Response to Reviewers' Comments

Reviewer #1:

This manuscript presents a comprehensive analysis of an extreme wind gust event associated with a quasi-linear convective system (QLCS) in Beijing on 30 May 2024. The study leverages a high-resolution observational mesonet, including radar wind profilers, a meteorological tower, and multi-source remote sensing data, to elucidate the multi-scale dynamical processes involved. The findings provide valuable insights into the mechanisms of convective gust generation and have potential implications for nowcasting and model improvement. Thus, I recommend the publication of this paper in Atmospheric Chemistry and Physics after the following points have been addressed:

Response: We appreciated tremendously your positive and invaluable comments, which indeed help improving the quality of our manuscript. We have addressed the reviewers' concern one by one to the best of our abilities. For clarity purpose, here we have listed the reviewers' comments in blue plain font, followed by our response in black bold italics, and the modifications to the manuscript are in black italics.

Major comments:

The manuscript would benefit from a detailed description about the conceptual model in Figure 10. A discussion about key findings of this observed mechanism compared with those in previous QLCS studies, especially from other terrain regions, would also enhance this study.

Response: Per your kind suggestions, we have supplemented section 5 in this revised manuscript, mainly including the following two points:

(1) A detailed description of the conceptual model (Fig. 10) in the main text has been added to elucidate the observed dynamical structures and multi-scale processes responsible for this Beijing extreme gust event:

"Before the merger of the QLCS (Fig. 10a), the northern convection portion maintained and developed rapidly due to the convergence of southerly winds along the southern slopes of Mt. Yan. Meanwhile, a convergence line formed at the boundary of convectively generated cold outflows, mostly associated with the southern portion. During the downhill process, the environmental

southerly winds in the near-surface layer facilitated efficient storm-relative inflow of highly unstable air, supporting the continued regeneration of strong convection along the advancing cold pool, where a very large area of nearly contiguous radar reflectivity echoes greater than 45 dBZ was concentrated over the foot of western mountains. The presence of pronounced convergence from the PBL in updrafts led to the rapid intensification of surface-based cyclonic vorticity through vertical stretching during the early stages. Evaporative cooling enhanced the generation of the extreme winds via downward momentum transport and pressure gradient forcing.

As shown in Fig. 10b, the two convective segments merged into a well-organized squall system, moving perpendicular to the mean deep-layer wind/shear and developing a larger-scale bow-echo structure after reaching the plain. In the merger stage, a midlevel layer of intense cyclonic vorticity favored the development of RIJ behind the precipitation area, driven by the superposition of ambient flow and the rotational flow on the west side of the mesovortex. The calculation of the zonal momentum budget further confirmed the importance of horizontal momentum downward transport in accelerating lower-level flows within the descending RIJ.

Large-scale analyses show that the deep, well-mixed PBL with very steep lower-tropospheric lapse rates and conditional instability provided a favorable background for consolidating the dispersed multicell thunderstorm. The emergence of pronounced low-level frontogenesis, coupled with significant shearing deformation, created a highly favorable synoptic-scale environment for sustained convection. These processes supplied persistent forcing for ascent and low-level convergence, continuously transporting moisture and instability to promote the organization and maintenance of the circulation. By further examining the property of turbulent kinetic energy transfer derived from three-dimensional ultrasonic anemometers on the meteorological tower, we found that the frequency and intensity of inverse energy cascades increased significantly during this near-surface high wind event. These findings bridge the gap between meso- and small-scale physical processes in the lower troposphere and large-scale weather system, which potentially consolidate our understanding of the dynamics and their roles in the evolution of convection."

(2) The discussion has been expanded to include a comparison between our observed mechanisms and previous QLCS studies:

"Based on the above results, this case shares commonality with other QLCS cases in previous studies while exhibiting terrain-modulated uniqueness. Similar to QLCS events documented over plains (e.g., the U.S. Central Plains), the storm exhibited a well-defined cold

pool, a descending RIJ, and strong low-level convergence leading to bow-echo development (Bentley and Mote, 1998; Bentley and Sparks, 2003; Wakimoto et al., 2006; Evans et al., 2014). However, its evolution was markedly influenced by complex topography (Houze, 2012). The initial convection was anchored and intensified by orographic lifting along the southern slopes of Mt. Yan, and the downhill propagation of the system resulted in an unusually concentrated zone of high reflectivity near the foot of Mt. Taihang. These findings underscore that while the overall dynamical framework of QLCS remains consistent, local topography can fundamentally alter the initiation, sustenance, and peak intensity of severe winds by modifying convergence patterns, cold-pool propagation, and vortex dynamics. Future nowcasting and high-resolution modeling for complex terrain regions should therefore explicitly incorporate such terrain–convection interactions."

Minor comments:

1. The acronym "RWP" is defined early on, but "QLCS" is used in the abstract before being spelled out in the introduction. Please ensure all acronyms are defined upon first use.

Response: All acronyms are defined upon first use.

2. The study relies heavily on RWP-derived parameters (e.g., divergence, vorticity, frontogenesis). The uncertainty associated with these calculations should be quantified and discussed.

