Response to Ruud van der Ent:

General comments:

Li and co-authors study the moisture sources of precipitation in 2 river basins for the (seemingly randomly chosen) 2022 July period with 2 moisture tracking algorithms WAM2layers and FLEXPARTWaterSip. They compare the methods and subsequently test sensitivities when changing certain parameters. The study is timely, relevant, generally easy-to-follow and substantiated with good figures and tables. However, I have two major comments:

1. The study is not at all reproducible as no detailed model settings are provided in relevant scripts. Moreover, people that use other moisture tracking models or settings would not be able to compare their results against that of the authors as no output data is provided. Only generic links to input scripts and data are available which are by far insufficient in this new era of FAIR and Open Science.
2. The authors make several strong statements and conclusions about the tracking models ability, which, in my opinion are mere hypotheses by lack of knowledge about an actual truth. These hypotheses should be substantiated by additional analysis and/or toned down.

Response: Thanks for your thorough review and valuable comments on our manuscript. We appreciate the time and effort you have dedicated to evaluating our work and are grateful for the constructive feedback provided. Please see below our summarized responses to your general comments:

1. Selection of river basins: First, the Tibetan Plateau (TP) is influenced by the interactions between the Indian monsoon and the westerlies (Yao et al., 2022). Specifically, the monsoon impacts the Yarlung Zangbo River Basin (YB) after traveling across the Himalayas, while the westerlies impact the upper Tarim River Basin (UTB) after crossing the Pamirs. Second, studying these basins will allow for an integrated approach to investigate basin-scale water balance (including both atmospheric moisture dynamics and runoff) in the future.

2. Model setups and code: In the revised manuscript, we will provide all relevant model settings and scripts in supplementary. In addition, we will release our simulation results in a publicly repository upon the publication of this work.

3. Experimental designs, statements, and conclusions about the tracking models: We will (1) conduct a meticulous sentence-by-sentence revision to enhance the description in the research background and results; (2) add further analyses, discussion, and sensitivity experiments to ensure that all conclusions are appropriately substantiated. More specifically, we will 1) conduct a set of sensitivity experiments for WAM-2layers (please see our Response to Specific comment 17 for details) and FLEXPART-WaterSip (including additional combinations of specific humidity and relative humidity thresholds), and 2) assess the relationship between the simulated moisture sources and actual evaporation.

Specific comments:

1. L. 23: "the Eulerian or Lagrangian method"
There is no such thing as 'the XXX' method and there are many other factors (possibly more dominant factors) that contribute to differences in moisture source attribution.
Response: Thanks for pointing this out. We will carefully revise all these inaccurate statements in our revised manuscript. For example, we consider modifying this sentence to: "However, despite the widespread use of various types of numerical models, the potential differences in their simulation results and the underlying causes of these discrepancies remain unexplored."

2. L. 29-31: "The inherent ability in WAM-2layers to distinguish between evaporation and precipitation makes it more effectively in identifying varying moisture contributions arising from distinct surface evaporation sources."
Effectively by what measure?
Response: Thanks for the comments. In our revision, we plan to further compare the simulations of the two modes with actual evaporation over the entire source region to better support this conclusion.

3. L. 31-33: "In contrast, in regions heavily influenced by smaller-scale convective systems with high spatial heterogeneity, such as the UTB when compared to the YB, simulations from FLEXPARTWaterSip tend to be more reliable."
Reliable by what measure?
Response: We plan to reorganize the relevant results to ensure that all conclusions are sufficiently supported by the corresponding evidence. Any speculative conclusions will be revised or removed from the manuscript. For more details about the new numerical experiments we will add, please see our Response to your general comments above.

4. L. 34: "However, FLEXPART-WaterSip is prone to introducing additional errors when using specific humidity information in particles to infer moisture uptake and loss, although it accurately depicts the three-dimensional movement of air particles."
Accurate by what measure?
Response: Thanks for pointing out this. Indeed, we did not quantify the accuracy here. In our revised manuscript, we will remove the second half of the sentence to ensure accurate description.

