

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.

#1 Reviewer

This work systematically explores water vapor transport characteristics and their modulation effects on stable water isotopes associated with two rare once-in-a-century events over the Dongting Lake basin: the June 2017 extreme rainstorm and the January 2008 major freezing event. This thematic focus bears strong scientific relevance for unpacking regional hydrometeorological evolution and the driving mechanisms of extreme synoptic phenomena across the East Asian monsoon domain. Consequently, it offers meaningful implications for hydrological cycle diagnosis, severe weather forecasting, and paleoclimatic proxy interpretation. The authors combine in-situ monitoring records, reanalysis datasets, and isotope model outputs to build a multi-angle analytical framework featuring coherent and robust experimental design. Several core discoveries advance our mechanistic knowledge of subtropical monsoon basin extremes—for instance, analogous large-scale circulation patterns governing seasonally disparate disasters, low-latitude southwest oceans acting as the primary water vapor sources, and systematic isotopic fractionation along long-distance transport pathways. Overall, the paper features clear organizational logic, reliable multi-source observational and simulated datasets, and interpretive conclusions that are largely supported by the quantitative analyses presented. Nevertheless, several aspects require refinement to strengthen the manuscript's scientific rigor, including standardized conceptual terminology, transparent data documentation, physically consistent inter-case comparisons, and uniform formatting across the text. Therefore, I recommend a Major Revision for this manuscript.

[Response: We sincerely appreciate your positive evaluation and constructive suggestions for improving the manuscript. We have addressed all comments as detailed below.](#)

Detailed review comments are as follows:

1. Incorporate historical baseline comparisons in moisture flux analyses: In Section 3.2.1, the authors contrast the four-directional mean moisture flux of Event A against climatological June averages; however, comparisons against historical synoptic-period background values are absent. Drawing on Table 1 in the Discussion section, the manuscript should incorporate a supplementary comparison between Event A and corresponding historical-period water vapor transport metrics. The mean inflow and outflow vapor flux across the four basin boundaries during matching historical windows should also be quantified. Identical revisions are requested for Section 3.3.1 (Event B) to better highlight the

anomalous water vapor circulation signatures characteristic of these extreme episodes.

Response: We fully agree that synchronous historical baseline comparisons are essential for quantifying event anomaly. In the revised manuscript, we will: (1) Calculate synchronous event climatological means: Compute multi-year (2008-2022) average water vapor fluxes and precipitation ^{18}O for the same event calendar windows (June 22-25 and January 25-28) using ERA5 reanalysis; (2) Add to Table 1: Insert a new row for “event climatological mean” for both June and January, enabling direct comparison with Event A, Event B, and monthly means; (3) Quantify anomaly percentages: In Sections 3.2.1 and 3.3.1, explicitly report the percentage increase of each boundary flux during the extreme event relative to the synchronous climatological mean.

2. Expand Figure 8 to include seasonal background isotopes: Figure 8 displays paired $\delta^{18}\text{O}$ and $\delta^2\text{H}$ scatter points covering the full observational dataset, alongside samples collected during the June 2017 rainstorm and the January 2008 freezing disaster. To enable direct comparison of isotopic signatures between extreme event intervals and typical background conditions, additional scatter panels illustrating multi-year January and June baseline precipitation isotopes should be added. The figure caption should be revised accordingly to reflect this expanded content.

Response: This is an excellent suggestion that will greatly improve the comparative power of Figure 8. In the revised manuscript, we will restructure Figure 8 as a 1×2 panel figure: (1) For Panel (a): Full dataset with all samples, June 2017 event, January 2008 event, and overall LMWL; (2) For Panel (b): January and June seasonal comparison—multi-year January and June baseline samples overlaid with exceptional January 2008 and June 2017 event samples. The figure caption will be expanded to describe all panels and summarize the key comparison result: that extreme event samples fall within the natural seasonal isotopic variability, with only modest shifts in slope and intercept.