Response: Thanks for your kind reminder. In our previous study (i.e., Guo et al., 2023), the uncertainties associated with the errors of horizontal wind retrievals, the spatial scales and the shape of triangles in the calculation of RWP-derived parameters have been discussed. To ensure the stability of the results, obtuse angles of more than 140° and areas of less than 500 km^2 should be avoided for constructing a reasonable triangle. Here, four triangles from west to east are constructed based on the positions of six RWPs to meet the consistency in shape and area. It is noteworthy that the value of four dynamic parameters is still inversely proportional to the area of triangle as the denominator. This coincides with the fact that the gradient of velocity between two points will increase when the distance is shortened. The discussion has been supplemented in section 2.4.

3. For the frontogenesis calculation, surface observations are implied for gradients of θe. Please comment on the potential implications of using surface data to represent low-level processes, and any associated limitations.

Response: We fully agree with your concern. In the revised manuscript, we elaborate on the underlying assumptions, key limitations, and their potential impact on the interpretation of results in section 2.5.

"Limited by the lack of vertical profiles of thermal parameters in real-time, the gradients of θ_e are obtained from surface observations from AWSs in Beijing. Indeed, the core drivers of frontogenesis are dynamic processes, while the gradient of θ_e mainly acts as a scaling coefficient that modulates the efficiency of these dynamic contributions. This simplification of assuming this "efficiency coefficient" remains relatively homogeneous in the lower layer is available to capture regions of dynamically dominated frontogenesis. However, it must be acknowledged that surface observations may not adequately represent baroclinic structures aloft, especially in the presence of temperature inversion or strong vertical shear. Consequently, the diagnostic results are most applicable to near-surface environments and shallow frontogenesis. Future improvements would benefit from incorporating vertically resolved thermal variables obtained from operational high-frequency detection (e.g., microwave radiometers) for a more comprehensive assessment."

4. Line 286: Hiamwari -> Himawari.

Response: Corrected as suggested.

5. Why you choose the 95th percentile of 10-m wind speed in the triangle rather than the maximum value or another percentile?

Response: Good question! We chose the 95th percentile instead of the maximum value primarily due to considerations of statistical robustness and representativeness. The maximum value can be easily influenced by extreme outliers or observational noise, and may not consistently reflect the overall distribution of wind speeds within the region. In contrast, the 95th percentile effectively captures strong wind signals while remaining less sensitive to extreme outliers, providing a more reliable representation of high wind speeds in the triangular area.

6. Section 4.4: The link between IEC and gust intensity is intriguing. but needs more physical explanation.

Response: Per your suggestion, we deeply explored the link between IEC and the organization of convection associated with high winds. More physical explanation has been added in Section 4.4, which is shown as follows:

"As the well-sustained mesoscale convection created a favorable dynamic environment for the evolution of small-scale turbulent processes, the interaction between the organized squall system (and its embedded mesovortex and rear-inflow jet) and the ambient flow laid the foundation for the subsequent intensification of turbulent energy transfer, which is essential for the evolution of severe convective gust and related convective activities (Adler and Kalthoff, 2014; Dai et al., 2014; Dodson and Griswold, 2021; Su et al., 2023). Understanding mechanisms of the turbulent kinetic energy (TKE) transferring in the PBL between the surface and atmosphere is crucial for turbulence parameterization in numerical models, especially for extreme wind events (Powell et al., 2003; Monahan et al., 2015; Lyu et al., 2023).

In contrast to the Monin-Obukhov similarity theory that TKE transfers from larger to smaller eddies until it is dissipated at the smallest scales (Kolmogorov, 1941; Monin & Obukhov, 1954), many studies discovered the phenomenon of inverse energy cascades (IEC) in a totally different way (Kraichnan, 1967; Byrne and Zhang, 2013; Tang et al., 2015). Despite these advances in theoretical and numerical studies, observational support for IEC in the atmosphere remains insufficient (Shao et al., 2023a; 2023b). This study further examined the direction of the energy cascade associated with wind gusts using three-dimensional ultrasonic anemometers at seven heights, denoted as z_1 to z_7, on the meteorological tower in Beijing. According to Eq.(11), we can detect the occurrence of IEC at each height in every moment with a time resolution of 0.1 s.

The frequency of IEC during a period was evaluated as the ratio of the number of time-height grids identified as IEC to the total number of samples. In this way, we got height-resolved occurrence frequency of IEC for the study period in Fig. 9a. It is shown that IEC is a more prevalent phenomenon within the near-surface wind field. Notably, the frequency and intensity of IEC at all heights increased significantly when near-surface wind speeds exceeded 10 m s^{-1}. The frequency of IEC reaches up to 45% after 1436 LST, indicating that strong winds are contributed to IEC. The result in Figure 9b and c revealed that the power spectral density (PSD) was higher *after 1436 LST in the lower-frequency area, especially for the u and v directions, which confirmed the activity of turbulent kinetic energy from smaller to larger eddies.*

