Response to Reviewer #1

Summary: This paper uses a combination of observation and reanalysis data to investigate the possible impact of large-scale meteorological conditions on surface air quality -- specifically ozone -- in eastern China. Empirical Orthogonal Function (EOF) analysis of summertime daytime meteorology identified two EOF patterns which explained over a third of the variance for the 2015-2018 period. The major drivers for high ozone in Eastern China were the location of the East Asia deep trough and the West Pacific Subtropical High, modulating favorable or unfavorable conditions for the formation of ground-level ozone.

1. I am not convinced that this study was ready for submission to ACP or exceptionally novel. This work looked to be a continuation of the research published by Zhao and Wang (2017) (referenced on Line 51-53) who identified the link between the WPSH and high ozone in eastern China using observations from 2014-2016, with a focus on 2014.

Reply:

Here, we explained the novelty of this study, particularly the differences with Zhao and Wang (2017), in the following **four points**. Also, we emphasized this novelty in the revised version.

(1) We revealed two dominant patterns, their varying sorts in different years and their associated anomalous atmospheric circulations. Although the north-south differential pattern was the first mode in 2014 (Zhao and Wang 2017), 2015 and 2016, it was sorted in the second place in 2017 and 2018 (Figure S5 in the revised manuscript). That is, our study not only revealed the two dominant patterns, what is more important, also **showed the varying features of the dominant patterns.** In the recent two years, the most dominant pattern was different from that in previous years, which is **a new feature and might related to the climate status**. Additionally, the comprehensive atmospheric circulations were analyzed, including the **location** of west Pacific subtropical high (WPSH), the East Asia deep trough and other atmospheric anomalies. In Wang and Zhao (2017), they solely focused on the impacts of the WPSH, particularly on the **accumulative enhancement** of WPSH.

(2) We clearly explained the anomalous atmospheric circulations related the O_3 pollution **both in North China and in South China**. However, in Wang and Zhao (2017), the **physical mechanisms to impact O_3 in North China was still not sufficiently explained** (referring to the weak correlation coefficients in the ***green***

boxes in Figure R1 d–f). We speculated the reason for insufficient explanations on O_3 conditions in North China might be that the impacts form the mid-high latitudes were significant which was not involved in Zhao and Wang (2017). In our study, we found **both of the WPSH and the East Asia deep trough** had impacts on the O_3 concentrations in the east of China (Table 1). Furthermore, we **paid more attentions to the O_3 concentrations in North China** where the surface O_3 polluted levels were much higher than in the Yangtze River Delta and Pearl River Delta. The **WPSH and East Asia deep trough jointly modulated** the local meteorological conditions to influence the O_3 concentrations.

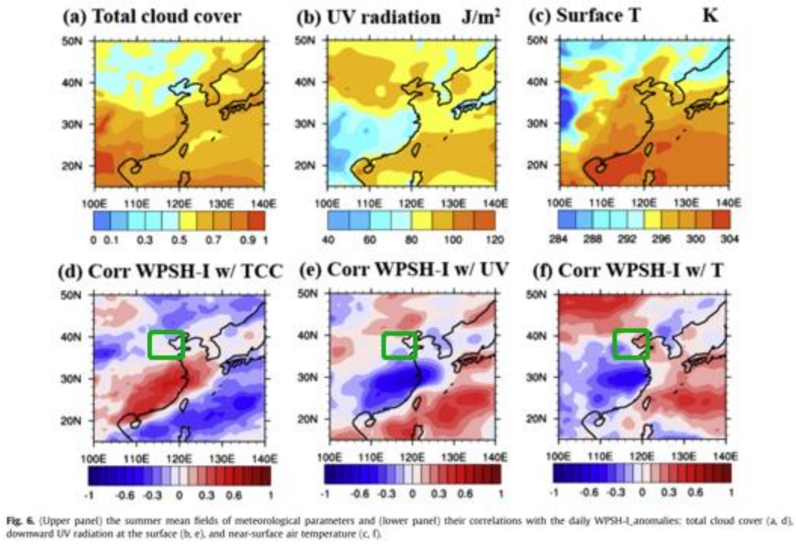

Figure R1. The Figure 6 in Zhao and Wang (2017). The summer mean fields of meteorological parameters (a–c) and their correlations with daily WPSH: total cloud cover (a, d), UV radiation (b, e) and near surface air temperature (c, f). The added green boxes indicate the location of North China.

Table 1. Correlation coefficients between the time series of PAT1 (PAT2) and the key indices of atmospheric circulations and meteorological conditions. "**" and "*" indicate that the correlation coefficients were above the 99% and 95% confidence level, respectively.

PAT1	**$MDA8_1$**	**EAT_1**	**$WPSH_1$**
	0.97^{**}	0.28^{**}	0.39^{**}
PAT2	**$MDA8_2$**	**EAT_2**	**$WPSH_2$**
	0.77^{**}	0.30^{**}	0.32^{**}

$MDA8_1$ is the NCH-area averaged MDA8, while the $MDA8_2$ is the MDA8 difference between NC and YRD. EAT_1 and EAT_2 indicate the intensity of the East Asia deep trough and were calculated as the mean –Z850, shown in the black boxes in Figure 7 and Figure 9, respectively. $WPSH_1$ ($Z500_{(125^0E,\ 20^0N)} - Z500_{(125^0E,\ 30^0N)}$) and $WPSH_2$ ($Z500_{(110^0E,\ 20^0N)} - Z500_{(110^0E,\ 30^0N)}$) represents the location of WPSH.

(3) The number and distribution of the sites are more sufficient and updated. In the EOF analysis of Zhao and Wang (2017), the number of O_3 sties was **only 191** in 2014 even in a larger study region than ours (Figure R2). The number (fewer than 200) and distributions (uneven) of the sites were limited, due to the establishment progress of the observation sites of atmospheric components in 2014.

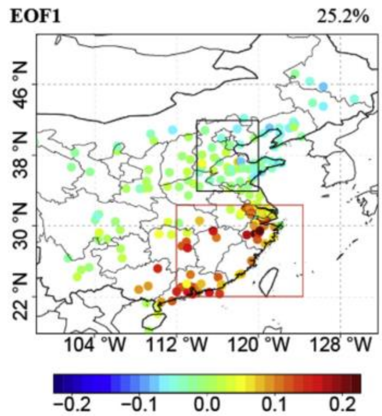

Fig. 3. The EOF1 of daily summer MDA8 ozone in 2014. The black rectangle outlines North China (NC); the red rectangle outlines South China (SC).

Figure R2. The Figure 3 in Zhao and Wang (2017), i.e., the EOF1 results in 2014 (also the sites distribution)

Since the severe air pollution events in 2013, the air pollution issues gained more attentions from the Chinese government and society, which aided to start the extensive constructions of operational monitoring stations of atmospheric components and resulted in continuous increasing number of sites (Figure S1). **The number of sites in eastern China (110ºE–125ºE, 22ºN–42ºN) was 677, 937, 937, 995 and 1007 from 2014 to 2018.** It is obvious that the data in 2014 were deficient, while the observations were broadly distributed in eastern China and continuously achieved since 2015. Thus, the summer O_3 data from 2015 to 2018 were processed (e.g., unifying the sites and eliminating the missing value) and ***868 sites in eastern China were employed here*** to reveal some new features of surface ozone pollutions and associated anomalous atmospheric circulations.

Although the number of sites in 2014 in our denser data source were nearly 4 times that in Zhao and Wang (2017), **the data in the green box in Figure S1 were almost a blank.** That is why our study period was 2015–2018. To make this point clear, we **added Figure S1**. From 2015 to 2018, the selected 868 sties relatively even. Certainly, the sites were almost located around the urban area, due to their observed purposes (related to air pollutions).

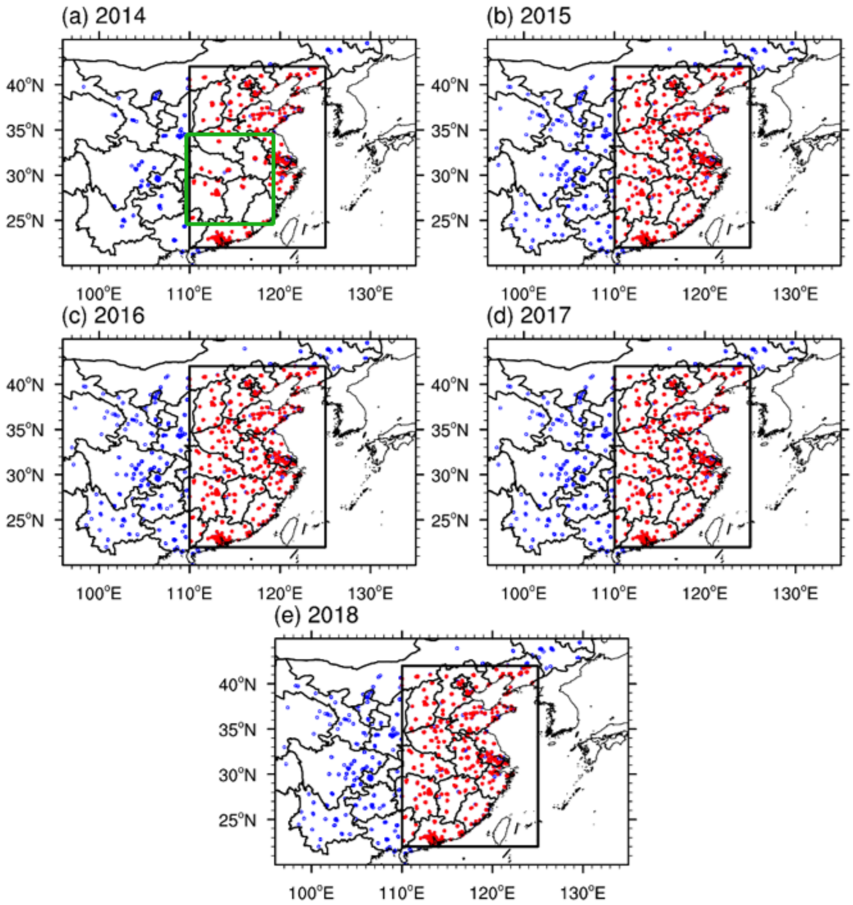

Figure S1. The distribution of measurement sites of atmospheric components (blue and red points) from 2014 to 2018. The red sites indicate the employed sites in this study related to O_3 pollution.

(4) In our study, we also discuss the **implications to interannual variability** in Sect 5, and pointed out that the **composites results from the daily data also provided useful signals for the interannual variability on the climate time-scale**. For example, the anomalous atmospheric patterns in 2016 were benefit for the occurrence of the north-south differential pattern of summer mean O_3 concentrations. Differently, the atmospheric circulations in 2018 resulted in positive O_3 anomalies in the whole eastern China.

The aforementioned four points, especially (1) (2) and (4), were **novel and we did not see similar researches so far**. Actually, there were some publications about the relationship meteorological elements (e.g., temperature, precipitation, etc.) and O_3

concentrations in single city, which provide basis for our study. **These kind of studies did not included the analysis of atmospheric circulations, the diagnosis of dominant patterns and their varying features, and the signals for interannual variability**. As for the results in Zhao and Wang (2017), we clearly and convincingly discussed the differences between their and our studies. Furthermore, in the Sect. 1 (Introduction), we referred a review article published in 2017 and point out "**Wang et al. (2017) reviewed the meteorological influences on ozone events, but the referenced findings were published mainly before 2010,** when measurements in China were still scarce."

Related references:

Wang, T., Xue, L. K., Brimblecombe, P., Lam, Y. F., Li, L., Zhang, L.: Ozone pollution in China: A review of concentrations, meteorological influences, chemical precursors, and effects, Science of The Total Environment, 575, 1582-1596, doi:10.1016/j.scitotenv.2016.10.081, 2017.

Zhao, Z. J., Wang, Y. X.: Influence of the west pacific subtropical high on surface ozone daily variability in summertime over eastern china, Atmospheric Environment, 170, 197–204, https://doi.org/10.1016/j.atmosenv.2017.09.024, 2017.

Revision:

In the last paragraph of Introduction:

……Basing on a case study in 2014, further studies showed that a strong west Pacific subtropical high (WPSH) was unfavourable for the formation of O_3 in South China (Zhao and Wang, 2017), **however the physical mechanisms to impact O_3 in North China was still not sufficiently explained**.

Wang et al. (2017) reviewed the meteorological influences on ozone events, but the referenced findings were published mainly before 2010, when measurements in China were still scarce. Since 2015, O_3 measurements in eastern China were steadily and widely implemented, but the O_3-weather studies mainly focused on **meteorological elements** (e.g. temperature, precipitation etc.) and **several synoptic processes** (Xu et al., 2017; Xiao et al., 2018; Pu et al., 2013). The dominant patterns of daily ozone in summer in east of China are still unclear. **Actually, in our study, we found the most dominant pattern was different with that in Zhao and Wang (2017) and the dominant patterns also showed interannual variations.** The findings of this study basically help to understand the varying features of surface ozone pollution in eastern China, their relationships with large-scale atmospheric circulations and the implications for the climate variability.……

In the Datasets and methods:

……Nationwide hourly O_3 concentration data since May 2014 are publicly available on http://beijingair.sinaapp.com/. Since the severe air pollution events in 2013, the air pollution issues gained more attentions from the Chinese government and society, which aided to start the extensive constructions of operational monitoring stations of atmospheric components and resulted in continuous increasing number of sites (Figure S1). The number of sites in eastern China (110°E–125°E, 22°N–42°N) was 677, 937, 937, 995 and 1007 from 2014 to 2018. It is obvious that the data in 2014 were deficient, while the observations were broadly distributed in eastern China and continuously achieved since 2015. Thus, the summer O_3 data from 2015 to 2018 were processed (e.g., unifying the sites and eliminating the missing value) and 868 sites in eastern China were employed here to reveal some new features of surface ozone pollutions and associated anomalous atmospheric circulations……

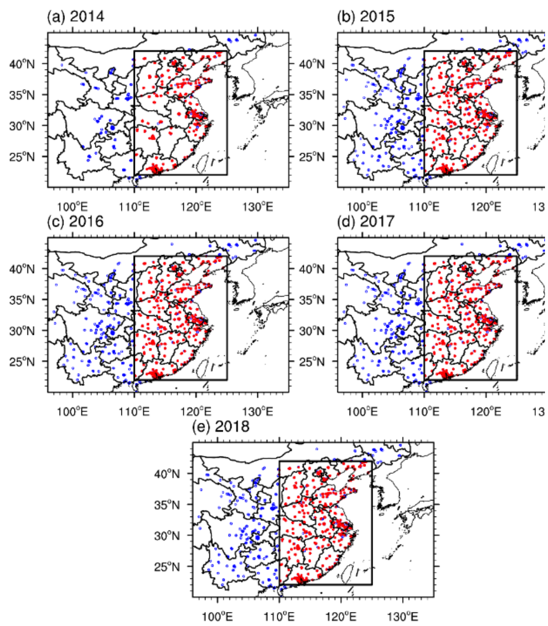

Figure S1. The distribution of measurement sites of atmospheric components (blue and red points) from 2014 to 2018. The red sites indicate the employed sites in this study related to O_3 pollution.

2. The flow of this ACPD paper was at times a real struggle to read, with incorrect figure references, figures included which were never referenced, and statements about meteorology which were either wrong or difficult to interpret from the figures.

Reply:

(1) Many apologies for the confusing writing. In the revised version, we almost rewrite the texts and decrease the number of Figures from 14 to 11. Some necessary information, e.g., the distribution of sites and cities, were added in the supplementary. An important Figure S2 was moved to the main texts as Figure 8.

(2) Most of the Figures were replotted to show the information in a clearer way.

(3) The incorrect figure references and statements were revised throughout the manuscript. The English were improved by the native English-speaker.

3. If there have been only a few years of ozone surface data to perform studies, I imagine there is not enough data to ascertain long-standing relationships (Line 57-59). The authors need to strengthen the paper to sell this idea to their readers.

I recommend the manuscript undergoes major revisions.

Reply:

The results of this study were robust, which were explained below. Some revisions were done to avoid confusions.

(1) The main parts of this manuscript, i.e., Section 3 & 4, based on the **daily data** to analyze the observed features and composite associated atmospheric circulations. The length of the daily data were **<u>368</u>** (92*4), which was enough to ascertain daily relationships.

(2) In section 5, we pointed out that the composites results from the daily data provided useful signals for the interannual variability on the climate time-scale. Here, what we wanted to show are the implications for interannual variations of O_3 and its dominant patterns. Thus, the results were not only significantly meaningful on the daily time-scale, but also were credibly extended to the interannual time-scale.

Revision in the last paragraph of Introduction:

……The dominant patterns of **daily ozone in summer** in east of China are still unclear. Actually, in our study, we found the most dominant pattern was different with that in Zhao and Wang (2017) and the dominant patterns also showed interannual variations. The findings of this study basically help to understand the **varying** features of **daily** surface ozone pollution in eastern China, their relationships with large-scale atmospheric circulations and the implications for the climate variability.……

Major Comments:

1. The authors should discuss the air quality thresholds of MDA8 O_3 either in the Introduction or prior to listing all the values in Section 3 (Line 80-83). It is not mentioned until lines 87-88, and 90.

Reply:

According to the reviewer's advice, the air quality thresholds of MDA8 were discussed earlier when introducing the definition of MDA8.

Because the maximum MDA8 in Figure 1b was actually a daily value and could be compared to the air quality thresholds of MDA8. Thus, the color bar of Figure 1b was redivided according to the thresholds.

Revision in the first paragraph of Section 2:

……MDA8 is generally used to represent the daily O_3 conditions. The MDA8 $\in$ [0, 100], (100, 160], (160, 215], (215, 265], (265, 800] μg/m³ corresponds to "Excellent", "Good", "Lightly polluted", "Moderately polluted", "Heavily polluted" levels of air quality in China…….

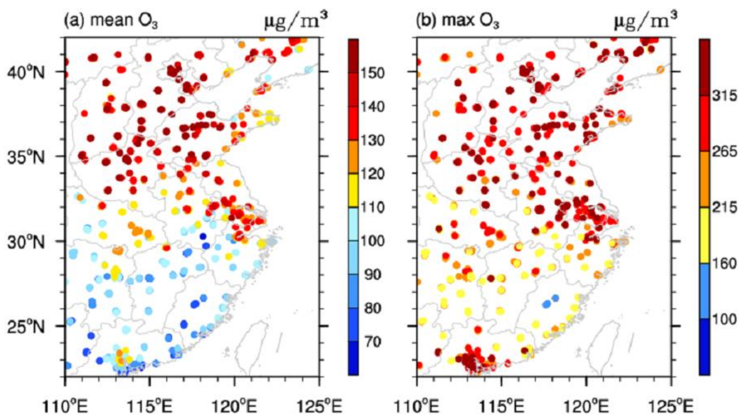

Figure 1. Distribution of the (a) mean values and (b) maximum values of MDA8 (Unit: μg/m³) in summer from 2015 to 2018.

2. (1) It is not clear what was the methodology used to interpolate the station-based observations into the surrounding areas to fill in the maps in Figure 1 and the rest of the paper.
(2) How many station sites are urban vs rural? How did the number of sites change from year to year?
(3) Regarding lines 83-85 starting with "In the YRD and PRD, high levels of MDA8 were around the large cities. However, the high-level O_3 values in the NH region were contiguous, indicating extensively severe surface O_3 pollution." Was this expected or does it have anything to do with location and number of monitoring stations, or the algorithm to weight the station data into the surrounding area they each represent.

Reply:

Three sub-questions are separately replied and according revisions are carefully processed.

(1) In the former version, to show the spatial distributions, the data of ground-based sites were interpolated using **iterative correction type objective analysis**. Now, to avoid confusions, we **directly show the sited values** in Figure 1, 3, 4, 7 and other Figures in the supplementary, instead of interpolation.

(2) Due to their observed purposes (related to air pollutions), the sites monitoring atmospheric components were **almost located around the urban area**. In the revised version, we pointed out that "**the results of this study were more suitable to the urban O_3 pollution**".

The air pollution became more and more severe since 2013, thus the air pollution issues gained more attentions from the Chinese government and society. Since then, the constructions of operational monitoring stations of atmospheric components resulted in continuous increasing number of sites. The number of sites in eastern China (110°E–125°E, 22°N–42°N) was **677, 937, 937, 995 and 1007 from 2014 to 2018**. Finally, after quality control, 868 sites in eastern China were employed here. To make this point clear, we **added a new Figure S1** (see Reply to the 1st comment).

(3) It is **expected**. In China, when we to assess the degree of air pollutions, we frequently use the parameters like concentration, duration, polluted number of sites and also the contiguous cover area. The contiguous cover area could reflect the **clustered and regional features of air pollutions**. Generally, when the air pollutions

occurred in dispersive cities, the difficulty of air managements was much smaller that clustered and regional (i.e., contiguous) air pollution.

In the revised Figure 1, the numerical values were **not interpolated**, and the contiguous features were still clear. That is, the O_3-polluted sites were located closely to each other. Although, the distributions of the sites were somewhat uneven, the conclusions on the contiguous features were substantially influenced. Detailed explanations were added to make this point clear.

Revision:

(1) In the Figure 1, 3, 4 and 7:

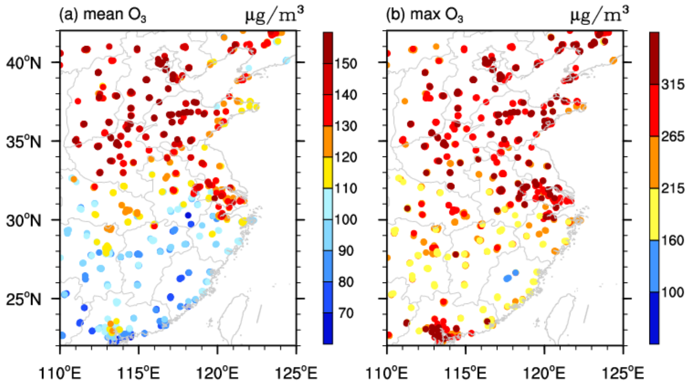

Figure 1. Distribution of the (a) mean values and (b) maximum values of MDA8 (Unit: μg/m³) at the observation sites in summer from 2015 to 2018.

