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Dear Dr. Wanders,

Please find our answers to the reviewers below. We have answered all questions and made all possible changes suggested by the reviewers. The revised version of the manuscript has been uploaded using the Hydrology and Earth System Sciences (HESS) online submission system.

Best regards,

Dipanjan Dey

Reply to Mr. Dominik Schumacher *Thank you for the response on our article. We are grateful for all your constructive suggestions, which have helped us improving the manuscript. Below you can see our answers. The line numbers are from the revised manuscript*

Comments

If at all possible, please reconsider the colormap - it is a very informative Figure, and would benefit from a, e.g., perceptually uniform colormap

Answer : *Thank you for the constructive advice. We have now changed the residence time colormap in the revised manuscript (Figure 6) and in the supplementary material. We sincerely hope this will lead to a clearer understanding of the atmospheric water residence time.*

Maybe it could be useful to conceptually distinguish between 'forward' (from a specific net evaporation event, or source, to any precipitation event, or sink) and 'backward' trajectories (going back in time from net precipitation to any evaporative source). Any hint along these lines in the main text (or the Fig. caption) could be useful for the reader, I am not sure if 'from the evaporation and precipitation point of view' as in the main text already makes it as clear as it could be.

Answer : *The way we had phrased it was clearly confusing. We have now removed the sentences consist of "evaporation and precipitation point of view" from both the revised manuscript and the supplementary material as it was misleading. Note that we have only performed a 'forward' trajectory run i.e. from net evaporation to net precipitation points. In the previous version of the manuscript, the global average residence time from the evaporation and precipitation point of view was meant to be indicating the residence time when averaging the trajectories at the net evaporation points (spatial average of Figure S1 (top)) and at the net precipitation points (spatial average of Figure S1 (bottom)) respectively and not from forward and backward trajectory runs. However, we realized the global average*

residence time at the net evaporation and net precipitation points is not an useful quantity and thus removed. We have now calculated the global average residence time using all the trajectories that precipitated using equation 6 and mentioned it on line no: 205.

Last but not least, I struggle with the fact that the global average residence time of water differs so much for the different perspectives; while discrepancies at smaller scales are to be expected and intuitive, I would expect the global averages to be nearly identical (not necessarily equal, as the atmosphere is warming and hence needs to gain moisture if maintaining a constant relative humidity). Could this be caused by the fact that trajectories are only initiated for 6-hourly net evaporation (and only end for net precipitation)? As I reasoned in my initial review, this probably works less well in the tropics than elsewhere, and could cause the apparent discrepancy between global residence times.

Answer : *If we had performed both the forward and backward trajectory runs and calculated the residence time then the atmospheric water residence time would have been same in both the runs. However, as clarified in earlier comment we have only performed a 'forward' trajectory run i.e. from net evaporation to net precipitation points. In the previous version of the manuscript, the global average residence time from the evaporation and precipitation point of view was meant to be indicating the residence time when averaging the trajectories at the net evaporation points (spatial average of Figure S1 (top)) and at the net precipitation points (spatial average of Figure S1 (bottom)) respectively and not from the forward and backward trajectory runs. However, we realized the global average residence time at the net evaporation and net precipitation points are not an useful quantity and thus removed from the revised manuscript. We have now calculated the global average residence time using all the trajectories that precipitated at the surface using equation 6 and mentioned it on line no: 205.*

Reply to Dr. Ruud van der Ent *Thank you for the response on our article. We are grateful for all your constructive suggestions, which have helped us improving the manuscript. Below you can see our answers. The line numbers are from the revised manuscript*

Comments

L228-230: "However using an updated moisture tracking model WAM-2layers Van der Ent et al. (2014) found that the continental precipitation recycling dropped to 36%". This is also not necessarily to an update in the moisture tracking, but probably more related to using evaporation data from a model (STEAM) instead of ERA-Interim to be precise.

Answer : *Thank you for the insight. We have now modified the sentence on line no: 228-230 as "However using an updated moisture tracking model WAM-2layers and land evaporative fluxes from the Simple Terrestrial Evaporation to Atmosphere Model (STEAM) Van der Ent et al. (2014) found that the continental precipitation recycling dropped to 36%".*

L231-232: "The strength of the hydrological cycle in the present study is stronger than previous estimates such as Chahine (1992); Trenberth et al. (2007)". The comparisons with the recycling estimates of other studies are interesting and a good addition, but what is missing is a quantitative comparison of the actual E, P and transport fluxes to other estimates (e.g. Trenberth, Rodell etc.)

