WAVE-EQUATION MIGRATION IN GENERALIZED COORDINATE SYSTEMS

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I certify that I have read this dissertation and that, in my opinion, it is fully adequate in scope and quality as a dissertation for the degree of Doctor of Philosophy.

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Abstract

Wave-equation migration using one-way wavefield extrapolation operators is commonly used in industry to generate images of complex geologic structure from 3D seismic data. By design, most conventional wave-equation approaches restrict propagation to downward continuation, where wavefields are recursively extrapolated to depth on Cartesian meshes. In practice, this approach is limited in high-angle accuracy and is restricted to down-going waves, which precludes the use of some steep dip and all turning wave components important for imaging targets in such areas as steep salt body flanks.

This thesis discusses a strategy for improving wavefield extrapolation based on extending wavefield propagation to generalized coordinate system geometries that are more conformal to the wavefield propagation direction and permit imaging with turning waves. Wavefield propagation in non-Cartesian coordinates requires properly specifying the Laplacian operator in the governing Helmholtz equation. By employing differential geometry theory, I demonstrate how generalized a Riemannian wavefield extrapolation (RWE) procedure can be developed for any 3D non-orthogonal coordinate system, including those constructed by smoothing ray-based coordinate meshes formed from a suite of traced rays. I present 2D and 3D generalized RWE propagation examples illustrating the improved steep-dip propagation afforded by the coordinate transformation.

One consequence of using non-Cartesian coordinates, though, is that the corresponding 3D extrapolation operators have up to 10 non-stationary coefficients, which can lead to imposing (and limiting) computer memory constraints for realistic 3D

applications. To circumvent this difficulty, I apply the generalized RWE theory to analytic coordinate systems, rather than numerically generated meshes. Analytic coordinates offer the advantage of having straightforward analytic dispersion relationships and easy-to-implement extrapolation operators that add little computational overhead. In particular, I demonstrate that the dispersion relationship for 2D elliptical geometry introduces only an effective velocity model stretch, permitting the use of existing high-order Cartesian extrapolators. The results of elliptical coordinate shot-profile migration tests demonstrate the improvements in steep dip reflector imaging facilitated by the coordinate system transformation approach.

I extend the analytic coordinate system approach to 3D geometries using tilted elliptical-cylindrical (TEC) meshes. I demonstrate that propagation in a TEC coordinate system is equivalent to wavefield extrapolation in elliptically anisotropic media, which is easily handled by existing industry practice. TEC coordinates also allow steep dip propagation in both the inline and cross-line directions by virtue of the associated elliptical and tilting Cartesian geometries. Observing that a TEC coordinate system conforms closely to the shape of a line-source impulse response, I develop an TEC-coordinate, inline-delay-source migration strategy that enables the efficient migration of individual sail-line data. I argue that this strategy is more robust than 3D plane-wave migration because of the reduced migration aperture requirements and, commonly, a lower number of total migration runs. Synthetic imaging tests on a 3D wide-azimuth data set demonstrate the imaging advantages offered by the TEC coordinate transformation, especially in the cross-line direction. Field data tests on a Gulf of Mexico data set similarly indicate the advantage of TEC coordinates.

Preface

The electronic version of this report[1] makes the included programs and applications available to the reader. The markings **ER**, **CR**, and **NR** are promises by the author about the reproducibility of each figure result. Reproducibility is a way of organizing computational research that allows both the author and the reader of a publication to verify the reported results. Reproducibility facilitates the transfer of knowledge within SEP and between SEP and its sponsors.

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Our testing is currently limited to LINUX 2.6 (using the Intel Fortran90 compiler) and the SEPlib-6.4.6 distribution, but the code should be portable to other architectures. Reader's suggestions are welcome. For more information on reproducing SEP's electronic documents, please visit *http://sepwww.stanford.edu/research/redoc/*.

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