6. STRATOSPHERIC OZONE

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About 90% of total column ozone resides in the stratosphere; only 10% resides in the troposphere. In 2024, total column ozone was well above the average of 1998–2008 over most of the globe except for two narrow zonal bands in the tropics and a patch over Antarctica (Plate 2.1af). In the NH, anomalies reached values of +60 DU or more in some regions, for example the Canadian Arctic. The time series in Fig. 2.75b show that the 2024 annual zonal mean at northern midlatitudes (35°N–60°N) was close to the high values observed during the 1960s. In March 2024, Arctic (60°N–90°N) total column ozone reached 475 DU, the highest value seen since 1979 (Fig. 2.75e). The variation in annual-mean total column ozone in the extratropics is largely driven by variations in the stratospheric circulation in winter/early spring. During boreal winter/spring 2024, the Brewer–Dobson (BD) circulation, which transports ozone from the tropical source region to middle and high latitudes, was particularly strong (Newman et al. 2024). Combined with the lower stratospheric quasi-biennial oscillation (QBO) in its easterly phase and the strong El Niño conditions in the first half of 2024, total column ozone was reduced in the tropics and strongly enhanced in the extratropics (Figs. 2.75a,b,d; Plate 2.1af; Baldwin et al. 2001; Oman et al. 2013; Butchart 2014; Domeisen et al. 2019).

In the SH midlatitudes and in October in the Antarctic (Fig. 2.75d,e), the last two years were closer to the high end of the range of interannual variability, ending the series of years of low total column ozone from 2020 to 2022, caused by Australian wildfires (Solomon et al. 2023) and a series of volcanic eruptions, including Hunga (Santee et al. 2023; Fleming et al. 2024).

Generally, observed total column ozone values in recent years have tended to be at the low end of projections from chemistry climate models (CCMs; see Figs. 2.75a–d), based on current scenarios for ODSs and GHGs. Overall, the data show the slow path of ozone recovery due to the ODS phase-out by the Montreal Protocol and its Amendments (WMO 2022).

