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GOCE Constraints on Thermomechanical Models of the Shallow Earth

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Current constraints on the process of glacial-isostatic adjustment in Northern Europe are mainly provided by relative sea level data and GPS measurements. Due to a lack of resolving power in the shallow earth (down to about 200 km), these datasets only provide weak constraints on the shallow viscosity structure and the thickness of the lithosphere. Future high-resolution gravity data, as expected from ESA's Gravity and Ocean Circulation Explorer (GOCE) satellite gravity mission to be launched May 15 2008, are predicted to provide additional information on the shallow earth, especially the viscosity structure. However, mass inhomogeneities due to chemical and thermal anomalies are expected to interfere with the gravity signals induced by shallow low-viscosity structures. We test therefore if heatflow data and laboratory-derived creep laws for the crust (plagioclase feldspars) and shallow upper mantle (olivine) can provide additional information on the shallow earth. For this, we use a thermal model constrained by surface heatflow data and a mechanical model based on the commercially available finite-element package Abaqus. We show estimates of lithospheric thickness and viscosities that can be expected in the shallow earth, and generate predictions for Northern Europe using heatflow data and representative creep laws, which induce lateral heterogeneities in the shallow earth. We use the RSES ice-load history to force our mechanical model and we test the sensitivity of our predictions using the ICE-5G ice-load history.

We show that perturbations, which are differences with a background model, due to shallow low-viscosity structures are one to two orders of magnitude larger than the predicted accuracy of GOCE, which is at the cm-level for a resolution of about 100 km. Moreover, some features are robust to changes in composition and creep regime, and have therefore a spatial signature that is representative for low-viscosity structures, without detailed a priori knowledge on these structures. We argue that these signatures are therefore more likely to be detectable by GOCE. We also compare the predictions with the accuracy of the BIFROST GPS-network and show that, though the perturbations due to shallow low viscosity structures are above the accuracy, the lack of spatial resolution limits the use of spatial signatures. Finally, we show, using normalized prediction errors, that GOCE is predicted to be sensitive to the creep regime in the lower crust, but not to the composition, at least not for the plagioclase feldspars used here. These conclusions are in general independent of assumptions (creep regime in the shallow upper mantle and the ice-load history) on the background model. However, if the wrong background model is assumed, we can no longer predict the correct properties of the lower crust, because prediction errors are larger than 60%.