Improved microseismic event detection and classification based on time-frequency analysis with CATS: A case study of the Quest CO_2 storage facility, Alberta.

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Summary

Robust and cost-effective microseismic event detection is a crucial component of Measurement, Monitoring and Verification (MMV) of Carbon Capture and Storage (CCS) sites. However, monitoring a relatively small Area of Review (AOR) within a wider region that contains various sources of regional seismicity and anthropogenic noise is challenging. We present the results of microseismic event detection at the Quest CO_2 storage facility in Alberta, using a novel event detection method, Cluster Analysis of Trimmed Spectrograms (CATS), on 15-months of downhole geophone monitoring data. We compare our results to the results produced by the traditional STA/LTA detection method in terms of precision (true positive/(true positive + false positive)) and recall (true positive/true positive + false negative) rates. CATS takes 80% longer to run (160 sec vs 33 sec for a 24-hour dataset) but produces 70% less potential events (35,698 vs 120,086) with higher precision (0.5% vs 0.14%) and higher recall (100% vs 96%) rates. The unusually low precision values are because the events of interest (3-4 microseismic events per week within the AOR) are intermingled with numerous other coherent events such as regional earthquakes at > 100km, mine blasts, active vibroseis sources from a local reflection seismic survey, and tube waves, most of which were removed manually in previous workflows.

We introduce an additional detection classification step based on analysis of the time-frequency attributes automatically calculated by CATS that reduces the total CATS potential events by 93% (2,278 vs 35,698) and increases the precision to 7.5% with a slight decrease in recall to 96.6%. This results in an average of 5 CATS potential events/day during the 15-month monitoring period, compared to 80 CATS potential events/day prior to classification. This is a more manageable number of events that greatly reduces the time and computational cost spent on further quality control and post-processing, especially due to the low magnitude events and low local microseismicity rate within the Quest AOR. Our work addresses the challenge of creating a robust and cost-effective event detection method for monitoring CCS sites surrounded by various sources of non-microseismic signals over the decades-long monitoring period of the CO_2 storage facility.

Theory / Method / Workflow

The Cluster Analysis of Trimmed Spectrograms (CATS; Grubas et al., 2023) event detection method is a simple, fast and accurate method that only requires eight free parameters. First, the method applies a Short Time Fourier Transform (STFT) to the data to obtain its amplitude spectrogram. Secondly, it applies an automatic noise estimation method (B-E-DATE; Mai et al., 2015) to the spectrogram to determine the noise level and trims the spectrogram to keep the signals above the minimum Signal-to-Noise-Ratio threshold. Finally, it clusters the trimmed spectrograms by neighboring pixels, and computes the likelihood and detection of the clustered signals based on the minimum cluster size and separation required in time and frequency. We apply the CATS event detection method to 15-months of data (17 May 2021 – 19 September 2022) recorded by a string of 8 downhole geophones at QUEST (Fadil et al., 2024). We then compare the CATS detections with those produced by the traditional Short-Term-Average/Long-Term-Average (STA/LTA) method.

In order to reduce the number of false positive detections, we apply an additional detection classification step based on analysis of the time-frequency attributes automatically calculated by CATS. We test multiple attributes and find that the duration of the detection interval and detected frequency range attributes produce the best distinction between local microseismic events and other coherent signals, mainly due to the short duration and high frequency content of local microseismic events. We determine a classification threshold in the cross-plot of frequency range vs interval duration that best separates the local microseismicity within the AOR (an area defined by three, 10km-radius circles centred on each of the three CO_2 injection wells) as potential true events from the various detected non-microseismic signals (e.g. regional seismicity outside of AOR, mine blasts, vibroseis and tube waves) as potential false events (Fig. 1). We then apply the classification threshold to all the CATS potential events in the 15-month dataset, in addition to other constraints which eliminate non-coherent and ultra-high frequency signals (e.g. must be detected on more than 3 geophone traces, frequency range < 700 Hz and min detected frequency < 150 Hz) (Fig. 2). We compare the detection results of STA/LTA, CATS and CATS with classification in terms of precision and recall rates.

Results, Observations, Conclusions

Compared to the traditional STA/LTA detection method, CATS takes 80% longer to run (160 sec vs 33 sec for a 24-hour dataset) but produces 70% less potential events (35,698 vs 120,086) with higher precision (0.5% vs 0.14%) and higher recall (100% vs 96%) rates. The additional detection classification step based on the detected frequency range and interval duration and other constraints reduces the total CATS potential events by 93% (2,278 vs 35,698) and increases the precision to 7.5% with a slight decrease in recall to 96.6% (Fig. 2). This results in an average of 5 CATS potential events/day during the 15-month monitoring period, compared to 80 CATS potential events/day prior to classification. This is a more manageable number of events that greatly reduces the time and computational cost spent on further quality control and post-processing, especially due to the low magnitudes (Mw < 1) and low local microseismicity rate within the Quest AOR (~3-4 events/week).

