Retrospective forecast of the ETAS model with daily parameters

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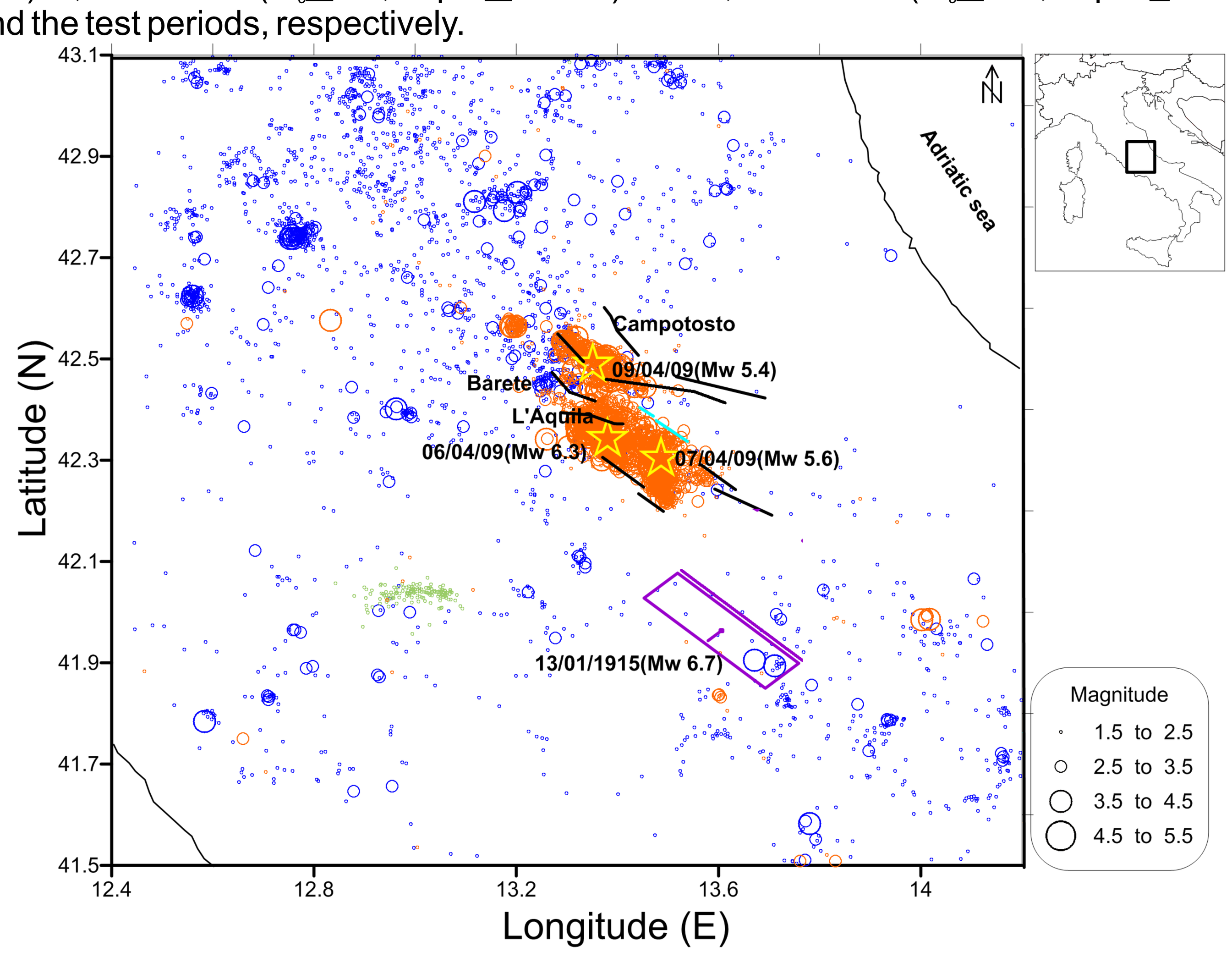
Introduction

