Response to Comments of Reviewer #1

Manuscript number: acp-2019-263

Authors: Cheng Gong and Hong Liao

Title: A typical weather pattern for the ozone pollution events in North China

General comments:

This study examined the possible mechanisms for the ozone pollution events (OPEs) in North China during 2014-2017 using GEOS-Chem model together with an integrated process rate (IPR) analysis. They found that OPEs in North China occurred under a typical weather pattern with high daily maximum temperature, low relative humidity, anomalous southerlies and an anomalous downward air flow caused by an anomalous high-pressure system at 500 hPa. The topic is of interest, the method is sound. I would suggest for publication after addressing my comments below.

Response:

Thanks to the reviewer for the helpful comments and suggestions. We have revised the manuscript carefully and the point-to-point responses are listed below.

Specific Comments:

Page 2 Lines 11 -13: Please reframe this sentence

Response:

We have reframed this sentence as:

'Zhang et al. (2015) showed that values of RH for days with top 10% O_3 concentrations were lower compared to those for days with bottom 10% O_3 concentrations by examining continuous observations of O_3 and meteorological parameters in Guangzhou during March 2013 to February 2014.'

Page 4 Lines 14-15: I don't think the original resolution of MERRA2 data is the same as GEOS-Chem model. The meteorological data authors used are modified to fit the model resolution.

Response:

We have revised the sentence to clarify: 'The original MERRA2 data has a horizontal resolution of 0.5° latitude x 0.625° longitude and 72 vertical layers (Molod et al., 2015). The GEOS-Chem model has the same horizontal resolution over the nested domain but the GEOS-Chem support team has lumped the 72 vertical layers into 47 layers to save computational resources. The lumped vertical levels are within the 32th model layer (about 190 hPa) and the top of atmosphere (about 0.01 hPa).'

Page 4 Lines 23-24: How did the authors detrend the meteorological parameters to *remove interannual or seasonal variability? Please specify the method or provide formula they used.*

Response:

Following the reviewer's comments, we have compared our analyses with and without detrending and found small impact on our results because of the relatively short time period (only 4 years over 2014-2017). To avoid confusion, we have removed the detrending process and updated the table and figures in the revised manuscript. The description here has been revised as follows:

'The daily time series of a meteorological parameter x at a specific model grid cell over May to July of 2014-2017 is standardized by:

$$[x_i] = \frac{x_i - \frac{\sum_i^n x_i}{n}}{s_i} \quad (1)$$

where x_i indicates the parameter x on day i, n is the total number of days over May to July in 2014-2017, s_i indicates the standard deviation of the daily time series. $[x_i]$ is the standardized anomaly for parameter x on day i.'

Page 5 Line 7: The annual emission from 2014 to 2017 are applied in the simulation, but the authors did not rule out the impacts of changing emissions on the OPEs selection and IPR analysis, although the changes in emissions in the four years are not likely to be very large.

Response:

We use emissions from 2014 to 2017 in the model to obtain OPEs with realistic changes in emissions. Following your suggestion, we have carried out a new simulation by fixing anthropogenic emissions at year 2014 levels. Twelve of the 17 observed OPEs with I_OPE >0 can be identified by applying the same threshold (136.6 μg m^{-3}) in the model (Figure R1). Compared with the simulation with year-by-year changes in emissions from 2014 to 2017, three OPEs (one in June of 2015, one in July of 2016, and one in May of 2017) are missed in the run with fixed emissions. The results from IPR analysis with fixed emissions are similar to those with changes in emissions except that the simulation with fixed emissions has lower changes in O_3 mass by net chemical production due to the changes in NO_x/VOCs ratio (Li et al., 2019). As a result, the changes in emissions have little impacts on the OPEs selection and IPR analysis (Figures R1 and R2 and Table R1).

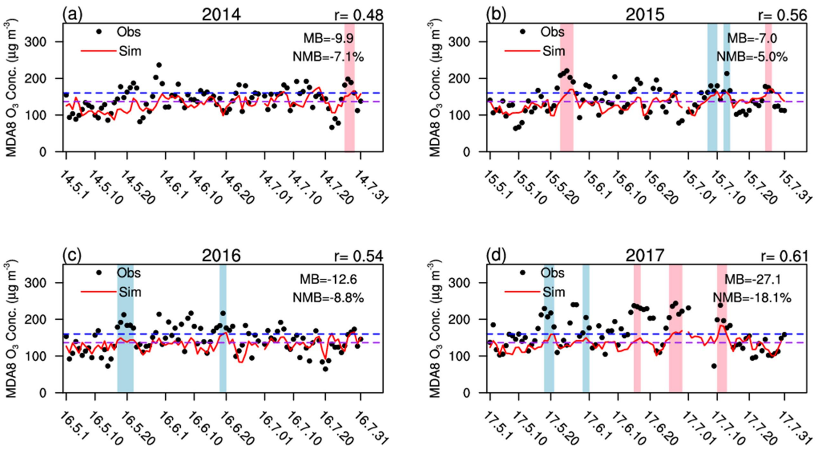

Figure R1. The same as Figure 7 in the revised manuscript but with fixed emissions at 2014 levels.

