Dear Editors and Reviewers:

Thank you very much for your careful review and constructive suggestions with regard to our manuscript “Impacts of synoptic forcing and cloud inhibition on aerosol radiative effect and boundary layer structure during winter pollution in Sichuan Basin, China” (Manuscript Number: EGUSPHERE-2023-1806). Those comments are valuable and helpful for revising and improving our paper. We have studied these comments carefully and made changes in the manuscript according the reviewers’ comments. The responses to the reviewer’ comments are listed as follows, and the main corrections are marked with blue in the PDF file named “revised manuscript egusphere-2023-1806.pdf”.

This study using long-term observation data from 18 air quality monitoring sites, combined with sounding data from four station in the Sichuan Basin, to explore the influence of synoptic forcing on the interactions between clouds, aerosols, and the PBL during wintertime. Further, the impacts of synoptic forcing and inhibition of cloud radiation interaction (CRI) on aerosol radiation interaction (ARI) with the PBL are discussed during an typical particle pollution episode. Some interesting results were present, but more in-depth analysis need to be provided. Here are some issues that need to be addressed for further improving this work.

Response: We are appreciated with your valuable and constructive comments, and have carefully considered these issues to improve this research.

1. Line 18-21, as six synoptic patterns were resolved and mentioned, a summary of these synoptic patterns should be provided.

Response: Thanks for pointing this out. We have incorporated a summary of these synoptic patterns in the abstract as: “The dominant 850 hPa synoptic patterns of winter SCB were classified into six patterns using T–model principal component analysis: (1) strong high pressure in the north, (2) east high west low (EHWL) pressure, (3) weak high pressure in the north, (4) weak ridge of high pressure after the trough, (5) low trough (LT), and (6) strong high pressure. ”. Please see Line 20-22 of the revised manuscript.

2. Line 21-23, cloud liquid content is mentioned here, is this data obtained from the observation or from the model simulation? In addition, the processes of converted aerosols into fog/cloud

drops that contributed to the high cloud liquid content is subjective, the related discussion was not found in the main text.

Response: We are thankful for your comment and feel sorry for the confusion caused by these issues.

The cloud liquid content data is obtained from the ERA5 reanalysis data, as previous studies have demonstrated the reliability of ERA5 data in estimating cloud properties, including the cloud liquid content (Yao et al., 2019; Nandan et al., 2022; Ojo et al., 2023).

As for the statement regarding the processes of aerosol conversion into fog/cloud drops contributing to the high cloud liquid content, it is a speculation by authors based on previous researches (Twomey, 1977; Lohmann and Feichter, 2005; Boutle et al., 2018), but not fully discussed in the main text. For the accuracy and rigor of this study, we have removed the statement. Please see Line 182-186 of the revised manuscript.

3. Line 42-44, “Understanding .... is crucial for ...understanding... ”it is not clear here, rewrite this sentence.

Response: We agree with the comment, and have rewritten this sentence in the revised manuscript as the following: “Studying interactions among cloud, aerosol and radiation from an air quality perspective is crucial for a scientific understanding of relationship between weather and pollution.”. Please see Line 52-53 of the revised manuscript.

4. Line 45-47, what about the role of secondary aerosol formation?

Response: Thank you for pointing this out. In addition to the emission of primary aerosols, secondary aerosol formation also plays significant role in comprehending the complete picture of air pollution. Meteorological conditions not only influence the formation of secondary aerosols, but also govern the transportation and distribution of both primary and secondary aerosols, and thereby impact regional and long-range air pollution. We have rephrased the sentences in Line 54-58 of the revised manuscript.

5. Line 68-70, it is better to indicate the specific areas to which the conclusion applies.

Response: Thanks for the comment. We have rephrased it as: “This positive feedback between unfavorable PBL meteorology and increasing aerosols was found to be responsible for the majority of the increase in $PM_{2.5}$ concentrations during cumulative stages in various regions of eastern China affected by aerosol pollution, including the North China Plain, the Guanzhong Plain, the Yangtze River Delta, the Two Lakes Basin, the Pearl River Delta and the Northeast China Plain. But in the Sichuan Bain, the feedback is weak due to the suppression of the cloudy mid-upper layer (Zhong et al., 2018; Zhong et al., 2019).". Please see Line 84-90 of the revised manuscript.

6. Line 88-91, The motivation of the present study was not clearly present, as the topic mentioned here had been reported previously for SCB region, like in Zhong et al., 2019.