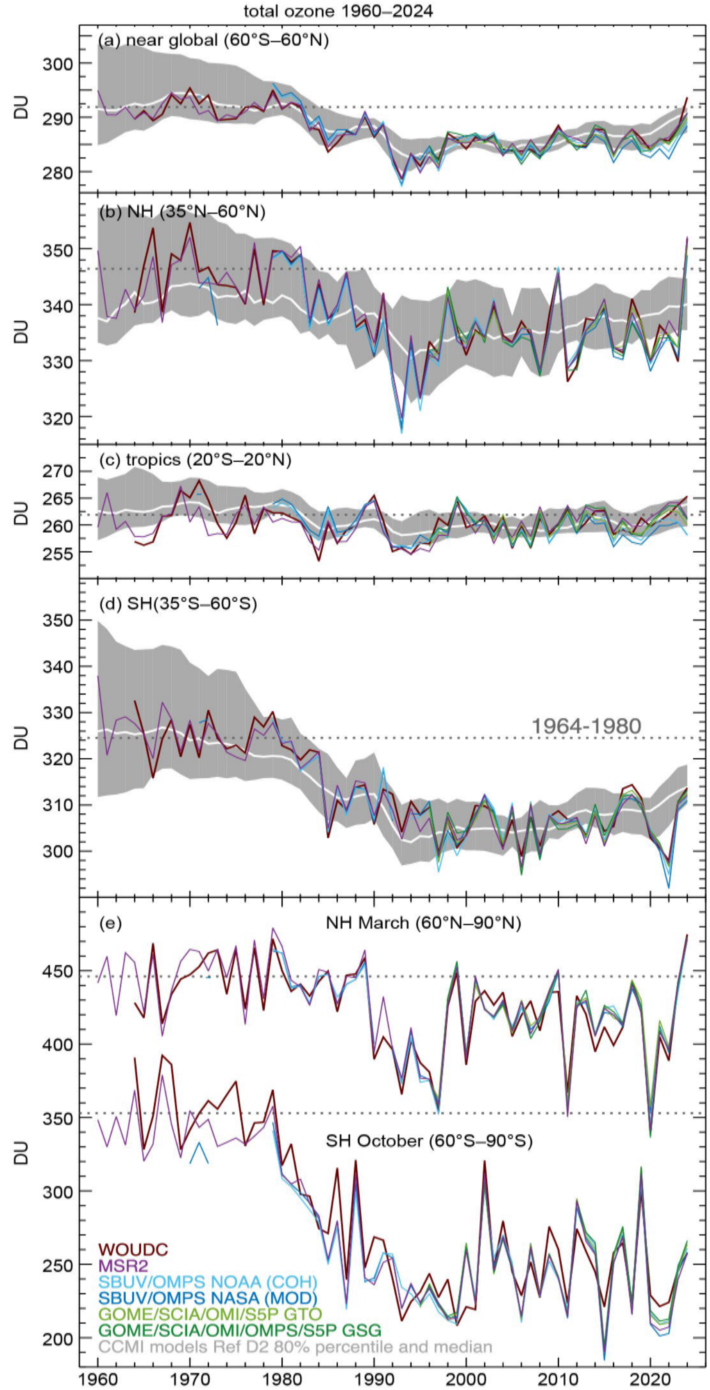
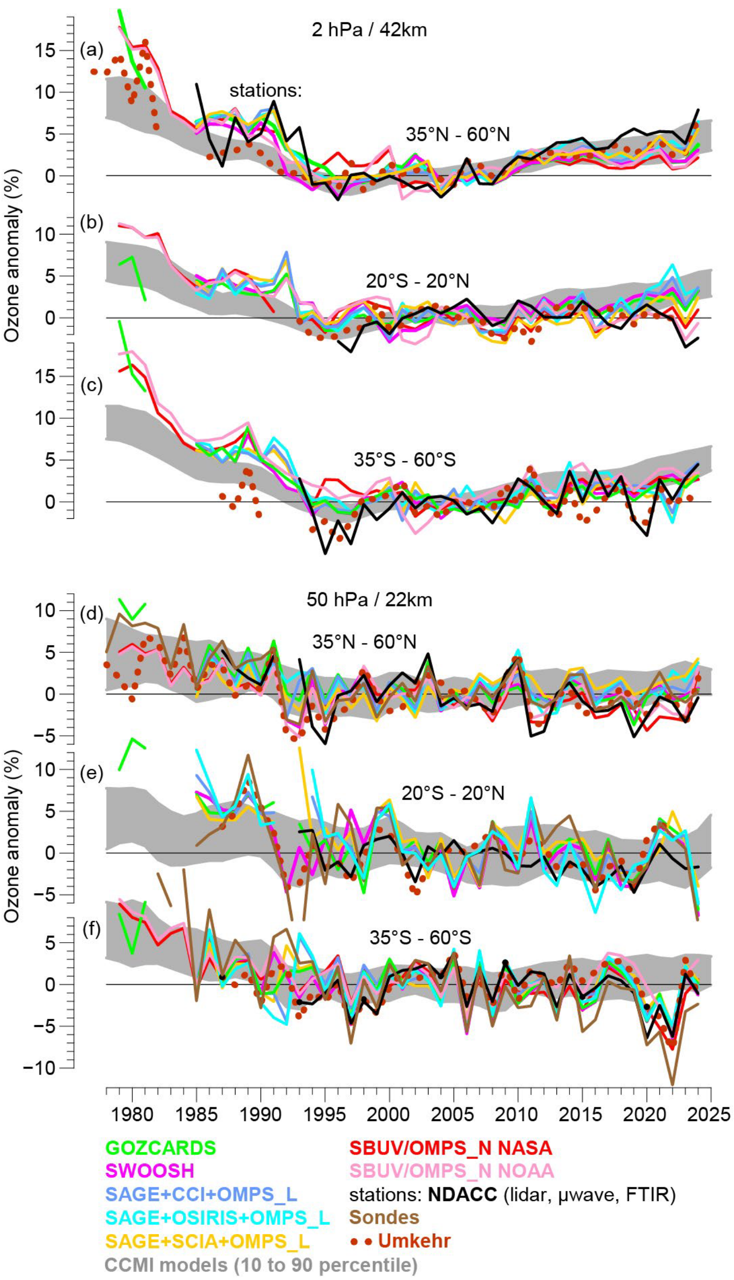


