

## ***Interactive comment on “Hydrologic Flowpath Development Varies by Aspect during Spring Snowmelt in Complex Subalpine Terrain” by Ryan W. Webb et al.***

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The authors would like to first thank you for taking the time and effort to review our manuscript. We appreciate the constructive comments that have been made and our replies can be found below following a reiteration of the original comment.

In this paper, authors measured temporal changes of soil water content and snow water equivalent to estimate the influences of surrounding topography. This study is important to estimate lateral flow in the snowpack and at the snow soil interface. It is expected that this study estimate the amount of lateral flow under the provided topography, snow and meteorological conditions. In my opinion, analysis and discussion in this paper remains

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qualitative discussion without quantitative estimation. Perhaps, quantitative analysis is performed in another paper referred in the manuscript as Webb et al. (in review). If so, division of the paper reduces the impact of this paper. Even so, quantitative analyses from the observation results are necessary. For example, if the ratio of water for lateral flow and infiltration into the soil is added in Fig. 6 based on the result of observation, this paper can provide scientific valuable information. In this paper, lateral flow is considered to be main cause of the increase of SWE at the toe. However, I think the authority of this consideration is not sufficient. If there are other evidence of large lateral flow (e.g. water saturated layer observed by snow pit observation), it should be shown.

Response: The other paper that is in review is a study at a different location and dataset with relevant results. However, we will certainly expand our citations to include other papers that we cited in the introduction. Given your comments, we agree that further quantification is justified and can certainly be addressed by adding an estimated ratio of lateral flow vs. infiltration to enhance this paper. We propose that an energy balance estimate of melt rates and accumulation along the hillslope required to produce the observed increases in SWE would provide an estimate of this ratio in revisions.

minor comments

In introduction, one of the objectives is to investigate if preferential flowpath in snow can be observed in P3 L24. So observation of preferential flow should be described in detail in the body text.

Response: Thank you for pointing this out. We should clarify this objective to say “evidence” of lateral flow can be observed at the hill slope scale since it is rarely investigated at this scale. We will directly address the re-phrasing of the objective and adding text to the main body of results to better fulfill this objective.

P4 L25 According to this sentence, authors measured snow pit. Did authors measure not only SWE but also profiles of snow density and grain size? Depending on grain

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size and density profile, capillary barriers formed at the boundary of snow layers and provides lateral flow in the snowpack. Ice layers also provide lateral flow. If snow profiles are measured, observed result should be shown and used in the discussion of the lateral flow. Also, measuring method of SWE should be described. In this manuscript, lateral flow at snow-soil interface is considered main cause of the increase in SWE. So I guess the snowpack at the toe includes large water saturated layer. But water saturated layer make accurate SWE measurement more difficult. Therefore, more detailed description for observation is necessary.

Response: Snow profiles of density and grain size were not measured at all locations due to time constraints of an individual surveyor collecting data at all locations (often more than 10) within a single day. We did, however, collect these data at a single location on the first survey date of each year and are happy to include these data in revisions. We understand that capillary barriers as well as permeability barriers can cause lateral flow and have observations of ice lenses and saturated snow zones that can be further discussed for clarity, though the wet snow layer is mentioned on P7 L8. We will add further discussion to these points in revisions. The measuring method of SWE is described on P4 L31.

P7L6 Ice veins were not observed in 2015. Is there a significant difference between 2014 and 2015? Comparison between 2014 and 2015 may suggest the influence of ice vein for lateral flow.

Response: The main difference between 2014 and 2015 was the timing of peak SWE and higher temperature in 2015. In 2015 no increases in SWE downslope were observed. We will further discuss this point in revisions.

P8 L33-36 The last, “where observations of ice veins were made at the SSI.”. Do authors think that the cause of lower water content at 20 cm depth in north facing slope is the existence of ice vein? But ice veins were not observed in 2015 according to P7 L6. I think that the slope affects water content. Lateral flow in soil prevents deep

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infiltration and leads to small water content at the depth area in north aspect slope.

Response: We agree with this point. The presence of ice veins shows evidence that lateral flow above the SSI is occurring and that lateral flow in the top layer of soil is also contributing to the lateral flow downslope. We will revise the text to clarify this point.

P9 L14 Is Fig 4 a reference mistake of Fig 3? In the body text, Fig. 4 is sometimes referred in unnatural context (e.g. P10L3).

Response: You are correct. We apologize for this mistake and will correct it.

P9 L20-22 Is this discussion for only in 2014 or both in 2014 and 2015?

Response: This is discussion that combines observations from all years to form the conceptual model in Fig. 6. We will revise the text to clarify this.

P9 L25 Fig. 4 is just a photo of ice vein. Do authors mean that this ice vein produces lateral flow? If so, it should be written in the caption of Fig. 4.

