Reply to Anonymous Referee #2:

We sincerely appreciate for the reviewer's careful dealing of our manuscript and valuable comments. We have read and discussed these comments in detail and answer them one by one in the followings. The corresponding revisions have also been added in the manuscript.

**General comments by Referee #2**

*This work evaluated the performance of a new surface layer scheme (Li) and a widely applied scheme (MM5) in simulating the momentum and sensible heat fluxes. Using the observational data in Gucheng station located in the southwest of Beijing from Dec 1, 2016, to Jan. 9, 2017, The authors found the Li scheme generally performed better than MM5 in calculating SL fluxes during the heavy pollution process. The study fits within the scope of the journal, and the manuscript is generally well written. The result presented is interesting as it shows the SL scheme performance in a polluted case. However, I found that some key details on the introductions are lacking and some of the discussions are not very well grounded.*

**Response:**

Thanks for the affirmation to our work. Yes, we agreed that some key points on the introduction were not enough and some discussions were not very well grounded. We have examined the introduction as well as whole text and the corresponding revisions have been added in the manuscript.

**Comment 1:** *The author should explicitly explain the scientific meaning of the paper. Since Li scheme has been published and evaluated in Li et al. (2014; 2015), why do we need additional evaluation using the observation during a severe haze episode from Gucheng station? I believe this evaluation may be necessary, but the authors need to illustrate clearly the specialty of this case. Also, the word "east China" appears several times in the paper. How did the author conclude Li generally performed better than MM5 in winter in east China since they only did one case in Beijing?*

**Response:**

The Li scheme consists of two parts (Li et al., 2014; 2015). The first part (Li et al., 2014) focused on the stable stratification, while the latter (Li et al., 2015) focused on the unstable conditions. The two parts have not been consolidated into a complete scheme in previous studies. In our study, the two parts were consolidated into one for both stable and unstable conditions. Furthermore, previous work (Li et al., 2014; 2015) was only compared with other iterative or non-iterative schemes. They have neither been compared with actual observations, nor evaluated under the transition process from unstable to stable conditions, which is essential and meaningful. We didn't introduce clearly in our old manuscript and we re-summarized this content in Line 74-83, Page 3 in the revised manuscript.

Yes, the word "east China" is not accurate in this paper. In fact, our study focuses on the Jing-Jin-Ji region in east China. We have replaced "east China" with "Jing-Jin-Ji" in the whole manuscript; In addition, we added Beijing station as well as Jing-Jin-Ji region to discuss the performance of Li and MM5 schemes for different land-cover types (added Figs. 9-10 and the related contents in the revised manuscript).

References:

1. Li, Y., Gao, Z., Li, D., Wang, L., and Wang, H.: An improved non-iterative surface layer flux scheme for atmospheric stable stratification conditions, Geosci. Model Dev., 7, 515-529, https://doi.org/10.5194/gmd-7-515-2014, 2014.

2. Li, Y., Gao, Z., Li, D., Chen, F., Yang, Y., and Sun, L.: An Update of Non-iterative Solutions for

Surface Fluxes Under Unstable Conditions, Bound.-lay. Meteorol., 156, 501-511, https://doi.org/10.1007/s10546-015-0032-x, 2015.

**Comment 2:** *The role of surface layer (SL) scheme in air quality modeling needs to be further discussed in the introduction. The authors made sufficient introduction to the current status of SL. However, a detailed introduction of the importance of SL schemes in simulating pollution episode is somewhat lacking. In other words, the interactions between pollutant transportation, momentum and sensible heat (and how current SL schemes perform in momentum and sensible heat modeling) should be well established in the introduction part.*

**Response:**

We agree that the introduction of the interactions between pollutant transportation, momentum and sensible heat was not enough and efficient, we read the new references list in the following and complemented the related contents in Line 42-52, Page 2 in the revised paper. The related references as follows were also added in the revised version.

