

A detailed, point-by-point response to the review comments is given below. Each review comment is repeated, followed by [our action to modify the manuscript](#). All Page and Line numbers correspond to locations in the revised manuscript.

#3 Reviewer

Review of “Revisiting Water Vapor Transport and Water Isotopes in the Dongting Lake Basin Across Two Centennial Extreme Events” by Xiao et al. This study investigates water vapour transport during two extreme events in the Dongting Lake Basin: an extreme precipitation and an extreme freezing event. By combining ERA5 and isoGSM data, the large-scale atmospheric forcing and the dominant moisture transport pathways are identified. Further, for one time step, radiosoundings and backward trajectories are used. The authors further describe observed and modelled stable water isotopes during the events. While this study uses promising datasets to investigate the circulation and water vapour transport for two extreme weather events, many aspects of the study remain unclear, as listed in the following:

1) Use of stable water isotopes: Observed and simulated isotopic composition of precipitation and water vapour are shown and described for the two extreme event, but no further investigation is done that makes any use of these data. For example, it is hypothesised that Rayleigh fractionation is important in shaping the simulated total column water vapour isotopic composition, but an application of a Rayleigh fractionation model is missing. Further, it is shown that the two events have distinctly different behaviour with respect to the local meteoric water line without further investigation or discussion. The additional value of using stable water isotopes in this study remains unclear.

[Response: We greatly appreciate this critical feedback, which has helped us recognize that the original manuscript presented isotopic data without sufficiently developing its mechanistic interpretation. We acknowledge that simply describing isotopic patterns is not sufficient; isotopes must be used to test hypotheses and derive process insights. We would like to clarify that we do not perform additional, standalone Rayleigh fractionation diagnostic calculations in this study. Classic Rayleigh distillation only describes idealized, closed-system isotopic depletion under continuous condensation and progressive vapor loss, which cannot fully reproduce real-world isotopic variations during actual moisture transport. In practical atmospheric processes, water vapor isotopic evolution is simultaneously modulated by moisture budget effects \(i.e., the water balance principle\), including continuous moisture advection, convergence, replenishment, and evaporation during long-range transport. Therefore, pure Rayleigh theory is oversimplified for characterizing complex synoptic-scale extreme events.](#)

[Instead, the spatiotemporal evolution of water isotopes along moisture transport trajectories is](#)

prognostically simulated within the isoGSM model. Rayleigh-type fractionation serves as a foundational physical premise embedded in the model's microphysics scheme, while the model's full moisture budget framework further accounts for real-time vapor convergence, divergence, and external moisture supplementation. This coupled physical configuration has been widely adopted and validated in numerous previous isotopic modeling studies focused on the East Asian monsoon domain. In other words, Rayleigh fractionation is not an independent diagnostic tool that we apply externally to interpret our outputs; instead, it is the built-in core physical assumption, and the complete isotopic evolution is governed by the model's integrated moisture budget and microphysical processes. Given that the isoGSM dataset we use has already demonstrated robust performance in reproducing precipitation isotopic signals across East Asia in existing publications, we consider it appropriate to rely on the model's native comprehensive isotopic physics rather than implementing an oversimplified offline Rayleigh model for this study.

We also clarify two common misconceptions regarding water vapor transport in this context: (a) Distinction between water vapor transport and monsoon circulation: Monsoon circulation arises from sea-land thermal differences, and its typical wind features are mostly present in the middle and lower troposphere; in the upper troposphere, planetary winds dominate, and the monsoon signal diminishes. Water vapor transport, however, is an integrated quantity across the full atmospheric column from the surface up to roughly 300 hPa. As such, monsoon circulation alone cannot fully characterize total-column water vapor transport. On synoptic time scales, particularly during extreme weather events, the actual intensity, direction, and pathway of water vapor transport can differ markedly from the seasonal mean monsoon state. (b) Isotopic characteristics of water vapor on the weather scale: We correct a common cognitive bias here. It is conventionally assumed that water vapor from low-latitude oceans is isotopically depleted and inland water vapor is isotopically enriched. In reality, water vapor derived from low-latitude marine sources has a relatively enriched baseline isotopic composition, while water vapor from inland evapotranspiration and continental recycling is generally more depleted. During long-range transport, marine water vapor becomes progressively depleted via continuous rainout along the transport pathway, establishing a systematic isotopic gradient. This gradient is the physical basis for using isotopic signatures to distinguish marine versus continental moisture sources and to identify dominant transport pathways.

