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Interactive comment on "Comparison of the glacial isostatic adjustment behaviour in glacially induced fault models" *by* Rebekka Steffen et al.

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Dear Reviewer,

We thank you for reviewing our paper and your feedback. Please find below our answers to your comments.

"In the introductory part (55, p.2) authors declare that the aim of his study is to compare two approaches (abbreviated as "WU" and "HA") based on benchmarking of two typical setups from the previous studies. However, authors also notes that they aim "... to verify (1) if the HA approach is suitable for GIA investigations and (2) if GIF results based on the HA approach are reliable in view of GIF activation due to GIA". This phrase might indirectly point on prejudice of the authors that won't pass for a comparative benchmarking study."

We will revise the introduction to remove any prejudging content.

"I'm totally agree with the authors that the using more realistic lithospheric structure and boundary conditions allow for more natural behaviour of the model. It is obvious and do not needs additional proofs. However, it makes numerical models unreasonably complex in some cases. That is why we use often such a simplified approaches like the WU and HA and both of them might be valid under certain conditions or not, and that is why I can not support the conclusion of the manuscript that the HA modeling approach is unappropriate."

We disagree, as we did not say the HA approach is inappropriate. We state that the HA approach cannot be recommended for typical GIA loads that are continental-scale ice sheets which require the inclusion of the whole mantle in the GIA model. In turn, we further state that the approach may work for load dimensions of <100 km diameter, thus, in a line with your comment that the HA approach may indeed be valid under this special condition. In addition, the aim of our study is not the inclusion of realistic lithospheric structure, but the presentation of the effect of neglecting the mantle in GIA models.

"In my opinion, comparison of two different approaches with the same model parameters like the mantle viscosity is unacceptable because of different limitations for both models. For instance, the WU model fits to observed data (Fig. 5) only for the particular viscosity structure but it does not mean that the used values of viscosity correspond to real ones. There are plenty of published radial viscosity profiles based on GIA studies and the geoid inversion. Using any of that within, say, WU or HA approach gives sufficiently different response on surface loading as well as including in the model such important factors as dependance of viscosity both on stress and temperature, changing of elastic thickness of the lithosphere under loading, compressibility, dynamic pressure caused by convection in the mantle due to inhomogeneous density structure, etc."

Thank you for your opinion. First, we would like to note that it is not only the mantle viscosity (or better say the mantle viscosity profile) which needs to be tuned for a good fit of GIA model results to observations. There is trade-off between lithospheric thickness and the viscosity in the asthenosphere below, so that altering one may change the other. We are certainly aware of the different viscosity profiles in the literature, but we cannot see a benefit of presenting results of other profiles which may give a worse fit to the observations for both the WU and HA approach. You made a good point that other important factors which may have an effect have not been taken into account in both approaches, however, this is not the goal of our manuscript – and therefore we focus on the two approaches as published to date. We will include this information in the revised manuscript. However, we disagree with your comment that both model approaches cannot be compared to each other. The HA model replaces the mantle with a boundary condition and as the approach is intended to model GIF movement, it is also modelling the GIA behavior. Therefore, both approaches are indeed comparable with respect to the GIA response, which is done in this study. In addition, models need to be compared to each other as they are used in their respective studies. A modification of one approach is not the goal and purpose of a benchmarking study. We can only repeat once more that both approaches (HA and WU) were according to their authors designed to explain the physics behind the motion of glacially induced faults, and a prerequisite for that is a correct description of the GIA behavior. We can assign different viscosity profiles to the HA or WU model, but we will always arrive at the conclusion that the HA approach cannot sufficiently describe the well-known GIA behavior for large-scale load scenarios. We will make our point clearer in the revised manuscript.

"A conclusion that "we see that the HA models with and without dashpots show no difference" is also very strange to me. Let's consider an end-member example: a dashpot with infinite viscosity (fixed boundary). It must change the solution, otherwise calculations are wrong."

