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Atmospheric Chemistry and Physics
Discussions

Interactive comment on "Dynamic Processes Dominating Ozone Variability in Warm Seasons of 2014–2018 over the Yangtze River Delta Region, China" *by* Da Gao et al.

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General comments: In this manuscript, the authors focus on the inter-annual variations of warm seasons (April–September) ozone over YRD, China from 2014 to 2018. The relations between the inter-annual ozone and synoptic-scale circulations and the associated meteorological controlling factors were revealed. The authors highlight five dominant synoptic weather patterns (SWPs) in the warm seasons in YRD using the t-mode principal component analysis and reconstructed the inter-annual O3 variation based on SWPs frequency and intensities. The analysis is mostly sound, especially on inter-annual ozone variations impact by SWPs induced meteorological factors. But

some analysis need deeper explanation in physical or photochemical principals, and some conclusions need more robust supports. My specific suggestions and comments are as follow.

Thanks for your comments and suggestions. All your comments and suggestions are very important. They have directive significance to our paper and research work.

Specific comments: 1.In the title and content of the paper, I feel the "Dynamic Processes" could not give a direct and effective cognition to reader. I suggest "Ozone Variability in Warm Seasons of 2014–2018 over the Yangtze River Delta, China induced by synoptic patterns" or similar titles should be better.

Thanks for your comments. "Dynamic Processes" originally emphasized the meteorological influences on ozone variability. In order to avoid confused cognition of readers, the old title is replaced by "Ozone Variability Induced by Synoptic Weather Patterns in Warm Seasons of 2014-2018 over the Yangtze River Delta, China". Please see the new title in the new revised manuscript.

2. In abstract line 37-41 and also in the context, the 2 sentences may conflict. I am not sure "the strengthening of the ridge and trough in the westerlies" is conflict with "the weakening of the continental high under SWP2" and "the southern low pressure weakening and WPSH weakening under SWP4, and the north China anticyclone weakening under SWP5.".

Thanks for your comments. The strengthening of ridge and trough in the westerlies are associated with the strengthening of dominated weather systems. However, under SWP2, 4 and 5, changes in troughs and ridges are not associated with changes in the continental high, the WPSH and the north China anticyclone. Specifically, the trough and ridge strengthening are associated with the Aleutian low shifting southward under SWP2, the southern low pressure weakening under SWP4 and Japan low pressure appearance under SWP5. To clarify the above findings, we add the following explanations on lines 463, 499 and 515 in the new revised manuscript.

Line 463: At 500 hPa, a trough located at approximate 120°E–125°E is strengthened associated with Aleutian low shifting southward,

Line 499: At 500 hPa, a shallow trough located at about 125°E strengthens associated with weakening of the southern cyclone pressure,

Lines 515: At 500 hPa, a trough located at about 130°E controlling the YRD strengthens associated the Japan low pressure appearance.

In comparison with the similar previous studies (Han, et al., 2020; and Gao et al., 2020), this paper is not clear in spatial distribution of pressure and lack of clear pictures in synoptics.

Thanks for your comments. In order to show clear pictures in synoptic, specific figures of atmospheric circulation at 850 hPa under each SWP are added in the supplement. As shown in Fig. 1, SWP1 is under control of the southwesterly flow introduced by the WPSH. SWP2 is influenced by the northwesterly flow introduced by a continental high pressure and the Aleutian low pressure. SWP4 is influenced by the southeasterly flow introduced by the WPSH and a cyclone. SWP3 and SWP5 are affected by a cyclone and an anticyclone. The above findings are added on lines 376-379 in the new revised manuscript as well.

These figures are similar with figures in Pos phase or Neg phase under each SWP, and we primarily explore the changes in atmospheric circulation between Pos and Neg phase of the SWPs. Therefore, these figures are only added in the supplement.

3.In figure 1, “43.40” need mention in the context.

Thanks for your comments. “43.40 ppb” represents the highest monthly mean O3 concentration value during the warm seasons in 2014-2018. Fig. 2a primarily shows the increasing trend during this period, so it is inappropriate to illustrate this maximum number in the figure. In the new revised manuscript, “43.40” is deleted.

4.In the EOF analysis, the spatial distributions of EOF1 are generally negative and

time series of EOF1 presents a decreasing trend. Actually, the O3 generally increase all over YRD in recent years. So, I suggest multiply -1 with spatial distributions of EOF1 and time series of EOF1 make the statement easy to follow.