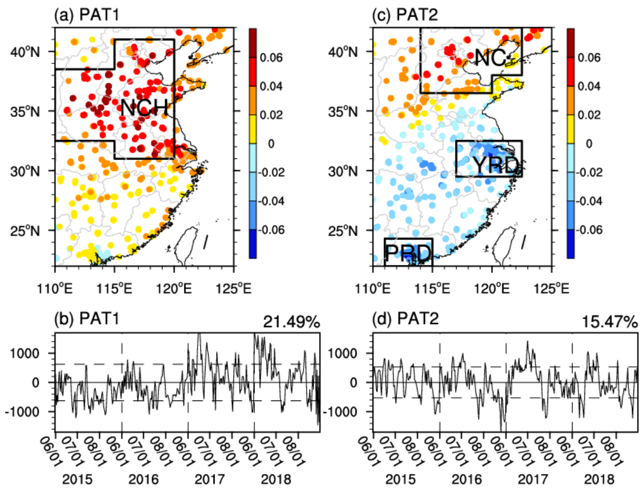

Figure 3. The first EOF pattern (PAT1: a, b) and second EOF pattern (PAT2: c, d) of MDA8 in summer from 2015 to 2018, including the spatial pattern (a, c) and the time coefficient (b, d). The black boxes in panels a and c are the selected North China and Huanghuai region (NCH), North China (NC) Yangtze River Delta (YRD) and Pearl River Delta (PRD). The EOF analysis were applied to the daily MDA8 anomalies at 868 stations to extract the relatively change features of the original data on the daily time-scale. The percentages on panel b and d were the variance contributions of the first and second EOF mode.

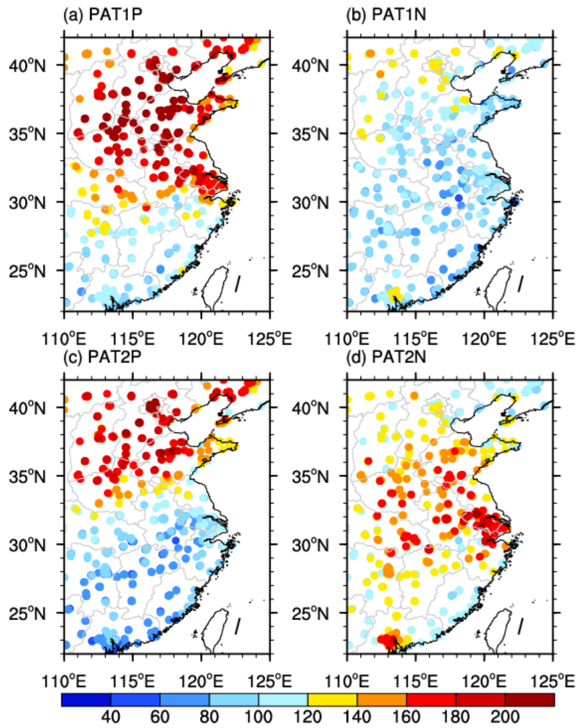

Figure 4. Composites of the MDA8 (Unit: μg/m³) for PAT1 (a, b) and PAT2 (c, d) in summer from 2015 to 2018. Panels a and c were composited when the time coefficient of EOF1 and EOF2 was greater than one standard deviation, while panels b and d were when the time coefficient was less than －1×one standard deviation.

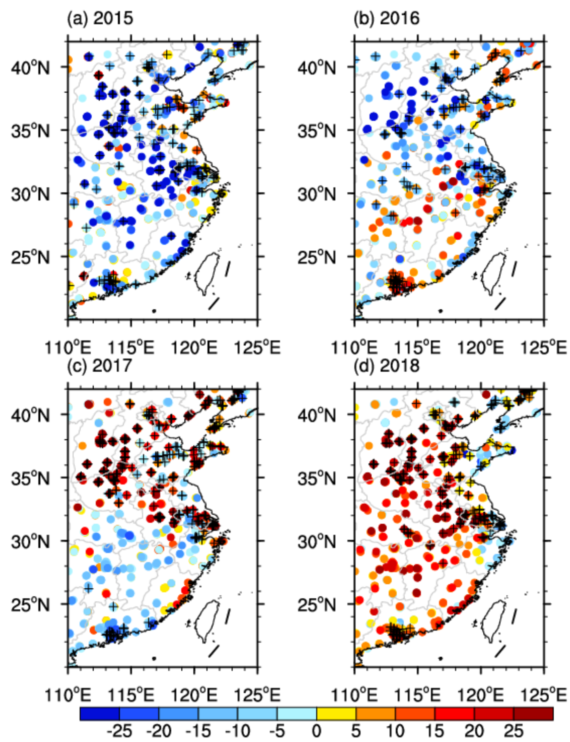

Figure 7. Anomalies in the summer mean MDA8 (Unit: μg/m³) in 2015 (a), 2016 (b), 2017 (c) and 2018(d), relative to the mean during 2015–2018. The black pluses indicate indicate that the maximum MDA8 was larger than 265 μg/m³.

(2) In the first paragraph of Section 2:

……Nationwide hourly O_3 concentration data since May 2014 are publicly available on http://beijingair.sinaapp.com/. Since the severe air pollution events in 2013, the air pollution issues gained more attentions from the Chinese government and society, which aided to start the extensive constructions of operational monitoring stations of atmospheric components and resulted in continuous increasing number of sites (Figure S1). The number of sites in eastern China (110°E–125°E, 22°N–42°N) was 677, 937, 937, 995 and 1007 from 2014 to 2018. It is obvious that the data in 2014 were deficient, while the observations were broadly distributed in eastern China and continuously achieved since 2015. Thus, the summer O_3 data from 2015 to 2018 were processed (e.g., unifying the sites and eliminating the missing value) and 868 sites in eastern China were employed here to reveal some new features of surface ozone pollutions and associated anomalous atmospheric circulations. Generally, severe air pollutions occurred more frequently in cites than in rural areas, therefore, the monitoring sites of atmospheric components mostly gathered around the urban areas, indicating the results of this study were more suitable to the urban O_3 pollution……

(3) In the first paragraph of Section 3:

……Surface O_3 pollution was closely linked to the anthropogenic emissions that dispersed and concentrated in the large cities (Fu et al., 2012), which was similar to the haze pollution (Yin et al., 2015). In the YRD and PRD, high levels of MDA8 were scattered around the large cities. However, the high-level O_3 values in the NCH region were contiguous, indicating extensively severe surface O_3 pollution both in large and small cities (Figure 1)……

3. There is a disconnect between the Figure 1 and the text on Line 87 where 265 μg/m^3 is referenced but it is not a value on the color bar. I could support changing this to 240 μg/m^3. If you want to highlight 265 μg/m^3, consider changing the intervals on the color bar to 15 μg/m^3, starting at 175 μg/m^3 instead of 140 μg/m^3.

Reply:

According to the reviewer's advice, the Figure 1b was replotted.

The maximum MDA8 in Figure 1b was actually a daily value and could be compared to the air quality thresholds of MDA8. Thus, the color bar of Figure 1b was redivided according to the thresholds.

Revision in the first paragraph of Section 2 and Figure 1b:

……MDA8 is generally used to represent the daily O_3 conditions. The MDA8 $\in$ [0, 100], (100, 160], (160, 215], (215, 265], (265, 800] μg/m³ corresponds to "Excellent", "Good", "Lightly polluted", "Moderately polluted", "Heavily polluted" levels of air quality in China……

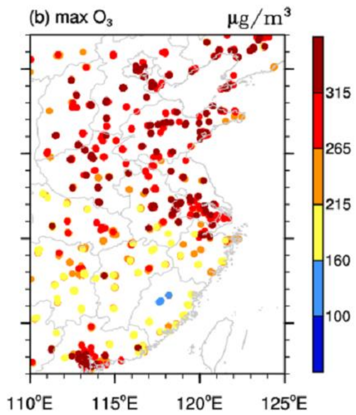

Figure 1. Distribution of the (b) maximum values of MDA8 (Unit: μg/m³) in summer from 2015 to 2018.

4. (1) There must have been a more scientific reason for making Figure 2 other than "from another angle" (Line 86).

(2) Are these stations close to each other? Alternative reasons may be the authors wanted to investigate how well the cities represented an area over time, or maybe seasonal cycles or the year-to-year variability not captured in Figure 1a or 1b. The authors should introduce this idea of the ten cities chosen as "representative stations with severe ozone pollution" (Line 102) earlier and describe what they are representative of. Is it the region or province or something else? Are they the top highest 2 or 3 cities in that region statistically or most populated in that region?

Reply:

(1) This comment on "from another angle (Line 86)" might connect with Figure 1b, instead of Figure 2.

In Figure 1b, the maximum values of MDA8 for four summers were extracted to evaluate the ***severest levels*** of daily O_3 pollution. This point was revised to be clear and scientific.

(2) According to the reviewer's comment, the purpose and the analysis of Figure 2 were rewrite and a map of ten selected sites was supplemented as Figure S2.

The reason for "representative" was "These cities had large populations and were with **heavily O_3 pollutions**".

The purpose of Figure 2 was "investigate the **temporal variations**" in "Ten cities, with severe O3 pollutions".

The locations of these ten cities were introduced as "including Beijing (capital of China), Tangshan, Tianjin near the capital city, Shijiazhuang, Weifang and Taiyuan in the south of NCH, Nanjing and Shanghai in YRD, Guangdong and Zhongshan in PRD (Figure S2)".

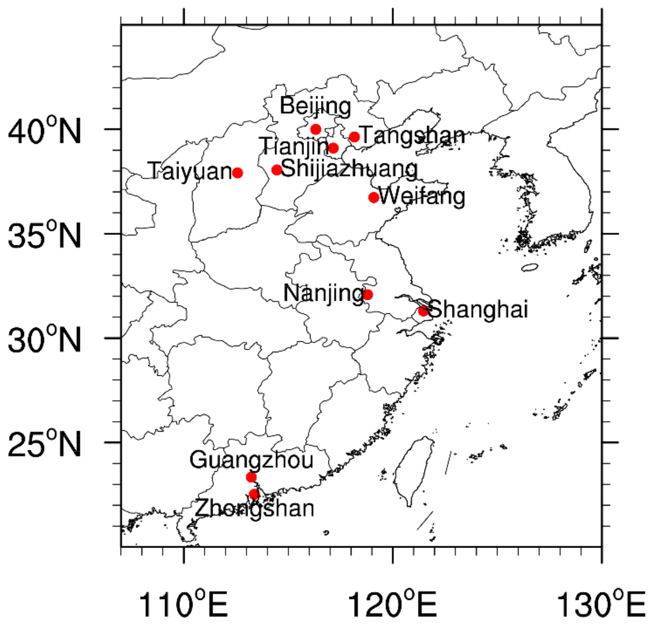

Figure S2. The distribution of ten representive cities with severe O_3 pollutions.

Revision:

……Ten cities, with severe O_3 pollutions, were chosen to investigate the temporal variations, including Beijing (capital of China), Tangshan, Tianjin near the capital city, Shijiazhuang, Weifang and Taiyuan in the south of NCH, Nanjing and Shanghai in YRD, Guangdong and Zhongshan in PRD (Figure S2). These cities had large populations and were with heavily O_3 pollutions. In Beijing, Tianjin and Tangshan, the MDA8 values were nearly above 100 μg/m³ and frequently exceeded 215 μg/m³

(Figure 2a). The percentage of non-O_3-polluted days (<100 μg/m³) and moderate O_3-polluted days (>215 μg/m³) were 14.9% and 15.5% for the mean MDA8 of these three cities. The former percentage indicated that more than 85% O_3 concentrations exceeded the health threshold, and the later meant, in more than 15% of summer days, O_3 concentrations moderately damaged human health in the Beijing-Tianjin-Hebei region. The maximum MDA8 in the north of Hebei province (e.g. Tangshan in Figure 2a) and in eastern Shandong province (e.g. Weifang in Figure 2b) even exceeded 320 μg/m ³, which badly injured the health of local citizens. In Shijiazhuang, Weifang and Taiyuan, the MDA8 levels were lower than those in Beijing and Tianjin during 2015–2016, but dramatically increased to levels comparable to those of Beijing and Tianjin in 2017 and 2018 (Figure 2b). In Nanjing and Shanghai, the MDA8 did not show a clear increasing trend (Figure 2c). Similar to the distribution of the mean MDA8, the maximum MDA8 to the south of 30°N was lower by comparison. Although approximately 60% of summer days were non-O_3-polluted in the cities of Guangzhou and Zhongshan (Figure 2d), severe O_3 pollution also occurred in the PRD (Figure 1b)……

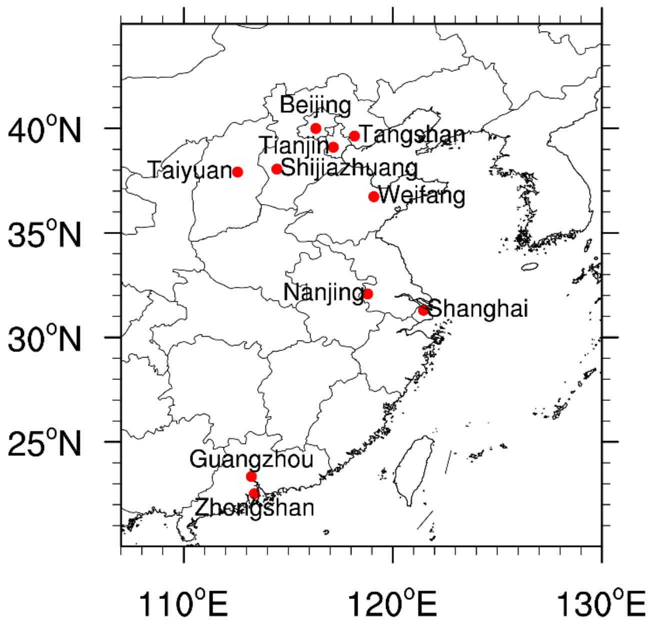

Figure S2. The distribution of ten representive cities with severe O_3 pollutions.

5. Any hypothesis why the seasonality in south china was different in summer of 2015 (Fig 3, Lines 105-107)? Did it have anything to do with the El Nino that year? This idea was not revisited later in the paper with the analysis of the

individual seasons EOF patterns.

Reply:

We speculated the differences of the seasonality between South China and North China might closely relate to the local precipitations. The length of the data (4 years) did not support the possibility to discuss the relationship with ENSO.

Because the limitation of the old Figure 3, we ***deleted it*** in the revised manuscript.

Revision:

~~For the ten representative stations with severe ozone pollution, the daily variations in MDA8 were evident (Figure 2–3), indicating large influences by the daily meteorological variables. Generally, the peak in the summer surface ozone concentrations occurred in June in the northeast China, and then decreased in July-August due to abundant rainfall in Beijing (Ma et al., 2016). Except for 2015, monthly MDA8 peaked in June and then declined in July and August for the sites to the north of 30°N, i.e., in Beijing, Tianjin, Tangshan, Taiyuan, Weifang, Shijiazhuang (Figure 3a–b). However, similar monthly peaks were not obvious for the cities to the north of 30°N (Figure 3c–d).~~

The authors need to reconsider the figures submitted with this paper. Two major comments below are brought up here plus many minor comments at the end of my review:

1. It is unclear to me what Figure 6 is showing by "variations" (Line 122-123, 412). There are no units on the right-hand side. Is this area-averaged O_3 for the different boxed regions (as outlined in Figure 4) for each summer? Could it be better summarized in a table instead of a histogram, or maybe a line plot would take up less space? There is also only the one sentence in the manuscript that references Figure 6. Does it really show additional information not shown in another figure to keep it in the paper?

Reply:

The old Figure 6 and the one related sentence was deleted, as no new information were shown.

Revision:

and the YRD for the PAT2. ~~From the variations in summer MDA8 (Figure 6), the surface O_3 concentrations in these three areas increased from 2015 to 2017 and remained high in 2018 (Figure 6).~~

2. (1) Figures 8 and 10 are not (correctly) referenced once in the text and therefore should be removed (or moved to the supplemental) and

(2) yet there are four lines of text referencing Figure S2 in the main text (Lines

175-179) and several lines of text referencing Figures S3-S6 (Lines 210-214). The authors should also add references to Figure S2 in the discussion of the variance explained and the percentages given on Lines 181-184 which means that there is a decent amount of discussion of Figure S2 in the results section and lead to Section 5. The authors should consider switching Figures 8 and 10 with Figure S2 in the supplemental material. Can the authors comment more on the switch from PAT2 being the dominant EOF pattern from Summer 2016 to PAT1 being the dominant EOF in Summer 2017 (Line 179).

Reply:

(1) Because no new information was showed in these two Figures, the Figure 8 and 12 were deleted.

(2) The old Figure S2 was re-plotted and moved to the main text as Figure 8 in the revised manuscript. Furthermore, the varying dominant patterns were a novel investigation of this study, thus, more comments were discussed now.

Revision in Abstract:

……In addition, **the most dominant pattern in 2017 and 2018 was different from that in previous years, which is investigated as a new feature.** Furthermore, the implications for the interannual differences in summer O_3 pollution have also proven to be meaningful......

Revision in the first paragraph of Section 5:

……Additionally, the observed summer MDA8 anomalies in eastern China presented evident interannual differences (Figure 7). The dominant spatial patterns of MDA8 anomalies in each year were also different (Figure 8). Although the relative variance contributions of the spatial coefficients varied, the first two EOF patterns of MDA8 were always PAT1 and PAT2 in different years, indicating that the extracted dominant patterns were reliable and steady. Sorting by the variance contribution, the dominant patterns were PAT2 and PAT1 in 2015 and 2016 (Figure 8a–d), however, they are PAT1 and PAT2 in the two subsequent years (Figure 8e–h). **The first EOF pattern in 2014 revealed by Zhao and Wang (2017) was similar with PAT2, however the most dominant pattern changed to PAT1 in the latest years (2017 and 2018)**……

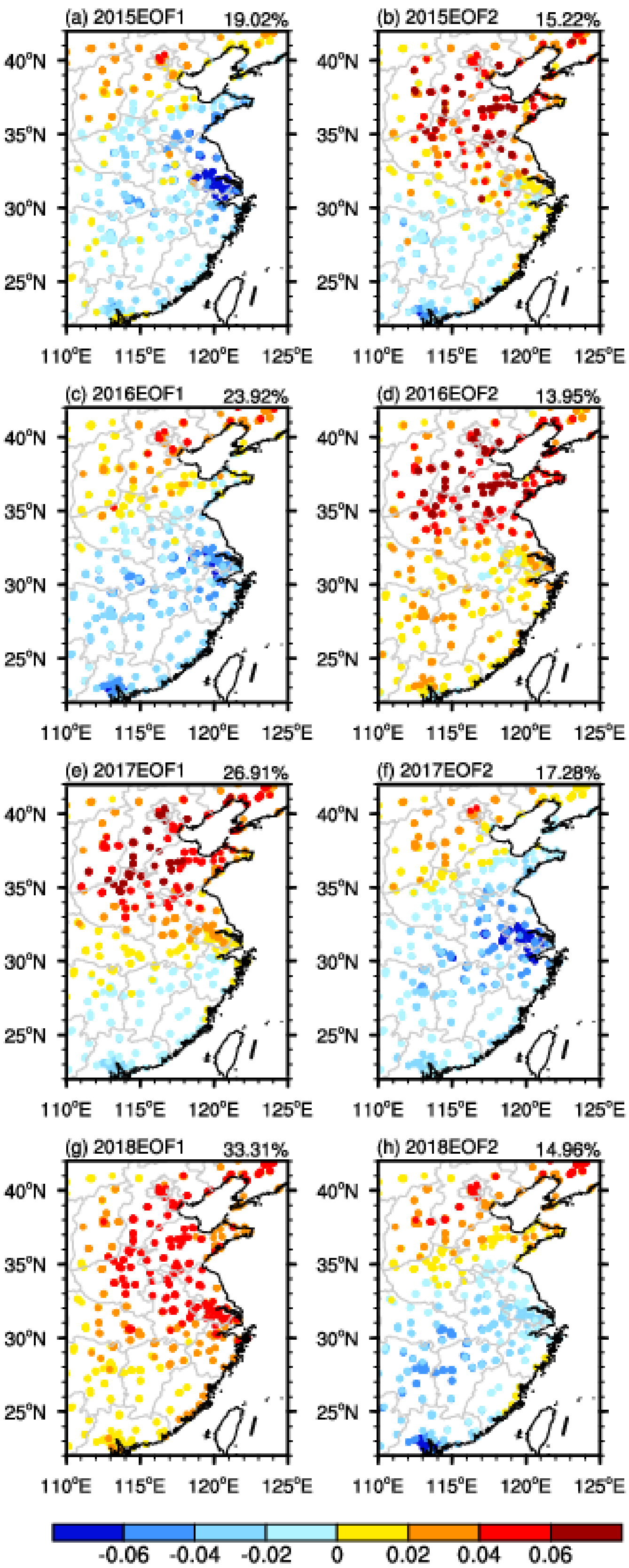

Figure 8. The first (a, c, e, g) and second (b, d, f, h) EOF spatial patterns of MDA8 in summer in 2015 (a, b), 2016 (c, d), 2017, (e, f) and 2018(g, h). The number in panels (a, c, e, g) and (b, d, f, h) are explained variances of PAT1and PAT2, respectively.

Minor and Technical Comments:

1. Line 23: 1) ozone at surface may come from the stratosphere through stratosphere to troposphere transport and 2) ozone is a secondary pollutant; it is not directly emitted. Declaring it is a 'man-made pollutant' is misleading.

Reply:

According to the reviewer's advice, this misleading statement was corrected throughout the manuscript.

Revision:

Abstract. Surface ozone~~, a man-made air pollutant,~~ has been severe during summers in the eastern parts of China, damaging human's health and flora and fauna. During 2015–2018, ground-level ozone pollution increased ~~year by year~~ and intensified

1. Introduction

Ozone occurs both in the stratosphere and at ground level. Stratospheric ozone forms a protective layer that shields us from the sun's harmful ultraviolet radiation. However, surface ozone is an ~~man-made~~ air pollutant and has harmful effects on

2. Line 24: need a space after "(Day et al., 2017)"

Reply:

This error was corrected.

Revision:

……damaging human lungs (Day et al., 2017) and destroying agricultural crops

3. Line 28: It would be helpful to reference the boxed regions for NC, YRD, and PRD are shown in Figure 4 (n.b., there is an error in Figure 4 caption (Line 407) where YRD is used twice when PRD should be used the second time)

Reply:

Limited by the order of the Figures, we introduced the locations of NC, YRD and PRD by the longitudes and latitudes.

This error in Figure 4 caption was corrected.

Revision:

anthropogenic emissions (Li et al., 2018), the high O_3 concentrations in China are mainly observed in urban regions, such as in North China (NC, 114°E–122.5°E, 36.5°N–42°N), the Yangtze River Delta (YRD, 117°E–122.5°E, 29.5°N–32.5°N) and the Pearl River Delta (PRD, 111°E–115°E, 22°N–24.3°N) where rapid development has occurred in recent decades (Wang et al.,

Figure 3. The first EOF pattern (PAT1: a, b) and second EOF pattern (PAT2: c, d) of MDA8 in summer from 2015 to 2018, including the spatial pattern (a, c) and the time coefficient (b, d). The black boxes in panels a and c are the selected North China and Huanghuai region (NCH), North China (NC) Yangtze River Delta (YRD) and Pearl River Delta (***PRD***).

4. Line 30 (and in several instances throughout the paper): the 3 in O_3 needs to be a subscript.

Reply:

This kind of error was corrected throughout the manuscript.

