Response to Reviewer 2's comments

We would like to thank the reviewer for their time and comments to improve the current manuscript. We have addressed the reviewer's comments below, with our responses indicated in blue.

Ozone recovery is a topic of great interest not only to scientists but also to the general public. In recent years, several unusually strong Antarctic ozone holes have occurred, posing challenges to our understanding of their driving mechanisms. Volcanic eruptions are known to cause ozone loss through the injection of aerosols, water vapour, and halogen species. An important and timely question is therefore: How will future volcanic eruptions affect projections of ozone recovery? The authors address this by conducting experiments with the plume-aerosol-chemistry-climate model (UKESM-PLUME) under different future volcanic eruption scenarios, analysing the resulting ozone loss and its contribution to delays in Southern Hemisphere ozone recovery. The topic is interesting, well-motivated, and suitable for ACP. My major concern, however, lies in the estimated delay (~5 years) in ozone recovery due to volcanic eruptions. The model shows substantial deviations from observations in its simulation of ozone loss following a major volcanic eruption. My detailed comments are below.

Major comments:

1. The authors have clearly shown the limitations of UKESM1.1. Both the timing (Fig. 7) and amplitude (Fig. 6c) of ozone loss, as well as the spread and amplitude of SAOD (Fig. 6a, 6c), differ considerably from observations. Importantly, volcanic impacts on ozone loss appear to be overestimated (Fig. 6d) in both the Antarctic and Arctic. How do there limitations influence the projection of ozone recovery date and the estimated decay attributed to volcanic eruptions?

   We acknowledge the limitations of UKESM1.1 in reproducing historical observations. UKESM1.1 has a high climate sensitivity and simulates greater stratospheric aerosol optical depth (SAOD) than the GloSSAC SAOD until mid-1992. The Antarctic total column ozone loss after the 1991 Mt. Pinatubo eruption appears earlier in NIWA-BS data (Figure 6e, now Figure 3e) than the UKESM1.1 simulations (Figure 3d). This discrepancy likely reflects differences between our free-running ensemble climatology and the 1991 atmospheric conditions, as our Pinatubo simulations are not nudged to observations. Despite the difference in the timing of ozone hole, the magnitude of Antarctic ozone loss between UKESM1.1 and NIWA-BS in 1991 and 1992 are comparable (Figure 3c). Figure 3c shows that the Antarctic ozone loss aligns well between UKESM1.1 and NIWA-BS by summer 1993, suggesting the model captures the overall temporal evolution and magnitude despite the initial timing discrepancy due to aerosol transport.

   UKESM1.1 simulates a prolonged ozone depletion over Antarctica due to the model's stratospheric cold bias and excessively strong polar vortex. As shown in the comparison with ML-TOMCAT (Figure S1), UKESM overestimates ozone loss

over Antarctica between 10 and 30 hPa, and underestimates lower stratospheric ozone loss over Antarctica. These biases will likely lead to an overestimation of the ozone loss over Antarctica. Regarding the projection of ozone recovery dates, while UKESM1.1 overestimates baseline total column ozone, our study focuses on the relative difference between VOLC and NOVOLC runs in order to isolate the volcanic-induced responses. Our simulations exclude volcanic halogens and very short-lived substances (VSLS), which would further delay ozone recovery if included. Therefore, our results likely represent a lower bound of the volcanic-induced delay in ozone recovery. We have revised the discussion section as follows,

L890-896, "We acknowledge that UKESM1.1 exhibits a stratospheric cold bias and excessively strong polar vortex that leads to prolonged ozone depletion over Antarctica (Fig. 4). The comparison of the UKESM1.1 simulation with ML-TOMCAT shows that the climatological mean of UKESM1.1 overestimates lower stratospheric ozone loss over Antarctica and SH mid-latitudes. Due to these model biases, our results likely overestimate the cumulative ozone loss over Antarctica and SH mid-latitudes. However, the relative volcanic effects on ozone in our simulated scenarios remain robust. In addition, our stochastic scenarios include stratospheric volcanic SO_2 emissions only, but not volcanic halogen species, water vapour and VSL chlorine and bromine compounds, which affect stratospheric ozone recovery."

