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Influence of temporal resolution of tracer data on estimates of streamwater transit time distributions

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Motivation

Over the past decades, streamwater transit time distributions (TTDs) and mean transit times (MTTs) of catchments were inferred from mostly weekly stable isotope tracer data of catchment waters. Despite recent studies, the exact effects of using a higher resolution of tracer data to estimate TTDs are not well understood.

In this study we investigated this issue by estimating TTDs of the Erkensruhr catchment (Fig. 3 and 4), Germany, using a stable isotope of water ($\delta^{18}O$) as a tracer.

Tracer Data

Precipitation-$\delta^{18}O$ was measured sub-daily while streamwater-$\delta^{18}O$ was measured daily or 4-hourly, depending on the water stage (Fig. 1).

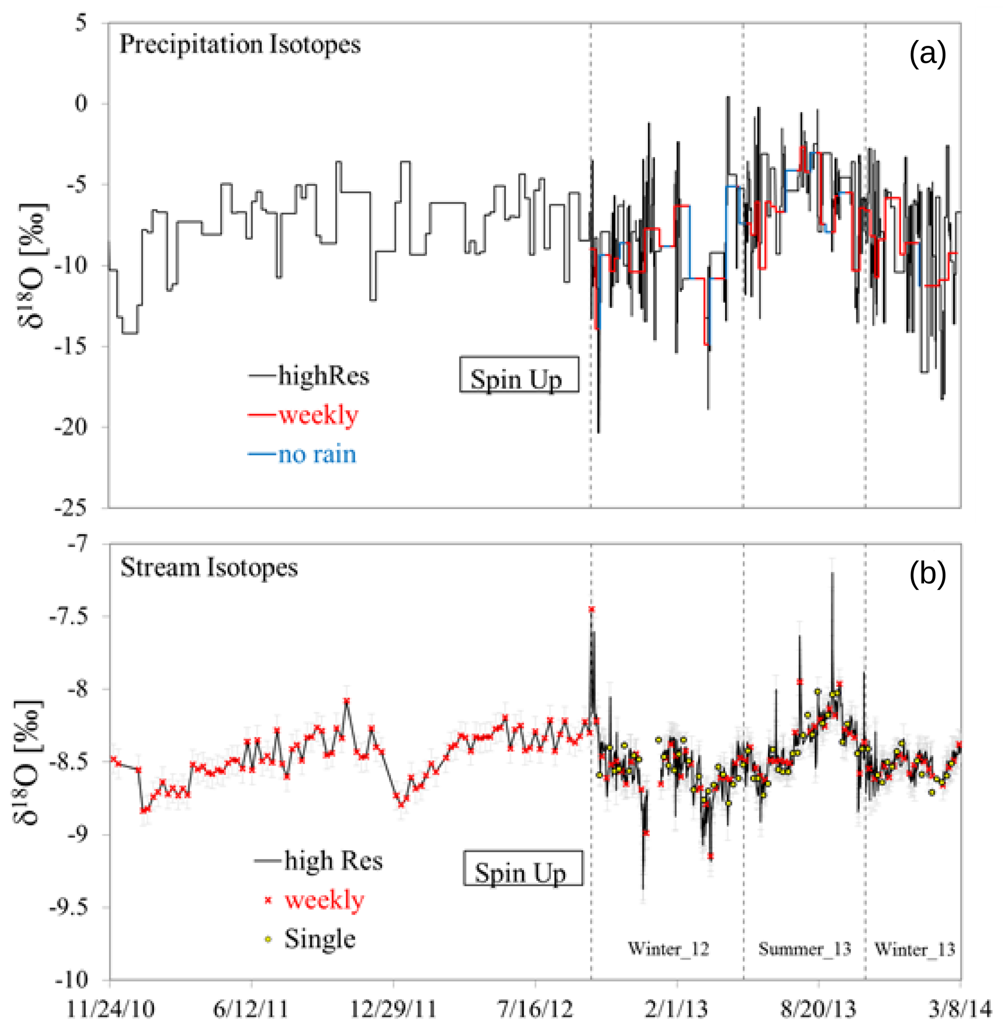

Fig. 1: Measured and calculated data of the Erkensruhr catchment used for TTD estimation: (a) precipitation isotopes and (b) stream isotopes. Isotopes were measured in high resolution (high Res) and calculated for weekly resolution (weekly), with manually taken stream samples for validation (Single, Panel b). Spin up phase (Spin Up) followed by the three modeling periods (grey, dashed lines).

