We would like to thank the editor for these helpful comments, we sincerely appreciate the thoughtful feedback and have rigorously reviewed the paper to address it. See our responses to the latest comments in blue. Do also note that all the line references mentioned refer to that in the track changes version.

Editor comments on "Resolving GIA in response to modern and future ice loss at marine grounding lines in West Antarctica" by Wan et al

I would like to thank the authors for providing a clear response to the reviewers, and for submitting a revised version of their article following completion of the additional model run. I am satisfied that the edits address all the points raised by the reviewers and there is no need to request further review by the original reviewers. However, in reading through the manuscript I have identified a number of issues that require clarification and a couple of areas where terminology is a little inconsistent. These are listed below (line numbers refer to version 3 of the manuscript).

This is an important study that is very thorough in its investigation of the impact of grid resolution and earth model choice when modelling GIA in Antarctica. There is a significant amount of work presented in the article and the conclusions are robustly supported by the results.

My decision is to publish this article subject to minor revisions (review by the editor). Although there are quite a few points listed below, the majority can be resolved very easily. Where I have requested additional detail on the modelling, you are welcome to address this by editing the supplementary material, if suitable.

Thank you for submitting your article to The Cryosphere. Pippa Whitehouse (editor)

Main points

Definition of GIA: The opening paragraph of the Introduction is very useful for introducing the range of processes associated with GIA but there is some discrepancy in how you use this term throughout the rest of text. For example, I think the sensitivity experiments (section 3) just consider solid Earth deformation but in section 4 you present results for sea-level change, which reflect deformation of both the solid Earth and the geoid. In both cases, the results are generally described as representing 'GIA', with no clarification of which components are included. You also use the term GIA to refer to the elastic response to surface load change and the rapid viscous response that is triggered in low mantle viscosity regions such as the Amundsen Sea Embayment – these are not standard definitions, and many people still consider the 'GIA signal' to be the decaying response to long-complete ice mass change immediately following the Last Glacial Maximum. Make sure you are explicit about what processes are captured by your use of the term GIA and, if necessary, clarify which components are included in the different sections of the paper.

We appreciate this point and found it a challenge to decide on terminology that would be interpreted consistently across research areas. We have further clarified or changed the terminology around GIA, sea level change and solid Earth deformation in a number of places throughout the manuscript, notably in the abstract, Introduction, and an added note in Methods Section 2.1 (see track changes).

Note that for the sensitivity tests in section 3, while we plotted the error in elastic deformation for comparison with recent literature, we performed a full sea level calculation with the GIA model described in section 2.1, including changes to the position of the geoid and solid surface. We have

further clarified which components of the sea level calculation are considered in each section of analysis in the following locations:

- Line 296: "Figure 3 summarises the error in the predicted elastic…"
- Line 300: "errors in the solid Earth deformation prediction reported relative to the result…"
- Line 350: "Throughout section 4, grid resolution error is defined as departures of predicted sea level changes from the finest resolution 1.9 km grid resolution result."
- Line 673: "These experiments indicate a minimum 1:3 ratio between the required grid resolution and the load radius (i.e. grid size should be $\leq \frac{1}{3}$ of the load radius) to minimise grid resolution error in predictions of solid Earth deformation."

Grid resolution vs load size: the abstract relates grid resolution to load radius, but care is needed when discussing this result because an *increase* in resolution equates to a *decrease* in grid size. It is stated in the abstract that a ratio of 1:3 is required to accurately capture the elastic response of the Earth – it would be useful if you could clarify whether this is an upper or lower bound (noting the care needed when talking about 'resolution'). Also, in some cases you quote a 1:3 ratio and in others a 3:1 ratio (with wording appropriately altered) – please be consistent in how this result is reported.

Thank you for spotting this – we have edited Line 331-333 to report a 1:3 ratio consistently.

We have also clarified whether the 1:3 ratio is an upper or lower bound in the following locations:

- Line 23 (abstract): "we find that a grid resolution at ~1/3 of the radius of the load or higher is required to accurately capture the elastic response of the Earth."
- Line 673: "These experiments indicate a minimum 1:3 ratio between the required grid resolution and the load radius (i.e. grid size should be $\leq \frac{1}{3}$ of the load radius) to minimise grid resolution error in predictions of solid Earth deformation."

Quantification of error: in all cases, you report errors relative to the results obtained using the finest- resolution grid (rather than relative to, e.g., an analytical solution). This is clear in most places, but please check for instances where it is ambiguous, e.g. line 24 of the abstract.

This point is clarified in the following:

- Line 25 (abstract): "predicted deformation and associated sea-level change along the grounding line converge to within 5% with grid resolutions of 7.5km or higher, and to within 2% for grid resolutions of 3.75 and higher, …"
- Line 300: "errors in the solid Earth deformation prediction, reported relative to the result…"
- Line 578: "In our simulations, a 3.75 km grid was sufficient to bring errors relative to the finest resolution simulation to < 2% along the grounding line for all scenarios (Fig. 9)."

