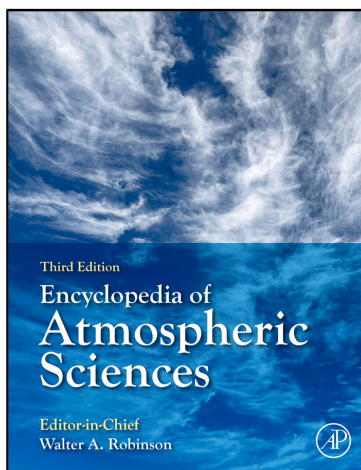


Provided for non-commercial research and educational use.
Not for reproduction, distribution or commercial use.

This chapter was originally published in Encyclopedia of Atmospheric Sciences, published by Elsevier, and the attached copy is provided by Elsevier for the author's benefit and for the benefit of the author's institution, for non-commercial research and educational use, including without limitation, use in instruction at your institution, sending it to specific colleagues who you know, and providing a copy to your institution's administrator.



All other uses, reproduction and distribution, including without limitation, commercial reprints, selling or licensing copies or access, or posting on open internet sites, your personal or institution's website or repository, are prohibited. For exceptions, permission may be sought for such use through Elsevier's permissions site at:

<https://www.elsevier.com/about/policies/copyright/permissions>

Harris, N.R.P., Hassler, B., 2026. Long-Term Ozone Changes. In: Robinson, W.A. (Ed.), Encyclopedia of Atmospheric Sciences, vol. 2. Elsevier, Academic Press, pp. 587–593. <https://dx.doi.org/10.1016/B978-0-323-96026-7.00047-3>. ISBN: 9780323960267

Copyright © 2026 Elsevier Ltd. All rights are reserved, including those for text and data mining, AI training, and similar technologies.

Long-Term Ozone Changes

N.R.P. Harris^a and B. Hassler^b, ^a Cranfield Environment Centre, Cranfield University, Bedfordshire, United Kingdom; and ^b Institut für Physik der Atmosphäre, Deutsches Zentrum für Luft & Raumfahrt (DLR), Oberpfaffenhofen, Germany

© 2026 Elsevier Ltd. All rights are reserved, including those for text and data mining, AI training, and similar technologies.

This is an update of N.R.P. Harris, OZONE DEPLETION AND RELATED TOPICS | Long-Term Ozone Changes, Editor(s): Gerald R. North, John Pyle, Fuqing Zhang, Encyclopedia of Atmospheric Sciences (Second Edition), Academic Press, 2015, Pages 353–358, ISBN 9780123822253, <https://doi.org/10.1016/B978-0-12-382225-3.00002-5>.

Introduction	587
Long-Term Ozone Measurements	588
Ozone Changes	589
Discussion	592
Outlook	592
References	593
Relevant Websites	593

Key Points

- Ozone declined from around 1980 as a result of ozone depleting substances (ODS).
- The rate of ozone decline slowed after the late 1990s when the ODS reached their maximum concentration with steady decrease thereafter.
- The impact of climate change and related influences has made it challenging to show rigorously that ozone is now recovering.

Synopsis

Continuous measurements of ozone have been made for several decades, with the longest record starting in 1926. While the longest records are from ground-based stations, global coverage was only achieved in 1979 with instruments carried on satellites. Together these show the following general features. In polar regions, severe ozone depletion occurs over Antarctica nearly every Austral spring (the Antarctic ozone hole), while large ozone losses have only occasionally appeared over the Arctic in Boreal spring. Smaller long-term decreases are seen over the midlatitudes in both hemispheres, with the larger losses occurring in the Southern Hemisphere. There are only small ozone trends over the tropics. Changes in chemical composition, particularly in chlorine and bromine containing species, and changes in atmospheric dynamics have influenced ozone. It is important to distinguish between these and other factors in order to assess the effect of the international treaty on phasing out of the emissions of ozone depleting substances and the possible influence of climate change on stratospheric ozone and UV radiation.

