Reply to Reviewer #2:

We thank the reviewer for his/her comments and suggestions. These comments are given below in black text, followed by our responses in blue text.

This paper reports on ozone results from TOMCAT chemistry-transport model (CTM) runs using two different meteorological ECMWF reanalyses as input, ERA5 and its predecessor ERAI. While agreement of model runs driven by ERA5 appear to agree better with total ozone observations, biases with respect to observations are larger in ozone profile data for ERA5 driven TOMCAT than for ERAI driven. In addition recent ozone trends in total columns and stratospheric ozone differ depending on the reanalysis data used. Their main conclusion is that the current ERA5 reanalysis is not able to reproduce in CTMs the observed ozone changes, in particular, in the lower stratosphere.

The topic of this paper is very relevant and is within the scope of ACP. Recent stratospheric ozone changes are governed by changes in ozone-depleting substances (chemical contribution) and circulation/transport (dynamical contribution), the latter strongly influenced by changes in greenhouse gases. In particular, the differences in the reanalyses mainly affect the circulation pattern in the model and ozone transport. Both CTMs and trend regression models applied to observations rely on input from meteorological analyses (forcing and proxies) in order to separate the dynamical and chemical part of the overall ozone trends. Uncertainties in the reanalyses therefore can affect trend estimates derived from CTMs and, possibly, observations.

I recommend publication in ACP after addressing the following points.

l.138: The sentence "Sofieva et al. and Steinbrecht et al. ..." does not belong here as they report on profile trends not total column trends.

Reply: Sorry for this error. We have removed the sentence and provided a web link for the validation document (https://datastore.copernicus-climate.eu/documents/satellite-ozone/C3S2_312a_Lot2_PQAR_O3_latest.pdf).

l.281: The table caption is confusing (what is the meaning of "… based on ..."). What is shown here are the correlations (r2) between the regression model and the data timeseries.

Reply: Sorry for this confusion. We have removed the table and added the information of correlations (r2) to Figure 4 in the revised manuscript as suggested by Reviewer #1.

Eq. 1 (and Fig. 5): I would suggest to use ILT (independent linear trends) rather than PWLT. PWLT are quite sensitive to the turning point (time of maximum of stratospheric halogen content) being quite close to the Pinatubo period. It could be that differences between the models and observations could become more pronounced with the ILT approach.

Reply: We thank the reviewer for this insightful comment and suggestion. In the revised manuscript, we have used independent linear trends (ILT) to replace PWLT. We have rewritten the regression methods in Section 2.3. The updated results for TCO trends and ozone profile trends for the models and observations are compared and shown in Figure 4, Figure 9 and Figure S4. We find the results are generally consistent with those using PWLT. Some detailed modifications are shown in red text in the revised manuscript.

