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Discussions

Interactive comment on "Aggregation in environmental systems: catchment mean transit times and young water fractions under hydrologic nonstationarity" *by* J. W. Kirchner

Anonymous Referee #1

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GENERAL COMMENTS

This manuscript extends the results of the companion paper ("Aggregation in environmental systems: seasonal tracer cycles quantify young water fractions, but not mean transit times, in spatially heterogeneous catchments") to the case of non-stationary hydrologic systems. Like in Paper 1, the author makes use of benchmark testing procedures based on a well-designed virtual experiment. Several results are presented from different system configurations, precipitation forcing, flow regimes, tracer data. Overall, the paper is well written and represents an important contribution to our understanding of catchment transport processes.

The first part of the manuscript (Sections 2-3.3) introduces and investigates the virtual hydrologic system. The author shows an interesting procedure to accurately solve the main transport equations and to reduce the equifinality of model parameters (which is typical of non-linear storage-discharge relationships). Although the author should add more reference to the existing literature (which in some cases already showed similar results with similar models – see Detailed Comments), the results are clear and of good scientific quality.

The second part (Sections 3.4-3.8) explores sine wave fitting methods applied to the virtual experiments. The results show that in a non-steady-state system, mean transit times (MTT) estimated from sine wave fitting methods generally do not match the "real" average MTT. Instead, such methods reliably estimate the average "young water fractions" (Fyw, introduced in Paper 1). This part is engaging and innovative, but, as such, it needs to be better framed. The central issues that, in my opinion, need to be solved are:

1) The reader may struggle with the definition of Fyw, because the definition of the threshold age is necessarily imprecise in real catchments (as shown in Paper 1). Hence, more effort could be put in explaining why the lack of a precise threshold age has minor importance. The imprecision in the threshold age also leads to a legitimate (though provoking) question: why bothering about young water fractions and not just studying tracer cycle amplitudes and shifts?

2) The author sets the threshold age for the virtual experiment equal to that of a stationary exponential TTD, even if the system is non-stationary and its marginal TTD does not resemble an exponential pdf. Such a choice is not discussed and may look arbitrary. To what extent are the results affected by this choice?

3) The procedure to estimate Fyw (Section 4.3) shows two possible strategies. The first one is clear (as it was explained in Paper 1), but the second one, which includes phase shift information, is not described in paper 1 and is not critically discussed in this

manuscript. Such a discussion is necessary (here, or in Paper 1) to understand how (and maybe why) this strategy works.

A last general note is that the paper presents quite some results (18 figures, more than 15000 words), so it makes it difficult for the reader to get till the end. Any effort to reduce the manuscript length is welcome.

DETAILED COMMENTS

3108 l. 29: "from tracer concentration" it should be specified that it regards sine wave fitting methods.

3109 l. 12: avoid referring to "effective precipitation", even if many tracer studies do, because it implies that evapotranspiration only affects particles with age 0, which is unrealistic.

3110 l. 4: this threshold age is not justified, nor it is checked a posteriori for the calibrated model. Indeed, depending on the parameter combination, the marginal distributions of the individual boxes and of the streamflow may resemble gamma distributions with shape parameter alpha quite different from 1.

3110 l. 9: this is also called "random sampling" scheme.

3110 l. 13: as the analytical solution exists for well-mixed volumes (e.g. Rinaldo et al., (2011)), why is the author tracking age numerically?

3116 l. 18-27: this paragraph could be moved earlier in the text (Section 2), to make the use of the model clear from the beginning.

3119 l. 12-29: this paragraph should include reference to other papers that showed these findings in theoretical and applied contexts (e.g. van der Velde et al., (2012), Botter (2012), Hrachowitz et al., (2013), Harman (2015)).

3120 l. 8: this was also shown by Harman (2015).

3125 l. 23-25: this is very well explained!

3129 l. 24: the definition provided by the author in Paper 1 is actually more complicated, because as one does not know the shape of the TTD, the threshold age cannot be specified.

3130 l. 1-11: this is quite unclear. The second of the two strategies is not described in paper 1, nor it is critically discussed prior to its use.

3130 l. 14: here the author could be more explicit and specify that the method was proved reliable for compositions of gamma distributions with shape parameter ranging from 0.5 to 2.

3130 l. 16: I am not totally sure this virtual experiment can be considered representative of a "homogeneous" catchment. Or I don't understand the author's definition of homogeneity. Indeed, the system is made of two different sub-systems, characterized by markedly different time-scales.

3130 l. 12-29 and Figure 10: when comparing the young water fractions (and MTT) derived from age tracking to those estimated from seasonal tracer cycle, please specify that the formers are average values (time-average, flow-average, over the whole dataset, over a specific flow regime, etc), otherwise it is confusing.

3131 l. 11: the author mentions "flow-weighted fits to seasonal tracer cycles". How is this done?

3132 l. 13: as commented above, this virtual experiment does not look homogeneous to me. So how can the author separate the effect of non-stationarity from that of heterogeneity?

3134 l. 12: please specify that the young water fraction is an average value (in this case, over a specific flow regime), because the real Fyw changes in time. Is this a time- of flow-average? Figure 12: same comment as above

3134 l. 20 and figure 13: please specify that the "real" young water fraction is an average value

3134 l. 21: this is an interesting results, it would be worth adding further comments.

3137 l. 27: the young water fraction has a rather specific meaning, so it does not just estimate the fraction of "relatively" fast flowpaths. It estimates the fraction of flowpaths that supply the stream with water younger than about 2-3 months.

3141 l. 21 to 3142 l. 27: these paragraphs are rather long and could be condensed

3142 l. 15: this "inductive leap" is important. What does one learn from the virtual experiment for applying the method to real catchments?

3142 l. 21-27: yes, but then one wants to apply the method to real-world catchments. So the model structure plays a role in suggesting whether the method is applicable to a real catchment at hand.

TECHNICAL CORRECTIONS

3132 l.15 "likely to be underestimated"

Figure 18 caption: there is some mismatch between the brackets at lines 8-9

CITED LITERATURE

Botter, G. (2012). Catchment mixing processes and travel time distributions. Water Resources Research, 48(5), http://doi.org/10.1029/2011WR011160.

Harman, C. J. (2015). Time-variable transit time distributions and transport: Theory and application to storage-dependent transport of chloride in a watershed. Water Resources Research, 51(1), 1–30. http://doi.org/10.1002/2014WR015707.

Hrachowitz, M., Savenije, H., Bogaard, T. a., Tetzlaff, D., & Soulsby, C. (2013). What can flux tracking teach us about water age distribution patterns and their temporal dynamics? Hydrology and Earth System Sciences, 17(2), 533–564.

http://doi.org/10.5194/hess-17-533-2013.

Rinaldo, A., Beven, K. J., Bertuzzo, E., Nicotina, L., Davies, J., Fiori, A., Botter, G. (2011). Catchment travel time distributions and water flow in soils. Water Resources Research, 47(7), http://doi.org/10.1029/2011WR010478

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