Supplementary materials

Model	Global IRF	NH IRF	SH IRF	IRF SW	IRF LW	CS IRF SW	CS IRF LW
EMAC	0.27 ± 0.01	0.24 ± 0.01	0.30 ± 0.01	0.14 ± 0.00	0.12 ± 0.00	0.10 ± 0.00	0.15 ± 0.00
GEOS-Chem	0.34 ± 0.01	0.25 ± 0.01	0.44 ± 0.02	0.16 ± 0.01	0.18 ± 0.01	0.10 ± 0.00	0.23 ± 0.01
GFDL-ESM4	0.33 ± 0.004	0.26 ± 0.01	0.40 ± 0.01	0.18 ± 0.003	0.15 ± 0.003	0.12 ± 0.003	0.18 ± 0.002
GISS-E2.1_FR	0.10 ± 0.03	0.11 ± 0.05	0.10 ± 0.05	0.05 ± 0.02	0.06 ± 0.01	N/A	N/A
GISS-E2.1_nudged	-0.014 ± 0.003	0.095 ± 0.002	-0.122 ± 0.005	0.010 ± 0.002	-0.024 ± 0.001	N/A	N/A
UKESM1-0-LL	0.40 ± 0.01	0.39 ± 0.02	0.40 ± 0.02	0.22 ± 0.01	0.18 ± 0.01	0.16 ± 0.01	0.22 ± 0.01
Multi-model mean	0.29 ± 0.10	0.25 ± 0.0910	0.33 ± 0.12	0.15 ± 0.06	0.14 ± 0.04	0.12 ± 0.02	0.19 ± 0.03

Table S1: Global multi-annual mean instantaneous radiative forcings (IRFs) and their standard errors for year-2050 whole atmosphere ozone relative to a year-2015 baseline (*pdClim-control*), including its SW and LW components for all-sky and clear-sky conditions based on online double radiation calls. Table also includes estimates for the northern and southern hemispheres. The multi-model means do not include GISS-E2.1_nudged and the uncertainties are the standard deviation of the model means.

Model	Global SARF	NH SARF	SH SARF	SARF SW	SARF LW	CS SARF SW	CS SARF LW
EMAC	0.19 ± 0.00	0.20 ± 0.01	0.18 ± 0.00	0.14 ± 0.00	0.05 ± 0.00	0.10 ± 0.00	0.08 ± 0.00

Table S2: Global multi-annual mean stratospherically-adjusted radiative forcing (SARF) and its standard error for year-2050 whole atmosphere ozone relative to a year-2015 baseline (*pdClim-control*) from the EMAC model, including its SW and LW components for all-sky and clear-sky conditions based on an online double radiation call for ozone and including a stratospheric temperature adjustment. Table also includes estimates for the northern and southern hemispheres.

	All-sky ERF					Clear-sky Global	
Model	Global	NH	SH	ERF SW	ERF LW	ERF SW	ERF LW
CESM2	0.23 ± 0.06	0.24 ± 0.08	0.23 ± 0.07	0.20 ± 0.05	0.03 ± 0.04	0.11 ± 0.02	0.20 ± 0.03
EMAC	0.22 ± 0.01	0.18 ± 0.02	0.27 ± 0.02	0.16 ± 0.01	0.06 ± 0.01	0.11 ± 0.00	0.16 ± 0.01
GFDL-ESM4	0.30 ± 0.04	0.27 ± 0.04	0.33 ± 0.05	0.24 ± 0.03	0.06 ± 0.03	0.14 ± 0.01	0.20 ± 0.02
GISS_FR	0.14 ± 0.18	0.16 ± 0.21	0.12 ± 0.27	0.07 ± 0.19	0.07 ± 0.23	0.02 ± 0.09	0.13 ± 0.15
GISS_nudged	0.005 ± 0.011	0.101 ± 0.016	-0.091 ± 0.014	0.005 ± 0.016	-0.000 ± 0.008	0.005 ± 0.003	-0.031 ± 0.004
NorESM	0.30 ± 0.06	0.25 ± 0.09	0.35 ± 0.08	0.22 ± 0.06	0.08 ± 0.04	0.09 ± 0.03	0.20 ± 0.02
UKESM1-0-LL	0.42 ± 0.03	0.32 ± 0.05	0.48 ±0.05	0.49 ± 0.03	-0.08 ± 0.02	0.21 ± 0.03	0.14 ± 0.03
Multi-model mean	0.27 ± 0.09	0.24 ± 0.05	0.30± 0.11	0.23 ± 0.13	0.04 ± 0.05	0.11 ± 0.06	0.17 ± 0.03

