Response to Reviewer 1 Comments

1. Summary

Thank you very much for taking the time to review our manuscript. We sincerely appreciate your constructive comments and suggestions, which have helped us improve the clarity, reproducibility, and scientific rigor of the manuscript. In response to your comments, we revised the manuscript by unifying the event information, rewriting the Introduction, clarifying the functions of HYSPLIT, ERA5, and tower observations, adding the anomaly baseline and spatial averaging definitions, improving the dynamic and thermal diagnostic analysis, revising the Discussion, standardizing terminology and figure captions, and removing overstated or insufficiently supported statements. The revised manuscript is provided with tracked changes, and the major textual changes are specified below by location, original wording, and revised wording.

2. Point-by-point response to Comments and Suggestions for Authors

Comments 1a

Reviewer comment: The study period and event sample are described inconsistently in the Abstract, Table 1, and the main text. Please unify the time span, total number of observed events, any excluded cases (with a brief reason), the final sample used for analysis, event numbering (Dust1–Dust8), and the definition of spring and summer throughout the manuscript.

Response: *Thank you very much for this important comment. We agree that inconsistent descriptions of the study period and event sample could cause confusion. We therefore revised the Abstract, Sect. 2.2, Table 1, the Results, and the Conclusion to use the same study period, event labels, excluded-event description, and seasonal grouping throughout the manuscript.*

Detailed changes made in the manuscript:

Location in revised manuscript: *Abstract*

Original text: *Based on dual-gradient observational experiments in the central and peripheral regions of the TD, combined with ERA5 data and HYSPLIT analysis, eight dust storms from April to June 2024 were studied.*

Revised text: *This study combined dual-gradient tower observations from Tazhong (TZ) and Xiaotang (XT), ERA5 reanalysis, and HYSPLIT backward trajectories to examine eight dust-storm events in spring and summer 2024.*

Reason for this revision: *The wording was revised to avoid the inconsistent April–June description and to state the final sample as eight complete events in spring and summer 2024.*

Location in revised manuscript: *Sect. 2.2 "Observational Data"*

Original text: *Nine dust storm events were observed between April 3 and July 10, 2024 ... Therefore, the remaining eight observations became the primary samples for this study.*

Revised text: *Nine dust storm events were observed between 31 March and 18 June 2024, and the corresponding dust samples were collected from 3 April to 10 July 2024. However, during the second observation, data from the TZ station were missing, preventing a complete paired record. Therefore, the remaining eight complete dust storm events became the primary samples for this study.*

Reason for this revision: *The observation period, sample-collection period, excluded case, and final sample were separated and clarified.*

Location in revised manuscript: *Table 1*

Original text: *Tab. 1 Sample details; event IDs were shown as 1–9; dates were partly written as 2024.3.31, 2024.4.3, etc.; the excluded event was not clearly labelled in the table.*

Revised text: *Table 1. Summary of observed dust-storm events and sample collection information; event IDs are now shown as Dust1–Dust8, with one row labelled "Excluded event"; dates and times are standardized as YYYY-MM-DD HH:MM.*

Reason for this revision: *The table was revised so that the event numbering and time format are consistent with the Abstract, Methods, Results, and Conclusion.*

Location in revised manuscript: *Table 1, representative row examples*

Original text: *1 / TZ / 2024.3.31 / 22 / 2024.4.3; 2 / XT / 2024.4.5 / 5 / 2024.4.6; 9 / TZ / 2024.6.18 / 58 / 2024.7.9.*

Revised text: *Dust1 / TZ / 2024-03-31 12:00 / 22 / 2024-04-01 09:00; Excluded event / XT / 2024-04-05 01:00 / 5 / 2024-04-05 06:00; Dust8 / TZ / 2024-06-18 07:00 / 2 / 2024-06-18 09:00.*

Reason for this revision: *Representative rows were corrected to show the exact onset time, duration, sample-collection time, and event label.*

Location in revised manuscript: *Sect. 3.2 and Sect. 3.3*

Original text: *In summary, the pressure gradient before dust storms in March and April is significantly greater than in May and June ... dust storms occurring from March to June were categorized into two periods for analysis: spring (March and April) and summer (May and June).*

Revised text: *These background fields indicate a seasonal contrast in the pre-storm environment. The March–April events were more closely associated with stronger pressure-gradient and lower-tropospheric circulation signals, whereas the May–June events showed a more evident thermal* *background. Therefore, the analyzed events were grouped into spring cases and summer cases for the following dynamic and thermal anomaly analysis.*

Reason for this revision: *The seasonal grouping was retained but rewritten more cautiously and consistently.*

Location in revised manuscript: *Sect. 5 "Conclusion"*

Original text: *The conclusion previously referred to the dust-storm sample in a less consistent way and included broader statements based on the original event numbering.*

Revised text: *This study examined eight complete dust-storm events over the Taklimakan Desert using HYSPLIT trajectories, ERA5 reanalysis, and dual-gradient tower observations.*

Reason for this revision: *The conclusion now uses the same final sample definition as the Abstract and Methods.*

Comments 1b

Reviewer comment: *The Introduction provides a solid background, but the narrative could be made more coherent. I suggest refining the logical progression from motivation to knowledge gaps and then to the specific objectives/contributions of this study, and updating the citations with the most relevant literature published in the last five years.*

Response: *Thank you for your valuable suggestion. We rewrote the Introduction to improve its logical progression. The revised Introduction now moves from the regional importance of East Asian dust storms and the Taklimakan Desert, to dynamic and thermal forcing, transport pathways, topographic effects, and the remaining observational gaps. Recent studies published in the last five years were also added where they directly support the revised scientific logic.*

Detailed changes made in the manuscript:

Location in revised manuscript: *Sect. 1, opening background*

Original text: *Dust storms are one of East Asia's most severe natural disasters, occurring frequently in arid and semi-arid regions such as the Taklamakan Desert in China and the Gobi Desert bordering Mongolia. These events are widespread in spring, impacting millions ...*

Revised text: *Dust storms are among the major natural hazards in arid and semi-arid regions of East Asia, where they are often accompanied by strong winds, air pollution, and reduced visibility, affecting transportation, agriculture, ecosystems, and public health ... Mineral dust can also influence atmospheric radiation, cloud processes, snow and ice albedo, and regional climate through long-range transport.*

Reason for this revision: *The opening was streamlined to introduce the regional relevance and scientific significance without excessive general descriptions.*

Location in revised manuscript: *Sect. 1, TD study-area motivation*

Original text: *The Taklamakan Desert is in Asia's arid and semi-arid regions, characterized by scarce precipitation, vast sandy terrain, and dry climatic conditions. Combined with the influence of Mongolian cyclones, these factors make the region prone to frequent dust storms in spring ...*

Revised text: *The Taklimakan Desert (TD) is located in the arid Tarim Basin and is surrounded by the Tianshan, Pamir, and Kunlun Mountains. Because of its extensive mobile sand surfaces, scarce precipitation, and unique basin topography, the TD is one of the major dust-source regions in East Asia.*

Reason for this revision: *The study-area motivation was rewritten to emphasize the TD as a major dust-source region shaped by surface and basin-topographic conditions.*

Location in revised manuscript: *Sect. 1, process framework paragraph*

Original text: *The formation of dust storms is a complex physical process driven by interactions between the atmosphere and surface soil, where dust source materials, dynamic conditions, and thermal factors play critical roles in influencing their occurrence ...*

Revised text: *The formation and development of dust storms are jointly controlled by atmospheric forcing and surface conditions. Among these controls, dynamic and thermal processes are particularly important because they determine whether surface particles can be lifted and whether the lifted dust can be transported vertically and horizontally ... Therefore, dust-storm processes cannot be explained by a single factor alone, but should be examined through the coupled effects of dynamic forcing, thermal instability, transport pathways, and terrain-modified local surface conditions.*

Reason for this revision: *The previous descriptive explanation was replaced by a clearer conceptual framework linking dynamic forcing, thermal forcing, transport pathways, and terrain effects.*

Location in revised manuscript: *Sect. 1, dynamic-forcing literature paragraph*

Original text: *In East Asia during spring, there is a significant positive correlation between strong winds and the frequency of dust storms. In East Asia, Mongolian cyclones frequently generate strong winds, which in turn lead to the formation of dust storms ...*

Revised text: *Previous studies have shown that dynamic forcing is a key driver of many spring dust storms in East Asia. Mongolian cyclones, cold fronts, cold high-pressure systems, and strong pressure gradients can generate strong near-surface winds and rapidly activate dust sources ... More recently, Mu et al. (2025) quantitatively assessed the role of atmospheric depressions and Mongolian cyclones in spring dust activity over East Asia ... However, many of them focus on northern China and the Gobi* *source region, whereas the pre-storm dynamic evolution over the Taklimakan Desert, especially its connection with local tower-based observations, remains less well documented.*

Reason for this revision: *Recent literature was added and the gap was clarified: dynamic evolution over the TD and its link to tower observations remain insufficiently documented.*

Location in revised manuscript: *Sect. 1, thermal-forcing literature paragraph*

Original text: *The original Introduction mentioned thermal factors mainly as general supportive conditions and did not clearly explain why thermal forcing is important for the TD or how it differs from dynamic forcing.*

Revised text: *Compared with the relatively well-recognized role of dynamic forcing, the influence of thermal forcing is more complex and is particularly important for inland desert regions such as the TD ... These findings suggest that distinguishing between dynamic and thermal controls is useful for understanding seasonal differences in dust-storm development. Nevertheless, how these seasonal differences are reflected in near-surface wind, temperature, and vertical meteorological profiles still requires further observational evidence ...*

Reason for this revision: *The revised paragraph explicitly introduces the thermal-forcing gap and connects it to vertically resolved observations.*

Location in revised manuscript: *Sect. 1, pathway and topography paragraphs*

Original text: *The original Introduction discussed dust transport and fluxes mainly from a broad transport or emission perspective, with less connection between pathways, dynamic–thermal forcing, and terrain constraints.*

Revised text: *Transport pathways provide an important way to connect dynamic and thermal forcing with dust-storm evolution ... These studies demonstrate the value of trajectory analysis, but pathway classification alone cannot fully explain why different dust storms develop under different dynamic or thermal backgrounds. Topography further modifies dust-storm occurrence, transport, and near-surface wind and temperature structures ...*

Reason for this revision: *The revised text now links pathway classification and terrain effects to the central dynamic–thermal interpretation of the study.*

Comments 1c

Reviewer comment: Please streamline the Methods and clarify how each method supports the study objectives and key conclusions. A short method–objective mapping paragraph at the beginning is sufficient. Briefly state the role of HYSPLIT (pathway classification and source indication), ERA5 diagnostics (dynamical: ΔP/wind/geopotential; thermal: ΔT/instability/BLH), and flux/profile calculations (vertical structure and terrain effects).

Response: *Thank you for this helpful suggestion. We revised the Methods and the corresponding Results structure to make the function of each method clearer. HYSPLIT is now used for pre-storm airflow pathway identification, ERA5 is used for synoptic background and dynamic–thermal anomaly diagnostics, and tower observations are used for near-surface vertical wind and temperature responses. The previous flux-centered Results section was replaced by tower-observed wind and temperature anomaly profiles to avoid overinterpretation of uncertain flux estimates.*

Detailed changes made in the manuscript:

Location in revised manuscript: *Sect. 2.2 "Observational Data"*

Original text: *The gradient collection system gathers dust samples during dust storms using BSNE (Big Spring Number Eight) dust collectors installed at each layer, which are used to determine the horizontal dust flux at different heights.*

Revised text: *In the present analysis, the meteorological gradient observations were mainly used to examine wind-speed, wind-shear, and temperature-profile responses during dust-storm development.*

Reason for this revision: *The role of tower observations was redefined to support the revised profile-based analysis.*

Location in revised manuscript: *Sect. 2.3 title and opening*

Original text: *2.3 Remote Sensing Data. To further investigate the causes of dust storms, the study analyzed relevant meteorological conditions using the ERA5 reanalysis dataset.*

Revised text: *2.3 ERA5 Reanalysis Data. To further investigate the meteorological conditions associated with dust storm occurrence, this study used the ERA5 reanalysis dataset.*

Reason for this revision: *The section title and opening sentence were revised to accurately describe ERA5 rather than remote-sensing data.*

Location in revised manuscript: *Sect. 2.3, ERA5 role paragraph*

Original text: *The original Methods did not distinguish between original ERA5 fields and diagnostic anomaly indicators.*

Revised text: *In this study, ERA5 data were used in two ways. First, the original ERA5 fields were used to describe the synoptic-scale meteorological background ... Second, selected ERA5-derived diagnostic indicators were used for anomaly analysis after background removal.*

Reason for this revision: *The revised Methods now explicitly map ERA5 to the synoptic-background analysis and anomaly-diagnostic analysis.*

Location in revised manuscript: *Sect. 2.4 "HYSPLIT Model"*

Original text: *The study used the Hybrid Single-Particle Lagrangian Integrated Trajectory (HYSPLIT) model to analyze the transport pathways of each dust storm event. This model utilizes grid data from the Global Data Assimilation System (GDAS) dataset to compute backward trajectories.*

Revised text: *The study used the Hybrid Single-Particle Lagrangian Integrated Trajectory (HYSPLIT) model to analyze the transport pathways of each dust storm event ... For each event, backward trajectories were initialized at the dust-storm onset time ... Three starting heights, 100, 500, and 1500 m above ground level (AGL), were selected ... Each trajectory was traced backward for 48 h.*

Reason for this revision: *The HYSPLIT role and major settings were added to make the pathway analysis reproducible.*

Location in revised manuscript: *Sect. 2.5 and Sect. 3.4*

Original text: *2.5 The calculation of horizontal dust flux (Q) and vertical dust flux (F); 3.4 Dust Flux Analysis.*

Revised text: *The previous flux-calculation section was removed from the main analysis, and Sect. 3.4 was revised as "Tower-observed wind and temperature anomaly profiles".*

Reason for this revision: *The analysis was streamlined and made more directly supported by the available meteorological observations.*

Location in revised manuscript: *Sect. 3.4 revised analysis*

Original text: *The original section focused on horizontal dust flux (Q), vertical dust flux (F), and their height-dependent changes at TZ and XT.*

Revised text: *The tower observations further support the regional dynamic and thermal characteristics identified from the ERA5-based analysis. Figure 11 shows the composite evolution of 10 m wind-speed anomaly, 2–10 m wind-shear anomaly, 0.5–10 m air-temperature-difference anomaly, and 2 m air-temperature anomaly from −24 to +3 h relative to dust-storm onset.*

Reason for this revision: *The revised Results section links tower observations directly to the dynamic–thermal interpretation.*

Comments 1d

Reviewer comment: Please improve reproducibility by clarifying key definitions and settings. Define the anomaly baseline used for "anomalous wind/anomaly wind field". Specify whether the 24/12/6/3 h windows are referenced to event onset or storm time/peak. Provide the spatial averaging domain and essential HYSPLIT settings, including starting height, back-trajectory duration, and pathway classification criteria.

