Introduction. The use of time-dependent models has been introduced recently in Italy to produce forecast seismicity maps (Marzocchi et al., 2012, 2014). This type of activity is expected by operational earthquake forecasting (OEF), a set of procedures for gathering and disseminating information about the time dependence of seismic hazards (Marzocchi et al., 2014).

The models that participate to the short-term OEF in Italy (Marzocchi et al., 2014), are rather well established and mainly focused on the short-term spatio-temporal clustering of earthquakes. Therefore, their great skill is the capacity to describe the evolution of sequences, whereas they have a poor predictive ability before the occurrence of the main events.

The establishment of robust short-term OEF procedures requests to increase our understanding of how and with how much precision earthquakes are predictable. A multidisciplinary scientific approach involving seismological, geodetic, geological and historical techniques can significantly improve knowledge of the cause of earthquakes and strengthen the physical basis for earthquake predictability.

Case studies may serve for the improvement of the OEF procedures, which should be able to forecast the spatio-temporal evolution of sequences and to improve the knowledge about the occurrence of main events. Firstly, I present an analysis of the first part of the 2016 central Italy sequence by means of the Epidemic Type Aftershock Sequences (ETAS) model (Ogata, 1998; Lombardi, 2015, 2016a, 2016b), to check the performance of the model on very provisional data. Particular care is taken in a sensitivity analysis of forecasts to both the input parameters of the model and to the occurrence history. Second, I provide some preliminary points of interest for a possible improvement of this type of models.

The analysis of the 2016 central Italy sequence. On August 24, 2016, at 01:36 UTC, a magnitude ML 6.0 earthquake hit part of the central Italy area, close to the villages of Amatrice and Accumuli, one of the most hazardous regions of Italy. The largest aftershock, of magnitude ML 5.4 (the only one event with magnitude above 5.0, for now), occurred near the Norcia city, about 1 hour after the main event.

Here, I apply the ETAS model to study the evolution of the first part of the seismic sequence. The model is set on the seismicity data of the official INGV bulletin (www.iside.rm.ingv.it), from April 16, 2005 up to August 24, 2016, occurred in the region [12.7-13.8E, 42.0-43.5N] and with magnitude ML $\geq$ 2.5, including the whole 2009 L’Aquila sequence. This region contains the smaller area [12.95-13.5E, 42.45-43.0N], interested by the 2016 central Italy sequence.

The version of the ETAS model used here has been implemented in SEDAv1.0 (Statistical Earthquake Data Analysis), a statistical software freely provided via the Zenodo open access platform (https://zenodo.org/record/55277; Lombardi, 2016a, 2016b).

To check the performance of the model, firstly, I compare the observed number of events with what expected by 10000 ETAS simulated catalogs (number of events test, Lombardi, 2016a). The test is performed for $N_D$ overlapping interval times of one day \{$D_i$, i=1,...,$N_D$\}, updated each hour, starting from the time occurrence of the mainshock (August 24, 2016, 01:36:32, ML6.0) up to September 15, 2016. This test also allows measuring the sensitivity of the model to the occurrence history, which fully participates to ETAS calculations.

Fig. 1 shows the comparison between the expected and the observed number of events with magnitude above MF=2.5, 3.0 and 4.0. It shows the median expected number of events (black line) together with the 95% confidence bounds (red lines), quantifying the uncertainty of predictions. The results show a strong underestimation in the first 8 hours, due to data incompleteness. Then the observations are above the median forecasts, but inside the confidence
interval, uninterruptedly in the first three days. After this period, the observations (blue points) and the median forecasts (black line) overlap. These results improve for larger values of MF, for which the period of underestimation is smaller (Fig. 1). Previous results do not depend on the length of the forecast interval $D_i$. None significant difference is found for $D_i$ equal to 3 hours, 1 day and 1 week, in the first 3 days of the sequence.

A second check consists in quantifying the sensitivity of the model to uncertainty on model parameters (including the background spatial distribution). Specifically, Fig. 2 shows the variation of the expected number of events, by considering the uncertainty on parameters. These calculations include the actual time history, up to the end of the forecast interval. The calculations are done for interval times of 1 day, updated each hour, and for MF=2.5, by integrating the conditional intensity of the ETAS model (Lombardi, 2015). As Fig. 2 shows, the parameter sensitivity of the model is negligible.

Some considerations on the improving of the ETAS model. Previous analysis shows that the ETAS model is able to describe the sequence, but for the first hours/days, due to the incompleteness of data. Clearly, the ETAS model has poor predictive ability before the main event. The probability of having an
event above ML5.5 in the next day, computed at 00:00 of August 24, is equal to 10^{-5} in the whole area, mainly given by the background rate.

The inefficiency of the ETAS model to predict imminent sequences, following the occurrence of strong events, mainly derives from the poor modeling of the background. Firstly, the poissonian model neglects possible long-term temporal variations of the seismic rate (Marzocchi et al., 2012). Second, the temporal window covered by instrumental catalogs should be too small to infer the actual spatial distribution of background. Regarding the second point, I compare the information coming from three different catalogs: the official INGV Bulletin, the instrumental CSIv1.1 (Castello et al., 2007; http://csi.rm.ingv.it/) and the historical CPTI15 catalogues (Rovida et al., 2016; http://emidius.mi.ingv.it/CPTI15-DBMI15/). Both the INGV Bulletin and the CSIv1.1 catalogues identify the areas around Norcia and Campotosto cities as the most hazardous regions (Fig. 3). Anyway, the size and the bounds of these areas are defined by the sequences included in the data (the 1997-1998 Colfiorito sequence, at north-west, for the CSIv1.1, and the 2009 L’Aquila sequence, at south-east, for the INGV Bulletin). The small size of the CPTI15 catalogue does not allow reaching detailed results. It seems to confirm what obtained from the other two catalogues, but assign a larger relative seismic potential to the area around Accumuli, struck by the 2016 earthquake (Fig. 3).

These results show that the background spatial distribution should be inferred by integrating information coming from different type of catalogs. Hard work must be still done about the temporal distribution of background and the integration of further data.

References