Introduction

Accurate determination of the magnitude and nature of trends in ozone is needed if the relative contributions of the various possible causes of decadal changes in ozone are to be distinguished (Staehelin et al., 2001; Godin-Beekmann et al., 2022; Weber et al., 2022). The Antarctic ozone hole is a good example where ozone measurements provided tight constraints on the possible causes of the rapid springtime depletion. High-quality measurements of the total ozone column (integrated from the ground to the top of the atmosphere) since the 1950s provided an excellent climatology, which showed that the decline first observable in the late 1970s was a new phenomenon and not part of the natural variability (Farman et al., 1985). These same measurements showed that total ozone dropped rapidly from the end of August and that extensive loss did not take place in the polar night, but only upon the return of sunlight. Measurements of the vertical distribution of ozone soon confirmed the latter point and, more importantly, showed that the loss occurred in the lower stratosphere, principally at altitudes between 15 and 20 km. By early October, the atmosphere between 14 and 21 km altitude in the core of the vortex is practically devoid of ozone. The average total ozone columns in Antarctic spring (September to November) in the 1990s were about 60% lower than those in the 1960s (Solomon, 1999). Since the 1990s, the Antarctic ozone hole of late winter and spring continued unabated, with exceptions in just 2002 and 2019 (Johnson et al., 2023). Those years apart, the final warming of the vortex, which effectively marks the end of the ozone hole, has taken place

a month or so later in the last two decades than in the 1960s to the 1980s. These observations tightly constrain possible explanations, especially when allied with the chemical and aerosol measurements made since the 1970s.

There is no other region where available ozone measurements provide such tight observational constraints. While this is partly due to the large size of the ozone loss over Antarctica that dwarfs the uncertainties in the ozone measurements and partly due to the relative homogeneity inside the Antarctic vortex, it is also testament to the perseverance of the people who made the measurements in such an adverse environment (Johnson et al., 2023). A record of similarly high quality and duration is not available for most of the globe, and our knowledge of global ozone trends is limited by the length and quality of the available ozone record. This limitation is compounded by the smaller magnitude of the trends outside Antarctica. Reviews of the understanding of global ozone trends are presented in the series of the World Meteorological Organization (WMO) assessments (WMO, 2022).

Long-Term Ozone Measurements

The importance of ozone lies principally in its ability to absorb UV-B radiation (light with wavelengths <310 nm). As a result, little UV-B radiation penetrates to the Earth's surface. A decrease in the total amount of ozone in the atmosphere (most of which is in the stratosphere) would lead to higher UV-B levels at the Earth's surface than occur naturally and can damage life-forms because they are not adapted to it. This same property (absorption of UV radiation) can be used to measure atmospheric ozone, with more ozone leading to greater absorption of UV and less ozone leading to less absorption. Most of the measurements referred to here are based on this basic principle. Applying it in practice is not straightforward, as proper account must be taken of factors such as atmospheric particles and sulfur dioxide, which also interact with UV radiation.

Our picture of the multidecadal variations in total ozone comes from the ground-based network, principally Dobson spectrophotometers, which was mainly located in the northern midlatitudes in the early years. Reliable records in this region have been available from several locations since the early 1960s. The quality of the global record is patchy, but it has been greatly improved over the last 40 years with the introduction of internationally agreed operating procedures and quality assessment. The longest near-continuous record of measurements at a single site is from Arosa/Davos in Switzerland, where measurements of ozone have been made since the 1920s. Fig. 1 shows the measurements from Arosa/Davos since the 1920s.

It is now over 40 years since the Nimbus 7 satellite was launched which included the ozone measuring TOMS and SBUV instruments in its payload. The two instruments worked for unexpectedly long times until 1993 and 1990, respectively. Subsequent versions of both sensor types have been flown, and it is possible to combine records from the different instruments, provided great care is taken with their absolute calibrations. In practice, the only independent means of assessing this is by comparison with the ground-based stations, a process that inevitably reduces the true independence of the ground and satellite systems. Other satellite instrument series have been operational since the 1990s. It is important that the various satellite systems are used in complementary ways that serve to increase the quality of the world's ozone observing system. Experience has shown the great value of the well-run, closely calibrated network of ground-based instruments that operate within WMO's Global Ozone Observing System (Fig. 2) and the need to continue this in the future. This is especially true with the gradual reduction in the number of satellite instruments measuring ozone. The average global ozone distribution is also shown in Fig. 2, with high values at higher latitudes.

