Response to Reviewer Comments

Manuscript: "Precursor dynamical factors in the local lower atmosphere of Warm-Sector Heavy Rainfall over South China: Evidence from Wind Profiler Radar Observations"

Manuscript number: **egusphere-2025-2955**

Dear Editor and Reviewers,

The authors sincerely thank the two reviewers for their thorough and constructive comments. Their critiques have led to substantial improvements in both the scientific content and the presentation. We have carefully addressed every point raised below.

Given the extent of the revisions, we first provide a Summary of Major Revisions to orient the editor and the reviewers to the content of the manuscript. The point-by-point responses that follow are structured according to the editor's requested format: (1) the referee's comment, (2) our response, and (3) the specific changes made to the manuscript

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Summary of Major Revisions

In response to the reviewers' comments, the manuscript has been substantially revised across its dataset, methodology, statistical framework, and structure. The major revisions are summarised below.

(1) Dataset expansion and objective event identification. The original manuscript was based on 8 manually selected WSHR events in 2019, observed at 8 wind profiler radar (WPR) stations and 2 550 automatic weather stations (AWS). The revised manuscript covers 226 objectively identified events during the 2016–2020 pre-flood seasons (April–June), using 14 WPR stations and over 3 000 AWS. Event identification has been redesigned from a simple case-selection procedure into a two-stage objective algorithm: Stage 1 screens candidate warm-sector days following Liu et al. (2019); Stage 2 independently identifies individual events in each of three sub-regions — western GD (n = 65), central GD (n = 88), and eastern GD (n = 73) — through a regional-mean precipitation threshold (≥1.0 mm h^{-1} for ≥3 consecutive hours), an inter-event gap criterion, an accumulation threshold (≥5 mm area-averaged), and a representative-station assignment rule linking each event to the WPR station nearest to its rainfall-weighted precipitation centroid (Sect. 2.2). A harmonic decomposition of the diurnal onset cycle (Fig. 4) further documents distinct bimodal distributions for each sub-region, motivating the subsequent stratification by onset time in Sect. 4.4. Hourly AWS precipitation records are adopted (in place of the 5-min data used for the single-year analysis) to ensure consistent coverage across the 5-year record.

(2) WPR data quality control added (Sect. 2.1). The original manuscript contained no description of QC procedures. Three steps are now documented: (i) removal of records flagged as invalid by the instrument; (ii) physical range checks (altitude ≤ 6 000 m, horizontal wind 0–40 m s^{-1}, vertical velocity −10 to +10 m s^{-1}); and (iii) a two-dimensional median filter in the time–height domain (±2 time steps, ±2 range gates). Known limitations — restricted vertical range (0–6 km), ground-clutter contamination below ~0.5 km, and hydrometeor-induced bias in vertical velocity near and after onset — are explicitly acknowledged in Sects. 2.1, 2.3, and 5.3.

(3) Replaced BLH estimation method (Sect. 2.3.4). Replaced BLH estimation method (Sect. 2.3.4). The original manuscript estimated BLH using a joint $C^2{}_\mathrm{n} + \sigma\_w$ method, which depends on the refractive-index structure parameter ($C^2{}_\mathrm{n}$) and is therefore not applicable across the full 2016–2020 record for which reliable $C^2{}_\mathrm{n}$ retrievals are not consistently available. The revised manuscript adopts a σ_w-based method following Heo et al. (2003), who first identified the convective boundary layer top from the level at which σ_w sharply decreases toward zero at the top of the turbulent layer using UHF wind profiler observations. Our implementation adapts this approach to the humid subtropical environment of coastal South China through layered σ_w computation in 15 × 200-m bins from 0 to 3000 m, a gradient criterion $\Delta\sigma\_w/\Delta z$ between adjacent layers, 3σ outlier removal, and recursive temporal smoothing of the native 6-min estimates. Validation against April–June 2016–2019 radiosonde data from Hong Kong Kings Park and Qingyuan reduces the mean bias from +1 524 m to +300 m (RMSE ≈ 351 m at 20 BJT). Residual uncertainties of ±300–500 m typical for radar-based estimates in humid subtropical regions are acknowledged.

(4) Reconstructed statistical framework (Sects. 2.4 and 4.2–4.4). The original sliding-window correlation (SWC) analysis has been replaced by a more rigorous framework. Raw index values are winsorised at the 5th and 95th percentiles across all events before composite analysis to reduce outlier influence; sensitivity tests without winsorisation produce consistent temporal patterns. The revised framework combines: (i) composite time series aligned by onset time with bootstrap 95 % confidence intervals of the median (2 000 resamples, percentile method) and interquartile ranges (Fig. 8); (ii) Spearman rank correlations between index values averaged over four non-overlapping pre-onset periods (t = −6 to −4 h, −4 to −2 h, −2 to −1 h, −1 to 0 h) and maximum accumulated rainfall, assessed at the 95 % level (Fig. 9); (iii) stratified composites by rainfall intensity, monsoon phase, and onset time, with significance tested via the Mann–Whitney U test (Fig. 10, Figs. S1–S3); (iv) regional comparisons of rainfall characteristics using Kruskal–Wallis one-way ANOVA (Fig. 3); (v) Δw diagnostics (Figs. 12–13) quantifying the pre-onset change in upper-level (3–5 km) vertical velocity; and (vi) CAPE diagnostics (Fig. 14) comparing pre-onset CAPE (ERA5, averaged over t = −6 to −2 h) between strong- and weak-rainfall events.

This framework reveals three regionally distinct precursor mechanisms at two complementary levels — temporal evolution and rainfall-intensity prediction. In **western GD**, LLJI shows the clearest temporal build-up (roughly doubling in the final 1–2 h before onset); Δw is positively correlated with rainfall (r = 0.37, p = 0.006) and with ΔLLJI (r = 0.34, p = 0.012), consistent with direct BLJ forcing of upper-level ascent, while CAPE does not distinguish strong from weak events. In **central GD**, VWS at 0.5–1.5 km is the most persistent intensity predictor, significantly correlated with rainfall across three consecutive pre-onset periods (r = 0.28–0.35, all $p < 0.05$); the partial-correlation analysis (Fig. S7) confirms the signal is confined to the boundary layer and independent of synoptic-scale geopotential height. In **eastern GD**, BLH shows the strongest intensity association (r = 0.46 at t = −6 to −4 h; r = 0.39 at t = −4 to −2 h); strong events exhibit significantly higher pre-onset CAPE and 925-hPa temperature, and significantly weaker pre-onset upper-level ascent (r = −0.43, p = 0.001), consistent with an energy-accumulation pathway driven by boundary-layer warming.

