Reviewer 1: Chad Greene

General comments In this paper, Miles et al. generate observations of velocity and calving front positions of Denman Glacier, then they apply various perturbations to the geometry of a simple ice sheet model to determine what mechanisms might explain the observed behavior of the ice system. The study is elegantly designed and the manuscript is very well written.

The historical context provided by the ARGON and other early satellite photography is valuable, and I appreciate the work the authors have done to sift through the archives, in which they found a coherent and story to tell. I especially appreciate that the authors present background information in a way that sets the stage for understanding why this research was performed and what the results might mean for the future. The paper is packed with little insights such as the fascinating link between ice shelf thinning and flow direction, yet despite the density of information the text flows effortlessly. It was an enjoyable read, I learned a bit, and I recommend the paper for publication after the data and code are made publicly available.

The authors thank Chad for taking the time to review our manuscript. We appreciate his positive comments and constructive suggestions throughout the review. We respond to each point below:

Data and code sharing: This is important work, and in the future there will undoubtedly be more studies of the flow speed of Denman Glacier. Part of that work will involve reporting on changes that will have occurred since the publication of this study, and there's a good chance the authors of such a future study will want to begin by plotting velocity profiles from the 2020s on top of the results shown in Fig 3e. To allow others to build on this work, please include the coordinates and measured velocities shown in Fig 3e as supplemental material to the manuscript or upload to a data repository such as PANGAEA. Similarly, the authors have generated a wonderful calving front extent dataset shown in Fig 2b...Please share it so others may build on this work! Same goes for the Úa model code that was used to generate these results—I would love to see it after reading this paper.

Thank-you for bringing this very important point to our attention. If the manuscript is accepted we will upload all data to the UK Polar Data Centre repository, this will include: All ice-front position shapefiles, historical velocity tifs, the coordinates and measured velocities in Figure 3e and the Ua code used to generate our simulations. The source code for Ua is already available at https://doi.org/10.5281/zenodo.3706624

L450-464: At the end of a near-perfect manuscript in which each sentence brings new insights while setting the stage gracefully for the sentence that follows it, the final couple of paragraphs transition into a series of miscellaneous ideas that are related to, but not clearly relevant to the 2 main story of the manuscript. Each of these points could be expanded by a few sentences to help glue them to the findings of the study, but I don't think there's a need. Rather, most of the last two paragraphs could be deleted without detriment to the manuscript. I recommend simply reminding readers of the key historical behavior and/or future potential of Denman, and placing your results firmly in that context.

In the revised version we have deleted the final paragraph of the manuscript. Our conclusion now simply reminds the reader of our key results and briefly notes the potential future vulnerability of Denman Glacier.

Technical corrections

L26-27: The general sentiment of the final sentence of the abstract is reasonably supported by the analysis presented in this manuscript, but the phrase "...over the coming century" constrains the prediction a bit too tightly, because timescales of ice response are not directly discussed in this paper.

Amended to: 'that it could be poised to make a significant contribution to sea level in the near future'

L63: "...a range of remote sensing observations..." Make this sentence more clear by stating explicitly that velocity and ice front position observations are analyzed.

We have amended the text to explicitly state velocity and ice front.

L94-95: Indicate how the 1 pixel and 0.5 pixel error estimates were obtained. L113-114: Again, indicate how the error estimates were obtained.

At the request of reviewer 2 we have included a more in depth analysis of velocity uncertainties from the historical 1970s data in supplementary figure 2. This is done by comparing manually tracked rift displacement at various locations across the Denman system to computed displacement values from the Cossi-Corr algorithm. The median value of the difference between the manually tracked rift displacement and the Cossi-Corr values is ±29 m yr^{-1} (~0.5 pixels), thus justifying our estimated error.

L113-114: Again, indicate how the error estimates were obtained.

The error associated with ice-front position mapping of large Antarctic outlet glaciers has been established in several previous studies and we now make this clear in the text:

'Several previous studies (e.g. Miles et al., 2013; 2016; Lovell et al., 2017) have demonstrated that the errors associated with the manual mapping of ice-fronts from satellites with a moderate spatial resolution (10-250 m) are typically 1.5 pixels, with co-registration error accounting for 1 pixel and mapping error accounting for 0.5 pixels.'

