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Role of viscoelasticity in mantle convection models

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A present limitation of global thermo-chemical convection models is that they assume a purely viscous or visco-plastic flow law for solid rock, i.e. elasticity is ignored. This may not be a good assumption in the cold, outer boundary layer known as the lithosphere, where elastic deformation may be important. Elasticity in the lithosphere plays at least two roles: It changes surface topography, which changes the relationship between topography and gravity, and it alters the stress distribution in the lithosphere, which may affect dynamical behaviour such as the formation of plate boundaries and other tectonics features.

A method for adding elasticity to a viscous flow solver to make a visco-elastic flow solver, which involves adding advected elastic stress to the momentum equation and introducing an "effective" viscosity has been proposed (e.g. Moresi, 2002). The proposed method is designed primarily for a regional-scale numerical model which employs tracers for advection and co-rotation of the stress field. In this study we test a grid-based version of the method in context of thermal convection in the Boussinesq approximation. A simple finite difference/volume model with staggered grid is used, with the aim to later use the same method to implement viscoelasticity into StagYY (Tackley, 2008).

The main obstacle is that Maxwell viscoelastic rheology produces instantaneous deformation if instantaneous change of the driving forces occurs. It is not possible to model such deformation in a velocity formulated convection model, as velocity undergoes a singularity for an instantaneous deformation. For a given Rayleigh number there exists a certain critical value of the Deborah number above which it is necessary to use a thermal time step different from the one used in viscoelastic constitutive equation to avoid this numerical instability from happening. Critical Deborah numbers for various Rayleigh numbers are computed. We then propose a method to decouple the thermal and constitutive equations in a way more suitable for global studies, which is different from the method refered to earlier. The computational domain is expected to be composed of two parts: One in which elastic effects are important and where material does not move significantly within one elastic time step and one where elastic effects are not important, where material is allowed to move across many cells within one elastic time step.

Local accumulation of stress in viscoelastic simulations is observed, suggesting elasticity could e.g. trigger plasticity in realistic cases.

References

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