Review-10.5194-egusphere-2023-2574

This paper presents an analysis of trends in stratospheric ozone for several widely used ozone profile datasets as well as total ozone column datasets and reanalysis data with a primary focus on the tropical stratosphere. The paper is a response to Lu [2022] who claimed to have found a significant tropical stratospheric "ozone hole" in one particular and not widely use stratospheric ozone profile dataset. Such an extraordinary claim – inconsistent with current understanding - requires a thorough analysis beyond just one arbitrary chosen dataset. Lu [2022] does not provide such in depth analysis of other data, hence why this paper fills an important void.

The paper convincingly shows that the findings in Lu [2022] are not supported by any other data and datasets. The main reason is the incompleteness of the TOST dataset used in Lu [2022] (TOST) which is inadequate for long term tropical stratospheric ozone trend analysis prior to the 1990s.

While diving deeper into the matter, use of the TOST data for the analysis presented in Lu [2022] should have been a no-no for anyone looking into the papers describing and using the TOST data. Figure 12 of Liu et al. [2013; 10.5194/acp-13-11441-2013] copied below should have been a stark and obvious reminder that the tropics lack sufficient data in the 1970s and 1980s in the TOST data. Hence why Liu et al. [2013] in their analysis using TOST data do not analyze tropical trends prior to the 1990s.

Liu et al. [2013] contains more statements signaling that great care must be taken in the tropics and for the period prior to the 1990s:

> Abstract: "The agreement is better in the Northern Hemisphere, where there are more ozonesonde stations, than in the Southern Hemisphere; it is also better in the middle and high latitudes than in the tropics where reanalysis winds are less accurate."
>
> "Noting that there are large gaps in the tropics as ozone values were taken only from the grid cells where data are available for all four decades …"
>
> "The mean is area-weighted and is computed by taking values only from grid cells where ozone data are available for all four decades. Therefore, the global means miss large areas in the tropics (see Fig. 12)."
>
> "The distribution of ozone at 19.5 km is shown by decade from the 1970s to the 2000s in Fig. 12. The large gaps in the tropics and in the middle latitudes of the Southern Hemisphere in the 1970s are largely filled in by the SHADOZ program." (referee note: SHADOZ fills these gaps from the 1990s onwards)
>
> Conclusions: "Overall, we have more confidence in this climatology over the Northern Hemisphere than over the Southern Hemisphere, and in the middle and high latitudes than in the tropics."

Furthermore, the efforts to construct the TOST dataset dates back prior to 2010 using a computationally efficient and straightforward method to fill gaps in ozone data. That was a valuable advancement at the time given in particular the lack of methods for more advanced data assimilation techniques. However, the TOST approach has since been superseded by significant advances in both more advanced data assimilation techniques and computational power as evidenced by the MERRA-2 and ERA-5 reanalysis data. Hence TOST data soon will be outdated completely and its use likely will become obsolete. Anyone

using TOST data should at least acknowledge that and present additional support for findings based on TOST data.

Returning back to the paper under considering, overall it is well and logically organized and the findings are well supported by the data and analyses and suitable for publication in ACP. However, it appears the paper appears to be written in a bit of a hurry so there is some work to be done as outlined in the detailed comments below.

