

ACPD Review of “Dominant Patterns of Summer Ozone Pollution in Eastern China and Associated Atmospheric Circulations” By Zhicong Yin, Bufan Cao, and Huijun Wang

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.

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.

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. 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.

Comments:

The authors should discuss the air quality thresholds of MDA8 O<sub>3</sub> 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.

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. How many station sites are urban vs rural? How did the number of sites change from year to year? 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<sub>3</sub> values in the NH region were contiguous, indicating extensively severe surface O<sub>3</sub> 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.

There is a disconnect between the Figure 1 and the text on Line 87 where 265  $\mu\text{g}/\text{m}^3$  is referenced but it is not a value on the color bar. I could support changing this to 240  $\mu\text{g}/\text{m}^3$ . If

you want to highlight  $265 \mu\text{g}/\text{m}^3$ , consider changing the intervals on the color bar to  $15 \mu\text{g}/\text{m}^3$ , starting at  $175 \mu\text{g}/\text{m}^3$  instead of  $140 \mu\text{g}/\text{m}^3$ .

There must have been a more scientific reason for making Figure 2 other than “from another angle” (Line 86). 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?

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.

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<sub>3</sub> 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?
2. Figures 8 and 10 are not (correctly) referenced once in the text and therefore should be removed (or moved to the supplemental) and 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).

Minor and Technical Comments:

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.

Line 24: need a space after “(Day et al., 2017)”

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).

Line 30 (and in several instances throughout the paper): the 3 in O<sub>3</sub> needs to be a subscript

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

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)

Line 42: Can the authors discuss in more detail the findings of the Li et al paper regarding the relationship between PM and O<sub>3</sub> pollution.

Line 50: This sentence “Large-scale descending motion, tropical cyclones....related to the evaluation of surface O<sub>3</sub>” does not make sense to me as large-scale descending motion is usually associated with high pressure systems, not low-pressure systems.

Lines 54, 70: period after “et al.”

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

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

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.

Line 69: What range and how many pressure levels?

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”. What time in UTC is equivalent to 8am-8pm Beijing time.

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

Line 78: Why have the authors switched to using  $\mu\text{g}/\text{m}^3$  from ppb in the Intro?

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.

Line 80: It looks more to me that the cut off at 32°N is closer to  $> 110 \mu\text{g}/\text{m}^3$  mean O<sub>3</sub> with much of the region  $> 130 \mu\text{g}/\text{m}^3$ , but not  $> 130 \mu\text{g}/\text{m}^3$  everywhere.

Line 83: How do the authors know this “Surface O<sub>3</sub> 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?

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?

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?

Line 93: Which figure is this quoted from “the north of Hebei province and in eastern Shandong province even exceeded  $320 \mu\text{g}/\text{m}^3$ ,”? Provide figure reference (I presume top panel of Figure 2 for Tangshan July 2018).

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?

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 from Figure 1 or Figure 2?

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?

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?

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

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?

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)."

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."

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.

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

Line 122: One could argue that there is higher O<sub>3</sub> in the PRD during PAT2 as well.

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." 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.

Line 126: Do the authors mean by "most O<sub>3</sub>-changed region" that the PAT1 positive and negative phases are defined by large differences in O<sub>3</sub> 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.

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; there is not positive Z850 but negative across the subtropical Pacific, to get the cyclonic flow pattern.

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

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

Line 137-139: reference heights are Z at 500 hPa but Figure 7a shows Z at 850 hPa. How can the authors say that the extent of WPSH is “indicated by Z500” if not shown anywhere and the reference to an  $R=0.24$  is not in the Table 1 for PAT1.

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.

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

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.

Line 146: Remove ‘sunny’

Line 149: Add figure references (maybe Fig 4c or Fig 5c,d) for the statement “Large amplitudes of PAT2 O3 were distributed in the NC and YRD regions”. 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.

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.

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

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

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. \*\*

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? Also, can the authors clarify they are referring to the mean summer MDA8 O3 in the sentence “The summer MDA8 in the PRD...(Figure 1a)” since they reference Fig 1a.

Line 174: Not all sites in the PRD had max MDA8 O3 greater than the threshold in all four years (Fig 11). The authors should clarify this point.

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

Line 184: I believe this sentence incorrectly references Fig 11d and it should reference Fig S2.  
Line 188: I believe this sentence incorrectly references Fig 10b and it should reference Fig 11b.  
Line 189: change 2105 to 2015.

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.

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 WSPH is near the YRD as described.

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

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. 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.

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

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

#### FIGURE specific comments:

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.

Line 90: It might be too cluttered to do this; but, adding dashed lines at  $215 \mu\text{g}/\text{m}^3$  and  $100 \mu\text{g}/\text{m}^3$  on Figure 2 could help the reader to see the frequency of O<sub>3</sub> concentrations above the moderate polluted level and below the non-polluted level.

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  $\mu\text{g}/\text{m}^3$ . 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.

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.

Line 406: missing comma (NC)

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

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.

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?

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.

Line 459: missing space "2018 (d)"

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