Solid Earth Discussions

Solid Earth Discuss., referee comment RC1
https://doi.org/10.5194/se-2021-151-RC1, 2022

Comment on se-2021-151

Wouter van der Wal (Referee)

Referee comment on "Regional mantle viscosity constraints for North America reveal upper mantle strength differences across the continent" by Anthony Osei Tutu and Christopher Harig, Solid Earth Discuss., https://doi.org/10.5194/se-2021-151-RC1, 2022

The long-wavelength geoid or gravity anomaly in North America is thought to reflect mantle density anomalies and associated flow, and glacial isostatic adjustment. The paper uses the gravity anomaly together with RSL data in North America in a joint inversion for the radial viscosity profile, showing large sensitivity to the seismic to density scaling. New in the paper is a regional inversion based on representations of the kernels by Slepian functions. The inversion is done separately for a western region and eastern region in North America. The obtained viscosity profiles show a weak asthenosphere in the west and and large viscosity jump in the eastern region, in agreement with the expected first order difference in mantle structure. A constraint on lateral viscosity variation for North America is welcome and would have implications for geodynamic models including glacial isostatic adjustment and tectonics. The method and figures re clear. However there are a few main issues that should be addressed, the first of which is likely to impact the results and hence will require a major revision of the paper. In addition, the text requires additional discussion on the potential impact of assumptions, and references on some aspects of the paper are currently missing, see the specific comments. There are several incomplete sentences and typos, please see the annotated pdf where some of the textual issues are pointed out. The references mentioned in the comments can be found at the end of the review.

best regards,
Wouter van der Wal

Main issues

The long-wavelength gravity field is not only caused by GIA and mantle convection but also anomalies in the crustal thickness and density anomalies in the lithosphere. Correcting for a crustal or lithospheric signal is done in recent papers that fit gravity anomaly data in North America (Kaban et al. 2014; Metivier et al. 2016, section 3.2; Reusen et al. 2020) and it is standard in global studies also when long-wavelength signal is studied (e.g. Wen and Anderson 1997). In North America the crustal signal contributes tens of mGal up to spherical harmonic degree 15 (Reusen et al. 2020 figure 6). This is especially significant in the western region where the gravity anomaly itself is not as large. Therefore the gravity anomaly needs to be corrected for variations in crustal thickness and density anomalies in the lithosphere before fitting the GIA and mantle convection model. There is the additional complication that crustal thickness variations will contain part of the GIA signal and isostasy can not be assumed in the region (Reusen et al. 2020).

The paper inverts a long-wavelength signal with a regional model. However, most of the variance in the gravity field is coming from degree 2 and 3 which are caused by very deep sources (e.g. Liu and Zhong 2016), which means the gravity anomaly will also be sensitive to anomalies in a much wider region surrounding the region of interest (I could not immediately find references that shows kernels as a function of horizontal distance). It is not clear how accurate the regional inversion is when signal outside the region of interest is not included, but in my opinion this should be demonstrated in the paper which proposes regional inversion.This can be investigated for example, by fitting only the higher degree signal, or by varying the size of the region of interest .

Referencing: The non-uniqueness in the inversion is mentioned (line 396) but not discussed. It is investigated for GIA by Paulson et al. (2007) and for mantle convection by Thoroval and Richards (1997). The effect of lateral viscosity variations on dynamic topography or the geoid is discussed in e.g. Ghosh et al. (2010), Cadek and Fleitout 2003. Results of viscosity inferences can be compared with other inversions of viscosity profiles for North America (Wolf et al. 2006; Kuchar et al 2019; Metivier et al. 2016; Reusen et al. 2020; Mao and Zhong 2021), at least the ones that also use gravity data.

In section 3.1 the gravity anomaly is fit with only the geoid kernels, resulting in a variance reduction of around 40%. The results are very different from those of the joined inversion. Since the added value of the manuscript is in doing a joined inversion, it would help the flow of the paper to remove section 3.1 or place it in an appendix.

