

This manuscript focuses on aerosol-driven precipitation modification over four major megacity clusters in China (BTH, YRD, YRM, PRD), systematically analyzing the spatiotemporal heterogeneity of precipitation microphysics and vertical structures using integrated datasets such as GPM DPR, MERRA-2, and ERA5. The research topic is highly relevant to regional hydrological cycles and climate model refinement, as aerosol-precipitation interactions in densely populated, polluted urban agglomerations remain a key uncertainty in atmospheric science. Overall, this manuscript is well organized: it investigates precipitation structural parameters, microphysical processes (e.g., coalescence, break-up), and the regulatory role of meteorological factors (RH, CAPE), providing a comprehensive framework for cross-regional comparisons. The conclusions regarding "regional precipitation disparities exceeding seasonal variations" and "aerosols mitigating regional differences in spring/summer" offer valuable insights for improving urban climate models. However, the manuscript has notable limitations that need to be addressed, including insufficient quantification of aerosol type contributions, lack of analysis on joint meteorological factor interactions, and minor issues in details (e.g., figures). With appropriate modifications to strengthen mechanistic analysis and technical rigor, the manuscript will likely meet the publication standards.

Major comments:

- 1) Quantitative contribution of different types of aerosols to precipitation lacks clarity: The manuscript claims that BTH's convective precipitation is dominated by dust aerosols (semi-direct effect), YRD/PRD by hygroscopic sea salt, and YRM by fine particles. However, it fails to provide quantitative data on the composition of aerosol types (DU, SS, SO₄, BC, OC from MERRA-2) across seasons and regions. For example: No temporal-spatial maps of aerosol type proportions (e.g., the proportion of dust column mass concentration in spring over BTH) are provided to support the "dust-dominated semi-direct effect" conclusion.
- 2) I strongly recommend the authors supplement (1) seasonal/regional distribution maps of MERRA-2 aerosol type proportions; (2) correlation analyses between individual aerosol types (e.g., DU in BTH, SS in PRD)

and precipitation parameters (e.g., RR, Dm); (3) absorption aerosol optical depth (AAOD) data to distinguish the role of absorbing (BC, DU) vs. scattering (SO₄, SS) aerosols in microphysical processes. This will clarify the mechanism of aerosol type-specific impacts.

- 3) Ambiguity in precipitation type classification: The manuscript excludes "shallow convection" from convective precipitation based on 2ADPR criteria but does not specify the 2ADPR threshold for shallow convection and report the proportion of shallow convection in total precipitation across regions/seasons. This will affect sample representativeness and undermine the robustness of the findings.
- 4) It is well acknowledged that favorable meteorological conditions are indispensable for the formation and evolution of precipitation, thereby inevitably making it elusive to disentangle the aerosol effect on precipitation. This manuscript analyzes RH (thermodynamic) and CAPE (dynamic) separately but ignores their synergistic or antagonistic effects on aerosol-precipitation interactions. The readers are more willing to see does aerosol-induced coalescence strengthen more than in single-factor conditions under the high RH (sufficient moisture) + high CAPE (strong updrafts) conditions. The authors may conduct a two-factor crossed analysis (e.g., 3 RH levels × 3 CAPE levels) to quantify aerosol impacts on precipitation parameters under different combined meteorological scenarios. This will reveal the regulatory mechanism of thermodynamic-dynamic synergy, improving the comprehensiveness of the conclusion.
- 5) In Results and discussion part: I recommend adding one or two paragraphs to focus on key findings and providing a comparative discussion on how these findings align with or diverge from previous studies on aerosol-precipitation interaction. This will help more effectively highlight the study's unique contributions to the community.

Minor comments

- 1) Lines 71-73: Except for the external synoptic conditions that can modulate the ACI process, entrainment, and other in-cloud meteorological factors, particularly that surrounding clouds and challenging to be measured, can affect the aerosol effect on clouds and precipitation.
- 2) Line 75: the citations are not correctly placed. Actually, these references are used to support "Significant research in recent years has focused

on aerosol-induced modifications of precipitation structures in key regions of China”.

- 3) The argument “analysis of specific seasons or precipitation types is frequently limited” is not correct. To my knowledge, the following references have investigated the aerosol effect on precipitation types, such as <https://doi.org/10.1073/pnas.1715386115>; <https://doi.org/10.1029/2019GL085442>
- 4) Aerosol loading" and "aerosol concentration" are used interchangeably. The authors may unify to one terminology. And "vertical structures" and "vertical profiles" (used for Ze, Dm) can be unified to "vertical profiles" for consistency.
- 5) The discussion mentions EarthCARE's potential for aerosol-cloud vertical profiling but does not specify how its data (ATLID lidar aerosol profiles, CPR cloud profiles) will address the current study's limitation of "inadequate 3D aerosol matching". I recommend adding 1–2 sentences on future research directions (e.g., combining EarthCARE's aerosol vertical distribution with GPM DPR's precipitation profiles to analyze aerosol-altitude-dependent impacts on cloud microphysics), enhancing the discussion's innovations.
- 6) Figure 1 caption can be rephrased as “Geographical distribution of four urban agglomerations over (a) the Yangtze River Middle Reaches, (b) Beijing–Tianjin–Hebei, (c) Pearl River Delta, and (d) Yangtze River Delta (d), which is superimposed with elevation.”
- 7) Fig. 3's y-axis for PEI lacks clarity—specify that “-” indicates dimensionless (after scaling by 1000). Also, “across the FOUR regions and seasons.” is not correct, I only saw three seasons corresponding to three rows of line plots.
- 8) Figure 5's title for X-axis lacks clarity—specify that “-” indicates dimensionless or directly delete “-” (as we all know AOD is dimensionless).
- 9) Figures 2–3, 5–7: Spr. Sum. and Aut are not standard abbreviation for three different seasons.
- 10) “Conclusion” -> “Conclusions”