Responses to Referees

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Title: The Relationship between Lower Stratospheric Ozone in the Southern High Latitudes and Sea Surface Temperature in the East Asian Marginal Seas in Austral Spring

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Response to Referee 1

This is the second review of this manuscript. The authors have made significant improvements. I especially appreciated their efforts to include satellite observations into the analysis. This addition indeed strengthen the paper. I have a few minor comments for the authors to consider.

Response: We thank again the reviewer for the helpful comments and valuable suggestions to improve the manuscript. We have revised the manuscript according to the reviewer's comments and suggestions. The detailed point-to-point responses to the reviewers' comments are listed as follows.

P10 L10-11: please consider reword this sentence.

P10 L13-14: "it is first necessary to confirm the causality of this connection". I don't see anything in the following text that can confirm the causality.

Response: Thanks for the comments. In our first version of the manuscript, there is a lead-lag correlation figure to confirm the causality of connection between **monthly** Antarctic stratospheric ozone and SST variations. In our second version, we only focus on investigating the connection in austral spring (**three-month average**). There is no better way to calculate the lead-lag correlation. However, the causality of the connection can be indirectly confirmed by the model simulations presented in the section 4 of the manuscript. Thus, we deleted the lead-lag correlation figure in the second version. The lines 10-14 in page 10 in the manuscript are also redundant, which are deleted in the revised manuscript.

P12 L3-5: I don't quite follow the logic here. Why wave rays refracting to lower latitudes implies upward propagation?

Response: Thanks for the comment. The sentence is a bit confusing. We have deleted the sentence "implying that the pathway of upward propagation of tropospheric waves from the marginal seas of East Asia possibly extends to 60 °S".

Fig. 5: Can you compare the teleconnection pattern with the climatology, especially the lower wavenumber components? The interference of the teleconnection pattern and the climatological eddies might explain the connection between the SST over East Asian Marginal Seas and the wave anomalies in the Southern Hemisphere, which remains unclear in the current manuscript. Similar mechanism is used to explained the connection between ENSO and northern polar vortex by Garfinkel and Hartmann (2008).

Response: Thanks for the important comment. This comment well helps us explain the connection between the SST over East Asian Marginal Seas and the wave anomalies in the Southern Hemisphere.

Following the Garfinkel and Hartmann (2008), Figure R1 shows the replotted Figure 5 in the manuscript, in which the climatological wave 1 in each season is overploted. It is apparent that positive/negative correlation coefficients correspond to positive/negative climatological wave 1 phases over Indo-Pacific warm pool but negative/positive climatological wave 1 phases in the middle and high latitudes of Southern Hemisphere in austral spring (Fig. R1a). The results in Fig. R1 implies that warm/cold SST events over East Asian Marginal Seas would increase/decrease the planetary wave activity at lower latitudes but decrease/increase the planetary wave activity at middle and high latitudes of Southern Hemisphere. The replotted Fig. 5 is in well agreement with the results in the study.

Above points have added and the reference has been cited in the revised paper.

Reference:

Garfinkel, C. I., and D. L. Hartmann, 2008: Different ENSO teleconnections and their effects on the stratospheric polar vortex, JGR, 113, D18114, DOI: 10.1029/2008JD009920.

