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Viscoelastic mantle convection and lithospheric stresses

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Accurate predictions of stress distribution in the lithosphere are of major importance for approaching more realistic numerical models of the mantle-lithosphere system. Since stress fields in the lithosphere computed in convection models differ substantially between viscous and viscoelastic rheologies, it is essential to employ a viscoelastic rheology when accurate stresses are to be predicted in mantle convection models involving the lithosphere. This difference in stress distribution and magnitude has important implications for accurate modeling of stress-dependent processes like power law creep, shear heating and plasticity. A further requirement for computation of accurate stress fields is to ensure numerically divergence-free solutions in the Boussinesq approximation. We present the technical background required for implementation of numerically incompressible solutions and for implementation of a Maxwell viscoelastic rheology in the frame of the Finite Element Method (FEM). We employ the Jaumann invariant stress derivative in our implementation and demonstrate that the choice of the invariant stress derivative is irrelevant for geodynamic simulations. We discuss potential numerical advantages of a viscoelastic rheology when large viscosity variations are applied in thermal convection models. Due to the physical transition from effectively viscous to elastic behaviour in a viscoelastic model, the introduction of viscosity cutoffs generally applied in viscous models can be avoided.