(5) Restructured Sect. 4.5 as a multi-event profiler analysis. The original Sect. 4.5 relied on a single case study (20 April 2019) to illustrate urban effects, which lacked statistical robustness. The revised Sect. 4.5 is a multi-event composite analysis across seven central-GD profiler stations, combining: (i) Spearman partial correlations controlling for ERA5 Z850 and Z925 to confirm the boundary-layer origin of the central-GD VWS signal (Fig. S7); (ii) per-station VWS anomaly composites with the 3-km urban fraction (LCZ 1–10) annotated for each station (Fig. 16); (iii) wind-speed anomaly profiles documenting spatially non-uniform frictional deceleration of the southerly inflow; and (iv) Bellamy-triangle divergence anomaly profiles that resolve a south-to-north dipole (+2.2 to -3.8×10^{-5} s^{-1} at 1.15 km), vertically confined below ~1.5 km (Fig. 17; triangle geometry in Fig. S9).

(6) Updated urban land-surface characterisation. The original manuscript used the land-cover dataset of Yang and Huang (2021) and the term "urban impermeable subsurface". The revised manuscript characterises urban extent using the Local Climate Zone (LCZ) classification of Stewart and Oke (2012), with LCZ 1–10 (built-type classes) treated as urban pixels; LCZ maps for Guangdong Province are obtained from Demuzere et al. (2022). This classification is used both for the province-wide map (Fig. 1) and for the 3-km urban fraction reported per profiler station in Sect. 4.5 and on the x-axis of Fig. 16. Sect. 2.1, the Fig. 1 caption, and the Data Availability statement have been updated accordingly.

(7) Expanded supplementary material, manuscript structure, and author contributions. The supplementary material now contains nine figures (Figs. S1–S9): S1–S3 present stratified composites for all five indices under the three stratifications; S4–S6 present pairwise relationships between ΔLLJI, ΔVWS, and Δw; S7 presents Spearman partial correlations controlling for geopotential height; S8 presents absolute divergence composites; S9 presents the Bellamy-triangle geometry overlaid on the LCZ map. Sections 5 and 6 of the original manuscript have been merged into a single "5 Conclusions and Discussion" section with three sub-sections (5.1 Summary, 5.2 Comparison with previous studies, 5.3 Limitations and future work). The Author Contributions section has been rewritten to name all eleven authors with specific individual contributions and to distinguish YY (Yang Yang) from YY (Yuanjian Yang).

Response to Reviewer 1

RC1.1 (General Comment 1)

Comment: The manuscript performed a study of eight Warm Sector Heavy Rainfall (WSHR) events in 2019 using wind profiler radar and other ground-based observations. Four selected precursor signals of WSHR are analyzed along with the impact of monsoon activities and topography considered. Despite the analysis is quite detailed, many are known. The novel part may be the time evolution of precursor signals and the implications for nowcasting. However, the number of cases is so few that the time estimation given in section 5.2 is not so meaningful. In addition, with only 8 WSHR events in total, I am not convinced any solid and general conclusions can be made in terms of the different mechanisms in western, eastern and central regions.

Response: We fully agree with this criticism and have comprehensively revised the study in response. The analysis has been expanded from 8 case studies drawn from 2019 to 226 objectively identified WSHR events spanning the 2016–2020 pre-flood seasons (April–June). Events were identified using an automated objective algorithm applied to hourly precipitation records from more than 3000 AWS. The three sub-regional samples are western GD (n = 65), central GD (n = 88), and eastern GD (n = 73). All findings are now supported by non-parametric statistical tests with bootstrap 95% confidence intervals. The formerly qualitative time-estimation is replaced by quantitative Spearman rank correlations across four pre-onset windows.

Changes in manuscript: Sect. 2.2 has been fully rewritten to describe the two-stage objective event identification algorithm yielding 226 events. Sect. 2.4 introduces the new statistical framework (Spearman rank correlations over four non-overlapping pre-onset periods, Mann–Whitney U tests, Kruskal–Wallis regional comparisons, and bootstrap 95 % CIs). Sects. 4.2–4.4 have been rewritten around multi-event composites and stratified analyses. Fig. 2 (event spatial distribution), Fig. 3 (regional rainfall statistics), Fig. 4 (diurnal harmonic analysis), Figs. 8–11 (composite and stratified evolutions) and Figs. 12–14 (Δw and CAPE diagnostics) are new or substantially redrawn. The former qualitative leading-time estimate in Sect. 5.2 has been replaced by the quantitative Spearman analysis in Sect. 4.3 (Fig. 9).

RC1.2 (General Comment 2)

Comment: Quality of figures needs to be improved, such as resolution, font size, and missing x or y axis.

Response: We agree. All figures have been redrawn to professional standards.

Changes in manuscript: Every figure has been redrawn at ≥300 dpi with enlarged fonts, clearly labelled and tick-annotated axes, and self-contained captions.

RC1.3 (L36)

Comment: front → frontal

Response: We agree with this correction.

Changes in manuscript: "front" has been changed to "frontal" in the original sentence, and a global check has been performed to ensure "frontal" is used consistently wherever the sense is that of a frontal system.

RC1.4 (L49)

Comment: a noun is missed after "southerly".

Response: We agree that a noun was missing.

Changes in manuscript: The phrase has been completed to "southerly low-level winds" at the original location, and the surrounding sentence has been edited for readability.

RC1.5 (L56)

Comment: 2022a?

Response: The "a" suffix was introduced because two different 2022 papers by Zhang are cited in the manuscript and need to be distinguished. Zhang et al. (2022a) refers to Zhang, L., Ma, X., Zhu, S., et al. (2022, *Atmos. Res.*, 280, 106425), which developed a methodology for identifying WSHR precursor signals at coastal Guangdong using LLJ intensity, warm-moist tongue, and low-level convergence indices. Zhang et al. (2022b) refers to a different paper by the same first author on the impacts of coastal terrain on MCSs (*Mon. Wea. Rev.*, 150, 603–624).

Changes in manuscript: Both references are now listed in full in the revised reference list, with the "a/b" distinction maintained consistently throughout the in-text citations.

RC1.6 (L70)

Comment: "a precipitation" → precipitation

Response: We agree.

Changes in manuscript: "a precipitation" has been corrected to "precipitation".

RC1.7 (L75)

Comment: "profiler" → profilers

Response: We agree.

Changes in manuscript: "profiler" has been changed to "profilers" at this location, and "wind profiler radars" (plural) is now used consistently throughout the manuscript wherever the instrument is referenced as a class.

RC1.8 (L89)

Comment: explain "c-averaged"

Response: We thank the reviewer for noting that "c-averaged" was undefined.

Changes in manuscript: The ambiguous term "c-averaged" has been removed. Sect. 2.1 now specifies at first use that all index calculations are based on the Guangdong Meteorological Administration's HOBS product (half-hour observation, quality-controlled, 30-min effective resolution).

RC1.9 (L106)

Comment: The two requirements in (3) appear redundant and conflicting. Please clarify.

Response: We thank the reviewer for identifying this ambiguity. Event identification has therefore been redesigned as an explicit two-stage procedure.