The limits on statistical significance imposed by natural variability and particularly by uncertainty in instrumental calibration do not necessarily equate with scientific importance. Two instances stand out—ozone over the tropics where a small change in ozone

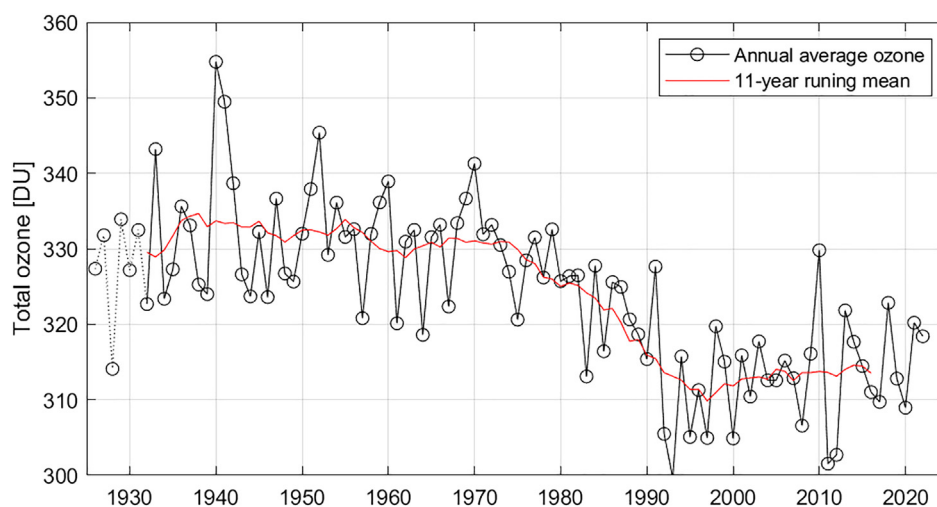


Fig. 1 Total ozone measurements at Arosa/Davos, Switzerland, from 1926 to 2022. The thin solid line and dots show the annual averages, with a dotted line prior to 1932 to indicate the large fractions of missing data at that time. The thicker line is the 11-year running mean. The measurements are performed by MeteoSwiss. Courtesy of R. Ruefenacht, MeteoSwiss.

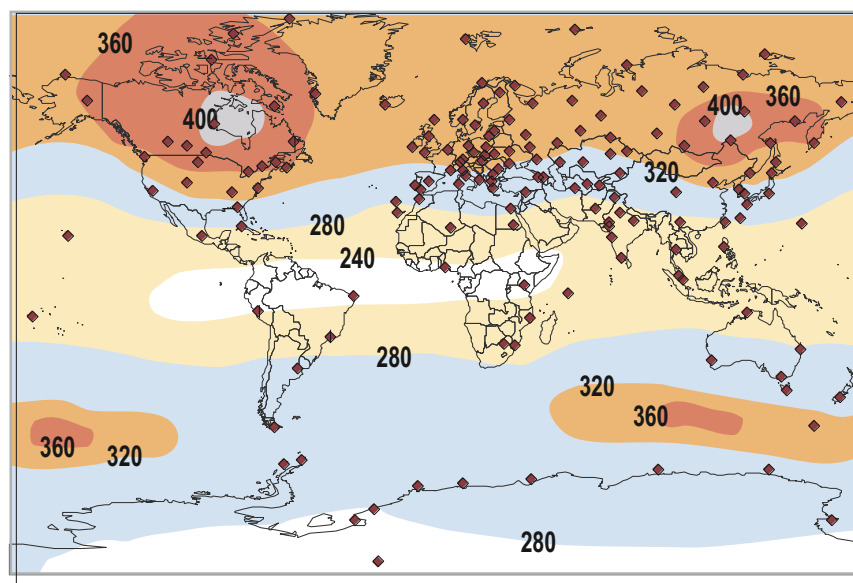


Fig. 2 The average global ozone distribution with low values in the tropics and higher values at higher latitudes. The diamonds illustrate the ground-based stations where ozone measurements are made within the World Meteorological Global Atmospheric Watch (WMO-GAW) network. Courtesy of WMO.

could have large radiative and climatic impact, and ozone in the lower stratosphere which is hard to measure with good precision and accuracy on the global scale.