Thanks for your suggestions. The spatial distributions and time series of EOF1 mode have been multiplied -1 in Fig. 3. In addition, we correspondingly change Fig. 4 and other illustrations. Please see Figs.2 and 9, and the words on lines 398-400 in the new revised manuscript. The revisions are listed as below:

Lines 398-400: the positive phase (Pos) represents that the EOF1 time series is more than 0 and it is beneficial to the production and accumulation of O3. On the contrary, the negative phase (Neg) corresponds low O3 concentration.

5.The authors reveal RH is the key factor dominating inter-annual variations of ozone, and indicate that its unclear in the relations between RH and ozone in previous study. I suggest the authors gives a further clear explanation of the RH effects on ozone. RH could related to the cloud cover (solar radiation), stable of air in BL and so on. In figure 3b, sunshine duration (may related to cloud cover?) is not important in ozone inter-annual variation, and opposite to RH, which may implicate that stable of air (accumulation of air pollutants) is important?

Thanks for your comments. We re-quantify the meteorological factors impact on the O3 variation, and stress influential mechanism on O3 variation from dominated meteorological factors.

In section 3.2.1, we quantify the meteorological impact on the O3 variation using meteorological adjustment method. In the original manuscript, we adopted sunshine duration, air temperature at 2m, wind speed at 10m and relative humidity as the input factors. According to the above suggestions, in order to clarify the effects of relative humidity (RH) on O3, we replace the sunshine duration with solar radiation (SR) and add the low cloud cover (LCC). There are two reasons for selecting LCC to analysis. Firstly, low clouds are more effective at blocking out sunlight (SR) than medium and high clouds. Secondly, LCC has the higher correlation coefficient with SR than total cloud cover, medium cloud cover and high cloud cover. As shown in Fig.5, RH is the most crucial factor and its variation is similar to the variation in the total meteorological impact. In addition, SR and LCC also play important roles and have large impacts on O3 variation. RH can impact O3 concentration in two ways. One is gas phase H2O reacting with O3 (O3 + H2O + hv = O2 +2OH). The other is its influencing on clouds and thereby shielding SR. During this process, specifically, under low RH circumstance, the reactions between water vapor and O3 are inhibited. Moreover, low RH leads to less cloud cover, and thereby there is more intensive SR. Strong SR can enhance O3 chemical reaction.

In a word, RH, SR and LCC all have important effects on O3 variation. Among them, RH plays the most significant role in modulating the inter-annual O3 variation. Low RH prevents O3 to react with gas phase H2O. Moreover, low RH caused by vertical downward motions results in less LCC and intensive SR, which can enhance the O3 chemical reactions and lead to higher O3 concentrations. The above-mentioned specific discussions have been added in section 3.2.1 in the new revised manuscript.

6.In line 402, “the cloud cover hard to form” should be “the cloud hard to form.”

Thanks for your suggestions. “the cloud cover hard to form” is changed to be “hinder cloud formation”. Please see line 440 in the new revised manuscript

7.What is the unit in figure 4 of W (vertical velocity), m/s or Pa/s?

The unit of W (vertical velocity) is “Pa/s”. In the new revised manuscript, the sub-figures (e) in Fig. 4, 5, 6, 7, 8 have been replaced by Table 3, and the unit of W “Pa/s” have been added in the Table 3. Please see line 527 in the new revised manuscript.

8.In line 427-428, the sentence “At 500 hPa . . ..” should indicate the area of downward motion.

Thanks for your suggestions. As shown in Fig. 6a and b, the northwest YRD area in

red box is located behind the strengthening trough. According to the potential tendency equation, downward motions are usually located behind the trough. Thus, in this case, the northwest YRD area is associated with stronger downward motion. The above discussion is added in the new revised manuscript. Please see lines 462-464.

9.What is SR in fig. 4 etc.? SD?

Thanks for your suggestions. SR and SD represent the solar radiation and sunshine duration, respectively. Solar radiation reanalysis data and sunshine observation data are acquired from the ERA-interim dataset and the air quality real-time publishing platform. SR is usually regarded as the directly influential factor of O3 formation. Therefore, in the section 3.2.1, we quantify the effect of meteorological conditions by using SR. In the new revised manuscript, SD is not used any more

10.From figure 4-8, a summary table with values of meteorological factors in 5 SWPs could be better than sub-figure (e) for comparisons.

