Responses to reviewer(s) comments

Anonymous Referee #3:

The authors use the T-mode PCA to objectively classify the summertime synoptic weather pattern across East-Asia and the western Pacific Basin aiming to identify the mode(s) most favorable for compound pollution events across sub-regions in China, specifically for PM2.5 and O3. Many factors governing these events operating across an array of scales are explored. The PCA identified 4 synoptic regimes characterizing the seasonal set up of the 500 hPa WPSH from 2015-2018. An additional large-scale circulation is also at work here, the East-Asian monsoon, which is discussed in context to the WPSH. Additionally, the authors discuss the effects of precipitation frequency and boundary layer characteristics on regulating compound pollution events. Occurrences of pollution are based on Chinese governmental standards.

While this work has great upward potential to be a significant contribution to the community, many revisions are required before publication.

RESPONSE: We highly appreciate your positive and constructive comments.

Secs. 1-2 are written quite well and motivate the questions at hand. Beyond that however, I believe that more concrete connections can be and must be made between processes unfolding at different scales (synoptic down to the mesoscale) of motion that lead to Types 1 and 2 dominating the regulation of compound pollution events. For instance, connecting the modulations in the WPSH to changes in favorable PBL conditions and thermal stratification need to be made, in addition to changing precipitation amounts between the types. All of these processes dictate the amount of pollution in the atmosphere at any given time. The final sentence of Sec. 1 states that this manuscript will examine the SWPs responsible for co-occurring pollution events, but the synoptic scale processes have bearing on finer scale processes such as PBL characteristics that are critical for air quality (e.g. inversions associated with tropospheric sinking motion). The authors analyze changes in PBL height between the types and provide loose discussion of their implications for air quality, but further analysis is needed.

RESPONSE: Thank you for valuable comments. Yes, our motivation is to demonstrate the causes of meteorological processes of the compound O_3-$PM_{2.5}$ pollution, as it is believed that the processes should be likely associated with local meteorological conditions (e.g., temperature, wind, humidity, rainfall, and PBL) under the influences of various weather types and modulation of large-scale WPSH movement. In addition, the impacts of PBL characteristics on air quality have been further discussed (lines 414-424 on page 15).

Please refer to the following information for more details:

"Particularly, Type1 has a significantly warmer temperature over the boundary layer during the compound pollution period of BTH region than that of the clean period. The daytime BLH under compound pollution condition was also higher than that of the clean condition. In addition, there were different directions of prevailing during the two periods, which prevailing winds during the compound pollution period were usually southward and could be driven by air pollutants transported from the southern plains (Fig. 11; see also Miao et al., 2019b, 2020). Co-influencing by the topographical effect of the northern mountainous areas, air pollutants could be trapped in the BTH region. In comparison, although there was southward wind prevailing in the BTH region (Figs. 11 and S11), the rain belt also located in the southern area of BTH might lead to the potential removal of $PM_{2.5}$ (Fig. 9j). Therefore, compound pollution

across the BTH region might mainly be due to local emissions of air pollutants."

Major comments:

1. The abstract needs to be shorted and be more specific.

RESPONSE: We have reorganized the abstract. Our abstract has been revised as follows: "Surface ozone (O_3) pollution during summer (June-August) over eastern China has become more severe, resulting in a co-occurrence of surface O_3 and $PM_{2.5}$ (particulate matter with aerodynamic diameter ≤ 2.5 μm in the air) pollution recently. However, the mechanisms regarding how synoptic circulation pattern could influence this compound pollution remains unclear. This study here applied the T-mode principal component analysis (T-PCA) method is used to objectively classify the occurrence of four synoptic weather patterns (SWPs) over eastern China, based on the geopotential heights at 500 hPa during summer (2015-2018). Four SWPs of eastern China are closely related to the western Pacific subtropical high (WPSH), exhibiting, significant intraseasonal and interannual variations. Based on the ground-level air quality and meteorological observations, remarkable spatial and temporal disparities of surface O_3 and $PM_{2.5}$ pollution were also found under the impacts of the four SWPs. Particularly, there were two SWPs sensitive to compound pollution (Type 1 and Type 2). Type 1 is characterized by a stable WPSH ridge with axis at about 22°N and the rain belt located in the south of Yangtze River Delta (YRD). High temperature, moderate humidity and low precipitation occurred in the region from BTH to northern YRD (BTH – NYRD), resulting in a co-occurrence of O_3 and $PM_{2.5}$ pollution. Additionally, air pollutants can be transported by the prevailing southerly winds from southern plains and accumulated in the southern BTH, resulting in a worsen pollution. Type 2 exhibits a WPSH dominance (the ridge axis ~25°N) and rain belt (over the YRD) in a higher latitude compared with Type 1. High temperature, medium-high humidity and low precipitation over the BTH were the conducive factors related to the occurrence of the compound pollution events under Type 2. Furthermore, low boundary layer height (BLH) and high frequency of light-wind days (FLWD) could create favorable conditions for pollution maintenance. Overall, synoptic weather patterns have played an important role as driving factors of surface O_3-$PM_{2.5}$ compound pollution in a regional context. In addition to the impacts of local emissions, our results may provide further insights regarding how regional environmental changes due to co-occurrence of high $PM_{2.5}$ and high O_3 level may be driven by the effects of meteorological factors. Overall, our findings demonstrate the important role played by synoptic weather patterns in driving regional surface O_3-$PM_{2.5}$ compound pollution, in addition to the large quantities of emissions, and may also provide insights into the regional co-occurring high $PM_{2.5}$ and high O_3 level via the effects of certain meteorological factors.".

2. How do the percentages of the PCs sum to 100%? Shouldn't there be other relevant synoptic patterns than just those 4, meaning that the leading 4 patterns account for most of the synoptic-scale pattern but not all?

RESPONSE: Thanks for your question. By using T-PCA, users can customize the number of synoptic patterns and determine the domain pattern(s), based on the following information: 1) a distinct direction of the air flow and its related short-term changes, 2) a regime of the pressure field (and vertical movements resulting from the field), 3) particular pattern(s) of

front passages, and 4) an inflow of air masses of a particular origin and their related changes. Based on the above method, the similarity of circulation pattern of each day to a particular type expressed by the corresponding loading, the greater similarity is expected between the day's type and the pattern (Huth, 1996). Therefore, no matter how many synoptic patterns are predefined, the sum of PCs could be 100%. The final number of patterns is determined by ΔECV, which larger ΔECV means an improved classification performance with stability (Ning et al., 2019). In our study, the highest ΔECV was used to classify to the four patterns. More information has been noted in the supplementary materials.

Reference:

Huth, R.: An intercomparison of computer-assisted circulation classification methods, Int. J. Climatol., 16(8), 893–922, doi:10.1002/(SICI)1097-0088(199608)16:8<893::AID-JOC51>3.0.CO;2-Q, 1996.

