## Response to Reviewers’ Comments.

## Reviewer 3

**General comments: This paper investigated the long term trend and seasonal variation of total column ozone (TCO) and total ozone low over Tibetan Plateau (TP) by using the regression analysis. The impacts of individual variables including solar cycle, QBO, and geopotential height (GH) have been discussed. They found that the GH may play an important role influencing the TCO especially on 150hPa levels. Moreover, they mentioned there might be the dynamical controlling of Inter Tropical Convergence Zone, ENSO events or Walker circulation in the lower stratosphere. In this paper, the scientific conclusions may need to be addressed more carefully and clarified. Some other details could be found beneath in the “specific comments”. I would also suggest the author to work on the writing of the manuscript.**

We thank the reviewer for the helpful comments and suggestions. We have made substantial modifications to improve the quality of the paper. The three main points based on our major results are listed as follows:

- The Tibetan Plateau (TP) is showing asymmetrical (slower) ozone recovery compared to the zonal mean over the same latitude band.
- The 150 hPa geopotential height (GH150) is a more realistic dynamical proxy (than previously used surface temperature) for TP column ozone. It influences summertime TCO variations over the TP through persistence of the wintertime ozone signal.
- Model results confirm that wintertime TP ozone variations are largely controlled by tropics-to-high latitude transport processes whereas summertime concentrations are combined effect of photochemical decay and tropical processes.

Based on the updated main points, we rename our manuscript: “Analysis and attribution of total column ozone changes over the Tibetan Plateau during 1979-2017”. The abstract and the conclusions are also revised based on the three main points and our updated major results.

Our replies to the reviewer’s specific comments are given below with a description of what we have changed in the revised manuscript.

### 1. Results of TOL in abstract?

Reply: In our updated abstract, we have added some results of TOL in lines 25-33: “We also compare the seasonal behaviour of the relative total ozone low (TOL) over the TP with the zonal mean at the same latitude. Both regression models show that the TP column ozone trends change from negative trends from 1979-1996 to small positive trends from 1997-2017, although the later positive trend based on PWLT is not statistically significant. The wintertime positive trend since 1997 is larger than that in summer, but both seasonal TP recovery rates are smaller than the zonal means over the same latitude band.”

2. **Some discussion of reasons for choosing 4 TP regions?**

Reply: In the revised manuscript (Section 2.1), we have added a discussion of reasons for choosing 4 TP regions (lines 184-187): “These regions represent the tropics and mid-latitudes with the TP and zonal TP in the critical zone. We choose them to compare the contribution of different dynamical proxies to their ozone variations, especially over the TP region.”

3. **Fig.1 shows results of C3S?**

Reply: The new Figure 1 in the revised manuscript shows the TCO time series based on C3S and SBUV. As C3S is based on model assimilation of meteorological and ozone observations, we use the direct ozone observations from the SBUV series of satellites to validate the results based on C3S. Their differences are less than 2-3% throughout the data record and are shown in the supplementary Figure S1.

4. **Fig.6, in QBO analysis, purple dots represent combined QBO at 30hPa and 10hPa?**

Reply: Yes, purple dots in the old Figure 6 represent combined QBO at 30 hPa and 10 hPa. In the revised manuscript, we have re-plotted the new Figure 3 with updated plot legend to make it easier to understand.

5. **SLIMCAT results show much smaller 150 hPa GH contribution in DJF due to coarser resolutions? Simulations with a finer resolution might be suggested to perform here. The values in JJA almost double in model simulations. It might need some discussions.**

Reply: Actually, our updated results (with the early 2018 data included to determine the last DJF value in 2017) show that SLIMCAT simulation results are similar to the C3S regression results, although contributions from most explanatory proxies are larger except for the GH150 in DJF. This difference is probably due to the coarse model resolution and the inhomogeneities in ERA-Interim data (lines 451-454).

TOMCAT/SLIMCAT is a global 3D off-line chemistry-transport model widely used to study the processes controlling tracer distributions in the atmosphere. The resolution of the simulations in the paper is $2.8^{o}\times 2.8^{o}$, which is coarser than the resolution of C3S ($0.5^{o}\times 0.5^{o}$). That may be one reason why SLIMCAT results are different from those based on C3S.

It is true that the version of the model with higher resolution would be expected to present a more realistic representation of ozone. Feng et al. (2005) has indicated that SLIMCAT with higher resolution ($2.8^{o}\times 2.8^{o}$) shows more reasonable transport and mixing than the lower resolution ($7.5^{o}\times 7.5^{o}$). With higher resolution, chemical ozone depletion reproduced by the model is generally larger, which agrees better with observations. However, it should be noted that Feng et al. (2011) also investigated the effect of resolution in the CTM (from $5.6^{o}\times 5.6^{o}$ to

1.1° ×1.1°) on the convective mass fluxes and found that the changes are small. For polar stratospheric studies, Grooß et al. (2018) also found that there is not much difference in the time series of HCl which affects the simulated ozone depletion using two resolutions (1.2°×1.2° and 2.8°×2.8°) of TOMCAT/SLIMCAT. Hence, simulations with a finer resolution may not promise a large improvement on the 150 hPa GH contribution compared to the C3S results. Given the prohibitive computational cost of performing high resolution simulations, and the improvement in the presented results compared to the submitted version, we have kept the moderate resolution 2.8°×2.8° simulations.

Our simulation results show overestimated contributions from the different explanatory factors when compared to the C3S regression results in both DJF and JJA (the values in JJA almost double). Some differences are expected because there are uncertainties in the model simulations. The complex set of processes in the model (e.g. chemistry, photolysis, dynamics and emission) and the quality of meteorological analysis data used will inevitably cause the uncertainties in the model. Therefore, in the revised manuscript, we briefly summarise the control simulation results, and our focus is on the two relative sensitivity experiments to investigate the role of wintertime GH150 on ozone transport (see also response to Reviewer 1). The simulated ozone profiles clearly show that wintertime TP ozone concentrations are largely controlled by tropics-to-mid-latitude pathways, whereas in summer variations associated with tropical processes play an important role (lines 42-44 and Section 5).

**References:**

Feng, W., Chipperfield, M. P., Davies, S., Sen, B., Toon, G., Blavier, J. F., Webster, C. R., Volk, C. M., Ulanovsky, A., Ravegnani, F., von der Gathen, P., Jost, H., Richard, E. C., and Claude, H.: Three-dimensional model study of the Arctic ozone loss in 2002/2003 and comparison with 1999/2000 and 2003/2004, Atmos. Chem. Phys., 5, 139–152, https://doi.org/10.5194/acp-5-139-2005, 2005.

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Grooß, J.-U., Müller, R., Spang, R., Tritscher, I., Wegner, T., Chipperfield, M. P., Feng, W., Kinnison, D. E., and Madronich, S.: On the discrepancy of HCl processing in the core of the wintertime polar vortices, Atmos. Chem. Phys., 18, 8647–8666, https://doi.org/10.5194/acp-18-8647-2018, 2018.