Supplement of Atmos. Chem. Phys., 24, 6743–6756, 2024
https://doi.org/10.5194/acp-24-6743-2024-supplement

Atmospheric Chemistry and Physics
Open Access

Supplement of

No severe ozone depletion in the tropical stratosphere in recent decades

Jayanarayanan Kuttippurath et al.

Correspondence to: Jayanarayanan Kuttippurath (jayan@coral.iitkgp.ac.in)

DATA

MERRA-2 and ERA-5 Reanalyses

MERRA–2 (Modern Era Retrospective analysis for Research and Analysis-2) is a reanalysis data developed at the Global Modelling and Assimilation office (GMAO). These data have 72 sigma pressure vertical layers with a spatial resolution of 0.625° × 0.5° (Bosilovich et al., 2015) and are available from 1980 onwards. The reanalysis also assimilates data from Infrared Atmospheric Sounding Interferometer (IASI) and Cross Infrared Sunder and Advanced Technology Microwave Sounder on board Suomi NPP. An adaptive bias correction scheme is also applied to the radiance data while assimilating the datasets in MERRA–2. A comprehensive discussion on this assimilation system is given in Gelaro et al. (2016).

We have also used the ECMWF Reanalysis 5th Generation (ERA-5) data, which has 137 vertical hybrid sigma pressure levels, and extends from the surface to 0.01 hPa. We use the monthly gridded data at a 0.25° × 0.25° resolution for the period 1984–2022 (Hersbach et al., 2019). Here, the ozone mass mixing ratio (MMR) in kg kg^{-1} is converted to parts per million (ppm) by multiplying it with the dividend of molar mass of dry air (28.9644) and molar mass of ozone (47.9982). However, from the middle to upper stratosphere, these ozone profiles show a bias within ±20% compared to the observations, whereas, the biases are even up to about 50% in the UTLS region (SPARC, 2017).

Table S1: The location of SHADOZ ozonesonde observations.

Location	Abbreviation	Latitude in °	Longitude in °
Ascension, UK	Ascen	-7.56	-14.22
Suva, Fiji	Fiji	-18.10	178.40
Hilo, Hawaii	Hilo	19.40	-155.40
Irene, S. Africa	Irene	-25.90	28.20
Watukosek, Java, Indonesia	Java	-7.60	112.70
Kuala Lampur, Malaysia	Kuala	2.73	101.70
Nairobi, Kenya	Nairobi	-1.30	36.80
Natal, Brazil	Natal	-5.40	-35.40
Paramaribo, Surinam	Paramaribo	5.80	-55.21
La Reunion Is, France	Reunion	-21.10	55.50
Pago Pago, Am. Samoa	Samoa	-14.20	-170.60
San Cristobal, Galapagos	Sancrist	-0.92	-89.60

Table S2: The trends (ppm yr^{-1}) at different altitude levels from GOZCARDS, SWOOSH and Reanalysis datasets (MERRA-2 and ERA-5) for the pre-1997 and post-1997 periods. Here, DJF is December-January-February, MAM is March-April-May, JJA is June-July-August and SON is September-October-December.

	Altitude	GOZCARDS (1984-2021)	SWOOSH (1984-2022)	ERA-5 (1984-2022)	MERRA-2 (1984-2022)
Pre-1997 (1984–1997)					
DJF	100 hPa	0.0000	-0.0046	-0.0001	-0.0004
	10 hPa	0.0023	-0.0616	0.0087	-0.0264
	1 hPa	-0.0058	-0.0091	0.0156	-0.0001
MAM	100 hPa	-0.0006	-0.0026	-0.0001	-0.0004
	10 hPa	-0.0005	-0.0258	0.0055	-0.0236
	1 hPa	-0.0067	-0.0125	0.0152	0.0000
JJA	100 hPa	0.0012	-0.0019	-0.0005	-0.0013
	10 hPa	-0.0106	-0.0718	0.0101	-0.0074
	1 hPa	0.0017	-0.0089	0.0155	-0.0001
SON	100 hPa	-0.0005	0.0037	0.0001	-0.0008
	10 hPa	0.0025	-0.011	0.0088	-0.0161
	1 hPa	-0.0068	-0.0088	0.0143	-0.0001
Post-1997 (1998–2022 and 1998–2021 for GOZCARDS)					
DJF	100 hPa	-0.0008	0.0003	-0.0006	-0.0010
	10 hPa	0.0029	0.0032	0.0006	-0.0137
	1 hPa	-0.0011	-0.0026	-0.0020	0.0041
MAM	100 hPa	-0.0003	0.0003	-0.0005	-0.0008
	10 hPa	0.014	0.0144	0.0024	-0.0126
	1 hPa	-0.0001	-0.0006	0.007	0.0046
JJA	100 hPa	0.0007	0.0003	-0.0009	-0.0012
	10 hPa	-0.0049	-0.0024	-0.0060	-0.0160
	1 hPa	0.0033	-0.0004	0.0011	0.0045
SON	100 hPa	0.0000	0.0003	-0.0012	-0.0013
	10 hPa	-0.0021	-0.0095	-0.0031	-0.0174
	1 hPa	0.0012	0.0003	0.0008	0.0049

