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Constraining Shallow Low-Viscosity Zones by GOCE Gravity Observations

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Future high-resolution gravity data, as expected from the ESA Gravity field and steady-state Ocean Circulation Explorer (GOCE), to be launched March 2009, are predicted to provide additional data on the shallow earth, especially for the viscosity structure derived from Glacial Isostatic Adjustment (GIA) models. 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 if heat flow data and laboratory-derived creep laws for the crust (plagioclase feldspars) and shallow upper mantle (olivine) can be used to further constrain uncertainties.

We derive estimates of lithospheric thickness and viscosity that can be expected in the shallow earth. Using a mechanical model based on the commercially available finite-element package Abaqus and representative creep laws, we generate predictions of deformation-induced geoid height variations for Northern Europe. We infer lateral heterogeneities in the shallow earth from heat flow data. We use the RSES ice-load history of Lambeck et al. (1998) to load our GIA model and we test the sensitivity of our predictions using the ICE-5G ice-load history of Peltier (2004).

We show that perturbations, i.e. differences with respect to 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 in geoid height perturbations seem to be robust to changes in composition and creep regime, and therefore have a spatial signature that is representative for low-viscosity structures, even without availability of detailed a-priori knowledge on these structures. We argue that these signatures are therefore more likely to be detectable by GOCE.

Finally, we show, using normalized prediction errors, that GOCE is 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, 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 turn out to be larger than 60 percent then.