Review of paper titled "Tracking the global flows of atmospheric moisture" submitted to Hydrology and Earth System Sciences,

Manuscript Number: hess-2019-597

Dear Dr. Louise

Thank you for sending the manuscript to me for a review. Below you will see a short summary of the manuscript, followed by my specific (major) comments, and then technical corrections (minor comments) at the end.

Summary

Tracking moisture in the atmosphere over time has many applications in the fields of hydrology and meteorology, such as finding the major moisture sources of particular extreme precipitation event at a given location. Moisture tracking models can be represented with a variety of schemes, which include Eulerian and Lagrangian (in two and three dimensions) frameworks, different integration time steps, different sets of vertical forcings, representations of vertical wind velocities, locations of moisture releases to the atmosphere, etc. The results of moisture tracking, for example evaporation recycling rate, the distance travelled by moisture, etc., will depend on the scheme chosen. The authors experiment a set of evaporation tracking schemes to asses the sensitivity of tracking results to different schemes. In summary, the steps used in the manuscript can be written as: a.) Select seven point-sources of evaporation across the globe, b.) track the evaporation (during first five days of July 2012) from these locations using a tracking scheme, c.) keep track of precipitation locations, i. e., latitude and longitude points where precipitation happened, d.) repeat the above three steps with different model settings, and e) compare the tracking results. Based on the comparisons among different schemes, the authors propose an "optimal" tracking scheme for general hydrological applications: 3D-

Lagrangian, 500 particles released per mm evaporation, moisture releases at surface, linear interpolation in time and space, adding as many vertical forcings as possible, etc.

The manuscript is very clearly written, and overall, I think it can be of interest to many readers of HESS and other similar journals. There, however, are some places in the manuscript where authors should provide more justifications and clarifications; I added these in the "specific comments" section below. I hope the authors can address these comments, after which the manuscript may be suitable for publication in HESS. I will be looking forward to reading a revised draft.

Specific comments

1. When an air parcel moves, it gains and losses moisture along its track, the gain and loss can be attributed directly to the location where the change happens if the parcel is within the boundary layer. When the parcel is out of the boundary layer, the change locations are not clearly evident, since they can come from remote sources (Sodemann et al., 2008), which are difficult to evaluate. It is not clear how the "original" evaporation (Lines 95-96) is maintained throughout the parcel's track. More clarity on this will help in interpreting many results presented in section 3, for example evaporation footprint.
2. Section 2.1.4: During convective up- and down drafts, horizontal winds also show significant changes in magnitude and direction; the particles can then be displaced vertical depending on the changes in the vertical winds, instead of assigning random vertical displacements to them, which seems arbitrary. If feasible, another scheme based on this large horizontal wind gradients may be added in the present framework.
3. The basic structure of the model is not presented anywhere. I suggest adding a stepwise procedure on how the tracking is performed. Actually, response to this might answer my first comment 1 also.

4. This baseline model is 3D Lagrangian with 10,000 parcels released per mm; the 3D model in L243, table 1, and other results almost identical to the baseline model. This does not seem a reasonable way to compare models and present results, since baseline itself is not "True Tracking" and cannot be a perfect reference. It might be a good idea to use other models' output as reference, such as HYSPLIT (Draxler and Hess, 1998), LAGRANTO (Wernli, H., and H. C. Davies, 1997).
5. In Section 3.2, it is argued that number of parcels released does not affect tracking results greatly. We should note, however, that number of parcels may matter to capture convective/converging and diverging events, as stated by the authors in section 2.2.4. Here, the simulations are run only for one case (July 2012), which may not have large convergence or divergence at any time. We should be careful in generalizing these results to all events, unless simulations results of some specific convective events show similar results.

Technical corrections

Define "footprints" at the beginning, somewhere in the introduction.

One of the aims of the manuscript was to evaluate model structure; however, it is not clear where model structures have changed. Perhaps, Eulerian and Lagranian can be taken as different model structures, but this needs to be written explicitly.

L25-26: Fig. 1 does not specifically show moisture recycling as indicated here.

L46-48: Rather than "assumptions", I feel they are more like user "choices".

L44: Here, I suggest writing "parcels" instead of "particles".

L51-54: It is not clear how the results will be incorrect; also, clearly explain why the Eulerian model simulations will not be as fast as Lagrangian when moisture is released from small areas.

L60: Do you mean "which resulted in Courant numbers exceeding one …"?

L125: I am not sure if I understand why vertical mixing is to be carried out every time interval and how is it performed; more details on this can help readers.

L130-L133: Rephrase for more clarity.

L150: Do you mean "particle" instead of "parcel"? Try to be consistent.

L153: No, this does not seem realistic; you might not be able to capture convergence or divergence with this scheme, just because it is random.

L178: Here, 10,000 particles are released per mm of evaporation over first 5 days of July 2012? Evaporation from a point source at any instant will be transported during each time step; are we releasing parcels at one instant, say t=0, or over multiple time steps (t =0, t=1, and so on.). Add a few lines to clearly explain how parcels are released, and how evaporation over 5 days will be captured by parcels released.

L189: In table 1: I would also add a simple metric "mean distance travelled".

L225-234: The entire section can be as a separate row in Table 1.

L250: Low value of CRR is observed in 2D Lagrangian case, not Eulerian; see Figure 3c also

L254: Fig. S5, not S4.

L259-262: Give clear reasons of so much computational time difference between 3D Lagrangian and 3D Eulerian schemes. In other words, why do we think 3-D Eulerian takes so much time?

Figures 6, 7 and other similar figures: Since these figures do not shown clear differences, perhaps it is better to show differences directly, i.e., map of baseline footprint minus footprint from the given set up.

Figure S25B: There is an unusual straight color line in this panel; can that be removed?

Section 3.5: Were the models run with interpolation or with nearest neighbor method. Also, the results here can be concisely presented in a tabular form, rather than text.

Section 3.6: Will it be feasible to test sensitivity to timestep dt = 3 hours?

Section 3.7: I am not sure if I clearly understand the purpose of mixing and its usefulness in practice. Perhaps provide more details.

References

1. Sodemann, H., C. Schwierz, and H. Wernli, 2008: Interannual variability of Greenland winter precipitation sources: Lagrangian moisture diagnostic and North Atlantic Oscillation influence. *J. Geophys. Res.*, **113**, D03107.

2. R. Draxler, R., and G. Hess, 1998: An overview of the HYSPLIT_4 modelling system for trajectories. *Aust. Meteorol. Mag.*, **47**.

3. Wernli, H., and H. C. Davies, 1997: A lagrangian-based analysis of extratropical cyclones. I: The method and some applications. Quart. J. Roy. Meteor. Soc., 123, 467–489

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