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REPLY TO REVIEWER 1:

Review of "South Pole Station ozonesondes: variability and trends in the springtime Antarctic ozone hole 1986-2021" by Johnson et al., 2022 for ACP

GENERAL COMMENTS

This is a straightforward paper written by a group of authors who have been doing this work for several decades. My comments are therefore very minor and shouldn't require more than a couple of hours to address. The paper will then be suitable for publication in ACP.

SPECIFIC COMMENTS

Line 19: What do you mean here by a 'minimum ozone profile'? Do you mean the ozone profile with the lowest integrated vertical column of ozone in any given year?

We adjusted the sentence to tie in the minimum ozonesonde profile with the lowest total column ozone date: "Here we show additional details of these three years by comparing annual minimum profiles observed on the date when the lowest integrated total column ozone occurs…"

Line 40: I thought that the Montreal Protocol focused primarily on phasing out the production of ODSs not the emission of ODSs. But maybe I am wrong.

Correction made: replaced "emission" to "phasing out the production of ODSs"

Line 54: Do you not want to be noting the importance of sudden stratospheric warmings here?

The 2002 sudden stratospheric warming showed the most extreme and sudden increase in the South Pole stratospheric ozone and temperature profiles over South Pole. The 2019 event shows a similar breakdown in the vortex. They are important and rare events, but we decided to let the references cover the details of these continental size events that fit well with our single point observations at South Pole. We note later in the manuscript in a table the dates when these extreme events were observed at South Pole and the date interval for those events that were not included in the median and percentile ozone climatology.We adjusted the last paragraph sentence here to separately note and reference the weaker polar vortex conditions in 1986 & 1988 (Stolarski et al., (1990) followed by referencing the extreme polar vortex disruptions in 2002 and 2019 (Hoppel et al., 2003; Safieddine et al., 2020; Wargan et al., 2020).

Line 66: Is it the case that at the 89 hPa layer ozone is most sensitive to ODSs, or is it that it is at the 89 hPa layer a change from negative to positive ozone trend shows the most statistical significance? If the former, then this can be called ozone recovery. If the latter then it can only be referred to as ozone increases as the attribution would not be available to refer to it as recovery.

The latter is the case. We therefore changed all terms indicating "ozone recovery" to terms related to observational data trends: "ozone increases/decreases" or "lower/higher loss rates" to be more precise in our description.

The previous update paper by Hassler et al., 2011 investigated observed ozone loss rate profiles trends with statistical significance - comparing South Pole, Georg-Forster, and Neumayer ozonesonde data records. The paper also included a model incorporating equivalent effective stratospheric chlorine concentration time series to estimate when a reduction in future ozone loss rates will be detectable outside the range of dynamic variability as EESC levels decline. Hassler noted that while higher loss rates occur at 33 hPa, the model and statistical analysis suggested that significantly lower loss rates will first be detectable in the lower stratosphere (around 89 hPa) during the 2017-2021 period.

In this study here we followed these analyses up with updating the ozone mixing ratio loss rate at 5 selected pressure levels (33, 48, 67, 89 and 119 hPa) showing lower loss rates in the 2016-2020 period.

Line 99: I know that at other stations, when the CMR method is used to estimate the partial column above the balloon burst altitude, the CMR is integrated from the burst pressure to 1 hPa, not to 0 hPa as that showed better agreement with the SBUV residual method. I wonder if this may be contributing to your ozonesondes having slightly too high TCO?

It would be interesting to compute and check the ozone integrated amount above 1 hPa. We think it may only be a very small contribution to our TCO. At NOAA we have always used the simple version of the CRM residual calculation whereby multiplying the final ozone partial pressure (mPa) at or near balloon burst by the constant 7.89 which then gives the ozone DU column from burst up to 0 hPa. This equation is only valid with the assumption that the partial pressure of ozone is decreasing at the same rate as ambient pressure (ozone mixing ratio is constant with altitude). The NOAA ozonesonde analysis software (SkySonde – written by Allen Jordan) and previous version of ozonesonde software (Strato - written by Holger Voemel) both use the 7.89 calculation of residual. We also have on file a few pages (copy) from an old ozonesonde manual document from the early ozonesonde era - I think it is part of the manual from Dutsch - that shows they also used the residual calculation as ozone mPa x 7.89.