5. L. 44-49: "In comparison, the Lagrangian method employs a particle trajectory tracking approach, inferring the movement of moisture through individual three-dimensional particle trajectories solved with differential equations. While Lagrangian models typically involves more complete physical mechanisms in particle dispersion processes, they exhibit substantially less numerical diffusion than Eulerian models, making them more adept at capturing small-scale atmospheric phenomena such as turbulence, convection, and dispersion, particularly over complex terrains (Wang et al., 2018; Tuinenburg and Staal, 2020)."

But do most or all Lagrangian models include actual diffusion through turbulence, velocity differences, rainfall re-evaporation etc.? If not, then having no diffusion either numerically or explicitly modeled would also lead to errors.

Response: Thanks for pointing this out. Indeed, both Eulerian and Lagrangian models include diffusion. By "less numerical diffusion" here we meant "less numerical diffusion error". Eulerian models use fixed grid system and track changes in each grid cell, which can potentially lead to less accurate results in tracking moisture movements when compared to particle (parcel)-based Lagrangian models. We will clarify this in the revision. In addition, we plan to thoroughly revise the Introduction section and narrow the scope of our current study to focus exclusively on moisture tracking over the TP. In this context, the introduction to the Eulerian and Lagrangian models will be narrowed to WAM-2layers and FLEXPART-WaterSip.

6. L. 53-55: "However, these studies have not extensively explored the limitations of different model types and the causes of discrepancies between moisture tracking results. Moreover, the studies on the generation mechanisms of model uncertainties through the moisture tracking intercomparison is severely lacking."

I think the authors' study is a good addition, but I do not think that objectively they do much more than these previous studies. So, they should tone down this comment and somewhere in the introduction explain the relevance of their own contribution. A missing moisture tracking model comparison study is also the one by Van der Ent et al. (2013).

Response: Thanks for the comment. The motivation of this study originates from the extensive literature on precipitation moisture tracking in the Tibetan Plateau (TP) (Table 1 presents only a subset of existing efforts). However, to the best of our knowledge, no effort has been made to address the disparities or uncertainties among these TP-focused studies. This situation has led us to develop this manuscript, aspiring to encourage future researchers to critically assess the reliability of their simulation outcomes. Toward this goal, we strive to identify potential factors contributing to these disparities among models over the TP region.

Per your Specific comments 5 and 6, we plan to thoroughly revise the Introduction section to emphasize the following three aspects:

1. We will narrow the scope of our current study to focus exclusively on moisture tracking over the TP. In this context, we will specifically highlight that the most widely used numerical moisture tracking models are WAM-2layers and FLEXPART-WaterSip. Our subsequent paragraphs in introduction will focus solely on these two representative models.

2. The aim of this manuscript is to investigate potential errors/uncertainties in existing moisture tracking research on the TP as well as to understand the underlying mechanisms that contribute to these errors/uncertainties. We will emphasize the significance of this study to inform future numerical moisture tracking over the TP.

3. We will caution readers against generalizing our comparison results from the TP to other regions in the absence of substantial evidence.

7. L. 64-65: “the Eulerian… the Lagrangian”
Same comment as above.
Response: Thanks. Please refer to our response to your Specific comments 1, 5 and 6.

8. Table 1: “Overview …”
- Please note that this overview table is non-exhaustive
- Particularly missing studies are those by Guo et al. (2019, 2020)
- Is CAM a tracking model?
- I'd say the moisture source diagnosis of WAM2layers is simply the E and P from the data (as in QIBT or UTrack)

Response: Thanks for your comments.
- In our revised manuscript, we will emphasize that this overview table is non-exhaustive. Nevertheless, some missing references will also be added to the Table.
- We are sorry for our oversight. “CMA” here should be “CAM5.1 with a tagging method”. The authors developed a moisture tracer technology for the CAM5.1 model (Pan et al., 2017), enabling it to trace moisture source (Pan et al., 2018).
- Thanks, these blank cells will be filled with “E and P”.

