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Discussions

Interactive comment on "Time-variability of the fraction of young water in a small headwater catchment" *by* Michael P. Stockinger et al.

Anonymous Referee #2

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This manuscript investigates the temporal variability of the young water fractions (Fyw) based on a 4.5-year time series of δ18O in precipitation and streamwater in the German Weiherbach catchment. For this, the authors fit sine curves to the entire 4.5-year data set to estimate the long-term average Fyw. Then, they cut out 189 individual 1-year δ18O time series from the 4.5-year data set (i.e., shifting each 1-year period by 1 week) and fit individual sine curves to these 1-year periods to estimate 189 Fyw-values. The goodness-of-fit of the sine curves to the δ18O data was quantified through adjusted R2 values. Three hypotheses were tested: "(1) Fyw estimates do not change over time (time-invariance) (2) Short-term changes in the start of a tracer sampling campaign do not influence the Fyw estimate (sampling-invariance) (3) Fyw estimates are similar for a given calendar month of different years (seasonal-invariance)" (P3L13-15). By

applying a Fyw-threshold value of 2%, the authors reject all hypotheses and conclude that Fyw-values based on 1-year isotope data sets can be highly variable over time. This time-variably of Fyw hampers catchment-comparison studies that utilize tracer data of different time series lengths or time periods.

I find the critical evaluation of new metrics (young water fraction Fyw) interesting and useful as this allows to better plan sampling campaigns or to use existing data sets more efficiently for a robust estimation of Fyw. In that regard, I consider the testing of hypothesis 2 the most useful scientific contribution of this study (Sect. 3.4) because it quantifies how much a 4-weeks delay can change the Fyw-values that are estimated from 1-year data sets. Unfortunately, these changes in Fyw do not correlate with any of the tested hydro-meteorological variables (Sect. 4.4) so that the authors cannot provide any suggestions about the optimal sampling strategy.

Besides the testing of hypothesis 2, I find it difficult to identify a clear motivation and the novel scientific contribution of this study. The fact that Fyw responds to changes in precipitation, discharge and/or catchment wetness has already been established (e.g., Kirchner, 2016b; Lutz et al., 2018; von Freyberg et al., 2018; Wilusz et al., 2017), and thus it can be expected that Fyw changes over time in a catchment with a variable hydro-climatic regime such as the Weiherbach. Thus, the temporal changes in Fyw that have been identified in the present study are likely related to the hydro-climatic conditions at the site, however, the scientific analysis of these relationships often remains too superficial (which is surprising, given that the Weiherbach catchment is an intensively-studied research site). As such, this study does not teach us something new about the catchment but rather shows that different tracer time series provide different young water fractions. Although it is interesting to quantify these temporal differences in Fyw, it remains to be tested how these findings for the 0.385km2 Weiherbach catchment are transferable to other landscapes and climates.

Major comments:

1. One of my largest concern is that the presented analysis did not provide any information on the uncertainties of the individual Fyw estimates. Only the adjusted R2 values of the sine fits are presented. Previous studies that calculated young water fractions for several other catchment reported uncertainties in Fyw between 1% and 41% (e.g., Jasechko et al., 2016; Stockinger et al., 2016; von Freyberg et al., 2018). Thus, it should be tested whether the individual young water fractions that were calculated from the 1-year time series are indeed statistically significantly different from each other when their uncertainties are considered. Looking at the low adjusted R2 values for the July 2014-October 2015 period (e.g. Figure 4), I would expect the uncertainties of the 1-year Fyw values to be rather large. However, instead of analyzing the uncertainties in Fyw, the authors mainly focus on the time-variability of the individual 1-year Fyw-values and conclude rather boldly (P12L22) "The obtained Fyw could be a potential outlier, a larger value or part of the Fyw baseline". I would argue that the uncertainty in Fyw (e.g., expressed as standard error) would allow us to objectively judge whether we can believe our Fyw estimates or not. Such an analysis is, however, missing here. In fact, knowing the uncertainties of the individual 1-year Fyw values would allow a more informative analysis of how the Fyw-uncertainty (not Fyw itself) is controlled by hydro-climatic conditions. Such an analysis might provide concrete guidelines for planning targeted sampling campaigns to robustly estimate Fyw.

2. Furthermore, given that the uncertainties in Fyw values can potentially be much larger than 2% (as it was shown in the previous studies cited above), to me the 2% threshold seems too low and the authors' justification for that 2% threshold is not convincing.

3. The hydro-meteorological conditions in the Weiherbach catchment were highly variable during the 4.5-year study period. For instance, only the winter 2013/2014 was snow-free in contrast to the other winters when a snowpack built up (Sect. 3.1). In addition, 21% "...of the forest were clear-cut in August/September 2013..." (P3L27), which significantly altered the streamflow regime of the Weiherbach creek (Wiekenkamp et

al., 2016). In Fig. 8d (P24) we find that the runoff coefficients for the Weiherbach catchment ranged between roughly 0.8 and 1.25, suggesting that hydro-climatic conditions at the site varied considerably over time. The authors do not, however, provide any data or figures that present the hydro-climatic conditions during the study period except for the scatter plots in Figure 8, which contrasts 1-year averages of four hydro-climatic metrics with the respective Fyw-values. Despite the highly variable streamflow regime of the catchment and the authors citing another study where flow weighting of the streamwater isotope values resulted in "...significant changes in Fyw..." (P2L4), the authors should more thoroughly investigate how catchment wetness might control Fyw. Why was streamflow-weighting not done here? Why was there no further analysis of potential factors that may control the large variability in 1-year Fyw values, particularly in the period July 2014-October 2015? It seems likely, that individual storm events may have had strong effects on the discharge of young water, so it may be useful to investigate extreme events rather than average behavior.

