



A multi-master method for detection of weak aftershocks at regional distances using waveform cross correlation

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Low-magnitude aftershocks of earthquakes and explosions (e.g., the DPRK underground tests) present a challenge to routine seismological methods of signals detection at regional distances and further association into seismic events. Even the method of waveform cross correlation (WCC), which is able to reduce detection threshold by a unit of magnitude, often fails to detect signals at several stations needed for association into reliable event hypotheses because of strong variation in seismic directivity of the earthquake-like sources. We have elaborated upon the WCC method based on a single master and developed a procedure based on the joint use of several adjacent master events with different source mechanisms. The method has been tested at the International Data Centre (IDC) of the Comprehensive Nuclear-Test-Ban Treaty Organization using observations of the aftershock activity induced by the DPRK underground explosions conducted on September 9, 2016 and September 3, 2017 and measured by the seismic network of the International Monitoring System (IMS) as well as by regional non-IMS stations. We used only regional stations in the range from 3.3 to 11 degrees. The set of master events and corresponding waveform templates includes the DPRK explosions and their aftershocks; the latter has been progressively updated with new events found. As a result, the IDC has successfully detected several small (estimated mb between 2.0 and 3.6) seismic events after two DPRK tests conducted on September 9, 2016 and September 3, 2017. The obtained detections were associated with reliable event hypothesis and then used to locate these events relative to the epicenters of the DPRK explosions. The multi-master WCC method also improves the accuracy of relative location for the DPRK explosions, including the first and the last events.