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Attribution of changes in winds over the Southern Ocean from 1950 to 2100

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Supplementary Figures

Fig. S1

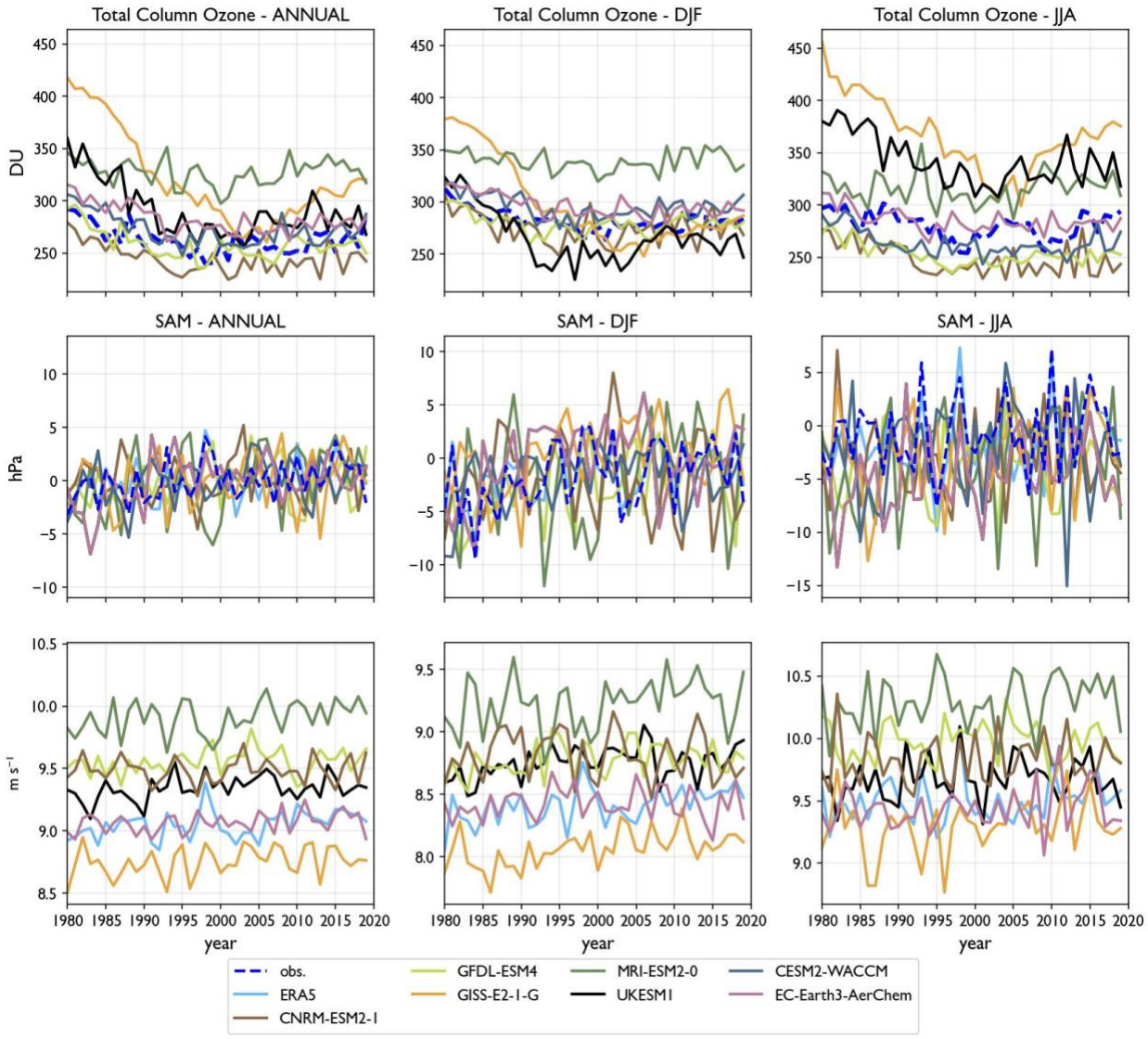

Fig. S1: Timeseries of Total Column Ozone (TCO) for 70-90°S, SAM index, and 10-m wind speed (40-60°S) for CMIP6 models with interactive chemistry. Relevant observations and reanalyses are shown as follows: the Bodecker observational TCO is shown in dashed blue in the top row. The Marshall station-based SAM index is shown in dashed blue in the middle row, and the ERA5 wind speed is shown in light blue in the bottom row.

