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3D velocity model optimization for enhanced absolute event locations: Application to Duvernay Subscription Array in western Canada

Yoones Vaezi, Aaron Booterbaugh, Mark Stacey, Sepideh Karimi, and Dario Baturan
Nanometrics Inc., Canada

Absolute hypocentral locations form the basis for characterizing natural and induced seismicity. The accuracy of these locations plays a crucial role in subsequent hazard estimation, risk management, performance measurements, and operation optimizations.

Apart from acquisition geometry and phase picking errors, velocity model errors are one of the main sources of event location inaccuracy. One should differentiate between precision and accuracy. Precision relates to error ellipsoids, origin times and depth uncertainties, while accuracy describes how close the located events are to the "actual" locations. It should be noted that on regional-scale networks with numerous stations where higher inaccuracies are expected, event locations are relatively less sensitive to unmodeled heterogeneities in the assumed velocity model. In contrast, on local arrays, commonly used for induced seismic monitoring, these uncertainties can significantly affect locations and subsequent analyses. In this study, we present a methodology for constructing and further calibrating/optimizing a 3D velocity model to improve the accuracy and precision of event locations recorded in the Duvernay Subscription Array (DSA) in Alberta, Canada.

In the first step, we build an initial 3D velocity model by interpolating numerous P- and S-phase sonic logs from nearby wells utilizing a combination of linear triangulation and nearest neighbor algorithms. We interpolate such that the model is geologically constrained by the structural horizon surfaces and formation tops obtained by surface seismic and seismic-to-well ties. This results in a more meaningful model in terms of its agreement with the actual Earth's subsurface velocities and their physical complexity. We perform a cross-validation driven outlier removal procedure prior to interpolation to remove poor data and limit unrealistic velocity contrasts. Next, we smooth the obtained model using an elliptical inverse distance weighted exponential function to further reduce sharp non-physical velocity contrasts in all directions.

In addition to the 3D velocity model, we calculate station statics at the location of the stations and take them into account through a grid search location algorithm. These parameters are used to relocate the existing event catalog in the DSA network that had initially been located using an existing simple 1D velocity model from western Alberta. The relocated events show higher precision as they result in tighter clusters with reduced RMS residuals and lower station phase residuals. They also show higher accuracy as they provide better agreement with common events in well-constrained microseismic catalogs. As expected for surface monitoring, the velocity model optimization affects the depths of the events more severely than their lateral position, which is more stable. We also suggest that adding extra stations for better azimuthal coverage of different event clusters can further lower the associated location uncertainty caused by the configuration bias and also allows for redundancy and therefore, lowers location uncertainty caused by arrival-time picks.