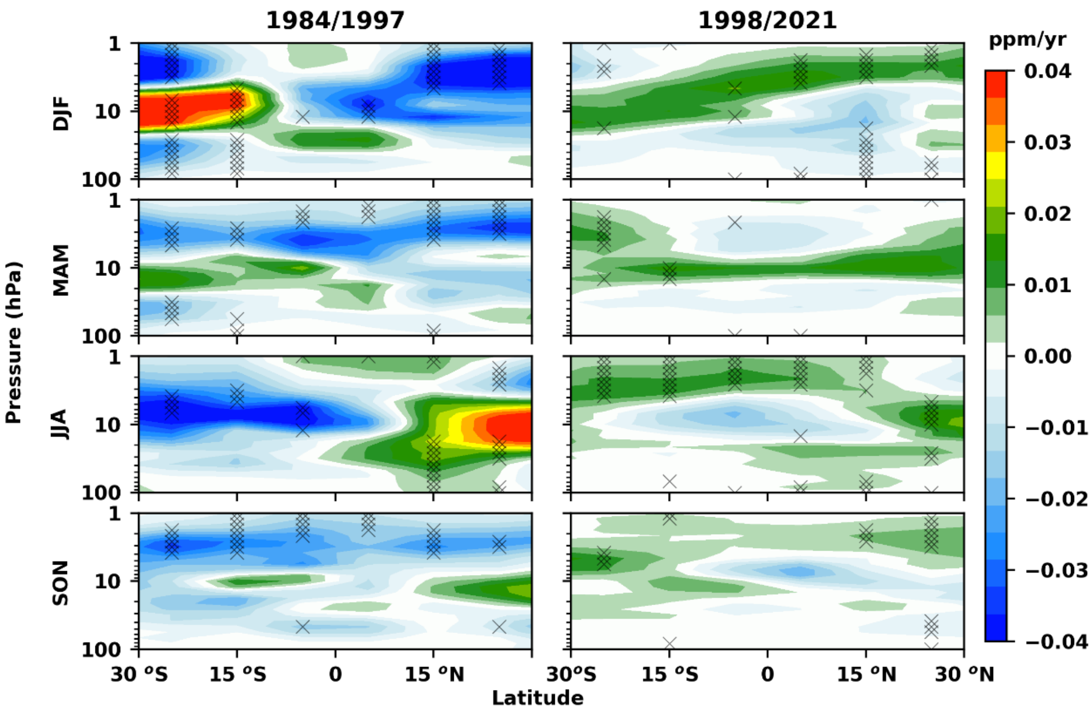

Figure S1: Trends in mixing ratio of ozone estimated for each season using the GOZCARDS data for the periods 1984–1997 and 1998–2021. The stippled regions are statistically significant at the 95% CI. Here, DJF is December-January-February, MAM is March-April-May, JJA is June-July-August and SON is September-October-December.

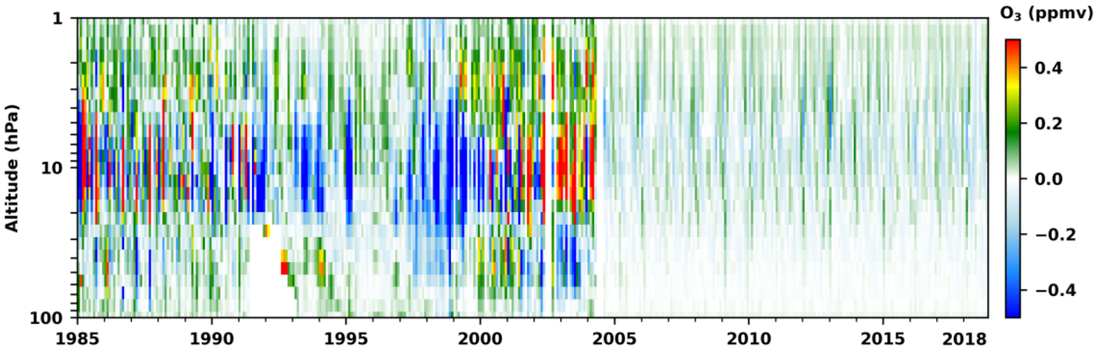

Figure S2: The difference in ozone estimated between GOZCARDS and SWOOSH ozone datasets for each month since 1985.

