Reply To Referee #1

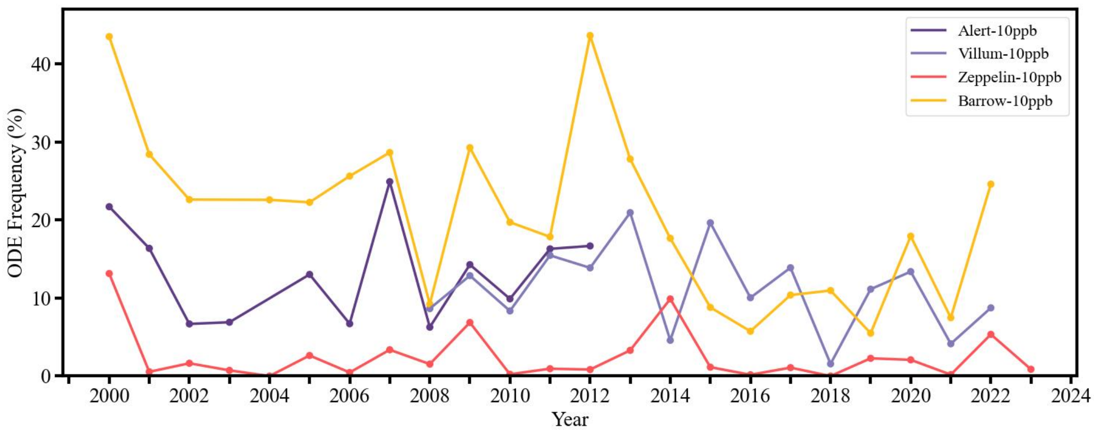
We would like to thank Referee #1 for the professional revision on our manuscript. We have modified our manuscript according to the suggestions. In the following, we made the point-to-point reply to the comments raised by Referee #1.

Q1.1 The paper is quite complete. However, some minor changes should be considered prior to its final acceptance.

A1.1 Thanks a lot for the positive evaluation on our manuscript and valuable suggestions that significantly improved our paper.

Q1.2 Since the analysis is made on a specific site, the interested readers could wonder about the result robustness, i.e., the authors should comment about limitations of the result extension to different sites.

A1.2 Thanks a lot for raising the issue regarding the robustness and limitations of our conclusions. We fully understood the potential concerns of Referee #1 about extending our findings to different observation sites. Therefore, during the revision process, we gathered more observational data from 7 other Arctic sites (Alert, Esrange, Tustervatn, Villum, Pallas, Summit, and Zeppelin) aside from the one (Barrow) we initially focused on. After applying the criteria we proposed in the present study (10ppb and 5ppb), only four of these sites (Alert, Barrow, Villum, and Zeppelin) were found to have ODEs (Ozone Depletion Events) occurrences (see Fig. A1 in this rebuttal). It should be noted that the availability and the quality of the observational data vary significantly among these sites. For instance, the Alert site only has data spanning from 2000 to 2012, which amounts to 13 years. In contrast, the Villum site possesses a dataset with a longer time range, covering a time period from 2008 to 2022, totaling 15 years.



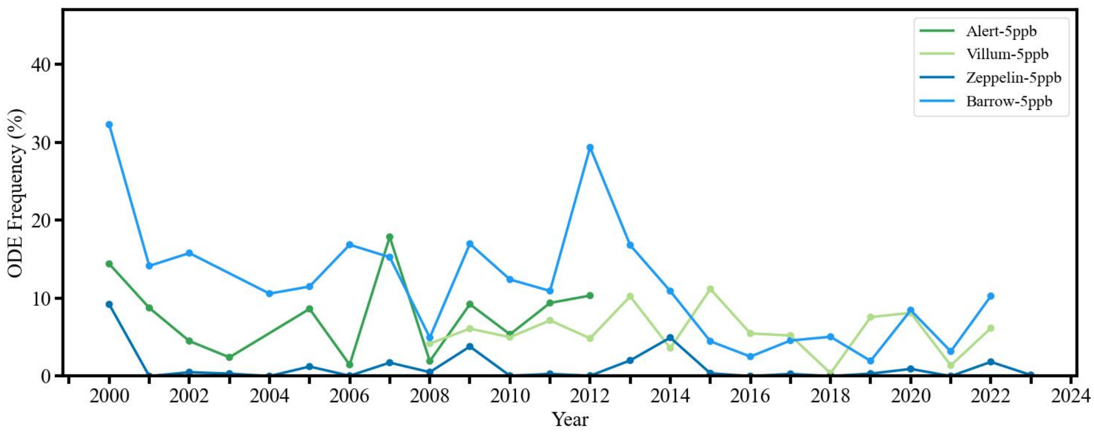


Figure A1 Occurrence frequency of ODEs at different stations (Alert, Utqiagvik, Villum, and Zeppelin). The occurrence frequency is calculated as the ratio of ODE hours to total hours, in which the ODE hours are identified using the TM1 and TM1-5 ppb screening criteria.

