Institute of Geophysics
Polish Academy of Sciences

SCHATZALP DAVOS 18–21 March 2025 4TH INDUCED SEISMICITY WORKSHOP

contact: mstaszek@igf.edu.pl

Multiplets for idenification of seismogenic structures at fluid injection sites of various tectonic complexity

Monika Staszek[1], Łukasz Rudziński[1], Jan Wiszniowski[1]

(1) Institute of Geophysics, Polish Academy of Sciences

(1) Introduction

In the areas of underground fluid injection best possible knowledge about existing fractures and faults and their development in time is needed in order to predict where the new fractures can be created and if they can lead to the activation of potentilly seismogenic faults. This knowledge can be gained i.a., through analysis of seismic events which usually accompany injection process.

Here, we show that similar seismic events can be successfully utilized for identification and delineation of seismogenic structures at fluid injection sites of various tectonic complexity. The multiplet analysis was performed on the small cluster of seismicity from The Geysers geothermal field (the area of Prati-9 and Prati-29 injection wells) and on the seismicity registered at Coso geothermal field.

(4) Summary

At The Geysers case study four structures were identified and delineated using double-difference relocation of very similar seismic events (3C-cc treshold = 2.7). The structures were classified as 3 fractures and 1 fault plane.

At Coso geothermal field case study we observed that similar seismic events tend to group in the vicinity of mapped tectonic faults. Moreover, the strongest events with M ≥ 2.9 seem to occur in the same areas as groups of multiplets.

(2) The Geysers geothermal field, CA, USA

We delineated four structures A-D within the seismicity cluster using waveform similarity analysis followed by double-difference relocation (Waldhauser and Ellsworth, 2000).

Steps:
1. 3C waveform similarity analysis in 1-15 Hz frequency range using signal cross-correlation,
2. identification of multiple events (ME) and single events (SE) with clustering methods (3C-cc treshold 2.7),
3. double-difference relocation of ME using both catalog and cross-correlation information,
4. visual identification of 3 fractures (structures A-C) and 1 fault plane (structure D)

Detailed description of method and results can be found in Staszek et al. (2021).

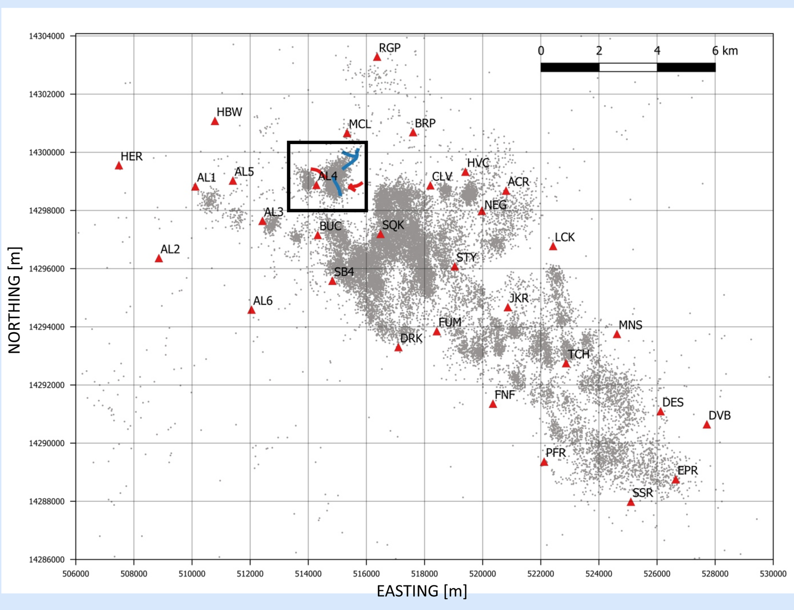

Figure 1. Spatial distribution of seismicity recorded at The Geysers geothermal field between November 2007 and August 2014 according to NCEDC catalog. The study area in the northwestern part of geothermal field is indicated roughly with black square.

