

## ***Interactive comment on “Snowmobile Impacts on the Physical and Mechanical Properties of Different Snowpacks in Colorado, U.S.A.” by Jared T. Heath et al.***

**Anonymous Referee #1**

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The paper describes snow cover measurements to quantify the impact of snow mobile travel. Specifically, differences in density, hardness and temperature between an undisturbed snow cover and a snow cover subjected to various degrees of snowmobile usage are presented. The authors describe partly novel and thorough field experiments which were used to investigate these changes in detail. However, the results remain very qualitative and not very new. Furthermore, since the goal of the study is not clearly defined in the introduction and the presentation and discussion of the results is rather poor, major revisions are required before the paper can be accepted for publication.

Overall, there are three main issues with the paper:

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1. After reading the introduction it does not become clear why this study is needed and why changes in snow properties due to snow mobile usage should be quantified. Indeed, the first paragraph deals with the economic importance of snowmobiling. It is completely unclear how this is at all relevant to the measurements presented in this paper. The second paragraph then lists several studies before stating the goals of this study. As such, there is no clear context, no knowledge gap is identified and it remains unclear why the authors performed these measurements.

2. The presentation of the results is rather poor and the broader relevance remains unclear. In the results section the authors show vertical density, temperature, hardness and ramm hardness profiles for all sampling dates. However, they mainly discuss mean (bulk) properties or the properties of the basal layer. As such, it would be better to show plots of the temporal evolution of the mean properties (e.g. mean density with time for the control, low use and high use) and the basal layer properties. Furthermore, the authors essentially list the results and the writing is very dry. I would suggest that the authors use the figures and tables more actively in their writing and focus on the main results. Finally, a more in-depth analysis is required to gain new insights into the effects of snow mobile travel on changes in snow cover properties and make the results more broadly relevant. Specifically, the authors could develop a simple model (e.g. linear regression) to predict snow densification after snow mobile usage and they should investigate how snow layering affects densification.

3. The discussion and conclusion sections need to be rewritten. The lack of a clear objective in the introduction translates to a very scattered discussion. Vague and out of context statements are made which do not really relate to the work presented in this paper. For instance, the third paragraph of the discussion deals with snow metamorphism. Some very general statement on the influence of ground and air temperature are made and then related to very specific increases in density observed in the measurements (lines 332 to 334). The line of thought is very hard to follow. Similarly, there are vague statements about the transferability of the results to snow grooming (lines

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306-316), minimum snow depth for skiing (lines 405-409) and snow making (lines 426-433) which seem completely out of context. The authors need to do a much better job at putting their results into context, discuss the limitations of their findings and highlight new insights.

Specific comments:

line 33: It is unclear to me why climate change will affect the amount of land available for snowmobiling. line 36-39: How can there be old snow below a shallow snow cover? This sentence is very unclear and should be rewritten. line 55: remove imperial units here and throughout the paper line 58-61: it is not clear to me why this section on conflicts among different user groups is relevant to the paper. line 67: The authors should describe what a SNOTEL station is and what they measure. line 68: "... was used to characterize the 2009-2010 winter on REP". Characterize is not very specific. line 69: it is unclear what is meant by operational sites. This only became clear after reading the results. line 92-100: a sketch of the experimental setup would make this description more easy to follow. line 107: remove "and continued through the duration of the winter season". line 110-113: rewrite to "Vertical snow profiles were observed to record snowpack properties including snow density, temperature, stratigraphy hardness and ramm resistance. " line 118: mL should be ml line 118: mention the thickness of the density cutters. line 119-121: remove the sentences "The density of snow ... and bulk snowpack density were compared." line 123-125: Unclear how a mean over 10 cm can be taken if the measurements are done every 10 cm. line 127-129: "However, repeatability for any ..." it is unclear what the authors want to say here. line 131: unclear what is meant by "point of zero". Do you mean the minimum temperature? line 141-142: remove sentence "The main crystal forms..." line 148: mention the area of the metal plate attachment. line 156-160: ramm and not ram. Also, better describe how ramm measurements are made. Right now it is not clear that this is a cone penetration test. Provide a reference, e.g. Gubler (1975) line 162-163: "bottom stratigraphic layer" is not defined. Do you mean basal layer as defined I layer 125? If so, consistently use