References:

1. Zhang, R., Li, Q., and Zhang, R.: Meteorological conditions for the persistent severe fog and haze event over eastern China in January 2013, Sci. China Earth Sci., 57, 26–35, https://doi.org/10.1007/s11430-013-4774-3, 2014.

2. Yang, Y., Liu, X., Qu, Y., Wang, J., An, J., Zhang, Y., and Zhang, F.: Formation mechanism of continuous extreme haze episodes in the megacity Beijing, China, in January 2013, Atmos. Res., 155, 192–203, https://doi.org/10.1016/j.atmosres.2014.11.023, 2015.

3. Liu, T. T., Gong, S. L., He, J. J., Yu, M., Wang, Q. F., Li, H. R., Liu, W., Zhang, J., Li, L., Wang, X. G., Li, S. L., Lu, Y. L., Du, H. T., Wang, Y. Q., Zhou, C. H., Liu, H. L. and and Zhao, Q. C.: Attributions of meteorological and emission factors to the 2015 winter severe haze pollution episodes in China's Jing-Jin-Ji area, Atmos. Chem. Phys., 17, 2971–2980, https://doi/org/10.5194/acp-17-2971-2017, 2017.

4. Zhong, J., Zhang, X., Dong, Y., Wang, Y., Liu, C., Wang, J., Zhang, Y., and Che, H.: Feedback effects of boundary-layer meteorological factors on cumulative explosive growth of PM2.5 during winter heavy pollution episodes in Beijing from 2013 to 2016, Atmos. Chem. Phys., 18, 247–258, https://doi.org/10.5194/acp-18-247-2018, 2018.

5. Li, Z., Guo, J., Ding, A., Liao, H., Liu, J., Sun, Y., Wang, T., Xue, H., Zhang, H., and Zhu, B.: Aerosol and boundary-layer interactions and impact on air quality, Natl. Sci. Rev., 4, 810–833, https://doi.org/10.1093/nsr/nwx117, 2017.

6. Li, T., Wang, H., Zhao, T., Xue, M., Wang, Y., Che, H., and Jiang, C.: The Impacts of Different PBL Schemes on the Simulation of PM2.5 during Severe Haze Episodes in the Jing-Jin-Ji Region and Its Surroundings in China, Adu. Meteorol., http://dx.doi.org/10.1155/2016/6295878, 2016a.

7. Vautard, R., Moran, M. D., Solazzo, E., Gilliam, R. C., Matthias, V., Bianconi, R., Chemel, C., Ferreira, J., Geyer, B., Hansen, A. B., Jericevic, A., Prank, M., Segers, A., Silver, J. D., Werhahn, J., Eolke, R., Rao, S. T., and Galmarini, S.: Evaluation of the meteorological forcing used for the Air Quality Model Evaluation International Initiative (AQMEII) air quality simulations, Atmos. Environ., 53, 15-37, https://doi.org/10.1016/j.atmosenv.2011.10.065, 2012.

**Comment 3:** *In the third conclusion (Line 342-343): The authors argued that "During the heavy pollution process, the calculated momentum and sensible heat fluxes by the Li scheme were better than*

*those by the MM5 scheme generally". If the authors only compared simulated momentum and sensible heat to the observation, why this work emphasized the "heavily polluted conditions"? Future work may consider coupling SL scheme with atmospheric chemistry models to compare the modeled pollutant concentration with observation directly.*

**Response:**

The statement "During the heavy pollution process, the calculated momentum and sensible heat fluxes by the Li scheme were better than those by the MM5 scheme generally" was inaccurate. In fact, the surface turbulent flux affects the stability of atmospheric stratification directly, which further influences the air pollution. The little turbulence flux transfer corresponds to stable atmospheric stratification and which may lead to the heavy pollution. In order to make our meaning clearly, we have rewritten this part in Line 377-384, Page 13 in the revised paper.

Thanks for the referee's kind advice. We are online coupling the new scheme into atmosphere chemical models to compare the modeled pollutant concentration with observation directly and the related results will be discussed in next paper.