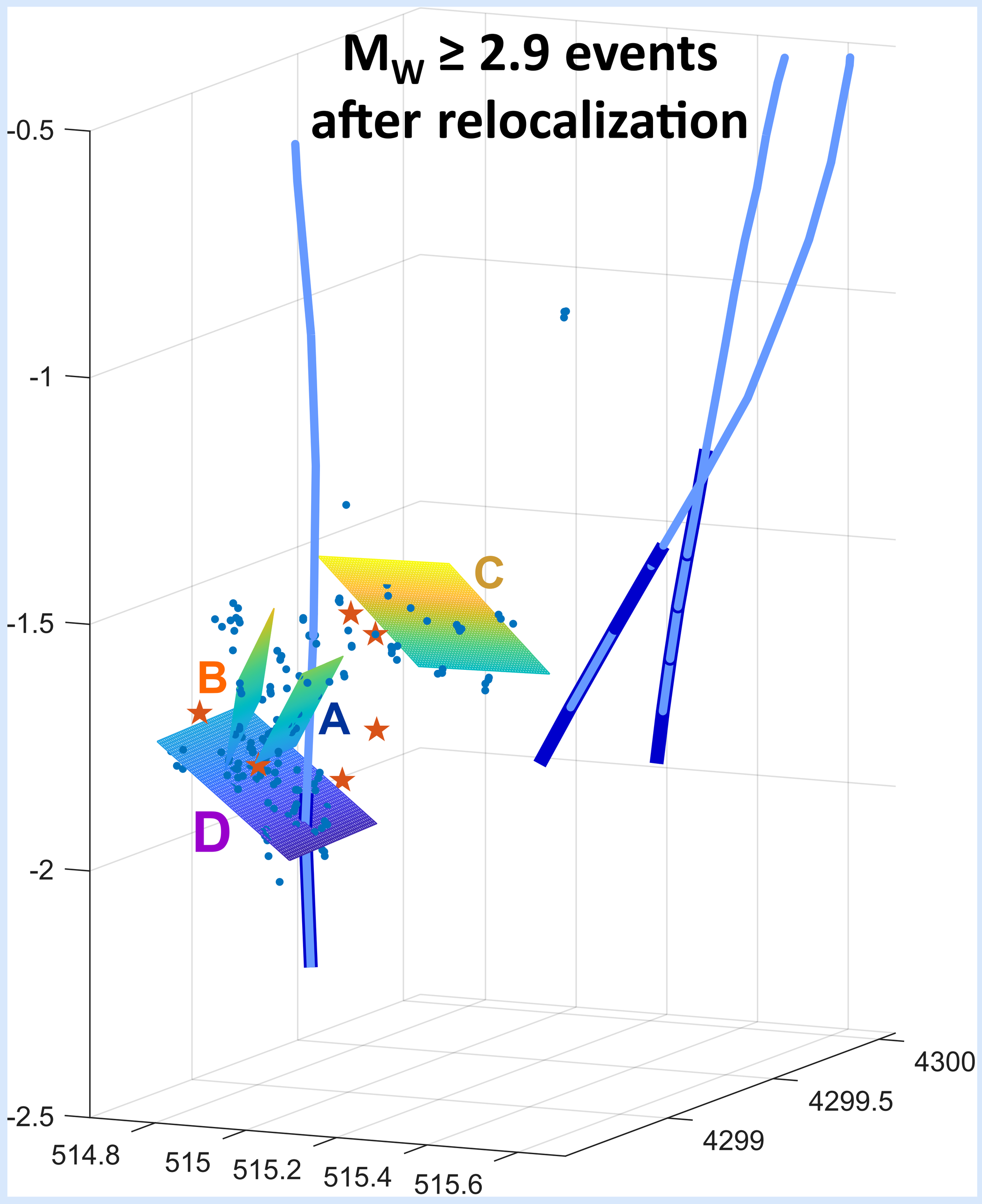

Figure 2. Locations of six M_W ≥ 2.9 events (red stars) after double-difference relocation. ME are indicated with blue dots, planes best fitted to structures A-D are also plotted.

