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Time variability and uncertainty in the fraction of young water in a small headwater catchment

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Supplementary material

Influence of the 2015 European heat wave

Here we show that the 2015 European heat wave interrupted the transmission of isotopic information from precipitation to streamflow. While usually the precipitation signal was transmitted quickly to streamflow, during this period the precipitation signal did not reach the stream and was either kept in the catchment or lost to evapotranspiration. As Fyw relies on the transmission of the signal, the uncertainty increased considerably. Omitting the precipitation isotope values in the critical period from 10th April to 10th July 2015 reduced uncertainty by up to 0.31 (Figure 3 of the main manuscript).

First, the 189 sine waves of precipitation and streamflow mimicked the general behavior of a single sine wave over the complete time series (Figure 3 of the main manuscript, result after omitting summer 2015 which can also be used to illustrate the point). The streamflow sine waves closely resembled the precipitation sine waves, indicating a good transmission of isotope information from precipitation to streamflow. However, summer 2015 sine waves had a distinct double-peak in precipitation with the two peaks separated by four months. This double-peak in precipitation does not appear in streamflow which pointed to an interruption of the signal transmission from precipitation to streamflow. Other data that pointed to this disconnection were the amplitudes of the 189 sine waves of precipitation and streamflow (Figure S2a). Before April 2015 the streamflow amplitudes instantly reacted to the precipitation amplitudes. From this point on, both amplitudes became disconnected from each other. What might first seem like an increase in precipitation amplitudes in August 2015 that was followed several months later by streamflow was actually an increase of streamflow amplitudes followed by precipitation. As an influence of streamflow on precipitation is impossible, this further highlighted the disconnection of precipitation and streamflow during this period. At the very end of the amplitude time series, precipitation and streamflow amplitudes seem to have reestablished their connection.

Based on the hypothesis of a disconnection between precipitation and streamflow we assumed that other variables also showed suspicious behavior during this period. First, the runoff coefficient (Q/P) was usually above 0.70 (Figure S2b). Starting from April 2015, it dropped as far as 0.53. The lowest values during the whole time series occurred in summer 2015 and only recovered in February 2016. A drop in the runoff coefficient indicates that less streamflow was generated per unit of precipitation volume. This indicated that precipitation entered the catchment but did not leave it anymore. Second, while daily data of precipitation amounts, temperature and relative humidity did not show suspicious behavior, they did after we looked at yearly quarters (Figure S2c). Starting with 10th October 2012, we divided the whole time series into three-month segments by summing up precipitation amounts and taking the average of temperature and relative humidity, respectively. April to July 2015 experienced the second lowest precipitation amounts, combined with the highest temperatures for the time period April to July and the lowest relative humidity by far. Combined, all this pointed to especially dry conditions which had the potential to withhold precipitation from becoming streamflow.

Finally, in the Northern Hemisphere the d-excess usually shows larger values during winter months than during summer months [*Steen-Larsen et al*., 2014]. This was the case for the Wüstebach catchment up until approximately May 2015, when a clear seasonal pattern in the d-excess was lost subsequently (Figure S2d).

Altogether, the d-excess and the double-peak in the 189 fitted sine waves pointed to special meteorological conditions during summer 2015. The temperature, precipitation amounts, relative humidity and the runoff coefficient pointed towards dry hydrological conditions that had the potential to withhold precipitation from the runoff generation process. The existence of the 2015 European heat wave proved these special conditions.

We thus postulate that during the 2015 European heat wave most of the summer 2015 isotope signal of precipitation never reached the stream. However, it negatively impacted fitting of the sine waves and significantly influenced Fyw(189) estimates and their respective uncertainties. As Fyw is a method that strongly relies on finding similar signals in streamflow and precipitation, naturally the Fyw and its uncertainty will be negatively impacted by 'false information', i.e., large proportions of isotope signals in precipitation that never reached streamflow. We thus omitted the precipitation isotope values between April to July 2015 (11 out of in total 156 precipitation isotope data; 7% of the measurements; Figure 3a) and significantly improved the uncertainty of Fyw(189) estimates (average improvement: 0.08, maximum improvement: 0.31), while minor increases of the uncertainty were observed as well (average increase: 0.03, maximum increase: 0.13). Naturally also the R^2adj mostly improved (average improvement: 0.03, maximum improvement: 0.07) but occasional deteriorated (average decrease: 0.01, maximum decrease: 0.03). We want to highlight that we did not omit precipitation data that was wrongly measured; to the best of our knowledge all the data was correct. We omitted data that ran contrary to the calculation principle of Fyw which necessitates comparable signals in precipitation and streamflow. If a third of the input signal has no connection to the output signal, this does not add information but uncertainty.

