The manuscript "Analysis of Antarctic ozone trends from 1979 to 2023" by He et al. provides an analysis of the long-term evolution of total column ozone over Antarctica from 1979 through 2023 based on four data sets: WOUDC ground-based measurements, the Multisensor Reanalysis (MSR-2),the Total Ozone Mapping Spectrometer/Ozone Monitoring Instrument (TOMS/OMI) record, and Chemical Transport Model (CTM) simulations from TOMCAT. The authors apply a standard multiple linear regression (MLR) approach taking into account various atmospheric key processes which affect ozone variability. They focus on the investigation of the role of the Brewer-Dobson Circulation (BDC) on ozone changes, and they perform two sensitivity experiments with TOMCAT also focused on the role of the BDC. The latter is limited to the period 2000-2009. On top of that, the authors investigate the divergence of the September and October trends. The topic of the manuscript fits into the scope of ACP. However, I think that the novelty of the investigation is somewhat limited, but I would recommend publication after revision.

Thanks for your suggestion and detailed remark. This manuscript has addressed and answered each of the relevant questions and suggestions. We focused on changes in BDC to ozone, extended the time period of sensitivity experiments (2001-2023), and reanalyzed ozone changes in recent years (2020-2023). The modified words, expressions and sentences have been highlighted.

Thank you.

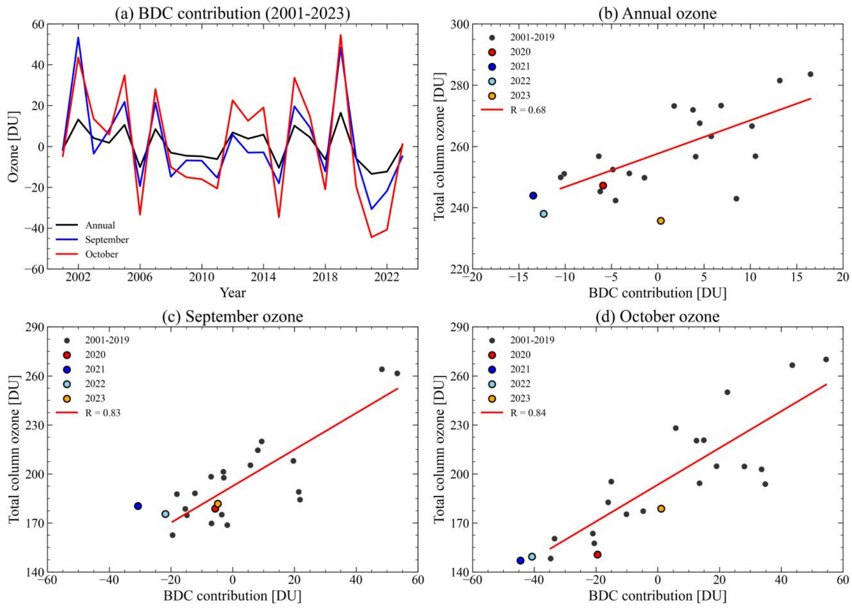
Major comments

In the abstract, you mention the distinctly low ozone values during 2020-2023 and the intention to assess the impact on long-term trends. Unfortunately, this assessment is limited to a short paragraph in Sec. 4. I recommend to elaborate on this in more detail, in particular with respect to the possible reasons for the reduced values, e.g. the exceptional atmospheric conditions during these years. Related to the previous point: Why did you limit the model sensitivity experiments to the period 2000-2009? The correlation between BDC and polar ozone for 1995-2010 was already investigated in detail in Weber et al. (2011). I think, analysing the behavior in the last years

(2020-2023) would be interesting. Is there any possibility to extend the model analysis?

Thank for your suggestion.

(1) We have added the Figure 6 and content about the connection between ozone changes in recent years (2020-2023) and BDC.



"Figure 6 shows the contribution of BDC to TCO changes from 2001 to 2023. BDC has a significant impact on the recent ozone variability, contributing up to -45 DU in October during 2020-2023. ... Although TCO remained relatively low in 2023, the corresponding BDC contribution was small." (L271-276)

(2) We have extended the sensitivity experiment time and focused on the analysis of low ozone levels from 2020 to 2023 (see Figure 7-9 and Section 5).