Response: We are appreciated with the comment and feel sorry for not clarifying the motivation of this study clearly. In the revised version, we have added the description of the motivation of the study as: "Many studies have emphasized the importance of the interactions between cloud, aerosols and radiation in air pollution processes (Wang et al., 2018; Hu et al., 2021). High pollutant emissions, combined with the prevalence of cloudy and foggy weather, make these interactions in the SCB even more complex than those in other regions. The aerosol radiation interactions (ARI) can be inhibited by clouds in cities like Chengdu (Zhong et al., 2019). However, there is a lack of in-depth quantitative discussions regarding the aspects in the SCB. On one hand, the complex terrain in the SCB leads to differences in the meteorological conditions between them (Ning et al., 2018; Lu et al., 2022). For example, Chengdu is a typical basin city while Chongqing is a mountain city located on the basin slope, so they have markedly different climatic conditions. It remains to be elucidated whether these conditions will result in spatial disparities in cloud inhibition on the aerosol radiation interactions (ARIs). On the other hand, synoptic forcing, as the primary driver of meteorological variations, undoubtedly play an unneglectable role in shaping cloud cover and boundary layer structures (Miao et al., 2020; Wang et al., 2022; Painemal et al., 2023). The discrepancies in cloud inhibition on ARI under different synoptic patterns also need to be revealed. Addressing these issues is crucial for understanding the persistent pollution processes and the intricate interactions between weather and pollution in the SCB. It holds important implications for the effective management of pollution processes in cloudy and foggy weather.". Please see Line 108-124 of the revised manuscript.

7. Line 108-110, brief description about the difference in the air pollution and meteorological conditions for the selected four sounding station should be provided.

Response: Thank you for the suggestion. We have incorporated a brief description in the revised version as: “The SCB has four sounding stations Wenjiang (CD), YB, DZ, and Shapingba (CQ), which are situated in the western, southern, northwestern, and eastern regions of the basin, respectively (Fig. 1b), and represent different pollution and meteorological conditions in different regions within the SCB. In all, the air pollution over the SCB exhibits a gradual decrease from southwest to northeast. Statistical analysis indicates that the western and the southern basin experience the most severe pollution. The western basin shows the highest pollution proportion, while the southern basin exhibits the highest occurrence of heavy pollution. In the northeastern basin, specifically in Dazhou, heavy pollution is more likely to occur during winter, which verifies it to be the third highest pollution zone outside the western and southern basin. This makes the spatial distribution during winter differs from the overall annual pollution pattern in the SCB (Lu et al., 2022; Qi et al., 2022). Regarding meteorological conditions, research reveals that DZ has the lowest ventilation coefficient during winter, while CQ has the highest. The SCB experiences frequent temperature inversions, with CD having a higher occurrence of inversions compared to the other three cities. CD also exhibits the strongest inversion intensity and is prone to multi-layer inversions. On the other hand, YB and CQ have greater inversion thickness, while CD has the smallest inversion thickness (Feng et al., 2020).”. Please see Line 146-161 of the revised manuscript.

8. Line 171-172, “other cities in the SCB also experienced pollution episodes and relevant physical processes”. Do the authors mean other cities in the SCB showed consistent or similar pollution episodes and relevant physical processes? Please clarify it and provide the data to support it.

Response: Thank you for this rigorous comment. We have provided Figure S1 to show the time series of daily mean $PM_{2.5}$ and potential temperature derived from the ERA5 data of January 2017 for other fourteen cities in the SCB. The other cities have experienced the same pollution episodes and relevant physical processes, except for GY (Figure S1). GY is located in the northern edge of the SCB, bordering Shaanxi and Gansu Provinces. The proportion of heavy $PM_{2.5}$ pollution in GY is the lowest in the basin, but the proportion of PM_{10} pollution is higher than other cities of SCB (Lu et al., 2022). Due to the lower $PM_{2.5}$ concentration, the two pollution processes in January 2017 in GY were not as significant as in other cities within the basin. However, the warming of upper air coincided with $PM_{2.5}$ increase could still be observed. Please see Figure S1 in supplement and Line 254-259 of the revised manuscript.

9. Line 182, why high wind speed above 1500m would contribute to the rapid increase in $PM_{2.5}$?

Response: We are thankful for the comment. The issue can be explained by our previous study (Lu et al., 2022). We have added the corresponding explanation in the revised version as: "The previous study has found that winter heavy pollution processes in the SCB are usually associated with abnormal warming above the 850 hPa (Lu et al., 2022). The warming is induced by strong southerly airflow above the basin. The southerly airflow in winter over the SCB originates from the Yunnan-Guizhou Plateau or the Indian Peninsula, characterized with high temperature, dryness, and high wind speed. The strong southerly airflow forms a "warm lid" over the basin, suppressing the vertical exchange of pollutants within the basin. As a result, pollutants accumulate rapidly, which may explain the phenomenon of rapid $PM_{2.5}$ growth accompanied by warming, dryness, and strong winds above 1500 m.". Please see Line 272-279 of the revised manuscript.

10. Line 223-225, why pattern 4 was identified as synoptic pollution patterns? Any statistic results support it? In addition, about Pattern 6 that identified as the "clean pattern", the pollution occurrence frequency of which was much higher for the cities located in the eastern part of the SCB than the other parts (Figure 5a), explain it.

Response: Thanks for the valuable comment.

