Response to Reviewers

Manuscript title: Dynamic and Thermal Analysis of Dust Storm Processes Based on Vertical Observation Data

General response: We sincerely thank the editor and both reviewers for their constructive comments. We have revised the manuscript to clarify the event-time definition, improve the methodological explanation, moderate the scope of the conclusions, strengthen the interpretation of the tower observations, and correct language, formatting, figure attribution, and reference issues. In the point-by-point responses below, the original manuscript text is shown in red, and the revised text is shown in blue.

Response to Reviewer #1

Comment R1.1: Event-time definition and consistency between TZ and XT

Reviewer comment: In Table 1, the occurrence times of some dust-storm events still show obvious differences between the TZ and XT stations, especially for Dust2, Dust3, and Dust4. However, the HYSPLIT backward-trajectory analysis and ERA5 composite analysis appear to use a single start time for each event. The manuscript should clearly explain whether one station-specific onset time was used, or whether the two stations were aligned. Because the definition of the onset time is sensitive for the composites from -24 h to +3 h, this clarification is important for interpreting dust-storm dynamics and thermal evolution.

Our understanding: We agree that the original presentation could lead to confusion. The station records describe local dust-storm or blowing-dust processes at TZ and XT, whereas the trajectory, ERA5, and composite analyses require one event-level reference time for each selected dust event. In the revision, we therefore separated the station-level observation windows from the event-level reference time used for analysis.

Response: We revised Sect. 2.2 and Table 1 to make the timing convention explicit. Table 1 now lists the station-specific selected event windows and a final column giving the event-level reference time used for HYSPLIT, ERA5, and composite analyses. We also added Supplementary Table S1, which provides the complete original station records in Beijing Time and explains the basis for choosing the event-level reference time. In general, the reference time was selected from the dust-storm occurrence record rather than from blowing-dust-only intervals, and non-hourly station records were adjusted to the analysis hour. This is particularly relevant for Dust4: the earlier XT record included a blowing-dust stage, whereas the selected event-level reference time was based on the earliest dust-storm occurrence within the paired event.

Original 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 (as detailed in Table 1). However, during the second observation, data from TZ were missing, preventing a complete paired record. Therefore, the remaining eight complete dust storm events 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 (Table 1). All times listed in Table 1 are in UTC, and duration values are rounded where necessary. The final column gives the event-level reference time used for the trajectory, ERA5, and composite analyses, rather than the exact onset time recorded at each station. When the station-recorded dust-storm onset was not exactly on the hour, the reference time was adjusted to the analysis hour. The complete station records in Beijing Time and the basis for selecting the event-level reference time are provided in Supplementary Table S1. The excluded event had no corresponding TZ record and therefore could not be used as a complete paired observation; thus, the remaining eight complete dust-storm events were used as the primary samples for this study.

Revised HYSPLIT-method text: For each event, backward trajectories were initialized at the event-level reference time listed in Table 1. The trajectory endpoint was set at 39.43? N, 85.97? E, corresponding to the observation region used in this study. Three starting heights, 100, 500, and 1500 m above ground level (AGL), were selected to represent airflow transport at different lower-tropospheric levels. Each trajectory was traced backward for 48 h.

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

Event ID	Station	Start time of selected event window (UTC)	Duration (h)	Reference time of selected dust event (UTC)
Dust1	TZ	2024-03-31 12:00	21	2024-03-31 12:00
Dust1	XT	2024-03-31 12:40	17.3	
Excluded event	XT	2024-04-05 01:00	5	2024-04-05 01:00
Dust2	XT	2024-04-12 04:00	7.5	2024-04-12 04:00
Dust2	TZ	2024-04-14 04:00	11	
Dust3	XT	2024-04-17 11:00	25	2024-04-17 11:00
Dust3	TZ	2024-04-18 10:00	36	
Dust4	TZ	2024-04-26 21:00	16.5	2024-04-26 21:00
Dust4	XT	2024-04-26 22:00	11	
Dust5	TZ	2024-05-12 07:00	24	2024-05-12 07:00
Dust5	XT	2024-05-12 07:30	7	
Dust6	TZ	2024-05-20 11:00	14	2024-05-20 11:00
Dust6	XT	2024-05-20 11:00	3.5	
Dust7	TZ	2024-06-04 04:00	12	2024-06-04 04:00
Dust7	XT	2024-06-04 04:00	3	
Dust8	TZ	2024-06-18 07:00	2	2024-06-18 07:00
Dust8	XT	2024-06-18 07:20	3.7	

Supplementary Table S1. Single event-level dust-storm windows and complete original station records

For non-hourly station records, the reference time was rounded to the analysis hour; therefore, it may differ slightly from the exact onset time listed in Supplementary Table S1.

