Reviewer 3: Janet Curran

Title: Can you find a term other than "hydrologic diversity" that better brings the topics of changes in runoff volume, seasonality, and drivers to mind? Hydrologic regime diversity. . .? Freshwater runoff . . .? Not sure I have the perfect term, might take a phrase to say it.

Response: This comment is similar to another reviewer's comment about the term 'hydrologic diversity' being undefined and potentially ambiguous. The authors will change the final version to *Seasonal Components of Freshwater Runoff in Glacier Bay, Alaska: Diverse Spatial Patterns and Temporal Change*.

Abstract, L 24-25: "a variety of changes" is vague. What is meant here?

Response: The authors have clarified the meaning of this sentence in the final draft, which reads, "The hydrographs of individual watersheds display a diversity of changes between the historical period and project scenario simulations, depending upon…"

P6, L15-17: The closest calibration point isn't always the most appropriate. Can you also say that the Mendenhall basin is the most similar?

Response: See the new added paragraph in the calibration Section 3.4 that addresses this comment and the comment below simultaneously.

Recent studies (Beamer et al., 2016; Lader et al., 2016) have investigated the accuracy and biases of the MERRA reanalysis product in coastal Alaska compared to other reanalysis products such as ERA-Interim (Dee et al., 2011), CFSR (Saha et al., 2010), NCEP-NCAR (Kalnay et al, 1996), NARR (Mesinger et al., 2006), and others. Many SnowModel parameters were tested by doing a sensitivity analysis for each reanalysis product, including monthly precipitation adjustment factors, snow/rain temperature thresholds, snow and ice albedo factors, and more (see Beamer et al. (2016) their Table 2). For each of 4 reanalysis products, they calibrated model parameters based on observations of streamflow (Q) and glacier mass balance (B). The MERRA simulation Coefficient of Determination scores (r2) for glacier mass balance (B) and stream discharge (Q) for the Beamer et al. (2016) study were 0.80 and 0.95, respectively, and the Nash Sutcliffe Efficiency (NSE) scores were 0.67 and 0.91, respectively. While Beamer et al. (2016) identified the CFSR product as the 'best overall' for the GOA region, they found that MERRA was superior at the Mendenhall Glacier observational station, which is the closest calibration point (< 25 km) to GBNPP. For these reasons, in this study we rely on the model calibration of Beamer et al. (2016; their section 3.4) and we adopt their calibration parameters for SnowModel from their Table 2 and Table A1.

Long-term glacial mass balance programs and long-term streamflow gauge datasets do not exist within the GBNPP study area, thus constraining our ability to conduct additional calibration *efforts. While the Mendenhall Glacier observation station is close in proximity to Glacier Bay, the glacier has receeded and thinned significantly since the early 1900's, glacial wastage is a significant component of annual streamflow (17%), and glacial meltwater contributes heavily to streamflow in the summer (50%; Motyka et al., 2003). As a result of these similarities in geography and hydrology, we rely on the calibration process, parameters, and best-performing reanalysis product (MERRA) from Beamer et al. (2016) for our study.*

Motyka, R.J., O'Neel, S., Connor, C.L. and Echelmeyer, K.A.: Twentieth century thinning of Mendenhall Glacier, Alaska, and its relationship to climate, lake calving, and glacier run-off. Global and Planetary Change, 35(1-2), pp.93-112, DOI: blah, 2003.

P6, L17-18: These metrics are for the Beamer et al. (2016) study, correct? Since this "calibration" section oddly refers to the calibration of a prior study, I suggest phrasing this clearly so the skimming reader doesn't assume these metrics are for your study.

Response: These metrics are from the Beamer et al. (2016) study. This paragraph in Section 3.4 has been re-written to clear up any vague phrasing that may exist for the final draft. The authors have also added some additional explanation of the calibration process for clarity due to the comments of at least one other Reviewer on the calibration process. See new, additional calibration paragraph above.

P8, L1: This sounds like a justification for a higher-than-expected result, but the wording isn't clear. Does the RCP8.5 scenario establish a minimum of 3 degrees change?