3. The language used to describe the synoptic scale features needs to be presented in a manner consistent with meteorological standards (see Bluestein 1992). In its present form, it is very difficult to follow the discussion. Here is an example. On lines 226-227, the authors state "The westward extension and southward motion of the WPSH in Type 1, as shown in Fig. 4a, transports water vapor into the YRD region, and the prevailing southwesterly in the YRD region and westward flow from the north form a cyclonic convergence area, with high temperature and high humidity during the Meiyu season." The 850 hPa flow associated with each PC correlates highly with the gradient in 500 hPa GH as rather expected, but what is meant by "southward motion of the WPSH?" Are the authors referring to the anticyclonic flow about the WPSH (i.e. northerlies to the west of the GH maximum)? Also, the sign of the relative vorticity should differ with height in the troposphere. For instance, should vorticity be negative in the lower troposphere (i.e. anticyclonic), it should be positive (i.e. cyclonic) in the upper troposphere (assuming a thermally direct circulation on a rotating sphere). Are the authors referring to the cyclonic shear vorticity anomaly apparent in the 850 hPa arrows around 120E/30N? The authors should use GH anomalies as reference points to describe the flow patterns, and they should make sure that it is clear which level in the atmosphere is being referenced in the text. More examples are given below.

RESPONSE: Thank you for your valuable suggestions. We apologize for the unclear descriptions regarding the location of the WPSH. More information regard to the location of the WPSH has now been reported in Table S2 of the revised manuscript. Following your suggestion, we have deleted the following word "cyclonic". We have also reworded the description of synoptic scale's features carefully (lines 266-274: "The location of western ridge point and northern boundary of the WPSH at 500 hPa in Type 1 is around 120°E and 30°N, respectively (Fig. 4a and Table S2). The southwestern flow of this WPSH could transport water vapor to the YRD region, resulting in a southwestward prevailing wind across the YRD region and westward flow from the north of the WPSH forming a convergence area at 850 hPa. These conditions were also associated with high temperature and humidity during the summer with Meiyu season, which Meiyu season is a climate phenomenon with continuous cloudy and rainy days generally occurring during June and July every year in the middle and lower reaches of Yangtze river, Taiwan of China, central/southern Japan, and southern Korea.".

4. Sec. 3.2: I feel as though the discussion of the PCs could be tied more explicitly to the vertical

motion field. Obviously, the WPSH is characterized by mid-tropospheric downward vertical motion and doesn't need much justification. However, the strength of the sinking motion and its co-occurrence with low wind events is driven by the synoptic pattern and could be shown. I would suggest at least a supplemental figure showcasing how the vertical motion varies with PC, perhaps overlaid with the 10-m windspeed. This would set up the next section nicely, which returns to examining the spatial characteristics of PM2.5 and O3.

RESPONSE: We appreciate these valuable suggestions. We have now added supplementary information for the vertical motion under impact of four SWPs, and latitude-height cross-sections of mean and anomalous vertical velocity averaged by longitudes over each region under four SWPs. in (Fig. S9). The strong updrafts and positive anomalies, which occurred in some regions (south YRD under Type 1, BTH and GZP under Type 3), is favorable for the formation of precipitation to decrease air pollution. In particular, the downward vertical motion and negative anomalies over BTH under Type 1 and Type 2 are associated with the co-occurrence of O_3-$PM_{2.5}$ pollution.

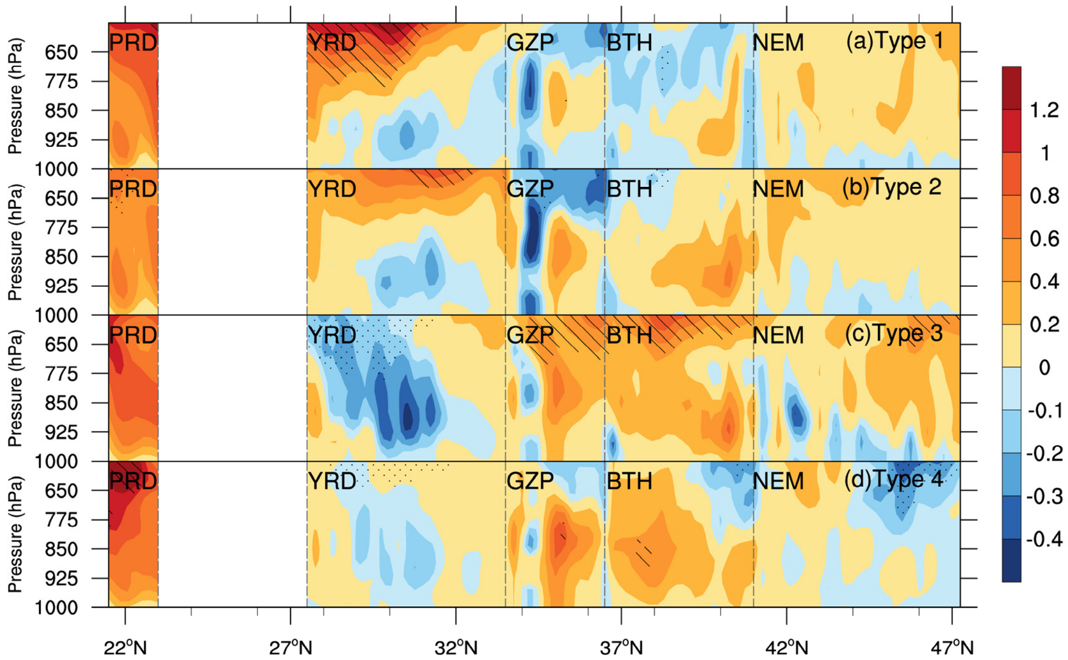

Fig. S9. Vertical cross-sections of the means (shading) and anomalies (filled patterns) of vertical velocity (unit: 10^{-2} m s^{-1}, derived from ERA5 reanalysis data) averaged by longitudes over each region of (a) Type 1, (b) Type 2, (c) Type 3, and (d) Type 4. The dotted and hatched areas represent the negative anomalies less than -3×10^{-2} m s^{-1} and positive anomalies greater than 3×10^{-2} m s^{-1}, respectively. The gray dashed lines indicate the boundaries of PRD, YRD, GZP, BTH and NEM, and the blank area (23°-27.2°N) is not our study region.

5. Diffusion of pollutants between the PBL and the free atmosphere is fundamentally related to the turbulent mixing and thermal stratification of the overlying atmosphere. While referenced here, I believe that this is an integral component of this work and must be explicitly addressed across the various subregions. How do the vertical profiles of temperature, moisture, and wind compare across the multiple PCs and subregions? How are these anomalies physically related to the different synoptic weather pattern differences between the PCs?

RESPONSE: Thank you for your comments. The vertical profiles of temperature, moisture,

and wind, as well as their anomalies under sub-regions of each SWP are provided in Fig. S8. Lower WS and its negative anomalies at low level over BTH under Type 1 and Type 2, is not conductive to the diffusion of pollutants. Meanwhile, the moderate RH and its negative anomalies also favor the formation of compound pollution. For GZP, Type 1 and Type 2 correspond to negative anomalies of WS and RH, favoring the occurrence of compound pollution. Note that the probability of compound pollution is relatively small, and it might be related to the local emissions. In other sub-regions, WS mainly affects the diffusion of air pollutants, and precipitation affects the occurrence of ozone and $PM_{2.5}$ pollution to a certain extent.

