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Enhanced microseismic event detection via template matching and PhaseNet at the Quest CCS site, Alberta, Canada

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Summary

Reliable and accurate event detection is the basis of microseismic monitoring. In this work, 5 years (July, 2016-March, 2022) of microseismic data acquired on a downhole, 3-component geophone network at the Quest CCS site in central Alberta, Canada are used to develop a new event detection workflow.

Low-threshold event detectors (e.g., template matching (TM), STA/LTA) detect a plethora of potential events and are used in tandem with a machine learning (ML) model (i.e., PhaseNet) to reduce the number of false positives. The tandem detectors resulted in a 65.87% recall improvement relative to the vendor-supplied catalog and a ~12% improvement in precision relative to using the TM and STA/LTA detectors alone, which can be further improved by manual screening of waveforms to identify any remaining false detections.

Workflow

TM offers an interesting approach to detect only specific arrivals, in particular those that occur repeatedly within a cluster location (Arrowsmith and Eisner, 2006; Bui and van der Baan, 2020, 2024; Skoumal et al., 2015). Figure 1 displays our three-step workflow of event detection using TM. First, we extract 32 template events by grouping events from a vendor-supplied catalog of events, located within the Area of Review (AOR, a 10 km radius around the three CO_2 injection wells) over 5 year period, based on their waveform similarity. Second, we obtain initial detections by cross-correlating the template waveforms with the continuous geophone data acquired between May 2021 and September 2022. A low detection threshold of 0.2 is set for the minimum correlation coefficient of a fast matched filter algorithm (Bui and Van der Baan, 2020) to allow for waveform variability and to be able to detect weaker events within noisier data. Lower thresholds lead to increased detection rates (true positives) alongside a higher number of false alarms (false positives). Therefore, a machine-learning-based detector (PhaseNet, Zhu and Beroza, 2019) is subsequently applied to remove the false alarms. The refined detections are verified by a careful visual inspection of waveforms.

We choose the evaluation metrics: precision and recall to test the performance of different detection approaches. Precision P and recall R are defined as:

$$P = \frac{T_p}{T_p + F_p}, \tag{1}$$

$$R = \frac{T_p}{T_p + F_n}, \tag{2}$$

where T_p is the number of true positives, F_p is the number of false positives, and F_n is the number of false negatives. A true positive denotes that the event identified by the detection approach is a real event, otherwise it is a false positive. A false negative indicates that a real event is not identified by the detection approach. Precision P is the ratio between the true positives and all the positives, representing the sensitivity of the approach to false alarms. Recall R is the measure of the used approach correctly identifying true positives, representing the sensitivity of the approach to missed events.

Results, Observations, Conclusions

Performance comparison of three detectors working individually

We extract a pilot dataset from the continuous geophone data recorded by 8 3C geophones, including waveforms of 110 local events within the AOR, 7 regional events outside the AOR, and 52 non-microseismic events. The application of three detectors (TM, PhaseNet, and STA/LTA) to the pilot dataset indicates that PhaseNet achieves the highest precision (83.9%-84.2%) with a detection threshold of less than 0.27 (Figure 2a). Once the detection threshold is above 0.27, TM outperforms PhaseNet in precision. Even with a high threshold (≥ 0.55), the precision of PhaseNet can't reach 100% because it can't remove all non-microseismic signals. Therefore, manually validating PhaseNet detections has practical value. At low thresholds (TM ≤ 0.2; PhaseNet ≤ 0.113; STA/LTA ≤ 1), the recall rates of the three detectors were 100% (Figure 2b) but at the cost of many false alarms (low precision).

We further test applying three detectors on two days of continuous recordings (33.6 GB). The processing time of PhaseNet and STA/LTA is 27.39 h and 10.88 h, respectively. Using a template (520 samples; 2000 Hz) to scan the same input data, the TM calculation time is 2.3 h. The TM method provides the fastest processing speed, most likely due to a more efficient implementation.