Changes in manuscript: Sect. 2.2 has been fully rewritten. Stage 1 screens candidate warm-sector days following Liu et al. (2019) using three criteria: (i) absence of typhoon or tropical depression disturbances; (ii) daily precipitation ≥50 mm at ≥3 neighboring stations within 100 km, with a consecutive 3-hour period in which each hourly precipitation ≥5 mm and the 3-hour cumulative total ≥30 mm; and (iii) vertical profiles of θ_se and temperature advection confirming warm-sector conditions. Stage 2 then independently identifies events in each sub-region through a regional mean precipitation threshold (≥1.0

mm h^{-1} for ≥3 consecutive hours), an inter-event gap criterion (≥3 consecutive dry hours), an accumulation threshold (≥5 mm area-averaged), and a representative WPR station assignment rule. The procedure yields 226 independent events (western GD n = 65, central GD n = 88, eastern GD n = 73).

RC1.10 (L160)

Comment: σ_w^3?

Response: The BLH estimation method has been rewritten to use the vertical velocity standard deviation σ_w (not $σ\_w^3$), following Heo et al. (2003).

Changes in manuscript: Sect. 2.3.4 has been rewritten. BLH is now estimated using the vertical velocity standard deviation σ_w following the approach of Heo et al. (2003), who identified the convective boundary layer top from the level at which σ_w sharply decreases toward zero at the top of the turbulent layer. In our implementation, σ_w is computed within 15 × 200-m bins from 0 to 3 000 m, and BLH is identified as the first height at which the adjacent-layer gradient $\Delta\sigma\_w/\Delta z$ drops sharply, with 3σ outlier rejection and recursive temporal smoothing of the native 6-min estimates. Validation against April–June 2016–2019 radiosonde data from Hong Kong Kings Park and Qingyuan reduces the mean bias from +1524 m to +300 m (RMSE ≈ 351 m at 20 BJT).

RC1.11 (L162)

Comment: two θ

Response: We agree.

Changes in manuscript: The duplicated "two θ " has been removed.

RC1.12 (L234)

Comment: what does "3 earlier" mean?

Response: We agree this was ambiguous.

Changes in manuscript: The ambiguous phrase has been removed; temporal references throughout the manuscript now explicitly state the relevant window (e.g. "in the 1–2 or 3 h preceding onset").

RC1.13 (Fig. 6)

Comment: do the numbers on the x axis indicate UTC hour? Add x axis and descriptions in the caption.

Response: We thank the reviewer for the comment. The x-axis represents the hour of the day in Beijing Time (BJT = UTC + 8 h). The original Fig. 6 has been removed in the revised manuscript, and all absolute time references (e.g., Fig. 4) have been standardized to BJT, with the time convention explicitly stated in the axis labels and captions.

Changes in manuscript: Remaining figures with time axes (e.g., Fig. 4) updated: x-axis labeled "Local Time (BJT)"; the time convention (BJT, UTC + 8 h) is stated in the main text."

RC1.14 (Fig. 7)

Comment: The definitions of "high altitude" and "low altitude" are unclear.

Response: We thank the reviewer for catching this inconsistency..

Changes in manuscript: The original Fig. 17 has been removed, as we agree it was difficult to interpret. In the revised Fig. 7, VWS is instead presented between adjacent altitude layers, which is more intuitive and avoids the caption issue noted by the reviewer..

RC1.15 (L256)

Comment: "the all" → all the

Response: We agree.

Changes in manuscript: "the all" has been corrected to "all the" at this location and at all other occurrences in the manuscript.

RC1.16 (Fig. 9)

Comment: The BLH in blue line appear fixed at 400 most of the time. Is that real? Also, red line indicates after in your legend, but the figure caption states "after (blue)".

Response: The reviewer correctly identified two problems. The BLH line appeared artificially flat for two reasons: the original 8-event sample was too small to produce a reliable composite, and the original BLH calculation method had inherent limitations. The colour-labelling inconsistency between legend and caption was a separate error. Both issues are resolved by the restructured analysis based on the full 226-event dataset.

Changes in manuscript: The original Fig. 9 has been removed. The monsoon-stratified analysis is now presented in Fig. 10a–c, based on pre-monsoon and post-monsoon subsets of the full 226-event dataset, with composite medians shown together with bootstrap 95 % confidence intervals. The colour convention (red = pre-monsoon, blue = post-monsoon) is now consistent between all figure panels and their captions throughout the manuscript.

RC1.17 (Fig. 11)

Comment: Why do VWS, ALI and BLH look so similar before and after the onset time for the western region?

Response: This apparent similarity was another consequence of the small 8-event sample in the original Fig. 11. In the revised 226-event composites, a clearer picture emerges: in western GD the dominant temporal precursor is LLJI (roughly doubling in the final 1–2 h before onset), while VWS, ALI, and BLH indeed show only limited systematic temporal change in that region. This finding is real and is now explicitly discussed.

Changes in manuscript: The original Fig. 11 has been restructured. Fig. 8 now presents the temporal evolution of all five indices based on the 226-event dataset, and stratified composites are presented in Fig. 10 and Figs. S1–S3. Sect. 4.2 now explicitly states that in western GD, LLJI is the only index showing substantial pre-onset temporal change, consistent with the direct BLJ-forcing mechanism.

RC1.18 (Fig. 17)

Comment: This is not "As in Figure 16" as you stated in the caption.

Response: We acknowledge this cross-reference error. As part of the restructuring of Sect. 4.5 into a multi-event composite analysis (see response to RC2.46), the original Fig. 17 has been removed, which resolves the caption problem automatically.

Changes in manuscript: The original Fig. 17 (3-hour mean VWS triangular diagrams at four stations) has been removed. In the revised manuscript, Fig. 16 now presents per-station VWS anomaly composites across seven central-GD stations, and Fig. 17 presents boundary-layer wind-speed anomaly profiles (panel a) and Bellamy-triangle divergence anomaly profiles (panel b). The erroneous "As in Fig. 16" caption reference no longer exists.

Response to Reviewer 2

RC2.1 (General Comment)

Comment: The authors investigated the precursor dynamical factors in the local lower atmosphere of Warm-Sector Heavy Rainfall (WSHR) over South China. However, this paper should be improved with much more work, including clarifying the data quality of wind profile radar observations, explaining some confusing issues, and determining the mechanisms contributing to the WSHR from the results in this study. Notably, this article requires thorough proofreading.

Response: We sincerely thank Reviewer 2 for the detailed and constructive evaluation. We agree with all general criticisms. The revised manuscript addresses them comprehensively through (i) a complete description of WPR data quality control; (ii) systematic resolution of all identified ambiguities in terminology, figure labels, and physical descriptions; (iii) quantitative diagnostics supporting the three distinct regional mechanisms; and (iv) a careful proofreading pass across the whole manuscript.