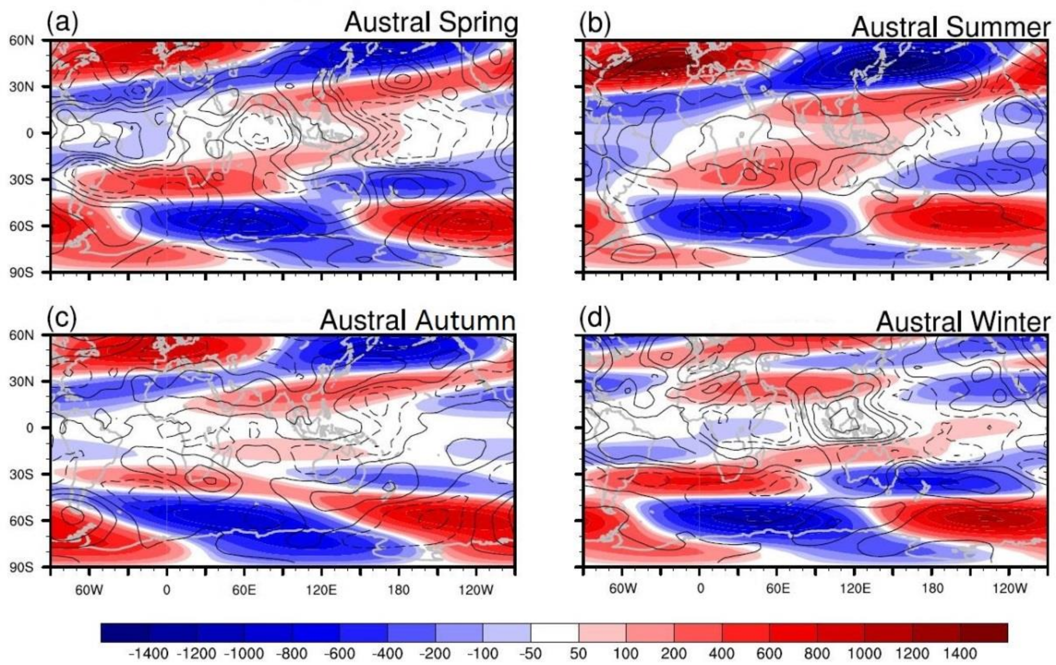

Figure R1. Correlation coefficients between the ST_MSEAI and 300-hPa geopotential height (contour level) associated with stationary waves of wavenumber 1 (color) from the ERA-Interim reanalysis in (a) austral spring, (b) austral summer, (c) austral autumn, and (d) austral winter between 1979 and 2015. Only statistical significance above 95% confidence level is colored. The seasonal cycles and linear trends were removed before calculating the correlation coefficients.

P12 L21-24: I suggested looking at OLR last time because the authors suggested the anomalous waves are generated from convection, and OLR is an index for convection. I don't think OLR can represent "generated wave activity". It is not clear to me what Fig. 6 intend to show.

Response: Thanks for the comment. The term is a bit misleading. The OLR can represent convective activity in the lower latitudes, while stronger convective activity often corresponds to enhanced wave activity. The text is rephrased in the revised text.

P13 L21-22: I don't see how Figs. 4 and 5 show that warm SST depress planetary wave activity.

Response: Thanks for the comment. Figure 5 is replotted in the revised paper following the above comment, which implies that warm SST anomalies depress planetary wave activity now.

P14 L17: It may be clearer to point out that the climatological v is negative (southward) in the Southern Hemisphere, so that a positive correlation with SST indicates a weakening of the stratopheric circulation associated with SST warming. It is also not clear whether the authors are referring to the negative correlations poleward of 60S or the positive correlation centered at 30S.*

Response: Thanks for the comments. The first point of the reviewer has been added in the revised manuscript following referee’s suggestion. For the second comment, the relevant text is rephrased as “are positively correlated with lower stratospheric TEM v* between 30 °S and 60 °S”.

P16 L2: “stronger convergence of the EP flux” It should be weaker wave breaking (convergence of EP flux).

Response: Thanks for your careful check. It should be “stronger divergence of the EP flux”. Corrected.

P16 L19-21: It seems from Fig. 11 that correlation with v is opposite below and above 20 hPa, while polar vortex does not show such dependence on height. It also looks quite different from the reanalysis (Fig. 7d). Can you comment on that? Also, since ozone concentration is higher above 20 hPa, I expect that the horizontal transport by v* above 20 hPa is more important than that below 20 hPa. Then we see more southward v* across 60S during the warm events, bringing more ozone from mid-latitues into the polar region, which is opposite to what is stated here.*

Response: Thanks for the comment. Figure R2 combines the Figure 7d and Figure 11a of the manuscript. See the red color between 60 °S and 0 and blue color between 60 °S and 90 °S in Fig. 7d (Fig. R2a) and Fig. 11a (Fig. R2b), the patterns in the two figures are actually very similar. It needs to point out that the positive center below 50 hPa near 60 °S in Fig. 11a (Fig. R2b) is more southward than that in Fig. 7d (Fig. R2a). It makes the correlations below and above 20 hPa in Fig. 11a (Fig. R2b) seem to be opposite. The difference between Fig. R2a and R2b may be because the simulated polar vortex isn’t completely same with observations.