Event	Reference station	Selected event-level dust-storm window (UTC)	Complete original station record(s) (BJT)	Basis for time selection
Dust1	TZ	2024-03-31 12:00 to 2024-04-01 09:00	TZ 80 m deposition: 2024-03-31 20:00 to 2024-04-01 17:00, dust storm. XT 100 m deposition: 2024-03-31 20:40 to 2024-04-01 14:00, rain plus dust storm.	A single event-level window was selected from the earlier dust-storm record.

Excluded event	XT	2024-04-05 01:00 to 2024-04-05 06:00	XT 100 m deposition: 2024-04-05 09:00 to 14:00, dust storm.	This single-station dust-storm event was excluded from the paired-event analysis because the corresponding TZ sample was unavailable.
Dust2	XT	2024-04-12 04:00 to 2024-04-12 11:30	XT 100 m deposition: 2024-04-12 12:00 to 19:30, dust storm; 2024-04-13 17:30 to 19:30, blowing dust. TZ 100 m deposition: 2024-04-14 12:00 to 23:00, dust storm; 2024-04-15 07:00 to 20:00, floating dust.	The earlier dust-storm interval with a complete original start and end time was selected.
Dust3	XT	2024-04-17 11:00 to 2024-04-18 12:00	TZ 80 m deposition: 2024-04-18 18:00 to 2024-04-20 06:00, dust storm plus blowing dust. XT 100 m deposition: 2024-04-17 19:00 to 2024-04-18 20:00, dust storm; 2024-04-19, thunderstorm and light rain at 03:00.	The XT dust-storm interval started earlier and was therefore used as the single event-level window.
Dust4	TZ	2024-04-26 20:50 to 2024-04-27 13:30	TZ 80 m deposition: 2024-04-27 04:50 to 21:30, dust storm; 2024-04-28, blowing dust all day; 2024-05-09 19:30 to 20:30, blowing dust. XT 100 m deposition: 2024-04-26 10:00 to 2024-04-27 06:00, blowing dust; 2024-04-27 06:00 to 17:00, dust storm; 2024-04-28 14:00 to 19:30, dust storm; 2024-05-09 16:30 to 22:30, blowing dust.	The TZ dust-storm interval was selected; the manuscript event time can be rounded from 20:50 to 21:00 UTC where hour-level timing is required.
Dust5	XT	2024-05-12 07:30 to 2024-05-12 14:30	TZ 80 m deposition: 2024-05-12 to 2024-05-13, dust storm. XT 100 m deposition: 2024-05-12 15:30 to 22:30, dust storm; 2024-05-13 to 2024-05-15, blowing dust and afternoon light rain.	The XT dust-storm interval was selected because it provides a complete original start and end time.
Dust6	XT	2024-05-20 11:00 to 2024-05-20 14:30	TZ 80 m deposition: 2024-05-20, blowing dust; 2024-05-22, blowing dust; 2024-05-26, blowing dust; 2024-05-27, blowing dust; 2024-05-31, blowing dust; 2024-06-01, rain. XT 100 m deposition: 2024-05-20 19:00 to 22:30, dust storm; 2024-05-21 22:00 to 23:00, blowing dust; 2024-05-29 20:00 to 22:00, blowing dust; floating dust every afternoon from 2024-05-17 to 2024-05-29; rain on 21, 22, and 27 May.	The XT dust-storm interval was selected because it is the clear dust-storm record for this event.
Dust7	TZ	2024-06-04 04:00 to 2024-06-04 16:00	TZ 80 m deposition: 2024-06-04 12:00 to 24:00, dust storm. XT 100 m deposition: 2024-06-01 16:00 to 17:00, blowing dust; 2024-06-04 12:00 to 15:00, dust storm; 2024-06-05 18:00 to 20:00, blowing dust.	Both stations recorded a dust storm from 2024-06-04 12:00 BJT; the longer TZ interval was used as the single event-level window.
Dust8	TZ	2024-06-18 07:00 to 2024-06-18 09:00	TZ 80 m deposition: 2024-06-15 17:30 to 19:40, blowing dust; 2024-06-16 15:00 to 15:40, blowing dust; 2024-06-18 15:00 to 17:00, dust storm; 2024-06-30 17:00 to 20:20, blowing dust; 2024-07-01 19:00 to 21:00, blowing dust; 2024-07-02 12:00 to 17:00, blowing dust; 2024-07-09 15:30 to 18:00, blowing dust. XT 100 m deposition: 2024-06-12 18:45 to 20:10, blowing dust; 2024-06-18 15:20 to 19:00, dust storm; 2024-06-25 21:00 to 21:40, blowing dust; 2024-06-26 10:00 to 19:00, blowing dust; 2024-07-01 10:00 to 16:00, blowing dust; 2024-07-02 20:20 to 21:10, blowing dust.	The TZ dust-storm interval on 18 June started earlier and was therefore used as the single event-level window.