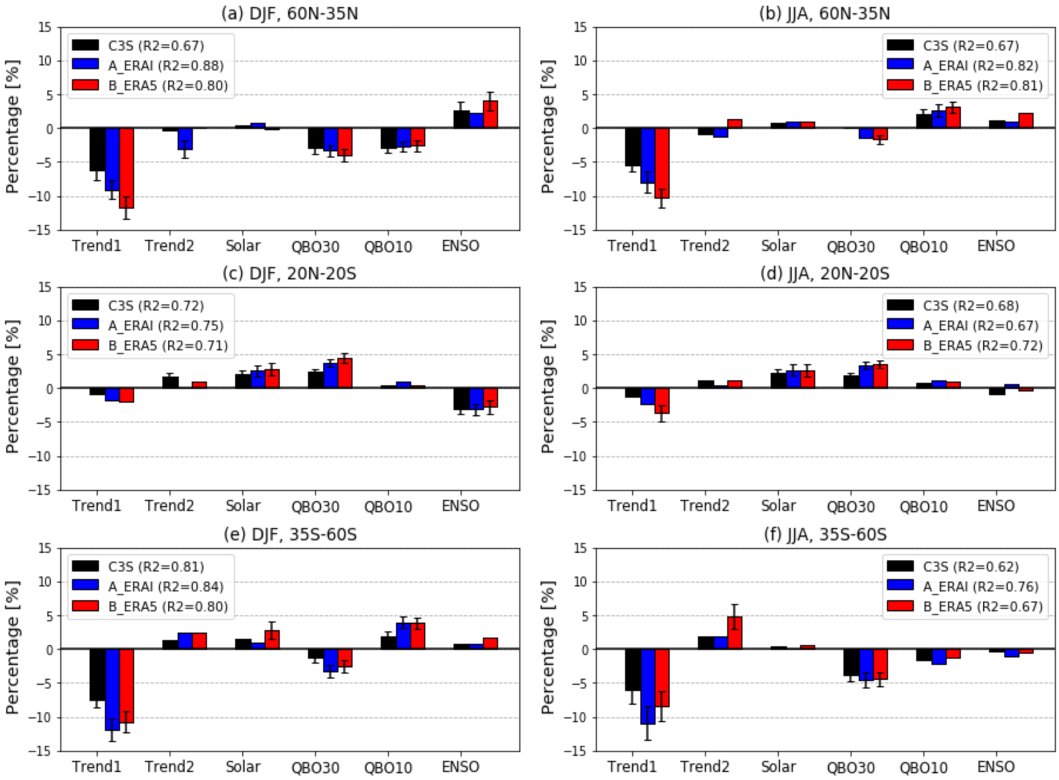

Figure 4: Peak contributions (in %) from piecewise linear trend and explanatory variable terms (see equation (1)) to the total ozone column variability during DJF and JJA for (a, b) 60°N-35°N, (c, d) 20°N-20°S and (e, f) 35°S-60°S for C3S, A_ERAI and B_ERA5 during 1979-2018. Error bars indicate the confidence bounds at the 95% statistical significance level quantified by ± 2 standard deviations (σ). The determination coefficients (R-squared) of the regression model for DJF and JJA mean TCO time series from C3S, A_ERAI and B_ERA5 over the 60°N-35°N, 20°N-20°S and 35°S-60°S regions are presented in each plot.

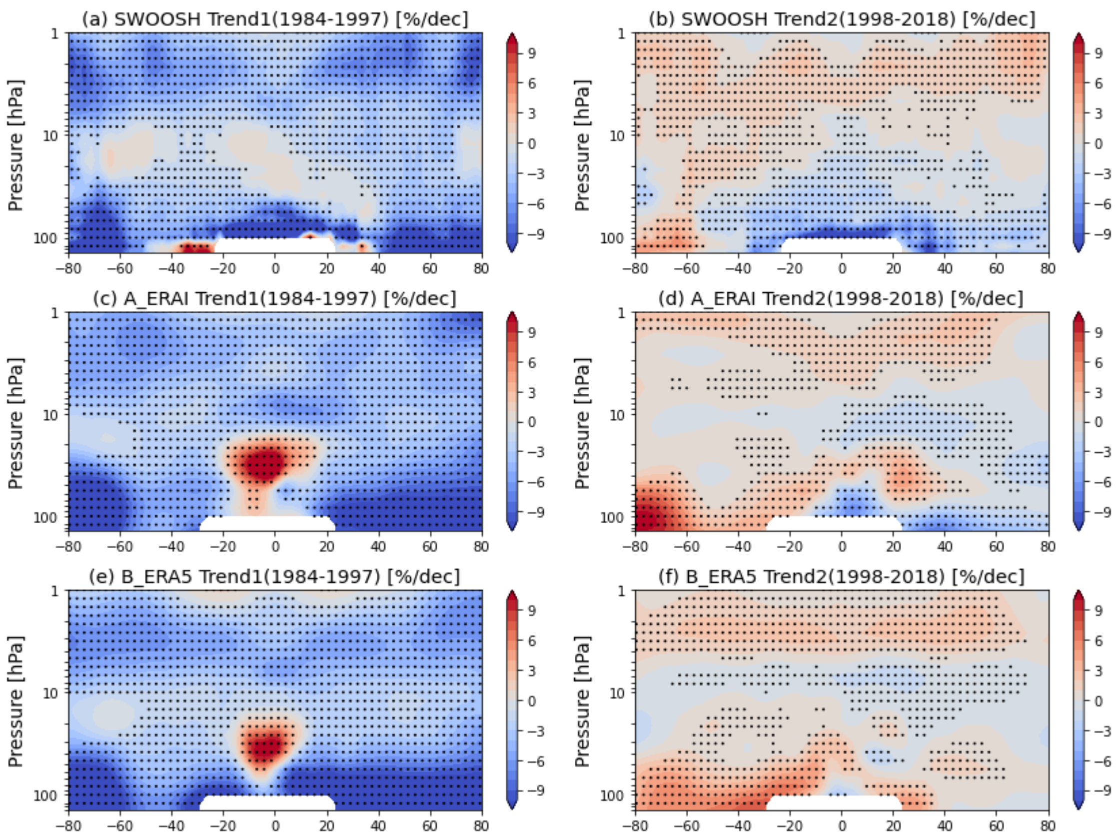

Figure 9: Latitude-pressure cross sections of the piecewise linear trends of ozone anomalies (%/decade) over the periods 1984-1997 and 1998-2018 for (a, b) SWOOSH, (c, d) A_ERAI and (e, f) B_ERA5, respectively. Stippled regions indicate where the trends are statistically significant at 95% level of confidence.

