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# High-harmonic geoid signatures related to glacial isostatic adjustment and their detectability by GOCE

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ABSTRACT

The Earth's asthenosphere and lower continental crust can regionally have viscosities that are one to several orders of magnitude smaller than typical mantle viscosities. As a consequence, such shallow low-viscosity layers could induce high-harmonic (spherical harmonics 50–200) gravity and geoid anomalies due to remaining isostasy deviations following Late-Pleistocene glacial isostatic adjustment (GIA). Such high-harmonic geoid and gravity signatures would depend also on the detailed ice and meltwater loading distribution and history.

ESA's Gravity field and steady-state Ocean Circulation Explorer (GOCE) satellite mission, planned for launch in Summer 2008, is designed to map the quasi-static geoid with centimeter accuracy and gravity anomalies with milligal accuracy at a resolution of 100 km or better. This might offer the possibility of detecting gravity and geoid effects of low-viscosity shallow earth layers and differences of the effects of various Pleistocene ice decay scenarios. For example, our predictions show that for a typical low-viscosity crustal zone GOCE should be able to discern differences between ice-load histories down to length scales of about 150 km.

One of the major challenges in interpreting such high-harmonic, regional-scale, geoid signatures in GOCE solutions will be to discriminate GIA-signatures from various other solid-earth contributions. It might be of help here that the high-harmonic geoid and gravity signatures form quite characteristic 2D patterns, depending on both ice load and low-viscosity zone model parameters.

## 1. Introduction

Since the finding that the most likely explanation for the deep geoid low over Canada is only partly attributable to glacial isostatic adjustment (GIA) (e.g. Mitrovica and Peltier, 1989; Peltier et al., 1992; Simons and Hager, 1997; Kaufmann, 2000), quasi-static components of the gravity field were long considered as not the best kind of constraints for GIA models compared to 3D (strandline, GPS, and VLBI) crustal displacements, sea-level (tide-gauge) data and even secular polar wander and temporal variations in the low-degree harmonics of the gravity field. With the launch of CHAMP and GRACE and the upcoming launch of GOCE this situation is changing. For example, Tamisiea et al. (2007) use GRACE data to constrain the ice geometry of the latest Pleistocene Ice Age. They show that free-air gravity anomalies indicate that the Laurentide ice sheet must have been composed of two major domes rather than a single one.

Something similar can be deduced for the Late-Pleistocene Fennoscandian Ice Sheet. Fig. 1 shows free-air gravity anomalies from GRACE model GGM02S in which long wavelengths (spherical harmonic degrees smaller than 9) have been filtered out. This filtering is necessary as both geoid and gravity anomalies are dominated by the large long-wavelength Icelandic geoid high.

Fig. 2 shows free-air gravity anomalies as predicted by a viscoelastic GIA model of which the earth model is schematically drawn in Fig. 3. The core is treated as an internal boundary condition for an inviscid fluid adjoining the viscoelastic lower mantle. The boundary between the viscoelastic upper and lower mantle is taken as a chemical one. The upper part of the earth model consists of a crust on top of the lithosphere. The crust can be subdivided into an elastic upper part and a viscoelastic lower part. The asthenosphere below the lithosphere has the same viscoelastic properties as the upper mantle. For the normal mode modelling method by

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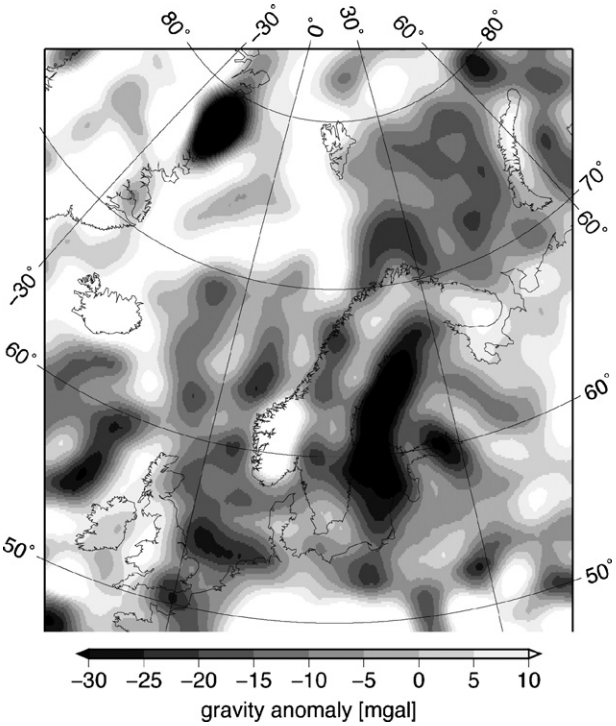

**Fig. 1.** Free-air gravity anomalies as observed by GRACE (model GGM02S) with long wavelengths (harmonic degrees smaller than 9) have been removed.