Comment R1.2: More cautious wording in the abstract and conclusion

Reviewer comment: The abstract has been improved, but some conclusions regarding seasonal differences in spring and summer dust-storm processes remain rather broad. Because the analysis is based on eight events, the authors should use more cautious wording, such as ?based on eight events? or ?case-based evidence?, to make the conclusion more consistent with the limited sample size.

Our understanding and response: We agree that the conclusions should not be phrased as universal climatological statements. The revised manuscript now explicitly frames the results as case-based evidence from eight complete events observed in 2024.

Original text: These results indicate seasonal differences in dynamic and thermal forcing during Taklimakan dust-storm development.

Revised text: Based on eight complete dust-storm events observed in 2024, this study provides case-based evidence for seasonal differences in dynamic and thermal preconditioning over the Taklimakan Desert. Together, the results show that Taklimakan dust-storm development depends on regional transport pathways, dynamic and thermal background conditions, near-surface wind response, and local terrain effects.

Comment R1.3: Rationale for dynamic and thermal indicators

Reviewer comment: The reason for selecting the dynamic and thermal indicators should be further explained. Variables such as pressure-gradient magnitude, 850 hPa geopotential-height-gradient magnitude, 10 m wind speed, surface-air temperature difference, net shortwave radiation, and boundary-layer height are related to dust-storm initiation, maintenance, or intensification, but their physical links with dust-storm processes should be stated more clearly.

Our understanding and response: We agree that the previous methods section listed the indicators but did not sufficiently explain why they were chosen. We expanded Sect. 2.3 to explain the physical meaning of the selected ERA5 fields and diagnostic indicators.

Original text: ERA5 data were used to analyze the meteorological background of the dust-storm events, including pressure, wind, temperature, radiation, and boundary-layer variables.

Revised text: Mean sea-level pressure, 10 m wind vectors, 2 m air temperature, and 850 hPa geopotential height were selected to characterize pressure configuration, near-surface airflow, thermal background, and lower-tropospheric circulation around the Taklamakan Desert. The dynamic indicators included mean sea-level pressure-gradient magnitude, 850 hPa geopotential-height-gradient magnitude, and 10 m wind speed, which together represent synoptic-scale pressure forcing, lower-tropospheric circulation contrasts, and near-surface momentum directly related to dust emission. The thermal indicators included 2 m air temperature, skin temperature, surface-air temperature difference, surface net shortwave radiation, and boundary-layer height, which were used to characterize near-surface warming, surface-air thermal contrast, radiative heating, and vertical mixing.

Comment R1.4: Meaning of the difference fields in Figs. 6-9

Reviewer comment: For Figs. 6-9, the meaning of the difference between the onset value and the earlier-time value may not be immediately clear to readers. The manuscript should explain the meaning of positive and negative values, and clarify that the maps are based on temporal differences rather than directly showing absolute anomalies or absolute fields.