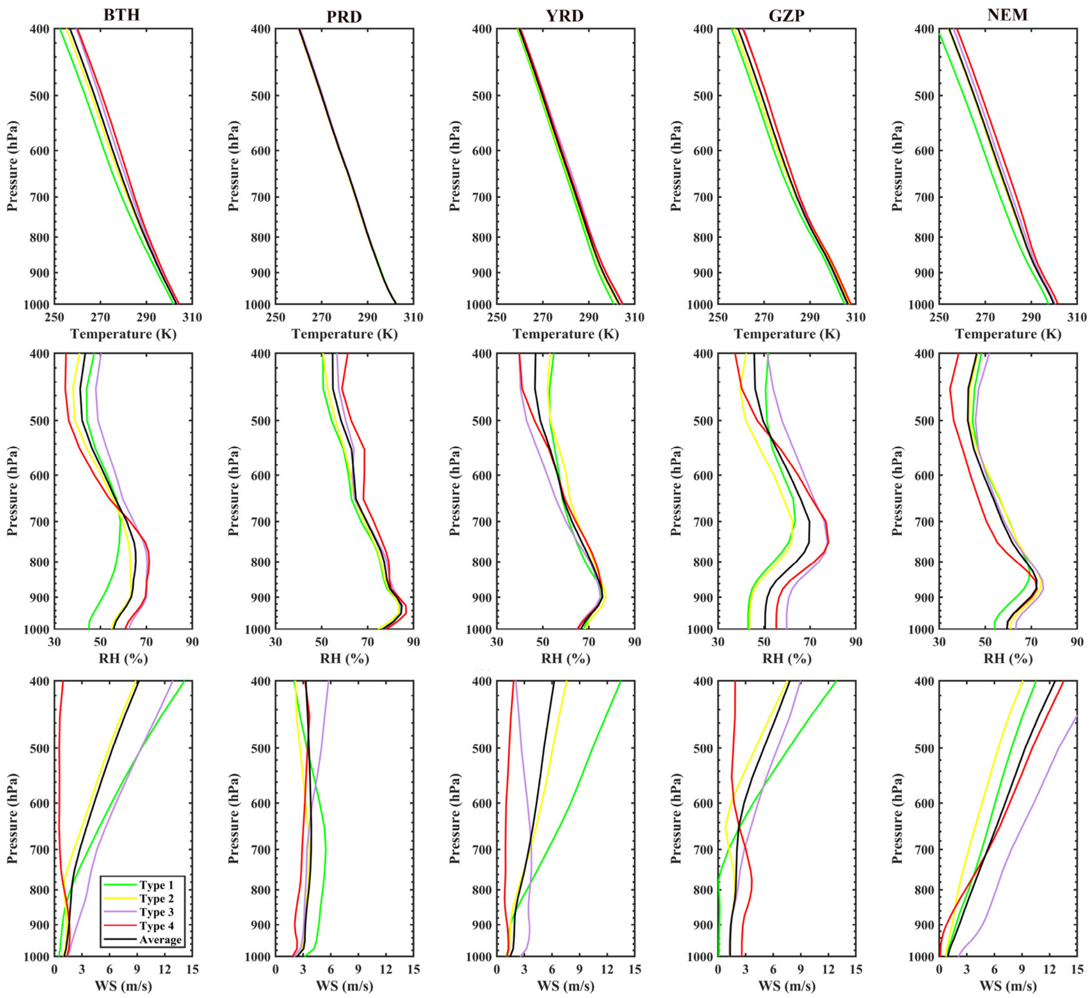

Fig. R5. The vertical profile of temperature, RH, WS (derived from ERA5 reanalysis data) over subregions under each SWP.

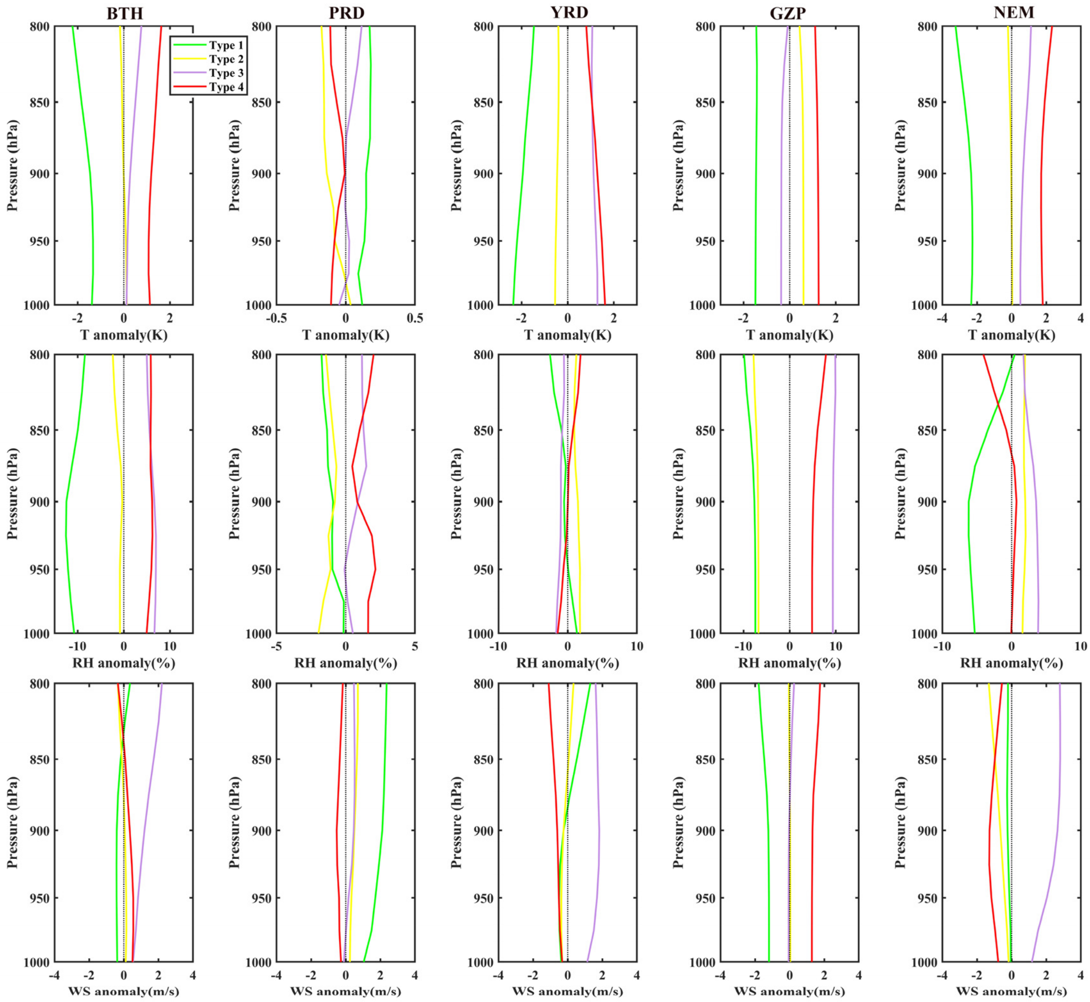

Fig. S8. The vertical profile of temperature, RH, WS anomalies over subregions under each SWP.

Other comments:

1. Line 32: “Slight” should be “low”

RESPONSE: Changed and thanks.

2. Line 57: insert a “the” before “economy”

RESPONSE: Inserted and thanks.

3. Line 72: Change “attached” to “caught”

RESPONSE: Changed and thanks.

4. Line 85: “US” should be “United States”

RESPONSE: Changed and thanks.