Answer : *In the revised manuscript we have now compared the ocean evaporation estimates obtained from the present study with the previous documented literature on line no: 231-237. Note that in the revised manuscript we have repeatedly mentioned that the present freshwater estimates are higher than than previous estimates (e.g., line no: 231, caption of Fig. 7) and as an example we have now compared the ocean evaporation values with previous studies. However, we think comparing ocean precipitation, land evaporation and land precipitation values*

from different studies will lead to a gathering of lot of numbers and the reader might get drifted away from the essence of the paper which is to understand the atmospheric freshwater connectivity within and between different ocean basins and global landmass.

L247-248: "missed a lot of detailed and important information" that seems exaggerated to me again.

Answer : *Removed "a lot of" on line no. 263.*

L251:252: "These shortcomings were overcome in the present study using a novel Lagrangian framework and presented a complete synthesised and quantitative view of the atmospheric water cycle" but only for net fluxes and with large biases respect to the actual quantities.

Answer : *It is repeatedly mentioned in the revised manuscript that we are tracing atmospheric water from the net evaporation to the net precipitation points and the probable reasons associated with the overestimation of the net freshwater transports.*

L257-258: "Only a handful of studies were able to put forward a quantitative and synthesized view of the global atmospheric water cycle (Chahine, 1992; Browning and Gurney, 1999; Trenberth et al., 2007, 2011)". By using the term "only a handful" you suggest the 4 references are an exhaustive list, which I think it's not, but if it is then it is not at all clear to me what criteria where used to end up in this list and why e.g. Van der Ent and Tuinenburg (2017) or Oki and Kanae (2006), several studies of Shiklomanov, several studies of Rodell et al, Bodnar et al. (2013) and others I've missed did not make the cut.

Answer : *We have now removed the sentence from the revised manuscript. However the suggested references are included now on line no: 277-278.*

L267-268: " 1 Sv using the surface water budget method. This 1 Sv is

practically the difference between the ocean-to-land (≈ 2 Sv) and land-to-ocean (≈ 1 Sv) transport" . "Sv" is not acceptable for reasons set out previously that still hold.

Answer : *We still insist on the fact that the quantity is mass transport of water and not a volume transport. The SI unit of the atmospheric mass transport is kg s^{-1} which is $\equiv 10^{-9}$ Sverdrup. Therefore Sverdrup is a valid unit to represent the atmospheric water-mass transport (not volume transport). We had also provided references in our earlier response where we showed that researchers in other studies also used Sveredrup as a unit to represent atmospheric mass transport. We have included the conversion on line 51 as " 1 Sverdrups (1 Sv $\equiv 10^9$ kg s^{-1} $= 31536$ km^3 $year^{-1}$, assuming water density is constant at 1000 kg m^{-3})" to compare the surface freshwater estimates with previous studies. We understand that the unit km^3 $year^{-1}$ can be used in the studies that deals only with surface freshwater transport and also if the surface water is in liquid phase and the density is ≈ 1000 kg m^{-3}. The atmospheric water density is not constant at 1000 kg m^{-3} when it is up in the atmosphere because water exists in different phases (e.g., vapour, ice). For this reason we do not deal with a constant atmospheric density. Dey and Döös, 2019 showed the the advective horizontal water-mass transports through the eastern (U) and northern (V) faces of the i, j, k grid box at time step n are*

$$U^n_{i,j,k} = \quad q^n_{i,j,k}\rho^n_{i,j,k}u^n_{i,j,k}\Delta y_{i,j}\Delta z^n_{i,j,k}, \tag{1}$$

$$V^n_{i,j,k} = \quad q^n_{i,j,k}\rho^n_{i,j,k}v^n_{i,j,k}\Delta x_{i,j}\Delta z^n_{i,j,k}. \tag{2}$$

The discretised hydrostatic equation yields

$$\Delta p^n_{i,j,k} = \rho^n_{i,j,k}\, g\, \Delta z^n_{i,j,k}\,, \tag{3}$$

$$U^n_{i,j,k} = q^n_{i,j,k} u^n_{i,j,k} \Delta y_{i,j} \Delta p^n_{i,j,k}/g, \quad (4)$$

$$V^n_{i,j,k} = q^n_{i,j,k} v^n_{i,j,k} \Delta x_{i,j} \Delta p^n_{i,j,k}/g. \quad (5)$$

The suggestion is to convert the unit from Sv or kg s^{-1} to km^3 $year^{-1}$ in the context that "Sv" in the SI system stands for Sievert is unusual as "year" in the suggested km^3 $year^{-1}$ is not a SI unit.