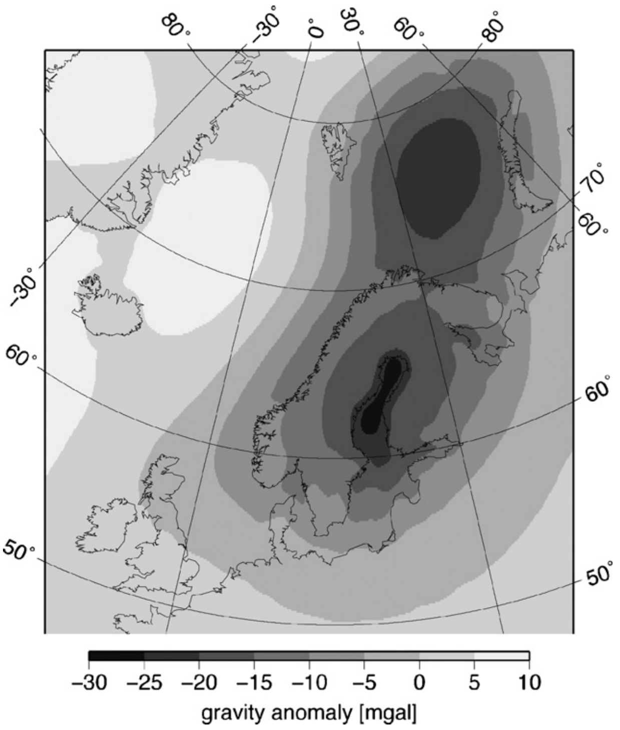

**Fig. 2.** Free-air gravity anomalies as predicted by the ICE-5G model of Peltier (2004) and the standard viscoelastic GIA model with the Earth structure as given in Fig. 3. Radial elastic and density parametrisation are taken from Dziewonski and Anderson (1981), while the radial viscosity structure is based on radial viscosity model VM-2 of Peltier (2004). The lower crust has been taken elastic, although the image would not be markedly different if the low-viscous value would have been assigned to this layer.

which solutions for this earth model were obtained, see Sabadini and Vermeersen (2004) and Schotman and Vermeersen (2005). In general there is good agreement between the modeled and GRACE-observed gravity anomalies for the gravity low above the Bothnic Gulf. The "foot-like" shape shows up in both solutions, although the GRACE solution has some quite distinct "blob-like" features that are most likely real signals that are smeared out due to a limited spatial resolution. Note that also at the Finnish Gulf (right of the center of the "foot") both solutions indicate a deeper gravity low, although this feature is much more prominent in the GRACE solution than in the GIA simulation. Something simular can be seen toward the White Sea, where the "heel of the foot" bends towards the right in both solutions. The western part of Norway shows a local gravity high in the GRACE solution that is also partly visibly, though with a smaller magnitude, in the GIA simulation.

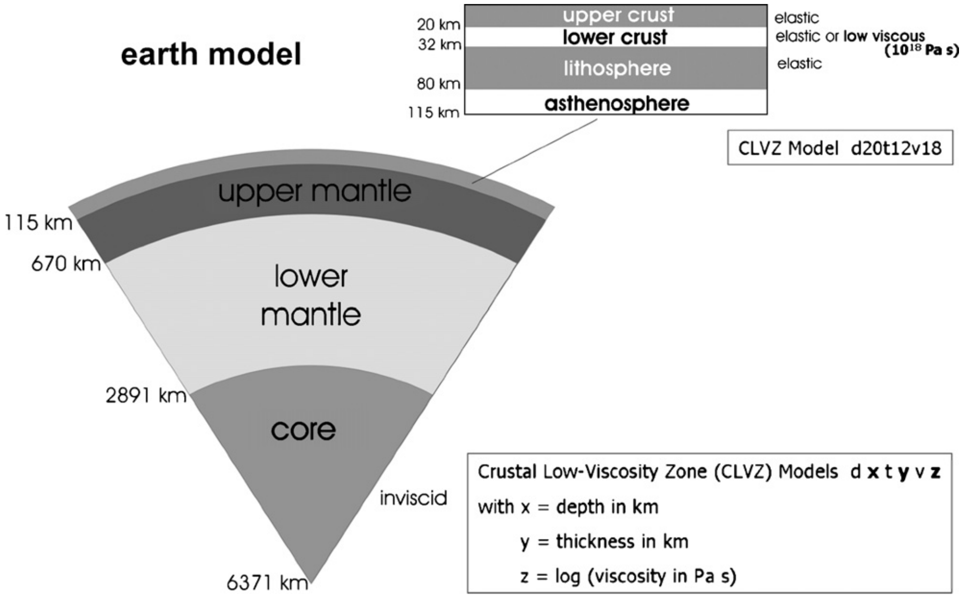

**Fig. 3.** Radial structure of the viscoelastic earth model as used in the simulations. The upper right part shows an enlargement of the top layering of the model. The numbers indicate values for the standard model that can be varied for depth, thickness and viscosity of the crustal low-viscosity zone.