In the revised manuscript, we will strengthen the isotopic analysis in the following specific ways: First, for the mechanistic interpretation of LMWL offsets, we will add a dedicated discussion of why the two events occupy different positions relative to the LMWL: (1) June 2017 rainstorm (below LMWL): Intense convective precipitation with strong rainout and minimal sub-cloud evaporation leads to low deuterium excess (d-excess). The deep convective column also produces greater isotopic depletion per

unit rainfall. (2) January 2008 freezing event (above LMWL): Mixed rain-snow precipitation with ice-phase fractionation leads to higher d-excess in solid precipitation. Lower condensation temperatures and weaker sub-cloud evaporation also contribute to the upward offset. This interpretation will be supported by calculated d-excess values for both event periods.

2) Meteorological description of event: The analysis is lacking a thorough description of the meteorological evolution of the events. Even though data from ERA5, isoGSM and observations is available at a temporal resolution up to 6h, the description is based on 4-day means or one single time step. It is not clear why these perspectives have been chosen in describing the events. Further, a description of observed precipitation isotopic composition, temperature and precipitation amount during the events is missing (e.g. zoom-in of Fig.2). Further, the role of the frontal passage described in Section 4.2 based on the radiosounding is not clear. Is this a stationary front leading to continuous rainfall, or is moving over the observations sites leading to a peak in precipitation? Where is it positioned in the large-scale flow?

Response: We acknowledge that the meteorological description of the events was overly condensed. We will expand the event description and clarify our analytical choices as follows:

Rationale for 4-day averaging and single-time sounding: (1) The 4-day averaging window (June 22-25, January 25-28) was selected to capture the peak intensity phase of each event, when water vapor transport was strongest, and precipitation was most intense. Averaging over 4 days filters out high-frequency diurnal and mesoscale fluctuations, revealing the dominant large-scale circulation and transport patterns that are the focus of this study. (2) Radiosonde stations are sparse relative to surface meteorological stations, with only three sounding sites across the entire Dongting Lake Basin. Sounding observations are routinely available at 07:00 BT and 19:00 BT each day. The selected vertical profiles at 19:00 BT on the final day of each 4-day window represent the mature phase of the frontal system when vertical structure was most fully developed and frontal intensity reached its maximum. These profiles confirm the presence of inversion layers, verifying the influence of quasi-stationary fronts and demonstrating that precipitation was driven by frontal lifting. Moreover, the large-scale circulation remained stable throughout both extreme events, with a balanced interaction between cold and warm air masses.

Day-by-day event evolution: In the revised manuscript, we will add a day-by-day description of meteorological evolution for both events, including the observed precipitation isotopic composition, air temperature, and precipitation amount during the events in the supplementary materials.

Frontal dynamics: Both events were dominated by quasi-stationary fronts rather than rapidly moving cold fronts. For June 2017: A stationary Meiyu front was trapped in the saddle field between the Lake

Baikal blocking high and the westward-extended western Pacific subtropical high. This near-stationary frontal system produced persistent heavy rainfall over the basin for 10 consecutive days. The Changsha station was located on the warm side of the front, in the region of intense convective precipitation. For January 2008: A persistent quasi-stationary front formed south of the Yangtze River, maintained by the Ural blocking high (supplying cold air from the north) and the southern branch trough (supplying warm, moist air from the southwest). This front produced prolonged freezing rain and snowfall over a period of nearly 4 weeks. The Changsha station was located within the frontal zone, experiencing mixed rain, sleet, and snow.

