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Spectral finite-element approach to three-dimensional viscoelastic relaxation in a spherical earth -extension for material compressibility

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A physical model of a postglacial rebound has an important role to derive information about the mantle rheology and viscosity from observed data. In previous studies, the influence of material compressibility has been often neglected for the mantle rheology. This is due to the fact that for present-day time changes the influence of the compressibility mainly appears in the flexural rigidity of the elastic lithosphere, whereas the viscous mantle is assumed to relax to an incompressible reference state. Another reason is that a compressible fluid is much more difficult to handle in a numerical model, where in addition to the usual relaxation modes also infinite sets of compressible modes appear due to the improper chosen reference state. In this study, a spectral finite-element approach is presented to investigate the effect of compressibility. This approach is a useful method when interpreting displacement rates and gravity fields in a global scale, because it allows us to consider strong lateral heterogeneities in viscosity and the self-gravitation effect of a spherical model is studied in a natural manner, which has been already applied to an incompressible case. A mathematical formulation of how to include the effect of compressibility is shown in a transparent way. Computational results are validated with results obtained by an independent method for a 1-D viscosity model. The load Love numbers calculated by both the methods agree with each other within 2%, which indicates that the presented method is set up correctly and valid for a compressible model. In order to assess the influence of material compressibility on GIA, the present time rates are modeled induced by Peltier's (2004) ICE5G/VM2 earth-model/glaciation-history combination for a compressible and an incompressible structure, respectively, with the sea-level equation of Hagedoorn et al. (2006). The result shows that the influence on the vertical displacement and the geoid is almost negligible. In contrast, the horizontal displacement rate is markedly enhanced. For example, the rate around Laurentia becomes twice as large when compressibility is considered. Furthermore, the spatial pattern of the horizontal rate becomes much more symmetric and abates faster with distance from the center of the postglacial uplift. This indicates a more constrained mass redistribution inside the mantle due to compressibility. These findings show that when considering horizontal motions induced by GIA, the consideration of material compressibility is mandatory.