Comparison of Inorganic Chlorine in the Antarctic and Arctic lowermost stratosphere by separate Late Winter aircraft measurements

We would like to thank again for the constructive comments on our manuscript. In the following, we address the respective proposals for improvement. The changes are explained in detail and answered point by point. Reviewer comments are in normal font. Our answers are in italic and changes to the manuscript in blue.

Response to Referee #2

Abstract & Section 1:

- L1: extend --> extent

  Done.

- L12-13: could be --> was (in all three places in these two lines)

  Done.

- L50: delete “results”

  Done.

Section 2:

- L78: No need to define “RGA” here as the airport codes are given in L84-85

  RGA was deleted at this point.

- L90: type --> types

  Done.

- L98: ERA-5 data --> ERA-5

  Data was deleted.

- L99: dynamic --> dynamical

  Done.

- L100: the 2 PVU --> 2 PVU

  Done.

- L101: potential temperature ... as tropopause --> the potential temperature ... as the tropopause

  Done.

- L110: the spelling of “ionisation” here is inconsistent with that in L111 and L144

  We changed “ionisation” to “ionization” to be consistent with L111. L144 does not contain information about the ionization.

- L122: precision ... measurement were --> precision ... measurements was

  Done.

- L128: 0.2% and 0.64% --> 0.2% and 0.64%, respectively

  Done.

Section 3:

- L146: region --> region of origin

  Done.

- L150: reanalysis --> reanalyses

  Done.

- L153: theta has already been defined in L53 and is again defined in L174, so it does not need to be defined here

  We excluded the (θ) in this line.

- L154-160: Much of this discussion repeats concepts that have already been covered adequately in the Introduction (L47-54). Since the audience for this paper is likely to be quite familiar with this background material, it is arguably not necessary to include it at all, but in any case it certainly does not need to be reiterated. I suggest merging and streamlining the description in these two places. In addition, it would be better not to have two sentences in one paragraph starting with “A tracer like N_2O ...”.

  We agree that the discussion regarding the polar vortex is repetitive in this section. We thus refer to the previous description of the polar vortex with the important insight for us that the trace gas mixing ratios inside and outside the vortex differ. Furthermore, as N_2O was introduced a few sentences before, the first “A trace like N_2O…” was rewritten. The new wording is as follows:

"[…] N_2O can be measured in situ with a high time resolution to reveal small scale structures in the atmosphere. As already mentioned in the introduction, air inside the polar vortex has a substantially different composition regarding trace gases than air outside the vortex. A tracer like N_2O … […]"

- L158: a subsidence --> subsidence

  By rewording, this expression is omitted.

- L160-161: a small variability --> small variability

  Done.

- L162-163: "the vertical gradient in mid-latitude N_2O" – is vertical gradient really meant here, or horizontal gradient?

  Yes, the vertical gradient is meant here. The vertical profile of N_2O in the mid-latitudes shows a smaller decrease with altitude but the variability of the profile is larger due to the influence of both, polar and tropical air. For less confusion, we have rewritten this sentence as follows:

  "[…] The vertical profile of N_2O in the mid-latitudes shows a weak gradient but a high variability as it is influenced by both tropical and polar air […]"

- L163: it would be clearer to say "both tropical and polar air"

  Done, see comment before.

- L171-172: affected by the diabatic decent --> affected by diabatic descent [typo: "decent"]

  Done.

- L176-202: Overall, the description of the reference profile derivation has been improved in the revised manuscript. However, additional points of clarification are needed:

  ○ L183: I am confused about the binning in θ (or Δθ). It is stated here that the measurements are binned in 5 K intervals. But according to the Appendix, that is true only for the vortex reference; for mid-latitudes, a 2 K bin was used. But then Figure S2 and its caption suggest that both 2 K and 5 K bins are used for both vortex and midlatitude profiles at different stages of the process. Please clarify.

  I am very sorry for the confusion. The 2 K bins are used for the iterative process mentioned in the appendix (5 K bin was a remnant from the first draft. We apologize and correct it). After the iterative process, as an intermediate step for both profiles, the remaining measurements are binned in 5 K bins as described in the text. This can be seen in Figure S 2 c) and d). Since we have only written "(see Figure S 2)" this can lead to confusion. Therefore, we added c) and d).