"Despite Antarctic ozone trends showing a decline during 2001-2023 in the annual mean and October, both EXP1 and EXP2 exhibited positive trends after controlling for BDC intensity, with notable consistency between the two experiments." (L304-306)

"TCO values dropped to approximately 150 DU in October-November during 2020-2022, significantly lower than in most years of the 2001-2019 period. ... Nevertheless, ozone levels in recent years (2020-2023) are significantly elevated compared with most of the past two decades." (L318-323)

"Figure 9a shows the monthly mean temperature at 50 hPa from 2001 to 2023. The cooler temperatures in the spring and winter from 2020 to 2022 were associated with the persistently low ozone values. ... The higher springtime temperature and EHF in 2023, compared with the springs of 2020-2022, contributed to the elevated ozone concentrations (Fig. 8a). " (L329-334)

Thank you.

Minor comments

p. 3, l. 89: consistancy -> consistency

Yes, we agree with you. "consistancy" has been modified to "consistency". (L92)

Thank you.

p. 4, Sec. 2.1: How many ground-based stations are located in the latitude band 60°S-90°S?

Thank for your suggestion. We have added this as follows.

"Antarctic ozone observations have drawn upon over 20 ground-based stations since monitoring was initiated." (L102-103)

Thank you.

p. 4, l. 100: Please use "MSR-2" consistently throughout the manuscript.

Thank for your suggestion. "MSR" has been modified to "MSR-2". And the corresponding expressions in the whole manuscript have been modified. (L104, L105, L131, L193, L200, L217)

Thank you.

p. 4, ll. 102-103: MSR-2 also includes SBUV/NOAA-17, -18, -19.

Thank for your suggestion. We have revised this as follows.

"These include the TOMS series (Nimbus-7 and Earth Probe), SBUV (Nimbus-7 and NOAA-9, -14, -11, -16, -17, -18, -19), BUV-Nimbus 4, GOME (ERS-2), SCIAMACHY (Envisat), OMI (EOS-Aura), and GOME-2 (Metop-A)." (L106-107)

Thank you.

p. 4, l. 107:For MSR-2, use "van der A et al., 2015". van der A, R. J., Allaart, M. A. F., and Eskes, H. J.: Extended and refined multi sensor reanalysis of totalozone for the period 1970–2012, Atmos. Meas. Tech., 8, 3021–3035, https://doi.org/10.5194/amt-83021-2015, 2015.

Thank for your suggestion. The corresponding reference has been added.

"The final global ozone dataset is generated using data assimilation techniques based on a chemical transport model driven by meteorological fields from the European Centre for Medium-Range Weather Forecasts (ECMWF) (Van Der A et al., 2015)." (L110-111)

"Van der A, R. J., Allaart, M. A. F., and Eskes, H. J.: Extended and refined multi sensor reanalysis of total ozone for the period 1970–2012, Atmos. Meas. Tech., 8, 3021-3035, https://doi.org/10.5194/amt-8-3021-2015, 2015." (L528-529)

Thank you.

p. 4, Sec. 2.3 TOMS/OMI: I suggest to delete the first sentence since EP TOMS was decommissioned in 2007. The datasets for TOMS and OMI are two separate data records with different spatial resolutions. Please describe, how you merge them for the analysis. Did you compare them during their overlap period? Did you apply any adjustment to one of the records in order to avoid artificial jumps? Please provide some more details here.

Thank for your suggestion. We have revised and supplemented this as follows.

"The TOMS and OMI data were processed using the Version 8 algorithm developed by the NASA Goddard's Ozone Processing Team (Wellemeyer et al., 2004). The TOMS program began in 1978, total column ozone measurements from TOMS onboard Nimbus-7, Meteor-3, and Earth probes were used." (L113-115)

"Despite the overlap of time periods measured by different TOMS platforms, the bias of ozone data between them is 1-2% (Kroon et al., 2008)." (L118-119)

Thank you.

p. 5, Table 1:The link https://woudc.org/archive/Projects-Campaigns/ZonalMeans provides only zonal means for the period until 2021 (file gb_1964-2021_za.txt). What is the source for the extended (until 2023) record? 3rd column (spatio-temporal resolution): Please (i) provide the resolution in degree [°] for MSR-2, TOMS/OMI, and TOMCAT, (ii) remove “lat*lon=….” in the second and third row, and (iii) explain T42 L32 for TOMCAT. 4th column, last row: “EAR 5” -> “ERA5”

Yes, you are right.