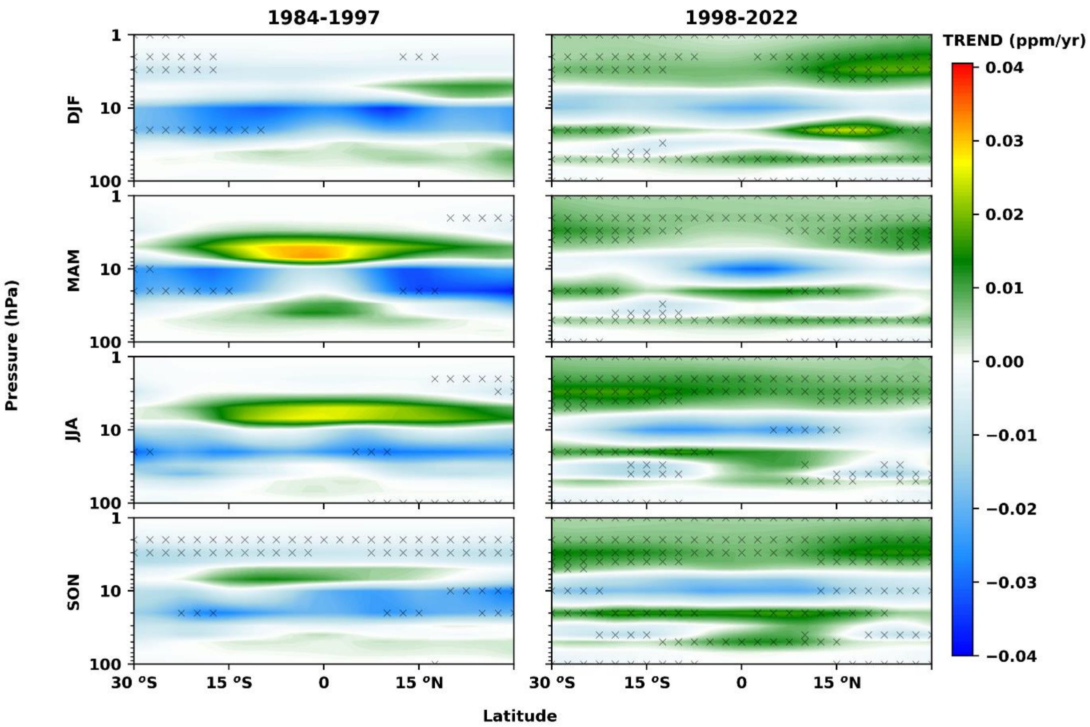

Figure S3: Trends in mixing ratio of ozone estimated for each season from MERRA–2 data for the periods 1984–1996 and 1997–2022. The stippled regions are statistically significant at the 95% CI. Here, DJF is December-January-February, MAM is March-April-May, JJA is June-July-August and SON is September-October-December.

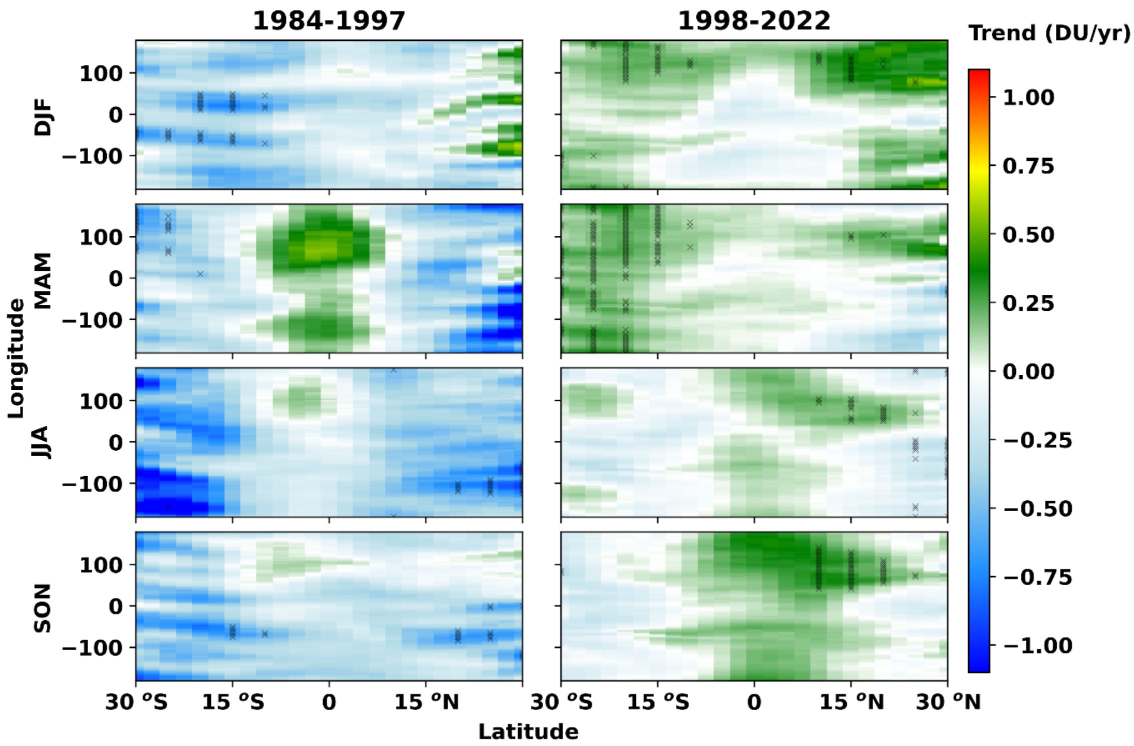

Figure S4: Trends in TCO estimated using the seasonally averaged data from MERRA–2 for the periods 1984–1997 and 1998–2022. The stippled regions are statistically significant at the 95% CI. Here, DJF is December-January-February, MAM is March-April-May, JJA is June-July-August and SON is September-October-December.

