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# OREGANO_VE: a new parallelised 3D solver for the general (non-)linear Maxwell visco-elastic problem: validation and application to the calculation of surface deformation in the earthquake cycle

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We have developed a new parallelized 3-D numerical code, OREGANO_VE, for the solution of the general visco-elastic problem in a rectangular block domain. The mechanical equilibrium equation is solved using the finite element method for a (non-)linear Maxwell visco-elastic rheology. Time-dependent displacement and/or traction boundary conditions can be applied. Matrix assembly is based on a tetrahedral element defined by 4 vertex nodes and 6 nodes located at the midpoints of the edges, and within which displacement is described by a quadratic interpolation function. For evaluating viscoelastic relaxation, an explicit time-stepping algorithm (Zienkiewicz and Cormeau, Int. J. Num. Meth. Eng., 8, 821-845, 1974) is employed.

We test the accurate implementation of the OREGANO_VE by comparing numerical and analytic (or semi-analytic half-space) solutions to different problems in a range of applications: (1) equilibration of stress in a constant density layer after gravity is switched on at t = 0 tests the implementation of spatially variable viscosity and non-Newtonian viscosity; (2) displacement of the welded interface between two blocks of differing viscosity tests the implementation of viscosity discontinuities, (3) displacement of the upper surface of a layer under applied normal load tests the implementation of time-dependent surface tractions (4) visco-elastic response to dyke intrusion (compared with the solution in a half-space) tests the implementation of all aspects. In each case, the accuracy of the code is validated subject to use of a sufficiently small time step, providing assurance that the OREGANO_VE code can be applied to a range of visco-elastic relaxation processes in three dimensions, including post-seismic deformation and post-glacial uplift.

The OREGANO_VE code includes a capability for representation of prescribed fault slip on an internal fault. The surface displacement associated with large earthquakes can be detected by some geodetic observations (e.g., GPS and/or InSAR). However, such observational data reflect the integrated effect of various processes including viscoelastic relaxation, poroelastic creep and after-slip on the fault plane. Interpretation of surface displacements therefore requires quantitative testing of the possible mechanisms using plausible boundary conditions and comparison of model predictions with observations. In this study, using the OREGANO_VE code, we evaluate the 3D time-dependent effects of viscoelastic behaviour in the earthquake cycle, and examine the dependence of surface deformation on the assumed sub-surface properties of the brittle crust and the fault plane.