Exploring New Data Analysis Techniques on an Extended Earthquake Catalog for Evaluating Seismic Hazard in Europe

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MOODY'S RMS

Abstract

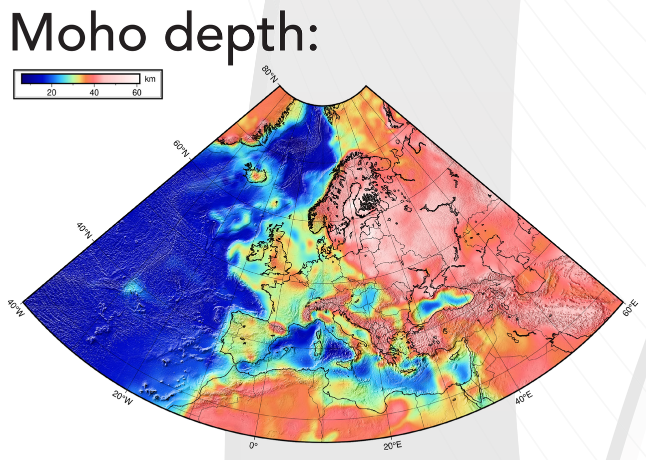
This paper presents new developments in processing and analyzing an updated European earthquake catalog for PSHA purposes. The updated catalogue (EUEQ25) expands on the work of the 2020 European Seismic Hazard Model (ESHM20) and now covers the period from 1000 to the begining of 2023, contributing an additional 5,800 earthquakes with magnitudes greater than 3.5 in the region. Using this dataset, we test various state-of-the-art procedures for analyzing spatial patterns, magnitude distributions, and seismicity rates. In particular, we explore the use of Machine Learning (ML) techniques to address long-standing issues, such as earthquake catalog declustering. We also introduce a new objective tectonic classification methodology that improves on current standards and enables the grouping of previously unclassified events via an iterative clustering approach. This work lays the foundation for creating a new standardized workflow for developing the next generation of the Moody's RMS European seismic hazard model.

Tectonic Regionalization

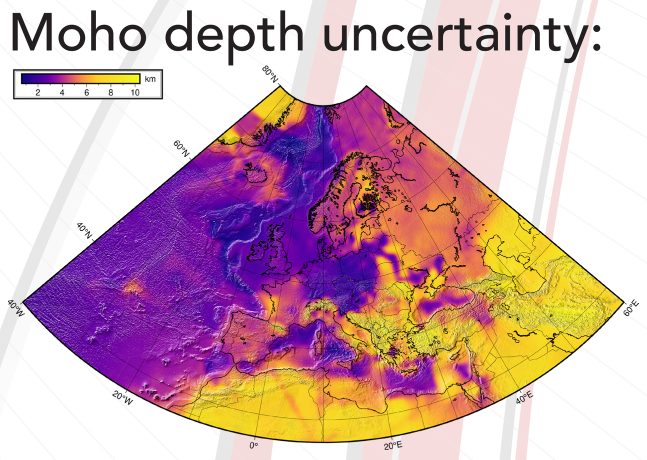
The European Hazard model includes seismic sources from many tectonic region types and we divide the EUEQ25 catalog accordingly (Pagani et al., 2021).

DATASETS

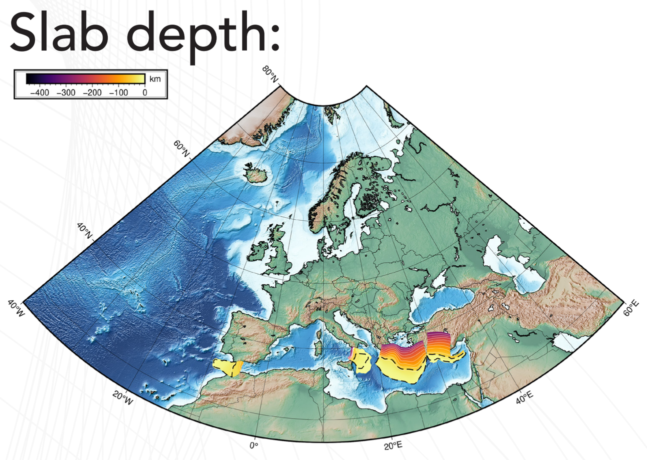
Moho depth:



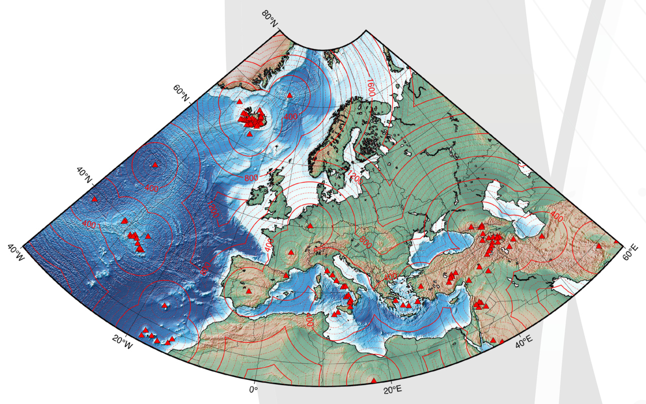
Moho depth uncertainty:



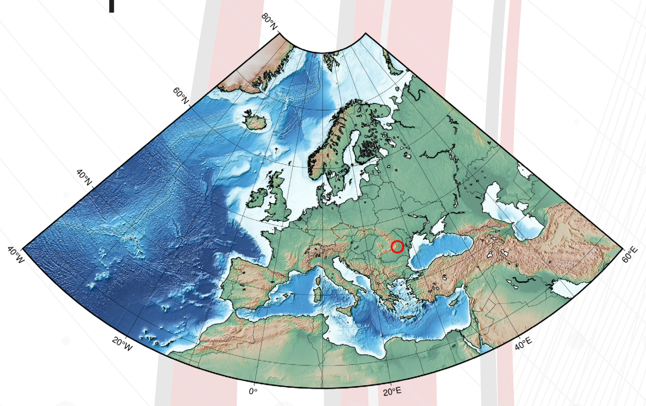
Slab depth:



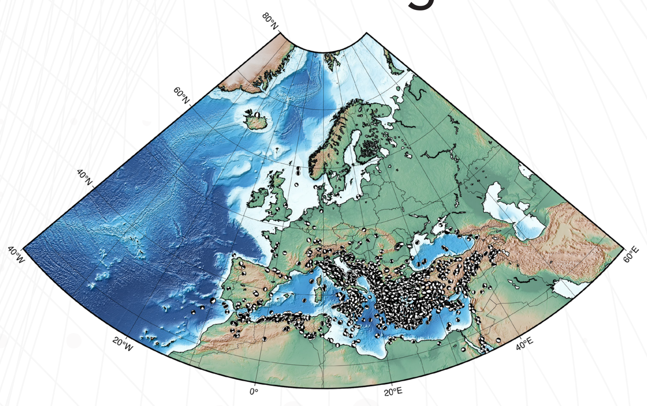
Volcano distance:



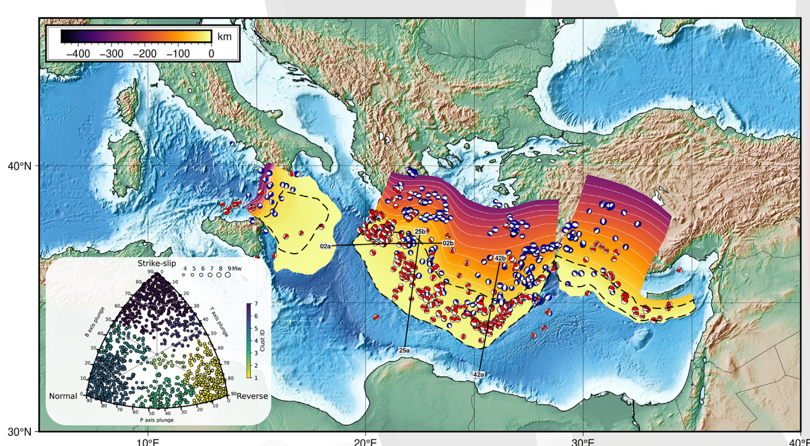
Deep seismic zone:



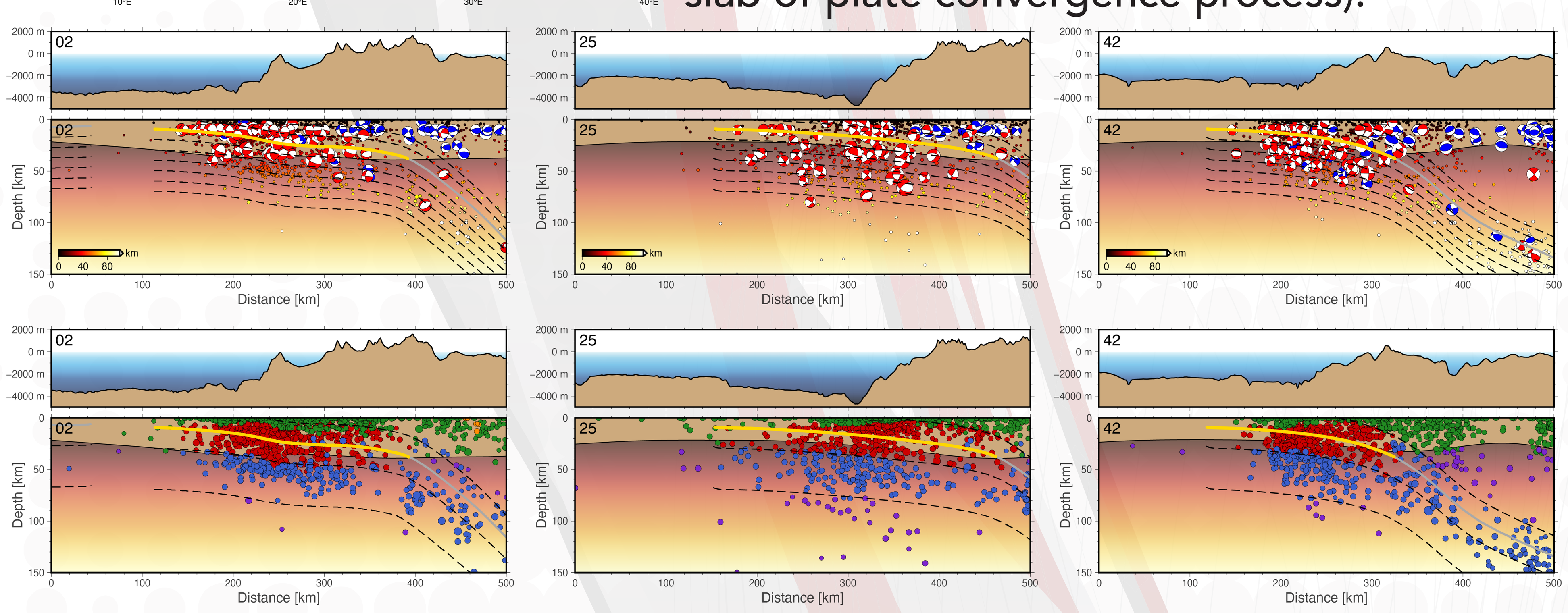
Euro-Med catalog:



SLAB INTERFACE DEFINITION



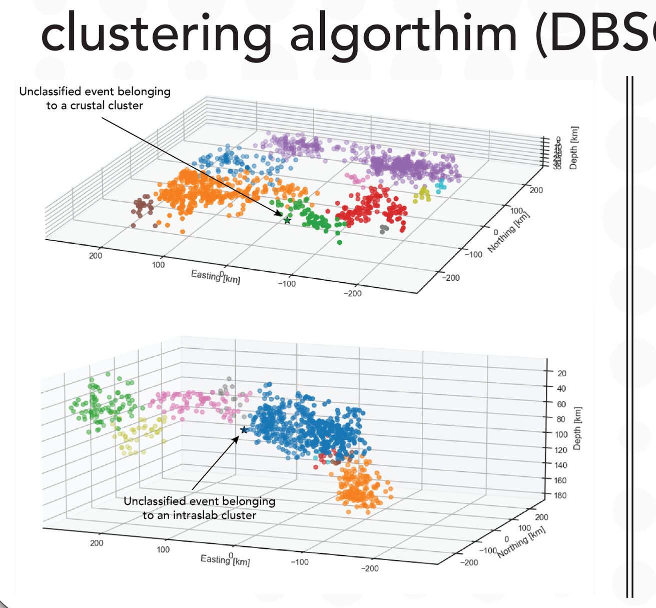
We classify focal mechanisms (FM) using a Kaverina projection. We then use the distribution of the reverse (red FM) and normal (blue FM) faulting events to define the depth and extent of the slab interface (i.e. reverse mechanism is dominantly controlled by subduction slab of plate convergence process).

