Response to Anonymous Referee #3

(Note: Reviewer comments are listed in grey, and responses to reviewer comments are in black. Pasted text from the new version of the paper is in italics.)

This is an interesting modelling study that examines how surface ozone is influenced by warmer SSTs over the Pacific, Atlantic and Indian oceans. With a one degree warming across these basins, the changes in seasonal-mean ozone in the oceanic basin and its surrounding continents are rather large at 1-5 ppb. An increase in SST leads to lower surface ozone over the Pacific and Atlantic oceans but a more mixed response over the Indian ocean. The authors probe the contribution of chemistry and transport processes to these ozone changes. The paper is mostly well written but a number conclusions lack clarity and are not well-substantiated for reasons relating to poor and inconsistent figure quality and interpretation as outlined below. Hence the manuscript, needs much improvement before publication.

We greatly appreciate the reviewer for these detailed and valuable comments. In our revised manuscript, we have significantly improved the quality and consistency of the figures. The IPR analysis in this study has been described more clearly and all the relevant text has been clarified. We have also expanded our explanation and discussion by adding more sensitivity tests. By addressing the reviewer's comments, we believe our manuscript has considerably improved. Please see our response to each comment below:

Major comments:

1) (i) As noted by the other reviewer, the map projections used vary by figure in a non-logical fashion, hence it is extremely difficult to compare results across different figures and hence verify the conclusions in the text. For example, the vertical velocity changes in Figure 6 versus the surface pressure pattern changes in Figure 5 versus the changes in ozone concentrations in Figure 7 (See specific comments also). (ii) In addition, the continental outlines and hence oceanic basins are too difficult to distinguish if they are visible at all. (iii) Finally, most figure panels are too small to be legible- except for Figures S2-S5 which are hugely improved on the other figures (although the continental outlines are still hard to see in Figure S2).

Thanks for pointing out this. In our revised manuscript, we have fixed these problems and consistently used map projection. Specifically, we use Polar projection to show hemispheric scale results (e.g., Figures 1-4) and the Mercator projection to show basin scale results (e.g., Figures 5-8). To make it more comparable, we also redraw Figures 1-4 using the Mercator projection and put them into the supplementary material (e.g., Figures S2, S14 and S15). Please see some examples of the improved figures below:

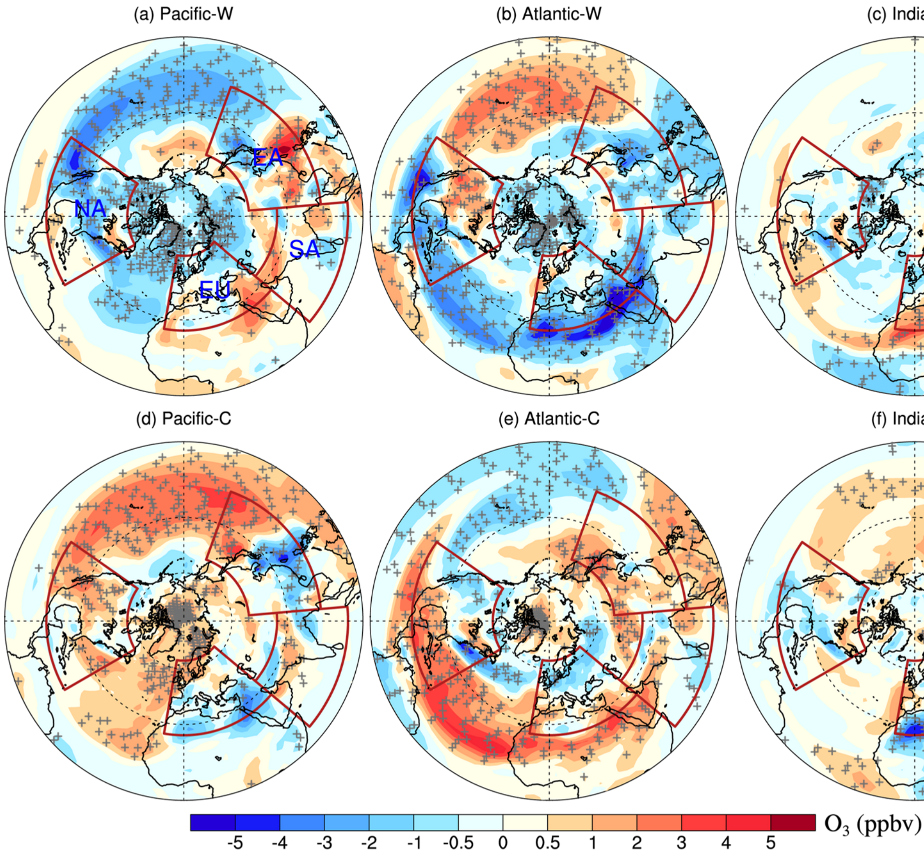

Figure 1. Changes in the summertime (June-August) surface ozone concentrations (ppbv) in the Northern Hemisphere induced by 1ºC warming (top) and 1 ºC cooling (bottom) in the North Pacific Ocean (left), North Atlantic Ocean (center), and North Indian Ocean (right) relative to CTRL. Four major regions of interest (i.e., NA (15°N–55 °N; 60°W–125°W), EU (25°N–65 °N; 10°W-50 °E), EA (15 °N–50 °N; 95°E–160 °E) and SA (5 °N–35 °N; 50 °E–95°E)) are marked with red polygons. The + symbols denote areas where results are significant at the 0.05 level as evaluated with a Student t-test using 20 years of data. (Plots using the Mercator projection are shown in Figure S2 in the supplementary material)

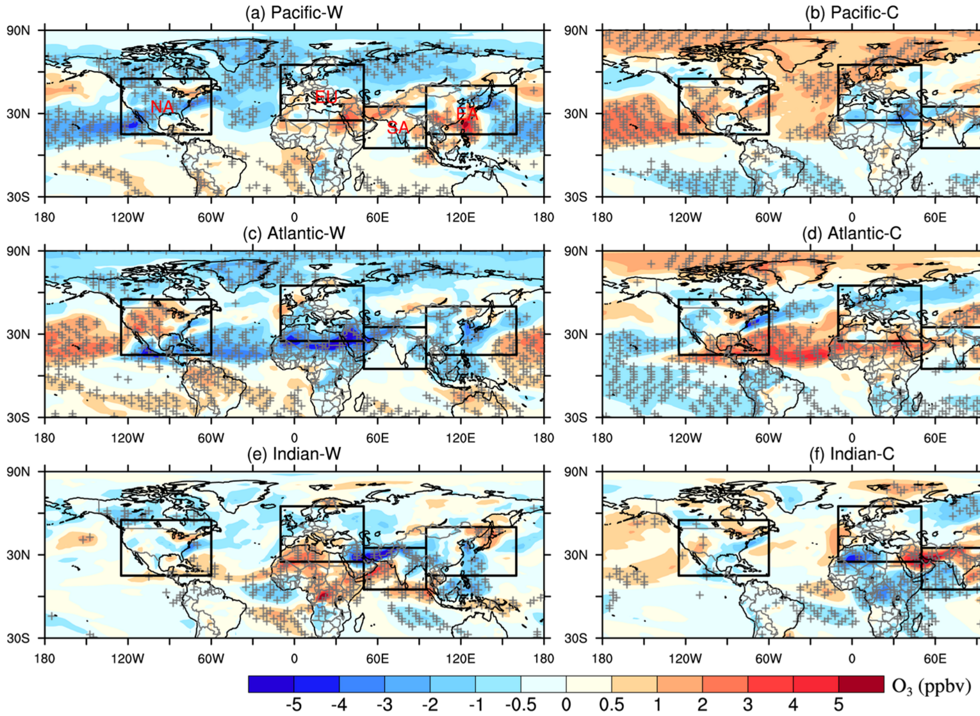

Figure S2. Changes in the summertime (June-August) surface ozone concentrations (ppbv) in the Northern Hemisphere induced by 1ºC warming (top) and 1 ºC cooling (bottom) in the North Pacific Ocean (left), North Atlantic Ocean (center), and North Indian Ocean (right) relative to CTRL. Four major regions of interest (i.e., NA (15°N–55 °N; 60°W–125°W), EU (25°N–65 °N; 10°W-50 °E), EA (15 °N–50 °N; 95°E–160 °E) and SA (5 °N–35 °N; 50 °E–95°E)) are marked with red polygons. The + symbols denote areas where results are significant at the 0.05 level as evaluated with a Student t-test using 20 years of data.

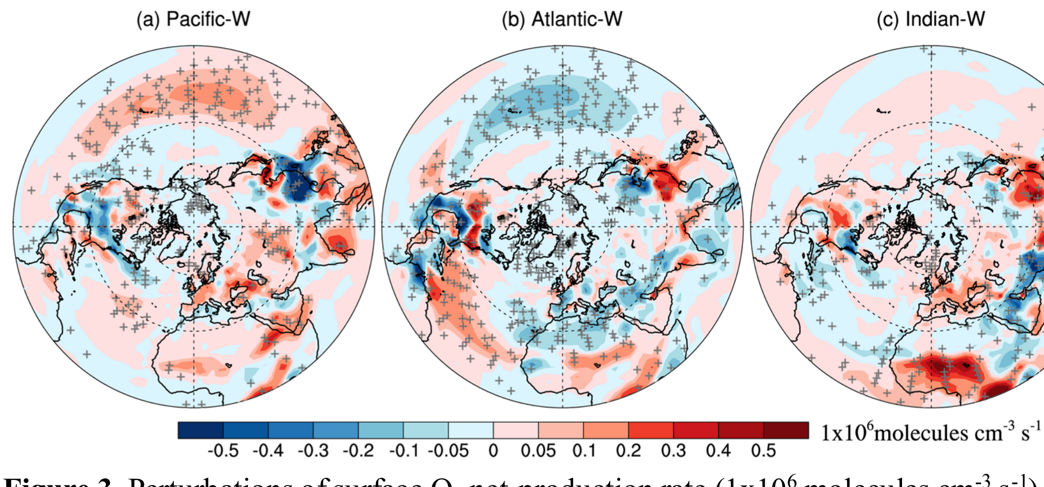

Figure 3. Perturbations of surface O_3 net-production rate (1×10^6 molecules cm^{-3} s^{-1}) for (a) Pacific-W, (b) Atlantic-W, and (c) Indian-W relative to CTRL in boreal summer. The +

symbols denote areas where results are significant at the 0.05 level as evaluated with a Student t-test using 20 years of data. (Plots using the Mercator projection are shown in Figure S14 in the supplementary material)

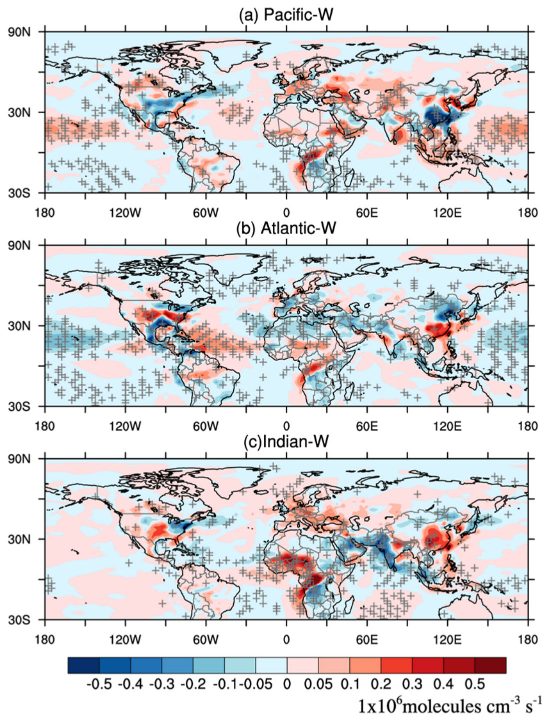

Figure S14. Perturbations of surface O_3 net-production rate ($1\text{x}10^6$ molecules cm^{-3} s^{-1}) for (a) Pacific-W, (b) Atlantic-W, and (c) Indian-W relative to CTRL in boreal summer. The + symbols denote areas where results are significant at the 0.05 level as evaluated with a Student t-test using 20 years of data.

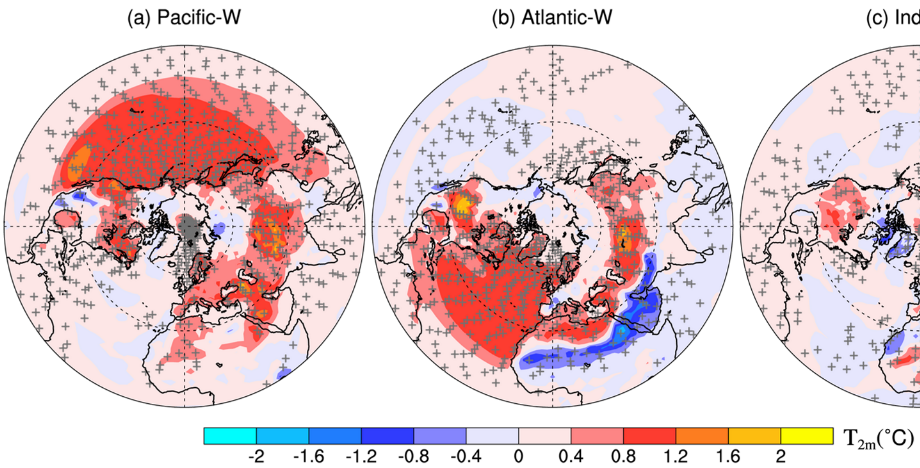

Figure 4. The difference in surface air temperature (℃) for (a) Pacific-W, (b) Atlantic-W,

and (c) Indian-W relative to CTRL in the Northern Hemisphere in boreal summer. The + symbols denote areas where results are significant at the 0.05 level as evaluated with a Student t-test. (Plots using the Mercator projection are shown in Figure S15 in the supplementary material)

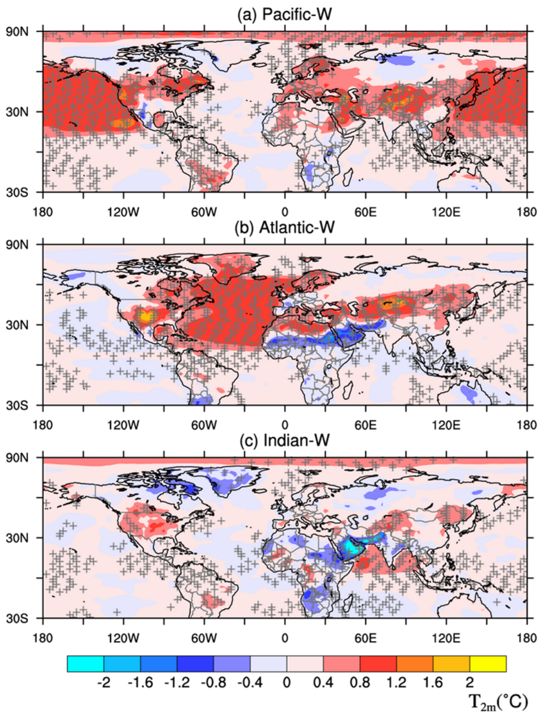

Figure S15. The difference in surface air temperature (ºC) for (a) Pacific-W, (b) Atlantic-W, and (c) Indian-W relative to CTRL in boreal summer. The + symbols denote areas where results are significant at the 0.05 level as evaluated with a Student t-test.

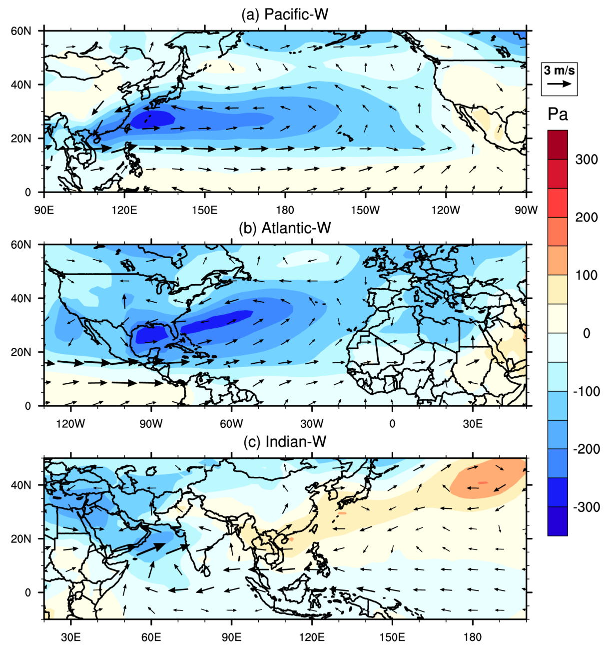

Figure 5. Changes in surface pressure (color contours, Pa) and 850 hPa wind(arrows, m/s) for (a) Pacific-W, (b) Atlantic-W, and (c) Indian-W relative to CTRL in boreal summer.

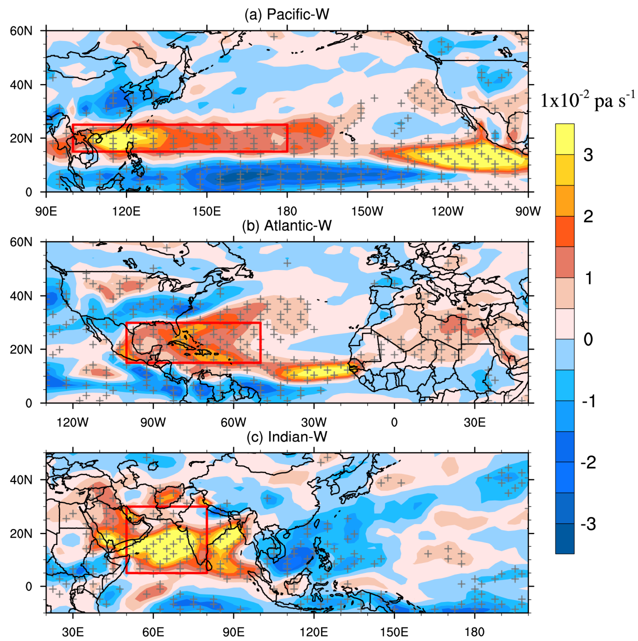

Figure 6. The spatial pattern of vertical velocity changes at 500 hPa (color contours, 1×10^{-2} Pa s^{-1}) for (a) Pacific-W, (b) Atlantic-W, and (c) Indian-W relative to CTRL in boreal summer. Positive values indicate upward motion. Red polygons denote the regions where the surface pressure responses to SST anomalies are significant (see Figure 5 a-c). The + symbols indicate areas where results are significant at the 0.05 level as evaluated with a Student t-test using 20 years of data.

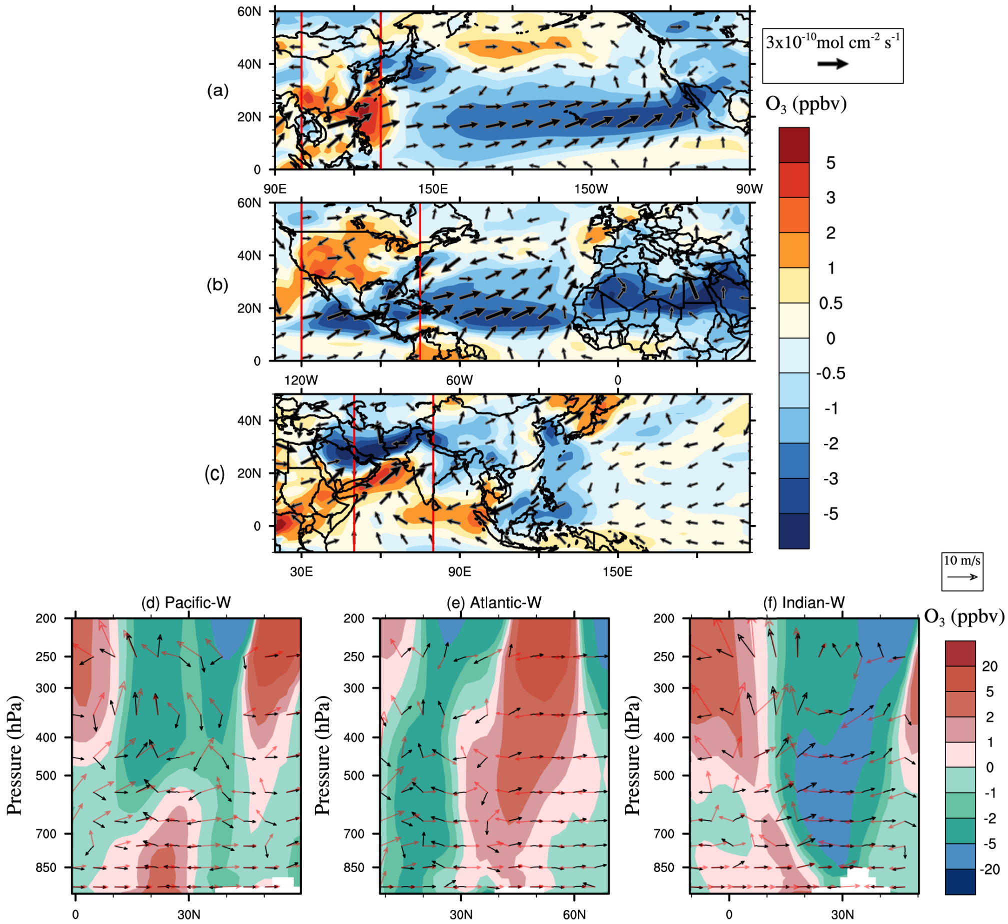

Figure 7. Top three rows: Changes in O_3 concentrations (color contours, ppbv) and horizontal fluxes (arrows, mol cm^{-2} s^{-1}) at surface level for (a) Pacific-W, (b) Atlantic-W, (c) Indian-W relative to CTRL in boreal summer. Last row: zonally averaged vertical and latitudinal distributions of tropospheric O_3 changes (color contours, ppbv) and wind pattern in CTRL (red arrows, m/s) and its perturbation (black arrows, m/s) in (d) Pacific-W, (e) Atlantic-W, (f) Indian-W relative to CTRL in boreal summer. The red rectangles in (a), (b) and (c) denote the longitudinal range used for zonal average in (d), (e) and (f), respectively. The vertical wind velocity is amplified 1000 times to be comparable with horizontal wind velocity and distinct in the panels.