Response: The RCP8.5 scenario, and corresponding SNAP temperature and precipitation anomalies, do not establish a minimum or baseline of 3 degrees change. The statement in the text is simply a description of the lower range of temperature changes that are found within each watershed group between the historical and projection scenario modeling results. In Section 4.1 we changed the end of this sentence to avoid confusion.

P10, L3: Is the 3.40 m/yr value actually for "runoff", not "precipitation" as stated? That would be more consistent with the value in the next line.

Response: In this case, for all watersheds in the GBNPP domain, the annual average historical precip value is 3.4m and the annual average historical runoff value is 3.4m. This is different within each grouped watershed. Remember, the authors are reporting the runoff value calculated by SnowModel, which includes all the water made available at each grid cell from precip (snow & rain) + glacier melt processes. ET is not subtracted from these runoff values, just simply plotted on the same graph for context (from Figure 7 and Appendix B). We also do not estimate long-term changes in the groundwater or glacial wastage (ΔStorage) within the 36-year historic and 30-year projection scenarios. For a further discussion of ET calculations and estimations, please refer to the responses to Reviewer 1.

Let's look more in depth at some of these runoff and precipitation values. See the table below for additional information. When PRECIP < RUNOFF like in the West watershed below, there is likely glacier ice melt occurring over the time period that is supplementing the freshwater flows in the basin. When the snowpack disappears from a glacier grid cell, the energy balance model melts the glacier ice and adds to water to the runoff variable. When PRECIP > RUNOFF, like the West-Arm and Tarr watersheds below, there is likely SWE left over at the end of the the year, on glacier surfaces and at the highest elevations, that gets zeroed out at the end of the water year in the SnowModel simulations. This is because SnowModel does not include glacier dynamics, and there will be net accumulation of snowpack above the equilibrium line. When running multi-year simulations, SnowModel offers the option to zero out all the grid cells that still contain SWE on the last day of the water year, in order to not carry over SWE into the next water year. In this study, we chose to zero out the SWE in this manner at the end of every water year, and this method is the recommended/default method for SnowModel users when running multi-year simulations in regions with glacier coverage. In watersheds like the West-Arm and Tarr, where there is 54%-68% glacier coverage, the amount of snow precipitation and leftover SWE is likely to be a substantial portion of the overall precipitation, and that is reflected in the Runoff and Precip values for these watersheds. However, we have not conducted the spatial or temporal end-of-water-year SWE analysis for all years and all watersheds because it is not directly related to the aims and scope of this study.

When PRECIP ~ RUNOFF, like in the GBNPP aggregated watershed, there is a balance between these glacial melt processes and leftover SWE at the end of the time period.

Watershed	Historical PRECIP (m)	Historical RUNOFF (m)
GBNPP	3.4	3.4
North	3.3	3.1
West	3.8	4.3
West-Arm	4.4	3.4
East-Arm	3.3	3.6
Tarr	6.1	2.9
Carroll	2.4	2.9
Dundas	2.4	3.1

P12, 13-14: This statement about a non-stationary system is inconsistent with the presentation of Figure 10 on P10, L20-22, which notes little significant change with one basin

as an exception. The trend for the excepted basin isn't very convincing (p > 0.05, short and discontinuous dataset, a bit noisy), making the comments on P12 seem overstated.

Response: Based on the current Figure 10, your observation and comment is warranted. This is an overstatement in this context. The sentence was originally written for a different figure showing more significant trends in the grouped GBNPP watershed overall, but we had previously decided to remove that figure and the previous results. We will adjust the wording accordingly, by taking out the reference to non-stationarity, and the authors have also decided to remove Figure 10, because the presence of this figure is not adding any additional, necessary information to the manuscript. We've adjusted the language in Section 4.6, paragraph 2.

Appendix B: Interestingly, the forecast runoff hydrographs, which admirably show the relative contributions of runoff processes, produce a few seasonalities that aren't apparent for individual streams in my present work characterizing historical hydrographs. The composite GBNPP and North basins appear to have a snowmelt-dominated spring peak and a larger rainfall-dominated fall peak, a reversal of the typical relative magnitudes for a bimodal glacierized basin hydrograph. Can this be explained by an increase in spatial distribution of future rainfall-dominated areas within the composite basin or any other observations from the modeling?