Ozone Changes

Past total ozone behavior can be broken down into 3 periods (**Figs. 1 and 3**). Prior to the 1970s total ozone was essentially constant though showing considerable variability on annual and longer timescales. This variability was ascribed to the annual changes in solar radiation, atmospheric dynamics and chemistry; natural dynamic changes related to the quasi-biennial oscillation in tropical winds and to the El Niño Southern Oscillation as well as to the influence of the solar cycle changes in solar radiation; and to sporadic events such as volcanic eruptions. After the late 1970s, ozone at midlatitudes declined with greater losses occurring in winter/spring. This depletion was caused by ozone depleting substances (ODS) emitted as a result of human activities. The ODS were controlled by the Montreal Protocol which led to decreases in their concentrations after reaching a maximum in atmospheric abundance in the late 1990s. This decline was broadly paralleled by a diminution in the ozone depletion. These three periods can be considered in turn.

Initially, total ozone measurements were used to study meteorology and atmospheric dynamics to improve our understanding about the annual cycle and the influence of the quasi-biennial oscillation (QBO) and solar cycle. The global network was not well calibrated until the 1970s around the same time as concerns about ozone depletion emerged. They had to be carefully revised before they could be considered as suitable for determining decadal trends of a few percent. The low values in the first half of the 1960s (**Fig. 1**) are seen at other stations worldwide and are a consequence of the Mt Agung eruption. This response was known before Mt Pinatubo eruption in the early 1990s.

Analyses of total ozone data from the middle period show a number of now familiar features. At midlatitudes in the Northern Hemisphere from the late 1970s to the late 1990s, there was a statistically significant decline in the total ozone in all seasons (**Figs. 1 and 3**) with larger reductions in winter and spring than in summer and autumn. The loss of ozone at southern midlatitudes is statistically significant throughout the year, albeit with a smaller seasonal variation. No statistically significant trends in total ozone were observed in the tropics. These features can all be seen in **Fig. 3** that shows five different sets of ozone measurements. These deseasonalized time series show remarkable consistency with excellent stability and agreement to about $\pm 1\%$.

The top plot in **Fig. 3** (60°S – 60°N) is a measure of the global total ozone amount: it is used because measurements in polar regions are limited by the availability of sunlight required to measure ozone. It shows a decrease in total ozone, starting around 1980. The largest decrease (4%–6%) occurred in the early to mid-1990s when the influence of the large amounts of volcanic aerosol (following the eruption of Mt Pinatubo in 1991) was strongest. This signal was driven by total ozone in the northern midlatitudes (35°N – 60°N) where the influence of Mt Pinatubo is seen most strongly both in the aerosol loading and in the ozone response. No statistically significant trends in total ozone have been found in the tropics (25°S – 25°N), though there are indications of a small decrease in the 1990s around the time of Mt Pinatubo.