Line 108: By 'Met Service' do you mean the National Weather Service of the USA?

We change the sentences in Line 109 and 111 to explain the Met service at South Pole and note that this collaboration results in 2 radiosondes measuring temperature on board the high-altitude plastic balloons during the dark, cold winter when the standard rubber balloons will not reach the PSC region of the stratosphere. In this manuscript we only selected around 3 seasons to show a simple comparison but it would be an excellent project at some time to analyze all the dual radiosonde flights at South Pole.

Changed sentences to:

"The ozonesonde radiosonde temperatures were not adjusted in the homogenization of the data record. However, temperature accuracy for each flight was validated by comparing with an additional radiosonde flown by the Antarctic Meteorological Research Center (AMRC) at South Pole. For nearly a decade, the AMRC/South Pole Meteorology Office radiosondes (using Vaisala RS92 and Vaisala RS-41 GPS models) were "piggy-backed" on board the NOAA ozonesonde package. This is an important ongoing collaboration during the winter months when NOAA switches to the cold-resistant polyethylene 18K balloons to maintain burst altitudes of 30-34 km. This results in two independent temperature profiles to monitor the coldest temperatures in the polar stratosphere where PSCs begin to form. The typical radiosonde rubber balloon profile will fail/burst at 14-15 km over South Pole under these extreme cold and dark conditions."

The rightmost axes in Figure 2 need to be labelled with pressure (hPa).

done

Line 144: Replace 'potential recovery' with 'potential recovery of ozone from the effects of ODSs'.

done

I think that the Y axis in the top panel of Figure 3 should be labelled "Ozone partial column (DU)"

done

Line 167: Replace 'slow recovery' with 'slow increase'. When you say 'slow recovery' it begs the question of 'recovery from what?'. I this case it wasn't clear what the ozone would be recovering from during this period. Likewise, when you say 'was the slowest recovery', recovery from what? Maybe you just mean the slowest increase in ozone concentrations?

A very good suggestion on changing the wording here. We have adjusted the sentences in lines 166-169 to refer to the 'slow ozone increase' which is more appropriate in describing the return to typical late spring ozone levels in November and December. Changed sentences to:
"Both years showed severe loss in the 14-21 km column with a minimum of 2 DU (2020) and 3 DU (2021) occurring on 01 October followed by a slow ozone increase during the remainder of the spring season. The latest date that TCO broke above the ozone hole threshold of 220 DU (Stolarksi et al., 1990) was in 2020 on December 12 when the Dobson spectrophotometer measured 236 DU, nearly 2 months after DS TCO measurements had resumed in mid-October at 109 DU. "

Line 185: Replace 'by recovery in' with 'by increase in' since you have not done the attribution to declining ODSs to call this recovery.

done

Line 216: Record high over what period? The full ozonesonde record period?

This was a record high measured by ozonesondes for the September/October period. We changed the sentence to:
"The following ozonesonde profile on September 25 in 2002 showed substantial ozone increases throughout the 15 to 32 km layer elevating TCO to 397 DU, the highest ever observed during September and October over South Pole."

Line 222: Can you be clear about what your definition is for 'ozone recovery' as it is used here?

Returning to the Hassler et al., 2011 paper, it was noted that a change in lower stratospheric loss rates will be observed. This is the more appropriate definition of the data analysis we are showing here and thus replacing references to ‘ozone recovery’ with either ‘increase’ or ‘change or improvement’.

Lines 257-258: Given your sentence 'Then in 2020 and 2021 ozonesondes observed the optimum cold polar vortex conditions in September to late October along with extensive near-zero ozone within 13.5 to 20.5 km altitude', would you say that over the period 2001-2021 that ozone, over this altitude range (13.5-20.5km), has been recovering form the effects of ODSs?