Revision:

The O_3 pollution levels in Beijing-Tianjin-Hebei (part of NC) were the most severe in China (Wang et al., 2006; Shi et al., 2015) and this situation has been getting worse. The O_3 concentrations in North China underwent a significant increase in the period of 2005–2015, with an average rate of 1.13±0.01 ppbv yr^{-1} (Ma et al., 2016). Even on the highest mountain over NC, Mount Tai, summer (June-July-August, JJA) O_3 increased significantly by 2.1 ppbv yr^{-1} (Sun et al., 2016). The O_3 levels generally presented increasing trends from 2012 to 2015 in the YRD (Tong et al., 2017), e.g., the O_3 concentrations in Shanghai (a mega-city) increased by 67% from 2006 to 2015 (Gao et al., 2017). In the PRD region, O_3 increased by 0.86 ppbv yr^{-1} from 2006 to 2011 (Li et al., 2014). Severe ozone pollution is projected to increase in the future over eastern China (Wang et al.,

5. Line 32: Is this ppb short for ppbv or ppbm? Please change appropriately.

Reply:

The reference (Ma et al., 2016) used the unit "ppb yr^{-1}", thus, we directly referred it in the former version. We contacted the authors and modified the unit as "ppbv yr^{-1}", which was consistent with the other sentences in the same paragraph.

Revision:

and this situation has been getting worse. The O_3 concentrations in North China underwent a significant increase in the period of 2005–2015, with an average rate of 1.13±0.01 ppbv yr^{-1} (Ma et al., 2016). Even on the highest mountain over NC, Mount Tai, summer (June-July-August, JJA) O_3 increased significantly by 2.1 ppbv yr^{-1} (Sun et al., 2016). The O_3 levels generally

6. Line 33: a space is required between the value and the unit, here "2.1 ppbv". There are other instances like this (e.g., Line 87)

Reply:

This kind of errors were corrected throughout the manuscript.

Revision:

……O_3 increased significantly by 2.1 ppbv yr^{-1} (Sun et al., 2016)……

7. Line 42: Can the authors discuss in more detail the findings of the Li et al paper regarding the relationship between PM and O_3 pollution.

Reply:

The methods adopted and the mechanisms reveled by Li et al (2018) were supplemented in the revise version.

Revision:

……Employed Goddard Earth Observing System Chemical Transport Model, Li et al (2018) found that rapid decreases in fine particulate matter levels significantly stimulated ozone production in NC by slowing down the aerosol sink of hydro-peroxy radicals……

8. Line 50: This sentence "Large-scale descending motion, tropical cyclones….related to the evaluation of surface O_3" does not make sense to me as large-scale descending motion is usually associated with high pressure systems, not low-pressure systems.

Reply:

This aforementioned sentence was revised to avoid the confusion.

Revision:

production in NC (Ding et al., 2013; Yin et al., 2019). Due to ~~their large-scale descending motion~~ the associated transports of pollution from inland, tropical cyclones are often related to the evaluation of surface O_3 levels in the coastal areas of PRD (Ding et al., 2004). Basing on a case study in 2014, ~~F~~further studies showed that a strong west Pacific subtropical high (WPSH)

9. Lines 54, 70: period after "et al."

Reply:

This kind of errors were corrected throughout the manuscript.

Revision:

……Wang et al. (2017) reviewed the meteorological influences on ozone events…..

……low and medium cloud cover and precipitation (Dee et al., 2011)……

10. Line 55-56: I have noticed also several papers coming out on this subject. Can the authors provide references here of example studies.

Reply:

Three references, including two new references, were referred.

Revision:

……but the O_3-weather studies mainly focused on meteorological elements (e.g. temperature, precipitation etc.) and several synoptic processes (Xu et al., 2017; Xiao et al., 2018; Pu et al., 2013)……

Related references:

Xiao, Z. , Wang, Z. , Pan, W. , Wang, Y. , Yang, S. Sensitivity of extreme temperature events to urbanization in the pearl river delta region. Asia-Pacific Journal of the Atmospheric Sciences., 2018

Xu, Z. , Huang, X. , Nie, W. , Chi, X. , Xu, Z. , Zheng, L. , et al. Influence of synoptic condition and holiday effects on vocs and ozone production in the Yangtze river delta region, china. Atmospheric Environment, S1352231017305496, 2017

11. Line 61, page 3: instead of "on the website" maybe say "publicly available" assuming this is true.

Reply:

This sentence was corrected.

Revision:

~~Public h~~Nationwide hourly O_3 concentration data since May 2014 are publicly available ~~on the website~~on

12. Line 68: I would like to see more information on the reanalysis dataset. 2.5x2.5 is not the native resolution (nominally 0.7 degree) but the authors may have downloaded the data from ECMWF at this coarser resolution or degraded it themselves.

Reply:

Yes, we directly downloaded the data of this coarser resolution (2.5 °×2.5 °). For the object of this study (i.e., large-scale atmospheric circulations), this resolution is enough. If we used the thinner resolution, the lines and arrows of Figure 5, 6, 10 and 11 would be too denser to be read.

More information on the reanalysis dataset were added, which was detailedly relied in the later three comments.

13. Line 69: What range and how many pressure levels?

Reply:

The range of geopotential height were 850 hPa and 500 hPa.

For the wind, relative humidity and air temperature, the range of pressure levels were from surface to 100 hPa.

For the other elements used in this study, there is not varying Z- coordinate.

Revision:

The 2.5°×2.5° ERA-Interim data used here include the geopotential height (Z) at 850 and 500 hPa, zonal and meridional wind, relative humidity, vertical velocity, air temperature at ~~different pressure levels~~from surface to 100 hPa, surface air temperature (SAT) and wind, downward solar radiation at the surface, low and medium cloud cover and precipitation (Dee et

14. (1) Line 70-72: What is the temporal resolution of the original data (Hourly? 3-hourly? 6-hourly?) before it was selected to be "sub-daily".

(2) What time in UTC is equivalent to 8am-8pm Beijing time.

Reply:

It is 6-hourly for the Z, wind, relative humidity, vertical velocity, air temperature and cloud cover, while 3-hourly for the precipitation and downward solar radiation.

The UTC is 8 hours earlier than the Beijing Time, which can be found in the following revisions.

Revision:

…… the daytime data were calculated by the **6-hourly reanalysis** (including Z, wind, relative humidity, vertical velocity, air temperature and cloud cover) and **3-hourly reanalysis** (precipitation and downward solar radiation) to composite the daytime atmospheric circulations and daytime meteorological conditions. Due to the different representative period of each element in ERA-Interim data, the daytime for Z, wind, relative humidity, vertical velocity, air temperature and cloud cover was from *05 a.m. to 05 p.m (Beijing Time; 21 p.m.–09 a. m. UTC), while it is from 08 a.m. to 08 p.m. (Beijing Time; 00 a.m. to 00 p.m. UTC) f*or precipitation and downward solar radiation……

15. Line 77: Superscript the circle to have a degree symbol. Check throughout paper for this (e.g., line 97)

Reply:

This kind of errors were corrected throughout the manuscript.

Revision:

3. Variations and dominant patterns

During 2015–2018, summer surface ozone pollution was severe in China, especially in the economically developed regions. Spatially, the JJA mean MDA8 increased from south to north in eastern China (Figure 1a). To the south of 28°N (i.e., South China), the mean MDA8 was mostly lower than 100 μg/m³ and the ozone pollution was obviously lower than that in North China and in the Huanghuai area (NCH). It is notable that, although the values of MDA8 in the PRD were not as large as those in NCH, they were relatively higher than those in the surrounding areas. The mean MDA8 was above 110 μg/m³ to the north of 32°N (i.e., the NCH area), and thereinto, the large values of MDA8 centred on the Beijing-Tianjin-Hebei region and in western Shandong province exceeded 150 μg/m³. In the transitional zone, i.e., between 28°N and 32°N, the MDA8 varied from

16. Line 78: Why have the authors switched to using μg/m³ from ppb in the Intro?

Reply:

The references in the introduction directly used the unit of ppbv, thus we did not modify them.

In the Technical Regulation on Ambient Air Quality Index of China (the Ministry of Environmental Protection of China, 2012), they used the unit of **μg/m³**. Thus, we **followed this regulation to focus on the issue of air pollution**.

17. Line 79: NH is a common abbreviation for Northern Hemisphere. Does it stand here for North China and Huanghuai? I suggest changing it to NCH, so as not to be confusing.

Reply:

The abbreviation of North China and the Huanghuai area was changed to NCH in the revised manuscript.

Revision:

South China), the mean MDA8 was mostly lower than 100 μg/m³ and the ozone pollution was obviously lower than that in North China and in the Huanghuai area (NCH). It is notable that, although the values of MDA8 in the PRD were not as large as

18. Line 80: It looks more to me that the cut off at 32°N is closer to > 110 μg/m^3 mean O_3 with much of the region > 130 μg/m^3, but not > 130 μg/m^3 everywhere.

Reply:

The value was changed to **110 μg/m^3.**

Revision:

……The mean MDA8 was above 110 μg/m^3 to the north of 32°N (i.e., the NCH area)……

19. Line 83: How do the authors know this "Surface O_3 pollution was closely linked to the anthropogenic emissions that dispersed and concentrated in the large cities"? Reference to another study or figure from this text?

Reply:

A related study was referenced.

Revision:

……Surface O_3 pollution was closely linked to the anthropogenic emissions that dispersed and concentrated in the large cities (Fu et al., 2012)……

Fu, J.S., Dong, X., Gao, Y.,Wong, D.C., Lam, Y.F. Sensitivity and linearity analysis of ozone in East Asia: the effects of domestic emission and intercontinental transport. J. AirWaste Manage. Assoc. 62, 1102–1114, 2012

20. Line 89: Why is Tangshan not mentioned in this sentence along-side Beijing and Tianjin if it is included in the same Figure 2a panel?

Reply:

The location and the polluted level of Tangshan were introduced now.

Revision:

Ten cities, with severe O_3 pollutions, were chosen to investigate the temporal variations, including Beijing (capital of China), Tangshan, Tianjin near the capital city, Shijiazhuang, Weifang and Taiyuan in the south of NCH, Nanjing and Shanghai in YRD, Guangdong and Zhongshan in PRD (Figure S2). These cities had large populations and were with heavily O_3 pollutions. In Beijing, Tianjin and Tangshan, the MDA8 values were nearly above 100 μg/m^3 and frequently exceeded 215 μg/m^3 (Figure 2a). The percentage of non-O_3-polluted days (<100 μg/m^3) and moderate O_3-polluted days (>215 μg/m^3) were

21. Line 90-92: Two percentages are given, 14.4% and 15.3%, but this seems insufficient. In the previous sentence the authors quote two cities, Beijing and Tianjin, frequently exceed moderate pollution levels, but in this sentence the authors refer to both non-polluted and moderate pollution days. Are these percentages for the two cities for frequency of pollution days, or for one city and the percentage of non-polluted and polluted days?

Reply:

This sentence was corrected as follows.

Revision:

……These cities had large populations and were with heavily O_3 pollutions. In **Beijing, Tianjin and Tangshan**, the MDA8 values were nearly above 100 μg/m³ and frequently exceeded 215 μg/m ³(Figure 2a). The percentage of non-O_3-polluted days (<100 μg/m³) and moderate O_3-polluted days (>215 μg/m³) were 14.9% and 15.5% **for the mean MDA8 of these three cities.** The *former percentage* indicated that more than 85% O_3 concentrations exceeded the health threshold, and the *later* meant, in more than 15% of summer days, O_3 concentrations moderately damaged human health in the Beijing-Tianjin-Hebei region……

22. Line 93: Which figure is this quoted from "the north of Hebei province and in eastern Shandong province even exceeded 320 μg/m³,"? Provide figure reference (I presume top panel of Figure 2 for Tangshan July 2018).

Reply:

This sentence was corrected as follows.

Revision:

……The maximum MDA8 in the north of Hebei province **(e.g. Tangshan in Figure 2a)** and in eastern Shandong provinc**e (e.g. Weifang in Figure 2b)** even exceeded 320 μg/m³, which badly injured the health of local citizens……

23. Line 94: Which region are the cities in Figure 2b (Shijiazhuang and Weifang). Why do the authors not reference the third city from this panel, Taiyuan, in the text here?

Reply:

(1) The locations of these ten cities were introduced as “including Beijing (capital of China), Tangshan, Tianjin near the capital city, Shijiazhuang, Weifang and Taiyuan in the south of NCH, Nanjing and Shanghai in YRD, Guangdong and Zhongshan in PRD (Figure S2)”.

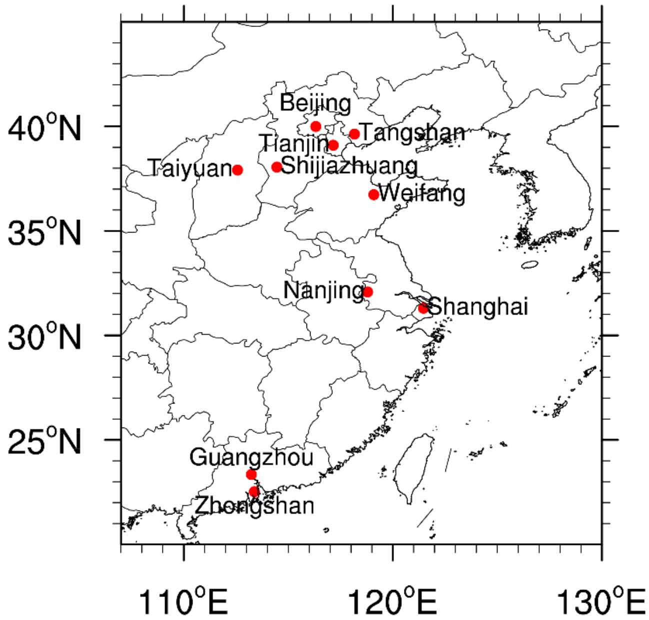

Figure S2. The distribution of ten representive cities with severe O_3 pollutions.

(2) Taiyuan, as a third city in the south of NCH, was referenced in the revised version.

Revision:

……In Shijiazhuang, Weifang and **Taiyuan**, the MDA8 levels were lower than those in Beijing and Tianjin during 2015–2016, but dramatically increased to……

24. Line 99-100: Where is the Fujian province? This isn’t labelled anywhere on a map and only referenced the once here in the paper, yet values are quoted. Are these values form Figure 1 or Figure 2?

Reply:

As you mentioned, the Fujian province was only referenced once, thus we deleted this sentence.

Revision:

Ministry of Environmental Protection of China, 2012). ~~The surface O_3 levels in Fujian province were the lowest seen in eastern China, represented by both the mean MDA8 of 70–90 μg/m³ and maximum MDA8 of 160–200 μg/m³.~~

25. Line 103: Is there any reason we cannot assume some daily variation in emissions to impact variability in ozone, or is it all down to meteorology?

Reply:

(1) In eastern China, the economic productions and human actives steadily developed in the recent four years and the emissions of ozone precursors were reasonably supposed to be relatively stable **on the daily time-scale.**

(2) Surely, the stability of the emissions is relative and the data of daily emission cannot be archived. Thus, in the numerical models of atmospheric chemistry, the **emission inventory was monthly or yearly updated**.

(3) What we stated is that "the impacts of daily meteorological conditions significantly contributed to the domain patterns of daily O_3 concentrations". It is **not "all down to meteorology".**

(4) To clearly state, we supplemented some presentations in the first paragraph of section 4 and the third paragraph in the "6. Conclusions and discussions", which were copied as follows:

Revision in the first paragraph of Section 4:

……In eastern China, the economic productions and human actives steadily developed in the recent four years and the emissions of ozone precursors were reasonably supposed to be relatively stable on the daily time-scale. Differently, the daily variations in MDA8 were evidently saw in Figure 2. Therefore, the impacts of daily meteorological conditions significantly contributed to the domain patterns of daily O_3 concentrations and their variations……

Revision in the third paragraph of Section 6:

……In this study, we mainly emphasized the contribution of the meteorological impacts and assumed the emissions of ozone precursors were relatively stable on the daily time-scale. There is no doubt that the human activities were the fundamental driver of air pollution even on the daily time-scale. However, the daily emission data were difficult to be acquired, thus the joint effects of the daily meteorological conditions and anthropogenic emissions needed to be discussed in future work……

26. Line 104: Abundant rainfall in Beijing only, or should it be more general "in South China" to have impact on all 6 stations in Fig 3a,b? Or is this sentence limited because the study referenced only looked at Beijing? Can the authors explain how that idea can be expanded to other cities in the north of China?

27. Line 105: Can the authors give a reason why 2015 was different for the northern cities?

28. Line 106-107: I presume the second reference to "cities north of 30" should actually be "cities south of 30". Can the authors provide a reason(s) why the southern cities show less consistency in the month-to-month variability?

Reply:

Comments 26–28 were replied together.

The length of the data (4 years) did not support to scrupulously discuss this relationship. Because the limitation of the old Figure 3, we ***deleted it*** in the revised manuscript.

Revision:

~~For the ten representative stations with severe ozone pollution, the daily variations in MDA8 were evident (Figure 2–3), indicating large influences by the daily meteorological variables. Generally, the peak in the summer surface ozone concentrations occurred in June in the northeast China, and then decreased in July-August due to abundant rainfall in Beijing (Ma et al., 2016). Except for 2015, monthly MDA8 peaked in June and then declined in July and August for the sites to the north of 30°N, i.e., in Beijing, Tianjin, Tangshan, Taiyuan, Weifang, Shijiazhuang (Figure 3a–b). However, similar monthly peaks were not obvious for the cities to the north of 30°N (Figure 3c–d).~~

29. Line 116: The use of brackets around PAT2P and PAT2N is confusing here. I suggest changing the start of the sentence to something like "The positive and negative phase for PAT1 and PAT2 are defined by the events that are greater than one standard deviation and less than - 1*standard deviation, respectively (Figures 4b and 4d)."

Reply:

According to the reviewer's suggestion, the presentation was improved in the revise manuscript as follows:

Revision:

……The positive (P) and negative (N) phases of PAT1 (PAT1P, PAT1N) and

PAT2 (PAT2P, PAT2N) are defined by the events that are greater than one standard deviation and less than －1×one standard deviation, respectively (Figure 3b, 3d)……

30. Line 117-118: The placement of the statement starting with "Figure 4 illustrates the composite results…" seems out of place here, and then the results of Figure 5 are buried at the end of this paragraph defining the PAT1 and PAT2. I suggest starting a new paragraph here but add to that sentence the connection to Figure 5: "Figure 4 illustrates the composite results …. surface ozone while Figure 5 shows the break down into the positive and negative phase composites."

Reply:

According to the reviewer's suggestion, the presentation was improved in the revise manuscript as follows:

Revision:

Figure 3 illustrates the composite results for the dominant patterns of surface ozone, which Figure 4 showed the MDA8 composites break down into the positive and negative phases. The ozone concentrations for the PAT1P classification (Figure 4a) were generally greater than those for PAT1N (Figure 4b). The MDA8 values in the NCH region were >160 μg/m³ and <120 μg/m³ for PAT1P and PAT1N, respectively. For the second pattern, the PAT2P appeared as a diminishing pattern from the north to the south (Figure 4c), however, there was severe ozone pollution in the YRD and PRD under PAT2N conditions. (Figure 4d). Therefore, the centres of O_3 variation were NCH for the PAT1, and NC and the YRD for the PAT2.

31. Line 119: I suggest adding figure references to Fig 5a and Fig 5b following the numbers so the readers know which panel to look at.

Reply:

According to the reviewer's suggestion, the presentation was improved in the revise manuscript as follows:

Revision:

……The ozone concentrations for the PAT1P classification (**Figure 4a**) were generally greater than those for PAT1N (**Figure 4b**). The MDA8 values in the NCH region were >160 μg/m³ and <120 μg/m³ for PAT1P and PAT1N, respectively. For the second pattern, the PAT2P appeared as a diminishing pattern from the north to the south (**Figure 4c**), however, there was severe ozone pollution in the YRD and PRD under PAT2N conditions (**Figure 4d**). Therefore, the centres of O_3 variation were NCH for the PAT1, and NC and the YRD for the PAT2……

32. Line 120: Have the authors performed a statistical analysis to claim the difference is significant?

Reply:

To be more precise, the texts "indicating significant difference" were deleted, which would not influence the intended meaning.

Revision:

4a) were generally greater than those for PAT1N (Figure ~~4~~5~~a~~-b). The MDA8 values in the NCH region were >160 μg/m³ and <120 μg/m³ for PAT1P and PAT1N, respectively~~, indicating significant differences~~. For the second pattern, the PAT2P

33. Line 122: One could argue that there is higher O_3 in the PRD during PAT2 as well.

Reply:

According to the reviewer's suggestion, the presentation was corrected as follows:

Revision:

appeared as a diminishing pattern from the north to the south (Figure 4c), however, there was severe ozone pollution in the YRD and PRD under PAT2N conditions~~.~~ (Figure 4d). Therefore, the centres of O_3 variation were NCH for the PAT1, and NC

34. (1) Line 125: The authors showed ozone composites of PAT1 and PAT2 in Figure 4, so these figures are not the same and it should be clarified, not just by showing the defined differences in the parentheses. I suggest changing the opening sentence here to "Anomalous atmospheric circulation associated with PAT1 (PAT1P composite minus PAT1N composite) and PAT2 (PAT2P composite minus PAT2N composite) are shown in Figures 7-10."

(2) The Figure 7 caption (Line 416) says "Composites of the daytime atmospheric circulations" but it would be good to remind the reader in the main text here that these are daytime only and reference Section 2.

Reply:

(1) According to the reviewer's suggestion, the presentation was corrected as in the following revisions. An example was also illustrated for conveniently understanding.

(2) The "daytime" atmospheric circulations were reminded twice in the first paragraph of Section 4.

Revision in the first paragraph of Section 4:

……Anomalous daytime atmospheric circulations associated with PAT1 (PAT1P composite minus PAT1N composite) and PAT2 (PAT2P composite minus PAT2N composite) were shown Figure 5–6. For example, the mean of the atmospheric circulations associated PAT1P (PAT1N) were firstly computed, and then the differences between PAT1P composites and PAT1N composites were calculated as the anomalous daytime atmospheric circulations associated with PAT1……

4. Associated atmospheric circulations

In eastern China, the economic productions and human actives steadily developed in the recent four years and the emissions of ozone precursors were reasonably supposed to be relatively stable on the daily time-scale. Differently, the daily variations in MDA8 were evidently saw in Figure 2. Therefore, the impacts of daily meteorological conditions significantly contributed to the domain patterns of daily O_3 concentrations and their variations. Anomalous daytime atmospheric circulations associated with PAT1 (PAT1P composite minus PAT1N composite) and PAT2 (PAT2P composite minus PAT2N composite) were shown Figure 5–6. For example, the mean of the atmospheric circulations associated PAT1P (PAT1N) were firstly computed, and then the differences between PAT1P composites and PAT1N composites were calculated as the anomalous daytime atmospheric circulations associated with PAT1. For the first pattern, the largest O_3 differences between the

35. Line 126: Do the authors mean by "most O_3-changed region" that the PAT1 positive and negative phases are defined by large differences in O_3 within the NH region. If so, I would change the sentence to something like my suggestion and reference Figure 5a,b instead of Fig 4.