5. Line 105: The Miao et al. findings should be reproducible here but for a multitude of areas. Cross-sections similar to their Figs. 6-7 would work, but regionally averaged vertical profiles would work as well. Vertical profiles of state variables (temperature, stability, vertical velocity, etc.) should be

included in this manuscript as these quantities' vertical variation help to significantly modulate PBL and free atmosphere exchange of heat, moisture, pollution, etc. I would also suspect that summertime surface winds would be lower due to more infrequent midlatitude cyclone occurrences, so pollution "pooling" would be more frequent.

RESPONSE: Thank you for your suggestion. Similar analysis as the Figs. 6-7 of Miao et al has been added to the revised manuscript (lines 402-425 on page 15 and Fig. 11). Vertical profiles of state variables are presented in Fig. S8.

Please also find the information as follow:

"In the last section, we have discussed how the SWPs and local meteorological factors modify summer O_3 and $PM_{2.5}$ pollution. However, how does the boundary layer structure interact with the co-occurrence of O_3-$PM_{2.5}$ pollution? In order to address this question, we conducted a further analysis. As mentioned, co-occurrence of O_3 and $PM_{2.5}$ pollution were mainly found in the BTH – NYRD under Type 1 and over BTH region under Type 2. Lower WS and its negative anomalies at lower boundary layer over BTH– NYRD under Type 1 and over BTH under Type 2 may not enhance the diffusion of air pollutants (Fig. S8). In contrast, moderate RH and its negative anomalies might favor the formation of compound pollution. Downward vertical motion and negative anomalies could also stabilize the atmospheric characteristics of boundary layer (Fig. S9). Furthermore, we summarized boundary layer structure, precipitation, and ground-level wind flow across the BTH region. Based on the characteristics, we separately defined Type 1 and Type 2 into clean (both concentrations of the O_3 and $PM_{2.5}$ are less than polluted level) and compound pollution periods (Figs. 11 and S10-S11). Particularly, Type1 has a significantly warmer temperature over the boundary layer during the compound pollution period of BTH region than that of the clean period. The daytime BLH under compound pollution condition was also higher than that of the clean condition. In addition, there were different directions of prevailing during the two periods, which prevailing winds during the compound pollution period were usually southward and could be driven by air pollutants transported from the southern plains (Fig. 11; see also Miao et al., 2019b, 2020). Co-influencing by the topographical effect of the northern mountainous areas, air pollutants could be trapped in the BTH region. In comparison, although there was southward wind prevailing in the BTH region (Figs. 11 and S11), the rain belt also located in the southern area of BTH might lead to the potential removal of $PM_{2.5}$ (Fig. 9j). Therefore, compound pollution across the BTH region might mainly be due to local emissions of air pollutants."

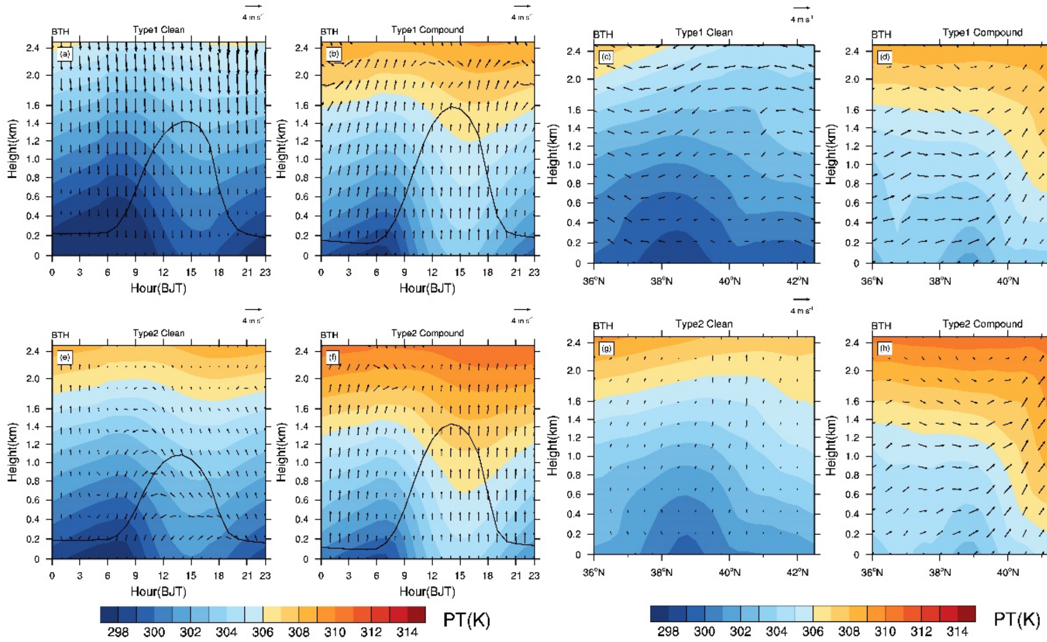

Fig. 11. The daily variation of horizontal wind, potential temperature (PT) and BLH of boundary layer in the BTH under clean and compound pollution period of Type 1 and Type 2 (a, b, e, f). The vertical cross-section of u-wind, w-wind and PT for the same situation of BTH (c, d, g, h). The w-wind is multiplied by 100 when used. The data has been derived from ERA5 reanalysis data.

6. Lines 146-147: Subregions should be labeled in a figure to orient the reader. This can be done in panel (a) of Fig. 1.

RESPONSE: Revised.

7. Fig 1.: There is no "red box"? If there is, it is not clear

RESPONSE: We have changed to the "black box".

8. Figs. 2 and 3: Please change the color of "heavily polluted" regions to something other than turquoise. It can easily be misinterpreted as a "good" category

RESPONSE: Changed.

9. Line 200: How is "pollution day defined" for O3? By the thresholds laid out earlier (160 ug/m3 threshold)? Also, what constitutes "moderate" pollution? Same question applies for PM2.5.

RESPONSE: The pollution levels of O_3 and $PM_{2.5}$ over each key area were verified according to the limit of air pollutant concentration, based on the Technical Regulation on Ambient Air Quality Index (on trial) (HJ633-2012) issued by the Ministry of Ecology and Environment of the People's Republic of China Specific standard limits are now shown in Table S1 of the supplementary materials.

Table S1. Thresholds for each pollution level of $PM_{2.5}$ and O_3-8h.

AQI	Pollution level	$PM_{2.5}$(μg m^{-3})	O_3-8h (μg m^{-3})
0~50	Good	0~35	0~100
51~100	Moderate	36~75	101~160
101~150	Lightly polluted	76~115	161~215
151~200	Moderately polluted	116~150	216~265
201~300	Heavily polluted	151~250	266~800

10. Line 219-220: This low-level transport feature and its variation with PC is not shown in any figure but is referenced. I believe that at least one figure should show this feature since it is being discussed in forthcoming results

RESPONSE: The low-level transport feature is shown in Fig. 11.

11. Line 226: How can you infer that water vapor is being transported into the YRD regions? The 850-hPa flow vectors are at best directed parallel to the YRD coastline. Otherwise they are directed offshore. Additionally, inferences about moisture transport should be made by wind/water vapor overlays or by integrated vapor transport/moisture convergence analysis (see Rahimi et al. 2018), which this figure does not have.

RESPONSE: Thank you for your valuable suggestion. We added the water vapor flux (WVF) in Fig. 4. WVF denotes the direction and magnitude of atmospheric moisture transport, which is simplified as : WVF = $V*q$/g, where q is specific humidity, g is the gravitational acceleration (= 9.8 g/m^2), and V is the horizontal wind. It can be seen that the southwesterly flow transports sufficient water vapor to the YRD region.

