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Modelling strategies and model assessment for wide-angle seismic traveltime data

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SUMMARY

Strategies for modelling seismic refraction/wide-angle reflection traveltimes to obtain 2-D velocity and interface structure are presented along with methods for assessing the reliability of the results. Emphasis is placed on using inverse methods, but a discussion of arrival picking and classification, data uncertainties, traveltime reciprocity, crooked line geometry and the selection of a starting model is also applicable to trial-and-error forward modelling. The most important advantages of an inverse method are the ability to derive simpler models for the appropriate level of fit to the data, and the ability to assess the final model in terms of resolution, parameter bounds and non-uniqueness. Given the unique characteristics of each data set and the local earth structure, there is no single approach to modelling wide-angle data that is best. This paper describes the best modelling strategies according to (1) the model parametrization, (2) the inclusion of prior information, (3) the complexity of the earth structure, (4) the characteristics of the data, and (5) the utilization of coincident seismic reflection data. There are two natural end-member inversion styles: (1) a regular, fine-grid parametrization when seeking a minimum-structure model, and (2) an irregular grid, minimum-parameter model when considering certain forms of prior information. The former style represents the 'pure' tomography approach. The latter style is closer to automated forward modelling, and can be applied best with a parameter-selective algorithm, that is, one that allows any subset of model parameters to be selected for inversion. If there is strong lateral heterogeneity in the near-surface only, layer stripping works well. If there is complexity at all depths, all model parameters should be determined simultaneously after careful construction of a starting model that allows the appropriate rays to be traced to all pick locations. The lateral spacing of model nodes to use will depend on the type of inversion and whether detailed prior information is included, but a general guideline based on model resolution when seeking a minimum-parameter model is a model node spacing equal to the shot spacing (receiver spacing for typical marine data), except perhaps in the upper layers where about half this may be necessary; node spacing is not an issue when using smoothing constraints, provided it is small enough to resolve the earth structure of interest. Traveltimes picked from pre-stack, unmigrated or migrated coincident reflection data can be (1) used to develop the starting model, (2) inverted simultaneously with the wide-angle data, or (3) inverted after modelling the wide-angle data to constrain interfaces that 'float' within the velocity model. Model assessment establishes the reliability of the final model. Presenting model statistics, traveltime fits, ray diagrams and resolution kernels is useful, but can only indirectly address this issue. Direct model assessment techniques that derive alternative models that satisfactorily fit the real data are the best means of establishing the absolute bounds on model parameters and whether a particular model feature is required by the data.

Key words: inversion, seismic modelling, seismic refraction, traveltime, wide-angle reflection.