Authors' Response to Referees' Comments

Anonymous Reviewer #1

This paper investigates the role of different weather conditions in modulating summertime boundary layer and further surface pollution in Beijing. A novel technique is applied to classify summertime circulation patterns into seven major weather types. More importantly, the authors thoroughly investigated the mechanism how different synoptic conditions impact on the variability of boundary layer height and structure, which is the major factor governing the vertical transport of pollutants and thus surface pollution level. The paper is also well presented and logically organized. I think this paper addresses an important issue and makes great contribution to our understanding of summer haze in Beijing. I thus recommend the paper be accepted for publication in ACP only with several minor comments.

First of all, we appreciate tremendously the reviewer's positive comments. In response to the reviewer's comments, we have made relevant revisions to the manuscript. Listed below are our responses and the corresponding changes made to the manuscript according to suggestions given by the reviewer. Each comment of the reviewer (in black) is listed, followed by our responses (in blue).

Specific comments:

1. The introduction seems too long (4 pages). I think it could be shortened with an emphasize on the relationship between summer time boundary layer height and pollution in Beijing, and the novel method and data used in this study.

Per your suggestion, the description was deleted with regard to the relationship between summer time boundary layer height and pollution in Beijing. Besides, several important literatures were added to the introduction as suggested by reviewer #2 to give a more comprehensive overview of current research and highlight the importance of this study as well.

2. Section 2.3: While the T-mode PCA is conventionally used in classification, the oblique rotation may not be familiar to the major audience. It's better to elaborate here with some mathematical explanation of this technique.

Per your suggestion, the following mathematical explanation with regard to T-mode PCA were added in the revised manuscript:

"To speed up the calculation of PCA, the data is split into ten subsets; and then, the principle components (PCs) obtained from each subset are projected on the rest data. The T-PCA classification based on cost733 software package includes the following steps:

(1) The data is standardized spatially. Each pattern's mean is subtracted from the data, and then the patterns are divided by their standard deviations.

(2) The data is split into ten subsets through selecting the data once every ten days. For example, the first subset consists of the 1st, 11th, 21st, 31st, etc. days, and the second subset consists of the 2nd, 12th, 22nd, 32nd, etc. days.

(3) The PCs are calculated using the singular value decomposition for each subset. And the PCs of each subset are ordered according to the magnitude of their explained variances.

(4) An oblique rotation (using direct oblimin) is applied on the PCs, employing an adaptation of the Gradient Projection Algorithm of Bernaards and Jennrich (2005). The main reason for using rotation is to facilitate the interpretation (Abdi and Williams, 2010). This transformation does not constrain the orthogonality, allowing for the PCs the freedom to better reflect the original data (Richman, 1981).

(5) The PC scores of each subset are projected onto the remaining data by solving the matrix equation: $\Phi A^T = F^T Z$, where F and Φ are matrices of PC scores and PC correlations, respectively, and Z is the full data matrix, and A are pseudo-loadings to be determined. Each day is classified with the PC (type) for which it has the highest loading.

(6) Contingency tables are finally used to compare the ten classifications, and the classification most consistent with the other nine classifications is selected as the

resultant one."

3. Section 3.2: The authors identified seven dominant weather types. I wonder how is the order (No. 1-7) of these seven types determined. In traditional PCA, the modes are usually ordered by the amount of variance explained**.** Here it does not seem to be the case as their frequencies of occurrence are not ordered from high to low? Perhaps some explanation would help?

Actually, the seven synoptic types (#1-7) were also determined by the amount of variance explained, which were 0.192415, 0.112347, 0.106, 0.092, 0.085, 0.079, and 0.077, respectively. To better understand the T-PCA, the detailed classification procedures were added on Page 9-10 in our revised manuscript (see our response to comment #2).

4. Also in this section, as types 1, 4 and 5 are associated with heavy pollution, I wonder if a composite analysis of these three types and the other four types would help better distinguish between their different characteristics in meteorological variables (RH, BLH, CLD, etc) and $PM_{2.5}$ concentration?

In the revised manuscript, we compared the meteorological variables and aerosol concentration of polluted synoptic types (1, 4, and 5) with that of other types (2, 3, 6, and 7), which were detailed in the newly added Table S2 in Supplementary Materials. It is noteworthy that the heavy aerosol pollution of Types 1, 4, and 5 are associated with the relatively low BLH, high RH2, high CLD, and high frequency of southerly PBL winds.