Novel/Additive Information

Our work addresses the challenge of creating a robust and cost-effective event detection method for monitoring CCS sites surrounded by various sources of non-microseismic signals over the decades-long monitoring period of the CO_2 storage facility. We apply a novel event detection method (CATS) that detects significantly lower false positives compared to the traditional STA/LTA method while simultaneously able to detect lower magnitude events with weaker signal-to-noise ratios. We also show that a detection classification step based on time-frequency analysis of the detection attributes can further increase the precision rate while maintaining sufficiently high recall rates, with no additional time and computational cost. This workflow can be automated and applied to future monitoring dataset to increase event detection robustness and efficiency.

Acknowledgements

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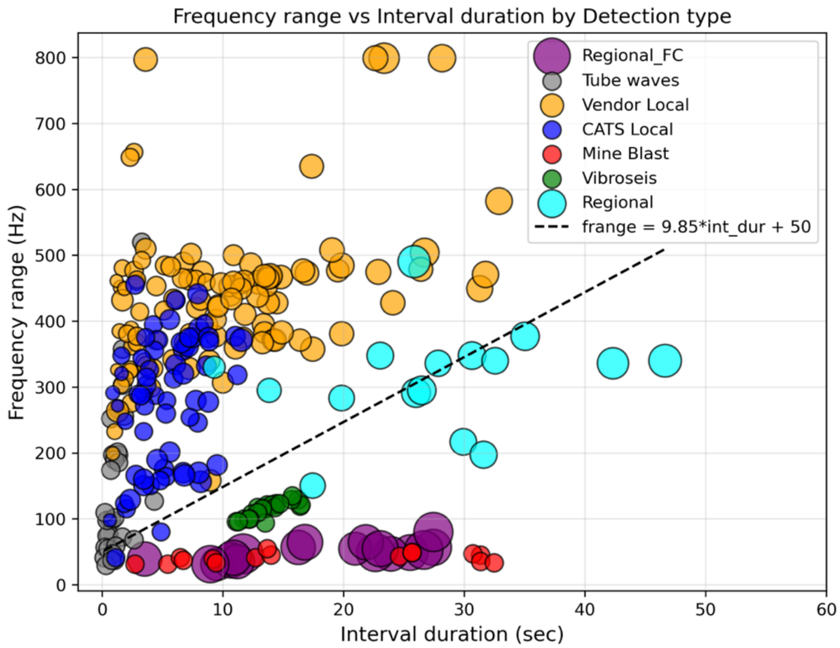

Figure 1. Cross-plot of detected frequency range vs detected interval duration of various types of signals detected by CATS in the 15-month downhole geophone dataset at Quest. The local microseismic events within the AOR (target detections) are represented by the blue and orange circles. The dashed line represents the classification threshold that best separates the target detections from other detected signals.

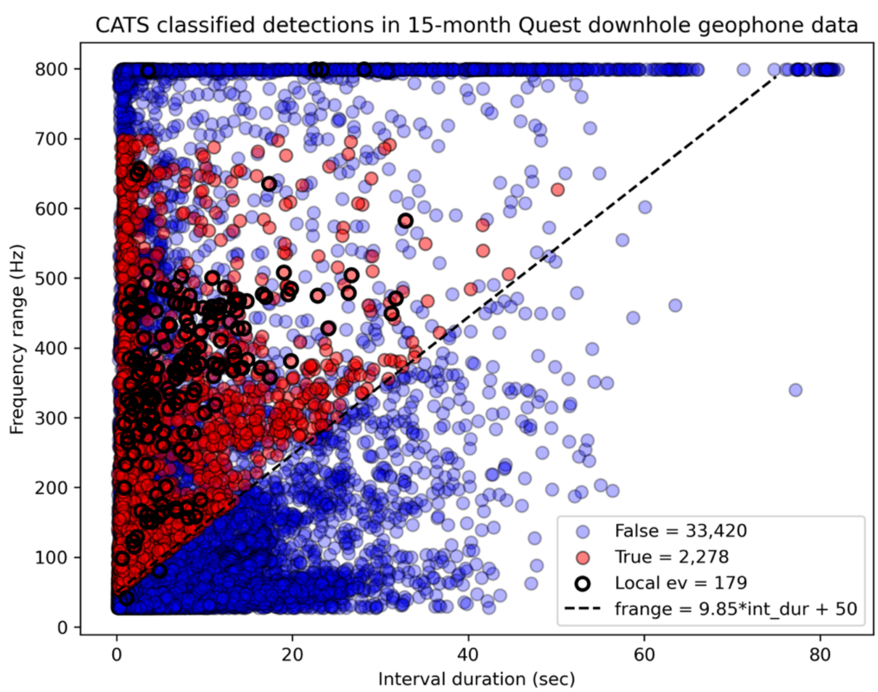

Figure 2. Cross-plot of detected frequency range vs detected interval duration of all CATS detections in the 15-month downhole geophone dataset at Quest, classified as potential true events in red or potential false events in blue. Local events within the Quest AOR (true positives) are outlined in black. The dashed line represents the classification threshold previously defined in Figure 1.