Identification of earthquake sequences in Greece by means of a clustering model

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Abstract

The Epidemic Type Aftershock Sequences (ETAS) model is among the most popular stochastic ones for describing earthquake occurrence and investigating clustering features for earthquake forecasting. A reference model proposed for the Greek territory is used, by means of the spatio-temporal ETAS model and a catalog covering the period 2009 –2018 with M_{th}=3.5 analyzing short–term seismicity features both in time and space. Individual earthquake sequences taking place in different tectonic regimes are identified and compared among other using the stochastic reconstruction method.

Study area

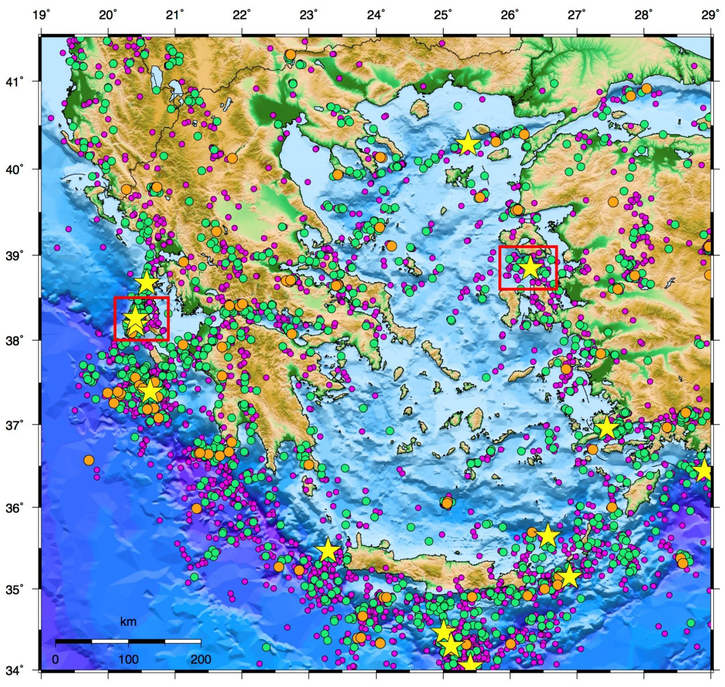


Figure 1. Spatial distribution of crustal (h≤40km) earthquakes with M_c≥3.5 of the broader Greek territory during the period 2009 to 2018. Small magenta, moderate green and large orange circles depict earthquakes in the magnitude ranges 3.5≤M_w<4.0, 4.0≤M_w<5.0 and 5.0≤M_w<6.0, respectively. Yellow stars depict the M_w≥6.0 events.

The clustering model (Ogata, 1998)

$$\lambda(t,x,y,m/H_t) = \left[\mu u(x,y) + \sum_{i:t_i<t} \frac{k exp^{\alpha(m_i-m_c)}}{(t-t_i+c)^p} \frac{c_{d,q,\gamma}(m_i)}{\left[r_i{}^2 + D^2 exp^{2\gamma(m_i-m_c)}\right]^q}\right] \times \frac{\beta exp^{-\beta(m-m_c)}}{1-exp^{-\beta(m_{max}-m_c)}}$$

✓ For the parameters estimation, the MLE method is applied through an algorithm developed by Lombardi (2015) based on Simulated Annealing.

Table 1. Estimated ETAS parameters based on Kourouklas et al. (2019)

Parameters	μ (events/day)	k	p	c (days)	α	d (km)	q	γ
Estimations	0.522	0.052	1.140	0.029	1.050	2.770	1.520	0.138

Stochastic Declustering method (Zhuang et al., 2002, 2004)