(1) What is the source for the extended (until 2023) record?

At present, there is a lot of missing data in 2025, so WOUDC does not provide the latest link. Our WOUDC data was provided by Dr. Vitali E. Fioletov, and we acknowledge his suuport in the acknowledgements. And we have added it to the data availability.

“Updated ozone data from WOUDC will be made available on request.” (L363)

(2) About “spatio-temporal resolution”, We have revised it (see Table 1).

Table 1. Sources and temporal coverage of ozone datasets.

Dataset	Spatio-temporal resolution	Source
WOUDC	Monthly, 5° zonal mean of TCO	http://woudc.org/archive/Projects-Campaigns/ZonalMeans (1970-2021), the dataset is continuously updated.
MSR-2	Monthly, 0.5° × 0.5° with TCO	https://www.temis.nl/protocols/O3global.php
TOMS/OMI	Monthly, TOMS: 1° × 1.25° with TCO, OMI: 1° × 1° with TCO	https://disc.gsfc.nasa.gov/datasets?keywords=TOMS&page=1&measurement=Atmospheric%20Ozone, https://www.earthdata.nasa.gov/learn/find-data/near-real-time/omi
TOMCAT	Daily, 2.8° × 2.8° and 32 vertical levels (about 0-60 km)	Simulation of global ozone data based on ERA5 (Chipperfield, 2006).

Thank you.

p. 5, 133-134: “These trend terms represent the only non-periodic terms of MLR…” -> Not sure, if this statement is correct. For example, AOD is non-periodic as well. Please explain what you mean here.

Yes, you are right. We have revised this as follows.

“The trend term is the only non-periodic term in the MLR, whereas other terms generally exhibit some form of periodic or peak. Changes in stratospheric ozone levels are driven by the combined influences of climate variability and ODS.

Consequently, the net ozone trend need not strictly track EESC variations before and after the ODS peak, and ILT will better represent the ozone changes caused by other non-periodic forcings." (L140-143)

Thank you.

p. 6, Eq. (1) and following text: Please explain all terms, e.g. QBO_10(t), QBO_30(t), S(t), E(t), …. Does "t" represent the month or the year?

Thank for your suggestion. We have added this as follows.

"t is the year (month) during period 1979-2023." (L149)

Thank you.

p. 6, l. 160: "…while other proxies use the monthly mean time series" -> In line 143, you indicate that "t" represents the year and not the month. Please clarify. Maybe "t" represents the month (see my previous comment).

Yes, you are right. We have revised this as follows.

"In the MLR, AAO and BDC are represented by the mean of the autumn-to-spring accumulation, while other proxies use the monthly mean time series for monthly analyses and annual mean time series for annual analyses with no time lags." (L175-177)

Thank you.

p. 6, Table 2:Please check URL for QBO indices and BDC.

Thank for your suggestion. We have revised it (see Table 2).

Table 2. Sources of impact proxies.

Proxy	Explanatory proxy	url / file
QBO 10 hPa, QBO 30 hPa	Singapore wind speed at 30 hPa and 10 hPa	https://www.iup.uni-bremen.de/OREGANO/proxy
SAOD(t)	Stratospheric aerosol optical depth at 550 nm	https://asdc.larc.nasa.gov/project/GloSSAC
S(t)	Bremen composite Mg II index	https://www.iup.uni-bremen.de/UVSAT/data/
BDC(t)	Eddy heat flux (100 hPa, 45°S-75°S)	https://www.iup.uni-bremen.de/OREGANO/proxy

E(t)	Multivariate ENSO Index (MEI V2)	https://psl.noaa.gov/data/climateindices/list/
AAO(t)	Antarctic Oscillation (AAO)	https://www.cpc.ncep.noaa.gov/products/precip/CWlink/daily_ao_index/aao/aao.shtml

Thank you.

p. 8, l. 172: "Antarctic ozone recovery exhibits strong seasonal dependence, particularly the contrasting behavior in September and October" -> Please provide some more explanation for this statement and a reference.

Yes, we agree with you. We have revised it and added references as follows.