We have examined the MERRA-2 reanalysis (Table S2 and Fig. S3) to find the trends in ozone. The trends are statistically nonsignificant in both periods, except in the topmost altitudes in the upper stratosphere (Table S2). The trends estimated are nonsignificant at most altitudes and seasons during the 1984–1997 period. However, the trends are significant in the upper stratosphere in SON, but the values are very small, within 0.01 ppmv yr^{-1}. The trends in the post-1997 period are positive and significant in the lower and upper stratosphere, about 0.01 ppmv yr^{-1}, but those in the middle stratosphere are negative and nonsignificant. The TCO trends (Fig. S4) also show insignificant negative trends in most regions and seasons, except around the equatorial region, in MAM during 1984–1997. The trend estimated for the next two decades are either positive (0.25 ± 0.50 DU yr^{-1}; Fig. S4) or neutral, but significant only at 15°–30° S at MAM.

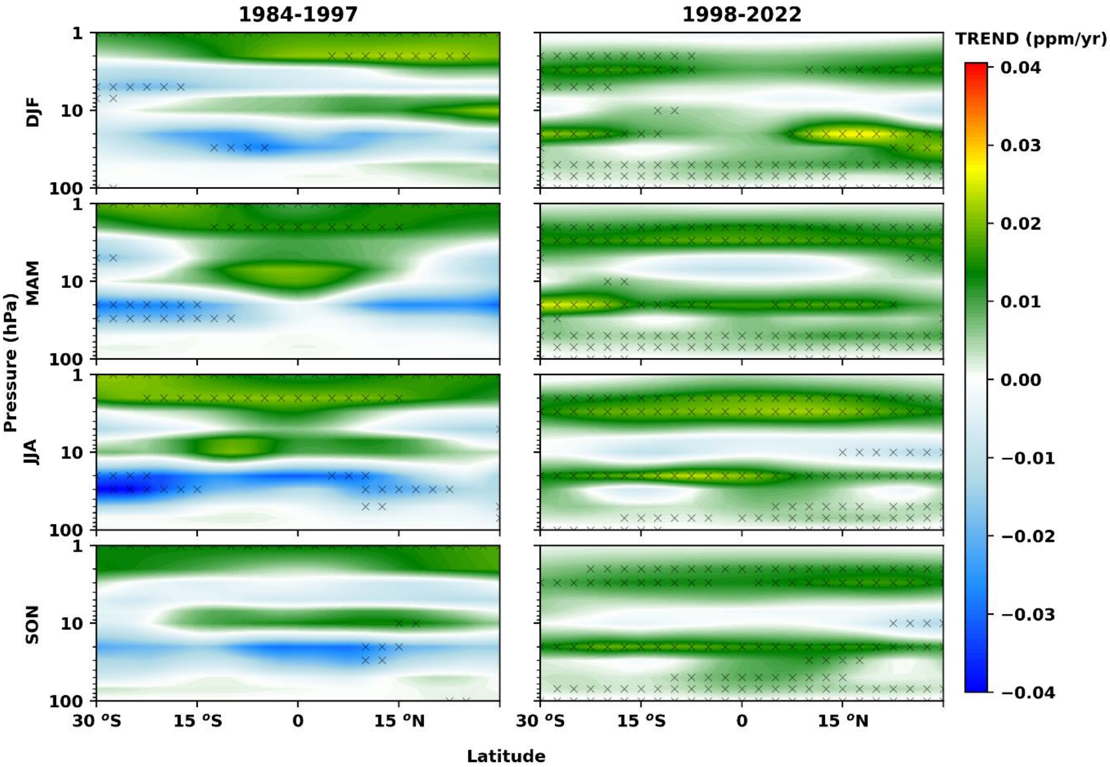

Figure S5: Trends in mixing ratio of ozone estimated for each season from ERA-5 data for the periods 1984–1996 and 1997–2022. The stippled regions are statistically significant at the 95% CI. Here, DJF is December-January-February, MAM is March-April-May, JJA is June-July-August and SON is September-October-December.

