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The Cryosphere Discussions

Interactive comment on "Brief communication: On calculating the sea-level contribution in marine ice-sheet models" *by* Heiko Goelzer et al.

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Summary

This paper discusses the complexities around making estimates of sea-level change (SLC) from models of marine-based ice sheets (i.e., ice sheets with portions of their domains grounded below sea level at some point during the course of a simulation). After pointing out complications that are commonly not addressed or discussed in assessing SLC from marine ice sheet models, the authors propose a mathematical framework for ensuring that such calculations are made consistently. Overall, this is a welcome contribution and one that should be of broad interest to anyone involved in ice sheet modeling for the purposes of estimating SLC. Questions, criticisms, and comments be-

low are mainly in the interest of making the paper more legible and understandable, and thus (hopefully) achieving the authors' goals of having other modelers adopt and use the proposed framework.

Major Comments

It is probably important to note that, while your framework allows for ice sheet models that are coupled to a GIA model, what you consider for the latter here is actually a somewhat limited version of a GIA models. That is, here it is assumed to account strictly for uplift or sinking of the bedrock beneath or proximal to an ice sheet, but does not include other (global) effects, such as SLC due to changes in Earth's rotation, regional SLC due to changes in the Earth's gravitational field, etc. Since some coupled "ice sheet and GIA models" (e.g., Gomez et al.) do account for all of these effects in a consistent way, it might be good to clarify that, here, you separate some of these effects out into "external" sea level forcing.

On that note, the use of "external" to describe all of the "other" ways in which sea level might change could be expanded on a bit (i.e., to clarify what you are lumping in as "external" here). To an ice sheet modeler, this partitioning might seem natural, but to someone else, it might not be immediately clear why you break things up this way.

For Figures 1 and 2, you might consider adding a relative sea-level plot going from one subplot to the next. Specifically, showing the relative change in sea level that occurs as we move from one subpanel to the next. For example, in the top panel of Fig. 1, SLC should be zero, which could be represented by a horizontal line. For the bottom panel of Fig. 1, there would be SLC (a relative increase for both cases I believe?) due to the illustrated changes (increases) in bedrock elevation (which, as shown, imply a decrease in the volume of the ocean basin).

A similar comment applies to Figure 3, but in this case, it would be helpful to include the time series of the "external" sea level forcing.

For the section on including the effects of "external" sea level forcing in your SLC calculation, it would be good to note if Equations 13-14 can be easily adjusted for the case where external sea level forcing is not a uniform value. For example, if external forcing and/or the reference sea level is spatially variable (a function of x, y or lat, lon), can the "z_0" term simply be adjusted to be "z_0(i,j)", where the indices refer to the local (x,y) value of sea level for that particular grid cell? This would be important for the framework to still be useful in the case where external sea level forcing, or the reference sea level, are supplied by a more complex model (i.e., one in which sea level is allowed to vary spatially, as it does in reality).

In general, I think it would help the paper quite a bit if, with each new section where you introduce a new set of terms or corrections, you first state in brief and plain English what that term or correction is and how it affects sea level (some specific examples of this are called out below). While the equations are all carefully laid out and discussed, it seems like you are assuming the reader will naturally and easily parse their importance and meaning, their relative impact on the SLC calculations, etc. It's probably safer to assume that the reader is a bit lazy and help them along right from the start.

When you discuss the impact of changes in bedrock elevation on SLC, in the absence of changes in ice sheet volume, I think it would help to be explicit that the way this impacts sea level is through changes in the volume of the ocean basins. That is, as bedrock is uplifted, ocean basin volume decreases (positive SLC) and as bedrock is lowered, ocean basin volume decreases (negative SLC).

Minor Comments

Minor comments are given in the context of page and line number, e.g. "5,4-10" refers to page 5, lines 4-10.

1,13-14: Make it clear that by "external" forcing of sea level, you mean sea level change that is NOT a result of mass changes of the ice sheet you are considering here.

1,23: " . . . one prognostic variable (ice thickness) . . ." -> " . . . one prognostic variable, ice thickness, . . ."

1,24-25: Again, clarify further what you mean by "external" – NOT from the ice seet being considered here.

1,26: The location of the reference to the Gomez and de Boer models here is odd, and makes it read as if these models are NOT coupled to the sea level equation, when if fact they are some of the few models that ARE. This could be corrected by re-writing the sentence more clearly.

1,26-27: "Consequently, the problem at hand is . . .". This would seem to need some additional wording to be clear. Specifically, here you are assuming that you have an ice sheet model and some form of a GIA model, but that you don't have a fully coupled ice sheet, sea-level model.

2,4-5: Last sentence -> "Our aim here is to provide guidelines and a central reference for . . ."