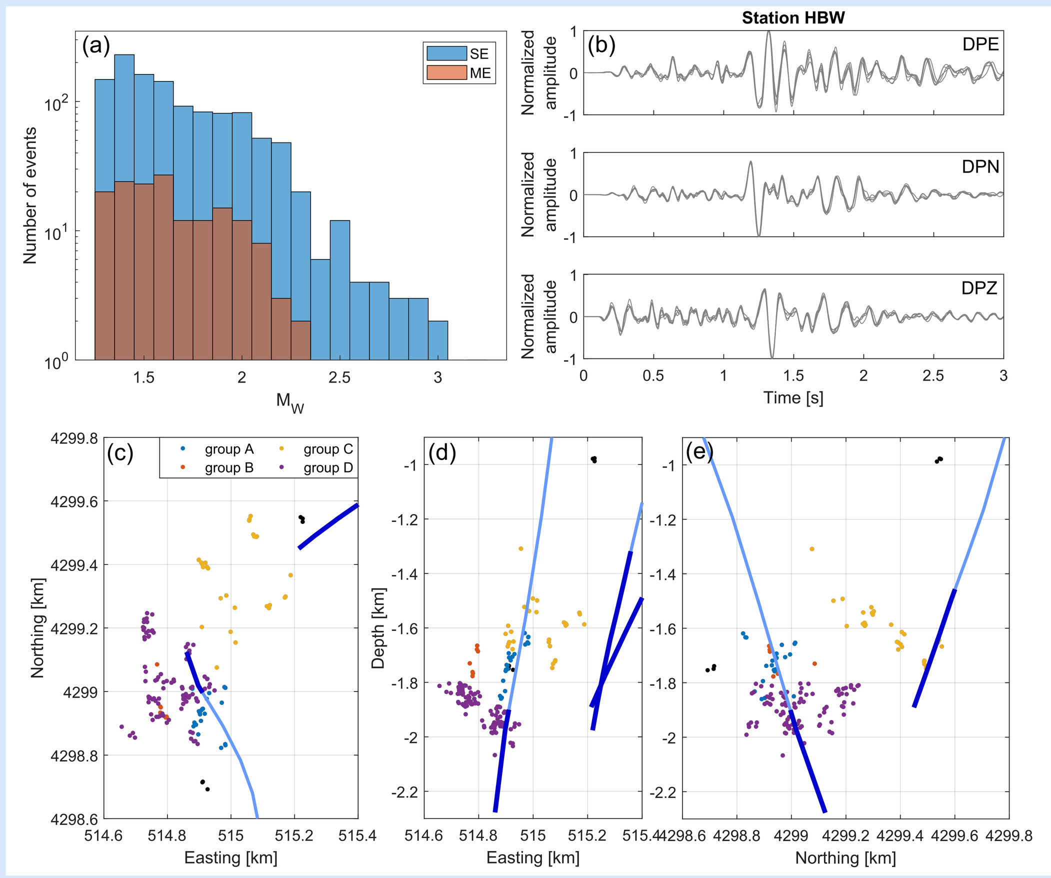

Figure 3. Cross-correlation statistics (a), signals (b) and the four structures A-D identified within the cluster (c-e).

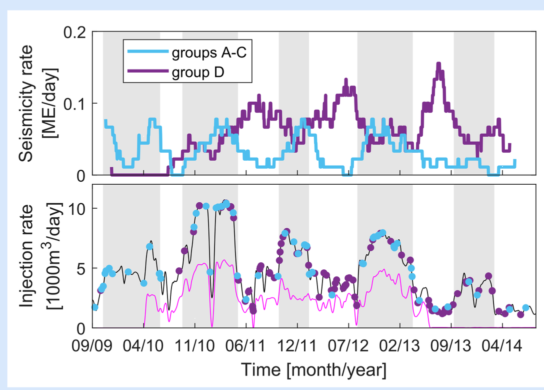
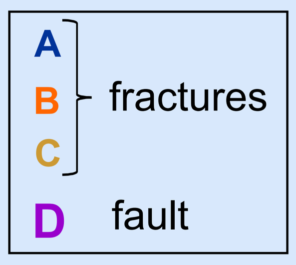

Figure 4. Seismicity rate in relation to injection rate for structures A-D.

(3) Coso geothermal field, CA, USA

We performed signal similarity analysis using signals of 640 seismic events recorded in time period 08/2014-12/2023 by 17 stations. Presented locations come from the catalog elaborated by Hauksson et al. (2012) after performing double-difference relocation.

Steps:
1. 3C waveform similarity analysis in 1-15 Hz frequency range using signal cross-correlation,
2. identification of multiple events (ME) and single events (SE) with clustering methods (3C-cc tresholds: 2.3, 2.5, 2.7).