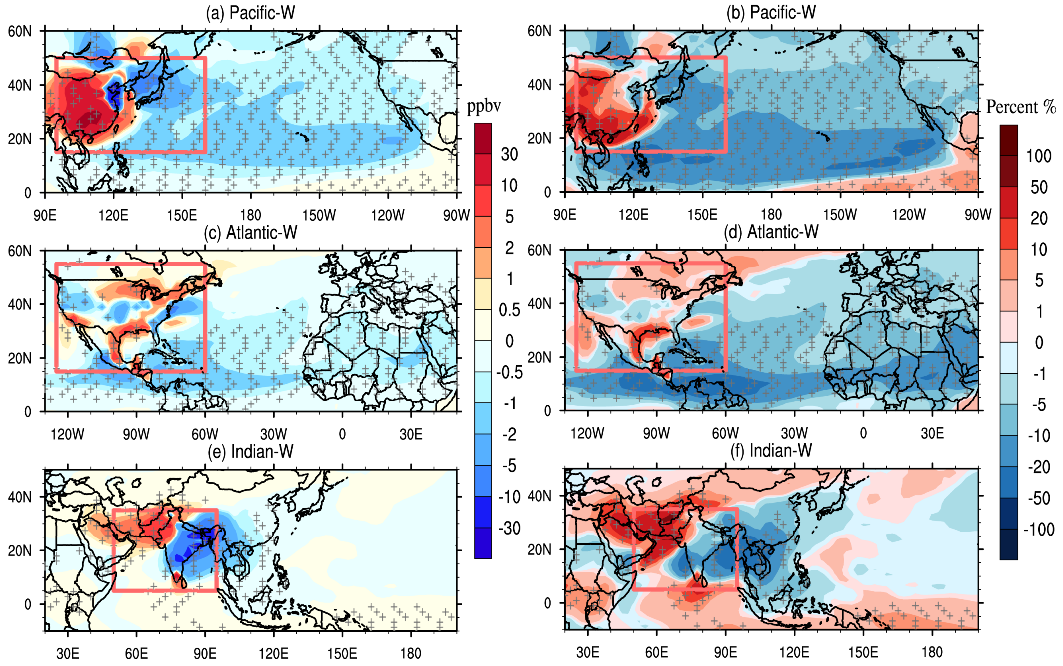

Figure 8.Left-hand panel: the difference in surface concentration (ppbv) of a CO-like tracer emitted from (a) East Asia for Pacific-W, (c) North America for Atlantic-W and (e) South Asia for Indian-W relative to CTRL in boreal summer. Right-hand panel: the percentage change in surface concentration of a CO-like tracer emitted from (b) East Asia for Pacific-W, (d) North America for Atlantic-W and (f) South Asia for Indian-W relative to CTRL in boreal summer. Red polygons denote the region where the CO-like tracer emitted from. The + symbol denotes areas where the results are significant at the 0.05 level evaluated with a Student t-test.

The continental outlines in all figures are now thicker and darker than previous ones. Please see Figure 4 above as an example and refer to the revised manuscript for more details.

Some figures have a set of small plots. In the previous version, we uploaded low-quality PDF plots. In this revised version, we have significantly improved the figure quality. Please see Figure 9 below for example:

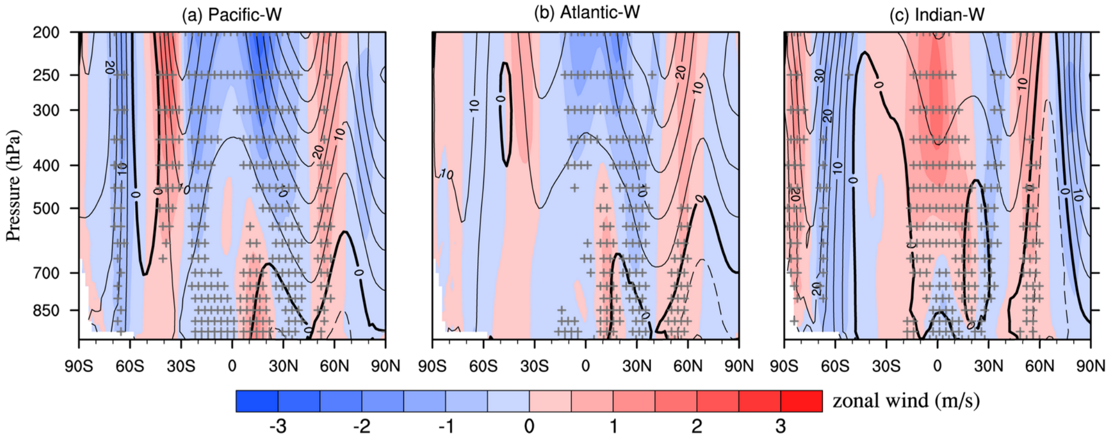

Figure 9. Zonally averaged changes in zonal wind (color contour, m/s) and geopotential height (contour, m) for (a) Pacific-W, (b) Atlantic-W and (c) Indian-W relative to CTRL in boreal summer. Black solid and dashed lines in the contours indicate positive and negative geopotential height anomalies, respectively (Contour interval: 5 m).The + symbol denotes areas where the zonal wind changes are significant at the 0.05 level evaluated with a Student t-test.

2) The seasonal mean surface ozone changes are quite large. This message could be brought out much more clearly. It would be beneficial to see some discussion of the magnitude of these surface ozone responses through comparison with previous papers even if these only relate to the effects of changes in air temperature or climate on surface ozone, as the further impacts of atmospheric circulation changes can be outlined.

Good suggestion. We add some discussion about the magnitude of these surface ozone responses in our revised manuscript, and compare our results with previous works:

"The responses of surface O_3 concentrations to basin-scale SST changes (i.e., ±1 ºC) are mainly within 3 ppbv in the Northern Hemisphere (Table 1 and Table S1), though large anomalies (i.e., up to 5ppbv) are also observed over the east coast of China, the Indian subcontinent, and certain oceanic areas (Figure 1 and Figure S2). This SST-O3 sensitivity is comparable to previous findings. For instance, Bloomer et al. (2009) reported a positive O_3-temperature relationship of 2.2~3.2 ppbv/℃ across the rural eastern United States. Wu et al. (2008) found that summertime surface O_3 may increase by 2-5 ppbv over the northeastern United States in the 2050s. Additionally, Fiore et al. (2009) demonstrated an intercontinental decrease of surface O_3 by no more than 1 ppbv in response to 20% reductions in anthropogenic emissions within a continental region. Our study indicates that basin-scale SST change alone may exert significant effects on the surface O_3 above specific ocean basin and its surrounding continents."

3) (i) The IPR analysis needs to be described more thoroughly and the processes selected would benefit with expanded definitions. In particular, gas-phase chemistry (CHEM) should be defined more clearly as later in the manuscript various other terms are used: net chemical production (Figure 3); photochemistry (line 265). Also vertical diffusion (VDIF) and dry deposition (DRYD) are combined into one term TURB- but these terms act in opposite directions in Figure 2. It would be useful to provide a brief outline as to why these terms are expected to act in opposite directions. (ii) All IPR related figures- Figures 2/S1 are very difficult to read. In addition the relationship between the fluxes and concentrations as plotted on figure 2 is unclear, and appears sensitive to the scaling's used on the right and left hand y-axes. See specific comments 3-8 below. (iii) The text discussing IPR results in section 4.1 is generally confusing and not well substantiated: often the season being referred to is not provided and general statements are sometimes given that only seem applicable to results in boreal summer. The text is section 4.3 also needs to be clarified and tightened in a good number of places- see specific comments. iv) For Figure 2/Table 1, it would be highly beneficial to also have results for the direct effect of a change in SSTs on regional surface ozone in that surface basin before any discussion of upwind or downwind continents. This would aid with interpretation as to the dilution of the ozone response with regional averaging.

(i)Good suggestion. The IPR analysis calculates the accumulated contributions of individual processes (e.g., net chemical production (production minus loss), advection, vertical diffusion, dry deposition, etc.) to the changes of O_3 concentrations. It is a widely used tool for air pollution diagnostics (Li et al., 2012;Zhang and Wu, 2013;Tao et al., 2015). In this study, we implemented the IPR scheme in the model to examine the O_3 flux in individual processes, including gas-phase chemistry, advection, vertical diffusion, dry deposition, shallow convection and deep convection. The wet deposition and aqueous-phase chemistry are ignored because of the low solubility and production rate of O_3 in water (Jacob, 1999). The sum of the IPR archived fluxes in CHEM. ADVE, VDIF, DRYD, SHAL and DEEP matches well the changes of O_3 concentration (Figure S1). Here the CHEM represents the net production (or production minus loss) flux of O_3 from gas-phase chemistry, which is consistent with the net production rate shown in Figure 3. DRYD represents the removal rate of O_3 by dry deposition. VDIF represents the transport of O_3 to the surface due to vertical diffusion. Both DRYD and VDIF are closely dependent on turbulent mixing. The efficiencies of O_3 vertical diffusion and the corresponding dry deposition are all positively related to the strength of turbulence, but with opposite sign. We therefore define a new term TURB to represent the sum of DRYD and VDIF, which can represent the overall effect of turbulence change on surface O_3. In the revised manuscript, we added more descriptions about the IPR method in Section 2.3 and Section 4.1. Please also refer to our reply to the specific comments for more details.

In Section 2.3:

"In this study, we added the IPR scheme to the CESM modeling framework to track the contribution of six physicochemical processes (i.e., gas-phase chemistry (CHEM), advection (ADVE), vertical diffusion (VDIF), dry deposition (DRYD), shallow convection (SHAL) and deep convection (DEEP)) to O_3 concentrations in every grid box. Wet deposition and aqueous-phase chemistry are ignored here due to the low solubility and negligible chemical production of O_3 in water (Jacob, 1999). Therefore, CHEM represents the net production (production minus loss) rate of O_3 due to gas-phase photochemistry. DRYD represents the dry deposition fluxes of O_3, which is an important sink for O_3. The other IPR terms (i.e., ADVE, VDIF, SHAL and DEEP) represent contributions from different transport processes. The IPR scheme tracks and archives the O_3 flux in each grid from every processes during each model time-step. The sum of O_3 fluxes from these six processes matches well the change of O_3 concentration."

In Section 4.1, we also add more explanations about the IPR results:

"The IPR analysis is used to evaluate the contribution of different physicochemical processes to O_3 evolution. It has been widely used in air quality studies to examine the cause of pollution episode (Wang et al., 2010;Li et al., 2012). When applied in climate sensitivity relevant analysis (usually measuring the difference between two equilibrium states), the net change of all IPRs approaches zero. Typically, the positive changes in IPRs are mainly responsible for the increase of surface O_3, which may further induce O_3 removal to balance these factors in an equilibrium state. Therefore, here the IPR analysis is not used to budget the SST induced O_3 concentration changes, instead it helps to examine the relative importance of different transport and chemical processes in driving the sensitivity of O_3 to a SST forcing. In this study, the SST induced process-level O_3 changes are spatially averaged over four populated continental regions (i.e., NA, EU, EA and SA, Figure 2) and three ocean basins (i.e., the North Pacific, North Atlantic and North Indian Oceans, Figure S9). In most cases, vertical diffusion (VDIF) and dry deposition (DRYD) are the key processes controlling the O_3 variation. The downward transport of O_3 through diffusion is an important source for surface O_3 while dry deposition act as a sink. Both processes are simultaneously determined by the strength of turbulence. The efficiencies of O_3 transport by vertical diffusion and its corresponding dry deposition are simultaneously determined by the strength of turbulence. Here we define a new term TURB as the sum of DRYD and VDIF, which can capture the overall effect of turbulence changes on surface O_3 concentrations. In addition, we merge SHAL and DEEP as CONV to represent the total contribution of convective transport to surface O_3 (Figure 2 and Figure S9). More detailed IPR results are shown in Figure S10 and S11 in the supplementary material."

(ii) As we have mentioned above, each of the IPR processes (i.e., CHEM. ADVE, VDIF, DRYD, SHAL and DEEP) archived hourly and the sum of them matches well the time-varying O_3 concentration changes. Figure S1 in the supporting materials (see below) demonstrates the performance of the IPR scheme.

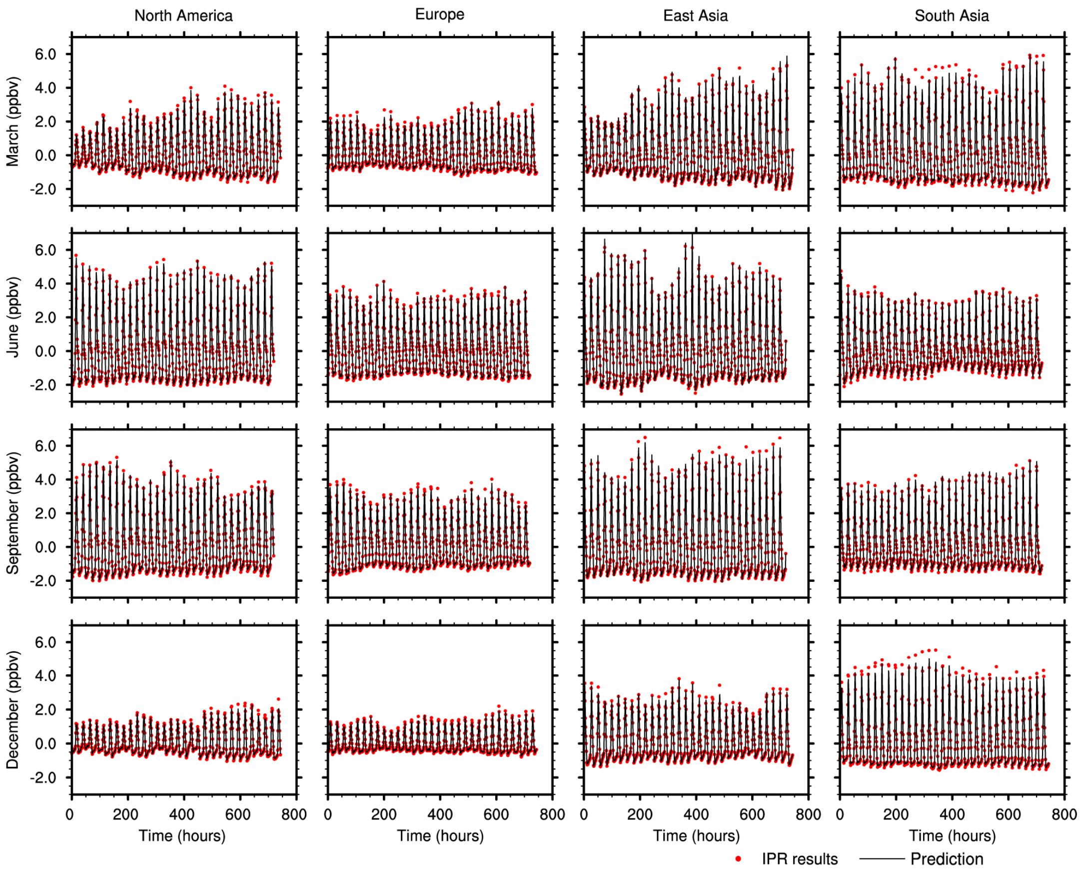

Figure S1.Comparison of hourly O_3 anomaly (black) and the sum of IPR results (red dots) averaged over four continental regions (i.e., North America (15°N–55 °N; 60°W–125°W), Europe (25°N–65 °N;10°W-50 °E), East Asia (15 °N–50 °N; 95°E–160 °E) and South Asia (5 °N–35 °N; 50 °E–95°E)) in March (first row), June (second row), September (third row) and December (last row) of in the CTRL.

Figure 2, on the other hand, demonstrates the seasonally averaged results rather than the time-series shown in Figure S1. Positive changes of fluxes are generally counterbalanced by the negative ones because the climatological O_3 concentrations reside in an equilibrium when averaged over a long period of time. Therefore, the net flux changes could not be directly compared with surface O_3 changes between two climatological cases. Here we compared these IPR fluxes individually to identify the impact of basin-scale SST changes on each O_3 evolution process. Typically, the positive change of a particular IPR process is mainly responsible for the increase of surface O_3, which may further induces O_3 loss process to counteract these factors. With this information, we can explore the relative importance of different processes closely linked to the SST changes, which helps to explain the variability of surface O_3 over different regions.

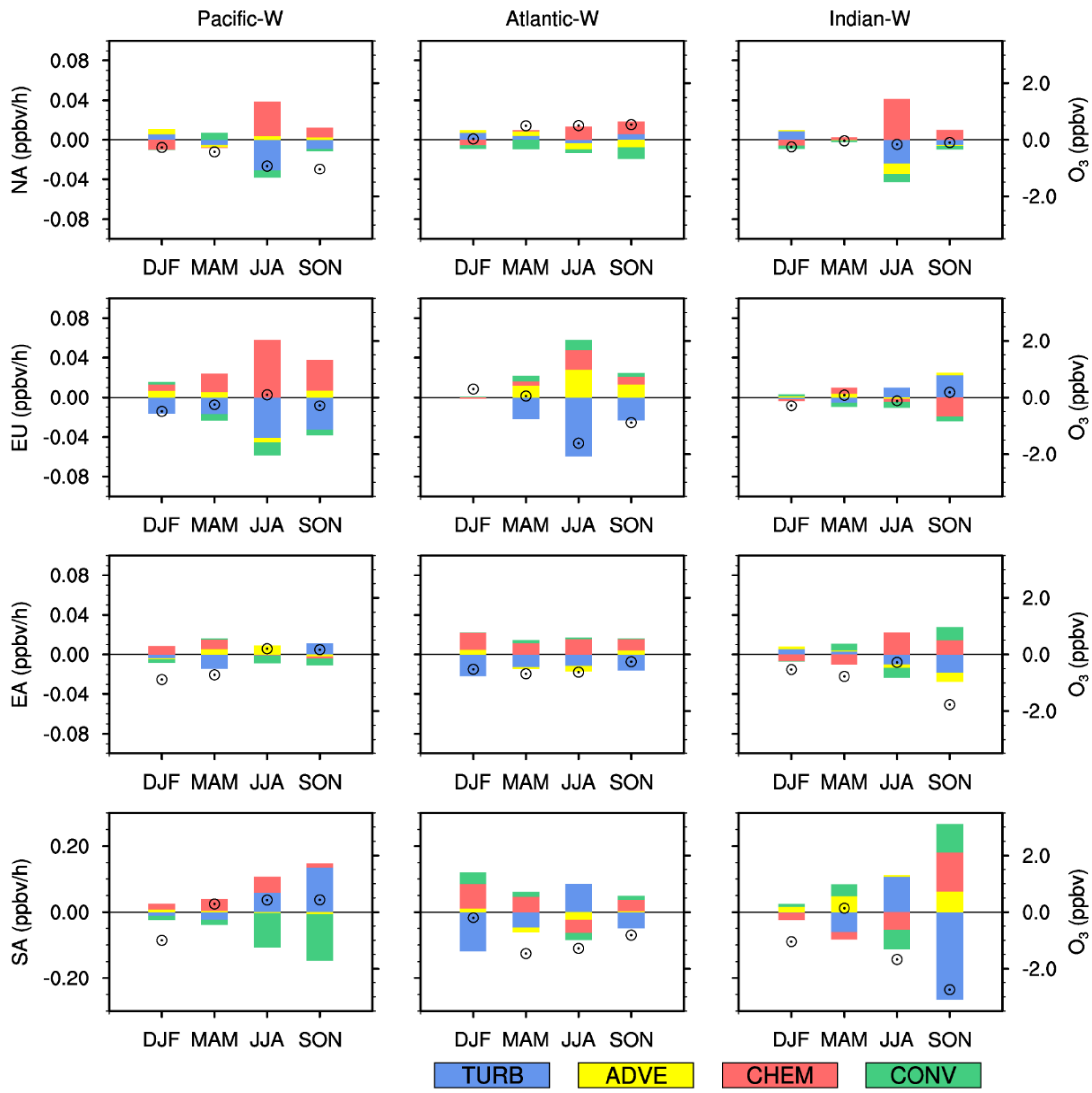

Figure 2. Seasonally averaged changes in IPR contributions (bars, ppbv/h, left scale) and surface O_3 concentrations (hollow circles, ppbv, right scale) for Pacific-W (left), Atlantic-W (middle) and Indian-W (right) relative to CTRL. Values are regionally averaged over NA (first row), EU (second row), EA (third row) and SA (last row), respectively. TURB is defined as the sum of VDIF and DRYD. CONV is the sum of DEEP and SHAL. IPR contributions from four processes (i.e., TURB, ADVE, CHEM and CONV) are represented by different colors. A more detailed IPR result is shown in Figure S10 in the supplementary material.

(iii) We agree that some text needs more clarification. This study focuses mainly on summertime since both surface O_3 levels and their response to SST changes are highest during this period. We also find that an increase in SST in the North Pacific or North Atlantic tends to elevate the VDIF of O_3 over upwind regions (i.e., East Asia and North America, respectively) but suppress it over downwind regions during JJA. In the revised manuscript, we have clarified the seasons we discussed and improved the consistency of the analysis. Please see our response to specific comments below.

iv) Good suggestion! We have added a similar table (Table S1) and figure (Figure S9) to examine the effect of SST changes on O_3 distribution over different ocean basins.

Table S1. Regionally and seasonally averaged (only ocean grid boxes are included) changes in surface O_3 concentrations (ppbv) over three ocean basins in the Northern Hemisphere (i.e., the North Pacific (15°N-65°N;100°E-90°W), North Atlantic (15°N-65°N; 100°W-20°E) and North Indian (5°N-30°N; 30°E-100°E) oceans) in each sensitivity test. Positive (negative) changes significant at the 0.05 level are illustrated with red (blue) numbers.