Response: This is an excellent question, and one that would require more in depth spatial analysis of the modeling results to answer quantitatively. At first glance, your suspicion about the increase in spatial distribution of future rainfall dominated areas within the composite basin contributing to the larger rainfall dominated fall peak makes sense in the context of the temperature and precipitation results. Looking at Figure 3 may shed some light on this question. We can see the largest increases in temperatures, the largest increase in precipitation, and the most significant decreases in snowfall occur for most watersheds during the months between Oct and Dec (appearing as a blob of darker colors during those months). However, to calculate the exact spatial extent (area in km^2) of the increase in rainfall-dominated areas would require additional spatial analysis of the results during both the historic and projection scenarios. Since a close look at Figure 3 contains some of the answers to your questions, the authors are comfortable keeping the Appendix A explanation in the manuscript and figure caption without changes.

Additionally, the freezing line altitude (FLA) analysis (see Figure 11) includes a ΔFLA from historic to projection scenario for the winter (+234 m) and summer (+1341 m) months. We did not include the spring (+910 m) and fall (+775 m) ΔFLA values in the figure due to simplicity's sake. These increases in the FLA during spring and fall would represent a large corresponding increase in the spatial distribution of the rainfall dominated areas in the RCP8.5 projection scenario, and makes sense with the changes in temperatures found in Figure 3.

Introduction: Trim and keep focused on the study by omitting details about GOA (especially in 1st and 2nd paragraph), minimizing drama (P2, L6-7), and considering moving setting

information to the Study Area section if it's actually needed (the long discussion of tidal mixing and stratification and the Etherington et al. study made me think this was the study focus on first read). It's all interesting, but it's not until the penultimate paragraph (P3, L37-39) that the problem is hinted at and not until the final paragraph (P3, L13) that the actual work of the study is introduced, and the reader can finally start understanding the direction of the manuscript.

Response: The discussion of the GOA in the intro paragraphs 1 & 2 are important to give the readers of the Cryosphere the geographical context within which the Glacier Bay region exists. However, some of the details and general statements about the region can be trimmed to keep the focus on Glacier Bay.

In Section 1, para 2, the word 'dramatic' will be changed to 'considerable'. Also the authors are comfortable taking out the end of the following sentence, which will now read 'Indeed, the coastal mountain ranges of Alaska have recently sustained rapid rates of deglaciation (Arendt et al., 2002; Arendt et al., 2009; Gardner et al., 2013; O'Neel et al., 2015).' Drama was not the intent with the previous sentence and wording, and these changes remove any question or potential of dramatic language.

Reviewers have requested both more information (Reviewer 1) about oceanographic processes (stratification, mixing, etc.) and less information about these processes (Reviewer 3). The authors are attempting to balance all the requests, while simultaneously keeping the original flow and intent of the article. In this case, we choose to keep the remaining paragraph structure of the intro intact.

P2, L31 and P3, L3-4: The number of references to particular places within Glacier Bay suggests Figure 2 could be presented earlier.

Response: This is a good suggestion. Figure 2 will now be referenced in this paragraph.

Study Area, paragraphs 1 and 2: Clearly define study area (all watersheds within GBNPP, which includes all the lands of GBNPP and some areas outside it?). The multiple nested, paired watersheds are a nice study design but are hard to keep track of. Suggest moving the parts of paragraph 2 that aren't obvious from the figure or table (P3, L29-30) into paragraph 1. Consider using a defining characteristics for the names or adding a column to Table 1 to associate basin names with a defining characteristic. It would be helpful to know "North" is the full Glacier Bay basin and that the choice of the three named basins allows comparison of basins having. . .(a range of elevation? a range of glacier characteristics?), for example.

Response: The authors have added text in this paragraph to clarify the study area boundary decisions in Section 2. In this section, para 1 describes the entire GBNPP study area, and para 2 describes the 4 grouped watersheds, and paragraph 3 describes the individual watersheds. The authors think this is an appropriate structure for the paragraphs, and some additional text has been added to these paragraphs to clarify.

P7, L23-24: This is one of the clearest statements of the goals/outcome of the study. Could use this earlier.

Response: This is a good suggestion from Reviewer 3. This sentence has been altered slightly and added to the last paragraph of the Section 1, in order to more clearly state the outcome of the present study.