The observed surge in the frequency of IEC during the passage of convective outbreak suggests a temporary reorganization of turbulent energy transferring. These features are similar to those proposed by the observational analyses in two-dimensional turbulence (Shao et al., 2022; Zhou et al., 2025), which revealed that the formation of rapid rotation is a crucial driver of IEC. Strong horizontal shear generated by the gust front likely imposes a quasi-two-dimensional constraint on the flow, suppressing the three-dimensional vortex-stretching mechanism that normally drives a forward cascade. In this regime, enstrophy (the square of vorticity) may become partially conserved. Just as vigorously stirring the water in a very shallow pond causes small swirls to merge into a single, large vortex, a massive storm can be seen as the end product of an inverse cascade, where energy from small-scale convection organizes into a giant, coherent vortex. Another possible explanation is that the rapid increase in wind speed abruptly shifts the Reynolds number, possibly triggering transient instabilities that further promoted the generation of quasi-two-dimensional vortex (Browand and Winant, 1973). The amplification of large-scale eddies transfer momentum downstream more efficiently and enhance wind gusts as a form of positive feedback. In addition, the reduction of surface drag coefficient under robust weather systems impedes the dissipation of energy throughout the boundary layer, prolonging the duration of high winds (Raupach, 1994; Mahrt et al., 2003; Powell et al., 2003).

This event illustrates how synoptic-scale disturbances can locally override the classical theory of energy dissipation, leading to a measurable, height-dependent signature of IEC in the PBL. In turn, this shear-driven IEC likely played a catalytic role in consolidating the storm's low-level circulation, demonstrating how microscale turbulent processes can feedback on the mesoscale storm organization. These findings provided favorable evidence for the unique features of 2D turbulence in high wind conditions. These findings have implications for turbulence parameterizations in numerical weather prediction and climate models. Future research should further investigate the mechanisms driving the formation of IEC in more detail and explore the potential link between IEC and different meteorological phenomena."

7. The use of "jet" should be more cautious. According to the definition, wind speed should be greater than a certain threshold to be called a "jet".

Response: We agree that the term "jet" typically implies a wind speed exceeding a certain threshold, which varies across studies and contexts (e.g., midlatitude vs. tropical systems, boundary layer jets vs. upper-level jets). By comparison, the threshold for the rear-inflow jet has not been clearly defined. It emphasizes more on a concentrated, relatively high-velocity channel of airflow within the wind field, whose speed is significantly stronger than the surrounding environment. As shown in Fig 7a, the rear-inflow region indeed features a localized, sustained core of wind speed maximum exceeding the environmental flow by 20 m s^{-1}. Therefore, we retain using jet here.

8. Ensure all cited references are included and formatted in accordance with ACP guidelines.

Response: Per your suggestions, all cited references are included and have been formatted to make sure their formats totally align with ACP guidelines.

Reviewer #2:

This manuscript presents a very nice, detailed analysis of intensive observations made of an extreme surface wind event produced by a quasi-linear convective system (QLCS), that occurred in Beijing. The QLCS was associated with a Mesoscale Convective System (MCS). The observational facilities included a network of 7 radar wind profilers, a 325-m meteorological tower with 7 ultrasonic anemometers, 2 sounding sites, 250 automated weather stations, and the national radar network. Himawari-8/9 satellite data are also used.

My only main criticism is the conjecture that is not supported by evidence. Mainly that is wording. I have made quite a few suggestions below. I hope (most of) these are useful.

Response: Thank you very much for your meticulous review and highly constructive comments, which have been invaluable for enhancing the scientific rigor and clarity of our manuscript. We fully agree with your critical point that certain speculative wording in the original draft lacked sufficient observational support—this is a key issue we have prioritized addressing. We have conducted a comprehensive, line-by-line review of the entire manuscript, focusing on refining expressions related to causal inferences and mechanism interpretations. Specifically, we have replaced ambiguous or conjecture-based phrasing with data-driven descriptions, supplemented observational evidence for inferences where necessary, and explicitly distinguished between definitive findings and tentative hypotheses.

For clarity purpose, here we have listed the reviewers' comments in blue plain font, followed by our response in black bold italics, and the modifications to the manuscript are in black italics. We sincerely appreciate your continued guidance as we refine the manuscript. The specific changes are detailed below:

1. L46-48. It would be helpful to say what these valuable insights are.

Response: We agree that explicitly stating the key insights will significantly strengthen the concluding part of the abstract. In response, we have revised the last several sentences to concisely summarize our core findings.

"This study offers valuable insights into the multiscale dynamical processes governing convective evolution—captured by the RWP mesonet—that would otherwise remain inaccessible via other

ways. Importantly, these findings support the validation of numerical simulation outputs, refinement of boundary-layer parameterization schemes in numerical weather prediction (NWP) models, and ultimately the enhancement of forecast skill for convection-associated extreme gust events."

2. L47. Specify RWP on L33.

Response: "RWP" has been specified as "radar wind profiler".

3. Abstract. Would it be useful to mention the record-breaking surface gust wind event that occurred on 30 April 2021 described by Chen et al, 24?

Response: Per your kind reminder, we have mentioned the record-breaking surface gust wind event that occurred on 30 April 2021 described by Chen et al. (2024) in the revised manuscript:

"For instance, Chen et al. (2024) examined a record-breaking surface gust wind that occurred in eastern China on 30 April 2021 by using the measurements from the RWP mesonet in the YRD region."

