6. STRATOSPHERIC OZONE

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Stratospheric ozone protects the ecosystem from harmful ultraviolet radiation. The total ozone column is an indicator of the level of protection from this radiation. About 90% of the total column amount resides in the stratosphere, and the number of ozone molecules is maximum at about 20-km to 25-km altitude (lower stratosphere), an altitude range that is called the ozone layer. Long-term changes in stratospheric ozone are governed by declining stratospheric halogens (chemistry) from man-made ozone-depleting substances (ODSs) and by the current and future greenhouse gas concentrations in the atmosphere (chemistry and circulation; WMO 2022).

In 2023, total column ozone was, on average, slightly lower compared to the 1998–2008 reference period in the NH, while in the SH from 35°S to 60°S, it was higher by up to 10 DU–15 DU (Plate 2.1ab). Antarctic total column ozone was close to the long-term mean except for in a small region south of Australia (Plate 2.1ab). The year 2023 ends a series of three years with below-average ozone values for the SH extratropics. The SH total column ozone was unusually low in 2022 (Figs. 2.71d,e), mainly due to circulation changes but also due to enhanced chemical destruction following the HTHH volcanic eruption in January 2022 (e.g., Santee et al. 2022; Evan et al. 2023; Fleming et al. 2024). In the tropics (Fig. 2.71c), total ozone was higher by a few DU compared to previous years but was within the year-to-year variability (two sigma) of the last two decades. Globally, total ozone levels