Response: *Thank you for this important comment. We revised Sects. 2.3 and 2.4 to specify the ERA5 anomaly baseline, lead-time definition, spatial averaging domains, latitude-weighted averaging, and*

HYSPLIT settings. We also clarified in Sect. 3.3 that the 24/12/6/3 h windows are referenced to dust-storm onset.

Detailed changes made in the manuscript:

Location in revised manuscript: *Sect. 2.3, ERA5 diagnostic indicators*

Original text: *The previous manuscript described anomalous wind fields and pressure/temperature changes but did not define the anomaly baseline or the spatial-averaging domains.*

Revised text: *The dynamic indicators included mean sea-level pressure-gradient magnitude, 850 hPa geopotential-height-gradient magnitude, and 10 m wind speed. These indicators were averaged over the regional domain of 70–100° E and 30–50° N ... The thermal indicators included 2 m air temperature, skin temperature, surface–air temperature difference, surface net shortwave radiation, and boundary-layer height ... The desert core was defined using a Taklimakan Desert polygon mask within 72–92° E and 35–43° N. Grid cells outside the desert mask were excluded from the thermal averaging.*

Reason for this revision: *The indicators and spatial domains were explicitly defined.*

Location in revised manuscript: *Sect. 2.3, anomaly baseline*

Original text: *The original manuscript did not explain how the ERA5 background state was calculated.*

Revised text: *For each dust-storm event and each lead time relative to storm onset, the corresponding 2024 ERA5 value was extracted. The background value was calculated from ERA5 records during 2015–2025, excluding 2024, using the same hour of the day within a ±3-day calendar window. The anomaly was then obtained by subtracting this background value from the corresponding 2024 event value. Area-mean values were calculated using latitude-weighted averaging with cos(latitude) as the weight.*

Reason for this revision: *The anomaly calculation is now reproducible.*

Location in revised manuscript: *Sect. 3.3, pressure-difference definition*

Original text: *Fig.6 and Fig.7 show the changes in average sea-level pressure over the 3, 6, 12, and 24 hours preceding the dust storms ...*

Revised text: *Figures 6 and 7 show the sea-level pressure differences at 24, 12, 6, and 3 h before dust-storm onset in spring and summer, respectively. The pressure difference was calculated as the sea-level pressure at onset minus that at each preceding time.*

Reason for this revision: *The reference time was clarified as dust-storm onset.*

Location in revised manuscript: *Sect. 3.3, surface–air temperature-difference definition*

Original text: *Figures 8 and 9 show the temperature changes 3, 6, 12, and 24 hours before the dust storms ...*

Revised text: *Figures 8 and 9 show the changes in surface–air temperature difference before dust-storm onset. The surface–air temperature difference was defined as Ts–T2m, and its change was calculated as the onset value minus the value at 24, 12, 6, and 3 h before onset.*

Reason for this revision: *The thermal diagnostic and its lead-time reference were clarified.*

Location in revised manuscript: *Sect. 2.4, HYSPLIT settings*

Original text: *The original HYSPLIT description did not include the complete model settings, start heights, endpoint, trajectory duration, or event ending times.*

Revised text: *The GDAS1 data have a horizontal resolution of 1° × 1° and a temporal interval of 3 h. Model vertical velocity was used for the vertical motion calculation. For each event, backward trajectories were initialized at the dust-storm onset time. The trajectory endpoint was set at 39.43° N, 85.97° E ... Three starting heights, 100, 500, and 1500 m above ground level (AGL), were selected ... Each trajectory was traced backward for 48 h. The trajectory ending times were 12:00 UTC on 31 March, 04:00 UTC on 12 April, 11:00 UTC on 17 April, 21:00 UTC on 26 April, 07:00 UTC on 12 May, 11:00 UTC on 20 May, 04:00 UTC on 4 June, and 07:00 UTC on 18 June 2024 for Dust1–Dust8, respectively.*

Reason for this revision: *The key HYSPLIT settings were added for reproducibility.*

Location in revised manuscript: *Sect. 3.1, pathway classification text*

Original text: *The original text described the pathways as east-to-west movement, transport across mountains, and west-to-east or thermal-factor-driven movement.*

Revised text: *Dust1, Dust3, Dust4, Dust5, and Dust6 mainly showed east-inflow transport, with air masses entering the TD through the northeastern opening of the Tarim Basin. Dust2 was characterized by a south-to-north pathway related to airflow crossing the Tibetan Plateau and Kunlun Mountains. Dust7 and Dust8 were associated with northwestern transport, with air masses passing over southern Russia and eastern Uzbekistan before crossing the Tianshan Mountains toward the TD.*

Reason for this revision: *The pathway categories were renamed and linked to actual airflow histories rather than interpreted as direct dust-source proof.*

Comments 1e

Reviewer comment: Please correct the inconsistency in Table 3 where ΔP appears in the header while the text discusses ΔT. Ensure the table title/header, in-text description, and any related figures/citations are consistent after revision, and confirm that Table 3 matches the variables plotted and discussed in the Results.

Response: *Thank you for pointing out this inconsistency. We agree that the previous Table 3 header was incorrect and could mislead readers. Instead of only changing the header, we removed the previous variance tables and replaced them with a more direct composite anomaly analysis in Fig. 10. The text and figure captions now consistently refer to dynamic and thermal anomalies from −24 to +3 h relative to dust-storm onset.*

Detailed changes made in the manuscript:

Location in revised manuscript: *Previous Table 3*

Original text: *Tab. 3 Variance and range 24h, 12h, 6h, and 3h before the dust storm; column headers included "Variance of ΔP24h", "Variance of ΔP12h", "Variance of ΔP6h", and "Variance of ΔP3h", although the surrounding text discussed temperature changes.*

Revised text: *The previous Table 3 was removed from the revised manuscript.*

Reason for this revision: *Removing the table avoided the variable mismatch between ΔP headers and ΔT interpretation.*

Location in revised manuscript: *Sect. 3.3, replacement diagnostic figure*

Original text: *The original text interpreted variance and range values in Tables 2 and 3 and emphasized a 12–6 h prediction window.*

Revised text: *Figure 10 further compares the composite evolution of dynamic and thermal anomalies from −24 to +3 h relative to dust-storm onset. The dynamic indicators are consistent with the spatial pressure-difference maps. The mean sea-level pressure-gradient anomaly and 850-hPa height-gradient anomaly remain higher in spring throughout the pre-onset period ...*

Reason for this revision: *The revised diagnostic analysis uses physically interpretable anomaly curves rather than variance/range tables.*

Location in revised manuscript: *Fig. 10 caption*

Original text: *No equivalent composite figure was provided in the original manuscript.*

Revised text: *Fig. 10. Composite evolution of dynamic and thermal anomalies from −24 to +3 h relative to dust-storm onset.*

Reason for this revision: *The new figure provides a consistent basis for dynamic and thermal comparison.*

Location in revised manuscript: *Sect. 3.3, thermal-anomaly interpretation*

Original text: *The original interpretation stated that temperature changes have a more significant impact on summer dust storms based mainly on Table 3 values.*

Revised text: *In summer, the net shortwave-radiation anomaly is strongly positive during the early pre-onset stage, and the surface–air temperature-difference anomaly is also positive before about −18* *h. Meanwhile, the boundary-layer-height anomaly reaches approximately 200–300 m, indicating that stronger radiation and surface heating promoted boundary-layer growth before summer dust storms.*

Reason for this revision: *The revised text provides a clearer and more directly interpretable thermal diagnostic result.*

Comments 1f

Reviewer comment: Please strengthen the Discussion by adding comparisons with previous studies from the Taklimakan Desert and other deserts. Focus on seasonal dynamical and thermal controls, profile differences over flat and undulating surfaces, and transport-pathway classifications. Reduce repetition of the Results, and consider organizing Sect. 4 as: summary, highlights, limitations, and outlook.

Response: *Thank you for this constructive suggestion. We substantially revised the Discussion to reduce repetition of the Results and to emphasize interpretation. The revised Discussion now connects HYSPLIT pathways with ERA5 circulation patterns, interprets the seasonal dynamic–thermal contrast, discusses tower-observed differences between TZ and XT, and adds a limitations/outlook paragraph.*

Detailed changes made in the manuscript:

Location in revised manuscript: *Old Sect. 4 structure*

Original text: *4.1 Dust Trajectory Analysis; 4.2 Discussion of Dynamic and Thermal Factors; 4.3 Key parameters are influenced by the terrain.*

Revised text: *4 Discussion, organized into integrated paragraphs on pathway–circulation linkage, seasonal dynamic–thermal differences, tower-observed vertical responses, and limitations/outlook.*

Reason for this revision: *The structure was simplified and repetition of Results was reduced.*

Location in revised manuscript: *Sect. 4, opening paragraph*

Original text: *The original Discussion repeated the main trajectory and pressure/temperature Results in separate subsections.*

Revised text: *The HYSPLIT pathway analysis, ERA5 diagnostics, and tower observations provide complementary evidence for interpreting dust-storm development over the Taklimakan Desert. HYSPLIT identifies the pre-storm airflow pathways reaching the observation sites, ERA5 explains the regional pressure, circulation, and thermal backgrounds behind these pathways, and the tower observations show how these regional conditions are expressed in near-surface wind, temperature, wind shear, and vertical profiles.*

Reason for this revision: *The revised opening explains how the three data sources jointly support the interpretation.*

Location in revised manuscript: *Sect. 4, transport-pathway interpretation*

Original text: *The original Discussion mainly stated that dust trajectories were complex and came from multiple directions.*

Revised text: *The pathway types are closely related to the ERA5 circulation patterns. East-inflow events are generally accompanied by clearer pressure differences between northern Xinjiang, surrounding high-pressure regions, and the Tarim Basin, together with organized 10 m winds entering the desert through the northeastern basin opening. Mountain-crossing events correspond more closely to lower-tropospheric circulation differences around the Tianshan–Pamir region, while the south-to-north pathway is related to pressure and wind configurations along the southern and southwestern margins of the desert.*

Reason for this revision: *The revised text links the pathway classification to circulation patterns and basin topographic constraints.*

Location in revised manuscript: *Sect. 4, seasonal dynamic–thermal interpretation*

Original text: *The original Discussion repeated that spring was more affected by pressure and summer by temperature, without enough integration of the new diagnostics.*

Revised text: *ERA5 further reveals a seasonal shift in the pre-onset conditions. Spring events show stronger and more persistent mean sea-level pressure-gradient and 850 hPa height-gradient anomalies, consistent with the more distinct dynamic pathways. Summer events show weaker pressure-gradient organization but stronger early thermal anomalies, including enhanced net shortwave radiation, surface–air temperature difference, and boundary-layer height.*

Reason for this revision: *The revised text uses the new anomaly diagnostics to support a more cautious seasonal interpretation.*

Location in revised manuscript: *Sect. 4, tower-profile interpretation*

Original text: *The original Discussion interpreted flux, temperature, and wind-speed differences in a more speculative way.*

Revised text: *The tower observations provide station-scale support for this interpretation. Summer events show more continuous vertical warming, while wind-speed and wind-shear anomalies strengthen closer to onset, indicating that thermal preconditioning alone is insufficient and that near-surface momentum enhancement remains necessary. The differences between TZ and XT further suggest that local terrain can modify the near-surface response to regional forcing. XT shows more regular vertical structures, whereas TZ exhibits more variable profiles, likely related to dune-induced flow disturbance and heterogeneous roughness.*

Reason for this revision: *The revised discussion emphasizes profile differences over relatively flat and undulating surfaces while avoiding overinterpretation of flux estimates.*

Location in revised manuscript: *Sect. 4, limitations and outlook*

Original text: *The original Discussion did not clearly state the limitations of the event sample and observational constraints.*

Revised text: *Several uncertainties remain. The analysis is based on eight events from one field season, and the identified pathway and seasonal characteristics need to be tested using longer-term samples. In addition, the lack of direct turbulence, vertical velocity, and lidar observations limits the interpretation of vertical transport processes. Future studies should combine multi-year observations, turbulence measurements, lidar data, and high-resolution simulations ...*

Reason for this revision: *A limitations and outlook paragraph was added to frame the results more appropriately.*

Technical comments

Comments 2a

Reviewer comment: Replace "HYSPIT" with HYSPLIT in the Sect. 2.4 title.