Our understanding and response: We agree that the figure interpretation needed to be stated explicitly. We added explanatory text before the discussion of Figs. 6-7 and Figs. 8-9.

Original text: Figures 6 and 7 show the sea-level pressure differences before spring and summer dust-storm onset. Figures 8 and 9 show changes in the surface-air temperature difference before dust-storm onset.

Revised text: Figures 6 and 7 show the temporal differences in sea-level pressure between the selected dust-event reference time and four lead times. Positive values indicate that sea-level pressure increased from the lead time to the event reference time, whereas negative values indicate a pressure decrease. These fields represent temporal changes relative to the selected event reference time, rather than absolute pressure anomalies. Figures 8 and 9 show the temporal changes in surface-air temperature difference; these maps describe temporal changes in thermal contrast, rather than the absolute surface-air temperature difference at each time.

Comment R1.5: Interpretation of TZ-XT tower differences

Reviewer comment: The explanation of the tower observations should include terrain, surface roughness, and station differences. The authors should discuss how local topography, surface roughness, or station location may influence the observed wind and temperature profiles.

Our understanding and response: We agree that the station-scale differences should not be interpreted only as regional dynamic or thermal forcing. We added discussion text explaining that local surface and terrain conditions can modulate the tower-observed anomalies.

Original text: The tower observations show differences between TZ and XT in wind-speed and temperature anomalies during the dust-storm events.

Revised text: This station-scale pattern is consistent with the ERA5-based interpretation, but the contrast between TZ and XT also indicates that regional forcing was locally modified by surface and terrain conditions. Although both towers are located within the Taklamakan Desert, differences in dune morphology, surface roughness, and station exposure can influence near-surface wind acceleration, turbulent mixing, and temperature profiles.

Comment R1.6: Observational contribution and vertical structure in the conclusion

Reviewer comment: The conclusion should be further improved to highlight the main observational contribution of the study, especially the vertical structures of wind, wind shear, and temperature anomalies before dust-storm occurrence.

Our understanding and response: We agree that the conclusion should more clearly identify the added value of the tower observations. We therefore revised the conclusion to emphasize the vertical structure revealed by the dual-gradient towers.

Original text: The tower observations further support the dynamic and thermal conditions associated with dust-storm development.

Revised text: The dual-gradient tower observations provided direct near-surface evidence for the vertical expression of regional forcing. In the analyzed summer cases, temperature anomalies were stronger and more vertically coherent, whereas wind-speed and wind-shear anomalies intensified closer to onset. This vertical structure suggests a staged process, with early thermal preconditioning followed by stronger momentum enhancement near onset.

Comment R1.7: Reference consistency and relevance

Reviewer comment: The reference list should be checked carefully for consistency, including DOI, journal title, publication year, volume, page numbers, and capitalization. References less closely related to the main topic should be reconsidered or replaced by more directly relevant studies on dust-storm dynamics, boundary-layer processes, or wind transport.

Our understanding and response: We agree that reference accuracy and relevance are important. We checked and standardized the reference list and retained references that directly support dust-storm dynamics, boundary-layer processes, transport pathways, ERA5/HYSPLIT methods, and Taklimakan Desert observations.

Original text: Some references contained inconsistent journal-title capitalization, incomplete bibliographic details, or less direct relevance to the main topic.

Revised text: The reference list has been checked and standardized. DOI information is included, journal titles and publication information have been corrected, and topic relevance has been improved.

Response to Reviewer #2

Comment R2.1: Acceptance after technical and language correction

Reviewer comment: The authors have made satisfactory revisions to the manuscript. Only technical corrections and language improvement during English editing are still needed. These changes are acceptable after minor correction.

Our understanding and response: We are grateful for the reviewer's positive assessment and helpful suggestion. In response, we carefully proofread the revised manuscript and made further technical and editorial corrections to improve clarity, consistency, and compliance with the journal format. In particular, we checked the terminology used for dust-storm events throughout the manuscript, revised several long or unclear sentences, standardized figure and table captions, corrected the author-contribution and funding statements, clarified the data and code availability statement, added figure-source and copyright attribution for the base map in Fig. 1, and rechecked the reference list for DOI and formatting consistency.