"[…] (see Figure S 2 c and d) […]"

- L189: the descending stops --> descent generally stops

Done.

- L192: I do not think that "calculated" is the right word here. Measurement points are being categorized to segregate them into the N_2O_{vor} and N_2O_{mid} data sets but saying that these data sets are "calculated" gives the impression that some other manipulation is being done.

The essential information is missing. We apologize for this inaccuracy. The N_2O_{vor} and N_2O_{mid} data set are calculated from θ or $\Delta\theta$ using the fit function for every N_2O measurement point of the UMAQS instrument for all flights. We have added this information with the following reformulation:

"[…] A vortex and mid-latitude reference N_2O data set (N_2O_{vor} and N_2O_{mid}) can be calculated from θ or $\Delta\theta$ by using the fit function for the vortex and mid-latitude profiles for every measurement point of the UMAQS instrument for all flights […]"

- L194-199: These sentences are particularly badly written and the English is very confusing. Words like "added" are misused, and, unless I have misunderstood, the N_2O data sets are being mixed up with the fit functions. Assuming this is an accurate description, I suggest rewriting these lines as: "The following then applies for each N_2O measurement: if the mixing ratio is below the vortex fit function plus the prescribed cutoff value, then it is assigned to the N_2O_{vor} data set. Otherwise, if the mixing ratio is above the mid-latitude fit function minus the associated variability, then it is assigned to the N_2O_{mid} data set. Mixing ratios above the vortex fit function plus the prescribed cutoff value and below the mid- latitude fit function minus the associated variability are assigned to the boundary region. Measurements for which the vortex fit function plus the prescribed cutoff value and the mid-latitude fit function minus the associated variability overlap cannot be uniquely classified and are assigned to both the vortex and the mid-latitudes in later analysis."

In the previous point we clarified that the N_2O measurements are not mixed up with the fit functions. Nevertheless, we have largely rewritten this section according to suggestions given.

"[…] The following then applies for each N_2O measurement: if the mixing ratio is below the respective N_2O_{vor} plus the prescribed vortex cutoff, then it is assigned to the vortex. Otherwise, if the mixing ratio is above the respective N_2O_{mid} minus the associated variability, then it is assigned to the mid-latitudes. Mixing ratios above the respective N_2O_{vor} plus the prescribed vortex cutoff and below the respective N_2O_{mid} minus the associated variability are assigned to the boundary region. Measurements for which the respective N_2O_{vor} plus the prescribed vortex cutoff and the N_2O_{mid} minus the associated variability overlap cannot be unique classified and are assigned to both the vortex and the mid-latitudes in later analysis. […]"

- L200: the prescribed cutoff value --> the prescribed vortex cutoff

  Done.

- L201: variability N_2O --> variability in N_2O

  Done.

- L201-202: The reader is referred to the supporting information "and reference therein". However, no references are given in the SI, and in fact this discussion has been moved from the SI to the Appendix. But rather than refer to the Appendix, it would probably be better to simply cite Strahan et al. (1999) here for this point.

  We apologize for this, which is a remnant of the first submission. We now cite Strahan et al. (1999) here as suggested.

- Figure 2 caption: Cutoff criterion --> The vortex cutoff criterion (see main text for details); where cutoff and mid-latitude variability crosses --> where the vortex cutoff and mid- latitude variability cross

  Done; Done.

- L213: Vortex and boundary region --> The vortex and boundary regions

  Done.

- L214: The first phase contains some flights that have predominantly sampled vortex --> The first phase includes some flights that predominantly sampled the vortex

  Done.

- L216: vortex boundary layer --> vortex boundary air

  Done.

Section 4:

- L222: took --> take; this means sampling air along --> this means that air is sampled along

  Took was changed to takes; Done.

- L228: both channels --> the two channels

  Done.

- Figure 4 caption: measured on ... and on --> measured in ... and in

  Done.

- L230: measurements on --> measurements in

  Done.

- L235: show a higher --> show higher

  Done.

- L238: up-sampled --> up-sampled data

  Done.

- Figure 5 caption: The first sentence of the caption needs to be re-written to make it clear what the comparison is with. Also, measured on --> measured in

  The second sentence explains the difference between the red and black profile. We deleted "Comparison" at the beginning so that it is clear that only CFC-11 is shown in this Figure; Done.

