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Waveform cross-correlations in earthquake location problems

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In this study we analyzed precision of the waveform cross-correlation technique when applied to a double-difference relative location problems of a small earthquake clusters (cluster size in kilometers). The waveform cross-correlation technique appeared to be easy and effective way for differential times estimation which are used as an input for the double-difference relocation algorithms. Such differential times are assumed to be very precise (with precision exceeding possibilities of manual phase picking). Our goal was to quantify this precision by comparison with carefully picked differential times. Earthquakes from three mainshock-aftershock sequences of 2014 in West Bohemia were used for the analysis and the analysis was carried out on multiple WEBENT stations on both, P and S waves. The results of the analysis showed several facts:

The error (deviation of cross-correlated differential time from the manually achieved one) was not equally distributed and was pronounced when differential times between pairs of earthquakes with significantly different magnitudes were used.

The error for P-waves was often exceeding 0.025 s when magnitude difference between the paired earthquakes exceeded 2.

The maximum error was always bound to the strongest earthquakes – mainshocks, and was varying between stations in range between 0.03 and 0.08 for P-waves and up to 0.1 for S-waves.
The error was always present with no obvious dependency on filtering parameters, stations selected or datasets used.

We interpreted the behavior of the error as a result of two undergoing effects – the difference in spectral content of two different-magnitude earthquakes and difference in source directivity. While the first one causes the error to be almost linearly dependent on the magnitude difference, the latter one causes scattered highly erroneous measurements associated always with strong earthquakes, where the source duration can't be approximated as a delta function.

The effect of this error is pronounced when small datasets with wide magnitude range are subject of interest. Such datasets are however very common in seismology – each mainshock-aftershock sequence. The deviation of cross-correlated arrival time difference has potential to systematically shift the positions of the strong earthquakes. Unfortunately, these are often the earthquakes whose location is of utmost importance for further analyses. The effect of the magnitude difference and the directivity on the differential times and thus resulting location solution was clearly observed on the West Bohemian datasets when cross-correlations were used. Hence a careful data-processing and considerable focus on the strong earthquakes have to be paid when applying the wave-form cross-correlation technique. In our case the substitution of the cross-correlated differential times in strong magnitude difference cases was used, however, final and elegant solution is still subject of research.