"Antarctic ozone recovery exhibits strong seasonal dependence, especially in the spring. While chemical processes dominate in September, dynamical factors exert greater control in October (Strahan et al., 2014; Solomon et al., 2016; Stone et al., 2021)." (L189-190)

"Strahan, S., Douglass, A., Newman, P., and Steenrod, S.: Inorganic chlorine variability in the Antarctic vortex and implications for ozone recovery, J. Geophys. Res.: Atmos., 119, 14,098-014,109, https://doi.org/10.1002/2014JD022295, 2014." (L521-523)

"Solomon, S., Ivy, D. J., Kinnison, D., Mills, M. J., Neely III, R. R., and Schmidt, A.: Emergence of healing in the Antarctic ozone layer, Science, 353, 269-274, https://doi.org/10.1126/science.aae0061, 2016." (L511-512)

"Stone, K., Solomon, S., Kinnison, D., and Mills, M. J.: On recent large Antarctic ozone holes and ozone recovery metrics, Geophys. Res. Lett., 48, e2021GL095232, https://doi.org/10.1029/2021GL095232, 2021." (L519-520)

Thank you.

p. 8, l. 177: "September shows signs of recovery" -> According to table 3, all trends are very close to zero and statistically not significant. I suggest to mention this here. The same holds for October; the negative trends are statistically not significant.

Yes, we agree with you. We have revised it.

"To ensure consistency across datasets with different temporal coverage, trends were analyzed for 2001-2023. During this period, the trends are not statistically significant, with September closer to zero and October exhibits a decline of approximately -1 DU/yr." (L194-196)

Thank you.

p. 9, ll. 190-194: September trends are positive for both periods (2001-2019 and 2001-2023), but for 2001-2023, the trends are very close to zero and reduced by a similar value as the October trends. Dynamical processes do not only affect October values (see also your Fig. 7).

Thank for your suggestion. We have revised this as follows.

"After 2000, September consistently exhibits positive trends. However, anomalously low ozone levels persistently observed during 2020-2023 attenuated the trend from 2001 to 2023, bringing it closer to zero. October trends shift from weakly positive (0.3 ± 3.2 DU/yr for 2001-2019) to negative (-1.5 ± 2.4 DU/yr for 2001-2023). This shift suggests that EESC might not accurately reflect the ozone changes in October. Furthermore, the decline in the trend over the past two months has been similar, indicating that other factors (e.g. BDC) have become more important for spring ozone depletion under ODS controls." (L208-213)

Thank you.

p. 11, l. 206: "September shows a weak positive trend of 0.1" -> I suggest to rephrase. This is rather "close to zero" than positive. And it has a large 2-sigma uncertainty (1.8DU/year).

Yes, we agree with you. We have revised this as follows.

"In September, the trend of TOMCAT was close to zero, while the trend estimated by the TOMCAT-based MLR showed a negative trend (-0.7 DU/yr)." (L226-227)

Thank you.

p. 11, l. 207: "can explaining" -> I suggest to rephrase, e.g.: "The independent variables in the MLR can explain about 85%..."

Thank for your suggestion.

"The long-term ozone changes in the MLR can explaining about 85 % of the variance in the interannual time series." has been modified to "The independent variables in the MLR can explain about 85 % of the variance in the interannual time series. " (L229)

Thank you.

p. 12, ll. 208-209: Can this be also related to the possibility that models do not entirely capture the complete variability of the atmosphere?

Yes, you are right. We can't guarantee that MLR models can entirely capture the complete variability of the atmosphere, but it can effectively reproduce the ozone time series. We have added this as follows.

"Table 3 indicates that the independent variables in the MLR models effectively reproduce the ozone time series for each dataset. ... Among these datasets, the MLR of TOMCAT accurately reproduced long-term ozone changes ,explaining 91% of the variance in the September time series." (L228-231)

Thank you.

Line 209: Replace "observed" with "simulated".

Sorry for my carelessness. We have modified it as follows.

"observed" has been modified to "simulated". (L230)

Thank you.

p. 12, l. 220: "However, positive trends dominate the middle and lower stratosphere" -> replace "middle" by "upper"; positive trends are found around 2-3 hPa.

Sorry for my carelessness. We have modified it as follows.

"middle" has been modified to "upper". (L243)

Thank you.

p. 14, l. 238: ", with BDC being the main driver of long-term ozone changes" -> I would suggest to rephrase: ", with BDC being the main driver of interannual ozone variation and an important contributor to long-term ozone changes."

Thank for your suggestion. We have modified it as follows.