155-156: I don't think "accelerations" should be plural here. I recommend replacing "...with accelerations of 19±5%..." with "...with an overall acceleration of 19±5%..." Unless I've misunderstood the meaning of the sentence, in which case, please clarify.

Amended.

L246-252: I had to make this table to keep the experiments straight in my head. It may save others the same trouble to have the experiments explicitly tabulated in the manuscript.

This is an excellent suggestion and we have added a similar table (Table 1) in the revised manuscript.

L259: I think "each simulation" should be "each of the seven simulations".

Amended.

L330-331: Comparing accelerations as scalar multiples of each other is confusing, because I don't have any intuition for what it means if one thing has three times the acceleration of another thing. Actually, the sentence says "the ice accelerated approximately three times 3 faster" and if a is three times more than b, then a=4b, which makes the sentence even more confusing. Reword.

We have amended to text to only refer to accelerations in percent:

'Between 1972 to 1990, observations indicate that ice accelerated 26 ±5% on the ice tongue (Fig. 3b) and 11 ±5% at the grounding line (Fig. 3c) in comparison to more limited accelerations of 9 ±1% and 3 ±2%, respectively, between 1990-2017'

L424: Explicitly state what "this event" is. i.e., "Thus, the next major calving event..." And if the implications are important, don't just imply them—directly state what is implied are. i.e., "...could dictate the flow speed and direction of the..."

We have amended the text to following:

'Thus, this calving event may have important implications for the evolution of the Denman/Shackleton system for multiple decades because it could influence both ice flow speed and direction.'

Figure 1: This figure shows bedrock topography, ice velocity, and the spatial distribution of pinning points in the Shackleton Ice Shelf. These are all valuable as context for the study, and I appreciate that the figure legend clearly states the important things that viewers should take note of. My only complaint is that each variable is plotted in a separate panel, so understanding relationships between velocity, bed topography, and pinning points requires pinballing between all three panels as a way to mentally try to bring the variables all into one figure. Reconstituting the three variables is made more difficult by the fact that each panel shows different spatial extents, and at different scales. I recommend experimenting with transparency, vectors, or contours to show all three variables on one plot. That would also allow more detail, as a single panel could be enlarged to fill the entire width of the page. For example, something like the following would be a way to show ice velocity in the context of surface features and the bed topography that ties Denman Glacier to the ASB:

We have revised figure 1 so that all three variables (velocity, bed topography and pinning points) are displayed on the same figure. On the basis of some of the other reviewer comments we also include a bed profile subplot taken over the Denman grounding line.

Figure 2: As a logical sequence, I'd also put panel b before panel a, because currently panel b shows the direct observations and then panel a shows a quantified version of the observations. I'm also having difficulty understanding where panels c-f are in relation to panel b. There are no recognizable reference points in any of the images, so it's difficult to place them in space. I would typically assume that the image orientation remains constant across all panels, but the spatial extent and even the spatial scale is different in each panel, so everything is in question.

It's also tempting to assume panels c-f depict a sequence of events, but they are presented out of chronological order, so there's an extra little bit of mental bookkeeping that viewers must do to reconstruct what has happened to this glacier tongue since 1962.

If it makes sense to do so, I'd like to see the spatial extents of panels c-f remain constant across all panels, so it will be easy to follow changes over time. I suspect the entire figure would be easier to digest if the panels were rearranged, and if the times of panels c-f were marked directly on the ice front position time series. Something along these lines feels much more intuitive to me:

Or perhaps the time series plot would fit best below the calving-front map, but however you do it, I think the sequence of the panels is important for understanding what story is being told by the figure, and drawing direct connections between all the panels (such as by labeling the times of panels c-f directly on the time series) will help viewers see how the information is all related.

Also, more can be done in the caption to help readers understand the connection between ice front position and ice morphology. This could be just a sentence or two, but just something to help viewers see why R1 through R7 are labeled.

In the revised figure with have added an additional panel (a) which provides a wider picture and highlight the location of the subsequent sub plots. We have also added a consistent reference grid to

all panels to provide a reference point on both the size and location of each figure. We have also added the times of the panels (d-g) to the ice-front time series.