In Fig. 11a (Fig. R2b), there are different responses of v* below and above 20 hPa at 60°S to SST anomalies over the East Asian Marginal Seas in simulations. It may be because the changes of v* below 20 hPa mainly caused by SST-induced polar vortex anomalies while v* variations above 20 hPa result from SST-induced BD circulation anomalies.

At lines 19–21of page 16, we mainly discuss the dynamical transport blow 50 hPa where is the region this study focusing on. We have clarified this information in the revised paper. Stronger southerly v* at 60°S above 20 hPa during the SST warm events (Fig. R2b) would bring more ozone from mid-latitudes into the South Pole at upper stratosphere. See the Figure R3 (it is Figure 7a in the revised manuscript), the ozone above 20 hPa at South Pole is indeed increased during the SST warm events which is associated with the Fig. 11a (Fig. R2b).

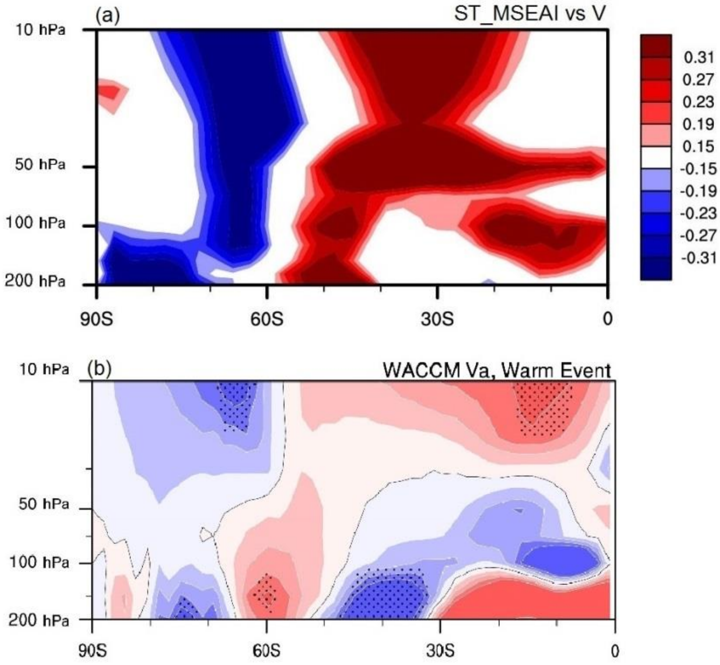

Figure R2. A combination of Figure 7d (a) and Figure 11a (b) of the manuscript. (a) Correlation coefficients between ST_MSEAI and zonal mean TEM v* in austral spring (the southward climatological TEM v* is negative). The seasonal cycles and linear trends were removed before calculating the correlation coefficients. (b) Zonal mean TEM meridional wind (m s^{-1}) anomalies caused by SST warm events in the East Asian Marginal Seas in austral spring from simulations. Only statistical significance above 95% confidence level is colored.

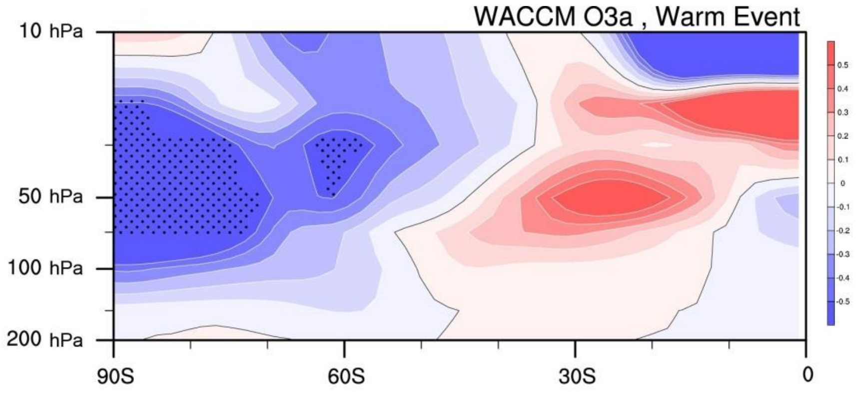

Figure R3. Zonal mean differences in ozone (ppmv) in austral spring during the SST warm events by WACCM simulations