The near-zero ozone layers under the optimum cold and stable vortex conditions shows that abundance of ODSs is in 2020 and 2021 still sufficient to have severe saturation loss, though not as severe as the record low in 2006 under the same polar vortex conditions. It would therefore not be correct to state that there was a recovery from ODSs, but there is an overall improvement when looking at the long-term evolution which shows an upward trend.

GRAMMAR AND TYPOGRAPHICAL ERRORS

Line 15: Replace 'from surface' with 'from the surface'.

done

Line 21: Replace 'minimum' with 'annual minimum'.

done

Line 23: Shouldn't this be 'loss saturation' since it is the loss that is being saturated?

Change made to “loss saturation”

Line 73: Replace 'proportional to ozone' with 'proportional to the ozone concentration'.

done

Line 75: The hPa acronym has already been used above so perhaps should be defined there (if required at all).

Moved ‘hectopascal’ to line 66 where it is used the first time in the manuscript where referring to the 89 hectopascal (hPa) layer.

Line 126-128: There is something grammatically wrong with this sentence.

We re-worded the sentences to note that on occasion the South Pole profiles may show some first signs of ozone depletion (typically above 21 km) from transported parcels originating near the vortex boundary where first sunlight begins the springtime ozone destruction cycle (references given).
The sentences now read as:
“The wintertime ozone profiles are similar to the long-term climatology each year and typically don’t provide any insight into how the polar vortex conditions and the severity of ozone depletion will unfold when rapid depletion begins by 01 September at South Pole. However, during the last two weeks of August the first signs of ozone loss are occasionally observed above 21 km, likely from transported air parcels originating near the polar vortex boundaries where sunrise, Cl2 photolysis, and chemical ozone destruction begins (Schoeberl et al., 1992; Lee et al., 2001; Hassler, et al, 2011a; Strahan et al., 2019).”

Line 132: Replace 'data was' with 'data were'. Likewise in the caption for Table 1.
done
Line 153: Replace ', this' with '. This'.
done
Line 192: Replace 'the 14-21 km' with '14-21 km'.
done
Line 213: Replace ‘year in 2002’ with ‘in 2002’
done
Line 235: Replace ‘degree’ with °C
done
Line 262: IUPAC convention is sulfate rather than sulphate.
done
Line 279: Replace ‘year in 2006’ with ‘in 2006’
done
Line 291: Replace ‘appears to’ with ‘appear to’
Done

REPLY TO REVIEWER 2:

Review of Johnson et al., "South Pole Station ozonesondes: variability and trends in the springtime Antarctic ozone hole 1986-2021".

General Comments

In this manuscript, Johnson et al. provide an overview of results from the long-running ozonesonde program conducted by NOAA at the South Pole station. This is an incredibly valuable dataset for atmospheric science and everyone involved should be congratulated for simply keeping the program running for such an extended period, not to mention maintaining a high standard of quality over multiple decades.

There are two main area of focus of the manuscript, firstly presenting details of the three specific years 2019, 2020 and 2021, and secondly, showing trends in various metrics derived from the observations over the full course of the program.

Both subjects are of interest and importance, but the long-term behaviour much more so because of the unique ability of the South Pole ozonesonde program, as against other observing systems, to provide high-resolution in-situ measurements from the core of the Antarctic Ozone Hole.

The subject is certainly central to the range of Atmospheric Chemistry and Physics and I definitely recommend publication.

The scope of the manuscript is essentially limited to presenting observations and simple derived quantities (such as loss rates), rather than attempting any attribution (although refer to my comment below about LOTUS).

Although temperatures are visually presented along with ozone in all cases (ie Figure 2 upper and lower panels, Figure 3 upper and lower panels, Figures 6&7, Figures 8&9) showing qualitatively the very tight relationship between these two quantities at both intra- and inter- annual scales, there is no quantitative analysis of this relation.

The manuscript is very clearly written and well referenced.

