Authors' response to interactive comment of the anonymous Referee #1

Black text: Referee comment

Blue text: Authors' response

We thank the reviewer for the valuable comments and suggestions to improve our contribution. We provide point-by-point reply below.

This paper investigates the role of snow (and rain) on streamflow across 59 Czech catchments. The objectives of the study are: to quantify how snow storages affect spring and summer runoff and to quantify how much runoff snowmelt in generates compared to rainfall. The study uses data of 50 catchments and simulations using the HBV model. They show the following results: 1. Snow runoff fractions exceed snowfall fractions (Fig 3), from which they conclude snow produces more runoff than rain. 2. How much runoff occurs in particular months varies between snow rich and snow poor years (Fig 4), with overall more runoff in snow rich years. 3. Several streamflow signatures vary between snow rich and snow poor years (Fig 5). 4. Summer base flow depends on both SWE and summer P (Fig 6+7) 5. That also in models annual and summer runoff strongly depend on the snow fraction (Fig 8).

These results are generally useful for the HESS' readership, as they address the important issue of how snow (and its anticipated future changes) affect river flow. However, before I can recommend publication of this article I think several things need to be addressed first:

- This HBV results suggest that snow produces runoff differently than rain. However, HBV treats snowmelt and rainfall largely similarly. This seems counterintuitive (or a paradox). It needs to become clearer in the modeling results how snowmelt is different than rain that leads to these runoff differences. Otherwise, I am not sure what we really learn from the presented results.

Thank you for this valuable comment. The changes in runoff due to snowfall/rain transition as simulated by modelling experiments (Fig. 8) pointed at two different aspects; 1) changes in annual water balance and 2) changes in seasonal runoff distribution. The first aspect was shown in Fig 8a and, in model, was caused by lower actual evapotranspiration (AET) for higher snowfall fractions due to more days with snow cover (AET is calculated only for days with no snow cover on the ground in the model). This is mainly discussed on lines 410-418 (section 4.4). We are aware that this particular result is influenced by the model structure which describes the whole rainfall-runoff process in a simplified way and thus the real catchment behaviour might not be captured correctly.

The second aspect, changes in seasonal distribution, was caused mainly by lower snow accumulation for lower snowfall fractions (more rain than snowfall) and by earlier snowmelt. This widely influenced the timing of groundwater recharge and thus spring and summer streamflow, low flows and deficit volumes (Fig. 8b-d). This second aspect is, in our opinion, more important (although expected) since it widely influences the water availability during the warm period when the water need is generally higher (for vegetation growth, agriculture, hydropower etc.).

We will describe it in a clearer way in the revised version (in results and discussion sections).

- The results listed above as 1-4 have all be shown before or are mostly trivial. There might be value in showing this again for the study catchments, but then I think the paper should better explain what we learn about the hydrology of these places, rather than largely use them as data for making some general statements.

We agree that most of findings are not surprising as they mostly support our existing qualitative knowledge of how snow contributes to spring and summer runoff. However, we believe that the findings are still important even if they do not change our process understanding, and the quantification is a valuable and novel contribution. Besides, we were concentrated on non-alpine (outside the Alps) region of Central Europe where there is only a little published information on how ongoing changes in snow storages and snow/rain distribution at different elevations affect seasonal distribution of runoff. This is specifically important for identification of regions which might become more vulnerable to drought occurrence in the future. We also benefit from modelling approach enabling us to simulate both snow and rain runoff components and thus track the snow and rain signal in runoff. We believe that the fact that our focus was on the interplay of different rainfall-runoff components goes beyond what has been done before and thus it might bring some new insight into this topic.

Nevertheless, we are aware that our results are limited to the specific region and may not be easily generalized. Therefore, it was our intention to write the text in this respect. However, maybe this is not always clear from our formulations. Therefore, we will go through the text again to describe it clearer, to better highlight the novelty and to put more emphasis on regional consequences of our results.

- All results of groundwater recharge rely on the model output of an unvalidated flux (since no GW data are used). How do we have confidence they reflect actual groundwater recharge behaviours?