Ozone (ppbv)			DJF	MAM	JJA	SON
North Pacific	+1ºC	North Pacific	-0.56*	-0.71*	-0.78*	-1.22*
		North Atlantic	-0.55*	-1.08*	-0.74*	-1.25*
		North India	-1.05*	-0.59	0.16	0.20
	-1ºC	North Pacific	0.32	0.55*	1.04*	1.00*
		North Atlantic	0.43*	0.53*	0.75*	0.80*
		North India	0.77*	-0.06	-0.03	0.16
North Atlantic	+1ºC	North Pacific	0.05	-0.02	0.38*	0.01
		North Atlantic	0.14	0.04	-1.00*	-0.86*
		North India	-0.45*	-1.31*	-0.63*	-0.72*
	-1ºC	North Pacific	0.11	0.32	0.11	-0.30
		North Atlantic	-0.02	-0.14	0.76*	0.43*
		North India	0.39	0.59	0.38*	0.48
North India	+1ºC	North Pacific	-0.34	-0.11	-0.14	-0.88*
		North Atlantic	-0.25	-0.46	-0.11	-0.23
		North India	-1.59*	-0.42	0.81*	-2.11*
	-1ºC	North Pacific	0.32	0.32	0.50*	0.52*
		North Atlantic	-0.07	-0.42	0.11	-0.37*
		North India	1.32*	0.89*	-0.38*	1.84*

*significant at the 0.05 level from Student t-test using 20 years model result

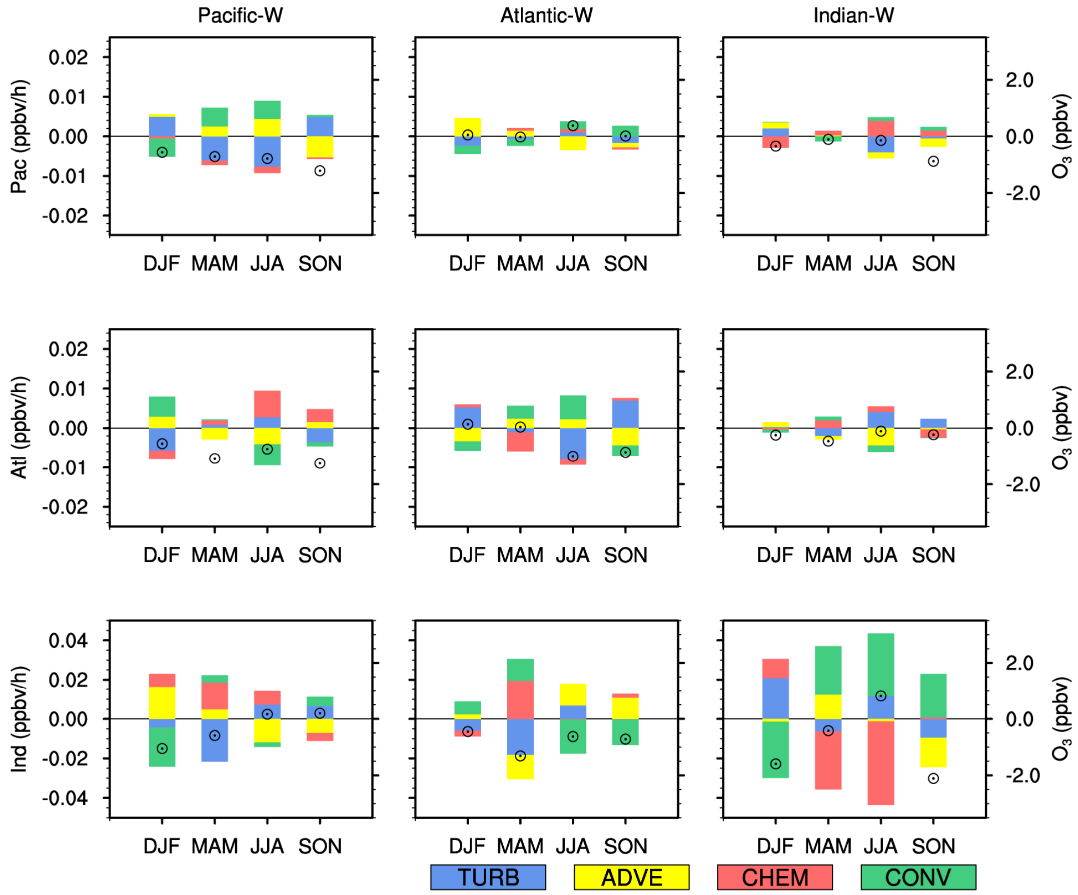

Figure S9. Seasonally averaged changes in IPR contributions (bars, ppbv/h, left scale) and surface O_3 concentrations (hollow circles, ppbv, right scale) for Pacific-W (left), Atlantic-W (middle) and Indian-W (right) relative to CTRL. Values are regionally averaged over North Pacific (15°N-65°N;100°E-90°W, demoted as Pac, first row), North Atlantic (15°N-65°N; 100°W-20°E , demoted as Atl, second row) and North Indian Ocean (5°N-30°N; 30°E-100°E , demoted as Ind, third row) defined in our study, respectively. IPR contributions from four processes (i.e., TURB, ADVE, CHEM and CONV) are represented by different colors.

It shows that during boreal summers, the warming of North Pacific or North Atlantic leads to a widespread decrease of surface O_3, while the warming of North Indian Ocean increases local surface O_3. The IPR results indicate that the warming of the North Pacific or North Atlantic induce a reduction of TURB (mainly caused by the decrease of VDIF) and CHEM, which are responsible for the significant decrease of surface O_3 in JJA (Figure S19). The North Indian Ocean warming, on the other hand, enhances the CONV and TURB locally, leading to an increase of local surface O_3 in JJA. In the revised manuscript, more discussions on these effects are given:

In Section 3:

"Generally, an increase in summertime SST over a specific ocean basin tends to increase surface O_3 concentrations over the upwind regions but reduce it over downwind continents. For instance, an 1ºC warming over the North Pacific leads to a widespread decrease of surface O_3 over North Pacific, North America and North Atlantic by approximately 1 ppbv (Table S1), but may enhance the surface O_3 by nearly 3 ppbv over South China. Similarly, in the "Atlantic-W" case, the surface O_3 levels decrease by 1~2 ppbv over North Atlantic and Europe, but increase (~1 ppbv) over North America and North Pacific. For the North Indian Ocean, positive SST anomalies tend to increase the surface O_3 over the Indian Ocean and Africa, but decrease the surface O_3 over South and East Asia (Table 1)."

In Section 4.1:

"The IPR analysis over the ocean basins shows that the warming of the North Pacific or North Atlantic induce a reduction of VDIF and CHEM, which is responsible for the significant decrease of surface O_3 above it in JJA (Figure S11). The North Indian Ocean warming, on the other hand, enhances the DEEP and VDIF, leading to an increase of surface O_3 locally in JJA."

…

"The IPR analysis indicates that, in general, a SST increase in the North Pacific or North Atlantic is more likely to enhance the vertical diffusion of O_3 over upwind regions (i.e., East Asia or North America, respectively) but suppress it over the ocean basin as well as downwind continents in JJA (Figure S12)."

4) As noted above for the IPR results, but also in general, the text on the various contributions or roles of intercontinental transport versus that of chemistry is difficult to follow in a number of places and some conclusions appear over-stated. For example, the abstract discusses "suppression of O3 intercontinental transport due to increased stagnation at mid-latitudes induced by SST changes". Stagnation is a localised process largely determined by boundary layer processes and entrainment. Hence, the authors should be cautious in their interpretation based on large-scale changes in wind vectors and vertical velocity to infer changes in stagnation/ventilation. Perhaps clear definitions of what is meant by these terms would be useful. See specific comments below.

Thanks for bringing this issue up. We agree that stagnation/ventilation were improperly used here. Throughout the analysis, we find that the basin-scale SST increase not only strengthens upward motions over the low-latitudes oceans, but also lead to decreases of upward velocity over mid-latitudes (Figure S23). Previous studies have revealed that strengthened deep convection will trigger large-scale subsidence over the nearby regions through modulating large-scale circulations, which may suppress convective air movement there (Lau et al., 1997;Roxy et al., 2015;Ueda et al., 2015). Here we also demonstrate a weaker vertical temperature gradient associated with regional SST warming (Figure S16). Both factors (i.e., large-scale subsidence and weaker vertical temperature gradient) tend to stabilize the atmosphere that may inhibit vertical air transport. In our revised manuscript, we further examine the vertical transport of O_3 based on the IPR analysis (shown in Figure S12). It shows a widespread reduction of vertical diffusion transport of O_3 to the surface (i.e. VDIF) except for the upwind regions. We also find that SST increases of a specific ocean in the Northern Hemisphere, especially for the North Pacific and North Atlantic oceans, tend to increase the air temperature (Figure S16) and geopotential height (Figure 9) more significantly at mid-latitudes than other latitudes. Consequently, the meridional geopotential height gradient is decreasing in the tropical-to-mid-latitude troposphere while increasing at higher latitudes. It tends to decrease the westerly wind at lower-middle latitudes (25°N - 45 °N) in the Northern Hemisphere (Figure 9). Based on these facts, the warming of SST over a specific ocean may stabilize the troposphere at mid-latitudes that suppress the O_3 intercontinental transport. This effect is also supported by the CO-tracer analysis, which shows a significant reduction of intercontinental transport (Figure 8). We have discussed these processes in detail in the revised manuscript.

Here we revised the texts as below:

In Abstract:

"This process, as confirmed by the tagged CO-like tracers, indicates a considerable suppression of O_3 intercontinental transport due to the negative response of mid-latitudes westerlies to SST changes"

In Section 4.3, we have:

"Meanwhile, air temperature increase in response to regional SST warming is more significant in the upper than lower troposphere, which leads to a decrease in the vertical temperature gradient (Figure S16). These factors tend to restrain the vertical exchange of air pollutants."

In the summary section:

"The basin-scale SST increases in the North Hemisphere reduce the troposphere temperature gradient at mid-latitudes that restrains vertical transport of O_3 over

continents and weakens westerlies at lower mid-latitudes. The response of CO-tracer also suggests that these factors may jointly exert a negative effect on intercontinental transport of O_3*."*

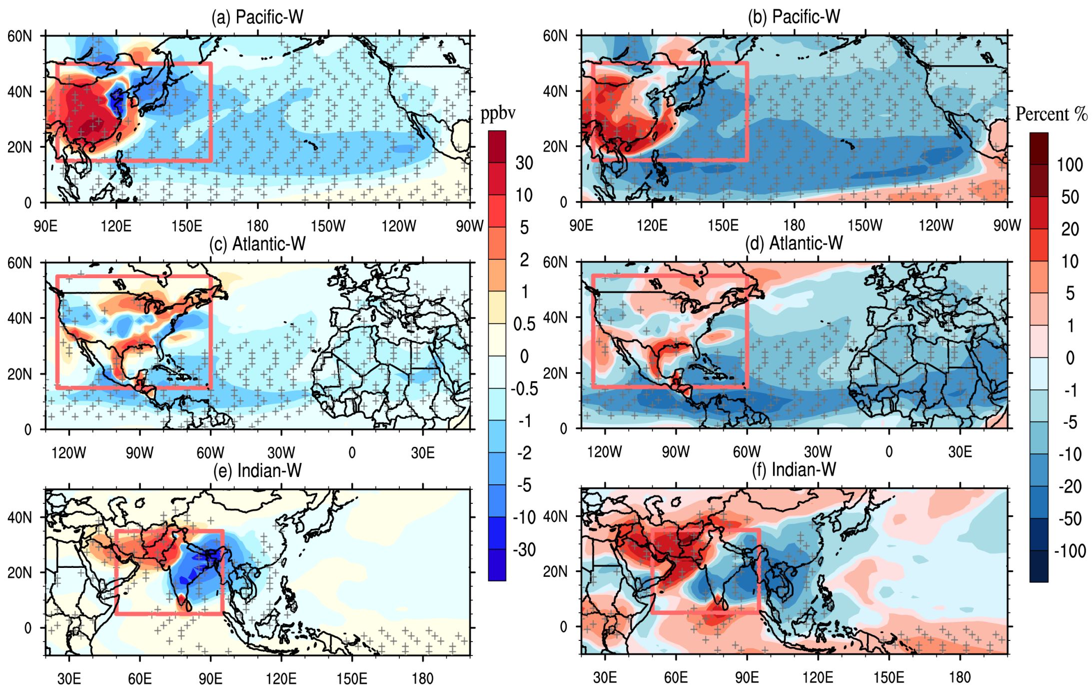

Figure 8.Left-hand panel: the difference in surface concentration (ppbv) of a CO-like tracer emitted from (a) East Asia for Pacific-W, (c) North America for Atlantic-W and (e) South Asia for Indian-W relative to CTRL in boreal summer. Right-hand panel: the percentage changes in surface concentration of a CO-like tracer emitted from (b) East Asia for Pacific-W, (d) North America for Atlantic-W and (f) South Asia for Indian-W relative to CTRL in boreal summer. Red polygons denote the region where the CO-like tracer emitted from. The + symbol denotes areas where the results are significant at the 0.05 level evaluated with a Student t-test.

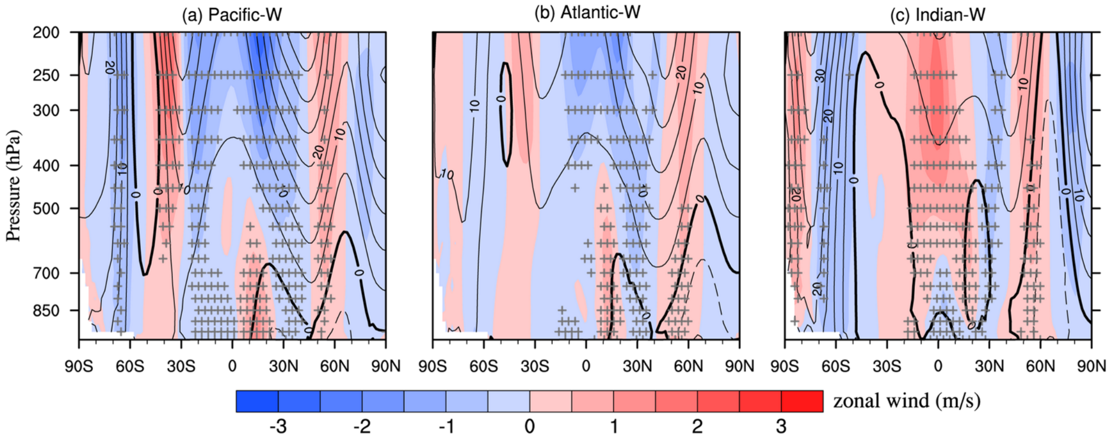

Figure 9. Zonally averaged changes in zonal wind (color contour, m/s) and geopotential height (contour, m) for (a) Pacific-W, (b) Atlantic-W and (c) Indian-W relative to CTRL in boreal summer. Black solid and dashed lines in the contours indicate positive and negative geopotential height anomalies, respectively (Contour interval: 5 m).The + symbol denotes areas where the zonal wind changes are significant at the 0.05 level evaluated with a Student t-test.

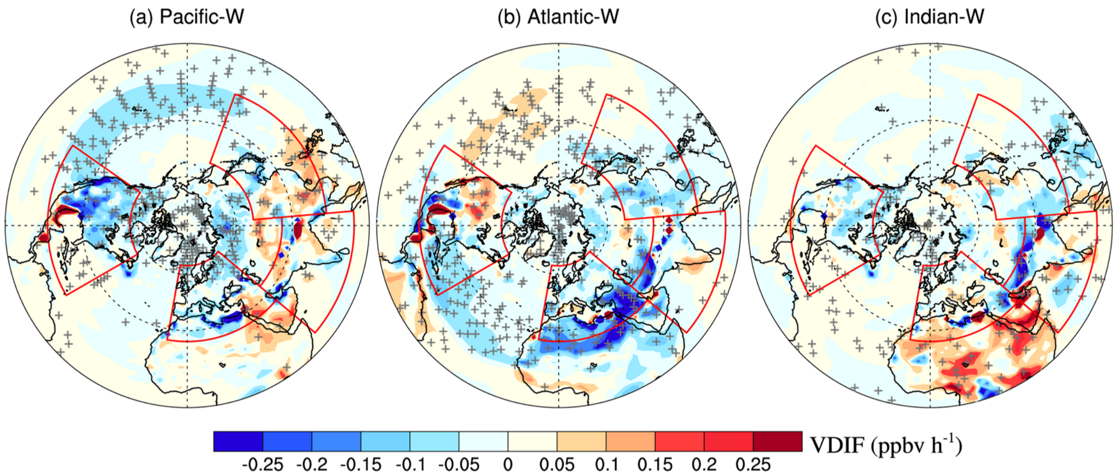

Figure S12. Changes in VDIF for (a) Pacific-W, (b) Atlantic-W and (c) Indian-W relative to CTRL in boreal summer. Four major regions of interest (i.e., NA (15°N–55 °N; 60°W–125°W), EU (25°N–65 °N;10°W-50 °E), EA (15 °N–50 °N; 95°E–160 °E) and SA (5 °N–35 °N; 50 °E–95°E)) are marked by red solid lines. The + symbols denote areas where results are significant at the 0.05 level as evaluated with a Student t-test using 20 years of data.

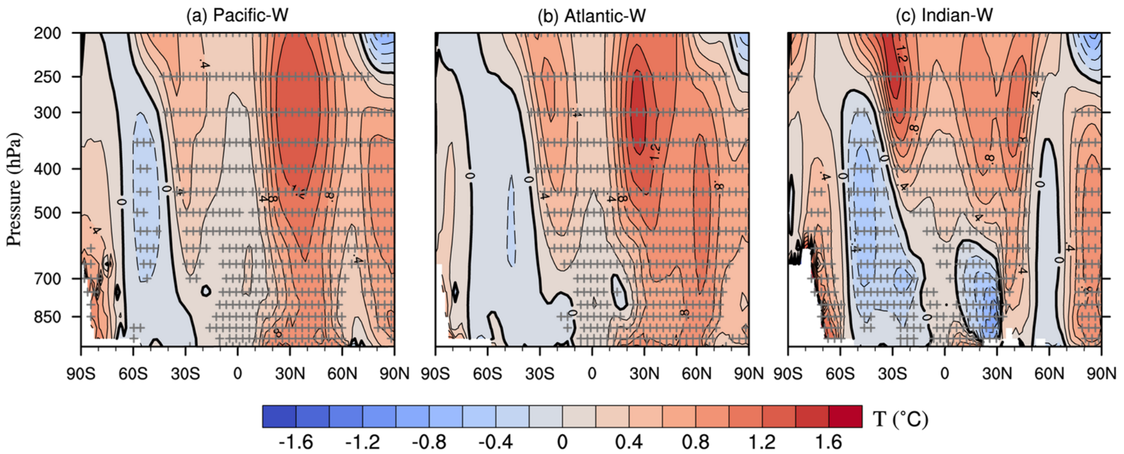

Figure S16. Vertical- and meridional distributions of air temperature differences (contours, ºC) between (a) Pacific_W (zonally averaged from 100°E-90°W) (b) Atlantic_W (100°W-180°W) (c) Indian_W (30°E-100°E) and CTRL in boreal summer. Black solid and dashed lines in the contours indicate positive and negative air temperature anomalies, respectively (contour interval: 0.2 ºC).The + symbol denotes areas where the changes of air temperature are significant at the 0.05 level evaluated with a Student t-test.

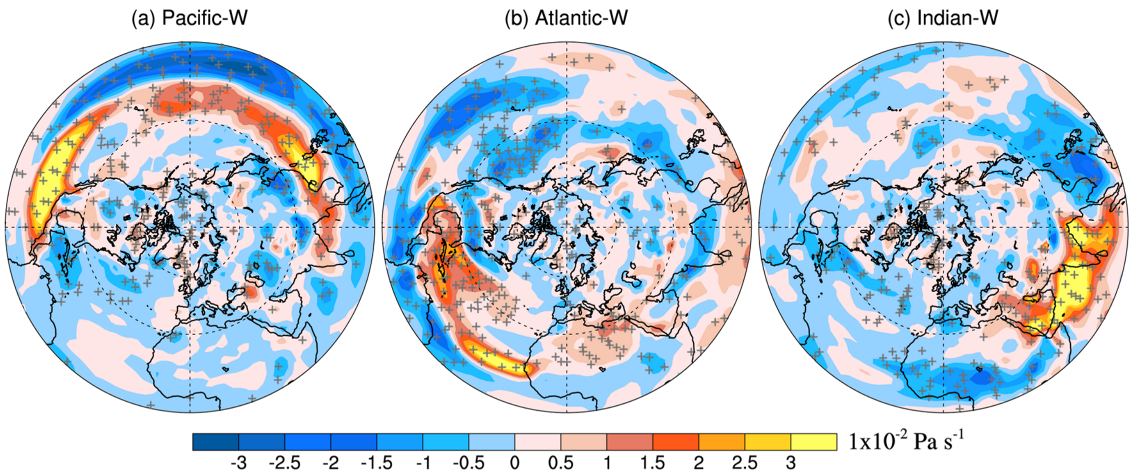

Figure S23. The spatial pattern of vertical velocity changes at 500 hPa (color contours, $1x10^{-2}$ Pa s^{-1}) for (a) Pacific-W, (b) Atlantic-W, and (c) Indian-W relative to CTRL in boreal summer. Positive values indicate upward motion. The + symbols indicate areas where results are significant at the 0.05 level as evaluated with a Student t-test using 20 years of data.

5) A number of references in the text are rather old, and some updated references would be highly beneficial. See specific comments below. Also with multi-references the logical order is unclear- chronological order is most commonly used.

Good suggestion! We have updated our references by citing more recent studies. Please see our response to specific comments below. We have also reordered references chronologically.

Specific comments:

1) As also noted by the other reviewer the frequent use of parenthesis to state a key result dilutes the message of the sentence and makes for a confusing read. Please rephrase when key points are being made in the abstract and main text (lines 223-230).

Good suggestion. We rephrased these key results following the reviewer's suggestions, see below or the revised abstract and text:

In Abstract:

"…The responses of surface O_3 associated with basin-scale SST warming and cooling have similar magnitude but are opposite in sign. Increasing SST by 1 ℃ in one of the oceans generally decreases surface O_3 concentrations, ranging from 1 to 5 ppbv."