9. L. 92-93: “The model prescribes a two-layer division (~810 hPa with a standard surface pressure)”
Probably good to stress that the layer separation is very different over the Tibetan Plateau.
Response: Thanks. In our revised manuscript, we will mention that the division varies with topography, and include a sentence to explain the situation over the TP region: “~520 hPa over 4000m altitude”

10. Figure 1: “method”
- In WAM2layers P also goes out the upper layer
- WaterSip is not necessarily 6 hours I suppose?

Response: Thanks.
- Indeed. We will add P in the upper layer in our revised Fig. 1.
- Yes, the output intervals can be changed in FLEXPART. We wrote 6-hours here because it represents the most commonly used time interval in WaterSip (we will mention this in our revised manuscript). Secondly, this description is also consistent with our illustration in “step two” in Fig. 1b.

11. L. 145-146: “Our numerical experiments, as illustrated in Fig. S2b, indicate that within the first 10 days (20 days), we traced 89% (99%) of the precipitation moisture in the YB and 97% (99%) in the UTB.”
The amount of attributed moisture seems very high to me. Do the authors think this realistic? How does the E simulated from WaterSip compare to actual E from ERA5?
Response: Thanks for the comments.

1. We found one paper using the same method (FLEXPART-WaterSip) for moisture tracking in Xingjiang (in the north of TP) (Yao et al., 2020), which provides a figure on

relationship between tacking days and cumulative contribution rates (see following Figure). Within 10 days, ~95% of the precipitation moisture was tracked in the region. This is consistent with our results here.

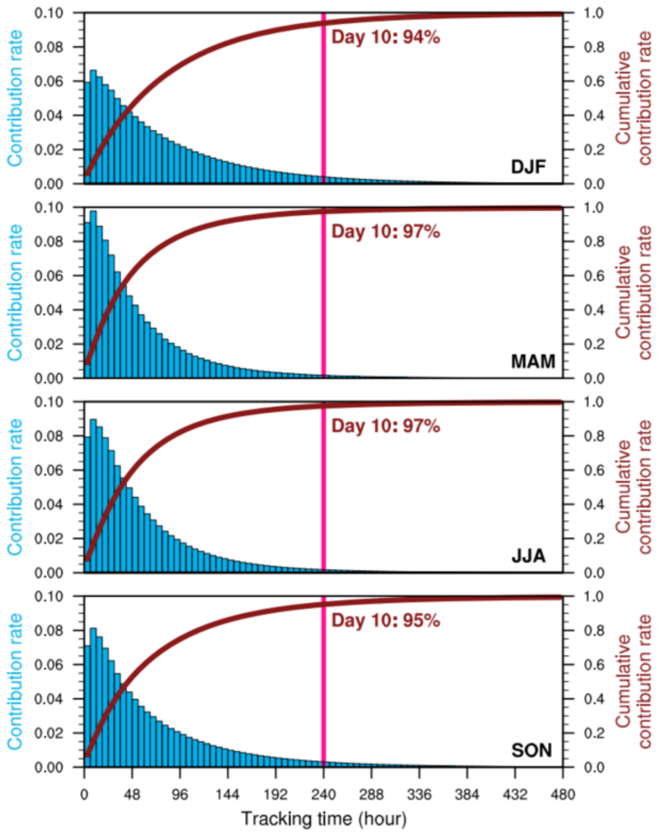


FIGURE 3 The contribution rates (bars) of moisture that can be traced by different backtracking times among seasons, together with their cumulative contribution rates (curves). The percentages are the cumulative proportions of moisture that can be traced back to 10 days

Our study follows the original WaterSip method as described in Sodemann et al. (2008). However, we observed that the attributed moisture accumulates faster in FLEXPART-WaterSip than in WAM-2layers. We believe this discrepancy may be related to the inherent features of WaterSip method itself, which is to some extent reflected in Fig. 10.