3) Combination of datasets: ERA5 and isoGSM data are used in combination to describe the events. But no comparison of the event between the two datasets is given: Are the events represented in a similar way in the two datasets? What is the effect of the (supposedly - not stated in the data description)) coarser isoGSM dataset on the evolution of the events? In the supplement, a comparison between observations and modelled data is given from a climatological view, missing a comparison of observed and modelled fields for the two events of this study.

Response: Thank you for this important question regarding the consistency between the two datasets, the impact of isoGSM resolution on event representation, and event-scale model validation. We clarify the functional division of the two datasets and resolution effects as follows, and we have supplemented targeted event-specific model evaluation as requested.

First, all precipitation amounts, water vapor flux (Q) calculations, and water stable isotope analyses ($\delta^{18}\text{O}$ in precipitation and atmospheric water vapor) in this study are exclusively derived from the IsoGSM dataset. ERA5 reanalysis is used for plotting the 500 hPa geopotential height (H_{500}) field to illustrate the large-scale synoptic circulation background of the two extreme events. This clear division ensures that all moisture-related and isotope-related analyses are performed within a consistent model framework, with no cross-dataset mixing of physical variables.

To address the lack of event-specific model-data comparison, we have now performed quantitative evaluation of isoGSM performance for both extreme events, comparing simulated daily precipitation and $\delta^{18}\text{O}_p$ against in-situ station observations. The evaluation metrics (Pearson correlation coefficient and mean bias) for both events will be presented in the Supplementary Material of the revised manuscript. The results confirm that while peak precipitation magnitude is moderately underestimated, the temporal evolution of precipitation and the event-scale isotopic signatures are well reproduced by isoGSM, consistent with the reliability demonstrated by our earlier climatological-scale validation.

In the revised manuscript, we will add this cross-dataset consistency discussion in Section 2.2, include the full event-specific model validation in the Supplementary Material, and briefly summarize the

implications for result reliability in Section 4.

4) Water transport pathways: Three major water vapour transport pathways were identified for each event “by identifying systematic water vapor currents in the Q field” (lines 237-238). The manuscript does not explain how this is done. Is this a subjective decision or based on objective criteria? By additionally using air parcel trajectories, these pathways could have been compared to an objective method, but (as described in point 5) the trajectory analysis itself has major weaknesses.

Response: We acknowledge that the pathway identification method was not sufficiently described. The procedure follows objective, quantitative criteria that are standard in atmospheric river and water vapor transport research. In the revised manuscript, we will formalize these criteria explicitly in Section 2.3: For objective pathway identification criteria: (1) Continuous high-flux band: The pathway follows the central axis of a spatially continuous band of enhanced vertically integrated water vapor flux, where flux magnitude is above the background level on either side of the band; (2) Consistent directionality: The flux vectors along the pathway maintain a consistent general direction from source region to basin, without abrupt directional reversals; (3) Hydrological connectivity: The pathway connects a known water vapor source region (ocean or large water body) to the study basin, with increasing flux convergence approaching the basin.

This method was first developed and applied in our previous climatic-scale study (Xiao et al., 2025a), where pathways identified by this method were shown to be consistent with established climatological transport patterns.

For the comparison with HYSPLIT as independent verification: Although trajectory analysis has limitations, the ensemble-averaged HYSPLIT trajectories at mid-tropospheric levels (3000 m, 5500 m) show general agreement with the Q -method pathways in terms of overall direction and source regions, provided that the direction of water vapor transport is indeed consistent with the wind direction, that is, the movement direction of the air parcels. In the revised discussion, we will explicitly compare the two methods and explain why their differences are informative about vertical shear in frontal systems.

5) Trajectory analysis: The trajectory analysis is based on a too low number of trajectories. Three trajectories for one time step are not enough to describe 4-days events. As the authors correctly show, the air parcel movement can differ strongly between two grid points. Similar differences are possible between time steps and starting height. In its current form, the trajectory analysis is inadequate to describe air parcel movements for moisture transport during a 4-days event. Note, the reference Sodemann et al. (2008) used in the methods section on HYSPLIT does not fit.

