Review egusphere-2025-6473

Detection of ozone recovery in the Arctic from ground-based measurements

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Overall:

This is an important relevant because it tries to integrate many different aspects of Arctic stratospheric ozone recovery. Due to strong natural dynamical variability, uncovering stratospheric ozone recovery signals over the Arctic is not a simple task. Furthermore, there are multiple sources of information (total columns from satellites, ozone disentangling different processes contributing to short and long term variability using and integrating different observational datasets is not a small and easy task, and the authors are applauded for trying to do so. It has unavoidably led to this data-rich and result-rich paper which I have no problems with.

The results indicate that there are clear indications of emerging recovery (statistically significant positive trends in stratospheric ozone) for certain locations. This is important as recovery detection of stratospheric ozone over the Arctic has for along time been underexplored (see the WMO Ozone Assessment 2022). As such, this paper contributes to a growing number of studies now starting to focus on Arctic stratospheric ozone recovery. The paper also importantly addresses the comparison of their results in relation to other published results, thereby serving the research community and supporting assessment efforts.

Assessment summary

The paper needs a bit more work, but one major issue had already been identified and reported previously and the effort the authors have put in is much appreciated. Below follows a list of comments and suggestions.

Abstract

Lines 10-15: trend significance levels missing so it is difficult to assess of these trends could be interpreted as true influences or modifications.

Line 21: replace "successfully detected" with "established"

Line 22: replace with "over Antarctica during the Ozone Hole onset period in September" ... recovery over Antarctic has not been established outside of approximately the September month.

Line 23: either delete "until recently" (Weber & WMO 2023 report no signs of Arctic recovery yet) or refer to a few recent papers indicating some changes consistent with Arctic recovery. WMO 2026 will report on this (not yet public) but is very careful in its wording, and it is not that relevant to refer to those recent papers here.

Line 23: signs --> indications

Line 24: observed --> reported

Line 27: about --> approximately … note that the authors are kindly requested to check the entire for the use of the word “about” (which is more informal) and replace it with “approximately” (which is more formal).

Line 29: "point toward an explanation of" --> "suggest these negative trends could be due to ..."

Line 31-32: change to “"Ozone layer depletion as is common over Antarctica does occasionally occur over the Arctic as well - unlike mid-latitudes - due to colder ..."

Line 33: “At springtime” --> “During springtime”

Line 34-35: Suggestion to delete the sentence starting with “The stratospheric cooling …”.

It is not necessarily true (for Antarctica this is (almost) not the case as it is always cold enough for PSC formation and a little bit colder does not change things that much while ozone depletion there is limited by other processes that saturate so that colder and more PSCs does not lead to more depletion. Furthermore, more coolinbg also affects atmospheric chemistry and reaction rates which also alter stratospheric ozone photochemistry and can lead to less depletion, not more depletion (see for example the phenomenon of super-recovery).

Line 35: If the previous sentence is remove then "Moreover" should also be removed.

Line 37: “expected stratospheric ozone trends”

Line 40: Paralelly to the stratospheric ozone ... --> In addition to stratopsheric ozone ...

Line 43: tropospheric ozone trends in ppbv/decade. It would be helpful to try to translate that already here to a tropospheric column change in Dobson Units.

Line 44: change to “… while Law et al. (2023) reported a strong seasonal cycle in tropospheric ozone trends, with ...”

Line 46: Suggestion to start this section with one sentence describing the aim of the study. For example: “In this study we analyze different atmospheric ozone observational records over the Arctic for signals of recovery.”

Line 65: “we focus on the period 2000-2024”. Add a justification on why this period is chosen (for example: it is well established that atmospheric concentrations of ozone depleting substances have decrease since approximately the year 2000. One or multiple recent Ozone Assessments could serve as reference if the phrase “well established” is used.)

2 Ground-based data sets

Line 94: change to “Appendix of Bjorklund et al. (2024)”

Line 110: about --> approximately

Line 112: delete the comma between active and correcting

Line 122: delete "lower", if a reference is to be made to another part of the paper, use "next in Section 2.4".

Line 124: It appears that what is meant here is that "If extreme outliers are found ... partial columns, they are removed ..." or "Extreme outliers that are found ... are removed ...". Otherwise it is a statement about a result that does not connect to the next sentence. Please clarify and/or correct.

Line 129: change to “use sunlight in the UV range (approximately 350-340 nm) to ...”

Line 136: delete “estimate”

Line 137: Recommendation to remove the focused-moon measurements from the record, they generally are not used due to questions about their quality and lack of assessment of their quality.

Line 148: preferably make this claim explicit by adding a few references and also briefly describe per season what typical tropopause heights are.

3 Comparison with satellite ozone data sets

Figures 4+5+6: Suggestion to add the time series (as in Figure 2) for each station separately to the appendix. It is quite informative to have that information available visually as a time plot. And as this is a paper already rich in data and information, it is OK to have an extensive appendix.