4. L54. It would perhaps be useful to mention the work of e.g. Browning et al, in considering the concept of transporting high momentum downwards to give damaging surface winds, even though the underlying systems were different. The paper by Browning et al 2010 (Q. J. R. Meteorol. Soc. 136: 354–373, DOI:10.1002/qj.582) is also worth considering. It provided an in-depth analysis of an MCS. It may be relevant (your L86-89) because of one of their conclusions: "The absence of strong winds at the surface within the MCS is consistent with the failure of the rear-inflow jet to reach the ground and produce a strong cold pool."

Response: Per your suggestion, we have carefully studied the paper by Browning et al. (2010) and cited it in the introduction section.

References:

Browning, K.A., Marsham, J.H., Nicol, J.C., Perry, F.M., White, B.A., Blyth, A.M. and Mobbs, S.D. (2010), Observations of dual slantwise circulations above a cool undercurrent in a mesoscale convective system. Q.J.R. Meteorol. Soc., 136: 354-373. https://doi.org/10.1002/qj.582

5. L68-74. Please explain the role of the various interactions on these wind gusts. Otherwise the sentence does not provide any information.

Response: We have revised the introduction to explicitly explain the role of the various interactions on these wind gusts:

" Specifically, mesoscale dynamics and thermodynamics interaction drives the generation of downdrafts to form the initial "engine" of the gust (Abulikemu et al., 2019; Johns & Hirt 1987; Taszarek et al., 2019; Vose et al., 2014). Microphysics processes governs latent cooling rates, which directly control the buoyancy and strength of downdraft (Adams-Selin et al. 2013; Mahoney and Lackmann 2011; Zhou et al. 2020). Then, the turbulence-convection interaction modulates these downdrafts and outflows by turbulent mixing near the surface and determines how efficiently momentum is transferred to the surface, thereby sharpening or dissipating the gust front (Shao et al., 2023a; 2023b; Tang et al., 2015; Tucker et al., 2009)."

6. L90. Significant progress?

Response: "some progress" has been amended as "significant progress".

7. L121-128. It would be better (here and later) to put the details (such as coordinates) in the caption.

Response: The details about RWP and sounding stations (such as coordinates) have been moved in the caption of Figure 1.

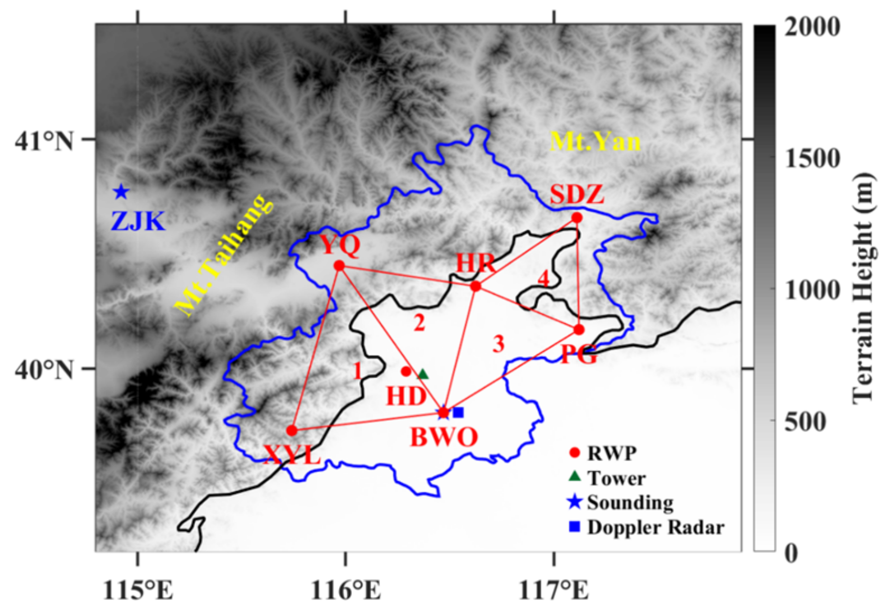

Figure 1. *Spatial distribution of the terrain height over Beijing and surrounding areas with the black and blue line denoting the plain line at 200 m terrain elevation and the provincial boundary, respectively. Seven RWPs (red dots) deployed at Xiayunling (XYL; 39.73°N, 115.74°E), Shangdianzi (SDZ; 40.66°N, 117.11°E), Huairou (HR; 40.36°N, 116.63°E), Yanqing (YQ; 40.45°N, 115.97°E), Haidian (HD; 39.98°N, 116.28°E), Pinggu (PG; 40.17°N, 117.12°E), and the*

Beijing Weather Observatory (BWO; 39.79°N, 116.47°E). Four red triangles with number denote the regions used to calculate the dynamic parameters with the triangle method. Blue five-pointed stars denote the L-band sounding at BWO and Zhangjiakou (ZJK; 40.77° N, 114.92° E) station. A S-band Doppler weather radar (blue square) is also deployed at BWO. Green small triangle represents the location of meteorological tower (39.97°N, 116.37°E).

8. L137. Is there any evidence that the mountains affect the soundings made at Zhangjiakou?

Response: There is no obvious evidence that the mountains affect the soundings made at Zhangjiakou. But we agree with you that the terrain-induced boundary layer processes such as mountain-valley breezes may affect the low-level winds. Thus, the analysis of the sounding made at Zhangjiakou in this study relied solely on mid-to-upper-level northwesterly wind, complemented by reanalysis data.