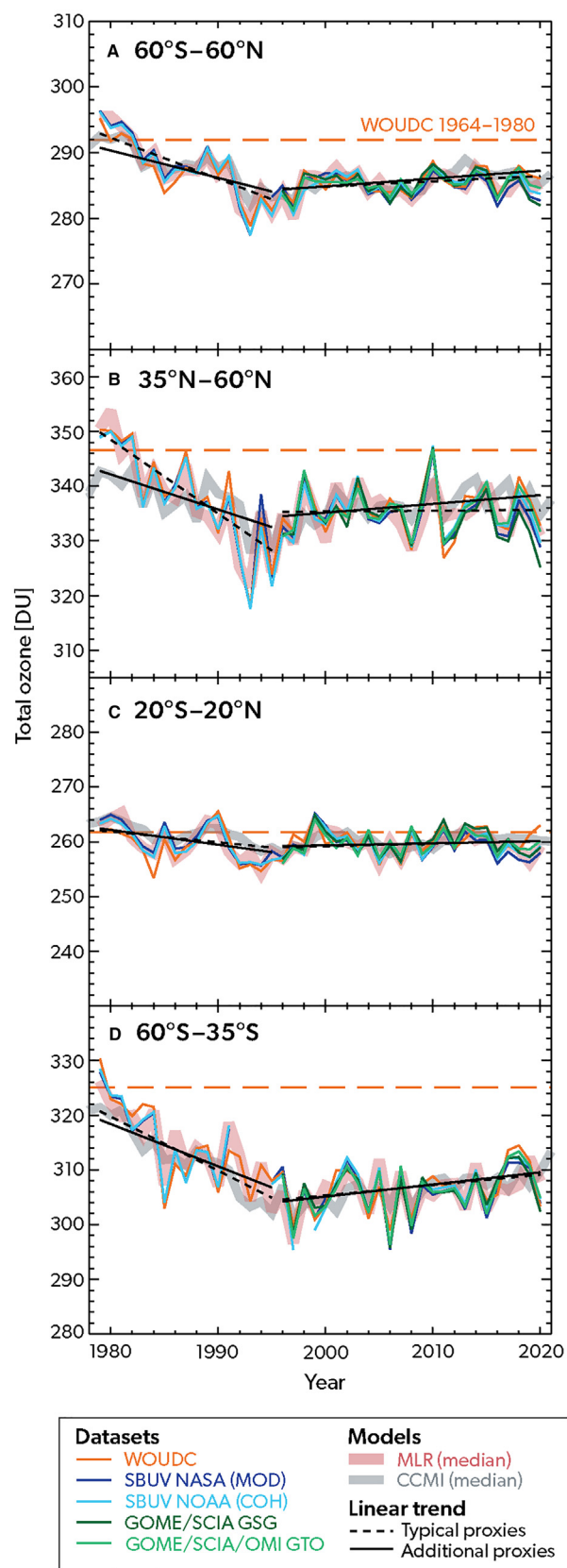


Fig. 3 Annual mean area-weighted total ozone deviations from the 1964–80 means for four latitude bands, estimated from different global data sets. Deviations are expressed as percentages of the ground-based time average for the period 1964–80. From Hassler et al. (2022).

Since the late 1990s (when the effects of Mt Pinatubo had largely dissipated), halogen levels in the stratosphere have been decreasing and so ozone increases ("recovery") might be expected. In reality, the global total ozone amount has not changed much, remaining roughly 2% below the pre-1980 levels. Similar behavior is seen in total ozone values over northern and southern midlatitudes which have stabilized at respectively about 4% and 5% lower than the 1964–80 average. In both hemispheres, there is little sign of increase in recent years. In the Tropics, there has if anything been a small decline.

When looking at changes of a few percent that result from several causes, there is a danger of over-interpreting changes of 1%—after all this is the estimated stability of the observational network for total ozone. It is clear, given the sizes of the changes and the measurement uncertainty, that care must be taken in discussions of the possible "recovery" of the ozone layer. For example, when interpreting the ozone record, the assumptions underlying the analysis must be valid.

The statistical models used to calculate ozone trends attempt to account for various influences on ozone. The standard approach is to describe the effects of natural phenomena such as the QBO, the 11-year solar cycle and ODS loading by assuming a linear relation between the strength of these phenomena and total ozone. The details of the statistical analysis would be of solely academic interest if the relationship of total ozone with the various influences was well established, but in practice this is not the case. One example is the role of climate change in determining ozone amounts: it will be having an effect, but it is very hard to be sure what that is based on current climate models.

Having said all that, there is clearly considerable scientific and public interest in being able to identify a recovery in ozone as a result of the ODS reductions occurring after the implementation of the Montreal Protocol (Harris et al., 2008). One of the places where this signal might be most easily discernible is the upper stratosphere, where (1) the effects of the ODS-related chemical ozone loss are relatively large and well understood; and (2) the measurements are of high quality. Fig. 4 shows a composite of ground-based and satellite measurements taken at five ground stations in northern midlatitudes, tropical latitudes, and southern midlatitudes. The most obvious feature is the upper stratospheric ozone decline from 1980 to the mid-1990s. It is also clear that decline has stopped and ozone has stabilized since 1995–96. However, no statistically significant trend can be seen in this period, although other, merged datasets do show a significant upward trend.