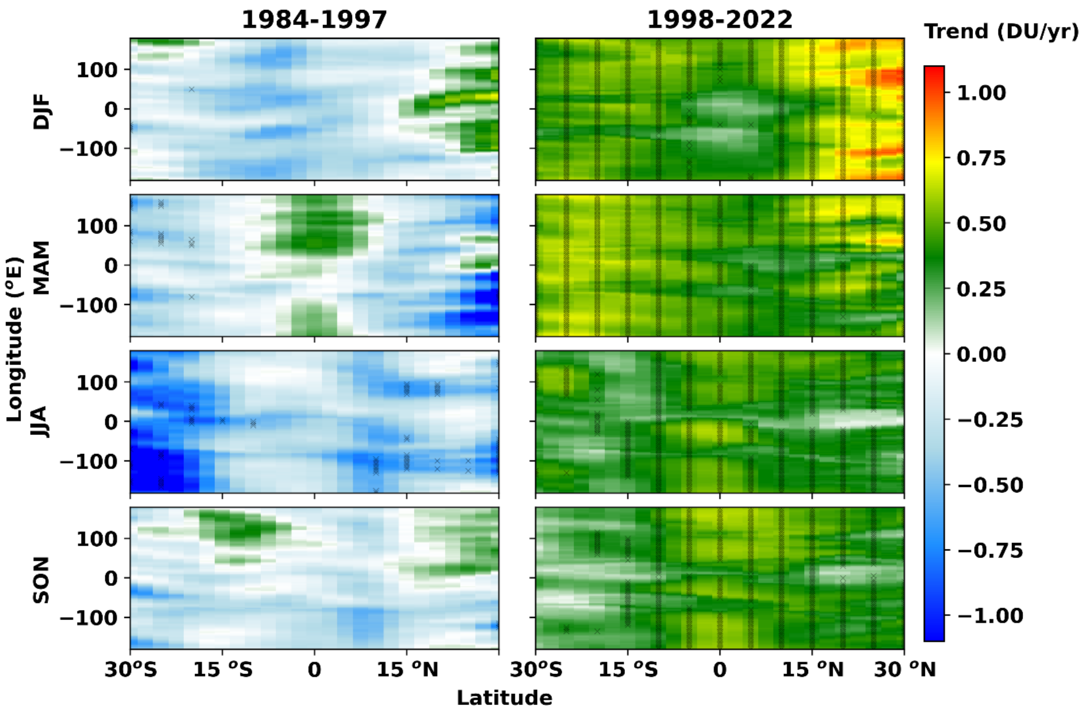

Figure S6: Trends in TCO estimated using the seasonally averaged data from ERA-5 for the periods 1984–1997 and 1998–2022. The hatched regions are statistically significant at the 95% CI. Here, DJF is December-January-February, MAM is March-April-May, JJA is June-July-August and SON is September-October-December.

The analyses with ERA-5 also yield similar trend estimates as for the MERRA-2 data in both periods (Table S2 and Fig. S5). The trends estimated with the TCO data for the 1984–1997 period show similar values. Conversely, the trends in the post-1998 period show consistently higher values of about 0.5 DU yr^{-1} and are statistically significant at most latitudes (Fig. S6).

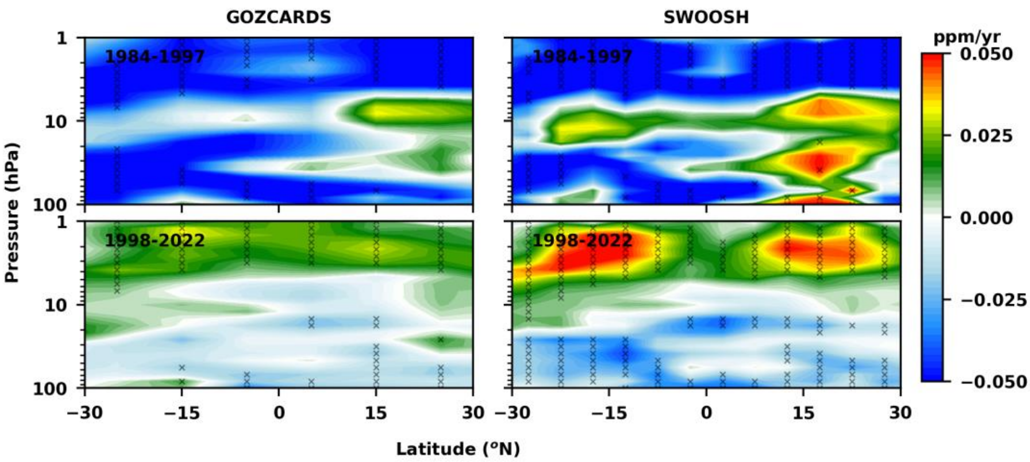

Figure S7: Trends in the annually averaged ozone estimated using the Multiple Linear Regression (MLR) model with GOZCARDS and SWOOSH data for the periods 1984–1997 and 1998–2022. The stippled regions are statistically significant at the 95% CI.