In Section 3:

"Surface O_3 changes in response to positive and negative SST anomalies generally pronounce a consistent spatial pattern but are opposite in sign, suggesting robust relationships between surface O_3 levels and SST anomalies (Figure 1). Generally, an increase in summertime SST over a specific ocean basin tends to increase surface O_3 concentration over the upwind regions but reduce it over downwind continents. For instance, an 1℃ warming over the North Pacific leads to a widespread decrease of surface O_3 over North Pacific, North America and North Atlantic by approximately 1 ppbv (Table S1), but may enhance the surface O_3 by nearly 3 ppbv over South China. Similarly, in the "Atlantic-W" case, the surface O_3 levels decrease by 1~2 ppbv over North Atlantic and Europe, but increase (~1 ppbv) over North America and North Pacific. For the North Indian Ocean, positive SST anomalies tend to increase the surface O_3 over the Indian Ocean and Africa, but decrease the surface O_3 over South and East Asia (Table 1). During boreal winter, a widespread decrease of surface O_3 is observed associated with the warming of different oceans. Significant changes (e.g., up to 5 ppbv) mainly occur over remote oceanic areas. Over the populated continents, the response of surface O_3 to basin-scale SST changes is typically insignificant. Details are shown in Figure S3 in the supplementary material."

2) Line 207/Table 1 – as noted above it would be beneficial to first show a similar table that examines the effect of SST changes within each basin and on other ocean basins.

Good suggestion. We add such a table in the supplementary material, see Table S1 below.

Table S1. Regionally and seasonally averaged (only ocean grid boxes are included) changes in surface O_3 concentrations (ppbv) over three ocean basins in the Northern Hemisphere (i.e., North Pacific (15°N-65°N;100°E-90°W), North Atlantic Ocean (15°N-65°N; 100°W-20°E) and North Indian (5°N-30°N; 30°E-100°E)) for basin-scale SST perturbation cases relative to the control simulation. Positive (negative) changes which are significant at the 0.05 level evaluated with a Student t-test are marked by red (blue).

Ozone (ppbv)			DJF	MAM	JJA	SON
North Pacific	+1ºC	North Pacific	-0.56*	-0.71*	-0.78*	-1.22*
		North Atlantic	-0.55*	-1.08*	-0.74*	-1.25*
		North India	-1.05*	-0.59	0.16	0.20
	-1ºC	North Pacific	0.32	0.55*	1.04*	1.00*
		North Atlantic	0.43*	0.53*	0.75*	0.80*
		North India	0.77*	-0.06	-0.03	0.16
North Atlantic	+1ºC	North Pacific	0.05	-0.02	0.38*	0.01
		North Atlantic	0.14	0.04	-1.00*	-0.86*
		North India	-0.45*	-1.31*	-0.63*	-0.72*
	-1ºC	North Pacific	0.11	0.32	0.11	-0.30
		North Atlantic	-0.02	-0.14	0.76*	0.43*
		North India	0.39	0.59	0.38*	0.48
North India	+1ºC	North Pacific	-0.34	-0.11	-0.14	-0.88*
		North Atlantic	-0.25	-0.46	-0.11	-0.23
		North India	-1.59*	-0.42	0.81*	-2.11*
	-1ºC	North Pacific	0.32	0.32	0.50*	0.52*
		North Atlantic	-0.07	-0.42	0.11	-0.37*
		North India	1.32*	0.89*	-0.38*	1.84*

*significant at the 0.05 level from Student t-test using 20 years model result

We also revised the text accordingly, see Section 3 or below:

"Surface O_3 changes in response to positive and negative SST anomalies generally pronounce a consistent spatial pattern but are opposite in sign, suggesting robust relationships between surface O_3 levels and SST anomalies (Figure 1). Generally, an increase in summertime SST over a specific ocean basin tends to increase surface O_3 concentration over the upwind regions but reduce it over downwind continents. For

instance, an 1℃ warming over the North Pacific leads to a widespread decrease of surface O_3 over North Pacific, North America and North Atlantic by approximately 1 ppbv (Table S1), but may enhance the surface O_3 by nearly 3 ppbv over South China. Similarly, in the "Atlantic-W" case, the surface O_3 levels decrease by 1~2 ppbv over North Atlantic and Europe, but increase (~1 ppbv) over North America and North Pacific. For the North Indian Ocean, positive SST anomalies tend to increase the surface O_3 over the Indian Ocean and Africa, but decrease the surface O_3 over South and East Asia (Table 1)."

3) Line 242- what is meant by atmospheric turbulence intensity and explain to the reader how this relates to VDIF and DRYD.

Good question. Both VDIF and DRYD processes are dynamically determined by the strength of turbulence. Stronger turbulence enhances the downward transport of O_3 to the ground level, which also induces more O_3 dry deposition. Therefore, DRYD tends to behave concurrently with VDIF, but with an opposite sign. We have clarified this in our revised manuscript:

"In most cases, vertical diffusion (VDIF) and dry deposition (DRYD) are the key processes controlling the O_3 variation. The downward transport of O_3 through diffusion is an important source for surface O_3 while dry deposition act as a sink. Both processes are simultaneously determined by the strength of turbulence. Here we define a new term TURB as the sum of DRYD and VDIF, which can capture the overall effect of turbulence changes on surface O_3 concentrations."

4) Line 248 "reducing it over North America. For the Pacific W panels in Figure 2 a reduction in VDIF is only seen in in summer in North America; VDIF increases just as strongly in North America in winter and spring.

This sentence only refers to summers. We have clarified this in Section 4.1 of the revised manuscript.

"In the "Atlantic-W" run, increases in VDIF are also observed over the upwind regions (i.e., North America) in JJA"

5) Line 248- "similar increases in VDIF are simulated over North America. Similar to ?

We state the increases in VDIF over North America in JJA is a "similar increase" because it also happens over upwind regions associated with the North Atlantic warming that is similar to the East Asia in the "Pacific-W" case. We realize that the word "similar" may induce confusion and we delete it in the revised manuscript.

"In the "Atlantic-W" run, increases in VDIF are also observed over the upwind regions (i.e., North America) in JJA."

6) Line 253- "the increase of CHEM tends to dominate the surface O3 increase over North America." This is not obvious from Figure 2 (and it is unclear which season/s are being discussed), and is unintuitive without a clearer definition of CHEM, and how fluxes relate to concentrations in Figure 2.

Here we show the key processes enhancing the surface O_3 over North America in JJA in the Atlantic_W case. CHEM tracks the surface O_3 flux due to net chemical production (i.e., production minus loss). In the revised Figure 2, we replaced VDIF and DRYD by TURB, and DEEP and SHAL by CONV. Now it is easier to see that a warmer SST over the Atlantic enhances O_3 chemical production, which positively contributes to the surface O_3 increase over North America. Please see the revised Figure 2 below:

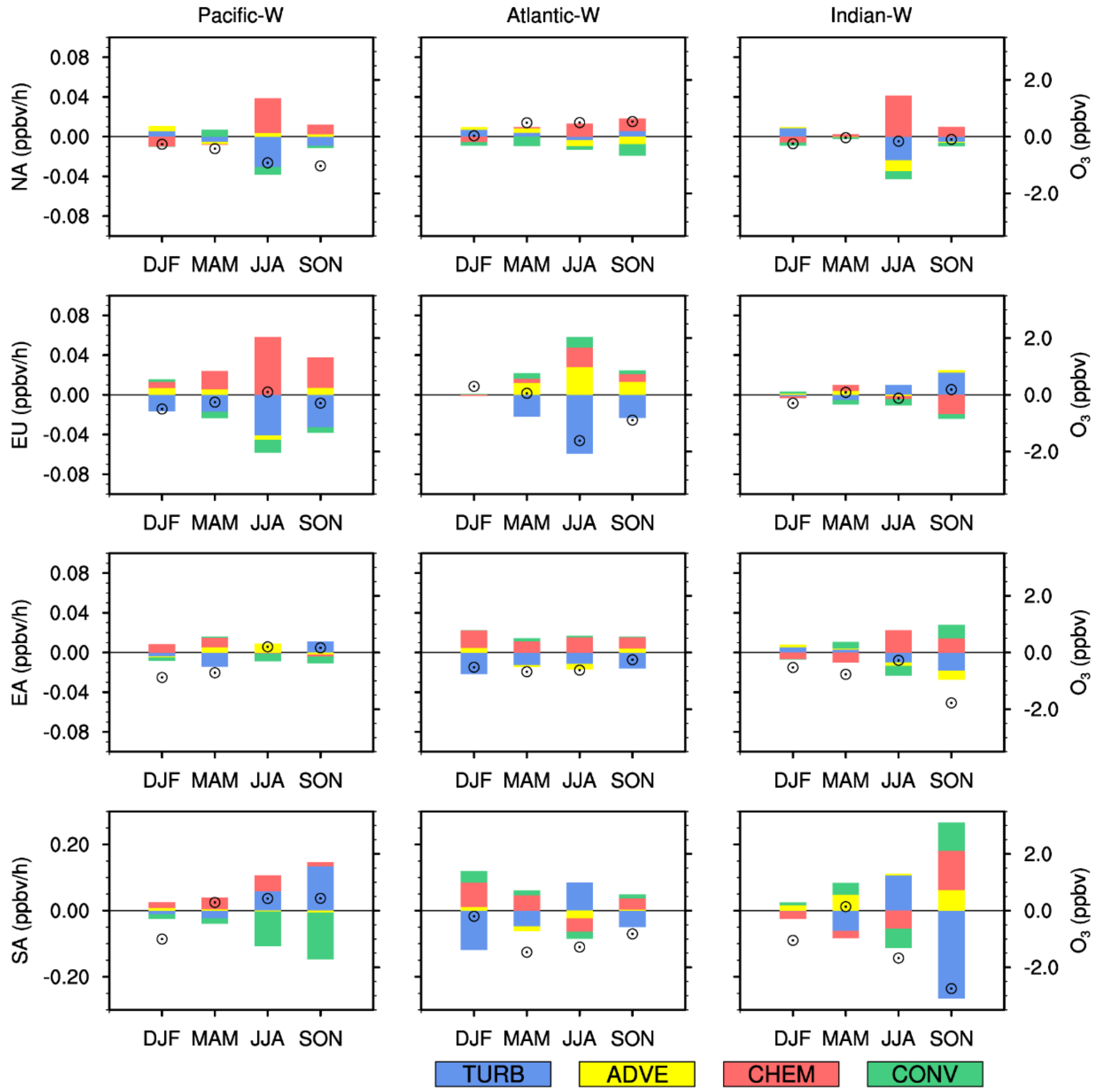

Figure 2. Seasonally averaged changes in IPR contributions (bars, ppbv/h, left scale) and surface O_3 concentrations (hollow circles, ppbv, right scale) for Pacific-W (left), Atlantic-W (middle) and Indian-W (right) relative to CTRL. Values are regionally averaged over NA (first row), EU (second row), EA (third row) and SA (last row), respectively. TURB is defined as the sum of VDIF and DRYD. CONV is the sum of DEEP and SHAL. IPR contributions from four processes (i.e., TURB, ADVE, CHEM and CONV) are represented by different colors. A more detailed IPR result is shown in Figure S10 in the supplementary material.

In the revised manuscript, we have rephrased this sentence:

"In the "Atlantic-W" run, increases in VDIF are also observed over the upwind regions (i.e., North America) in JJA. However, it is accompanied by commensurate decreases in

DRYD, resulting in an insignificant overall change in TURB (Figure 2). The increase of CHEM therefore is mainly responsible for the surface O_3 increase over North America in JJA."

7) Line 254- "TURB is more important ... leasing to reduced surface O3 concentrations." Again the positive and negative fluxes in JJA and SON look to balance so why are there reduced ozone concentrations. Line 257- as above the fluxes look as though they balance (especially in JJA) but ozone concentrations are reduced.

As mentioned in our reply to comment (3), the IPR scheme in our study tracks all processes that are related to the O_3 formation. It has been widely used in air quality studies to examine the cause of pollution episodes (Wang et al., 2010;Li et al., 2012). When applied in climate sensitivity relevant analysis (usually measuring the difference between two equilibrium states), the net change of all IPRs approaches zero. The multi-year seasonally averaged positive and negative fluxes are balanced with each other after model spin-up. Typically, the positive change of a particular IPR process is mainly responsible for the increase of surface O_3, which may further induce O_3 removal to counteract this forcing. Therefore, here the IPR analysis is not used to budget SST induced O_3 concentration changes. Instead, it helps to screen out the key processes driving the sensitivity of O_3 to a SST forcing. In the revised manuscript, we have clarified this issue and focused mainly on the individual process-level responses to SST changes. Please see our revised text in Section 4.1 or below:

"The IPR analysis is used to evaluate the contribution of different physicochemical processes to O_3 evolution. It has been widely used in air quality studies to examine the cause of pollution episodes (Wang et al., 2010;Li et al., 2012). When applied in climate sensitivity relevant analysis (usually measuring the difference between two equilibriums), the net change of all IPRs approaches zero. Typically, the positive changes in IPRs are mainly responsible for the increase of surface O_3, which may further induce O_3 removal to balance this forcing in a new equilibrium. Therefore, here the IPR analysis is not used to budget SST induced O_3 concentration changes, instead it helps to examine the relative importance of different transport and chemical processes in driving the sensitivity of O_3 to a SST forcing. In this study, the SST induced process-level O_3 changes are spatially averaged over four populated continental regions (i.e., NA, EU, EA and SA, Figure 2) and three ocean basins (i.e., North Pacific, North Atlantic and North Indian, Figure S9). In most cases, vertical diffusion (VDIF) and dry deposition (DRYD) are the key processes controlling the O_3 variation. The downward transport of O_3 through diffusion is an important source for surface O_3 while dry deposition act as a sink. Both processes are

simultaneously determined by the strength of turbulence. Here we define a new term TURB as the sum of DRYD and VDIF, which can capture the overall effect of turbulence changes on surface O_3 concentrations. In addition, we merge SHAL and DEEP as CONV to represent the total contribution of convective transport to surface O_3 (Figure 2 and Figure S9). More detailed IPR results are shown in Figures S10 and S11 in the supplementary material."

"In the "Pacific-W" case, a 1 ºC SST warming over the North Pacific increases VDIF over eastern China in JJA (Figure S12), which is insignificant if averaged over the whole East Asia region. Meanwhile, this Pacific warming considerably reduces VDIF over North America (Figure S10). The corresponding decrease of TURB over North America mainly determines surface O_3 reduction in JJA and SON while the reduction of CONV exerts additional negative impact (Figure 2). In the "Atlantic-W" case, increases in VDIF are also observed over the upwind regions (i.e., North America) in JJA. However, it is accompanied by commensurate decreases in DRYD, resulting in an insignificant overall change in TURB (Figure 2). The increase of CHEM therefore is mainly responsible for the surface O_3 increase over North America in JJA. Relatively, TURB is more important over Europe (JJA and SON only), leading to a reduced surface O_3 abundance. For the "Indian-W" case, both CHEM and CONV are reduced over South Asia in JJA, leading to overall reductions in surface O_3 over the Indian subcontinent (Figure 2). The IPR analysis over the ocean basins shows that the warming of the North Pacific or North Atlantic induce a reduction of VDIF and CHEM, which is responsible for the significant decrease of surface O_3 above it in JJA (Figure S11). The North Indian Ocean warming, on the other hand, enhances the DEEP and VDIF, leading to an increase of surface O_3 locally in JJA."

8) Lines 260-263- It would be helpful to define remote versus downwind. Remote is used in this sentence and downwind in the following sentence. If North America is the remote continent in the Pacific W simulation then VDIF is only suppressed in summer, but not in winter and spring.

Good suggestion. To avoid confusion, we have replaced "remote" with "downwind" for consistency:

"The IPR analysis indicates that, in general, a SST increase in the North Pacific or North Atlantic is more likely to enhance the vertical diffusion of O_3 over upwind regions (i.e., East Asia or North America, respectively) but suppress it over the ocean basin as well as downwind continents in JJA (Figure S12). These opposite changes of VDIF over upwind and downwind regions lead to opposite surface O_3 responses."

9) Line 266- "change in photochemistry. . . advection . . . dominates the feedbacks of Indian Ocean warming- CHEM appears as a substantial component in the lowermost right hand panel of Figure 2.

Good question! As shown in Figure 2, the North Indian warming leads to substantial decreases of CHEM and CONV, which are responsible for the reduction of surface O_3 over South Asia. We have clarified this sentence in Section 3 of the revised manuscript:

"For the "Indian-W" case, both CHEM and CONV are reduced over South Asia in JJA, leading to overall reductions in surface O_3 over the Indian subcontinent (Figure 2)."

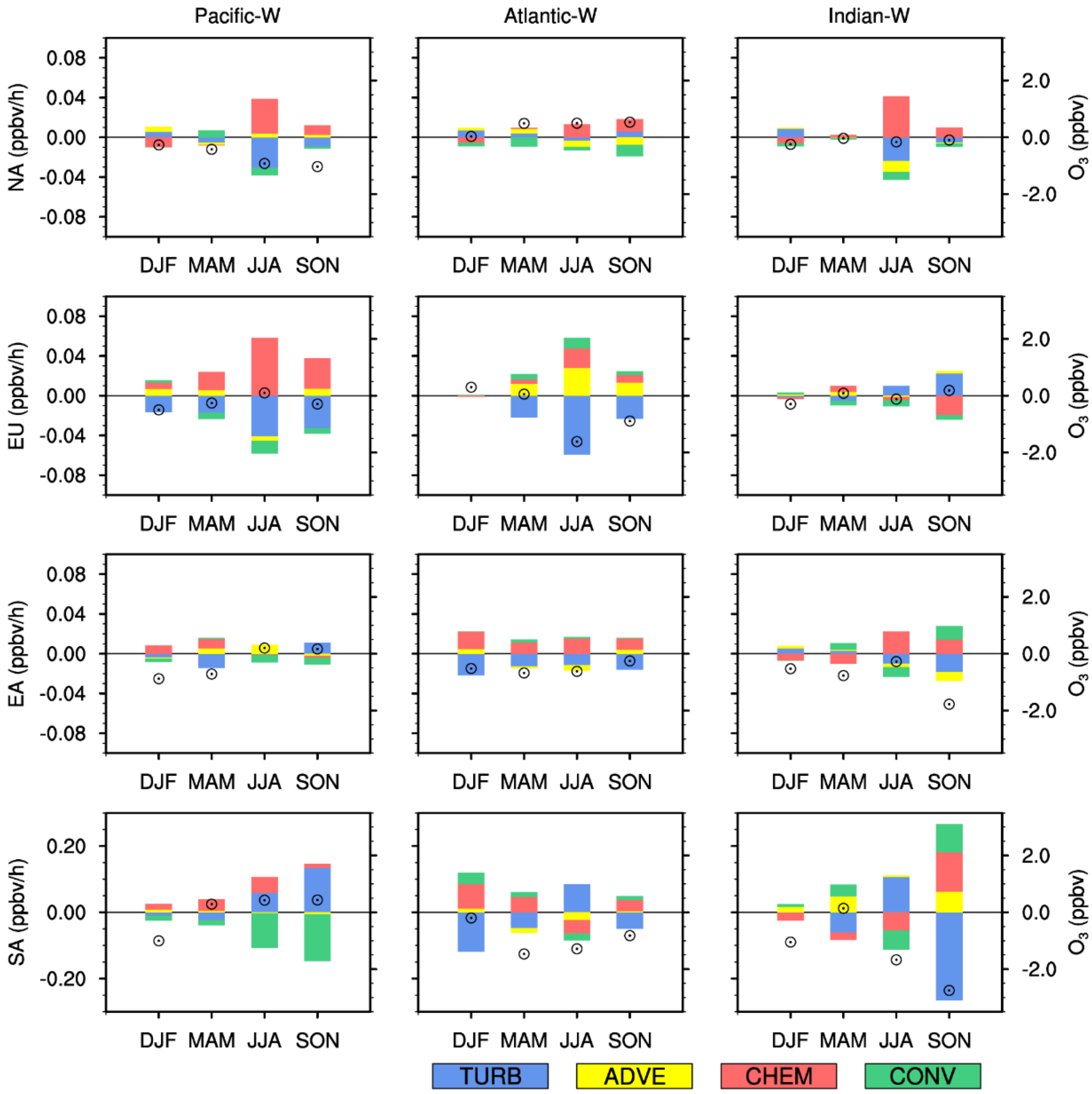

Figure 2. Seasonally averaged changes in IPR contributions (bars, ppbv/h, left scale) and surface O_3 concentrations (hollow circles, ppbv, right scale) for Pacific-W (left), Atlantic-W (middle) and Indian-W (right) relative to CTRL. Values are regionally averaged over

NA (first row), EU (second row), EA (third row) and SA (last row), respectively. TURB is defined as the sum of VDIF and DRYD. CONV is the sum of DEEP and SHAL. IPR contributions from four processes (i.e., TURB, ADVE, CHEM and CONV) are represented by different colors. A more detailed IPR result is shown in Figure S10 in the supplementary material.

10) Line 275- "Peak changes are confined to the polluted region because of their high precursor emissions". This is not obviously related. Please explain this statement more clearly. The examples that follow to the end of the paragraph referring to Figure 3 (the regions discussed are hard to see) do not clearly substantiate this.

As shown in Figure 3, changes of O_3 net production rate are generally highest over North America, East and South Asia where O_3 precursors' emissions are high. In addition, significant change also happens in tropical Africa, when North Indian SST is warmer. Therefore, we agree with the reviewer that our original explanation is not clear. Please see our revised text in Section 4.2 or below:

"Changes in net-production rate (i.e., chemical production rate minus loss rate) of O_3 at the surface in JJA associated with basin-scale SST increases are shown in Figure 3. Peak changes are mainly confined to regions where O_3 precursors are abundant (e.g., South and East Asia, North America, etc.). For example, a warmer North Pacific SST exerts a positive (negative) impact on net O_3 production in the northern (southern) regions of East Asia. Similarly, the warming of the North Atlantic promotes a dipole impact on the surface O_3 production over North America, while the warming of North Indian Ocean significantly decreases the O_3 net-production rate over South Asia."

