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Discussions

Interactive comment on "The residence time of water in the atmosphere revisited" *by* Ruud J. van der Ent and Obbe A. Tuinenburg

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Comments by Kevin E. Trenberth, NCAR 4 Sept 2016

This paper addresses the issue of residence time of atmospheric moisture and concludes that the value originally proposed by Trenberth (1998) of 8.9 days still applies. It provides a partial commentary on an earlier paper by Läderach and Sodemann (2016) which suggested that the residence time was less than half, namely 3.9 days. Two methods are used to assess the lifetime and age of moisture in the atmosphere and the basic fields used come from ERA-Interim reanalyses.

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Although some issues in addressing these scientific questions are discussed, many outstanding issues and reasons for different results are not. The tracking models used in this paper deal with particles and not finite volumes; and hence they do not appear to deal with the water budgets and precipitation processes or the storms and how they reach out to gather in moisture. Tracking a parcel is not the same as tracking the overall moisture flow from source to sink. Mixing and convection do not appear to be dealt with and "precipitation events" are not defined. These processes are not reversible (one can not go backwards, but in this paper they do). It is not that the exercise in this paper is without merit, but rather that it involves huge unstated assumptions and many questions are left outstanding.

Evaporation, as the source of moisture, is continuous and rates are modest. In contrast, precipitation is inherently intermittent; it typically precipitates only about 7 to 10% of the time (depends on threshold), and the precipitation processes vary enormously. Most precipitation occurs in the Tropics and is convective in nature, and this is generally true in summer over continents as well. Weather systems are typically much smaller in scale in summer over land than in winter where large extratropical baroclinic storms provide the main storms. None of these aspects are addressed in this paper. Atmospheric and climate models, including high-resolution numerical weather prediction models, have grid scales of tens to hundreds of km, and convection is parameterized. It has been shown in many studies that precipitation in models occurs too frequently and with insufficient intensity owing to the convective parameterizations, so that the lifetime of moisture in the atmosphere is much too short in all models. The easiest way to show this is via the strong summer diurnal cycle in precipitation and it's timing, which is too early in the day in all models (see Trenberth et al. 2003 for a discussion of all these points.).

Because precipitation rates (when raining) average 10 to 25 times evaporation rates (see Trenberth et al. 2003) (owing to the fact that most of the time it does not rain), any moderate or intense precipitation comes from advection and convergence of water

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vapor, not local evaporation. Monsoons are an example where moisture is transported great distances in reality to supply the monsoon rains, and a chronic error in most models is that the precipitation is deficient in monsoon areas (see Christensen et al. 2013), because the moisture falls out prematurely.

The difficulty of dealing with precipitation processes realistically, and especially convection, is a major outstanding issue in all studies that address the lifetime of moisture in the atmosphere. No doubt the problems in the Läderach and Sodemann (2016) paper stem from these issues. The methods applied in this paper do not appear to suffer from the premature onset of convection because they do not deal with realistic precipitation processes at all!

Results should be reconciled with estimates of "recycling" of moisture, which refers to the amount of moisture over a particular area that is precipitated from evaporation within that area (see Trenberth 1999). That paper also discusses and presents estimates of the older concepts of "intensity of the hydrological cycle", "precipitation efficiency" and "moistening efficiency" which have unfortunately been lost in this paper.

There remain major issues also in the datasets used in all such studies. Here, the evaporation and precipitation are from ERA-interim, which is a model-based assimilated set of values. Over land, evaluation of precipitation using Global Precipitation Climatology Centre (GPCC) high resolution data (Becker et al. 2013) shows considerable shortcomings in the reanalysis values (Schneider et al., 2013); also Trenberth et al. (2011). Globally, the Global Precipitation Climatology Project (GPCP) analyses are most widely accepted as having best values, although these are monthly means. Evaporation analyses suffer from shortcomings associated with bulk flux estimates, and are only useful in the context of a complete water cycle (as in Rodell et al. 2015).

Some further questions that arose for me are as follows. It makes no sense to me to separately compute a "precipitation residence time" and "evaporation residence time". Perhaps they should be called something else (e.g. see Trenberth 1999)? It states

"The places of low precipitation residence times (Fig. 2c) coincide mostly with areas of low precipitation (Fig. 2a)." Yet if it does not rain, then perhaps moisture hangs around for a long time? It seems count-intuitive? Or is it because in subtropical high pressure systems perhaps the moisture is transported away? "The intertropical convergence zone (ITCZ) has increasing precipitation residence times" yet it is pouring with rain? Is this because the moisture has been transported from afar? Isn't the age of atmospheric moisture dependent on the precipitation processes? Several of the results here related to regional residence times also do not appear to make sense from a standpoint of the physical process associated with precipitation and the water cycle. The seasonal differences over the southern hemisphere in Figure 3 are surprising to say the least (I am from New Zealand), and seem very suspicious elsewhere too (such as over the northern ocean storm tracks). Extratropical storms are every bit as active in summer in the southern hemisphere as they are in winter, just for a narrower latitudinal band (Trenberth 1991). The results cry out for explanations.

There appear to be problems in Eq (1) since it deals with t, t-1, and Δt. The units are inconsistent because "1" has no units.

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