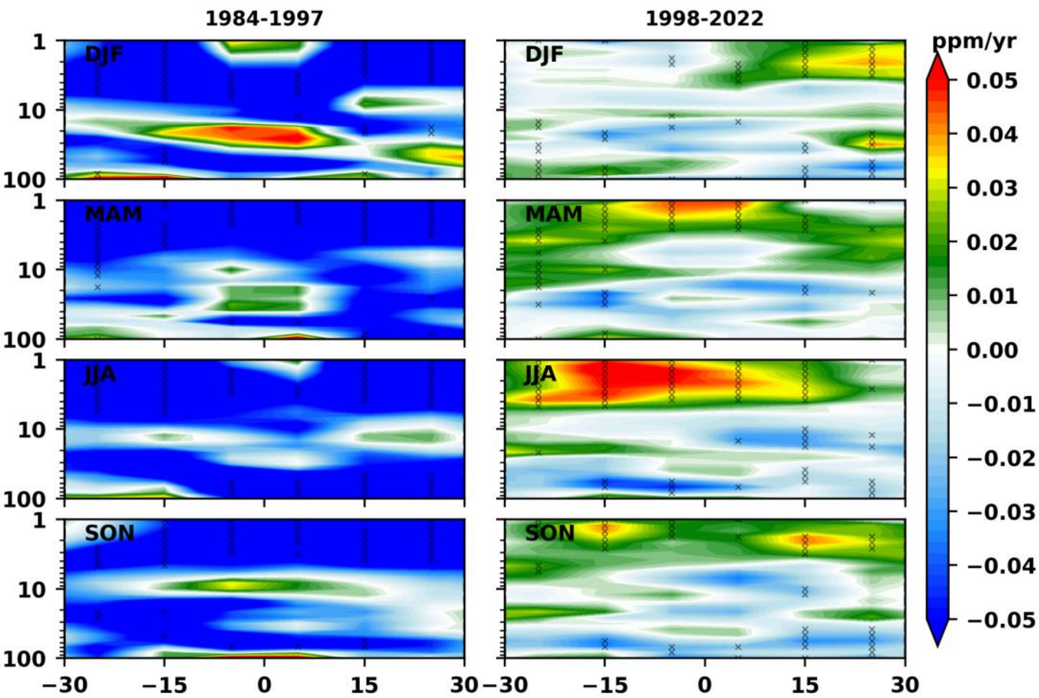

Figure S8: Trends in mixing ratio of ozone estimated using a multiple linear regression model for each season using the GOZCARDS data for the periods 1984–1997 and 1998–2021. The stippled regions are statistically significant at the 95% CI. Here, DJF is December-January-February, MAM is March-April-May, JJA is June-July-August and SON is September-October-December.

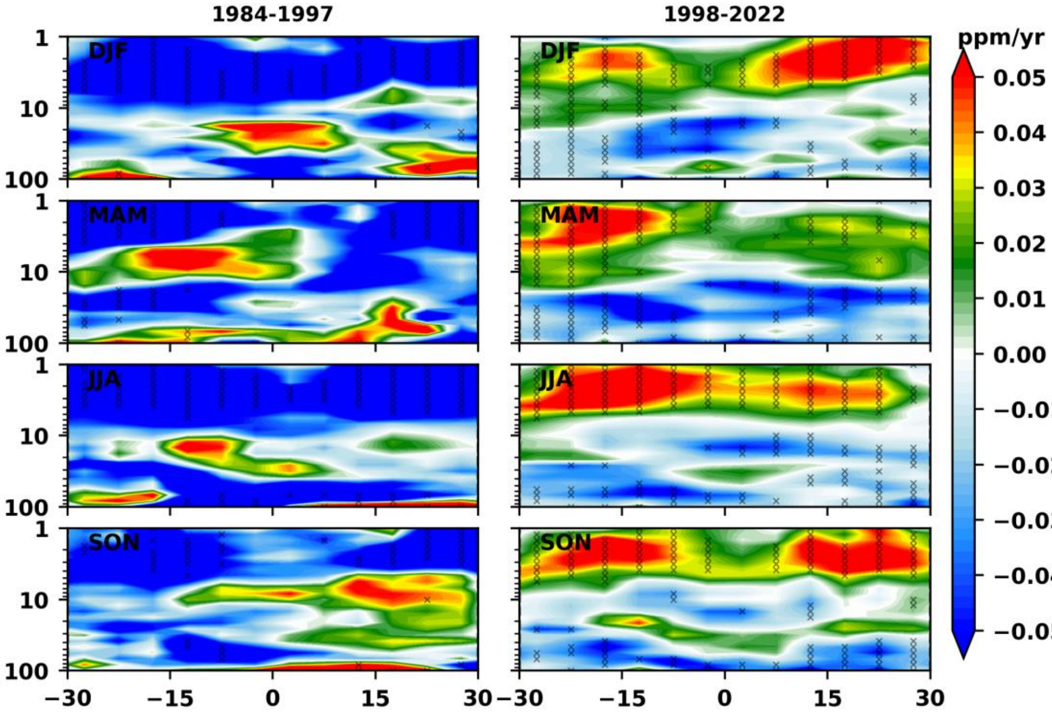

Figure S9: Trends in mixing ratio of ozone estimated for each season using the SWOOSH data by applying a multiple linear regression model for the periods 1984–1997 and 1998–2022. The stippled regions are statistically significant at the 95% CI.

