Editor comment:

Dear Dr. van Calcar,

thanks again for your careful consideration of all reviewer comments in drafting your revised manuscript. I would have an additional note to the fact that the ice sheet model setup seems to represent a highly responsive ice sheet illustrated in the fact that even for the scenario SSP1-2.6 the West Antarctic Ice Sheet collapses. This means (as you have already mentioned in the manuscript) that WAIS is probably undergoing MISI from the get-go of your simulation. This narrows the applicability of your study somewhat which could be reflected in the title and abstract, e.g.: Approximating the moderating role of 3D bedrock deformation in scenarios of West Antarctic Ice Sheet collapse (i'm sure there's a formulation more elegant than this, it's just to illustrate the point). The alternative would be that you include an ice sheet model setup which is relatively stable/showing linear retreat for the strong mitigation scenario. One could imagine that the careful consideration of the bedrock response you exercise here could lead to a bifurcation in the sea level response for weak, intermediate or strong climate forcing scenarios instead of linearly modulating the extent of WAIS and EAIS sea level contributions. I think this could strongly influence your best estimates of relaxation times when calibrating the 1D with the 3D approaches. But this is just speculation. As i am aware that this is computationally expensive and time consuming (and might be a promising topic for a follow up study) the discussion of the fact that you only consider cases where the ice sheet is already collapsing needs to be robust.

With kind regards,
Johannes Sutter

Response:

Thank you very much for your careful consideration of our manuscript and for raising this important point. We would like to clarify that the West Antarctic Ice Sheet (WAIS) does not collapse in scenario SSP1-2.6. In this scenario, retreat in WAIS is limited to Pine Island and Thwaites glaciers, while the remainder of WAIS is still intact by 2500. This can be seen in Fig. 5 showing the grounding lines for both 3D Earth structures and the ELRA model with a 300-year relaxation time. A substantial part of the barystatic sea-level contribution in this scenario originates instead from East Antarctica, particularly the Wilkes Basin. This can be seen in the contributions per drainage basin (see figure below, to be added to the supplementary material and discussed in the text as explained below)

We agree that the ice-sheet model applied here is relatively responsive to climate forcing compared to other published models. We have addressed this point in lines 259–266 of the last version of the manuscript. The new figure shows that there are basins with both rapid retreat (e.g. basin 14) and slower retreat (e.g. basins 1 and 18), Thus, these variations across basins provide some insight in whether best relaxation times would change in case of a different ice sheet response to the climate forcing. The 300 year relaxation time does quite well in all, with a somewhat underestimated GIA feedback in West Antarctica.

Furthermore, we can discuss potential variations in the relaxation time dependent on the sensitivity of the ice model to climate forcing in light of regional differences. The main reason for a different relaxation time is that the ice retreat may occur in a region with a different mantle viscosity. The difference in grounding line retreat in the current simulations between the high and the low emission scenario is very large (no collapse vs collapse) and this has only a small effect on the ideal relaxation time. It is likely that the difference in grounding line retreat between the current simulations of the low emission scenario and a less responsive ice sheet is significantly smaller than the difference between the low and the high emission scenario because the retreat of the low emission scenario only covers a small region of retreat. Within a small region, the Earths viscosity doesn't vary much. We would therefore expect the result for a less responsive ice sheet to stay close to an average relaxation time of 300 years, or an average 1D viscosity of 10^{20} Pa s. For this reason, we think that our findings can be applied to a wide range of scenarios and model simulations.

Please find below the detailed changes to the manuscript. We hope these clarifications address your comment.

