Response to Reviewer Comment by Anonymous Reviewer on "Changing Characteristics of Runoff and Freshwater Export From Watersheds Draining Northern Alaska" by M. A. Rawlins et al.

We are very grateful to the reviewer for the comments on this manuscript. We provide responses in blue below. Line numbers refer to the updated manuscript.

Review #2

General Comments: This paper evaluates how discharge(surface/subsurface flow) and active layer thaw is changing across the North Slope of Alaska and NW Canada. It uses a detailed permafrost water balance model to simulate flow and examine changes in the active layer across 42 catchments in this continuous permafrost area. Overall the objectives of the paper are clearly outlined. Model performance is compared with measured runoff data, namely the Kuparak watershed. The authors' model was not able to capture large discharge peaks and time of simulated spring snowmelt runoff was 10 days earlier than observed estimates. Overall, the authors provide adequate explanation for model inconsistencies, and indicate that better performance may be tied to an improved understanding of lag effects (e.g. antecedent moisture conditions), landscape micro-topography (surface storage), soil type and soil organic content. They also demonstrate that large tracts of the North Slope area are thawing, which is leading to slightly higher cold season discharge, and earlier snowmelt ~ 4 days. They link their modelled and observed results to recent arctic discharge and groundwater flow studies occurring elsewhere (e.g. Middle Lena Basin) and biogeochemistry. Overall, this paper is interesting and furthers our understanding of runoff and ground thaw changes across the Alaskan North Slope and NW Canada. The paper could be improved by a model flow-chart and further details on model parameter choices (e.g.effective velocity) (please see below for further comments).

Specific Comments:

1)Line 28. Do you mean in 24 of 42 study basins? Also, it would be worthwhile to have a table of the 42 study basins describing basin areas, elevation range and locations (latitude/longitude). Perhaps, this site information could be placed into a Supplementary Table or an Appendix.

We have added "for" to the sentence. It now reads: "A significant increase in the proportion of subsurface runoff to total runoff is noted for the region and **for** 24 of 42 study basins, with the change most prevalent across the northern foothills of the Brooks Range."

2) Line 38. Can you add subsurface flow to the list of keywords.

Yes. Added.

3) Line 76. Do you mean increased hydrological connectivity instead of hydrological conductivity? If the ground thaws, then the flow of water further down in the active layer is usually much slower than it is in the near surface or when the active layer is frozen, and overland flow occurs.

Yes, although we believe an increase in conductivity would accompany the increase in connectivity. Word changed. Line 79.

4) Line 98. You can just put NW Canada.

Done.

5) Line 104. Just put NW Canada. Please take out extreme, and also just use NW, instead of northwest, since you used NW in Line 98.

Word ‘extreme’ removed.

6) Line 106. In your map, please indicate some major communities: Utqiakvik, Prudoe Bay(or Sagavanirktok) and perhaps a Canadian northern community too.

New map of domain now included as Figure 1. Major communities indicated. The hamlet of Aklavik, Canada is just south of the small river basin nearby.

7) Line 107. Again, it would be good to have a list of these 42 watersheds, particularly information on their catchment size, location of outlets and source for discharge information (e.g. USGS, Water Survey of Canada), etc.

We have added a table of the 42 river basins defined by the simulated topological river network. The table includes outlet coordinates, name where applicable, and basin area. Discharge information is used for the Kuparuk and Colville. There are no gauged data available for the small area in NW Canada. We reference USGS data source in the Data section. Lines 120-122.

8) Line 180. Could you clarify what you mean by ‘transient ponded surface evaporation’?

Sentence added to clarify: “Transient surface storage consists of water connected to the surface flow that is delayed in its transport to stream networks.” Line 215.

9) Lines 197-198. I don't understand what you mean by .... 'Following initial assessments we increased soil carbon amounts by 10% in areas of sandy soils....' Was this based on model runs or on the research from Nicolsky et al.(2017). Please clarify- thank you!

The statement is based on initial model runs. During our assessments we concluded that the model parameterizations for soil carbon amounts and hydrological properties in the Brooks Range were inconsistent with our understanding of the region. We have modified the sentence: "Based on analysis of initial model simulations we increased soil carbon amounts by 10% in areas (24 grid cells) of sandy soils and reassigned the texture to loam, …" Line 209.

10) Lines 204-209. I don't understand what you are doing in lines 204-209. Can you provide more details for adjusting evaporation and runoff functions?

We have modified the first three sentences of that paragraph to be clearer on our motivation. Paragraph begins at line 213.

11) Line 219. It is not clear why you set the effective velocity at 0.175. Can you provide additional justification here for this parameter?

