Reply to Reviewer #2

The paper introduces a method to combine snow-course data with precipitation gauges to improve the water balance modelling in complex terrain. The mapper is very well written and the results are well presented. Please find minor comments listed below.

> We thanks Reviewer #2 for their constructive comments. We confirm that all requested revisions are feasible and we will work in this direction as soon as the interactive discussion will be finalized.

Title: I would suggest changing the title as I think the snow course data are used to get more information on lapse rates of precipitation affected by a lot of different processes at the mountain and the ridge scale rather than only orographic enhancement.

> Agreed. The new title will be *"Learning about precipitation **lapse rates** from snow-course data improves water-balance modeling*

Introduction: the spatial variability of precipitation and in particular of snow can be caused by different processes acting at different scales. At mountain to ridge scales orographic enhancement but also the effect of preferential deposition of precipitation can drive the spatial distribution of precipitation and can also have large effects on the snow course measurements as well as snow gauges. I would ask the authors to shortly add a discussion on that to the Introduction part as many previous studies could show that preferential deposition of solid precipitation might have strong effects on snow distribution at high elevations (.e.g Gerber et al., 2017; Gerber et al., 2019).

> Agreed. This concept will be briefly mentioned in the Introduction.

L 156: please provide some details on the typical location of those snow courses - are those similar to snow stations typically located at wind-sheltered locations? Please also provide more details how the transects f such snow courses were selected. This might have an important effect on the representative of such snow courses.

> Snow courses are not snow stations, they are a snow-survey protocol: snow depth is manually measured every 50 to 100 m along transects of several kilometers (see line 146ff in the manuscript). This protocol aims at capturing snow-depth distribution in a way that is more representative of the landscape than stand-alone stations like ultrasonic depth sensors, which instead tend to overestimate both peak SWE and the duration of the snow season (Malek et al., 2017). In the present study, another asset of snow courses is that they captured the orographic gradient in snow depth (and so SWE), as they were collected from the local snow line up to the catchment divide (see Figure 1(b) in the manuscript for some examples).
>
> The term *snow course* is widely used in areas of the world where water-supply forecasting decisively depends on snow, such as the western US (Rice and Bales, 2010) or Finland (Lundberg and Koivusalo, 2003) – also see `https://www.wcc.nrcs.usda.gov/factpub/sect_4a.html`. We will add details above in the manuscript (line 146ff).

Figure 3 – how did you classify between low snow medium snow and high snow. Does low

snow class also include ephemeral snowpack?

Low-, medium-, and high-snow water years were estimated based on percentiles of mean seasonal snow depth at Beauregard (see caption of Figure 3). Any water year with mean seasonal snow depth below the 33° percentile was classified as low-snow water year. Likewise, medium-snow water years had mean seasonal snow depth between the 66° and the 33° percentiles, with high-snow water years having mean seasonal snow depth above the 66° percentile. Ephemeral-snow water years were not attributed to any of these classes *a priori*, since this attribution depends on the magnitude of mean seasonal snow depth. Yet, it is likely that ephemeral-snow water years also have a low mean seasonal snow depth. We will add this in the manuscript.

L 180: there are studies such as Grünewald et al., 2014 or Colladon-Lara et al., 2018 who showed a decrease in snow height at very high elevations - i.e. inverse trend above a certain elevation. Did you also account for that? This might have a strong effect on your factors if using elevations above 3000 m ASL as natural precipitation gauge.

Good point! This decrease in snow height for very high elevations may be the result of various processes, including exhaustion of orographic-precipitation effects (Napoli et al., 2019), an increase in snow sublimation due to strong winds, or more generally interactions between high-elevation steep topography and snow redistribution processes (i.e., wind erosion, avalanches). Because we spatially averaged snow-course data above 3000 m ASL, rather than considering each data point, such multilinear trends in SWE at very high elevations were not explicitly modeled, but only implicitly embedded in our estimates of precipitation lapse rates. While one may consider spatially averaging snow-course data across smaller elevation bands to capture such multilinear patterns, we argue that such small-scale gradients based on snow courses may be counfounded by other processes, such as snow deposition in concave features and snow erosion in convex features. Because our predictions of the water balance dramatically improved even by using only spatially averaged snow-course data above 3000 m ASL, we conclude that multilinearity in lapse rates for very high elevations is likely a second-order effect in mountain hydrology compared to orographic enhancement across elevation gradients of various kilometers. We will add this discussion to the manuscript.

Figure 7: no colour blind-figures are used.

Agreed. We will improve Figure 7.

L 195: as convection driven storms will totally change precipitation distribution I would suggest only using peak-season SWE measurements for solid precipitation

This was indeed the intended meaning of that sentence. The implicit hypothesis here was that liquid precipitation during winter above 3000 m ASL is negligible. We will clarify that passage.

Could you elaborate on measurement accuracy of precipitation gauges in case of solid precipitation (i.e. wind drift on falling snow flakes)

The evaluation of measurement accuracy of precipitation gauges involved comparing precipitation totals at snow-depth sensor locations with concurrent snow-depth increases. So the stated accuracy (see lines 125ff in the manuscript) is actually more representative of solid than liquid precipitation. We will clarify this in the manuscript.

L 229: I not fully understand why at this point the elevation threshold of 2700 m is used

2700 m ASL represents the "precipitation-gauge line" in this region, that is, the elevation above which no precipitation gauge is located (see the Introdution and Figure 1(c)). We will clarify this at line 229ff.

L 306: in favour L 475: please list also preferential deposition of snowfall which might have an effect on your measurements

Agreed.

References

Lundberg, A., Koivusalo, H., 2003. Estimating winter evaporation in boreal forests with operational snow course data. Hydrological Processes 17, 1479–1493. doi:`10.1002/hyp.1179`.

Malek, S.A., Avanzi, F., Brun-Laguna, K., Maurer, T., Oroza, C.A., Hartsough, P.C., Watteyne, T., Glaser, S.D., 2017. Real-Time Alpine Measurement System Using Wireless Sensor Networks. Sensors 17. doi:`10.3390/s17112583`.

Napoli, A., Crespi, A., Ragone, F., Maugeri, M., Pasquero, C., 2019. Variability of orographic enhancement of precipitation in the alpine region. Scientific reports 9, 1–8. doi:`10.1038/s41598-019-49974-5`.

Rice, R., Bales, R.C., 2010. Embedded-sensor network design for snow cover measurements around snow pillow and snow course sites in the Sierra Nevada of California. Water Resources Research 46, W03537.