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Influence of Laterally Heterogeneous Mantle Viscosity Structure on the Signal of Glacial Isostatic Adjustment in GRACE

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Geodetic data is essential to understanding interactions between the solid-Earth, ice sheets, and ocean and for accurately measuring ice mass loss and sea level rise. Glacial isostatic adjustment (GIA) – the viscoelastic response of the solid-Earth to changes in ice sheets and sea level – has a strong signal in geodetic datasets, particularly the Earth's gravity field. Traditional GIA models assume a 1D radial mantle viscosity structure that is often inconsistent with 3D viscosity fields estimated from seismic tomography. However, laterally heterogeneous viscosity affects both the magnitude and spatial pattern of GIA and hence the correction applied for the level-3 GRACE(-FO) data. We quantify the degree to which such variations change the GIA response by systematically increasing lateral heterogeneity away from a 1D model. We model GIA using the spherical finite-element surface loading code CitcomSVE to predict vertical land motion, geoid rates, and equivalent water height (EWH). 3D viscosity structure is derived from seismic tomography and parameterized by an activation parameter that controls the temperature dependence of the viscosity and hence the strength of the lateral variations, which can vary by more than six orders of magnitude. Using a suite of viscosity models and GIA solutions, we assess the biases that arise when using GIA models that neglect 3D viscosity and illustrate the changes in the ocean mass trend that arise from incorporating stronger variations. Compared to models with 3D viscosity, the 1D model currently employed for GRACE(-FO) corrections tends to underestimate uplift rates and EWH changes in the formerly glaciated regions of North America. Differences between 1D and 3D GIA solutions are also pronounced throughout the North Atlantic, where increasingly strong lateral heterogeneity increases the rate of geoid change at present day due to GIA. Such differences may have implications for the interpretation of AMOC trends from the long-term GRACE(-FO) record. From the significant differences in the GIA solutions, particularly at the local and regional level, we propose that 3D viscosity should not be ignored in GIA solutions used for GRACE(-FO). Accurately accounting for GIA in such datasets is essential to estimates of surface water mass balance and projections of sea level rise. Future work will address the optimization and uncertainty quantification of the 3D viscosity structure used in such models.