My only substantial negative comment of substance is on the topic of using the LOTUS regression model to establish trends in the crucial 14-21 km partial ozone column (Figure 4). By using the term "LOTUS model" the reader will understand this to mean you are regressing the ozone partial column against the LOTUS proxies including QBO, ENSO, Solar cycle and aerosol loading. (If you are in fact not using these proxies then you shouldn't say you are using the LOTUS model). These proxies, while selected by LOTUS for understanding vertically resolved ozone in the mid-latitudes and tropics, are still relevant for Antarctica, however if you want to use them you have to give a much lengthier description of how the 14-21 km partial column is related to each of them. These relations will be quite

different to those found in the mid-latitudes. You would also want to make sure the proxies are relevant for Antarctica (eg the aerosol loading and the lag of the QBO, ENSO and Solar Cycle). The trend result will not have convincingly accounted for the effects of these factors unless you provide much more detail of these regressions.

This was addressed and changed based on reviewer comments below for lines 185-187.

Doing this properly would require a not insignificant expansion to the current manuscript, so I offer as suggestions two alternative approaches, either to adopt a much simpler regression using only one well-established proxy such as eddy heat flux, or just calculate the trend and don't attempt to attribute its cause.

Although temperatures are visually presented along with ozone in all cases (ie Figure 2 upper and lower panels, Figure 3 upper and lower panels, Figures 6&7, Figures 8&9) showing qualitatively the very tight relationship between these two quantities at both intra- and inter- annual scales, there is no quantitative analysis of this relation.

Specific comments

Line 17 – I think you could highlight the fact that the trend in the mid-September 14-21 km partial column is now significant at the two sigma level. This seems to me quite an important finding.

The mid-September partial ozone column (14-21 km) was added in Figure 4 to show any potential trend in the long-term record (since the minimum tends to fall flat during ozone loss saturation years. We used the 1-sigma level for all median uncertainty calculations (following Hassler et al., 2011) and note that this is significant and consistent with ozone hole analysis papers (referenced in the introduction) that refer to healing and recovery after 2000 and 2001.

Line 41 For a specific reference like this you should refer to the particular chapter (in this case chapter 4 - Langematz & Tully et al. see full reference below)

The Reference was adjusted to highlight chapter 4 and the lead authors of this chapter.

Line 57 "Most" doesn't seem correct, eg ground-based and satellite lidars and microwave instruments

We adjusted this sentence to just noting the solar UV methods: “The South Pole ozonesondes play a key role in monitoring ozone and temperature during all phases of the ozone hole. These unique measurements are critical after the Antarctic sunset when several months of darkness limits the ground-based Dobson spectrophotometer and solar ultraviolet satellite optical measurements.”

Line 73 You can check the style guide but I think "cc" would be better as cm-3

The volume units for the solution volume was changed to ml (the syringes for dispensing sensor solutions show units as “ml”)

Line 74 You should explain where the value of 0.07 comes from.

We added references (Vömel & Diaz, 2010; Smit & Thompson GAW report #263, 2021) to the text that present laboratory measurements and recommendations of sensor cell background current (lowest ~ 0.01 microamps). We changed the text to describe the procedure better with which the 0.07 was derived: microamps were converted to ozone partial pressure to get the approximate LOD from 3 x background = 0.10 mPa or in mixing ratio (0.10 x 10/ 50 hPa) = 0.02 ppmv at 50 hPa ambient pressure.

Line 79 You should explain what you mean by "18k-19k"

Changed to: 18,000 standard cubic feet polyethylene balloons.

Line 88-89 Do you mean the previous GAW report? (Noting the publication dates you give as the homogenization in 2018 'following' the report of 2021).

We updated the references and restructured the sentence to:

“A thorough review and homogenization of the ozonesonde record was completed by Sterling et al. (2018) following homogenization methods that were formulated from the Assessments of Standard Operating Procedures (ASOPOS) workshops (Smit and ASOPOS, 2012: Deshler et al., 2017). The ozonesonde guidelines, presented in the ASOPOS GAW/WMO report # 268, (2021), are based on the Jülich World Ozonesonde Calibration Center Ozone Intercomparison Experiments (JOSIE).”

