Dear Editors and Referees:

Thank you very much for your review and comments concerning our manuscript entitled "Elevated 3D structures of $PM_{2.5}$ and impact of complex terrain-forcing circulations on heavy haze pollution over Sichuan Basin, China" [MS No.: acp-2020-1161]. Those comments are all valuable and helpful for revising and improving manuscript. We have studied comments carefully and have accordingly made the revisions. Revised parts are highlighted with Track Changes in the revised manuscript. In the following we quoted each review question in the square brackets and added our response after each paragraph.

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Response to Referee #2

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[This paper analyzed the three-dimensional distribution of PM2.5 concentrations in Sichuan Basin during a heavy haze pollution episode in January 2017. The topic is quite interesting; However, many discussions are only general descriptions of phenomena and processes, lacking in-depth analysis and discussion. This makes the article as a whole difficult to follow.]

Response 1: Many thanks for your encouraging comments. We have revised the manuscript accordingly with in-depth analysis and discussion. All the revisions have been highlighted with Track Changes in the revised manuscript. The point-by-point responses to the reviewer's comments are as follows.

[1. Line 115: The Multi-resolution Emission Inventory for China (MEIC) has been updated to 2017 (http://www.meicmodel.org), while the authors used the data of 2012 for the simulation period in January, 2017. The author should explain the mismatch. Further, the first domain (D1) of the study area includes China and its neighboring countries/regions. In this section, the author only stated that the anthropogenic emission sources used in their study is MEIC data, but as far as I know, MEIC data only includes the anthropogenic emission sources in China, while the emissions from natural sources and neighboring countries/regions are not included. How did the author consider this in their simulation process? If the emission data of neighboring countries/regions are not included, there will be great uncertainty about the results of the section 3.5 (Contribution of local emission and outflow transport), because the surrounding emissions are ignored.]

Response 2: Thanks for the comments. We have accordingly added the following explanation and discussions in the revised conclusions (Sect. 4.):

"The MEIC 2017 was not available for our WRF-Chem modelling experiments. The SCB is located in Southwest China with larger uncertainties in anthropogenic emission inventory comparing to Eastern China. The accurate emission inventory could improve air pollution simulations and air quality change assessments in further study."

Furthermore, we have clarified the emissions from natural sources and neighboring countries/regions in the revised manuscript (Sect. 3.5) as follows:

"The Model of Emissions of Gases and Aerosols from Nature (v2.1) was applied for the natural emission sources in the simulation with dust emission parameterization. The SCB in the northeastern part of Southwest China with a deep-bowl structure is isolated by the plateaus (TP in west and YGP in south) and mountains with a clean atmospheric environment. High local anthropogenic emissions in the SCB dominate the regional air pollution (Liao et al., 2017). The transport of air pollutants from neighboring countries/regions are mostly concentrated in the neighboring regions in the southern Tibetan Plateau and the southern Yunnan-Guizhou Plateau (Wang et al., 2018; Zhao et al., 2019; Yin et al., 2020). Therefore, the anthropogenic emission data of neighboring countries/regions are not included in the WRF-Chem simulation on haze pollution over SCB during 2-8 January, 2017, considering the less effects of air pollutant cross-border transport on wintertime air pollution in SCB with the ignorable contribution to the wintertime heavy haze pollution over the SCB region."

References

Liao, T., Wang, S., Ai, J., Gui, K., Duan, B., Zhao, Q., Zhang, X., Jiang, W., and Sun, Y.: Heavy pollution episodes, transport pathways and potential sources of $PM_{2.5}$ during the winter of 2013 in Chengdu (China), Science of the Total Environment, 584, 1056-1065, https://doi.org/10.1016/j.scitotenv.2017.01.160, 2017.

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Zhao, S., Yu, Y., Qin, D., Yin, D., Dong, L., and He, J.: Analyses of regional pollution and transportation of $PM_{2.5}$ and ozone in the city clusters of Sichuan Basin, China, Atmospheric Pollution Research, 10(2), 374-385, https://doi.org/10.1016/j.apr.2018.08.014, 2019.

