Response to reviewer #1:

General comments:

1. The authors simulate flow dynamics in a karst system via a CTRW particle tracking approach. The approach is based on the idea of representing a flow in (partially) saturated domain analogous to transport dynamics involving accumulation and release of tracer substances. The authors demonstrate that the model is able to recover the combined effects of both the slow and rapid flow components by using suitable parameterizations for the probability density functions governing particle movement in space and time of each domain. Furthermore the authors demonstrate limitations of the approach which is attributed to piston-type flow processes that could potentially be modeled via a third component.

Reply: We thank the reviewer for the positive appraisal of the manuscript.

2. The paper is concise (partially it could be slightly extended) and I could follow the main points of the authors. The graphics are mostly of high quality. In my manuscript figures showing discharge (e.g. 4, 6...) are partially blurry, though this may be a problem of my pdf viewer or the manuscript draft quality.

Reply: In a revised submission, higher quality figures will be generated.

3. In the following I have a few content related remarks. I have not found typographic errors.

Reply: See below our comments for the specific content-related remarks.

Specific comments:

1. (line 209) Flow paths are assumed to be linear elements connecting each point in the catchment with the spring. With a tortuosity factor unknown features of the flow geometry are taken into account. While this approach is efficient it potentially neglects various aspects of the internal system geometry. Here or in

the discussion it would be helpful to add some further information about the catchment (if available). What is the thickness of the vadose zone and roughly what volume of the system is considered phreatic? While the chosen flow paths approach may be more realistic for systems which negligible vadose zone and/or thin phreatic zone in other cases a more realistic flow paths distribution may be chosen. Ma loszewski and Zuber (1996, 2001) in their works have for example often assume various flow distribution patterns (though mostly assuming phreatic settings).

Reply: We agree that the internal system geometry is very complex, and this is true for the fractioning of the aquifer to vadose and phreatic zones as the comment states, but also for the structural characteristics of both zones. We argue that both of these complexities are represented in our simulations by the choice of model parameters. However, we do agree that in presenting a single case study for testing our model we should further expand about the nature of the system. In the revised text, we add a more detailed hydrogeological description of the system to address this: *"The surface of the karst system is composed mainly of bare limestone with very limited soil coverage, resulting in negligible surface runoff. The plateau is characterized by dolines and depressions, further facilitating the direct flow of water into the subsurface. The vadose zone is estimated to be several hundred meters thick (Frank et al., 2021)."*. We also revise the discussion to point out that the thickness of the zones might play an important role in the calibration of the model: *"The SF_l and SF_r are thus important parameters as they allow application of the CTRW-PT model to different karst systems. The Disnergschroef system, presented here as a case study, is characterized by a thick vadose zone and negligible surface runoff. Different karst systems are likely to show different SF_l and SF_r parameters."*.

2. (line 248) Recharge is estimated with a rather simple approach neglecting more complex processes in the soil water balance or runoff dynamics. How is baseflow computed? The authors should briefly discuss how the simplification might influence the results. Certain effects of this process spectrum might for example affect the peak recharge and hence discharge dynamics (e.g. more runoff might

decrease the input during strong precipitation events). As the peak discharge components are difficult to fit without a third component according to the authors this may already be one potential issue here.

Reply: We agree that the estimation of recharge from rainfall is rather simple. It is estimated using a bulk ratio factor which considers the total discharge, rainfall and the baseflow (which is calculated from the minimum of the observed discharge). In the revised text, we will expand the methods section accordingly to clarify the following points:

a. The baseflow is the discharge minimum: *"The minimum measured discharge represents the baseflow discharge"*.
b. The rainfall to recharge ratio may be dependent upon time, rain intensity and spatial characteristics. The sensitivity of the three aforementioned quantities should be taken into account in future studies especially when they display high variability: *"While a constant recharge capacity factor is employed in this study, due to the negligible surface runoff, it is important to note that the rainfall-to-recharge ratio may be influenced by temporal variations, rainfall intensity, and spatial characteristics. Future research should consider the sensitivity of these variables for the specific scenarios considered. In cases where there is significant variability among them, other temporal and/or spatial ratios may be applied."*.