P9, L11-12: Delete information repeated from methods.

Response: This is another good suggestion that makes the manuscript more concise. The first sentence in Section 4.3 summarizes paragraphs found in the methods section and has been removed from the final draft.

P9, L25-35: Many details of computations, and the discussion of the omission of routing, seem like methods. Consider moving to Section 3.1 or elsewhere in Methods.

Response: Again, this comment from Reviewer 3 makes sense for the flow of the paper and for keeping a clear delineation between methods and results. This paragraph has been moved to the methods section and removed from this results paragraph in the final draft.

P10 and 11, Section 5, first and second paragraphs: Most of the main points are made in the first paragraph; suggest combining the two and reducing detail. Consider moving computation of FLAs to methods.

Response: The authors think the detail in this paragraph is a warranted discussion of the FLA analysis and the landscape dependencies of seasonal snow patterns. However, there are a few sentences in this section that have been appropriately moved to the methods section in accordance with this suggestion.

P12, L5-6: Nice explanation of why CTD dataset was included, could use this earlier.

Response: This is an important point, and the authors have restated this in Section 1, para 7.

P11, L11-12 and L20: Check figure number. I assume you mean figure 11a and b, respectively.

Responses: Good catch, yes, this was previously Figure 9 and was changed in the final stages of drafting.

References: References are used appropriately. I did not check to make sure all are used, or that all references cited are included. The recommended citation for USGS reports includes the report series title and report number. For Curran et al. (2003) that's Water-Resources Investigations Report (or WRIR, if preferred) 03-4188 and for Wiley and Curran (2003) it's Water-Resources Investigations Report 03-4114.

Response: These two citations have been changed to include the Water Resources Investigations Report.

Fig. 1: Labeling Alaska and Canada (a) and Glacier Bay (b and c) would help reader comprehension.

Response: Agreed, the labeling of Glacier Bay is a missing piece of these maps and they will be added to the final figures. As for labeling Alaska and Canada, the authors want to keep the maps as simple as possible, without clutter, and do not think it is necessary to know exactly where the international boundary lies, since we have no other non-physical geographical locations (cities/towns, boundaries, roads, etc.) labeled.

Fig. 2: Label Glacier Bay. The Alaska/Canada boundary is referenced in the text but not shown here.

Response: Again, the authors think it's worth mentioning the boundary in the text but it is not a necessary part of the maps. Glacier Bay has been labeled in the final draft figure.

Fig. 5 : Shading of forecast glaciers is distractingly similar to ocean. The title "Glacier Change" doesn't match the legend items, which include two glacier positions and the GBNPP boundary.

Response: For the final draft, the legend title 'Glacier Change' has been removed completely from the legend of the figure. The authors agree that the color palette for the forecast glaciers needs to be different for reader comprehension, and the final draft of the figure has a different color palette.

Fig. 6: Suggest being consistent with the x-axis scale used for other monthly plots (use Jan-Dec, not Sept-Aug)

Response: The reason the SWE climatologies are presented in water year format, from Sept-Aug, instead of presenting them in the previously used calendar year format is because the progression of snow water equivalence is simpler, and possibly more intuitive to visualize and understand when the winter is not split in two parts. Often, but not always, when SWE climatologies are presented in the literature they span the water year and not the calendar year. For these reasons, the authors think the SWE climatology is easiest to understand in its current format.

Fig. 7 caption, last sentence for (a): Check for typo in "the modeled for runoff climatology"

Response: This typo has was changed in the final draft.

Tables 1 and 3, and Appendix A and B: Suggest some structure to convey basin/sub-basin relationship and the various pairings of nested basins (a line or spacing, for example). At a minimum, keep the same order in the Appendices as is used for the tables.

Response: The authors have divided the tables into groupings, and the order of the Tables and Appendices are kept the same in all instances.

Appendices: These plots are useful results and would lend themselves well to being reduced in size. Consider rearranging to fit each Appendix on 1 page with a single legend for each and including in the text.

Response: The authors are open to including the appendices in the main text, and to reducing them in size, instead of including these sets of figures as appendices. This decision can be ultimately be left up to the editors discretion at the Cryosphere.