"Consistent with the ERA5 reanalysis data, the sounding at the ZJK revealed upstream conditions in which thunderstorms were likely to develop (Fig. 4c). These conditions consist of a strong northwesterly wind oriented perpendicular to the Mt. Taihang range at middle level, accelerating the downhill process of storm (Wilson et al., 2010; Chen et al., 2012; 2014; Li et al., 2017; Xiao et al., 2017; 2019; Guo et al., 2024). The potential for terrain-triggered gravity waves in the leeside that can modulate localized uplift and cloud organization (Neiman et al., 1988; Lombardo and Kumjian, 2022; Rocque and Rasmussen, 2022)."

9. L150-154. Does this mean that the maximum reflectivity in a pixel column is shown? How long does a volume scan take? Is there confidence that the maximum reflectivities are between 60 and 65 dBZ?

Response: Thank you for your insightful questions regarding the radar reflectivity data presentation. We have clarified the relevant details by aligning with the manuscript's original data description as follows:

- ***The composite radar reflectivity used for identifying and tracking the mesoscale convective system (MCS) has a spatial resolution of approximately 0.01° × 0.01° (latitude × longitude), derived from the China Meteorological Administration (CMA) Doppler radar network. As you inferred, it specifically integrates the maximum reflectivity measurements across different vertical levels for each horizontal grid pixel, ensuring comprehensive capture of the system's vertical echo structure.***

- ***For the operational CMA Doppler radars employed in this study, a complete volume scan typically takes 6 minutes. This temporal resolution is sufficient to track the dynamic evolution of the MCS and the propagation of the gust front, which is also supplemented by Doppler radial velocity data from the S-band radar in BWO as described in the manuscript.***
- ***The sepcific reflectivity range of 60-65 dBZ wasn't mentioned in the text. For the observed QLCS in this study, the maximum reflectivity in intense convective cores is mainly distributed within the range of 55–65 dBZ. Among this range, 60–65 dBZ corresponds to typical deep intense convective cores, which is a reasonable and widely recognized intensity interval for such events in previous studies.***

We have supplemented these technical details (including resolution and data integration logic) in this revised manuscript to avoid ambiguity.

10. L155-156. Mention the radar at BWO in the caption to Fig 1?

Response: Revised as suggested. Please see the caption of Fig 1 in Question 7.

11. L157-160. Are the AWSs in the valleys? There will be limited radar information in the valleys.

Response: Yes, there are AWSs in the valleys. Figure 3 in this revised manuscript (original Fig. 2) shows the location of AWSs with the wind speed and rainfall observation during this event, which make up for the limited radar information.

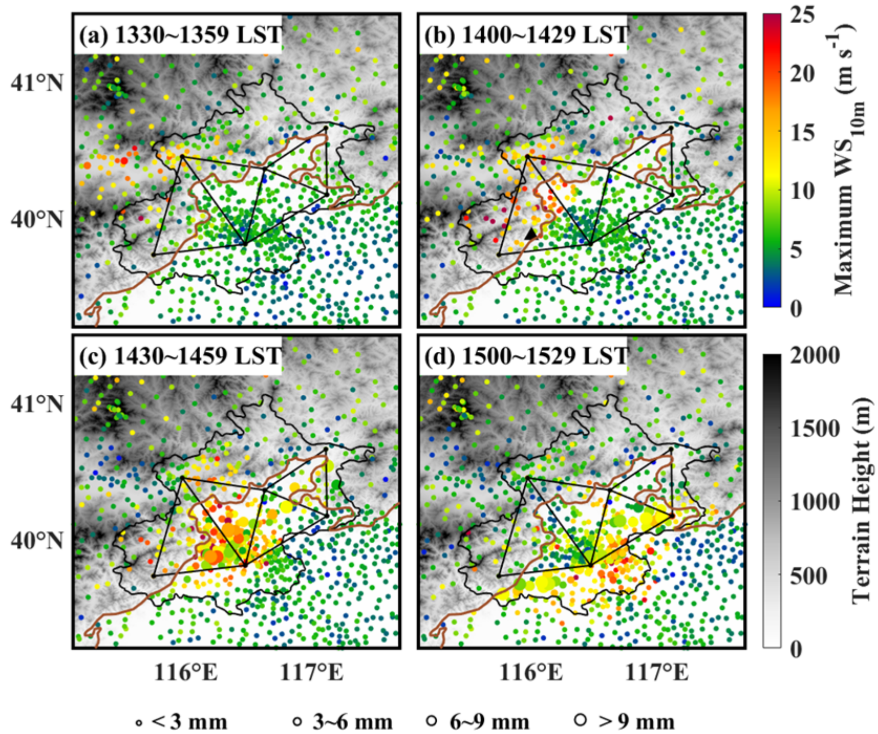

Figure 3. *Terrain height (gray shadings; m) over Beijing and surrounding areas superimposed with the maximum 10 m wind speed (shading of dots, m s^{-1}) observed during (a) 1330-1359 LST, (b) 1400-1429 LST, (c) 1430-1459 LST, and (d) 1500-1529 LST. The size of dots denoted the accumulated rainfall in 30 minutes. Black small triangle in (b) represents the location of the Qianling Mountain site (39.87°N, 116.07°E).*

12. L241-242. In my opinion, it would be helpful to show the radar plots in Fig 4 at this stage. Also two questions, what does a downhill thunderstorm really mean and secondly, is there a single thunderstorm involved, or is it the MCS?

