Response to Referee2

Manuscript number: acp-2016-1053

Title: The Relationship between Lower Stratospheric Ozone in the Southern High Latitude and Sea Surface Temperature in the East Asia Marginal Seas

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Summary of changes for Referee2 and the Editor

We sincerely thank the reviewers for their important comments and the editor for their kind assistance with our manuscript. The major revisions are summarized as follows:

1. In the revised paper, we focus on investigating the relationship between lower stratospheric ozone in the southern high latitudes and sea surface temperature in the East Asian Marginal Seas **only** in austral spring. The title of the manuscript has been changed to “The Relationship between Lower Stratospheric Ozone in the Southern High Latitudes and Sea Surface Temperature in the East Asian Marginal Seas in Austral Spring”.

2. Using two kinds of satellite ozone data (SWOOSH and GOZCARDS) to investigate the relationship between lower stratospheric ozone in the southern high latitudes and sea surface temperature in the East Asian Marginal Seas. The results are in good agreement with those from the MERRA2 reanalysis and SLIMCAT output. This improves the confidence level of the ozone–SST relationship in our study.

3. The significance of the results from the WACCM4 outputs is tested.

In this study, the authors observed a correlation between sea surface temperature over East Asian Marginal Seas and ozone in the southern high latitude lower stratosphere (the targeted region) from assimilated MERRA data and a model simulation (SLIMCAT). Using the WACCM model (WACCM4) and a defined temperature index from the HadISST data, they separated warm and cold events over the East Asian Marginal Seas and found distinct differences between the two groups of the events in ozone concentrations in targeted region. The model simulation further reveals large differences,generally in the opposite directions, between the warm and clod events in dynamic and chemical conditions that modulate transport and formation/depletion of stratospheric ozone. Finally, the impact of such a connection on the ozone trend in the targeted region was quantified with a series of numerical experiments using WACCM4. The authors attributed 17% of decreasing ozone trend in the targeted region to increasing SST over the marginal seas of East Asia. The authors proposed a hypothesis that establishes the connection between SST variation over the marginal seas of East Asia and ozone in the targeted region (P12-13). The paper is well written in articulating the connection and explaining the hypothesis. The proposed connection is novel and important. I suggest that the authors use some additional datasets to confirm or adjust their proposal. These data include ozonesonde data (there are about 7 stations over the Antarctic region during different periods), the TOST data (the Trajectory-mapped Ozonesonde dataset for the Stratosphere and Troposphere), and satellite data (although satellite data quality usually decreases with latitude). For the long-term ozone trend over the targeted region, the ozone concentrations from MERRA, SLIMCAT should be compared with the WACCM simulation. More importantly, all simulated or assimilated data can be compared with observations so the estimated 17% contribution of increasing SST over the marginal seas of East Asia to the ozone trend in the targeted region can be confirmed or refined.

Response: We thank the reviewer for the positive evaluation of our study and we sincerely appreciate the reviewer's 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.

According to the referee's comment, the major revision is using the observed ozone to confirm the relationship between SST changes in the East Asian Marginal Seas and southern high latitude lower stratospheric ozone. Since the satellite ozone observations cover wider range compared with Ozonesonde data, we have added two types of satellite ozone data to investigate the relationship between the lower stratospheric ozone in the southern high latitudes and the sea surface temperature in the East Asian Marginal Seas. One is the Global OZone Chemistry And Related trace gas Data records for the Stratosphere (GOZCARDS) (Froidevaux et al. 2015) and the other is the Stratospheric Water and OzOne Satellite Homogenized (SWOOSH) ozone satellite data (Davis et al. 2016). The zonal mean satellite-based GOZCARDS is produced from high quality data from past missions (e.g., SAGE, HALOE data) as

well as ongoing missions (ACE-FTS and Aura MLS). Its meridional resolution is 10 ° with 25 pressure levels from the surface up to 0.1 hPa. The zonal mean SWOOSH dataset is a merged record of stratospheric ozone and water vapor measurements taken by a number of limb sounding and solar occultation satellites (SAGE-II/III, UARS HALOE, UARS MLS, and Aura MLS instruments). Its meridional resolution is 2.5 ° with 31 pressure levels from 300 to 1 hPa.

Figure RR1 shows the correlation coefficients between southern high latitude lower stratospheric ozone variations from the four ozone datasets and SST from HadISST in austral spring. It is apparent from Figure RR1 that the regions of significant correlation are generally different for the four ozone datasets except for the East Asian Marginal Seas; i.e., 5 °S–35 °N, 100 °E–140 °E, where the most significant correlations between Antarctic stratospheric ozone variations and SST are seen in all four ozone datasets. This result improves the confidence level of the ozone–SST relationship in our study.

Figure RR1 is Figure 2 in the revised paper.