Thanks for your suggestions. We change sub-figures (e) in Fig. 4, 5, 6, 7, 8 into a summary table. Table 1 shows regional mean $\pm$ the standard error of meteorological factors in Pos phase and Neg phase and their difference (Pos minus Neg) under each pattern. The meteorological factors include relative humidity (RH), solar radiation (SR), air temperature (T2), low cloud cover (LCC), total cloud liquid water (TCLW), zonal wind speed at 850 hPa (V850) and vertical motion (W). Table 1 is different to show in this text, So It present in the form of figures and is added after Fig. 6.

RH, SR and T2 are dominated meteorological factors affecting O3 variation. V850 is an important element of bringing water vapor to the YRD and result in RH variations. Moreover, under the condition of vertical upward or downward motion (W), RH would change low cloud cover (LCC) and total cloud liquid water (TCLW), leading to the variation of SR.

11.In section 3.4, I wonder why do you reconstruct the EOF1 time series? It could be more valuable to reconstruct the inter-annual variations of ozone concentration based on SWPs frequencies and intensities. And What's SWPIIs?

Thanks for your suggestions. We reconstruct the EOF1 time series to replace the regional mean O3 concentration. There are two reasons for this decision. Firstly, the time series of EOF1 shows a high negative correlation with the O3 time series (R = -0.98). More importantly, we primarily focus on why O3 concentration increases in the entire YRD region, rather than why the increases in O3 differ spatially inside the YRD. Therefore, it is more appropriate to reconstruct EOF1 time series than O3 time series.

SWPIIs represent synoptic weather pattern intensity indexes. They are defined as maximum geopotential height in zone 1(25°N–40°N, 110°E–130°E) for SWP3 and SWP5, maximum geopotential height in zone 2 (20°N–50°N, 90°E–140°E) for SWP1 and SWP4, and average geopotential height in zone 3 (10°N –40°N, 110°E–130°E) for SWP2, according to their high correlation coefficients with EOF1 time series under each SWP. Especially, zone1, 2 and 3 were selected in term of location of dominated weather systems under each SWP. Please see lines 255-257 and 559-570 in the new revised manuscript.

Technical corrections: 1.In the caption of figure 2, are they "orange dash line"? Pink? 2.There are several typo need carefully check. For example, meddle in line 313; "wins" in line 468; "SR" in 336 could be SD. Thanks for your suggestions. The above-mentioned typos have been corrected. For example, "orange", "meddle" and "wins" are modified as "pink", "middle", "winds". Please see lines 314, 332 and 495 in the new revised manuscript. In the new revised manuscript, Sunshine duration (SD) is not used any more, as mentioned in the response to the specific comment 9.

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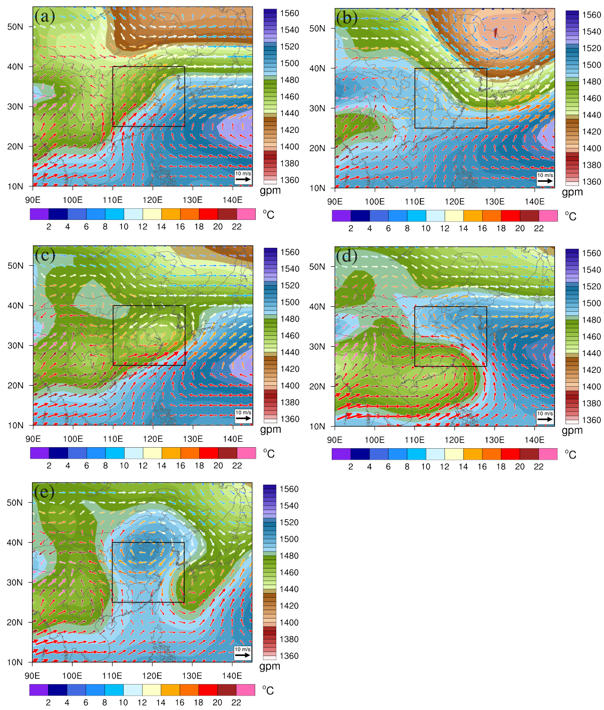

Fig. 1. The geopotential height (shaded) and 850 hPa wind with temperature (color vector) under (a) SWP1, (b) SWP2, (c) SWP3, (d) SWP4, (e) SWP5. The boxed area in Figs.1a-e encloses the YRD.