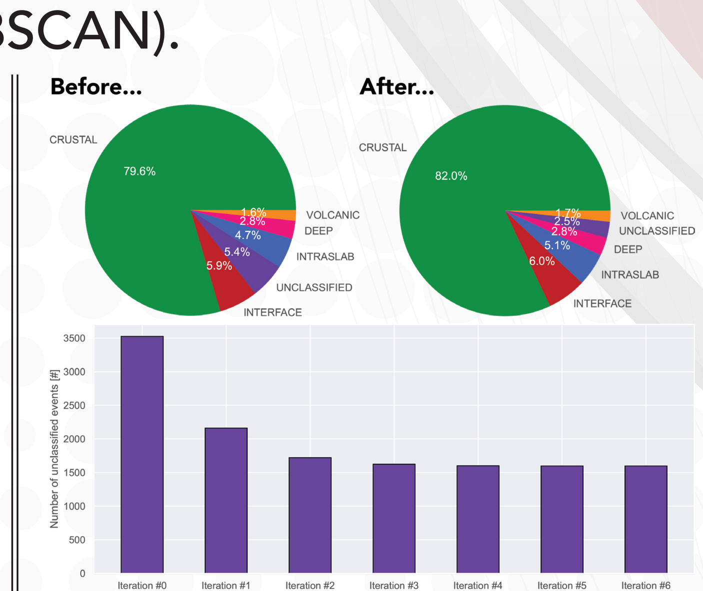


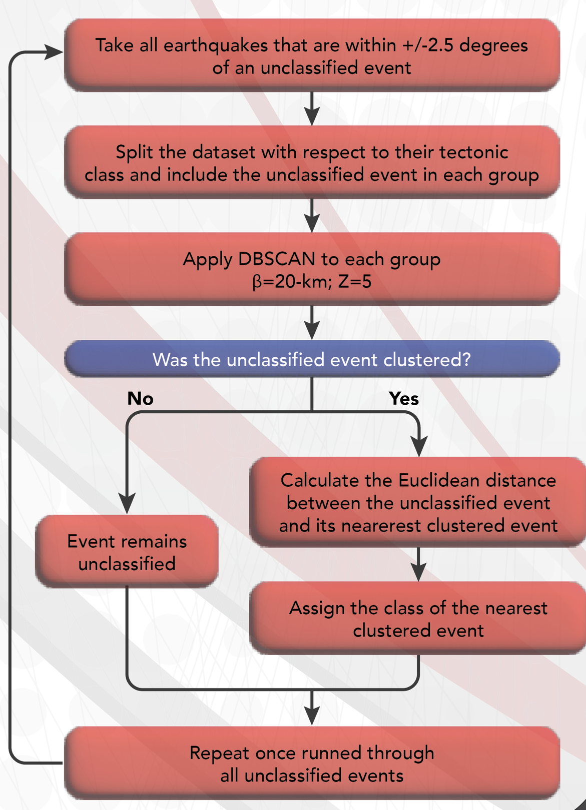
Green is Crustal, Red is Interface, Blue is Intraslab, Orange is Volcanic, Magenta is Deep, Purple is Unclassified. The gray line marks the top of the slab model.