"with BDC being the main driver of long-term ozone changes" has been modified to "with BDC being the main driver of interannual ozone variation and an important contributor to long-term ozone changes " (L272)

Thank you.

p. 14, Fig. 6: Do I understand correctly, that these peak contributions shown in Fig. 6 were obtained from the curves in Figure 5? If so, I do not see peak contributions of the BDC of 80-100DU (Fig. 6) in the curves of Fig. 5 (b) and (c). Please explain, what you mean with "rate of ozone change [in percent]"?

Thank you for pointing this out. We have deleted Figure 5 and added explanations about peak contributions (see Eq. (2)).

"To quantitatively describe the contribution of different factors on the ozone, we calculated the peak contribution of the proxies to ozone and its rate of change. The contribution equation is shown in Eq. (2):

$$\triangle TCO[\%]=\frac{max(X(t))-min(X(t))}{mean(y(t))}\times 100\% \qquad (2)$$

where max(X(t))−min(X(t)) represents the peak contribution, X(t) is the contribution of different factors to ozone during the period 1979-2023, and y(t) is the TCO time series." (L155-161)

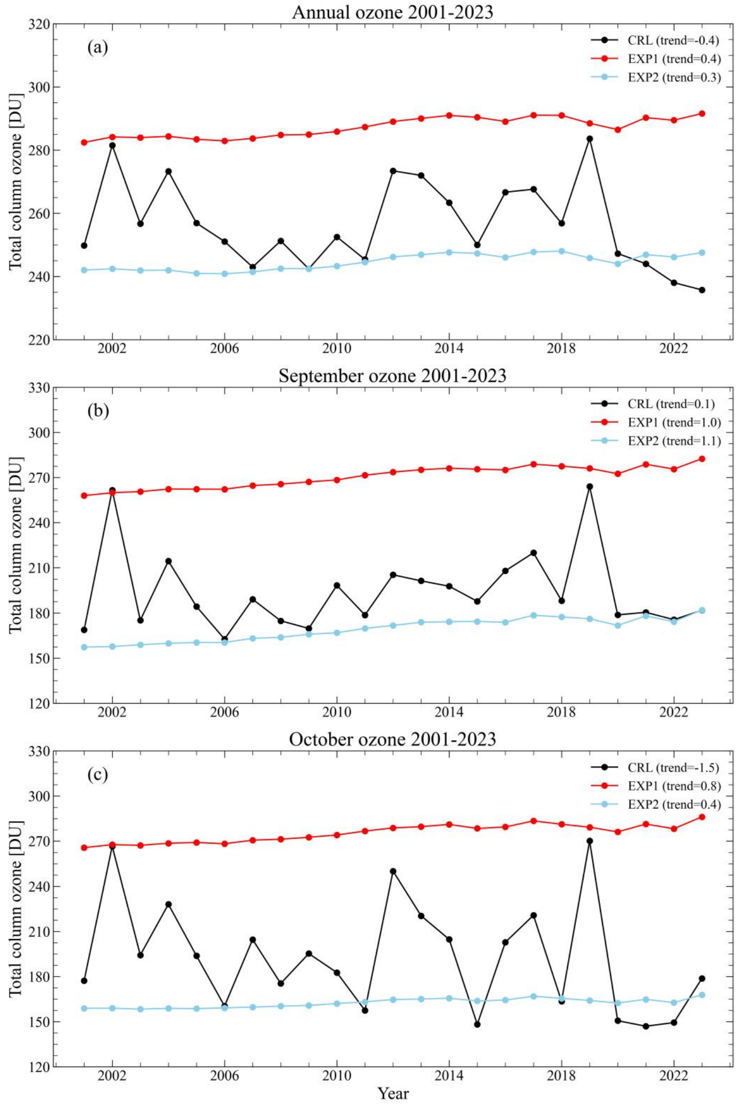
"The rate of peak contribution in percent is labelled above each bar." (L251)

"Based on Eq. (2), we evaluated the peak contribution of each proxy to TCO (Fig.5)." (L254)

Thank you.

p. 17, Figure 7: Title: the period shown here is 2000-2009.

Sorry for my carelessness. We have revised it (see Figure 7).



Thank you.

p. 18, Fig. 8(b) and p. 19, Fig. 9(b): The year 2000 is quite different in EXP1; lower ozone values compared to the subsequent years, but EHF (Fig. 9b) is also quite low in October (green curve). Do you have an explanation?