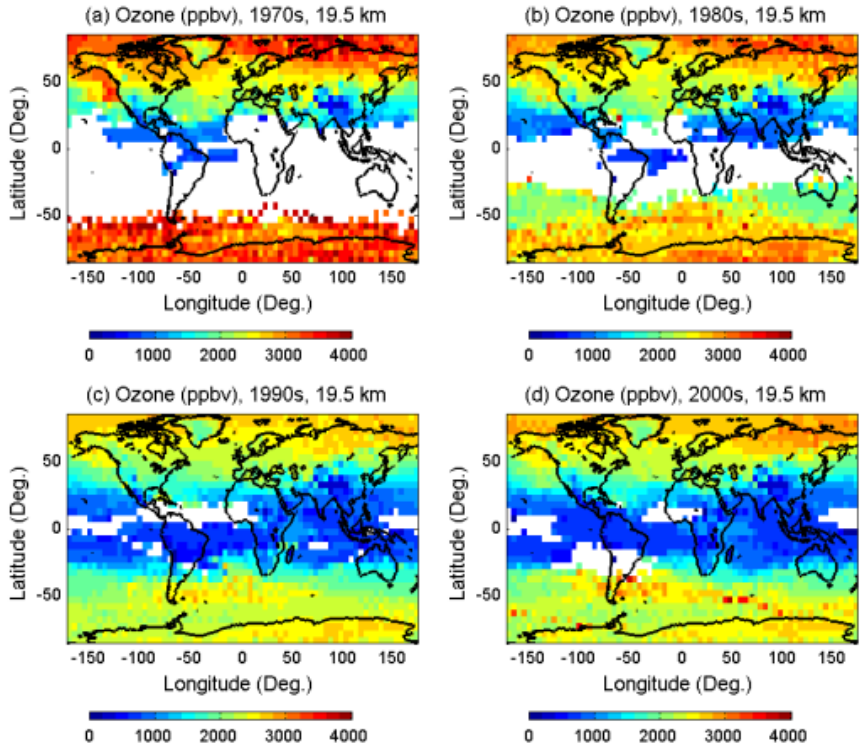


**Fig. 12.** Decadal variation in ozone at 19.5 km for **(a)** the1970s, **(b)** the 1980s, **(c)** the 1990s, and **(d)** the 2000s. White areas indicate missing data.

Figure 12 from Liu, J., Tarasick, D. W., Fioletov, V. E., McLinden, C., Zhao, T., Gong, S., Sioris, C., Jin, J. J., Liu, G., and Moeini, O.: A global ozone climatology from ozone soundings via trajectory mapping: a stratospheric perspective, Atmos. Chem. Phys., 13, 11441–11464, https://doi.org/10.5194/acp-13-11441-2013, 2013.

**General:**

- “i.e.” and “e.g.” should be in italics.

- Southern Hemisphere should be in capitals.

- check consistent use of either ERA-5, ERA 5 or ERA5 (now all three are used)

**Specific comments, suggestions, typos**

Abstract, line 16: change to “the amount of column ozone is relatively small”

Abstract, line 17: add the range of TOC values at “high and mid-latitudes” (NH 275-425 DU; SH 275-350 DU; see for example Coldewey-Egbers et al. [2020] 10.5194/amt-13-1633-2020).

Abstract, line 18-19. Change to “No observational evidence was found of indications or signatures of severe stratospheric ozone depletion ...”

Abstract, line 20-21. Change to “Finally, current understanding and observational evidence does not provide any support for the possibility of an ozone hole occurring outside Antarctica today with …"

Introduction, line 26, add reference to Coldewey-Egbers et al. [2020]. Given what the paper is about it makes sense to add a recent reference in conjunction with London (1992).

Introduction, line 26-27. Change to “The production of ozone is effective at low latitudes hence ozone mixing ratios at middle and high latitudes are smaller …"

Introduction, line 28-30. The main reason why ozone columns increase is that atmospheric transport (Brewer-Dobson circulation) at high(er) latitudes is vertically downward. That causes air with similar mixing ratios to be to vertical levels with higher pressures and thus higher densities, even if mixing ratios remain the same or decrease, while the stratospheric column increases in geometrical thickness way from the tropics (tropical tropopause is at 16-18 km, outside of the tropics it is on average around 10 km). Somehow this should be reflected here.

Introduction, line 33. Change to “has shown a dramatic seasonal decrease”

Introduction, line 34, suggest to change to “Understanding of stratospheric ozone chemistry, model simulations” … “ozone loss theories” is a bit vague.

Introduction, line 37. “e.g.” should be in italics.

Introduction, line 38. Change to “... deepened in the 1980s and peaked ...”

Introduction, line 39. Change to “... Antarctic lower stratosphere ...”

Introduction, line 43-52. This needs a makeover:

In contrast, Arctic stratospheric temperatures are relatively high and the polar vortex is frequently disturbed by planetary waves formed by the interaction of upper tropospheric winds, orography and land-sea contrasts, manifested as sudden stratospheric warmings (SSWs). The lack of persistent cold temperatures restricts Arctic stratospheric chlorine activation and ozone loss *(e.g*. Solomon, 1999) and causes strong year to year variability (von der Gathen et al., 2021) with generally column ozone staying

above 220 DU. Over Antarctic, on the other hand, springtime column ozone frequently falls below 220 DU. A weaker Brewer-Dobson circulation leads to lower stratospheric ozone amounts. In addition, a stronger, more persistent and much colder stratospheric vortex generally favors rapid springtime catalytic ozone destruction. Hence why the 220 DU column ozone threshold is widely used for characterizing the Ozone Hole. Such low values have been present …" … … Ozone loss in other regions, including the Arctic, never reach similar and widespread low levels of ozone like during Antarctic spring. Note that occasionally localized atmospheric dynamics can result in short lived small areas with low column ozone, so-called mini ozone holes (McCormack and Hood, 1997; James, 1998; Millán, L. F. and Manney, 2017).

