Review 1

Comment: This study was aimed to explore the possible contribution of atmospheric circulation anomaly on the interannual variation of winter PM2.5 over northern China. Six dominate synoptic circulation types that favorable and unfavorable for the PM2.5 diffusion are revealed, which is interesting and quite important for us. Furthermore, the authors revealed that there is approximately 76.5% of the observed decrease in PM2.5 concentrations in 2017 over BTH could be attributed to the improvement of the atmospheric diffusion conditions. This paper is well written and organized, and there is no big flaw. I recommend it to be published in ACP after several minor corrections.

Response: Thank you very much for the through and helpful comments and suggestions. Please find the following point-point response.

General comments:

Comment 1: In this study, the authors have explored that there is approximately 76.5% of the observed decrease in PM2.5 could be attributed to the improvement of the atmospheric diffusion conditions. That is, the contribution of effect of atmospheric anomaly exceeded 70%, which presented far larger than that from the early studies and also confused me. As description in Introduction, the effect of atmospheric anomaly was just accounting for about 5% or 12%. Is there any idea about this large difference? Moreover, the additional discussion about the uncertainty of the evaluated contribution should be added. Is it related to the large bias of the WRF-CHEM model?

Response 1: Chinese government issued the Clean Air Action in 2013 to mitigate PM2.5 pollution. Most of the existing researches we involved in Introduction are focused on the evaluation of Clean Air Action from 2013 to 2017 or 2018. During the five to six years, the average contribution of meteorological conditions to the air quality improvement is assessed as 5% or 12% depends on different methods and domains. The primary concern of our paper is to investigate the effects of meteorological elements on the interannual variation of air quality, the magnitude of which may be larger than the multiyear averaged value. Moreover, based on the occurrence of different circulation types in Fig. 9, 2016 and 2017 winters are the most unfavorable and the most favorable diffusion conditions during the study period, respectively, which may be the reason for the significant and high contribution of meteorological factor in our result. In addition, the observed PM2.5 variation average between 2016 and 2017 was calculated based on the PM2.5 observations at 114 stations, while, the simulated PM2.5 differences are derived from the grid results over the region of 113º-117.5ºE and 36º-42ºN in our original version. However, both observed and simulated PM2.5 different between 2016 and 2017 show obvious spatial distribution in Fig. 10. To exclude the effects of spatial distribution, the simulated grid results are interpolated to PM2.5 observation stations in the revised version. The simulated PM2.5 difference between 2016 and 2017 reduced from the original 28.4% to current 22.6%, and the relative contribution rate of meteorological elements is 60% from 2016 to 2017 winter. That is to say, 40% of the 37.7% (i.e., 15%) reduction in PM2.5 concentration can be attributed to the emission reduction between the two consecutive years. It is generally known that one of the goals of Clean Air Action is to decrease PM2.5 concentrations by 25% in Jing-Jin-Ji regions from 2013 to 2017. Based on our simulation, the 15% reduction of emission from 2016 to 2017 accounts for large part of the overall target of 2013 to 2017, which verified the robust of the relative 60% contribution of meteorological elements during the selected two consecutive years.

Some discussions about the uncertainty of WRF-Chem simulation are added in Lines 431-439: *The quantitative evaluation of meteorological elements contribution to the interannual variation of PM2.5 concentrations between winters of 2016 and 2017 is derived from the WRF-Chem simulation in this study. Although the model performance for PM2.5 is generally satisfactory in Fig. S7, it shows obvious underestimation in the severe haze days. Reasons for these biases might be the overestimation in surface wind speed, uncertainties of emission inventory and insufficient treatments of some new chemistry mechanisms of particle formation, which need be further discussed in the future. In addition, some emission modules are turned off to reduce the computation cost, i.e., dust, sea salt, dimethyl sulphide, biomass burning and wildfires, which would result in the uncertainty of simulated PM2.5 mass concentrations.*

Comment 2: The winter season should be highlighted in the abstract.

Response 2: We clarify the wintertime as the study period in the abstract and introduction sections.

Comment 3: More detailed introduction about the rotated T-mode PCA method was suggested.

Response 3: More detailed information about T-mode PCA is involved to further improve the method of atmospheric circulation classification in Lines 133-138 and Lines 149-152.

Lines 133-138: *In this model, the input data matrix is space-time two-dimensional: the rows represent spatial grids, and the columns is time series. The data are divided into ten subsets to speed up computations, and the principal components (PCs) are achieved using the singular value decomposition for each subset and an oblique rotation is applied to the PCs to achieve better classification effects. Then, chi-square test is used to evaluate the ten classifications based on the subsets and the subset with the highest sum is chosen and assigned to a type.*

Lines 149-152: *Prior to using Cost733, the number of principal components need to be defined manually. To exclude the influences of various number of principal components, sensitivity tests with principal components from 2 to 10 are conducted in this study, the explained variances of which are shown in Fig. S1.*

Comment 4: The synoptic types of CT1 and CT2 is favorable for the air pollution divergence, while CT3-CT6 is unfavorable. CT3-CT6 can account for 56% of the weather types. How about it from the WRF-CHEM model?

Response 4: The occurrence of CT3-CT6 is 56% throughout the study period, which may be different in the specific year. The circulation classification can be considered as a semiquantitative method to evaluate the capacity of air pollution diffusion, but the explained variances of classifications is 70% as show in Fig. S1, which indicates some uncertainty of the method. To give a quantitative assessment of meteorological elements contribution to the air quality improvement, distribution of air pollutants and meteorological condition in winters of 2016 and 2017 are simulated in our work. We evaluated the performance of simulated meteorological fields based on the station observed daily mean wind speed, temperature, pressure and relative humidity in Fig. S6, which is more quantitative than the occurrence frequency of circulation classifications.

Comment 5: How about the atmospheric circulation patterns in year 2016? The PM2.5 in this year was recovered and higher than the other years. How large contribution of the atmospheric circulation effect in your mind? Or the high PM2.5 is mainly sourced from the emission.

Response 5: The atmospheric circulation pattern in 2016 winter (Dec. 2016 to Feb. 2017) is almost the most unfavorable for the air pollutants diffusion based on our circulation classification, with the most frequent occurrence of unfavorable circulation types and second lowest frequency of favorable circulation types. The unfavorable circulation pattern in 2016 winter is partly responsible for its obvious rebound in PM2.5 concentration. In contrast, atmospheric condition in 2017 winter has the most frequent favorable and relative infrequent unfavorable circulation types, which is benefit for the significant decrease in PM2.5 concentration from 2016 to 2017. Except for 2016, the annual mean air pollutants concentrations have begun steadily reducing since 2013, which indicates the effects of emission reduction. Admittedly, it would go a long way toward dealing with the overall treatment of the air pollution, and the current occurrences of air pollution episodes are strongly depended on the meteorological background.