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Hydrology and Earth System Sciences
Discussions

Interactive comment on "Seasonal partitioning of precipitation between streamflow and evapotranspiration, inferred from end-member splitting analysis" *by* James W. Kirchner and Scott T. Allen

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We thank Dr. Ala-aho for his thoughtful review of our manuscript.

The main issue that Dr. Ala-aho identifies is the possibility that isotopic fractionation during snowpack sublimation could bias our results (or indeed any isotopic results that rely on sampling of snowfall rather than snowmelt). We agree that snowpack fractionation is a potential confounding factor, particularly where a significant fraction of snowfall is intercepted by the canopy and subsequently fractionates. In the revised manuscript we will mention this possibility. In the case of the Hubbard Brook analysis, however, we expect that canopy interception and snowpack fractionation are much smaller than the 15-25 per mil suggested by Dr. Ala-aho, for three reasons.

First, interception and sublimation losses at Wastershed 3 are likely to be small. Penn et al. (2012) found significant interception at Hubbard Brook in conifer forests at higher altitudes on north-facing slopes, but Watershed 3 is a deciduous forest at lower altitudes on a south-facing slope. For the south-facing slopes at Hubbard Brook, which are dominated by deciduous trees, Penn et al. found no statistically significant difference in snowpack accumulation between forest plots and adjacent clearings (mean difference 1.41 cm, standard error 1.4 cm, p=0.3). This is less than 10 percent of peak SWE and only about 3 percent of average winter precipitation.

Second, most of the studies that have been used to quantify canopy interception and sublimation losses, such as those reviewed by Varhola et al. (2010), involved conifer forests and therefore much higher rates of canopy interception than one would expect from the bare branches of a wintertime deciduous forest like that of Watershed 3 at Hubbard Brook. Most of these sites are also in the arid west of North America, where one would expect greater sublimation losses than in the more humid northeast, where Hubbard Brook is situated.

Third, the isotope data plotted in Fig. 2b show no evidence of evaporative fractionation; indeed, if anything the streamwater plots slightly above the local meteoric water line rather than below, as one would expect if there were significant moisture loss due to evaporation or sublimation.

Below we respond (in bold type) to Dr. Ala-aho's specific comments (in normal type).

P3 L60: if by "this example" you refer to the proof-of-concept analysis in the paper, to be precise you study where winter season precipitation, not snowmelt, ends up.

Correct. We will change "snowmelt" to "precipitation".

P4 EQ7: Q_a*n_A->M: M should be X?

Nice catch! We will fix this.

P12 L342-P13 L371: not sure how interesting this analysis is, in context of the message you put forward in the paper. I suggest to consider if this analysis is crucial to your work - leaving it out would further streamline the paper.

We did consider this. Although it is not a main point, we do think that in some contexts it may be helpful to compare end-member mixing and end-member splitting results to a "null model" in which no source, or output, is preferred over another. Thus we have provided the mathematical background for such null model comparisons.

L373: I would not think it is striking that large part of the snowy season precipitation leaves the catchment during rainy season because of snowmelt in April and May happens in the rainy season, as you discuss later on in the chapter.

We actually discuss this two sentences later. Of course inter-seasonal transfer from the snowy season to the rainy season via snowpack accumulation and melt is not particularly surprising, but the magnitude is still worth knowing. And given that 18% (+/-3%) of summer precipitation is carried over to become winter streamflow (and this must be groundwater, since there is no snowpack storage of summer rainfall), it is likely that a substantial amount of the carryover of winter precipitation also takes place via groundwater storage, rather than snowpack. This illustrates the potential of our approach: without tracer data, and the right tools to interpret them, inter-seasonal carryover in groundwater storage would remain invisible.

P13 L378 do you imply that _30% of winter precipitation is lost to evapora-

tion/sublimation over the snow season? According Penn et al. (2012) seems like snow interception sublimation can account for 10-30% of snowfall in the region (not accounting for sublimation from ground snow), and numbers alike are typically reported (Varhola et al 2010). Relating this with your ET composed of snowy season precipitation 18 +-18% in Fig. 4, bulk of winter-sourced ET would be from snow sublimation (sublimation by definition sourced from winter precipitation), which leaves little to none winter precipitation for summer ET. This does not seem intuitive, referring to your very nice Allen et al. (2019) paper. From the water balance equation (13) sublimation should be embedded in the total ET, but to me the numbers don't add up. Can you please clarify how your analysis takes snow sublimation into account?

Your numbers don't add up because you are assuming that any winter precipitation that does not appear in the snowpack must have fallen as snow and must have been lost to evaporation and sublimation, and those assumptions are not correct at Hubbard Brook. At Hubbard Brook, there is significant rainfall and snowmelt during winter, so one cannot compare snowpack accumulation to winter precipitation and attribute the difference to evaporation or sublimation. Trying to estimate evaporation or sublimation by mass balance is made even more difficult by inter-seasonal groundwater storage. That is why end-member splitting only uses long-term mass balances, and only infers seasonal contributions to total annual ET (not ET losses in individual seasons). The end-member splitting result is 18+/-18 percent for total ET losses, at any time of the year, that originate as winter precipitation.

Penn et al.'s data for south-facing, deciduous forests at Hubbard Brook (which would apply to Watershed 3) show only 1.4+/-1.4 cm of evaporation or sublimation from the snowpack (Penn et al., 2012, p. 2530). This is statistically indistinguishable from zero, and is only 7% of the average SWE (19 cm) in south-facing forest plots on Penn et al.'s March 4th sampling date. Furthermore, 1.4 cm of evaporation or sublimation would be only 3% of the long-term average

annual precipitation that falls during the snowy period from December through March (40 cm), and only about 1% of total annual precipitation. Of the 33 studies summarized by Varhola et al. (2010), all but two examined snow accumulation in conifer forests. Thus Varhola et al.'s results greatly exaggerate the degree of canopy interception and sublimation that should be expected in deciduous forests like Watershed 3 at Hubbard Brook.

Fig.6: typo in the caption, Figure x6

Sorry! We'll fix it.

L548: do you mean "precipitation", instead of "discharge"?

Yes we do, thanks! We'll fix that.

P20L596: "we" instead of "I"?

Another nice catch! We'll fix it.

P26 L770-779: I was surprised by the discrepancy between your analysis the Allen et al (2019) results, even though the environment is different. Looking forward to the end-member splitting analysis with xylem and soil water data.

We are intrigued by this too. We do not necessarily expect similar results from Hubbard Brook and the Swiss sites, since (as we wrote) the potential for soil water storage is quite different in the two settings.