Fig. S2

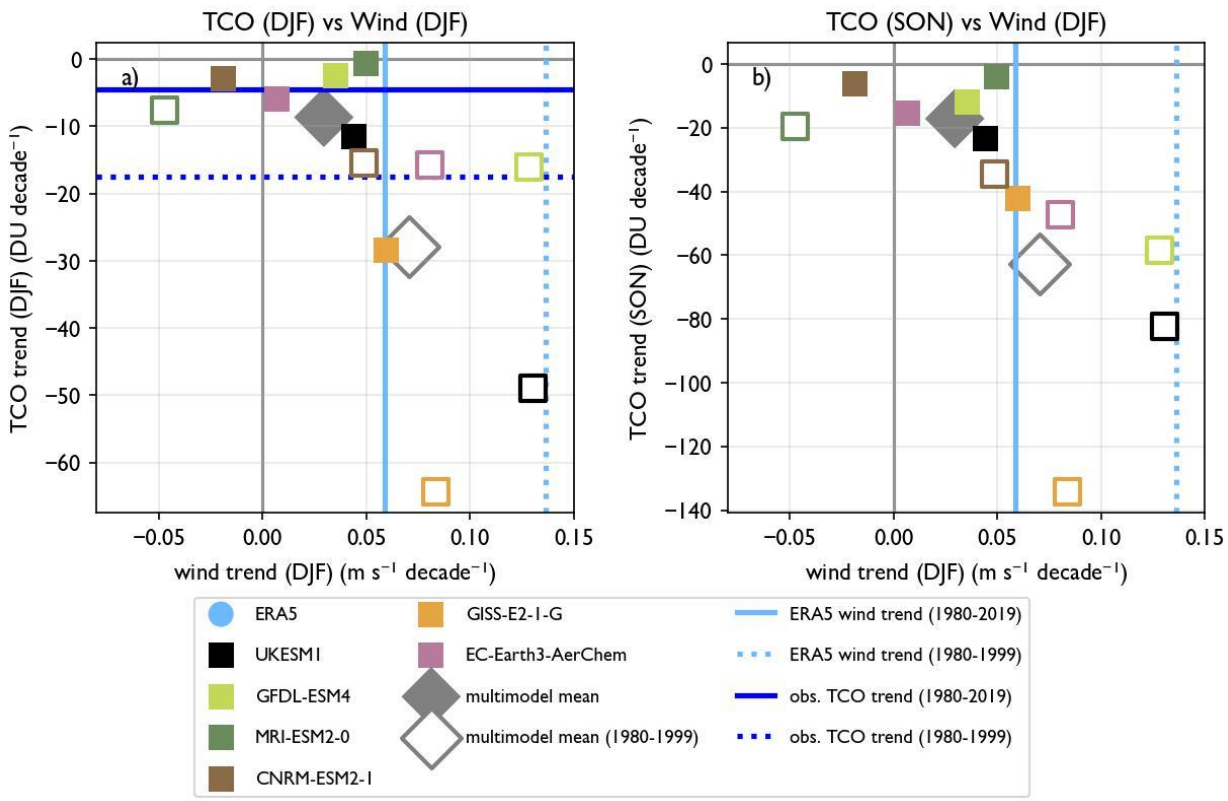

Fig. S2: Trends in TCO (DJF and SON) vs. trends in 10-m winds in DJF. Though maximum ozone depletion is seen in SON, inter-model TCO trends and their relationship with wind speed trends are consistent whether wind speed trends in DJF are plotted relative to TCO trends in SON or DJF.

