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Discussions

Interactive comment on "Partitioning snowmelt and rainfall in the critical zone: effects of climate type and soil properties" *by* John C. Hammond et al.

John C. Hammond et al.

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Referee comment: 1. The authors find that, overall, high intensity melt events are more effective in producing groundwater recharge in dry regions. This is in line with previous investigations (Jasechko Taylor, 2015) and could be stated more clearly in the abstract and conclusions.

Response: We agree that we should add additional concise summary of previous work on rapid melt leading to more effective recharge in dry regions. We will edit the text to state this clearly in the abstract and conclusions. The references below will also be added to the manuscript:

Jasechko, S., S. J. Birks, T. Gleeson, Y. Wada, P. J. Fawcett, Z. D. Sharp, J. J. McDonnell, and J. M. Welker (2014), The pronounced seasonality of global groundwater recharge, Water Resour. Res., 50, 8845–8867, doi:10.1002/ 2014WR015809.

Jasechko, S., Wassenaar, L. I., & Mayer, B. (2017). Isotopic evidence for widespread coldâĂŘseasonâĂŘbiased groundwater recharge and young streamflow across central Canada. Hydrological processes, 31(12), 2196-2209.

Referee comment: 2. The abstract is not very concise since it is not entirely clear from the abstract alone what was unknown beforehand and what the study confirms.. Currently, the abstract seems more like a list of everything that was done in the study and it is hard to get the key take away points. The authors might want to reduce the abstract length and condense the key take away points..

Response: In an effort to more effectively demonstrate what this study contributes, we will shorten the list of specific methods and concentrate more on take away points: -Snowmelt is a more efficient runoff generator than rainfall due to both higher input rates and higher antecedent moisture -Deep drainage also tends to be higher with more snowmelt, but its connection to input type is weaker because soil storage buffers the effects of changing input -When soil storage is lower than mean annual precipitation, surface runoff and deep drainage substantially increase -Soil texture modifies daily wetting and drying patterns but has limited effect on annual runoff and deep drainage -In dry climates snowmelt produces greater concentration of input in time, which also increases runoff and deep drainage

Referee comment: 3. The paper mostly shows how streamflow generation and groundwater recharge depends on snow fraction. As has been shown in past (Barnhart et al., 2016; Musselman et al., 2017), snowmelt rates (i.e. melt intensity) and not snow fraction control hydrologic partitioning. The study would greatly benefit from reporting additional insights about how streamflow generation and groundwater recharge depend on snowmelt rates in the different climate regimes, and from a comparison of the model results with previous observation-based studies.

Response: In addition to reporting partitioning response to snowmelt fraction, we also show how this partitioning relates to annual precipitation, soil saturation, and finally the concentration of input in time, which is comparable to input rate. This study extends what is shown by Barnhart et al., 2016; Musselman et al., 2017 on on the importance of snowmelt to generating runoff and deep drainage using detailed soil profiles modeled at a daily timestep. Indeed, the rate of input, and concentration of this input in time, makes snowmelt an efficient generator of runoff and deep drainage.

We have a brief comparison of runoff and deep drainage magnitude from this study to previous research on lines 462 to 469, but we will add additional comparison to other studies.

Referee comment: 4. The authors do not consider rain-on-snow and mixed precipitation events in this analysis. This is probably because they work with SWE data obtained directly from the SNOTEL network, and do not use a snow model. It might be useful to mention the different event statistics in the text (eg: how much of the annual precipitation is in the form of mixed events). This should also be mentioned as a limitation in section 4.2 (which would probably benefit from a change in the title, “limitations” instead of “uncertainties”).

Response: We agree that this additional information (how much of the annual precipitation is in the form of mixed events) would be helpful for the reader in interpreting the results of our study, and we will add this information both in relevant results and discussion sections on the subject of limitations.

Referee comment: P1 L24: Snowmelt fraction is not a commonly used term. Can instead write snowmelt as a fraction of annual precipitation. Alternatively, snowmelt fraction can be defined a priori and then be used.

Response: We currently define snowmelt fraction on line 241 of page 7: “We also

report the maximum SWE and snowmelt fraction as the annual total snowmelt divided by annual total input,” but will clarify this terminology further.

Referee comment: P2 L57-58: The phrase “rainier futures” is a bit awkward. Remove?