Yin, D., Zhao, S., Qu, J., Yu, Y., Kang, S., Ren, X., Zhang, J., Zou, Y., Dong, L., Li, J., He, J., Li, P., and Qin, D.: The vertical profiles of carbonaceous aerosols and key influencing factors during wintertime over western Sichuan Basin, China, Atmospheric Environment, 223, 1352-2310, https://doi.org/10.1016/j.atmosenv.2020.117269, 2020.

[2. Line 157: 3.1 Model evaluation As we know, China has adopted active pollution source control policies in the last 5 years, and the intensity, the temporal and spatial distribution of emission sources will vary greatly from year to year. The author selected the 2012 MEIC inventory as its emission data. Thus the model evaluation result may not be convincing.]

Response 3: We agree with the referee that China has adopted active pollution source control policies in the last 5 years, and the intensity, the temporal and spatial distribution of emission sources will vary greatly from year to year. We have added the explanation and discussions about the 2012 MEIC emission data in the revised conclusions as follows:

"The MEIC 2017 was not available for our WRF-Chem modelling experiments. The SCB is located in Southwest China with larger uncertainties in anthropogenic emission inventory comparing to Eastern China, The accurate emission inventory could improve air pollution simulations and air quality change assessments in further study."

[3. Line 216: To examine the vertical structures of PM2.5 concentrations over SCB, we selected the urban site 1 (104.02◦ E; 30.67◦ N) in Chengdu (cf. Fig. 1) as a reference point to investigate the distributions of PM2.5 and the atmospheric circulations respectively in the vertical-meridional and vertical-zonal cross-sections. Why do you select the urban site 1 (104.02◦ E; 30.67◦ N) in Chengdu for the vertical discussion. Do you have any special purpose? Chengdu is located in the far west side of the SCB, and other sites in the central area of SCB maybe are better choices, as the wind vectors shows in Figure 6.]

Response 4: We selected the urban site 1 (104.02° E; 30.67° N) in Chengdu for the vertical discussion with the following purposes:

1) The terrain effect of TP, the "world roof" on the mid-latitude westerlies could modulate haze pollution in the downstream region over China (Xu et al., 2016). The SCB is immediately to the east of TP with a large elevation drop exceeding 3000 m over a short horizontal distance. The unique terrain effect generates the asymmetries of meteorological and air pollutant distribution (Zhang et al., 2019). To better understand the elevated 3D structures of $PM_{2.5}$ with the impact of TP terrain-forcing circulations over the pollution episode.

2) Chengdu (site 1), is a metropolis in SCB with high anthropogenic emissions and the most polluted environment in Southwest China (Ning et al., 2018). It is important to investigate how the urban surface high $PM_{2.5}$ levels evolved vertically with the combination between the high urban emissions and TP's terrain-forcing lifting over the SCB.

Furthermore, we have plotted the cross-sections of $PM_{2.5}$ and wind vectors along the near-surface prevailing northeastern wind across the central SCB (blue line in Figure S4 of manuscript supplement). The vertical changes of $PM_{2.5}$ with the terrain-forcing local circulations by YGP-terrain effects were remarkably presented in the different stages of the heavy haze pollution event.

