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SULEC: Benchmarking a new ALE finite-element code

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We have developed a 2-D/3-D arbitrary lagrangian-eulerian (ALE) finite-element code, SULEC, based on known techniques from literature. SULEC is successful in tackling many of the problems faced by numerical models of lithosphere and mantle processes, such as the combination of viscous, elastic, and plastic rheologies, the presence of a free surface, the contrast in viscosity between lithosphere and the underlying asthenosphere, and the occurrence of large deformations including viscous flow and offset on shear zones. The aim of our presentation is (1) to describe SULEC, and (2) to present a set of analytical and numerical benchmarks that we use to continuously test our code.

SULEC solves the incompressible momentum equation coupled with the energy equation. It uses a structured mesh that is built of quadrilateral or brick elements that can vary in size in all dimensions, allowing to achieve high resolutions where required. The elements are either linear in velocity with constant pressure, or quadratic in velocity with linear pressure. An accurate pressure field is obtained through an iterative penalty (Uzawa) formulation. Material properties are carried on tracer particles that are advected through the Eulerian mesh. Shear elasticity is implemented following the approach of Moresi et al. [J. Comp. Phys. 184, 2003], brittle materials deform following a Drucker-Prager criterion, and viscous flow is by temperature- and pressure-dependent power-law creep. The top boundary of our models is a true free surface (with free surface stabilisation) on which simple surface processes models may be imposed.

We use a set of benchmarks that test viscous, viscoelastic, elastic and plastic deformation, temperature advection and conduction, free surface behaviour, and pressure computation. Part of our benchmark set is automated allowing easy testing of new code versions. Examples include Poiseuille flow, Couette flow, Stokes flow, relaxation of viscous topography, viscous pure shear, viscoelastic pure shear, viscoelastic simple shear, and half-space cooling. More demanding tests include for example the Blankenbach convection benchmark (Geophys. J. Int. 98, 1989), the Schmeling et al. subduction benchmark (Phys. Earth Planet. Int. 171, 2008), and the angle of shear bands in compression and extension. While we do not aim to provide the most complete set of tests for new numerical codes, we do hope that our tests may help future code developers.