Changes in manuscript: Sect. 2.1 has been extended with a full WPR quality-control description and a statement of known limitations. All specific points raised in RC2.2–RC2.67 are addressed individually below. Three distinct regional mechanisms are now supported by Spearman correlations, Mann–Whitney *U* tests, and ERA5-based Δw and CAPE analyses with explicit *p*-values (Sects. 4.2–4.4). The entire manuscript has been proofread; all grammatical errors and technical inconsistencies identified by the reviewer have been corrected.

RC2.2 (Line 61)

Comment: How to define the onset of WSHR events? And the "vertical profiles" is unclear. Please clarify.

Response: Both points have been addressed.

Changes in manuscript: Sect. 2.2 now defines WSHR event onset explicitly as the first hour at which the sub-regional mean precipitation rate reaches $\geq$1.0 mm h^{-1} for $\geq$3 consecutive hours. We note that our original wording was misleading: "vertical profiles" did not refer to instrument profiles, but to the third step of the Stage-1 WSHR identification procedure, in which vertical cross-sections of θ_se and temperature advection along the representative station longitude are used to confirm warm-sector conditions. This has now been clarified in the revised manuscript.

RC2.3 (Lines 65–67)

Comment: Please consider rewriting this sentence, as it is overly long and difficult to read. Many sentences in this paper are recommended to be rewritten as short, simple sentences (e.g., lines 17–22).

Response: We agree that the original sentence was overly long, and that several other passages also required simplification.

Changes in manuscript: The original sentence at lines 65–67 has been rewritten as "Wind profiler radars continuously measure horizontal wind and vertical velocity profiles in the lower and middle troposphere at high temporal and vertical resolution (Liu et al., 2020), making them well suited to resolving the pre-onset wind field evolution associated with mesoscale weather systems." The long compound sentences at original lines 17–22 have been similarly restructured into shorter declarative sentences, and a pass has been made across the entire Introduction to apply the same principle.

RC2.4 (Line 71)

Comment: "lower level" is an unclear description. Please clarify.

Response: We agree.

Changes in manuscript: The phrase "lower level" has been removed from the revised Introduction. Elsewhere in the manuscript, specific altitude ranges are used throughout (e.g. "below 2 km" in the wind field description of Sect. 4.1; "below 3 km" in the VWS discussion).

RC2.5 (Line 76)

Comment: "BLH". The abbreviation should be defined at its first occurrence.

Response: We agree.

Changes in manuscript: "Boundary Layer Height (BLH)" is now defined at its first occurrence. All other abbreviations have been checked across the manuscript and defined at their first use.

RC2.6 (Line 82)

Comment: How did the authors combine the observations from wind profile radars and automatic weather stations? Please clarify. Please consider evaluating the data quality of the wind profile radars. It is vital to understand the limitations/flaws of such data.

Response: We thank the reviewer for raising both points. Sect. 2.1 now fully describes how the two datasets are combined and how WPR data quality is assessed.

Changes in manuscript: Sect. 2.1 now states that WPR and AWS data play complementary roles: WPR data provide vertical wind profiles used to compute the five dynamical indices, while AWS hourly precipitation records are used for event identification. The two datasets are combined through a representative-station assignment rule: for each identified event, the WPR station nearest to the rainfall-weighted precipitation centroid (within 100 km, same sub-region) is designated as the representative station, linking the precipitation-based event record to a specific WPR observation time series. WPR quality control follows three steps: (i) removal of records flagged by instrument quality flags; (ii) physical range checks (altitude ≤ 6000 m, horizontal wind 0–40 m s^{-1}, vertical velocity −10 to +10 m s^{-1}); and (iii) a two-dimensional median filter (±2 time steps, ±2 height gates) in the time–height domain. Known limitations — restricted vertical range (0–6 km), ground-clutter contamination below ~0.5 km, and hydrometeor-induced bias in vertical velocity near and after onset — are stated in Sects. 2.1 and 5.3.

RC2.7 (Line 83)

Comment: "the f electromagnetic". What is meaning of "f"?

Response: This was a typographic error.

Changes in manuscript: The erroneous phrase has been removed and the sentence rewritten to avoid the problematic phrasing entirely.

RC2.8 (Line 100)

Comment: The caption of Figure 1. Profile or profiler? Please check this carefully throughout the paper.

Response: We thank the reviewer for flagging this inconsistency.

Changes in manuscript: "Profiler" (the instrument) and "profile" (the vertical data record) have been carefully distinguished throughout the manuscript. The Fig. 1 caption now reads "wind profiler radar network". All occurrences of "profile" that had been used to mean "profiler" have been corrected.

RC2.9 (Line 101)

Comment: "subsurface" should be "impermeable subsurface".

Response: We agree that "subsurface" alone was imprecise. Rather than modify the existing term, we have updated the underlying land-surface characterisation to one that is more physically appropriate for this study (the Local Climate Zone classification).

Changes in manuscript: The sentence containing "subsurface" has been removed. Fig. 1 now shows the spatial distribution of urban pixels defined using the LCZ classification of Stewart and Oke (2012), with LCZ 1–10 (built-type classes) treated as urban pixels; LCZ maps from Demuzere et al. (2022) are used. The caption of Fig. 1, Sect. 2.1, and the Data Availability statement have all been updated to reflect this change.

RC2.10 (Line 111)

Comment: The limitations and sources of potential error in these calculations should be stated.

Response: Limitations and error sources are now addressed at two complementary levels: at the data level (in the QC description) and at the method level (in each index sub-section), and at the broader methodological level in the Discussion.

Changes in manuscript: Sect. 2.1 documents the known WPR biases and their mitigation (see response to RC2.6). Sect. 2.3 acknowledges the index-specific limitations: the LLJI precision is limited by WPR horizontal wind uncertainty (~1–2 m s^{-1}) and by the inability to resolve winds below 0.5 km AGL (Sect. 2.3.1); the lower VWS bound of 0.5 km is adopted to avoid ground-clutter contamination and is supported by the observed VWS maxima and the typical BLJ core height over coastal South China (Du and Chen, 2018; Sect. 2.3.2); ALI values near and after onset should be interpreted with caution due to hydrometeor fall-speed contributions (~0.5–2 m s^{-1}; Sect. 2.3.3); and the BLH residual uncertainty of ±300–500 m after validation is stated in Sect. 2.3.4.

RC2.11 (Line 123)

Comment: Please clarify the meaning of "D".

Response: "D" in the LLJI formula denotes the lowest altitude at which the wind speed reaches 12 m s^{-1} in a given time period. This definition was absent from the original manuscript.

Changes in manuscript: Sect. 2.3.1, immediately after Eq. (7), now states: "where V is the maximum wind speed below 2 km altitude and D is the lowest altitude of the 12 m s^{-1} wind speed in a given time period. When the maximum wind speed does not reach 12 m s^{-1}, D is set to the altitude of the maximum wind speed." The divergence computed in Sect. 2.3.5 uses a distinct symbol and is defined separately with units of s^{-1}.

RC2.12 (Lines 126–127)

Comment: What did the authors want to explain via this description "thereby allowing the hydrometeors in the updraft to separate from the updraft."? If authors want to describe the tilted updrafts, I suggest to rewrite this sentence.