- L244: Air enters predominantly --> Air enters the stratosphere predominantly

  Done.

- Section 4.2: The discussion of the semi-direct and indirect calculations of Cl_y remains quite confusing.

  - Unless I am mistaken, what is referred to here as the "semi-direct" calculation – that is, Eqn. (1) – is performed twice: once with CCl_y obtained from up-sampled GhOST-MS measurements, and a second time with CCl_y calculated from CFC-12 alone. This is not immediately clear from the current text, but it should be spelled out explicitly. For example, the distinction can be drawn between the calculations mentioned in L257-258 and those mentioned in L282-284, with Eqn. (1) referenced in both places.

    We have taken the suggested changes and referred to Eq. 1 at proposed places:

    "[…] In the following, Cl_y derived from the difference between the estimated entry mixing ratios and observed CCl_y from the in situ measurements (see Eq. 1) is referred to as the semi-direct calculation of Cl_y. […] As already mentioned earlier, Cl_{total} is also needed for the calculation of Cl_y (see Eq. 1). […]"

  - L275-277: These lines talk about comparing the semi-direct Cl_y values from SouthTRAC to "indirectly determined" values, but Figure 6 shows only the correlations of various species with CFC-12, not Cl_y. Also, indirectly determine --> indirectly determined

This sentence is meant to introduce the reader to what follows in the rest of this subsection. After carefully reading this sentence again, it is indeed confusing that only the semi-direct Cl_y is mentioned at this point. It would have been better to mention both semi-direct and indirect Cl_y or to delete both from the sentence. For more clarity, we have deleted "semi-direct Cly" at this point in the text, as the next lines only show the comparison of the correlations and the comparison of Cl_y appears later in this subsection.

- L280: form --> from

Done.

- L284: delete "hereafter"

Done.

- Then, again assuming that I have understood the process, once CCl_y has been derived just from CFC-12 data (the second step above), a curve is fit to those values to obtain the coefficients for the "indirect" method of Eqn. (2). Is that correct? The problem is, at this point the reader has no idea why this extra step is needed. So far only SouthTRAC measurements have been discussed, and for them Cl_y can be obtained semi-directly from Eqn. (1) with the in situ CCl_y data (the first step above). The justification of the need for the indirect approach should come *before* it is presented, not after.

It is correct, that at this point CCl_y is derived from CFC-12 alone. Additionally, Cl_{total} is also derived from the mean age of air from the balloon measurements, already mentioned in the paragraph. The justification of the indirect method can be found at the beginning of this paragraph with "For the case where no measurements of chlorine containing substances …". We now complete the introductory sentence of this paragraph with an outlook that the indirect method is needed for the comparison with the NH.

"[…] For the case where no measurements of all major chlorine containing substances are available, Cl_y has in the past been calculated indirectly based on correlations derived from previous measurement campaigns. This also applies to Cl_y from the Northern Hemisphere, later in the analyses (see section 4.4). […]"

- In addition, the paragraph in L259-294 is extremely long and tiring to read. Thus I suggest inserting a paragraph break in L284, after "between Cl_{total} and CCl_y". The new paragraph should begin with a brief sentence of explanation as to why it is necessary to go through the effort of implementing the indirect approach, maybe something along the lines of: "With the good agreement between the two semi-direct Cl_y calculations, we explore whether Cl_y can be successfully estimated from CFC-12 for situations in which measurements of CCl_y are not available. That is, a correlation function ...".

We acknowledge that this paragraph is very long, and potential readers can thereby lose track. We further therefore now start a new paragraph after "between Cl_{total} and CCl_y". The beginning of the new paragraph was changed slightly as follows:

"[…] With the good agreement between observed correlations and scaled correlations from the balloon measurements and the previously described determination of Cl_y, we explore whether Cl_y can be successfully estimated from CFC-12 alone. That is, a correlation function… […]"

- L288: correlation to --> correlation with

Done.

- L291: Just to be really clear: CFC-12 ... is used for --> CFC-12 ... is used as the reference in Eqn. (2) for

Done.

- L297: Very young air also shows larger differences between the two Cl_y estimates.

To be more precisely, we have rewritten the following sentence:

"[…] The difference between the two methods is rather small, with less than around 30 ppt difference between 1 and 4 years of mean age and a maximum difference of about 65 ppt at 5 years of mean age. […]"

- L298: the suggested lifetime --> its suggested lifetime

Done.