In this work we present a retrospective ETAS (Epidemic Type of Aftershock Sequence) model based on the daily updated free parameters during the background, the learning and test phase of a seismic sequence. As example we show the evolution of these parameters during the last two strong seismic sequences in Italy: the 2009 L'Aquila and the 2012 Reggio Emilia. The performance of this model is compared with same model where the parameters remain fixed during the test time. The idea born after the 2011 Tohoku-Oki earthquake. The Collaboratory for the Study of Earthquake Predictability in Japan provided an appropriate test for the five 1-day models submitted. Of all the models only one was able to predict the number of events that really happened. This result was verified using both the catalog in real time and the revised one. The main cause of the failure was the underestimation of the forecasted events, due to fixed model parameters during the test. Moreover, the absence in the learning catalog of an event similar to the magnitude of the mainshock (M9.0), which drastically changed the seismicity in the area, makes the learning parameters not suitable to describe the real seismicity (*Nanjo et al.*, 2010).

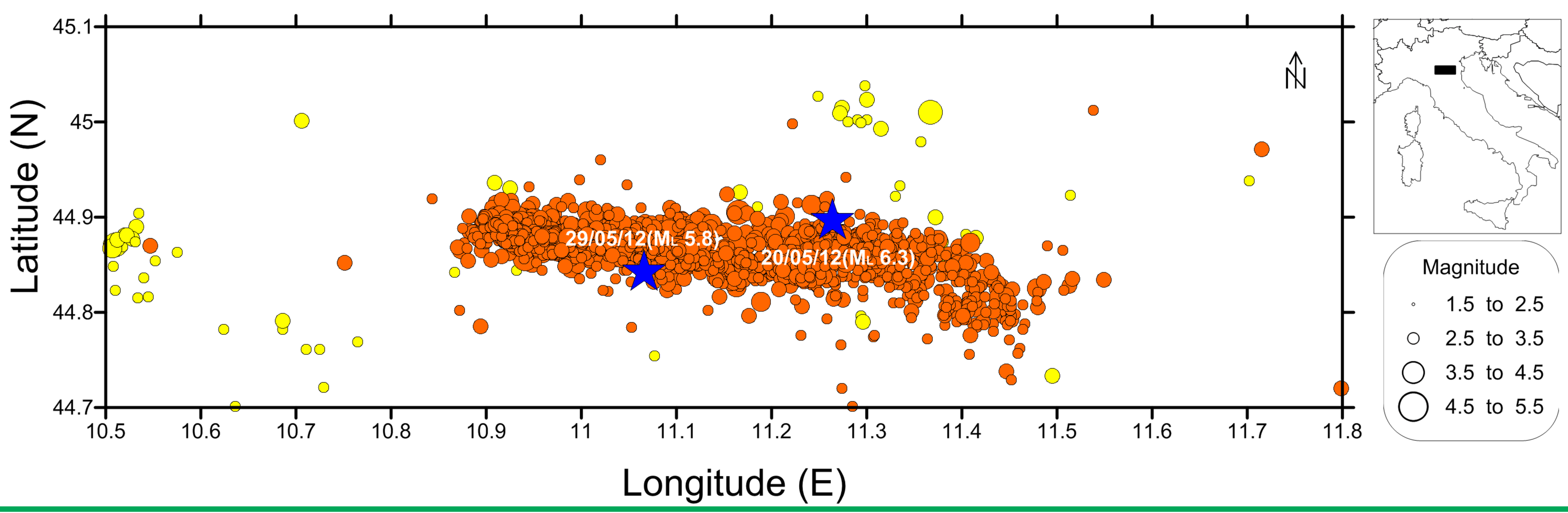
Data

The data used for this study are drawn from ISIDE (**iside.rm.ingv.it**).

For L'Aquila area, the period April 16, 2005-March 15, 2009 and March 16, 2009-June 30, 2009 was used for the learning and test phase, respectively. The area of the learning is the same of the test (12.4°E–14.2°E ,41.5°N–43.1°N). 2,588 events ($M_c \geq 1.6$, depth $\leq$ 30 km) and 3,007 events ($M_c \geq 2.0$, depth $\leq$ 30 km) occurred in the learning and the test periods, respectively.