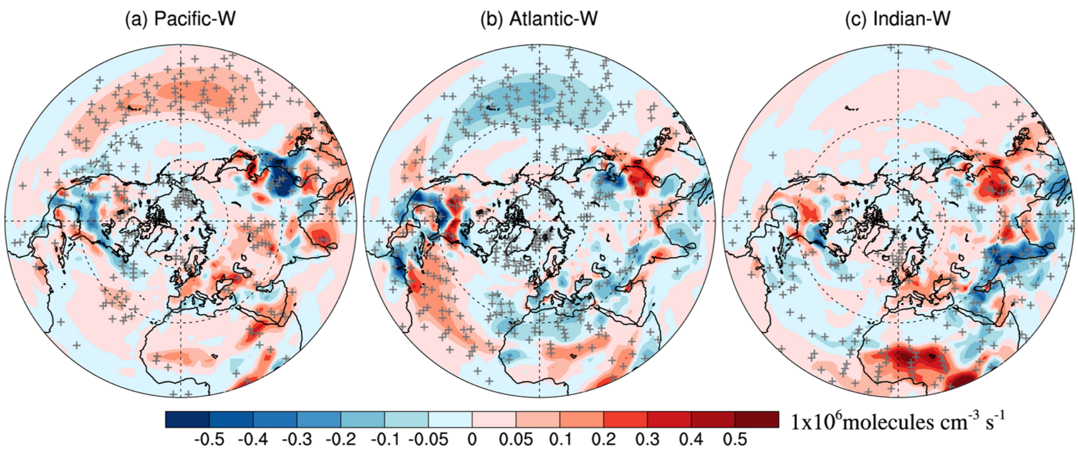

Figure 3. Perturbations of surface O_3 net-production rate ($1x10^6$ molecules cm^{-3} s^{-1}) for (a) Pacific-W, (b) Atlantic-W, and (c) Indian-W relative to CTRL in boreal summer. The +

symbols denote areas where results are significant at the 0.05 level as evaluated with a Student t-test using 20 years of data. (Plots using the Mercator projection are shown in Figure S14 in the supplementary material)

11) Lines 290 to end of paragraph- "Increase in SST facilitates moist convection... Lau. . .1997)"- Figure 2 for summer for the Indian W influence on SA suggests a decrease in deep convection. Please clarify? Here the references used are rather old. This is an interesting find, an increase in SST would be normally accompanied by an increase in surface air temperature directly above the ocean, but yet figure S3 shows cooling but with warming above. Hence it would be beneficial to provide an expanded interpretation of this finding, compare the results with those from more recent papers on how elevated SSTs in the Indian Ocean region or tropics affect surface air temperature and convection.

Good suggestion. Figure S11 shows that a warmer North Indian Ocean increases the DEEP (i.e., the contribution of deep convection to surface O_3) while Figure S10 suggests a decrease in the DEEP over South Asia. Actually, this SST increase facilitates deep convection over the North Indian Ocean while suppresses deep convection over the Indian subcontinent. Generally, an increase in SST for tropical oceans are more likely to enhance evaporation and vertical movement of warm moist air above its surface (Lau and Nath, 1994;Lau et al., 1997;Hartmann, 2015). However, its effects on convection over nearby and remote regions are rather complicated. In this case, the SST increase over the Indian Ocean strengthens deep-convection above it according to our analysis as well as previous studies (Roxy, 2014;Xi et al., 2015;Chaudhari et al., 2016). The enhanced upward movement of warm moist air above the Indian Ocean promotes cloud formation in the upper troposphere. As demonstrated in our study, there is a remarkable reduction of solar radiation received at the surface (Figure S17) and a significant decrease of surface air temperature (Figure 4) over Indian subcontinent. This decrease of surface temperature over the Indian subcontinent suppresses the development of deep-convection above. Additionally, the latent heat release from convective activity warms the air temperature in upper troposphere significantly (Sabeerali et al., 2012;Xi et al., 2015), leading to opposite changes of air temperature between upper and lower troposphere over South Asia. We have discussed these processes with some most recent references in Section 4.2 of the revised manuscript.

"An exception is the North Indian Ocean, where an increase in SST tends to cool the Indian subcontinent by 1-2°C. This temperature decrease is not only limited to the surface, but also spreads to 600hPa (Figure S16). Associated with this temperature decrease, there is a remarkable reduction of solar radiation received at the continent beneath (more than 15 W/m^2, Figure S17). Previous studies have revealed that moist convection is more sensitive to the SST changes in the tropical oceans rather than mid- or high- latitude oceans (Lau

and Nath, 1994;Lau et al., 1997;Hartmann, 2015). The SST increase over the North Indian Ocean tends to strengthen moist convection that eventually facilitates cloud formation in the upper troposphere (Roxy et al., 2015;Xi et al., 2015;Chaudhari et al., 2016). The latent heat released from convective activities warms the air temperature over upper troposphere significantly (Sabeerali et al., 2012;Xi et al., 2015). Meanwhile, the corresponding increase of cloud-cover blocks solar radiation reaching the surface of Indian subcontinent and reduce the air temperature of lower troposphere there. These processes lead to opposite air temperature changes between upper and lower troposphere over South Asia in response to North Indian warming (as shown in Figure S16), which may further suppresses the development of deep convection over the Indian subcontinent."

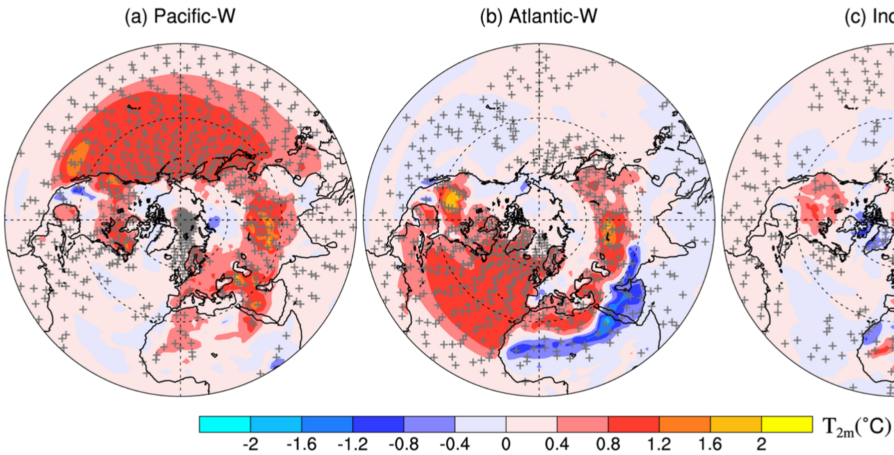

Figure 4. The difference in surface air temperature (ºC) for (a) Pacific-W, (b) Atlantic-W, and (c) Indian-W relative to CTRL in the Northern Hemisphere in boreal summer. The + symbols denote areas where results are significant at the 0.05 level as evaluated with a Student t-test. (Plots using the Mercator projection are shown in Figure S15 in the supplementary material)

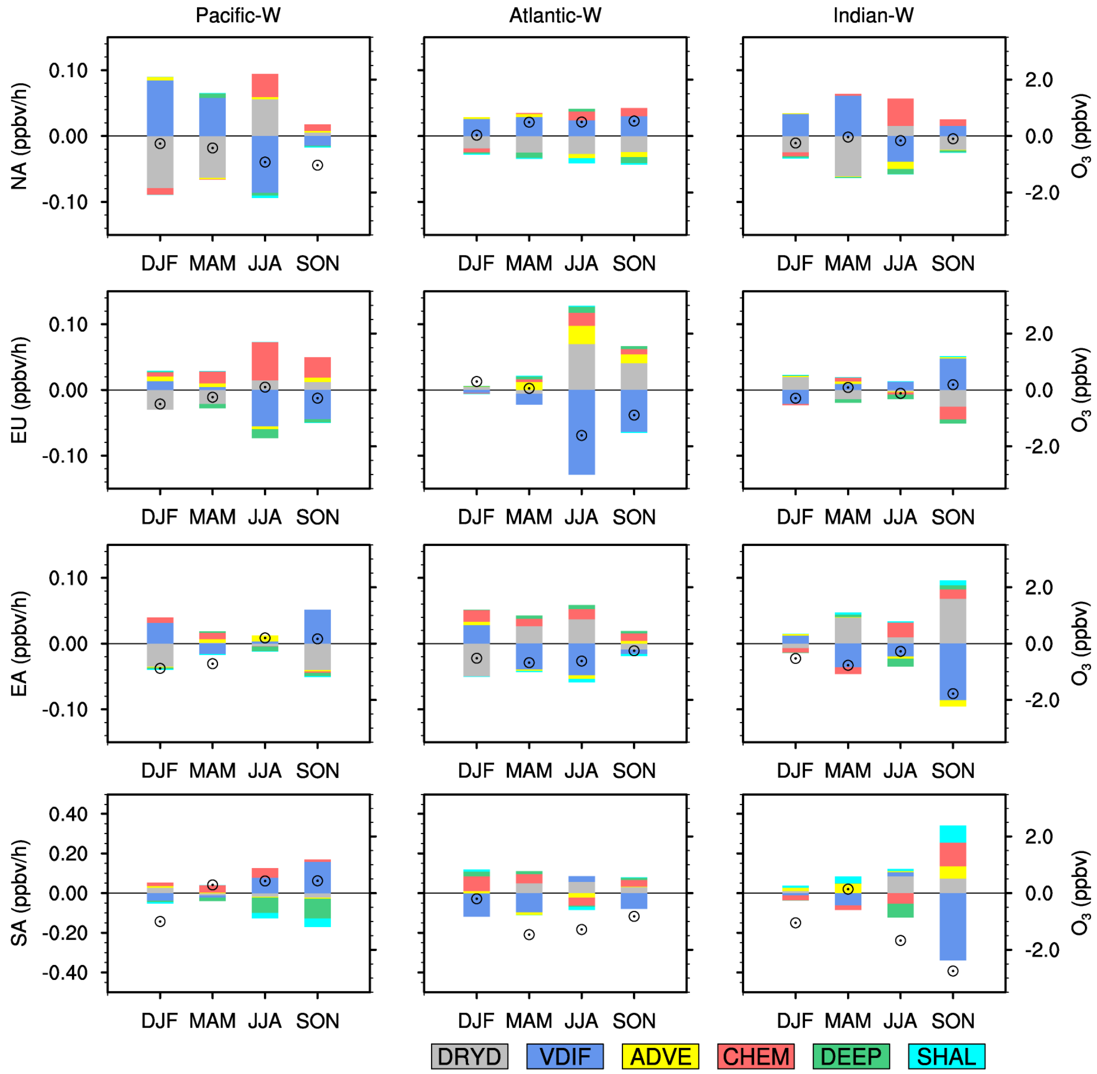

Figure S10. Seasonally averaged changes in IPR contributions (bars, ppbv/h, left scale) and surface O_3 concentrations (hollow circles, ppbv, right scale) for Pacific-W (left), Atlantic-W (middle) and Indian-W (right) relative to CTRL. Values are regionally averaged over NA (first row), EU (second row), EA (third row) and SA (last row), respectively. IPR contributions from six processes (i.e., dry deposition (DRYD), vertical diffusion (VDIF), advection (ADVE), gas-phase chemistry (CHEM), deep convection (DEEP) and shallow convection (SHAL)) are represented by different colors.

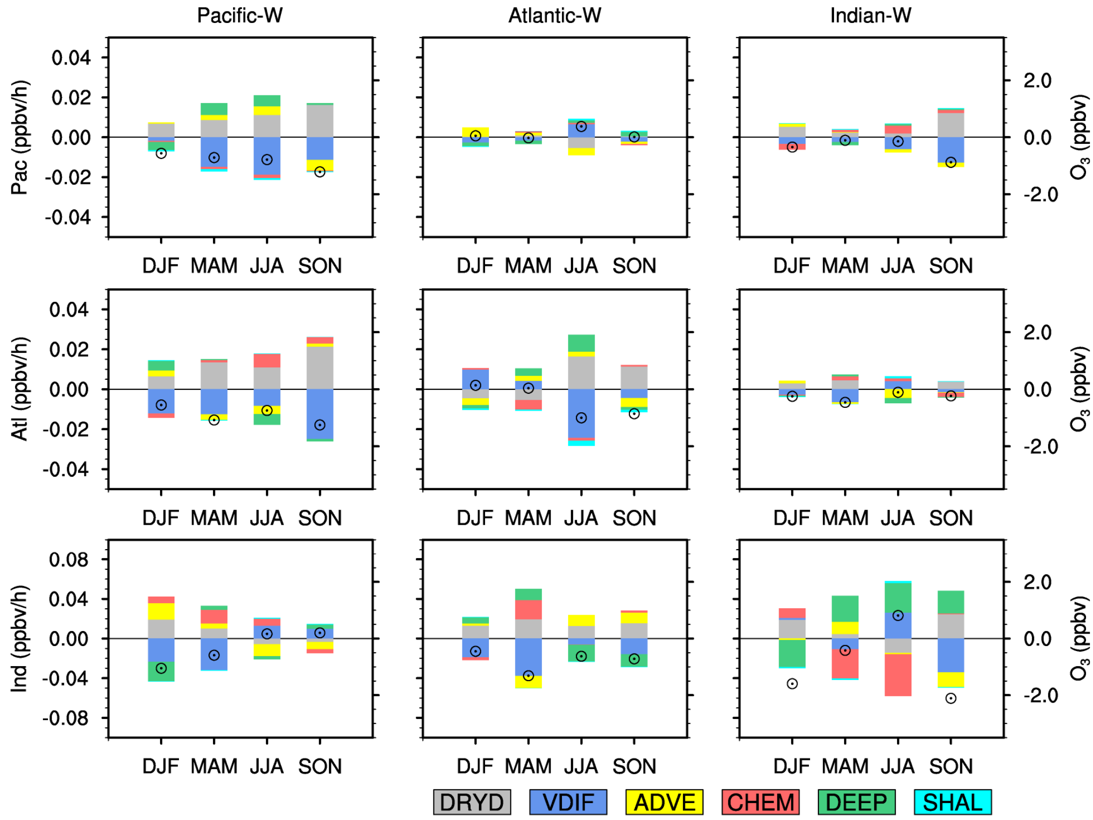

Figure S11. Same as Figure S10 but for three ocean basins defined in our study.

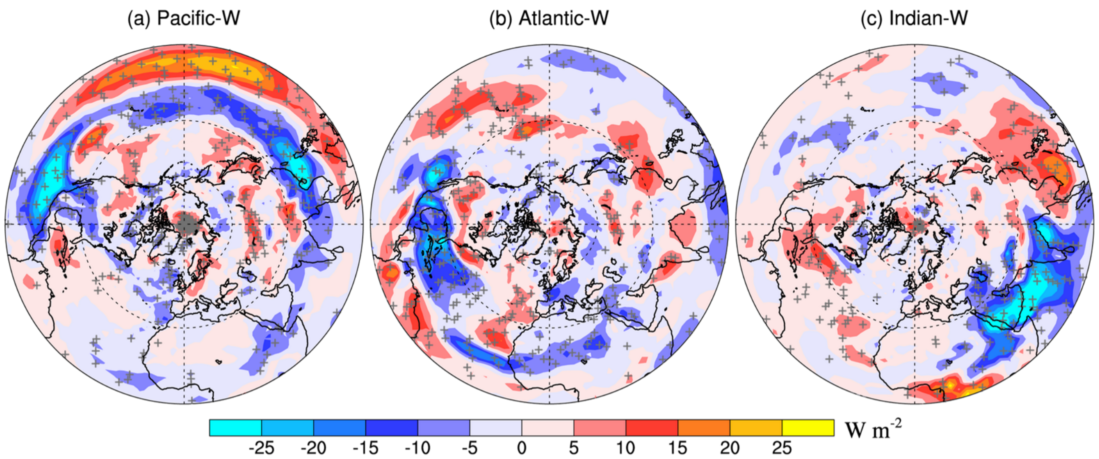

Figure S17. Perturbations of surface solar radiations (W m^{-2}) for (a) Pacific-W, (b) Atlantic-W, and (c) Indian-W relative to CTRL in boreal summer. The + symbols denote areas where results are significant at the 0.05 level evaluated with a Student t-test.

12) Line 297- The text relating ozone production -temperature relationships to net surface ozone production relationships with temperature should be clarified: it is the ozone not

the ozone production that is related to temperature in the references cited, and as the authors note both ozone production and destruction rates will increase with temperature (directly and indirectly through higher humidity).

Good suggestion. Figure S19 compares the O_3 chemical production rate and destruction rate. The former usually dominates the net chemical production over continental regions, whereas the latter is relatively important over oceans. This indicates that although both ozone production and destruction rates increase with temperature, the response of O_3 is more relevant to the changes of O_3 production rate over continental regions. In contrast, the effects of humidity on O_3 destruction and concentrations are more important over coastal and oceanic areas. Please see the revised text below in Section 4.2:

"Previous studies indicated that air temperature positively affects both O_3 production and destruction rates (Zeng et al., 2008;Pusede et al., 2015). As shown in Figure S19, changes in net O_3 production rate are mainly dominated by O_3 production over continents while by O_3 destructions over oceans. An increase of SST leads to a widespread enhancement of air temperature, resulting a positive net O_3 production over most continental regions (Figure 3). However, a warmer SST also increases air humidity (Figure S21), which enhances O_3 destruction over most coastal and oceanic areas."

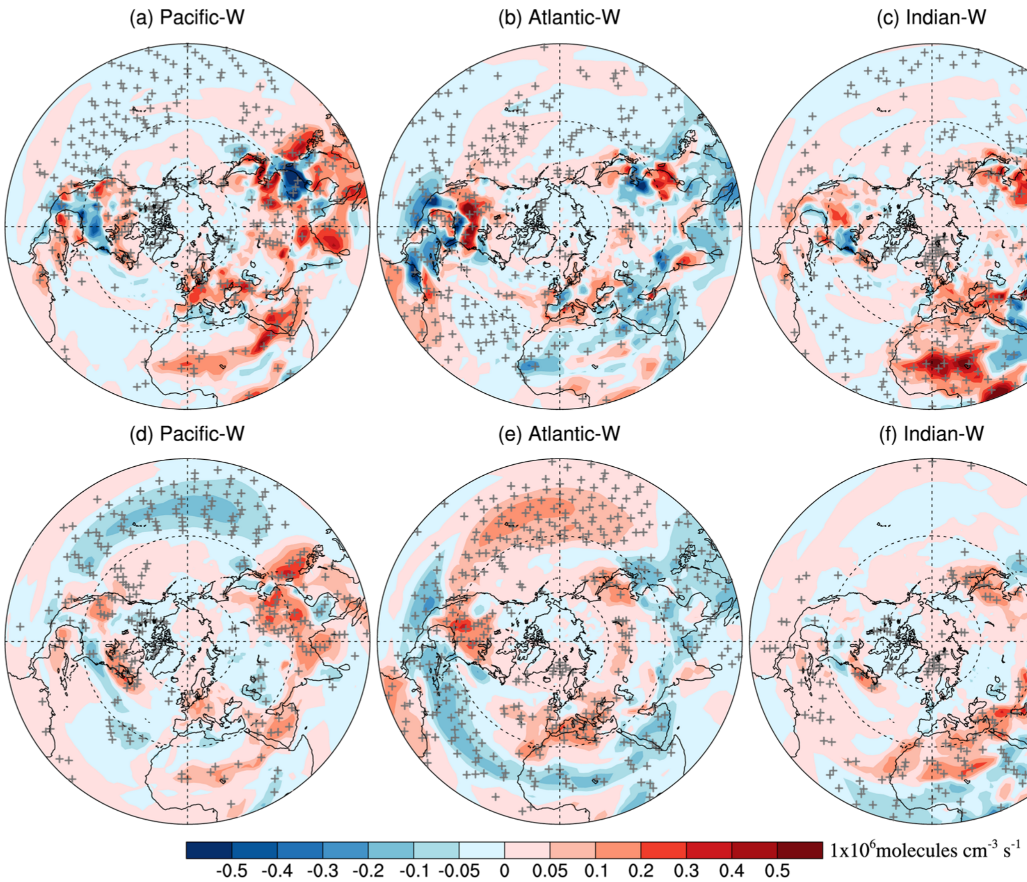

Figure S19. Top row: Perturbations of surface O_3 chemical production rate (1×10^6 molecules cm^{-3} s^{-1}) for (a) Pacific-W, (b) Atlantic-W, and (c) Indian-W relative to CTRL in boreal summer. Bottom row: Perturbations of surface O_3 chemical loss rate (1×10^6 molecules cm^{-3} s^{-1}) for (d) Pacific-W, (e) Atlantic-W, and (f) Indian-W relative to CTRL in boreal summer. The + symbols denote areas where results are significant at the 0.05 level as evaluated with a Student t-test using 20 years of data.

13) Line 318- As shown in Figure 6. . . surface pressure reduction is closely associated with enhanced upward motion. Please use the same map in Figures 5 and 6 in order to see this association.

Good suggestion. Now we use the same map for Figures 5 and 6 (see below), and put the original Figure 6 (using polar projection) into the supporting information (i.e., Figure S23):

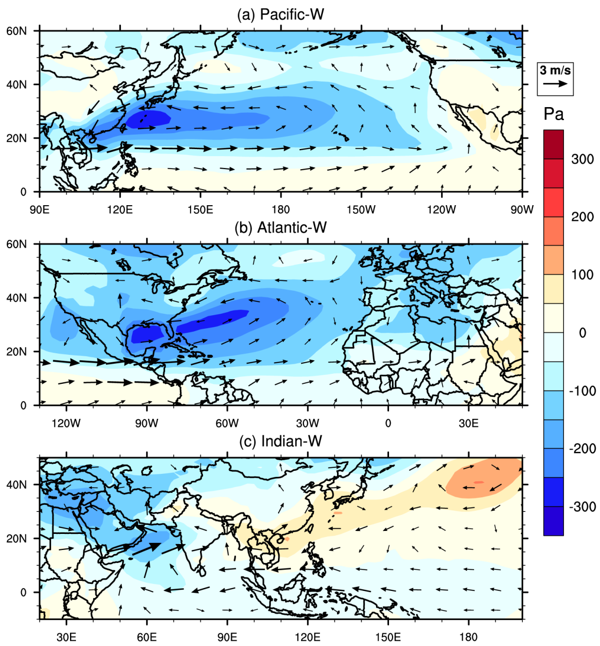

Figure 5. Changes in surface pressure (color contours, Pa) and 850 hPa wind (arrows, m/s) for (a) Pacific-W, (b) Atlantic-W, and (c) Indian-W relative to CTRL in boreal summer.