Response: *Thank you for pointing out this typographical error. We corrected the model name in the section title and checked the manuscript for consistency.*

Detailed changes made in the manuscript:

Location in revised manuscript: *Sect. 2.4 title*

Original text: *2.4 HYSPIT model*

Revised text: *2.4 HYSPLIT Model*

Reason for this revision: *The spelling and capitalization of the model name were corrected.*

Location in revised manuscript: *Sect. 2.4 first sentence*

Original text: *The study used the Hybrid Single-Particle Lagrangian Integrated Trajectory (HYSPLIT) model ...*

Revised text: *The study used the Hybrid Single-Particle Lagrangian Integrated Trajectory (HYSPLIT) model ...*

Reason for this revision: *The full model name and abbreviation are now consistent with the corrected section title.*

Comments 2b

Reviewer comment: Standardize terminology throughout, e.g., use "850 hPa geopotential height" consistently. In the flux/parameter section, unify units, cm s−1 and m s−1, and clearly state any conversions where needed.

Response: *Thank you for this important comment. We standardized terminology throughout the manuscript and reduced the unit-related uncertainty by removing the previous flux-centered Results section from the main analysis. The revised analysis now focuses on ERA5 diagnostics and tower-observed wind-speed, wind-shear, and temperature anomaly profiles.*

Detailed changes made in the manuscript:

Location in revised manuscript: *Figure captions and Results text*

Original text: *Fig.4 Mean sea level pressure, 10m wind vector, 850Phm altitude field; Fig.5 2m temperature, 10m wind vector, 850Phm altitude field.*

Revised text: *Fig. 4. Mean sea-level pressure, 10 m wind vectors, and 850 hPa geopotential height before the analyzed dust-storm events. Fig. 5. 2 m air temperature, 10 m wind vectors, and 850 hPa geopotential height during the analyzed dust-storm events.*

Reason for this revision: *Terminology, spacing, and units were standardized.*

Location in revised manuscript: *Sect. 2.3 and Sect. 3.3*

Original text: *The original manuscript used terms such as average sea-level pressure, altitude field, 850Phm, 2m temperature, and wind vector plume field inconsistently.*

Revised text: *The manuscript now consistently uses "mean sea-level pressure", "850 hPa geopotential height", "10 m wind speed" or "10 m wind vectors", "2 m air temperature", and "surface–air temperature difference".*

Reason for this revision: *The revised terminology is more standard and consistent with atmospheric-science usage.*

Location in revised manuscript: *Sect. 2.5 and old Sect. 3.4*

Original text: *The original manuscript contained a flux-parameter section involving horizontal dust flux (Q), vertical dust flux (F), friction velocity, cm s−1 and m s−1 units, and concentration conversions.*

Revised text: *The previous flux-calculation section was removed from the main Results and Sect. 3.4 was revised as "Tower-observed wind and temperature anomaly profiles".*

Reason for this revision: *This avoids unsupported or unit-sensitive interpretations and keeps the main analysis aligned with the directly available meteorological observations.*

Comments 2c

Reviewer comment: Several figure captions show numbering or formatting issues, e.g., "Fig.11 10 …". Please verify figure order/numbering and standardize caption style and wording.

Response: *Thank you for your careful observation. We checked the figure order, numbering, and captions throughout the manuscript. The captions were standardized, and the revised manuscript now uses consistent figure numbering and wording.*

Detailed changes made in the manuscript:

Location in revised manuscript: *Fig. 1 caption*

Original text: *Fig. 1 Location and topography of the Taklimakan Desert, and the TZ and XT observation towers (maps and site photos)*

Revised text: *Fig. 1. Location and topography of the Taklimakan Desert, including the Tazhong (TZ) and Xiaotang (XT) observation towers and site photographs.*

Reason for this revision: *Caption style and station names were standardized.*

Location in revised manuscript: *Fig. 2 and Fig. 3 captions*

Original text: *Fig. 2 Schematic diagram of the backward trajectory of these dust storms; Fig. 3 10m wind vector plume field diagram.*

Revised text: *Fig. 2. Backward trajectories of the eight dust-storm events. Fig. 3. ERA5 10 m wind-vector fields during the eight dust-storm events.*

Reason for this revision: *Captions were revised for clarity and consistency.*

Location in revised manuscript: *Fig. 4 and Fig. 5 captions*

Original text: *Fig.4 Mean sea level pressure, 10m wind vector, 850Phm altitude field; Fig.5 2m temperature, 10m wind vector, 850Phm altitude field.*

Revised text: *Fig. 4. Mean sea-level pressure, 10 m wind vectors, and 850 hPa geopotential height before the analyzed dust-storm events. Fig. 5. 2 m air temperature, 10 m wind vectors, and 850 hPa geopotential height during the analyzed dust-storm events.*

Reason for this revision: *Terminology and figure-caption format were corrected.*

Location in revised manuscript: *Old Fig. 10–13 captions*

Original text: *Fig.10 Schematic Diagram of Horizontal Dust Flux during Sandstorms; Fig.11 10 Schematic Diagram of Vertical Dust Flux during Sandstorms; Fig.12 Schematic Diagram of Wind Speed and Temperature during Sandstorms; Fig.13 Schematic Diagram of Wind Speed and Temperature Changes ...*

Revised text: *Fig. 10. Composite evolution of dynamic and thermal anomalies from −24 to +3 h relative to dust-storm onset. Fig. 11. Composite evolution of tower-observed wind-speed, wind-shear, air-temperature-difference, and 2 m air-temperature anomalies from −24 to +3 h relative to dust-storm onset. Fig. 12. Vertical profiles of wind-speed anomalies at TZ and XT during spring and* *summer dust-storm events. Fig. 13. Vertical profiles of air-temperature anomalies at TZ and XT during spring and summer dust-storm events.*

Reason for this revision: *The revised figures and captions now match the revised analytical focus.*

Comments 2d

Reviewer comment: The reference list includes clearly irrelevant items and possible duplicates. Please remove unrelated references, merge duplicates where appropriate, and ensure one-to-one consistency between in-text citations and the reference list.

Response: *Thank you for this helpful comment. We checked the in-text citations and reference list, removed unrelated or duplicated references where appropriate, and added recent references closely related to East Asian dust storms, Taklimakan dust transport, dynamic and thermal forcing, boundary-layer processes, and terrain effects.*

Detailed changes made in the manuscript:

Location in revised manuscript: *References and in-text citations throughout the manuscript*

Original text: *The original manuscript contained possible duplicate citations, less relevant references, and some citation-format inconsistencies.*

Revised text: *The reference list and in-text citations were checked for one-to-one consistency. Recent and relevant studies were added or retained, including studies on East Asian dust events, Taklimakan dust transport, dynamic/thermal forcing, boundary-layer processes, and terrain effects.*

Reason for this revision: *The reference list was revised to better support the rewritten Introduction, Methods, Discussion, and Results interpretations.*

Location in revised manuscript: *Sect. 1 rewritten Introduction*

Original text: *The original Introduction relied more heavily on broad background references and did not sufficiently emphasize recent studies.*

Revised text: *Recent studies were incorporated into the dynamic-forcing, thermal-forcing, transport-pathway, and topographic-effect paragraphs, including recent work such as Bao et al. (2023), Chen et al. (2023a, 2023b), Li et al. (2023), Mu et al. (2025), Su et al. (2024), Xiong et al. (2023), and Zhang et al. (2025).*

Reason for this revision: *The added references place the study more clearly within recent dust-storm research.*

Comments 2e

Reviewer comment: The keywords include "Causation Analysis", but corresponding methods/results are not clearly presented. Please remove this term from the keywords and any related statements to avoid overstating the scope.

Response: *Thank you for this important suggestion. We agree that the term "Causation Analysis" may overstate the scope of the study. We revised the keywords and softened causal wording throughout the manuscript.*

Detailed changes made in the manuscript:

Location in revised manuscript: *Keywords below the Abstract*

Original text: *Keywords: Dust Storms, Backward Trajectory Analysis, Causation Analysis, Horizontal And Vertical Dust Flux Analysis.*

Revised text: *Keywords: Dust storm; Taklimakan Desert; HYSPLIT; ERA5; dynamic and thermal anomalies; vertical observation.*

Reason for this revision: *The unsupported keyword "Causation Analysis" was removed and the keywords were aligned with the actual data and methods used.*

Location in revised manuscript: *Abstract and Results/Discussion wording*

Original text: *The original manuscript used stronger causal expressions such as "caused", "triggered", and "dominated" in several places.*

Revised text: *The revised manuscript uses more cautious wording such as "is associated with", "suggest", "indicate", "is consistent with", and "may have enhanced" when interpreting dynamic and thermal processes.*

Reason for this revision: *This avoids overstating causation and makes the interpretation more consistent with observational evidence.*

Location in revised manuscript: *Abstract conclusion sentence*

Original text: *The original Abstract emphasized direct causes and a critical prediction window based on the original variance-table analysis.*

Revised text: *These findings provide observational evidence for seasonal differences in TD dust-storm processes.*

Reason for this revision: *The final statement was made more cautious and better aligned with the revised evidence.*

Response to Reviewer 2 Comments

1. Summary

Thank you very much for taking the time to review our manuscript and for providing detailed and constructive comments. We sincerely appreciate your critical assessment of the manuscript. Your comments helped us recognize that the previous version relied too heavily on qualitative descriptions and map-based interpretation, while the quantitative support, methodological clarity, and technical presentation were insufficient.

In response to your comments, we substantially revised the manuscript by weakening overgeneralized conclusions based on the limited event sample, removing the unsupported 12–6 h "key prediction window" statement, adding quantitative ERA5-based dynamic and thermal anomaly diagnostics, clarifying the anomaly baseline, lead-time definition, spatial averaging domains, and HYSPLIT settings, presenting the HYSPLIT pathway interpretation more cautiously, replacing the previous flux-centered analysis with tower-observed wind and temperature anomaly profiles, revising the Discussion to include limitations and outlook, and correcting technical issues related to Table 1, station names, HYSPLIT spelling, Table 3, figure captions, terminology, and references. The revised manuscript is provided with tracked changes, and the major textual changes are specified below by location, original wording, and revised wording.

2. Point-by-point response to Comments and Suggestions for Authors

Major issues

Comments 1

Reviewer comment: *Too small sample size: The study is effectively based on only eight dust-storm cases from a single season in 2024, after one event was excluded because of missing data at one station. This is too limited a sample to robustly establish generalized trajectory classes, seasonal controls, or forecasting windows. The manuscript often phrases its findings in broad terms, but the evidence is based on a very small number of cases, making it difficult to separate systematic behavior from event-specific variability.*

Response: *Thank you very much for this important and helpful comment. We fully agree with the reviewer that eight dust-storm events from one field season are not sufficient to establish generalized trajectory classes, universal* *seasonal controls, or validated forecasting windows. We also appreciate this comment because it helped us reconsider and clarify the actual scope of the present study.*

In the revised manuscript, we have made it clearer that the purpose of this study is not to propose a new universal classification of dust-storm pathways over the Taklimakan Desert, since dust-storm transport pathways in this region and its surroundings have already been investigated by many previous studies. Instead, our intention is to examine several relatively recent dust-storm processes observed in 2024 with comparatively complete tower observations. Based on these cases, we aim to analyze how the pre-storm airflow pathways corresponded to changes in the meteorological background before dust-storm onset, and how the associated wind-speed, wind-shear, and temperature responses were reflected at one desert-interior station and one desert-margin station.

Following the reviewer's suggestion, we have revised the manuscript to avoid broad or generalized statements that are not supported by the limited event sample. The pathway interpretation is now restricted to the analyzed cases, the seasonal dynamic–thermal contrast is described as event-based observational evidence, and the previous 12–6 h "key prediction window" conclusion has been removed. We have also added a limitation statement in the Discussion, noting that longer-term event samples are needed to further test the pathway-related and seasonal characteristics identified in this study.

