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# Putting global warming to use in accessing the 3D viscosity structure of the uppermost mantle beneath Iceland

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Located directly south of the arctic circle, approximately 11 % of Iceland is covered by glaciers. However, a general regression trend of the Icelandic glaciers commenced around 1890. Over the period 1890-2004, the largest glacier in Iceland, Vatnajökull, is estimated to have lost an ice-volume of 435 $km^3$, causing the land to uplift due to Glacial Isostatic Adjustment (GIA). At present, vertical velocities up to 20 mm/yr have been measured close to the ice-edge.

Iceland is located on top of a mantle plume and cut through by the mid-Atlantic spreading ridge. Due to the presence of the plume, the crust is found to be anomalously thick and significant viscosity variations can be expected in the upper-most part of the underlying mantle. Using 3D visco-elastic Finite Element models and including all major Icelandic glaciers, we present the first GIA-study of Iceland investigating the 3D viscosity structure in the mantle. In addition, we study the influence on the model results by lateral variations of the elastic thickness of the lithosphere, $T_e$, as well as the presence of the spreading ridge. The models are evaluated against vertical velocities estimated from observations of a nation-wide GPS network in 1993 and 2004 (ISNET), as well as data from continuous GPS stations. Sensitivity tests indicate that the GPS data are potentially capable of detecting viscosity contrasts at depths down to 250-500 km, for an upper most mantle viscosity in the range of $10^{18}$ - $10^{19}$ Pa s as found in previous studies.

Starting with simple models with an elastic layer underlain by a visco-elastic half space, we find a best fit model with an $T_e$ of 35 km and a half-space viscosity of $10^{19}$ Pa s. Although models with $T_e$ in the range 10-60 km combined with a half-space viscosity in the range 6-15 x $10^{18}$ Pa s, detoriates only slightly in the fit to the GPS data. We observe that the viscosity of the half-space is better constrained than $T_e$, in accordance with previous studies. We also note a slight preferred trend of lower viscosity combined with higher $T_e$. Incorporating lateral variations of $T_e$ in the models, or a weak zone representing the spreading ridge, we observe a significant effect on the vertical velocities predicted by the models. However, the difference between the vertical uplift rates predicted from models with uniform $T_e$ and models with laterally varying $T_e$ is most pronounced in regions below or close to the glaciers, where we have few data. Therefore the fit to the dataset is hardly affected.

Proceeding to simple plume models (vertical cylindrical conduit with a plate-like head), we cannot find a model that fits the data well for a uniform plume viscosity, unless the plume head extends to great depth and the viscosity contrast between the plume and the mantle is small. For example, using a mantle viscosity 5 times higher than in the plume, the plume head needs to extend to depths greater than 200 km. This can however be resolved if we allow for a higher viscosity in the plume head, such that the viscosity in the plume head is higher than in both the mantle and the plume conduit. The best fit model has an elastic thickness of 30 km, a depth to the base of the plume head of 120 km and a conduit radius of 100 km. The viscosity of the plume head is 2 x $10^{19}$ Pa s, of the conduit 3 x $10^{18}$ Pa s, and in the mantle $10^{19}$ Pa s. We note that this model can fit the data almost as well as the best fit uniform mantle model. We systematically test a range of models by varying one of the six model parameters: the viscosity in the head, the viscosity in the conduit, the viscosity in the mantle, $T_e$, depth to base of head, and conduit radius. The predicted vertical velocities appear most sensitive to the viscosity in the plume head and mantle, and least sensitive to $T_e$ and the viscosity conduit radius.

Finally we present results from models where the viscosity structure is derived from dynamic plume modeling. However, dynamic plume models generally demand higher viscosities than those inferred from GIA studies of Iceland, which requires us to rescale the former. We discuss the implications of this rescaling and show how the resulting GIA models fit the GPS data.