P38 Table4: Can you also list trends from T2 and T3, separately? This will give readers a sense how large the internal variability may be and how variable the 17% is.

Reponse: Thanks for the comment. The two trends have been added in Table 4 as below:

Table 4. Linear trends of ozone variations over the region 200–50 hPa and 60–90°S from experiments with (T1) and without SST (T2 +T3) variations in the East Asian Marginal Seas (T1–3 see Table 3).

Experiments	Values
Linear trend of ozone variations over the region 200–50 hPa and 60–90°S from T1 (Trend1)	-1.2×10^{-3} ppmv/month**
Same as Trend1, but from T2 (Trend 2)	-1.0×10^{-3} ppmv/month*
Same as Trend1, but from T3 (Trend 3)	-0.89×10^{-3} ppmv/month*
Same as Trend1, but from (T1 – (T2+T3)/2) (Trend1_23)	-0.2×10^{-3} ppmv/month*

**: the trend is significant at 99% confidence level. *: the trend is significant at 95% confidence level. The calculation of the statistical significance of the trend uses the two-tailed Student’s *t*-test.

P45 L3: “meridional wind” I thought you are using TEM v.*

Response: Revised. Thanks.

P52 Fig. 14: Change the label to "-SST" or reverse the labels on the left y-axis so that negative values are at the top and positive values are at the bottom.

Response: Figure 14 is replotted as below Figure R4 following the comment. Thanks.

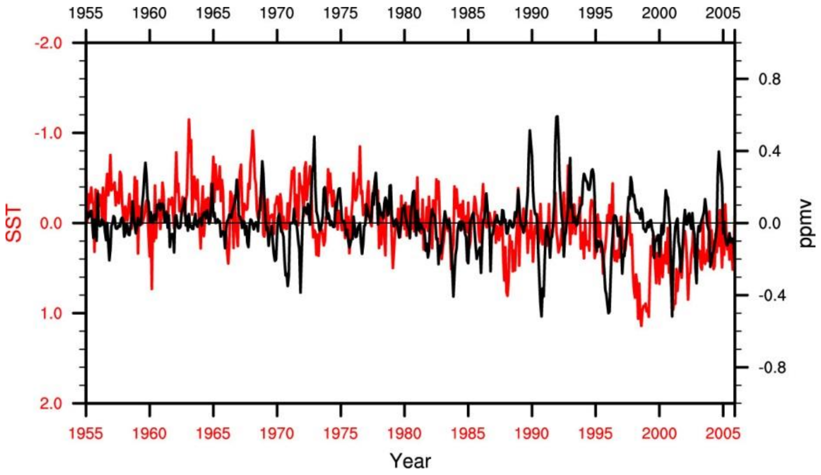

Figure R4. The difference in southern high latitude lower stratospheric ozone variations between T1 and (T2+T3)/2) (black line) and SST variations in the marginal seas of East Asia (5°S–35°N, 100°E–140°E) based on the HadISST data (red line). The seasonal cycle is removed from two time series.

Response to Referee 2

This revision has addressed the questions in my earlier review. There are some minor issues.

Response: We thank the reviewer again for the very helpful comments, which have helped us to greatly improve our paper. We have revised the manuscript carefully according to the reviewer's comments and suggestions.

1. Figure 3, the color bar is missing.

Response: Added, thanks.

2. Figure 1, label ozone molecules in the y-axis using subscripts.

Response: Revised, thanks.