Thank for your suggestion. We have redrawn the Figure 7-9 and mainly analyzed the changes from 2020 to 2023.

"TCO values dropped to approximately 150 DU in October-November during 2020-2022, significantly lower than in most years of the 2001-2019 period. ... Nevertheless, ozone levels in recent years (2020-2023) are significantly elevated compared with most of the past two decades." (L318-323)

"Figure 9a shows the monthly mean temperature at 50 hPa from 2001 to 2023. The cooler temperatures in the spring and winter from 2020 to 2022 were associated with the persistently low ozone values. ... The higher springtime temperature and EHF in 2023, compared with the springs of 2020-2022, contributed to the elevated ozone concentrations (Fig. 8a). ” (L329-334)

Thank you.

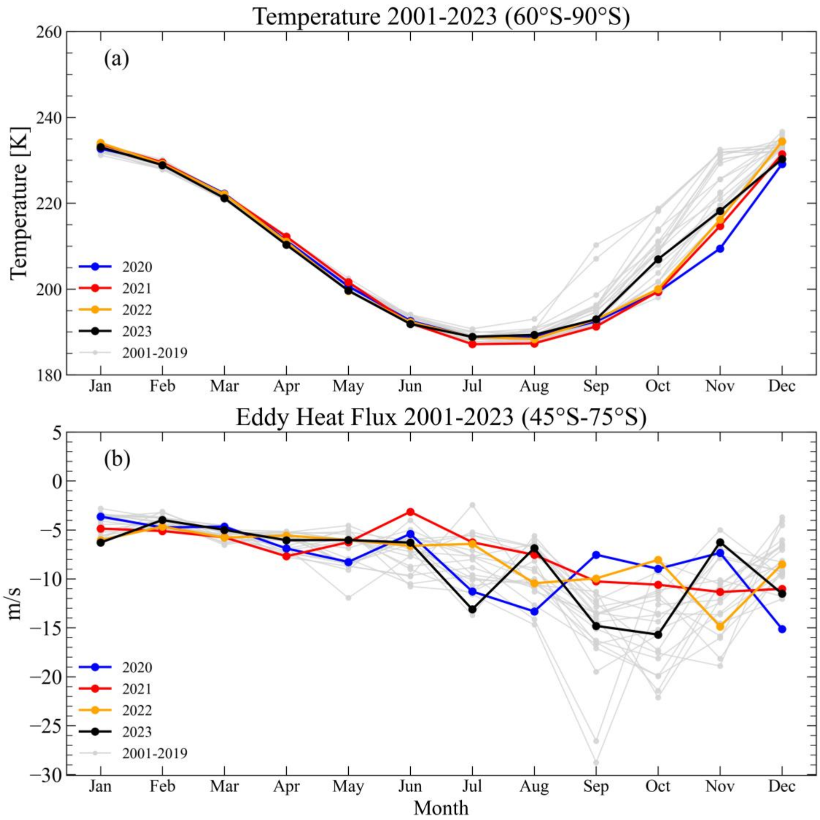
p. 19, Figure 9:

(i) Title of top panel: “Tempetature” -> “Temperature”

(ii) I would suggest to highlight the exceptional years 2002 and 2006 in both panels a bit more for better visibility.

Thank you for pointing this out. We have revised it (see Figure 9) and mainly analyzed the changes from 2020 to 2023.

“Figure 9a shows the monthly mean temperature at 50 hPa from 2001 to 2023. The cooler temperatures in the spring and winter from 2020 to 2022 were associated with the persistently low ozone values. ... The higher springtime temperature and EHF in 2023, compared with the springs of 2020-2022, contributed to the elevated ozone concentrations (Fig. 8a). ” (L329-334)



Thank you.

p. 19, l.306: “(Fig. 8 and Fig. 9a)” -> Do you mean Fig. 7 and Fig. 8a?

Yes, you are right. We have modified the expression.

“Figure 9a shows the monthly mean temperature at 50 hPa from 2001 to 2023.” (L329)

“As shown in Fig. 9b, EHF was high in the spring during 2020-2022, indicating the weakened circulation and reduced ozone transport from the tropics to the polar regions.” (L331-332)

Thank you.

p. 20, ll. 331-332: I suggest to rephrase this sentence. Please explain the impact of the BDC. The start a new sentence for volcanic aerosols.