We appreciate the comment and concern. The river flow routing routine is new. We addressed this in response to comment by reviewer 1. The model is relatively insensitive to specification of flow velocity. See statements in lines 292-299.

12) Lines 256-268. Interesting that simulated freshet leads observed freshet by 10 days, indicating that your snowmelt routine and routing are likely too fast. Does your snowmelt routine take into account a snowpack cold content, which can slow down melt progression? Along stream channels does your model account for the effects of channel snow or snow dams,which can pond meltwater and slow down runoff? Small terrestrial ponds can open up quickly too during snowmelt, and can retain much overland flow, especially if they have sufficient storage (low snow year, or antecedent storage conditions). I do realize that you mentioned lag effects in the system but a 10 day spread in modelled versus simulated results appears to be on the high side.

We agree that the source of the error is likely a model snowpack that melts too rapidly. Given its length, travel time through the Kuparuk is too short to conclude that the river routing is too fast at the velocity we use. Our snowmelt routine is a function of air temperature and precipitation. We are working now on implementing a new snowmelt module that takes into account snowpack temperature. The PWBM contains no channel snow, but does account for the effects of snow damming, as described in Rawlins et al. (2003). We disagree that the magnitude of error is problematic, as our primary interest is in quantifying seasonal export of riverine constituents like dissolved organic carbon. We anticipate that new model updates will ameliorate the early bias. We have described the bias in a transparent way and feel strongly that daily accuracy is not required for a model used to quantify seasonal freshwater and constituent exports across this remote region that is lacking in measured data.

13) Line 296. Is cold season discharge simulated for the basins? It was not clear to me whether these data were modelled or measured. Low flows can have large uncertainties due to the ice cover, so how confident are you in these results?

Yes, here we are addressing simulated discharge. Word added at line 366. There are no measured data that will allow for comprehensive evaluations of simulated cold season discharge. We are very confident that the PWBM includes all key processes necessary to simulate the water cycle at spatial and temporal scales critical to understanding the nature of hydrological change across the region. Uncertainties are indeed larger for low flows.

14) Lines 342-343. I don’t have access to Figure S6. Could this supplementary figure be added to the paper?

It is our understanding that the supplemental section was made available for review and will be available to readers upon publication.

15) Lines 352-353. What is going on in the one basin where you see a large shift in maximum peak discharge?

The change in timing of maximum daily discharge for that basin is not much different from several others. It is simply the case that, for that one river, the change is statistically significant. Many of the 42 rivers show a peak discharge nearly one week earlier over the 30 years. The change does not achieve significance above the 95% level due to the high interannual variability. We have added a sentence to make this clearer. Line 425.

16) Line 365. I think that ‘Arctic’ should be arctic here.

Yes. Changed.

17) Line 370. Can you clarify what you mean by ‘insufficient surface storages in the model’? Do you mean pond storage, or depression storage arising from hummock/hollow micro-topography?

We mean the latter. Sentence modified to be more clear. Lines 446-449.

18) Lines 371-372. Yes, I agree. You need to improve your surface storage sub-routine, especially if you are losing near-surface ground ice, as your landscape micro-topography is probably evolving.

We agree. Modeling changes in micro-topography will require implementation and parameterization of a numerical model at finer spatial resolution and across smaller regions.

19) Lines 402-406. Can you clarify your statement about the role of permafrost and the link between your study and that of the Lena River. It wasn't quite clear to me, even after I read the Gautier et al. (2018) paper. They appeared to indicate that the size of the spring freshet was more important in controlling the maximum and minimum ratio rather than an increase in fall groundwater flow.

We have reworked the sentence. Gautier et al. (2018) suggested that the change in ratio was mainly due to the increased minimum river base flow in winter. Also documented by Yang et al. (2002). Line 481-484.

20) Line 424. It should be 'exert'

Corrected.

Technical Corrections:

1) Check over references. Some of the titles have all caps, others not. Some of the page numbers for recent journal articles should be double checked.

We checked all references against the published work. Reference title matches the title in the published paper.

2) Table 1. Figure S2 indicated in the Figure title is not available. I did not have access to it or it is missing.

It is in the supplemental section.

3) Table 2. You may as well list the details for all 42 catchments.

New Table S1 included.

4) Figure 1. Can you add the air temperature to Figure 1, and can you show the ratio of snow to rainfall in the bar diagram for precipitation.

Yes. Done. See revised Figure 2

5) Figure 4. Is this modelled discharge or observed discharge. Perhaps, clarify in the figure title-thank you!

Figure shows model simulated river discharge. Word ‘simulated’ has been added to figure title and caption.

6) A flow chart of your permafrost water balance model would be most helpful.

A schematic diagram of the PWBM was published in Rawlins et al. (2013). A flow chart would likely be simply input -> model -> outputs.