It is true that our results are not based on direct measurements of all individual runoff components since such measurements were not available for all analysed components. Therefore, we calibrated a model to simulate those components of the water cycle, for which observational data were not available. The HBV model, which was used in our study is, despite its simplicity (and thus limiting ability to represent rainfall-runoff process in a fully physical way), widely used and accepted by the scientific community, especially for impact modelling at a catchment scale. To better address the model uncertainty, we used an integrated multi-criteria approach to calibrate the model using three objective functions to validate our model against both streamflow and SWE. The model allows using also groundwater (GW) data for calibration, but these data are not easily available for all study catchments. Besides, the density of the measuring network does not allow us to find the GW stations (either boreholes or springs as a proxy) which would sufficiently represent the whole catchment since the spatial variability in GW storages in a catchment is very large due to the variability in geology and soils. In contrast, the streamflow used to calibrate the model represents the integrated output from the whole catchment, and also the observed SWE data usually represents the catchment snow storage well enough (at least at a specific elevation zone). Therefore, it is questionable to which degree the use of the GW data for model calibration would result in more accurate simulations.

Additionally, we were concentrated on relative differences (year-to-year variations) between groundwater fluxes in individual catchments rather than on absolute values. Some studies also showed (Staudinger et al. 2017) that catchment storage calculated using different methods (water balance calculations, recession curve analysis, HBV modelling) are, in general, comparable and correlated, although the quantitative estimates may differ. Therefore, we believe that using HBV simulations for assessing the relative inter-annual differences in GW storage is acceptable approach even when GW data were not used for model calibration.

We will include the above explanation into the discussion section to better describe all uncertainties and limitations of using such model for this topic.

- The paper contains a lot of unclear statements or language that if (interpreted as written) is wrong. I made a list of suggestions below, but this list is far from comprehensive. Please check the paper another time critically. This is really important because for too many statements it remains unclear what the authors claim to be true, and thereby makes it even impossible to review

Thank you for the comment. Although, the text was corrected by a native speaker (hydrologist), there could be still some unclear statements or wrong formulations. We will carefully go through the text again to correct all potential English errors.

Detailed comments

L9: add the word “often” (or something similar), otherwise this general statement is false.

Added.

L11: (and in winter runoff). Not necessary to state, but maybe not bad to mention.

Changed to “winter to summer runoff”.

L14: model output, not model performance.

Changed.

L15: the simulations are not “hypothetical” as they have been performed. I the paper intends to say something like “Hypothetical scenarios were modelled”

Changed to “hypothetical scenarios”.

L19-20: “This was documented by [: : :] from snow to rain” This does not seem to be a logical statement. Maybe change the verb “documented”?

“Documented” changed with “demonstrated”,

L22: would “reduced” be more specific than “affected” and therefore more informative?

The word “affected” was used in the original manuscript because the baseflow was not reduced in all catchments (as explained in the next sentence). Therefore, we prefer to keep the sentence as is to avoid confusions, although it is less informative.

L29: “largely affects” seems a bit odd. Maybe “often affects” or “can affect”.

Changed to “significantly” since the snow impact on runoff seasonality is really important and often substantial.

L30: “tend to occur” not “occurs”.

Changed.

L32: “to increase [: : :] climate changes“. Why mention “precipitation”? And reword “to increase in air temperature” to “to increasing air temperatures”. (And probably make “climate changes” singular).

Changed.

L34: “during winter” may be an unnecessary (and sometimes wrong) specification here. In many mountain areas the shift from snow towards rain will be biggest in spring and fall (when temperatures are often near 0) compared to winter (when temperatures are generally below zero even when it gets a bit warmer)

We removed “during winter”.

L34: “a rate of”? I do not think this makes sense here. Please check what is intended to be said here.

We changed “rate” with “proportion”. The whole part is a definition of “snowfall fraction” (which is firstly used here) to avoid confusion about this term.