Large changes were seen at lower altitudes (between 10 and 25 km) in the extratropics with no significant change at 30 km (Ball et al., 2019). It is hard to assess the recent changes at these altitudes, partly because there are large natural variations that have strong regional dependencies and partly because the available measurements do not give a coherent, long-term picture. This is a concern

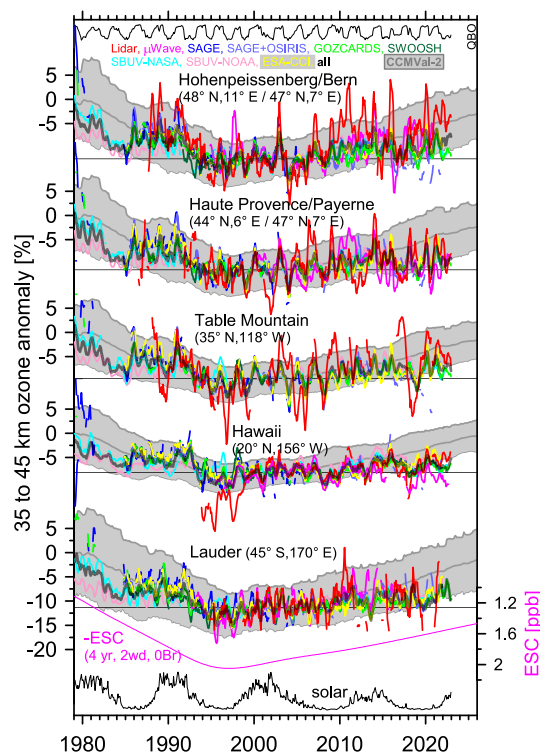


Fig. 4 Ozone anomalies at altitudes of 35–45 km from 1979 to mid-2023 for nine data sets at five ground-based stations in the Network for the Detection of Atmospheric Composition Change. The gray underlay shows the range for an ensemble of climate-chemistry models. The thin black lines at the top and bottom show negative 10 hPa zonal wind at the equator as a proxy for the quasi-biennial oscillation, and 10.7 cm solar flux as a proxy for the 11-year solar cycle, respectively. The thin magenta line near the bottom shows inverted effective stratospheric chlorine (ESC) as a proxy for ozone destruction by chlorine. Updated from Chapter 2 of WMO Scientific Assessment of Ozone Depletion: 2010. World Meteorological Organization Global Ozone Research and Monitoring Project, Report No. 52, Geneva, Switzerland, 2011. Courtesy of W. Steinbrecht, Deutscher Wetterdienst.

because changes of ozone in the tropical lower stratosphere and upper troposphere are of great potential importance to climate change.

Finally, it is interesting to compare what happens over the Arctic with the dramatic changes that have occurred over Antarctica—and the picture is certainly more complex. The observed ozone losses in the Arctic vary a great deal from winter to winter, with large losses in cold winters when the processes leading to chemical ozone loss are favored. Large ozone losses (20%–30% in the column and 40%–70% at altitudes around 18 km) caused by chemistry have occurred in the colder winters, most notably in spring 2011 and 2020. Here, over 80% of the ozone between 18 and 20 km was destroyed, and the column ozone loss was similar to that which occurs in the Antarctic. Important differences remain, including the facts that ozone amounts in the Arctic are naturally higher than in the Antarctic (so that a greater loss is required to reach the same level) and the Arctic is not cold every year so that such large losses will remain exceptional.

Discussion

It is clear that chlorine and bromine compounds resulting from ODS breakdown lead to ozone depletion, but it is also clear that they do not account quantitatively for all of the observed trends. There is no doubt that rapid chemical ozone loss occurs over the Antarctic and Arctic in winter/spring. The signal is large and a whole host of chemical measurements allow unambiguous identification of perturbed chlorine and bromine chemistry as the cause. There is equally no doubt that the ozone-depleted air is subsequently mixed over larger areas and leads to reduced ozone amounts over midlatitudes.

Other factors are also involved. Statistical analyses of total ozone trends routinely include terms to describe the influence of the solar cycle and the QBO on total ozone. With over 40 years of global satellite data and nearly 50 years of ground-based observations—i.e. longer than the periods of these or other natural phenomena that could affect ozone—any total ozone changes resulting from the increase in ODS are reasonably robust to possible errors in the description of these phenomena. However, identification of any recovery (based on 20–25 years of measurements since the ODS maximum) still requires correct attribution of these factors.

