Geophysical Research Abstracts
Vol. 15, EGU2013-3034, 2013
EGU General Assembly 2013

A pseudo-spectral method for simulating poro-elastic wave propagation in complex borehole environments

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We present a novel approach for the comprehensive, flexible, and accurate simulation of poro-elastic wave propagation in 3D cylindrical coordinates. An important application of this method is the realistic modeling of complex seismic wave phenomena in fluid-filled boreholes, which represents a major, and as of yet largely unresolved, computational problem in exploration geophysics. To this end, we use numerical mesh consisting of three concentric domains representing the borehole fluid in the center followed by the casing and/or mudcake, and the surrounding porous formation. The spatial discretization is based on a Chebyshev expansion in the radial direction and Fourier expansions in the vertical and azimuthal directions as well as a Runge-Kutta integration scheme for the time evolution. A domain decomposition method based on the method of characteristics and trigonometric interpolation is used to match the boundary conditions at the fluid/porous-solid and porous-solid/porous-solid interfaces as well as to reduce the number of grid points in the innermost domain for computational efficiency. We apply this novel poro-elastic modeling approach to assess the sensitivity of Stoneley waves to formation permeability in the presence of a casing as well as to evaluate the effects of various kinds of heterogeneity in the porous formation on the recorded signals. Our results indicate that Stoneley waves are indeed remarkably sensitive to the average permeability of the heterogeneous porous formation behind a perforated PVC casing. Our results do, however, also indicate that the amplitudes of the Stoneley decay very rapidly from the borehole wall towards the center of the borehole and hence are correspondingly difficult to measure with conventional centered borehole logging tools.