Detailed changes made in the manuscript:

Location in revised manuscript: *Abstract*

Original text: *Based on dual-gradient observational experiments in the central and peripheral regions of the TD, combined with ERA5 data and HYSPLIT analysis, eight dust storms from April to June 2024 were studied. The findings include that dust-storm trajectories in the TD fall into three types and that significant pressure and temperature changes 12–6 hours before a storm provide a critical prediction window.*

Revised text: *This study combined dual-gradient tower observations from Tazhong (TZ) and Xiaotang (XT), ERA5 reanalysis, and HYSPLIT backward trajectories to examine eight dust-storm events in spring and summer 2024. The Abstract now describes "pre-storm airflow pathways" and concludes that the findings provide observational evidence for seasonal differences in TD dust-storm processes.*

Reason for this revision: *The Abstract was revised to state the limited event sample clearly, avoid broad pathway generalization, and remove the unsupported forecasting-window claim.*

Location in revised manuscript: *Sect. 3.1 "Dust Storm Trajectory Analysis"*

Original text: *The original text stated that "the conclusion can be drawn that the dust storm trajectories in the TD are complex" and described pathway categories as general dust-storm trajectory types for the TD.*

Revised text: *The revised text states that "the analyzed dust-storm events were associated with three main types of pre-storm airflow transport pathways" and that east-inflow transport was the most frequent "in the analyzed cases".*

Reason for this revision: *The wording now limits the pathway interpretation to the eight analyzed events instead of implying a general TD pathway classification.*

Location in revised manuscript: *Sect. 3.3 "Analysis of Dynamic and Thermodynamic Factors"*

Original text: *The original text inferred broad seasonal dominance from pressure and temperature maps, including that pressure changes play a more direct role in spring and that temperature changes have a more significant impact on summer dust storms.*

Revised text: *The revised text states that spring events were "more closely linked to persistent dynamic forcing", whereas summer cases showed "stronger early thermal preconditioning", and it adds that the seasonal difference is not a complete separation between dynamic and thermal mechanisms.*

Reason for this revision: *The revised wording separates event-based evidence from broad mechanistic generalization and avoids treating the limited sample as a climatological proof.*

Location in revised manuscript: *Sect. 4 "Discussion"*

Original text: *The previous Discussion repeated results and stated that the combined analysis "further proves" the seasonal differences in dust-storm formation.*

Revised text: *A limitations paragraph was added: "The analysis is based on eight events from one field season, and the identified pathway and seasonal characteristics need to be tested using longer-term samples."*

Reason for this revision: *This revision explicitly acknowledges the sample-size limitation and frames the findings as requiring longer-term verification.*

Location in revised manuscript: *Sect. 5 "Conclusion"*

Original text: *The original Conclusion stated that dust-storm trajectories in the TD can be classified into three types and that the 12–6 h period can be used as a key prediction window.*

Revised text: *The revised Conclusion states: "The analyzed events exhibited three main types of pre-storm airflow transport pathways ..." and removes the 12–6 h key-prediction-window conclusion.*

Reason for this revision: *The conclusions now match the limited evidential scope of the study and no longer overstate pathway classification or forecasting applicability.*

Comments 2

Reviewer comment: *The central claim that spring storms are dynamically dominated while summer storms are thermally dominated is reasonable, but the manuscript does not provide sufficiently strong quantitative evidence to support this as a robust mechanistic conclusion. Much of the argument relies on visual comparison of maps, narrative interpretation of pressure and temperature changes, and descriptive contrasts between a few cases. Similarly, the proposed 12–6 hour "key prediction window" is inferred from variance behavior rather than validated with any formal predictive framework or skill assessment. These conclusions therefore appear suggestive rather than firmly demonstrated.*

Response: *Thank you for this valuable and critical comment. We agree that the previous version relied too much on qualitative map interpretation and variance-table descriptions. We added ERA5-based quantitative anomaly diagnostics and revised the language from a strict "spring dynamic dominance versus summer thermal dominance" framework to a more cautious interpretation. We also removed the previous 12–6 h key prediction-window conclusion because no formal predictive framework or skill assessment was conducted.*

Detailed changes made in the manuscript:

Location in revised manuscript: *Sect. 2.3 "ERA5 Reanalysis Data"*

Original text: *The original manuscript described ERA5 mainly as a source of meteorological fields and did not define quantitative diagnostic indicators or anomaly baselines.*

Revised text: *The revised manuscript defines dynamic indicators as mean sea-level pressure-gradient magnitude, 850 hPa geopotential-height-gradient magnitude, and 10 m wind speed. It defines thermal indicators as 2 m air temperature, skin temperature, surface–air temperature difference, surface net shortwave radiation, and boundary-layer height.*

Reason for this revision: *These additions provide a quantitative basis for comparing the dynamic and thermal backgrounds of spring and summer events.*

Location in revised manuscript: *Sect. 2.3, anomaly calculation method*

Original text: *The original manuscript did not clearly explain how "anomalous" fields were calculated.*

Revised text: *For each dust-storm event and each lead time relative to storm onset, the corresponding 2024 ERA5 value was extracted. The background value was calculated from ERA5 records during 2015–2025, excluding 2024, using the same hour of the day within a ±3-day calendar window. The* *anomaly was then obtained by subtracting this background value from the corresponding 2024 event value. Area-mean values were calculated using latitude-weighted averaging with cos(latitude) as the weight.*

Reason for this revision: *The anomaly calculation is now reproducible and supports the new quantitative diagnosis.*

Location in revised manuscript: *Sect. 3.3, Fig. 10 analysis*

Original text: *The original Results relied on maps and variance/range tables, for example the interpretation that the pressure difference between ΔP12h and ΔP6h showed the most pronounced fluctuation and could represent key prediction windows.*

Revised text: *Figure 10 was added to show the composite evolution of dynamic and thermal anomalies from −24 to +3 h relative to dust-storm onset. The revised text states that the mean sea-level pressure-gradient anomaly and 850 hPa height-gradient anomaly remain higher in spring throughout the pre-onset period, while the 10 m wind-speed anomaly increases more sharply near onset.*

Reason for this revision: *The revised analysis provides quantitative evolution curves rather than relying only on visual map comparison or variance-table interpretation.*

Location in revised manuscript: *Sect. 3.3, thermal diagnostics*

Original text: *The original text inferred summer thermal dominance mainly from temperature maps and qualitative discussion of surface heating and convection.*

Revised text: *The revised text states that, in summer, the net shortwave-radiation anomaly is strongly positive during the early pre-onset stage, the surface–air temperature-difference anomaly is also positive before about −18 h, and the boundary-layer-height anomaly reaches approximately 200–300 m.*

Reason for this revision: *These indicators provide more direct quantitative support for early thermal preconditioning before summer events.*

Location in revised manuscript: *Abstract and Sect. 5 "Conclusion"*

Original text: *The original manuscript stated that spring dust storms are dominated by dynamic factors, summer storms are influenced by thermal factors, and significant changes 12–6 h before storms provide a critical prediction window.*

Revised text: *The revised manuscript states that spring events were associated with stronger pressure-gradient and 850 hPa height-gradient anomalies, while summer events showed weaker pressure-*

gradient signals but stronger early thermal anomalies. The 12–6 h key-prediction-window statement was removed.

Reason for this revision: *The conclusions are now framed as suggestive observational evidence rather than as a validated predictive rule.*

Comments 3

Reviewer comment: *The paper attributes summer dust storms to stronger surface-atmosphere temperature contrasts, convection, and vertical motions, and discusses terrain effects on vertical and horizontal dust fluxes. These ideas are plausible, but they are not supported by direct analysis of quantities that would better establish the proposed mechanisms, such as vertical velocity, boundary-layer depth, turbulent mixing, instability indices, or a more formal decomposition of forcing terms. In several places, the manuscript presents interpretations as conclusions even though they are more appropriately framed as hypotheses.*

Response: *Thank you for this insightful comment. We agree that the previous version interpreted convection, vertical motion, and terrain-related flux mechanisms too strongly. We revised the manuscript in three ways: we added boundary-layer height to the ERA5 thermal diagnostics, replaced the flux-centered results with directly observed wind and temperature anomaly profiles, and softened unsupported mechanistic wording. We also added a limitations paragraph acknowledging the lack of direct turbulence, vertical velocity, and lidar observations.*

Detailed changes made in the manuscript:

Location in revised manuscript: *Sect. 2.3 and Sect. 3.3, boundary-layer diagnostic*

Original text: *The original manuscript discussed thermal instability and vertical motion but did not include a boundary-layer-depth diagnostic in the quantitative analysis.*

Revised text: *Boundary-layer height was added as one of the thermal indicators, and Fig. 10 now includes boundary-layer-height anomalies together with surface–air temperature difference and net shortwave radiation.*

Reason for this revision: *The added BLH diagnostic gives a more appropriate basis for discussing thermal preconditioning and boundary-layer development.*

Location in revised manuscript: *Sect. 3.2 "Dust Storm Dynamic and Thermal Meteorological Background"*

Original text: *The original text stated that the land–atmosphere temperature difference caused warm air to rise, generated strong winds, and triggered dust storms.*

Revised text: *The revised text states that stronger surface heating "may have enhanced the surface–air temperature difference, promoted boundary-layer development, and provided favorable thermal conditions for dust mobilization."*

Reason for this revision: *The revised wording avoids presenting unmeasured convection and vertical motion as direct conclusions.*

Location in revised manuscript: *Sect. 3.3, interpretation of summer thermal processes*

Original text: *The original text stated that summer dust storms were mainly influenced by surface–atmosphere temperature differences and intense instability.*

Revised text: *The revised text states that summer thermal forcing "mainly provided early preconditioning" and that final onset still required near-surface wind enhancement.*

Reason for this revision: *This revision makes the mechanism interpretation more balanced and avoids overattributing onset to thermal forcing alone.*

Location in revised manuscript: *Sect. 3.4 title and content*

Original text: *The original main analysis focused on horizontal dust flux (Q), vertical dust flux (F), and their terrain-dependent differences.*

Revised text: *Sect. 3.4 was revised as "Tower-observed wind and temperature anomaly profiles". The new analysis focuses on 10 m wind-speed anomaly, 2–10 m wind-shear anomaly, 0.5–10 m air-temperature-difference anomaly, 2 m air-temperature anomaly, and vertical profiles of wind-speed and air-temperature anomalies.*

Reason for this revision: *The revised section is based on directly observed meteorological variables and avoids overinterpreting flux mechanisms without uncertainty assessment.*

Location in revised manuscript: *Sect. 4 "Discussion", limitations paragraph*

Original text: *The original Discussion did not sufficiently acknowledge missing diagnostics for vertical transport processes.*

Revised text: *The revised Discussion states that "the lack of direct turbulence, vertical velocity, and lidar observations limits the interpretation of vertical transport processes" and suggests combining multi-year observations, turbulence measurements, lidar data, and high-resolution simulations in future work.*

Reason for this revision: *The limitations now clearly distinguish supported results from mechanisms that require further testing.*

Comments 4

Reviewer comment: *HYSPLIT interpretation: The paper classifies dust trajectories into three pathway types using HYSPLIT and ERA5 wind fields. However, the manuscript itself notes that the station-based backward trajectories cannot fully represent wind direction and sources across the full desert region. This limitation is important because air-mass back trajectories do not automatically identify true dust source regions or emission processes, especially over complex terrain. The pathway classification should therefore be presented more cautiously.*

Response: *Thank you for this important comment. We agree that HYSPLIT backward trajectories should be interpreted cautiously, especially over complex terrain. We revised the manuscript to describe the trajectories as pre-storm airflow histories or airflow transport pathways reaching the observation region, rather than as direct evidence of dust source regions or emission processes. We also clarified the model settings and used ERA5 10 m wind fields only as supporting regional context.*

Detailed changes made in the manuscript:

Location in revised manuscript: *Sect. 2.4 "HYSPLIT Model"*

Original text: *The original text stated that HYSPLIT was used to analyze the transport pathways of each dust storm event, but the model settings and interpretive limits were insufficiently specified.*

Revised text: *The revised section states that the simulations used GDAS1 data at 1° × 1° and 3 h resolution, with model vertical velocity for vertical motion calculation. Backward trajectories were initialized at dust-storm onset, the endpoint was set at 39.43° N, 85.97° E, starting heights were 100, 500, and 1500 m AGL, and each trajectory was traced backward for 48 h.*

Reason for this revision: *The HYSPLIT procedure is now reproducible and more clearly limited to airflow-pathway interpretation.*

Location in revised manuscript: *Sect. 2.4, interpretation sentence*

Original text: *The original manuscript included wording that could be read as tracing dust sources directly.*

Revised text: *The revised text states: "The resulting trajectories were used to characterize the main pre-storm airflow histories reaching the observation region and to support the interpretation of airflow transport pathways together with ERA5 10 m wind fields."*

Reason for this revision: *This sentence clarifies that the trajectories indicate airflow histories, not direct dust-source attribution.*

Location in revised manuscript: *Sect. 3.1 "Dust Storm Trajectory Analysis"*

Original text: *The original text described the HYSPLIT results as "dust trajectories" and stated that HYSPLIT reveals "dust source trajectories passing through the stations".*

Revised text: *The revised text states that the analyzed dust-storm events were associated with three main types of "pre-storm airflow transport pathways": east-inflow transport, south-to-north pathway, and northwestern transport/mountain-crossing airflow.*

Reason for this revision: *The revised wording separates air-mass pathway information from dust-emission/source identification.*

Location in revised manuscript: *Sect. 3.1, ERA5 support statement*

Original text: *The original manuscript stated that ERA5 wind maps could reveal anomalous wind speeds corresponding to HYSPLIT and provide a more comprehensive data basis for dust trajectory analysis.*

Revised text: *The revised text states that ERA5 10 m wind fields provide regional support for the trajectory results and that these results suggest the analyzed events were influenced by multiple airflow pathways.*

Reason for this revision: *The ERA5 fields are now presented as contextual support rather than independent proof of source attribution.*

Location in revised manuscript: *Sect. 5 "Conclusion"*

Original text: *The original Conclusion stated that dust-storm trajectories in the TD can be classified into three types.*

Revised text: *The revised Conclusion states that the analyzed events exhibited three main types of pre-storm airflow transport pathways.*

Reason for this revision: *The revised wording is more cautious and matches the limitations of station-based backward trajectories.*