L904-905, "Therefore, our model-simulated effects on ozone represent a lower bound of the potential effects of future volcanic eruptions on ozone depletion."

2. The authors use the 1978-1982 mean October TCO as the historical baseline. Is a 5-year average sufficient? What is the year-to-year variability of October TCO during this period? This uncertainty may propagate to the estimated return year.

The 1978-1982 October TCO over Antarctica ranges between 328DU to 346DU, with a standard deviation of 6.5 DU. We used this 5-year average from 1978 to 1982 to represent a 1980 baseline to reduce the effect of year-to-year variability. While the choice of baseline period introduces some uncertainty in the absolute return years, the difference in return years between VOLC and NOVOLC runs is insensitive to this choice as both simulations used the same baseline.

Specific comments:

1. Line 65: At the end of the sentence (before the full stop), add something like "and cause additional chemical ozone loss (eg., Santee et al., 2023)"Santee, M. L., Manney, G. L., Lambert, A., Millán, L. F., Livesey, N. J., Pitts, M. C., et al. (2024). The influence of stratospheric hydration from the Hunga eruption on chemical processing in the 2023 Antarctic vortex. Journal of Geophysical Research: Atmospheres, 129, e2023JD040687. **https://doi.org/10.1029/2023JD040687**

We have added the suggested reference and revised the text as follows,

L67-69, "Volcanic eruptions may also inject water vapour and halogen species into the stratosphere in addition to volcanic SO$_2$ and cause additional chemical ozone loss (Bobrowski et al., 2003; Pyle and Mather, 2009; Evan et al., 2023; Santee et al., 2024)."

2. Figure 1: It is misleading by putting "leading to net ozone formation in the stratosphere" for future volcanic eruption. Volcanic eruptions increase aerosol surface area density for heterogeneous reaction, promoting heterogeneous reactions that lead to ozone loss. This mechanism should be similar under present-day and future scenarios.

    We have decided to remove Figure 1 from the main text.

3. Line 77 and elsewhere: Klobas et al., 2017 is cited in the text but missing from the Reference list.

    We have revised the reference list.

4. Line 134: How is the stratospheric aerosol prescribed in the NOVOLC run? Is it based on background levels during the volcanic quiet period?

    In the NOVOLC run, we did not include non-volcanic background stratospheric aerosols in the simulation. All of our simulations (VOLC and NOVOLC) considered only stratospheric sulfate aerosols.

5. Line 194: Formatting is inconsistent after "odd oxygen".

    We have revised the formatting in the text.

6. Figure 6c: A typo here. "TOC" in legend should be "TCO". The NIWA-BS line shows a decrease in 1992 summer, but the UKESM line shows an increase. How does the UKESM line in Fig. 6c relate to Fig. 6d?