Response: The reviewer correctly identified that the original wording was physically imprecise. The sentence has been rewritten.

Changes in manuscript: Sect. 2.3.2 now reads: "Strong VWS tilts the convective updraft, enabling precipitation particles to fall out of the updraft region, thereby reducing hydrometeor loading on the updraft and sustaining its buoyancy. Strong VWS also enhances the entrainment of dry cold air into the middle layer, strengthening the downdraft and cold outflow near the ground, which forces the inflowing warm, moist air to rise more intensely."

RC2.13 (Line 162)

Comment: Please check these terms.

Response: We agree that the BLH estimation section required terminological clean-up.

Changes in manuscript: Sect. 2.3.4 has been fully rewritten with consistent and precise terminology: "vertical velocity standard deviation (σ_w)", "boundary layer height (BLH)", and "gradient criterion ($\Delta\sigma\_w/\Delta z$)". All terms are defined on first use. The methodological basis (Heo et al., 2003) is also now cited explicitly.

RC2.14 (Lines 206–208)

Comment: The authors should note that the described phenomenological characteristics should be accompanied by corresponding figures.

Response: We agree.

Changes in manuscript: All phenomenological descriptions in the revised Sect. 4 are now directly linked to specific figures. The composite wind field evolution (Sect. 4.1) is illustrated in Fig. 6; the VWS vertical structure in Fig. 7; the temporal evolution of all indices in Fig. 8; and the stratified composites in Fig. 10. Cross-references to the corresponding figures have been added at every relevant point.

RC2.15 (Table 1)

Comment: The meanings of number in first row should be explained.

Response: Table 1 has been removed from the revised manuscript. The information it contained has been superseded by the objective event identification algorithm.

Changes in manuscript: The original Table 1 (event start times, representative stations, maximum rainfall intensities, and regional assignment for the 8 cases) has been removed. The relevant information is now provided through the objective event identification algorithm in Sect. 2.2 and the statistical overview in Figs. 2–3.

RC2.16 (Figure 4)

Comment: The information in this figure is difficult to discern; it is recommended that the figure be redrawn and zoomed in.

Response: We agree. The original Fig. 4 (synoptic fields for 8 individual cases, 8 sub-panels) has been replaced by a cleaner composite figure.

Changes in manuscript: The original Fig. 4 has been replaced by revised Fig. 5, which presents composite mean geopotential heights and wind fields at 500, 850, and 925 hPa for the three sub-regions (9 panels arranged as 3 rows × 3 columns). The composite approach yields a clearer and more readable representation of the typical synoptic environment for each region.

RC2.17 (Lines 239–240)

Comment: The authors are encouraged to explain how did you get the Figure 7. And more details should be clarified for this sentence.

Response: We agree that the computation of the original Fig. 7 was under-described. The figure has been replaced with a composite presentation whose construction is now documented in detail.

Changes in manuscript: The original Fig. 7 (8-case two-dimensional triangular VWS matrix) has been replaced by revised Fig. 7, which shows composite VWS vertical profiles averaged over $t = -3$ to 0 h for all events in each sub-region. VWS is computed between adjacent 60-m range gates from quality-controlled WPR profiles, and the resulting profiles are composited across events (median with 25th–75th and 10th–90th percentile ranges). The averaging window $t = -3$ to 0 h is chosen to capture the most active pre-onset evolution while minimising contamination by convective-scale disturbances after onset. The full computational description is given in Sect. 4.1.

RC2.18 (Lines 240–242)

Comment: "There is strong... onset of precipitation." The authors should clarify where the information comes from.

Response: We agree that the claim required an explicit figure reference.

Changes in manuscript: The revised Sect. 4.1 states that two features are shared across all three regions — "(i) a progressive strengthening of low-level winds in the hours before onset, and (ii) a transition from near-zero to positive vertical velocity anomaly beginning 1–3 h before onset" — with explicit reference to Fig. 6.

RC2.19 (Lines 245–246)

Comment: How to explain the differences between Figures 6b, e, g, h and Figures 6a, c, d?

Response: The differences between the panels in the original Fig. 6 reflected the seasonal transition associated with the onset of the South China Sea monsoon: pre-monsoon cases showed a predominantly southerly flow, while post-monsoon cases showed a southwesterly flow as the monsoon became established. This contrast has been preserved but is now presented in a clearer and statistically meaningful form.

Changes in manuscript: The original Fig. 6a–h (individual-case wind fields) has been replaced by composite time–height cross-sections for each sub-region in revised Fig. 6, which clearly display the typical regional wind structure. The monsoon-phase contrast is now addressed through the stratified composite analysis in Fig. 10a–b.

RC2.20 (Lines 246–247)

Comment: The corresponding wind direction is southerly in Figure 6g but that is southwesterly in Figure 6h.

Response: The contrast between southerly (pre-monsoon, western region) and southwesterly (post-monsoon, eastern region) in the original figure reflected the seasonal transition associated with the onset of the South China Sea monsoon.

Changes in manuscript: As in RC2.19, the individual-case panels have been replaced by composite time–height cross-sections (revised Fig. 6), and the monsoon-phase stratification is addressed through the stratified composite analysis in Fig. 10a–b.

RC2.21 (Figure 7)

Comment: This Figure is difficult to understand. Please provide more details for clarification.

Response: We agree. The original 2-D triangular matrix format provided a comprehensive view of cross-level shear but proved difficult to interpret for our specific research question. The figure has been completely replaced.

Changes in manuscript: Revised Fig. 7 shows composite VWS vertical profiles (median ± percentile ranges) averaged over $t = -3$ to 0 h for all three sub-regions. The two analysis layers (Layer 1: 0.5–1.5 km; Layer 2: 1.5–3.0 km) are marked directly on the figure with grey bands. The caption specifies the computation method, averaging window, and the meaning of the shading. The physical rationale for both layer bounds is given in Sect. 4.1.

RC2.22 (Line 267)

Comment: Why do authors select this range, 0.5–1.5 km? As they shown, the maximum values occurred at 0–1 km height. Please clarify.

Response: The 0.5 km lower bound is adopted for instrumental reasons: WPR measurements below ~0.5 km AGL are subject to ground clutter and strong frictional variability, making them unreliable across the event sample. The true near-surface VWS maximum is therefore excluded not because it is unimportant, but because it cannot be measured reliably with this instrument network. The 1.5 km upper bound encompasses the BLJ core (typically near 0.5–1 km over coastal South China).

Changes in manuscript: The justification for the 0.5–1.5 km layer choice is now given explicitly in Sect. 2.3.2 and reiterated in Sect. 4.1.

RC2.23 (Figure 8)

Comment: The authors should carefully check their results (e.g., the 25%–75% quantiles are presented, but the mean values are absent), and the median values are encouraged to be shown in this figure.

Response: We agree. The central tendency is now shown alongside the spread.