3. (line 266) My understanding is that particles are able to transition from the fast into the slow domain. While this is conceptually often the case, in the bulk aquifer system the opposite case can occur in both the phreatic and especially vadose zone. Karst conduits connected via rapid infiltration features to the surface (dolines, sinks) may transmit water during recharge events into the matrix when a gradient inversion occurs. In addition within the vadose zone typically the matrix receives water from adjacent rapid flow elements (e.g. fractures) due to the differences in capillary pressure, (though this effect may not be present under nonequilibrium conditions as preferential flowpaths may partially overcome the effect of capillary suction). This limitation in the approach should be briefly mentioned in the discussion section.

Reply: We agree that both slow to fast and fast to slow transitions may occur. However, CTRW results are essentially an ensemble average, and represent processes as statistical outcomes. In the specific context, the chance of slow to fast transition represents the net total transition. If particles can also transition back from fast to slow, then this can be represented by simply lowering the chance of transition from slow to fast. We revise the text accordingly to address this point: *"While transition of fast to slow flow is also possible in karst aquifers, i.e., when the pressure gradient allows water from the conduits to enter the matrix, the slow to fast transition is more prominent for this site. Thus, the likelihood of transition represents the net transition from slow to fast flow. When more particles transition back from fast to slow flow, the transition likelihood is lower. In this context, it is important to note that the CTRW-PT is a stochastic approach, in which the system parameters are represented by statistical properties. The results of CTRW-PT simulations are, therefore, representative of an ensemble average of many realizations."*.

4. (line 374) "without the prominent peaks" What is exactly meant by this? Are you removing exactly one datapoint (15min intervals)?

Reply: In light of this comment and other comments made by reviewer #2, we have re-examined the peak removal, and decided to omit it from the manuscript.

5. (line 386) Why would this need a third component? Is it impossible to fit this with the available parameters or possibly a different form instead of the TPL? Many karst springs have been successfully modeled with dual-domain approaches (spatially distributed, lumped parameter approaches). I wonder wether this is a limitation of the approach or caused by the distribution of heterogeneities (fractures, conduits) specific to this spring system.

Reply: We agree that the option of adding a third flow component is not sufficiently clear in the text. The application of the CTRW modeling framework for karst flow is a new approach and this is the first implementation. Specifically, we applied it for this karst system as dual flow approaches did not adequately fit the observational data, essentially because of the distribution of heterogeneities. The main purpose of the simulation was to demonstrate the ability to fit the extremely long tails which can be observed in many karst systems. In doing so, we highlight that the peaks are less in agreement, and therefore offer possible ways to deal with peak data in future studies. A third flow component is one option (as discussed in the text for celerity), but we do not think this is the only option or the most appropriate one. We therefore point out that this is a possibility that should be considered outside of the scope of this paper. We revise the text to better convey this message: *"The model herein does not explicitly take this effect into account, which creates the negative bias in modeling the high peaks. While outside the scope of this study, this feature might be addressed in the future by adding a third flow component, or by further refining the CTRW parameters of the particles present in the system prior to the rainfall event to represent the increase in flow velocity."*.

6. Conclusion chapter: Here I feel it would be good to slightly extend the scope and relate the results to other modeling approaches. Why should one employ the demonstrated approach? What are the benefits in terms of process representation and computationally efficiency?

Reply: We agree that the conclusions can be expanded to better convey the possible use of our model. The main purpose of the application of the CTRW model for this case (see reply #5 above as well), was to address the long tails in karst discharge data. We revise the text to convey this: "*The application of the CTRW-PT model for the Disnergschroef system, specifically, has shown that it is particularly advantageous in predicting the long tails observed in discharge data, compared to other modeling approaches*.".