Response: Per your suggestion, we adjust original Fig 4 to Fig 2 in this revised manuscript. Firstly, the south portion of MCS experienced a downhill process when it subsequently propagated eastward and entered into plain according to the moving path of echo shown in the radar plots. That's why we call it "downhill thunderstorm".

Secondly, it was a MCS rather than a single thunderstorm. The event was characterized by a large, organized cluster of thunderstorms exhibiting a continuous leading convective line with trailing stratiform precipitation, as evident from the brightness temperature.

Based on the above two points, we have explicitly emphasized that it is the MCS instead of "a single downhill thunderstorm" in the revised manuscript.

13. L245. There are also high winds shown in Fig 2a before 1400. And... is it possible to place some height contours on Fig 2.

Response: Thanks for your kind reminder. The terrain height has been added on this Fig (Please see Fig 3 in Question 11). Although there were indeed high winds before 1400 LST, we intended to concentrate on the intensification of this MCS as it propagated after 1400 LST, which is the key focus of this study due to its greater impact on populated plain areas. We have revised this sentence to make it more rigorous:

"During the evolution of the MCS, a number of high winds (instantaneous 10 m wind speed ⩾17.2 m s^{-1}) were observed by automatic weather stations in Beijing after 1330 LST (Fig. 3a). What we focus on is that high winds became more widespread in the western mountainous areas of Beijing from 1400 to 1429 LST (Fig. 3b) during the downhill progress of the developing MCS (Fig. 2b-d)."

14. L247. Mark the Qianling Mountain site on Fig 2?

Response: Marked as suggested. Please see Fig 3b in Question 11.

15. L249-250. Again, referring to the radar plots would be helpful. This is the first mention of the merger of two convective segments and formation of the squall line.

Response: Per your suggestion, we adjust original Fig 4 to Fig 2 in this revised manuscript.

16. L251. Similarly here. Also, the size of the dots are just as large in Fig 2c and there are maximum radar echoes before 1500, at 1448 and possibly 1436. Why is the squall line mature during 1500-1529?

Response: Thank you for your question. We agree that intense radar reflectivity (exceeding 50 dBZ) indicates the presence of vigorous deep convection before 1500 LST. However, our designation of 1500-1529 LST as the mature stage of the squall line is based on a synthesis of multiple observational criteria, not solely on the first appearance of maximum radar reflectivity. Our reasoning is as follows:

a. Structural Organization and Evolution: While the merger of convective segments into a linear system were evident at around 1436-1448 LST (new Figure 2e, f), the organizational process continued. In the subsequent 12 minutes (1448 to 1500 LST), the convective line further consolidated, developing a more coherent, organized, and sharp leading edge—the hallmark structure of a mature squall line (new Figure 2g and 5g). Therefore, 1500 LST represents a stage of more stable and classic structural maturity.

b. Peak in Associated Severe Weather: Our definition emphasizes the peak period of the squall line's most impactful surface weather. The maximum rainfall exceeding 9 mm occurred in the 1500-1529 LST period with the strongest cool pool (new Figure 3d and 5h).

In summary, we define 1500-1529 LST as the mature stage because it represents the period when the fully organized linear structure and the observed peak rainfall rates were all co-located in time and space. We revise the manuscript to explicitly state the criteria for the mature stage to prevent potential misunderstanding.

"After 1430 LST, both rainfall and the number of stations recording high winds increased remarkably (Fig. 3c) associated with the merger of two convective segments and formation of the squall line at around 1436-1448 LST (Fig. 2e, f). The squall line further consolidated and reached its mature stage after 1500 LST, defined by the fully coherent, organized linear structure (Fig. 2g, h). The wind gust coincided with the intensification of deep convection with the peak rainfall exceeding 9 mm during 1500-1529 LST along the leading line (Fig. 3d), after which the squall line moved eastward away from the major urban area of Beijing."

17. Fig 3. What do the black contours represent?

Response: The black lines represent provincial administrative boundaries. The administrative boundary of Beijing is highlighted as red curve.

18. L262. Likely dynamic contribution?

Response: We have revised the statement to more accurately reflect the likely dynamic contribution of the short-wave trough with horizontal wind shear.

"A short-wave trough at 850 hPa, located to the west of Beijing (Fig. 4b), likely *contributed to synoptic-scale lifting ahead of the trough axis. The associated ambient wind shear offered a key dynamic ingredient for the subsequent deepening organization of convection."*

19. L268-272. What is the mountaintop level? What are the orographic effects due to the interaction of the strong northwesterly winds and the mountains? It is not clear what point is being made and in what way the citations are relevant.

Response:* *"mountaintop level" refers to the mean terrain height of the Taihang Mountain, approximately 1500-2000 meters above sea level. This corresponds to the 850-700 hPa pressure layer in the ERA5 data and soundings. For minimize the influence of the mountains on the vertical profiles in the lower atmosphere from soundings at Zhangjiakou (ZJK), only winds above the mountaintop level were analyzed. For the sake of clarification, "the mountaintop level" has been revised as "the middle level".