From the results shown in Fig. A1 in this rebuttal, we found that the ODE hours picked out by the criteria proposed in this study seem appropriate. For instance, Barrow, which has a low altitude, is featured with high frequency of ODE occurrence. In contrast, Zeppelin, which is located at a higher altitude, has fewer ODE hours, because the air mass arriving at Zeppelin usually represents the air in the free troposphere so that more ozone can be transported from the stratosphere and less halogens released from the surface can reach the free troposphere due to the barrier at the top of the boundary layer. Additionally, the ODE curves for Villum and Barrow (see Fig. A1 in this rebuttal) both show a declining trend, which is consistent with the conclusion achieved in this study. However, more observational data for other species such as halogen species (i.e., BrO) are still needed to validate these results, which is also a limitation of the present study.

Because the ODE occurrence at different stations depend on many factors such as the altitude and the location of the station, and a thorough comparison of the results and a detailed discussion on this topic can form another interesting paper, at present we only discussed the screened results briefly in the conclusion section and attributed this work to a future publication. We appreciate the valuable suggestion from Referee #1. The added discussion can be found in lines 441-454 in the revised manuscript and Fig. S8 in the revised Supplementary Information.

Q1.3 In paragraph between lines 245 and 254, the authors discuss about the suitable number of ODE hours. They should indicate a reason for such suitable number or when a number could be excessive.

A1.3 Thank you for the comment regarding the suitable number of ODE hours in our manuscript. In the case shown in the present manuscript, when we set the parameter α in Eqn. (6) to −0.8, this criterion can identify a significantly high number of ODE hours. Specifically, for the year 2021 (see Fig. A2 in this rebuttal), this method recognized many data points with ozone mixing ratios between 15 and 20 ppb, which are often referred to as “partial ozone depletion” events in previous studies (Ridley et al., 2003; Piot and von Glasow, 2008). However, the springtime average ozone mixing ratio at BRW for the year 2021 was calculated to be 23.93 ppb. It means that many time points picked up by this criterion possess an ozone value close to the average ozone level in springtime at BRW. In that case, we feel that many of these time points cannot be viewed as ODE hours, which also indicates that the criterion overestimates the ODE hours. This overestimation in ODE hours may also lead to a misunderstanding of the trend of ODE occurrence.

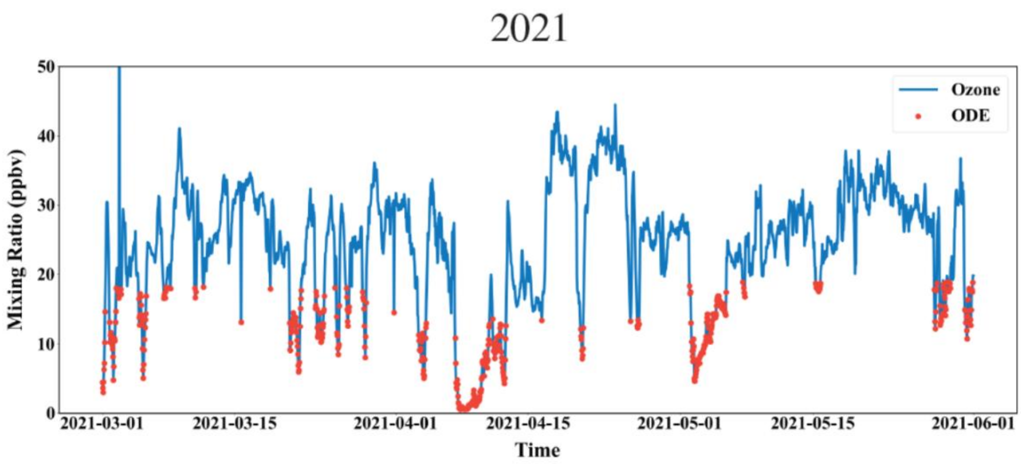


Figure A2. Screened results for the year 2021 using the modified VM criteria, in which α is set to -0.8. The blue curve represents the hourly time series of the ozone mixing ratio, and the red dots denote the ODE hours identified by the criterion.

Please see lines 275-281 in the revised manuscript for explanations added to the manuscript to clarify this issue.

Q1.4 Finally, the references used for discussion are unevenly distributed. For instance, they are frequent for the relationship with meteorological parameters, but less frequent in previous result sections. References should be the link between this research and previous studies.