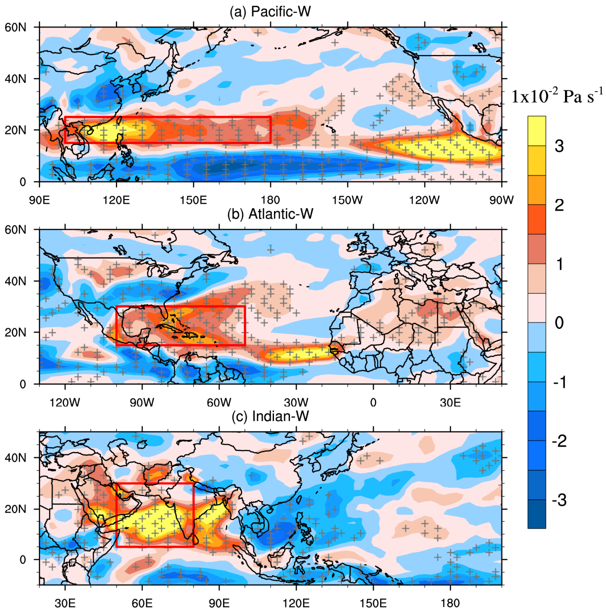

Figure 6. The spatial pattern of vertical velocity changes at 500 hPa (color contours, $1\text{x}10^{-2}$ Pa s^{-1}) for (a) Pacific-W, (b) Atlantic-W, and (c) Indian-W relative to CTRL in boreal summer. Positive values indicate upward motion. Red polygons denote the regions where the surface pressure responses to SST anomalies are significant (see Figure 5 a-c). The + symbols indicate areas where results are significant at the 0.05 level as evaluated with a Student t-test using 20 years of data.

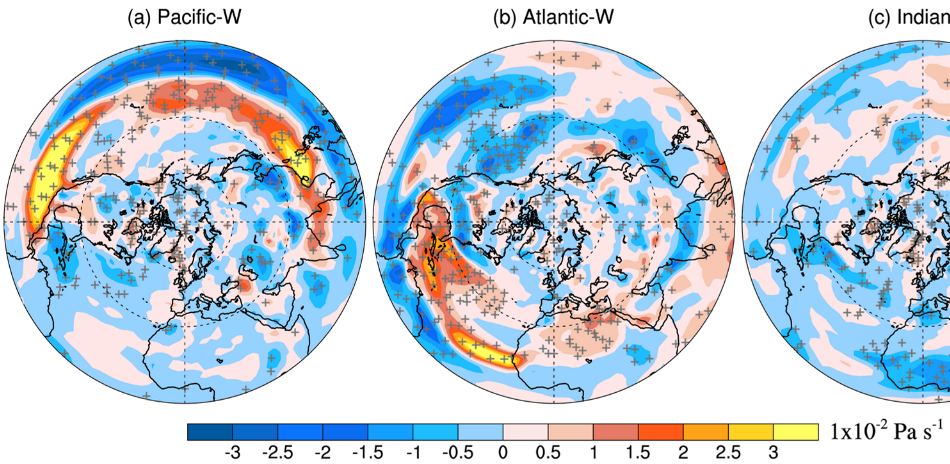

Figure S23. The spatial pattern of vertical velocity changes at 500 hPa (color contours, $1\text{x}10^{-2}$ Pa s^{-1}) for (a) Pacific-W, (b) Atlantic-W, and (c) Indian-W relative to CTRL in boreal summer. Positive values indicate upward motion. The + symbols indicate areas where results are significant at the 0.05 level as evaluated with a Student t-test using 20 years of data.

14) Line 329- "This effect is confirmed by widespread decreases of upward vertical velocity". Again it is hard to see if vertical velocity reductions are occurring only over the adjacent regions to the regions where the authors suggest enhanced convection may occur.

As shown in Figure 6, a basin-scale SST increase strengthens the upward motions locally. Adjacent to these anomalous upward motion, significant decreases of upward velocity are observed. For example, decreases of upward velocity are shown over East Asia associated with the North Pacific warming, and similarly the changes over North America associated with the North Atlantic warming. Additionally, decreases of upward vertical velocity are also demonstrated over higher latitudes and remote regions (shown in Figure S23). For example, the warming of the North Atlantic may induces a decrease of upward vertical velocity over the North Pacific. These effects have been reported in previous studies (Lau et al., 1997;Roxy et al., 2015;Ueda et al., 2015). We have optimized the relevant figures to verify our conclusion, please refer to our response to the former comment for the relevant figures (Figure 6 and Figure S23). We also modified the text below in Section 4.3 for clarification:

"Strengthened deep convection will trigger large-scale subsidence over nearby regions through modulating large-scale circulations, which may suppress convective transport (Lau et al., 1997;Roxy et al., 2015;Ueda et al., 2015). This effect is verified by the decreases of upward velocity at 500 hPa. As depicted in Figure 6, significant changes of upward velocity happen over regions adjacent to the strengthened deep convection. Similar effects are also observed over higher latitudes or remote oceans (Figure S23)."

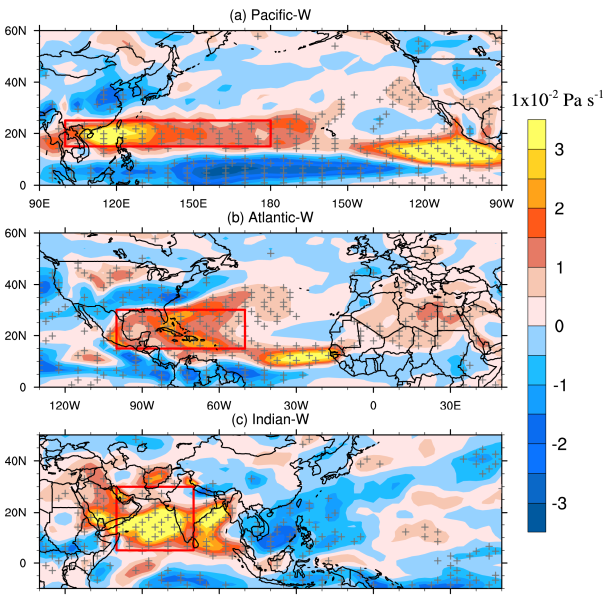

Figure 6. The spatial pattern of vertical velocity changes at 500 hPa (color contours, 1x10-

^{2} Pa s^{-1}) for (a) Pacific-W, (b) Atlantic-W, and (c) Indian-W relative to CTRL in boreal summer. Positive values indicate upward motion. Red polygons denote the regions where the surface pressure responses to SST anomalies are significant (see Figure 5 a-c). The + symbols indicate areas where results are significant at the 0.05 level as evaluated with a Student t-test using 20 years of data.

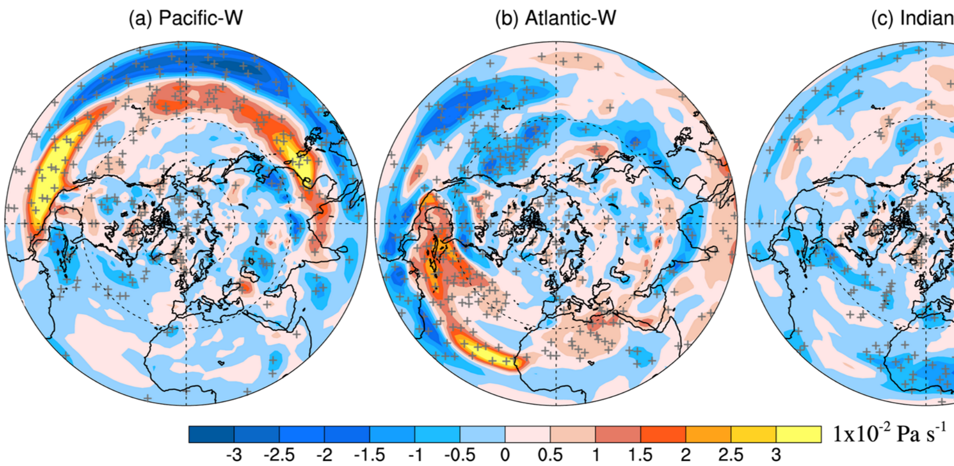

Figure S23. The spatial pattern of vertical velocity changes at 500 hPa (color contours, 1x10^{-2} Pa s^{-1}) for (a) Pacific-W, (b) Atlantic-W, and (c) Indian-W relative to CTRL in boreal summer. Positive values indicate upward motion. The + symbols indicate areas where results are significant at the 0.05 level as evaluated with a Student t-test using 20 years of data.

15) Line 333-end of paragraph. This first sentence of the paragraph discusses atmospheric stability based on zonal mean large-scale temperatures changes between the upper and lower troposphere (a weaker vertical temperature gradient; Figure S3) and stagnation/ventilation which are local processes often related to surface winds. Hence these processes may not be as simply related as suggested. In addition, a differential ozone response over clean and polluted regions seem unlikely to be associated with change in atmospheric stability associated with large-scale increases in upper tropospheric temperature. The final sentence of the paragraph needs substantiated especially given the link proposed in the previous section between clean regions with reduced net ozone production due to greater destruction.

Referring to our response to major comment 4, we agree that stagnation/ventilation were improperly used here and have rephrased our explanation in the revised manuscript. The basin-scale SST increase not only strengthens upward motions over the low-latitudes of the specific ocean, but also leads to the decrease of upward velocity over mid-latitudes (Figure S23). Previous studies have revealed that strengthened deep convection will trigger large-scale subsidence over other regions through modulating large-scale circulations, which may suppress convective air movement there (Lau et al., 1997;Roxy et al., 2015;Ueda et al., 2015). Here we also demonstrate a weaker vertical temperature gradient associated with regional SST warming (Figure S16). Both factors (i.e., large-scale subsidence and weaker vertical temperature gradient) tend to slow down vertical air movement. In the revised manuscript, we further examined the vertical transport of O_3 based on the IPR analysis (shown in Figure S12). It shows a wide-spread reduction of transport of O_3 by vertical diffusion to the surface (i.e. VDIF). Considering that the responses of O_3 destructions to SST anomalies are more important over oceans than land (referring to our reply to previous comment 12), it is reasonable for us to infer that this reduced vertical transport may also exert a negative effect on surface O_3 over clean continents. Please see the relevant figures below. A detail explanation is provided in Section 4.3 of our revised manuscript:

"Strengthened deep convection will trigger large-scale subsidence over nearby regions through modulating large-scale circulations, which may suppress convective transport (Lau et al., 1997;Roxy et al., 2015;Ueda et al., 2015). This effect is verified by the decreases of upward velocity at 500 hPa. As depicted in Figure 6, significant changes of upward happen over regions adjacent to the strengthened deep convection. Similar effects are also observed over higher latitudes or remote oceans (Figure S23). Meanwhile, air temperature increase in response to regional SST warming is more significant in the upper than the lower troposphere, which leads to a decrease in the vertical temperature gradient (Figure S16). These factors tend to restrains the vertical exchange of air pollutants at mid-latitudes. This helps surface O_3 accumulation over polluted continental regions in JJA, but may weaken the intrusion of O_3 from the upper troposphere to the surface in most clean areas. This explains the wide–spread decrease of surface O_3 over clean regions associated with a SST increase (as described in Section 3), and can be further verified by the wide-spread reduction of VDIF shown in Figure S12."

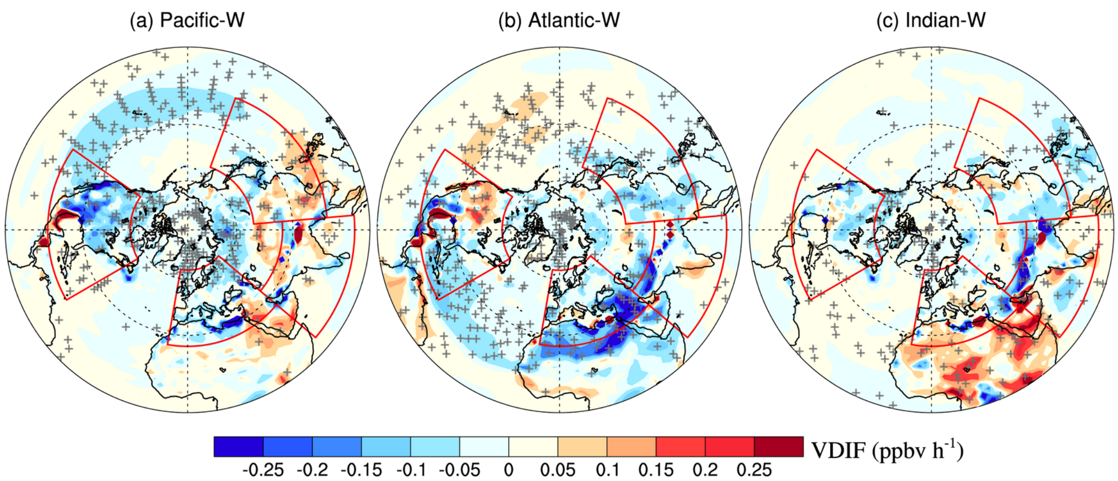

Figure S12. Changes in VDIF for (a) Pacific-W, (b) Atlantic-W and (c) Indian-W relative to CTRL in boreal summer. Four major regions of interest (i.e., NA (15°N–55 °N; 60°W–125°W), EU (25°N–65 °N;10°W-50 °E), EA (15 °N–50 °N; 95°E–160 °E) and SA (5 °N–35 °N; 50 °E–95°E)) are marked by red solid lines. The + symbols denote areas where results are significant at the 0.05 level as evaluated with a Student t-test using 20 years of data.

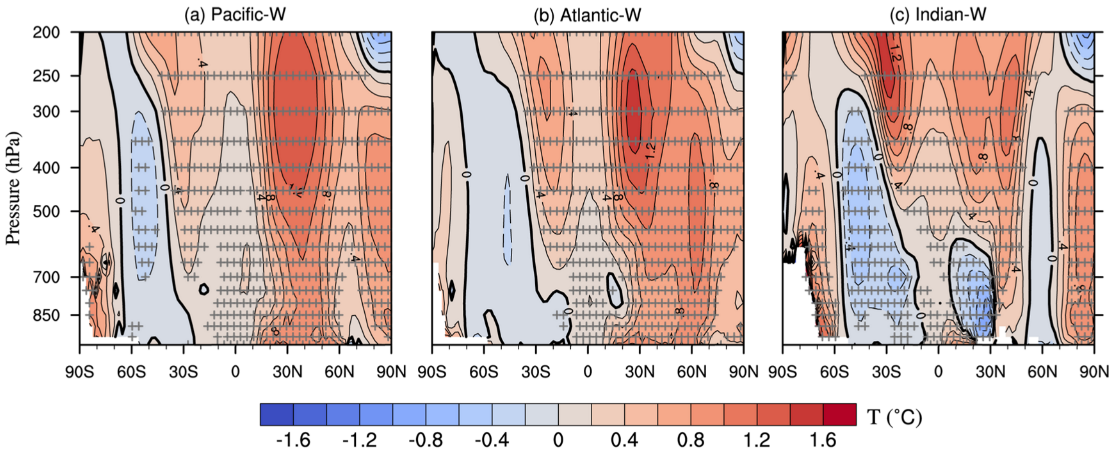

Figure S16. Vertical-meridional distributions of air temperature differences (contours, ºC) between (a) Pacific_W (zonally averaged from 100°E-90°W) (b) Atlantic_W (100°W-180°W) (c) Indian_W (30°E-100°E) and CTRL in boreal summer. Black solid and dashed lines in the contours indicate positive and negative air temperature anomalies, respectively (contour interval: 0.2 ºC).The + symbol denotes areas where the changes of air temperature are significant at the 0.05 level evaluated with a Student t-test.

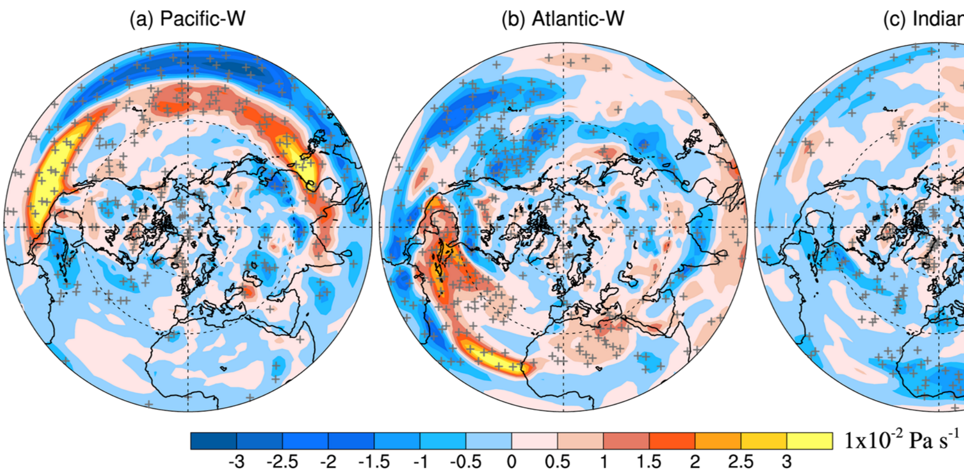

Figure S23. The spatial pattern of vertical velocity changes at 500 hPa (color contours, $1x10^{-2}$ Pa s^{-1}) for (a) Pacific-W, (b) Atlantic-W, and (c) Indian-W relative to CTRL in boreal summer. Positive values indicate upward motion. The + symbols indicate areas where results are significant at the 0.05 level as evaluated with a Student t-test using 20 years of data.

16) Line 341- please explain how a reduction in low pressure weakens the East Asian monsoon?

Good question. As shown in Figure 5, this low pressure induces a cyclonic anomaly in the lower troposphere over the subtropical northwestern Pacific. This weakens southwesterly winds to East China and thus the East Asian summer monsoon. However, East Asian summer monsoon is a rather complicated phenomenon when considering its onset, withdrawal, and relationship with precipitation. These factors are beyond the focus of this study. We therefore removed this discussion in Section 4.3. Now we have:

"For example, the low-pressure anomaly centered over the subtropical northwestern Pacific in the "Pacific-W" case causes the convergence of wind in the lower troposphere (Figure 5a). Consequently, surface O_3 pollution is enhanced in southern China due to an increase of O_3 transport from the more polluted northern China (Figure 7a)."

17) Line 349/Line 357- if the IPR analysis refers to Figure 2 there seem to be a few inconsistencies – the influence of Pacific W on EA then VDIF appears to have the strongest role, yet advective transport is discussed here? The influence of the Atlantic W on NA then CHEM seems only to have a small contribution in Figure 2 and not be the main contribution discussed here. Furthermore, the logic of the argument that physical transport is not important because of large changes in the upper troposphere but small changes at the surface is unclear.

Thanks for pointing out this. The IPR analysis here does not refer to Figure 2. In Figure 2, we averaged IPR changes over East Asia. In this sentence, the IPR analysis only focus on southern China. The warming of the North Pacific increases the surface O_3 over upwind region in JJA, but this effect is insignificant when averaging over the whole East Asia (shown in Table 1). Correspondingly, the increase of VDIF over EA is also insignificant in JJA based on the IPR analysis. As shown in Figure 1, the increases of surface O_3 are highest over southern China while accompanied with a slight decrease over the North China. We find that the wind pattern anomaly induced by the warming of the North Pacific may be responsible for this dipole changes through modulating surface O_3 transport. The IPR analysis indicates that the increase in advective transport is mainly responsible for the surface O_3 increase in southern China. These results are not shown in the manuscript.

As for the cases of "Atlantic-W", we find that the VDIF and DRYD are two processes that changes significantly over NA (Figure S10). However, they tend to offset each other in most places, resulting in an insignificant overall change in TURB (please see our revised Figure 2). Therefore, the change of CHEM are higher than TURB and dominates the surface O_3 increase over NA in "Atlantic-W" (as discussed in Section 4.1). Please refer to our response to specific comment 6 for more details. Here we further demonstrated the changes in horizontal fluxes of O_3 over NA in "Atlantic-W", which shows no significant effect on the increase of surface O_3 (Figure 7b). Therefore, we conclude that the response of ground-level O_3 over North America to the North Atlantic warming is mainly caused by the enhanced chemical production, rather than physical transport. The discussion of the difference in O_3 changes between upper troposphere and surface is not a supporting argument. It only indicates that O_3 transport maybe more important over upper troposphere.

We have clarified our descriptions in Section 4.3 as follows:

"The surface pressure anomalies induced by SST changes can play a dominant role in modulating surface O_3 transport at specific locations. For example, in the "Pacific-W" case the low-pressure anomaly centered above Japan causes a southward wind anomaly (Figure 5a), which has a tendency to enhance the transport of O_3 from the more polluted north China to the south (Figure 7a). The vertical distribution of the corresponding O_3 changes also shows that the increase of O_3 over southern China happens below 700hPa, accompanied with noticeable decreases above 700hPa as well as over the nearby northern China (Figure 7d). The IPR analysis indicates that the increase in advective transport and downward turbulent transport are mainly responsible for the surface O_3 increase in southern China."

"In the "Atlantic-W" case, the SST warming induced surface pressure anomalies lead to substantial O_3 redistribution, especially over the North Atlantic Ocean (Figure 7b). As for North America, changes in O_3 horizontal fluxes show no significant effect on the O_3 concentration increase. In addition, O_3 changes are observed to be larger in the upper troposphere than at the surface (Figure 7e). As demonstrated in Section 4.1, the response of lower altitude NA O_3 to the North Atlantic warming is mainly caused by enhanced chemical production, rather than physical transport."