    We have revised the legend in Figure 3c (previously Figure 6c). The NIWA-BS total column ozone anomaly presented in Figure 3 (previously Figure 6) is relative to the 1986-1990 climatology. Apart from the June 1991 Mt. Pinatubo eruption, another volcano in the Southern Hemisphere, Cerro Hudson (Chile), erupted in August 1991. The anomaly shown by GloSSAC and NIWA-BS reflects the responses of both eruptions. In Figure 3c, we see a negative anomaly of Antarctic TCO for NIWA-BS after June 1991, which changed to a positive anomaly towards the end of 1991. This shows that the onset of Antarctic ozone loss started much earlier in year 1991 than the 1986-1990 climatology. The TCO anomaly in UKESM simulations are relative to the control simulation without volcanic eruption.
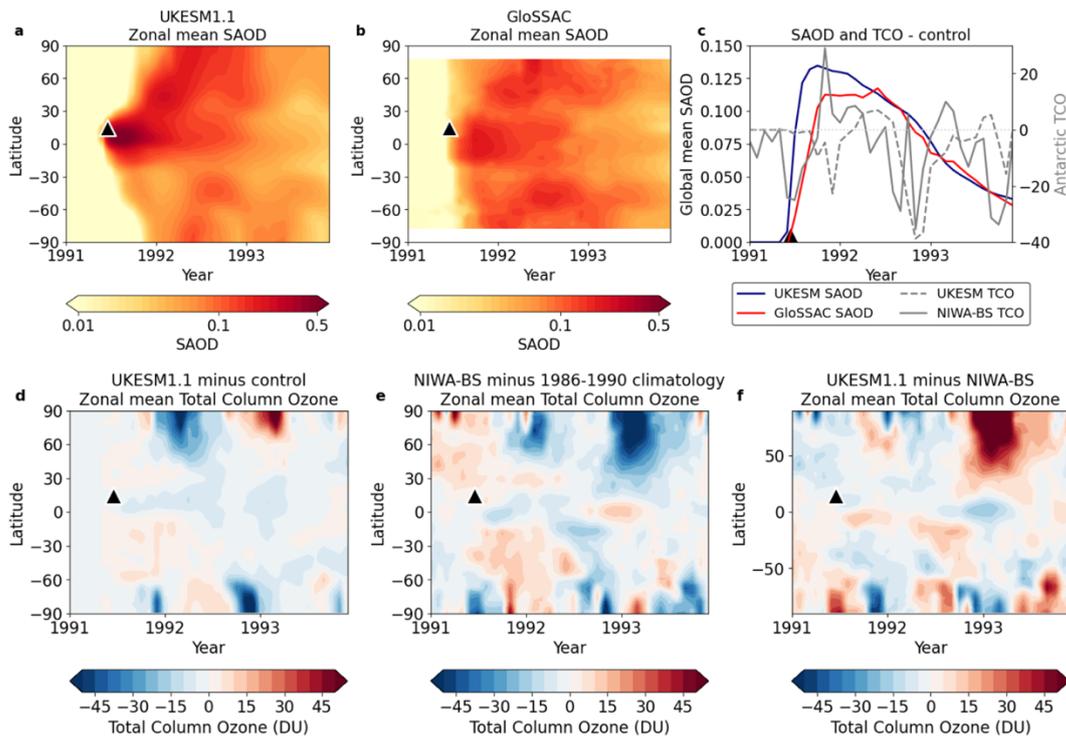
Figure 3. Stratospheric aerosol optical depth (SAOD) and total column ozone responses following the 1991 Mt. Pinatubo eruption. (a,b) Zonal monthly mean SAOD from the UKESM1.1 simulation and GloSSAC. (c) Time series of global monthly mean SAOD anomalies (UKESM1.1 relative to control and GloSSAC relative to 1986-1990 climatological mean) and Antarctic monthly mean total column ozone anomalies (UKESM1.1 relative to control and NIWA-BS relative to 1986-1990 climatological mean). (d,e) Zonal monthly mean total column ozone anomalies from UKESM1.1 (relative to control) and NIWA-BS (relative to 1986-1990 climatological mean). (f) Difference in total column ozone anomalies between UKESM1.1 and NIWA-BS (panel d minus e).

7. Line 252: "with a magnitude comparable to NIWA-BS total column ozone loss (Fig. 6c to 6f)." Fig. 6c does not show ozone loss in the 1992 summer; it should be removed from this comparison.

   We have revised in the text.

8. Figure 7: What do the colored shadings represent? The authors state that UKESM reproduces the October Antarctic TCO reasonably well, which I agree with. However, the October differences between NOVOLC and VOLC, which are important to quantifying volcanic impacts, are not discussed.

   The colour shading shows the maximum and minimum range of the UKESM ensemble members. We have added this information in the figure caption. Figure 4 (previously Figure 7) shows the 5-year averaged Antarctic ozone hole area for one of the stochastic scenarios (VOLC50-1) to illustrate the prolonged ozone hole simulated in UKESM compared to the historical period. The results related to the October mean TCO differences between VOLC and NOVOLC are discussed in Figure 5 and L731-733.

   L589-591, "Figure 5c shows the time series of the October-mean Antarctic total

column ozone. Compared to the NOVOLC run, our stochastic scenarios show a 0.5% to 2.8% (1.5 DU to 8 DU) lower Antarctic total column ozone averaged over 2030 to 2050, which lasts until around 2060s for some stochastic scenarios."