Dear reviewer,

we are thankful for the constructive criticism and the suggestions made about the manuscript. In the following, we give detailed answers about the raised questions.

Reviewer's comments and author's answers:

This manuscript introduces a combination of a data assimilation method with a GIA model. The new combination approach is supposed to, ideally, better determine mantle viscosities or, in future, 3D earth parameters. To achieve this, a set of global synthetical relative sea level rates is generated. The authors perform a number of tests to convince the reader about the favourable outcome of their new approach. They seem to be new in the field of GIA modelling. I am not aware of any previous GIA work with the exception of Volker Klemann, who has a strong background in this field.
The study is very interesting and the approach may receive much interest in the GIA and earth rheology communities. The text is well written and a smooth read. Figures and tables are clear and support the text.

Nonetheless, I am somewhat disappointed about the whole manuscript. Main reasons are that, despite the nice presentation and different tests made by the authors, (1) nothing is presented about the performance of the new approach compared to 'GIA standard' methods, (2) no interesting conclusions are drawn that present a step forward in GIA/earth rheology research, and (3) it is a very idealized experiment because the synthetic data does not represent typical data used in GIA modelling. RSL rates is not used, moreover, rates are hard to find in real data as there is rarely a large number of samples at a certain location available. Also, uncertainties of rates are much larger than used in these setups. Overall, the main message is that the technical combination of two codes is working and gives results that are expected. The results thus, at this stage, cannot help to further advance our understanding of GIA or earth parameters.

However, I think the manuscript can be elevated if my main concerns can be addressed.

(1) Especially, I would like to see a comparison with a 'standard' GIA investigation, where modelled RSL rates from a set of pre-defined models (e.g., 50 models covering the viscosity ranges in your experiment) is compared to the synthetic set and the misfit is determined so that a best model of such set is identified. Is the best-fitting model comparable to the final assimilation model? Which misfit is better? What is the computation time for both approaches? At which point is it better to use the assimilation approach? This would help the reader to get more perspective if this approach can help advance our understanding of GIA and the determination of earth parameters.

A: While we have to admit that this is a really interesting piece of information, it is hard to make this comparison with our study. We have used synthetic observations from a synthetic scenario. Making comparison to a real-world model is hardly possible. We can, however, give RMS errors of the modeled RSL which can then be compared to RMS *errors from literature. One has to keep in mind that the resulting RMS errors depend on the assumed observations uncertainties. In the update of our manuscript we have added an experiment with more realistic RSL uncertainties (case E in setup one) which give a better estimate of the accuracy that can be expected when using the DA approach with real data. The sea-level RMS errors from this experiment E are now used for a comparison to viscosity estimations using real observations.*

(2) I miss new findings or hints that can help the community. The manuscript presents the approach with some tests, which gives it the style of a technical note rather than a scientific study. The authors should at least present 1 or 2 major conclusions that can be drawn from the tests.

A: The aim of this paper is to show that the data assimilation approach is a versatile method that is able to estimate the correct mantle viscosities from a synthetic Earth model. We have shown that we obtain the correct mantle parameters within an uncertainty range defined by the quality of the observations. With our method we can obtain model parameters that are not part of the initial guess, but the ensemble members can evolve towards the correct solution. This is very different from the classic approach. Especially, when going towards higher-dimensional parameter spaces, e.g., higher resolved 1D profiles or 3D viscosity distributions, this will be very helpful.

(3) The reliability of the rates set should be further discussed in comparison to real world data. You mention some shortcomings but they are not put into perspective with real data availability. How many locations can actually give you solid RSL rates? What is a realistic error of such RSL rates? This should definitely be addressed as RSL data are concerned with time and height errors. You did not include time errors which are actually much larger! Are there enough locations with rates at times where there is a strong RSL fall? Such discussion would help the reader to get more insight on the reliability and evaluate the success of your approach.

A: From the number of available sites which are commonly used to reconstruct the temporal evolution of the sea level from the late Pleistocene or Holocene to present day, about 20 to 30 % contain more than 10 samples. This percentage might suite as an estimation of the availability of sites which can be used to derive past rates of sea-level change. On the other hand e.g. the study of Khan et al. (2015) lists average RSL rates for a large number of locations, indicating that rates are available at least for the last 10 to 12 kyrs. This is now mentioned in the manuscript.

(4) A discussion is needed on the tested parameters. Just analyzing two mantle viscosities is very idealized. There is a trade-off between the thickness of the lithosphere and mantle viscosity. The reader should be informed.

A: A short discussion of the trade-off between lithosphere thickness and mantle viscosity has been added. Unfortunately, at the moment our approach does not allow to vary lithosphere thickness. Therefore, we focused on mantle viscosity and kept the lithosphere thickness constant.

Similarly, a note on ice model uncertainty and its potential impact on the results should be added.

A: Uncertainty in GIA is a big problem. Usually, no uncertainties are provided for global ice models. Ice histories from different approaches (e.g., ICE-5G by Peltier (2004), ICE-6G by Argus et al. (2015), PaleoMIST 1.0 by Gowan et al. (2021), and NAICE by Gowan et al. (2016)) reveal large deviations between ice distributions (thickness and extension) during deglaciation. A different ice load significantly affects the outcome of the viscosity determination. A short discussion of these relations was added.

Minor remarks

The paper is written from a quite technical perspective. In the introduction, focus is a lot on the assimilation approach but I would like to see a paragraph from the 'GIA site' with an overview of previous attempts to get more insights from GIA modelling with alternate approaches. Studies by Steffen & Kaufmann (2005), Al-Attar & Tromp (2013) and Caron et al. (2017) should help here.

A: A paragraph describing efforts to determine mantle viscosity through GIA modelling or sea level observations was added in the introduction.

Similarly, the discussion does not contain much references to other works. Are all these findings/conclusions new?

A: While data assimilation is used in GIA to estimate past sea levels, we are not aware of any other study attempting to constrain mantle viscosity with a particle filter. References to other attempts to infer mantle viscosities by means of data assimilation in general have been added to the introduction.
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References

Al-Attar, D., Tromp, J., 2013. Sensitivity kernels for viscoelastic loading based on adjoint methods. GJI, doi:10.1093/gji/ggt395.

Caron, L. et al., 2017. Inverting Glacial Isostatic Adjustment signal using Bayesian framework and two linearly relaxing rheologies. GJI, doi: 10.1093/gji/ggx083.

Steffen H., Kaufmann, G., 2005. Glacial isostatic adjustment of Scandinavia and northwestern Europe and the radial viscosity structure of the Earth’s mantle. GJI, doi:10.1111/j.1365-246X.2005.02740.x.