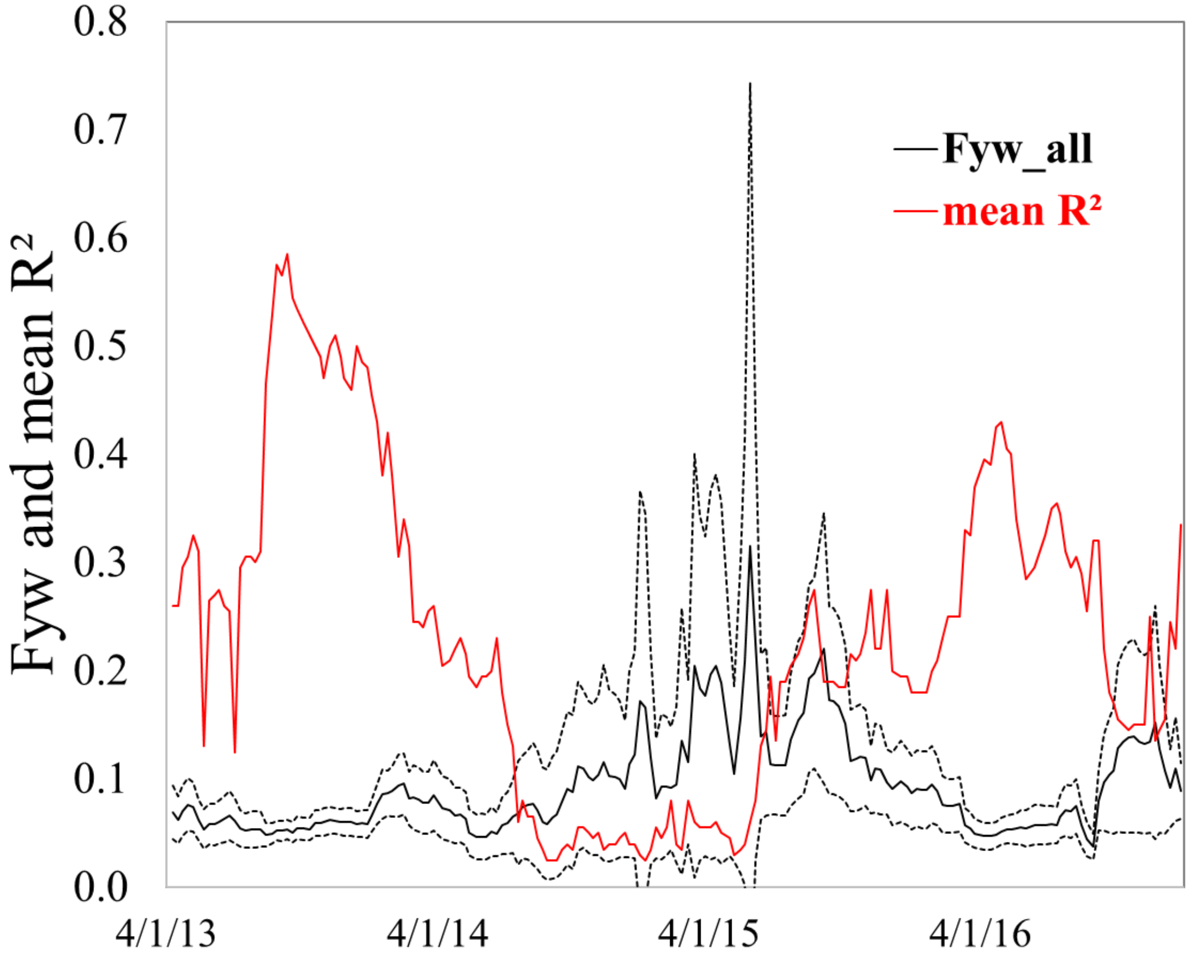

Figure S1. Fyw(189) and its uncertainty using all data (black solid and dashed lines) compared with the average of streamflow and precipitation adjusted R^2 values of the respective sine wave fits (mean R^2).