**Minor comments:**

**Comment 1:** *Line 65-66: Why is the pollution episode important? The author may need to specify and add more discussion instead of arguing "few studies discussed it based on a pollution episode corresponding various atmospheric states".*

**Response:**

Yes, this part was not clearly descripted. We read some new references (list in the following) and add the related content to explain why the pollution episode is important in Line 76-83, Page 3, instead of "few studies discussed it based on a pollution episode corresponding to various atmospheric states".

References:

1. Wang, H., Tan, S. C., Wang, Y., Jiang, C., Shi, G., Zhang, M., and Che, H. Z.: A multisource observation study of the severe prolonged regional haze episode over eastern China in January 2013, Atmos. Environ., 89, 807-815, https://doi.org/10.1016/j.atmosenv.2014.03.004, 2014.

2. Zhang, B., Wang, Y., and Hao, J.: Simulating aerosol-radiationcloud feedbacks on meteorology and air quality over eastern China under severe haze conditionsin winter, Atmos. Chem. Phys., 15, 2387–2404, http://doi.org/10.5194/acp-15-2387-2015, 2015.

3. Li, T., Wang, H., Zhao, T., Xue, M., Wang, Y., Che, H., and Jiang, C.: The Impacts of Different PBL Schemes on the Simulation of PM2.5 during Severe Haze Episodes in the Jing-Jin-Ji Region and Its Surroundings in China, Adu. Meteorol., http://dx.doi.org/10.1155/2016/6295878, 2016a.

4. Liu, T. T., Gong, S. L., He, J. J., Yu, M., Wang, Q. F., Li, H. R., Liu, W., Zhang, J., Li, L., Wang, X. G., Li, S. L., Lu, Y. L., Du, H. T., Wang, Y. Q., Zhou, C. H., Liu, H. L. and Zhao, Q. C.: Attributions of meteorological and emission factors to the 2015 winter severe haze pollution episodes in China's Jing-Jin-Ji area, Atmos. Chem. Phys., 17, 2971–2980, https://doi/org/10.5194/acp-17-2971-2017, 2017.

**Comment 2:** *Line 172-180: The observation and method should be introduced in further details. What is the spatial representativeness of the station? Can it represent the whole east China? If not, should add more cases in other parts of China or considering changing this word. What is the measuring height for the fluxes? (Could refer to Liu et al. 2016 as an example for the introduction)*

**Response:**

This suggestion is very valuable and we revised the manuscript as following according to this

suggestion and the recommended reference.

We have added some introduce about the observation and method in details. Please see Line 183-202, Page 7. The measuring height for the fluxes in Gucheng station is 4 m, which is added in Line 188, Page 7.

Gucheng station is a farmland site where rice is planted in summer and wheat in winter, its surroundings are mainly farmland and scattered villages which represents suburban with smooth surface and it does not represent the whole east China. In fact, our study focuses on "Jing-Jin-Ji" region in east China. We changed "east China" as "Jing-Jin-Ji" in the manuscript; According to the referee's comment, the similar experiment and discussion at Beijing station which represents megacity with rough surface, were added in the revised manuscript (Fig. 9), and the difference of the two schemes in Jing-Jin-Ji region (Fig. 10) was also added in the manuscript.

**Comment 3:** *Line 182-189: The data processing should be explained in further details and add more reference in data processing methods (Line 182-Line 189). For example, how was the quality control conducted? The reference for quality control may be included if they have been applied in the study (e.g., frequency response correction (Moore, 1986) and WPL correction (Webb et al., 1980), or quality control (Foken et al., 2004)).*

**Response:**

Thanks very much for the references recommended by the referee. We have read these references and explained the data processing in more details (Line 196-202, Page 7) and added the relevant reference in Line 197, Page 7.

**Comment 4:** *Please explain why z = 10 m has been used (line 218)?*

**Response:**

"Considering the lowest level in mesoscale models is usually about 10m, $z = 10\mathrm{m}$ is set as the reference height." The revised part can be found in Line 244, Page 9.