ITERATIVE CLUSTERING CLASSIFICATION

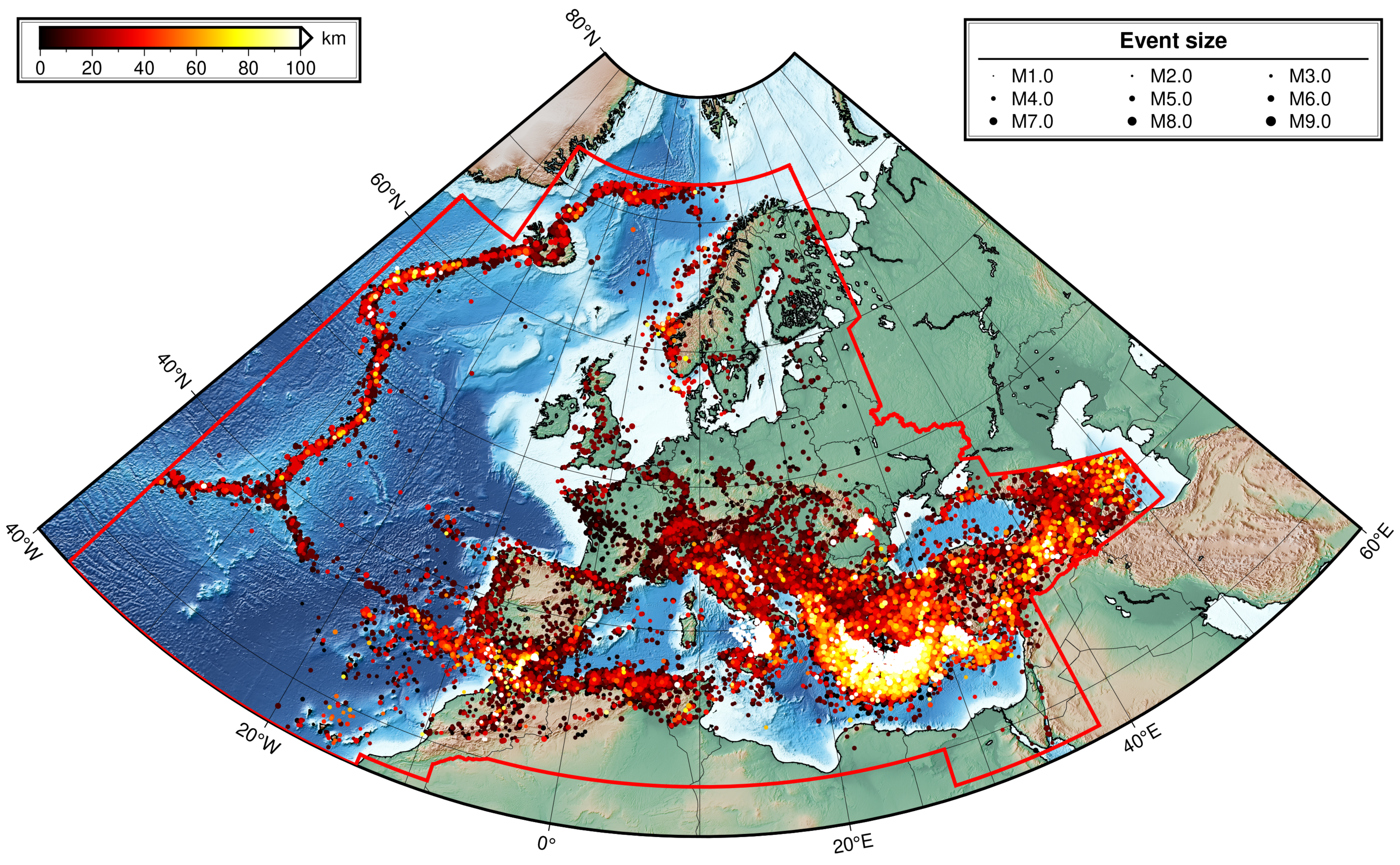
To reduce the number of unclassified events, we test whether these can be grouped together with any of the successfully classified events via a density-based clustering algorthim (DBSCAN).