4. Sect. 3.5 and Figure 9: It is not clear to me how the Fyw values for testing hypothesis 3 (seasonal invariance) were determined. As far as I understood, Fyw-values were calculated for 189 1-year periods (Sect. 2.3). How were month-specific Fyw-values extracted from these annual Fyw-values? Wouldn't each 1-year Fyw-value be affected by the isotope values of all 12 months that comprise this 1-year period? If so, I doubt that the analysis presented in Sect. 3.5 and Figure 9 provides useful information.

5. Part of the analysis presented in "4.2 Fraction of young water" is not valid. First, the authors calculated Fyw from the entire 4.5-year data set (Fyw,4.5=10.8%) and compared this to the average of the 186 1-year Fyw values (9.3%), concluding that both values are similar with regard to their 2% threshold. A second comparison was carried out with Fyw,4.5 and the average of a much smaller number of 1-year Fyw values that neglects the Fyw values from the period July 2014-October 2015 (7.5%). This second comparison should, however, use another Fyw value as a reference based on the same isotope data set (i.e., 4.5 years minus the period July 2014-October 2015)

- otherwise the authors compare apples with oranges.

6. At the very end of the Discussion section the authors state that a previous analysis has been carried out that used a 3-year isotope times series from the Weiherbach catchment. This previous study already showed that the Fyw values differed substantially between three 1-year periods (Stockinger et al., 2017, data in the supplement). In the present study, the authors simply repeat this analysis with a 4.5-year isotope data set from the same site knowing that their hypothesis "(1) Fyw does not deviate more than ±2% from the mean of all Fyw results indicating long-term invariance [. . .]" will likely be rejected. I was surprised to read about a very similar previous study at the very end of the current manuscript and wondered why is it necessary to repeat the analysis when the result (rejection of hypothesis 1) is already known?

Minor comments:

P3L8-9: "However, it remains to be tested how sensitive the Fyw method is towards the timing and the length of the available data." Why does this need to be tested? Can you provide an example of where the length and the timing of the isotope data resulted in different Fyw values? Otherwise, a clear motivation for your analysis is missing.

P4L25: "Because of this on average 43 isotope values were available for precipitation compared to 53 values for streamflow." Does this average refer to a 1-year period? Please clarify. It would also be nice to provide the total number of streamwater and precipitation samples of the entire 4.5-year period.

P5L22-23: I would suggest to move these two sentences to the beginning of the chapter to make clear where the number "189" comes from.

P5L13: 24*365.25 is 8766 not 1/8766

P5L31-32: What do you mean with "the timing of peaks and the individual amplitudes"? Do you refer to the isotope time series or to the fitted sine functions?

P6L3: Here you switch units of Fyw (0.02 and 2%). Also, in the text you express Fyw

in percent, whereas in the figures you use the scale from zero to one. Please be consistent throughout the manuscript.

P7L13-14: Please be more specific about what water isotopes you are talking about, e.g. add δ18O.

P8L28-30: Please provide some metrics for the strength of these correlations (e.g., Pearson correlation coefficients).

P8L29: Was the runoff coefficient calculated with catchment-average precipitation or throughfall? I would suggest to add the runoff coefficients to Fig. 3 since the relationship between Q/P and the sine wave fits to the isotope data are discussed in Sect. 4.1.

P9L16-20: You suddenly present groundwater isotope data without providing information about the source (location, sampling procedure, number of samples etc.) of these data. Please include this information into Sect. 2.2.

P10L13: "The double-peak in precipitation of autumn 2015 was not found in streamflow (Figure 3)." Do you refer to the δ18O in precipitation and streamflow or to the sine fits to the isotope data?

P11L33: "Thus, during the 4.5-years Fyw never fell below the baseline of 5% [. . .]" This statement is incorrect. Figures 6 and 7 clearly show that Fyw fell below 5% on several occasions, such as around June 2014 and September 2016.

P12L5: "The variability in Fyw of this study could not be explained by most meteorological or hydrometric variables". Could a lack of correlation be explained by the large distance (3km) of the meteorological station to the study site? What about median values of the hydro-climatic variables or metrics that describe extreme events?

P12L9: ". . . the different sampling periods of all mentioned studies. . .". This contradicts a previous statement: ". . . Lutz et al. [2018] used the same sampling period for precipitation and streamflow for all 24 investigated catchments." (P11L25).

P12L23: "As the violation of hypothesis 2 did not correlate with any meteorological or hydrometric data . . .". How can a violation correlate with anything? Please clarify.

Figures: The date formats in all figures are confusing. Does 4/10/13 mean 4th October 2013 or 10 April 2013? Also, I would suggest to have each tick mark at the first of the month and to have consistent date axes in all figures.

Figure 4: This figure misses a proper legend (e.g., What does "Mean" stand for?). The unit and numbers of Fyw on the right vertical axes don't match. Do panels a and b share the same legend? Why are the shown time series much shorter than 4.5 years?

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