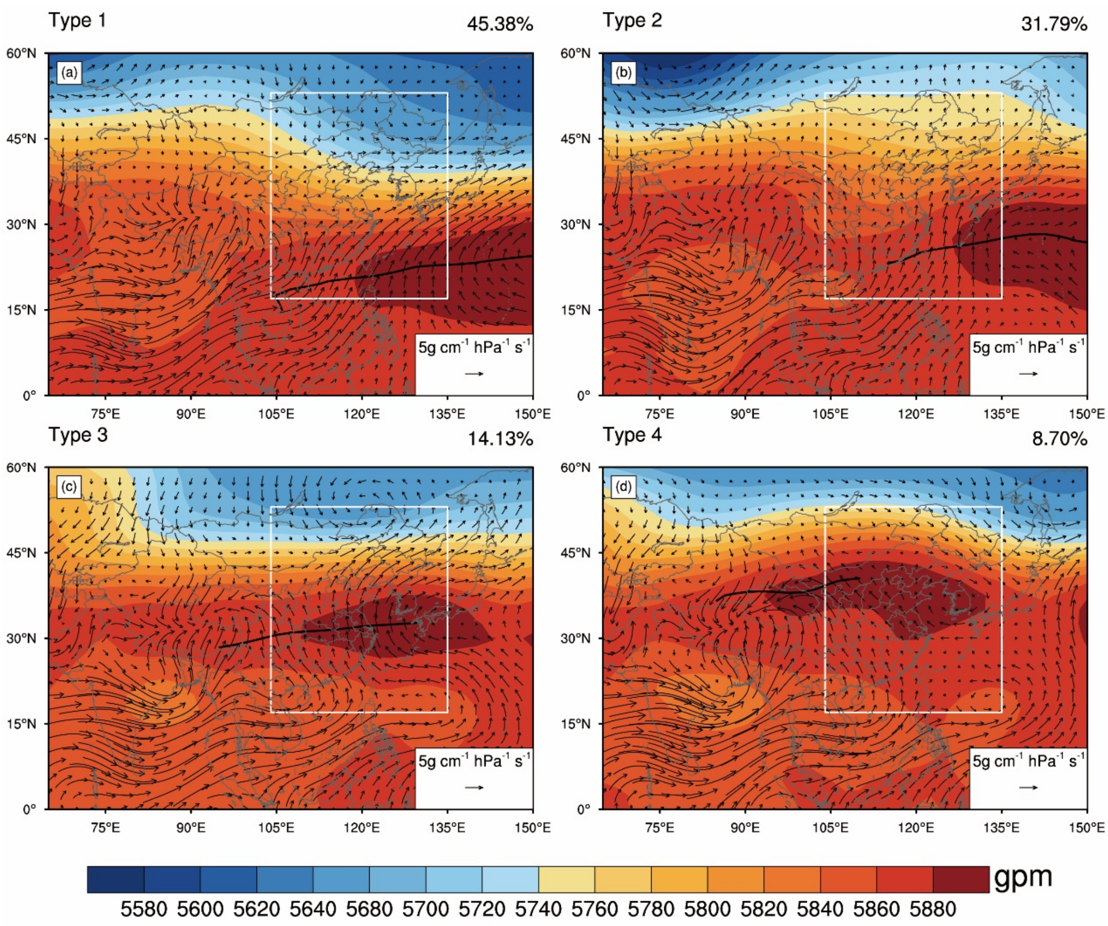

Fig. 4. 850-hPa water vapor flux (WVF =V*q/g, q is specific humidity, g is gravitational acceleration, V is horizontal wind; vectors; see scale arrow at the bottom right in units of 5 g $cm^{-1}hPa^{-1}s^{-1}$) and 500-hPa GH (contours; see scale bar at bottom in units of gpm) patterns based on objective classification (see text for details). White box area is for the area of eastern China, the number at the upper right corner of each panel indicates the frequency of the occurrence of each pattern type, the black line of each panel presents the ridge axis of the WPSH.

12. Line 227: Flow shifting from southwesterly to westerly with northward extent is anticyclonic, which we see in the figure. At the same time, we see a cyclonic sped shear maximum, so it is impossible without quantifying the vorticity explicitly to say if this is anticyclonic or cyclonic. Please remove "cyclonic."

RESPONSE: Thanks for your comment. Removed.

13. Line 229: Is it the WPSH retreating or advancing? Its axis appears to shift north slightly. . .

RESPONSE: The WPSH shifts northward slightly from Type 1 to Type 2; and it retreat southeastward from Type 3 to Type 2. Thanks for the suggestion and we have now revised the content (Lines 274-275 on page 10).

14. Line 230: Consider deleting, "and the GH over northern China at 500 hPa is higher compared with Type 1 (Fig. 4b)." The change in the magnitudes of GH are not terribly important; it is the

change in their gradients that regulates the winds in each PC. Line 231: The only Type 2 onshore flow (at 850 hPa) I see is around 120E by 30N, which lies directly west of the Type 2 GH maximum. This is an example of how you can use certain language relating flow properties to GH anomalies for specific PCs. Currently the authors state, ". . .southerly wind blowing from the ocean to the continent lies in front of the bottom of the high pressure,. . .", which is very unclear. More generally, I recommend the authors refrain from using "top" and "bottom" unless they are referring to the vertical axis (i.e. up and down).

RESPONSE: Thank you for your comment. The related sentence in Line 230 has been deleted. We also changed ". . .southerly wind blowing from the ocean to the continent lies in front of the bottom of the high pressure,. . ." to "The southerly wind from the ocean could interact with northern periphery of the WPSH".

15. Line 233: "and the rain belt moves northwards to the east of the YRD region." Are the authors referring to the belt as it compares to other PCs? If so, the different PCs may be compared to one another, but it is not guaranteed that any type will necessarily evolve from another type. Please clarify and reword throughout the text.

RESPONSE: Thank you for your suggestion. We have reworded the descriptions for the rain belt and plotted the rain belt in Fig. 8 (i-l). The discussion about rain belt is moved to Sec.3.4 as follows:

"Type 1 is characterized by humid condition in the southern area and dry condition in the northern region owing to an extensive southwestern flow of the WPSH, resulting in a rain belt found in southeastern coastal area such as PRD and YRD regions. Type 2 is associated with meridional flow and dry and wet anomalies in northern China, resulting in a rain band locating at the central areas of between BTH and YRD regions due to the northern advance of the WPSH compared with Type 1. Furthermore, there is a greater RH for most of the study sites under Type 3 and Type 4, possibly a result of the shifted rain belt in the BTH and NEM regions under Type 3 once the northern boundary of the WPSH reaching at 37.5°N, and an occurrence of heavy precipitation across the western PRD region as well as central areas of between BTH and YRD regions under Type 4 (Fig. S6)".

16. Lines 237-238: ". . .which implies that the rainy season in the YRD region ends in midsummer and the weather becomes hot and dry." How is this implied? 850-hPa flow is onshore beneath the western edge of the 500 hPa monomer of the WPSH. This linkage is not implicit and should be explained. Moreover, references made to shifts in precipitation need to be explicitly shown if they are going to be frequently referred in the text.