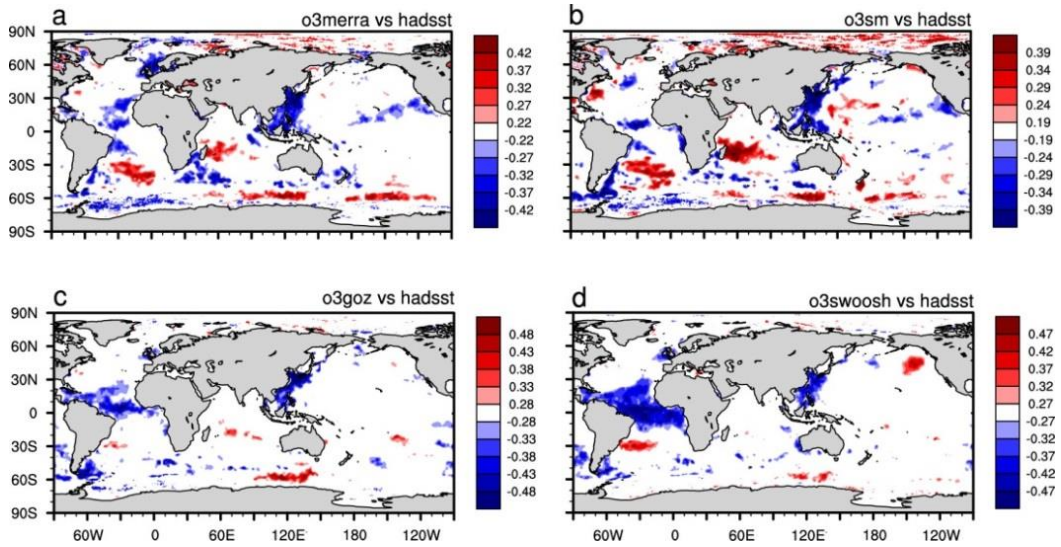

Figure RR1. Correlation coefficients between southern high latitude lower stratospheric ozone variations and SST from HadISST in austral spring. The ozone variations are averaged over the region 60–90 °S at 200–50 hPa in austral spring. (a) Ozone from MERRA2 and (b) ozone from SLIMCAT for 1979–2015. (c) Ozone from GOZCARDS for 1979–2012. (d) Ozone from SWOOSH for 1984–2015. Only regions with statistical significance above the 95% confidence level are colored; statistical significance is calculated using the two-tailed Student's *t*-test and the N^{eff} of DOF. The seasonal cycles and linear trends were removed prior to calculating the correlation coefficients.

References:

Davis S M et al. 2016, The Stratospheric Water and Ozone Satellite Homogenized (SWOOSH) database: A long-term database for climate studies, *Earth Syst. Sci. Data*, **8**, 461–490.

Froidevaux L et al. 2015, Global OZone Chemistry And Related trace gas Data records for the Stratosphere (GOZCARDS): methodology and sample results with a focus on HCl, H2O, and O3, *Atmos. Chem. Phys.* **15(18)**, 10471–10507.

The authors also looked into the seasonal variation of the proposed connection in some aspects (P13, L 20-22, Figures 5-6). Does removing the seasonal cycle enhance or smooth the signal of this connection? As some lags appear in the MERRA data (Figure 4), will the connection be more significant if the authors use monthly data with consideration of the lags?

Response: Thanks for the comment. In the analysis of Figure 6 of the original manuscript, the seasonal cycle had been removed. In line with the comment, Figure 6 has been replotted as Figure RR2. It is found that there is no obvious difference between the new figure and Figure 6.

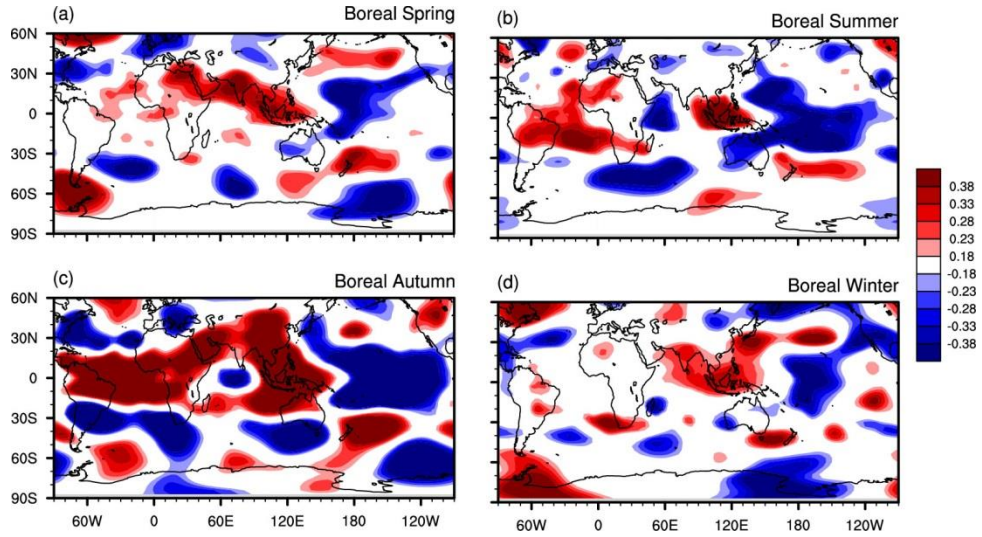

Figure RR2. Correlation coefficients between the ST_MSEA index and 300-hPa geopotential height in the four seasons. When calculating the correlation coefficient in one season, the ST_MSEA index is averaged over the first two months and the geopotential height averaged over the last two months. For example, when calculating the correlation coefficient in spring, the ST_MSEA index uses the average for March and April and geopotential height uses the average for April and May.