Comments 5

Reviewer comment: *The study's conclusions about differences in horizontal and vertical dust flux between the two sites are potentially interesting, but the manuscript does not adequately discuss uncertainty, observational error, sampling representativeness, or sensitivity of the flux calculations to assumptions in the method. Since the flux results are central to the paper, this omission weakens the reliability of the interpretation.*

Response: *Thank you for this important comment. We agree that the previous flux-centered analysis did not sufficiently discuss uncertainty, observational error, sampling representativeness, or sensitivity* *to methodological assumptions. To avoid overinterpreting uncertain flux estimates, we removed the flux-centered analysis from the main Results and Conclusion. The revised manuscript instead focuses on tower-observed wind-speed, wind-shear, and temperature anomaly profiles, which are more directly supported by the available gradient-tower observations.*

Detailed changes made in the manuscript:

Location in revised manuscript: *Abstract*

Original text: *The original Abstract included horizontal dust flux (Q) and vertical dust flux (F) as central findings, including statements about Q patterns at Xiaotang and terrain effects at Tazhong.*

Revised text: *The revised Abstract no longer presents Q/F flux conclusions. It focuses on airflow pathways, ERA5 dynamic and thermal anomaly diagnostics, and tower-observed warming, wind-speed, and wind-shear enhancement.*

Reason for this revision: *The Abstract now reflects the revised evidence base and avoids unsupported flux-centered conclusions.*

Location in revised manuscript: *Keywords*

Original text: *The original keywords included "Horizontal And Vertical Dust Flux Analysis".*

Revised text: *The revised keywords are: Dust storm; Taklimakan Desert; HYSPLIT; ERA5; dynamic and thermal anomalies; vertical observation.*

Reason for this revision: *The keywords were aligned with the revised focus of the manuscript.*

Location in revised manuscript: *Sect. 2.2 "Observational Data"*

Original text: *The original text stated that the gradient collection system was used to determine horizontal dust flux at different heights.*

Revised text: *The revised text states that the meteorological gradient observations were mainly used to examine wind-speed, wind-shear, and temperature-profile responses during dust-storm development.*

Reason for this revision: *The data-use description was revised to match the new tower-profile analysis.*

Location in revised manuscript: *Old Sect. 2.5 and old Sect. 3.4*

Original text: *The original manuscript included "2.5 The calculation of horizontal dust flux (Q) and vertical dust flux (F)" and a main Results section centered on Dust Flux Analysis.*

Revised text: *The flux-calculation section and flux-centered Results interpretation were removed from the main analysis. Sect. 3.4 was revised as "Tower-observed wind and temperature anomaly profiles".*

Reason for this revision: *This avoids presenting flux estimates as central conclusions without a full uncertainty and sensitivity assessment.*

Location in revised manuscript: *Sect. 3.4 revised Results*

Original text: *The original Results compared Q and F profiles between TZ and XT and interpreted terrain effects from flux-profile behavior.*

Revised text: *The revised Results compare wind-speed anomaly profiles and air-temperature anomaly profiles at TZ and XT. The text states that XT shows more regular vertical structures, whereas TZ profiles are more irregular and may reflect the influence of undulating dune topography and local flow disturbance.*

Reason for this revision: *The interpretation of terrain effects is now based on directly observed meteorological profile differences rather than uncertain flux estimates.*

Location in revised manuscript: *Sect. 5 "Conclusion"*

Original text: *The original Conclusion included Q/F relationships at XT and TZ and linked them to flat or undulating terrain.*

Revised text: *The revised Conclusion states that XT displayed more regular wind and temperature anomaly structures, whereas TZ showed more variable profiles, suggesting that local terrain heterogeneity may modulate the near-surface response to regional dynamic and thermal forcing.*

Reason for this revision: *The revised conclusion retains the terrain-effect discussion but avoids unsupported flux-specific claims.*

List of technical glitches and editorial problems

Comments 6

Reviewer comment: *Table 1: XT(, XT), XT should be the same?*

Response: *Thank you for pointing out this typographical inconsistency. We checked Table 1 and corrected station-name errors. The station names are now consistently written as TZ and XT throughout the table and the manuscript.*

Detailed changes made in the manuscript:

Location in revised manuscript: *Table 1*

Original text: *Some station names appeared as "XT(", "XT)", "XTTZ", "TZ(", or other inconsistent forms.*

Revised text: *All station names in Table 1 were standardized as "TZ" or "XT".*

Reason for this revision: *This correction removes typographical inconsistencies and makes the table consistent with the rest of the manuscript.*

Location in revised manuscript: *Sect. 2.2 "Observational Data"*

Original text: *The original text used inconsistent naming such as "XT Station", "X Station", and station-name fragments.*

Revised text: *The revised text defines the two stations as Xiaotang (XT), located on the northern edge of the TD, and Tazhong (TZ), situated in the desert interior.*

Reason for this revision: *The station abbreviations are now defined once and used consistently.*

Comments 7

Reviewer comment: *Event dates and periods are not consistent.*

Response: *Thank you for this comment. We revised the Abstract, Sect. 2.2, Table 1, Results, and Conclusion to ensure consistency in event dates, event numbering, and seasonal grouping. The analyzed events are now consistently labeled as Dust1–Dust8, and the seasonal grouping is defined as spring for March–April events and summer for May–June events.*

Detailed changes made in the manuscript:

Location in revised manuscript: *Abstract*

Original text: *The original Abstract described eight dust storms from April to June 2024 and included broader event descriptions.*

Revised text: *The revised Abstract states that the study examined eight dust-storm events in spring and summer 2024.*

Reason for this revision: *This revision avoids inconsistency between the Abstract and Table 1, because the first event started on 31 March 2024.*

Location in revised manuscript: *Sect. 2.2 "Observational Data"*

Original text: *The original text referred to observations between April 3 and July 10, 2024, which mixed event onset dates with sample-collection dates.*

Revised text: *The revised text states that nine dust-storm events were observed between 31 March and 18 June 2024, and that the corresponding dust samples were collected from 3 April to 10 July 2024.*

Reason for this revision: *The event observation period and sample-collection period are now separated clearly.*

Location in revised manuscript: *Table 1*

Original text: *The original table used mixed date formats such as 2024.3.31 and incomplete or inconsistent event labels such as Dust32, Dust43, Dust98.*

Revised text: *The revised table uses standardized date-time format (YYYY-MM-DD HH:MM), labels the final analyzed events as Dust1–Dust8, and includes one row labelled "Excluded event".*

Reason for this revision: *The table now provides a consistent basis for the Methods, Results, and Conclusion.*

Location in revised manuscript: *Sect. 3.2 and Sect. 3.3*

Original text: *The original manuscript described the spring/summer grouping after mixed references to March–June and April–June.*

Revised text: *The revised text states that the March–April events were grouped as spring cases and the May–June events were grouped as summer cases for the dynamic and thermal anomaly analysis.*

Reason for this revision: *The seasonal grouping is now consistently applied throughout the Results.*

Location in revised manuscript: *Sect. 5 "Conclusion"*

Original text: *The original Conclusion stated that eight observational samples were obtained from April to June.*

Revised text: *The revised Conclusion states that the study examined eight complete dust-storm events over the Taklimakan Desert using HYSPLIT trajectories, ERA5 reanalysis, and dual-gradient tower observations.*

Reason for this revision: *This avoids the inconsistent April–June description and uses the same sample definition as the Abstract and Methods.*

Comments 8

Reviewer comment: *Station naming is not consistent throughout the manuscript.*

Response: *Thank you for pointing this out. We standardized the station names throughout the manuscript. The desert-interior station is consistently referred to as Tazhong (TZ), and the northern desert-margin station is consistently referred to as Xiaotang (XT). We removed inconsistent forms such as "X Station", "XiaoTang", and typographical station-name errors in the table.*

Detailed changes made in the manuscript:

Location in revised manuscript: *Abstract*

Original text: *The original Abstract referred generally to central and peripheral regions of the TD without clearly defining the two station names.*

Revised text: *The revised Abstract states: "dual-gradient tower observations from Tazhong (TZ) and Xiaotang (XT)".*

Reason for this revision: *The station names and abbreviations are introduced at the beginning of the manuscript.*

Location in revised manuscript: *Sect. 2.2 "Observational Data"*

Original text: *The original text used inconsistent phrases such as "Xiaotang (XT)X Station", "TZ Station", and "X Station".*

Revised text: *The revised text states: "The observational data were obtained from two stations: Xiaotang (XT), located on the northern edge of the TD, representing flat terrain, and TZ, situated in the desert interior, representing undulating terrain."*

Reason for this revision: *The station descriptions are now concise and consistent.*

Location in revised manuscript: *Table 1 and figure captions*

Original text: *The original table and captions contained inconsistent abbreviations and formatting, including station-name fragments.*

Revised text: *The revised Table 1 uses only "TZ" and "XT", and the Fig. 1 caption identifies the Tazhong (TZ) and Xiaotang (XT) observation towers.*

Reason for this revision: *The same naming system is now used in the table, captions, Results, Discussion, and Conclusion.*

Location in revised manuscript: *Sect. 3.4 and Sect. 5*

Original text: *The original text sometimes referred to flat and undulating terrain without consistently linking them to XT and TZ.*

Revised text: *The revised text states that XT displayed more regular vertical structures, whereas TZ showed more variable profiles, suggesting terrain-related modulation of near-surface responses.*

Reason for this revision: *The station-specific interpretation now uses consistent abbreviations and terrain descriptions.*

Comments 9

Reviewer comment: *HYSPIT?*

Response: *Thank you for identifying this spelling error. We corrected "HYSPIT" to "HYSPLIT" in the section title and throughout the manuscript.*

Detailed changes made in the manuscript:

Location in revised manuscript: *Sect. 2.4 title*

Original text: *2.4 HYSPIT model.*

Revised text: *2.4 HYSPLIT Model.*

Reason for this revision: *The model name was corrected and capitalized consistently.*

Location in revised manuscript: *Sect. 2.4 first sentence*

Original text: *The original section title and nearby text contained the misspelling "HYSPIT".*

Revised text: *The revised text states: "The study used the Hybrid Single-Particle Lagrangian Integrated Trajectory (HYSPLIT) model to analyze the transport pathways of each dust storm event."*

Reason for this revision: *The full model name and abbreviation are now correct and consistent.*

Location in revised manuscript: *Abstract, Keywords, Sect. 3.1, Discussion, and Conclusion*

Original text: *The original manuscript used inconsistent HYSPLIT/HYSPIT spelling in several places.*

Revised text: *All occurrences were checked and standardized as "HYSPLIT".*

Reason for this revision: *This correction removes a technical spelling error throughout the manuscript.*

Comments 10

Reviewer comment: *Table 3: mislabeled?*

Response: *Thank you for pointing out this problem. The previous Table 3 was mislabeled because the header referred to ΔP while the text discussed temperature differences. In the revised manuscript, the previous variance tables were removed and replaced by a composite anomaly analysis in Fig. 10. This revision avoids the inconsistency between table headers, variable names, and text interpretation.*

Detailed changes made in the manuscript:

Location in revised manuscript: *Old Table 3*

Original text: *The Table 3 title and header referred to variance and range of 24 h, 12 h, 6 h, and 3 h before the dust storm, while the column headers still included "Variance of ΔP24h", "Variance of ΔP12h", and related pressure labels even though the text discussed temperature differences.*

Revised text: *The previous Table 3 was removed from the main Results.*

Reason for this revision: *Removing the table avoids a variable-label mismatch and prevents readers from confusing pressure and temperature diagnostics.*

Location in revised manuscript: *Sect. 3.3, replacement analysis*

Original text: *The original text interpreted variance and range values from Tables 2 and 3 and used them to support the 12–6 h prediction-window statement.*

Revised text: *The revised Results instead use Fig. 10, "Composite evolution of dynamic and thermal anomalies from −24 to +3 h relative to dust-storm onset," to present the diagnostic indicators consistently.*

Reason for this revision: *The replacement figure directly matches the revised variables and provides clearer support for the dynamic–thermal comparison.*

Location in revised manuscript: *Sect. 3.3, terminology after removing Table 3*

Original text: *The original text used mixed terms such as ΔP for pressure and ΔT/temperature changes in adjacent table and figure descriptions.*

Revised text: *The revised text consistently distinguishes mean sea-level pressure-gradient anomaly, 850 hPa geopotential-height-gradient anomaly, 10 m wind-speed anomaly, surface–air temperature-difference anomaly, net shortwave-radiation anomaly, and boundary-layer-height anomaly.*

Reason for this revision: *Terminology and variables are now consistent between the text, figure captions, and revised analysis.*

Location in revised manuscript: *Sect. 5 "Conclusion"*

Original text: *The original Conclusion included the statement that the 12–6 h period before the dust storm can be used as a key time window for prediction.*

Revised text: *The revised Conclusion removes this statement and instead states that the tower observations indicate a staged process from early background adjustment to near-surface wind enhancement.*

Reason for this revision: *This avoids drawing a forecasting conclusion from a mislabeled or insufficiently validated variance-table analysis.*

Response to Reviewer 3 Comments

1. Summary

Thank you very much for taking the time to review our manuscript and for your positive evaluation of the topic and observational dataset. We sincerely appreciate your constructive comments and suggestions, which helped us improve the methodological clarity, diagnostic analysis, and technical presentation of the manuscript.