Reply:

The presentation was corrected and the reference of the Figure was revised as Figure 4 a, b (i.e., Figure 5 in the old version).

Revision:

……For the first pattern, the largest O_3 differences between the PAT1P and PAT1N was within the NCH region (Figure 4a, b)…….

36. (1) Line 128-131: The authors need to be careful to get all their positive and negative descriptions correctly matching Figure 7a: e.g., Negative Z850 anomalies would indicate lower geopotential heights or a trough, not necessarily a ridge;

(2) There is not positive Z850 but negative across the subtropical Pacific, to get the cyclonic flow pattern.

Reply:

(1) In summer, high ridge frequently occurred near the Ural Mountains. Overlapped with negative Z850 anomalies could weaken the intensity or frequencies of the high ridge, which was our meaning in the old version. To avoid confusion, the "indicating a weaker high ridge" was deleted, which would not change the meanings.

(2) The region was revised to "tropical zone" as follows.

Revision:

NCH-averaged MDA8 was 0.97 (Table 1). Thus, the effects of the anomalous atmospheric circulations mainly acted on the photochemical reactions near the surface in NCH. There were negative Z850 anomalies over the Ural Mountains~~, indicating a weaker high ridge~~. Over the broad region from eastern Eurasia to the north Pacific, the anomalous atmospheric circulations were located zonally, i.e., positive Z850 on the ~~sub~~tropical zone, with cyclonic anomalies at the mid to high latitudes and positive anomalies on the polar region (Figure 5~~7~~a). The East Asia deep trough was enhanced and extended to northeast China

37. Line 134: Can the authors provide approximate coordinates of Lake Baikal to help the reader identify the lake drawn at approximately 110°E, 50°N. I did not notice the lake at first; I thought it was a miscellaneous contour.

Reply:

The longitude and latitude of Lake Baikal was supplemented.

Revision:

……Lake Baikal (centring at 107 °E, 53.5 °N)……

38. Line 136: WPSH shifted southward compared to what? Do I understand correctly further south during the PAT1N than PAT1P.

Reply:

Necessary information (i.e., compared to its climate status in summer) was added.

Revision:

Influenced by the enhanced East Asia deep trough, the main body of WPSH shifted southward (compared to its climate status in summer). The location of WPSH ($Z500_{(125°E,\ 20°N)} - Z500_{(125°E,\ 30°N)}$) also showed a positive correlation with

39. (1) Line 137-139: reference heights are Z at 500 hPa but Figure 7a shows Z at 850 hPa.

(2) How can the authors say that the extent of WPSH is "indicated by Z500" if not shown anywhere

(3) and the reference to an R=0.24 is not in the Table 1 for PAT1.

Reply:

(1) For PAT1, the signals of atmospheric circulations were clearer at the lower troposphere (i.e., 850 hPa). Differently, the signals for PAT2 could be recognized both at the low- and mid- troposphere. These are the reasons why we plotted Z850 in Figure 5a and Z500 in Figure 6a.

(2) However, it is popular to represent the west Pacific subtropical high with Z500. To agree with the convention and stay correspondences in Table 1, the $WPSH_1$ and $WPSH_2$ were calculated with Z500.

It is not contradictory. We used the Figure 5a with Z850 anomalies to clearly show the patterns of associated atmospheric circulations, while we calculated the $WPSH_1$ using Z500 to focus on the change of WPSH.

(3) We did not put the R=0.24 in Table 1. This correlation coefficient was solely important for the PAT1, thus, we did not contain similar R for PAT1 in Table 1.

40. Line 140: Start a new paragraph with "Although…." Hard to tell if the authors intend this to be a new paragraph since paragraphs do not start indented from the left margin.

Reply:

According to the reviewer's suggestion, the presentation was corrected as follows:

Revision:

YRD (Figure 1a), but maximum O_3 concentration exceeded 265 μg/m³ could be observed in certain larger cities of PRD in each year (Figure 7). Additionally, the observed summer MDA8 anomalies in eastern China presented evident interannual differences (Figure 7). The dominant spatial patterns of MDA8 anomalies in each year were also different (Figure 8). Although the relative variance contributions of the spatial coefficients varied, the first two EOF patterns of MDA8 were always PAT1 and PAT2 in different years, indicating that the extracted dominant patterns were reliable and steady. Sorting by the variance contribution, the dominant patterns were PAT2 and PAT1 in 2015 and 2016 (Figure 8a–d), however, they are PAT1 and PAT2 in the two subsequent years (Figure 8e–h). The first EOF pattern in 2014 revealed by Zhao and Wang (2017) was similar with PAT2, however the most dominant pattern changed to PAT1 in the latest years (2017 and 2018).

41. Line 142: I read Fig 7c to be statistically drier from the surface to 400hPa, not just up to 500hPa.

Reply:

This sentence was revised as follows:

Revision:

……resulted in a dry environment in NCH from surface to 400 hPa (Figure 5c)……

42. Line 143-144: The authors should not put the reference for 7c after adiabatic heating since this is not shown in the figure and it is very difficult to read the contours on 7d to know anything about convective activity, unless they are referring to the higher downward solar radiation at the surface only, and if that is true, that should be made clearer.

Reply:

The discussion about "adiabatic heating" was replaced by the "corresponded to the warmer surface air temperature".

The convective activity was related to the low and medium cloud cover, which was showed in Figure 5d. In the revised version, additional explanation was supplemented.

Revision:

……Furthermore, the associated descending motions (Figure 5c) not only corresponded to the warmer surface air temperature (Figure 5a), but also suppressed the development of convective activity (indicating by less low and medium cloud, Figure 5d)……

43. Line 146: Remove ‘sunny’

Reply:

"sunny" was removed.

Revision:

which exceeded the 99% significance test (Table 1). The large-scale atmospheric circulations led to ~~sunny~~ days with high temperatures near the surface (Figure ~~7~~5a), less precipitation (Figure ~~7~~5b), a dry environment (Figure ~~7~~5c) and intense solar

44. (1) Line 149: Add figure references (maybe Fig 4c or Fig 5c,d) for the statement "Large amplitudes of PAT2 O_3 were distributed in the NC and YRD regions".

(2) I ask for this clarification as I do not understand what the authors mean by ‘large amplitudes’; I can imagine the authors referring to higher ozone in NC during PAT2P while it is low in YRD and opposite pattern for PAT2N as shown in Figure 5c,d, but this needs to be made clear.

Reply:

(1) In the revised version, the correct figure references were added.

(2) We used the "large amplitude" to mean the obvious differences of O_3 between PAT2P and PAT2N. This statement was revised as follows.

Revision:

……For PAT2, **largest O_3 differences** (PAT2P composite minus PAT2N composite) were observed in the NC and YRD regions (Figure 3c, Figure 4c, d)……

45. Line 152: Why are the authors now showing Z500 in Fig 9a when they showed Z850 in Fig 7a? Same question applies for Figures 13a and 14a.

Reply:

This comment closely related to Comment 39.

For PAT1, the signals of atmospheric circulations were clearer at the lower troposphere (i.e., 850 hPa). Differently, the signals for PAT2 could be recognized both at the low- and mid- troposphere. These are the reasons why we plotted Z850 in Figure 5a and Z500 in Figure 6a.

Same answer applies for Figure 10a and 11a.

46. Line 156: Is “Extruded” supposed to start a new paragraph or why is it slightly indented from the left margin?

Reply:

This error was corrected.

Revision:

the mid and high latitudes generally led to significantly positive SAT anomalies (Figure 6a). The East Asia deep trough was stronger (R=0.3), but was limited to the east of Japan.

Extruded by the East Asia deep trough and cyclonic anomalies from the Siberian plains to the YRD, the WPSH moved southward and exhibited southwest-northeast orientation (Figure 6a). The location of WPSH ($Z500_{(110^{o}E,\ 20^{o}N)} - Z500_{(110^{o}E,\ 30^{o}N)}$) was positively correlated with the time series of PAT2 (R=0.32, Table 1). The southwest-northeast

47. Line 162-163: I do not understand the term “weak cold activity”. Are the authors referring to less cold air advection from the north?

Reply:

According to the reviewer’s advice, the “weak cold activity” was replaced by “less cold air advection from the north” throughout the manuscript.

Revision:

concentration in the YRD region. On the other hand, sinking motion with efficient adiabatic heating (Figure ~~9~~6c) and ~~weak~~ less cold air advection~~activity (Figure 9a)~~ from the north (Figure 6a) both resulted in a temperature increase in NC (Figure ~~9~~6a).

48. Line 172: Figure 11 is referenced before Figure 10 in the manuscript. The figures should be renumbered to match the order they are presented in the paper. **NOTE, after reading further it looks to be that Figure 10 was incorrectly referenced and this is part of a bigger issue regarding which figures should be included in the main text. **

Reply:

The references of the Figures were corrected throughout this manuscript. Detailed revision could be found in the main text. In addition, the tracked manuscript was also uploaded for convenience.

49. (1) Line 173: Can the authors quantify the change in the number of stations with polluted levels of MDA8, from how many in 2015 to how many in 2018?

(2) Also, can the authors clarify they are referring to the mean summer MDA8 O_3 in the sentence "The summer MDA8 in the PRD….(Figure 1a)" since they reference Fig 1a.

Reply:

(1) The variation in the number of sites with maximum MDA8 > 265 μg/m³ in NCH (YRD) was qualified in the revised version. The associated presentation was also revised.

(2) The reference was added.

Revision in the first paragraph of Section 5:

5. Signals for interannual variability

The O_3 pollutions in NCH and YRD ~~became~~ were ~~persistently~~ severe over the past four years, reflected in both the O_3-polluted areas and in the O_3 concentration (Figure ~~11~~1). The number of sites with maximum MDA8 > 265 μg/m³ in NCH (YRD) was 94 (35), 55 (22), 180 (58), 160 (46) from 2015 to 2018 (Figure 7). ~~In addition, the number of sites with maximum MDA8 > 265 μg/m³, located in NH and the YRD, also increased year by year.~~ The summer mean MDA8 in the PRD was not as

The summer mean MDA8 in the PRD was not as high as that in in NC and the YRD (**Figure 1a**), but maximum O_3 concentration exceeded 265 μg/m³ could be observed in certain larger cities of PRD in each year (**Figure 7**).

50. Line 174: Not all sites in the PRD had max MDA8 O_3 greater than the threshold in all four years (Fig 11). The authors should clarify this point.

Reply:

This sentence was clarified as follows:

Revision:

……The summer **mean** MDA8 in the PRD was not as high as that in in NC and the YRD (Figure 1a), but maximum O_3 concentration exceeded 265 μg/m³ could be observed **in certain large cities of PRD in each year** (Figure 7)……

51. Line 175: Is “eastern China” referring to the YRD region or the full region 110-125E, 22-42N?

Reply:

The region was eastern China (110°E–125°E, 22°N–42°N), which was annotated in the first paragraph of Section 2.

52. Line 184: I believe this sentence incorrectly references Fig 11d and it should reference Fig S2.

Reply:

The old Figure S2 was moved into the main text and referenced as Figure 8 now. This error was revised.

Revision:

……The dominant pattern of 2016 was PAT2 (explaining approximately 24% of the variance, **Figure 8c**), while that in 2018 changed as PAT1, with nearly 34% variance contributions (**Figure 8g**)……

53. Line 188: I believe this sentence incorrectly references Fig 10b and it should reference Fig 11b. Line 189: change 2105 to 2015.

Reply:

These errors were corrected.

Revision:

……The MDA8 anomalies in 2016 were negative in NC, but positive in the YRD and PRD (**Figure 7b**), which was the opposite pattern of PAT2. The interannual anomalies of atmospheric circulations in 2016, **with respect to the mean of 2015–2018** (Figure 10)……

54. Line 190 and 199: The anomalous pattern in Figure 13a looks to me to be the opposite of Figure 9a, so do I interpret this correctly that 2016 is predominately in the negative phase of the PAT2. If that is correct, it should be

discussed as such.

Reply:

According to the reviewer's advice, the presentation was discussed as "opposite to the PAT2".

Revision:

……The MDA8 anomalies in 2016 were negative in NC, but positive in the YRD and PRD (Figure 7b), which was **the opposite pattern** of PAT2. The interannual anomalies of atmospheric circulations in 2016, with respect to the mean of 2015–2018 (Figure 10), **were opposite to** the anomalous atmospheric circulations associated with PAT2 (Figure 6)……

55. Line 194: I am having a hard time following the authors description without the purple boxes to indicate on the map the NH, NC, and YRD, e.g., I do not see the WPSH is near the YRD as described.

Reply:

(1) The locations of the key areas were indicated in the revised Figures.

(2) In Figure 10a, positive Z500 anomalies located near the YRD, indicating the WPSH moved westward and northward.

Revision:

……The western segment of the WPSH was stronger and moved northward, which occupied the YRD and south China (Figure 10a) and brought moist air flows to North China (Figure 10b)……

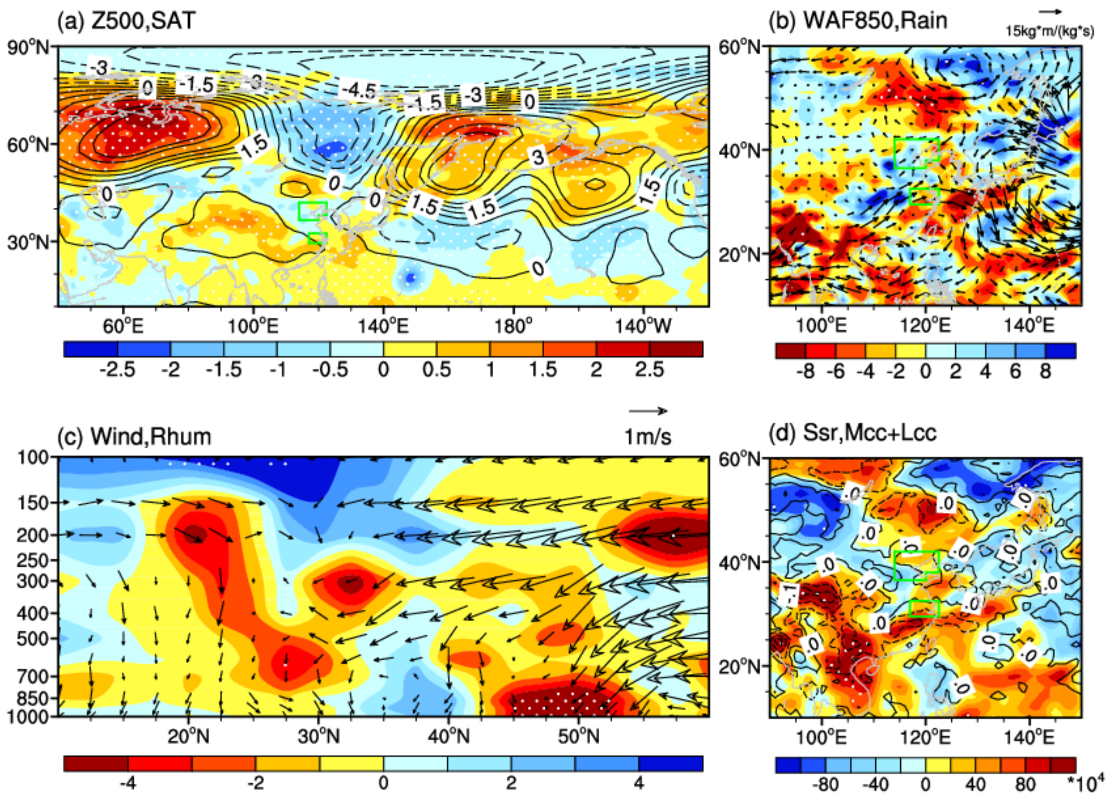

Figure 10. Anomalies of summer mean daytime atmospheric circulations in 2016, with respect to the mean during 2015–2018. (a) Geopotential height at 500 hPa (Unit: 10gpm, contours) and surface air temperature (Unit: K, shading), (b) water vapor flux (Unit: kg*m/(kg*s)) at 850 hPa (arrows) and precipitation (Unit: 0.1mm, shading), (c) 100°E–120°E mean wind (Unit: m/s, arrows) and relative humidity (Unit: %, shading), (d) downward solar radiation at the surface (Unit: $10^4 J/m^2$, shading) and the sum of low and medium cloud cover (Unit: 1, contours). The green boxes in panel (a), (b) and (d) are the NC and YRD regions. The white dots indicate that the shading was above the 95% confidence level.

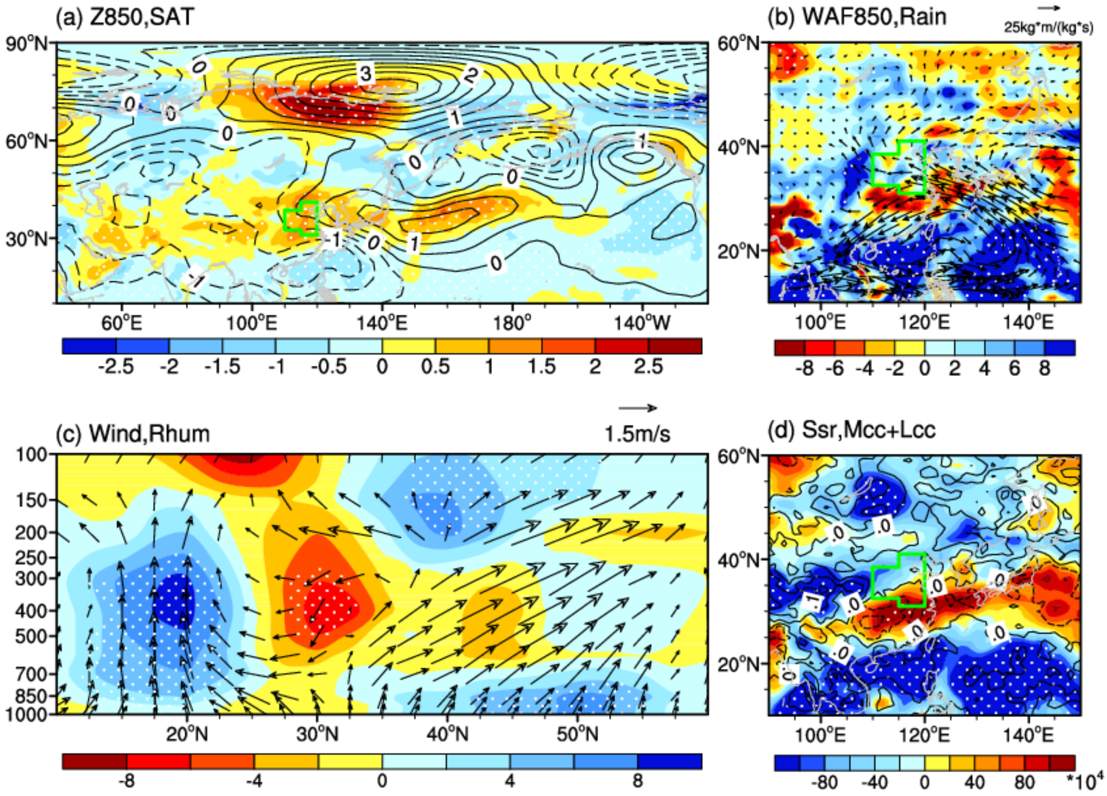

Figure 11. Anomalies of summer mean daytime atmospheric circulations in 2018 with respect to the mean during 2015–2018. (a) Geopotential height at 850 hPa (Unit: 10gpm, contours) and surface air temperature (Unit: K, shading), (b) water vapor flux (Unit: kg*m/(kg*s)) at 850 hPa (arrows) and precipitation (Unit: 0.1mm, shading), (c) 100°E–120°E mean wind (Unit: m/s, arrows) and relative humidity (Unit: %, shading), (d) downward solar radiation at the surface (Unit: $10^4 J/m^2$, shading) and the sum of low and medium cloud cover (Unit: 1, contours). The green boxes in panels (a), (b) and (d) show the NCH region. The white dots indicate that the shading was above the 95% confidence level.

56. Line 202: I believe this sentence incorrectly references Fig 10d and it should reference Fig 11d.

Reply:

The reference was revised to Figure 7d.

Revision:

The MDA8 anomalies were mostly positive in the east of China in 2018 (Figure ~~10~~7d). "–+–" Z850 anomalies were located over the Ural Mountains and to the north of Lake Baikal and the Aleutian Islands (Figure 1~~2~~1a), which was consistent

57. (1) Line 202-205: I am struggling with the description of the negative, positive, negative pattern in the Z850 and the link to the Figure 7.

(2) Also, is the description of the shift in the East Asia deep trough and the

WSPH "northward" relative to Figure 7 or to something else? The authors could include again a black box to indicate the location of the East Asia deep trough similar to Figure 7 and 9 and also the coordinates or a box to indicate the WSPH.

Reply:

(1) This "–+–" pattern of Z850 anomalies was distributed like a Rossy wave train, which **occurred both in the Figure 5a and Figure 10a (Figure R3).**

"–+–" Z850 anomalies were located over the Ural Mountains and to the north of Lake Baikal and the Aleutian Islands (Figure 11a), which was consistent with the anomalous patterns in Figure 5.

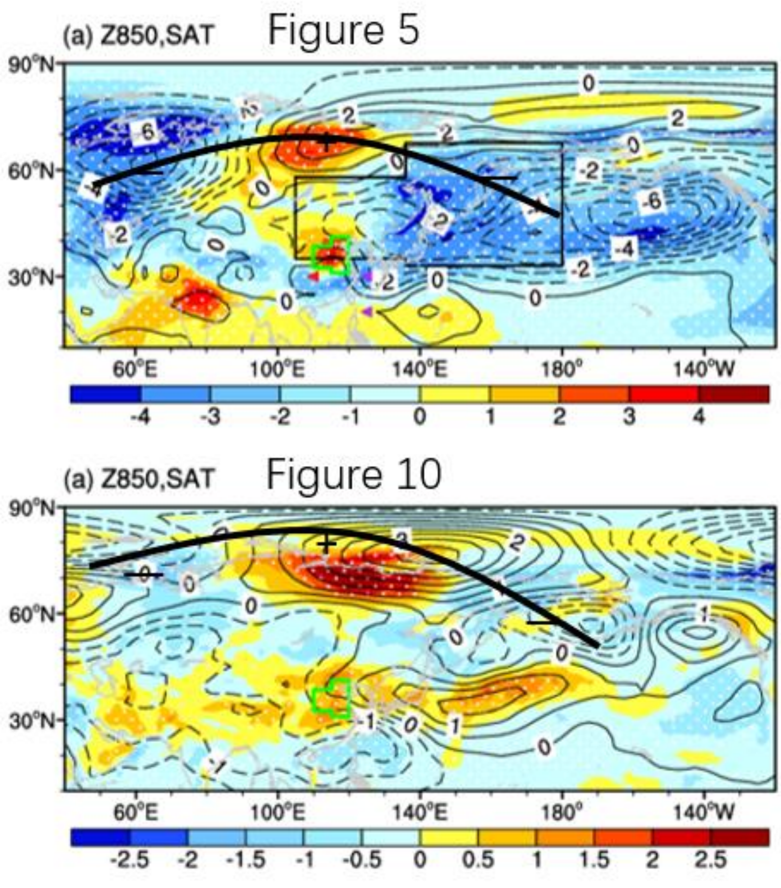

Figure R3. The similarity between Figure 5a and Figure 10a, particularity showing the "－+–" pattern of Z850 anomalies.