For the Reggio Emilia area, we used the period January 1, 2009-May 18, 2012 and May 19-June 18, 2012 for the learning and test phase, respectively. The area considered for the learning and forecast was 10.50°-11.80° E / 44.70°-45.10°N.



Brief outline of the adopted model

Following *Ogata* (1998), *Console and Murru* (2001), *Console, Murru and Lombardi* (2003), *Helmstetter and Sornette* (2002, 2003), earthquakes are regarded as the realization of a point process modeled by a generalized Poisson distribution. In this model the clustering of earthquakes is described by a process in which every earthquake is a main shock with its own aftershock sequence decaying according to the modified Omori law, and with magnitude distribution of all the earthquakes in a sample, with a constant *b*-value following the *Gutenberg-Richter* law. The occurrence rate density of earthquakes in space and time $\lambda(x,y,t,m)$ is modeled as the sum of two terms, one representing the independent, or spontaneous, activity, and the other representing the activity induced by previous earthquakes:

$$\lambda(t,x,y,m) = f_r \cdot \lambda_0(x,y,m) + \sum_{j:t_j<t} \lambda_j(t,x,y,m)$$

The background seismicity rate is:

$$\lambda_0(x,y,m) = \lambda_0(x,y)\beta e^{\beta(m-m_c)}$$

$\beta = b$ ln *10* and m_c is the threshold magnitude. The triggering kernel is factorized into three terms depending on time, space, and magnitude, as:

$$\lambda_j(t,x,y,m) = K\, f(x-x_j, y-y_j, m_j)\, h(t-t)_j$$

where *K* is a constant parameter, and *f*(*x, y, m*) and *h*(*t*) represent the space and time distributions, respectively. The spatial distribution of the triggered seismicity is modeled by a function with circular symmetry around the point of coordinates(x_j, y_j):

$$f(r,\theta) = \left(\frac{d_0^2 10^{\alpha'(m_j-m_c)}}{r^2 + d_0^2 10^{\alpha'(m_j-m_c)}} \right)^q$$

The Omori-Utsu formula is adopted for the time dependence:

$$h(t) = c^{p-1}(p-1)(t+c)^{-p} \qquad p>1,$$

All free parameters of the algorithm (k,c,p,d_0,α' and f_r) were determined daily for the background and the learning phase through one procedure of best fit based on the maximum likelihood criterion.

Performance of Models in the Test period (Log-likelihood)

Sequence	Poisson	ETAS fixed parameters	ETAS updated parameters
L'Aquila	28303.19	48917.29	49554.17
Reggio Emilia	6649.526	17533.12	19305.04