RESPONSE: We appreciate your advice. We have revised this sentence as follow: "This has led to a condition completely controlled by the monomer of the WPSH over the YRD region, resulting a hot and dry weather at the end the rainy season at the beginning of mid-summer.". As for rainy season, we have determined the location of the rain belt based on the amount of precipitation and PF under each SWP, which can be seen at Fig.8(i-l).

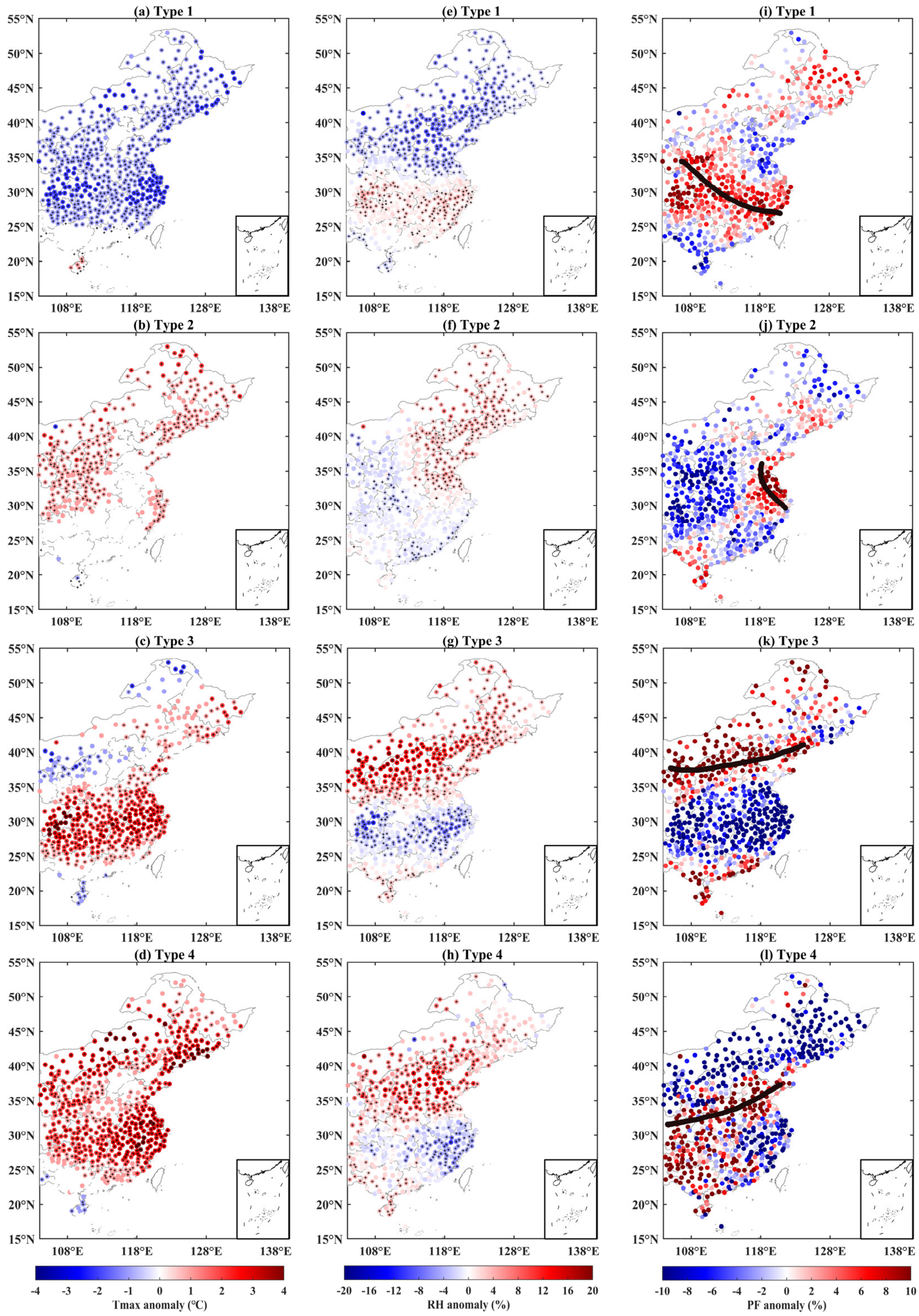

Fig. 8. Same as Fig. 6 but for Tmax (a–d), RH (e–h), and PF (i–l). The black solid line presents the rain belt of each SWP.

17. Lines 239-240: "continues to extend westwards and shift northwards," shifts westward and northward compared to PC3. Again, please indicate it's the synoptic pattern's position more explicitly. Something like, "In Fig. 4d, the monomer is located north and west of the feature in Fig. 4c". The word accordingly relates this sentence to the previous one, but it isn't clear what that

linkage actually is. Also, please explain the linkage or remove the word “accordingly.”

RESPONSE: This sentence has been changed as follow: “Figure. 4d indicated that the location of WPSH monomer was more western and northern with respect to other SWPs, controlling the northern China for a long time; the western ridge point was around 95°E and the northern boundary was around 40°N.”.

18. Line 241: Heat wave? How is PC4 related to a heat wave? Where is this shown in the figures or analyses?

RESPONSE: Sorry for the confusion. The words related to “heat wave” have now been removed from this sentence.

19. Figs 3-4: How are levels of air quality defined? Are they arbitrary? If so, then a brief justification is required. If they are a community standard, then a source is needed.

RESPONSE: The pollution levels of O_3 and $PM_{2.5}$ over each key area were verified according to the limit of air pollutant concentration, based on the Technical Regulation on Ambient Air Quality Index (on trial) (HJ633-2012) issued by the Ministry of Ecology and Environment of the People’s Republic of China Specific standard limits are now shown in Table S1 of the supplementary materials.

20. Fig. 4 shows the PCs of the synoptic weather pattern and associated percentages of occurrence for the study period.

RESPONSE: Yes.

21. Fig. 5: 2017 is labeled twice. Should the second instance be 2018?

RESPONSE: Revised and thanks.

22. Line 263: Any hypothesis for why the lowest MDA8O3 occurs for PC3? Could it be related to the synoptic pattern of Fig. 4 and associated precipitation (not shown)?

RESPONSE: The analysis of light O_3 pollution under Type 3 is revised as follow (lines 448-455 on pages 16-17):

“High temperature, low humidity and few precipitations over the YRD region tend to generate a large amount of O_3, while the positive BLH and negative FLWD anomalies are unfavorable to O_3 accumulation. On the other hand, summer typhoon activities might weaken the WPSH intensity over the YRD region, leading to the eastward retreat and northward shift of the WPSH. As a result, high WS across coastal areas could ease the ground-level O_3 pollution (Shu et al., 2016). For the BTH and PRD regions, high PF tends to suppress O_3 production. Only 6.8% of the compound pollution occurrence days at all sites occurred under Type 3, in accordant with the light O_3-only pollution over the areas of the BTH, YRD and PRD (Fig. 12).”

23. Line 279: Delete “in the eastern region”

RESPONSE: Deleted.

24. Fig. 8, Lin3 285: What constitutes “serious?” Perhaps it would be good to plot the pollution threshold values here for O3 and PM2.5. Plotting these curves (they would be straight lines) would

help the reader to identify how bad (or good) the air quality actually is in terms of PM2.5 and O3. The authors discuss "over-standard" rates, so a threshold must have been used (plot it). I believe these values are 160 and 75 ug/m3 for O3 and PM2.5, respectively. . .