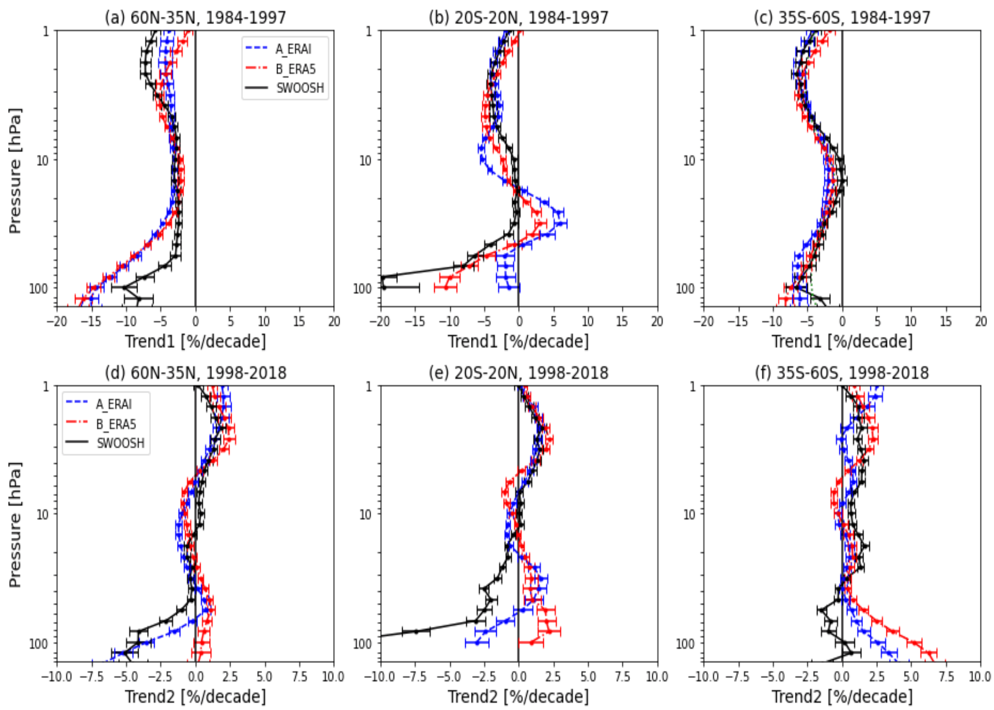

Figure S4: Vertical profile of linear trends in ozone (%/decade) from SWOOSH (black solid line), A_ERAI (blue dashed line) and B_ERA5 (red dash-dot line) over the periods (a-c) 1984-1997 and (d-f) 1998-2018. Results are for 60°N-35°N, 20°N-20°S and 35°S-60°S zonal regions. Error bars show standard deviations at 2σ.

l. 362: here the large differences in temperatures between A_ERAI and B_ERA5 before 1998 is seen as a proof that ERA5 upper stratospheric temperatures are improved (due to some corrections in the assimilation of MLS). Has this been validated? A comparison of ERAI/ERA5 with MLS or other temperatures could show this.

Reply: The upper stratospheric temperatures are improved by ERA5, this has been validated in previous studies: Simmons et al. (2020) examined the performance of ERA5 using radiosonde and satellite observations. They showed that temperature bias in the upper stratosphere of ERA5 was significantly affected by the addition of the Advanced Microwave Sounding Unit-A (AMSU-A) satellite data between 2000 and 2007 at heights above 15 hPa. Marlton et al. (2021) identified the temperature biases in the upper stratosphere in ECMWF reanalyses (ERA-Interim and ERA5) using a network of temperature lidars. They found a cold bias of −3 ~ −4 K between 10 and 1 hPa in ERA-Interim, while in ERA5 a small bias of magnitude 1 K was found. ERA5 shows a much improved thermal representation of the upper stratosphere up to 1 hPa due to the inclusion of more measurement systems (e.g. the AMSU-A and the Constellation Observing System for Meteorology, Ionosphere, and Climate (COSMIC)), improved bias correction techniques and model physics, CMIP5 radiative forcings, and a 4Dvar data assimilation system (Hersbach et al., 2020).