Response: We will reword this to clarify the reduction of snow accumulation and subsequent melt in future climates.

Referee comment: P2 L74: “energy hinders.. “. Do you mean that solar radiation is low during early melt and not supportive enough to drive vegetation growth, assuming snow melts very early? Then how will the growing season length increase? Should be clarified.

Response: We will clarify this statement with logic from the source below:

Harpold, A. A. (2016). Diverging sensitivity of soil water stress to changing snowmelt timing in the Western US. Advances in water resources, 92, 116-129.

Referee comment: P3, line 82: “moisture content on north-facing slopes”: moisture content of the snow pack, of the soil? This requires a reference

Response: Sentence should read:

“leading to higher sustained soil moisture content on north-facing slopes compared to south-facing slopes with the same input”

And can be supported by the following references:

Williams, C. J., McNamara, J. P. and Chandler, D. G.: Controls on the temporal and spatial variability of soil moisture in a mountainous landscape: The signature of snow and complex terrain, Hydrol. Earth Syst. Sci., doi:10.5194/hess-13-1325-2009, 2009.

Hinckley, E. L. S., Ebel, B. A., Barnes, R. T., Anderson, R. S., Williams, M. W. and Anderson, S. P.: Aspect control of water movement on hillslopes near the rain-snow transition of the Colorado Front Range, Hydrol. Process., doi:10.1002/hyp.9549, 2014.

Webb, R. W., Fassnacht, S. R. and Gooseff, M. N.: Wetting and Drying Variability of the Shallow Subsurface Beneath a Snowpack in California's Southern Sierra Nevada, Vadose Zo. J., doi:10.2136/vzj2014.12.0182, 2015.

Webb, R. W., Fassnacht, S. R. and Gooseff, M. N.: Hydrologic flow path development varies by aspect during spring snowmelt in complex subalpine terrain, Cryosphere, doi:10.5194/tc-12-287-2018, 2018.

Referee comment: Variable names should be in italics (examples: L101-102, L138-145). The usage of semicolon (;) in lines 101 and 102 is incorrect and reading these sentences is difficult. Please check the usage of the semicolon throughout the paper.

Response: We will change variable names to be in italics and also avoid multi letter variables as mentioned in the HESS manuscript preparation description (https://www.hydrology-and-earth-system-sciences.net/for_authors/manuscript_preparation.html)

We will also rephrase these sentences to avoid the use of semicolons and will check the use of semicolons throughout.

Referee comment: P3 L105: The water balance equation is written in terms of volumes rather than fluxes, which is unusual; a change to fluxes (with the change in storage over a time increment,deltaS/deltat) seems more appropriate.

Response: The water balance can be written in terms of volumes or fluxes. In the manuscript we state that the equation applies for a given interval of time.

Referee comment: P3 L101 vs P4 L140: In L101, runoff is defined as lateral export of water from the domain. In L140, runoff is defined as overland flow resulting from saturation- or infiltration excess . Please clarify how runoff is defined and make it consistent throughout the manuscript.

Response: Runoff in this 1-D study is input that does not infiltrate, which may be due to infiltration or saturation excess as discussed on lines 299 to 301 on page 9:

We will clarify use of the runoff term throughout.

Referee comment: P6 L221: Mention what percentage of annual precipitation is accounted by mixed events

Response: We will add this statistic.

Referee comment: P7 L230: for the calendar year or the hydrological year? If the calendar year: how is the snow carryover handeled?

Response: Calculated for the water year, lines 229 to 232 page 7:

"At the annual scale, soil water input and partitioning components (rain, snowmelt, Q, ET, D) were totaled for each year, and the change in water year storage (S) determined by subtracting the values of S at the end of the year from the value at the beginning of the year. In addition to S, mean saturation (Sat) at each observed depth was calculated as the average annual VWC divided by soil porosity."

Referee comment: P7 L242-244: Define PCI and ICI indices with the possible range and mentioning what increasing PCI/ICI values mean

Response: We will add common ranges of these indices and what they mean in greater detail to what is currently on lines 242 to 244.

Referee comment: P7 L253 and following: it is not clear what was tested via indicator-variable regression; what is indicator-variable regression? Which results are based on this?