RESPONSE: We appreciate your comment. The threshold values of O_3 and $PM_{2.5}$ for "over-standard" refer to the 24-h concentrations, and we explained the threshold values for O_3 and $PM_{2.5}$ in the Data and methods as "Based on the Ambient Air Quality Standards (GB3095-2012) issued by the Ministry of Ecology and Environment of the People's Republic of China, O_3 ($PM_{2.5}$) pollution occurs when the MDA8 O_3 ($PM_{2.5}$ 24-h) concentration exceeds 160 (75) μg m^{-3}." In order to more clearly compare the concentration differences under different SWPs in various regions, we have changed the Fig. 8 to daily anomalies variation.

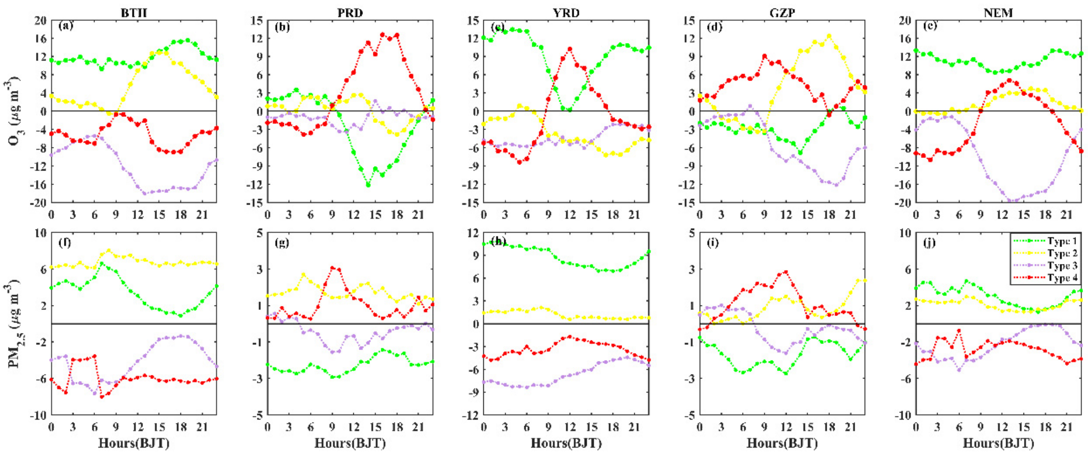

Fig. 7. Daily anomalies variation of O_3 and $PM_{2.5}$ under four SWPs in key urban clusters. The black solid line presents the averaged value of each urban cluster.

25. Line 286: For (2), over-standard rates are not plotted – concentrations are. Please clarify. If the authors are suggesting that O3 an PM2.5 concentrations are similar between PCs, then please reword.

RESPONSE: The over-standard rates are shown in Table 1. Reworded it to "in the PRD region, the over-standard rates and concentrations of O_3 and $PM_{2.5}$ is similar under four SWPs".

26. Line 287: For (3), it looks like Type 4 is leading, not Type 1, for O3 concentrations from 0900-1500. Since this is when concentrations are largest, the "Type 1 > Type 4 > . . ." may mischaracterize your argument.

RESPONSE: The O_3 pollution over-limit ratio is calculated via stations* days, it presents as Type 1 > Type 4 > Type 2 > Type 3" in the YRD. But it is true that Type 4 is leading, not Type 1, for O3 concentrations from 0900-1500, this is because the daily variation is counted by regional average concentrations.

27. Line 302: "Activities"? Do the authors mean "modulations"? This is unclear..

RESPONSE: Thank you for the suggestion. We have now used "modulations" (line 87, page4) as suggested.

28. Line 308: "Makes summer always hot and moist" grammar needs revisions

RESPONSE: Revised. We changed it to "induces a hot and humid condition over the summer".

29. Line 316: "presents negative" should be followed by "(Fig. 9a)" to guide the reader. Also, why are Tmax anomalies negative under this PC?

RESPONSE: We have added the tags to guide the reader. The reason of negative Tmax anomalies under Type 1 is that Type 1 is always occurring early summer.

30. Lines 312-321: Precipitation is integral to the lifecycle of PM2.5 and O3. The linkages between the precipitation anomalies and Fig. 4 should be explicitly discussed. I believe the authors attempt to do this in Sec. 3.2, but that discussion is more appropriate here.

RESPONSE: Thanks for your advice. We have moved the discussion of precipitation to subsection 3.4. Please refer to lines 352-361 on page 13: "Type 1 is characterized by humid condition in the southern area and dry condition in the northern region owing to an extensive southwestern flow of the WPSH, resulting in a rain belt found in southeastern coastal area such as PRD and YRD regions. Type 2 is associated with meridional flow and dry and wet anomalies in northern China, resulting in a rain band locating at the central areas of between BTH and YRD regions due to the northern advance of the WPSH compared with Type 1. Furthermore, there is a greater RH for most of the study sites under Type 3 and Type 4, possibly a result of the shifted rain belt in the BTH and NEM regions under Type 3 once the northern boundary of the WPSH reaching at 37.5°N, and an occurrence of heavy precipitation across the western PRD region as well as central areas of between BTH and YRD regions under Type 4 (Fig. S6).".

31. Lines 328-331: This sentence is unclear and should be revised. Also, there is an instance here where the authors use an acronym in one part of the sentence but not the other. Please be consistent. Also, how do negative FLWD anomalies result in a deeper PBL?

RESPONSE: Thank you for your comment. It has been revised to "As can be seen from Fig. 9, when the BLH has a positive anomaly, on the contrary FLWD has a negative anomaly (e.g., BTH in Type 1), which indicates the higher BLH, the lower FLWD, the more conducive to the diffusion of pollutants, otherwise, lower BLH and higher FLWD (BTH in Type 2) do not support the diffusion.". The averaged WS would be higher when negative FLWD anomalies, usually the BLH is higher in this case.

32. Sec. 4.1, P3: I believe that stability should be discussed here in addition to a more detailed discussion of precipitation "anomalies" associated with each PC. Thermal stratification of the PBL will dictate the mixing depth of the PBL and thus regulate the pooling of these aerosol/pollution plumes. Looking at the correlation between Tmax, PF, FLWD, etc. is not enough.

RESPONSE: Thank you for your suggestion. The stability discussion is linked to thermal stratification of the PBL in Sec. 4. Please refer to the response to major comments 3 of referee #1 and major comments 4-5 of yours.

33. Lines 346-349: Here is a wonderful chance to discuss what is special about PC4 on a synoptic level. Why is PC4 leading to the largest O3 events synoptically? Do these same conditions favor the co-occurrence of O3 and PM2.5?

RESPONSE: We appreciate your suggestions. We have discussed these questions in the

Discussion as follows:

"High temperatures, medium-high humidity and few precipitations in the GZP and PRD regions can cause O_3-$PM_{2.5}$ compound pollution, but $PM_{2.5}$ pollution in the both regions is are not heavy, which is possibly in relation to local lower pollutant emissions. The probability of compound pollution occurrence under Type 4 is about 5.1%. Under the control of the WPSH, there are strong photochemical reactions at high temperatures and little rainfall in some eastern region (such as North BTH, YRD), which is also conducive to O_3 generation (Fig. 12). Meanwhile, relative to Type 1, O_3 pollution is lighter in the BTH, due to the differences of RH, BLH and FLWD."

34. What is the difference between the Yangtze River and the YRD? These should be labeled on a map for readers. . .

RESPONSE: It should be "YRD" there.