Table S3: Global multi-annual mean effective radiative forcings and their standard errors for year-2050 whole atmosphere ozone relative to the year-2015 baseline, including its shortwave (SW) and longwave (LW) components for all-sky and clear-sky conditions. Table also includes estimates for the northern and southern hemispheres. The multi-model means do not include GISS-E2.1_nudged and the uncertainties are the standard deviation of the model means.

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	SW clear	SW	LW inst. clear	LW inst.	LW adj.	NET adj.
CESM2	0.099 ± 0.003	0.141 ± 0.004	0.234 ± 0.003	0.168 ± 0.002	0.123 ± 0.002	0.265 ± 0.004
EMAC	0.112 ± 0.002	0.164 ± 0.003	0.249 ± 0.003	0.177 ± 0.002	0.076 ± 0.004	0.240 ± 0.003
GEOS-chem	0.120 ± 0.002	0.180 ± 0.003	0.326 ± 0.005	0.236 ± 0.004	0.138 ± 0.002	0.319 ± 0.005
GFDL-ESM4	0.109 ± 0.002	0.157 ± 0.002	0.226 ± 0.002	0.162 ± 0.002	0.079 ± 0.002	0.235 ± 0.002
GISS-E2.1_FR	0.035 ± 0.003	0.050 ± 0.004	0.111 ± 0.003	0.079 ± 0.002	0.084 ± 0.003	0.134 ± 0.004
GISS-E2.1_nudged	0.027 ± 0.000	0.031 ± 0.000	0.019 ± 0.000	0.002 ± 0.000	0.001 ± 0.000	0.032 ± 0.001
NorESM2	0.078 ± 0.003	0.113 ± 0.004	0.203 ± 0.005	0.145 ± 0.004	0.127 ± 0.004	0.240 ± 0.006
UKESM1-0-LL	0.175 ± 0.005	0.252 ± 0.007	0.307 ± 0.007	0.217 ± 0.006	0.025 ± 0.005	0.277 ± 0.007
Multi-model mean	0.104 ± 0.043	0.151 ± 0.062	0.236 ± 0.071	0.169 ± 0.051	0.093 ± 0.040	0.244 ± 0.057

25   **Table S4: The radiative forcing for total ozone calculated offline using the radiative kernel as shown in Fig. 6. The results are separated for short wave clear sky (SW clear), short wave all sky (SW), long wave instantaneous clear sky (LW inst. clear), long wave instantaneous all sky (LW inst.), long wave including stratospheric temperature adjustments (LW. adj) and the net SARF (NET adj.). The uncertainty is the standard error calculated from the interannual variability. The multi-model means do not include GISS-E2.1_nudged and the uncertainties are the standard deviation of the model means. All values are in W m⁻².**

