Reply to Anonymous Referee #2

We thank the reviewer very much for the careful reading of our manuscript and helpful comments. We have revised the manuscript following the suggestions, as described below.

Comment to "Impacts of aerosol-radiation and aerosol-cloud interactions on a short-term heavy rainfall event - A case study in the Guanzhong Basin, China" by Bei et al.

This study investigates the impacts of aerosol-radiation and aerosol-cloud interactions on a short-term heavy rainfall event occurred in the Guanzhong Basin of central China using a cloud-resolving fully-coupled Weather Research and Forecasting model with Chemistry, with interesting findings. Particularly, the synergetic effect consistently decreases the precipitation in the whole domain with increasing aerosols, but ARIs play a more important role in the decreasing trend of the precipitation with deterioration of PM pollution. Personally, I think this study is worthy for publication with necessary modifications.

1. Line 48-53, Actually, it is also related to the relative location of aerosol and cloud vertical locations.

Response: We have revised the sentence in L55-56 as "*The impact of ACIs on precipitation varies under different meteorological conditions (Khain et al., 2008; Storer et al., 2010; Lebo and Morrison, 2014; Guo et al., 2016; Chen et al, 2020), cloud types (Tao, 2007; Lee et al., 2008), precipitation types (Guo et al., 2018; Sun and Zhao, 2021), cloud/precipitation development stages (Guo et al., 2014), aerosol composition and size distribution (Zhang et al., 2002; Jiang et al., 2018; Xi et al., 2024), the relative location of aerosol and cloud vertical locations (Ackerman et al., 2005; Sand et al., 2020; Senf et al., 2021), and orography conditions (Yang et al., 2014; Nugent et al., 2016).*"

Sand, M., Samset, B. H., Tsigaridis, K., Bauer, S. E., and Myhre, G.: Black Carbon and Precipitation: An Energetics Perspective, J. Geophys. Res.-Atmos., 125, 10.1029/2019jd032239, 2020.

Senf, F., Quaas, J., and Tegen: Absorbing aerosol decreases cloud cover in cloud-resolving simulations over Germany, Q. J. R. Meteorol. Soc., 147, 4083-4100, 10.1002/qj.4169, 2021.

2. Line 54-57, Supporting references should be provided, with Zhao et al. (2018, doi: 10.1002/2017EA000346) as suggested.

Response: We have added the supporting reference to the sentence in L60 as "*It has been well established that elevated aerosol concentrations increase the cloud droplet number concentration (CDNC), thus reducing cloud particle sizes, inhibiting collision and coalescence processes and increasing the cloud liquid (Zhao et al., 2018).*"

Zhao, C., Qiu, Y., Dong, X., Wang, Z., Peng, Y., Li, B., Wu, Z., and Wang, Y.: Negative aerosol-cloud re relationship from aircraft observations over Hebei, China, Earth Space Sci., 5, 19-29, doi:10.1002/2017EA000346, 2018.

3. Line 80-82, Why do previous studies focus on the mountain regions?

Response: We have added statements in L90-93 as "*Studies on the aerosol impact on precipitation in the GZB and surrounding areas (GZBs) are mostly focused on the rainfall over the mountain area due to the extensive long-term observational data available from Mt. Hua's summit. Additionally, the area is highly prone to orographic precipitation and is significantly influenced by aerosol transport from the heavily polluted upwind areas (Rosenfeld et al., 2007; Yang et al., 2013a; 2013b).*"

4. Line 87-90, Are there other similar studies regarding the synergetic effects of ARIs and ACIs over this region? If there are, a short introduction along with their findings are appreciated.

Response: We appreciate the reviewer's insightful query regarding regional studies on aerosol-radiation-cloud interactions. Following a systematic literature review, we confirm that peer-reviewed studies explicitly addressing the synergistic effects of ARIs and ACIs over the GZB remain exceptionally limited. All related studies in the region have been cited in our manuscript. This scarcity of regional studies further underscores the significance of our work in advancing process-level understanding of aerosol impacts on hydrological extremes in heavily polluted midlatitude environments.

5. Line 100-105, Why one-way instead of two-way nested grids are used?

Response: We used one-way nesting to strictly isolate aerosol effects (ARI/ACI) under controlled conditions. Two-way nesting would allow aerosol-induced changes in D02 to feedback to D01, altering meteorological initial/boundary conditions for D02. This would confound attribution of precipitation changes specifically to aerosol effects (ARI/ACI), as dynamical drivers (e.g., wind, moisture) would vary across simulations. One-way nesting ensures identical meteorological forcing (from D01) for all D02 sensitivity tests (e.g., F_BASE vs. F_ARI0), isolating aerosol impacts from external dynamical variability. We have added related statements in L117-121: "*The one-way nesting approach is intentionally adopted to prevent aerosol-induced changes in D02 from dynamically feeding back to D01, thereby maintaining identical meteorological forcing across all sensitivity experiments (e.g., F_BASE vs. F_ARI0). This isolation ensures that precipitation differences in D02 are solely attributable to aerosol effects (ARIs/ACIs) rather than confounding meteorological variability.*"

6. Line 110-114, How long for the spin-up?

Response: We have added spin-up time in the sentence in L133 as "*The WRF-Chem is first integrated for an 84-h period from 1200 UTC (2000 LT) of July 21 to 0000 UTC (0800 LT) of July 25, 2016 for D01, with a 30-h spin-up time.*"

7. Line 162-164, For these discrepancies, how do the authors explain them or how would they affect the study results?

Response: We have added discussions in L231-234 as "*These discrepancies primarily stem from uncertainties in meteorological field simulations (e.g., moisture transport, vertical wind shear), yet their consistent propagation across all sensitivity experiments minimizes impacts on aerosol effect quantification, as differences between simulations solely reflect aerosol perturbations.*"

8. Line 205, "Increased anthropogenic emissions …"

Response: Corrected.

9. Line 265-267, Actually, various studies have shown different results. While invigoration effects of clouds and enhancement of precipitation are found by many studies, a recent study has shown the vertical dependency of precipitation response to aerosols (Sun et al. 2023, doi: 10.1029/2022GL102186) – only precipitation relatively close to cloud bases are enhanced by the invigoration effect. In another word, evaporation effect could also play a role, which should be discussed.

Response: *We have added discussions in L419-422 as* **"***Multifarious measurements and numerous modeling simulations have revealed that increased aerosols invigorate convective clouds and enhance precipitation (Cerveny and Balling, 1998; Shepherd and Burian, 2003; Khain et al., 2005; Lin et al., 2006; Tao, 2007; Li et al., 2008; Lee et al., 2018). Recent study has demonstrated aerosol-induced nonlinear regulation of convective precipitation-top heights via phase-change energy partitioning, showing invigoration-to-suppression transitions, with negligible near surface rainfall sensitivity due to boundary layer evaporation dominance (Sun et al., 2023)."*

Sun, Y., Wang, Y., Zhao, C., Zhou, Y., Yang, Y., Yang, X., Fan, H., Zhao, X., and Yang, J.: Vertical dependency of aerosol impacts on local scale convective precipitation, Geophys. Res. Lett., 50, e2022GL102186, doi: 10.1029/2022GL102186, 2023.