Specific comments

Title: strength of a material usually refers to yield stress. I suggest to change the title to something like the following: Regional gravity constraints for North America reveal upper mantle viscosity differences across the continent.

49: It is stated that Mitrovica and Forte showed considerable potential, but it is not clear what is the gap in the literature that you will address. The text from line 225 onwards is useful to add in the introduction.

82: subset: this seems important information that is not discussed further in the paper. How is the choice made which functions are included and how could that affect the results?

128: scaling with the 10^21 Pa s value. This effect of this choice should be discussed.

133: The paper of Tarasov et al. (2012) does not present a single ice model as far as I know.

233: The scaling is a crucial parameters and constraints on them have implications for other models. I suggest to better introduce the choices made for the scalings. Are the chosen values common in the literature? Is it expected that they hold for North America?

299: ICE-6G is created by fitting RSL data, therefore a good fit with RSL data is to be expected. Is the fit obtained here better than the fit of the original model?

325: The fit with RSL data is poor as you also note in line 434. Looking at figure 9 it is unlikely that that is due to missed tectonic signal. It is likely that the crustal signal plays a large role in explaining the gravity anomaly; this should be quantified.

334: That is surprising given that most of the gravity anomaly signal is in the eastern region. Can you speculate why the joined inversion is dominated by the solution for the western region?

References mentioned in the review comments

- Ä□adek, O. and Fleitout, L., 2006. Effect of lateral viscosity variations in the core-mantle boundary region on predictions of the long-wavelength geoid. Studia Geophysica et Geodaetica, 50(2), pp.217-232.

- Ghosh, A., Becker, T.W. and Zhong, S.J., 2010. Effects of lateral viscosity variations on the geoid. Geophysical Research Letters, 37(1).

- Kaban, M.K., Tesauro, M., Mooney, W.D. and Cloetingh, S.A., 2014. Density, temperature, and composition of the North American lithosphere—New insights from a joint analysis of seismic, gravity, and mineral physics data: 1. Density structure of the crust and upper mantle. *Geochemistry, Geophysics, Geosystems*, *15*(12), pp.4781-4807.

- Kuchar, J., Milne, G. and Latychev, K., 2019. The importance of lateral Earth structure for North American glacial isostatic adjustment. Earth and Planetary Science Letters, 512, pp.236-245.

- Mao, W. and Zhong, S., 2021. Constraints on mantle viscosity from intermediateâ□□wavelength geoid anomalies in mantle convection models with plate motion history. Journal of Geophysical Research: Solid Earth, 126(4), p.e2020JB021561.

- Métivier, L., Caron, L., Greff-Lefftz, M., Pajot-Métivier, G., Fleitout, L. and Rouby, H., 2016. Evidence for postglacial signatures in gravity gradients: A clue in lower mantle viscosity. Earth and Planetary Science Letters, 452, pp.146-156.

- Paulson, A., Zhong, S. and Wahr, J., 2007. Limitations on the inversion for mantle viscosity from postglacial rebound. Geophysical Journal International, 168(3), pp.1195-1209.

- Sella, G.F., Stein, S., Dixon, T.H., Craymer, M., James, T.S., Mazzotti, S. and Dokka, R.K., 2007. Observation of glacial isostatic adjustment in "stable" North America with GPS. Geophysical Research Letters, 34(2).

- Thoraval, C. and Richards, M.A., 1997. The geoid constraint in global geodynamics: viscosity structure, mantle heterogeneity models and boundary conditions. Geophysical Journal International, 131(1), pp.1-8.

- Wen, L. and Anderson, D.L., 1997. Layered mantle convection: A model for geoid and topography. Earth and Planetary Science Letters, 146(3-4), pp.367-377.

- Wolf, D., Klemann, V., Wünsch, J. and Zhang, F.P., 2006. A reanalysis and reinterpretation of geodetic and geological evidence of glacial-isostatic adjustment in the Churchill region, Hudson Bay. Surveys in Geophysics, 27(1), pp.19-61.

Please also note the supplement to this comment:
https://se.copernicus.org/preprints/se-2021-151/se-2021-151-RC1-supplement.pdf