3. Revise the “centennial extreme events” terminology for accurate description of extreme event return period: The manuscript employs “centennial extreme events” to describe the magnitude of the two studied extreme events. In climatological and paleoclimatic research, “centennial extreme events” specifically denotes the temporal resolution or time span of a study period, not the recurrence interval of individual synoptic events. For the 2017 rainstorm and 2008 freezing disaster that represent once-in-a-century extremes, please replace “centennial extreme events” and analogous expressions with accurate terms such as “Extreme rainstorm once-in-a-century” and “Major freezing disaster once-in-a-century” throughout the text to avoid conceptual confusion between research time scale and event recurrence property.

Response: We fully agree with this terminological correction. We will replace all instances of

“centennial extreme events” with “once-in-a-century extreme events” throughout the entire manuscript, including the title, abstract, main text, figure captions, and conclusions. We will use phrasing such as “once-in-a-century extreme rainstorm” and “once-in-a-century major freezing disaster” where appropriate to clearly indicate return period.

4. Address data gaps and ERA5 precipitation biases in Figure 2: A data gap is visible in the second half of 2019 in Figure 2b. The authors should explain the root cause of this missing interval (e.g., gaps in raw observational inputs or temporary breaks in model simulation runs). Furthermore, while Figure 2a shows that measured rainfall during the 2017 extreme rainstorm ranks highest across all recorded years, the ERA5 reanalysis dataset in Figure 2b fails to reproduce this record-breaking magnitude. It is necessary to evaluate whether this deviation affects the analysis of isotopic signatures under intense rainfall and discuss how this mismatch might influence the reliability of the core interpretations.

Response: Thank you for this valuable comment. The data gap visible in late 2019 in the original Fig. 2b resulted from an error during data extraction and plotting, rather than inherent missing values in the isoGSM dataset. We have reprocessed the full time series and will fill this gap in the revised figure. We also clarify that precipitation shown in revised Fig. 2b will be sourced from isoGSM instead of ERA5, consistent with the overall data usage throughout this work. ERA5 is only used to generate synoptic maps of 500 hPa geopotential height and is not adopted for quantitative analysis of precipitation or isotopic signals. We recognize that global model outputs like isoGSM tend to underestimate the absolute peak intensity of local extreme rainfall. We have added event-specific quantitative model evaluation in Supplementary Table S2, comparing station observations against isoGSM outputs for precipitation, temperature, and $\delta^{18}\text{O}_p$. The validation shows that, although the model underestimates peak rainfall magnitudes, it reasonably captures daily precipitation variability and event-scale isotopic anomalies. Our core conclusions are built on relative isotopic gradients, LMWL offsets, and departures from seasonal climatological baselines, rather than the instantaneous peak precipitation values. Therefore, this underestimation does not undermine our key physical interpretations.

Should we receive the opportunity to submit a revised manuscript, we will correct the extraction error to remove the artificial gap in Fig. 2, update the figure caption to clarify data sources, and keep the supplementary event-scale evaluation along with its discussion in Section 4.

5. Clarify the motivation for comparing static vs. dynamic trajectories: Regarding Sections 3.2.3, 3.3.3, and 4.3, the vapor pathways derived in Sections 3.2 and 3.3 represent static long-term mean fields without temporal fluctuations, which differ fundamentally from the time-evolving airflow tracks

generated by the HYSPLIT model. The manuscript should elaborate on the scientific merit of comparing these two distinct trajectory approaches and explain how this dual-pathway analysis enhances our understanding of moisture transport dynamics during severe weather events.

Response: This is a very insightful comment. In the revised manuscript, we will explicitly explain the scientific rationale for comparing the two approaches:

First, complementary perspectives on water vapor transport: (1) Eulerian Q -method pathways (event-averaged, column-integrated): These represent the bulk mass transport of water vapor. They answer: what is the net transport of water vapor, and through which major corridors does it flow? This is the relevant quantity for understanding precipitation budgets and large-scale circulation impacts. (2) Lagrangian HYSPLIT trajectories (instantaneous, height-resolved): These represent the motion of individual air parcels at specific levels. They answer: where did an air parcel at a specific location and altitude come from, and how did it evolve vertically? This is the relevant quantity for understanding three-dimensional flow structure and vertical mixing.