Changes in manuscript: Revised Fig. 8 now shows (i) the composite median (solid line); (ii) the bootstrap 95 % CI of the median (dark shading, 2000 resamples with replacement; 2.5th and 97.5th percentiles); and (iii) the interquartile range (light shading).

RC2.24 (Line 298)

Comment: "2 hours". Why did authors use the 2 hours before the onset of WSHR? Please clarify.

Response: The choice of the four pre-onset periods is now motivated explicitly.

Changes in manuscript: Sect. 2.4 now states that the four pre-onset periods ($t = -6$ to -4 h, -4 to -2 h, -2 to -1 h, -1 to 0 h) are chosen based on the composite wind field analysis (Sect. 4.1, Fig. 6), which identifies $t \approx -2$ h as the onset of the most active pre-onset wind field evolution phase across all regions. The innermost period (−1 to 0 h) also represents a practically relevant nowcasting time window for WSHR.

RC2.25 (Lines 316–317)

Comment: Including the 95% confidence interval in Figure 11 would improve the clarity of the figure.

Response: We agree. The original Fig. 11 has been restructured, and confidence intervals are now shown systematically.

Changes in manuscript: The original Fig. 11 (composite mean temporal evolution across three regions) has been replaced by revised Fig. 8, which shows composite medians with both bootstrap 95 % CIs (dark shading) and interquartile ranges (light shading). Revised Fig. 11 now shows composite wind speed profiles for strong- and weak-rainfall events (a different analysis), also with IQR shading. The content originally in Fig. 11 is fully represented in Fig. 8.

RC2.26 (Lines 318–319)

Comment: "VWS values...before the onset." Where is the information from? Figure 11d and e did not show this feature. In addition, the higher VWS is absent from Figure f. Following above context, the "0.5–1 km" should be "0.5–1.5 km".

Response: We thank the reviewer for identifying the inconsistency between the text and the small-sample panels. The "0.5–1 km" was also a typographic error.

Changes in manuscript: "0.5–1 km" has been corrected to "0.5–1.5 km" throughout the manuscript. The VWS characterisation is now supported by explicit reference to Fig. 8d–f (composite temporal evolution) and Fig. 9 (Spearman rank correlation heat map), rather than the original Fig. 11 panels, which showed individual time series that were difficult to interpret in the small-sample setting.

RC2.27 (Lines 321–322)

Comment: The increased ALI over central region is true but the trend of ALI over western region is unclear.

Response: We agree. With the full 226-event dataset, ALI shows no systematic pre-onset trend in any region.

Changes in manuscript: Sect. 4.2 now reads: "The ALI (Fig. 8g–i) is episodic, with intermittent pulses in western and central GD but no sustained build-up; eastern GD remains low and flat." No systematic pre-onset ALI trend is claimed.

RC2.28 (Lines 330–332)

Comment: A question: Is the trend of VWS significant or not?

Response: This question touches on an important distinction between two aspects of the VWS analysis, which we now address explicitly. On the **temporal trend**, VWS at both layers shows no systematic change across $t = -6$ to 0 h in any region; the bootstrap 95 % CIs of the median overlap substantially at all time steps, so VWS does not intensify as onset approaches. On the **relationship between VWS magnitude and rainfall intensity** — a separate question — events in central GD with higher pre-onset VWS at 0.5–1.5 km tend to produce more intense rainfall (Spearman $r = 0.28$–0.35 over three consecutive periods). These two findings are not contradictory: the absolute magnitude of VWS reflects the steady-state urban-friction effect on the BLJ, which discriminates strong from weak events without necessarily evolving in the hours before onset.

Changes in manuscript: Sect. 4.2 (accompanying Fig. 8d–f) now states explicitly that neither VWS layer shows a systematic change in the hours preceding onset. Sect. 4.3 (accompanying Fig. 9b) reports the Spearman rank correlations for central GD VWS at 0.5–1.5 km across the three consecutive pre-onset periods. A new paragraph in Sect. 4.3 distinguishes the temporal-trend question from the magnitude–

intensity question and explains why both findings can be true simultaneously.

RC2.29 (Lines 333–335)

Comment: "The ALI...formation." Which region did authors describe?

Response: We agree that the multi-region sentence was ambiguous.

Changes in manuscript: Sect. 4.2 now gives a region-specific description: "The ALI (Fig. 8g–i) is episodic, with intermittent pulses in western and central GD but without sustained build-up; eastern GD remains low and flat." This makes clear which regional behaviour is being described.

RC2.30 (Line 335)

Comment: "BLH, LLJI...the onset are positively." It should be negative.

Response: The original sentence, based on the sliding-window correlation (SWC) analysis of 8 events, claimed that BLH, LLJI, and VWS 2–3 hours before onset were positively correlated with precipitation in central GD, later becoming negatively correlated 90 minutes before onset. This entire framework has been replaced.

Changes in manuscript: The SWC analysis has been removed. Sect. 4.3 now reports, for central GD, that VWS at 0.5–1.5 km shows a positive correlation with rainfall intensity that persists across three consecutive pre-onset periods ($r = 0.28$–0.35, all $p < 0.05$; Fig. 9b), while BLH and LLJI do not show significant correlations in central GD in any pre-onset period.

RC2.31 (Lines 338–339)

Comment: "Moreover, convergence of wind speed, weaker VWS, inhibited lifting and lower BLH are observed 90 minutes prior to the onset." How did authors get the information about convergence of wind speed here? And why the convergence of wind speed will inhibit lifting? Please clarify.

Response: This sentence was part of the SWC analysis based on 8 events, describing an apparent sign reversal at 90 minutes before onset in central GD. We agree that the underlying framework was not robust and the interpretation was unclear. The SWC framework has been removed.

Changes in manuscript: The SWC analysis and its associated "convergence of wind speed inhibiting lifting" interpretation have been removed from the revised manuscript. Sect. 4.3 now focuses on period-averaged Spearman rank correlations, which show that the absolute magnitude of VWS at 0.5–1.5 km — rather than its temporal change — is the relevant predictor of rainfall intensity in central GD.

RC2.32 (Lines 341–342)

Comment: "Overseeing...to precipitation." This is not convinced enough, especially for the 2-3 hours leading time.

Response: We agree that the original claim was under-supported. The revised text provides explicit quantitative evidence for the 2–3 h lead time.

Changes in manuscript: In Sect. 4.3, the sentence has been replaced with explicit quantitative evidence from Fig. 9: VWS at 0.5–1.5 km in central GD is significantly correlated with rainfall intensity at $t = -4$ to -2 h ($r = 0.28$, $p < 0.05$), $t = -2$ to -1 h ($r = 0.25$, $p < 0.05$), and $t = -1$ to 0 h ($r = 0.35$, $p < 0.05$). The persistence across three consecutive pre-onset periods provides the statistical basis for the 2–3 h leading-time claim.

RC2.33 (Lines 344–345)

Comment: The trend of VWS is unclear during this period, i.e., the VWS decreased during 90–120 minutes.