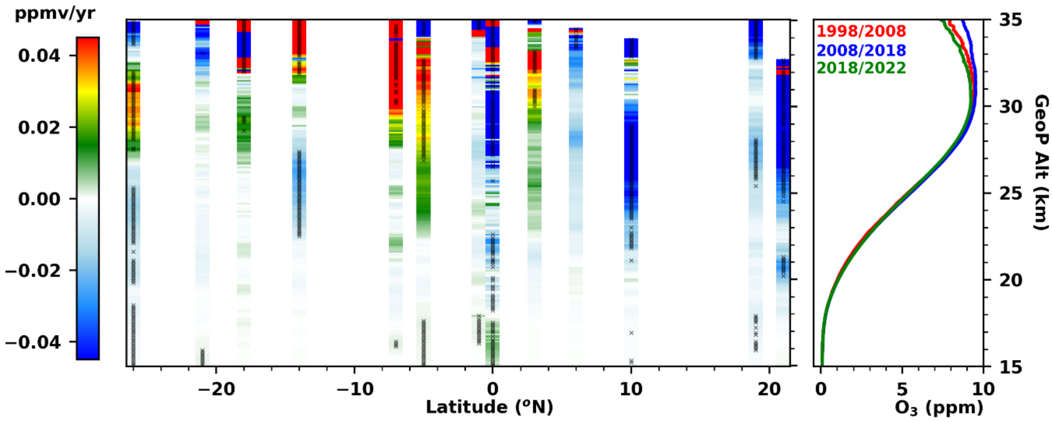

Figure S10: The latitudinal distribution of vertical trends in ozone estimated using the SHADOZ observations for the period 1998–2022. The average of ozonesonde profiles in different periods is shown on the right. The stippled regions are statistically significant at the 95% CI.