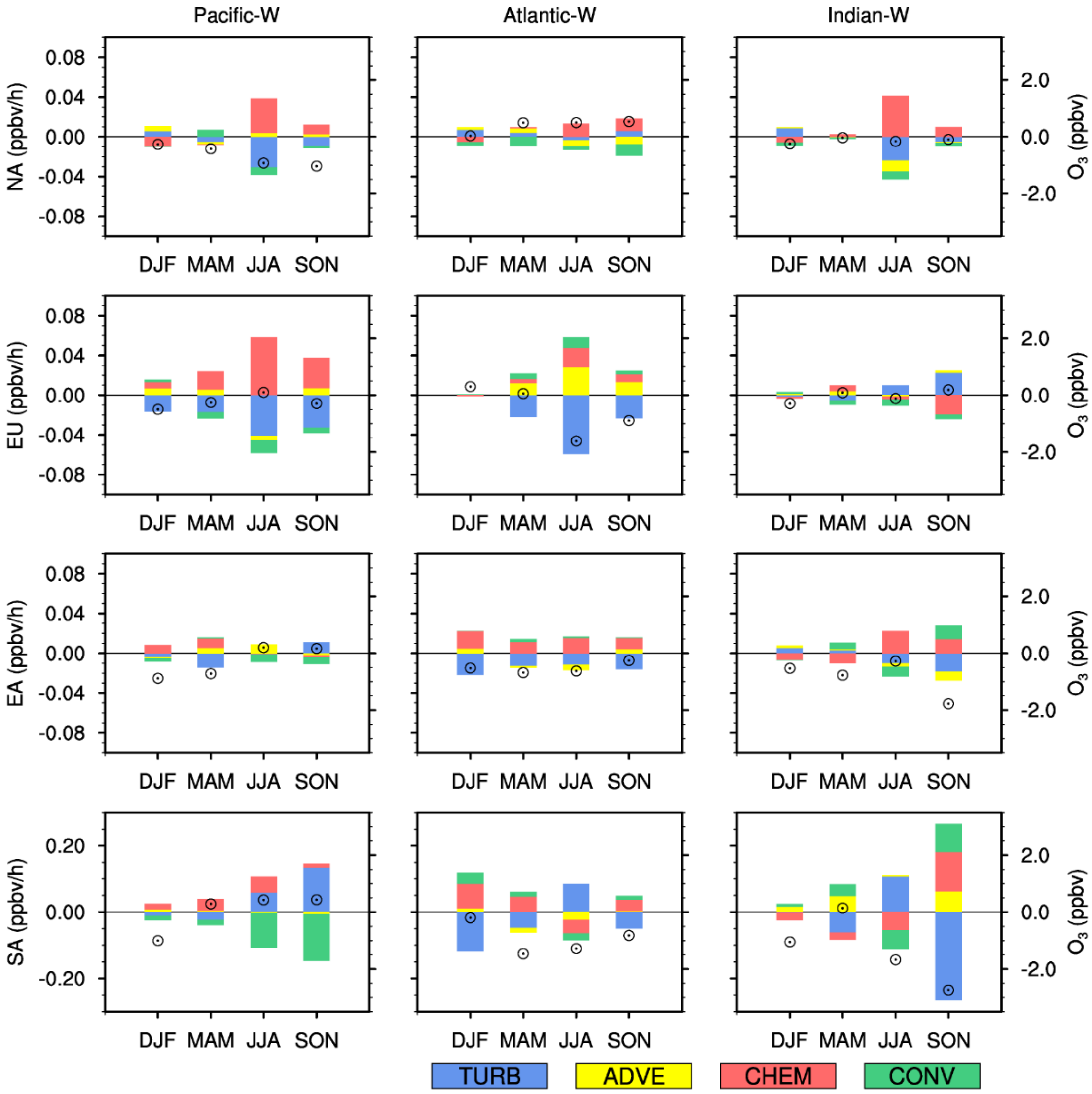

Figure 2. Seasonally averaged changes in IPR contributions (bars, ppbv/h, left scale) and surface O_3 concentrations (hollow circles, ppbv, right scale) for Pacific-W (left), Atlantic-W (middle) and Indian-W (right) relative to CTRL. Values are regionally averaged over NA (first row), EU (second row), EA (third row) and SA (last row), respectively. TURB is defined as the sum of VDIF and DRYD. CONV is the sum of DEEP and SHAL. IPR contributions from four processes (i.e., TURB, ADVE, CHEM and CONV) are represented by different colors. A more detailed IPR result is shown in Figure S10 in the supplementary material.

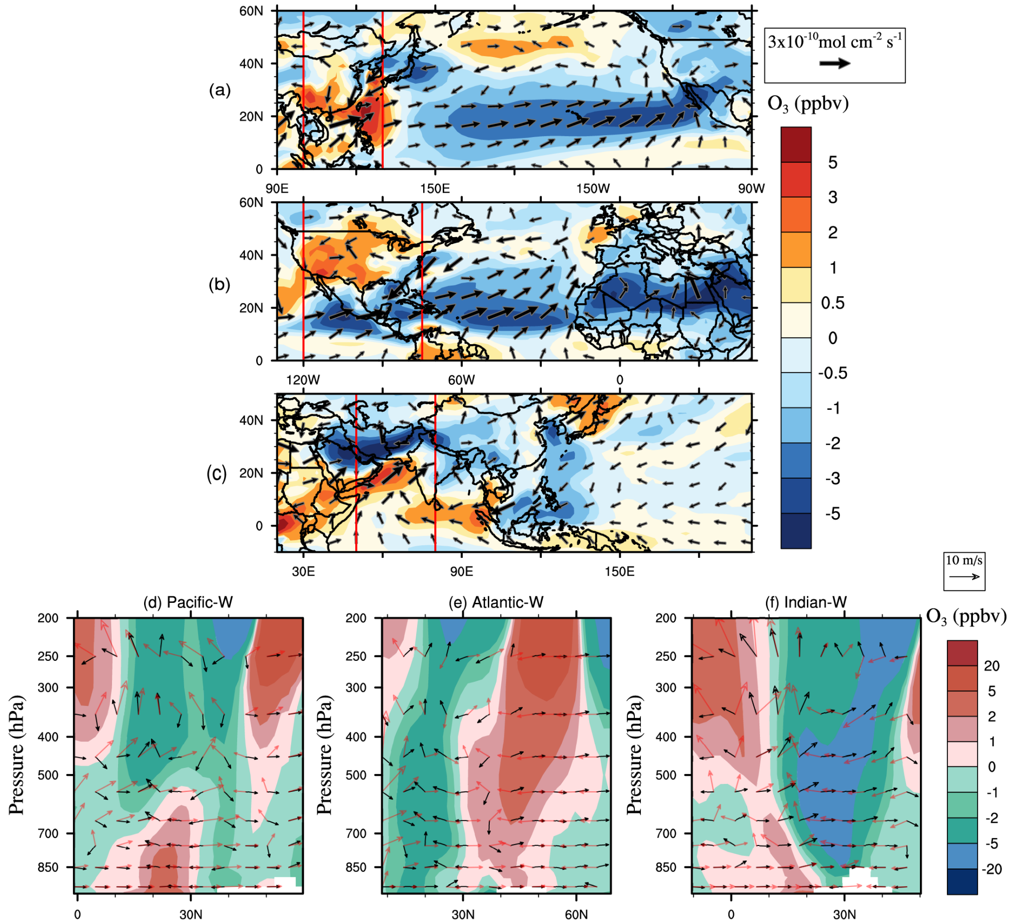

Figure 7. Top three rows: Changes in O_3 concentrations (color contours, ppbv) and horizontal fluxes (arrows, mol cm^{-2} s^{-1}) at the surface level for (a) Pacific-W, (b) Atlantic-W, (c) Indian-W relative to CTRL in boreal summer. Last row: zonally average of tropospheric O_3 changes (color contours, ppbv) and wind fluxes in CTRL (red arrows, m/s) and its perturbation (black arrows, m/s) in (d) Pacific-W, (e) Atlantic-W, (f) Indian-W relative to CTRL in boreal summer. The red rectangles in (a), (b) and (c) denote the longitudinal range used for zonal average in (d), (e) and (f), respectively. The vertical wind velocity is amplified 1000 times to make it comparable to horizontal wind velocity.

18) Line 380 to end of paragraph- The results in figures 8 (CO tracer) and 7 (ozone concentrations) look similar and reinforce each other except over the Indian Ocean. Please comment on this.

Good suggestion! Given that the CO-like tracers added in our simulation are idealized with fixed decay lifetime, their concentration changes associated with SST anomalies can be completely attributed to the corresponding changes of air mass. As shown in Figure 8a, changes in surface concentrations of CO-like tracer emitted from EA resembles that of surface O_3 depicted in Figure 7a. This indicates that changes in transport associated with North Pacific warming play an important role in redistributing the surface O_3 over East Asia. As for the CO-like tracer emitted from NA in the "Atlantic-W" case, it shows a slight increase at the surface over the NA source. However, the spatial pattern of its concentration change (Figure 8c) is not consistent with that of O_3 (Figure 7b). This is because the increase of surface O_3 over NA is mainly caused by the enhanced chemical production, which deviates it substantially from the CO-like transport pattern. The response of the South Asia CO tracer to North Indian Ocean warming also shows an inconsistent spatial pattern with that of surface O_3 concentrations, suggesting the importance of chemistry on surface O_3.Therefore, the diagnosis of CO-like tracers not only infers the response of O_3 long-range transport to SST anomalies, but can also help to verify our previous arguments. We have improved this text and added more discussions in the revised manuscript.

"Given that the CO-like tracers added in the simulation have a fixed decay lifetime, their concentration changes therefore are completely caused by the SST-induced transport anomalies. The decrease of CO tracer concentrations over downwind regions suggests that the warming of basin-scale SST tends to suppress the long-range transport of air pollutant. Additionally, in the "Pacific-W" case, changes in East Asian CO (Figure 8a) generally resemble the changes of surface O_3 over East Asia (Figure 7a), indicating the dominant role of physical transport played on O_3 evolution over East Asia. As for North American CO in response to the North Atlantic warming or the South Asian CO in response to the North Indian Ocean warming, their concentration changes are spatially inconsistent to O_3 (see Figure 7 and Figure 8). This further indicates the distinct roles that different basin-scale SSTs play on nearby air quality."

19) Line 395 to end of paragraph- Is significance plotted in figure 9? The text cannot be followed well here with the current figure quality. The conclusion on vertical diffusion is hard to follow, given text in previous sections discussing areas of both enhanced convection and subsidence in the ocean basin and downwind.

Thanks for pointing this problem out. We have improved the quality of Figure 9. The changes of zonal wind depicted in Figure 9 have been verified to be significant at 0.05 level with the Student t-test using 20 years of data.

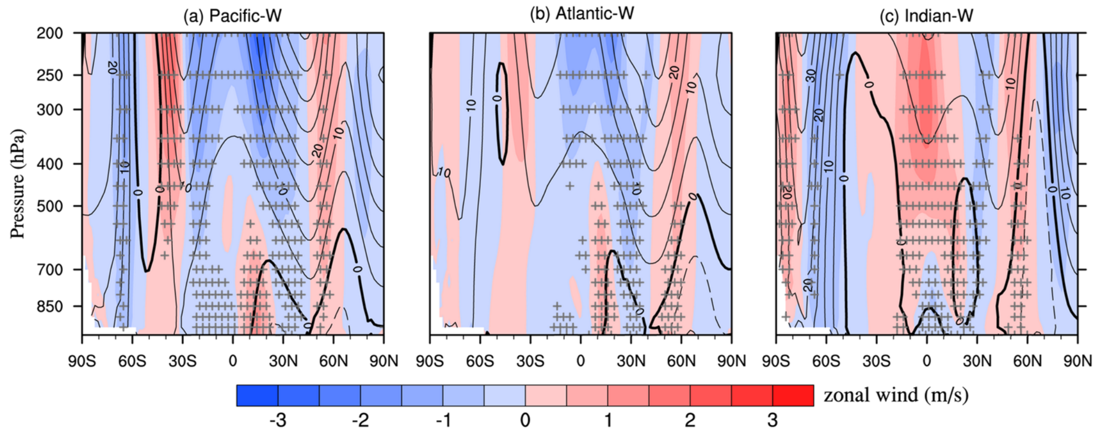

Figure 9. Zonally averaged changes in zonal wind (color contour, m/s) and geopotential height (contour, m) for (a) Pacific-W, (b) Atlantic-W and (c) Indian-W relative to CTRL in boreal summer. Black solid and dashed lines in the contours indicate positive and negative geopotential height anomalies, respectively (contour interval: 5 m). The + symbol denotes areas where the zonal wind changes are significant at the 0.05 level evaluated with a Student t-test.

This discussion here mainly focuses on the circulation pattern changes induced by basin-scale SST changes. Our result shows that the response of air temperature to a warmer North Pacific or North Atlantic mainly happens in the mid-latitudes (Figure 9). Thus, the associated meridional temperature gradient is decreasing at lower latitudes while increasing at higher latitudes. Consequently, it weakens the westerly wind at lower mid-latitudes (25°N - 45 °N) while intensifies it at higher latitudes. As for vertical transport (mainly discussed in Section 4.3), a warmer basin-scale SST facilitates the deep convection over tropical regions while suppresses the upward transport at higher latitudes. The decreases of upward velocity at mid-latitudes are also demonstrated in Figure 6 and Figure S6. A detail description is provided in Section 4.3 (see our response to specific comments 13 and 15). Therefore, here we attribute the decreases in CO tracer transport to remote regions (Figure 8a and 8c) to the suppressed vertical transport and weakened westerlies at mid-latitudes. We have clarified this text in our revised manuscript.

"Further investigations on zonal wind suggest that an increase in SST over different oceans consistently decrease the westerly wind at lower mid-latitudes (25°N - 45 °N) in the Northern Hemisphere while increase it at higher latitudes (Figure 9). In general, increases of the geopotential height induced by basin-scale SST warming are more significant at mid-latitudes than other latitudes, consistent with air temperature changes. Consequently, the meridional geopotential height gradient is decreasing at lower latitudes while increasing at higher latitudes, leading to corresponding changes in the

westerly wind. The latitude band 25°N - 45 °N covers many polluted regions (i.e., North America and East Asia). A weakened westerly wind may reduce O_3 long-rang transport. As demonstrated in Section 4.3, the basin-scale SST increases also exert negative effects on upward transport of air mass at mid-latitudes. Therefore, the decreases in CO tracer over downwind regions (Figure 8a and 8c) can be explained by both suppressed vertical transport and weakened westerly wind."

20) Line 435- "90% of surface O3"- first mention of this in the text.

Thanks for pointing out this. We have rephrased this in the revised manuscript.

"Specifically, the photochemical production changes account for most of surface O_3 increase over North America in response to the North Atlantic SST warming, but exert a negative effect on South Asia in response to the North Indian SST warming."

Minor comments:

1) Line 49- it would be useful to state why ground-level ozone affects food security. Also it would be useful to provide a more up to date reference than 2006 for WHO.

Good suggestion! We have specified the ground-level ozone effects on human health and food security. We have also provided more recent references:

"High ground-level ozone (O_3) concentrations adversely impact human health through inducing respiratory diseases, and threaten food security by lowering crop yields (Brown and Bowman, 2013;Organization, 2013;Chuwah et al., 2015)."

2) Line 54- again can the authors use a more recent reference than Vingarzan et al. 2004.

We have added several more recent references here

"These precursors originate from both natural and anthropogenic sources (Vingarzan, 2004;Simon et al., 2014; Jiang et al., 2016)."

3) Line 66- an enhanced description of what is meant by atmospheric circulations would be useful e.g. Barnes and Fiore (2013) specifically discuss the effect of the Jetstream in

the northern midlatitudes at 500 hPa. Other processes to mention are mid-latitude cyclones and the North Atlantic Oscillation for the N. Atlantic. Some further useful references include: Creilson et al. 2003; Christiadios et al. 2012; Knowland et al. 2014. Line et al. (2012/14) and references therein are useful for circulations relating to atmospheric circulations in the N. Pacific.

Creilson, J. K., Fishman, J., and Wozniak, A. E.: Intercontinental transport of tropospheric ozone: a study of its seasonal variability across the North Atlantic utilizing tropospheric ozone residuals and its relationship to the North Atlantic Oscillation, Atmos. Chem. Phys., 3, 2053–2066, doi:10.5194/acp-3-2053-2003, 2003

Christoudias, T., Pozzer, A., and Lelieveld, J.: Influence of the North Atlantic Oscillation on air pollution transport, Atmos. Chem. Phys., 12, 869–877, doi:10.5194/acp-12-869-2012, 2012 Knowland, K. E., Doherty, R. M., and Hodges, K. I.: The effects of springtime mid-latitude storms on trace gas composition determined from the MACC reanalysis, Atmos. Chem. Phys., 15, 3605-3628, doi:10.5194/acp-15-3605-2015, 2015.

Good suggestion. These references are valuable and closely related to our work. We have cited them and expanded our introduction with more detailed descriptions.

"Atmospheric circulation considerably determines the timescale and pathway of O_3 transport (Bronnimann et al., 2000;Auvray and Bey, 2005;Hess and Mahowald, 2009;Pausata et al., 2012;Barnes and Fiore, 2013). The efficiency of O_3 transport varies coherently with atmospheric circulations in different scales. Knowland et al. (2015) have demonstrated the important role of mid-latitude storms in redistributing O_3 concentrations during springtime. The North Atlantic Oscillation (NAO) significantly affects surface and tropospheric O_3 concentrations over most of the Europe through influencing the intercontinental transport of air mass (Creilson et al., 2003;Pausata et al., 2012;Christoudias et al., 2012). Lamarque and Hess (2004) indicated that the Arctic Oscillation (AO) can modulate springtime tropospheric O_3 burdens over North America. The shift of jet stream position associated with climate change are found to strongly affect summertime surface O_3 variability over eastern North America(Barnes and Fiore, 2013)."

4) Line 79- what is meant by "SST is an indicator for both marine and terrestrial meteorology"?

Here we want to emphasize the important role of SST played in the climate system. The SST anomalies have been widely used to indicate the climate variability and have great implications for climate predictions. We have rephrased this in the revised manuscript:

"Sea surface temperature (SST) is an important indicator characterizing the state of the climate system."

5) Line 83- perhaps the reference to the text book is unnecessary.

We agree that the reference to the text book is unnecessary here and have removed it.

6) Line 87- some recent references from the IPCC AR5 report will be relevant here.

We have updated our references with more recent studies.

"A number of studies have shown that SST changes over different oceans and latitudes lead to significant different meteorological sensitivities and climate responses (Webster, 1981;Lau and Nath, 1994;Lau, 1997;Sutton and Hodson, 2007;Sabeerali et al., 2012;Ueda et al., 2015)."

7) Line 92- it would be more useful to the reader to refer to the specific chapter in IPCC AR5- the science of climate change that discusses SST changes rather than broadly reference the IPCC synthesis report.

Good suggestion! We have changed our reference to the Chapter 2 in IPCC AR5:

"SSTs are generally increasing due to the impacts of anthropogenic forcings on global climate change (IPCC, 2013, Chapter 2)."

8) Line 102- is "according to observations" needed?

We agree that it is an unnecessary description here and has removed it in our revised manuscript.

"The North Atlantic Ocean pronounces various modes of low-frequency SST variability (Kushnir, 1994;Wu and Liu, 2005;Fan and Schneider, 2012;Taboada and Anadon, 2012)."

9) Line 105 "Emissions of aerosols.. complicate regional SST variability because of their climate effects"- this sentence is unclear.

Here we state that regional SST can be significantly influenced by the aerosol and GHGs emitted from anthropogenic and natural sources through modulating the solar radiation at an oceanic surface. These processes may contribute to the SST variability, especially in the regional scale. For example, the responses of SST to volcanic eruptions have been identified to vary between regions. We have clarified these sentences in the revised manuscript.

"…Aerosols and greenhouse gases (GHGs) emitted from anthropogenic and natural sources also contribute to regional SST variability through modulating the solar radiation received by the oceanic surface (Rotstayn and Lohmann, 2002;Wu and Kinter, 2011;Hsieh et al., 2013;Ding et al., 2014;Meehl et al., 2015)."

10) Line 113- besides Lin et al. 2014, Liu et al. (2005) is also a valuable reference here in relation to ENSO and pollution transport from East Asia. Liu, J., D. L. Mauzerall, and L. W. Horowitz (2005), Analysis of seasonal and interannual variability in transpacific transport, J. Geophys. Res., 110, D04302, doi:10.1029/2004JD005207.

Good suggestion. Liu et al. (2005) evaluated the meteorological component of the seasonal and interannual variability of transpacific transport. It is a valuable reference that relates the transpacific pollution transport to ENSO. Their analysis is mainly based on idealized tracer with constant emissions and chemical lifetimes. This finding has valuable implication for the ENSO effects on O_3 long-rang transport. We have discussed it in our revised manuscript.

"Liu et al. (2005) revealed that El Niño winters are associated with stronger transpacific pollutant transport, which also has implications for the long-range transport of O_3."

11) Line 119- it would be useful to first discuss the surface ozone response for the specific ocean basin relative to the experiment and then discuss effects on surrounding continents. The four continental regions used in Fiore et al. (2009) and elsewhere should be defined here, as they are used throughout the text.

Good suggestion. We agree that it is beneficial to provide some discussion about the surface O_3 changes above ocean basins associated with regional SST anomalies. We have added some descriptions and explanations about those effects. The relevant table and figure are placed in the supplementary material. Please refer to our reply to major comment 3 for details. The major focus of this study is on the responses of surface O_3 over polluted continents to regional SST changes. The surface O_3 levels over these regions are much higher than remote oceans, which may negatively impacts human health and threatens food security. This SST-O_3 relationship over the populated continents may help air quality management. We have also clearly defined the four continental regions in the revised manuscript.

"To fill this gap, this study focuses on examining O_3 formation over four polluted continental regions in the Northern Hemisphere (i.e., North America (NA, 15°N–55 °N; 60°W–125°W), Europe (EU, 25°N–65 °N; 10°W-50 °E), East Asia (EA, 15 °N–50 °N; 95°E–160 °E) and South Asia (SA, 5 °N–35 °N; 50 °E–95°E), defined in Fiore et al. (2009)), and its response to nearby basin-scale SST changes."

12) Line 157 typo- AEROCOM

Thanks for catching this typo. We have corrected it.

"Anthropogenic emissions of chemical species are from the IPCC AR5 emission datasets (Lamarque et al., 2010), whose injection heights and particle size distributions follow the AEROCOM protocols (Dentener et al., 2006)."

13) Line 161 – "scientifically" is unnecessary.

We have removed this unnecessary description.

"The performance of CESM in simulating tropospheric O_3 has been validated by comparing with ozonesonde and satellite observations (Tilmes et al., 2014)."

14) Line 251- "similar increases in VDIF" compared to?

We have clarified this in the revised manuscript.