In response to your comments, we substantially revised the manuscript by adding quantitative ERA5-based dynamic and thermal anomaly diagnostics, removing the overstatement that the 12–6 h period represents a general "key prediction window", weakening causal language related to seasonal dynamic and thermal controls, removing the previous Q/F-centered flux analysis from the main Results and Conclusion because of uncertainties in flux calculation and sampling consistency, refocusing the tower-observation analysis on wind-speed, wind-shear, and air-temperature anomaly profiles, clarifying the ERA5 anomaly baseline, spatial averaging domains, and HYSPLIT settings, and correcting technical problems related to terminology, station names, Table 1, Table 3, formulas, units, and figure presentation.

The revised manuscript is provided with tracked changes. For clarity, the major textual and structural revisions are specified below by revision location, original wording, revised wording, and the reason for each change. In this response letter, the original text is shown in red italics, and the revised text is shown in blue italics.

2. Point-by-point response to Comments and Suggestions for Authors

Major issues

Comments a

Reviewer comment: The manuscript suggests that spring dust events are mainly controlled by dynamic forcing, whereas summer events are more closely related to thermal forcing, and it further identifies the 12–6 h period before onset as a key prediction window. At present, however, this interpretation is still supported mainly by descriptive evidence, and more direct diagnostic analysis would be needed to make the argument more convincing.

Response: Thank you very much for this important and helpful comment. We agree that the previous version relied too much on descriptive interpretation and did not provide sufficient direct diagnostic evidence to support the seasonal dynamic–thermal contrast. We therefore added quantitative ERA5-based anomaly diagnostics and revised the wording to avoid presenting the seasonal contrast as a strictly demonstrated causal separation. We also removed the statement that the 12–6 h period represents a general key prediction window.

Detailed changes made in the manuscript:

Location in revised manuscript: Abstract

Original text: *Spring dust storms (March–April) are dominated by dynamic factors, while summer storms (May–June) are influenced by thermal factors. Significant pressure and temperature changes 12–6 hours before a storm provide a critical prediction window.*

Revised text: *ERA5 anomaly diagnostics show that spring events maintained stronger mean sea-level pressure-gradient and 850 hPa geopotential-height-gradient anomalies throughout the pre-onset period, while 10 m wind-speed anomalies increased rapidly after approximately −12 h. In contrast, summer events showed stronger thermal signals before approximately −18 h, including enhanced surface–air temperature contrast, positive net shortwave radiation anomalies, and boundary-layer growth.*

Reason for this revision: The Abstract now presents quantitative diagnostic evidence and removes the unsupported "critical prediction window" statement.

Location in revised manuscript: Sect. 2.3 "ERA5 Reanalysis Data"

Original text: *The original manuscript described ERA5 mainly as a source of meteorological background fields and did not clearly define diagnostic indicators for dynamic and thermal analysis.*

Revised text: *The revised manuscript defines dynamic indicators as mean sea-level pressure-gradient magnitude, 850 hPa geopotential-height-gradient magnitude, and 10 m wind speed, and defines thermal indicators as 2 m air temperature, skin temperature, surface–air temperature difference, surface net shortwave radiation, and boundary-layer height.*

Reason for this revision: These definitions provide a more direct quantitative basis for evaluating the seasonal dynamic and thermal background before dust-storm onset.

Location in revised manuscript: Sect. 2.3, anomaly baseline and averaging method

Original text: *The original manuscript did not sufficiently explain how the background field and anomalies were calculated.*

Revised text: *For each dust-storm event and each lead time relative to storm onset, the corresponding 2024 ERA5 value was extracted. The background value was calculated from ERA5 records during 2015–2025, excluding 2024, using the same hour of the day within a ±3-day calendar window. The anomaly was then obtained by subtracting this* *background value from the corresponding 2024 event value. Area-mean values were calculated using latitude-weighted averaging with cos(latitude) as the weight.*

Reason for this revision: This addition makes the anomaly analysis reproducible and strengthens the diagnostic basis of the revised interpretation.

Location in revised manuscript: Sect. 3.3 "Analysis of Dynamic and Thermodynamic Factors"

Original text: *The original analysis mainly interpreted pressure and temperature maps and inferred that spring storms were dynamically dominated and summer storms were thermally influenced.*

Revised text: *Figure 10 further compares the composite evolution of dynamic and thermal anomalies from −24 to +3 h relative to dust-storm onset. The mean sea-level pressure-gradient anomaly and 850 hPa height-gradient anomaly remain higher in spring throughout the pre-onset period, whereas summer cases show stronger early thermal preconditioning, expressed as enhanced surface–air temperature contrast, positive radiation anomalies, and boundary-layer growth.*

Reason for this revision: The revised text supports the seasonal contrast with quantitative anomaly curves rather than relying only on visual map-based interpretation.

Location in revised manuscript: Sect. 3.3 and Sect. 5 "Conclusion"

Original text: *The previous version stated that the 12–6 h period before onset could be regarded as a key prediction window.*

Revised text: *The revised manuscript removes the 12–6 h key-prediction-window conclusion and instead describes near-onset wind-speed and wind-shear enhancement as an observed feature of the analyzed events.*

Reason for this revision: The revision avoids overstating the forecasting significance of a limited event sample without a formal prediction or skill-assessment framework.

Comments b

Reviewer comment: The conclusion that 12–6 h represents a key time window is drawn largely from the contrasts in variance and range shown in Tables 2 and 3. However, the individual events do not show a fully consistent pattern, and some still display marked variability at shorter timescales. As a result, the broader applicability of this conclusion is not yet fully clear.

Response: Thank you for this valuable comment. We fully agree that the 12–6 h conclusion in the previous manuscript was too strong and was not supported by a formal predictive framework or sufficient event consistency. In the revised manuscript, we removed this conclusion and replaced the previous variance-based interpretation with composite dynamic and thermal anomaly curves from −24 to +3 h relative to dust-storm onset.

Detailed changes made in the manuscript:

Location in revised manuscript: Previous Tables 2 and 3

Original text: *Table 2 and Table 3 presented variance and range values at 24, 12, 6, and 3 h before the dust storm, and these values were used to infer that 12–6 h represented a key prediction window.*

Revised text: *The previous variance-based Tables 2 and 3 were removed from the revised manuscript.*

Reason for this revision: Removing these tables avoids using event-specific variance behavior as evidence for a general forecasting window.

Location in revised manuscript: Sect. 3.3, replacement analysis

Original text: *The original text stated that the pressure difference between ΔP12h and ΔP6h showed significant variation and that this period could represent a key window for spring dust-storm prediction.*

Revised text: *The revised text uses Fig. 10 to show the composite evolution of dynamic and thermal anomalies from −24 to +3 h relative to dust-storm onset. It describes stronger spring dynamic anomalies, stronger early summer thermal anomalies, and closer-to-onset wind-speed enhancement without defining a predictive window.*

Reason for this revision: The replacement analysis is more physically interpretable and avoids overgeneralizing from inconsistent event-level variance changes.

Location in revised manuscript: Sect. 3.4 "Tower-observed wind and temperature anomaly profiles"

Original text: *The original manuscript did not provide tower-based anomaly curves to support the temporal evolution near onset.*

Revised text: *Figure 11 was added to present the composite evolution of tower-observed wind-speed, wind-shear, air-temperature-difference, and 2 m air-temperature anomalies from −24 to +3 h relative to dust-storm onset.*

Reason for this revision: The added tower-observation figure provides station-scale support for the near-onset wind and shear enhancement, while still avoiding the claim of a validated prediction window.

Location in revised manuscript: Sect. 5 "Conclusion"

Original text: *The original Conclusion stated that the 12–6 h period before dust-storm occurrence could be used as a key time window for prediction.*

Revised text: *The revised Conclusion removes this statement and instead emphasizes the staged evolution from early background adjustment or thermal preconditioning to near-surface wind and shear enhancement closer to onset.*

Reason for this revision: The revised conclusion better matches the evidence provided by the limited event sample and the new anomaly diagnostics.

Comments c

Reviewer comment: Section 2.5 provides the general framework for calculating Q, F, and u*, but several important methodological details remain insufficiently explained. In particular, the treatment of F, the assumptions used in estimating u*, the source of z0, the wind-speed averaging timescale, and the consideration of stability effects should be clarified, as these directly affect the reproducibility and reliability of the results.

Response: Thank you for this important and detailed comment. We agree that the previous description of Q, F, and u* was not sufficient to ensure reproducibility, especially because the calculation of vertical dust flux is sensitive to assumptions regarding concentration gradients, friction velocity, roughness length, wind-speed averaging, and stability effects. After carefully reconsidering the scope and reliability of the analysis, we removed the Q/F-centered flux calculation and interpretation from the main manuscript and refocused the analysis on directly observed tower meteorological variables.

Detailed changes made in the manuscript:

Location in revised manuscript: Previous Sect. 2.5

Original text: *The previous manuscript included "2.5 The calculation of horizontal dust flux (Q) and vertical dust flux (F)" and presented formulas for Q, F, dust concentration, and friction velocity.*

Revised text: *The original Sect. 2.5 on Q, F, and u* calculations was removed from the main manuscript.*

Reason for this revision: This avoids presenting flux estimates that require additional uncertainty analysis, clearer temporal matching, and more complete assumptions about u*, z0, and stability effects.

Location in revised manuscript: Sect. 2.2 "Observational Data"

Original text: *The original text emphasized that the gradient collection system was used to determine horizontal dust flux at different heights.*

Revised text: *In the present analysis, the meteorological gradient observations were mainly used to examine wind-speed, wind-shear, and temperature-profile responses during dust-storm development.*

Reason for this revision: The data-use description was revised to match the new profile-based analysis and to avoid overemphasizing uncertain flux calculations.

Location in revised manuscript: Sect. 3.4 revised title and content

Original text: *The original Results section focused on "Dust Flux Analysis" and interpreted Q/F structures at the two stations.*

Revised text: *Sect. 3.4 was revised as "Tower-observed wind and temperature anomaly profiles". The new section focuses on wind-speed anomaly, wind-shear anomaly, air-temperature-difference anomaly, 2 m air-temperature anomaly, and vertical profiles of wind-speed and air-temperature anomalies.*

Reason for this revision: The revised section is more directly supported by available tower measurements and better supports the dynamic–thermal interpretation of the study.

Location in revised manuscript: Sect. 4 and Sect. 5

Original text: *The original Discussion and Conclusion used Q/F differences to support terrain-effect interpretations.*

Revised text: *The revised Discussion and Conclusion no longer use Q/F as central evidence. Terrain-related differences are discussed in terms of wind and temperature anomaly profiles at TZ and XT.*

Reason for this revision: This revision reduces uncertainty and prevents flux-calculation assumptions from weakening the reliability of the manuscript.

Comments d

Reviewer comment: The manuscript states that BSNE samples were collected and weighed after each dust event, indicating that the measurements represent cumulative mass over a sampling interval. In contrast, the calculation of F requires a clearly defined concentration difference between two levels, together with the corresponding average wind speed and u* over the same period. At present, the sampling interval, event-based integration procedure, temporal consistency among sampling heights, and the matching with meteorological data are not sufficiently clear.

Response: Thank you for this careful and technically important comment. We agree that BSNE samples represent cumulative mass over sampling intervals, whereas calculating vertical dust flux requires strict temporal consistency between concentration differences, wind speed, and friction velocity. Because the previous manuscript did not adequately describe this matching procedure, we removed the vertical dust flux calculation and its interpretation from the main analysis.

Detailed changes made in the manuscript:

Location in revised manuscript: Sect. 2.2 "Observational Data"

Original text: *The original text described the BSNE dust collectors and stated that dust samples were collected and weighed after each dust storm, but it did not fully explain the temporal matching between sampled mass, wind speed, and u* for flux calculation.*

Revised text: *The BSNE dust collection information is retained only as part of the observation-system description. The revised analysis focuses on meteorological gradient observations, including wind speed, wind shear, and temperature profiles.*

Reason for this revision: This revision keeps the observation-system description while avoiding insufficiently constrained flux calculations.

Location in revised manuscript: Previous Sect. 2.5 and flux-related Results

Original text: *The original manuscript calculated vertical dust flux using concentration differences and friction velocity, but the sampling interval and event-based integration procedure were not fully specified.*

Revised text: *The vertical dust flux calculation and the flux-centered Results were removed from the revised manuscript.*

Reason for this revision: The revision addresses the concern that temporal inconsistency between BSNE samples and meteorological variables could affect the reliability and reproducibility of F.

Location in revised manuscript: Sect. 3.4 "Tower-observed wind and temperature anomaly profiles"

Original text: *The original analysis used F to interpret vertical dust transport and terrain-related differences between the two sites.*

Revised text: *The revised analysis compares tower-observed wind-speed and air-temperature anomaly profiles at TZ and XT, together with wind-shear and temperature-difference anomalies from −24 to +3 h relative to onset.*

Reason for this revision: These variables have clearer temporal correspondence with the tower observations and are more appropriate for the revised dynamic–thermal interpretation.

Location in revised manuscript: Sect. 4 "Discussion" and Sect. 5 "Conclusion"

Original text: *The previous Discussion and Conclusion used F to support interpretations of summer variability and terrain effects.*

Revised text: *The revised Discussion and Conclusion no longer use F as supporting evidence. Differences between TZ and XT are discussed in terms of wind and temperature anomaly profiles.*

Reason for this revision: This change avoids overinterpreting cumulative dust-sample data without a fully documented temporal-matching procedure.