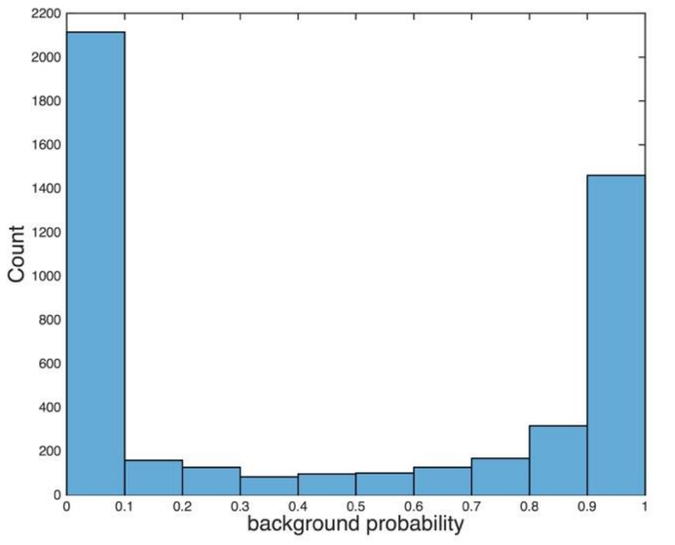


Figure 2. Background probabilities histogram using the estimated model for the Greek catalog covering the period 2009 - 2018 containing events above M_{th}.

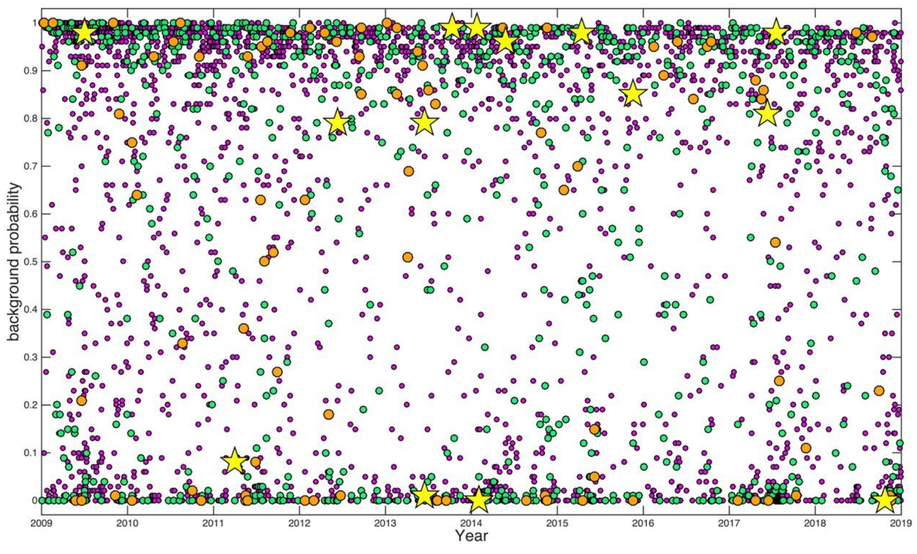


Figure 3. Background probabilities against earthquake occurrence times plot for the period 2009–2018 in the study area. Symbols same as in Fig. 1.

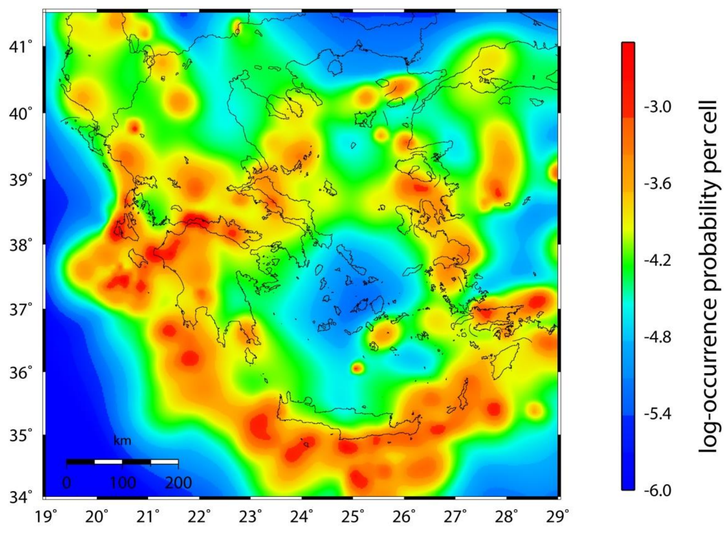


Figure 4. Background spatial distribution of Greek territory according to the estimated ETAS model based on earthquakes above M_{th} occurred during the period 2009 – 2018.