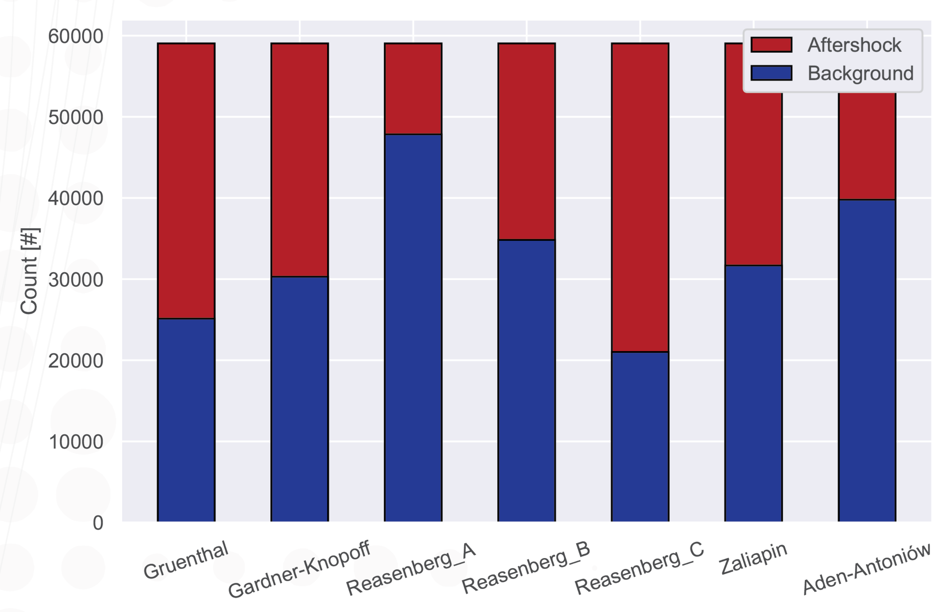
Earthquake Catalog



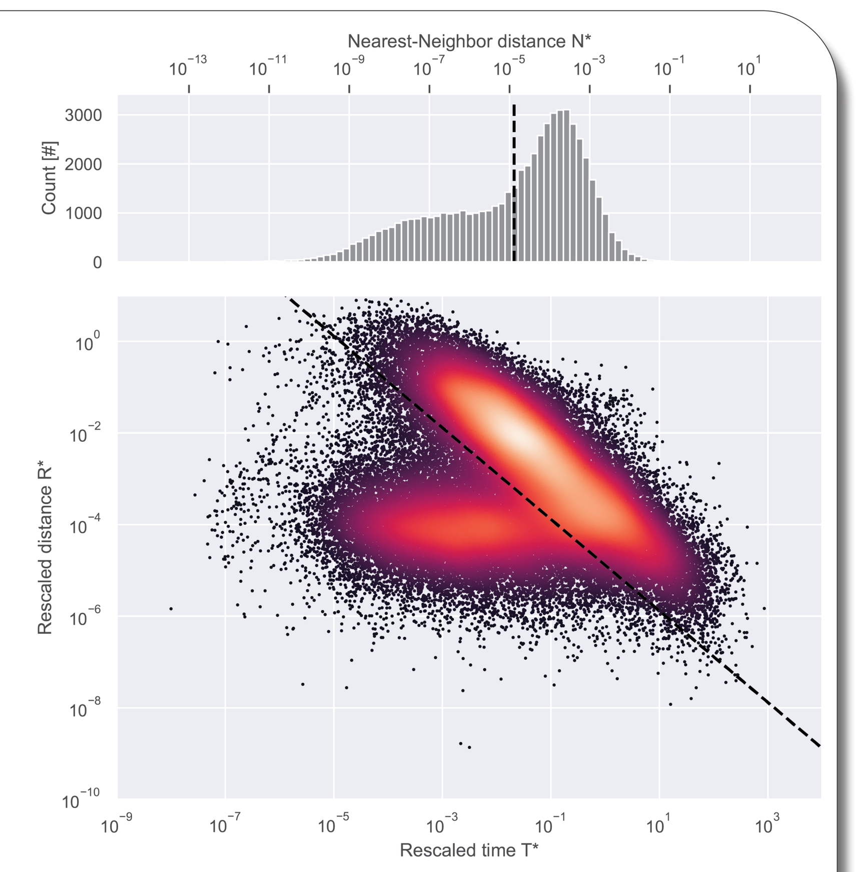
The EUEQ25 catalog comprises 65,000 events and is a combination of the ESHM20 (1000-2015) and the ISC (2015-2023) earthquake catalogs.