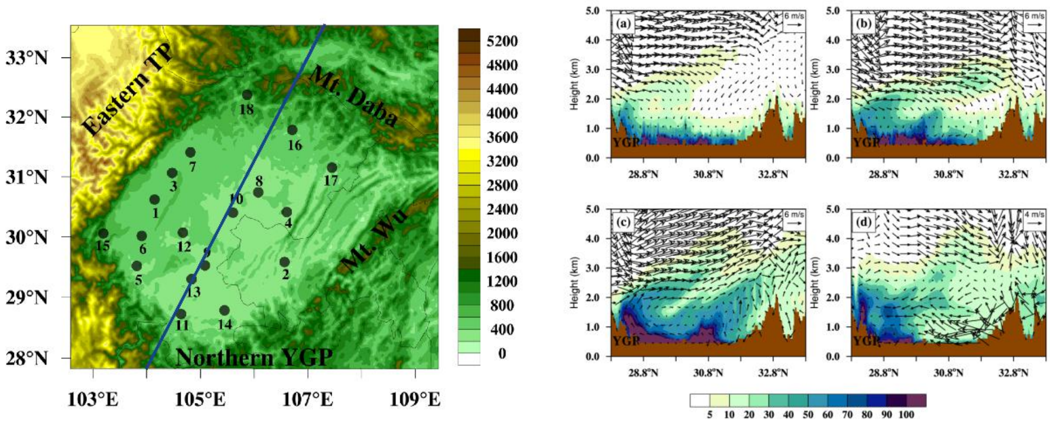

Figure S4. Northeast-southwest cross-sections along the near-surface prevailing wind (blue line) over SCB (left panel), $PM_{2.5}$ concentrations (color contours: μg m^{-3}) and wind vectors (right panel) in (a) the relative clean environment at 12:00 a.m. on 2 January, (b) heavy air pollution formation stage at 12:00 a.m. on 3 January and (c) maintenance stage at 8:00 a.m.on 6 January 6 and (d) dissipation stage at 8:00 a.m. on 7 January, 2017.

References

Xu, X., Zhao, T., Liu, F., Gong, S. L., Kristovich, D., Lu, C., Guo, Y., Cheng, X., Wang, Y., and Ding, G.: Climate modulation of the Tibetan Plateau on haze in China, Atmos. Chem. Phys., 16, 1365–1375, https://doi.org/10.5194/acp-16-1365-2016, 2016.

Zhang, L., Guo, X., Zhao, T., Gong, S., Xu, X., Li, Y., Luo, L., Gui, K., Wang, H., Zheng, Y, and Yin, X.: A modelling study of the terrain effects on haze pollution in the Sichuan Basin, Atmos. Environ., 196, 515 77–85, https://doi.org/10.1016/j.atmosenv.2018.10.007, 2019.

Ning, G., Wang, S., Ma, M., Ni, C., Shang, Z., Wang, J. and Li, J.: Characteristics of air pollution in different zones of Sichuan Basin, China, Sci. Total. Environ., 612, 975–984, 440 https://doi.org/10.1016/j.scitotenv.2017.08.205, 2018.

[4. Line 275: Figure 10 showed the PM2.5 concentrations emitted from the regional air pollutant sources over the SCB region and the relative contribution rates to air pollution changes.
The expression here shows the author's conceptual misunderstanding of the source of PM2.5. How can the "PM2.5 concentrations" be "emitted"?]

Response 5: We modified the expression as "Figure 11 shows the $PM_{2.5}$

concentrations originated from local emissions of primary $PM_{2.5}$ and gaseous precursors of $PM_{2.5}$ over SCB and the relative contribution rates to air pollution changes."

[5. Line 278: The SCB's regional air pollutant emissions provided surface PM2.5 concentrations from 40.6 to 136.2 μg m-3, contributing 75.4–94.6 % of surface PM2.5 concentrations for the heavy pollution episode over SCB, indicating its dominant role over this isolated deep basin in Southwest China.
What does "indicating its dominant role over this isolated deep basin in Southwest China" mean? It is hard to follow.]

Response 6: In the revised manuscript, we have clarified this sentence as "The SCB's regional air pollutant emissions provided surface $PM_{2.5}$ from 40.6 to 136.2 μg m^{-3}, contributing 75.4–94.6 % proportion of total concentrations for the heavy pollution episode over SCB, indicating the dominant role of local air pollutant emissions on air quality changes over this isolated deep basin in Southwest China."

[6. Line 279: The regionally emitting PM2.5 concentrations averaged over SCB were 88.64, 91.04 and 65.96 μg m-3 for the formation, maintenance and dissipation periods, respectively.
Same as above. How can the "PM2.5 concentrations" be "emitted"?]

Response 7: The expression has been corrected as "The surface $PM_{2.5}$ concentrations sourced from the regional air pollutant emissions over SCB were averaged respectively with 88.64, 91.04 and 65.96 μg m^{-3} for the formation, maintenance and dissipation periods of air pollution."

[7. Line 284: We think the exchanges of PM2.5 between the polluted air over SCB and the cleaner environment air over the surrounding plateaus and mountains in Southwest China play a role in this process. (Figs. 7 and 8).
How do you think the PM2.5 can be "exchanged" between the polluted air over SCB and the cleaner environment air?]

Response 8: Thanks for the referee's careful review. The sentence has been modified as ", which could be attributed by the exchanges between the $PM_{2.5}$-rich airmass over

SCB and $PM_{2.5}$-poor airmass in the surrounding plateaus and mountains over Southwest China."