*McCormack, J. P., & Hood, L. L. (1997). The frequency and size of ozone "mini-hole" events at northern midlatitudes in February. Geophysical research letters, 24(21), 2647-2650.*

*James, Pi M. "A climatology of ozone mini-holes over the Northern Hemisphere." International Journal of Climatology: A Journal of the Royal Meteorological Society 18.12 (1998): 1287-1303.*

*Millán, L. F. and Manney, G. L.: An assessment of ozone mini-hole representation in reanalyses over the Northern Hemisphere, Atmos. Chem. Phys., 17, 9277–9289, https://doi.org/10.5194/acp-17-9277-2017, 2017.*

Introduction, line 53: change to "Long term analyses show that column ozone loss ..."

Introduction, line 62, reference to Weber et al. (2005) in relation to stable TCO values since 2000 should be replaced with reference to Weber et al. (2018 and/or 2022, both in ACP). Weber et al. (2005) is hardly relevant for post year-2000 conditions.

Introduction, lines 66-67. I do not understand the reference to Godin-Beekman et al. (2022) here. Does it mean that that paper like Bognar et al. (2022) shows a 1-3% reduction in lower stratospheric ozone since 2000? Or do you something else? Please clarify and modify the section accordingly.

Introduction, line 77. Change to "Chipperfield et al. (2022) in response showed that ..."

Introduction, line 82, change to "Southern Hemisphere" (capitals)

Introduction, line 83. What "reprocessing" is referred to here? SHADOZ? And if so, does that mean that before the reprocessing SHADOZ data was not good enough? Please clarify.

Introduction, line 85. Possibly replace "thorough" with "in-depth".

Section 2, data: given the importance of exploring a range of ozone datasets a table with estimated errors/precisions (in %) would be useful (for limb also as a function of altitude). If not, errors/precisions are missing GOZCARDS, WOUDC-ECC, TOST, MERRA-2 and ERA5 and should be added.

Section 2.1, line 96. Change to "ozone mixing ratios and standard errors … hPa and in 10° latitude bins."

Section 2.1, line 97-98. Change to "... ozone measurements. More details can ..."

Section 2.1, line 99. Change to "... are based on measurements of limb-sounding …"

Section 2.1, lines 102-103. Change to "... by applying corrections calculated ..."

Section 3.1, line 187. Change to "... from the satellite dataset GOZCARDS."

Section 3.1, line 189. I don't know what is meant here with "effective". Probably what is meant is that the tropical stratosphere is a region of net ozone production where as middle to high latitudes are regions of net ozone destruction. Please clarify.

Section 3.1, line 191. minimum => minimal

Section 3.1, line 193. Change to the 3-month nomenclature (DJF, MAM, JJA, SON) rather than seasons in the tropics middle-to-high latitude seasonality is not useful to describe tropical seasonality. Furthermore, also later there are frequent references to particular seasons but given the inverse seasonality between NH and SH preferably use the 3-month nomenclature (DJF, MAM, JJA, SON) which, depending on what is described, could be augmented with its season. Otherwise it is confusing to read as mentally one continuously has to think "which months are what season in which hemisphere"

Section 3.1, line 206. "very low values in the southern hemisphere spring and autumn". I assume what is meant is spring and summer? SH ozone is not "very low" during autumn. Furthermore, probably better to write "very low values in the SH spring and low values in SH summer".

Section 3.1, line 223. "... no substantial loss in the tropics." => add the time period for which this statement is made and valid.

Section 3.1, line 225-227. Trend values for reanalysis data and the GSG data is missing. Possibly a table summarizing the various trends in various time periods/seasons/altitudes would be beneficial.

Section 3.1, line 237. Change to "We have also estimated ..."

Section 3.1, line 239. What is meant with "high statistically nonsignSeificant"? Please clarify.

Section 3.1, lines 260 & 262. Both lines mention differences in ppbv, but shouldn't that be ppmv?

