

1 Introduction

Glacial Isostatic Adjustment (GIA) is one of the dominant processes causing vertical crustal motions in Southeast Alaska. The extreme uplift rates (>30 mm/yr, Fig. 1) are the result of ice thickness changes from the Little Ice Age to the present combined with a low viscosity asthenosphere. Previous GIA studies have found that a thin lithosphere (50–70 km) underlain with a low viscosity asthenosphere ($2.5 \cdot 10^{18}$ – $3.0 \cdot 10^{19}$ Pa s) are required to fit the data. However, some areas remain underpredicted or overpredicted. These discrepancies are likely due to systematic errors in the ice load model or the Earth model. In this research we aim to improve the Earth model and setup a 3-D Earth model in which viscosities are derived from shear wave velocities. Additionally, we aim to constrain the thermal effect on seismic anomalies.

We aim to answer the following research questions:

1. What is the effect of lateral viscosity variations on GIA model predictions?
2. What is the thermal contribution to shear wave anomalies in the region?

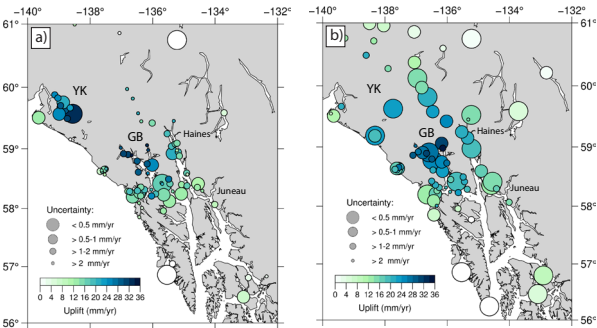


Fig. 1: Average GPS uplift rates (mm/yr) over the periods (a) 1992-2003 and (b) 2003-2012 derived by Hu & Freymueller (2019). Large uplift rates (>30 mm/yr) are seen at Glacier Bay (GB) and Yakutat Icefields (YK).

2 Ice load model

The ice load model consists of three sub-models spanning the last 2 ka defined for selected areas (Fig. 2). We model the Little Ice Age and Present-Day Ice Melt rates together.

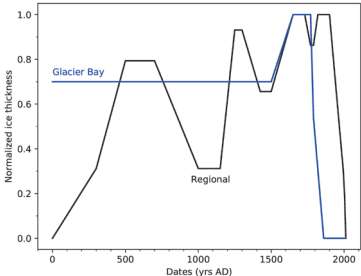


Fig. 2: The ice load model consists of a “Regional” “Glacier Bay” and Yakutat (not shown) model. The Yakutat model has an increased ice loss rate for the last two decades (3 times higher than the Regional model). The ice load model is constructed by Hu & Freymueller (2019).

3 Viscosity profiles

We use a shear wave velocity model to compute viscosity anomalies using the scaling relation (Wu, et al., 2013):

$$\log_{10}(\Delta\eta) = \frac{-\log_{10}(e)\beta}{\left[\frac{\partial \ln \nu_s}{\partial T}\right]_{tot}} \frac{E + PV}{RT_0^2} \frac{\partial \nu_s}{\partial \nu_{s,0}}$$

where $\Delta\eta$ is the viscosity anomaly, β is a scaling factor, $\left[\frac{\partial \ln \nu_s}{\partial T}\right]_{tot}$ is a velocity derivative, E is the activation energy, P is the pressure, V is the activation volume, R is the gas constant, T_0 is the background temperature and $\frac{\partial \nu_s}{\partial \nu_{s,0}}$ is the shear wave anomaly (Fig. 4). The scaling factor represents the thermal contribution to shear wave anomalies which varies between 0 and 1. We test a number of combinations for the scaling factor and background viscosity which best fit the data (Fig.3).

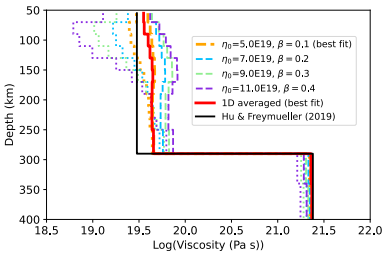


Fig. 3: Viscosity profiles derived from shear wave velocity anomalies for selected background viscosity and scaling factor. The upper and lower viscosity bounds are given by the dashed and dotted lines, respectively.