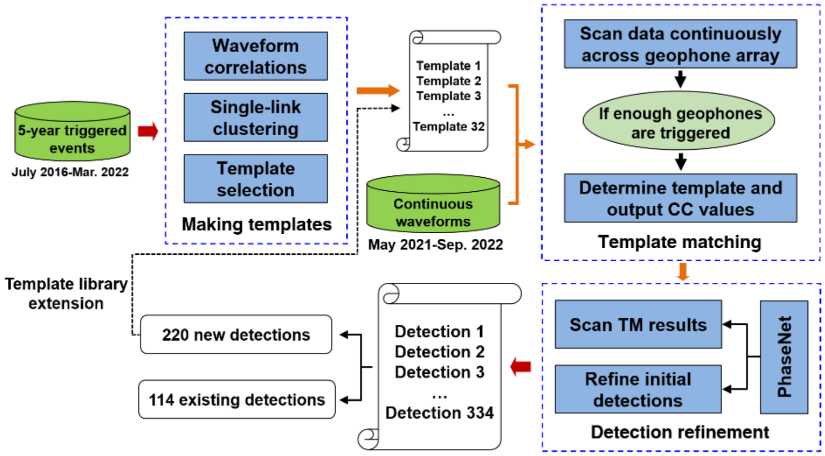

Figure 1. Workflow of event detection using template matching (TM). Cross-correlation (CC) values.

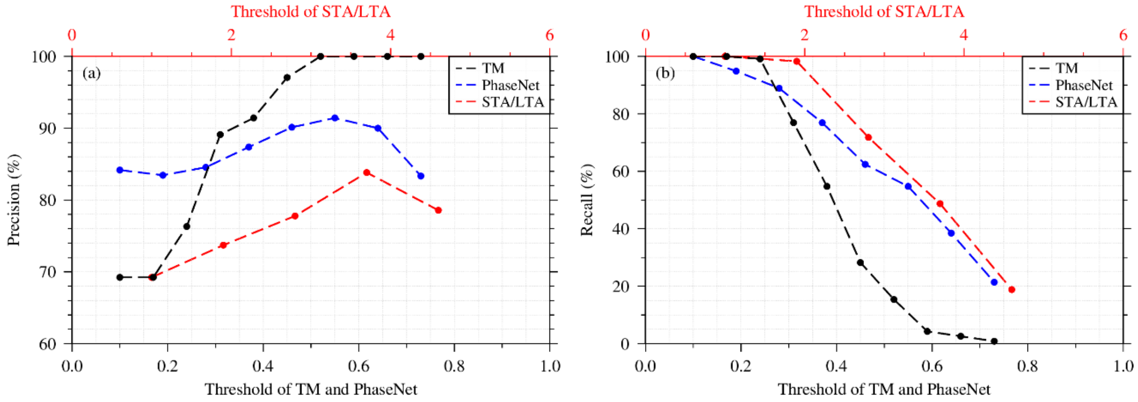

Figure 2. Precision (a) and recall (b) comparison of TM, PhaseNet, and STA/LTA.

Improved precision via the combination of two detectors

Using the obtained comparison results, we tested two detector combinations on the pilot dataset: TM+PhaseNet and STA/LTA+PhaseNet. Compared to only using a single detector (TM: 72.2%, Figure 3a; STA/LTA: 69.2%, Figure 3d), the tandem detectors have higher precision (TM+PhaseNet: 84.2%, Figure 3b; STA/LTA+PhaseNet: 84.2%, Figure 3e). The precision of the tandem detectors is comparable; but the TM+PhaseNet shows a slight advantage in the initial detection quality due to fewer false positives from TM compared to STA/LTA (Figures 2, 3a, and 3d). Manual screening of waveforms removed the remaining false positives (Figures 3c and 3f).