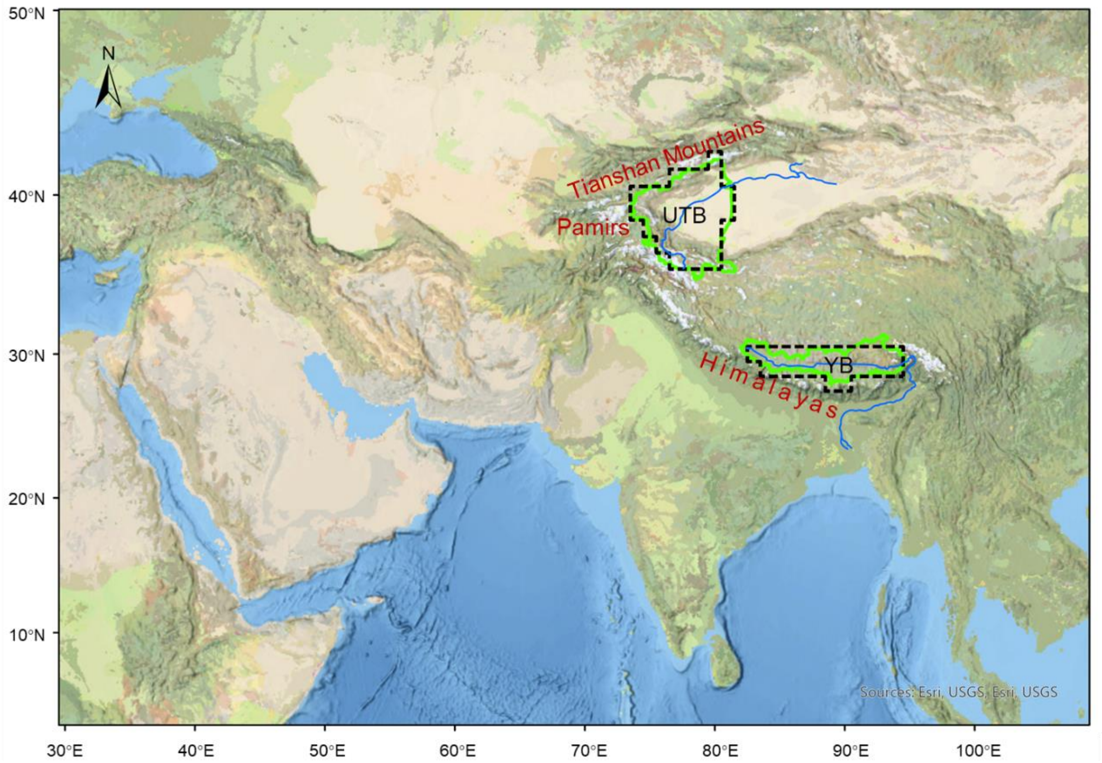
2. In the revision, we will further evaluate the relationship between the simulated moisture sources and actual evaporation. Particularly, in the WaterSip, the regional moisture uptake simulated with specific humidity threshold will be directly compared with actual evaporation.

12. L. 156-159: "Another noteworthy detail is the clear north-eastward extension of moisture sources for UTB precipitation resolved by FLEXPART-WaterSip, reaching almost to the easternmost Tianshan Mountains (Fig. 2d), a feature absent in the results of WAM-2layers (Fig. 2b)."

It is not clear exactly where the Tianshan Mountains are in Figure 2. Moreover, the word 'resolved' suggests that there is orthogonal evidence for those moistures to be the ‘truth’, but I fail to see where that is presented.

Response: Thanks for the comments.

1. We will label all the mountain ranges around the study areas in Fig. S1 (as following figure) in our revised manuscript, including the Tianshan Mountains.



2. Currently, we cannot confirm whether the “north-eastward extension of moisture sources for UTB precipitation” accurately represents the saturation. We plan to enhance our discussion about this phenomenon, including the atmospheric vertical motion across different regions, and will revise the manuscript to avoid similar inaccuracies in our descriptions.