L272: please use "e.g." as again there are many more studies

Answer : *Done (line no. 286).*

L273-374: "unable to provide the integrated water circulation pathways in the zonal-vertical or meridional-vertical framework". I don't understand what this exactly refers to and why you think this would be missing from the studies you refer (and not refer) to.

Answer : *This refers to Figure 3 and Figure 4 which shows the integrated atmospheric water circulation pathways in the meridional-vertical and zonal-vertical framework. As per our knowledge and understanding these integrated water circulation pathways have never been showed in any previous studies.*

L286-287: "The global average residence time of the atmospheric waters from the evaporation and precipitation perspectives was calculated to be around 7.5 days and 11 days respectively". how can that be different? global E equals global P, thus the number should exactly match.

Answer : *The way we had phrased it was clearly confusing. We have now removed the sentences consist of "evaporation and precipitation point of view" from both the revised manuscript and the supplementary material as it was misleading. Note that we have only performed a 'forward' trajectory run i.e. from net evaporation to net precipitation points. In the previous version of the manuscript, the global average residence time from the evaporation and precipitation point of view was meant to be indicating the residence time when averaging the trajectories at the net evaporation points (spatial average of Figure S1 (top)) and at the net pre-*

cipitation points (spatial average of Figure S1 (bottom)) respectively and not from forward and backward trajectory runs. However, we realized the global average residence time at the net evaporation and net precipitation points is not an useful quantity and thus removed. We have now calculated the global average residence time using all the trajectories that precipitated using equation 6 and mentioned it on line no: 205.

"The reason for this could be explained by the way E - P has been computed in the current study which omits diffusive atmospheric water transports, specific rain and snow water content". I could imagine that this may lead to a 5% difference, or let's say 10%, but a doubling? Even if you have to other effect of P and E in reality coinciding that should lead to underestimation? If you check the study of Cloux et al. (Sara Cloux, Daniel Garaboa-Paz, Damian Insua-Costa, Gonzalo Miguez-Macho, and Vicente Perez-Munuzuri Hydrol. Earth Syst. Sci., 25, 6465-6477, https://doi.org/10.5194/hess-25-6465-2021, 2021) and all the discussion we had in the review process you will find that similar E-P schemes have larger problems than just these factors.

Answer : *We strongly believe the overestimation of the net freshwater transports in the present study are associated with the omission of diffusive atmospheric water transports, specific rain and snow water content and time correlations in the atmospheric water-mass conservation equation. We have now provided an example on line no: 240-257 with a hypothetical situation how these factors could lead to an overestimation. We defer from the comment that we are using similar E - P schemes. The FLEXPART and the TRACMASS model is different in their fundamental way of freshwater and trajectory calculation. TRACMASS computes E - P from the atmospheric water-mass conservation equation (Dey and Döös, 2019) using 6 hourly data (the water-mass conservation equation includes the rate of change of water mass with time) and starts trajectories when at the surface E > P. Then it will be advected by the 3-D mass transport of water until they reached*

back to the surface where P > E. We do not interpolate specific humidity along air trajectories and also do not consider the mass of the atmosphere is constant as in FLEXPART. So we do not suffer from errors like nonphysical specific humidity fluctuations due to convergence or divergence.

"Additional reason might be related to the use of 6-hourly cumulative net freshwater transport in the present study which prohibits the inclusion of processes occurring at a shorter timescale". Which should work the other way around, leading to an underestimation of E. If not, please include a helpful a numerical example to be able to understand the reasoning in line 231-242.

Answer : *Thank you for raising this point. We have now provided an example in line no: 246 - 257 that will indicate how the use of 6-hourly cumulative net freshwater transport could lead to overestimation of the net freshwater transports in the present study.*

"However, we think it would be unreadable to put the limitations everywhere. Every study has its own limitations and it should be mentioned and discussed, which we have done in the present study now". I agree, but 2 points: - The most important place to note limitations is in the caption of Figure 7, because that's what quick readers would look at. - limitations and assumptions are not a problem at all and I have no problem with that, but a doubling of land evaporation without a convincing reason is in my opinion not acceptable.

Answer : *In the revised manuscript we have now mentioned in the caption of figure 7 that "It is important to mention that the net evaporation and net precipitation transports presented here are higher than the previous estimates such as Trenberth et al. (2007); Chahine (1992) and it might be due to the way E - P has been computed in the present study which omits diffusive atmospheric water transport and time correlations". Additionally, on line no: 246-257 we have*

also showed with numerical example that how the time correlation could lead to overestimation of the net freshwater transports in the present study.