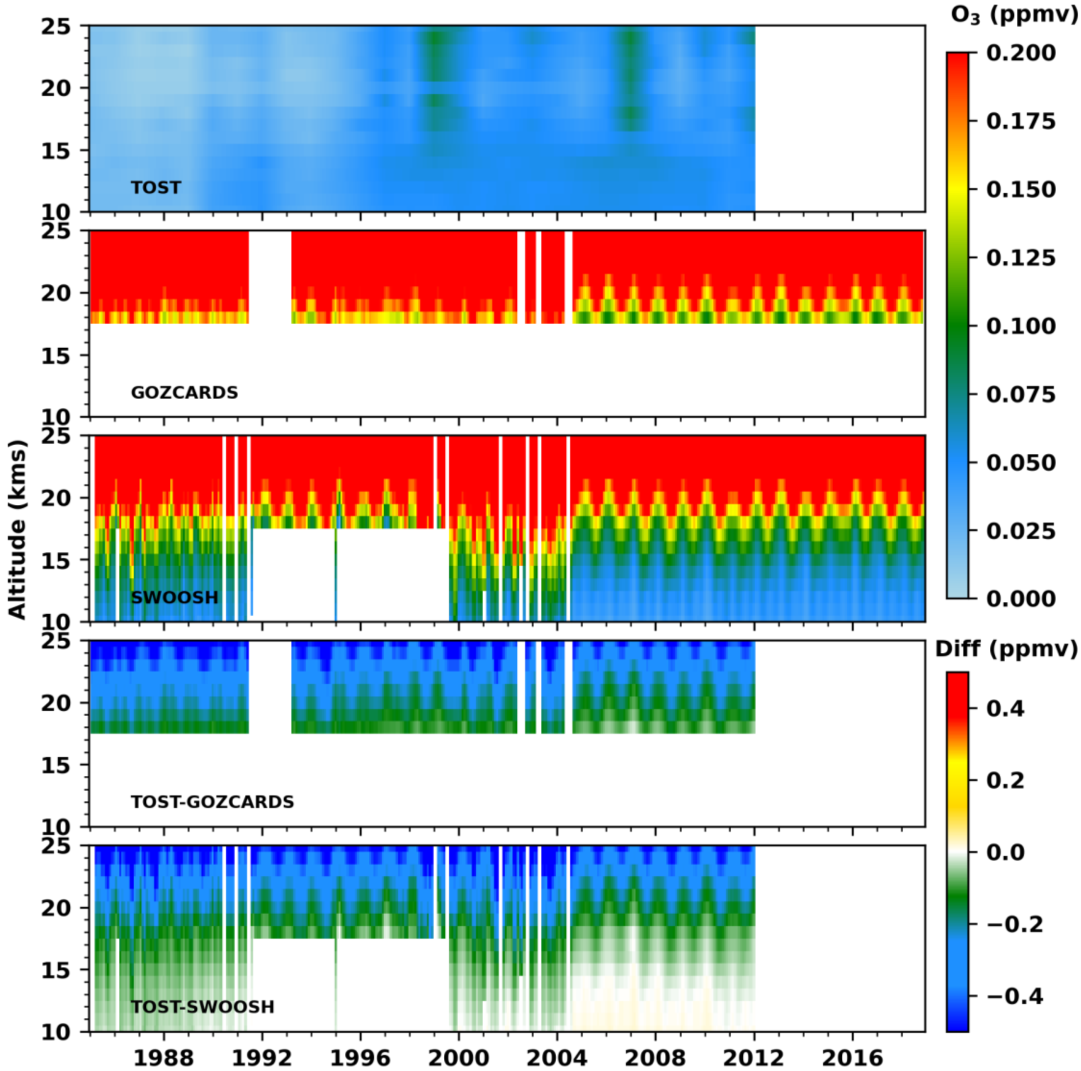

Figure S11: Yearly averaged ozone values in the TOST, GOZCARDS and SWOOSH data (top three panels), and the difference in ozone values found between TOST and GOZCARDS and TOST and SWOOSH (bottom two panels) data sets.

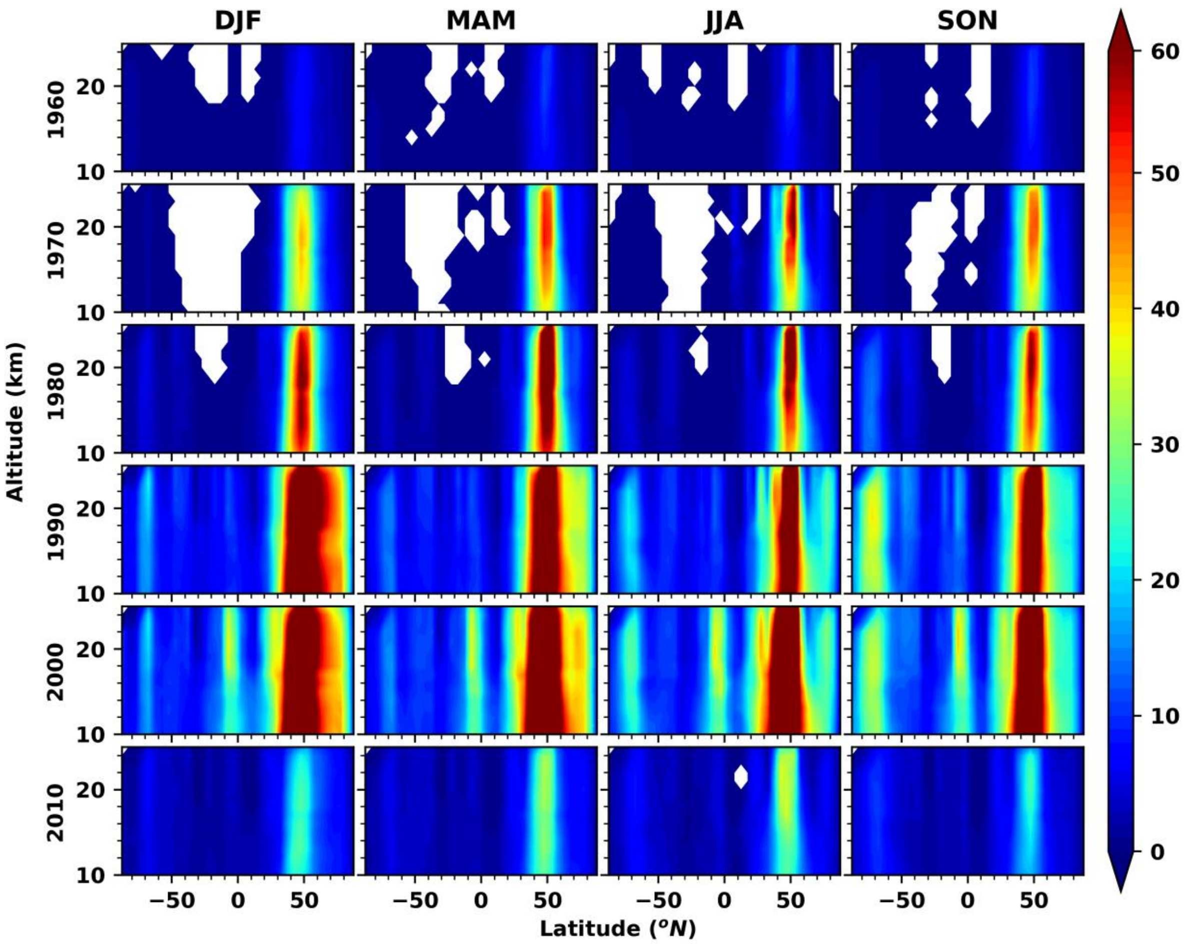

Figure S12: The number of profiles in TOST data in each period and altitude.