Author response to Referee #1 comments

Manuscript hess-2017-106, "Using isotopes to constrain water flux and age estimates in snow-influenced catchments using the STARR (Spatially distributed Tracer-Aided Rainfall-Runoff) model" by Ala-aho, P. et al.

We are grateful for the comments by anonymous referee #1 on our manuscript and referee's constructive suggestions for improvement in revision. We have now carefully addressed the comments suggest corrections, clarifications and deeper discussion requested. We hereby provide our point by point responses how the comments by referee #1 will be addressed in the revised manuscript.

Yours sincerely,

Pertti Ala-aho

Referee #1 comments

The paper presented a new study on specifically the stream water oxygen isotope by spatially distributed STARR model coupling with the snow evaporation fractionation and snow melting fractionation at three northern northern catchments with different annual precipitation and winter snow accumulation. The improved simulation work captured pretty well the observed seasonal stream water oxygen isotope variations at two of the catchments. The study also demonstrated the importance of snow evaporation and melting in the adjusting the temporal variations of steam water isotope. This work has the potential of wide applications in isotope hydrology in other catchments with significant snowpack in winter season.

We thank Referee #1 for her/his support of our work

1. A comparison between local precipitation and river water 18O may help to see the the impact of precipitaiton on river water 18O. And I wonder if we can see the lag between precipitaion 18O and river water 18O, and this lage is related to the age of water?

Good suggestion; prior work at the sites has used the phase lag in precipitation and stream water to estimate water transit times through convolution integral techniques. Work for Krycklan by Peralta-Tapia et al. (2016) was readily referenced in the discussion, a reference for Bruntland Burn by Hrachowitz et al. (2010) will be added.

2. Isotope fractionation in the surface evapotranspiration should be introduced in the paper, even it is included in the previous publications, since it is another process significantly affect the stream water isotope.

We agree with the comment that the missing evaporation fractionation processes can deteriorate the model performance in the summer months, which is most evident in the Bruntland Burn timeseries, as discussed in the manuscript (P14L7). We will expand this discussion by:

"Smith et al (2016) have successfully included the soil evaporative fractionation in their spatially distributed tracer-aided simulations, and similar approaches could be adopted to the STARR model to improve model realism during summer periods with elevated evaporation."

3. The d-excess in water may more sensitive to evaporation, and therefore, provide more unequivical proof in the water cycle in snow evaporation and melting.

Thank you for the good suggestion. Parsimonious conceptualisation of our snow isotope simulations does not differentiate between equilibrium and kinetic fractionation processes, therefore we cannot readily simulate d-excess. Furthermore, during winter when air temperature is low and relative humidity high, the equilibrium fractionation process can be expected to dominate over kinetic fractionation, which would imply minimal d-excess signal. We propose to add the following explanation and discussion in the manuscript:

"In our parsimonious isotope simulation approach we did not differentiate between kinetic and equilibrium fractionation in snow sublimation, and we only simulated only the $\delta^{18}O$ isotope because of better data availability in all sites. This simplification prevented us from simulating additional isotopic indices for evaporation, such as the d-excess (Dansgaard 1964), that would indicate deviations from the meteoric water caused by kinetic fractionation. In typical winter conditions with low air temperature and high relative humidity, we would expect the equilibrium fractionation to dominate over kinetic fractionation (Gat and Gonfiantini 1981), therefore making the differentiation between the two processes of lesser importance."

4. The inconsistence between the simulated stream water 18O and observed stream water18O probablly hints the impac of underground water at Krycklan. With decreasing trend in both river discharge and stream water 18O, there is probably a increasing ratio of deep underground water with lower water 18O. This agree with the increasing water age. However, the underground water 18O data is necessary for further discussion.

This is a perceptive insight to the modelling results which was not discussed in the initial manuscript. We suggest to add the following discussion on groundwater contribution on stream isotopes and water age at the Krycklan site, and discuss the wider implications of the difficulties in defining initial conditions for the groundwater storage in the MC calibration of conceptual models:

"Another parameterisation issue in our work rises from specifying initial conditions for the groundwater storage for the Monte-Carlo runs. If the initial GW storage is not in "balance" with the magnitude of the outflow coefficient (kG), which is randomly varied in the calibration, it can lead to GW storage reduction or increase over time. Our simulations at the Krycklan site show symptoms of such imbalances between the kG parameter and the initial GW storage, as the variability and median in the simulated stream water age declines over the ten year period (Fig. 5). The non-stationarity in age suggest that the groundwater influence (GW storage has older water) reduces over time. In further analysis (data not show) in most of the behavioural simulations the total GW storage in Krycklan in fact grows smaller over time. A longer spin-up period for the Krycklan simulations would alleviate the issue, with the burden of increased runtimes. In addition, even though our simulations for streamflow during winter is well captured (Fig. 5), the isotope composition in some winters does not shift adequately towards more depleted values (isotopes in deep groundwater between -13 and -14 ‰ (Peralta-Tapia et al. 2015)), suggesting a too low groundwater contribution. The misfit in winter isotopes suggests that the model has problems in switching from soil source to a more depleted groundwater source during winter. It should be pointed out, that such analysis and insights are only possible because of the ability of the STARR model to simulate stable water isotopes and water ages – these issues would not become apparent if using only streamflow hydrograph to evaluate the model performance."

5. From Figure 11 it is difficult to to see how different parametering can affect the simulated results.

We assume the referee is here referring to Fig. 10. This is a fair point, as the only the sensitivity of the parameter is plotted, not the range in which the parameters in the behavioural parameters calibrate in the parameter space. The purpose of the figure is to identify the most sensitive parameters and discuss why sensitivities differ between sites, and for this purpose the parameter values are in our opinion of lesser importance.

There are minor questions:

6. In all the text, please include the full name for the term while they are first mentioned, e.g. SWE (snow water equivalen?), DCEW, MET, SNOTEL,

Full names for abbreviations on their first occurrence will be added

7. There are dummy text in Line 25-27, Page 3ïijŽ "Suspendisse a elit ut leo pharetra cursus sed quis diam. Nullam dapibus, ante vitae congue egestas, sem ex semper orci, vel sodales sapien nibh sed lectus. Etiam vehicula lectus quis orci ultricies dapibus. In sit amet lorem egestas, pretium sem sed, tempus lorem."

Apologies, this will be removed

8. Page 11ïijˇN Line 29, change from "different to" to "different from".

Will be changed

9. What is passive storeage?

We agree that the passive storage concept was not properly explained given its importance to the model. We propose to add the following clarification:

"Like its predecessors, the STARR model utilises a concept of passive storage in isotopic mixing in the soil (Birkel et al. 2015). Passive storage parameterises the water stored in the soil that does not relate to changes in discharge, but increases the total mixing volume of isotopes."

List of suggested additional references:

Dansgaard, W.: Stable isotopes in precipitation, Tellus, 16, 436-468, 1964.

Gat, J. R. and Gonfiantini, R.: Stable isotope hydrology. Deuterium and oxygen-18 in the water cycle, IAEA, Vienna, 1981.

Peralta-Tapia, A., Sponseller, R. A., Ågren, A., Tetzlaff, D., Soulsby, C. and Laudon, H.: Scale-dependent groundwater contributions influence patterns of winter baseflow stream chemistry in boreal catchments, Biogeosciences, 120, 847-858, 2015.