The reason why Pattern 4 was identified as a synoptic pollution pattern has been given in Line 306-309 of the revised manuscript. The reasons for Pattern 2 and 5 were also added. Some statistic results have been illustrated as: "Patterns 2, 4, and 5 exhibited higher frequencies of pollution occurrence ($PM_{2.5}$ daily concentration ≥ 75 μg/m^3) according to statistical results from 18 cities in the SCB during the 2015–2021 winters (Fig. 4a). " and "The days under Patterns 2, 4, and 5 exhibited higher average daily $PM_{2.5}$ concentrations. The average values under these three synoptic patterns were 99.19, 103.43 and 111.97 μg/m^3 for CD, 95.44, 87.98 and 94.26 μg/m^3 for

YB, 79.14, 83.96 and 74.77 μg/m^3 for CQ, and 91.02, 104.64 and 91.51 μg/m^3 for DZ, respectively. ”.

The average $PM_{2.5}$ concentrations under Pattern 6 were lower in all cities of SCB than other three pollution patterns (Fig. 4a). Besides, the day to day $PM_{2.5}$ variations under Pattern 6 exhibited negative growth trend in the four representative cities (Fig. 4c). As a result, Pattern 6 was identified as the “clean pattern”. For Pattern 6, strongest northerly airflow affected the basin. The eastern part of the basin consists of parallel ridges and valleys, which reduces wind speed. The stronger the wind is, the more obvious the reduction of wind by terrain is. In contrast, the western part is relatively flat, which can result in higher surface wind speeds. The difference in wind impacted by terrain led to a weaker pollution removal effect in the eastern region, thus contributing to a higher proportion of pollution days under Pattern 6. Besides, differences in precipitation rates between eastern cities and other regions were not significant (the proportion of rainfall with a daily accumulated precipitation exceeding 10 mm in CD, CQ, YB and DZ under Pattern 6 were all less than 3%), which might not the main reasons why eastern cities in the SCB experience higher pollution frequency. Please see Line 313-326 of the revised manuscript.

11. Line 243-236, Better to provide the precipitation information in Figure 6 to support this conclusion.

Response: Thanks for the suggestion. We have incorporated the daily accumulated precipitation in the figure. When the northerly airflow dominates the SCB (Pattern 1, 3 and 6), it is sometimes accompanied by weak precipitation that results to wet deposition and the removal of pollutants. Please see Figure S3 of the revised manuscript.

12. Line 247-248, it should be Pattern 6 with the highest PBL (1500m) as showed in Fig.7.

Response: We apologize for the error and have corrected it as: “The PBLH under Patterns 2 and 5 was approximately 900–1000 m, lower than that under the influence of clean synoptic Pattern 6 at 1500 m or Pattern 1 and 3 at 1200–1300 m (Fig. 5).”. Please see Line 366-367 of the revised manuscript.

13. Line 271-274, If the low temporal resolution of sounding data made it not suitable to be adopted to compare, why the authors mentioned the good consistency of PBL in ERA5 with

sounding data in Guo et al., (2016)? Discussion about the comparison of PBL from the sounding data and the ERA5 is conflict here. At least, the PBL from sounding data and the comparison with the ERA5 and model results should be provided during the simulation period.

Response: Thanks for the comment. In Figure 9(a)-(d), the PBLH calculated based on the sounding data has been incorporated to compare with the ERA5 and model results during the simulation period. We calculated the PBLH with sounding data using the bulk Richardson number with a threshold value of 0.25, because the ERA5 and YSU boundary parameterization scheme also calculate the PBLH with the same method and the threshold (Hong et al., 2016; ECMWF, 2017). Sounding data are commonly regarded as reliable vertical observation records. PBLH calculated based on sounding data can be used as the true values to compare with other data for long-term validation (Guo et al., 2016). However, for short-term studies, due to limited availability of sounding data at only 00:00 and 12:00 UTC, the ERA5 data were also incorporated for the model evaluation of PBLH in this study (Fig. 6 and Fig.S5). The simulation PBLH showed a consistent trend with those calculated from ERA5 and sounding data. Please see Figure 6 and S5, Line 167-177 and Line 405-410 of the revised manuscript.

14. Line 341-343, As showed in Figure 13 and 15, the solar radiation and PBL induced by ARI was more distinct in Pattern 5 than in Pattern 2, data, and the authors attributed it to the denser aerosol in Pattern 5. Here, the denser aerosol is deduced from the higher $PM_{2.5}$ concentration from ground observation? If so, the analysis of the vertical profile of aerosol would be better to show the difference of aerosols' impacts on PBL development in Pattern 2 and Pattern5.

Response: We appreciate your valuable suggestion. Zonal average of $PM_{2.5}$ concentration between 104° E and 105° E was conducted, and the meridional vertical distribution of $PM_{2.5}$ between 27° N and 35° N was illustrated in Figure 11(a)-(b) in revised manuscript. Figure 11(c) provides an average of $PM_{2.5}$ concentration within 28° N and 31° N, showing the vertical distribution profiles under Pattern 2 and 5. Due to the inhibition of "warm lid" above the SCB, the vertical exchange was not prominent under both Pattern 2 and 5, and $PM_{2.5}$ was more concentrated at the middle and lower levels. The $PM_{2.5}$ concentration under Pattern 5 was higher than Pattern 2 throughout the atmospheric column, indicating stronger aerosol radiative forcing and a more significant impact on the boundary layer structure under Pattern 5. Please see Figure 11 and Line

486-493 in the revised manuscript.