Line 215: Personally I would leave out referring to the 5 sigma level, a reader should be able to determine that from the numbers themselves. It also now gives rise to questions: 11.51/3.58 and assuming 3.58 is the 2-sigma error actually is > 6-sigma (6.43), so why the 5-sigma? There is no particular reason why 5-sigma is relevant. And one would round the sigma values to whole numbers, so in this case 6-sigma. Suggest to change to "... with a statistically highly significant drift ..." or even just leave it as it is and delete the "significant beyond the 5-sigma level". The "clearly" already signals there is very likely a problem with that time series.

Figure 3: Resolution of the image is OK for a pre-print and a review but presumably will be improved if the paper is accepted.

Lines 222-224: Which sonde type and is there literature supporting this notion that measurements from the two sonde types systematically differ?

Also, the papers by Stauffer et al. [2020, https://doi.org/10.1029/2019GL086791; 2022, https://doi.org/10.1029/2022EA002459] are not referenced. Both papers explore the long term stability of ozone sonde measurements due to a reported "sudden post-2013 TCO “dropoff” of ~3%–4%" and an "ozonesonde TCO drop is 3–7% compared to satellite and ground-based TCO, and 5–10% or more compared to satellite stratospheric O3 profiles". Scoresbysund is one of the stations for which a TCO dropoff is report (5.6%) based on a comparison with OMI.

The positive drift in sonde-IASI tropospheric ozone comparison for Scoresbysund should be discussed within the context of the findings of Stauffer et al. [2020, 2022].

Line 252: change the first part of this sentence to" "For assessing satellite drift in the Arctic zonal band, we average all ..."

Line 252-253: remove the brackets and change to "... mean with weights given by ..."

Line 260: It appears this provides a justification for not doing a more precise determination of the IASI-CDR tropospheric drift. If so, add that, for example by noting "which is beyond the scope of this paper which focuses on stratospheric ozone".

Line 264-265: suggestion to have all brackets removed here, it makes it less readable. The text is fine without all the brackets. Add a comma before “respectively”.

Line 265: about --> approximately

Line 268: Change to "The MEGRIDOP data shows a positive drift with ..."

Lines 272-275, 282, 283, 288: similar to one of the previous comments, remove all the brackets.

Line 288: add a comma before “respectively”

4. Representativeness study

Line 295: “square kilometers”

Line 295-296: change to "small relative to the large ..."

Line 301: “(2019) of ozone” --> space missing between bracket and “of”

Line 313: change to "in the Arctic between 60N-90N" plus add degree signs

Lines 314-316, equation (7): Delete this equation: the Pearson correlation coefficient is so well-known and widely used that there is no need to define it.

Lines 328-329: change to " we define a group of stations as having CAMS correlations of ... ... member stations higher than $r > 0.8$

5. Regional trends

Line 358: change to “Long term trends in Arctic stratospheric ozone due to changes in ozone depleting substances are expected ...”

Line 370: change to “... during winter, following Brunner et alo. (2006)”

Line 376: change to “... compared to Vigouroux et al. (2015)”

Line 390: note a big fan of this type of writing (“Let us now ...”). Rather keep it more formal, for example “Figure 13 shows the total coefficient of determination R2 ...”.

Line 393: Similar here to the previous comment online 390. If there is a need to announce what will be done, announced that in the first paragraph of this section, for example “in this section we will explore this-and-that” or “in this section, we first ... then ...”.

Line 397: about --> approximately

Line 414: this is not really the volume of PSCs but the potential volume, so please rephrase.

Line 415: cloud --> clouds

Line 417: about --> approximately

Line 420: change to “form predominantly between …”, they can occur up to 30 km altitude but occurrence above 25 km is rare, see Pitts et al., [2018], https://doi.org/10.5194/acp-18-10881-2018.

Line 422: change start of the line to “For the total column”

Line 423: change to “As with partial columns”

Line 427: change to “much less well explained”

Line 429: “during spring”

Line 430: the use of “drives” sounds awkward, please rephrase

Lines 432-433: change to “in particular the BDC”

Line 433: if this is correct one then would expect some correlation between VPSC and BDC, so the suggestion is to add here the correlation value between both for the proxies used in this study.

Lines 438-439: This begs for an explanation: why do results differ on this point from Bernet et al. (2023)?

Line 444: delete “due to climate forcing”, definitely not everyone is convinced about that interpretation

Line 451: add which errors are referred to (presumably the errors associated with the trend calculation)

Lines 452-453: it is not fully clear what the "absolute difference" refers to; presumably the difference in ozone trends without detrending and with each proxy is detrended (the text mentions only "impact on effective ozone levels and conclusions"). Please clarify.

Lines 464-467: This should be moved to earlier in the section (maybe even to the start of the section at line 452)

Line 501: The data in this study covers the period 2000-2021 so the effect of an additional 3 years as a possible explanation for the differences in trend significance can be assessed (and is not unimaginable, for a period of 21 years a few additional years can push trend significance levels over the threshold when significance levels are near 2-sigma).

Line 505: change to "Trends for Lapland are, however, positive ...".

Line 508: change to “indicates” ("means" is a too strong conclusion based on only a statistical analysis).

Lines 515-516: suggestion to modify this, ("These results agree within the 2-sigma error margin.") ... the agreement within error bounds means that differences should not be considered relevant.

Line 547: change to "especially during Spring."

Line 556: change to "for the North Pole"