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A new Bayesian Inference-based Phase Associator for Earthquake Early Warning

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State of the art network-based Earthquake Early Warning (EEW) systems can provide warnings for large magnitude 7+ earthquakes. Although regions in the direct vicinity of the epicenter will not receive warnings prior to damaging shaking, real-time event characterization is available before the destructive S-wave arrival across much of the strongly affected region. In contrast, in the case of the more frequent medium size events, such as the devastating 1994 Mw6.7 Northridge, California, earthquake, providing timely warning to the smaller damage zone is more difficult. For such events the "blind zone" of current systems (e.g. the CISN ShakeAlert system in California) is similar in size to the area over which severe damage occurs. We propose a faster and more robust Bayesian inference-based event associator, that in contrast to the current standard associators (e.g. Earthworm Binder), is tailored to EEW and exploits information other than only phase arrival times. In particular, the associator potentially allows for reliable automated event association with as little as two observations, which, compared to the ShakeAlert system, would speed up the real-time characterizations by about ten seconds and thus reduce the blind zone area by up to 80%.

We compile an extensive data set of regional and teleseismic earthquake and noise waveforms spanning a wide range of earthquake magnitudes and tectonic regimes. We pass these waveforms through a causal real-time filterbank with passband filters between 0.1 and 50Hz, and, updating every second from the event detection, extract the maximum amplitudes in each frequency band. Using this dataset, we define distributions of amplitude maxima in each passband as a function of epicentral distance and magnitude.

For the real-time data, we pass incoming broadband and strong motion waveforms through the same filterbank and extract an evolving set of maximum amplitudes in each passband. We use the maximum amplitude distributions to check whether the incoming waveforms are consistent with amplitude and frequency patterns of local earthquakes by means of a maximum likelihood approach. If such a single-station event likelihood is larger than a predefined threshold value we check whether there are neighboring stations that also have single-station event likelihoods above the threshold. If this is the case for at least one other station, we evaluate whether the respective relative arrival times are in agreement with a common earthquake origin (assuming a simple velocity model and using an Equal Differential Time location scheme). Additionally we check if there are stations where, given the preliminary location, observations would be expected but were not reported ("not-yet-arrived data"). Together, the single-station event likelihood functions and the location likelihood function constitute the multi-station event likelihood function. This function can then be combined with various types of prior information (such as station noise levels, preceding seismicity, fault proximity, etc.) to obtain a Bayesian posterior distribution, representing the degree of belief that the ensemble of the current real-time observations correspond to a local earthquake, rather than to some other signal source irrelevant for EEW.

Additional to the reduction of the blind zone size, this approach facilitates the eventual development of an end-to-end probabilistic framework for an EEW system that provides systematic real-time assessment of the risk of false alerts, which enables end users of EEW to implement damage mitigation strategies only above a specified certainty level.