Thank for your suggestion. We have revised and supplemented this as follows.

“Proxy analysis highlights the dominant role of BDC in the Antarctic spring, and BDC contributions to ozone changes exhibited a positive correlation with TCO during 2001-2023. Despite SAOD contributes about 25 DU to long-term ozone interannual variability, this signal was largely driven by the elevated aerosol loading following the Pinatubo (1991) volcanic eruptions.” (L350-353)

Thank you.

p. 23, ll. 395-397: Reference refers to article in ACPD. Replace with reference to final revised version in ACP.

Dhomse, S. S., Kinnison, D., Chipperfield, M. P., Salawitch, R. J., Cionni, I., Hegglin, M. I., Abraham, N.L., Akiyoshi, H., Archibald, A. T., Bednarz, E. M., Bekki, S., Braesicke, P., Butchart, N., Dameris, M., Deushi, M., Frith, S., Hardiman, S. C., Hassler, B., Horowitz, L. W., Hu, R.-M., Jöckel, P., Josse, B., Kirner, O., Kremser, S., Langematz, U., Lewis, J., Marchand, M., Lin, M., Mancini, E., Marécal, V., Michou, M.,Morgenstern, O., O'Connor, F. M., Oman, L., Pitari, G., Plummer, D. A., Pyle, J. A., Revell, L. E., Rozanov,E., Schofield, R., Stenke, A., Stone, K., Sudo, K., Tilmes, S., Visioni, D., Yamashita, Y., and Zeng, G.:Estimates of ozone return dates from Chemistry-Climate Model Initiative simulations, Atmos. Chem.Phys., 18, 8409–8438, https://doi.org/10.5194/acp-18-8409-2018, 2018.

Thank you for pointing this out. The corresponding reference has been revised.

“Dhomse, S. S., Kinnison, D., Chipperfield, M. P., Salawitch, R. J., Cionni, I., Hegglin, M. I., Abraham, N. L., Akiyoshi, H., Archibald, A. T., Bednarz, E. M., Bekki, S., Braesicke, P., Butchart, N., Dameris, M., Deushi, M., Frith, S., Hardiman, S. C., Hassler, B., Horowitz, L. W., Hu, R. M., Jöckel, P., Josse, B., Kirner, O., Kremser, S., Langematz, U., Lewis, J., Marchand, M., Lin, M., Mancini, E., Marécal, V., Michou, M., Morgenstern, O., O'Connor, F. M., Oman, L., Pitari, G., Plummer, D. A., Pyle, J. A., Revell, L. E., Rozanov, E., Schofield, R., Stenke, A., Stone, K., Sudo, K., Tilmes, S., Visioni, D., Yamashita, Y., and Zeng, G.: Estimates of ozone return dates from Chemistry-Climate Model Initiative simulations, Atmos. Chem. Phys., 18, 8409-8438, https://doi.org/10.5194/acp-18-8409-2018, 2018.” (L432-438)

Thank you.

p. 23-24, ll. 427-430: Something seems to be wrong with initials, please check.

Sorry for my carelessness. The corresponding reference has been revised.

“Harris, N. R. P., Kyrö, E., Staehelin, J., Brunner, D., Andersen, S. B., Godin-Beekmann, S., Dhomse, S., Hadjinicolaou, P., Hansen, G., Isaksen, I., Jrrar, A., Karpetchko, A., Kivi, R., Knudsen, B., Krizan, P., Lastovicka, J., Maeder, J., Orsolini, Y., Pyle, J. A., Rex, M., Vanicek, K., Weber, M., Wohltmann, I., Zanis, P., and Zerefos, C.: Ozone trends at northern mid- and high latitudes - a European perspective, Ann. Geophys., 26, 1207-1220, https://doi.org/10.5194/angeo-26-1207-2008, 2008.” (L460-463)

Thank you.

p. 26, ll. 504-505: Year is missing.

Sorry for my carelessness. The corresponding reference has been revised.

“Wellemeyer, C., Bhartia, P., Taylor, S., Qin, W., and Ahn, C.: Version 8 Total Ozone Mapping Spectrometer (TOMS) Algorithm, paper presented at Quadrennial Ozone Symposium, Eur. Comm., Kos, Greece, 2004.” (L545-546)

Thank you.