L35: would “reduced” be more specific than “affected” and therefore more informative?

Changed.

L37-38: I understand why you say “On the contrary” but this only makes sense by having the reader guess that this has an opposite effect on total streamflow generated (which you don’t say, nor make it clear that this is what you’re thinking about). Therefore I would try to reword this a little.

We removed the sentence since the mentioned information has no link to previous information and thus, we think it is redundant in this context.

L39-40: “Changes in [: : :] and occurs earlier”. Or “Reduced snow accumulation, and earlier and slower snowmelt cause earlier and less groundwater recharge (Beaulieu et al., 2012; Foster et al., 2016).”

Changed, thank you for the suggestion.

L41: to “lower elevations” (make plural)

Changed.

L44-45: “Higher snowpack generates higher groundwater flow driven by snowmelt rates and thus contributes more to streamflow 45 (Barnhart et al., 2016).” Does not seem to be a logical statement. Do you mean something like “Higher snowpack disproportionally feed groundwater leading to more to streamflow (Barnhart et al., 2016)”?

Changed, thank you for the suggestion.

L54: “were” seems redundant.

Removed.

L57: Thus “using” not “uses”

Corrected.

L96: Consider removing “the” at the start of the sentence.

The sentence was reworded.

L110-111: “For this, we used a bucket-type HBV model (Lindström et al., 1997) in its implementation, called HBV-light (Seibert and Vis, 2012)” This sentence is clear, but I would recommend to rephrase it. (E.g. remove ‘in its implementation”)

We wanted to mention that we used HBV-light version of the model, which is the specific software implementation of the original HBV model. We slightly reworded the sentence.

L121: “Different weights were tested to achieve the best possible performance of the model” This seems somewhat vague and arbitrary. What made you choose the particular weight in the end (i.e. what made them the “best”)?

Although we tested different weights, it is true that we did not use any consistent approach to find the best values of these weights. The testing was done just based on our experiences with the model and based on a literature. Therefore, it is true that the choice was rather arbitrary, although it reflected the main purpose of the model use (accurate simulation of both high and low flows, water balance and snow storages). We will reformulate the respective part to be clearer.

L133-134: “The similar procedures for model set-up and calibration was also used earlier in (Jenicek et al., 2018), although in different region.” Fix the language of this sentence. For example by: something like “This procedure for model set-up and calibration was also used in Jenicek et al. (2018), although for different region”.

Changed, thank you for the suggestion.

L137: the simulations are not “hypothetical” as they have been performed. I the paper intends to say something like “Hypothetical scenarios were modelled”

Changed.

L182: I am unsure what “simulated correctly” would really mean here. Do you mean “accurately simulated”?

Yes, we mean “accurately simulated”. We changed it.

L192-200: It is unclear to me to what extent these results originate from snow being more effective in producing runoff than rain or whether this is because of the seasonal timing of precipitation (independent whether it’s snow or rain).

We don’t know whether we correctly understand this comment. The results here (Fig. 3) were analysed for individual hydrological years (1 Nov – 31 Oct) and thus any deviations from 1:1 line (Fig. 3a), in our opinion, should indicate the differences in annual water balance rather than differences in seasonal runoff distribution. We will add more explanation to the revised version.

L435: “This particular result proves that snow is more effective in generating catchment runoff compared to liquid precipitation” seems like an overly strong statement. Tone down the word “prove” and choose something like “indicates” or “suggests”.

We agree, changed to “suggests”.

L454-456: “. An understanding of potential model artifacts might be important : : :” is very vague. Can it be made more specific?

This conclusion refers to the issue about how the model structure could influence results discussed in section 4.1 (mainly L334-343). We agree that the mentioned formulation in the conclusion section could be more specific. We will reformulate the respective part of the text.

References

Staudinger, M., Stoelzle, M., Seeger, S., Seibert, J., Weiler, M. & Stahl, K. (2017) Catchment water storage variation with elevation. Hydrol. Process. 31(11), 2000–2015. doi:10.1002/hyp.11158.