Response: We will add additional clarification to define indicator-variable regression and note which results use this in support of what is currently on lines 252-255 on page 7: "Additionally for question 2, we tested the pairwise difference in linear regression slopes using indicator-variable regression with interaction in JMP (SAS-based statistical software) to determine whether the rate of change between explanatory and response variable differed by climate or soil depth grouping."

Referee comment: P9 L327: Not clear based on the second panel of Figure 8a that you can arrive at this conclusion.

Response: We will update text corresponding with this figure to indicate how much earlier and how much longer response is in loam and sandy loam profiles as compared to sandy loam profile.

Referee comment: P10 L371: Also mention Figure S2 which shows that a transition from snow-dominated regime to a rain-dominated regime may increase the amount of deep drainage. The Figure S2 is probably worth including in the main paper.

Response: We will add the reference to Figure S2 on line 371, but believe Figure S2 should stay in supplemental information as it is only an example at one site, and don't believe any of the figures in the manuscript could be swapped with Figure S2.

Referee comment: P11 L388 – 390: Which figure is this argument based on? If it is based on Table 3, please reference it in the text.

Response: Will add reference to Figure 6 and Table 3.

Referee comment: P11 L402: How do the relative amounts of Q and D change? It is more useful to state how they change than simply mentioning they change.

Response: We have similar information on lines 361 - 365:

"The initial hypotheses for this study were that runoff and deep drainage would be greater from snowmelt than 362 rainfall. Multiple lines of evidence from our 1-D hydrologic simulations point towards snowmelt as a more efficient driver of runoff, and to a lesser extent deep drainage, than rainfall. Results confirmed that runoff efficiency from snowmelt events was elevated because snowmelt events were 22% greater in input rate, and occurred on 17% wetter soils than rainfall."

We will add similar references to L402, providing relevant percentages.

Referee comment: P11 L406: Incorrect figure citation.

Response: This figure reference referred to the precipitation axis range on Figure 3, but for clarity we will instead present the precipitation range in parentheses in this sentence

Referee comment: P13 L458: Figure S2 does not show difference between model runs using daily vs hourly inputs. Incorrect figure citation.

Response: Reference should be changed to Table S2.

Referee comment: Usage of the phrase "input concentration" is a bit ambiguous (eg: L203, L376). The authors use concentration in terms of length of melt period or temporal clustering of events. However, it can also be misunderstood as the intensity of melt. This should to be clarified in the text.

Response: We will clarify the use of input concentration throughout the text to emphasize temporal clustering of input, and explain how this relates to intensity of input through time in addition to what already exists on lines 242 to 244.

Referee comment: There are a number of very long sentences in the paper which can be reframed to make the text easier to read. Some examples are: L81-85: This can be broken into two sentences. L116-120: The sentence can be shortened or converted into two sentences. L438, 464: The use of phrase "biased wet" does not sound right. L466: Reframe the sentence

Response: We agree that several run on sentences can be more effectively broken into several shorter sentences and will edit the manuscript throughout to improve readability.

Referee comment: Figure 2: What does different shades of gray mean? Is it related to hydraulic conductivity?

Response: We will clarify in the caption that shades of grey are just meant to show different soil layers, but do not imply characteristics of that layer.

Referee comment: Figure 3: In the second panel of (B), the y-axis label does not correspond with the figure label description. In the y-axis label, S/P is written whereas in figure label, ΔS/P is written.. What can we learn from panel B? Would it be interesting to present a Budyko-plot instead?

Response: Panel B sets up use of normalized response throughout rest of paper. The Y axis will be changed to ΔS/P. We believe the existing plots in figure 3 show the hydroclimatic variability captured at the sites without the need for an additional Budyko plot.

Referee comment: Figure 5: Put correlation values in the figure

Response: We will add these values to the figure.

Referee comment: Figure 6: * means P-value of <0.5. Did the authors mean to write < 0.05? Its uncommon to report p-value of < 0.5. The same p-values have been reported in Tables 3, S3, S4 and S5.

Response: Yes, should be <0.05.

Referee comment: Figure 8: Instead of plots of Q and D, might want to show cumulative plots of Q and D as not much can be clearly seen in Q and D plots. Increase contrast between lines corresponding to 1.5x and 2x of soil depth.

Response: We will increase the contrast between lines corresponding to 1.5x and 2x of soil depth and also include cumulative response lines on this figure to aid in visualization.

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