Lines 95-97 Yes, but the Dobson and its algorithm has known problems, such as the temperature dependence of the cross-sections, calculation of the airmass and stray-light – for an extreme location like South Pole I would have the thought the uncertainties would be at least 2% (but I might be wrong), in other words this offset might be well within the uncertainties of the two measurement systems.

We added the uncertainty (with the reference: Köhler, et al., 2018) of the Dobson Direct Sun AD wavelength of +/- 1 %. This value was also confirmed in a personal conversation with Glen McConville (co-author and managing NOAA Dobson operations). However, at South Pole the low sun angle and location of the measured air mass from the Dobson versus the ozonesonde ascent may add additional uncertainty so the two TCO measurements and may often be well within uncertainty range.

Lines 100-103 The current recommendation (from the GAW Reports) is:

McPeters, R. D., and Labow, G. J. (2012), Climatology 2011: An MLS and sonde derived ozone climatology for satellite retrieval algorithms, J. Geophys. Res., 117, D10303, doi:10.1029/2011JD017006.

The climatology is based on ozonesondes and MLS so polar night shouldn't matter. If you have found you get better results with extrapolation of the mixing ratio you should say that.

We added the McPeters (2012) reference and changed the last three sentences to: " Additional verification of the ozonesonde record at South Pole station is conducted through the ongoing comparison of total column ozone (TCO) with the NOAA ground-based Dobson spectrophotometer direct sun (DS) AD wavelength pair measurements over South Pole station from 20 October to 20 February (Komhyr et al., 1997). The DS/AD Dobson observations, accurate to within ±1% (Köhler, et al., 2018), are an important long-term stable reference for ozonesonde sites around the globe and useful for identifying drifts in satellite platforms (McPeters & Komhyr, 1991; Bodeker et al., 2005; Thompson et al., 2017). Figure 1 shows the homogenized ozonesonde TCO record is a constant 2 ± 3% offset compared to the Dobson observations. The ozonesonde TCO includes a residual value to account for estimated ozone above the balloon burst altitude by extrapolating a constant mixing ratio (CMR) from the balloon burst pressure (occurring between 20 to 7 hPa) to zero pressure. While the satellite SBUV global climatological residual table from McPeters et al. (1997, 2011) is the recommended procedure for determining ozonesonde residuals (Smit & Thompson, GAW Report #263), we have found that the CMR extrapolation is more consistent when comparing with the Dobson spectrophotometer TCO at South Pole Station.

Lines 101-103 I'm afraid I don't follow the reasoning here.

The last three sentences (addressed in previous comment) were adjusted to note that he CMR extrapolation is more consistent with the Dobson observations at South Pole.

Line 109 Explain "Met Service" for an international readership.

We change the sentences in Line 109 and 111 to explain the Met service and note that the collaboration (2 radiosondes) flown when standard rubber balloons will not reach the PSC region of the stratosphere:

"The ozonesonde radiosonde temperatures were not adjusted in the homogenization of the data record. However, temperature accuracy for each flight was validated by comparing with an additional radiosonde flown by the Antarctic Meteorological Research Center (AMRC) at South Pole. For nearly a decade, the AMRC/South Pole

Meteorology Office radiosondes (using Vaisala RS92 and Vaisala RS-41 GPS models) were “piggy-backed” on board the NOAA ozonesonde package. This is an important collaboration during the winter months when NOAA switches to the cold-resistant polyethylene 18K balloons to maintain burst altitudes of 30-34 km. This results in two independent temperature profiles to monitor the coldest temperatures in the polar stratosphere where PSCs begin to form. The typical radiosonde rubber balloon profile will fail/burst at 14-15 km over South Pole under these extreme cold and dark conditions.”

Line 111 I don't understand why you say the comparison "is important in the dark and coldest winter months"? I would expect the disagreement would be worst in sunlight due to radiation bias.