2,8: "external sea-level changes" – Maybe this is a good place to be a bit more explicit about what you mean by this? Probably the best way to do that is to be very explicit about what you do NOT consider to be external.

2, 14: Clarify if / that you are assuming that bedrock elevation is a negative number if below sea level.

2,16-17: Because you so often refer to what happens in a single column below here, I think you may want to call that out a bit more explicitly when you first introduce it. E.g., something like, "Below, we will often simplify the discussion in order to examine the interplay between ice sheet thickness, bedrock elevation, and sea level for a single column, which can be conceptualized as the values occurring in any single model grid cell (in map view)."

2,24: ". . . but on longer timescales this is not necessarily correct." This idea is left hang-

ing here. It sounds like you intend to note that "A_ocean" can and should be allowed to change over time (at least for the two reference time periods you are calculating SLC over), and that will affect your SLC calculation. But you don't really follow through on that discussion, so it's left a bit ambiguous.

2, Equation 3: I puzzled over the negative sign out in front of the parentheses for a while before I was sure it was correct. You could help the reader here by pointing out that this is necessary since your SLE change is a function of VAF, and a positive change in VAF (increase) over time is associated with a drop in sea level.

3,1-4: It's not clear to me why you discuss the SLC assuming all grounded ice contributes to sea level (here, and elsewhere). No one does this as far as I can tell, so it seems like a weird reference case (if that's what you intend it to be).

3,6-12: You may want to remind the reader here that you are only considering a single column, not the entire ice sheet domain.

3,6-12: Somewhere here, you may want to just be very explicit about how uplift / lowering of bedrock affects relative sea level for an ocean basin of fixed area, and in the absence of any other forcing (i.e., bedrock uplift would be seen as a relative sea level rise and bedrock lowering would be seen as a relative sea level fall).

5,1: "We argue that the differences . . ." -> "The differences . . ."

5,7-9: Here you are explicit about what the impacts of rising / falling bedrock are, but it would be helpful to say this earlier, as you've already gone through Fig. 1 at this point, where this concept is necessary to understand to interpret the figure and discussion.

5,8: "The additional contribution could be calculated from . . ." The use of "could" is confusing as it sounds like you are going to suggest doing something else. If this is what you want us to understand / do (for now), then change "could" to "is".

7,1-7: This section was a little bit opaque to me. I think what you are doing is just coming up with the correction necessary to deal with the small difference between

freshwater (melted snow / ice) and saline ocean water densities. If that is indeed the case, it would help to just come right out and say it explicitly and up front.

7,9-11: I suggest omitting the lead in to this section related to paleo simulations. Since everything you write here applies at any time that sea level is changing – as it always is – I think it would read better to simply start this section as, "External sea-level forcing can drive transitions between floating and grounded ice in the model . . ."

7,16-17: ". . . from just grounded to floating ice [ADD] (with no SLC from the ice sheet itself)."

8, section 6: You should be explicit here up front that you are (presumably?) using an ice sheet model that is coupled to / with a GIA model.

8,19-20: You have multiple "present day[s]" here. Suggesting rewording this as, "Various sea level corrections . . . against the initial configuration at 120 Ka BP (Figure 3a) and the present day configuration (Figure 3b,c)." Noting again that I'm not clear on the two "present days" discussed.

8,20: Again, the use of a scenario where any / all ice grounded below sea level is counted for in the SLC calculation seems odd to me, as no one actually does this. It seems like the base / reference case should be what everyone already does, which is just naively calculate the change in volume above floatation without any of the other corrections you discuss here.

9,5-9: Clarify if you allow the area of the ocean basins to change in these calculations. Is that one of the effects we are seeing here (even if it is buried in the overall change in ocean volume).

9,11: "dominated by the changing ocean floor" – for us to really understand this, I think you need to be clear about whether or not you are talking about open ocean (no ice) or under ice shelves / sheets.

10,15: ". . . while changes in external sea-level forcing are accounted for." It's not clear

what “accounted for” means here. I think what you mean is that you remove or correct for them so that you end up with the SLC contribution from the ice sheet and bedrock changes alone.

10,16: “When bedrock changes occur under ice that is grounded . . .” – Do you mean bedrock changes that are independently driven (e.g., by tectonics) or driven in response to changes in the overlying ice volume (GIA)?

11,2: “. . . that lead to differences in the sea-level contribution [ADD] (i.e., due to changes in ocean basin volume).”

11,3: “. . . yields unbiased results.” Be more specific. This is ambiguous.

Editorial

I have a fairly extensive list of minor, editorial level suggestions that I did not include here, but that can be made available upon request (e.g., through an edited pdf file).

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