2D/3D Numerical Modelling of Lithosphere-Mantle interaction.

B.J.P. Kaus[1].

[1] Geophysical Fluid Dynamics, Department of Earth Sciences, ETH Zurich, Switzerland.
boris.kaus@erdw.ethz.ch

Whereas 3D numerical modelling of mantle convection is a standard procedure these days, numerical modelling of lithospheric-scale processes have so far mainly been performed in two spatial dimensions. Part of this is probably due to the somewhat more complicated rheologies that are thought to be important for lithospheric-scale processes. Rather than just behaving viscously, surface-near rocks may also deform in an elastic or plastic (brittle) manner, which manifests itself in faults or shear zones. Moreover, rocks on a lithospheric scale are fairly heterogeneous, undergo complex phase transitions, partial melting and have strain-dependent material properties. All of these complexities result in numerical simulations with a rather large number of adjustable ("free") parameters. In order to get an insight in the physics of geodynamic processes, various workers have therefore concentrated on smaller scale problems (e.g. crustal deformation) in which the "bigger" picture was introduced by kinematically pre-scribed boundary conditions. Whereas such studies undoubtedly increased our understanding of geodynamic processes, it is also important to understand the lithosphere-mantle system in a more self-consistent manner (in which mantle flow drives lithospheric deformation).

From a theoretical point-of-view it is clear how this can be done: take a mantle flow code, add a free-surface, elasticity and plasticity and work on ways to track heterogeneous phases (with phase transitions). From a practical point of view, things appear to be slightly more complicated. The self-consistent free-surface requires a very small time step for stability reasons; elasticity requires tracking of stress tensors and plasticity and material heterogeneities may result in large variations in viscosity over small length scales (which deteriorates the efficiency of multigrid solvers). Questions arise whether the low-order (inadmissible) elements typically used in mantle flow code are still sufficient or whether higher order (admissible) elements are necessary.

Here we discuss how we addressed some of these issues in a 2D thermo-mechanical finite element code (SloMo) that has been employed to study coupled lithosphere-mantle interaction processes. A semi-implicit free surface algorithm (SIFSA) was developed to overcome some of the time step restrictions related to the presence of a free surface. Tracers are used to track material properties, stress tensors and temperature and the governing equations are solved on a Lagrangian background solver (with remeshing to allow large deformations). Furthermore we discuss a recently developed 3D parallel finite element code that was written in the PETSc framework, has direct, iterative and multigrid solvers and both linear and higher order elements (as well as tracers to track material properties).

Finally we give examples of self-consistent modelling of lithosphere-mantle interaction (a case study on Taiwan), as well as address questions such as: does elasticity modify large-scale geodynamic processes? What is the effect if surface-processes on mantle and crustal deformation? Do we need a free-surface or is a free-slip upper boundary condition sufficient?