In this paragraph (now reworded – see previous comment) we intended to highlight the importance of measuring temperatures in the stratosphere during the dark, cold months when rubber balloons (burst at 14-15 km) will not reach the altitudes where PSCs are forming. That is true and a good point on the radiation bias in summer. This would be an excellent data set for a more thorough investigation and comparison of the several years of dual radiosondes (comparing different models in sunlight and dark).

Lines 113-116 You've talked about the temperature but I don't think you make any quantitative use of temperature data anyway? What about pressure, which is also known to have problems in the older radiosondes? Couldn't that also introduce an inhomogeneity in your time series when you are reporting on pressure levels or altitudes which would have been calculated using pressures?

Correcting for radiosonde pressure offsets is part of the NOAA data processing software (SkySonde) editing functions. This includes adding a constant pressure offset (typically around 0.5 to 2 hPa) to adjust the ozone and temperature profile altitude in order to match the GPS geometric altitude profile. In the case of older (no GPS) RS-80 radiosondes, we compared the adjusted pressure offsets with the long-term climatology temperature and ozone mixing ratio profiles and the TCO with the Dobson. For the older RS-80 radiosondes this becomes more or less a visual inspection which gives an added uncertainty but very difficult to quantify for ambient pressure.

This would be an interesting project to analyze the temperatures (especially the wintertime dual radiosondes) and relationships with ozone loss along with trajectory analysis. However, for this manuscript we followed a similar format of two of the earliest South Pole ozonesonde papers by Hofmann where the main focus was presenting the ozone and temperature data records from an observational viewpoint showing simple ozone trends with an eye on watching for temperature trends that may enhance (cooling) stratospheric cloud particle surface area.

Lines 185-187 As written in more detail in the "general comments" above, if you are using the LOTUS model then you have to give details of how you treated the proxies and what you found for the dependence on the 14-21 km partial column on 15 September of each of the proxies. As well as pinning this down being a very interesting scientific question, it's also important to know because the credibility of the trend depends on how well the regression has accounted for the explanatory variables.

We agree that applying the LOTUS model to the 14-21 km column data is not sufficient for this manuscript without additional details on the selection and description of proxies. Therefore, we will follow the suggestion to calculate the simple trend. This is consistent with the overall theme of the paper - to provide an updated data quality/field observations reference for the South Pole ozonesonde long-term record for future analyses and modeling studies.

Lines 204 You don't really explain to the reader why it is appropriate to be looking for a linear fit, so I suggest referring here to figure 3 would be helpful.

Added linear loss referring to Figure 3.

Lines 211 "improved" seems too value-laden (but I appreciate when talking about the loss rates "increase" and "decrease" can be confusing).

Reviewed and adjusted terminology to be consistent.

Lines 211 You say the minimum of -3.8 DU/day – wouldn't this be the maximum of the loss rate, not the minimum?

Adjusted text

Lines 224-225 I don't have any objection to the grouping into 5 year blocks but I do have some comments. (i) If you're trying to avoid biennial influence, don't you need an even number of years not an odd number? (ii) Saying "other dynamical processes" is very vague – what exactly do you mean here? Couldn't there be a confounding trend in these "other dynamical processes"? (iii) In fact, no biennial effect is very evident in figure 5 (iv) Presumably, you have already accounted for the QBO influence when you used the LOTUS regression model - this could be referred to here.

We used 5-year blocks to match and update the analysis by Hassler et al., 2011 looking at the ozone mixing ratio loss rates. We also looked back look at Figure 5 showing individual year loss rates for the 14-21 km layer which, though not a detailed analysis, doesn't appear that 5 or 6-year blocks would change the analysis. We removed the reference to the LOTUS model and just used simple linear regression.

Lines 229-236 It is not clear to me what the purpose of figure 7 is – is it to support figure 6 by showing the absence of temperature trends? Or perhaps to put 2019, 2020 and 2021 into context?

