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On the current state and prospective of waveform cross correlation in seismic studies: improvements in signal detection, parameter estimation, relative location, and identification of seismic sources

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Solicited talk

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In the matched filter approach, cross correlation of fixed waveform templates and unknown signals is used to maximize the signal-to-noise ratio, SNR, in the presence of additive stochastic noise. The ambient seismic noise in many cases is a good approximation of such noise, allowing for optimal detection of repeating signals. In the long run, natural seismicity is a highly repeatable process. Mining activity also creates clusters of repetitive seismic signals. Therefore, waveform cross correlation, WCC, significantly reduces detection thresholds for repeating events, improves arrival time estimation as well as the estimation of relative signals amplitudes. The usage of WCC allows for significant improvements in the quality, consistency, and completeness of the global and regional seismic catalogs. For example, the estimates in various oceanic and continental regions demonstrate that the catalog of the International Data Centre (IDC) also used by the ISC misses from 30% to 70% of valid (according to the IDC definition) events.

The gain in relative and absolute location accuracy is demonstrated by the series of six underground explosions conducted by the DPRK between 2006 and 2017 within the Punggye-ri test site. All explosions were well detected by the seismic network of the International Monitoring System (IMS) of the CTBTO at regional and teleseismic distances. The travel time differences from the six events at the same stations are determined with the accuracy of 0.005 s corresponding to the relative location accuracy of less than 100 m. The smaller events located with fewer stations borrow the absolute location accuracy of the best located events. As a result, all six events are located within a circle of 3 km in diameter instead of 15 km for standard location method.

The capability of signal detection by the WCC method is demonstrated by finding of the low-magnitude aftershocks of the DPRK underground explosions. After the fifths test with mb(IDC)~5.1, the first aftershock with the estimated relative mb of 2.5 was detected by IMS and non-IMS regional stations. After the sixths test with mb(IDC)~6.1, many aftershocks were detected at regional and teleseismic distances. The signals generated by the biggest aftershocks of the DPRK 6 and DPRK 5 were used to detect weaker aftershocks using the multi-master technique also based on WCC. The sequence of low-magnitude seismic events from the Punggye-ri test site has not stopped yet, with the most recent detected on March 15, 2024. The total number of found low-magnitude events (DPRK aftershocks and likely seismic events of different origin) exceeds 200. Based on relative cross correlation level, there were two clusters of aftershocks found as related to the DPRK 5 and DPRK 6 epicentral zones. Comprehensive retroactive processing with the multi-master method, which significantly reduces the detection threshold and has higher statistical reliability for event hypotheses, has found several aftershocks of the DPRK 3 and 4, which were all missed by standard detection methods.