Fig. 2.75. Time series of annual mean total column ozone (DU) in (a)–(d) four zonal bands, and (e) polar (60°–90°) total column ozone in Mar (Northern Hemisphere; NH) and Oct (Southern Hemisphere; SH), the months when polar ozone losses usually are largest. Values are plotted at the tick mark start of each year. The dotted gray lines in each panel show the average ozone level for 1964–1980 calculated from the World Ozone and Ultraviolet Radiation Data Centre's (WOUDC) data. Most of the observational data for 2024 are preliminary. The thick white lines in (a)–(d) show the median from Chemistry-Climate Model Initiative (CCMI)-2022 ref D2 model runs (Plummer et al. 2021). The model data have been smoothed using a three-point triangle function. The gray-shaded areas provide the 80th percentile range. All datasets have been bias-corrected by subtracting individual data averages and adding the multi-instrument mean from the reference period 1998–2008.

Figure 2.76 shows the evolution of ozone profiles at two stratospheric levels and for three latitude bands. The 2-hPa level (or 42-km altitude) represents the upper stratosphere (Figs. 2.76a–c), and the 50-hPa level (or 22-km altitude) the lower stratosphere (Figs. 2.76d–f).



Ozone in the upper stratosphere is controlled to a large degree by photochemistry. The year 2024 continued the slow upper-stratospheric ozone increase due to declining ODSs and cooling of the upper stratosphere, as predicted by models (e.g., WMO 2022), although observed values in recent years have tended to be at the lower end of expectations from CCM simulations (gray-shaded region in Figs. 2.76a–c).

Ozone in the lower stratosphere (Figs. 2.76d–f) is controlled to a large degree by transport variations and is the main contributor to the already discussed total column ozone variations. Consistent with the strong El Niño and the easterly shear phase of the QBO in the lower stratosphere from January to April, ozone values were very low in the tropical band in 2024 (Fig. 2.76e; see also the El Niño years 1998 and 2016). In the Northern Hemisphere extratropical band in 2024 (Fig. 2.76d), ozone at 50 hPa was near the high end of recent values for almost all individual datasets. However, the enhancement was not as large as that seen for total column ozone in Fig. 2.75b, because a large fraction of the total column enhancement in 2024 came from levels lower than 50 hPa. In the SH (Fig. 2.76f) in 2024, ozone at 50 hPa from the zonal-mean satellite datasets again approached the range predicted by CCMs, ending the low excursions from 2020 to 2022 due to the Australian wildfires and recent volcanic eruptions, events which were not considered in the CCM projections.

Fig. 2.76. Annual mean anomalies of ozone in the (a)–(c) upper stratosphere near 42-km altitude or 2-hPa pressure, and in the (d)–(f) lower stratosphere near 22 km or 50 hPa for three zonal bands: (a),(d) 35°N–60°N, (b),(e) 20°S–20°N (tropics), and (c),(f) 35°S–60°S, respectively. Anomalies are referenced to the 1998–2008 baseline. Annual means are plotted at the tick marks of the start of each year. Colored lines are long-term records obtained by merging different limb (Global Ozone Chemistry and Related Trace Gas Data Records for the Stratosphere [GOZCARDS], Stratospheric Water and Ozone Satellite Homogenized [SWOOSH], Stratospheric Aerosol and Gas Experiment [SAGE]+Climate Change Initiative [CCI]+Ozone Mapping and Profiler Suite Limb Profiler [OMPS-LP], SAGE+Scanning Imaging Absorption Spectrometer for Atmospheric Chartography [SCIAMACHY]+OMPS-LP, SAGE+Optical Spectrograph and InfraRed Imaging System [OSIRIS]+OMPS-LP) and nadir-viewing (Solar Backscatter Ultraviolet Radiometer [SBUV], OMPS Nadir Profile [OMPS-NP]) satellite instruments. The nadir-viewing instruments have a much coarser altitude resolution than the limb-viewing instruments. This can cause differences in some years, especially at 50 hPa. Red dots are results from ground-based Umkehr data (Petropavlovskikh et al. 2025). The black line is from merging ground-based ozone records at seven Network for the Detection of Atmospheric Composition Change (NDACC) stations employing differential absorption lidars and microwave radiometers. See Steinbrecht et al. (2017), WMO (2022), and Arosio et al. (2019) for details on the various datasets. Gray shaded area shows the range of chemistry-climate model simulations from the Chemistry-Climate Model Initiative (CCMI)-1 refC2 (SPARC/IO3C/GAW 2019). Ozone data for 2024 are not yet complete for all instruments and are still preliminary.