Model

Estimates of TTDs were derived for the two tracer data resolutions with the conceptual model TRANSEP using the convolution integral (Equation 1 and 2):

$$Q(t) = \int_0^t g(\tau)\, p_{\mathrm{eff}}(t-\tau)\, d\tau$$

Equ. 1: By simulating runoff Q(t), the hydrological response of the system g(τ) and effective precipitation (p_{eff}) is calibrated.

$$C(t) = \frac{\int_0^t C_{\mathrm{in}}(t-\tau)\, p_{\mathrm{eff}}(t-\tau)\, h_b(\tau)\, d\tau}{\int_0^t p_{\mathrm{eff}}(t-\tau)\, h_b(\tau)\, d\tau}$$

Equ. 2: TTDs $h_b(\tau)$ are estimated by simulation of observed stable isotopes in streamwater C(t). Used input data is stable isotopes in precipitation $C_{in}(t-\tau)$ and p_{eff} from Equation 1.

Event Modeling

Modeling results of the hydrograph (Fig. 5a) are based on splitting it into periods of uniform hydrological behavior. To delineate "Events", we used the hydrograph gradient in daily and hourly resolution (Fig. 2).

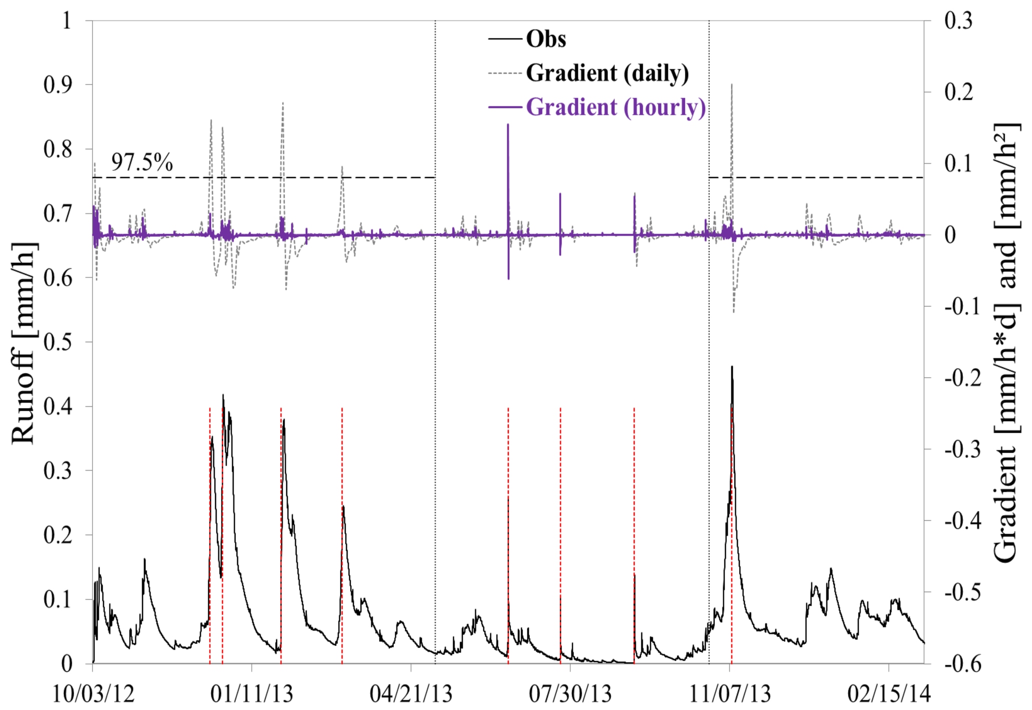

Fig. 2: Identification of runoff events in the hydrograph (Obs) by using the 97.5% confidence interval of daily hydrograph gradient (Gradient (daily)) during the catchment's wet states. For the dry catchment state the hourly hydrograph gradient was used (Gradient (hourly)). Identified events are marked by dashed, red lines.

