Response to reviewer 3

We would like to thank this anonymous reviewer for his/her valuable comments and detailed insights into the manuscript. The reviewer raises two major points stated below:

It remains unclear how the model is initiated and which data coming from field data or other studies were used. In this context, I recommend to report more experimental data, on which you rely in a second step to drive your modelling approach.
Figure 3: What do you mean by "different random seeds"? Please see also the general comment regarding the modelling initiation.

HydroMix is initiated by setting a prior distribution for the model parameters. HydroMix requires concentration data for the different components that mix linearly. In the revised version we will make clearer what kind of data is used as input for HydroMix.

In order to sample the prior distribution of the model parameters, a random number generator is required. To make the results reproducible, it is a recommended practice to specify what is sometimes called the random seed, i.e. a number used to set the random number generator to a specified state, which results in a reproducible set of random numbers (the same seed will give the same random numbers). This will be clarified in the revised version.

As also suggested by the Executive editor, we will provide the experimental data used for the Vallon de Nant case study through zenodo and include a link of the same in the revised manuscript.

The study partly relies on the mixing model of precipitation and snow, not snowmelt. While snow and snowmelt have different isotopic signatures, it is conceptually more correct to use snowmelt for mixing models to estimate its contribution to groundwater. I strongly recommend to better justify why snow instead of snowmelt was used to infer the meltwater supply of groundwater if you cannot extend your calculations to snowmelt.
P11L20: It is well known that the isotopic signature of snow is isotopically much more negative and thus much different from the one of snowmelt, which actually forms the 'true liquid' runoff component. Beside, which logistical constraints did prevent from sampling? Snowmelt sampling can easily be carried out by installing PCS collectors or grab sampling the dripping snowmelt

We agree with the reviewer's point on the usage of snowmelt isotopic ratio instead of snowfall or snowpack isotopic ratio as it is the water from snowmelt that infiltrates and recharges groundwater. However, a recent review of previous investigations that explored the differences in isotopic ratio between snowfall and snowmelt by Beria et al., (2018) revealed that snowfall and snowmelt isotopic ratios have similar mean values but different variances, with lower variance in snowmelt than snowfall isotopic ratios. Snowfall isotopic ratio was found to be the most variable followed by snowpack and then snowmelt isotopic ratio. The lower variance in snowmelt isotopic ratios is because of snowpack homogenization caused by mixing of liquid meltwater between different snowpack layers due to diffusion and dispersion.

There also exists a strong temporal variability in the meltwater isotopic ratios, with more negative isotopic ratios in the early part of the melt season (also referred to as the 'melt-out effect'), and less negative isotopic ratios in the later part of the melt season. However, on an aggregate basis, the mean values of the snowfall and snowmelt isotopic ratios are similar, except in regions with substantial sublimation, which is not the case in the Swiss Alps. This makes snowfall isotopic ratios a reasonable proxy for snowmelt isotopic ratios, which is also supported by results of the synthetic case study (Figure 6). We use snowpack isotopic ratio in the mixing case study because Vallon de Nant is a remotely located catchment with very limited winter access. The catchment experiences frequent winter avalanches and mudslides ("https://www.20min.ch/schweiz/news/story/Schlammlawine-begraebt-Strasse-unter-sich-30186734," 2019), making it hard to monitor during the winter season. This is why we were unable to install snowmelt lysimeters or PCS collectors to regularly sample meltwater. Also, as shown in the review paper of Beria et al., (2018), it is reasonable to replace snowmelt with snowpack isotopic ratios.

We will give some more details in the revised version.

P3L37: Please consider to address also the assumptions of mixing models and the corresponding violation. This aspect may also help to justify Bayesian mixing approaches you describe well.

Some limitations of the different mixing approaches were already discussed in the original Section 5 (Limitations and Opportunities). We will also include a short discussion in the Introduction section.

P4L3: Please add here that the case studies you report later refer to mountainous (high-elevation) catchments

Thanks for pointing this out. We will mention the Vallon de Nant case study here in the revised manuscript.

P5L17: Please clarify the time-integrated processes you refer to

This refers to a comment also made by reviewer 1 about the model formulation and the time step change. The model formulation will be clarified in the revised manuscript.

P8L14-15: How is the sine function defined? How do you derive the amplitude and time lag? Table 4: How do you justify the values of precipitation isotopic lapse rate? Can you provide field data or further references on experimental data?

The precipitation isotopic ratio time series was assumed to be sampled from a sinusoidal distribution, which is in-line with previous studies in Switzerland (Allen et al., 2018). The mean value and amplitude of the precipitation isotopic ratio closely corresponds with values obtained with the field data in Vallon de Nant. As already pointed out by the Executive editor, we will provide the used database of precipitation isotopic data through zenodo and include the link in the revised manuscript.

We used an offset value of (-π/2) in the sine function of the precipitation isotopic ratio (mentioned in Table 4). This corresponds to the commonly obtained seasonal variation of the precipitation isotopic ratio in Switzerland, where the ratio is lower (or more negative) during the winters and higher (or less negative) during the summers. Such a seasonal trend has also been reported previously (Allen et al., 2018; Beria et al., 2018).

P8L22: Please add some references to justify the temperature boundaries you have chosen? Other common boundaries are -1 to 3_C or-1.5 to -1.5, for example.