Specific

1. *P2, L2, no satellite data are directly used in this study.*

Response: Satellite datasets are added in the revised paper. Thanks.

2. *P3, L2, in this and other places (e.g., P7, L8-9, P16, L7-9), the authors stated similar sentences like "Ozone variations over recent decades exhibit a strong decreasing trend. . .". This may be the case for the Antarctic region, which is the focus of this study. It is not necessarily the case for other regions. In the Northern Hemisphere, stratospheric ozone recovery has been observed since the late 1990s after the Montreal Protocol and its amendments, although some surprising declines in*

ozone there were observed in recent years. So, please be specific.

Response: Thanks. We have revised these sentences as following:

"Ozone variations over recent decades exhibit not only strong trends, ……"

The relevant text in other places in the manuscript are also modified accordingly.

3. *P6, L4, what is the horizontal resolution for MERRA2 data used in this study, 2_x2.5_? How about SLIMCAT?*

Response: The horizontal resolution (lon × lat) for MERRA2 ozone is 1.25^{o} × $1.25^{o}$and for SLIMCAT ozone is 5.625^{o} × 5.5^{o}. It has been clarified in the revised paper.

4. *P8, L4-6, what is the significant level? 90%? 95%?*

Response: It is at 95% confidence level. This has been stated in the captions of corresponding figures.

5. *P8, L17, add "phi (using the Greek letter) is latitude".*

Response: Thanks. Added.

6. *P13, L20-22, not shown?*

Response: Yes, it is not shown. It is stated in the revised paper.

7. *P14, L4-6, please rephrase the sentence.*

Response: According to referee 1's comment. This sentence has been deleted in the revised paper. The discussion on how SST warming over East Asian Marginal Seas leads to a weaker wave activity in the Southern Hemisphere stratosphere please see Page 16 Line 22 to Page 17 Line 8 in the revised paper.

8. *P11, L11, use "further support" to replace "validate".*

Response: Replaced. Thanks.

9. *P18, L19, "observation"? No observation data are directly shown in this paper. The MERRA data may not be taken as "observation".*

Response: The corresponding sentence has revised to as below, the "observation" changed to "statistical analysis".

"The above results are based on statistical analysis but are also supported by time-slice experiments conducted using the CESM."

10. *Indicate whether boreal or austral seasons (including months) are referred earlier in the paper.*

Response: In the revised paper, we have unified the description of the season in the whole manuscript. Sorry for the confusion.

11. *Figure 1, is the ozone variation the same as or different from ozone anomaly? Is this normalized ozone anomaly? Are the seasonal cycle and trend removed? If not, add a trend to the figure. Indicate if the trend is significant. The variation is not straightly downward. A slight increase in ozone appears during 2010-2015.*

Response: The ozone anomaly variations in Figure 1 have the seasonal cycle and trend removed. This is why the ozone anomaly variations do not uniformly decrease before 2000. As we mainly focus on investigating the interannual variability of the ozone in the paper, we removed the long-tern linear trend of the ozone time series. The above information has been clarified in all relevant figures in the revised paper.

12. *Figures 2, 6, and 10, what is the significant level?*

Response: It is at 95% confidence level. This has been stated in the captions of corresponding figures.

13. *Figure 4, the label for the x-axis is Lag (month). Is the long-term trend removed fromthe data?*

Response: Yes, the long-term trend is removed. This information has been stated in all relevant figures in the revised paper.

14. *Figure 6, indicate these are boreal or austral spring, summer, autumn and winter, including months. Should the seasonal cycles be removed?*

Response: In the revised paper, we have unified the description of the season in the whole manuscript. Sorry for the confusion. Yes, the seasonal cycle is removed.

15. *Figures 7-11, the y-axis is not in the same format. Some have no unit, and some no label.*

Response: All the figures are corrected. Thanks very much for the carefully check.

16. *Figure 9, the annotation for the arrow is too small to see clearly.*

Response: The annotation has been enlarged. Thanks.

17. *Figure 13, the unit for SST variation should be K as shown in an earlier version. Also, please provide label for the y-axes. Is the ozone variation the same as Figure 1? Or the ozone trend in Figure 1 is removed? Why are they different?*

Response: Thanks for the comment. We are sorry for the confusion in Figure 13. We have made the caption of Figure 13 clearer in the revised paper.

The unit for SST has been modified to "K". The ozone variations in Figure 13 are different from those in Figure 1. In Figure 1, the ozone variations come from MERRA2 and SLIMCAT ozone from 1979 to 2015. The ozone in Figure 13 is the output from the WACCM4 transient experiments from 1955 to 2005. As we explained in **Response 11**, the ozone variations in Figure 1 have the linear trend removed to investigate the interannual variability. Figure 13 is shown to investigate the trend, so the ozone trend is not removed.

18. *There are a few inconsistency in the reference format. For example, some capitalize each word, some not.*

Response: The reference format are checked and corrected. Thanks.