In order to separate the various influences, close attention is paid to examining the time series of ozone measurements in order to extract information on possible mechanisms from the observed interannual variations. For example, 2D and particularly 3D models of stratospheric chemistry and dynamics have been used to investigate this, with their simulations including the effect of observed aerosol amounts on the trends calculated for the chlorine and bromine changes and observed changes in stratospheric transport. The calculated ozone changes following the major volcanic eruptions in the 1980s and the 1990s are consistent with variations in the observed total ozone record. In particular, a difference in behavior is found in the northern and southern midlatitudes. The reasons for this difference include a greater loss in the Antarctic that dilutes the ozone amount more in southern midlatitudes than does the smaller loss in the Arctic; a greater effect of Mt Pinatubo on the Northern Hemisphere; and a greater decadal variability in the dynamic influence on ozone in the Northern Hemisphere.

Outlook

Long-term changes in the circulation of the atmosphere connected with climate change are and will be causing long-term changes in total ozone. A number of changes are already occurring that will have important consequences for the stratosphere and stratospheric ozone: changes in stratospheric temperature, with episodic jumps associated with volcanic eruptions superimposed on a long-term cooling trend; an increase in tropopause height (and decrease in tropopause pressure) which at a simple level means that the stratosphere is getting smaller; and a widening of the tropical belt. More recently the importance of the increasingly intense wildfires which lift material into the lower stratosphere has become clear (Bernath et al., 2022; Solomon et al., 2022). These changes are all associated with climate change and are all having important, though incompletely understood consequences for stratospheric ozone amounts and distribution.

Looking to the future, total ozone will be subjected to chemical and dynamical influences. The major chemical influence is from the declining levels of ODS as a result of the success of the implementation of the Montreal Protocol. The secondary chemical influence is from the likely changes in the chemically important greenhouse gases methane (CH_4) and nitrous oxide (N_2O): the main uncertainty in predicting these changes arises from uncertainties in their future emissions. However, the dynamical influences associated with climate change could be greater and are currently known with far less certainty.

Unambiguous identification of the effect of the Montreal Protocol on ozone observations has been a “holy grail” for a few years as there is real value to providing definitive proof of a success of environmental legislation. However, with so many competing influences on ozone to account for, it is extremely hard to achieve. Scientists have looked at regions where the influence of ODS-related chemistry is particularly strong such as the upper stratosphere (Fig. 4) and the Antarctic ozone hole. To date, marginally significant upward trends in total column ozone have been seen in the global mean and at southern midlatitudes, and more clearly in the upper stratosphere (Hassler et al., 2022). Here, however, the stratospheric cooling due to increasing greenhouse gases affects the speed of the ozone chemistry in such a way that more ozone is expected to be present when the ODS are gone than before they were introduced. The sustained increase in N_2O concentration is perturbing the chemistry further. The Antarctic may be a better place to look, but even there it may be some time before an ozone recovery resulting from the Montreal Protocol can be rigorously shown. Currently, the picture is still unclear as some exceptional ozone losses are observed in particularly cold years—the chemical

processes are well understood but the interaction between ozone depletion and climate change is less well understood and is complicating the picture.

Finally, deliberate modification of stratospheric aerosols has been suggested as a way to ameliorate temperature increases (Haywood et al., 2022). It is clear that undesirable or unintended consequences will arise (e.g. increased ozone depletion, regional impacts through changed circulations with enhanced rainfall in some places) and that such an approach is likely to lead to winners and losers. As a result, many scientific, ethical, legal and political issues remain to be resolved before the approach can be used with broad international scientific support.

