Author responses to: "Brief Communication: Early season snowpack loss and implications for over-snow vehicle recreation travel planning"

Responses to reviewers are in **bold,** *new text is in italics* ***(bold italics for emphasis)***

Responses to Reviewer 1

Review comments by Glenn Patterson on Hatchett and Eisen, 2018, Brief Communication: Early season snowpack loss and implications for over-snow vehicle recreation travel planning.
Thank you for the opportunity to review this brief communication. In general I found the paper to be well-written, representing a significant contribution to our understanding of climate change, snowpack trends, and winter recreation.

Dear Dr. Patterson,
We appreciate your constructive comments and positive feedback. Please find below responses and our revisions to address all of your comments.

My only substantive suggestions are: (1) Based on figure 1(b) and on intuition, median timing of achieving SWEmin appears to be negatively, not positively, correlated with elevation.

Thank you for pointing out this oversight. You are correct, the timing of SWEmin is negatively correlated with elevation. We have changed the text to "*negatively correlated*".

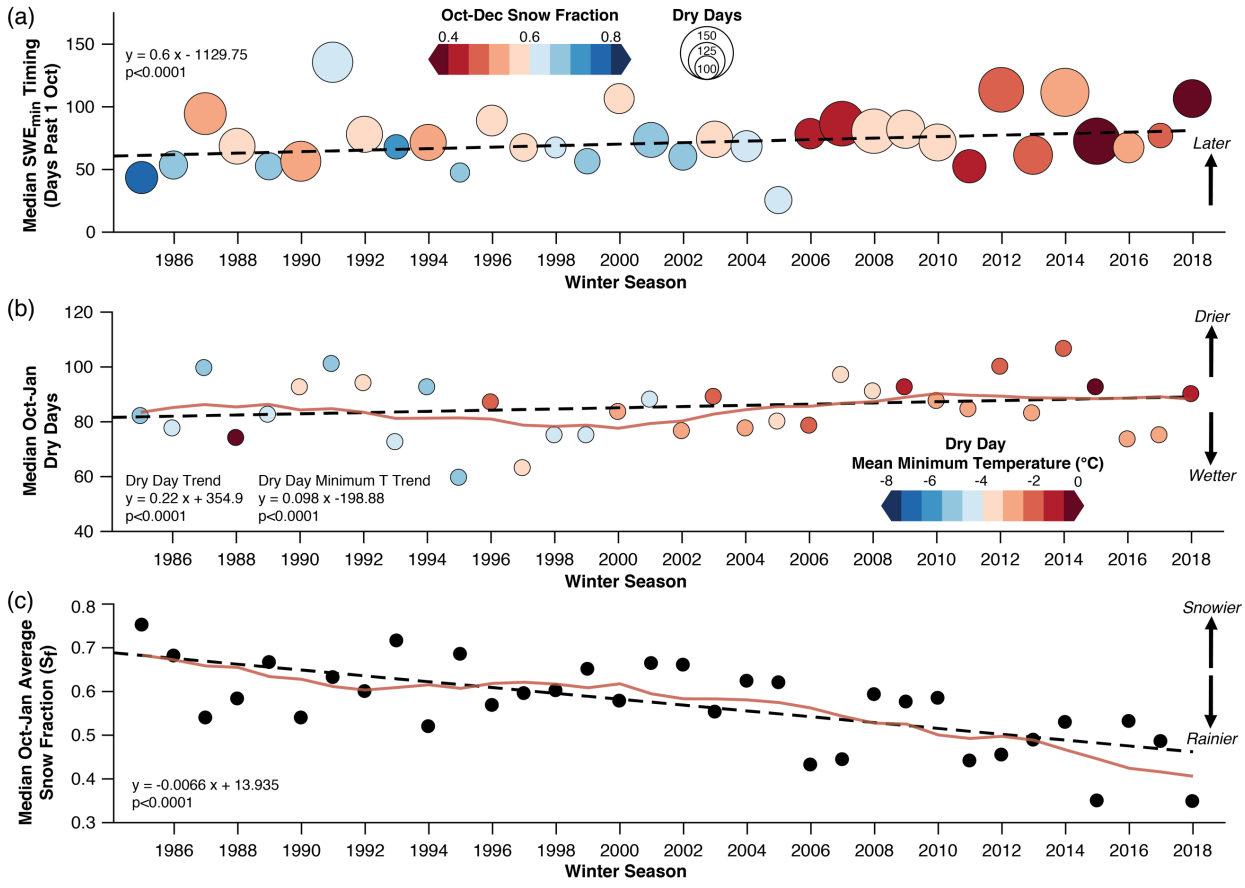
(2) I realize that it might not be feasible to add another parameter to the analysis at this late date, and I also realize that SNOTEL temperature records can be suspect, but I still feel it's worth bringing up this point. As you state well on page 4, line 23, warming temperatures are likely to be an important driver for the trends toward later SWEmin, and are also likely to be the primary factor involved in the shift toward more rain and less snow. Would it be possible to add a figure showing the trend in a relevant measure of temperature? It could be something like average daily (or max daily) early cold-season (Oct-Dec) temperature, or something like that. From what you are describing, one would expect to see a shift from predominantly freezing to melting temperatures.

