



## Using waveform cross correlation for automatic recovery of aftershock sequences

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Aftershock sequences of the largest earthquakes are difficult to recover. There can be several hundred mid-sized aftershocks per hour within a few hundred km from each other recorded by the same stations. Moreover, these events generate thousands of reflected/refracted phases having azimuth and slowness close to those from the P-waves. Therefore, aftershock sequences with thousands of events represent a major challenge for automatic and interactive processing at the International Data Centre (IDC) of the Comprehensive Nuclear-Test-Ban Organization (CTBTO). Standard methods of detection and phase association do not use all information contained in signals. As a result, wrong association of the first and later phases, both regular and site specific, produces enormous number of wrong event hypotheses and destroys valid event hypotheses in automatic IDC processing. In turn, the IDC analysts have to reject false and recreate valid hypotheses wasting precious human resources. At the current level of the IDC catalogue completeness, the method of waveform cross correlation (WCC) can resolve most of detection and association problems fully utilizing the similarity of waveforms generated by aftershocks. Array seismic stations of the International monitoring system (IMS) can enhance the performance of the WCC method: reduce station-specific detection thresholds, allow accurate estimate of signal attributes, including relative magnitude, and effectively suppress irrelevant arrivals. We have developed and tested a prototype of an aftershock tool matching all IDC processing requirements and merged it with the current IDC pipeline. This tool includes creation of master events consisting of real or synthetic waveform templates at ten and more IMS stations; cross correlation (CC) of real-time waveforms with these templates, association of arrivals detected at CC-traces in event hypotheses; building events matching the IDC quality criteria; and resolution of conflicts between events hypotheses created by neighboring master-events. The final cross correlation standard event lists (XSEL) is a start point for interactive analysis with standard tools. We present select results for the biggest earthquakes, like Sumatra 2004 and Tohoku 2011, as well as for several smaller events with hundreds of aftershocks. The sensitivity and resolution of the aftershock tool is demonstrated on the example of  $m_b=2.2$  aftershock found after the September 9, 2016 DPRK test.