Fig. 1.

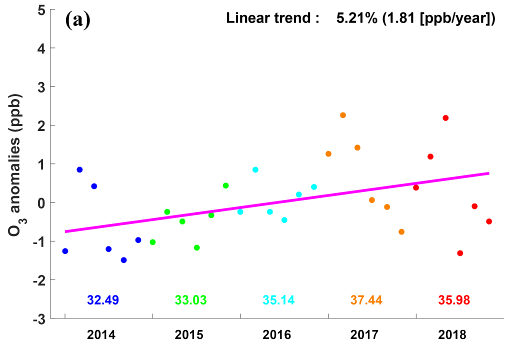

Fig. 2. (a) Anomalies of monthly average O3 concentration from April to September during 2014–2018. The purple solid line represents the linear fitted curve, and the color number represents the annual (April–September) mean of O3 concentration.

Fig. 2.

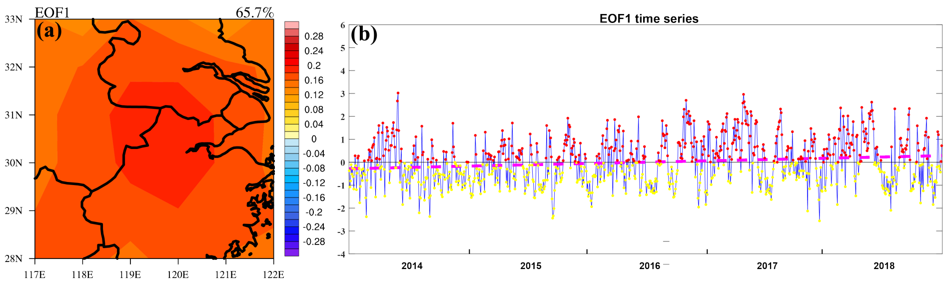

Fig. 3. First EOF patterns of O3 concentration in the warm seasons from 2014 to 2018, including the spatial pattern (a) and time coefficient (b). The percentage in panels (a) is the variance contribution of each EOF mode. The pink dash line in panels (b) represents the linear fitted curve.

Fig. 3.

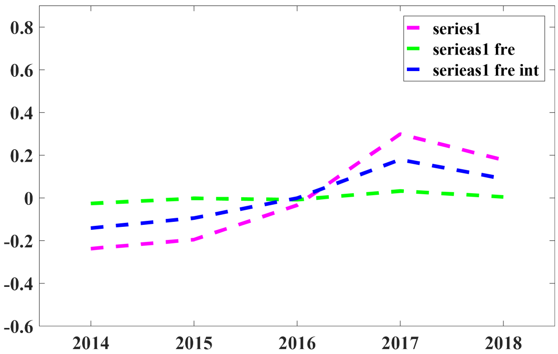

Fig. 4. The trend of the inter-annual EOF1 time series in the warm seasons. The pink curve represents the original inter-annual EOF1 time series in the warm seasons, the green line represents the reconstructed EOF1 time series only accounting the frequency variation in SWPs, and blue line represents the reconstructed one accounting both the frequency and the intensity variations in SWPs.

Fig. 4.

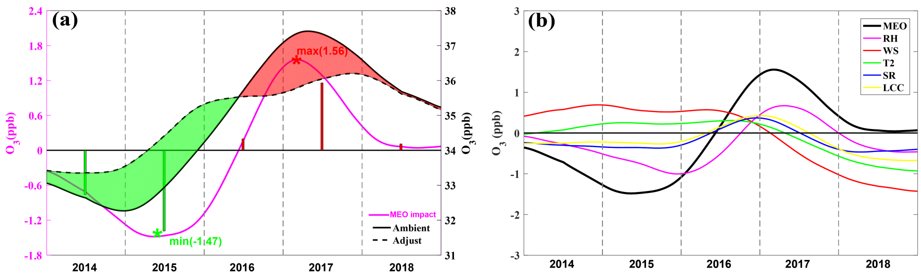

Fig. 5. (a) 5-year trends of ambient O3 (solid black line), meteorological adjusted O3 (dashed black line), and the meteorological impact (pink line) over the YRD during 2014–2018. Periods with positive and negative meteorological impacts are shaded in red and green, respectively; red and green bars represent the O3 increases and decreases attributable to meteorological influence in each year. (b) 5-year variations in the meteorological impact of different meteorological factors (MEO), including relative humidity (RH), solar radiation (SR), air temperature (T2), wind speed (WS) and low cloud cover (LCC).