We appreciate this useful suggestion. The snow fraction calculation is based upon average temperature and thus captures the shift from snow to rain you mention, but for non-precipitating (dry) days, we have added the average early season dry day minimum temperature value to Panel b on Figure 2. Minimum temperature is an excellent metric to observe how regional warming (via changes in longwave radiation balance driven by changes in atmospheric composition) is impacting the study area. The Mann-Kendall trend test was applied to the minimum temperature timeseries. It yielded a statistically significant trend of 0.098°C yr^{-1} ($p<0.0001$). This suggests regional warming is reducing precipitation falling as snow on wet days and is driving a warming of an ever-increasing number of dry days, both of which will act to negatively force the snowpack. For consistency, we have calculated dry days,

average dry day minimum temperature, and snow fraction over the early season (mid fall through early winter) period spanning October-January. The main text and figure 2 have been updated with the adjusted results.

The new text is as follows:

The new figure 2 and caption:



We also agree that the SNOTEL temperature records can be suspect (based on the Oyler et al. 2015 work and have noted this in the text at the end of section 3.2 (possible drivers of SWE loss):

"The analysis of SNOTEL temperature is limited by inhomogeneities introduced by temperature-dependent sensor biases leading to over-estimation of trends (Oyler et al., 2015). While over-estimation is greatest at elevations above 3000 m, additional assessments are needed to validate the robustness of the role of regional warming in reducing early season snowpack"

Added reference:

Oyler, J.W., Dobrowski, S.Z., Ballantyne, A.P., Klene, A.E. and Running, S. W.: Artificial amplification of warming trends across the mountains of the western United States, Geophys. Res. Lett., 42(1), 153-161, https://doi.org/10.1002/2014GL062803, 2015.

(3) I like the discussion pertaining to table 1, and the suggestions contained in the table. I would like to suggest one additional management strategy. As both human-powered and OSV winter recreational use are likely to be confined in the future to smaller geographic areas and shorter-duration seasons, conflicts among user groups are likely to increase. In the Rabbit Ears Pass area of Colorado, managers from Routt National Forest minimize those conflicts by clearly designating separate areas for motorized and non-motorized use (non-motorized can actually occur in both areas). In this case it is the east side and the west side of the pass. My suggestion is to develop such conflict-reduction strategies for the Lake Tahoe area, as well.

Thank you for the suggestion, we have added this strategy to the table. From personal experience, although some areas are well-signed (designated), problems can still arise due to lack of resources to enforce closures, but such an issue should be addressed during the travel management planning process and through subsequent budget requests.

Below are some specific suggestions for minor editorial issues.
Abstract: In the first sentence (line 8), it would be good to clarify whether "negative impacts" refer to impacts on the over-snow vehicle recreational experience, or on the environment. Based on the paper, it appears to be the latter.

You are correct, it is the latter. We have added "*on the environment*" to clarify.

I agree with the previous suggestion, that it would be good to speak (line 11) in terms of later onset of SWE sufficient for recreation, rather than increasing date.

We have changed the text to reflect '*later onset*' rather than increasing date.

Introduction:
Page 1
Line 15: I would be a little more comfortable with "warming" of the cryosphere, rather than "decline". "Warming" is clear; "decline" carries complex connotations.

We have changed the text to "*warming*".

Line 27: "Economic revenue" strikes me as redundant. I would suggest either "revenue" or "economic impact". Also, it would be helpful to specify that the revenue is on an annual basis: "…annual revenue…"

Thank you for the suggestions. We have changed the text to "*estimates of annual economic impact*".