We have also added more detail to the figure caption and included more detail on the importance of R1-R7:

'Figure 2: a) Overview of the Denman ice tongue with the coloured boxes indicating the locations of c-g. b) Reconstructed calving cycle of Denman Glacier 1940-2018. c) Examples of ice-front mapping 1962-2018. Note the change in angle of the ice shelf between its present (light blue – dark blue lines) and previous (pink-red lines) calving cycle. d) ARGON image of a large tabular iceberg in 1962 which likely calved from Denman at some point in the 1940s. e) Landsat-1 image of the Denman ice tongue in 1972, note the pattern of rifting labelled R1-R7. f) Landsat-4 image of a large tabular iceberg which calved from Denman in 1984. Note the rifting pattern and the absence of R7, meaning R7 likely propagated during its calving event in 1984. g) Landsat-8 image of the Denman ice tongue. Note the absence of rifting.'

Figure 3: State which grounding line dataset is being shown here. Partly to give credit to the data producers, but also because InSAR and break-in-slope grounding lines don't agree here, and knowing which GL is plotted would help readers visually identify where certain features are relative to a particular GL

The grounding line product used in Figure 3 is from Depoorter et al. (2013). We use this product for display purposes on the figure because it shows a clear and continuous grounding line across the study area. We have added the citation to the figure caption.

Figure 5: The mental ledger keeping required to interpret this figure is not terribly onerous, but it involves more steps than are necessary. For example, if I want to know what's being depicted in panel g, I must go to the legend in the bottom left, where I see g corresponds to E6, then I find E6 in panel i, and then I say, "okay, E6 falls closer to a dashed line than most of the other dots do." And then I get curious about the outlier dot corresponding to E4 on the x axis. "I wonder what that is," I think, and so I repeat the process backward, going to the legend in the lower left of the figure to find that E4 corresponds to panel e, so then I look at panel e and I see a mostly blank white panel. At no point in that process is there any indication of what any of 7 these letters and numbers mean, because the figure has been stripped of all links to physical processes.

I recommend eliminating the legend from the bottom left and simply labeling "E1: ice shelf thinning," "E2: grounding line retreat," etc., directly on panels a-h, either as titles outside the plot or in the empty space in the bottom of each panel. That would also free up the text of the figure caption to focus on physical processes, rather than bookkeeping.

In the text caption, hammer home the main point by stating that E7 most closely matches observed velocities, suggesting that ice shelf thinning, grounding line retreat, and unpinning from Chugunov Island have all occurred since 1972.

Panel c shows the effects of grounding line retreat, but grounding line retreat itself is not shown. It's hard to gauge spatial scales here, but would a 10 km retreat be visible at this scale? If so, show both the 1972 and 2009 grounding lines.

Panel e shows the effects of unpinning from Chugunov Island. It would be helpful to label Chugunov Island directly on that panel.

I appreciate that panel i puts most meaningful region of velocities of each experiment in context with each other, while also showing the observed 1972 and 2009 velocities, but the panel comes up short in communicating the main point. It's relatively innocuous, so keep the panel if it feels important, but know that it adds a layer of complication to interpreting the figure as a whole. If you'd like to keep it, I recommend including Box D velocities from panel a as a data point. That would make it more clear how E4 got so out of line relative to the others. If you decide to eliminate panel i, the ice speed values could simply be printed next to Box D in their respective panels and/or included as a column in the table I recommended above.

I find myself leaning in close and squinting to see the details around the grounding line. Then I zoom the pdf to 300% and realize the problem isn't my eyesight, but the coarse resolution of the graphics. I recommend recreating the figure at higher resolution (If it's Matlab, try export_fig myfigure.png -r600 for 600 dpi) and enlarging the figure to fill the full width of the page so readers can see the beautiful details that are surely present in this data.

We have added a text description of the experiment number and the perturbations forced in each panel of the figure to prevent the reader having to constantly flick between the caption and the figure. We have also labelled Chugunov Island on the appropriate figures. The scale is too coarse to the differing grounding line positions to be visible, but we do note that a close up version of the grounding line positions used in the simulations are in Fig S3. We have decided to keep panel I, which shows the velocities at box D to be consistent with the time series of speed change in Figure 3. We have also increased the resolution of the figure so more detail can be observed when zooming in and amended the figure caption.