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Investigating the spatial features of earthquake clusters: insights from different methods

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Earthquake clustering is a fundamental aspect of seismicity, with typical features in space, time, and energy domains that may provide key information about earthquake dynamics and about the physical properties of the crust within a given region. In spite of the overall agreement about the existence and relevance of clusters of different types, including (but not limited to) aftershocks sequences and swarms, there is no unique formal method to identify them. Most of the algorithms for clusters identification available so far are based on a deterministic space-time-window scheme or on a stochastic branching model (e.g. ETAS model), which generally works well for large earthquakes, characterized by prominent aftershock series, clearly emerging from the background seismicity. Since different declustering methods, relying on different physical/statistical assumptions, may lead to diverse identification and characterization of earthquake clusters, we explore the classification differences and the possible contribution to clusters description provided by different techniques.

Various techniques, including classical space-time windows methods and temporal stochastic ETAS process, are considered for this purpose. In particular, a statistical method for detection of earthquake clusters, based on "nearest-neighbor distances" between events in space-time-energy domain, is applied. The method allows for a robust data-driven identification of seismic clusters, and permits to disclose possible complex features in the internal structure of the identified clusters.

In this study we investigate the spatial features of earthquake clusters in Northeastern Italy, based on a systematic analysis of robustly and uniformly detected seismic clusters reported in the local bulletins, compiled at the National Institute of Oceanography and Experimental Geophysics since 1977. To assign the scaling parameters that characterize earthquakes occurrence in the region, namely the b-value and the fractal dimension of epicenters distribution, and that are required for the application of the nearest-neighbor technique, we consider we consider average robust estimates of the parameters of the Unified Scaling Law for Earthquakes (USLE) in the study region. The comparative analysis shows that clusters identification by the nearest-neighbor method is fairly robust with respect to the time span of the input catalogue, as well as to minimum magnitude cutoff. Moreover, the identified clusters are well consistent with those identified by classical windowing methods, as well as by detailed manual aftershocks identification.

The statistical properties of earthquake sequences and their structure are analyzed by different metrics, including measures of the topological complexity of cluster related structure, and by ETAS modeling of selected sequences. We demonstrate that the earthquake clusters have distinct preferred geographic locations, and we identify two areas that differ substantially in the examined clustering properties. Specifically, burst-like sequences are associated with the north-western part and swarm-like sequences with the south-eastern part of the study region. The territorial heterogeneity of earthquakes clustering is in good agreement with spatial variability of scaling parameters identified by the USLE. In particular, the fractal dimension is higher to the west (about 1.2–1.4), suggesting a spatially more distributed seismicity, compared to the eastern part of the investigated territory, where fractal dimension is very low (about 0.8–1.0).