Second, why their difference is scientifically important: The comparison reveals that in intense frontal systems, bulk column-integrated water vapor transport direction can differ substantially from wind direction at any single height. Q represents the full column-integrated water vapor transport and inherently counteracts water vapor fluxes from competing directions. By contrast, HYSPLIT trajectories only depict moisture transport at selected discrete levels (e.g., three heights), which cannot identify which layer contributes the moisture for precipitation nor quantify the total moisture flux feeding the extreme rainfall. This has significant implications for studies that use only trajectory methods for water vapor source attribution—such studies may misrepresent total column water vapor transport if they only sample one or a few height levels. The dual-method approach therefore provides a more complete and physically nuanced picture of water vapor transport in complex weather systems. We will also clarify that the Q -method pathways are not “static long-term mean fields” in this study—they are 4-day event-averaged fields, capturing the synoptic state of the extreme event itself.

6. Revise the physical mechanism behind low-latitude vapor isotope stability: Revisions are needed for statements in Section 4.1 and the Abstract. The manuscript claims that the isotopic composition of oceanic vapor at low latitudes displays weak seasonal shifts due to stable largescale atmospheric backgrounds. In reality, low-latitude regions are frequently disturbed by the Intertropical Convergence Zone (ITCZ), tropical cyclones, easterly waves, and other synoptic systems, leading to highly variable atmospheric states. The muted seasonal variability of primary marine vapor isotopes is primarily driven by subtle seasonal fluctuations in isotopic ratios over evaporative ocean surfaces. The text should be reworded to accurately reflect these tropical atmospheric dynamics.

Response: Thank you for this important physical correction. We completely agree that our original explanation was inaccurate and oversimplified. In the revised manuscript, we will rewrite the relevant passages in the Abstract and Section 4.1 to accurately reflect the underlying physics: The isotopic composition of water vapor evaporated from low-latitude oceans shows pronounced seasonal variability. This arises from seasonal changes in sea surface temperature and surface seawater isotopic ratios, the two dominant controls on the isotopic composition of evaporating marine vapor. The ITCZ, tropical cyclones, easterly waves, and other synoptic systems further modulate atmospheric circulation and local precipitation on short timescales, jointly shaping the seasonal cycle of marine vapor isotopes. This revision properly accounts for the clear seasonal variation in low-latitude oceanic water vapor isotopes, rather than assuming muted seasonal signals in the marine source air masses.

7. Specify isoGSM grid coordinates for transparency: Section 3.1 mentions that 6-hourly $\delta^{18}\text{O}$ outputs from isoGSM at the Changsha matching grid cell are used, but the text fails to specify whether this grid corresponds to the QXY or MPL observation station (Figure 2 contains the same ambiguity). To ensure data transparency and reproducibility, the exact geographic coordinates (latitude and longitude) or the designated monitoring station corresponding to the target isoGSM grid cell must be clearly stated (Lines 270–282).

Response: We will add explicit grid coordinate information in Section 2.2(3) and Section 3.1: (1) The isoGSM target grid cell is centered at 28.125° N, 112.500° E; (2) This grid cell corresponds to the QXY precipitation sampling station (28.20° N, 113.01° E), with a horizontal distance of approximately 55 km between station and grid center; (3) The MPL sounding station (28.12° N, 113.05° E) falls within the same isoGSM grid cell. This revision ensures full transparency and reproducibility of the data extraction procedure.

8. Add labels to Figure 4 and Figure 6: The red rectangular frames in Figures 4 and 6 lack textual labels. The authors should confirm whether these boxes delineate the Dongting Lake Basin domain and add corresponding explanatory notes in each figure caption.

Response: We will enhance the red rectangular boxes for better visibility and add an explicit statement in each figure caption confirming that the red rectangles delineate the Dongting Lake Basin study domain. We will also add a “Dongting Lake Basin” label directly on the map panels for immediate visual identification.

9. Standardize geographic presentation in Figure 10:

(1) Remove national boundary lines where feasible.

- (2) Adopt a uniform format for latitude and longitude notation throughout the manuscript.
- (3) Align the geographic extent and central coordinates across all subplots to facilitate intuitive cross-comparison.
- (4) Unify the line color and thickness for all trajectory curves to maintain visual consistency.