- L301: I think it would be clearer to say "... age tracers. The fundamental picture does not change, however, hence we use the uncorrected mean age of air."

Thanks for the more appropriate description. Changes were done as suggested.

- L314: delete "of θ"

Done.

- L315: errorbars --> error bars

Done.

- L316-317: Cl_y is given for all measurements --> the Cl_y is estimated based on all measurements

Done.

- L317-318: Cl_y is given according to the region --> Cl_y is estimated separately in each region

  Done.

- L320-322: First, Figure 8 should be referenced again at the beginning of this paragraph. Second, it is stated that the SouthTRAC measurements of long-lived chlorinated substances are consistent with the Cl_{total} from AGAGE, but I'm not sure exactly what that means. Is this statement referring specifically to the troposphere?

  We included "In Figure 8 …" at the beginning of this paragraph. Yes, this statement is referring to the troposphere. The near zero Cl_y throughout the troposphere indicates, that the observations during the SouthTRAC campaign is very close to Cl_{total} that we have determined using the AGAGE time series. However, one can also draw the conclusion that the calibration of our stratospheric measurements of the chlorinated substances is consistent with the AGAGE calibration scales. We have rewritten the sentence regarding the consistency with the AGAGE measurements as follows:

  "[…] The tropospheric measurements during SouthTRAC are thus consistent with Cl_{total} derived from ground based AGAGE measurements. […]"

- Figure 8 caption: -90° to -40° --> 40°-90° S

  Done.

- L329: at highest --> at the highest

  Done.

- L330: that in 2018 mid-September --> that in mid-September 2018

  Done (L332 not L330).

- L344-345: provide comparable --> provide values comparable

  Done.

- L352-353: With a mean PV-based tropopause at 306 K, during PGS, it is only slightly lower than during SouthTRAC with 308 K --> The mean PV-based tropopause was at 306 K during PGS, only slightly lower than that during SouthTRAC at 308 K

  Done.

- L355-357: First, I'm not sure what "considering the long-lived chlorinated substances" means. Does this statement refer to WMO (2018)? More importantly, the difference between the rate of decline seen in this study and that reported in WMO (2018) (~16 vs. 12.7 ppt/yr) is nonnegligible (~25%). Can the authors speculate on what is giving rise to this discrepancy? Does it imply something about the accuracy of their estimated Cl_y values?

The value of 12.7 ppt/yr from the WMO (2018) represents the total controlled chlorine, e.g. all CFCs, CCl_4, HCFCs, CH_3CCl_3 and halon-1211. Instead of saying "considering the long-lived chlorinated substances", the more correct expression is "for the controlled substances", which we included in our manuscript.

We have deleted the decline rate derived from the difference in Cl_{total} during PGS and SouthTRAC (the given 16±2.6 ppt/year). Instead, we use the decline rate from the WMO Report (2018) to show that around 45 ppt of the difference in Cl_{total} between the two campaigns (60 ppt) can be explained by the decline rate of -12.7±0.9 ppt derived in WMO (2018). The remaining 15 ppt can be explained by the higher Cl_{total} in the Northern Hemisphere. We added the following information to the manuscript as follows:

"[…] The difference between Cl_{total} from controlled substances during PGS and SouthTRAC is about 60±9.6 ppt. This difference can be explained by a combination of temporal trends of controlled substances and interhemispheric gradients. Using the rate of decline from Engel and Rigby (2018) of -12.7±0.9 ppt $year^{-1}$ for the controlled substances, a difference of about 45 ppt is expected due to the time difference between the two campaigns. The remaining difference of about 15 ppt can be explained by the higher Cl_{total} in the Northern Hemisphere […]"

- L362-364: This sentence is very difficult to read and confusing. Assuming that I have interpreted it correctly, I suggest re-writing as: "The maximum fraction of total chlorine in the form of Cl_y during PGS at the same distance from the local tropopause as the maximum SouthTRAC Cl_y fraction is about 20% in the mid-latitudes (not shown) and about 40% inside the vortex (Fig. 9b)." Note that the original sentence suggested that the comparison was being made at the same Δθ as the largest values *inside the vortex* during SouthTRAC, but I assume that that was not what was actually done for the mid-latitudes. Also, if the NH mid- latitude result has been shown in this paper, then a specific pointer to it should be added.

