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# *Interactive comment on* "21st century estimates of mass loss rates from glaciers in the Gulf of Alaska and Canadian Archipelago using a GRACE constrained glacier model" *by* Lavanya Ashokkumar et al.

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Dear Reviewer,

Thank you for the comments on our manuscript, *"21st century estimates of mass loss rates from glaciers in the Gulf of Alaska and Canadian Archipelago using a GRACE constrained glacier model"*. We have highlighted the referee comments in italics and our response in regular font. Here we have provided a summary of our response to the



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Discussion paper

comments stated by the reviewers.

First, there is a reference to the methods section for the lack of clarity in representation of glacier mass. This is an issue due to the terminology that was used for representing the glacier mass loss from the model and GRACE observation. This comment is also mentioned by the referee 2. We will be providing a detailed methodology and proper use of the glaciological terms that is consistent with the glacier modeling communities. Second, there is a minor issue related to the use of terrestrial water storage. The comment was mentioned by the reviewer 4 (Line 73, page C2). We will provide a clarification of how the hydrological signals from GLDAS is capable of resolving mass loss trends from gravity signals. Third, comparsion to the field or local observations using a regional glacier model. This is also one of the important question raised by the reviewer 3 (point 2b). We will be providing a section on the model validation to indicate how well the local observations are represented by our glacier model.

1. Referee: *The methods used here follow the Wahr, Burgess and Swenson (2016, hereafter WBS16) approach to simulate the mass balance of several mountain glacier regions. There are differences in the way GRACE data are processed, with this study using Slepian functions, whereas WBS16 use spherical harmonics combined with fitting functions to assign mass changes to specific 0.5 degree mascons. The overall mass budget modeling approach is nearly identical. WBS16 do separate calculations for glacier versus non-glacier terrain, whereas this study appears to only focus on glacier covered areas.*

**Slepian based processing technique**: There is a difference in the GRACE processing method used by WBS16 and the current paper for obtaining the regional mass balance. In the WBS16 technique, mass loss is obtained from small defined regions called mascons that spans 100 km$^2$, roughly 0.5 degree grid resolution. The mascon formulation, developed by the JPL, utilizes a 2 deg spherical cap to resolve the spherical harmonics from the GRACE K-band inter-satellite range rate observations into gravity signals, accounting for full Stokes noise covariance (Luthcke et al., 2008; Ivins et al., 2011). The gravity signals are resolved for each grid and it accounts for both glaciers and non-glacierized sources within a mascon. The non-glacierized components are eliminated from the glacier signals by using terrestial water storage (TWS) and other non-anthropogenic water sources using Community Land Model. In contrast, slepian basis function has been successfully implemented for smaller spatial regions such as the Gulf of Alaska (North and South) (Harig et al., 2016). We will provide detailed methods on how we seperate glacier and non-glacier sources from GRACE gravity signals in the methods section.

2. Referee: *Another example is equation 15, equating the time evolution of glacier volume to the mass balance corrected for density, which is different from WBS16's equation used to estimate the initial state of glacier mass based on a global glacier volume inventory. Differences in these formulations relate to the time span under consideration, because an instantaneous addition or removal of glacier mass does not necessarily have the density of glacier ice. Finally, Line 223 is particularly problematic, with $\Delta M$ labeled as a change in mass balance, which would be the second derivative of the glacier mass, and $\Delta M(t)$ labeled as the change in mass, which is just the mass balance. The authors are recommended to stick with the WBS16 terminology to minimize confusion, or to identify their own variables these are aligned with the Glossary of Mass Balance Terms (Cogley et al., 2011).*

We agree that the equation 15 was incorrect, as it should have represented the initial state of glaciers. We will provide an explanation of how we derive mass loss rates from modeled glaciers in the revised submission.

3. Referee: *Corrections for terrestrial water storage: note that Beamer et al.,*

*2016 (doi.org/10.1002/-2015WR018457) simulated the water budget of glacier and nonglacier terrain in the Gulf of Alaska. They show that GRACE solutions are capturing the full land + ice signal. This mirrors a similar finding for the Canadian Arctic Archipelago (Lenaerts et al., 2013, doi:10.1002/grl.50214). These studies show that even those GRACE solutions that forward model the terrestrial water balance, for example by using GLDAS data, are not capable of isolating the glacier mass budget signals alone. This means the earlier work of Arendt et al (2008, 2013) was incorrect in asserting that GRACE Gulf of Alaska signals represented just the glacier mass balance. This likely explains why your modeled time series show smaller seasonal amplitudes than the GRACE observations (e.g. Figure 1).*

It is true that our modeled mass balance does not represent the seasonal amplitudes compared to GRACE observations. This is because our model is based on temperature indexed degree day, where the model inputs are based on ERA-Interim temperature and precitation. As mentioned in the reviewer comments 4, we will provide a detailed methodology on how we recover mass loss trends from GRACE gravity signals.

Regarding the seasonal amplitudes in the modeled mass loss, we will be updating our model based on ERA5 temperature and precipitation data products. Then, we will optimize the modeled estimates with GRACE mass loss trends. Our results will change based on this revision.

**Specific comments**

4. *Line 69-70: Arendt et al. (2008) calculate 7 Gt/yr as the LIA contribution. Be sure to reference Larsen et al. (2005)*.

We agree that the LIA correction for Alaska is 7 Gt/yr and it will be included with reference in the manuscript.

5. *Line 120: RGI 6.0 describes the most updated glacier state. Do earlier RGI versions represent ice conditions closer to the start of the GRACE record? Alaska glacier areas have changed considerably in the 2002-2017 period.*

The RGI version 6.0 inventory has been used in this study to understand the glacier geometry and dynamic response due to area-elevation feedback. We agree that the glaciers in Alaska has undergone a rapid change between 2002 and 2017, but the inventories prior to version 3.0 are mostly incomplete, since ∼48 - 58% of global glacier outlines were not included (Pfeffer et al, 2014). When the extrapolation to future projections was attempted with incomplete inventory, it can lead to large uncertainties. Hock et al (2019) has made a comparsion with different version of inventory and how it impacted the future mass loss and SLE rates. Therefore, we followed the guidelines for glacier models in the GlacierMIP project to use the RGI version 6.0 in our model calibration phase (?).

6. *Line 131: There is a problem with terminology related to glacier regions. This study appears to focus on the RGI first order region 01 ("Alaska"), but excludes the second order region 01 ("North") including the glaciers of the Brooks Range in northern Alaska. I believe the confusion arises from Harig and Simons (2016) designation of north and south Gulf of Alaska regions aimed at distinguishing between RGI first order regions 01 and 02 (Alaska and Western Canada). All of this traces back to Arendt et al.'s (2013) decision to extend the label "Gulf of Alaska" to those glaciers extending into the coast ranges of BC, since they also drain into the Gulf of Alaska. In any event, your manuscript is covering well over 20,000 glaciers in Alaska/Yukon/NW BC. I recommend revisiting the RGI subregions and using those to specify which glaciers are included here.*

We are willing to check with RGI regions and sub-regions for Gulf of Alaska and use it in accordance with region specification set by the GlacierMIP project

All other minor corrections such as figure title, reference to appropriate papers and other typos will be revised in the manuscript submission.

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