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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.

Anonymous Referee #1

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Overview: This paper develops a model to simulate the mass balance of glaciers in the Gulf of Alaska and Canadian Arctic Archipelago region. It calibrates the model to GRACE gravity observations and then uses the model, forced by GCM projections, to predict future glacier changes through 2100. The simulations show greater rates of glacier mass loss than most other published studies.

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

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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.

General comments: There is a lack of clarity in the description of the methods in this paper. One challenge is that the terminology is similar but not identical to WBS16. For example, the authors use "M" to represent the glacier mass balance, whereas for WBS16 "M" is the total glacier mass. This creates problems later, for example in Eq. 11 where the mass balance M(t), which is by definition the change in glacier mass at time t, is incorrectly related directly to the GRACE-derived mass. Note that the GRACE solution, if it was perfectly isolated from other sources of mass change, could be correctly labeled the cumulative glacier mass balance, or the total glacier mass relative to an unknown starting mass (M_0 in WSB16) representing the glacier state at the start of the GRACE mission. However it is not correct to say the GRACE data are the same as glacier mass balance.

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).

Corrections for terrestrial water storage: note that Beamer et al., 2016 (doi.org/10.1002/2015WR018457) simulated the water budget of glacier and non-glacier 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).

Comparison to field observations: The comparison between the model and conventional mass balance observations (e.g. Line 239-) is unclear. It appears the model is being tuned to a specific location, presumably the model grid closest to the centroid of the field observations? This use of a generalized regional model to predict the mass balance at a single location is advised against in WBS16. As justification for this approach, the authors point to a related analysis in Arendt et al. (2013), but that is a different method that was exploring how representative "index glaciers" were of regional mass balance patterns reflected in a 1x1 degree GRACE mascon. In other words, that was a scaling up of the area-averaged mass balance of a single glacier to a region for direct comparison with GRACE observations, with no tuning involved. It is not too surprising that a degree-day model could be sufficiently tuned to represent ground observations especially for those glaciers whose mass balances are most controled by temperature, such as Gulkana.

Specific Comments:

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

Line 70: This is the first time RGI is introduced. Be sure to spell out the acronym and provide a reference. Also, how exactly is the mask generated, for example, does the cell need to have >50% glacier cover to be considered a glacier, or just any amount?

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.

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.

Figure 1: The y-axis is the cumulative mass change from an arbitrary starting mass. The label "mass change" is incorrect since this would be the first derivative of the mass and would need to be in units of mass / time.

Line 135-136: Arendt et al's (2002) work refers to differences in northern Alaska glaciers (e.g. Brooks Range) and those along the southern coast (e.g. St. Elias, Chugach mountains). Harig and Simons (2016) would be a better reference here.

Line 214: Specify which assumptions of the initial state are used, becaues the use of area-volume scaling requires estimation of the initial volume state of the glaciers.

Line 240-242: "Gulkana and Wolverine..." This sentence should include a reference to the data (O'Neel et al., 2019, doi: doi.org/10.1017/jog.2019.66).

Figure A2: Check the units on the y-axis, as thousands of Gt each year would be far too much mass change. State explictly that these are annual mass balances. A reference should be provided rather than saying "from WGMS". I suggest different colors are not needed to distinguish Alaska from Canadian Arctic glaciers.

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