(2) The location and intensity of WPSH and East Asia deep trough were compared to the mean status during 2015–2018, which was clarified in the revised version.

Revision:

……"–+–" pattern of Z850 anomalies were located over the Ural Mountains and to the north of Lake Baikal and the Aleutian Islands (Figure 11a), which was consistent **with the anomalous patterns in Figure 5.** The East Asia deep trough shifted northward **than the mean status during 2015–2018**, and meanwhile, the western ridge point of WPSH also shifted northward……

58. Line 207-208: I believe this sentence incorrectly references Fig 12 when it should be Figure 14b and 14d, respectively.

Reply:

The reference was revised to Figure 11.

Revision:

vapor in southeast China (Figure 1~~2~~1b). Due to the lack of moisture, it was difficult for cloud cover to form, and more solar radiation directly reached the ground (Figure 1~~2~~1d). The large-scale atmospheric circulations led to high temperatures near the

59. Line 227: Again, I do not understand what is meant by "cold air activities".

Reply:

According to the reviewer's advice, the "weak cold activity" was replaced by "less cold air advection from the north" throughout the manuscript.

Revision:

showed remarkable south-north differences. Broad positive geopotential height anomalies at the high latitudes significantly increased the surface air temperature and thus decreased cold air advection from the north~~activities~~. These positive anomalies

FIGURE specific comments:

60. Line 89: Consider labeling or marking the cities of interest (e.g., Beijing and Tianjin; actually, all cities from Figure 2) on Figure 1a so it is easier for readers less familiar with Chinese geography. Another idea would be to provide a map next to Figure 2 time series with the cities labelled, possibly within the boxed regions shown in Figure 3.

Reply:

According to the reviewer's comment, the purpose and the analysis of Figure 2 were rewrite and a map of ten selected sites was supplemented as Figure S2.

The locations of these ten cities were also introduced as "including Beijing (capital of China), Tangshan, Tianjin near the capital city, Shijiazhuang, Weifang and Taiyuan in the south of NCH, Nanjing and Shanghai in YRD, Guangdong and Zhongshan in PRD (Figure S2)".

Revision:

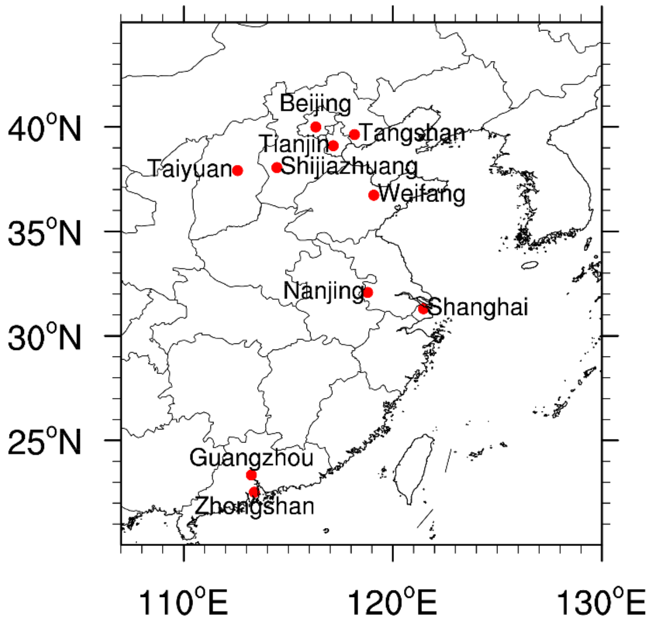

Figure S2. The distribution of ten representive cities with severe O_3 pollutions.

61. Line 90: It might be too cluttered to do this; but, adding dashed lines at 215 µg/m^3 and 100µg/m^3 on Figure 2 could help the reader to see the frequency of O_3 concentrations above the moderate polluted level and below the non-polluted level.

Reply:

According to the reviewer's advice, Figure 2 was re-plotted and improved. The horizontal dash lines indicated the value of 100 µg/m^3 and 215 µg/m^3.

Revision:

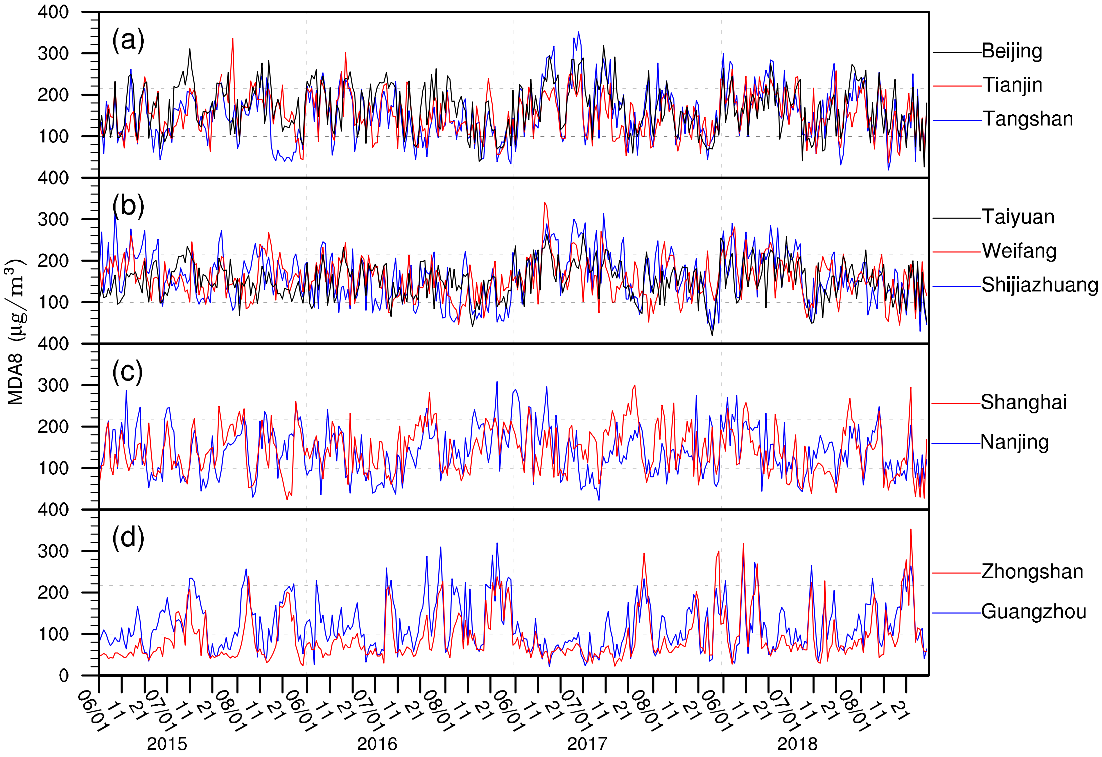

Figure 2. Variations in MDA8 (Unit: μg/m³) of polluted cities from 2015 to 2018, including (a) Beijing, Tianjin and Tangshan; (b) Taiyuan, Weifang and Shijiazhuang; (c) Shanghai and Nanjing; and (d) Zhongshan and Guangzhou. The cites in panels a-d were located from north to south. **The horizontal dash lines indicated the value of 100 μg/m³ and 215 μg/m³.**

62. Line 330, 395: There are no units in the Figure 1 caption nor on the Figure itself by the color bar. From the text on Page 3, I presume μg/m³. I suggest removing the y-axis latitude labels of Figure 1b, since the same as Figure 1a, to reduce the amount of text between panels.

Reply:

The units were added throughout the manuscript.

Because the maximum MDA8 in Figure 1b was actually a daily value and could be compared to the air quality thresholds of MDA8. Thus, the color bar of Figure 1b was redivided according to the thresholds.

Revision:

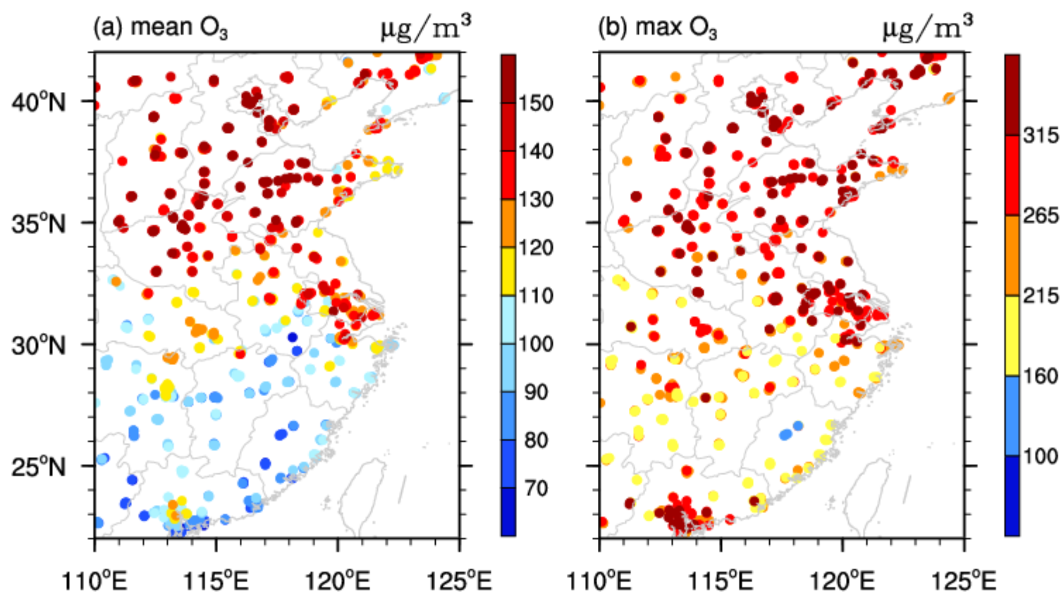

Figure 1. Distribution of the (a) mean values and (b) maximum values of MDA8 (Unit: μg/m³) at the observation sites in summer from 2015 to 2018.

63. Line 332,397: Label each panel a) b) c) d) in Figure 2 to match the figure caption. Should there be a ‘g’ at the end of Tianjin as the line label shows in Figure 2a? Flip the order of the legend labels (i.e., Beijing on the top of the list, not the bottom) to match the order listed in the figure caption and to match the stacking of the box and whisker plots in Figure 3. Also, add labels maybe to the left of each panel, indicating which region each panel represents. If I followed the paper correctly, a) NC, c) YRD, and d) PRD, but from the text I wasn’t sure where the cities in panel b come from, but only one left is NH.

Reply:

The Figure 2 was re-plotted and revised all of the problems mentioned;

Panel a: Beijing (capital of China), Tangshan, Tianjin near the capital city;

Panel b: Shijiazhuang, Weifang and Taiyuan in the south of NCH;

Panel c: Nanjing and Shanghai in YRD;

Panel d: Guangdong and Zhongshan in PRD (Figure S2)”.

The Figure 3 was deleted.

Revision:

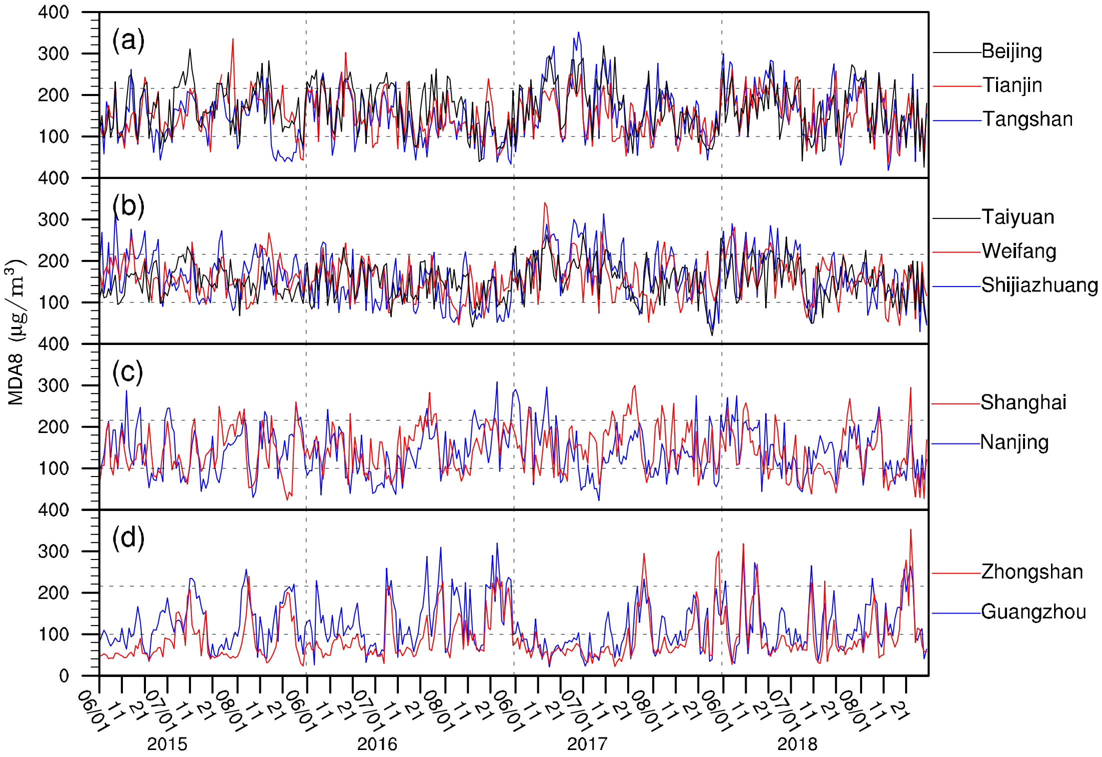

Figure 2. Variations in MDA8 (Unit: μg/m³) of polluted cities from 2015 to 2018, including (a) Beijing, Tianjin and Tangshan; (b) Taiyuan, Weifang and Shijiazhuang; (c) Shanghai and Nanjing; and (d) Zhongshan and Guangzhou. The cites in panels a-d were located from north to south. **The horizontal dash lines indicated the value of 100 μg/m³ and 215 μg/m³.**

64. Line 406: missing comma (NC)

Reply:

This error was corrected.

Revision in the Figure 3 caption:

……North China and Huanghuai region (NCH), North China (NC), Yangtze River Delta (YRD)……

65. Line 415: What are the red crosses on Figure 7a. They are not mentioned in the figure caption.

Reply:

The red crosses were replaced by purple triangles, which was explained in the Figure captions.

Revision:

Figure 5. ……The purple triangles indicated the data used to calculate the $WPSH_1$, while the red triangle represented the west ridge point of WPSH……

Figure 6. ……The purple triangles indicated the data used to calculate the $WPSH_2$……

66. Line 416, 436: Figures 7 and 8 are not simply a composite, but a difference of the composites, if I understand the "(i.e., PAT1P-PAT1N)" correctly. I also find the use of blue/red color bar counter-intuitive to show drier air as blue and more precipitation/moist air as red in Fig 7b and c. I suggest using either different color bar colors (such as brown/blue or brown/green) or flip the blue/red so red is for negative and blue for positive.

Reply:

(1) Yes, what are shown in Figure 5 and 6 are the differences (PAT1P minus PAT1N). To be clearer, the Figure caption was revised.

(2) The color bar of Figure 5 b-c and Figure 6 b-c were flipped.

Revision:

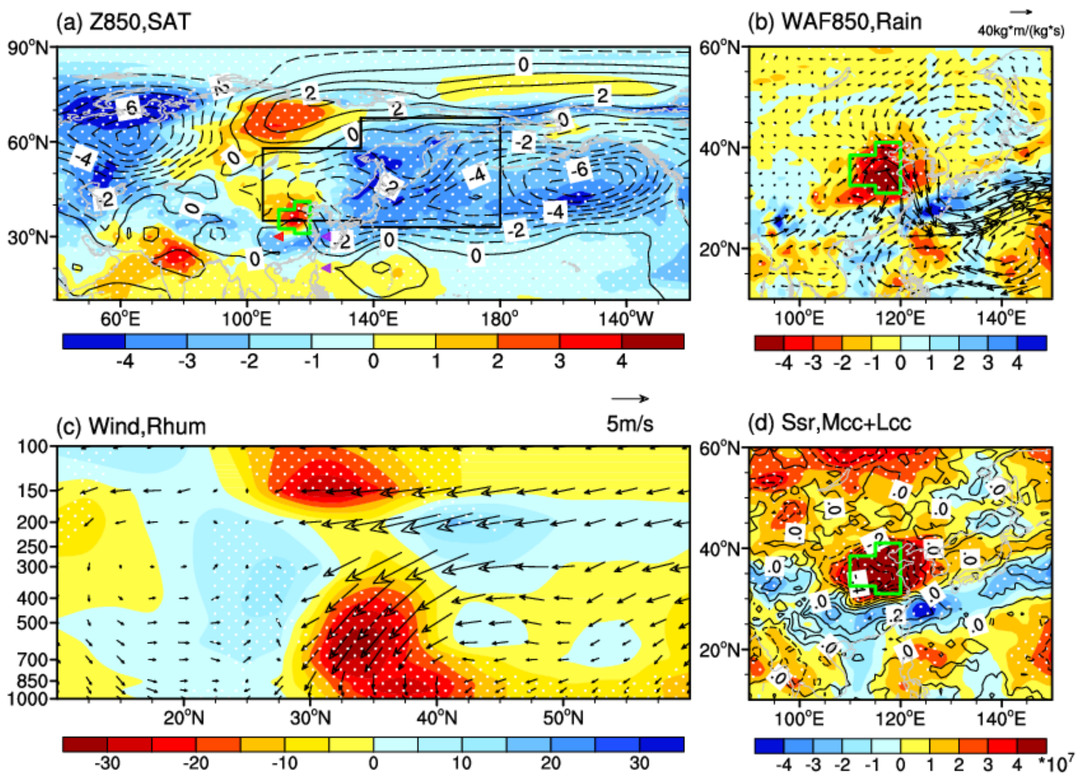

Figure 5. Differences of the daytime atmospheric circulations (i.e., PAT1P minus PAT1N). (a) Geopotential height at 850 hPa (Unit: 10gpm, contours) and surface air temperature (Unit: K, shading), (b) water vapor flux (Unit: kg*m/(kg*s)) at 850 hPa (arrows) and precipitation (Unit: mm, shading), (c) 100°E–120°E mean wind (Unit: m/s, arrows) and relative humidity (Unit: %, shading), (d) downward solar radiation at the surface (Unit:10^7 J/m^2, shading) and the sum of low and medium cloud cover (Unit: 1, contours). The white dots indicate that the shading was above the 95% confidence level. The green boxes in panels a, b and d show the NCH region, and the black box in panel a indicates the location of the East Asia trough. The purple triangles indicated the data used to calculate the WPSH$_1$, while the red triangle represented the west ridge point of WPSH.

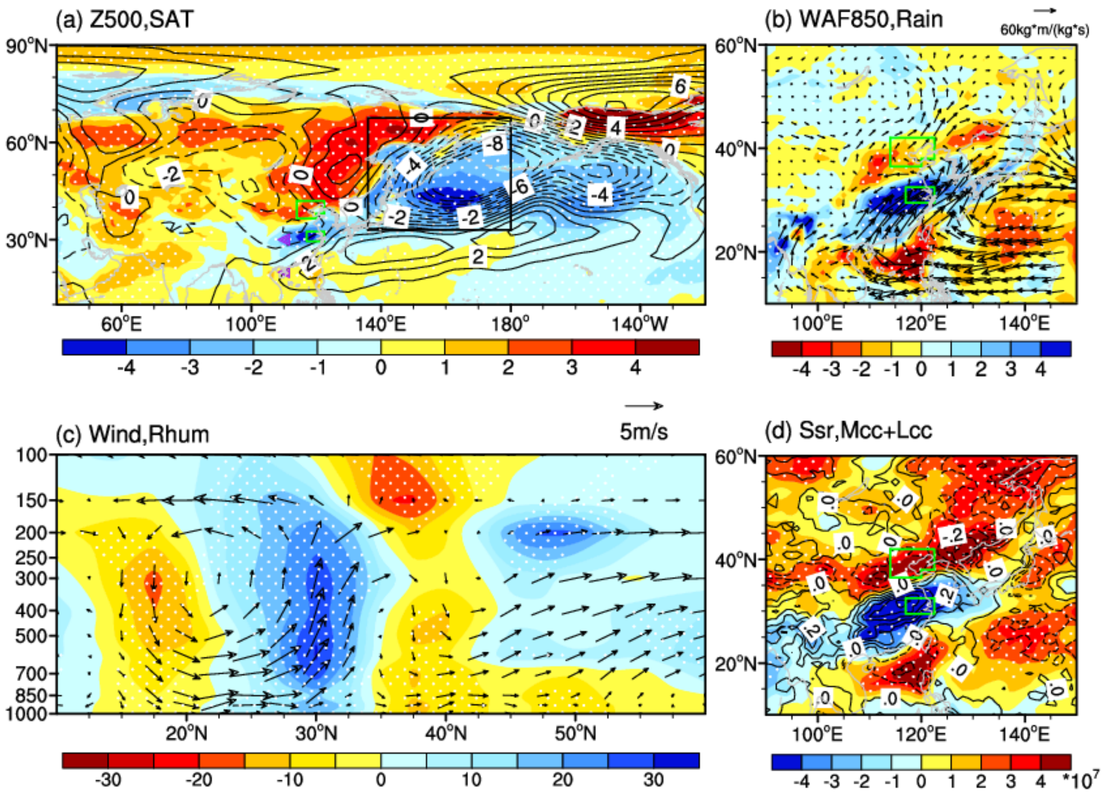

Figure 6. Differences of the daytime atmospheric circulations (i.e., PAT2P minus PAT2N). (a) Geopotential height at 500 hPa (Unit: 10gpm, contours) and surface air temperature (Unit: K, shading), (b) water vapor flux (Unit: kg*m/(kg*s)) at 850 hPa (arrows) and precipitation (Unit: mm, shading), (c) 100°E–120°E mean wind (Unit: m/s, arrows) and relative humidity (Unit: %, shading), (d) downward solar radiation at the surface (Unit: 10^7J/m^2, shading) and the sum of low and medium cloud cover (Unit: 1, contours). The white dots indicate that the shading was above the 95% confidence level. The green boxes in panel a, b and d are the NC and YRD regions, and the black box in panel a indicates the location of the East Asia trough. The purple triangles indicated the data used to calculate the WPSH$_2$.