Response: As discussed in the responses to RC2.28 and RC2.31, the original SWC analysis and its associated 90-minute sub-window interpretation were sample-size artifacts and have been removed. VWS does not exhibit a systematic temporal trend in any region.

Changes in manuscript: Sect. 4.2 and Fig. 8d–f now state explicitly that neither VWS layer shows a systematic change in the hours preceding onset. The 90–120 minute feature claimed in the original analysis was not reproduced in the 226-event dataset.

RC2.34 (Figure 12 caption)

Comment: For avoiding the confusing, this lag time should be a negative value.

Response: The lag-time axis of the original Fig. 12 has been removed together with the SWC framework.

Changes in manuscript: The original Fig. 12 (SWC of precursor signals with precipitation as a function of lag time) has been replaced by revised Fig. 9, which presents the Spearman rank correlation heat map between pre-onset index values and maximum accumulated rainfall for all three sub-regions. Correlations are now computed over four discrete non-overlapping pre-onset periods ($t = -6$ to -4 h, -4 to -2 h, -2 to -1 h, -1 to 0 h).

RC2.35 (Lines 350–351)

Comment: "the water vapor fluxes oner the three regions" should be "over".

Response: We agree.

Changes in manuscript: "oner" has been corrected to "over" at this location, and a global check has been performed.

RC2.36 (Line 357)

Comment: The authors should not ignore the magnitude of water vapor in the lower altitude (i.e., 1000–800 hPa).

Response: We agree that the low-level layer was previously underemphasised.

Changes in manuscript: The revised caption of Fig. 14 now explicitly states: "IVT is integrated between 1000 and 850 hPa." The composite moisture flux fields in revised Fig. 14 cover the full 1000–500 hPa range in the vertical cross-section panels, making the dominant role of the low-level layer visually apparent.

RC2.37 (Line 374)

Comment: "radiation" should be "divergence".

Response: We agree.

Changes in manuscript: "radiation" has been corrected to "divergence" at this location.

RC2.38 (Line 375)

Comment: "which may be related to the ...jets." Please further explain the mechanisms.

Response: We agree that the mechanistic argument required substantial strengthening. The revised manuscript develops it quantitatively from profiler composites across seven central-GD stations.

Changes in manuscript: Sects. 4.3, 4.4, and 4.5 have been expanded to develop the mechanism explicitly. Central GD lies at the confluence of Indian-Ocean southwesterlies and western-Pacific southeasterlies (Fig. 15). Within this convergent environment, multi-event profiler composites show that the WSHR-enhanced southerly inflow is progressively decelerated inland, with a ~+2.4 m s^{-1} enhancement in the lowest 0.5 km at the coastal station NS, ~+0.8 m s^{-1} at LG, and near zero at HD (Fig. 17a). Because the inflow at 1.5 km is much less disturbed, this inland deceleration of the 0.5-km layer manifests at each profiler as an enhancement of the 0.5–1.5 km VWS, which correlates with rainfall intensity in Fig. 9b. By mass continuity, the deceleration produces a south-to-north divergence dipole: the four Bellamy triangles trace a monotonic gradient at 1.15 km from $+2.2 \times 10^{-5}$ s^{-1} at NS–ZC–SZ, through -1.5 and -2.6×10^{-5} s^{-1}, to -3.8×10^{-5} s^{-1} at LG–HD–CH (Fig. 17b). The dipole is vertically confined below ~1.5 km, and its convergent northern branch provides a favourable dynamical environment for convective initiation.

RC2.39 (Lines 375–376)

Comment: "There is...stronger convection." If the CAPE value is got from the moment of rainfall onset, it cannot be used to indicate the convection intensity right now.

Response: We agree. CAPE values are now pre-onset values, not onset-time values.

Changes in manuscript: In the revised manuscript, CAPE values are averaged over $t = -6$ to -2 h before rainfall onset (ERA5). This is stated in the text and in the caption of revised Fig. 14: "Pre-onset CAPE (ERA5, averaged over $t = -6$ to -2 h) for strong-rainfall (red) and weak-rainfall (blue) events."

RC2.40 (Line 377)

Comment: "there is sufficient water vapor". I am not sure whether the authors mean that there is sufficient water vapor throughout the vertical zone or not.

Response: We agree that the phrase was vague. The vertical moisture structure is now documented directly from ERA5 composites.

Changes in manuscript: The vague phrase "sufficient water vapor" has been removed. Revised Fig. 15 now presents composite ERA5 moisture flux cross-sections (1000–500 hPa) and IVT fields (1000–850 hPa) for all three regions based on 226 events, making clear that moisture flux is concentrated in the low-level layer in all three regions.

RC2.41 (Lines 380–384)

Comment: How did the authors conclude these results? Where is the evidence? Please clarify.

Response: We agree that the original conclusions lacked direct statistical support. The original water-vapour budget decomposition (Eq. 13 and Fig. 14 in the original manuscript) was based on selected individual cases and has been removed. The regional mechanism conclusions are now grounded in four independent composite diagnostics, each supported by specific figures and p-values.

Changes in manuscript: The original Eq. 13 and its associated budget analysis have been removed. The revised regional mechanism conclusions in Sects. 4.3, 4.4, and 5.1 are supported by (i) ERA5 composite moisture flux fields (Fig. 15); (ii) the Δw diagnostic linking LLJI intensification to upper-level ascent in western GD and documenting upper-level suppression in eastern GD (Fig. 12a and Fig. 12c); (iii) pre-onset CAPE comparisons between strong and weak events (Fig. 14); and (iv) the triangle-method divergence analysis in central GD (Fig. 17b). Each conclusion in Sect. 5.1 is now linked to specific figures and p-values.

RC2.42 (Figure 14 caption)

Comment: The authors are encouraged to describe more details to clarify this Figure.

Response: We agree.

Changes in manuscript: The original Fig. 14 (vertical profiles of water vapour budget decomposition terms and CAPE values for three regional representative cases) has been replaced by revised Fig. 15, which shows composite ERA5 water vapour flux fields based on all 226 events: vertical cross-sections of moisture transport flux along a regional transect (upper panels) and spatial distributions of vertically integrated water vapour transport (lower panels). The revised caption specifies the transect location (purple line in the lower panels), the amplification factor applied to vertical velocity for visibility (×50), the units, the IVT integration limits (1000–850 hPa), and the averaging window ($t = -6$ to -2 h before onset).

RC2.43 (Line 403)

Comment: "70 minutes". The authors need to describe more about the X-axis in Figure 15.

Response: Rather than re-labelling the X-axis of the original single-event figure, Sect. 4.5 has been restructured as a multi-event composite analysis, which removes the ambiguity at its source.

Changes in manuscript: The original Fig. 15 and its associated single-event references, including the "70 minutes" remark, have been removed. Sect. 4.5 has been rewritten as a multi-event composite analysis across seven profiler stations (Figs. 16 and 17).