Project Site

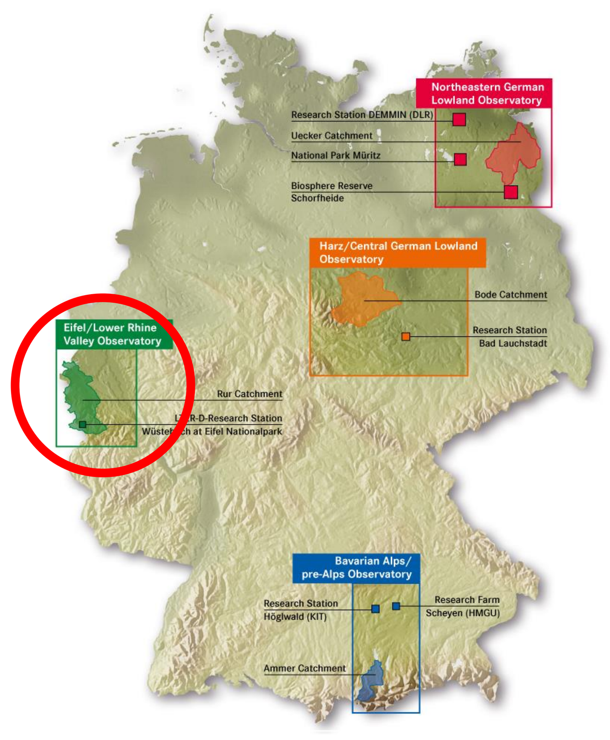

Fig. 3: TERENO (Terrestrial Environmental Observatories) test sites with Eifel/Lower Rhine Valley, where the Erkensruhr is located, highlighted.

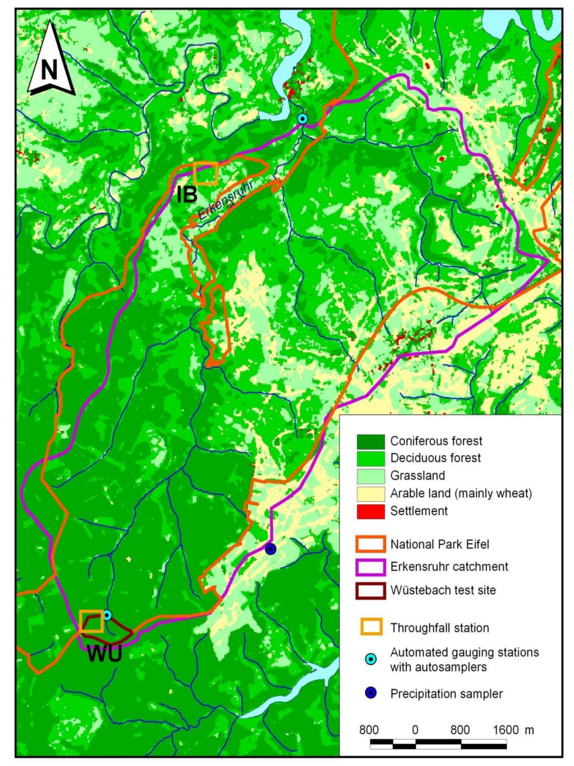

Fig. 4: Erkensruhr catchment (41.7 km²), with Wüstebach (WU) and Im Brand (IB) throughfall sampling locations for input data.