3. The authors answered a question related to the original Figure 4 but the figure was removed in this version, why?

Response: Thanks for the comments. In our first version of the manuscript, there is a lead-lag correlation figure to confirm the causality of connection between **monthly** Antarctic stratospheric ozone and SST variations. In our second version, we only focus on investigating the connection in austral spring (**three-month average**). There is no better way to calculate the lead-lag correlation. However, the causality of the connection can be indirectly confirmed by the model simulations presented in the section 4 of the manuscript. Thus, we deleted the lead-lag correlation figure in the second version. The lines 10-14 in page 10 in the manuscript are also redundant, which are deleted in the revised manuscript.

4. Figure 1 shows a time series of ozone variations, removing seasonal cycles and linear trends in MERRA2, SLIMCAT, GOZCARDS and SWOOSH. May the original and absolute ozone concentrations from these data sets be shown, as also asked by *the other reviewer?*

Response: Thanks for the comment. Since this study only focuses on austral spring, the Figure 1a is replaced by the variations of original ozone concentrations in austral spring from these four datasets (See Figure RR1 below). We can see the original ozone concentrations from MEERA2 and SLIMCAT are somewhat lower than that from the GOZCARDS and SWOOSH (Fig. RR1a); however, the variabilities of ozone concentrations from these four datasets are similar (Fig. RR1b).

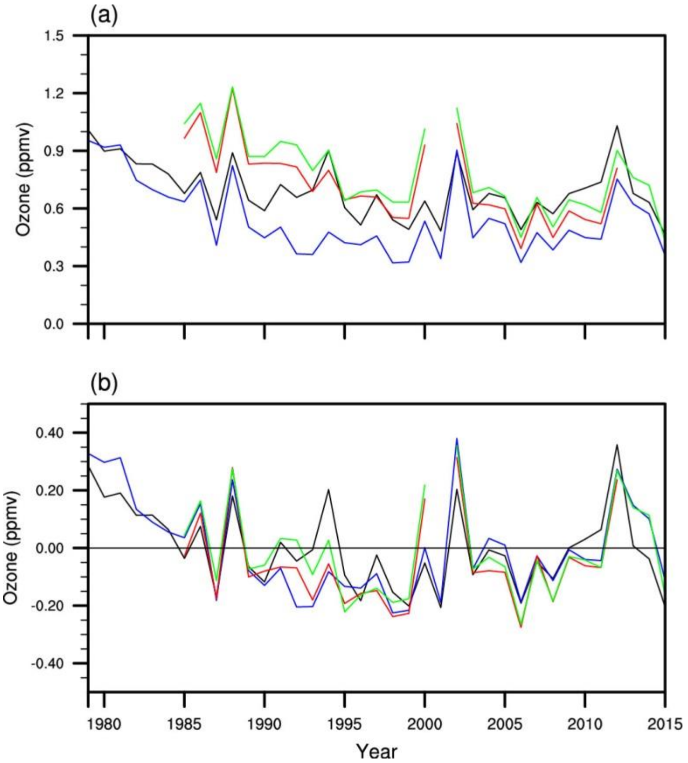

Figure RR1. (a) Time series of original and absolute ozone concentrations at southern high latitude lower stratosphere averaged over the region 60–90 °S at 200–50 hPa in austral spring from the MERRA2 (black line), SLIMCAT (blue line), GOZCARDS (red line) and SWOOSH (green line) ozone datasets. (b), Same as (a), but the ozone variations are removed the seasonal cycles and linear trends.

5. The satellite datasets used in this study are based on SAGE, HALOE, ACE-FTS, and Aura MLS. Some of the data have no or very limited coverage in the southern polar region so the regional mean may not be extended to 90 °S. Please comment.

Response: Thanks for the comment. We calculate the correlation coefficients of ozone variations between averaged over 60–90 °S at 200–50 hPa and over 60–75 °S at

200–50 hPa from four datasets. Please see the below Table RR1. It is found that all these correlation coefficients are very large. It means that the results are not sensitive to the average latitude range.

Table RR1.

over 60–90 °S at 200–50 hPa vs	MERRA2	SLIMCAT	GOZCARDS	SWOOSH
over 60–75 °S at 200–50 hPa	0.82	0.80	0.87	0.89