Kefalonia 2014 Sequence

- the two main events of the doublet (M_w 6.1 and M_w 6.0) are separated by seven days in time (26 January 2014 and 03 February 2014) and about 10 km in space
- rich aftershock production

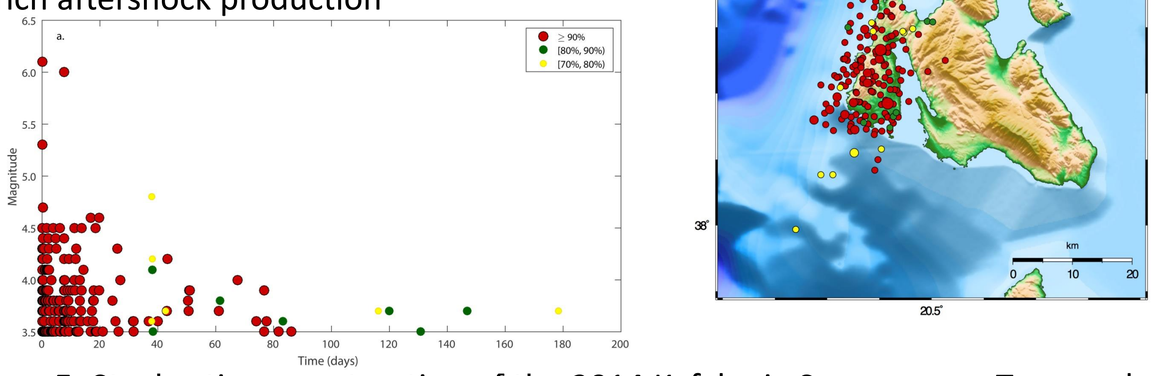
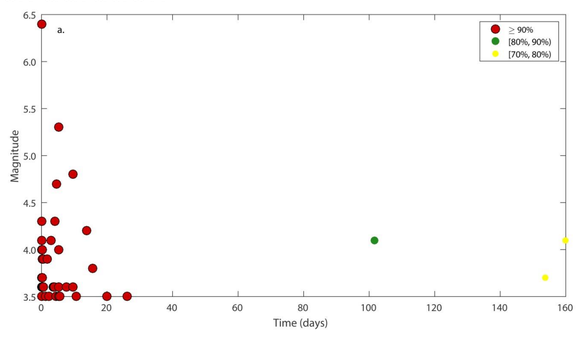


Figure 5. Stochastic reconstruction of the 2014 Kefalonia Sequence. **a.** Temporal and **b.** Spatial distribution of the events with probability ≥70% to be triggered by the 6.1 mainshock.

Lesvos 2017 Sequence

- the mainshock (M_w 6.4) occurred on 12 June 2017, offshore the south-eastern coast of Lesvos island
- rich aftershock activity with restrained aftershock duration



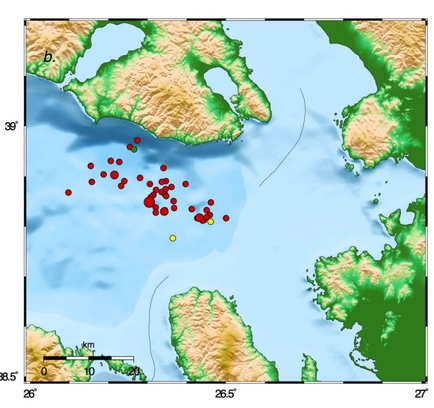


Figure 6. Stochastic reconstruction of the 2017 Lesvos Sequence. **a.** Temporal and **b.** Spatial distribution of the events with probability ≥70% to be triggered by the 6.1 mainshock.

Conclusions

- Seismicity in Greek territory exhibits considerable clustering features.
- Most earthquakes are found to be triggered.
- The background map reflects the intense seismic activity in the well-known active seismic zones.
- Lesvos sequence, with shorter duration, is more clustered than Kefalonia sequence.

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