Shallow Low-Viscous Earth Layers in Flat 3D Finite-Element Models of Glacial Isostatic Adjustment

Hugo Schotman[1,2]**Bert Vermeersen**[1] **and Patrick Wu**[3]

[1]*DEOS, Faculty of Aerospace Engineering, Delft University of Technology, Kluyverweg 1, 2629 HS Delft, The Netherlands*

[2]*SRON National Institute for Space Research, Sorbonnelaan 2, 3584 CA, Utrecht, The Netherlands*

[3]*Department of Geology & Geophysics, University of Calgary, Calgary, Alberta, Canada T2N-1N4*

In recent papers (van der Wal et al. 2004, Schotman & Vermeersen 2005) we have shown the effect of crustal and asthenospheric layers with low viscosity on gravity field perturbations as predicted by models of glacial isostatic adjustment, and compared these to the expected performance of the satellite gravity mission GOCE (Visser et al. 2002) and the realized performance of GRACE (GGM02S, Tapley et al. 2005). In these studies, we used a semi-analytical viscoelastic relaxation model (Vermeersen & Sabadini 1997) based on the normal-mode formalism (Peltier 1974, Wu & Peltier 1982).
The spectral model is very fast and accurate, but does not allow for lateral variations in the properties of the earth layers. Therefore we use a finite-element (FE) model based on the commercially available software package Abaqus. As we are interested in the short-wavelength gravity field (up to harmonic degree 250 or spatial scales down to 80 km), the use of spherical 3D FE models (see e.g. Wu et al. 2005) is not yet feasible. We therefore use a flat 3D model that can be applied to loads as large as the Laurentide ice sheet (Wu 2005).
We compute gravity potential perturbations by solving Laplace's equation, as described for a spherical model by Wu (2004). For a flat model, we perform a 2D Fourier transform and solve Laplace's equation in the spectral domain, using the computed displacements as boundary conditions. In future studies this method can be used to include self-graviation in the earth and ocean.
We benchmark the FE model with our spectral model for gravity field perturbations and 3D velocities. We show for an axisymmetric parabolic ice load that the accuracy of computed radial velocities is high, but that horizontal velocities are less accurate. Furthermore, geoid heights can be computed accurately underneath and just outside the load.
We shortly review the characteristics of flow induced by shallow low-viscous earth layers, using relaxation times and strengths and the concept of channel versus whole-mantle flow (Cathles 1975). Upon including a low-viscous layer, the accuracy of the perturbations in geoid height deteriorates underneath the load. Finally, we show the effect of lateral heterogeneities on geoid heights.
In future studies, we will use the flat 3D FE model, available recently developed ice-load histories and estimates of shallow earth viscosities from seismic data, to compute realistic gravity field perturbations and confront these with satellite gravity data.

References:

W. van der Wal, H.H.A. Schotman, L.L.A. Vermeersen, Geoid heights due to a crustal low viscosity zone in glacial isostatic adjustment modeling; a sensitivity analysis for GOCE, Geophys. Res. Lett. 31 (2004) 10.1029/2003GL019139.

H.H.A. Schotman, L.L.A. Vermeersen, Sensitivity of glacial isostatic adjustment models with shallow low-viscosity earth layers to the ice-load history in relation to the performance of GOCE and GRACE, Earth Planet. Sci. Lett. (2005, in press).

P.N.A.M. Visser, R. Rummel, G. Balmino, H. Sünkel, J. Johannessen, M. Aguirre, P.L. Woodworth, C. Le Provost, C.C. Tscherning, R. Sabadini, The European earth explorer mission GOCE: impact for the geosciences, in: J.X. Mitrovica, L.L.A. Vermeersen (Eds.), Ice Sheets, Sea Level and the Dynamic earth, AGU Geodynamics Series 29, AGU, Washington DC, 2002, pp. 95–107.

Tapley, B., J. Ries, S. Bettadpur, D. Chambers, M. Cheng, F. Condi, B. Gunter, Z. Kang, P.Nagel, R. Pastor, T. Pekker, S.Poole, F. Wang, GGM02 - An improved Earth gravity field model from GRACE, Journal of Geodesy (2005), 10.1007/s00190-005-0480-z.

W.R. Peltier, The impulse response of a Maxwell earth, Rev. Geophys. Space Phys. 12 (1974) 649–669.

P. Wu, W.R. Peltier, Viscous gravitational relaxation, Geophys. J. R. astr. Soc. 70 (1982) 435–485.

P. Wu, H. Wang, H. Schotman, Postglacial induced surface motions, sea-levels and geoid rates on a spherical, self-gravitating, laterally heterogeneous Earth, J. Geodyn. 39 (2005) 127–142.

P. Wu, Using commercial finite element packages for the study of earth deformations, sea levels and the state of stress, Geophys.J.Int. 158 (2004) 401–4008.

P. Wu, Effects of lateral variations in lithospheric thickness and mantle viscosity on glacially induced surface motion in Laurentia, Earth and Planetary Science Letters, 235, 549–563 (2005).

L.M. Cathles, The Viscosity of the Earth's Mantle, Princeton Univ. Press, Princeton, 1975, 390 pp.