Comments e

Reviewer comment: The manuscript attributes the mid-level anomalies at TZ and the enhanced summer variability of F to secondary dust entrainment from surrounding dunes or to stronger topographic effects. However, these interpretations are not supported by sufficiently direct evidence, such as terrain parameters, wind-direction conditions, local turbulence characteristics, or surrounding geomorphological information.

Response: Thank you for this important comment. We agree that the previous interpretation of mid-level anomalies and enhanced summer F variability at TZ was too speculative, especially because direct evidence such as terrain parameters, local turbulence observations, detailed wind-direction analysis, or high-resolution geomorphological information was not available. We therefore removed the F-based interpretation and rewrote the terrain discussion more cautiously based on observed wind-speed and air-temperature anomaly profiles.

Detailed changes made in the manuscript:

Location in revised manuscript: Old Sect. 3.4 and flux-related interpretation

Original text: *The original manuscript attributed mid-level anomalies at TZ and enhanced summer F variability to secondary dust entrainment from surrounding dunes or stronger topographic effects.*

Revised text: *These F-based statements were removed from the revised manuscript.*

Reason for this revision: The revision removes speculative interpretations that were not supported by direct turbulence, wind-direction, terrain-parameter, or geomorphological evidence.

Location in revised manuscript: Sect. 3.4 revised profile analysis

Original text: *The original Results interpreted terrain effects mainly through horizontal and vertical dust-flux structures.*

Revised text: *The revised Results state that XT shows more regular vertical structures, whereas TZ shows more variable wind-speed and air-temperature anomaly profiles, which may reflect the modulation of regional forcing by local terrain heterogeneity.*

Reason for this revision: The revised interpretation is based on directly observed meteorological profile differences and uses cautious language.

Location in revised manuscript: Sect. 4 “Discussion”

Original text: *The original Discussion included stronger claims linking terrain and dunes to secondary dust entrainment and enhanced vertical dust flux.*

Revised text: *The revised Discussion states that local terrain heterogeneity may modulate the near-surface meteorological response to regional dynamic and thermal forcing, rather than directly concluding that dunes caused secondary entrainment or enhanced F.*

Reason for this revision: The revised wording better matches the available evidence and avoids unsupported causal claims.

Location in revised manuscript: Sect. 4, limitations and outlook

Original text: *The original manuscript did not sufficiently acknowledge the lack of direct evidence for terrain-flow and vertical transport mechanisms.*

Revised text: *A limitations paragraph was added, noting that the lack of direct turbulence, vertical velocity, lidar observations, and detailed terrain-flow measurements limits the interpretation of local vertical transport processes. Future work should combine turbulence observations, lidar-based vertical profiling, high-resolution terrain data, and numerical simulations.*

Reason for this revision: This addition clearly separates supported findings from mechanisms that require further testing.

Technical issues

Comments a

Reviewer comment: The presentation of formulas and units is not sufficiently rigorous. The definition of c and the use of mixed units for u*, u, z, and z0 should be reviewed carefully to ensure dimensional consistency.

Response: Thank you for pointing out this problem. We agree that the previous formula presentation and unit definitions were not sufficiently rigorous. Because the Q/F flux calculation has been removed from the main manuscript, the previous formulas involving c, u*, u, z, and z0 have also been removed. The revised manuscript now focuses on ERA5 and tower-observed meteorological variables, and the text and figure captions use standard atmospheric-science terminology and SI units where applicable.

Detailed changes made in the manuscript:

Location in revised manuscript: Previous Sect. 2.5

Original text: *The original manuscript presented formulas for F, dust concentration c, and friction velocity u*, with mixed units such as cm s^{-1} and m s^{-1} for related variables.*

Revised text: *The previous formula section was removed from the main manuscript together with the Q/F-centered analysis.*

Reason for this revision: This eliminates unit inconsistency and avoids unsupported flux calculations without a full methodological and uncertainty description.

Location in revised manuscript: Sect. 2.3, Sect. 3.3, Sect. 3.4, and figure captions

Original text: *The original manuscript used inconsistent unit and variable expressions in parts of the flux and meteorological analysis.*

Revised text: *The revised manuscript focuses on mean sea-level pressure-gradient anomaly, 850 hPa geopotential-height-gradient anomaly, 10 m wind speed, surface–air temperature difference, net shortwave radiation, boundary-layer height, wind-speed anomaly, and temperature anomaly profiles.*

Reason for this revision: The revised variables are directly supported by ERA5 and tower observations and are described with clearer terminology and units.

Comments b

Reviewer comment: HYSPIT should be corrected to HYSPLIT.

Response: Thank you for identifying this typographical error. We corrected “HYSPIT” to “HYSPLIT” in the section title and throughout the manuscript.

Detailed changes made in the manuscript:

Location in revised manuscript: Sect. 2.4 title

Original text: *2.4 HYSPIT model*

Revised text: *2.4 HYSPLIT Model*

Reason for this revision: The model name was corrected and capitalization was standardized.

Location in revised manuscript: Abstract, Keywords, Sect. 2.4, Sect. 3.1, Sect. 4, and Sect. 5

Original text: *The original manuscript contained inconsistent HYSPLIT/HYSPIT spelling in several places.*

Revised text: *All occurrences were checked and standardized as "HYSPLIT".*

Reason for this revision: This correction removes a technical spelling error throughout the manuscript.

Comments c

Reviewer comment: X Station and XT Station are used inconsistently and should be unified throughout the manuscript.

Response: Thank you for this comment. We standardized the station names throughout the manuscript. The desert-interior station is consistently referred to as Tazhong (TZ), and the northern desert-margin station is consistently referred to as Xiaotang (XT). Inconsistent expressions such as "X Station", "XT Station", and "XiaoTang" were removed or revised.

Detailed changes made in the manuscript:

Location in revised manuscript: Abstract

Original text: *The original Abstract referred generally to dual-gradient observational experiments in the central and peripheral regions of the TD without clearly defining the station names.*

Revised text: *This study combined dual-gradient tower observations from Tazhong (TZ) and Xiaotang (XT), ERA5 reanalysis, and HYSPLIT backward trajectories to examine eight dust-storm events in spring and summer 2024.*

Reason for this revision: The two station names and abbreviations are now introduced at the beginning of the manuscript.

Location in revised manuscript: Sect. 2.2 "Observational Data"

Original text: *The observational data were obtained from two stations: Xiaotang (XT)X Station ... and TZ Station ... At XT Station ...*

Revised text: *The observational data were obtained from two stations: Xiaotang (XT), located on the northern edge of the TD, and Tazhong (TZ), situated in the desert interior.*

Reason for this revision: The station descriptions were revised to remove inconsistent forms and to clarify the geographic and terrain settings of the two sites.

Location in revised manuscript: Table 1, Sect. 3.4, Sect. 4, and Sect. 5

Original text: *The original manuscript used inconsistent station names and abbreviations in tables, captions, and interpretive text.*

Revised text: *The revised manuscript consistently uses "TZ" and "XT" after their first definition.*

Reason for this revision: Consistent station naming improves readability and avoids confusion between site identity and terrain setting.

Comments d

Reviewer comment: Table 1 contains obvious typographical errors such as XT(and XT).

Response: Thank you for pointing out these typographical errors. We carefully checked and corrected Table 1. The station names are now consistently written as TZ and XT, and typographical errors such as "XT(", "XT)", "TZ(", and other station-name fragments have been removed.

Detailed changes made in the manuscript:

Location in revised manuscript: Table 1

Original text: *Examples of original entries included "TZ(", "XT)", "XTTZ", and mixed event labels such as Dust32, Dust43, and Dust98.*

Revised text: *The revised Table 1 uses standardized station names "TZ" and "XT", unified event labels Dust1–Dust8, one row labelled "Excluded event", and date-time format YYYY-MM-DD HH:MM.*

Reason for this revision: The revised table now matches the event numbering, station naming, and timing used in the Abstract, Methods, Results, and Conclusion.

Location in revised manuscript: Sect. 2.2 "Observational Data"

Original text: *The original text and table mixed observation dates, sample-collection dates, and event labels.*

Revised text: *Nine dust storm events were observed between 31 March and 18 June 2024, and the corresponding dust samples were collected from 3 April to 10 July 2024. However, during the second observation, data from the TZ station were missing, preventing a complete paired record. Therefore, the remaining eight complete dust storm events became the primary samples for this study.*

Reason for this revision: This revision clarifies the observation period, sample-collection period, excluded event, and final sample.

Comments e

Reviewer comment: The heading of Table 3 still refers to Variance of ΔP24h and related terms, which does not match the temperature-difference content of that table.

Response: Thank you for pointing out this inconsistency. We agree that the previous Table 3 heading was incorrect. In the revised manuscript, the previous variance tables were removed and replaced by a more direct composite anomaly analysis in Fig. 10.

Detailed changes made in the manuscript:

Location in revised manuscript: Previous Table 3

Original text: *The heading and column labels still referred to "Variance of ΔP24h", "Variance of ΔP12h", and related pressure terms, although the surrounding text discussed temperature differences.*

Revised text: *The previous Table 3 was removed from the revised manuscript.*

Reason for this revision: Removing the table avoids mismatch between the table heading, variable names, and the thermal-difference interpretation.

Location in revised manuscript: Sect. 3.3 and Fig. 10

Original text: *The original Results used Tables 2 and 3 to interpret pressure and temperature changes and to support the 12–6 h prediction-window statement.*

Revised text: *The revised Results use Fig. 10 to present the composite evolution of dynamic and thermal anomalies from −24 to +3 h relative to dust-storm onset.*

Reason for this revision: The revised figure provides a consistent set of diagnostic variables and avoids confusion between pressure and temperature indicators.

Comments f

Reviewer comment: The presentation of Figures 10–12 should be improved, especially with regard to image resolution, uniform font sizes, and the overly small subtitles in Figures 10 and 11.

Response: Thank you for this helpful comment. We agree that the previous figures had problems with resolution, font size, and subtitle readability. In the revised manuscript, the original flux-related figures were removed, and new or revised figures were prepared to support the updated analysis. These figures were redrawn with improved resolution, clearer labels, and more consistent font sizes.

Detailed changes made in the manuscript:

Location in revised manuscript: Old Figures 10–12

Original text: *The original figures included flux-centered panels and small subtitles, and the figure presentation did not sufficiently support the revised diagnostic analysis.*

Revised text: *The original flux-related figures were removed or replaced by new diagnostic figures.*

Reason for this revision: This revision improves both figure readability and consistency with the revised analytical focus.

Location in revised manuscript: Fig. 10

Original text: *No equivalent composite diagnostic figure was provided in the original manuscript.*

Revised text: *Fig. 10. Composite evolution of dynamic and thermal anomalies from −24 to +3 h relative to dust-storm onset.*

Reason for this revision: This new figure summarizes the ERA5-based dynamic and thermal anomaly diagnostics in a clearer and more quantitative form.

Location in revised manuscript: Fig. 11

Original text: *The original manuscript did not present a comparable tower-based composite anomaly figure.*

Revised text: *Fig. 11. Composite evolution of tower-observed wind-speed, wind-shear, air-temperature-difference, and 2 m air-temperature anomalies from −24 to +3 h relative to dust-storm onset.*

Reason for this revision: This new figure connects the regional dynamic–thermal background with the station-scale tower observations.

Location in revised manuscript: Figs. 12 and 13

Original text: *The original Figures 10–12 were not sufficiently clear in image resolution, font size, or caption wording.*

Revised text: *Fig. 12. Vertical profiles of wind-speed anomalies at TZ and XT during spring and summer dust-storm events. Fig. 13. Vertical profiles of air-temperature anomalies at TZ and XT during spring and summer dust-storm events.*

Reason for this revision: The revised figures directly support the tower-observed profile analysis and use clearer figure presentation.