Representation of loading: (i) Figures 2a-c show total ice thickness change, but this does not reflect net surface mass change in locations where there is a transition from marine-grounded ice to ocean because much of the ice load will be replaced by water load. Have you plotted the net surface mass change, and would it be useful to include such plots to aid interpretation of the results? (ii) Errors peak along the location of the final grounding line in experiments ICE-GOL and ICE-RD (fig. 4). This is described as the 'load edge' at various points in the text but if I have correctly interpreted how net surface mass change is computed the grounding line will not necessarily align with the 'edge' of the load. Did you consider whether the misfit along the final grounding line position may be fundamentally related to representation of this transition within the GIA model? (iii) To understand

how you calculate the 'Mass Factor' (fig. 3) a little more information is needed on how the model applies the load. Using the sensitivity experiments as an example; is the same load (i.e. 100m ice) applied to all elements that lie within, or partially within, the footprint of the load, or is the load scaled according to how much of each element is covered by the footprint of the cylinder?

(i) These plots are meant to represent the ice loads inputted into the model, while the net surface load is an output of the model. In other words, we need to know how the solid Earth and geoid will adjust after the ice load is removed to understand how the area will inundate with water. This is a non-trivial result to produce without re-running the simulations, and the solution will be different for each different adopted Earth model and grid resolution. While this would be an interesting calculation to consider, we are weary of the length and detail of our study as is, and feel that this calculation would require substantial added text to properly explain and incorporate the results into the discussion in a meaningful way. We have therefore chosen not to include it.

(ii) We agree that the grounding line and load edge are not synonymous in the realistic ice loss scenarios and have adjusted the wording accordingly.

(iii) We have clarified the method for which the model applies the load in Lines 270-274 in the methods section 2.4 as the following: "When inputting a given ice load into the 3-D GIA model, the load mapper algorithm interpolates via a non-linear scheme, the equivalent load acting on each triangular area in the computational grid. Subsequently, an equivalent of 1/3 of the share of the load falling on each triangle grid area incident on the node is summed onto the loaded computational grid node. Within the computational grid triangle area, the load is assumed to be a linear function in triangular coordinates."

Minor clarifications

Place names: rather than 'the West Antarctica' we tend to refer to 'West Antarctica' or 'the West Antarctic Ice Sheet' (similarly for East Antarctica), however, we do refer to 'the Antarctic Peninsula'. 'Central Antarctica' (line 218) is not standard terminology.

We adopted the 'central Antarctica' phrasing from Heeszel et al. (2016) but agree that it is not standard terminology. We have revised the place names accordingly.

Section 2.2: I think the 15 km grid is used to produce results for section 4 but not section 3; it would be useful to clarify this somewhere in this section.

Thank you, we have clarified this point in lines 171-174 of the paper.

Line 162: 'incrementally smaller regions' – please clarify whether you use a series of nested regions, i.e. the 3.75km grid is always located within a slightly larger 7.5km grid, which is located within the 15km grid, or whether each higher-resolution grid is inserted directly into the 15km grid.

We have clarified that it is a "incrementally smaller series of nested 3-D regions" in line 173.

Line 164: 'a few layers down to 10 km' – line 158 states that the shallowest layer in the grid is at 12km; do you add extra layers when creating the higher-resolution grids?

Yes, extra layers are added in creation of higher-resolution grids due to the nature of the refinement which is to bisect the grid nodes throughout the 3-D grid which are found over a specific 3D region. We've clarified this point on line 164.

Line 170: is the elastic/density structure used in the purely elastic model the same as that used in the 3D models (described on line 174)? What is the lithosphere thickness used in the elastic model?

We have clarified this in line 185: "For the idealized sensitivity tests in section 3, we adopt a purely elastic Earth model with a 1-D elastic and density structure based on Preliminary Reference Earth Model (Dziewonski and Anderson, 1981)." Note that we discuss the lithospheric thicknesses for the viscoelastic models already.

Line 203: 'close to the preferred value in Kaufmann et al.' – I couldn't work out what this refers to since there is no mention of a scaling factor in the cited article. In general, it is not clear how the scaling factor is applied, making it difficult to derive useful insight from the values quoted here.

We have revised the text in section 2.3 to provide more information on how to relate the scaling factor in our model to the results of Kaufmann et al. (2005), and we added a supplementary section that elaborates further for readers who are interested in the details of this.

Lines 209-210: suggest '...viscosity estimates derived from GPS bedrock uplift rates in three regions' (note that the Antarctic Peninsula is often defined to be a separate region to the WAIS)

Thank you for spotting this, we've made the suggested change.

Line 227: is initial bedrock topography (as well as ice thickness) derived from Bedmap2?

Yes, we've clarified this on line 251.