[8. Line 560: Table 5. Please give the definite range of the eastern TP edge (ETP), northern YGP edge (YGP) and DBM region.]

Response 9: The definite ranges of three regions were defined with the altitudes of 750–3500 m over 30.5–33.0° N, 102.7-105.3 °E (the eastern TP edge), 750–3000 m over 27.8–29 °N, 103.5–108.5 °E (northern YGP edge) and above 750 m over 31.5–33.0 °N, 106.0–109.4 °E (DBM region), which were marked in Figure S5.

The above description has been added in the Sect. 2.3.

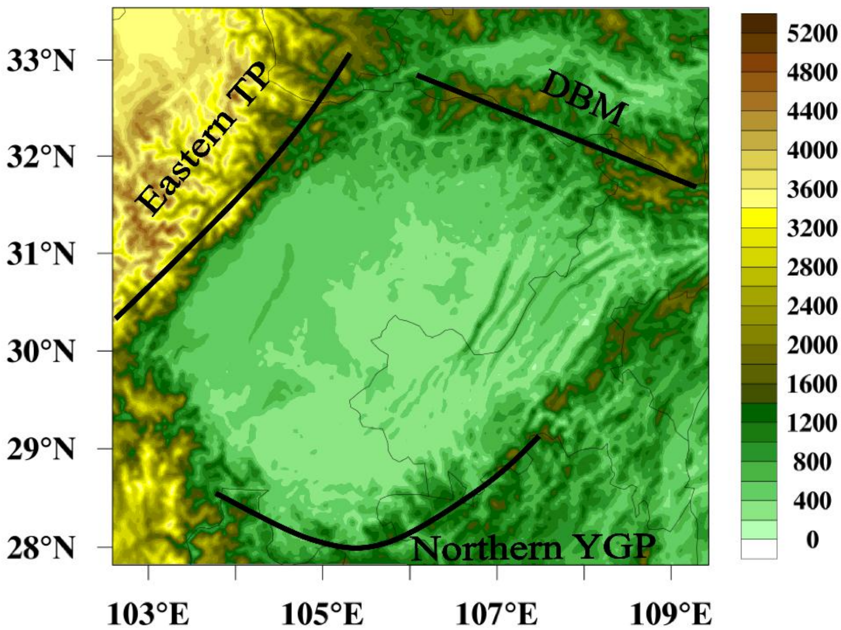

Figure S5. The eastern TP edge (ETP), northern YGP edge (YGP) and DBM region (black lines) in the study with the terrain heights.

[9. Line 600: Figure 5(a). Why only 8 hours data are presented here? There is an abnormal value around half past 10 a.m., please give the reason.]

Response 10: The MPL is located at site 15 of the western margin of SCB (Fig. 1). The layer of high $PM_{2.5}$ concentrations with the vertical hollow was observed between 1-2 km during the 8-hr haze maintenance stage P2 at site 15.

The abnormal values as might be caused by the background noise of MPL, giving rise to an aberrant point of observation with extremely high extinction coefficients at this point. The abnormal values around half past 10 a.m. have been removed in the modified Figure 6.