We provide the following clarification that the deep northwesterly winds perpendicular to the mountains is favorable for the propagation and enhancement of downhill storms. A strong northwesterly wind oriented perpendicular to the Mt. Taihang range at middle level is favor for accelerating the downhill process of storm. The potential for terrain-triggered gravity waves in the leeside that can modulate localized uplift and cloud organization (Neiman et al., 1988; Rocque & Rasmussen, 2022; Lombardo & Kumjian, 2022). We rewrite the paragraph to explicitly articulate this chain of mechanisms and adjust the citations accordingly in the revised manuscript.

Reference:

Lombardo, K., and Kumjian, M. R.: Observations of the Discrete Propagation of a Mesoscale Convective System during RELAMPAGO–CACTI. Mon. Wea. Rev., 150, 2111–2138, https://doi.org/10.1175/MWR-D-21-0265.1*, 2022.*

Neiman, P. J., Hardesty, R. M., Shapiro, M. A., and Cupp, R. E.: Doppler Lidar Observations of a Downslope Windstorm. Mon. Wea. Rev., 116, 2265–2275, https://doi.org/10.1175/1520-0493(1988)116<2265:DLOOAD>2.0.CO;2*, 1988.*

Rocque, M. N., and Rasmussen, K. L.: The Impact of Topography on the Environment and Life Cycle of Weakly and Strongly Forced MCSs during RELAMPAGO. Mon. Wea. Rev., 150, 2317–2338, https://doi.org/10.1175/MWR-D-22-0049.1*, 2022.*

20. L277-280. What do you mean that the dry column provided a favorable environment for the evaporation of precipitation particles? Do you mean the humidity below the LCL indicated on the skew-T diagrams? It may be the case that there is a favorable environment that affect a fraction of the precipitation. However, it isn't right to use the words "intense evaporative cooling" and "thus leading to". It really is conjecture as stated.

Response: We appreciate your comment, which helps us strengthen the manuscript by replacing conjecture with a more careful, evidence-based discussion. Yes, the dry column refers to the deep layer of low humidity (RH < 60%) below the LCL indicated on the skew-T diagrams. Our inference is based on the well-established physical mechanism where evaporative cooling of precipitation generates negatively buoyant downdrafts. The observed co-location of the deep dry layer, the moving storm, and the subsequent wind gust event is consistent with this mechanism. However, as you note, without direct microphysical or vertical motion observations, we cannot conclusively quantify the cooling or prove it was the sole driver. We modify the text to present this as a plausible and likely contributing mechanism rather than a definitive causal statement:

"The evaporative cooling might have enhanced cold downdraft air, potentially contributing to the generation of the wind gust event. "

21. L282. What "heat release" do you mean?

Response: The description here was indeed erroneous. We revise the text to avoid the ambiguous term "heat release" in the context.

"After the passage of the MCS, a surface-based temperature inversion layer below 880 hPa with larger CIN was captured by the sounding at 2000 LST (not shown) as a result of the rapid decrease in surface temperature."

22. L283-284. The sentence doesn't make sense as written.

Response: As suggested, we have deleted the sentence to improve the clarity of the manuscript.

23. L297-298. It is an impressive set of temperature data shown in Fig 5. Is there evidence that the sub-cloud air was dry?

Response: As we state in section 3.1, it's unfortunate that no sounding was available to elucidate the temporal evolution of thermal stratification during the gusty wind event. We can only indicate the sub-cloud air by the soundings at 0800 LST from the radiosonde at the ZJK and BWO sites shown in new Fig 4c and d. A deep dry layer was evident with large difference between temperature and dew point below LCL.

24. L306-308. The radar reflectivity is 50 dBZ or greater at 1424 (and actually well before that time), which is indicative of heavy precipitation. It is important to know what is actually shown in Fig 4. Fig 2 shows the accumulation of rain in a 30 min period.

Response: Figure 2 in this revision shows the composite radar reflectivity exceeding 50 dBZ before 1424 LST, which generally indicates the potential for heavy precipitation aloft. However, a pronounced dry layer in the low level caused significant sublimation, melting, and evaporation of precipitation particles, severely reducing the rainfall reaching the ground. To verify this explanation, we provided the reflectivity at the elevation angle of 0.5° from the S-band Doppler weather radar at BWO in Fig R1. The low reflectivity near the surface before 1424 LST, consistent with weak measured rainfall (rain rate <3 mm/30 min shown in Fig 3b), visually confirmed the evaporation layer that attenuated the precipitation. We also explain this discrepancy between the intense composite radar reflectivity and the very light measured rainfall at the surface in the text.