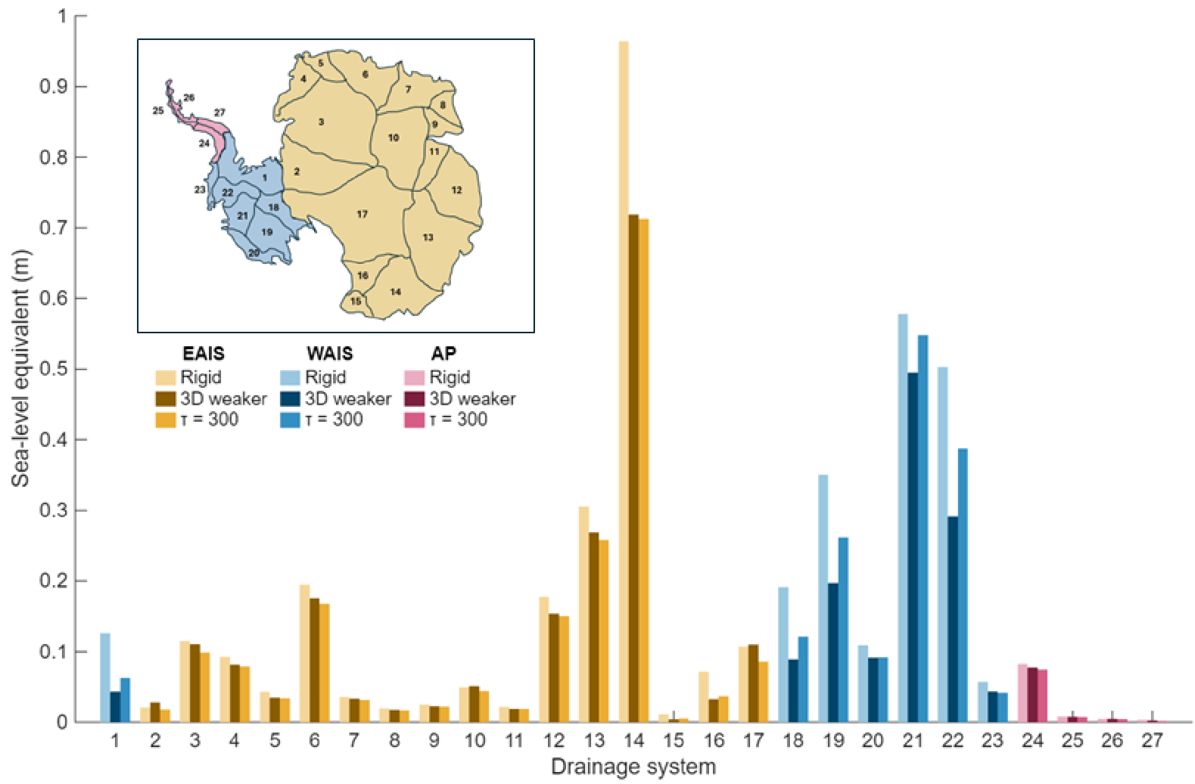

Fig. 1: Antarctic drainage systems 1–27 (according to Zwally et al. 2012), grouped into East Antarctica (yellow), West Antarctica (blue), and the Antarctic Peninsula (green) following the basin definition of Zwally et al. (2012). For each basin, the accumulated barystatic sea-level contribution in 2500 is shown for three Earth structures: Rigid (light colors, left bar), 3D weaker (dark colors, middle bar) and ELRA with a relaxation time of 300 years (middle light colors, right bar).

We add the figure above as supplementary Fig. 2 and add the following to the manuscript

Line 369: “To include uncertainty due to unknown magnitude of retreat, we include a scenario where the West Antarctic Ice Sheet collapses (SSP5-8.5), and a scenario where the Twaithes and Pine Island glaciers retreat significantly whereas the rest of the West Antarctic Ice Sheet is relatively stable (SSP1-2.6). Both scenarios include significant ice mass loss in Wilkes basin in East Antarctica. Together, these simulations capture both rapidly retreating and relatively stable drainage basins across different Antarctic regions.”

Line 413: “ELRA300 also performs well when evaluated on the contribution of individual drainage basins to barystatic sea level change, for both fast and slow retreating basins. For example, the drainage basin in Queen Maud Land in East Antarctica contributes significantly to barystatic sea level change, however the impact of GIA is neglectable as the grounding line position is insensitive to bedrock deformation in this ice sheet model (basin 6 in Supplementary Fig. 2). Therefore, the choice of relaxation time becomes arbitrary. Ice loss in the Wilkes basin in East Antarctica also contributes significantly to the barystatic sea level rise but GIA has a large effect in this region because of the relatively low mantle viscosity (basin 14 in Supplementary Fig. 2). ELRA300 provides a very good fit for this basin. In West Antarctica, the contribution differs per basin, but the effect of GIA is significant in almost all basins due the relatively low mantle viscosity at the present-day grounding line of the West Antarctic Ice Sheet (basins 1, 18, 18, 21 and 22 in Supplementary Fig. 2). Here, ELRA300 somewhat underestimates the effect of GIA but still provides a stabilising effect.”

Line 583: “Finally, the sea level projections are relatively high compared to literature (Seroussi et al., 2024). A different calibration of the ice sheet model, or a completely different ice sheet model could lead to lower projections of sea level contribution. We include a scenario with fast retreat leading to a collapse of the West Antarctic Ice Sheet and a scenario with slower retreat without a collapse. The difference in grounding-line retreat between these scenarios means the ice sheet is sensitive to a somewhat different part of the mantle, which leads to a small difference in preferred relaxation time. If the low-emission scenario were to produce less grounding-line retreat than in our current simulations, the region over which ice mass loss occurs cannot be very different from the low emission case. Hence, the preferred ELRA and 1D GIA models are also expected to remain applicable.”

References:

Zwally, H. J., Giovinetto, M. B., Beckley, M. A., & Saba, J. L. (2012). Antarctic and Greenland drainage systems. *GSFC Cryospheric Sciences Laboratory*, *265*.