  We thank you for the suggestion, which we almost completely used in the manuscript. We get these rough percentages at the same $\Delta\theta$ as the largest values inside the vortex during SouthTRAC, as you suggested.

  "[…] The fraction of total chlorine in the form of Cl_y during PGS at the same distance from the local tropopause as the maximum SouthTRAC Cl_y fraction is about 20% in the mid-latitudes (not shown) and about 40% inside the vortex (Fig. 9b). […]"

- Figure 9 caption: It would be better to turn the fourth sentence around: PV tropopauses for PGS (black) and SouthTRAC (green) are displayed as dashed horizontal lines with the 1σ variability as shaded areas.

  Done.

- L367-368: of each respective hemisphere --> of the two hemispheres

  Done.

- L376: For maximum clarity, add “(Fig. 9)” after “measurements”. Also, rather than “vortex and outer vortex”, it would be better to say “vortex core and vortex edge”.

  We added “(Fig. 9)” at the suggested position and changed “vortex and outer vortex” to “vortex core and vortex edge”.

- L376-379: It doesn’t make sense that two sentences about the mid-latitudes (L377-378) are interposed between sentences (L376 and L379) talking about the vortex comparisons. Thus the sentence “It must be noted that ... transport barrier.” should be moved up and edited/merged with the sentence in L376.

  We rearranged theses lines according to the suggestion as follows:

  “[…] Thus, it is very likely that vortex core and vortex edge values are compared due to the different Arctic and Antarctic vortex size, stability and strength of the transport barrier. Therefore, performing the comparison in equivalent latitude/potential temperature coordinates removes only some of the sources of discrepancy. The stratosphere of the mid-latitudes shows consistently higher Cl_y values during PGS. The highest values of Cl_y reached are 315 ppt greater during PGS between 65 and 70 K of $\Delta\theta$ and 40 to 45 ° equivalent latitude. […]”

- L380: The comparison on equivalent latitude is therefore only possible to a limited extent --> Therefore performing the comparison in equivalent latitude / potential temperature coordinates removes only some of the sources of discrepancy

  Done (see point above).

- L380-395: The entire discussion of the interhemispheric differences in Fig. 10 is poorly written and not well thought-through. The authors have placed on the reader the burden of figuring out how previously reported BDC and age of air differences may be related to the differences in Cl_y that they observe. The linkage between differences in age of air (and the trends therein) and Cl_y differences must be drawn much more explicitly in the paper. The discussion of how their results relate to previous mid-latitude trends is also muddled.

  We address this discussion by responding to the following comments that relate to it.

  - L382: Konopka et al. (2015) showed, that north of 60 °N, age of air is always younger than south of 60 °S in the same season --> Konopka et al. (2015) showed that the age of air is always younger north of 60 °N than south of 60 °S in the corresponding season

    Done.

  - Since air is younger north of 60N than it is south of 60S, it seems to me that lower values of Cl_y are expected at NH high latitudes than at SH high latitudes, as seen in Figs. 9 and 10. I do not believe that such a statement is made in the manuscript.

We have linked to our results in this regard following the findings of Konopka et al. (2015). The following was added right after presenting the result of Konopka et al. (2015):

"[…] Older air will be higher in Cly as a larger fraction of total chlorine has already been transformed to the inorganic form. The differences in age of air found by Konopka et al. (2015) are therefore consistent with the observed differences in Cl_y with higher Cl_y values in the southern high latitudes than in the northern high latitudes (see Fig. 9 and 10). […]"

- How do the differences in Cl_{total} between the two campaigns – which are not well explained as noted above – interact with / affect the interhemispheric Cly differences?