67. Line 430, 455: Figures 8 and 10 legends are hard to see as there is not much white space between the legend lines and the contours and they are close to the dashed lines separating the years. Can they be added to the side, outside the panels?

Reply:

Because no new information was showed in these two Figures, the Figure 8 and 10 were deleted.

68. Line 440: It is near impossible to see the purple boxes indicating NC and YRD regions, especially in panels a and d, when I printed the figures. It is also hard to read the arrows in Fig 9b in the region of NC and where the arrows are long and dense over China and Japan.

Reply:

(1) The boxes were in green now, which was revised throughout the manuscript.

(2) The scale of the arrows was modified.

Revision:

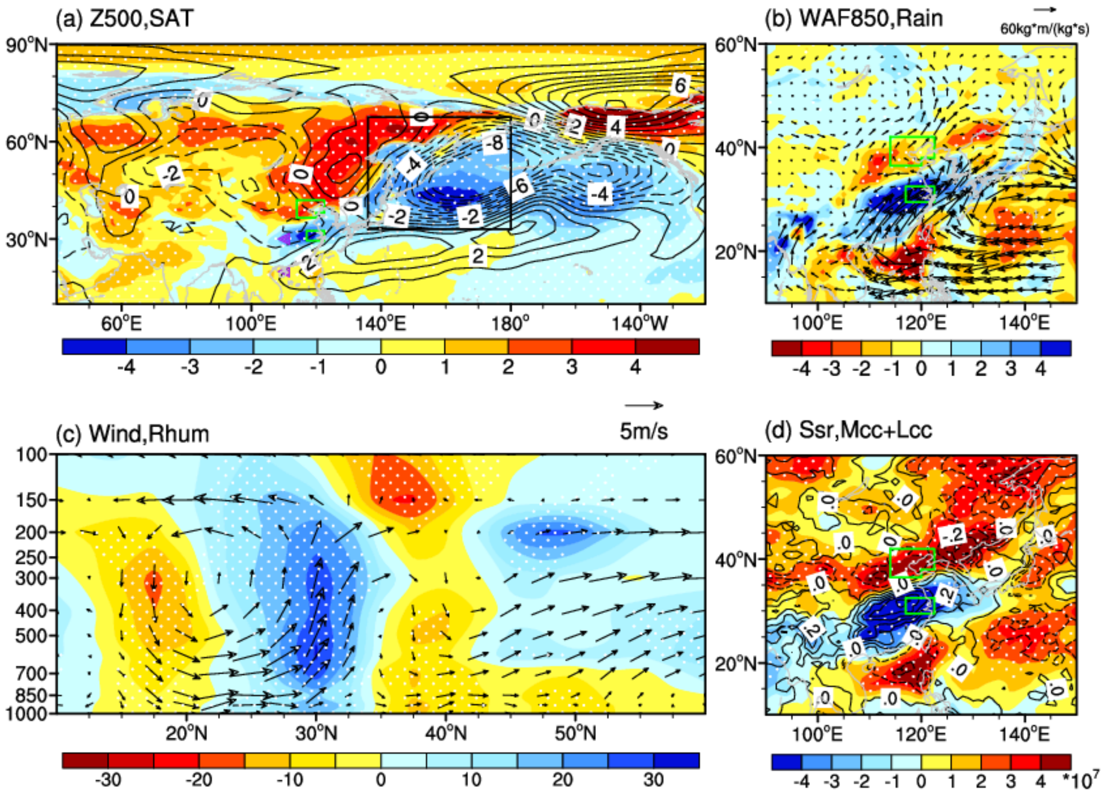

Figure 6. Differences of the daytime atmospheric circulations (i.e., PAT2P minus PAT2N). (a) Geopotential height at 500 hPa (Unit: 10gpm, contours) and surface air temperature (Unit: K, shading), (b) water vapor flux (Unit: kg*m/(kg*s)) at 850 hPa (arrows) and precipitation (Unit: mm, shading), (c) 100°E–120°E mean wind (Unit: m/s, arrows) and relative humidity (Unit: %, shading), (d) downward solar radiation at the surface (Unit: 10^7J/m^2, shading) and the sum of low and medium cloud cover (Unit: 1, contours). The white dots indicate that the shading was above the 95% confidence level. The

green boxes in panel a, b and d are the NC and YRD regions, and the black box in panel a indicates the location of the East Asia trough. The purple triangles indicated the data used to calculate the $WPSH_2$.

69. Line 459: missing space “2018 (d)”

Reply:

This error was corrected.

Revision:

Figure 7. ……2016 (b), 2017 (c) and 2018 (d),……

70. Line 465, 472: Are the anomalies in Figure 13 and Figure 14 also “daytime”. If so, include like in Figures 7 and 9.

Reply:

In Figure 13 and 14, the anomalies were also the daytime atmospheric circulations.

Response to Reviewer #2

Summary

This manuscript aims to analyze the dominant patterns of summer ozone over China in recent years, and associated circulations. While the topic is of importance to the field, the conclusions drawn from the study are not convincing to me.

1. The general patterns of ozone pollution and the association with meteorology have been reported in previous papers.

The authors need to clarify the novelty and scientific contribution of this study.

The methods in general lack novelty.

Reply:

The novelty of this study was sufficiently explained from three perspectives, listing as ***(1)-(3)***. Also, we revised the manuscript to present the novelty in a clearer way.

(1) In most of previous studies related to ozone pollution, the most popular topic was the relationship *meteorological elements* (e.g., temperature, precipitation, etc.) and O_3 concentrations in *single city*. These kind of studies **did not included the analysis of large-scale atmospheric circulations**, the diagnosis of **dominant patterns** and their **varying features**, and the **signals for interannual variability**.

Furthermore, in the Sect. 1 (Introduction), we referred a review article published in 2017 and point out "Wang et al. (2017) reviewed the meteorological influences on ozone events, **but the referenced findings were published mainly before 2010**, when measurements in China were still scarce."

These kind of studies was quite different from our submitted manuscript. The detailed novelty was illustrated in the following point (2).

(2) Actually, Zhao and Wang (2017) also talked about the dominant pattern of surface ozone and the impact of WPSH. Here, we emphatically explained the novelty of this study by the differences with Zhao and Wang (2017). That is, using the following **four sub-points**, we emphasized this novelty.

(2.1) We revealed **two dominant patterns, their varying sorts** in different years and their **associated anomalous atmospheric circulations.** Although the north-south differential pattern was the first mode in 2014 (Zhao and Wang 2017), 2015 and 2016, it was sorted in the second place in 2017 and 2018 (Figure S5 in the revised manuscript). That is, our study not only revealed the two dominant patterns, what is more important, also **showed the varying features of the dominant patterns.** In the recent two years, the most dominant pattern was different from that in previous years, which is **a new feature and might related to the climate status**. Additionally, the comprehensive atmospheric circulations were analyzed, including the **location** of west Pacific subtropical high (WPSH), the **East Asia deep trough** and other atmospheric anomalies. In Wang and Zhao (2017), they solely focused on the impacts of the WPSH, particularly on the **accumulative enhancement** of WPSH.

(2.2) We clearly explained the anomalous atmospheric circulations related the O_3 pollution **both in North China and in South China**. However, in Wang and Zhao (2017), the **physical mechanisms to impact O_3 in North China was still not sufficiently explained** (referring to the *weak correlation* coefficients in the ***green boxes*** in Figure R1 d–f). We speculated the reason for insufficient explanations on O_3 conditions in North China might be that the impacts form the mid-high latitudes were significant which was not involved in Zhao and Wang (2017). In our study, we found **both of the WPSH and the East Asia deep trough** had impacts on the O_3 concentrations in the east of China (Table 1). Furthermore, we **paid more attentions to the O_3 concentrations in North China** where the surface O_3 polluted levels were much higher than in the Yangtze River Delta and Pearl River Delta. The **WPSH and East Asia deep trough jointly modulated** the local meteorological conditions to influence the O_3 concentrations.

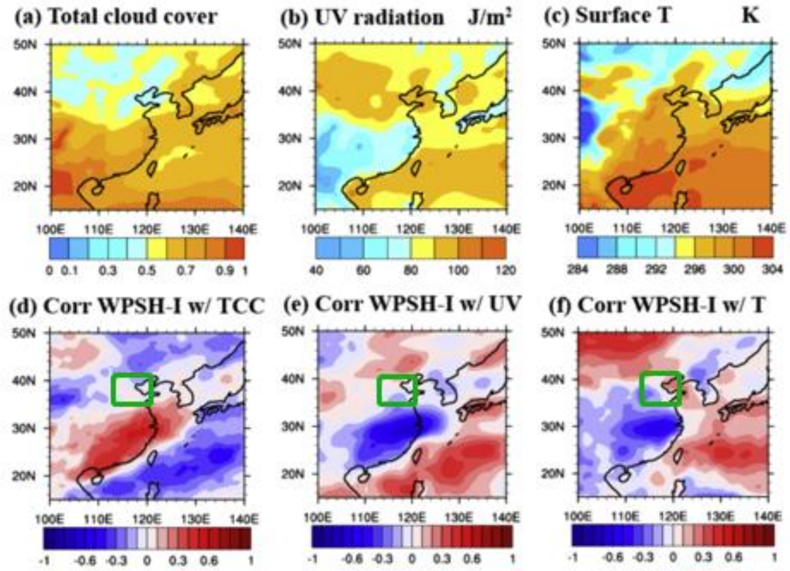

Fig. 6. (Upper panel) the summer mean fields of meteorological parameters and (lower panel) their correlations with the daily WPSH-I_anomalies: total cloud cover (a, d), downward UV radiation at the surface (b, e), and near-surface air temperature (c, f).

Figure R1. The Figure 6 in Zhao and Wang (2017). The summer mean fields of meteorological parameters (a–c) and their correlations with daily WPSH: total cloud cover (a, d), UV radiation (b, e) and near surface air temperature (c, f). The added green boxes indicate the location of North China.

Table 1. Correlation coefficients between the time series of PAT1 (PAT2) and the key indices of atmospheric circulations and meteorological conditions. "**" and "*" indicate that the correlation coefficients were above the 99% and 95% confidence level, respectively.

PAT1	**$MDA8_1$**	**EAT_1**	**$WPSH_1$**
	0.97^{**}	0.28^{**}	0.39^{**}
PAT2	**$MDA8_2$**	**EAT_2**	**$WPSH_2$**
	0.77^{**}	0.30^{**}	0.32^{**}

$MDA8_1$ is the NCH-area averaged MDA8, while the $MDA8_2$ is the MDA8 difference between NC and YRD. EAT_1 and EAT_2 indicate the intensity of the East Asia deep trough and were calculated as the mean –Z850, shown in the black boxes in Figure 7 and Figure 9, respectively. $WPSH_1$ ($Z500_{(125^0E,\ 20^0N)} - Z500_{(125^0E,\ 30^0N)}$) and $WPSH_2$ ($Z500_{(110^0E,\ 20^0N)} - Z500_{(110^0E,\ 30^0N)}$) represents the location of WPSH.

(2.3) The number and distribution of the sites are more sufficient and updated. In the EOF analysis of Zhao and Wang (2017), the number of O_3 sties was **only 191** in 2014 even in a larger study region than ours (Figure R2). The number (fewer than 200) and distributions (uneven) of the sites were limited, due to the establishment progress of the observation sites of atmospheric components in 2014.

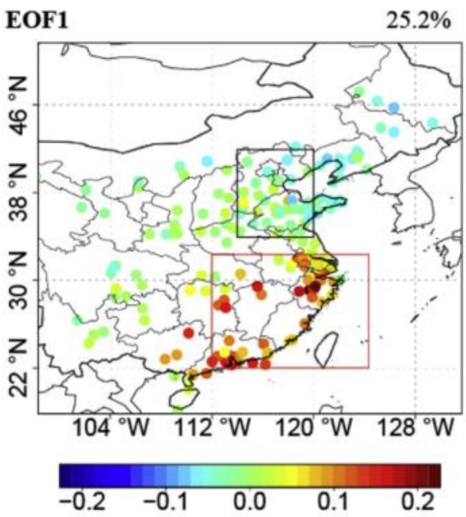

Fig. 3. The EOF1 of daily summer MDA8 ozone in 2014. The black rectangle outlines North China (NC); the red rectangle outlines South China (SC).

Figure R2. The Figure 3 in Zhao and Wang (2017), i.e., the EOF1 results in 2014 (also the sites distribution)

Since the severe air pollution events in 2013, the air pollution issues gained more attentions from the Chinese government and society, which aided to start the extensive constructions of operational monitoring stations of atmospheric components and resulted in continuous increasing number of sites (Figure S1). **The number of sites in eastern China (110ºE–125ºE, 22ºN–42ºN) was 677, 937, 937, 995 and 1007 from 2014 to 2018.** It is obvious that the data in 2014 were deficient, while the observations were broadly distributed in eastern China and continuously achieved since 2015. Thus, the summer O_3 data from 2015 to 2018 were processed (e.g., unifying the sites and eliminating the missing value) and ***868 sites in eastern China were employed here*** to reveal some new features of surface ozone pollutions and associated anomalous atmospheric circulations.

Although the number of sites in 2014 in our denser data source were nearly 4 times that in Zhao and Wang (2017), **the data in the green box in Figure S1 were almost a blank.** That is why our study period was 2015–2018. To make this point clear, we **added Figure S1**. From 2015 to 2018, the selected 868 sties relatively even. Certainly, the sites were almost located around the urban area, due to their observed purposes (related to air pollutions).

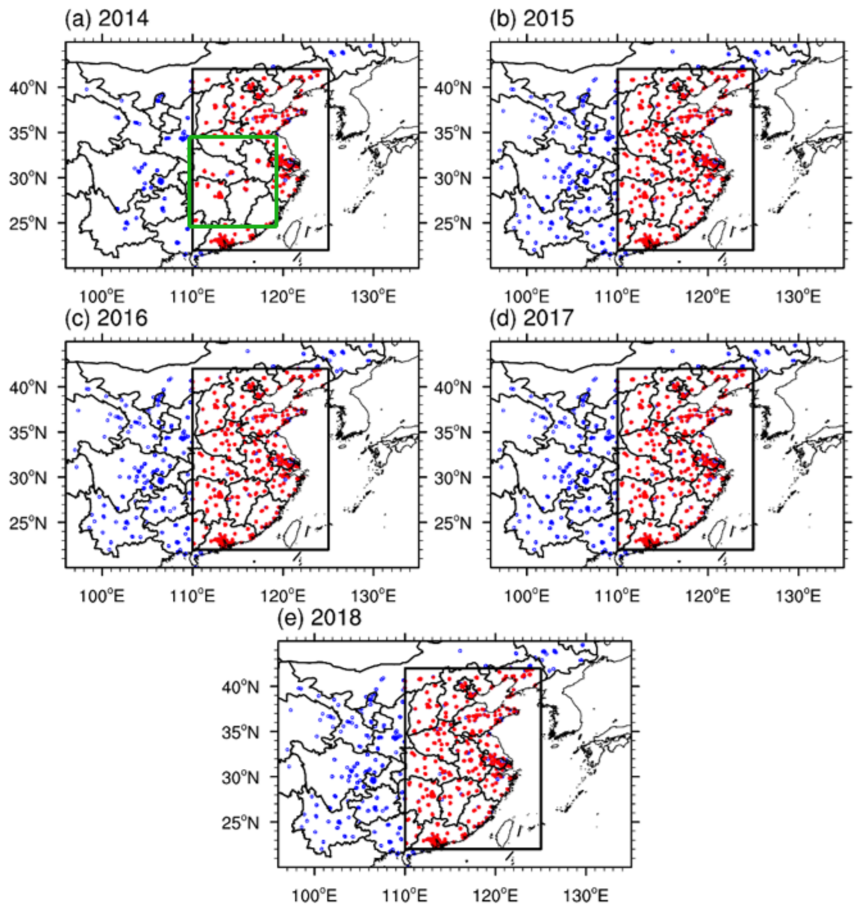

Figure S1. The distribution of measurement sites of atmospheric components (blue and red points) from 2014 to 2018. The red sites indicate the employed sites in this study related to O_3 pollution.

(2.4) In our study, we also discuss the **implications to interannual variability** in Sect 5, and pointed out that the **composites results from the daily data also provided useful signals for the interannual variability on the climate time-scale**. For example, the anomalous atmospheric patterns in 2016 were benefit for the occurrence of the north-south differential pattern of summer mean O_3 concentrations. Differently, the atmospheric circulations in 2018 resulted in positive O_3 anomalies in the whole eastern China.

The aforementioned four points, especially (1) (2) and (4), were **novel and we did not see similar researches so far**. Actually, there were some publications about the relationship meteorological elements (e.g., temperature, precipitation, etc.) and O_3 concentrations in single city, which provide basis for our study. **These kind of studies did not included the analysis of atmospheric circulations, the diagnosis of**

dominant patterns and their varying features, and the signals for interannual variability. As for the results in Zhao and Wang (2017), we clearly and convincingly discussed the differences between their and our studies. Furthermore, in the Sect. 1 (Introduction), we referred a review article published in 2017 and point out "**Wang et al. (2017) reviewed the meteorological influences on ozone events, but the referenced findings were published mainly before 2010,** when measurements in China were still scarce."

(3) The methods in this study were mainly the empirical orthogonal function (EOF) analysis and the composite approach, which were widely and classically used in the meteorology, even in the recent years. In addition to the approach, **the data sources and the conclusions were latest and novel**.

Related references:

Wang, T., Xue, L. K., Brimblecombe, P., Lam, Y. F., Li, L., Zhang, L.: Ozone pollution in China: A review of concentrations, meteorological influences, chemical precursors, and effects, Science of The Total Environment, 575, 1582-1596, doi:10.1016/j.scitotenv.2016.10.081, 2017.

Zhao, Z. J., Wang, Y. X.: Influence of the west pacific subtropical high on surface ozone daily variability in summertime over eastern china, Atmospheric Environment, 170, 197–204, https://doi.org/10.1016/j.atmosenv.2017.09.024, 2017.

Revision:

In the last paragraph of Introduction:

……Basing on a case study in 2014, further studies showed that a strong west Pacific subtropical high (WPSH) was unfavourable for the formation of O_3 in South China (Zhao and Wang, 2017), **however the physical mechanisms to impact O_3 in North China was still not sufficiently explained**.

Wang et al. (2017) reviewed the meteorological influences on ozone events, but the referenced findings were published mainly before 2010, when measurements in China were still scarce. Since 2015, O_3 measurements in eastern China were steadily and widely implemented, but the O_3-weather studies mainly focused on

meteorological elements (e.g. temperature, precipitation etc.) and **several synoptic processes** (Xu et al., 2017; Xiao et al., 2018; Pu et al., 2013). The dominant patterns of daily ozone in summer in east of China are still unclear. **Actually, in our study, we found the most dominant pattern was different with that in Zhao and Wang (2017) and the dominant patterns also showed interannual variations.** The findings of this study basically help to understand the varying features of surface ozone pollution in eastern China, their relationships with large-scale atmospheric circulations and the implications for the climate variability……

In the Datasets and methods:

……Nationwide hourly O_3 concentration data since May 2014 are publicly available on http://beijingair.sinaapp.com/. Since the severe air pollution events in 2013, the air pollution issues gained more attentions from the Chinese government and society, which aided to start the extensive constructions of operational monitoring stations of atmospheric components and resulted in continuous increasing number of sites (Figure S1). The number of sites in eastern China (110°E–125°E, 22°N–42°N) was 677, 937, 937, 995 and 1007 from 2014 to 2018. It is obvious that the data in 2014 were deficient, while the observations were broadly distributed in eastern China and continuously achieved since 2015. Thus, the summer O_3 data from 2015 to 2018 were processed (e.g., unifying the sites and eliminating the missing value) and 868 sites in eastern China were employed here to reveal some new features of surface ozone pollutions and associated anomalous atmospheric circulations……

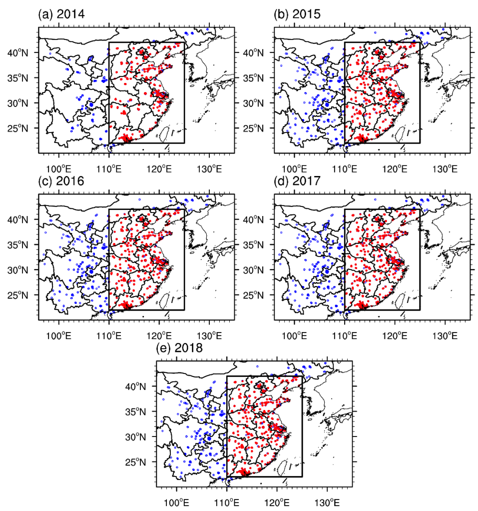

Figure S1. The distribution of measurement sites of atmospheric components (blue and red points) from 2014 to 2018. The red sites indicate the employed sites in this study related to O_3 pollution.

2. The presentation of this paper is also confusing. I had a hard time following the manuscript. The authors presented 14 figures, but most of them are quite confusing without clear explanations. There are a number of issues that should be addressed in order to make this paper suitable for publication. I have the following major comments and some minor comments.
Overall, the language of the manuscript should be further polished. There are several grammatical errors, which should be edited carefully.

Reply:

(1) Many apologies for the confusing writing. In the revised version, we almost rewrite the texts and decrease the number of Figures from 14 to 11. Some necessary information, e.g., the distribution of sites and cities, were added in the supplementary. An important Figure S2 was moved to the main texts as Figure 8.

(2) Most of the Figures were replotted to show the information in a clearer way.

(3) The incorrect figure references and statements were revised throughout the manuscript.

(4) The English were improved by the native English-speaker.

Major Comments:

1. (1) The spatial and temporal patterns of ozone could also be driven by anthropogenic emissions. The manuscript gave me an impression that ozone pattern in China is purely driven by circulation, which is not true. It's possible that the North-South pattern is mainly driven by emission variations.
(3) Also, the inter-annual variability in ozone may also be related to the emission changes in past years. The authors need to discuss how emission variations would affect their analysis.

Reply:

There was no doubt that the ozone pollutions closely related to the anthropogenic emissions. **In the old version of manuscript**, we presented it as "Due to their **close relationship with anthropogenic emissions** (Li et al., 2018), the high O_3 concentrations in China are mainly observed in urban regions" and "Surface O_3 pollution was **closely linked to the anthropogenic emission**s that dispersed and concentrated in the large cities".

In the beginning of the second paragraph in Introduction, we directly pointed out "Although deep stratospheric intrusions may elevate surface ozone levels (Lin et al., 2015), **the main source of surface ozone is the photochemical reactions between the oxides of nitrogen (NO_x) and volatile organic compounds (VOC), i.e., NO_x + VOC = O_3.** The concentrations of NO_x and VOC are fundamental drivers impacting ozone production, and are sensitive to the regime of ozone formation, i.e., NO_x-limited or VOC-limited (Jin and Holloway 2015). The changes in fine particulate matter are also a pervasive factor for the variation in ozone concentration."

In the revised version, we enhanced the discussion about the relative impacts of the human activities and the atmospheric circulation **in the following three points**.