35. It seems as though there is a window of moisture availability that is large enough to allow hygroscopic growth of PM2.5 but is sufficiently small to allow for the important photochemical processes that regulate O3. It would seem to me that identifying this moisture window, as well as its sensitivity to PCs, would be a very significant contribution and I recommend that it be studied further to more precisely identify the PCs responsible for co-occurring O3/PM2.5 events. Identification of this moisture window can be based on an optimal relative humidity for compound pollution events too. This window can change by region and PC type.

RESPONSE: Thank you for your valuable comment. We selected the BTH region, an area with high frequency of compound pollution, to analyze the RH condition under four period (compound pollution, clean, O_3-only, $PM_{2.5}$-only). Indeed, there is a moisture window here, higher RH would restrain the production of O_3, and lower RH would not favor hygroscopic growth of $PM_{2.5}$. The moderate RH is more conducive to the formation of compound pollution.

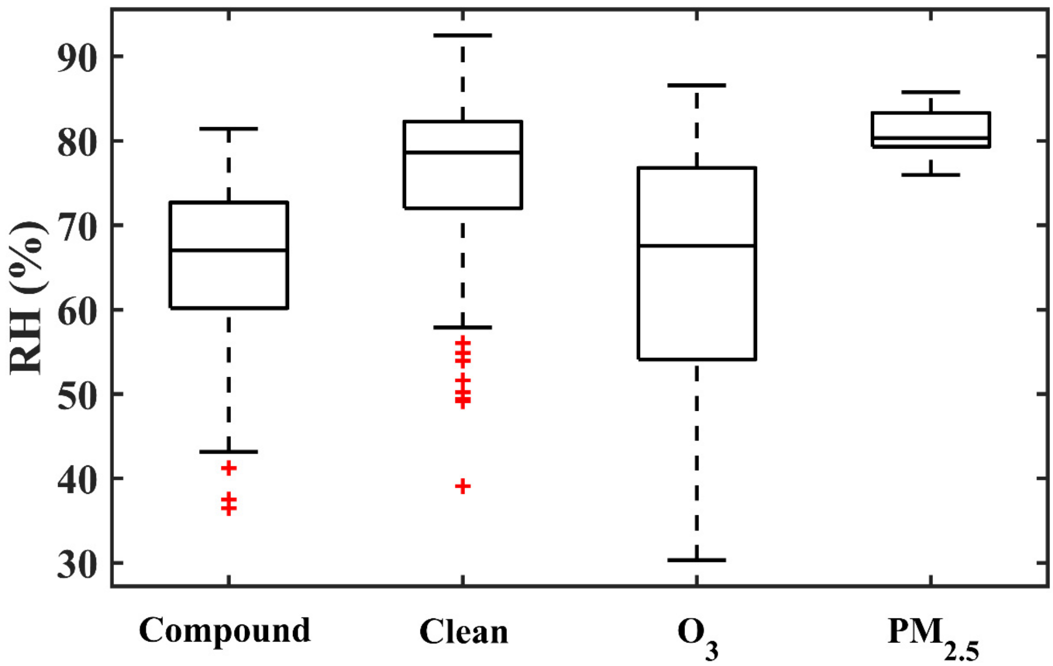

Fig. S14. Box-Whiskers for the RH under compound pollution, clean, O_3-only, $PM_{2.5}$-only

period. In the Box-Whiskers plot, the central box represents the values from the lower to upper quartile (25th to 75th percentile). The vertical line extends from the maximum to the minimum value. The middle solid line represents the median, and the red plus represents the outlier.

36. Line 368: Strengthens compared to Type 1? Type 2's trough does not necessarily strengthen from the Type 1 pattern. Please reword.
RESPONSE: Thank you for your suggestion. We have reworded it to "As the northern advance of WPSH from Type 1 or the retreat from Type 3 or Type 4, and the northern region is still controlled by the westerly zone".

37. Lines 357-387: The authors give the percentage of days with compound pollution for types 1 and 2. However, this does not elucidate which type is more efficient at producing compound pollution. The authors should include the percentages of compound pollution days for types 3 and 4. From the results here, I'd suspect that types 1 and 2 are the most efficient compound pollution setups, but this can be confirmed by including the percentages as for types 1 and 2.
RESPONSE: Thanks for your suggestion. The probability of compound pollution occurrence under Type 3 and Type 4 are 6.8% and 5.1%, which are added in lines 453 and 459.

38. Lines 396-397: These percentages need to be presented for Types 3 and 4 as higher percentages may indicate that PCs 3 and 4 are more efficient setups for co-occurring pollution events, even if the PCs occur less frequently.
RESPONSE: Thanks and added.

39. Line 398: "line" should be "axis"
RESPONSE: Revised and thanks.

40. Line 400: Again, what is "Meiyu" season for non-local readers?
RESPONSE: The explanation about "Meiyu" is added to lines 270-274 on page 10: "These conditions were also associated with high temperature and humidity during the summer with Meiyu season, which Meiyu season is a climate phenomenon with continuous cloudy and rainy days generally occurring during June and July every year in the middle and lower reaches of Yangtze river, Taiwan of China, central/southern Japan, and southern Korea".
41. Lines 400-401: How do higher temperatures suppress O3 production? I would suspect that the higher relative humidifies are primarily responsible. . ..
RESPONSE: Yes, you are right. We have revised it.

42. Line 403: Is the low pressure trough at the surface or at 500 hPa?
RESPONSE: It is referring to the condition at 500 hPa. We have added related information to Lines 478, page 17.

43. Lines 402-404: Again, this "small amount of water vapor transport" suggests that there is a nominal vapor pressure deficit conducive to compound pollution events. In an environment of appropriate stability and PBL characteristics, compound pollution may be especially severe.
RESPONSE: Thank you for your valuable suggestion. We have revised it as "The hygroscopic

growth of $PM_{2.5}$ occurs in the corresponding area in front of the trough with a small amount of water vapor transported by the WPSH. Particularly, the prevailing southerly winds in the boundary layer can transport the pollutants emitted from southern cities to the BTH region, and the atmospheric stratification is stable when the air mass is sinking. Thus, the compound pollution can be severe. In general, the synoptic circulation might be responsible for the concentration of pollutants under this SWP".

44. Lines 407-408: It appears that the WPSH only shifts north in your objective PC analysis, not southwards and eastwards. . .can the authors clarify?

RESPONSE: From Type 1 or Type 2 to Type 3 or Type 4 presents the shift north of WPSH in early summer, in the contrary, from Type 3 or Type 4 to Type 2 or Type 1 presents southwards and eastwards retreat. We have added the location of the WPSH (Table S1) and re-described the motion of the WPSH. Please refer to lines 266-285 on pages 10-11, lines 474-475 and 486-489 on pages 17-18.

45. Line 411: Why does water vapor lead to a sink of O3? Water vapor by itself cannot remove O3 from the atmosphere or prevent its formation. Are the authors referring to the supersaturation, dew point depression, etc.?

RESPONSE: Sorry for the confusion. We did not refer to the supersaturation or dew point depression. Instead, we are referring to water vapor flux at 850 hPa (Fig. 4). This is based on the following context: as water vapor can absorb part of the short-wave solar radiation, and this can weaken the photochemical reaction and reduce ozone production. The details have now been revised in the manuscript (Lines 489-490of Pages 18).