Response: We will implement all four suggestions for Figure 10: (1) Remove national political boundary lines, retaining only coastlines and major topographic features for geographic reference; (2) Standardize all latitude/longitude labels to the format with consistent font size and placement; (3) Set identical geographic extent (10°S–60°N, 40°E–180°E) and central projection for all three subplots (MPL Event B, MPL Event A, ChD Event A) to enable direct visual comparison; (4) Unify trajectory line styling: 1000 m (red dashed), 3000 m (blue dashed), 5500 m (green dashed), with consistent line thickness and dot size across all panels.

10. Standardize time references to Beijing Time: The manuscript alternates between UTC and Beijing Time (e.g., sampling timestamps in Section 2.2 versus radiosonde observation hours in Section 4.3). Given that the study domain is located in China, all time references should be uniformly converted to Beijing Time, with all relevant text updated accordingly.

Response: We will standardize all time references to Beijing Time (BT) throughout the manuscript. The abbreviation will be defined on first use, and all sampling times, observation times, and model output times will be consistently expressed in BT. We will verify that no UTC references remain in the text, figure captions, or tables.

11. Standardize coordinate formatting: Coordinate notation is inconsistent throughout the manuscript, switching between discrete points (e.g., “28.20°N, 113.01°E”) and zonal/meridional ranges (e.g., “24.63°N–30.42°N, 107.27°E–114.12°E”). A single, standardized format (with consistent decimal precision and punctuation separators) should be applied to all geographic coordinates to improve readability and presentation.

Response: We will standardize all coordinate notation throughout the manuscript: (1) Point coordinates: “XX.XX°N, XX.XX°E”; (2) Coordinate ranges: “XX.XX°N–XX.XX°N, XX.XX°E–XX.XX°E”. All coordinates will retain two decimal places and use consistent punctuation and spacing.

12. Include event-specific model evaluations: The manuscript infers high model confidence for extreme events based solely on good seasonal agreement between simulated and observed meteorological and isotopic data. To further validate the model’s reliability during synoptic extremes, event-specific comparisons of these variables for the two studied disasters should be included as

supplementary analysis.

Response: We fully agree that dedicated event-oriented validation is essential to establish model performance under synoptic extreme conditions, rather than relying only on seasonal-scale agreement. We have therefore carried out quantitative event-specific comparisons between in-situ station observations and collocated isoGSM outputs for both the 2017 rainstorm and 2008 freezing-disaster events. Key evaluation metrics, including root-mean-square error (RMSE), mean bias, and Pearson correlation coefficient for daily precipitation, near-surface temperature, and precipitation $\delta^{18}\text{O}_p$ are compiled into Supplementary Table S2. A concise summary of these validation outcomes together with their implications for result reliability will be integrated within Section 3.1 of the revised manuscript. The evaluation results demonstrate that isoGSM achieves reliable performance for the two target extreme events, especially for the simulation of precipitation isotopic composition.

13. Revise the inaccurate southwest transport statement and clarify water vapor transport direction and source regions: The expression referring to southwest transport as the primary water vapor source is conceptually imprecise. “Southwest” indicates the direction of water vapor transport rather than the geographic origin category of air masses. The water vapor supplied via the southwest transport pathway essentially originates from low-latitude ocean surfaces including the Bay of Bengal and the Indian Ocean, and is transported to the basin under the control of southwesterly circulation. Please revise relevant descriptions in the main text to distinguish transport direction from air mass source attributes, and explicitly specify that water vapor is mainly delivered through the southwest pathway with source areas over the low-latitude Bay of Bengal and Indian Ocean.

Response: This is an excellent suggestion for improving conceptual precision. We will systematically revise all relevant descriptions throughout the manuscript to clearly distinguish between transport direction and source regions. For example, the original: “Southwest transport contributed the largest water vapor share for both extreme events” was revised to “Water vapor is primarily transported into the basin via the southwestward transport corridor, with source regions located over the low-latitude Bay of Bengal and Indian Ocean”. This clarification will be applied consistently in the Abstract, Introduction, Results, Discussion, and Conclusions sections, ensuring that direction and origin are never conflated.