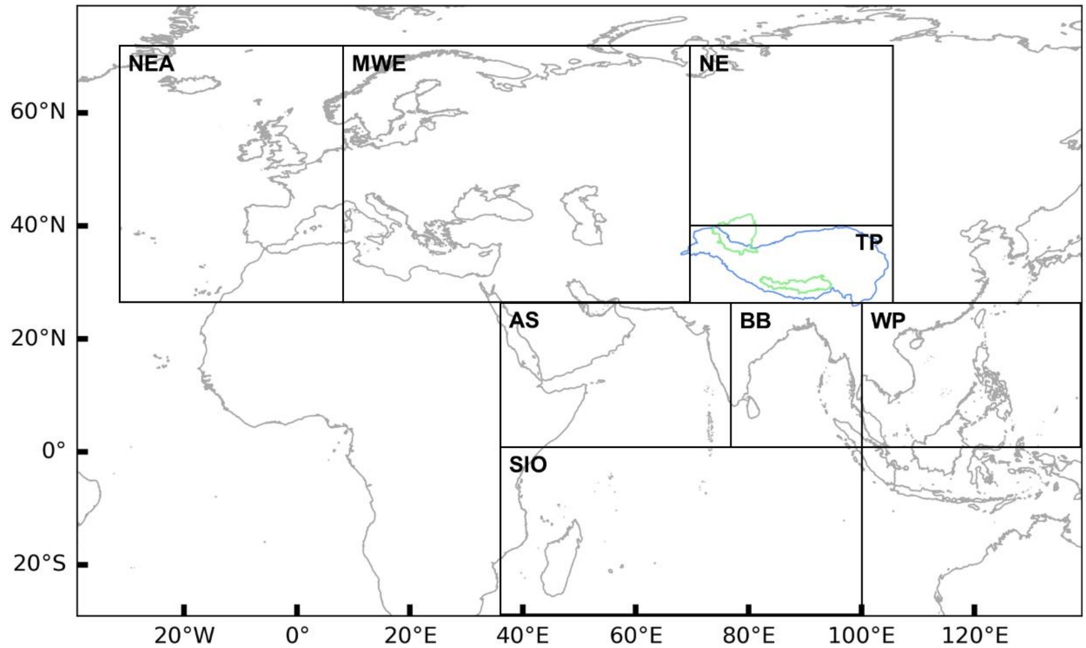
13. Figure 2: “Spatial distributions …”

- FLEXPART-WaterSip attributes vast areas of evaporative sources from as far away as the Arabian Desert and the Sahara in the same order of magnitude as evaporative contributions from the Red Sea, Gulf of Aden and Gulf of Oman. With actual evaporation being several orders of magnitudes lower in the desert, this feature is completely unrealistic and warrants more investigation by the authors. What does this tell in general about the trustworthiness of this method?
- The blank area between MWE and AS seems not a very logical way to separate regions.

Response: Thanks for the comments.

1. Indeed, this “unrealistic” phenomenon requires further investigation. In our revised manuscript, we plan to further explore the relationship between simulated moisture source contributions (in both WAM-2layers and FLEXPART-WaterSip), simulated moisture uptake (in FLEXPART-WaterSip), and actual evaporation over the entire source regions. We hope these new comparisons will enhance our understanding of the trustworthiness of these methods.

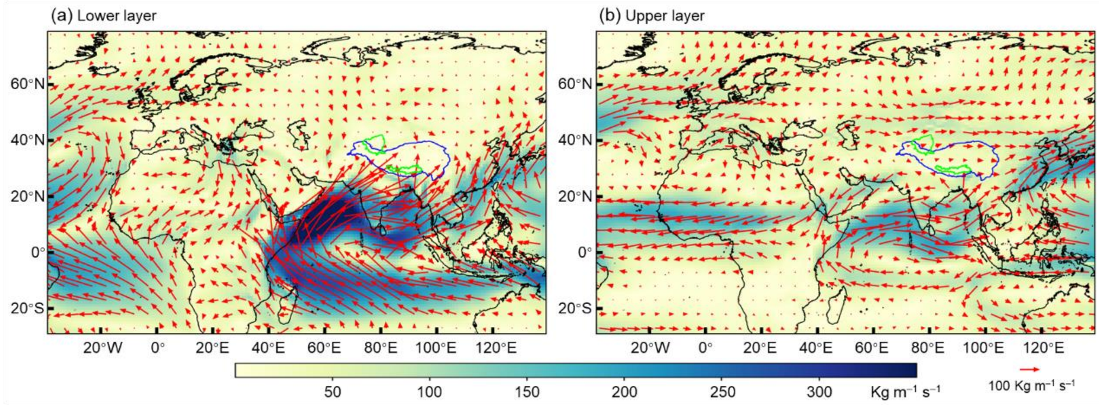
2. In the revision, we will optimize the division of the eight major moisture sources as shown in the figure below. All relevant figures and results will also be revised accordingly.