Fig. 5.

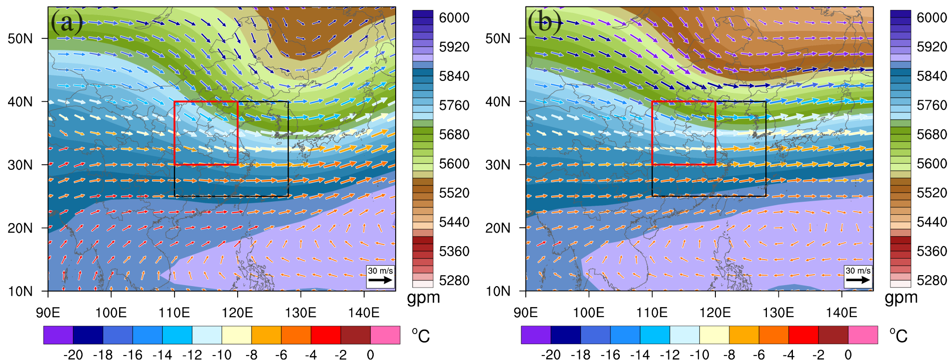

Fig. 6. The geopotential height (shaded) and 500 hPa wind with temperature (color vector) under (c) SWP2_Pos and (d) SWP2_Neg. The red values represent regional average wind speed at 500 hPa in the zone around black lines. The boxed area in Figs.6a-d encloses the YRD.

Fig. 6.

TABLE 1. Regional mean ± the standard error of meteorological factors in Pos phase and Neg phase and their difference (Pos minus Neg) under each pattern.

SWP	phase	RH	SR(W/m^2)	T2(℃)	LCC	TCLW	V850(m/s)	W(Pa/s)
	Pos	69.70±9.69	1970.97±403.19	29.90±4.76	0.07±0.15	0.06±0.08	2.89±2.24	0.00±0.05
P1	Neg	84.94±6.53	1240.93±460.18	27.45±4.78	0.37±0.27	0.17±0.14	4.27±2.73	-0.05±0.05
	Diff	-15.24	730.04	2.45	-0.30	-0.11	-1.38	0.05
	Pos	66.49±10.96	1968.41±377.12	28.81±4.32	0.07±0.14	0.06±0.09	-2.47±3.09	0.02±0.05
P2	Neg	81.29±10.78	1178.34±479.58	23.89±5.90	0.48±0.31	0.19±0.14	-1.37±3.21	-0.03±0.06
	Diff	-14.79	790.06	4.91	-0.41	-0.13	-1.10	0.05
	Pos	76.89±7.09	1371.42±605.82	27.83±2.45	0.34±0.18	0.21±0.19	-0.67±3.43	-0.02±0.04
P3	Neg	88.62±5.14	854.96±395.09	24.77±4.58	0.58±0.24	0.31±0.16	1.93±3.65	-0.09±0.06
	Diff	-11.73	516.45	3.06	-0.24	-0.10	-2.60	0.07
	Pos	71.11±7.15	1882.33±388.10	30.62±3.69	0.11±0.16	0.12±0.16	0.57±2.40	0.01±0.04
P4	Neg	83.37±6.76	1343.80±547.50	28.93±4.19	0.35±0.24	0.19±0.19	2.46±3.60	-0.04±0.06
	Diff	-12.26	538.53	1.69	-0.24	-0.07	-1.89	0.05
	Pos	68.47±14.19	1827.46±447.37	29.60±5.25	0.07±0.11	0.09±0.14	-1.83±3.42	0.01±0.04
P5	Neg	85.81±3.45	1199.21±397.17	26.43±3.82	0.43±0.30	0.16±0.09	-2.31±5.25	-0.02±0.04
	Diff	-17.34	628.26	3.17	-0.35	-0.07	0.48	0.03
Others		/	/		/		/	/

Fig. 7.