A1.4 Thanks for your suggestions. In fact, our findings about the trend of ODE occurrences are in good agreement with those of Law et al. (2023), who reported a notable increase in observed surface ozone levels in springtime especially in April of BRW from 1993 to 2019. Hung et al. (2025) also observed an increasing trend in Arctic spring ozone concentrations at Eureka, Nunavut, Canada (80°N, 86°W) from 2008 to 2022, further supporting the notion of declining ODE frequency. Burd et al. (2017), in their study on the Arctic BrO season, found a decrease in BrO concentrations and an early end of the BrO season at BRW from 2012 to 2016, which may also imply a reduction in the occurrence of ODEs, aligning with our findings.

We have added these references and related discussions into the parts about trend of ODE occurrences in the revised manuscript. Please see lines 339-343 in the revised manuscript.

Q1.5 Advantages and disadvantages of the presented procedures should be highlighted in the conclusions.

A1.5 Thanks a lot for your comment. We added a discussion about the advantages and disadvantages of the present study in the conclusion section as suggested. The added content is as follows:

“We found the criteria using a constant threshold (e.g., 10 ppbv) and using thresholds based on the monthly averaged ozone values more suitable for identifying ODEs at BRW than the other criteria. In contrast, the criterion considering both the mean value and standard deviation of ozone (i.e., the VM criterion) is able to identify time points when the surface ozone drops to an uncommon low level instead of a fixed threshold, which is more adaptive and sensitive. However, extra caution is required when determining the parameter value of this criterion. Apart from these criteria, the machine learning method adopted in this study (i.e., the IF method) can automatically detect ODE hours. But this method has a poor interpretability in screening results and sometimes is unable to correctly identify ODE hours when ODEs occur very frequently.”

Please also see lines 412-419 in the revised manuscript.

Minor remarks.

Q1.6 Line 46. Replace “1999),.” By “1999).”

A1.6 Modified. Thanks.

Q1.7 Since curves are superposed in Fig. 2. Perhaps, additional information could be obtained if each criterion is represented by its mean and standard deviation and all of them are ordered following their means.

A1.7 Thank you very much for the suggestion. We have modified Figure 2 in the manuscript according to the suggestion (see Fig. A3 in this rebuttal). At present, the figure is divided into two subplots. The upper subplot presents the results of the TM series methods, while the lower subplot shows the results of the VM and IF methods. Furthermore, we have re-ordered the curves in each subplot according to the mean values of the criteria. Additionally, mean values and standard deviations are also added into the figure according to the reviewer’s suggestion. We believe that these modifications will provide additional information and make the figure more informative and easier to understand. Thanks again for your valuable suggestion.

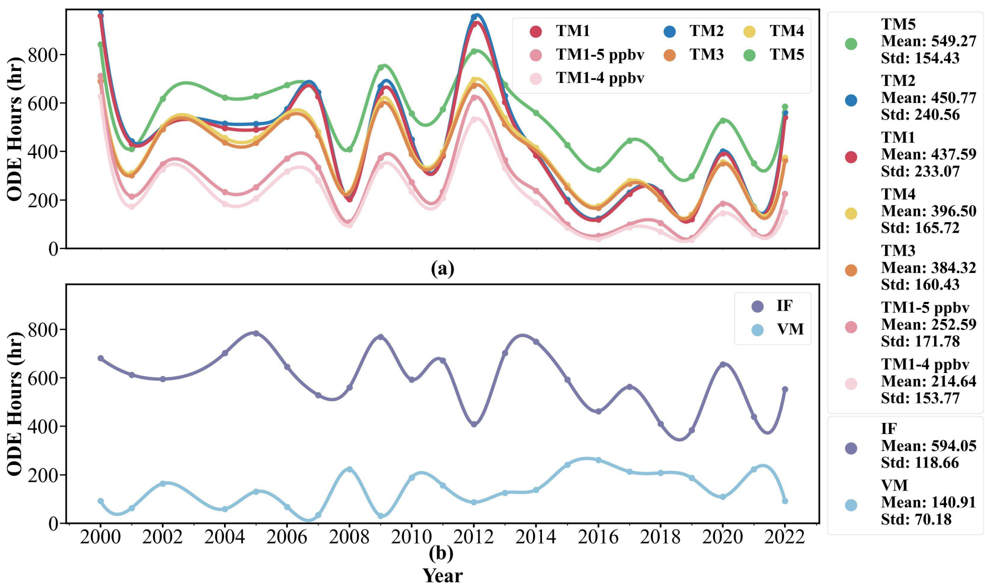


Figure A3 Number of ODE hours identified by each criterion from 2000 to 2022.

References

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