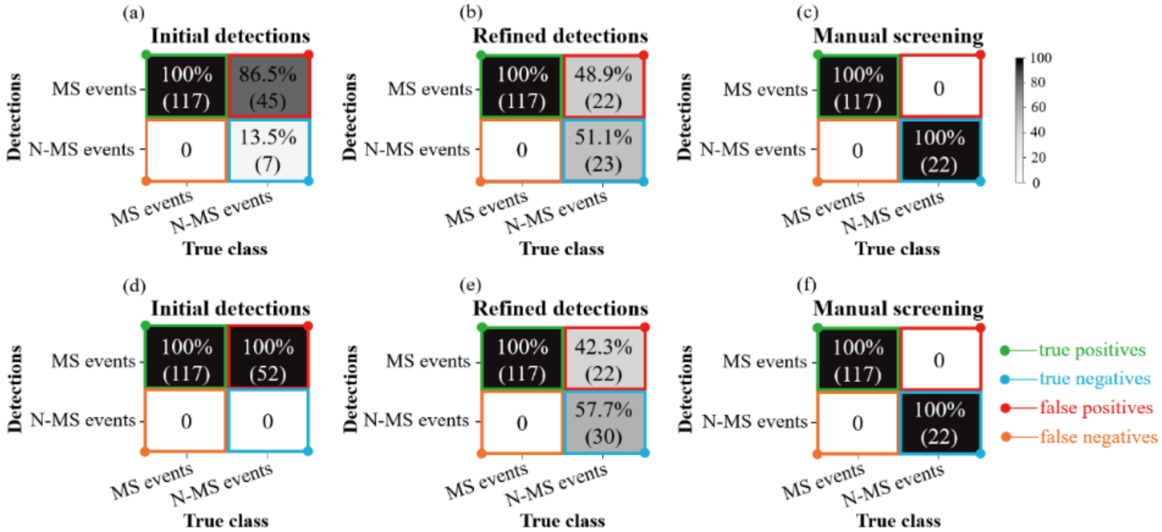

Figure 3. The confusion matrixes visualize the performance of tandem detectors TM+PhaseNet (a-c) and STA/LTA+PhaseNet (d-f). These matrixes compare the detections against the true class, revealing the gradually decreased false positives after refinement (the second column) and manual screening (the third column). Correct identifications of microseismic (MS) detections are considered as true positives (green) and correct removals of all non-microseismic (N-MS) events are regarded as true negatives (blue). Red and orange frames denote false positives and false negatives, respectively. The upper value in each cell is normalized by the class element size; the lower value is the absolute amount.

Enhanced detectability of microseismic events at the Quest CCS site

The tandem detector (TM+PhaseNet) complemented by manual screening was then applied to the continuous downhole data recorded between 17 May 2021 and 19 September 2022 at the Quest CCS site. Using TM and 32 template events, a plethora of potential events (26,846 detections) were detected. The application of PhaseNet removed 91% of false alarms (24,116 detections). Combined with manual screening, 334 of the 2,730 PhaseNet detections were confirmed as true microseismic events based on waveform characteristics in the time and frequency domains. The 334 events detected (Figure 4) are approximately three times more than those recorded by the vendor-provided catalog (114 events).

Novel/Additive Information

Our work demonstrates that integration of TM, PhaseNet, and manual screening can improve the detectability of microseismic events in downhole monitoring. To reduce the amount of manual quality control and implement effective long-term monitoring at Quest, we propose a quality assessment scheme to eliminate false alarms by using multiple waveform features in both time and frequency domains for different types of signals. Its application to one-month TM detections

(518 detections) indicates that all false alarms (485 false positives) were removed, increasing the detection precision to 100%.

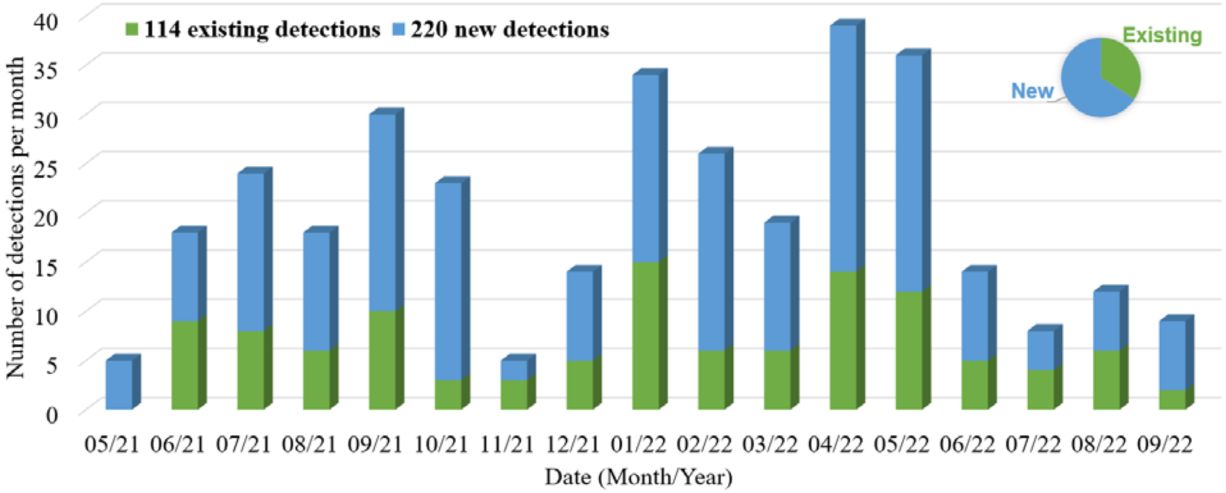

Figure 4. Our results of applying TM and PhaseNet methods on the continuous downhole geophone recordings between 17 May 2021 and 19 September 2022. Green: vendor-provided catalog. Blue: new detections.

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