Fig. S3

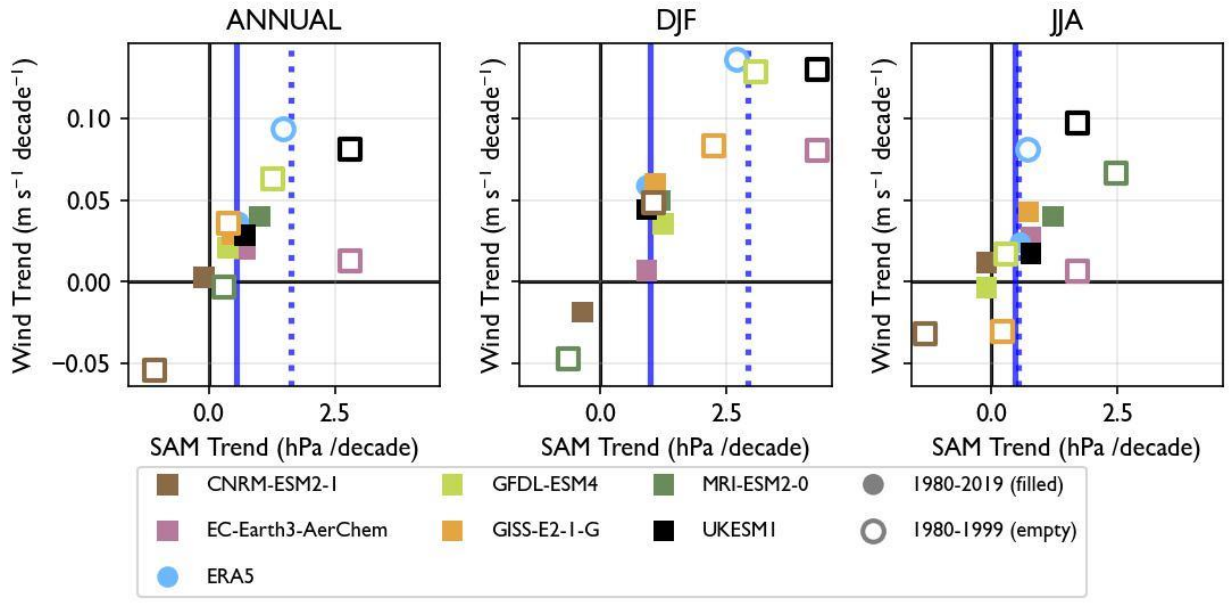

Fig. S3: Trends in 10-m winds vs SAM trends for CMIP6 models with interactive chemistry and ERA5. See also Fig. 5. For this intercomparison, one ensemble member is used for each model, including UKESM1, so SAM trends here are somewhat higher than in the ensemble mean shown in Fig. 5.

Supplementary Tables

Table S1

interannual variability (% of climatological mean wind speed)				
	ERA5	MERRA2	JRA3Q	UKESM
full year	1.18	1.80	1.13	1.00
DJF	1.67	2.20	1.58	1.53
MAM	1.35	2.23	1.42	1.39
JJA	1.72	2.20	1.69	1.63
SON	1.94	2.07	1.76	1.72

Table S1: Interannual variability (IAV) of mean open-ocean wind speed between 40°S and 60°S for 1980-2019. IAV calculated as the unbiased standard deviation of the timeseries normalized by its mean, shown in percent of the mean climatological wind speed.

Table S2

extreme low 10-m winds (m s^{-1}): weighted average of lowest 5% of daily values				
	ERA5	MERRA2	JRA3Q	UKESM1
full year	2.04	0.07	0.13	0.00
DJF	1.87	0.07	0.14	0.00
MAM	2.03	0.07	0.12	0.01
JJA	2.16	0.08	0.13	-0.01
SON	2.09	0.07	0.14	-0.02
extreme high 10-m winds (m s^{-1}): weighted average of highest 95% of daily values				
	ERA5	MERRA2	JRA3Q	UKESM1
full year	15.61	-0.35	0.59	0.32
DJF	14.75	-0.45	0.51	0.27
MAM	15.76	-0.42	0.57	0.31
JJA	16.23	-0.19	0.67	0.36
SON	15.68	-0.33	0.61	0.37

Table S2: High and low tails of the wind distribution. Tails given in m s^{-1} for ERA5 and as a bias in m s^{-1} for the remaining products. To calculate extreme winds, we calculate the daily weighted 95th (5th) percentile of winds from the 1°x1° gridded product, then take the weighted

average of all cells above (below) this percentile. For any season, the seasonal extreme winds are then the average of these daily extreme winds.