We further explained the difference in Cl_{total}, as can be seen above in the comments. As explained above, the difference of around 60±9.6 ppt can be explained by a combination of temporal decline and interhemispheric differences and is consistent with tropospheric observations. This maximum difference of 60±9.6 ppt would only propagate completely to Cl_y when all chlorine is converted to the inorganic form. Taking into account the difference in Cl_{total} between the two campaigns will reduce the observed differences in the mid-latitudes with higher MR during PGS and increase the differences in the high latitudes with higher MR of Cl_y during SouthTRAC. However, the effects should be small, and the differences shown between NH and SH Cl_y are considerably larger than can be explained by the differences in Cl_{total}. We have tried to briefly mention the effect of Cl_{total} decline in the text with the following statement in section 4.4:

"[…] The already mentioned difference of Cl_{total} between PGS and SouhTRAC amounts to 60±9.6 ppt. This maximum difference of 60±9.6 ppt will only propagate completely to Cl_y when all chlorine is converted to the inorganic form. Taking into account the difference in Cl_{total} between the two campaigns will reduce the observed differences in the mid-latitudes with higher mixing ratios of Cl_y during PGS and increase the differences in the high latitudes with higher Cly derived for the SouthTRAC campaign. The observed differences in Cl_y are thus clearly larger than they can be explained by the temporal difference of Cl_{total}. […]"

- The authors mention recent work quantifying interhemispheric differences in the trends in AoA, but again the connection to their Cl_y results is not made explicitly. If there is a positive trend in AoA in the NH (i.e., air is getting older) and a negative trend in AoA in the SH (i.e., air is getting younger), then wouldn't that mean that Cl_y should be getting slightly larger in NH mid-latitudes and smaller in SH mid-latitudes? But surely these trends are very small and could not be expected to be evident above interannual variability over the three-year interval between the campaigns. Thus I am not convinced that AoA trends have any relevance for the observed Cl_y differences.

Assuming that you are referring to the set of results from Heanel et al. (2015). We agree that the given age of air trends have no relevance for our observed Cly differences. Therefore, we deleted this sentence.

- L385-390: The discussion of long-term trends in mid-latitude HCl and $ClONO_2$ has been largely lifted from WMO (2018) without attribution. While I applaud their desire to go back to original sources, the authors have been sloppy and careless in presenting this material. For example, they state that Mahieu et al. (2014) reported data "through the end of 2016". In fact, Mahieu et al. (2014) only show data through 2011; the plots are updated through 2016 in the WMO Report. Then it is stated that GOZCARDS lower stratospheric HCl shows "larger" decreases at SH latitudes – larger than what? Than the increases seen in the NH? The citation for this statement is Froidevaux et al. (2015), but a more recent paper by Froidevaux et al. published in 2019 would be a more up-to-date reference. Most importantly, nowhere in these lines in the manuscript are the actual trends for HCl and $ClONO_2$ quoted. According to WMO (2018), for the period 1997–2016, total column HCl decreased by $0.42\pm0.23\%yr^{-1}$ and total column $ClONO_2$ decreased by $0.60\pm0.39\%yr^{-1}$. It doesn't seem to me that trends of that magnitude could account for the >200 ppt difference in estimated mid-latitude Cl_y between the PGS and SouthTRAC campaigns seen in Fig. 10. Therefore the statement that "higher values of Cl_y in the mid- latitudes during PGS [seem] to be plausible" is not supported.

We apologize for the sloppy work in presenting the material and have carefully revisited this section. Regarding HCl and $ClONO_2$ from Mahieu et al. (2014), we clarify that Engel and Rigby (2018) reported an update from Mahieu et al. (2014). We now also present the trends listed in the WMO Report (2018). We updated the reference as well as the reported outcome by Froidevaux et al. (2015 and 2019). In addition, we have replaced the sentence " Thus, higher values of Cl_y in the mid-latitudes during PGS seems to be plausible ". The trends shown do not explain the difference shown in Fig. 10, but they do help to understand that there is an interhemispheric difference and in which direction it is moving.

"[…] In addition, Engel and Rigby (2018) showed an updated report to the long-term total column data for HCl and ClONO2 (representing Cl_y) by Mahieu et al. (2014) in the stratosphere, at Jungfraujoch (46.5 °N) and at Lauder (45 °S), through the end of 2016. A negative trend of Cl_y is observed at both stations but with a non-significant trend for the Jungfraujoch data over the last decade and a slightly larger negative trend from the Lauder data. In addition, trends between 1997 and 2016 are given at both stations with $-0.42\pm0.23\%$ year^{-1} for HCl and $-0.60\pm0.39\%$ year^{-1} for $ClONO_2$ at Jungfraujoch station and $-0.51\pm0.12\%$ year^{-1} and $-0.74\pm0.59\%$ year^{-1} at Lauder station, respectively. Furthermore, the Global Ozone Chemistry And Related trace gas Data records for the Stratosphere (GOZCARDS) shows short-term lower-stratospheric HCl trends, which are negative at southern latitudes and slightly positive (marginal significance) at northern mid-latitudes between 2005 and 2015/2018 (Froidevaux et al., 2015, 2019). Although the trends given are indicative of the interhemispheric differences in Cl_y, they do not explain the difference in Cl_y at mid-latitudes of about 200 ppt and above shown in Fig. 10 explicitly. […]"