In case the boundary conditions are correctly applied, the last sentence is a true state-

ment. We have therefore tested the HA approach with the two different boundary conditions used by HA according to publications, i.e. with and without dashpots. As there are no differences, we arrived at the conclusion that the boundary conditions are imperfect. Therefore, an end-member example as suggested will not change the solution. We refer this strange behavior to the large foundation applied at the bottom. On another note, Schotman et al. (2008) calculated the displacement using infinite elements instead of dashpots at the 670 km boundary, and, as expected, differences were obtained. However, the foundation prescribed at this boundary was small and is not comparable to the values as used within HA models. Hence, changes at the bottom of the model definitely change the solution as long as the boundary condition allows it at all. To verify our answer, we have tested the HA and WU model approach using upper mantle viscosities of 4*1018 Pas and 4*1022 Pas. The RSL as well as GPS uplift rates are shown in the Figures 1 to 4. Please note that the viscosity used in the benchmark study is 4*1020 Pas. The figures show that a change in viscosity has no effect on the behavior of the HA model due to the large foundation value. In contrast, the WU model shows large changes in the displacement field and no fit to the observations can be obtained. The low viscosity of 4*1018 Pas leads to a very short Maxwell time and the lithosphere rebounds back quickly and almost no rebound is left today. The higher viscosity of 4*1022 Pas refers to a larger Maxwell time and the lithosphere cannot sink into the mantle. Therefore, the land uplift (Fig. 2) is small. We have added Fig. 1 and 2 to the manuscript.

"I realize, that the objective and impersonal benchmarking study that includes at least three different approaches is really important for further advances in the GIA modeling, but not a criticism of the particular modeling approach (HA) that I can see from the manuscript."

We are sorry that we do not understand this comment. Our manuscript deals with the comparison of two published approaches for GIF modeling. To our best knowledge there is no third (or fourth…) approach for GIF modeling published so far, which can and should be benchmarked regarding the GIA behavior with the WU and the HA approach.

Please also note the supplement to this comment:
http://www.geosci-model-dev-discuss.net/gmd-2016-43/gmd-2016-43-AC2-supplement.pdf

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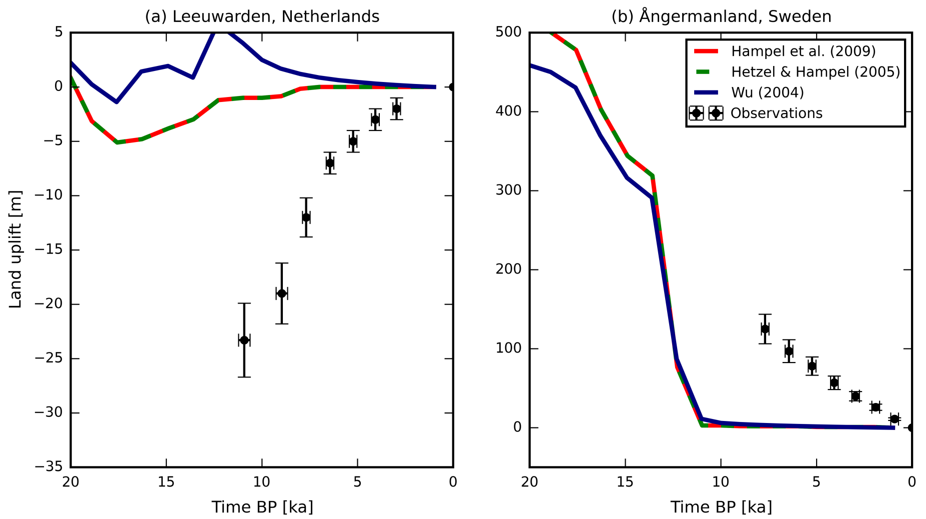

Fig. 1. Land uplift curves using an upper mantle viscosity of 4*1018 Pas. For more information please see Figure 5 in the benchmarking paper.