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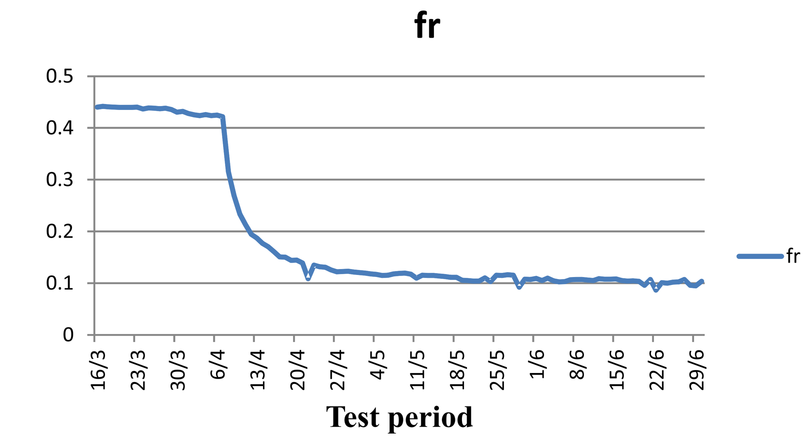
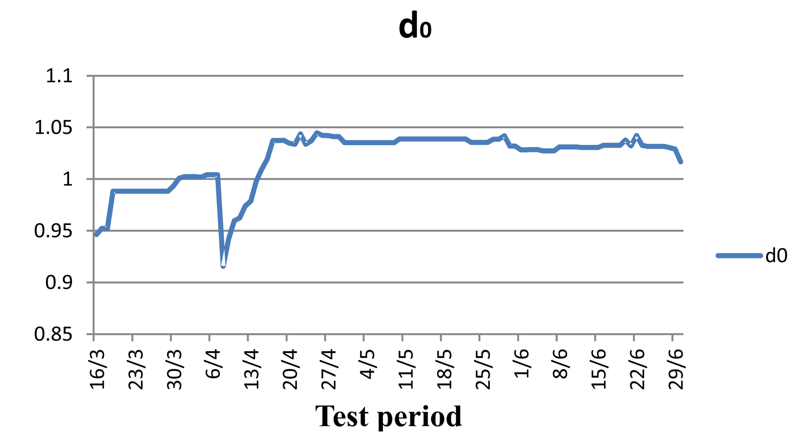
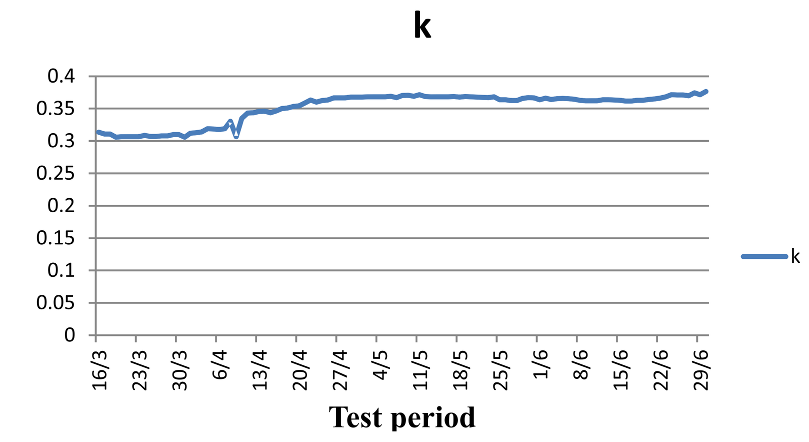
Results

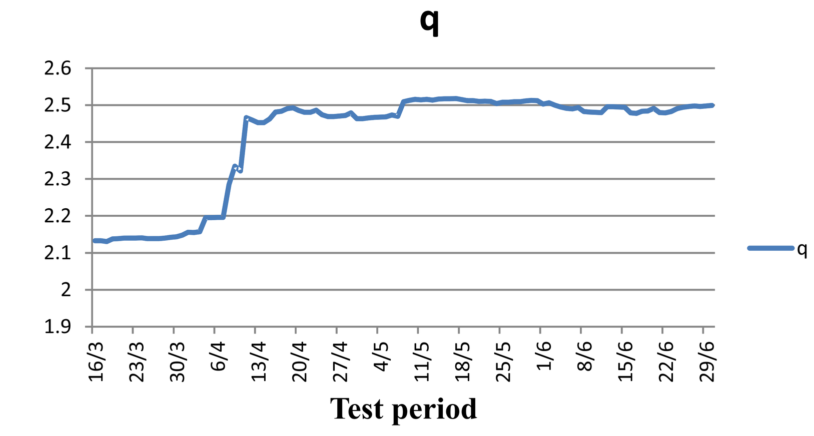
The model free parameters were updated daily for the test period for two sequences analyzed:
fr(fraction of background events over the total number of events),
K (productivity coefficient),
d_0 (characteristic triggering distance),
q (exponent of the spatial distribution of triggered events),
c (time constant of the Omori-Utsu formula),
p (exponent of the Omori-Utsu formula,
alfa (coefficient of the exponential relation between the magnitude of triggering earthquakes and their average distance).