We have modified this sentence and also cited some references (e.g. Simmons et al., 2020; Marlton et al., 2021) in the revised manuscript (Lines 412-417): “Large biases in temperature anomalies between two simulations (B_ERA5-A_ERAI) appear in the upper stratosphere for all latitude regions until around 1998, confirming that some of the inhomogeneities seen in ERA-Interim upper stratospheric temperatures (Dhomse et al., 2011; McLandress et al., 2014). Some recent studies argue that there has been significant improvements in ERA5 temperatures as it includes more measurements, and uses updated bias correction techniques and model physics, CMIP5 radiative forcings in a 4Dvar data assimilation system (Hersbach et al., 2020; Simmons et al., 2020; Marlton et al., 2021).”

Related references:

Hersbach, H., Bell, B., Berrisford, P., Hirahara, S., Horányi, A., Muñoz-Sabater, J., Nicolas, J., Peubey, C., Radu, R., Schepers, D., Simmons, A., Soci, C., Abdalla, S., Abellan, X., Balsamo, G., Bechtold, P., Biavati, G., Bidlot, J., Bonavita, M., De Chiara, G., Dahlgren, P., Dee, D., Diamantakis, M., Dragani, R., Flemming, J., Forbes, R., Fuentes, M., Geer, A., Haimberger, L., Healy, S., Hogan, R. J., Hólm, E., Janisková, M., Keeley, S., Laloyaux, P., Lopez, P., Lupu, C., Radnoti, G., de Rosnay, P., Rozum, I., Vamborg, F., Villaume, S., and Thépaut, J.-N.: The ERA5 global reanalysis, Q. J. Roy. Meteorol. Soc., 146, 1999-2049, doi:10.1002/qj.3803, 2020.

Marlton, G., Charlton-Perez, A., Harrison, G., Polichtchouk, I., Hauchecorne, A., Keckhut, P., Wing, R., Leblanc, T., and Steinbrecht, W.: Using a network of temperature lidars to identify temperature biases in the upper stratosphere in ECMWF reanalyses, Atmos. Chem. Phys., 21, 6079–6092, doi:10.5194/acp-21-6079-2021, 2021.

Simmons, A, Soci, C, Nicolas, J, Bell, B, Berrisford, P, Dragani, R, Flemming, J, Haimberger, L, Healy, S, Hersbach, H, Horányi, A, Inness, A, Munoz-Sabater, J, Radu, R, Schepers, D.: Global stratospheric temperature bias and other stratospheric aspects of ERA5 and ERA5.1, ECMWF Technical Memoranda, 859, doi: 10.21957/rcxqfmg0, 2020.

l.368: "Thus, the differences in the upper stratospheric temperatures from the reanalysis data sets drive the differences in ozone anomalies in this region." Please explain why this is the case, e.g. cooler (warmer) temperatures produce more (less) ozone.

Reply: Thank you. We have added the explanation in the manuscript (Lines 420-422): “the differences in the upper stratospheric temperatures from the reanalysis data sets drive the differences in ozone anomalies in this region, as cooler (warmer) temperatures causes more (less) ozone when photochemical processes dominate (e.g. Stolarski et al., 2012).”

Related references:

Stolarski, R. S., Douglass, A. R., Remsberg, E. E., Livesey, N. J., Gille, J. C.: Ozone temperature correlations in the upper stratosphere as a measure of chlorine content, J. Geophys. Res., 117, D10305, doi:10.1029/2012JD017456., 2012.

l.482: "The increasing AoA in B_ERA5 after 1998 as well as the older age in the NH lower stratosphere, suggest that other transport pathways (such as downward transport/reduced transport in the troposphere) might have been responsible for the increasing ozone in the NH extratropical lower stratosphere in B_ERA5". It should be mentioned that the aging of AoA in the NH appears, however, consistent with SWOOSH (observational) trends and the notion of reduced downward transport. Could this mean that there is some model issue here (uncertainties in transport patterns in the model). Please discuss.

Reply: Yes. To make the discussion more complete, we have added some information to the revised manuscript (Lines 546-554): “A possible explanation might be changes in the vertical resolution (and changes in number and type of observations) assimilated in ERA5. For example, in NH mid-high latitude, B_ERA5 shows somewhat older AoA in the lowermost stratosphere (near 100 hPa), but between 70 to 10 hPa, B_ERA5 shows slightly younger AoA compared to A_ERAI. In contrast, B_ERA5 minus A_ERAI ozone differences seen in Figure 7 (a, b) remain positive throughout the stratosphere with an exception of slightly negative values near 10 hPa. This clearly shows that changes in vertical transport can lead to larger changes in lower stratospheric ozone as ozone lifetime increases exponentially from a few days near middle stratosphere to a few years in the lower stratosphere. A similar feature is observed in the SH mid-latitudes. However, at SH high-latitudes, B_ERA5 shows somewhat positive AoA compared to A_ERAI but simulated ozone differences are negative in the lower-middle stratosphere.”