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Implementation of non-linear rheology in spectral finite-element code

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The improvement in understanding of dynamic processes in the earth mantle demands to consider a non-linear rheology of mantle material. Whereas this rheology is accepted in the studies of mantle convection, the need of a non-linear material behaviour in modelling of glacial isostatic adjustment (GIA) is still under discussion. Almost all the predictions of ongoing present-day processes induced by GIA are based on the assumption of a linear Maxwell viscoelastic rheology. The influence of non-linear rheology on the GIA-induced motion is discussed since decades, but it is not accepted yet.

To study this phenomenon, we implemented a non-linearly stress-dependent rheology in the spectral finite-element formulation of a viscoelastic self-gravitating sphere. We identified the following features of non-linearity on the GIA-induced motion: The main deviation from a linear flow of mantle material appears for times when a surface ice-mass load is changing most rapidly because of large induced loading stresses. The displacement rates differ mainly at the load margins with amplitudes strongly depending on the rheological stratification considered. This implies that the present-day motion induced by GIA can still be considered as linearly viscous. However, the earth's response during a glacial cycle has to be remodelled when considering non-linearity in the earth's mantle. In addition, when combining a non-linearity of rheology with its material compressibility, we have to be even more careful, because the instabilities due to an inconsistent description of a compressible reference state can be amplified by large effective viscosity variations due to a non-linear rheology.