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Taking Surface Seismic Monitoring to the Nano-Seismic Scale: Results from Natural and Induced Seismic Sequences in Switzerland.

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To a large part, the seismicity of Switzerland is characterized by swarm-like earthquake sequences of natural, and to a minor extent of man-made origin. Many of these sequences have been studied using relative location techniques, which often allowed to constrain the active fault plane of the larger events in a sequence and shed light on the tectonic processes that drive the seismicity. Yet, in the majority of cases the number of located earthquakes was too small to infer the details of the space-time evolution of the sequences, and their statistical parameters (e.g. magnitude-frequency distribution, Omori parameters). Therefore, it has been largely impossible to resolve clear patterns in the seismicity of
individual earthquake sequences that are needed to improve our understanding of the mechanisms behind, and the differences between natural and induced earthquake sequences.

Here we show how a combination of well-established seismological tools can significantly improve the completeness of detected and located earthquakes in surface network catalogs. By taking advantage of the waveform similarity in natural and induced earthquake sequences in Switzerland we are able to
detect seismic events several orders of magnitude below the detection threshold of classical signal energy based detectors. For this purpose we have implemented a multi-trace cross-correlation detector that either runs in "template mode" using a set of representative earthquakes (templates) of a sequence, or in "sub-space mode" using characteristic waveforms derived from the templates by
singular value decomposition. Waveform similarity is then further exploited to derive accurate and consistent earthquake magnitudes for the sequences. Finally we derive a similarity-distance relationship from a set of double-difference re-located events with larger magnitudes (DD reference set) for each sequence. These relationships are then used to locate tiny earthquakes, which are often
only recorded at one station, with respect to the DD reference sets using a cross-correlation location technique.

In this way it is possible to provide earthquake scientist with the data they need to better understand the processes and physics behind natural and induced microseismicity.