Response: Thank you for pointing out the limitations of our HYSPLIT trajectory setup. Given the core

goals of this work, we will explicitly redefine and narrow the scientific role of the existing trajectory results: these single-time-step trajectories are not used for quantitative water vapor source attribution for the full 4-day event. They only serve as a supplementary Lagrangian diagnostic to illustrate representative height-resolved air-parcel pathways at the mature phase of each extreme event, for comparison against the Eulerian vertically-integrated moisture-transport pathways derived from isoGSM Q -fields. Our main conclusions regarding water-vapor sources and transport pathways are entirely built upon the isoGSM Eulerian water vapor flux analysis, rather than HYSPLIT trajectories. To avoid misleading readers, we will revise Section 2.3 and Section 4.3 to clearly state this limited scope of the trajectory analysis, and explicitly note the known limitation that these trajectories only represent one snapshot and cannot capture the full temporal variability over the 4-day event.

Regarding the reference issue: we agree that Sodemann et al. (2008) is unsuitable as a reference for the HYSPLIT model itself. We will remove this citation from the model-method description. The official HYSPLIT reference, Stein et al. (2015), will be adopted. Should we receive the opportunity to submit a revised manuscript, we will revise the method text, clarify the limited interpretive scope of trajectory results, correct the reference, and add the above-stated limitation in the main text.

Stein, A. F., Draxler, R. R., Rolph, G. D., Stunder, B. J. B., Cohen, M. D., and Ngan, F.: NOAA's HYSPLIT atmospheric transport and dispersion modeling system, *Bull. Am. Meteorol. Soc.*, 96, 2059-2077, <https://doi.org/10.1175/BAMS-D-14-00110.1>, 2015.

6) Data availability: The isoGSM link leads to a monthly isoGSM dataset until 2017, which does not correspond to the used isoGSM dataset, where data until 2022 are available. This has to be corrected. Further, a statement that isotope observations are available upon reasonable request does not follow the ACP data policy (see https://www.atmospheric-chemistry-and-physics.net/policies/data_policy.html – “In rare cases where the data cannot be deposited publicly (e.g., because of commercial constraints), a detailed explanation of why this is the case is required. The data needed to replicate figures in a paper should in any case be publicly available, either in a public database (strongly recommended), or in a supplement to the paper”).

Response: Thank you for pointing out these two data-availability issues, which we have fully revised to comply with ACP FAIR data policy.

First, we have removed the incorrect Dryad link pointing to the older monthly isoGSM2 dataset (only up to 2017). In the revised manuscript, we cite the correct isoGSM3 Zenodo repository (<https://zenodo.org/records/14681370>), which provides 6-hourly outputs, matching the dataset used in our study. We also include the corresponding methodological references, Yoshimura et al. (2008) and Bong et al. (2024), and note that we have obtained permission from the dataset curators for academic

use.

Second, we have deleted the “available upon reasonable request” statement for observational data. Upon manuscript acceptance, all observational datasets required to reproduce our figures will be deposited in Zenodo with a persistent DOI, including sounding data, meteorological station records, and precipitation isotope observations for the two extreme-event periods. Should we be granted the opportunity to submit a revised manuscript, the updated Data availability section with corrected links, citations, and data-deposition plan will be implemented accordingly.

7) Language: in several places, inadequate (non-scientific) language is used, e.g. “super-strong” (lines 31, 439,559) “abnormally deep” (line 338, 443), “abnormally strong” (line 340, 448)

Response: We will revise all colloquial and subjective descriptors to standard scientific terminology throughout the manuscript: (1) revise “super-strong” to “extremely intense” or “anomalously strong”; (2) revise “abnormally deep” to “anomalously deep”; (3) revise “abnormally strong” to “anomalously strong”. The entire text will be reviewed for consistent formal scientific language.

8) Conclusions: The conclusions remain vague or do not give any new insight. E.g. “Water vapor is a necessary condition for precipitation production, but not a sufficient condition. The production of precipitation requires not only water vapor input but also dynamic conditions to lift the water vapor and thermal conditions for water vapor condensation” is well known and does not provide any new insight.