Section 3.1, line 276. Remove comma in "note that, all these trends ..."

Section 3.1, line 277: replace "show" with "are"

Section 3.1, line 288. Change to "MAM, where trends are positive (0.25 +/- …; Fig. S4)."

Section 3.1, line 288. "all datasets" … please clarify which datatsets are meant here. Presumably all datasets discussed in the this section?

Section 3.1, lines 283 to 285. It appears there is an inconsistency with the previously used "ERA-5" as here it is "ERA 5" under the assumption this is not a print problem at my side.

Section 3.1, lines 286-287. Change to "In all datasets estimated post-1997 trends at tropical latitudes are either ..."

Section 3.2, line 296. "past decades (1990-2000)" should be "(1990-2020)"

Section 3.2, line 309. Add the following:

Third, Lu [2022] incorrectly assigns tropical altitudes above 10 km to the stratosphere whereas the tropical troposphere extends to 16-18 km [Seidel et al., 2001] and where very low ozone concentrations

can be found over the tropical Pacific due to vertical transport of clean tropical Pacific boundary layer air by convection [Kley et al., 1996]. Lu [2022] thereby incorrectly claims that Polvani et al. [2017] and Newton et al. [2018] report very low ozone values in the tropical lower stratosphere. Polvani et al. [2017] only discusses ozone at 70 hPa (18 km) and higher while Newton et al. [2018] assigns the low ozone observations to "uplift of almost-unmixed boundary-layer air" to altitudes of 100-150 hPa (14-17 km).

*Kley, D., Crutzen, P. J., Smit, H. G. J., Vömel, H., Oltmans, S. J., Grassl, H., & Ramanathan, V. (1996). Observations of near-zero ozone concentrations over the convective Pacific: Effects on air chemistry. Science, 274(5285), 230-233.*

*Seidel, D. J., Ross, R. J., Angell, J. K., and Reid, G. C. (2001), Climatological characteristics of the tropical tropopause as revealed by radiosondes, J. Geophys. Res., 106(D8), 7857–7878, doi:10.1029/2000JD900837.*

Section 3.2. end of section, add: "And finally, already more than two decades ago it was well established that - based on all available observational data - trends in tropical stratospheric ozone were largely absent or minimal at best for the period 1979-1997 [Staehelin et al., 2001], something neither acknowledged nor discussed in Lu [2022]."

*Staehelin, J., Harris, N. R. P., Appenzeller, C., and Eberhard, J. (2001), Ozone trends: A review, Rev. Geophys., 39(2), 231–290, doi:10.1029/1999RG000059.*

Section 3.2, line 316. Delete "there"

Section 3.2, line 318. about => approximately

Section 3.2, lines 320-321. In the tropical ozone => in tropical (lower) stratospheric ozone

Section 3.2, line 333. Change to "at Southern Hemispheric stations."

Section 3.2, line 348. Change to "in polar regions and therefore the comparison"

Section 3.2, line 352. Change to "No TCO measurements show"

Section 3.2, line 353. Change to "Formation of PSC particles is"

Section 3.3, line 362. Change to "are very small (20-30 ppb), which is expected there, the data"

Section 3.3, line 366. Change to "in the past decades according to our analysis of a wide range of available data."

Section 3.3, line 367. Delete the "However", just start the sentence with "The recent strengthening"

Section 3.3, line 378. mentioned => noted

Section 3.3, line 381. Change to "Henceforth, tropical lower stratospheric"

Section 3.3, line 384. Remove the comma in "and certainly there is no"

Section 3.3, line 386. Change to "However, the peak in ozone is around 30-35 km at these"

Section 3.3, line 387. Change to "Hence, the analyses of Lu (2022) miss"

Section 3.3, line 389. Change to “is solely based on one decadal dataset which has only four profiles”

Figure 2 caption. Change to “TCO less than 220 DU”

Figure 4. Since most of the trends are statistically insignificant, I think it would be better for the hatching to reflect the statistically significant trends. Hatching generally is used to identify statistically significant trends. Alternatively a second panel could be included showing only the significant trends. Same for Figure S1, S3, S4, S5 and S6.

Figure S8. Hatching of statistically significant trends is difficult if not impossible to discern. Maybe provide a second plot with only the statistically significant trends. Also, the figure caption should read “... ozonesonde profiles for different periods … at the 95% CI level.”