Results

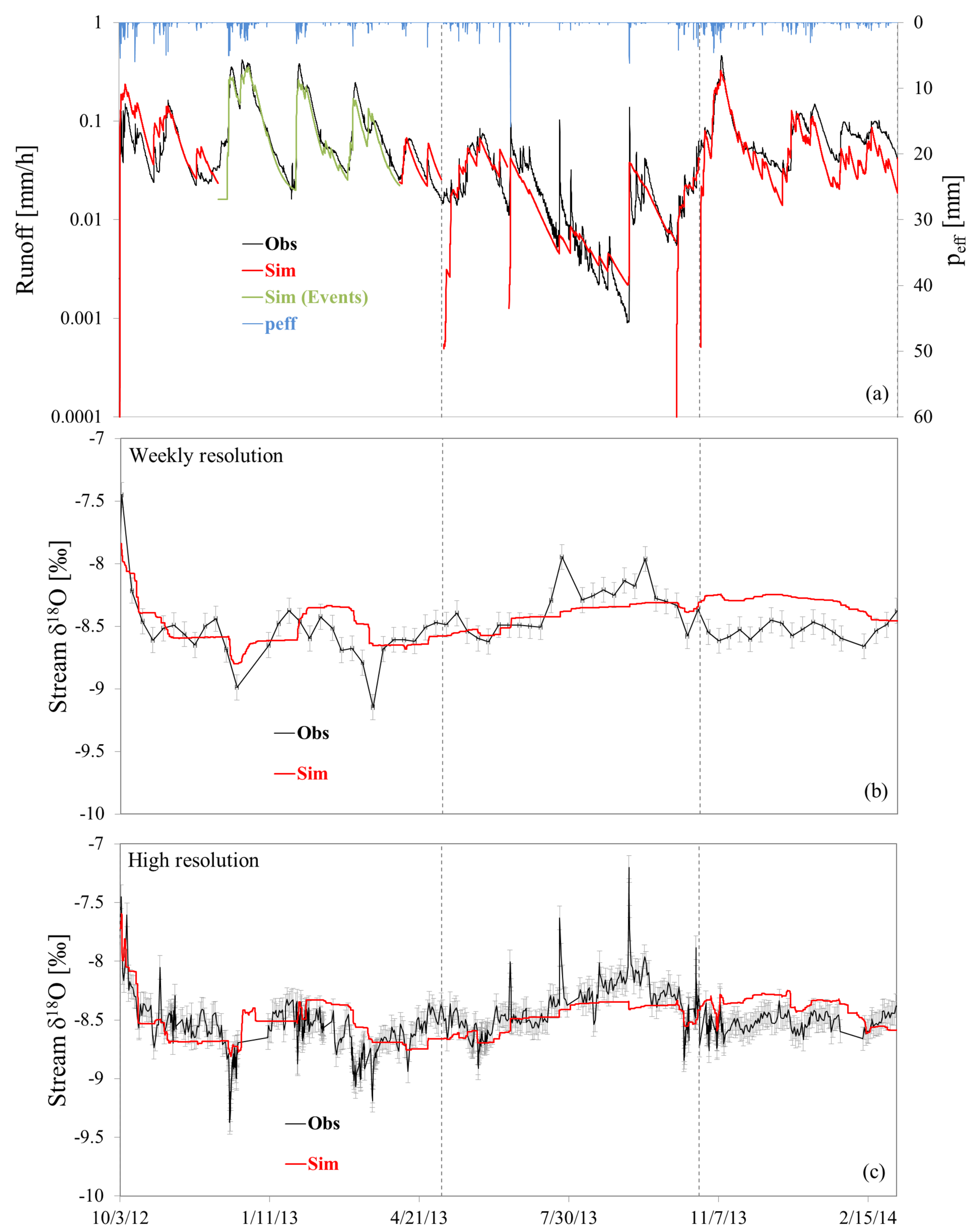

Fig. 5: (a) Simulated runoff (Sim) with event modeling (Sim (Events)) plotted against observed runoff (Obs). Effective precipitation (peff) is shown as blue bars from the top. (b) and (c) Stream isotope modeling results (Sim) plotted against observed stream isotopes (Obs) using weekly and high temporal resolution. Vertical, dashed grey lines in all panels denote the three modeling periods.