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basal layer. line 171: typo "sets samples of samples" line 173-174: clearly state what you define as significant and highly significant. line 177-185: The definition of a deep and shallow snowpack seems rather arbitrary since the difference in snow depth is not very large. Furthermore, I would not qualify a snow cover of 150 cm as deep. line 223 changes in temperature gradient line 228-229: remove "favoring sintering and bonding of snow crystals" as it is not relevant here. line 229-231: rewrite this sentence line 245: unclear what is meant by "the deeper snowpack" line 266: unclear what "These" refers to. line 267-268: unclear what is meant by "treated transects were approaching control values by the last sampling date" since the colored hardness profiles in bottom of figure 5c were not close to the control profile. line 269: change "orders" to "one to two orders". line 309-311: rewrite to clarify line 312: change to "on the underlying snowpack" line 322: change "also gets more dense" to "increases in density" line 325: this statement does not fit well with the temperature measurements shown in Figure 4. In particular the measurements in Figure 4b show a temperature of -4 at the base of the snow cover. It is not clear what the authors want to discuss here and this entire paragraph seems out of place. line 330-331: not clear what the authors mean by "easily sinter". Rounded grain do not sinter more readily than faceted grains, as was shown in van Herwijnen and Miller (2013). line 331-332: "Rounding increases density and snowpack strength" it is not clear what the point of this statement is. line 340: typo "snowthrough" line 360: this is speculation since the authors did not make any observations of grain arrangements. line 362: not clear what is meant by "avalanche evaluation" line 370: how can the precision of the ramm penetrometer be determined?? line 371: not clear what the authors mean by "undisturbed snowpack" since the ramm penetrometer is widely used to characterize the hardness of undisturbed snowpacks throughout the world. line 382-383: unclear how the reference to de Quervain is relevant here. line 384-387: remove this since the explanation in terms of edge effect and heat transfer from the buffer areas is very speculative and not convincing. line 396: "temperature gradients and thus vapour pressure gradients were less" unclear what this statement is based on since there was no significant difference in temperature gradients and vapour

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pressure gradients were not measured. line 397-399: this sentence is contradictory, is it similar or different? line 405-409: unclear how these minimum snow depth guidelines fit in the discussion here. line 414-415: cooler snowpack at the end of the summer? line 418: snow depth was not less for the disturbed sites in Figure 3! line 431: typo "create surface different conditions" line 432-433: It is unclear how to consider artificial snow with the present results. line 442-444: I do not understand how the results presented in this paper can help when modelling the impact of snow grooming or snow making. line 448-449: the authors did not show that the amount of snowfall influenced their results! line 453-454: this statement is incorrect since there were no significant differences between low and high snow mobile usage. Figure 1: improve the caption and describe what is shown in the figure. Figure 2: It would be better to show snow depth rather than SWE to be consistent with the other figures. Also, there is no need to show data from July to September. Finally, please show the first of each month on the x axis. Figure 3: it would be better to show the mean snow density with time. Also, the snow depth is sometimes larger for the disturbed sites than for the undisturbed site, which seems counterintuitive. Figure 4: why are there vertical jumps in the temperature profiles? Also, it would be better to show the mean temperature gradient with time. Figure 5: The results shown in this figure are odd. It is not clear to me how and why the hardness of certain layers would decrease in the second half of the season. This is also not in line with the density measurements which show an overall increase over the course of the season. And again, it would be better to show mean hardness with time. Figure 6: better to use a logarithmic x axis. Also, show mean ramm hardness with time.

Gubler, H., 1975. On the rammsonde hardness equation. IAHS Publication, 114: 110-121. van Herwijnen, A. and Miller, D.A., 2013. Experimental and numerical investigation of the sintering rate of snow. *Journal of Glaciology*, 59(214): 269-274.

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