14. Figure 5 and 6:

What is the exact meaning in a quantitative sense of the red arrows?

Response: Sorry for the confusion. In revised Fig. 5, we will add a quantitative legend for the red arrows (see the revised figure below).



In Fig. 6, the red arrows in (a) and (b) are somewhat redundant. We will delete these arrows in our revised manuscript.

15. L. 242-244: "This further implies that the modelling capability of WAM-2layers for moisture sources of the UTB may be less robust than for the YB, consistent with the observation that the simulation disparities between the two models are more pronounced in the UTB than that in the YB (Fig. 4)."

As mentioned before, this hypothesis is not substantiated by any quantitative analysis. Alternatively, my hypothesis would be that while moisture goes to the northeast (back in time), there was very little evaporation in that area from the ERA5 data, so it wasn't identified as a source, whereas FLEXPART-WaterSip erroneously assigns an imbalance in its Lagrangian moisture budget as surface evaporation which may also have be caused by, for example, convergence. I do not have any evidence directly for my hypothesis either, but it is up to the authors to investigate the matter in more detail before jumping to conclusions.

Response: Thanks for your insightful comments. In our revised manuscript, we will include additional analyses and discussions to avoid these speculative conclusions. For example, we will investigate the relationship between the moisture source simulations and actual evaporation (for details please see our response to your General comments above).

16. L. 268-270: "A notable difference between WAM-2layers and FLEXPART-WaterSip, as highlighted in Fig. 2, is that FLEXPART-WaterSip model fails to capture most moisture source regions across the entire northwestern Eurasia for both basins when compared to WAM-2layers."

The word fails suggests that we know that WAM2layers would be more correct, but we don't know, do we?

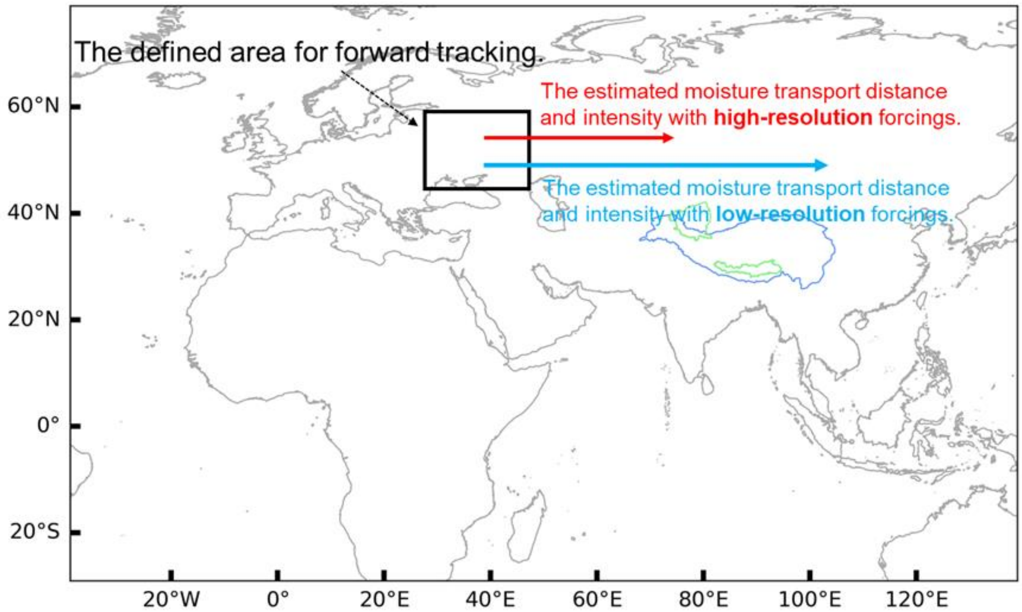
Response: We are sorry for the inaccurate description. We will thoroughly revise the manuscript and substantiate this statement with additional analyses and sensitivity experiments (for details please see our response to your General comments above).