- L391-392: It is not clear to me what is meant by “the lowest 20 K above the local tropopause show weak impact of the stronger Antarctic”. Is this sentence referring to the Antarctic vortex? Even if it is, its meaning is unclear. Moreover, in Fig. 10 bins in the lowest 20 K above the tropopause are not filled at the highest EqLs, so the relevance of the vortex is not clear.

  We agree that this statement is unclear. Moreover, the following sentence does not match well to the given statement here. We have therefore rewritten this sentence to not focus on the impact of the stronger Antarctic vortex. Instead, the statement should be, that the lowest 20 K above the local tropopause show in general minor differences between the two hemispheres, beside the exception given in the text.

  “[…] The lowest 20 K above the local tropopause show in general minor differences between the two hemispheres […]”

- L392: Two exceptions are singled out for discussion, but other bins in the vicinity show differences nearly as large.

  Only the exceptions with differences around 200 ppt were singled out. Other bins show slightly higher mixing ratios either toward PGS or SouthTRAC and are therefore not mentioned explicitly.

- L394: this range --> this θ range; almost zero --> generally small

  Done; Done.

Section 5:

- L411: Since a reference is included for the Arctic winter of 2015/2016, it would be appropriate to include one here for the Antarctic winter of 2019 as well.

  We included a reference for the statement of the weakened and shifted polar vortex in 2019. Reference used are Wargan et al. (2020) and Safieddine et al. (2020).

- L422: can be --> was (twice)

  Done.

- L423: vortex --> vortices

  Since we refer to respective vortex, vortex seems to be the appropriate form.

- L425: Elsewhere “inter annual” has been written as “inter-annual” (L18) and “interannual” (L37). Please be consistent.

  We now use inter-annual in all places in the manuscript.

- L431: can be --> were (twice)

  Done.

- L432-433: The statement “These hemispheric differences can also be found in simulations based on reanalysis, e.g., Konopka et al. (2015)” is a bit misleading here because the preceding sentence was about Cl_y, whereas Konopka et al. (2015) did not discuss Cl_y. Again, the connection between AoA and the Cl_y calculated in this work needs to be made directly.

  The connection between mean age and Cl_y was shortly introduced in section 4.2 in the discussion of Fig 7. “… inorganic chlorine increases with mean age of air, as more molecules of the organic sources are converted to the inorganic form”. Nonetheless, we agree that this sentence is misleading, as the reader may think Cl_y simulations were done in Konopka et al. (2015) which was not the case. We have rewritten this sentence as follows:

  “[…] Cl_y increases with increasing mean age of air, for which Konopka et al. (2005) derived similar hemispheric differences based on model simulations using meteorological reanalyses data. […]”

- L434: should be subject to --> should be the subject of

  Done.

- L435: which are not only used to --> which are used to not only

  Done.

- L436: reveal --> reflect

  Done.

Appendix, References, & Supplemental Material:

- L455: this corresponds --> 6 ppb corresponds

  Done.

- L460: outlier --> outliers

  Done.

- L628: implivations --> implications

  Done.

- L632: Arctiv --> Arctic

  Done.

- SI, L4: requieres --> requires

  Done.

- SI,L5:FigureS5-->FigureS4

  We changed it to "Figure S 4 and S 5 display … ".

- SI,L10:Fig.S7-->FigureS6

  Done.

- Figure S 7: It needs to be made clear in the caption that the displayed curves were derived from CFC-12 from GhOST-ECD and N_2O from UMAQS.

  We added the information leading to the following caption:

  "[…] **Figure S 7**: Indirectly determined inorganic chlorine using balloon based correlations and CFC-12 from the GhOST-ECD (green) and N_2O from UMAQS (black) during the SouthTRAC campaign as the reference substance. Absolute difference in red. […]"