Section 3.1/figs 3, 4, 7: when calculating the RMSE/percentage error in fig. 3, and the misfits shown in figs 4 and 7, how do you quantify the difference between results determined using different grids, i.e. in situations where output is produced at different resolutions?

For section 3, all results are interpolated onto a 200 m resolution grid over the study region. This is now clarified in line 293. Similarly fr section 4, all results are projected onto the same lat-lon grid – this is clarified in line 179 of methods section 2.2.

Line 320: I think the ICE-SH model covers 25 years, between 1992-2017 (also check caption to fig. 2).

Thank you for spotting this error – we have made the necessary revisions in Line 358 and caption to fig. 2.

Line 373: should include references to fig. 2, not fig. 3?

Thank you for spotting this error – we have made the necessary revisions.

Line 400-401: 'Along the final grounding line...' – based on fig. 7c, I don't think this statement holds.

Agreed, we have removed this line.

Line 403: you mention five earth models, but only four are described in this paragraph. I suspect the fifth model is the 1D/WAIS model described in the next section, but this is not clear.

Yes, apologies for the oversight we have clarified this in line 445.

Line 407: I think the EM1_L and EM1_M models are derived using different 1D viscosity profiles as well as different viscosity scaling factors – this may be worth mentioning.

Yes, this is clarified in line 449.

Lines 437-444: statements about time in this paragraph (e.g. 'after 50 years', 'within decades') are ambiguous because it is not clear whether they are referenced to the start of the model run (in 1950) or the start of the 21st century (as suggested by the opening sentence).

It is from the start of the 21st century at year 2000. This is clarified in line 481.

Line 452: is the 'maximum' value defined by the 75th percentile *plus* 1.5 times the interquartile range (I think 'minus' is correct for the 'minimum' value)? Comment also applies to various figure captions.

Thank you for spotting this error, we have clarified this on line 498-499 and the captions for fig. 5 and 9.

Line 469: 'the difference in predictions associated with earth model configuration lies between ~2-10% ...' – this statement is based on a comparison between results derived using the EM1_L and EM1_M models, which are derived from the same underlying seismic model, i.e., this is not the most extreme comparison that could be made. This statement may require a caveat.

We have clarified this in line 515 "Over the 25-year modern observed ice loss scenario, the difference in predictions associated with earth model configuration between results using EM1_L and EM1_M lies between ~2-10% within 10-km of the grounding line"

Line 482: 'the elastic signal' -> 'the total signal'?

We have clarified this point on line 529.

Line 539: a value of 7 +/- 3 is quoted elsewhere (e.g. line 300, caption to figure 3) – which is correct?

Thank you for catching this, 7+/-3 is the correct value. We have revised this in line 590.

Figures: please add latitude and longitude labels to relevant figures.

We have added the latitude and longitude labels to all relevant figures.

Figures 1c,d and S1: I think the black line marks the edge of the ice shelf and the grey line marks the grounding line – not the 0 m contour, which is typically much further inland.

Yes, we apologise for the error and have clarified the captions accordingly.

Figure 3: (i) 'calculated within 2 km of the loaded region' – does this statement apply to multiple plots in the figure? (ii) The ratio between cylinder radius and grid resolution is quoted as 3:1, not 1:3, in the main text (lines 298-299). (iii) Do the colours saturate in plots b-e?

We have edited the figure 3 caption to clarify the points raised: "Errors displayed on (c), (d), (e) are calculated within 2 km of the loaded region. Dashed black lines represent the 1:3 ratio between the surface grid resolution and idealized load cylinder radius whereby average absolute percentage error becomes < 7 $\pm$ 3 ($\boldsymbol{\sigma}$) % for all scenarios. In panels (b) – (e) the colour bars are saturated according to the arrows on the respective colour bars."

Figure 5: (i) the reference to plot (a) is not needed. (ii) The reference to 'left to right' when describing what is represented by the edges of the boxes does not make sense – plot rotated?

Thank you for spotting this error, we have removed the reference to plot (a), and changed the reference from "left to right" -> "bottom to top".

Figure 8: (i) in the lower panel of fig. 8b, why does ice thickness not reach zero by 2100? My understanding is that the grounding line retreats upstream of this point during the model run. (ii) I suggest splitting the sentence that describes what is shown in plot (b) – it is very long! (iii) Please refer to Powell (2021) rather than the article in review.

The ice thickness includes when the ice becomes floating ice. We have plotted the grounded ice thickness in Fig. 8 instead.

Figure 9: please clarify which earth models were used to produce each set (row) of results.

Good point, we have updated figure 9 axes labels to clarify which earth model was used

Figure S1: please include a label indicating the depth associated with each plot in panels (a) and (b).

Great idea, we have included the depth labels for Fig. S1.

There are occasional small words missing or grammatical errors – please carry out a final check for such issues before resubmitting the article. Please also check that all values quoted in the text agree with values listed in the figures (e.g. line 344).

We have carried out a final check for these issues and made a number of minor adjustments (hyphens, missing words, long sentences, etc.)