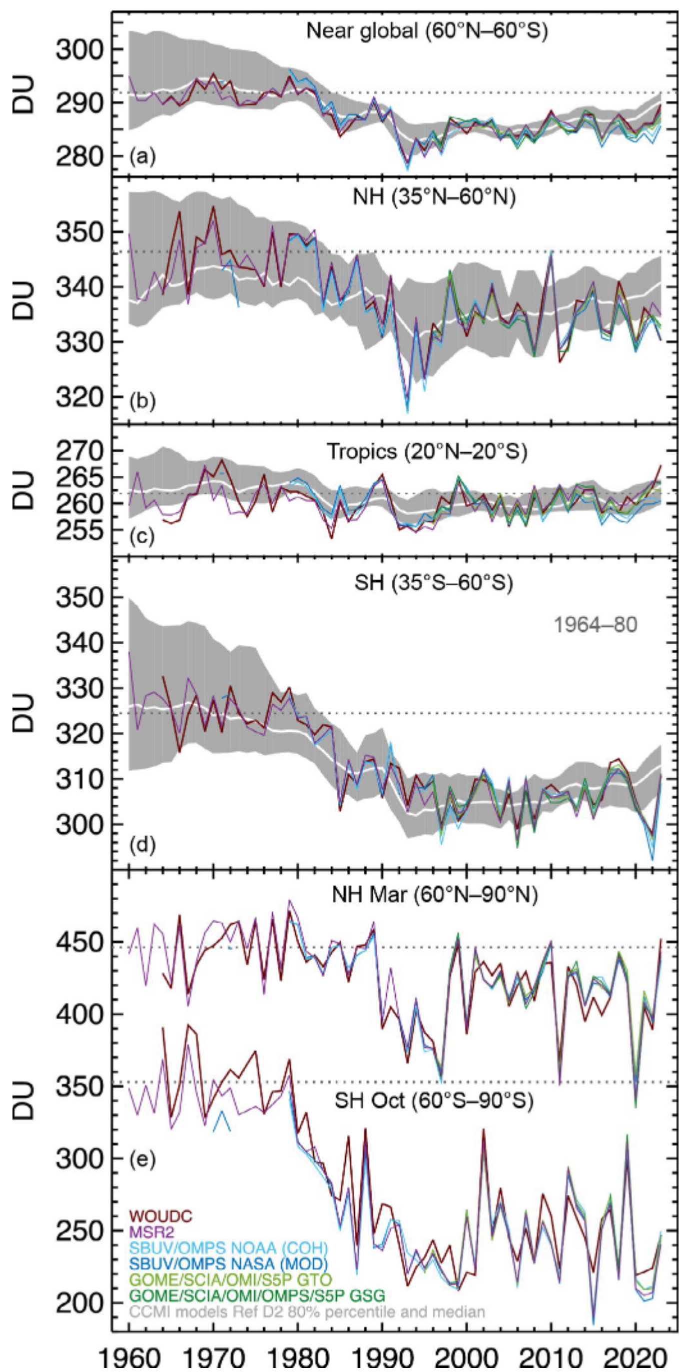

Fig. 2.71. Time series of annual mean total column ozone (DU) in (a)–(d) four zonal bands and (e) polar (60°–90°) total column ozone in Mar (Northern Hemisphere [NH]) and Oct (Southern Hemisphere [SH]), the months when polar ozone losses usually are largest. Data are from the World Ozone and Ultraviolet Radiation Data Centre (WOUDC) ground-based measurements combining Brewer, Dobson, SAOZ, and filter spectrometer data (red: Fioletov et al. 2002, 2008); the BUV/SBUV/SBUV2/OMPS merged products from NASA (V8.7; dark blue; Frith et al. 2014; 2017), and NOAA (SBUV V8.6, OMPS V4r1; light blue; Jeannette Wild, NOAA, 2024, personal communication); the GOME/SCIAMACHY/GOME-2/OMPS/TROPOMI products (GSG) from University of Bremen (dark green, Weber et al. 2022), and GTO from the EU's German Aerospace Center (DLR; light green; Coldewey-Egbers et al. 2022; Garane et al. 2018). MSR-2 (purple) assimilates nearly all ozone datasets after corrections based on the ground-based data (van der A et al. 2015). The dotted gray lines in each panel show the average total column ozone level for 1964–80 calculated from the WOUDC data. Most of the observational data for 2023 are preliminary. The thick white lines in (a)–(d) show the median from chemistry-climate 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 80% percentile range for the model data. All datasets have been bias-corrected by subtracting individual data averages and adding the multi-instrument mean in the reference period (1998–2008).

in 2023 were close to the long-term average of the last 20 years and broadly agree with projections from chemistry-climate models (CCMs) using current scenarios of ODSs and greenhouse gases, as shown in Figs. 2.71a–d.

Figures 2.72d,e show that ozone at 50 hPa (~22-km altitude) in the tropics and northern midlatitudes behaved similarly to the total column (Figs. 2.71b,c). In 2023, the NH annual mean was nearly unchanged from previous years (Fig. 2.72d). Ozone at 50 hPa was slightly higher in the tropics in 2023 but still within the year-to-year variability of the last decade (Fig. 2.72e), and larger than in 2022 by about 5% in the SH (Fig. 2.72f), bringing it closer to the long-term average. In the upper stratosphere (2 hPa or 42-km altitude; Figs. 2.72a–c), ozone observations show a clear increase since the mid-1990s, averaging 0.2±0.15% yr^{-1}. The 2023 annual means follow the long-term trend, again in general agreement with the broad range predicted by CCMs.

In the SH midlatitude, elevated total column ozone (Plate 2.1ab; Fig. 2.71d) and ozone in lower stratosphere (Fig. 2.72f) in 2023 compared to 2022 is probably related to the strong El Niño that started to emerge in the middle of 2023. El Niños are linked to a strengthening of the Brewer-Dobson (BD) circulation and a weakening of the polar vortex, which both increase extratropical ozone by enhancing ozone transport from the tropical stratosphere to higher latitudes and by reducing the potential for the formation of widespread polar stratospheric clouds and subsequent large chemical ozone depletion in polar spring (e.g., Domeisen et al. 2022; Butchart 2014). The quasi-biennial oscillation (QBO) was in its westerly phase from September 2022 until the end of boreal summer 2023. This is associated with a weaker BD circulation and typically results in lower extratropical and higher tropical ozone columns. In the first half of 2023, this resulted in lower stratospheric ozone in the NH (e.g., Baldwin et al. 2001). The QBO turned easterly during the second half of 2023, coinciding with the strengthening of El Niño. The combined effect on SH ozone resulted in positive anomalies at southern midlatitudes (Plate 2.1ab; Figs. 2.71d,e, 2.72f).