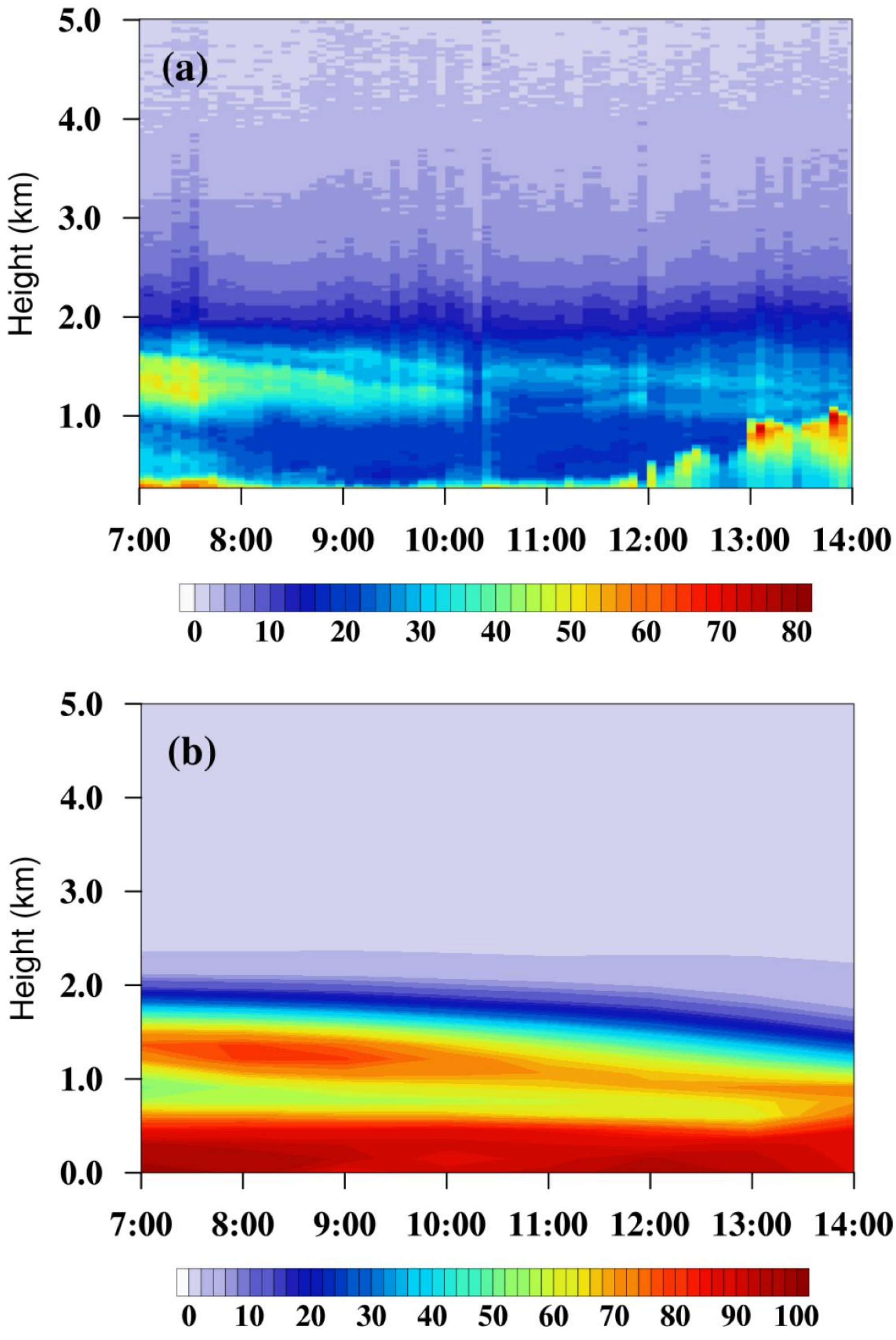

Figure 6. Vertical and time cross-sections of $PM_{2.5}$ mass concentrations (μg m^{-3}) from (a) MPL-4B retrievals products and (b) simulation results at site 15 (Fig. 1; Table 1) in the western SCB edge during 7:00 a.m.−2:00 p.m. on 5 January 2017.

[10. Line 610 -615: Figure 8. Does this cross section along 104.02◦ E? Please specify. Same as previous mentioned, why do you select this site 1 (104.02◦ E; 30.67◦ N)? Do you think it may be a better choice if you put the cross section along the wind vectors from northeast to southwest?]

Response 11: Yes, Figure 9 (in the revised manuscript) actually exhibited the cross sections along the Chengdu (104.02 °E). The vertical cross section along the northeast-southwest wind vectors were provided in Figure S4 (please see our response 4). The separate height-longitude and height-latitude cross sections could better represent the vertical circulation changes and $PM_{2.5}$ distribution over SCB.

[11. Line 625: Figure 10. How the values of surface PM2.5 concentrations are calculated? The regional average of the SCB or the average of several monitoring sites in SCB?]

Response 12: Both surface $PM_{2.5}$ concentrations and the contribution proportions in Figure 11 (in the revised manuscript) were calculated with the regional averages over SCB rather than the averages of several monitoring sites in cities. The caption of Figure 11 has been revised as follows:

"Figure 11. Hourly variations of surface $PM_{2.5}$ concentrations originated from the SCB's anthropogenic emissions (blue filled areas) and the contribution proportions to the basin surface $PM_{2.5}$ levels (red curve) during 1–8 January 2017 based on the regional averages over SCB. "