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Traveltime tomography using irregular parameterised grids

IMMO TRINKS (trinks@esc.cam.ac.uk)[1], SATISH SINGH (singh@ipgp.jussieu.fr)[2], CHRIS CHAPMAN (chapman@cambridge.scr.slb.com)[3], PENNY BARTON (barton@esc.cam.ac.uk)[1] and MIGUEL BOSCH (bosch@esc.cam.ac.uk)[1]

[1] LITHOS group, Bullard Labs, Madingley Road, Cambridge CB3 OEZ, UK
[2] LITHOS group, IPG Paris, 4 Place Jussieu, 75252 Paris Cedex 05, France
[3] Schlumberger Cambridge Research, High Cross, Madingley Road, Cambridge CB3 0EL, UK

Introduction

Seismic wide angle surveys with simulated streamer lengths up 30 km have recently been recorded for the purpose of sub-basalt imaging. The aim of these measurements is to record refracted and converted phases at long offsets and thereby being able to gain more energy from below basalt layers. The huge size of these densely sampled long offset data sets does not allow for an inversion of all the data with present tomography approaches; typically it would be necessary to decimate the data set by discarding entire shot records in order to use one of the available methods, which are optimised for relatively sparsely-sampled data sets (OBS, borehole, etc.), and do not scale well to dense multi-channel surveys. Therefore a more efficient inversion technique is needed, which is capable of handling such densely sampled data sets without the need for data decimation.

Our method is based on the work of McCaughey & Singh (1997) but uses an irregular parameterised grid of Delaunay triangles instead of a regular mesh, and incorporates not only traveltimes but also traveltime derivatives. The geometry of marine long offset surveys can generally be regarded as two dimensional, and therefore our algorithm is developed for 2-D applications.

Model parameterisation

Regular parameterisations of velocity models are appealing because of their simplicity, but they can cause the over-parameterisation of large regions of the model in the case when high resolution of some structures is required. Therefore we use an irregular parameterisation to construct an optimal grid by adapting the local resolution to the available ray density. In two dimensions we can group irregularly distributed velocity nodes together using Delaunay triangulation. A comparable parameterisation was described by Böhm *et al.* (2000). While their model is constructed of Voronoi cells, with constant velocities within each cell, our model uses triangular shaped cells with a linear interpolation of the squared slowness over each cell. Thus we avoid velocity discontinuities between cells and achieve a smooth ray path.

Our velocity model is composed of a sequence of layers separated by interfaces. The velocity within each layer is described by a set of velocity nodes which may be distributed randomly. At these node points the velocity and the squared slownesses are determined. For ray tracing the quadratic slowness ($1/V^2$) model was chosen instead of the propagation velocity V, since it offers the simplest analytical solution for an inhomogeneous medium with constant gradients (Cerveny, 1987). Böhm et al. (2000) described an algorithm for automatic re-gridding that is able to fit the local resolution to the available ray paths. The algorithm inserts additional velocity nodes in regions of large velocity gradients and reduces them elsewhere. We plan to adapt the model grid between the inversion steps. The adjustment of the model will be driven by the model resolution depending on the ray coverage.

Ray Tracing

To ensure the efficiency of the code we use analytic initial-value ray tracing in an isotropic medium, as formulated by Farra (1990). The two-point problem is avoided by shooting a fan of rays and interpolating the traveltimes at the receiver locations. After shooting a first coarse fan the intersections of the rays with the receiver-array are determined. Then the ray fan is densified to obtain wherever possible one ray between each bracketing pair of receivers. The observed traveltimes are then interpolated from the receiver locations to the positions of the ray-streamer intersections in order to calculate the traveltime misfit. Reflected rays and turning rays will be calculated and used in the inversion.

Inversion

Our aim is to determine both the velocity distribution and the shape of the reflectors by joint reflection and refraction traveltime tomography. Therefore, we plan to implement a linearized simultaneous inversion of reflector depths and velocities.

Fréchet derivatives are calculated for each ray and assigned to the velocity nodes. The covariance of the model parameters and of the traveltime data is taken into account in the formulation of the inversion. A biconjugate gradient solver is used to calculate the model update.

To increase the efficiency of the inversion it is planned to use the local slowness as additional information about the traveltime curve in order to invert traveltime curves rather than traveltime points alone. Slownesses can be computed along with the traveltimes during the forward modelling step at no extra cost. Since the data are collected at very fine sampling intervals, it is possible to pick apparent slownesses accurately at the same time as picking traveltimes. A semi-automated algorithm for traveltime and slowness picking (Di Nicola-Carena, 1999) will be used for the inversion of long offset seismic data from the North Atlantic region.

Conclusion

High resolution traveltime tomography based on adaptive gridding will provide well constrained velocity models. This new approach will be used to study densely sampled long offset seismic data with the goal of imaging beneath high velocity layers in geologically complex regions.

References

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