Figure 7 was added to support Figure 6 to show that temperatures during the PSC formation months (July 15 – Aug 15) have remained relatively constant in the 34-year record. Temperature remained constant as well during the ozone depletion month (September).We added the following sentence for referencing the absence of temperature trends. " These data indicate that there have been no systematic winter temperature trends at these altitudes that may affect stratospheric cloud particle surface area and heterogeneous ozone destruction chemistry.

Line 255 Interestingly the lower boundary did not seem to be moving downwards during this time.

We also thought this was interesting to see the consistency along the lower boundary, except for additional depletion occurring at lower altitudes following the eruption of Mount Pinatubo.

Lines 266 58 km! (Carr et al.)

Changed to higher altitude "nearly 55 km" reported in Abstract by Carr et al., 2022).

Line 267 Probably more pertinently, unprecedented water vapor in the stratosphere – Millan et al. 2022, Vömel et al. 2022

Thank you for the two references – they are now included in the manuscript here.

Lines 274 As mentioned earlier, I would reword this slightly to say a bias with respect to the Dobson of 2± 3% - the Dobson would have considerable uncertainty of its own.

Changed wording as recommended in this sentence.

Line 290 I think you could be a little more definitive given the trend is significant at the 2 sigma level.

We agree and have rephrased and added a little extra text to note the trend significance.

Line 321-323 It is very good to acknowledge the sad loss of your colleague in this way.

Yes, it was a sad time at NOAA when we learned of Johan's rapidly declining health. Johan Booth had developed many friendships during his years in the Antarctic program and with NOAA. He was one of the most valuable station operators/engineer for Dobson and ozonesondes, taking great care to understand all of the operating principles, running tests to evaluate ozonesonde performance, obtaining the best Dobson measurements possible (including moon obs) and coming up with unique ways to maximize plastic balloon performance during the cold and challenging South Pole winters.

Line 540 Have you tried to calculate the effect the homogenization has had on the trends? By eye It looks like the 1985-2000 values have on the whole been decreased and 2000-2005 increased.

The changes in standard operating procedures are related to the post-homogenization decrease in 1985-2000 data when the standard 1% KI full buffer sensor solution was used – which generates a positive artifact from the secondary reaction related to the higher buffer concentration. We switched to 2% KI unbuffered during the 2000-2005 period at South Pole station which removed the buffer artifact but we found that the best compromise for a stable sensor accurate response was the 1% KI with $1/10^{th}$ of the standard full buffer solution. The South Pole SOPs have not changed since 2006 using EnSci 2Z ozonesondes with the 1% KI $1/10^{th}$ buffer sensor solutions and obtain consistent results.

Sterling et al., 2018 Figure 3 shows a summary of all NOAA long-term ozonesonde sites with the type of sensor solution, sonde models and radiosondes used.

References

added

Carr, J. L., Horvath, A., Wu, D. L., & Friberg, M. D. (2022). Stereo plume height and motion retrievals for the record-setting Hunga Tonga-Hunga Ha'apai eruption of 15 January 2022. Geophysical Research Letters, 49(9), e2022GL098131. https://doi.org/10.1029/2022GL098131

Langematz U, & Tully M (Lead Authors), Calvo N, Dameris M, de Laat ATJ, Klekociuk A, Müller R, & Young P (2018). Polar stratospheric ozone: Past, present, and future, chapter 4 in scientific assessment of ozone depletion: 2018, global ozone research and monitoring project–Report No. 58. Geneva, Switzerland: World Meteorological Organization. [Google Scholar]

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Millán, L., Santee, M. L., Lambert, A., Livesey, N. J., Werner, F., Schwartz, M. J., et al. (2022). The Hunga Tonga-Hunga Ha'apai Hydration of the Stratosphere. Geophysical Research Letters, 49, e2022GL099381. https://doi.org/10.1029/2022GL099381

Vömel, H., S.Evan, M. Tully (2022). Water vapor injection into the stratosphere by Hunga Tonga-Hunga Ha’apai. Science Vol 377, Issue 6613 pp. 1444-1447, DOI: 10.1126/science.abq2299