Response: We agree that this statement is general knowledge and does not represent a novel finding of the study. We will thoroughly rewrite the Conclusions section to highlight the specific novel contributions of this research:

Rewritten conclusions will emphasize three key novel findings: (1) Unified circulation mechanism: Two phenomenologically distinct extreme events—a summer rainstorm and a winter freezing disaster—are driven by nearly identical large-scale circulation architectures, with the same configuration of a Blocking High, East Asian Trough, Southern Branch Trough, and westward-shifted Subtropical High. This suggests a common dynamical template for different types of extreme weather in the region. (2) Isotopic baseline robustness: Despite record-breaking water vapor transport intensities, precipitation isotopic compositions remain anchored to their seasonal baselines, with only ~1–1.5‰ of additional depletion. This stability arises because source-region ocean vapor isotopes are seasonally consistent, and rainout effects scale roughly with transport intensity. (3) Methodological insight: Eulerian flux-based methods and Lagrangian trajectory methods yield systematically different results in intense frontal zones due to strong vertical wind shear. Studies relying solely on trajectory

methods may mischaracterize bulk column-integrated water vapor transport in frontal precipitation systems.

The general statement about water vapor being necessary but not sufficient will be removed from the conclusions and integrated into the discussion of frontal precipitation mechanisms where it provides context.

In its current form, I do not recommend this study for publication in ACP. There are major gaps describing the data and method, in the analysis of the events themselves and in the data availability. Further, it is not clear how this study contributes new insight in water vapour transport for extreme precipitation or freezing events.

Response: We sincerely thank the reviewer for the critical and constructive overall evaluation. We fully acknowledge that the original manuscript contained notable deficiencies in data documentation, methodological description, event-scale analysis, and data availability, which weakened the clarity, robustness, and scientific contribution of this work. We have comprehensively addressed all major concerns through systematic revisions, as summarized below. Importantly, while we carefully rectify these technical and descriptive shortcomings, our core focus remains on the formulation and mechanistic interpretation of the scientific questions rather than merely data presentation.

First, we have thoroughly revised the data description to eliminate dataset confusion. We explicitly clarify that all precipitation, temperature, water vapor transport, and isotopic analyses are exclusively based on isoGSM outputs, while ERA5 is only used for synoptic background visualization and is not involved in any quantitative diagnosis. All ambiguous statements regarding dataset usage have been corrected in the revised manuscript.

Second, we have substantially strengthened model validation and physical interpretation. We have added event-specific quantitative evaluations of simulated precipitation, temperature, and $\delta^{18}\text{O}_p$ against in-situ observations for both extreme events in the supplementary material. We further clarified the embedded Rayleigh-fractionation physics within the isoGSM model and expanded mechanistic discussions on the distinct LMWL offsets and d-excess behaviors between the warm-season rainstorm and cold-season freezing event, highlighting the unique diagnostic value of water isotopes for distinguishing cloud microphysical and moisture transport processes.

Third, we have updated the data availability section to fully comply with ACP FAIR data policies. We corrected the outdated isoGSM dataset link and will publicly deposit all observational meteorological and isotopic data for the two extreme events into the Zenodo repository with a permanent DOI upon acceptance, ensuring full transparency and reproducibility.

Finally, we explicitly clarified the novelty of this study. This work is a weather-scale extension of our

previous climatic-scale study published in ACP in 2025. Moving beyond long-term seasonal mean patterns, it focuses on once-in-a-century extreme events and verifies whether the climatic-scale circulation-transport-isotope relationships still hold under far-from-equilibrium synoptic conditions. Unlike conventional dynamic and water vapor analyses for extreme events, our study adopts stable water isotopes as natural tracers to contrast the transport pathways, condensation regimes, and microphysical mechanisms governing two types of extreme hydrometeorological events over the Dongting Lake Basin. The distinct isotopic anomalies and LMWL deviations provide new observational evidence for differentiating extreme warm- and cold-season event mechanisms. We sincerely hope the reviewer will reconsider the revised manuscript for submission to ACP.