(1) The main point of Section 3 is to **find the first two dominant patterns** of ozone concentration and the **varying features** of these patterns.

The main point of Section 4 is to **show the anomalous atmospheric circulation which *resulted in fluctuation of MDA8 on the basis of the existing distribution patterns***, which is evidently different from "The spatial and temporal patterns is purely driven by circulation".

To summarize, what we concerned is the MDA8 anomalies ***on the basis of the existing distribution patterns.***

(2) In eastern China, the economic productions and human actives steadily developed in the recent four years and the emissions of ozone precursors were reasonably supposed to be relatively stable **on the daily time-scale.** Surely, the stability of the emissions is relative and the data of daily emission cannot be obtained. Thus, in the numerical models of atmospheric chemistry, the **emission inventory was monthly or yearly updated**.

(3) As regards the inter-annual time scale, the impacts of anthropogenic emission played **more important roles** on the variations in MDA8 anomalies. The summer mean atmospheric circulation anomalies meant that the daily atmosphere more frequently and more strongly remained in a condition which is similar with the anomalous atmospheric circulations in summer. Thus, the summer mean atmospheric circulations partially modulated the levels of the ozone pollutions, i.e., resulting in fluctuations, rather than changed the basic situations.

In Lu et al., (2019), they explored the contributions to 2016–2017 surface ozone pollution over China and found that "the 2017 ozone increases relative to 2016 are **largely due to higher background ozone driven by hotter and drier weather conditions,** while changes in domestic anthropogenic emissions alone would have led to ozone decreases in 2017". Thus, *even on the interannual time-scale, the impacts of meteorological conditions were still significant*.

Reference: Lu, X., Zhang, L., Chen, Y., Zhou, M., Zheng, B., Li, K., Liu, Y., Lin, J., Fu, T.-M., and Zhang, Q.: Exploring 2016–2017 surface ozone pollution over China: source contributions and meteorological influences, Atmos. Chem. Phys., 19, 8339–8361, 2019

To clearly state, we supplemented some presentations in the first paragraph of section 4 and the third paragraph in the "6. Conclusions and discussions", which were copied as follows:

Revision in the first paragraph of Section 4:

……In eastern China, the economic productions and human actives steadily developed in the recent four years and the emissions of ozone precursors were reasonably supposed to be relatively stable on the daily time-scale. Differently, the daily variations in MDA8 were evidently saw in Figure 2. Therefore, the impacts of daily meteorological conditions significantly contributed to the domain patterns of daily O_3 concentrations and their variations……

Revision in the third paragraph of Section 6:

……In this study, we mainly emphasized the contribution of the meteorological impacts and assumed the emissions of ozone precursors were relatively stable on the daily time-scale. There is no doubt that the human activities were the fundamental driver of air pollution even on the daily time-scale. However, the daily emission data were difficult to be acquired, thus the joint effects of the daily meteorological conditions and anthropogenic emissions needed to be discussed in future work……

2. The authors use ground-based observations of ozone describe the general patterns of ozone, but the distribution of ground-based sites is uneven. Most sites in China are urban sites, and there are few rural sites. There is no information how the authors infer spatial distribution of ozone (i.e. Figure 1) from limited sites.

Reply:

(1) **The number of sites in eastern China (110°E–125°E, 22°N–42°N) was 677, 937, 937, 995 and 1007 from 2014 to 2018.** The summer O_3 data from 2015 to 2018 were processed (e.g., unifying the sites and eliminating the missing value) and ***868 sites in eastern China were employed here*** to reveal some new features of surface ozone pollutions and associated anomalous atmospheric circulations.

The aforementioned observations were the densest ozone data source in China. The distribution of the ozone observed sites was supplemented as Figure S1.

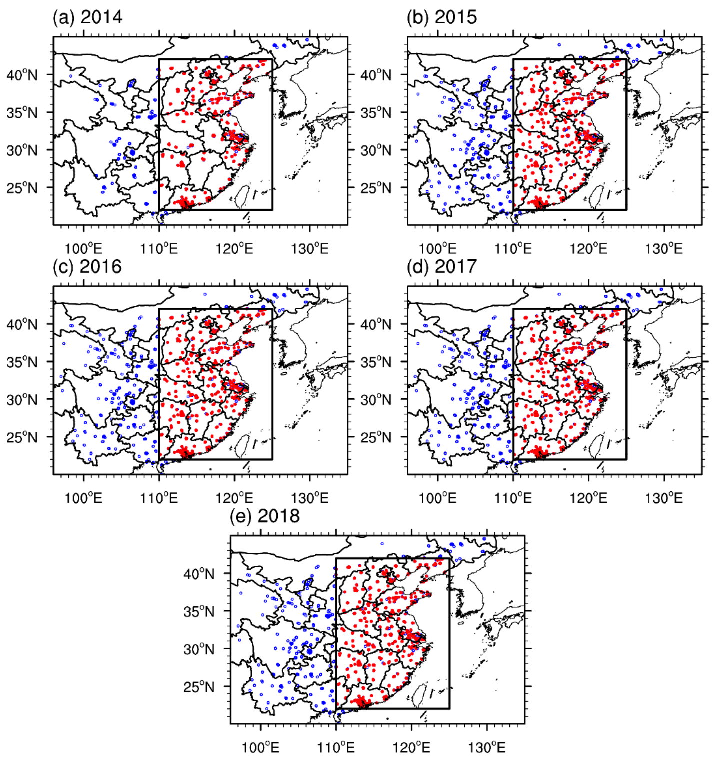

Figure S1. The distribution of measurement sites of atmospheric components (blue and red points) from 2014 to 2018. The red sites indicate the employed sites in this study related to O_3 pollution. The black box was the region of eastern China.

(2) Due to their observed purposes (related to air pollutions), the sites monitoring atmospheric components were **almost located around the urban area**. In the revised version, we pointed out that "**the results of this study were more suitable to the urban O_3 pollution**".

(3) In the former version, to show the spatial distributions, the data of ground-based sites were interpolated using **iterative correction type objective analysis**. Now, to avoid confusions, we **directly show the sited values** in Figure 1, 3, 4,

7 and other Figures in the supplementary, instead of interpolation.

For example, in the revised Figure 1, the numerical values were **not interpolated**, and the features were still clear. That is, the O_3-polluted sites were located closely to each other. Although, the distributions of the sites were somewhat uneven, the conclusions on the contiguous features were substantially influenced. Detailed explanations were added to make this point clear.

Revision:

(1) In the Figure 1, 3, 4 and 7:

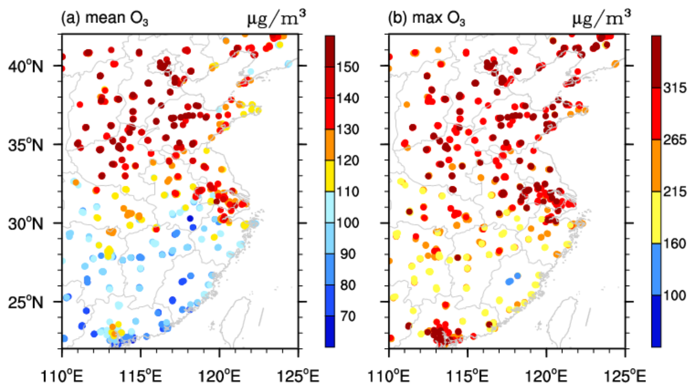

Figure 1. Distribution of the (a) mean values and (b) maximum values of MDA8 (Unit: μg/m³) at the observation sites in summer from 2015 to 2018.

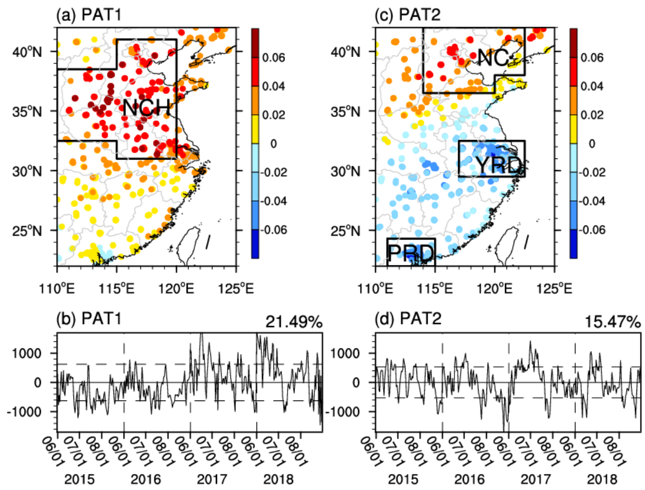

Figure 3. The first EOF pattern (PAT1: a, b) and second EOF pattern (PAT2: c, d) of MDA8 in summer from 2015 to 2018, including the spatial pattern (a, c) and the time coefficient (b, d). The black boxes in panels a and c are the selected North China and Huanghuai region (NCH), North China (NC) Yangtze River Delta (YRD) and Pearl River Delta (PRD). The EOF analysis were applied to the daily MDA8 anomalies at 868 stations to extract the relatively change features of the original data on the daily time-scale. The percentages on panel b and d were the variance contributions of the first and second EOF mode.

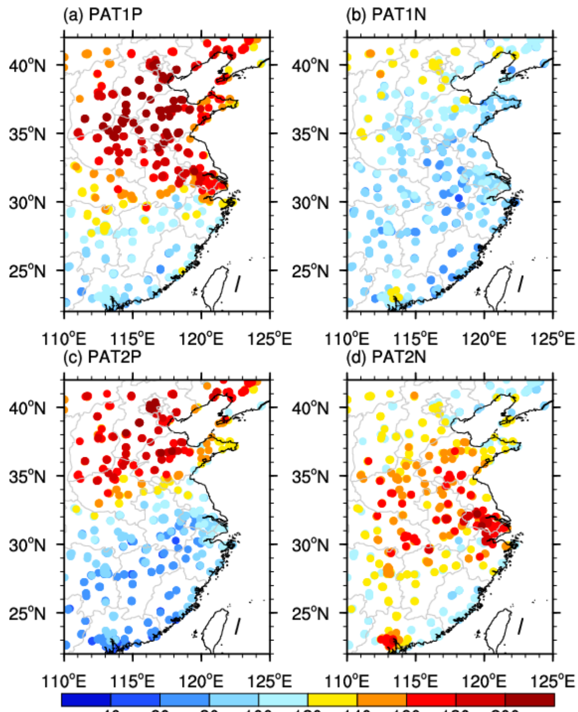

Figure 4. Composites of the MDA8 (Unit: μg/m³) for PAT1 (a, b) and PAT2 (c, d) in summer from 2015 to 2018. Panels a and c were composited when the time coefficient of EOF1 and EOF2 was greater than one standard deviation, while panels b and d were when the time coefficient was less than －1×one standard deviation.

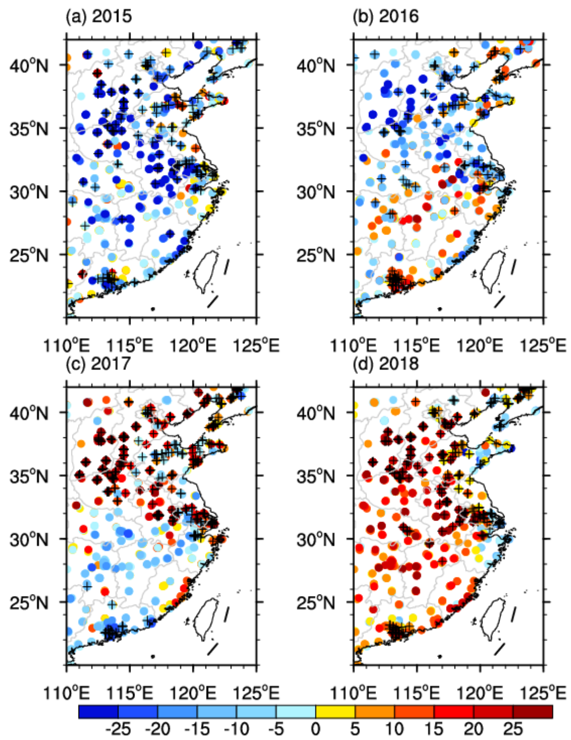

Figure 7. Anomalies in the summer mean MDA8 (Unit: μg/m³) in 2015 (a), 2016 (b), 2017 (c) and 2018(d), relative to the mean during 2015–2018. The black pluses indicate indicate that the maximum MDA8 was larger than 265 μg/m³.

(2) In the Datasets and methods:

……Nationwide hourly O_3 concentration data since May 2014 are publicly available on http://beijingair.sinaapp.com/. Since the severe air pollution events in 2013, the air pollution issues gained more attentions from the Chinese government and society, which aided to start the extensive constructions of operational monitoring stations of atmospheric components and resulted in continuous increasing number of sites (Figure S1). The number of sites in eastern China (110°E–125°E, 22°N–42°N) was 677, 937, 937, 995 and 1007 from 2014 to 2018. It is obvious that the data in 2014 were deficient, while the observations were broadly distributed in eastern China and continuously achieved since 2015. Thus, the summer O_3 data from 2015 to 2018 were processed (e.g., unifying the sites and eliminating the missing value) and 868 sites in eastern China were employed here to reveal some new features of surface ozone pollutions and associated anomalous atmospheric circulations……

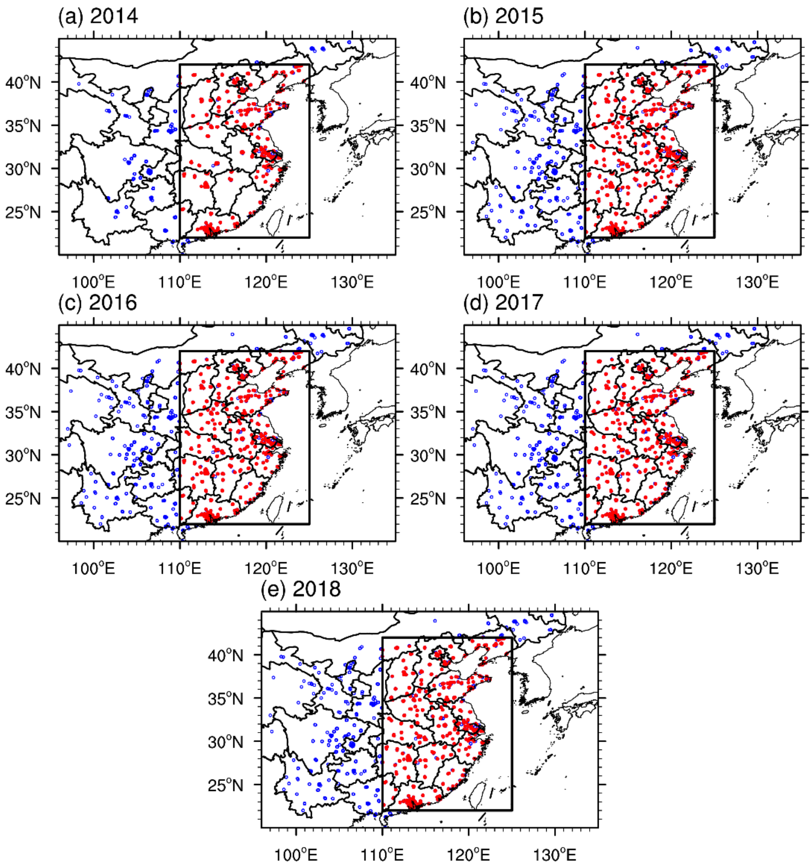

Figure S1. The distribution of measurement sites of atmospheric components (blue and red points) from 2014 to 2018. The red sites indicate the employed sites in this study related to O_3 pollution.

3. The study relies on EOF analysis, but there is almost no explanations of how the EOFs are constructed, and why the first two patterns are indicative of the dominant patterns of ozone pollution. Only 37% variance can be explained with the first two EOFs (∽20% for the first EOF), which is even less than half. I think it's necessary to explain the limitation of this statistical approach.

Reply:

(1) The EOF approach was introduced in the third paragraph of Section 2, which could be found in the revised presentations. The EOF analysis is a widely used statistical method in meteorology to **reconstruct the original variables into several irrelevant patterns** (Wilks, 2011). The EOF analysis, applied to the daily anomalies (MDA8 anomalies at 868 stations in this study), **extracted the relatively change features of the original data on the daily time-scale**. The orthogonal modes included spatial and temporal coefficients, and contained information of some proportion (variance contributions) from the original fields

(2) **Significance test** was supplemented following the test method form North et al., (1982). That is, if the eigenvalue (λ) satisfied the condition as $\lambda_i - \lambda_{i+1} \geq \lambda_i (2/n)^{1/2}$, the eigenvalue λ_i was significantly separated. We performed this significance test on the selected patterns from EOF decompositions, and **confirmed that these dominant patterns in this study were all significant.** Thus, the first two pattern were significantly separated and are indicative of the dominant patterns of ozone pollution.

(3) As regards the contribution variance, we also **performed similar EOF analysis on the surface air temperature and precipitation** (Figure R3, R4). The first contribution variance of temperature (52.3%) was big, indicating uniform change. However, the first contribution variance of **precipitation was only 10.4%**, which is even smaller than that of ozone concentrations. Thus, we believe that the contribution variance of the first EOF modes of MDA8 (21.5% and 15.5%) **were enough to determine the dominant patterns, whether basing on the significance test or the above-mentioned comparison.**

As expected, the variance contributions here were not as large as surface air temperature in eastern China. Possible reasons might related to the complexity of generative mechanism of surface O_3 and the urban property of the monitoring sites, which was not the topic of this study.

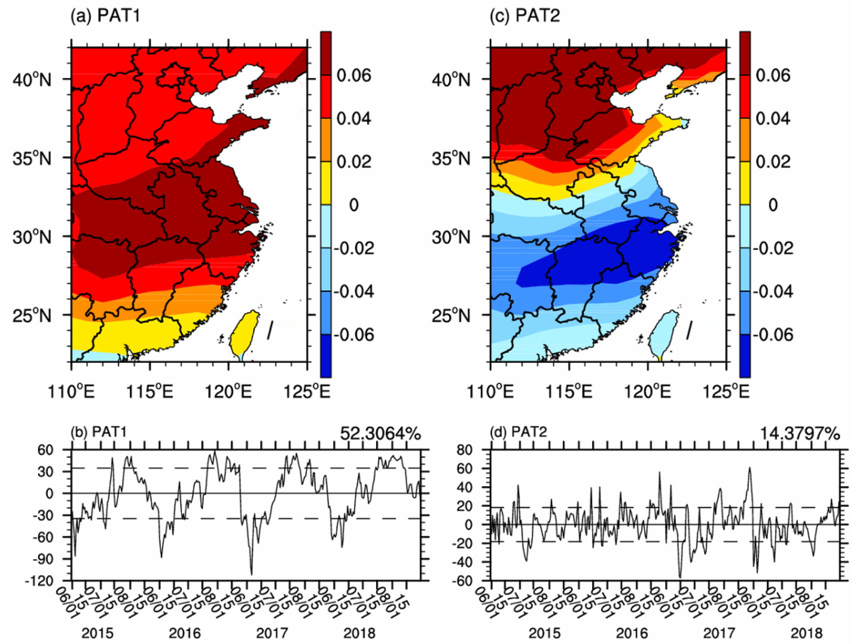

Figure R3. The first EOF pattern (a, b) and second EOF pattern (c, d) of surface air temperature in summer from 2015 to 2018, including the spatial pattern (a, c) and the time coefficient (b, d). The EOF analysis were applied to the daily temperature anomalies at 868 stations to extract the relatively change features of the original data on the daily time-scale. The percentages on panel b and d were the variance contributions of the first and second EOF mode.

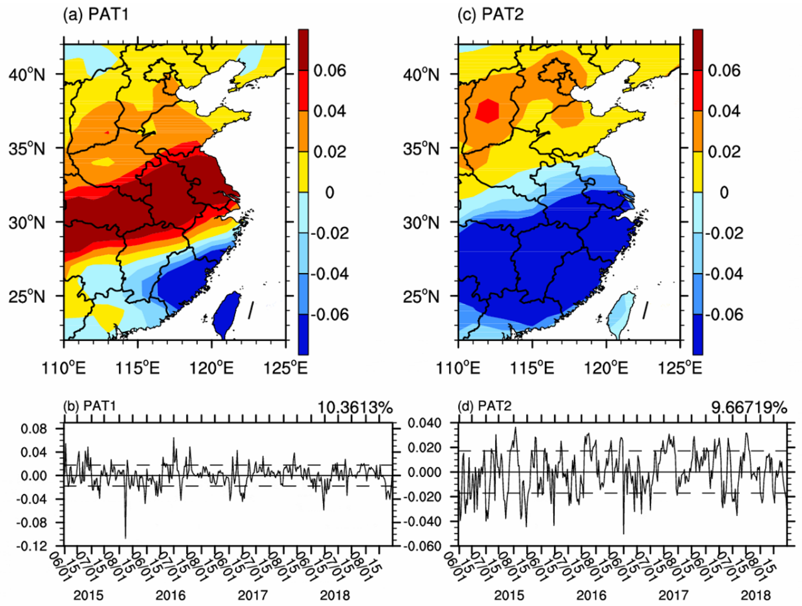

Figure R4. The first EOF pattern (a, b) and second EOF pattern (c, d) of **precipitation** in summer from 2015 to 2018, including the spatial pattern (a, c) and the time coefficient (b, d). The EOF analysis were applied to the daily precipitation anomalies at 868 stations to extract the relatively change features of the original data on the daily time-scale. The percentages on panel b and d were the variance contributions of the first and second EOF mode.

Revision:

The empirical orthogonal function (EOF) analysis is a widely used statistical method in meteorology to reconstruct the original variables into several irrelevant patterns (Wilks, 2011). The EOF analysis, applied to the daily anomalies (MDA8 anomalies at 868 stations in this study), extracted the relatively change features of the original data on the daily time-scale. The orthogonal modes included spatial and temporal coefficients, and contained information of some proportion (variance contributions) from the original fields. Significance test must be execute to confirm whether the decomposed patterns had physical meanings. In this study, we used the test method form North et al., (1982). That is, if the eigenvalue (λ) satisfied the condition as $\lambda_i - \lambda_{i+1} \geq \lambda_i(2/n)^{1/2}$, the eigenvalue λ_i was significantly separated. We performed this significance test on the selected patterns from EOF decompositions, and confirmed that these dominant patterns in this study were all significant. The aforementioned EOF analysis programs were finished by the NCAR Command Language.

4. (1) The authors included a lot of figures, but some seem to be redundant. For example, Figures 2 and 3 seem to be repetitive. Most of the figures are not very clear, yet the authors only spend one or two sentences explaining these figures.
(2) None of these figures is labeled clearly. There is even no unit for the numbers presented, which is unacceptable to me.
(3) I'd recommend the authors only keep those most important figures (e.g Figures 7 and 8), and expand their discussions on these figures.

