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Automatic Classification of Extensive Aftershock Sequences Using Empirical Matched Field Processing

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The aftershock sequences that follow large earthquakes create considerable problems for data centers attempting to produce comprehensive event bulletins in near real-time. The greatly increased number of events which require processing can overwhelm analyst resources and reduce the capacity for analyzing events of monitoring interest. This exacerbates a potentially reduced detection capability at key stations, due the noise generated by the sequence, and a deterioration in the quality of the fully automatic preliminary event bulletins caused by the difficulty in associating the vast numbers of closely spaced arrivals over the network. Considerable success has been enjoyed by waveform correlation methods for the automatic identification of groups of events belonging to the same geographical source region, facilitating the more time-efficient analysis of event ensembles as opposed to individual events. There are, however, formidable challenges associated with the automation of correlation procedures.

The signal generated by a very large earthquake seldom correlates well enough with the signals generated by far smaller aftershocks for a correlation detector to produce statistically significant triggers at the correct times. Correlation between events within clusters of aftershocks is significantly better, although the issues of when and how to initiate new pattern detectors are still being investigated. Empirical Matched Field Processing (EMFP) is a highly promising method for detecting event waveforms suitable as templates for correlation detectors. EMFP is a quasi-frequency-domain technique that calibrates the spatial structure of a wavefront crossing a seismic array in a collection of narrow frequency bands. The amplitude and phase weights that result are applied in a frequency-domain beamforming operation that compensates for scattering and refraction effects not properly modeled by plane-wave beams. It has been demonstrated to outperform waveform correlation as a classifier of ripple-fired mining blasts since the narrowband procedure is insensitive to differences in the source-time functions. For sequences in which the spectral content and time-histories of the signals from the main shock and aftershocks vary greatly, the spatial structure calibrated by EMFP is an invariant that permits reliable detection of events in the specific source region.

Examples from the 2005 Kashmir and 2011 Van earthquakes demonstrate how EMFP templates from the main events detect arrivals from the aftershock sequences with high sensitivity and exceptionally low false alarm rates. Classical waveform correlation detectors are demonstrated to fail for these examples. Even arrivals with SNR below unity can produce significant EMFP triggers as the spatial pattern of the incoming wavefront is identified, leading to robust detections at a greater number of stations and potentially more reliable automatic bulletins. False EMFP triggers are readily screened by scanning a space of phase shifts relative to the imposed template. EMFP has the potential to produce a rapid and robust overview of the evolving aftershock sequence such that correlation and subspace detectors can be applied semi-autonomously, with well-chosen parameter specifications, to identify and classify clusters of very closely spaced aftershocks.