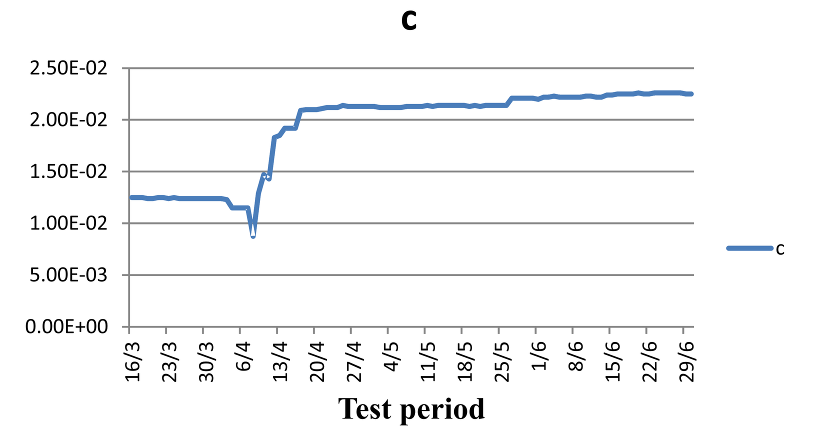
Here are shown the preliminary results for the 2009 L'Aquila sequence.

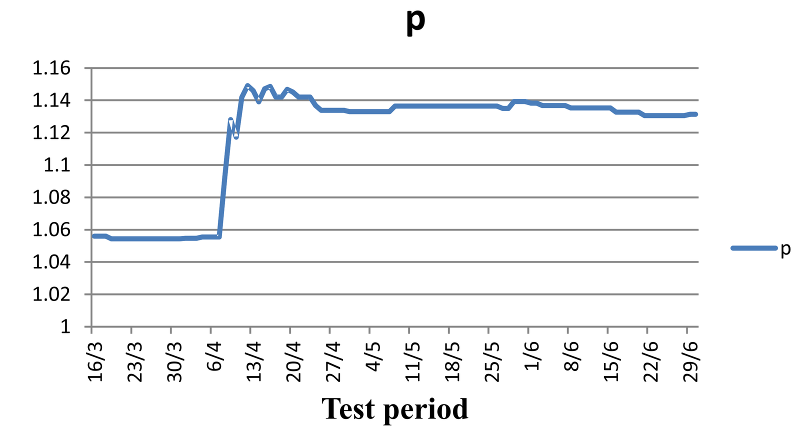


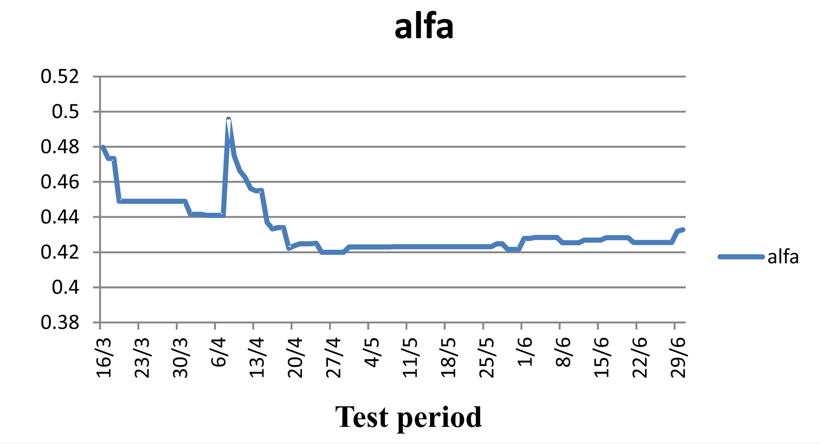


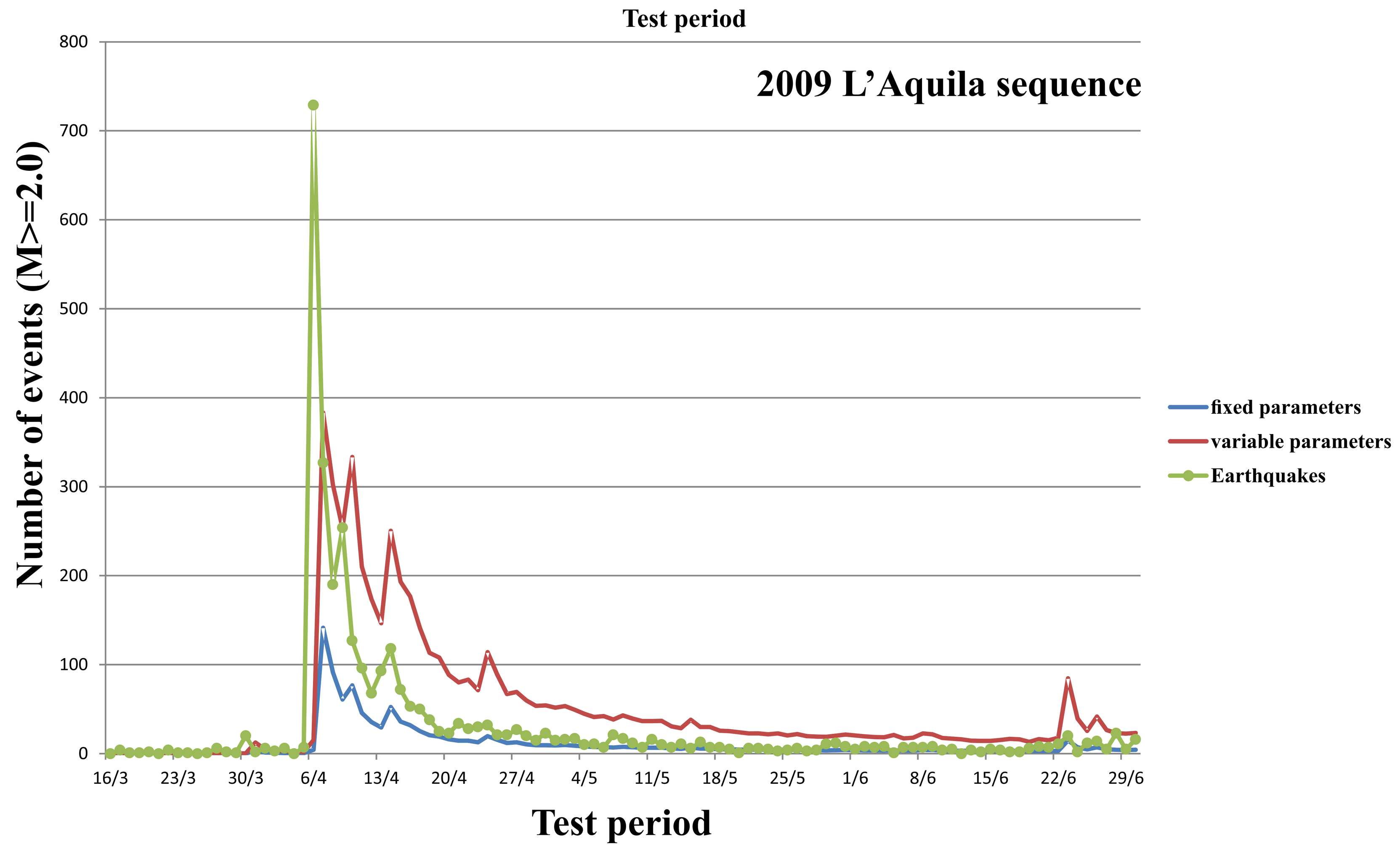


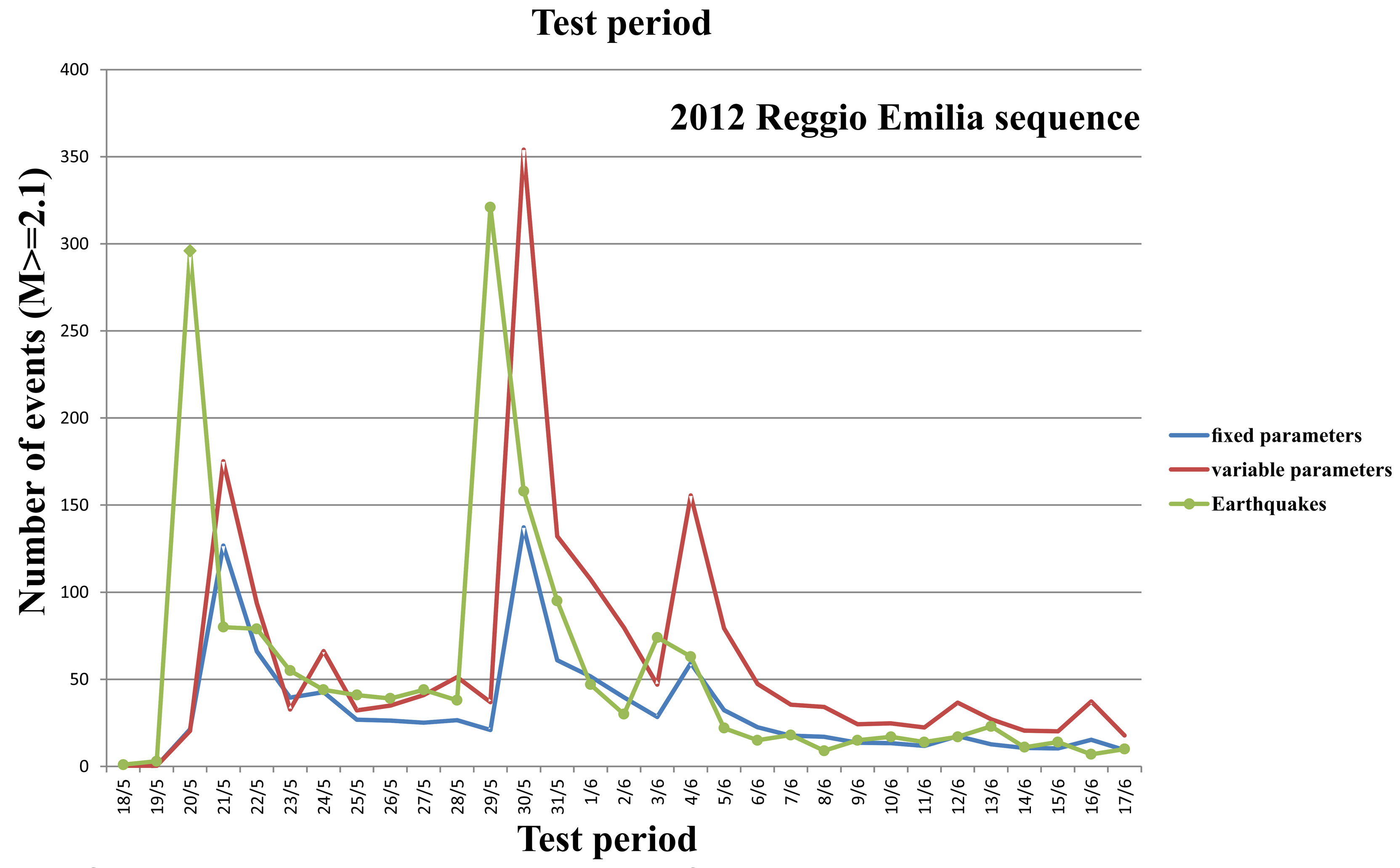












Number of expected events by using the model with fixed parameters and daily updated parameters compared with the real seismicity.

Conclusions

- The Performance obtained for both sequences by using the ETAS with daily updated parameters is larger than the same model with fixed parameters.
- The number of events under the ETAS model with variable parameters overestimates the real seismicity in the tail seismicity, as the number of events occurred after the main shock influences deeply the trend.
- The temporal trend of the free parameters is in agreement with the results of the other studied sequences, for example 1992 Landers aftershock sequence (*Hainzl, Cristophersen and Enescu*, 2008).
- Updating the free parameters tend to predict better the number of events that really happened.