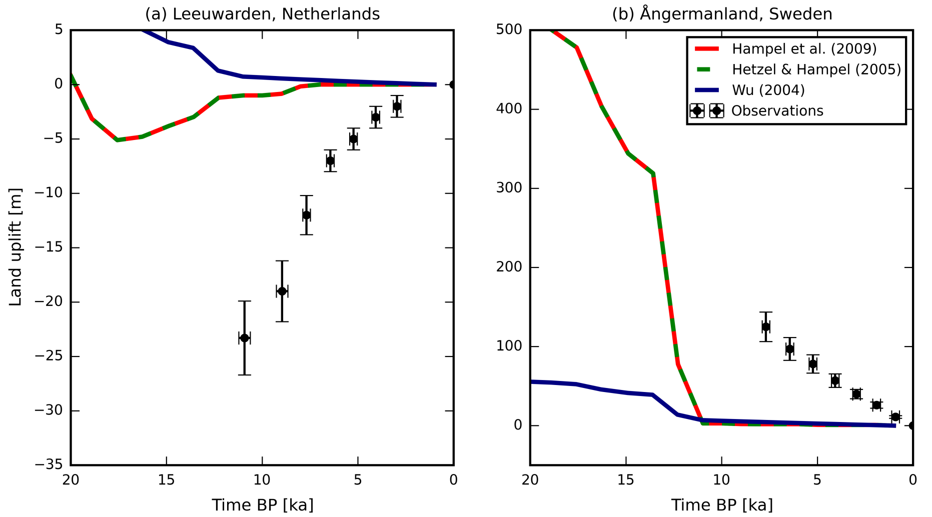

Fig. 2. Land uplift curves using an upper mantle viscosity of 4*1022 Pas. For more information please see Figure 5 in the benchmarking paper.

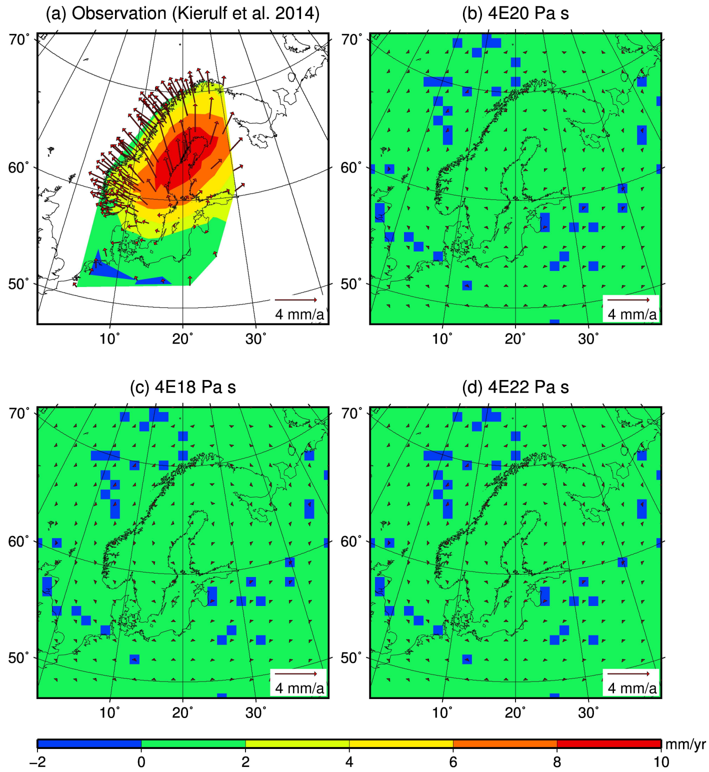

Fig. 3. Uplift rates of the HA model approach for different viscosities.

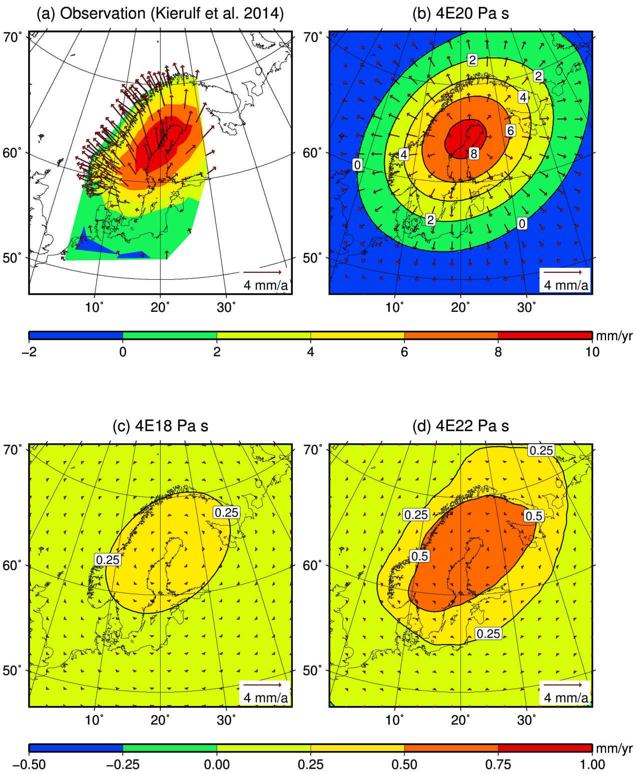

Fig. 4. Uplift rates of the WU model approach for different viscosities. Please note the different color bars for the top and bottom rows.