References

- Ball, W.T., Alsing, J., Staehelin, J., Davis, S.M., Froidevaux, L., Peter, T., 2019. Stratospheric ozone trends for 1985–2018: sensitivity to recent large variability. *Atmos. Chem. Phys.* 19, 12731–12748. <https://doi.org/10.5194/acp-19-12731-2019>.
- Bernath, P., Boone, C., Crouse, J., 2022. Wildfire smoke destroys stratospheric ozone. *Science* 375, 1292–1295. <https://doi.org/10.1126/science.abm5611>.
- Farman, J.C., Gardiner, B.G., Shanklin, J.D., 1985. Large losses of total ozone in Antarctica reveal seasonal ClO_x/NO_x interaction. *Nature* 315, 207–210.
- Godin-Beekmann, S., Azouz, N., Sofieva, V.F., Hubert, D., Petropavlovskikh, I., Effertz, P., Ancellet, G., Degenstein, D.A., Zawada, D., Froidevaux, L., Frith, S., Wild, J., Davis, S., Steinbrecht, W., Leblanc, T., Querel, R., Tourpali, K., Damadeo, R., Maillard Barras, E., Stübi, R., Vigouroux, C., Arosio, C., Nedoluha, G., Boyd, I., Van Malderen, R., Mahieu, E., Smale, D., Sussmann, R., 2022. Updated trends of the stratospheric ozone vertical distribution in the 60° S–60° N latitude range based on the LOTUS regression model. *Atmos. Chem. Phys.* 22, 11657–11673. <https://doi.org/10.5194/acp-22-11657-2022>.
- Harris, N.R.P., Kyrö, E., Staehelin, J., Brunner, D., Andersen, S.B., Godin-Beekmann, S., Dhomse, S., Hadjinicolaou, P., Hansen, G., Isaksen, I., Jrrar, A., Karpetchko, A., Kivi, R., Knudsen, B., Krizan, P., Lastovicka, J., Maeder, J., Orsolini, Y., Pyle, J.A., Rex, M., Vanicek, K., Weber, M., Wohltmann, I., Zanis, P., Zerefos, C., 2008. Ozone trends at northern mid- and high latitudes—a European perspective. *Ann. Geophys.* 26, 1207–1220. www.ann-geophys.net/26/1207/2008/.
- Hassler, B., Young, P.J., Ball, W.T., Damadeo, R., Keeble, J., Maillard Barras, E., Sofieva, V., Zeng, G., 2022. Update on Global Ozone: Past, Present and Future, Chapter 3 in Scientific Assessment of Ozone Depletion: 2022. WMO, Geneva, p. 509. GAW Report No. 278.
- Haywood, J., Tilmes, S., Keutsch, F., Niemeier, U., Schmidt, A., Visioni, D., Yu, P., 2022. Stratospheric Aerosol Injection and Its Potential Effect on the Stratospheric Ozone Layer, Chapter 6 in Scientific Assessment of Ozone Depletion: 2022. WMO, Geneva, p. 509. GAW Report No. 278.
- Johnson, B.J., Cullis, P., Booth, J., Petropavlovskikh, I., McConville, G., Hassler, B., Morris, G.A., Sterling, C., Oltmans, S., 2023. South Pole Station ozonesondes: variability and trends in the springtime Antarctic ozone hole 1986–2021. *Atmos. Chem. Phys.* 23, 3133–3146. <https://doi.org/10.5194/acp-23-3133-2023>.
- Solomon, S., 1999. Stratospheric ozone depletion: a review of concepts and history. *Rev. Geophys.* 37, 275–316.
- Solomon, S., Dube, K., Stone, K., Yu, P., Kinnison, D., Toon, O.B., Strahan, S.E., Rosenlof, K.H., Portmann, R., Davis, S., Randel, W., Bernath, P., Boone, C., Bardeen, C.G., Bourassa, A., Zawada, D., Degenstein, D., 2022. On the stratospheric chemistry of mid-latitude wildfire smoke. *Proc. Natl. Acad. Sci. U. S. A.* 118 (10). <https://doi.org/10.1073/pnas.2117325119>.
- Staehelin, J., Harris, N.R.P., Appenzeller, C., Eberhard, J., 2001. Ozone trends: a review. *Rev. Geophys.* 39, 231–290.
- Weber, M., Arosio, C., Coldewey-Egbers, M., Fioletov, V.E., Frith, S.M., Wild, J.D., Tourpali, K., Burrows, J.P., Loyola, D., 2022. Global total ozone recovery trends attributed to ozone-depleting substance (ODS) changes derived from five merged ozone datasets. *Atmos. Chem. Phys.* 22, 6843–6859. <https://doi.org/10.5194/acp-22-6843-2022>.
- World Meteorological Organization (WMO), 2022. Scientific Assessment of Ozone Depletion: 2022. WMO, Geneva, p. 509. GAW Report No. 278.

Relevant Websites

- BAS Ozone Page—http://www.antarctica.ac.uk/about_antarctica/geography/ozone.php.
- NASA OZONE Watch—<http://ozonewatch.gsfc.nasa.gov/>.
- NDACC—<http://www.ndsc.ncep.noaa.gov/>.
- WMO Ozone Page—<https://www.wmo.int/pages/prog/arep/gaw/ozone/index.html>.