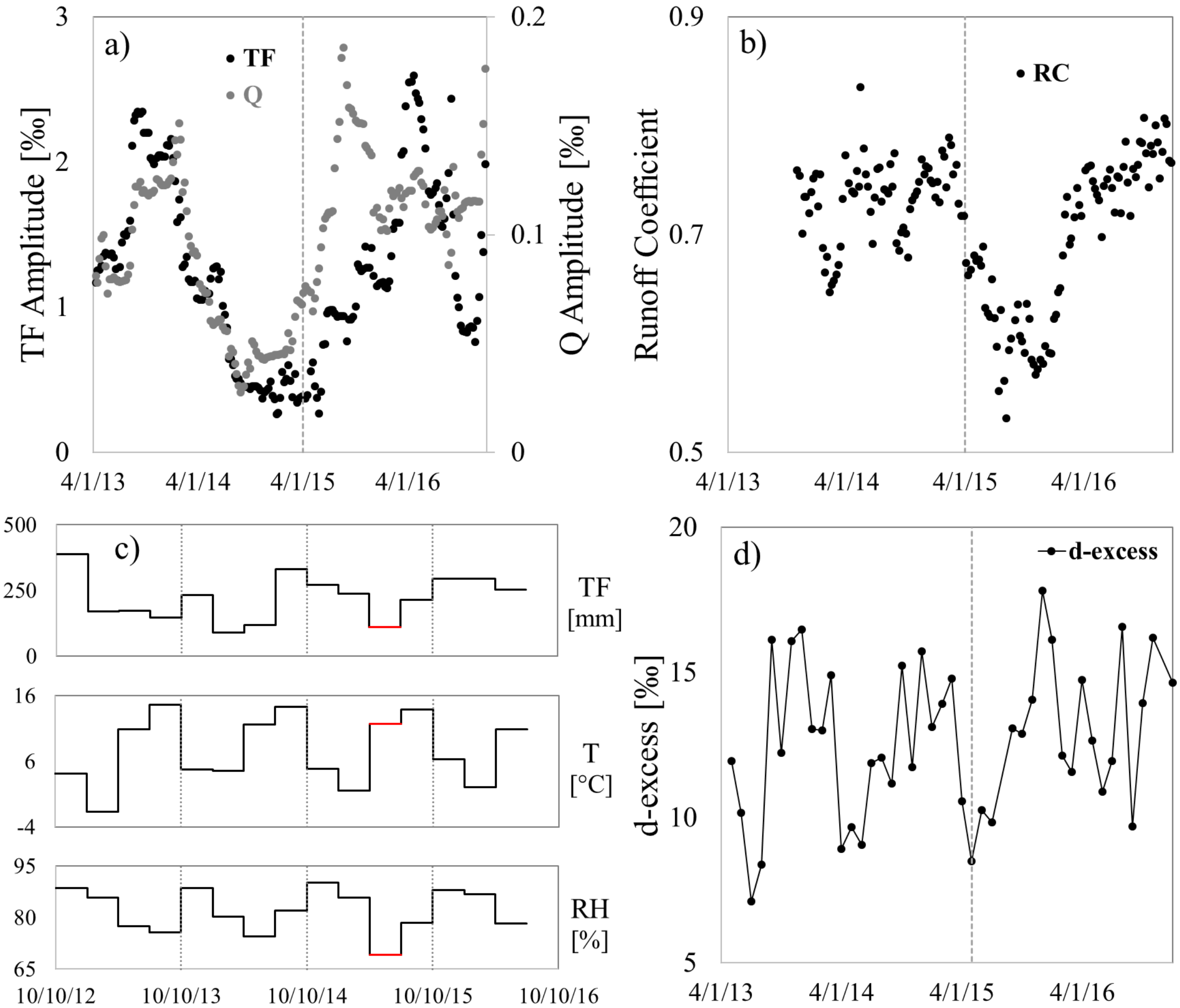

Figure S2. Analysis results of hydrometeorological and isotopic data for the whole time series pointing to special hydrometeorological conditions during summer 2015: (a) amplitudes of throughfall (TF) and runoff (Q) with 1st April 2015 (vertical, dashed line); (b) runoff coefficient (RC) calculated as Q/P with 1st April 2015 (vertical, dashed line); (c) quarterly period values of the sum of throughfall (TF), the average temperature (T) and average relative humidity (RH). Red highlighted quarters represent the period from 10th April to 10th July 2015. For better orientation the vertical grey lines indicate full years; (d) monthly average d-excess with 1st May 2015 (vertical, dashed line).