RC2.44 (Line 404)

Comment: "The ALI...". The Figure 15c shows it is named "ARI". It is confused.

Response: We thank the reviewer for catching this inconsistency. "ARI" in the original Fig. 15c was a typographic error; the intended term was "ALI".

Changes in manuscript: The original Fig. 15 has been removed as part of the restructuring of Sect. 4.5. Throughout the revised manuscript, "ALI" is used consistently.

RC2.45 (Lines 405–406)

Comment: "The maximum ALI at Luogang is the largest among the four sites, indicating that the vertical motion of the atmosphere is closely related to the subsurface." I think the causal link here is reversed.

Response: The reviewer is correct: the original sentence inverted the physical causality, placing atmospheric motion as the subject driving the surface. The surface environment drives the atmospheric response, not the reverse.

Changes in manuscript: In the restructured Sect. 4.5, all statements of this kind are phrased with the upstream surface environment as the driver and the observed boundary-layer anomalies as its consequence.

RC2.46 (Figure 15)

Comment: The authors should note that the boxes of these figures are not appropriate.

Response: We agree. The original box-plot presentation has been replaced with formats that match the quantities being displayed.

Changes in manuscript: The original Fig. 15 has been removed. Per-station spatial comparisons are now shown as median anomalies with bootstrap 95 % confidence intervals (Fig. 16), and vertical profiles are shown as composite medians with interquartile shading (Fig. 17).

RC2.47 (Lines 418–419)

Comment: "there is...SLJ". Is this feature for each panel in Figure 16?

Response: We agree that the original text referred generally to an SLJ without tying the claim to specific panels. The revised manuscript quantifies the low-level inflow per station.

Changes in manuscript: Sect. 4.5 now characterises the low-level inflow per station with explicit quantitative anomalies — ~+2.4 m s^{-1} at NS, ~+0.8 m s^{-1} at LG, and near zero at HD in the lowest 0.5 km (revised Fig. 17a).

RC2.48 (Figure 16)

Comment: For each Figure, it is recommended that the information for the X- and Y-axes be described.

Response: We agree.

Changes in manuscript: The original Fig. 16 (wind field time–height diagrams) has been removed (see response to RC2.47). Revised Fig. 17 presents wind speed anomaly profiles (panel a) and divergence anomaly profiles (panel b) computed using the triangle method. The caption of Fig. 17 now specifies the computation method, the definition of the anomaly (event composite minus onset-hour-matched background median), the units, and the four Bellamy triangles used (arranged from south to north).

RC2.49 (Figure 17)

Comment: Please clarify more information about this Figure.

Response: Fig. 17 has been replaced by a multi-event divergence anomaly analysis.

Changes in manuscript: The original Fig. 17 has been replaced by a multi-event divergence anomaly analysis using the triangle method (Bellamy, 1949) applied to seven central-GD profiler stations forming four Bellamy triangles, resolving a south-to-north gradient at 1.15 km. Each triangle is labelled by station name and each quantity is given with explicit units and altitude, so that the diagnostic can be read directly from the figure.

RC2.50 (Lines 439–441)

Comment: "The vorticity...urban area." Where did the authors define the urban area in the caption of Figure 18?

Response: We agree that the definition of urban extent was not clearly linked to the figure. The definition is now consolidated in Sect. 2.1 and applied consistently throughout.

Changes in manuscript: The original Fig. 18 has been removed as part of the restructuring of Sect. 4.5. The definition of urban extent is consolidated in Sect. 2.1: urban pixels are defined as LCZ 1–10 in the LCZ classification of Stewart and Oke (2012), using the LCZ maps of Demuzere et al. (2022). This definition is used both for the province-wide map in Fig. 1 and for the 3-km urban fraction reported per profiler station on the x-axis of revised Fig. 16. In this classification, Huadu (HD, 99 %), Conghua (CH, 78 %), and Shenzhen (SZ, 70 %) lie well within the PRD urban agglomeration. Luogang (LG), although situated within the Changling National Trail System — a forested recreation area in eastern Guangzhou, with a low 3-km urban fraction of 22 % — reflects the cumulative frictional influence of the upstream urban agglomeration; the low local urban fraction confirms that the LG signal cannot be attributed to the local surface beneath the profiler.

RC2.51 (Sections 5 and 6)

Comment: Section 5 and 6 should be combined, which named "Conclusion and discussion".

Response: We agree.

Changes in manuscript: The original Sects. 5 and 6 have been merged into a single section "5 Conclusions and Discussion" with three sub-sections: 5.1 Summary, 5.2 Comparison with previous studies, and 5.3 Limitations and future work.

RC2.52 (Author contributions)

Comment: According to the list of authors, the contributions of all authors are not fully listed here.

Response: We agree. The Author Contributions section has been rewritten to list all eleven authors with their individual contributions.

Changes in manuscript: The Author Contributions section now reads: "WL performed the main data analysis and prepared the manuscript. ZH developed the precursor index calculations. SX contributed to data processing. LS, XB and LY provided important scientific comments and suggestions throughout the study. SL, YY (Yang Yang), CL and JW contributed to the manuscript revision. SL provided expertise on wind profiler radar data quality assessment. YY (Yuanjian Yang) conceived of the study, provided overall scientific guidance, and supervised the project. All authors reviewed and approved the final manuscript." The two authors sharing the initials YY are explicitly distinguished as Yang Yang and Yuanjian Yang.

RC2.53–RC2.67 (Technical corrections)

Comment: "WVS" should be "VWS" (Lines 23, 287, 319). Line 65 punctuation. Line 86 "Th" → "The". Lines 92–94 grammatical mistake. Line 97 punctuation. Lines 105–106 capitalisation. Line 133 missing period. Lines 150–151, 176, 222 formatting issues. Figure 9 caption formatting. "Author contributions.s"

→ "Author contributions".

Response: We thank the reviewer for this detailed list of corrections. All items have been implemented.

Changes in manuscript: "WVS" has been corrected to "VWS" globally (find-and-replace, manually verified). All the listed punctuation, capitalisation, grammatical, and formatting issues have been corrected. "Author contributions.s" has been corrected to "Author contributions". A final proofreading pass has been made across the whole manuscript to eliminate remaining typographical inconsistencies.

Additional Corrections Identified During Revision

In addition to the points raised by the reviewers, we identified and corrected the following issue proactively during revision.

Variable sample sizes across figures. Sample sizes differ between figures because different analyses impose different data-availability thresholds after quality control.

Changes in manuscript: A clarifying statement has been added to Sect. 2.4: "Sample sizes vary slightly across figures because each analysis requires continuous WPR data over a different time window; events with substantial data gaps in the required window are excluded. Exact counts are reported in each figure caption."

We hope that the revised manuscript, together with this detailed response and the accompanying marked-up version, satisfactorily addresses all concerns raised by the reviewers and the editor. We remain fully available to provide any further clarifications or revisions that may be required.

Sincerely,

The Authors