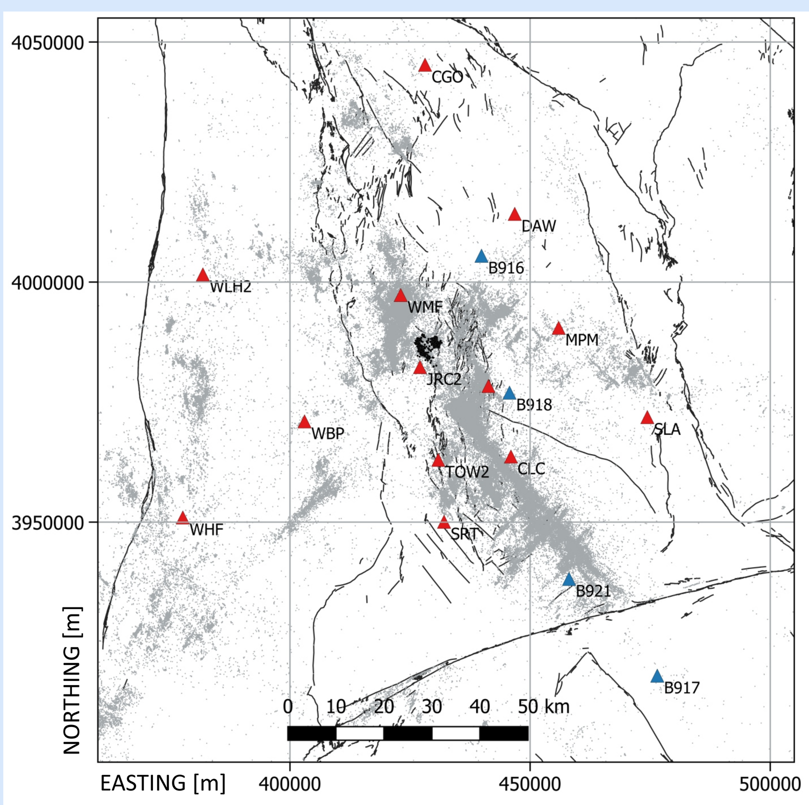

Figure 5. Spatial distribution of seismicity recorded in the vicinity of Coso geothermal field between January 1981 and December 2023 (Hauksson et al., 2012). Analyzed 640 events are marked with black. Broadband surface stations are denoted as red triangles. Blue triangles indicate borehole short-period stations.

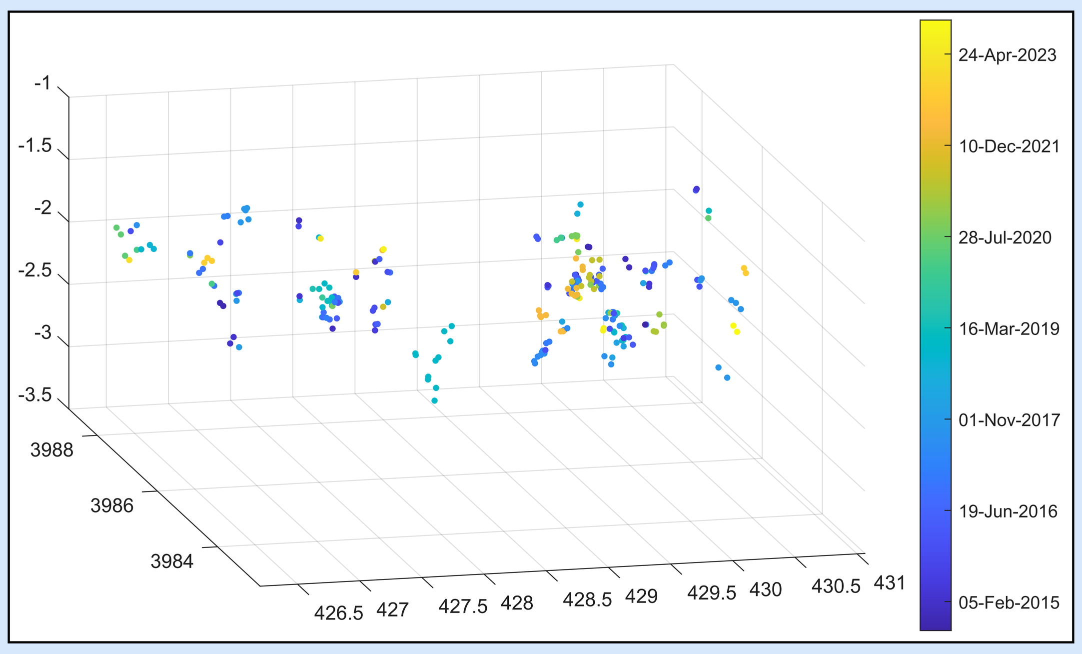

Figure 7. Locations of ME identified with 3C-cc treshold equal 2.3. The events are coloured by the time of their occurrence.

