Dear Editor Marc von Hobe,

We have addressed all of the reviewer's comments, and the manuscript has been revised accordingly to incorporate the suggestions while preserving the original intent of the paper. We are confident that the current version now meets the high standards of *Atmospheric Chemistry and Physics* (ACP) in terms of scientific rigor and adequately addresses all the points raised by the reviewer.

For your reference, we have attached a document containing the reviewer's comments (in black) along with our point-by-point responses (in red). We hope that this revised manuscript will be positively considered for publication in *ACP*.

Reviewer I

Second Review of "Lightning-intense deep convective transport of water vapour into the UTLS over the Third Pole region", by Prashant Singh and Bodo Ahrens, submitted to Atmospheric Chemistry and Physics (ACP)

The paper has improved significantly. In particular, the focus on the advantages gained through the ICON-CLM simulations—especially in comparison to ERA5—is convincing. However, it is still not a proof that Lagrangian trajectories driven by ICON-CLM winds result in moistening of the stratosphere. The freeze-drying effect along the trajectories is not considered, so only qualitative statements are possible.

Reply: We thank the reviewer for appreciating the revised version of our manuscript and for providing valuable feedback to further improve its quality. We fully agree that deep convective events are generally limited to moistening the upper troposphere and only rarely penetrate directly into the lower stratosphere. Our km-scale ICON-CLM simulations indeed show a lower frequency of air parcels reaching near the tropopause, while they frequently ascend into the upper troposphere above 300 hPa—consistent with previous studies.

Another issue remains with the application of the Lagrangian method and, in my opinion, an insufficient description of how it is used to reconstruct stratospheric water vapour transport. Specifically, the freeze-drying process and the ascent of trajectories into the stratosphere above the level of zero convective heating are key to our understanding of water vapour entry into the lower stratosphere. I do not suggest that the authors must implement all these calculations; however, without them, no quantitative statements about moistening of the lower stratosphere can be supported.

A minimum requirement, in my opinion, is to at least **describe these processes** in the introduction, because they form the basis of our understanding of water vapour transport into the stratosphere, and the authors rely on Lagrangian methods for their most important conclusions.

Reply: We thank the reviewer for this valuable comment. The main objective of our study is to highlight the performance of the km-scale ICON-CLM simulations in resolving deep convective transport to the UTLS compared to ERA5. Following the reviewer's suggestion, we have revised the Introduction to include a description of key processes governing stratospheric water vapour transport—specifically, the role of the cold-point tropopause and the freeze-drying effect on lower stratospheric moistening (Line 42-74).

Therefore, I would still recommend **major revision**, due to the following points:

Abstract:
Please replace: "result in direct moistening" with "may lead to direct moistening" to better reflect the uncertainty in the findings.

Reply: We have revised the sentence in the Abstract accordingly (Line 14).

Introduction:
I still miss a section describing the Lagrangian methods used to quantify the transport of water vapour into the stratosphere, particularly by identifying the coldest temperatures encountered along troposphere-to-stratosphere trajectories (Lagrangian cold points, LCPs). See, for example: Fueglistaler et al.; Fueglistaler and Haynes, 2005; Liu et al., 2010; Schoeberl and Dessler, 2011; Smith et al., 2021. This is our current understanding of how moistening of the stratosphere happens.

Reply: As per suggestion we have added the introduction section explaning CPT and freeze-drying effect on LS moistuning (Line 43-58).

Here, you could also explain the concept of the level of zero radiative heating—only above this level do trajectories typically begin their slow ascent into the stratosphere, and after freeze-drying at the LCP, air parcels acquire their final amount of water vapour for entry into the stratosphere. Based on this framework, overshooting convection may indeed play a role (see, e.g., Avery et al., 2017; Ueyama et al., 2020; Jensen et al., 2020; Ueyama et al., 2023; Homeyer et al., 2023), and perhaps with ICON-CLM it is possible to represent this process in the model.

Reply: As per suggestion we have added the introduction section explaning slow transport process above CPT, as per the suggested literarure (Line 59-70).

A few other minor but important points:

– **Figure 1:** Certainly an improvement. However, the cold-point tropopause appears to be closer to 90 hPa than 100 hPa. Also, when using Lagrangian modeling, the Lagrangian cold point is more relevant than the Eulerian cold-point tropopause. This further supports the point that your statements regarding transport into the stratosphere remain rather qualitative.

Reply: We thank the reviewer for the helpful observation. In our analysis, we considered the cold-point tropopause to be approximately 100 hPa, as maximum height varies from about 88 hPa at 26° N to 110 hPa at 40° N (as Figure 1a and b). The Lagrangian trajectories (specially for ERA5) show vertical transport above the Himalayas and subsequent advection toward the Tibetan Plateau. We agree that, with this tropopause height, our discussion of moistening in the UTLS region remains qualitative primarily representing upper tropospheric rather than lower stratospheric moistening.

– **Figure 4:** This figure is not well explained. Panels (b) and (e) cannot be the initial points—they are clearly not the same. I think these panels show trajectory positions after some time has passed. Here, by the way, the results of ICON-CLM (localized convection, strong vertical motion, and short timescales), in comparison to ERA5-driven calculations, are presumably more physically realistic. In my opinion, this is the strongest part of your paper.

Reply: We thank the reviewer for this valuable observation. Indeed, Panels (b) and (e) for ICON-CLM and ERA5 differ because 100 air parcels were released within each 1° × 1° grid box around the lightning location. The convective updraft strength and activated grid points can vary between the two datasets (Lines 306–307). Consequently, the initial point of air parcels that reach 300 hPa or higher may differ for the same event in ERA5 and ICON-CLM simulation, even within the same 1° grid box.

Final remarks:
I think the lightning-based approach is certainly innovative and shows potential as a new source of information related to the UTLS water vapour budget. Because of this, the work is worth publishing. The points mentioned above can certainly be clarified with some effort.

Reply: We sincerely thank the reviewer for the kind appreciation and insightful comments that helped us improve our manuscript. We have made significant revisions to the Introduction, particularly addressing the reviewer's suggestions regarding the cold-point tropopause (CPT) and the freeze-drying effect. In addition, we have added a new supporting figure A4 showing the highest altitude reached by air parcels with respect to various respective tropopause heights, and discussd the reulsts (Line 323-333).

I look forward to your kind response.

Prashant Singh