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A new Bayesian formulation to integrate body-wave polarisation in non-linear probabilistic earthquake location

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Earthquake location is most of the time computed using the arrival time of the seismic waves observed on monitoring networks. However, three-component seismometers enable measurement of the seismic wave polarisation which is also hypocentre dependent. This information is necessary when considering single-station locations but may also be applied to local and sparse seismic networks with poor coverage to better constrain the local earthquake hypocentres, as typically seen in hydraulic fracturing or geothermal field monitoring.
In this work, we propose a new Bayesian formulation that integrates the information associated with the P-wave polarisation into a probabilistic earthquake location scheme. The approach takes a single 3C-sensor perspective and uses the covariance matrix to quantify the polarisation. This matrix contains all necessary axial information including uncertainties. According to directional statistics, the tri-variate Gaussian distribution represented by the covariance matrix corresponds to an angular central Gaussian distribution when axial data are considered. This property allows us defining a simple probability density function associated with a modelled polarisation vector given the observed covariance matrix. With this approach, the non-linearity of the location problem is kept. Unlike existing least-square misfit functions, this formulation does not reduce the polarisation to a single axis and avoids inexact estimate of a priori angular uncertainties. Furthermore, it replaces the polarisation information in the spherical data space, which yields correct probability density normalisation and prevents from any weighting when combined with e.g. travel-time probability density function.
We first present the Bayesian formalism. Then, several synthetic tests on a 1D velocity model are performed to illustrate the technique and to show the effect of integrating the polarisation information. In this synthetic test, we also compare the results with an existing alternative formalism which considers azimuth and inclination of the P-wave arrival as independent to locate earthquakes. Finally, induced seismicity recorded in a geothermal field is located using this technique and the results compared to hypocentres obtained from travel-times only.
Besides location, this new Bayesian formalism can be used to compute the orientation of three-component seismometers.