17. L. 281-287: "Experiment 1 …"

This is a nice sensitivity test, however, its results can only be interpreted in case we also know how the timestep was adjusted, which together with spatial resolution drives the numerical diffusion and hence the average travel distance.

Response: To better understand how the spatiotemporal resolutions of forcing dataset influence moisture tracing results, in the revision, we will conduct two additional sensitivity experiments for WAM-2layers model. In total, there will be four different configurations: 3h and 1°×1°, 1h and 1°×1°, 3h and 0.25°×0.25°, and 1h and 0.25°×0.25° resolutions.

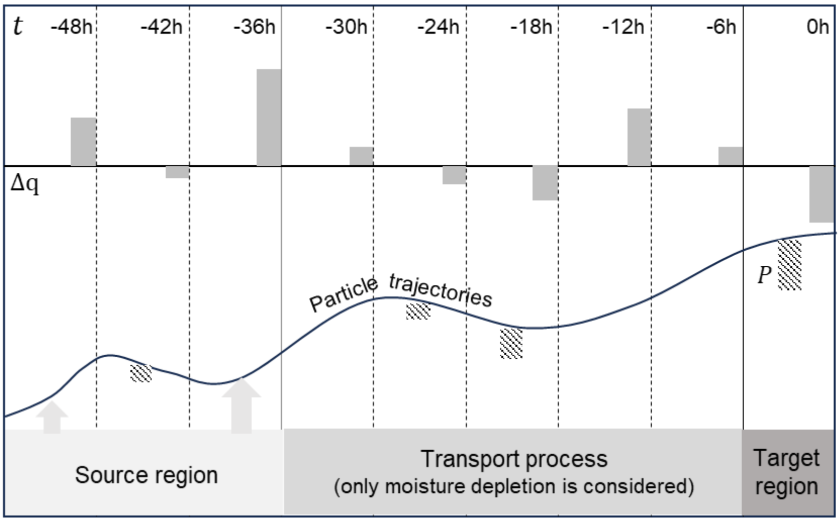
Additionally, we plan to design an additional experiment that involves: (1) identifying a westly source area with substantial simulation discrepancies between the two models (as depicted by the rectangular box in the Figure below), and (2) conducting forward tracking of evaporated moisture from this rectangular box using WAM-2layer with both low-resolution and high-resolution forcings. This experiment will help determine whether using lower resolution forcing overestimates the distance and intensity of moisture transport.



18. L. 297-304: "Experiment 3 …"

More details on the areal source-receptor attribution method are needed here as well.

Response: In the revision, we will add a new schematic diagram of the "areal source-receptor attribution method" to the Supplementary (see the Figure below). Consistent with Fig. 1b, this will clearly illustrate the differences between WaterSip and "areal source-receptor attribution method".



19. Figure 8: "Relative moisture contributions …"

- What is the remaining percentage from other regions?
- What is the remaining percentage from outside the domain?
- What is the remaining percentage unaccounted for altogether?
- The labelling should be more precise for WAM2layers in terms of resolution for both exp 1 and the original run.

Response: Thanks for the questions. In the revision, we will add an extra set of histograms to show the moisture contributions from areas outside the eight selected regions. We will also rename all experiments to include resolutions, e.g., WAM-2layers (1h, 0.25°×0.25°) and WAM-2layers (3h, 1°×1°).

20. L. 328: "original WAM-2layers"

I think both experiments are WAM-2layers with different settings, so the word 'original' is perhaps a bit misleading.

Response: Thanks for pointing out this. We will rename all experiments to include resolutions.

