthquake precursors in non-stationary condition, Proc. VI Int. Conf. on application of statistics and probability in civil engineering, Mexico City.

[Jones, 1985] Jones L., (1985,). Foreshocks and time-dependent earthquake hazard assessment in southern California, Bull. Seism. Soc. Am., 75, 1669-1679.

[Kagan, 2014] Kagan,Y.Y., (2014). Earthquakes: Models, Statistics, Testable Forecasts, book, American Geophysical Union, Wiley, 306 pp.

[Kagan and Jackson, 1991] Kagan,Y.Y. & Jackson, D.D., (1991). Long-term earthquake clustering, Geophys. J. Int., 104, 117–133.

[Lahr, 1999] Lahr, J.C. (1999, revised 2012). HYPOELLIPSE. A computer program for determining local earthquake hypocentral parameters, magnitude and first motion pattern, U.S. Geological Survey Open-File report, 99-23. version 1.1, available at http://pubs.usgs.gov/of/1999/ofr-99-0023.

[Margheriti et al., 2011] Margheriti, L., Chiaraluce L., Voisin C., Cultrera G., Govoni A., Moretti M., Bordoni P., Luzi L., Azzara R., Valoroso L., Di Stefano R., Mariscal A., Improta L., Pacor F., Milana G., Mucciarelli M., Parolai S., Amato A., Chiarabba C., De Gori P., Lucente F.P., Di Bona M., Pignone M., Cecere G., Criscuoli F., Delladio A., Lauciani V., Mazza S., Di Giulio G., Cara F., Augliera P., Massa M., D'Alema E., Marzorati S., Sobiesiak M., Strollo A., Duval A.M., Dominique P., Delouis B., Paul A., Husen S., and Selvaggi G., (2011), Rapid response seismic networks in Europe: the lesson learned from L'Aquila earthquake emergency, Annals of Geophysics, 54, 4, doi: 10.4401/ag-4953.

[Marzocchi and Lombardi, 2008] Marzocchi, W. and Lombardi A.M., (2008). A double branching model for earthquake occurrence, J. Geophys. Res., 113, B08317, doi:10.1029/2007JB005472.

[Marzocchi and Lombardi, 2009] Marzocchi, W. and Lombardi A.M., (2009). Double branching model to forecast the next M ≥ 5.5 earthquakes in Italy, Tectonophysics, 475, 514–523.

[Marzocchi and Zhuang, 2011] Marzocchi, W. and Zhuang, J., (2011). Statistics between mainshocks and foreshocks in Italy and Southern California, Geophys. Res. Lett., 38, L09310.

[Marzorati and Cattaneo, 2016] Marzorati, S. and Cattaneo C. (2016). Stima automatica della magnitudo minima rilevabile dalla rete sismica ReSIICO, Quaderni di Geofisica, 136, pp.21.

[Marzorati et al., 2014] Marzorati, S., Massa M., Cattaneo M., Monachesi G., and Frapiccini M. (2014). Very detailed seismic pattern and migration inferred from the April 2010 Pietralunga (northern Italian Apennines) micro-earthquake sequence, Tectonophysics, 610, 91-109, DOI: 10.1016/j.tecto.2013.10.014.

[Monachesi et al., 2013] Monachesi, G., Cattaneo M., Ladina C., Marzorati S., Frapiccini M., Carannante S., Ferretti M., Sebastianelli M., Delladio A., and Selvaggi G., (2013). Esperienze di monitoraggio integrato: il caso della Rete Sismometrica dell'Italia Centro Orientale, di quella Accelerometrica Marchigiana e dei suoi servizi, Quaderni di Geofisica, 106, pp.30.

[Moretti et al., 2012] Moretti et al., (2012). Rapid-response to the earthquake emergency of May 2012 in the Po Plain, Northern Italy, Special Issue "The Emilia seismic sequence of May-June, 2012: preliminary data and results", Annals of Geophysics, 55, 4, 583-590.

[Mulargia and Geller, 2003] Mulargia, F. and Geller R.J., (2003). Earthquake Science and Seismic Risk Reduction, Kluwer, 338pp.

[Omori, 1894] Omori, F. (1894). On the aftershocks of earthquakes, Journal of the College of Science, Imperial University of Tokyo, 7, 111–200.

[Papadopoulos et al., 2010] Papadopoulos, G.A., Charalampakis M., Fokaefs A., and Minadakis G., (2010). Strong foreshock signal preceding the L'Aquila (Italy) earthquake (Mw 6.3) of 6 April 2009, Nat. Hazards Earth Syst. Sci., 10, 19-24.

[Parsons et al., 2015] Parsons, T., Segou, M. and Marzocchi W., (2015).The global aftershock zone, Tectonophysics, 618, 1–34.

[Scafidi et al., 2016] Scafidi D., Spallarossa D., Turino C., Ferretti G. and Viganò A. (2016). Automatic P and S-Wave Local Earthquake Tomography: Testing Performance of the Automatic Phase-Picker Engine "RSNI-Picker", Bull. Seism. Soc. Am., doi: 10.1785/0120150084.

[Spallarossa et al., 2014] Spallarossa D., Ferretti G., Scafidi D., Turino C. and Pasta M. (2014). Performance of the RSNI-Picker. Seism. Res. Lett., 85/6, doi:10.1785/0220130136.

[Sugan et al., 2014] Sugan, M., Kato A., Miyake H., Nakagawa S., Vuan A., (2014). The preparatory phase of the 2009 Mw 6.3 L'Aquila earthquake by improving the detection capability of low-magnitude foreshocks, Geophys. Res. Lett., 41, doi:10.1002/2014GL061199.

[Valoroso et al., 2013] Valoroso, L., Chiaraluce L., Piccinini D., DiStefano R., Schaff D., and Waldhauser F., (2013), Radiography of a normal fault system by 64,000 high-precision earthquake locations: The 2009L'Aquila (central Italy) case study, J. Geophys. Res. Solid Earth, 118, 1156–1176, doi:10.1002/jgrb.50130.

[Vere-Jones et al., 1998] Vere-Jones, D., Harte D., and Kosuch M., (1998). Operational requirements for an earthquake forecasting programme in New Zealand, Bull. of the New Zealand Nat. Soc. For earth. Eng., 31, 194-205.

[Waldhauser and Ellsworth, 2000] Waldhauser, F., and Ellsworth W.L. (2000). A double-difference earthquake location algorithm: Method and application to the northern Hayward Fault, California, Bull. Seismol. Soc. Am., 90, 1353–1368, doi:10.1785/0120000006.

[Wessel et al., 2013] Wessel, P., Smith W. H. F., Scharroo R., Luis J. and F. Wobbe (2013). Generic Mapping Tools: Improved Version Released,Eos Trans. AGU, 94(45), 409.

[Wiemer, 2001] Wiemer, S. (2001). A software package to analyse seismicity: ZMAP, Seismol. Res. Lett., 72, 3, 373-382.