TTD Results

Using weekly resolution, the streamwater isotopes were less well modeled compared to high resolution data (NSE = 0.24 compared to 0.34, Fig. 5). The higher resolution data better captured short term dynamics in the isotope signal. The streamwater TTD changed drastically with the higher resolution data (Fig. 6). The MTT changed from 9.5 to 5 years.

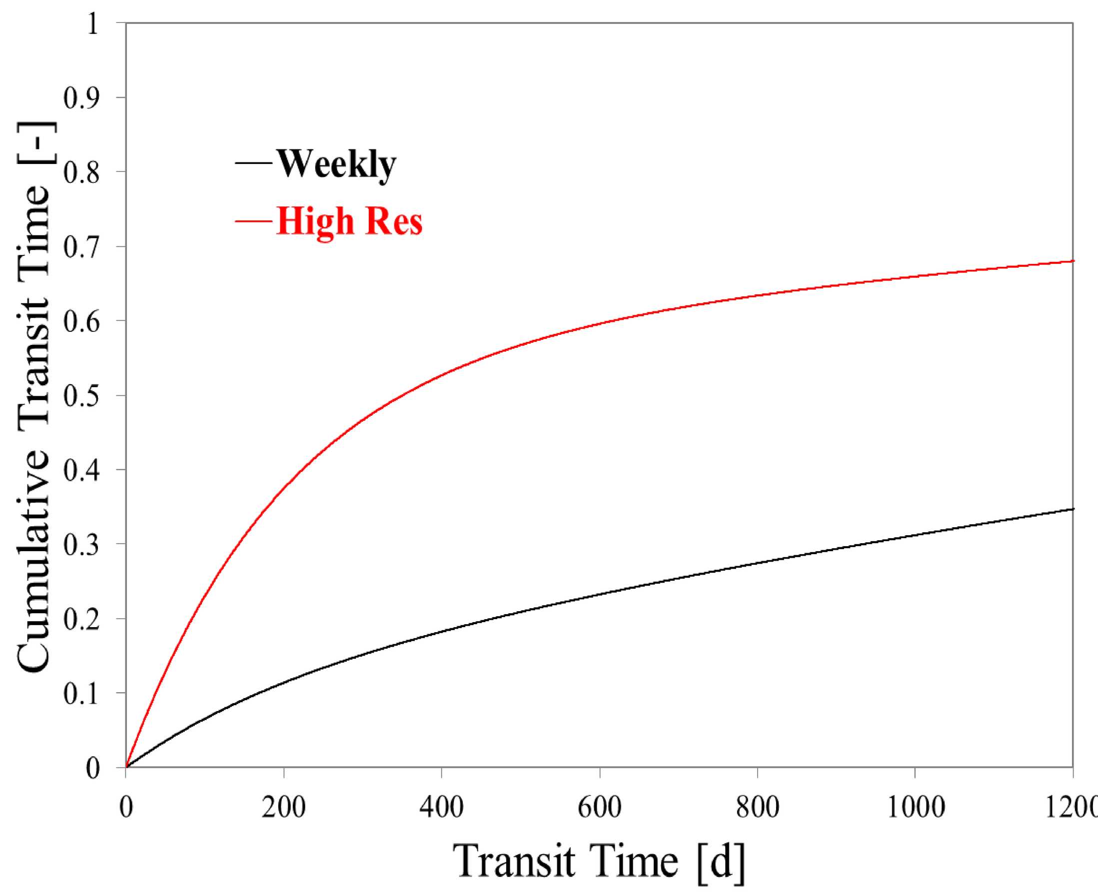

Fig. 6: Transit Time Distributions based on weekly (Weekly) and high (High Res) resolution of precipitation and stream stable isotope data.

Conclusion

In this study we investigated the influence of sampling frequency on estimates of TTDs and MTTs. We used weekly and high resolution data consisting of at least daily stream and sub-daily precipitation isotopes. TTDs and MTTs changed drastically (Fig. 5 and 6).

Our results highlight the importance of sub-weekly isotope data when estimating TTDs. Future research should focus on establishing the high resolution isotope data base needed for improved TTD estimation.

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