21. Fig. 10. "Time series …"

- Please improve the caption to make sure all details are explained.
- Is precipitation and evaporation the ERA5 data, or the inferred data from the WaterSip algorithm.
- If the latter, how does it compare to actual ERA5 data?

Response: Thanks.

1. We will revise the caption to: "Time series of particle heights (m), 1.5 times boundary layer height (1.5 BLH, m), changes of specific humidity (g kg–1 6h–1), vertical velocities in 700 hPa (Pa s–1), precipitation (mm), and evaporation (mm) at 6-hourly interval in the two selected trajectories. Trajectory (a) is from SIO to YB during 12:00 21-July and 12:00 1-July. Trajectory (b) is from NEA to UTB during 12:00 14-July and 12:00 24-June." We will also mention the numerical setups in the revised caption. Considering Dr. Sodemann's suggestion, we will move this figure to supplementary.
2. The particle heights, 1.5BLH, and changes of specific humidity are all from FLEXPART simulation, while the vertical velocities in 700 hPa, precipitation, and evaporation are actual ERA5 data. We will emphasize the differences in our revised manuscript.

22. L. 382-385: "Its effectiveness in regions with complex weather conditions is generally inferior to that of FLEXPART-WaterSip when operating with forcing datasets of the same resolution."

By lack of a clear benchmark 'truth', observational or orthogonal evidence, these conclusions are not substantiated. The authors should refrain from using words like 'inferior' and/or provide additional analysis to substantiate or revise such conclusions.

Response: Thanks for the comments. We will thoroughly revise the manuscript and substantiate this statement with additional analyses and sensitivity experiments (for details please see our Response to your General comments).

23. L. 402-405: "Nevertheless, compared to WAM-2layers, FLEXPART-WaterSip offers a precise depiction of the three-dimensional distribution of moisture sources, especially in capturing smaller-scale convective systems with high spatial heterogeneity."

In the lines before the authors discuss the shortcomings of WaterSip, but then they go on to conclude that FLEXPART-WaterSip offers a precise depiction … This reasoning does not seem logical to me.

Response: Thanks for pointing this out. We will revise this part to enhance the logical flow and substantiate our conclusions with additional analyses and sensitivity experiments (for details please see our Response to your General comments).

24. L. 415-420: "Code availability … data availability …"

This is insufficient. The authors should revisit the policy of sharing data https://www.atmosphericchemistry-and-physics.net/policies/data_policy.html and make the actual code and data they used during their research publicly available to the community. If software is used, they should refer to exact versions with doi's and the scripts the authors used themselves to run the models, so not to generic websites that are subject to change. All data underlying the figures should also be deposited meaning numeric values for moisture sources, masks for the tagging region etc.

Response: In the revision, we will strictly adhere to ACP's policies and clearly specify all used data and algorithms, including: (1) Provide accurate DOIs for models and data references; (2) Share model configurations and customized code in the supplementary materials; (3) Post all simulation results in a publicly accessible data repository upon the publication of this work.

Technical corrections:

1. Equation (1): The equation as used by Findell et al. (2019) is more correct than the one in Van der Ent et al., (2014)

Response: Thanks. This Equation will be revised to "$\frac{\partial S_{g,lower}}{\partial t} = \frac{\partial (S_{g,lower}u)}{\partial x} + \frac{\partial (S_{g,lower}v)}{\partial y} + E_g - P_g \pm F_{v,g}$" to be consistent with Findell et al. (2019).

2. Figure 3: "Absolute differences ..."

The green outline with red underlying data is not color-blind friendly.

Response: Thank you for pointing this out. We will modify the color combinations to be color-blind friendly in the revision.

3. L. 380: "WAM-2layers model"

The WAM2layers model

Response: We will correct this error in the revision.

References:

Pan, C., Zhu, B., Gao, J., Kang, H.: Source apportionment of atmospheric water over East Asia – a source tracer study in CAM5.1, Geosci. Model Dev. 10, 673-688, https://doi.org/10.5194/gmd-10-673-2017, 2017

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