# Response to Referee #1

Please find below our responses to Referee #1, with the original comments in black and our responses in blue.

The paper addresses the non-stationary theory of transit time distribution under simplified assumptions, derives analytical solutions for a simplified case, explains them, and presents some conceptual applications. Overall, I believe the paper has merit. The concepts developed, while not entirely novel, have not yet broken through to the broader hydrological community's consciousness. However, the applications require clarification of several aspects to be truly useful. I find value in the paper, but for the sake of reproducibility, I recommend that the authors more clearly specify the conditions under which the simulations were conducted. I recommend minor revisions.

We are grateful to Referee #1 for their time to review our manuscript and for the positive evaluation of our work. We hope that the revisions made in response to Referee #1's specific comments will improve the clarity of the numerical implementation of our theoretical developments.

Detailed Comments:

Page 8 - Equation (17): Is the so-called "mass-normalized breakthrough curve" not simply the discharge at time T+t_i generated by the input at time t_i? Additionally, how can one determine the partition coefficient at any finite time? More practically, how can this be approximated given that the partition is not known in advance? This concern extends to systems with multiple partition coefficients. It would also be valuable to understand the seasonal variation of these coefficients, as I assume ET, for instance, varies seasonally. Furthermore, how was ET determined?

The mass-normalized breakthrough curve (mNBTC) refers to tracer mass, not water fluxes, as described throughout Section 3. It becomes analogous to water only for an ideal tracer. Even in that special case, however, it does not correspond to "the discharge at time $T + t_i$ generated by the input at time $t_i$," but rather to the *fraction of the input* at time $t_i$ that exits via discharge at time $t_i + T$, as explained on line 110 for the water breakthrough curve. To clarify this point, we will modify sentence on line 197 as follows:

"To derive the formula for the mass breakthrough curve in streamflow <u>(i.e. the fraction of the input tracer mass found in streamflow at subsequent lag times),</u> we proceed as we did with the water breakthrough curve […]"

The partitioning coefficient can be retrieved *a posteriori* by integrating the mNBTC over the entire age domain. In practice, this can be done reliably only after long-enough time has passed since the input time, by integrating over a sufficiently long age range until the integral converges to a plateau close to its asymptotic value (*sensu* Rigon et al. (2016) in the case of water partitioning). We have taken great care to ensure this condition is met. More details on the partitioning coefficient are provided in Section 5.4 and in Appendix B. We believe that the case of multiple partitioning coefficients is addressed in the same sections.

We agree that partitioning coefficients likely vary seasonally due to changes in hydrological fluxes and storage. As this partly explains the spread of values shown in Figure 5, we will add a mention to this effect on line 328 as follows:

“The spread of the partitioning coefficients in the box plots is primarily driven by variations in hydrological fluxes and storage, which may include a seasonal component, and is therefore largely influenced by the specific time series used in this study.”

Evapotranspiration was retrieved from Duchemin et al. (2025) which computed fluxes based on a three-compartment model based on Kirchner (2016b, 2019) (see line 238), but we did not include additional methodological details for computing potential ET and ET because these fluxes are not intended to represent any specific real-world system. Potential ET is obtained from the Hargreaves method. ET is then obtained from the three-compartment model, where PET is multiplied by a linear soil-moisture stress function, with parameters derived from a Budyko equilibrium.

Page 9 - Line 233: The information that the models were implemented in Python is not essential. More relevant would be information about code availability and licensing. I consider code availability an important step toward understanding implementation details, which can be technically challenging.

We agree and will remove the mention of the programming language on line 233. Code availability is already noted at the end of this section on line 260. Upon revision, we will replace the current GitHub link with a permanent public repository (e.g., Zenodo) to ensure long-term accessibility, proper versioning, and clear licensing.

Page 9 - Line 239: The authors state they use the Kirchner 2016b model as a foundation. I would therefore expect the overall TTD model to address convolutions of two reservoirs, not just one. Have the authors done this? This point remains unclear and requires clarification. A treatment of this specific subject can be found, for instance, in Rigon and Bancheri (2021). That said, there is nothing inherently wrong with addressing a simpler system.

The Kirchner (2016b) model was used solely to generate realistic input and output fluxes; it was not used to compute transit times. These fluxes were then used to drive a single randomly sampled box model, deliberately avoiding convolutions of two or more reservoirs.

We emphasize that the focus of this study is on randomly sampled systems (which by definition are represented as single-box model), as stated for example on line 5 of the abstract, in Section 2.2 and in Figure 1. We will add a recall in Section 5 in the description of the numerical implementation, immediately after the mention of the Kirchner (2016b, 2019) model on line 239:
“While generated from a multiple-box model, these fluxes were subsequently used to drive a single randomly sampled box model in our study.”

Also, we thank the Referee for pointing out the Rigon and Bancheri (2021). We will include it in the “Water age equations” section in the “Starting points” section.

References:

Duchemin, Q., Zanoni, M. G., Floriancic, M. G., Seybold, H., Obozinski, G., Kirchner, J. W., & Benettin, P. (2025). Data-driven estimation of the hydrologic response using generalized additive models. Geoscientific Model Development, 18(22), 8663-8678.

Kirchner, J. W. (2016b). Aggregation in environmental systems–Part 2: Catchment mean transit times and young water fractions under hydrologic nonstationarity. Hydrology and Earth System Sciences, 20(1), 299-328.

Kirchner, J. W. (2019). Quantifying new water fractions and transit time distributions using ensemble hydrograph separation: theory and benchmark tests. Hydrology and Earth System Sciences, 23(1), 303-349.

Rigon, R., Bancheri, M., & Green, T. R. (2016). Age-ranked hydrological budgets and a travel time description of catchment hydrology. *Hydrology and Earth System Sciences*, *20*(12), 4929-4947.

Rigon, R., & Bancheri. M. (2021). On the Relations between the Hydrological Dynamical Systems of Water Budget, Travel Time, Response Time and Tracer Concentrations. Hydrological Processes 35 (1).