**Comment 5:** *What variables have been used in Li and MM5 schemes? In the third part (Observational data and methods), the paper only introduced the data acquired from the Gucheng station, without specifying what variables would be used in the two schemes.*

**Response:**

Both Li and MM5 schemes use same variables acquired from Gucheng and other stations. The variables used in the two schemes were add in the paper "The measured meteorological variables including wind speed and direction, temperature, humidity, pressure, radiation are used to calculate the momentum and sensible heat fluxes both in the Li and MM5 schemes." The new revision can be seen in Line 189-191, Page7.

**Comment 6:** *Straight from 5. Line 247, the authors mentioned: "Given the observational data, a dataset of Z0m (Z0h) then is generated". What variables were used in calculating Z0m and Z0h? This may be clarified in the third part (observational data and methods).*

**Response:**

The specific variables are added including pressure, temperature, humidity, wind speed and direction, flux for momentum and sensible heat at 4m height, surface skin temperature and we moved this part to the Section 3.3 (Determination of roughness length $z_{0m}$ ($z_{0h}$) ) according to the referee's

suggestion. The revised details can be found in Line 214-223，Page 8.

**Comment 7:** *Line 250 to Lint 264: The author may consider comparing their conclusion with analysis from other papers (Chen et al. 2009; Chen et al. 2011). The reference used here is somewhat out of date.*

**Response:**

This part (Section 4.3) mainly compared the Li and MM5 schemes in flux calculation during observation. We have not any references in this section, so we are not sure which reference used here is somewhat out of date. However, we read the two papers and added the two references in our manuscript (Line 282-283, Page 10) for the related content with our study.

**Comment 8:** *In the Fig. 4, the authors showed the effect of the roughness length on flux calculation by choosing different z0m values. Since the z0m and Z0h has already been determined in the crop field, I feel it may not be necessary to discuss the influence of roughness length on the calculation of turbulent flux.*

**Response:**

$z_{0m}$ is mainly determined by land-cover type and canopy height, but $z_{0h}$ is also affected by nature of the atmospheric flow (Brutsaert, 1975), the underlying surface is neither the only one, nor the most important factor for $z_{0h}$. Furthermore, the different treatment of $z_{0m}$ and $z_{0h}$ in different schemes (e.g., Li and MM5) has great impact on flux calculation and this is also the main reason why the Li scheme is superior to MM5 discussed in the manuscript (Figs. 5, 7, and 8). Therefore, it is necessary and important to discuss the effects of $z_{0m}$ and $z_{0h}$ on the calculation of turbulent flux.

Reference:

Brutsaert, W., The roughness length for water vapor, sensible heat, and other scalars, J. Atmos. Sci., 32, 2028 – 2031, 1975.

**Comment 9:** *Line 315-316: In the previous results and discussion, the authors only analyzed the superiority of Li scheme in modeling sensible heat and momentum flux. More analysis is needed discussing the SL flux influence the air pollution process should be illustrated before concluding "the superiority of Li scheme in the air pollution modeling."*

**Response:**

The expression of the paragraph "Therefore, the superiority of the Li scheme in the air pollution process, especially in this stage is of great reference value for improving the forecast of pollutant concentration in the current air quality model. In stage 3, the difference between the two schemes is not obvious" is not clear enough. Offline study of the two schemes in this work could not draw the conclusion "the superiority of Li scheme in the air pollution modeling", but it is expected to better performance in online simulation of $PM_{2.5}$ based on its obvious superiority in the offline study results. So, this paragraph was replaced by "The error of Li is much less than that of MM5. Considering the importance of atmospheric stratification in the generation and accumulation of $PM_{2.5}$ in stage 2, the Li scheme is expected to show better performance in online simulation of $PM_{2.5}$ than MM5." The details can be found in Line 330-332, Page 12 in the revised paper.