A probabilistic, multi-parametric real-time earthquake location method

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For network-based Earthquake Early Warning Systems (EEWS), the real-time earthquake location is crucial for a correct estimation of event location/magnitude and therefore, for a reliable prediction of the potential expected shaking at the target sites in terms of predicted maximum ground shaking. Different approaches have been recently proposed for the real-time location which mainly use absolute (or differential) P-wave travel times at a set of minimum available stations or measurement of the initial P-wave arrival time (Elarms, Presto, Horiuchi), polarization (Eiserman and Bock) or amplitude and time (Yamada). In this work, we propose a new method which is able to exploit the continuous, real-time information available from both time, amplitude and polarization of initial P-wave signals acquired by dense three component arrays deployed in the source zones. The methodology we propose is an evolutionary and Bayesian probabilistic technique that combines three different observed parameters: 1) the differential arrival times of P-waves (which are computed using a 1D velocity model for the estimation of the theoretical arrival times); 2) the differential P-wave amplitudes in terms of P-wave peak velocity [reference] (which are computed using an existing P-peak motion prediction equation) and 3) the real-time estimation of back-azimuthal direction, measured shortly after the P-wave arrival. These three parameters are measured in real-time and are used as prior and conditional information to estimate the posterior probability of the event location parameters, e.g. the hypocenter coordinates and the origin time. The method is evolutive, since it updates the location parameters as new data are acquired by more and more distant stations as the P-wavefront propagates across the network. The output is a multi-dimensional Probability Density Function (PDF), which contains the complete information about the maximum likelihood parameter estimation with their uncertainty. The method is computationally efficient and optimized for running in real-time applications, where the earthquake location has to be retrieved in a very short time window (around 1 sec) after data acquisition. We tested the proposed strategy on a sequence of 29 earthquakes of the 2016-2017 central Italy seismic sequence acquired by the RAN (Rete Accelerometrica Nazionale) network with a magnitude range of 4.2-6.5. For the testing phase, we also simulated non-optimal conditions in terms of source-to-receiver geometry. Specifically, we tested the method by simulating the case of “offshore” earthquakes recorded by a coastal network and in the case of a linear “barrier-type” geometry of the network. Our approach turned out to be suitable to work in condition of a sparse network, with a limited number of nodes and poor azimuthal coverage. In most of the cases, reliable location errors, less than 10 km, are achieved within few seconds from the first recorded P wave. As compared to other classical
location techniques (i.e RTLOC in PRESTo) our approach shows an improvement of the solutions, especially for the first instants (2 seconds after the first P-wave arrival at network) when a poor number of stations (less than 4) is available.