4 Shear wave velocities and viscosity maps

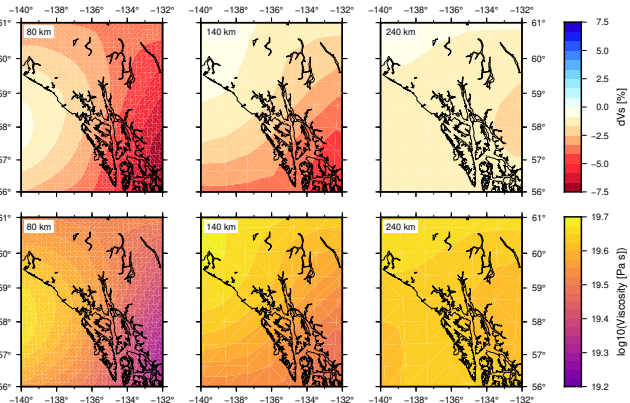


Fig. 4: Shear wave anomaly and viscosity maps (corresponding to the best-fit 3-D model) at depths 80 km, 140 km and 240 km. Shear wave anomalies were lineally interpolated from the SL2013sv model (Schaeffer & Lebedev, 2013).

5 Results

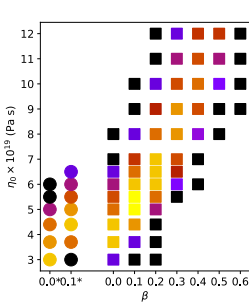


Fig. 5: Scatter plot of the χ^2 values. The square symbols are results from a compressible model, whereas the round symbols are resultuant from an incompressible model.

- The best fit parameters are $\beta = 0.1$ and $\eta_0 = 5.0 \cdot 10^{19}$ Pa s, resulting in $\chi^2 = 13.7$ (Fig. 5). The low scaling factor implies that non-thermal effects control seismic anomalies.
- The viscosities of the best fit model vary between $1.8 \cdot 10^{19}$ and $4.5 \cdot 10^{19}$ Pa s (Fig. 3).
- Fig. 5 shows that a higher scaling factor (i.e. larger lateral variations) can be compensated by a larger background viscosity, due to the fact that shear wave anomalies are dominantly negative in this area (Fig. 4).

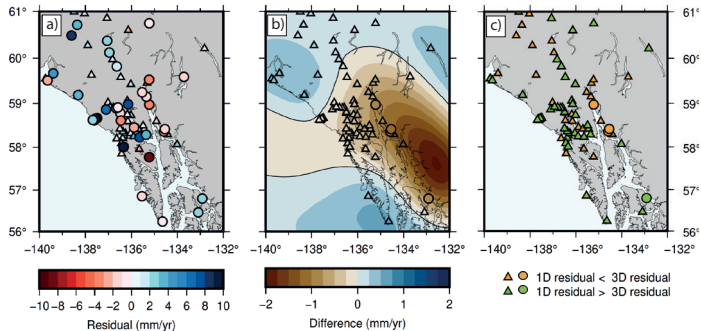


Fig. 6: (a) Residuals of our best fit 3-D model, (b) differences between a 3-D and 1-D “averaged” model and (c) locations indicating where residuals decrease or increase between the 1-D and 3-D models. Triangles indicate that the models cannot be differentiated within 2σ uncertainty, whereas circles show that they can be resolved. All plots are for the period 2003-2012.

6 Conclusions

1. 3-D variations do not have significant impact on the predicted uplift, given the current accuracy and spatial distribution of measurements (Fig. 6).
2. A low scaling factor implies that the contribution of thermal effects on shear wave velocity variations is small which implies that seismic anomalies in the shallow upper mantle are mainly controlled by non-thermal effects such as hydration. The presence of hydration and/or partial melt is consistent with the tectonic history of the region.

References

Hu, Y., & Freymueller, J. T. (2019). Geodetic Observations of Time-Variable Glacial Isostatic Adjustment in Southeast Alaska and Its Implications for Earth Rheology. *Journal of Geophysical Research: Solid Earth*, 124(9), 9870-9889.

Schaeffer, A. J., & Lebedev, S. (2013). Global shear speed structure of the upper mantle and transition zone. *Geophysical Journal International*, 194(1), 417-449.

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