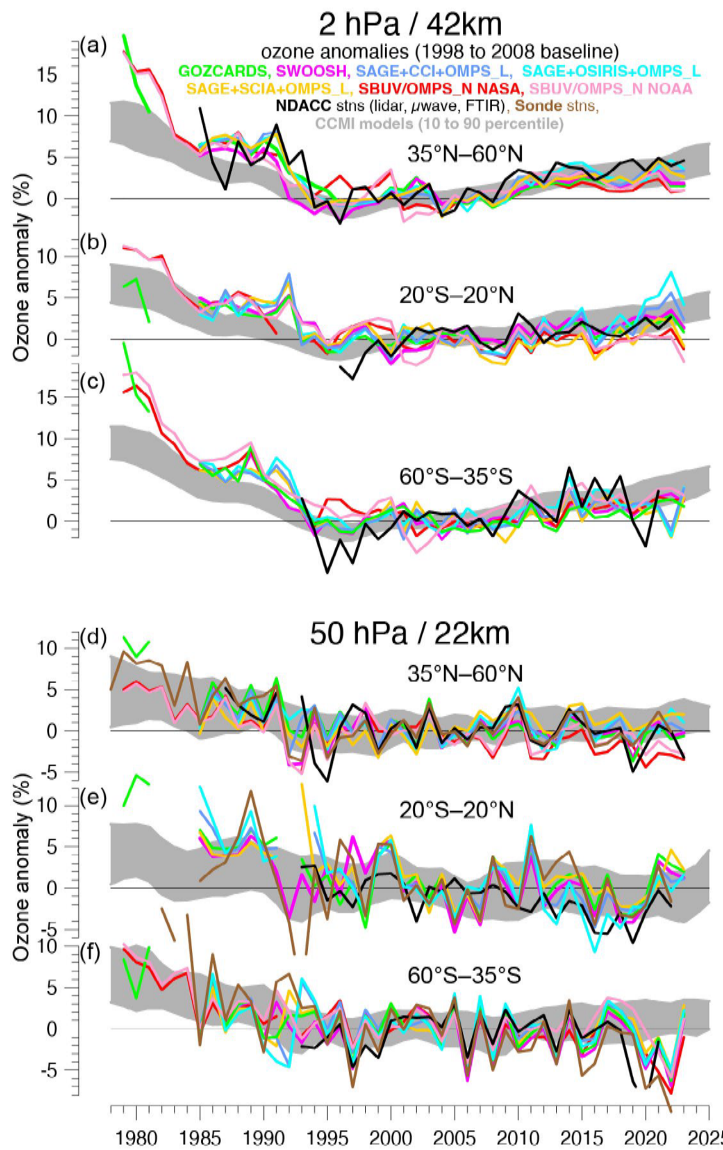

Fig. 2.72. Annual mean anomalies of ozone (%) in (a)–(c) the upper stratosphere near 42-km altitude or 2-hPa pressure, and (d)–(f) the lower stratosphere, near 22 km or 50 hPa for three zonal bands: 35°N–60°N, 20°S–20°N (tropics), and 35°S–60°S, respectively. Anomalies are with respect to the 1998–2008 baseline. Colored lines are long-term records obtained by merging different limb (GOZCARDS, SWOOSH, SAGE+CCI+OMPS_L, SAGE+OSIRIS+OMPS_L, SAGE+SCIAMACHY+OMPS_L) or nadir-viewing (SBUV, OMPS_N) satellite instruments. The nadir-viewing instruments have much coarser altitude resolution than the limb-viewing instruments. This can cause differences in some years, especially at 50 hPa. The black line is determined 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), Arosio et al. (2019), and Godin-Beekmann (2022) for details on the various datasets. Gray-shaded areas show the range of chemistry-climate model simulations from CCMI-1 refC2 (SPARC/IO3C/GAW 2019). Ozone data for 2023 are not yet complete for all instruments and are still preliminary.