Mainly Added and Revised Figures and Tables

Table 1. Summary of observed dust-storm events and sample collection information

Event ID	Station	Start time of dust storm	Duration (h)	Sample collection time
Dust1	TZ	2024-03-31 12:00	22	2024-04-01 09:00
	XT	2024-03-31 12:40	17.3	2024-04-01 06:00
Excluded event	XT	2024-04-05 01:00	5	2024-04-05 06:00
Dust2	XT	2024-04-12 04:00	7.5	2024-04-12 14:00
	TZ	2024-04-14 04:00	11	2024-04-14 15:00
Dust3	XT	2024-04-17 11:00	23	2024-04-18 10:00
	TZ	2024-04-18 10:00	36	2024-04-19 22:00
Dust4	TZ	2024-04-26 21:00	16.5	2024-04-27 13:30
	XT	2024-04-26 02:00	31	2024-04-27 09:00
Dust5	TZ	2024-05-12 07:00	24	2024-05-12 14:30
	XT	2024-05-12 07:30	7	2024-05-12 14:30
Dust6	TZ	2024-05-20 11:00	14	2024-05-20 14:30
	XT	2024-05-20 11:00	3.5	2024-05-20 14:30
Dust7	TZ	2024-06-04 04:00	12	2024-06-04 16:00
	XT	2024-06-04 04:00	3	2024-06-04 07:00
Dust8	TZ	2024-06-18 07:00	2	2024-06-18 09:00
	XT	2024-06-18 07:20	3.7	2024-06-18 11:00

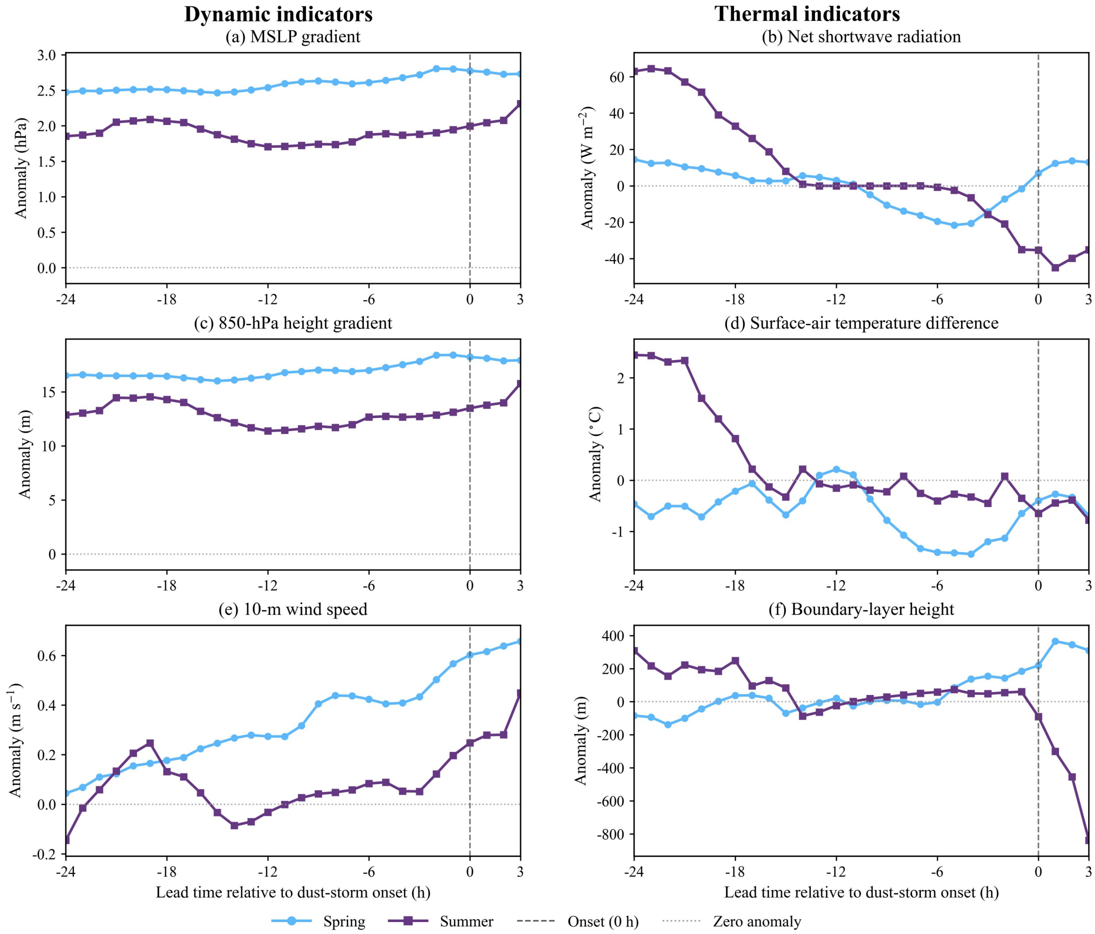

Fig. 10. Composite evolution of dynamic and thermal anomalies from −24 to +3 h relative to dust-storm onset.

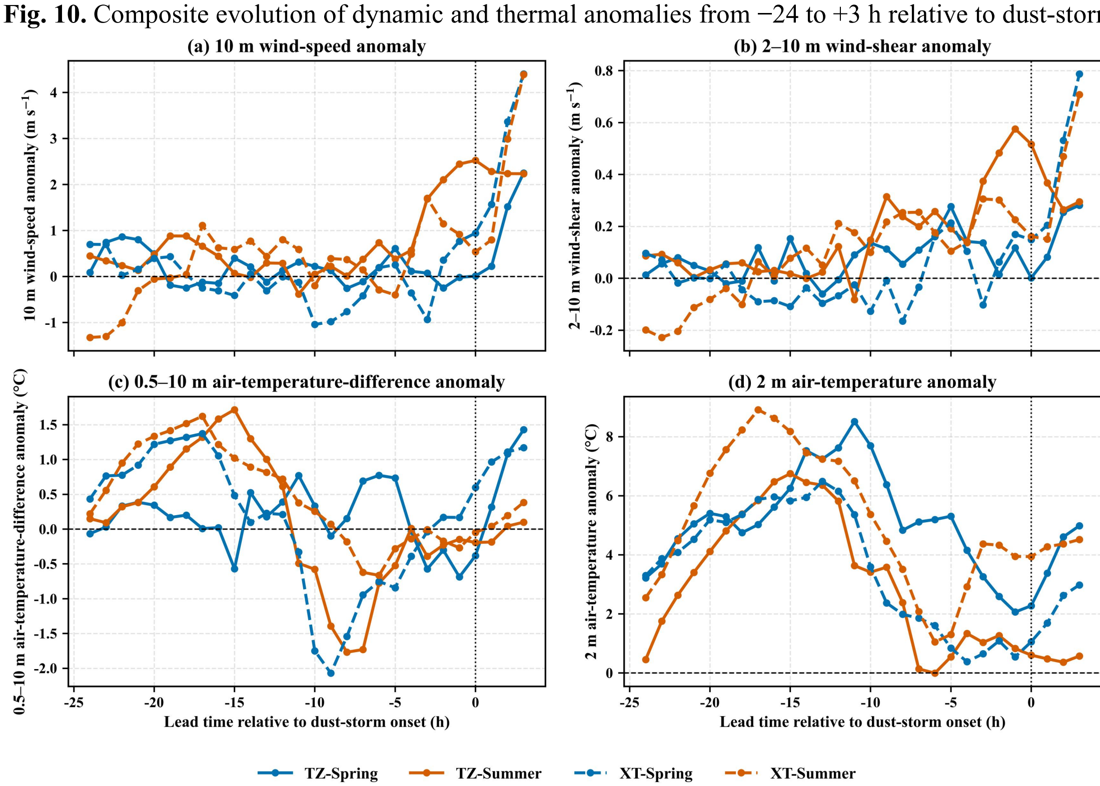

Fig. 11. Composite evolution of tower-observed wind-speed, wind-shear, air-temperature-difference, and 2 m air-temperature anomalies from −24 to +3 h relative to dust-storm onset.

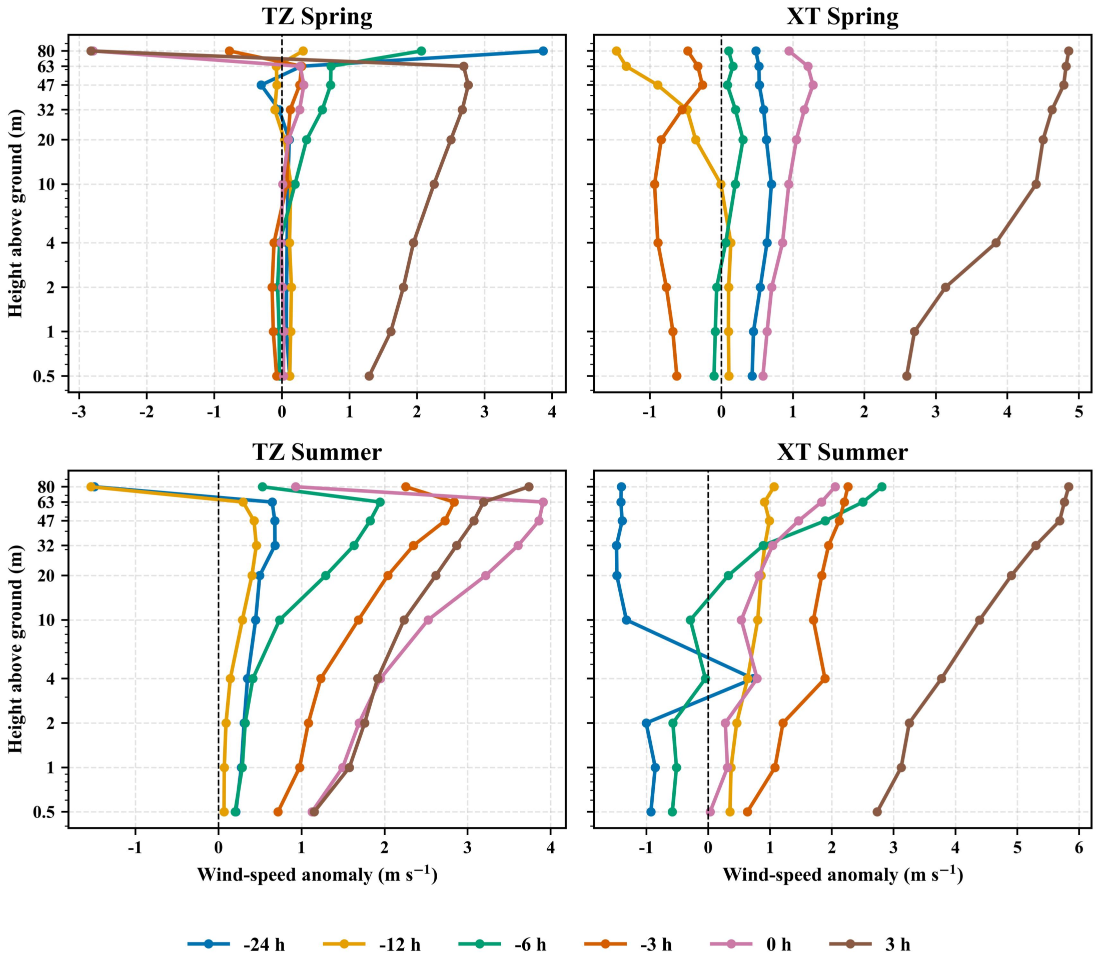

Fig. 12. Vertical profiles of wind-speed anomalies at TZ and XT during spring and summer dust-storm events.

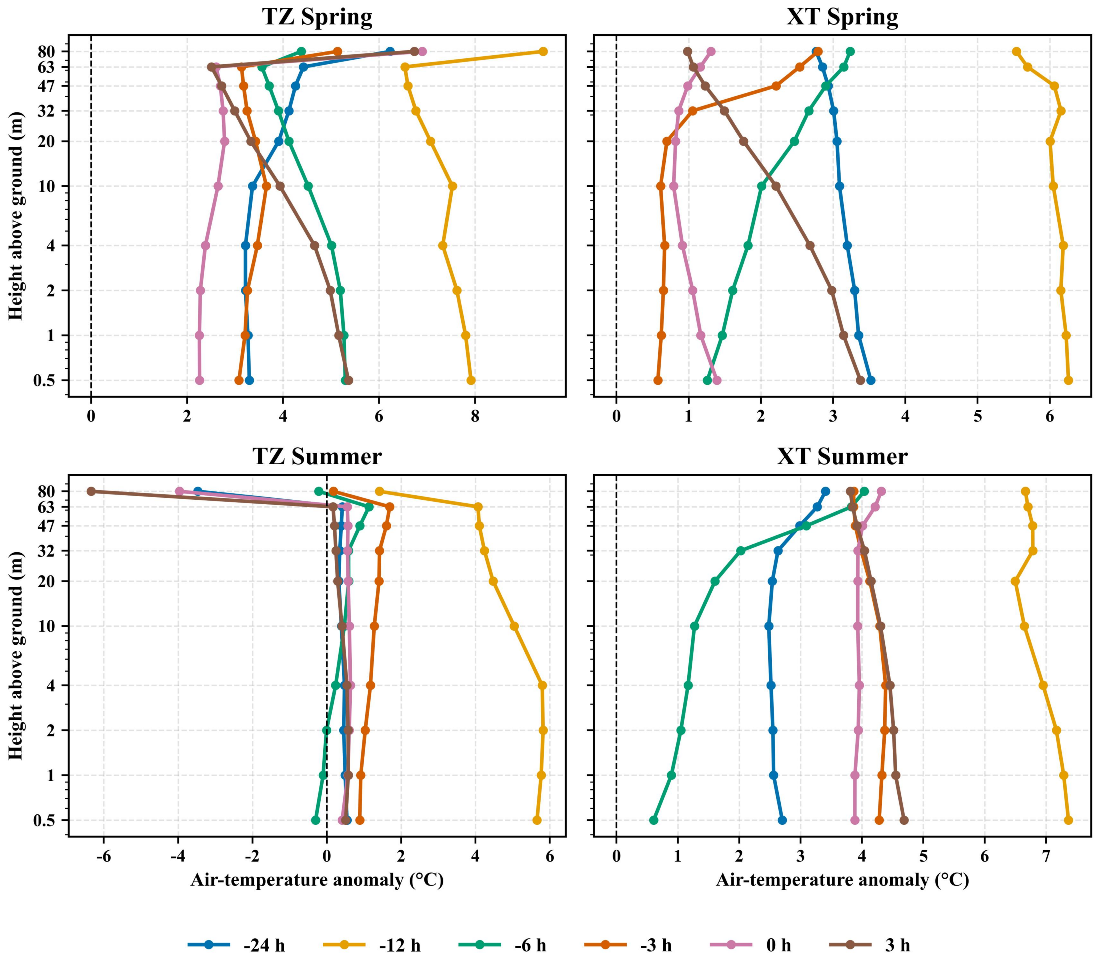

Fig. 13. Vertical profiles of air-temperature anomalies at TZ and XT during spring and summer dust-storm events.