The relevant discussion was added on Page 13 in the revised manuscript.

Table S2. *Statistics of the correlation between PM2.5 concentrations and meteorological variables corresponding to the polluted synoptic types (1, 4, and 5) and other synoptic types. The meteorological variables (mean values ± one standard deviation) include 2-m temperature (T2), 2-m relative humidity (RH2), wind speed at the 925-hPa level (WS), southerly wind frequencies at the 925h-hPa level (WD), total cloud cover at 1400 BJT (CLD), and the BLH at 1400 BJT. The correlation coefficients (R) between the meteorological variable and PM2.5 concentration are also given, which are calculated based on the seven pairs of mean values for each* *synoptic pattern.*

#	Polluted types (1, 4, and 5)	Other types (2, 3, 6, and 7)	R (#, $PM_{2.5}$)
$PM_{2.5}$ (μg m^{-3})	*99.7 ± 51.9*	*56.8 ± 40.2*	*/*
BLH (km)	*1.17 ± 0.59*	*1.63 ± 0.69*	*-0.97**
RH2 (%)	*68.1 ± 14.3*	*59.4 ± 14.1*	*0.85**
CLD (%)	*92 ± 22*	*74 ± 36*	*0.84**
925-hPa WD (South) (%)	*61 ± 6*	*49 ± 7*	*0.78**
T2 (K)	*299.5 ± 2.5*	*299.8 ± 2.7*	*-0.33*
925-hPa WS (m s^{-1})	*5.1 ± 3.1*	*4.9 ± 3.3*	*-0.02*

5. Previously, there are also studies on the relationship between synoptic (circulation) patterns and pollution over the Beijing area, such as those cited by the authors in the introduction section. I wonder how the current study compared with these previous results. Some discussions in a general context would help.

The following discussions were added on Page 13:

"The relationship between synoptic patterns/circulations and pollution in Beijing unraveled in this study is similar to that of previous studies of Zhang et al. (2012) and Ye et al. (2016). When high pressure located to the east/southeast of Beijing, the resultant southerly PBL winds would bring the pollutants emitted from the southern Hebei to Beijing."

6. Figure 9 caption: “seasonally” should be “summer” because only summer data is analyzed here.

Amended as suggested.

Typos:

Page 2, line 23: in the further suppression

Page 3, line 25: the past decades

Page 4, line 5: On local scale, or “On regional scale”

Page 4, line 15: impacts on

Page5, line 25: which subjectively defines a priori … and in which the case assignment

Page 9, line 2: ...PCA which is in the S-mode …

Page 11, line 12: the lifting condensational level can drop …

Page 12, line 3: understanding the effects of …

Page 12, line 7: As illustrated in Fig. 8, …

Page 12, line 18: well captured

Page 12, line 2d: over the ENTIRE study region

Page 12, line 26: impose a negative thermal anomaly ON the PBL there

Page 13, line 5: leading to THE suppression of …

All the typos have been revised as suggested.

References:

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Bernaards, C. A. and Jennrich, R. I.: Gradient projection algorithms and software for arbitrary rotation criteria in factor analysis, Educ. Psychol. Meas., 65(5), 676–696, doi:10.1177/0013164404272507, 2005.

Richman, M. B.: Obliquely rotated principal components: An improved meteorological map typing technique?, J. Appl. Meteorol., 20(10), 1145–1159, doi:10.1175/1520-0450(1981)020<1145:ORPCAI>2.0.CO;2, 1981.

Ye, X., Song, Y., Cai, X., and Zhang, H.: Study on the synoptic flow patterns and boundary layer process of the severe haze events over the North China Plain in January 2013, Atmos. Environ., 124(January 2013), 129–145, doi:10.1016/j.atmosenv.2015.06.011, 2016.

Zhang, J. P., Zhu, T., Zhang, Q. H., Li, C. C., Shu, H. L., Ying, Y., Dai, Z. P., Wang, X., Liu, X. Y., Liang, A. M., Shen, H. X., and Yi, B. Q.: The impact of circulation patterns on regional transport pathways and air quality over Beijing and its surroundings, Atmos. Chem. Phys., 12(11), 5031–5053, doi:10.5194/acp-12-5031-2012, 2012.