The residence time of water in the atmosphere revisited

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Response to the review of Jiangfeng Wei

We thank Jiangfeng Wei for the positive and constructive review. Comments by the referee are in italic and replies are in normal text. The detailed adjustments to the revised manuscript will follow after the public discussion period.

General comments

This paper revisited the issue of atmospheric moisture residence time, especially the estimation from an earlier study, by using two different models, one Eulerian and one Lagrangian. They argue that the estimation from the earlier study is not correct. The methods are sophisticated, but I feel that some issues are not clear to me. I hope the authors can clarify them and make the paper easier to understand.

We will clarify the issues, pointed out by the referee, in our responses below and in the revised version of the manuscript.

I do not understand why the residence time estimated from a precipitation perspective, an evaporation perspective, and the age of atmospheric water are different (Fig. 2c- 2e). Do they indicate the same physical characteristic? Are the differences caused by the different methods and imbalance of the hydrological data?

Globally averaged, precipitation residence time, evaporation residence time and age of atmospheric water should be the same. Indeed, estimates may differ due to imbalances in the data of the atmospheric hydrological cycle. However, these three metrics also have a different physical meaning, and thus, a different spatial pattern (Figs. 2c–e). Let us consider a particular location in the world, let say Portugal, as an example. As can be seen from Fig. 2d, moisture which evaporates from Portugal stays in the atmosphere on average about 14–15 days before it rains out again. In other words: the atmospheric residence time of evaporation is 14–15 days. The local recycling of atmospheric water is only a few percent (e.g., Dirmeyer et al. 2009; van der Ent and Savenije, 2011), and much of the evaporated atmospheric moisture is, in fact, transported towards relatively dry regions in the Mediterranean and Africa (e.g., Schicker et al., 2010; van der Ent et al., 2010), hence the relatively long atmospheric residence time of evaporation. On the other hand, the precipitation in Portugal comes for a large part from oceanic evaporative sources relatively nearby (e.g., Dirmeyer et al. 2009; Gimeno et al., 2012; van der Ent and Savenije, 2013), and we estimate that is has resided in the atmosphere for about 7–8 days (Fig. 2c) before it fell as precipitation in Portugal. In other words: the atmospheric residence time of precipitation is 7–8 days. The spatial image of the age of atmospheric water (Fig. 2e) is very similar to the precipitation residence time (Fig. 2c). For our Portugal example, the average age of atmospheric water is about about 8–10 days. Precipitation draws its water from the atmospheric reservoir with a certain age, but apparently, the atmospheric moisture in the drier months has a higher age. Hence, for Portugal, the time averaged age of atmospheric moisture can be somewhat higher than the precipitation weighted atmospheric residence time of precipitation. We hope that this issue will be made clear by the following change to our manuscript:

- In Section 4, we will use a shortened version of the Portugal example above to clarify the differences between the three metrics displayed in Figs. 2c–e.

In the top of page 6, you criticized Läderach and Sodemann (2016) by arguing that horizontal moisture transport is irrelevant for the global average residence time. I think Läderach and Sodemann (2016) showed results of both with and without moisture transport, and both of them are about half of 8 days. So it is not clear to me what is main problem of the study of Läderach and Sodemann (2016) that leads to the estimated low residence time if your paper and their paper are talking about the same physical quantity (e.g., there are difference between the residence time and depletion time constants as shown in Läderach and Sodemann (2016)).

We derive a global average residence time of atmospheric water of 8.9 ± 0.4 days (uncertainty given as one standard deviation), whereas Läderach and Sodemann (2016) derive this to be 3.9 ± 0.8 days (spatial variability indicated by one standard deviation) for 15-day backward trajectories. These estimates are clearly different. The controversy is, in fact, not in the depletion time constants (with or without the transport approximation) as we agree with that Läderach and Sodemann (2016) that depletion time constants are different from actual residence times.

Specific comments

In the introduction, you reviewed many past studies on the residence time. It will be more clear and organized if you use a table to list all the residence time values.

We thank the referee for this suggestion. Initially, we were a bit hesitant to include such a table because a table could suggest completeness, whereas there are most likely more textbooks, general water papers and educational web pages that include an estimate of the global average residence time. Moreover, several other numbers consider quantities which are a bit different as they are depletion times, or consider residence times only above land or only of recycled moisture. However, to increase readability we will follow the referee's suggestion to include a table in the manuscript with the following headers: Study – Physical quantity estimated – Value – Method. We will add a note that the table is non-exhaustive.

Page 2, Line 3. "local moisture feedback" is not clear here and needs more explanation.

We intend to change the wording here to: "However, it is safer to interpret them as local time scales of atmospheric moisture recycling (van der Ent and Savenije, 2011)".

Page 2, Line 14-15. "No details were given whether these experiments were performed in summer or winter." This statement is hard to believe for published papers.

We have checked the references again. In Bosilovich and Schubert (2002) it appears that the experiment in question was performed in May, but for Bosilovich et al. (2002) we could not find when this experiment was exactly performed. The latter reference is in fact a publication in GEWEX News and not a publication in a journal. We will update the revised manuscript accordingly.

Page 4, Eq.(1). Why the last term "$E_g \Delta t \frac{\Delta t}{2}$" is different from other flux terms?

Because fluxes are per unit of time these are all multiplied by the time step Δt. Next, they are multiplied by the age at timestep t. Thus:

Flux * time step * age.

For the outgoing fluxes the age at time step t is given by $(N_g^{t-1} + \Delta t)$. At the time a water particle evaporates its age is actually 0, however, we assume evaporation uniformly distributed over Δt, thus the resulting age of evaporated water from time step $t-1$ to time step t is $\frac{\Delta t}{2}$.

Page 6, Line 20. "the most likely value". What is it?

This concerns the value in Eq. (3) of $8.9\,\mathrm{days}$. We will specify this between brackets in the revised version.

Page 6, line 26-27. "In the precipitation perspective, the time from the previous evaporation is stressed, while in the evaporation perspective, the time to the next precipitation event is stressed." Can you clearly explain what this means?

See the response above concerning Figs. 2c–e.

Page 8, Lines 4 and 17. Can you give some explanation why the residence time over the ocean is about 2 days lower than over land?

The atmospheric hydrological cycle is apparently more intense over the ocean than over land as indicated also at the end of Section 3. We will add this in the revised version.

Technical corrections

Page 7, Line 9. "amount of atmosphere"?

This should have read "amount of atmospheric water"

Page 6, Line 18, There should be a comma after "ERA-I data"

OK

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