"In the "Atlantic-W" run, increases in VDIF are also observed over the upwind regions (i.e., North America) in JJA."

15) Line 273- explain how net production rate in this section related to CHEM in the previous section.

Good question. The CHEM refers to the net cumulated contributions of the chemical production and loss of O_3 during a specific period. The net production rate is calculated by chemical production rate minus loss rate of O_3. Therefore, the CHEM and net-production rate are consistent with each other but indicate the O_3 change at different timescale. We have clearly defined these two variables in our revised manuscript.

In Section 2.3:

"Wet deposition and aqueous-phase chemistry are ignored here due to the low solubility and negligible chemical production of O_3 in water (Jacob, 1999). Therefore, CHEM represents the net production (production minus loss) rate of O_3 due to gas-phase photochemistry."

In Section 4.2:

"Changes in net-production rate (i.e., chemical production rate minus loss rate) of O_3 at the surface in JJA associated with basin-scale SST increases are shown in Figure 3."

16) Line 305 – rephrase "jointly destructs O3 production".

We have rephrased this:

"In addition, over South Asia, a warming of the North Indian Ocean decreases solar radiation and air temperature, and simultaneously increases air humidity, which jointly exert negative effects on O_3 production there."

17) Lines 320-323, "Given that . . .)." This sentence contains a number of grammar errors. The following sentence starting line 323 seems to state that the pressure difference induced by warmer SSTs would be greater at lower latitude but notes this is not shown here in Figure 5. Please comment further on this or remove.

Thanks for pointing out this problem. We have revised this sentence to correct grammars errors. We also linked the warmer SST directly to the enhanced upward motion instead of the surface pressure changes (as showed in Figure 6). Please see the revised text in Section 4.3 or below:

"Previous studies have identified a SST threshold (about 26°−28°C) to generate deep convection (Graham and Barnett, 1987;Johnson and Xie, 2010). Therefore, the sensitivity of deep convection to a SST anomaly is strongly dependent on the distribution of base SST. As depicted in Figure 6, the enhanced upward motion in response to a uniform increase in basin-scale SST mainly happens over regions with high climatological SST. Regions with a low climatological SST have little effects on vertical movement of air mass."

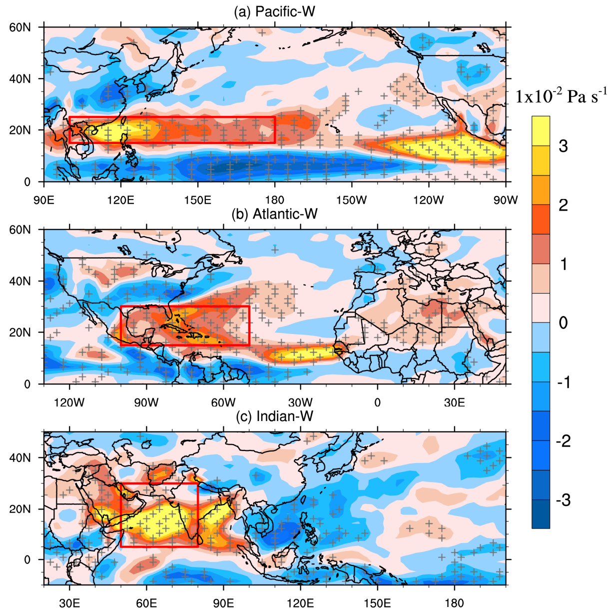

Figure 6. The spatial pattern of vertical velocity changes at 500 hPa (color contours, 1×10^{-2} Pa s^{-1}) for (a) Pacific-W, (b) Atlantic-W, and (c) Indian-W relative to CTRL in boreal summer. Positive values indicate upward motion. Red polygons denote the regions where the surface pressure responses to SST anomalies are significant (see Figure 5 a-c). The + symbols indicate areas where results are significant at the 0.05 level as evaluated with a Student t-test using 20 years of data.

18) Line 363- Mediterranean?

As shown in Figure 5, the warming of the North Indian SST leads to a low-pressure anomaly that spreads to the Saudi Arabia and eastern Mediterranean. However, its effects on the Europe has proved to be insignificant (as shown in Table 1). To avoid confusion, we revised this sentence in Section 4.3 and confined our analysis to the Indian Ocean and the Indian Subcontinent.

"The North Indian SST warming leads to a low-pressure anomalies centered over the Arabian Sea (Figure 5c)."

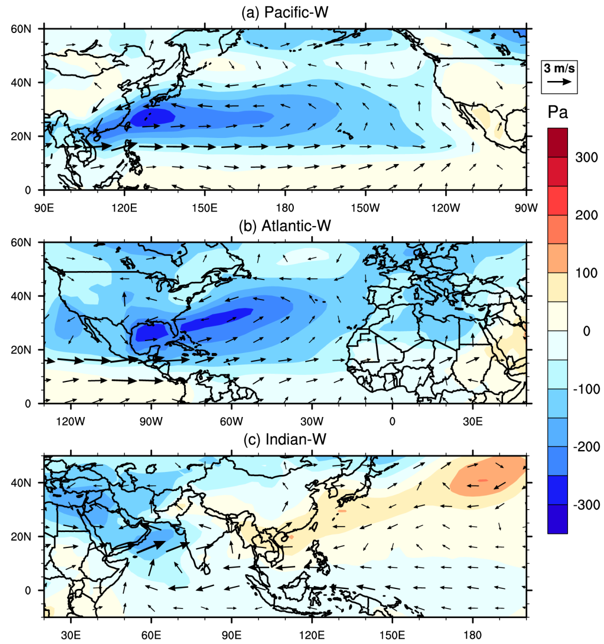

Figure 5. Changes in surface pressure (color contours, Pa) and 850 hPa wind (arrows, m/s) for (a) Pacific-W, (b) Atlantic-W, and (c) Indian-W relative to CTRL in boreal summer.

19) Line 367-"Downward diffusion from the upper troposphere"- please clarify what is meant here as this is not a region of STE.

According to the IPR analysis, we find that the surface O_3 increase over the Indian Ocean associated with North Indian warning is mainly attributed to the enhanced vertical transport of O_3 to the surface through deep convection and vertical diffusion processes (Figure S11). It is not related to the STE. We have clarified this in Section 4.3 of our revised manuscript.

"...According to the IPR analysis, the surface O_3 increase over the Indian Ocean is mainly caused by the enhanced vertical transport of O_3 to the surface through deep convection and vertical diffusion processes (Figure S11)."

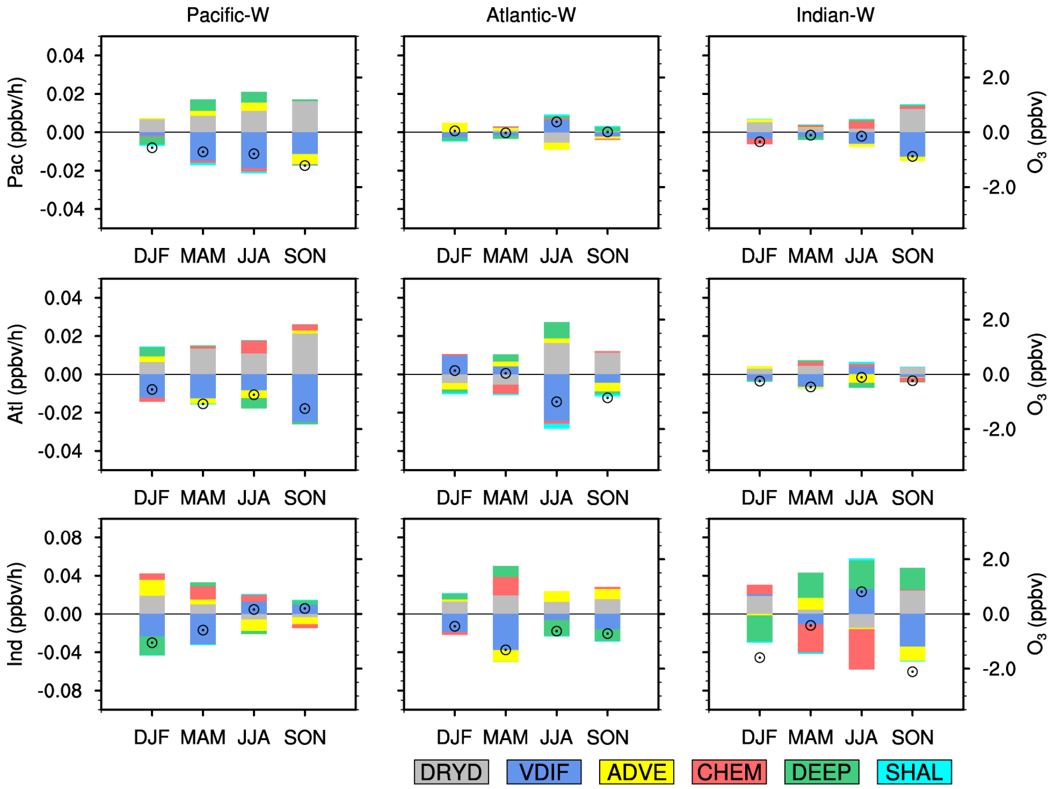

Figure S11. Seasonally averaged changes in IPR contributions (bars, ppbv/h, left scale) and surface O_3 concentrations (hollow circles, ppbv, right scale) for Pacific-W (left), Atlantic-W (middle) and Indian-W (right) relative to CTRL. Values are regionally averaged over North Pacific (demoted as Pac, first row), North Atlantic (demoted as Atl, second row) and North Indian Ocean (demoted as Ind, third row) defined in our study, respectively. IPR contributions from six processes (i.e., gas-phase chemistry (CHEM), advection (ADVE), vertical diffusion (VDIF), dry deposition (DRYD), shallow convection (SHAL) and deep convection (DEEP)) are represented by different colors.

20) Line 374- why only at mid-latitudes? Figure S3 shows large temperature increases in temperature above all 3 basins.

Good question. As we have discussed in Section 4.3, the SST warming over a specific ocean basin tends to enhance the deep convection over tropical oceans. Strengthened deep convection further trigger large-scale subsidence over other areas through modulating large-scale circulations, which may suppress air convective movement there (Lau et al., 1997;Roxy et al., 2015;Ueda et al., 2015). As depicted in Figure S23, decreases of upward vertical velocity are significant over mid-latitudes and other oceans. As shown in Figure S16, the warming of air temperature are more significant over free troposphere at mid-latitudes, which leads to a remarkable decrease in the vertical air temperature gradient. This weakens vertical movement of air pollution.

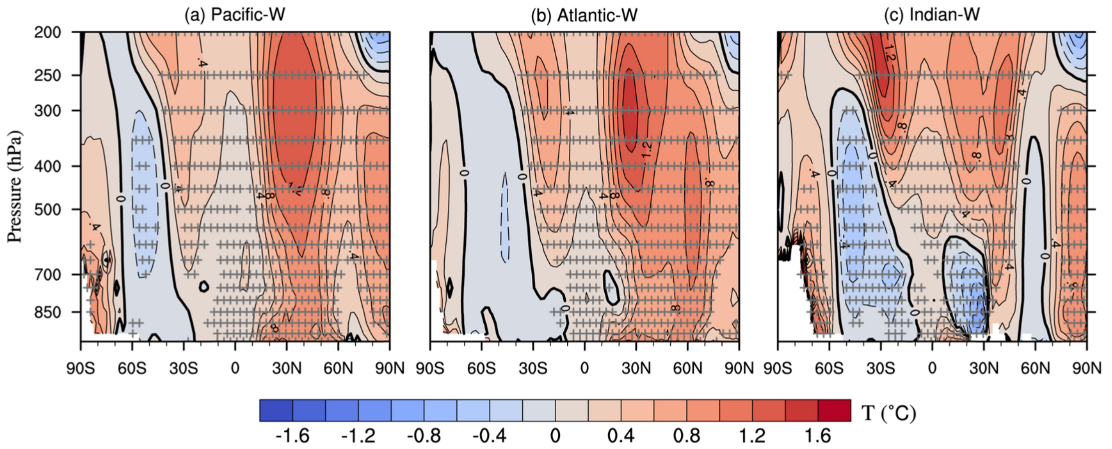

Figure S16. Vertical-meridional distributions of air temperature differences (contours, ºC) between (a) Pacific_W (zonally averaged from 100°E-90°W) (b) Atlantic_W (100°W-180°W) (c) Indian_W (30°E-100°E) and CTRL in boreal summer. Black solid and dashed lines in the contours indicate positive and negative air temperature anomalies, respectively (contour interval: 0.2 ºC).The + symbol denotes areas where the changes of air temperature are significant at the 0.05 level evaluated with a Student t-test.

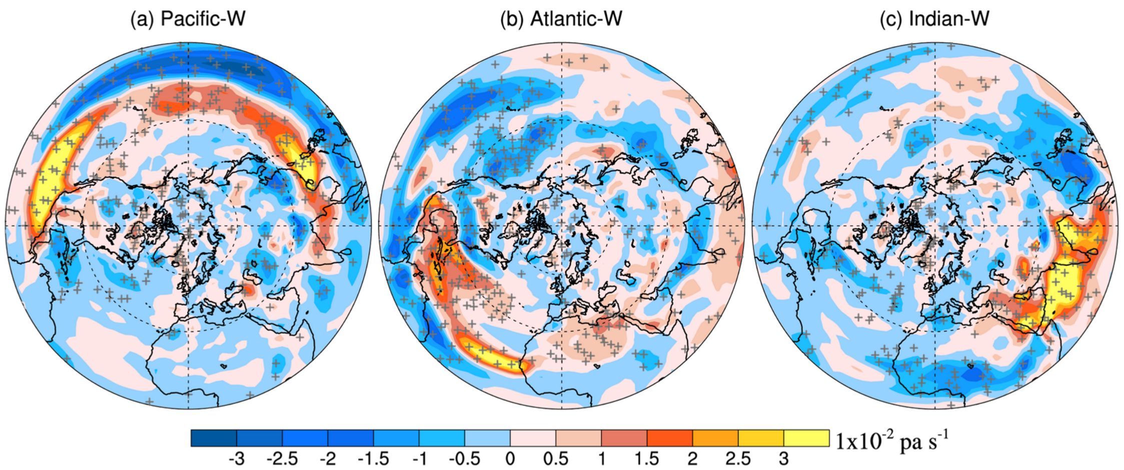

Figure S23. The spatial pattern of vertical velocity changes at 500 hPa (color contours, 1x10^{-2} Pa s^{-1}) for (a) Pacific-W, (b) Atlantic-W, and (c) Indian-W relative to CTRL in boreal summer. Positive values indicate upward motion. The + symbols indicate areas where results are significant at the 0.05 level as evaluated with a Student t-test using 20 years of data.

21) Line 439/line 440 – rephrase "increasing influence on surface O3 concentrations" as this is confusing e.g. regional surface ozone over SA decreases under the Indian W simulation.

We have rephrased this sentence in Section 6.

"Decrease in convective transport of O_3 to the surface is significant over South Asia associated with North Indian warming, which exerts a negative influence on surface O_3 concentrations."

22) Line 465 – natural variability is not discussed in this paper (although used for significance testing so it is odd to mention here).

The natural variability mentioned here is referred to the variability existed in the SST. As we have discussed in the Introduction section, regional SST exhibits natural periodic or irregular oscillations with timescales ranging from months to decades. In this study, we used idealized SST anomalies to generally compare the role of SST over different oceans in modulating the surface O_3 distributions. Our results highlight the sensitivity of the surface O_3 distribution to basin-wide SST changes. To provide a more realistically understanding of this SST-O_3 relationship, further studies are necessary and realistic SST variability should be taken into account. We have rephrased the relevant sentences in our summary section for clarification.

"Overall, our study highlights the sensitivity of O_3 evolution to basin-wide SST changes in the Northern Hemisphere and identifies the key chemical or dynamical factors that control it. However, to provide a more comprehensive understanding of the SST-O_3 relationship, further studies using realistic SST variability are necessary. This may help the management of O_3 pollution by considering the influence of specific SST variability."

23) Figure 6 refers to Figure 7 re surface pressure- should the reference be to Figure 5?

Thanks for pointing out this mistake. We have corrected the caption of Figure 6.

***"Figure 6**. The spatial pattern of vertical velocity changes at 500 hPa (color contours, $1x10^{-2}$ Pa s^{-1}) for (a) Pacific-W, (b) Atlantic-W, and (c) Indian-W relative to CTRL in boreal summer. Positive values indicate upward motion. Red polygons denote the regions where the surface pressure responses to SST anomalies are significant (see Figure 5 a-c). The + symbols indicate areas where results are significant at the 0.05 level as evaluated with a Student t-test using 20 years of data."*

24) Figure 7 – swap panels b) and c) to be consistent with text.

We have corrected this in the Figure 7.

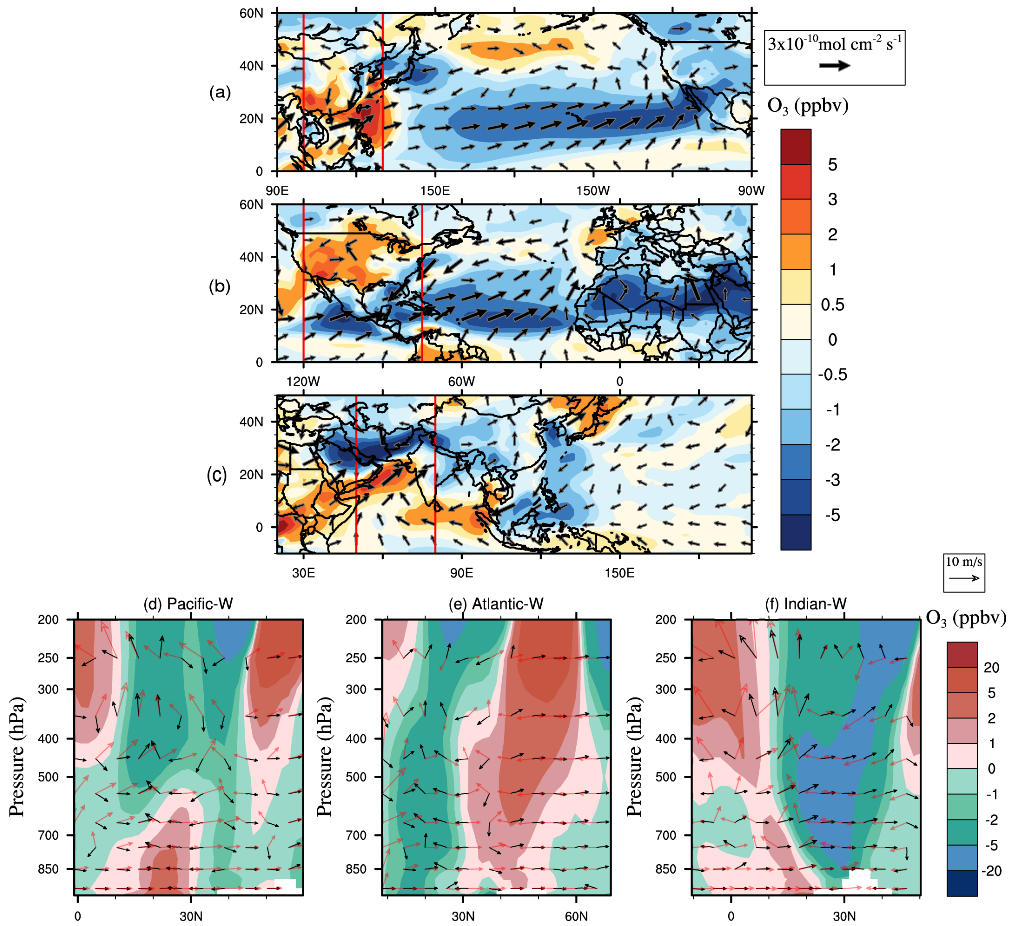

Figure 7. Top three rows: Changes in O_3 concentrations (color contours, ppbv) and horizontal fluxes (arrows, mol cm^{-2} s^{-1}) at the surface level for (a) Pacific-W, (b) Atlantic-W, (c) Indian-W relative to CTRL in boreal summer. Last row: zonally average of tropospheric O_3 changes (color contours, ppbv) and wind fluxes in CTRL (red arrows, m/s) and its perturbation (black arrows, m/s) in (d) Pacific-W, (e) Atlantic-W, (f) Indian-W relative to CTRL in boreal summer. The red rectangles in (a), (b) and (c) denote the longitudinal range used for zonal average in (d), (e) and (f), respectively. The vertical wind velocity is amplified 1000 times to make it comparable to horizontal wind velocity.

25) Figures 8, 9, S3: the season is omitted from the figure caption.

Thanks for pointing out these errors. These figures are all referring to boreal summers. We have revised the captions of these figures and clarified the relevant season:

*“**Figure 8**.Left-hand panel: the difference in surface concentration (ppbv) of a CO-like tracer emitted from (a) East Asia for Pacific-W, (c) North America for Atlantic-W and (e) South Asia for Indian-W relative to CTRL in boreal summer. Right-hand panel: the percentage changes in surface concentration of a CO-like tracer emitted from (b) East Asia for Pacific-W, (d) North America for Atlantic-W and (f) South Asia for Indian-W relative to CTRL in boreal summer. Red polygons denote the region where the CO-like tracer emitted from. The + symbol denotes areas where the results are significant at the 0.05 level evaluated with a Student t-test.”*

*“**Figure 9.** Zonally averaged changes in zonal wind (color contour, m/s) and geopotential height (contour, m) for (a) Pacific-W, (b) Atlantic-W and (c) Indian-W relative to CTRL in boreal summer. Black solid and dashed lines in the contours indicate positive and negative geopotential height anomalies, respectively (contour interval: 5 m). The + symbol denotes areas where the zonal wind changes are significant at the 0.05 level evaluated with a Student t-test.”*

*“**Figure S16.** Vertical-meridional distributions of air temperature differences (contours, ºC) between (a) Pacific_W (zonally averaged from 100°E-90°W) (b) Atlantic_W (100°W-180°W) (c) Indian_W (30°E-100°E) and CTRL in boreal summer. Black solid and dashed lines in the contours indicate positive and negative air temperature anomalies, respectively (contour interval: 0.2 ºC).The + symbol denotes areas where the changes of air temperature are significant at the 0.05 level evaluated with a Student t-test.”*

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