Response: Language will be added to the caption. No, we do not believe that the ice vein produces lateral flow, but is rather evidence of lateral flow occurring.

P9 L28-31 As this sentence show, increasing snow depth with SWE means less certainty of lateral flow. So figures of snow depth and discussion with snow depth are necessary. Also, if the snow profile was observed by pit observation, details of snow density profile should be shown.

Response: This was the only location that depth also increased. We have the depth and bulk density information that will be added to help clarify. Though snow profiles at all pit locations were not collected on each survey date, detailed profiles were collected on the first survey dates each year and will be added.

P9 L32-34 Is this less stratified snowpack due to strong radiation in south facing slope confirmed by pit observation?

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Response: It is confirmed through observations of ice lenses but not through detailed profile measurements. Additionally, data from other studies that show North aspect slopes to have more stratified snowpacks as a result of solar radiation loading in this region.

P9 L34-35 In author's opinion, which is the main reason of large lateral flow in north facing slope, ice vein, stratified snowpack or small hydraulic conductivity of soil?

Response: It is a combination, but the main reason would be the north facing slope causing lesser melt rates and low hydraulic conductivity of the soil. Just to be clear, the ice veins are a result of lateral flow, not the other way around. This will be clarified.

P10 L20 Increase of 250 mm in SWE is too large to consider caused by lateral flow. Change in snow depth should be also shown to discuss.

Response; Snow depth decreased at this location. It is also a result of the rising of the water table as discussed on P11 L7.

P10 L32 Did the author observed preferential flow visually? In this paper, preferential flow formed in early snowmelt season on north facing slope and south facing slope displayed matrix flow in this time. However, preferential flow may form on south facing slope in earlier period before this observation. Snowmelt starts earlier on south facing slope than on north facing slope.

Response: This is true. It is possible that preferential flow occurred during a time that observations were not being made. Here, we are comparing results to the Hinckley et al., 2014 study that is mentioned in the previous sentence. We are also making the argument based on the physics of flow through porous media. This will be further clarified and discussion of the possibility of pref. flow occurring on the S-Aspect earlier in the season added.

P11 L1-7 In this paragraph, cause of increase in SWE is considered lateral flow. But the authority of this seems insufficient. Especially, increase of 250 mm in 2014 is too

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large even if the effect of rising water table is considered. I wonder this discussion is based on the confirmation by snow pit observing large water ponding layer. Therefore, discussion about the reason why the cause of SWE increase is lateral flow is necessary. Description of “Wind is not likely causing increased deposition on any particular part of a hillslope since winds run perpendicular to slopes.” is not sufficient to determine lateral flow as cause. Explanation of confirmed fact by observation and authority of the cause are necessary.

Response: As mentioned in previous comments, we will provide more of the available data to further clarify these points. We also made a point to not measure locations that formed snow drifts behind trees, etc. and snow depth decreased as well as a deep saturated layers were observed.

P11 L12 Is Fig.4 reference mistake of Fig. 3?

Response: Yes, this is a mistake. Thank you for noticing this.

Again, I would like to reiterate our appreciation of the reviewer’s constructive comments. Addressing these concerns will certainly improve the quality of the paper. Attached to this comment is a draft revision of the figure that shows the snow depth along with SWE.

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Interactive comment on The Cryosphere Discuss., <https://doi.org/10.5194/tc-2017-12>, 2017.

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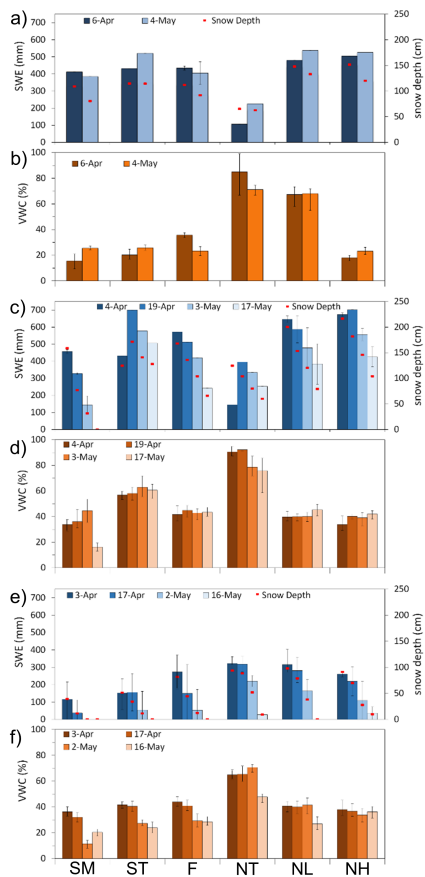


Fig. 1.