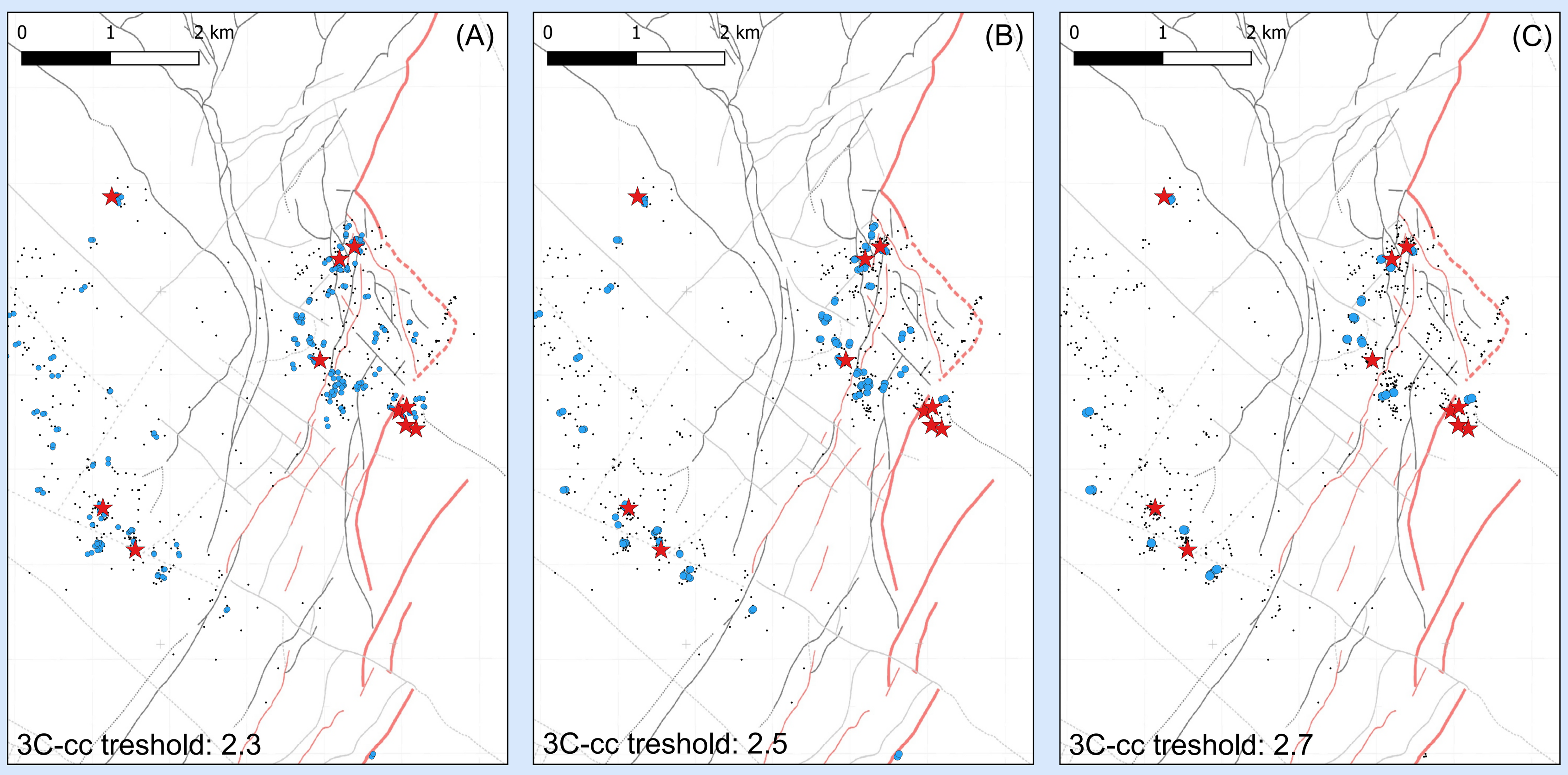

Figure 6. Locations of ME identified with various 3C cross-correlation tresholds applied during clustering (blue dots). Black dots indicate SE. Red stars denote locations of the events with M ≥ 2.9. The faults were plotted on the basis of map published by Davatzes and Hickman (2006). Red lines indicate modern faults, black lines the faults active since 1.6 Ma and grey lines - ancient and probably inactive faults.

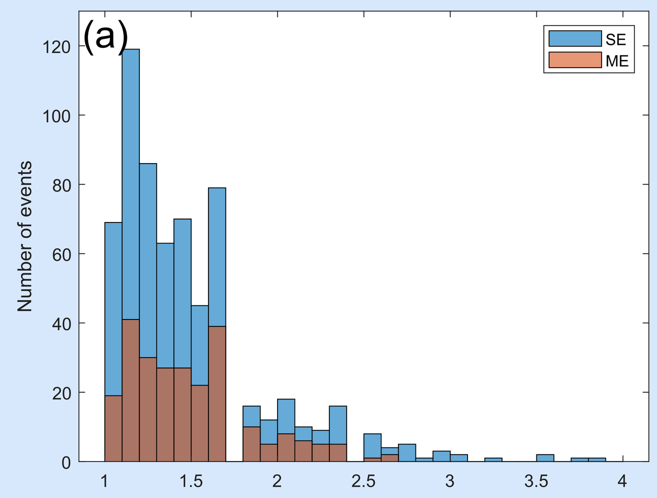
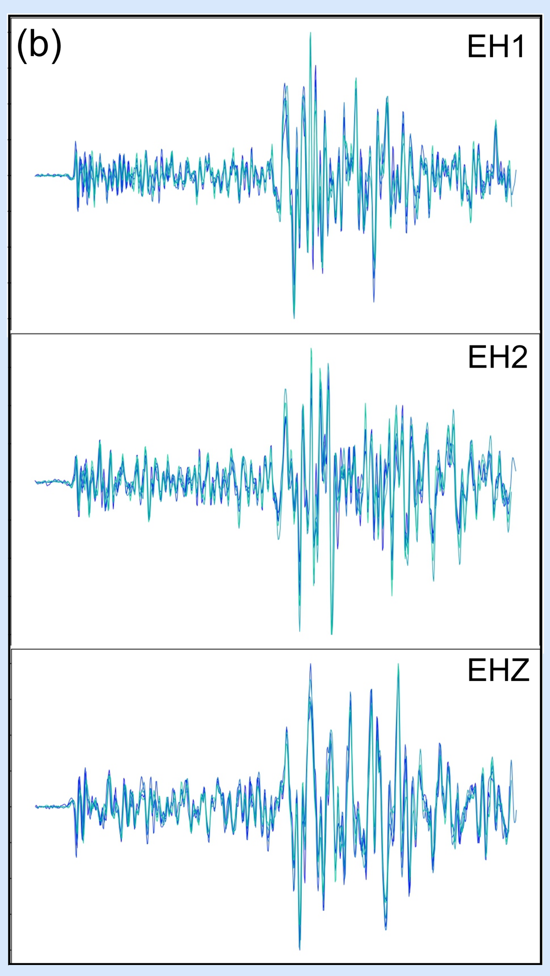

Figure 8. Cross-correlation statistics (a), signals (b) for 3C-cc treshold = 2.3. The signals in (b) were recorded on B916 borehole station and origin from 5 different seismic events.

References

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Acknowledgements

This research was supported by research project no. 2022/45/N/ST10/02172, funded by the National Science Centre, Poland, under agreement no. UMO-2022/45/N/ST10/02172. This work was also partially supported by a subsidy from the Polish Ministry of Science and Higher Education for the Institute of Geophysics, Polish Academy of Sciences. We gratefully acknowledge Polish high-performance computing infrastructure PLGrid (HPC Center: ACK Cyfronet AGH) for providing computer facilities and support within computational grant no. PLG/2025/018120.