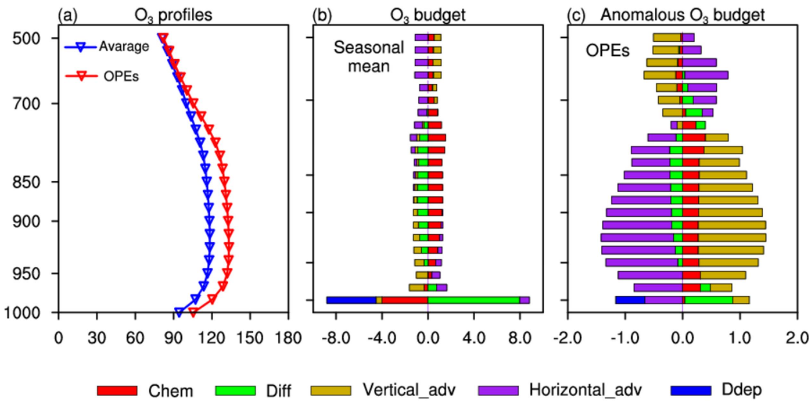

Figure R2. The same as Figure 8 in the revised manuscript but with fixed emissions at 2014 levels

Table R1. The same as Table 1 in the revised manuscript but with fixed emissions at 2014 levels.

	Average [a]		OPEs [b]		OPEs-Average [c]
	NC	PC	NC	PC	MF
	(Gg O_3 day^{-1})	(%)	(Gg O_3 day^{-1})	(%)	(Gg O_3 day^{-1})
Net Chemical production	4.6	21.8	7.5	28.8	+2.9
Diffusion	2.4	11.4	2.1	8.1	-0.3
Dry deposition	-4.3	-20.4	-4.8	-18.5	-0.5
Horizontal advection	3.5	16.6	-8.0	-30.8	-11.5
Vertical advection	-6.3	-29.8	3.6	13.8	+9.9

Figures: All the figures and analysis are lack of significance test. Please add in.

Response:

We have added the significance test with 95 % confidence in Figures 4, 5, 9 and S2 in the revised manuscript and supplementary material.

Page 7 Line 9: I on day 'd'.

Response:

The 'd' has been added.

Page 8 Line 9: It should be 850 hPa 'meridional winds' and 500 hPa 'zonal' winds.

Response:

Corrected.

Page 11 Line 9: Before analyzing vertical profiles of each process, the authors should give vertical profile of O3 concentrations in terms of seasonal mean and anomalies during OPEs.

Response:

Following the reviewer's suggestion, we have added a new panel in Fig. 8 (Fig. 8a) in the revised manuscript to show the vertical profiles of O_3 concentrations in terms of seasonal mean and anomalies during OPEs. We have also added the following sentences to describe these vertical profiles of O_3 in the text:

'The vertical profile of simulated daily O_3 concentrations averaged over May to July in 2014-2017 as well as that composited over the 15 OPEs are shown in Fig. 8a. For both profiles, the O_3 concentrations are highest between 950 hPa and 850 hPa and are relatively lower at the surface due to the titration by high NO_x concentrations. When OPEs occur, O_3 concentrations are higher from the surface to 700 hPa (about 3 km altitude) but change little above 700 hPa, indicating that the enhancement of O_3 concentrations during OPEs occurs not only at the surface but also in and above the boundary layer.'

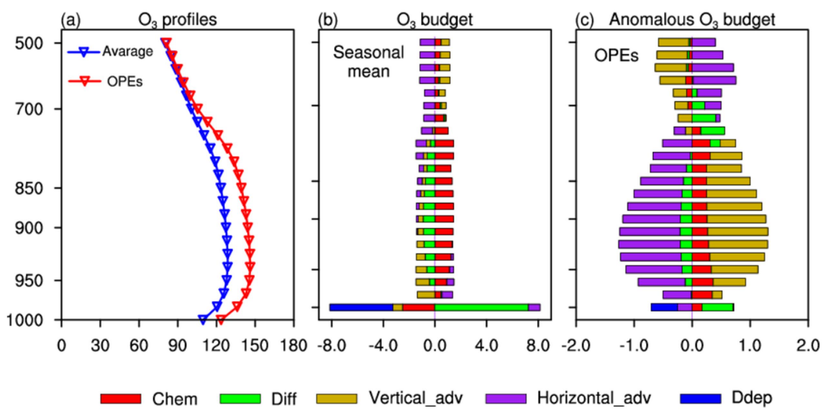

Figure 8. (a) Vertical profile of simulated daily O_3 concentrations (μg m^{-3}) averaged over May to July in 2014-2017 (blue line and triangle) as well as that composited over the 15 simulated OPEs with I_OPE>0 (red line and triangle) in North China. (b) Vertical profile of O_3 mass flux (Gg O_3 day^{-1}) over North China for each process that is averaged over all days in May-July of 2014-2017. (c) Anomalous vertical profile of each process during the 15 OPEs relative to the mean value of May-July of 2014-2017. The vertical axis is the same for all the panels with a unit of hPa.

Page 11 Line 24: 'horizontal advection' is the compensating from the increasing ozone from the figure. I don't think it should be listed as the dominant processes that lead to OPEs, although the negative value is large.

Response:

'horizontal advection' has been removed.

References:

Li, K., Jacob, D. J., Liao, H., Shen, L., Zhang, Q., and Bates, K. H.: Anthropogenic drivers of 2013-2017 trends in summer surface ozone in China, Proceedings of the National Academy of Sciences of the United States of America, 116, 422-427, 10.1073/pnas.1812168116, 2019.

Molod, A., Takacs, L., Suarez, M., and Bacmeister, J.: Development of the GEOS-5 atmospheric general circulation model: evolution from MERRA to MERRA2, Geoscientific Model Development, 8, 1339-1356, 10.5194/gmd-8-1339-2015, 2015.