Table S3

climatological jet position (°S), 1980-2019				
	ERA5	MERRA2	JRA3Q	UKESM1
full year	-52.1	-0.2	-0.2	0.5
DJF	-52.3	-0.2	-0.2	0.6
MAM	-52.7	-0.1	-0.2	0.3
JJA	-52.3	-0.3	-0.3	0.2
SON	-51	-0.2	-0.3	0.9

Table S3: Seasonally-subdivided climatological jet position. Absolute position is given for ERA5, and differences from ERA5 are given for the other reanalyses and UKESM1 (positive numbers indicate a less southerly jet position).

Table S4

trends in jet position (°S dec^{-1}), 1980-2019				
	ERA5	MERRA2	JRA3Q	UKESM1
full year	-0.11	-0.01	-0.09	**-0.2**
DJF	**-0.24**	-0.22	-0.22	**-0.4**
MAM	-0.13	-0.12	-0.14	**-0.23**
JJA	-0.01	0.19	0.04	0.1
SON	-0.05	0.11	-0.05	**-0.27**
trends in jet position (°S dec^{-1}), 1980-1999				
full year	-0.21	-0.25	-0.17	**-0.51**
DJF	**-0.68**	**-0.84**	-0.58	**-1.39**
MAM	-0.6	-0.67	-0.56	**-0.63**
JJA	0.02	0.08	0.09	0.13
SON	0.4	0.42	0.38	-0.16

Table S4: Seasonally-subdivided trends in climatological jet position. Trends significant at the 5% level are given in bold.

Table S5

	trends in SAM index (hPa dec^{-1}), 1980-2019				
	observations	ERA5	MERRA	JRA3Q	UKESM
full year	**0.55**	**0.6**	**0.62**	**0.48**	**0.59**
DJF	**1**	**0.92**	**1.08**	**1.07**	**0.93**
MAM	**0.81**	**0.81**	**1.1**	**0.77**	**0.75**
JJA	0.47	0.57	**0.39**	0.27	0.61
SON	-0.09	0.1	-0.08	-0.2	0.08
	trends in SAM index (hPa dec^{-1}), 1980-1999				
	observations	ERA5	MERRA	JRA3Q	UKESM
full year	**1.64**	**1.47**	**2.19**	**1.64**	**1.53**
DJF	**2.93**	**2.7**	**3.06**	**2.87**	**3.13**
MAM	**2.91**	1.94	**2.82**	2.05	1.54
JJA	0.52	0.71	1.64	0.89	1.1
SON	0.18	0.53	1.23	0.74	0.34

Table S5: **Seasonally-subdivided trends in the natural SAM index.** Trends significant at the 5% level are given in bold.

Table S6

1980-1999	GHG + ozone	GHG only	ozone only
FY	**0.06**	-0.01	**0.08**
DJF	**0.11**	-0.03	**0.14**
MAM	0.02	**-0.05**	**0.07**
JJA	**0.08**	-0.03	**0.10**
SON	0.04	0.05	-0.01

1980-2019	GHG + ozone	GHG only	ozone only
FY	**0.03**	0.01	0.01
DJF	**0.04**	0.02	0.03
MAM	0.02	-0.01	**0.03**
JJA	0.02	0.02	-0.01
SON	0.02	0.02	0.00

Table S6: Attribution of wind trends (m s^{-1} dec^{-1}) to GHG and ozone forcing for 1980-1999 and 1980-2019 in the UKESM1 model runs. Values for GHG + ozone refer to the ensemble mean trend of the OZONE-HIST run, while the GHG only column refers to the OZONE-1950 run. The effect of ozone only is then obtained by subtracting OZONE-1950 from OZONE-HIST. Statistically significant trends are given in bold.