DETECTING CRUSTAL VELOCITY CHANGES DURING THE 2016-2017 CENTRAL ITALY SEISMIC SEQUENCE WITH AMBIENT NOISE MONITORING

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The 2016-2017 Central Italy seismic sequence. Starting from August 2016, Central Italy has been hit by a sequence of earthquakes that activates a 80-km normal-fault system. The sequence has been characterized by three main phases: the August 24, Mw6 mainshock, with epicenter close to Amatrice town, located in the middle part of the region interested by the whole sequence; the October 26 Mw 5.9 and October 30 Mw 6.5 earthquakes, between the towns of Norcia and Visso, about 15 km north of the first event, and finally the four earthquakes with $5.0 \leq M_L \leq 5.5$ which occurred in the southernmost segment of the activated area on January 18, 2017.

The mainshocks showed NW-SE striking normal faults, lateral extension of 15-20 km, and confined within the upper 10-12 km of the crust (Marchetti et al., 2017; Michele et al., 2016).

This sequence fills the gap on the Apenninic chain between the 1997 Colfiorito and the 2009 L’Aquila earthquakes. The whole set of high-angle normal faults is bounded below by a gently east dipping 2–3 km thick layer in which small events plus a series of larger extensional aftershocks (~ Mw 4) occurred, as seen in Chiaraluce at al. (2017) that analyzed the spatio-temporal evolution of seismicity from January 1 to November 29, 2016 for a total of nearly 26,000 earthquakes.

From the analysis of the spatio-temporal distribution of the earthquake occurred in the area during the year before the beginning of the sequence, it is not possible to identify any conventional foreshock activity on the main fault plane (Michele et al., 2016 and Marzorati et al., 2016).

Soon after the first event on August 24, the aftershock activity started covering a 30-km long sector.

This first mainshock occurred close to the village of Accumuli, while the largest aftershock with Mw 5.4, occurred only one hour later, and was located further north, close to the city of Norcia. For at least 10 days the sequence was very active with a series of earthquakes with magnitude larger than 4.0, causing devastation in the village of Amatrice (Chiaraluce at al., 2017).

The second part of the sequence started on October 26 with two large events (Mw 5.4 and 5.9) nearby Ussita and Visso, and the activation of another 20-km long segment in the northwest
direction. Then it reaches the climax on October 30 with the Mw 6.5 earthquake, the largest event of the sequence, that hits right in between Norcia and Ussita.

The third part of the sequence started January 18, 2017, with the occurrence of four moderate-magnitude earthquakes (5.0 ≤ Mw ≤ 5.5) located in the area south of Amatrice, close to the Campotosto area, elongating the seismogenic volume activated by the sequence in the South-East direction.

**Ambient noise seismic monitoring.** Noise-based seismic monitoring of relative velocity variations is a recently developed technique that has been proved as an efficient way for tracking crustal changes at the time of earthquake occurrences (Brenguier *et al.*, 2008a), and even before impending eruptions (Brenguier *et al.*, 2008b). This analysis base on the property of seismic noise cross-correlation function computed between two stations, which corresponds to the impulse response of the medium (the Green’s function) recorded at one station as if the source was placed on the other station location (Weaver and Lobkis, 2001). Thus, any change in travel times measured from noise cross-correlation functions corresponding to different time periods reflects relative velocity variations, i.e. the elastic property modification, in the propagation medium within the stations. We adopt the Multi-Window Cross-Spectrum analysis firstly applied to earthquake coda waves (Poupinet *et al.*, 1984; Ratdomopurbo and Poupinet, 1995), and then transferred to cross-correlation codas (Brenguier *et al.*, 2008a).

We apply this technique to the 2016-2017 Central Italy seismic sequence in order to get the temporal variability of the crustal modifications

**Crustal velocity changes.** We considered here two years (from January 2016 to December 2017) of continuous seismic recordings from 28 stations of the Italian Seismic Network inside a radius of 90 km around the Amatrice village (see map on Fig. 1). After some preliminary operations on the data (instrument correction, 1-bit normalization, whitening in the [0.1 1] Hz frequency band), we computed the 1-hour cross-correlations for the entire period between the 378 couples of stations. We then stacked the 1-hour cross-correlations in order to obtain a reference function from the sum over the two years of data, and many current functions by stacking 50 days sliding 2 days, for each station couple. Finally, putting together the result of the comparison between currents and reference functions of each station couples, we end up with the temporal evolution of the relative seismic velocity undergone in the whole volume of crust encircled by the seismic stations from the surface to a depth of few km (Fig. 2). After a nearly constant trend during the first months of 2016, the relative velocity variations exhibit three distinct drops, suddenly starting at the time of occurrence of the major events (Mw ≥ 5.5), and a slower increasing trend, starting after the last mainshock occurrence and almost completely recovering to pre-mainshock values towards the end of 2017. These patterns are
compatible with those observed for other mainshock-aftershock sequences around the world (Brenguier et al., 2018a; Chen et al., 2010), and may be explained in terms of more rapid co-seismic damaging of the shallow crust, and slower post-seismic recovery towards the background conditions (Zaccarelli et al., 2011). We could also create a sequence of maps for the spatial relative velocity variations by interpolating over the surface the single station values at different times. From these images we can observe that the area that shows the most intense variations is not merely restricted around the earthquake occurrences, but it also elongates in the NE direction. This zone corresponds to the gas trapped area of the Apennines (Chiarabba and Chiodini, 2013), thus confirming the findings by Brenguier et al. (2014).

Finally, we try to model the post-seismic trend, with a best fit regression. It is noteworthy how our best fit estimate is composed by not only a logarithmic contribution (typical of the post-seismic crustal recovery), but also a linear trend, as already found for the Mw 6.1 L’Aquila sequence by Soldati et al. (2015).
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