Catalog Declustering

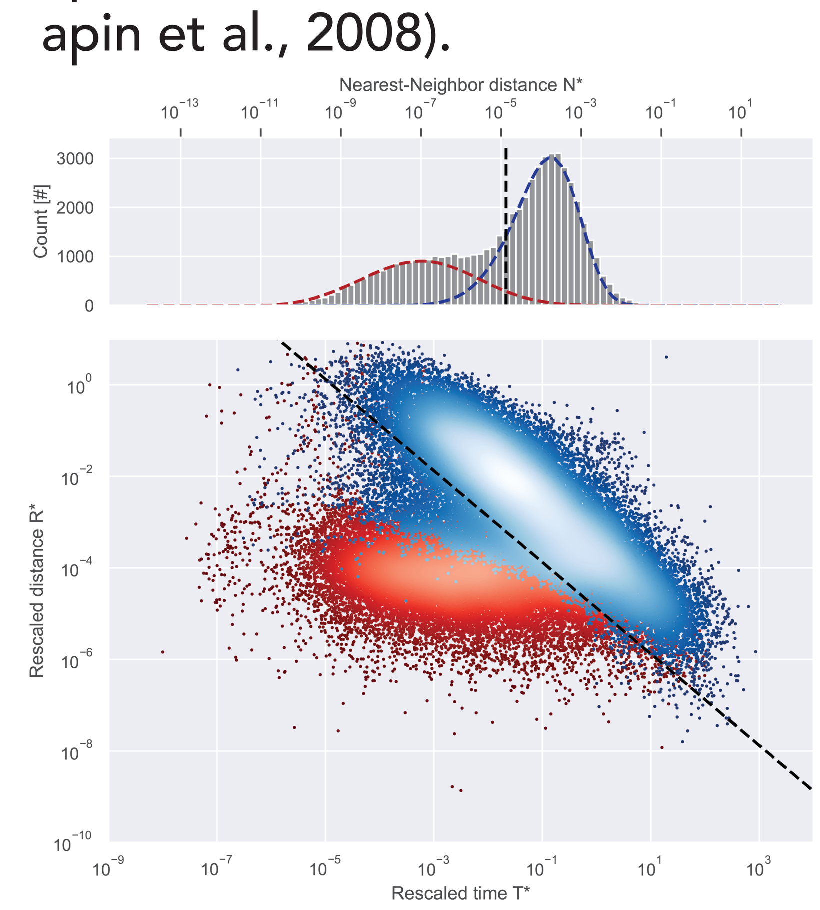
Catalog declustering is typically employed to identify and eliminate aftershocks from earthquake catalogs. Nevertheles, declustering algorithms are not entirely accurate and some earthquakes that are actually independent may be removed as aftershocks, and vice versa. We expand on the ESHM20 declustering work and implement the Random Forest (RF) model of Aden-Antoniow et al. (2022) for declustering the EUEQ25 catalog. The model was trained on synthetic catalogs built following ETAS models with a different set of parameters. We argue that this approach can reduce the biased identification of background earthquakes and aftershock sequences, and enables the use of more catalog information to evaluate the true background seismicity rate.



C) Performance of the different declustring algorithms on the ESHM20 catalog. From left to right: Gruenthal declustering, Gardner-Knopoff declustering, Reasenberg declustering with rfact=10, Reasenberg declustering with rfact=20, Reasenberg declustering with rfact=30, NN declustering, and RF declustering.



A) Nearest-Neighbor (NN) distances for the EUEQ25 catalog. The dashed black line represents the treshold used in most NN aproaches for declustering (Zaliapin et al., 2008).



B) Same as above but here the color of the marker indicates if the RF model classified the event as background (blue) or aftershock (red). The dashed black line shows where the classical NN approach would have separated the two populations.

References

1. Danciu, L., Nandan, S., Reyes, C. G., Basili, R., Weatherill, G., Beauval, C., ... & Giardini, D. (2021). The 2020 update of the European Seismic Hazard Model-ESHM20: Model Overview. EFEHR Technical Report, 1.
2. Pagani, M., Johnson, K., & Garcia Pelaez, J. (2021). Modelling subduction sources for probabilistic seismic hazard analysis. Geological Society, London, Special Publications, 501(1), 225-244.
3. Basili, R., Danciu, L., Carafa, M. M. C., Kastelic, V., Maesano, F. E., Tiberti, M. M., ... & Vilanova, S. (2020). Insights on the European Fault-Source Model (EFSM20) as input to the 2020 update of the European Seismic Hazard Model (ESHM20) (No. EGU2020-7008). Copernicus Meetings.
4. Zaliapin, I., Gabrielov, A., Keilis-Borok, V., & Wong, H. (2008). Clustering analysis of seismicity and aftershock identification. Physical review letters, 101(1), 018501.
5. Aden-Antoniów, F., Frank, W. B., & Seydoux, L. (2022). An adaptable random forest model for the declustering of earthquake catalogs. Journal of Geophysical Research: Solid Earth, 127(2), e2021JB023254.