Reply:

(1) In the revised version, we almost rewrite the texts and decrease the number of Figures from 14 to 11. Some necessary information, e.g., the distribution of sites and cities, were added in the supplementary. An important Figure S2 was moved to the main texts as Figure 8.

(2) Most of the Figures were replotted to show the information in a clearer way.

(3) The incorrect figure references and statements were revised throughout the manuscript. The units were added throughout the manuscript.

Minor Comments:

71. Line 70: It’s not clear what 'sub-daily' means here. If it’s four-hour data, which composites did you select?

Reply:

It is **6-hourly** for the Z, wind, relative humidity, vertical velocity, air temperature and cloud cover, while **3-hourly** for the precipitation and downward solar radiation. We directly downloaded the 6-hourly data form the ECWMF website. Due to different representative period of each element, thus we performed distinguishing composites. The 'time' and 'steps' of ERA-Interim can be found on the website of https://confluence.ecmwf.int/pages/viewpage.action?pageId=56658233.

Finally, the daytime atmospheric circulations are the geopotential height, wind, air pressure, cloud cover and relative humidity from 05 a.m. to 05 p.m (Beijing Time)., and the precipitation and downward solar radiation from 08 a.m. to 08 p.m. (Beijing Time).

Revision:

…… the daytime data were calculated by the **6-hourly reanalysis** (including Z, wind, relative humidity, vertical velocity, air temperature and cloud cover) and **3-hourly reanalysis** (precipitation and downward solar radiation) to composite the daytime atmospheric circulations and daytime meteorological conditions. Due to the different representative period of each element in ERA-Interim data, the daytime for Z, wind, relative humidity, vertical velocity, air temperature and cloud cover was from *05 a.m. to 05 p.m (Beijing Time; 21 p.m.–09 a. m. UTC), while it is from 08 a.m. to 08 p.m. (Beijing Time; 00 a.m. to 00 p.m. UTC) f*or precipitation and downward solar radiation……

72. Please double check the subscripts and superscripts of units and chemical names.

Reply:

The subscripts and superscripts were checked throughout the manuscript, and the errors were corrected.

Revision:

The O_3 pollution levels in Beijing-Tianjin-Hebei (part of NC) were the most severe in China (Wang et al., 2006; Shi et al., 2015) and this situation has been getting worse. The O_3 concentrations in North China underwent a significant increase in the period of 2005–2015, with an average rate of 1.13±0.01 ppbv yr^{-1} (Ma et al., 2016). Even on the highest mountain over NC, Mount Tai, summer (June-July-August, JJA) O_3 increased significantly by 2.1 ppbv yr^{-1} (Sun et al., 2016). The O_3 levels generally presented increasing trends from 2012 to 2015 in the YRD (Tong et al., 2017), e.g., the O_3 concentrations in Shanghai (a mega-city) increased by 67% from 2006 to 2015 (Gao et al., 2017). In the PRD region, O_3 increased by 0.86 ppbv yr^{-1} from 2006 to 2011 (Li et al., 2014). Severe ozone pollution is projected to increase in the future over eastern China (Wang et al.,

3. Variations and dominant patterns

During 2015–2018, summer surface ozone pollution was severe in China, especially in the economically developed regions. Spatially, the JJA mean MDA8 increased from south to north in eastern China (Figure 1a). To the south of 28°N (i.e., South China), the mean MDA8 was mostly lower than 100 μg/m³ and the ozone pollution was obviously lower than that in North China and in the Huanghuai area (NCH). It is notable that, although the values of MDA8 in the PRD were not as large as those in NCH, they were relatively higher than those in the surrounding areas. The mean MDA8 was above 110 μg/m³ to the north of 32°N (i.e., the NCH area), and thereinto, the large values of MDA8 centred on the Beijing-Tianjin-Hebei region and in western Shandong province exceeded 150 μg/m³. In the transitional zone, i.e., between 28°N and 32°N, the MDA8 varied from

73. Lines 95 - 100: How did you calculate ozone levels in each province? Are the ground-based measurements spatially representative?

Reply:

In the O_3 datasets, there is an attribute indicating the subordinate city, thus we can calculate the ozone levels of certain geographic position.

74. Line 125: How did you compose atmospheric circulations? This is an important step, but there is almost no explanation of the method.

Reply:

In the revised version, the composite steps were detailedly introduced in the first paragraph of Section 4. For convenience, an example was given.

Revision:

……Anomalous daytime atmospheric circulations associated with PAT1 (**PAT1P composite minus PAT1N composite**) and PAT2 (PAT2P composite minus PAT2N composite) were shown Figure 5–6. **For example,** the mean of the atmospheric circulations associated PAT1P (PAT1N) were firstly computed, and then the differences between PAT1P composites and PAT1N composites were calculated as the anomalous daytime atmospheric circulations associated with PAT1……

75. Line 189: 2105 -> 2015

Reply:

These errors were corrected.

Revision:

……The MDA8 anomalies in 2016 were negative in NC, but positive in the YRD and PRD (**Figure 7b**), which was the opposite pattern of PAT2. The interannual anomalies of atmospheric circulations in 2016, **with respect to the mean of 2015–2018** (Figure 10)……

76. Line 200: The conclusion that atmospheric circulation accelerated ozone formation in YRD but weaken in NC is interesting, but this does not agree with ground-based observations, which do not show any enhancement of ozone in YRD in 2016 (nor decreased ozone in NC, Figure 6).

Reply:

According to the comment "too much Figures", the old Figure 6 and the one related sentence was deleted, as no new information were shown.

The "increasing in YRD" and "decrease in NC" was **with respect to the mean status during 2015–2018.** Although the old Figure 6 was deleted, the same information could also be read from the Figure 7b. It is evident there were negative anomalies in the NC region. In the YRD region, particularly in the south of YRD, positive anomalies occurred.

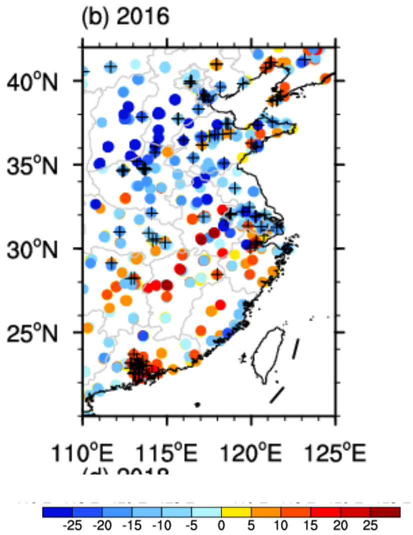

Figure 7. Anomalies in the summer mean MDA8 (Unit: μg/m³) in 2015 (a), 2016 (b), 2017 (c) and 2018(d), ***relative to the mean during 2015–2018.*** The black pluses indicate indicate that the maximum MDA8 was larger than 265 μg/m³.

77.Line 205 - 201: The figure numbers are wrong?

Reply:

The incorrect figure references and statements were revised throughout the manuscript. The units were added throughout the manuscript.

Revision:

The MDA8 anomalies were mostly positive in the east of China in 2018 (Figure ~~10~~7d). "–+–" pattern of Z850 anomalies were located over the Ural Mountains and to the north of Lake Baikal and the Aleutian Islands (Figure 1~~2~~1a), which was consistent with the anomalous patterns in Figure ~~7~~5. The East Asia deep trough shifted northward than the mean status during 2015–2018, and meanwhile, the western ridge point of WPSH also shifted northward, resulting in a higher SAT in the east of China and accelerating the photochemical conversion for elevating the surface ozone concentration. The local anomalous anti-cyclone over the NCH and the Japan Sea also existed in the interannual signals, which induced the divergence of water vapor in southeast China (Figure 1~~2~~1b). Due to the lack of moisture, it was difficult for cloud cover to form, and more solar

78.Line 210: How did you draw the conclusion that positive MDA8 anomalies are observed in 2018? This conclusion seems to be inconuistunt with Figure 6.

Reply:

According to the comment "too much Figures", the old Figure 6 and the one related sentence was deleted, as no new information were shown.

The "positive anomalies in 2018" was **with respect to the mean status during 2015–2018.** Although the old Figure 6 was deleted, the same information could also be read from the Figure 7d. It is evident there were positive anomalies in the eastern China.

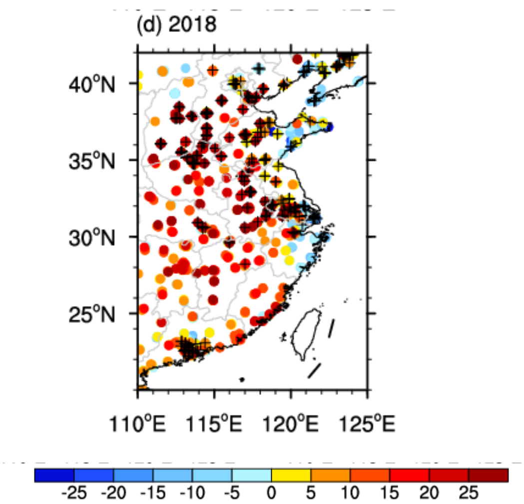

Figure 7. Anomalies in the summer mean MDA8 (Unit: µg/m³) in 2015 (a), 2016 (b), 2017 (c) and 2018(d), ***relative to the mean during 2015–2018.*** The black pluses indicate indicate that the maximum MDA8 was larger than 265 µg/m³.

79.Figure 1,7, 11: missing units.

Reply:

The units were added throughout the manuscript.

Revision:

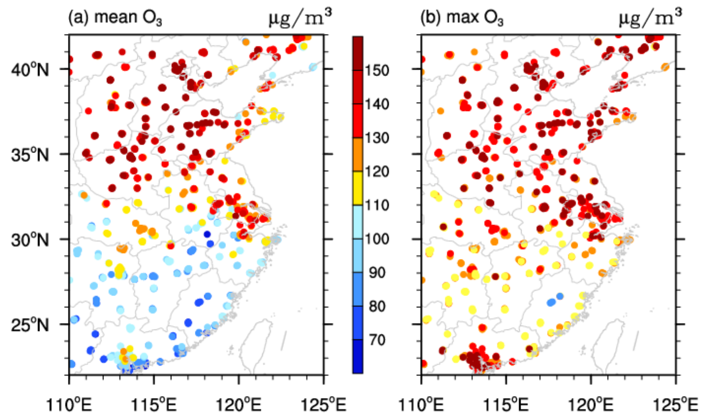

Figure 1. Distribution of the (a) mean values and (b) maximum values of MDA8 **(Unit: µg/m³)** at the observation sites in summer from 2015 to 2018.

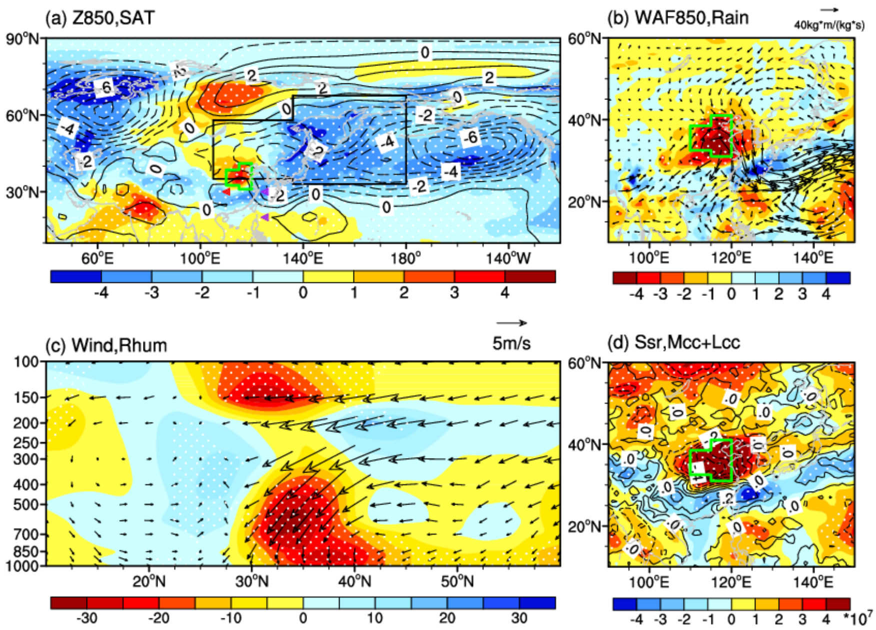

Figure 5. Differences of the daytime atmospheric circulations (i.e., PAT1P minus PAT1N). (a) Geopotential height at 850 hPa (Unit: 10gpm, contours) and surface air temperature (Unit: K, shading), (b) water vapor flux (Unit: kg*m/(kg*s)) at 850 hPa (arrows) and precipitation (Unit: mm, shading), (c) 100°E–120°E mean wind (Unit: m/s, arrows) and relative humidity (Unit: %, shading), (d) downward solar radiation at the surface (Unit:10^7 J/m^2, shading) and the sum of low and medium cloud cover (Unit: 1, contours). The white dots indicate that the shading was above the 95% confidence level. The green boxes in panels a, b and d show the NCH region, and the black box in panel a indicates the location of the East Asia trough. The purple triangles indicated the data used to calculate the WPSH$_1$, while the red triangle represented the west ridge point of WPSH.

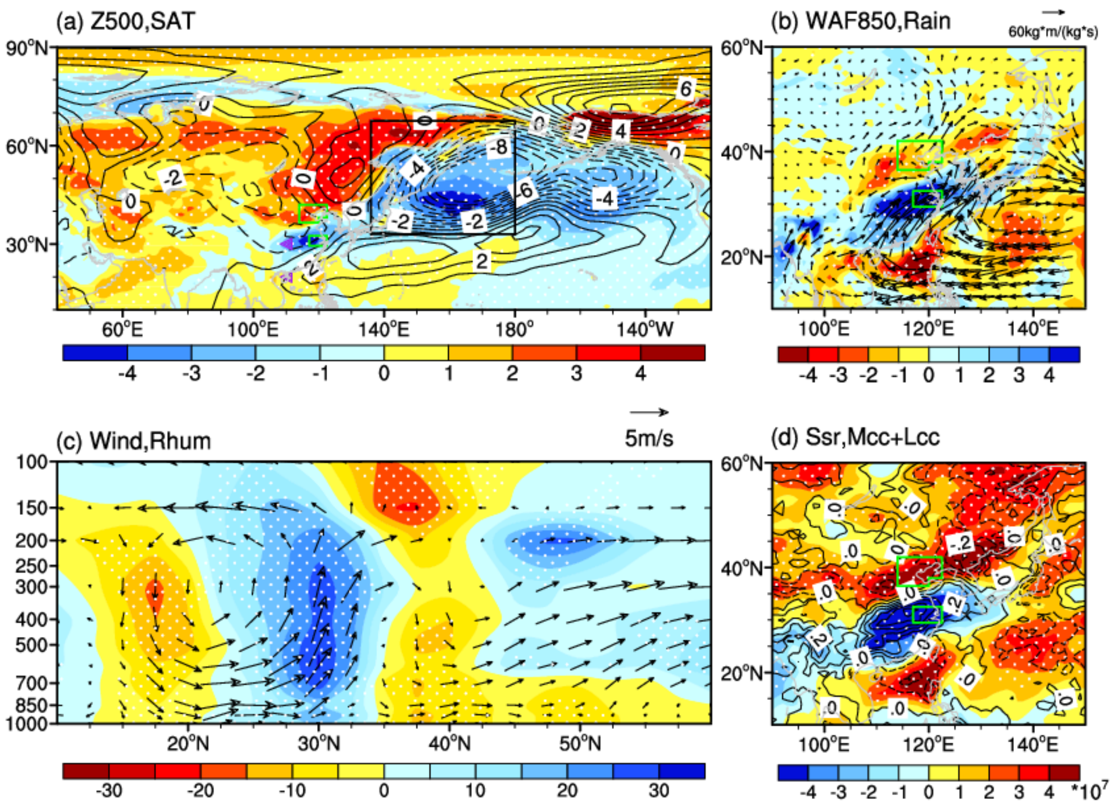

Figure 6. Differences of the daytime atmospheric circulations (i.e., PAT2P minus PAT2N). (a) Geopotential height at 500 hPa (Unit: 10gpm, contours) and surface air temperature (Unit: K, shading), (b) water vapor flux (Unit: kg*m/(kg*s)) at 850 hPa (arrows) and precipitation (Unit: mm, shading), (c) 100°E–120°E mean wind (Unit: m/s, arrows) and relative humidity (Unit: %, shading), (d) downward solar radiation at the surface (Unit: $10^7 J/m^2$, shading) and the sum of low and medium cloud cover (Unit: 1, contours). The white dots indicate that the shading was above the 95% confidence level. The green boxes in panel a, b and d are the NC and YRD regions, and the black box in panel a indicates the location of the East Asia trough. The purple triangles indicated the data used to calculate the $WPSH_2$.

80. Figures 2, 3, 8, 12: Missing y label.

Reply:

The y-label of Figure 2 and 9 was added.

The old Figure 8 and 12 presented the variations in standardized indices, thus there was no y-label. Because no new information was showed in these two Figures, the Figure 8 and 12 were deleted.

Revision:

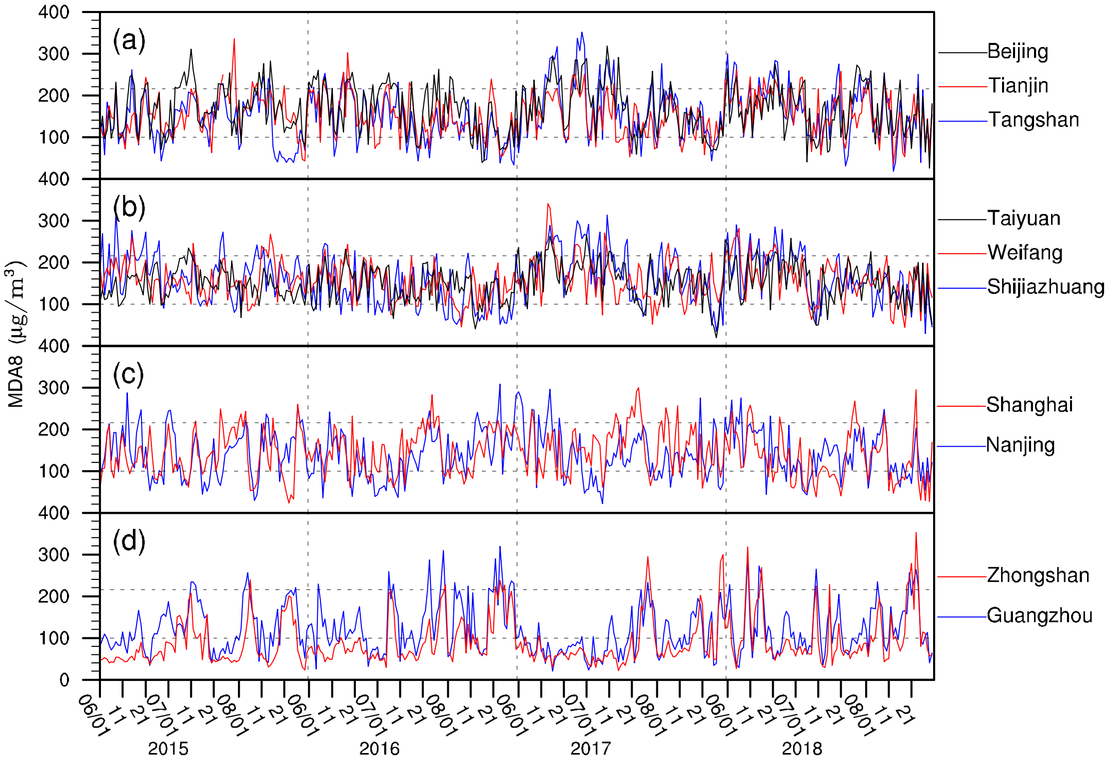

Figure 2. Variations in MDA8 (Unit: μg/m³) of polluted cities from 2015 to 2018, including (a) Beijing, Tianjin and Tangshan; (b) Taiyuan, Weifang and Shijiazhuang; (c) Shanghai and Nanjing; and (d) Zhongshan and Guangzhou. The cites in panels (a)-(d) were located from north to south. The horizontal dash lines indicated the value of 100 μg/m³ and 215 μg/m³.

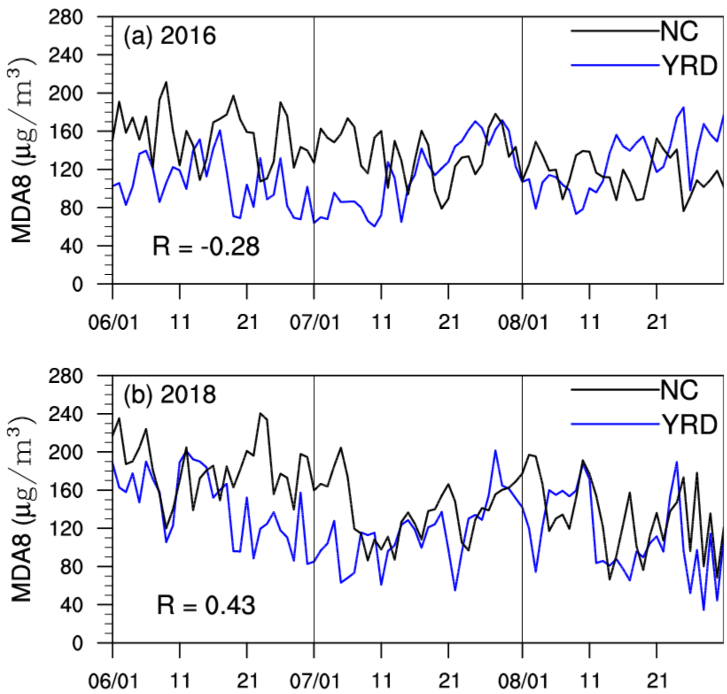

Figure 9. Variations in the MDA8 (Unit: μg/m³) of NC (black) and the YRD (blue) in 2016 (a) and 2018 (b).

81. Figure 4: The authors need to explain how they construct spatial and temporal EOFs, and what the figures show here. What do the numbers represent?

Reply:

This comments were closely **related to the Major comment 3**, thus the information was not repeated here.

In the Figure caption, we clarified the meaning of the percentage number.

Revision:

Figure 3. ……The EOF analysis were applied to the daily MDA8 anomalies at 868 stations to extract the relatively change features of the original data on the daily time-scale. The percentages on panel b and d were the v**ariance contributions of the first and second EOF mode**……

Figure 8….. The **percentages were the variance contributions** of the first and second EOF mode……

82. Figure 5: It's not clear why it is necessary to composite to positive and negative patterns. How does this help explain the results?

Reply:

By composite the MDA8 for PAT1 and PAT2, we can clearly see the meaning of the EOF analysis. The real MDA8 values for PAT1 and PAT2 showed more information than the extracted spatial coefficient of the EOF.

83. Line 202: Where is Figure 10d?

84. Figure 14 not referenced in the manuscript.

Reply:

Most of the Figures were replotted to show the information in a clearer way.

The incorrect figure references and statements were revised throughout the manuscript. The units were added throughout the manuscript.