Page 2
Lines 4-9: This would be a good place to address one of the important aspects of the SWE-depth relationship that is central to this discussion. I would suggest stating that the 30-cm minimum depth refers to 30 cm of uncompacted or fresh snow, something like this: "Minimum snow depth restrictions have been proposed by several forests undergoing winter travel management planning across the Sierra Nevada. This restriction is usually proposed as a minimum depth of 30 cm of uncompacted snow (United 5 States Forest Service (USFS), 2013)"

Good point, we have changed the text to follow your suggested phrasing:
"…across the Sierra Nevada. This restriction is usually proposed as a minimum depth of 30 cm of un-compacted snow (United States Forest Service (USFS), 2013)."

Data and Methods:
Page 3
Line 9: This is a little nit-picky, but this sentence seems to indicate that SWE is a measure of depth. I would suggest rewording to: "…we specified 90 mm SWE (hereinafter SWEmin) as the required minimum SWE corresponding to a minimum uncompressed depth of 30 cm for approval of OSV use."

Change has been made, thank you for helping to clarify this and hopefully reduce confusion. The new text is as follows:
"…we specified 90 mm SWE (hereafter SWE_{min}) as the required minimum SWE corresponding to a minimum un-compacted depth of 30 cm for approval of OSV use."

Line 14: I agree with the earlier suggestion to maintain consistency of depth units by sticking with cm instead of mm.

We are now using cm as the primary unit with respect to depth and mm for snow water equivalent. The text has been changed to "*30 cm*".

Line 24: I would suggest using "when" instead of "that": "Dry days were days when zero precipitation was measured…"

Change has been made to "*when*", thank you.

Results and Discussion:
Page 3
Lines 31-31: Based on figure 1(b) and on intuition, median timing of achieving SWEmin appears to be negatively, not positively, correlated with elevation.

Change to "*negatively correlated*" has been made, again we apologize for the oversight.

Page 4
Line 1: Delete unneeded "in" after "trends".

We have removed "in".

Line 8: Thanks for looking at the elevation dependency of the SWEmin trends. I, too, found indications of elevation-dependent warming, meaning steeper trends at higher elevations. Some of the references in my 2016 dissertation go into this in a little more detail.

While our station-based SWE analysis did not find a relationship between trend in onset date, the gridded SWE analysis did indicate more significant trends at higher elevations, however this is still likely due to the early season weather variability (as previously noted in the original submission) and the bias of reanalysis validation data (snow pillows and snow courses) being located at intermediate elevations.

We added some additional text to the concluding remarks suggesting further assessment of the controls of elevation-dependent warming (notably, changes in humidity):
"*However, further research is needed to estimate specific contributions from each cause and constrain the role of surface-albedo and/or humidity feedbacks at various elevations throughout the region (Patterson, 2016; Walton et al., 2017).*"

Line 23: I realize that it might not be feasible to add another parameter to the analysis at this late date, and I also realize that SNOTEL temperature records can be suspect, but I still feel it's worth bringing up this point. As you state well here, warming temperatures are likely to be an important driver for the trends toward later SWEmin, and are also likely to be the primary factor involved in the shift toward more rain and less snow. Would it be possible to add a figure showing the trend in a relevant measure of temperature? It could be something like average daily (or max daily) early cold-season (Oct-Dec) temperature, or something like that. From what you are describing, one would expect to see a shift from predominantly freezing to melting temperatures.

This is a great suggestion and we have added this analysis to the manuscript, despite the limitations of the SNOTEL temperature data. Please see the response to main suggestion 2) above.

Table 1--Page 11:
I like the discussion pertaining to table 1, and the suggestions contained in the table. I would like to suggest one additional management strategy. As both human-powered and OSV winter recreational use are likely to be confined in the future to smaller geographic areas and shorter-duration seasons, conflicts among user groups are likely to increase. In the Rabbit Ears Pass area of Colorado, managers from Routt National Forest minimize those conflicts by clearly designating separate areas for motorized and non-motorized use (non-motorized can actually occur in both areas). In this case it is the east side and the west side of the pass. My suggestion is to develop such conflict-reduction strategies for the Lake Tahoe area, as well.

Thank you for the suggestion, we have added this strategy to Table 1.