We will include the relevant references in the revised manuscript.

P10L39: Please clarify, to which small glaciers do these area proportions of 4.4 % and 10.1 % belong to?

The line mentioned by the reviewer reads: "*Despite the relatively low elevation, there is a small glacier with an extended moraine that covers 4.4% and 10.1% of the catchment area*"

Vallon de Nant has a small glacier on its South-western tip which covers around 4.4% of the catchment area, below which an extended moraine occupies 10.1% of the catchment area. We will clarify this in the revised manuscript.

Table 1: What do you mean by top snowpack layer?

Top snowpack layer refers to the top most layer of the snowpack, which we use as a proxy for recent snowfall as we do not sample snowfall.

P12L34- 35: Please rephrase and clarify here. The catchment average isotopic ratio does not simply depend on the elevation gradient, which may hold better for precipitation variabilities. But on the presence of the snowpack and where the snowpack is isothermal so that melting could start.

We agree with the reviewer that the spatial variability in precipitation isotopes is not only a function of elevation, but also depends on the source of moisture origin, cloud condensation temperature and snow metamorphism effects. The case study of lapse rate effect is a mere demonstration that HydroMix allows inference of additional parameters that can account for various physical processes that may modify precipitation isotopic ratio. We will clarify this in the revised manuscript.

With regards to the spatial variability in snowpacks, we use a spatially lumped hydrological model and do not explicitly simulate the spatial variability in snowpack isotopic ratios. We acknowledge that snowpacks at lower elevations melt first and they have isotopic ratios which are different from higher elevation snowpacks. We do not account for this spatial heterogeneity as this lies beyond the scope of this paper. However, we will mention this as a limitation in the revised manuscript.

P15L4-8: Please consider moving this paragraph to section 3.2

The reviewer refers to the following text:
"The parameters used to generate daily precipitation, air temperature and precipitation isotopic ratios for a run time of 100 years are shown in Table 4. The static volume of groundwater that does not interact directly with the stream, GC is set to 1000 mm. Figure 4 shows the resulting variation in the isotopic ratio of groundwater over the entire 100 year period, showing the system achieves a steady state condition after ~15 years of simulation"

Thank you for the suggestion. We will move this section to section 3.2 in the revised manuscript.

Figure 6: How did you define the number of days on which rainfall, snowfall and snowmelt occurred?

In order to simulate precipitation, time between two successive precipitation events is modelled as a Poisson process, with the number of yearly precipitation events specified as 30. The snow accumulation and the degree-day snowmelt model are then used to compute the number of snowfall days and of snowmelt events. This will be made clear in the revised version.

P17L17, P20L3-59: Please rephrase

P17L17 reads:
"In this study, we have used a relatively simple normalization based weighting function (Eq. (24)). Testing other weighting functions which have been proposed in the past (Vasdekis et al., 2014) is certainly possible, and is left for future research."

The last sentence part is indeed not well formulated. We will rephrase it in the revised manuscript

Figure 9: Please enlarge axis tick labels. Why did you use different x axis scales?

We will use larger tick labels in the revised manuscript.

The x axis of the top subplot of Figure 9 shows the lapse rate in ^2H whereas the bottom subplot shows the lapse rate in ^{18}O. As the isotopic ratios in ^2H and ^{18}O are different, the lapse rates are also different, which is why the two subplots have different x-axis scales.

P22L7: What is small sampling number in your opinion?

Small sampling sizes can be anywhere less than 20-30 samples. We will mention this in the revised version.

P21L31: I do not see how sediment dynamics fit in here. Sediment dynamics may be coupled with specific runoff components or also decoupled.

Mixing models are frequently used in sediment fingerprinting to quantify the sediment contribution from different parts of a catchment. Blake et al., (2018) is a recent example where a Bayesian mixing model was used to understand the spatial origin of river sediments. This will be made clearer in the revised version.

Typing errors: P1L29: Please change to “that effectively weight”
P21L17: Rephrase to “tracer data being available”

Thanks, will be changed.

Reference:

Allen, S. T., Kirchner, J. W., & Goldsmith, G. R. (2018). Predicting spatial patterns in precipitation isotope (δ2H and δ18O) seasonality using sinusoidal isoscapes. *Geophysical Research Letters*, *45*(10), 4859–4868. https://doi.org/10.1029/2018GL077458

Beria, H., Larsen, J. R., Ceperley, N. C., Michelon, A., Vennemann, T., & Schaefli, B. (2018). Understanding snow hydrological processes through the lens of stable water isotopes. *Wiley Interdisciplinary Reviews: Water*, *5*(6), e1311. https://doi.org/10.1002/wat2.1311

Blake, W. H., Boeckx, P., Stock, B. C., Smith, H. G., Bodé, S., Upadhayay, H. R., et al. (2018). A deconvolutional Bayesian mixing model approach for river basin sediment source apportionment. *Scientific Reports*, *8*(1), 13073. https://doi.org/10.1038/s41598-018-30905-9

https://www.20min.ch/schweiz/news/story/Schlammlawine-begraebt-Strasse-unter-sich-30186734. (2019). Retrieved from https://www.20min.ch/schweiz/news/story/Schlammlawine-begraebt-Strasse-unter-sich-30186734