A study of earthquake clustering in central Ionian Islands through a Markovian Arrival Process

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INTRODUCTION

The study of earthquake clustering can provide crucial information on the seismogenesis properties of a region. The seismicity may then be separated into background and clustered one, which is an important step for short-term earthquake forecasting. Several clustering algorithms exist with different underlying assumptions [1-4]. In our study, we assume that the prevailing parameter to separate the background seismicity from seismic excitation is the temporal variations of the seismicity rate. The method applied for this purpose is based on a stochastic point process, the Markovian Arrival Process (MAP) [5], that captures the temporal evolution of both mainshock-aftershock sequences and swarms combined with a density-based spatial clustering algorithm of applications with noise (DBSCAN) [6] that separates events close in space from sparse seismicity (low density areas). The efficiency of the method is tested in the area of Central Ionian Islands, Greece, which is an active boundary characterized by remarkably high seismic activity, with frequent strong mainshocks (M ≥ 6.0) and under continuous monitoring by a dense seismological network.

STUDY AREA

- Spatial distribution of 4360 events with M_L > 2.4 in Central Ionian Islands from Jan 2011 to Aug 2016
- Three strong (Mw ≥ 6.0) main shocks occurred during this period, the 2014 Kefalonia doublet (Mw6.1 and Mw6.0) and the 2015 Lefkada Mw6.5 earthquake

METHODOLOGY

- Definition of the study area, S, time interval, T and completeness magnitude M_c
- Estimate \( \theta = [\lambda_1, ..., \lambda_M, q_{ij} (1)] \) → EM algorithm [7]
- Optimal number of states \( \rightarrow \) AIC or BIC
- Estimate seismic rate in time \( \rightarrow \) Reveal hidden states \( \lambda_k \) = arg max \( \sum P(U_{ij} = k | T) \) [8]
- Primary clusters \( \rightarrow \) Events with \( \lambda_k \geq \lambda_{thr} \)
- Merging clusters \( \rightarrow \) Events \( \pm t_d \) probably merged with background seismicity
- Final clusters \( \rightarrow \) Implement DBSCAN and discard low density events

MAP AND DBSCAN FORMULATION

MAP: Bivariate stochastic point process \( N(T) = \{N_l (T)\}_{l=1}^{L} \)

- \( N_l \): counting process \( \rightarrow \) number of events in \([0, t]\)
- \( \lambda_l \): Hidden Markov process, \( E = \{1, ..., m\} \) \( \rightarrow \) unobserved states

Model parameters:

- \( D_m = -d \) diag \( (\lambda_1, ..., \lambda_m) \) and \( D_1 = \{ q_{ij} (1) \}_{i,j,E} \)
- \( q_{ij} (1) \rightarrow \) transition rate from \( i \rightarrow j \) with earthquake occurrence
- \( \lambda_j = \sum k q_{ij} (1) \rightarrow \) distinct occurrence rate at state \( i \in \bar{E} \)
- \( \mu_j (i) = \frac{D_k (i, j)}{D_k (i, j) + \sum_{m \neq k} D_m (i, j)} \rightarrow \) forward-backward vectors and \( L(\theta | T) \) likelihood value

DBSCAN: Density-based algorithm separates

- i) Highly concentrated points in arbitrary shape
- ii) Low density areas-Noise

Two parameters:

- Distance threshold \( \varepsilon \rightarrow \) how far do we search for neighbors
- Density level \( minPts \rightarrow min\) number of neighbors

APPLICATION TO CENTRAL IONIAN ISLANDS

- Top: Clusters with minimum number of events equal to 10 for different time periods
- Left: Spatio-temporal evolution of the initial data set and the declustered one

RESULTS

- Identified seismic excitations consistent with ones that have been derived by manually studied aftershock sequences, like the 2014 Kefalonia doublet (Mw6.1 and Mw6.0)
- Clustered component of seismicity is dominant in Central Ionian Islands due to the large seismic energy release of the two main sequences (2014 Kefalonia and 2015 Lefkada earthquakes)
- Main clusters are identified according to the spatiotemporal patterns of the background seismicity

REFERENCES


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