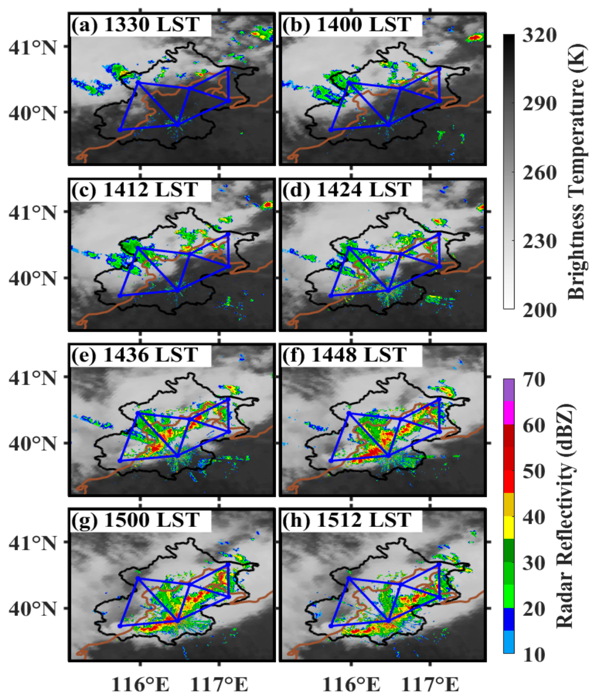

Figure R1. *Brightness temperature from 10.8 μm channel of Himawari-8 geostationary satellite (gray shadings; K), superimposed with the radar reflectivity (color-shaded; dBZ) at the elevation angle of 0.5° at (a) 1330, (b) 1400, (c) 1412, (d) 1424, (e) 1436, (f) 1448, (g) 1500, and (h) 1512 LST on 30 May 2024. The four blue triangles and brown line denote the RWP mesonet and the 200 m terrain elevation line, respectively.*

25. L323. Please state the time.

Response: The time is stated as "1330 LST".

26. L376-378. Is this conjecture at this stage?

Response: This statement is not merely conjecture but is supported by both theoretical understanding and observational evidence from our study. The intense cold pool generated by the storm enhances the mesohigh and surface pressure gradient shown in Fig 5, which is a well-established driver of high winds in convective systems (Haerter et al., 2019; Houze, 2014, Hadavi and Romanic, 2024). Furthermore, the downdraft-induced momentum transport contributes significantly to surface wind acceleration, which is supported Fig 7 in the revised manuscript. We added relevant references in this sentence and emphasize that it will be further examined in Section 4.2.

Reference:

Haerter, J. O., Böing, S. J., Henneberg, O., and Nissen, S. B.: Circling in on convective organization. Geophysical Research Letters, 46(12), 7024–7034. https://doi.org/10.1029/2019GL082092*, 2019.*

Houze, R. A. Jr.: Chapter 9—Mesoscale convective systems. In R. A. Houze, Jr. (Ed.), International geophysics (pp. 237–286). Academic Press. https://doi.org/10.1016/B978-0-12-374266-7.00009-3*, 2014.*

Hadavi, M., and Romanic, D.: Atmospheric conditions conducive to thunderstorms with downbursts in Canada and a downburst precursor parameter. Atmos. Res., 305(107), 428, https://doi.org/10.1016/j.atmosres.2024.107428, 2024.

27. L395. Should this be Fig 5?

Response: Yes, corrected.

28. L431. Incorrect figure numbers.

Response: Incorrect figure numbers have been deleted.

29. L466. I think there is value in showing Fig 8 earlier. It helps to put some things into perspective clearly.

Response: Thank you for your suggestion. In the revised manuscript, we move Fig 8 to Fig 7.

30. L540. It would be useful to refer to previous studies in this section.

Response: Following the suggestion, we have added the discussion comparing our observed mechanisms with previous QLCS studies in this section:

"Based on the above results, this case has both commonality and terrain-modulated uniqueness with other QLCS cases in previous studies. Similar to QLCS events documented over plains (e.g., the U.S. Central Plains), the storm exhibited a well-defined cold pool, a descending RIJ, and strong low-level convergence leading to bow-echo development (Bentley & Mote, 1998; Bentley & Sparks, 2003; Evans et al., 2014; Wakimoto et al., 2006). However, the evolution here was markedly influenced by complex topography. The initial convection was anchored and intensified by orographic lifting along the southern slopes of Mt. Yan (Houze, 2012). Furthermore, the downhill propagation of the system resulted in an unusually concentrated zone of high reflectivity near the foot of Mt. Taihang. These findings underscore that while the overall dynamical framework of QLCS remains consistent, local topography can fundamentally alter the initiation, sustenance, and peak intensity of severe winds by modifying convergence patterns, cold-pool propagation, and vortex dynamics. Future forecasting in complex terrain regions should therefore explicitly consider such terrain–convection interactions in nowcasting and high-resolution modeling."

31. L591-593. The sentence is a bit ambiguous. An important novelty is the high density of multiple observations. Is that correct?

Response: Yes, corrected. The important novelty of this study is indeed the high density of multiple observations, which enabled us to obtain vertical profiles with higher resolution. This fine-scale mesonet allowed us to explicitly resolve the multiscale processes governing the generation of an extreme gusty wind event, particularly the interactions across boundary-layer, convective-scale, and turbulent-scale processes. We have revised the sentence as follows:

"Moreover, the novelty of this study lies at the utilization of high-resolution vertical observation derived from a rarely fine mesonet. The multiple observation with high density enables us to explore multiscale processes governing the generation of an extreme gusty wind event."