	SW clear	SW	LW inst. clear	LW inst.	LW adj.	NET adj.
CESM2	0.025 ± 0.000	0.037 ± 0.000	0.117 ± 0.001	0.083 ± 0.001	0.128 ± 0.001	0.165 ± 0.002
EMAC	0.023 ± 0.000	0.033 ± 0.000	0.115 ± 0.001	0.081 ± 0.001	0.120 ± 0.001	0.153 ± 0.001
GEOS-chem	0.030 ± 0.000	0.044 ± 0.000	0.140 ± 0.001	0.098 ± 0.001	0.143 ± 0.001	0.186 ± 0.002
GFDL-ESM4	0.024 ± 0.000	0.035 ± 0.000	0.103 ± 0.001	0.072 ± 0.001	0.110 ± 0.001	0.144 ± 0.002
GISS-E2.1_FR	0.019 ± 0.000	0.028 ± 0.001	0.091 ± 0.002	0.064 ± 0.001	0.098 ± 0.002	0.125 ± 0.002
GISS-E2.1_nudged	0.016 ± 0.000	0.023 ± 0.000	0.082 ± 0.000	0.057 ± 0.000	0.081 ± 0.000	0.104 ± 0.000
NorESM2	0.023 ± 0.000	0.034 ± 0.001	0.109 ± 0.002	0.076 ± 0.002	0.117 ± 0.003	0.150 ± 0.003
UKESM1-0-LL	0.029 ± 0.001	0.042 ± 0.001	0.114 ± 0.003	0.079 ± 0.002	0.116 ± 0.003	0.158 ± 0.004
Multi-model mean	0.025 ± 0.004	0.036 ± 0.005	0.113 ± 0.015	0.079 ± 0.010	0.119 ± 0.014	0.155 ± 0.019

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Table S5: The radiative forcing for tropospheric ozone calculated offline using the radiative kernel as shown in Fig. 6. The results are separated for short wave clear sky (SW clear), short wave all sky (SW), long wave instantaneous clear sky (LW inst. clear), long wave instantaneous all sky (LW inst.), long wave including stratospheric temperature adjustments (LW. adj) and the net SARF (NET adj.). The uncertainty is the standard error calculated from the interannual variability. The multi-model means does not
35   **include GISS_nudged and the uncertainties are the standard deviation of the model means. All values are in W m⁻². The tropopause is defined by the 150 nmol mol⁻¹ ozone mole fraction isoline in the *pdClim-control* simulations.**

	All sky Forcing					Global clear sky	
Model	Global	NH	SH	SW	LW	SW	LW
EMAC-sens-ERF	0.17 ± 0.01	0.19 ± 0.01	0.15 ± 0.02	0.06 ± 0.01	0.11 ± 0.00	0.03 ± 0.00	0.15 ± 0.00
EMAC-sens-IRF	0.08 ± 0.00	0.10 ± 0.01	0.07 ± 0.01	0.02 ± 0.00	0.06 ± 0.00	0.02 ± 0.00	0.07 ± 0.00
EMAC-sens-SARF	0.14 ± 0.00	0.17 ± 0.01	0.11 ± 0.00	0.02 ± 0.00	0.12 ± 0.00	0.02 ± 0.00	0.13 ± 0.00
UKESM1-sens-ERF	0.17 ± 0.03	0.21 ± 0.04	0.14 ± 0.04	0.14 ± 0.03	0.03 ± 0.03	0.06 ± 0.02	0.12 ± 0.02
UKESM1-sens-IRF	0.13 ± 0.01	0.14 ± 0.02	0.11 ± 0.01	0.05 ± 0.01	0.08 ± 0.01	0.04 ± 0.01	0.09 ± 0.01
GFDL-ESM4-sens-ERF	0.11 ± 0.03	0.09 ± 0.05	0.12 ± 0.05	0.05 ± 0.03	0.06 ± 0.02	0.06 ± 0.00	0.14 ± 0.00
GFDL-ESM4-sens-IRF	0.17 ± 0.00	0.17 ± 0.01	0.17 ± 0.01	0.06 ± 0.00	0.11 ± 0.00	0.04 ± 0.00	0.13 ± 0.00
Multi-model mean ERF (± inter-model standard deviation)	0.15 ± 0.03	0.16 ± 0.05	0.14 ± 0.01	0.08 ± 0.04	0.07 ± 0.03	0.05 ± 0.01	0.14 ± 0.01
Multi-model mean IRF (± inter-model standard deviation)	0.13 ± 0.04	0.14 ± 0.03	0.12 ± 0.04	0.04 ± 0.02	0.08 ± 0.02	0.03 ± 0.01	0.10 ± 0.02

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Table S6: Global multi-annual mean forcings (IRF, SARF, and ERF) and their standard errors for year-2050 whole atmosphere ozone from the sensitivity simulation *pdClim-2050ssp370fODS-radO3* relative to the year-2015 baseline (*pdClim-control*), including its shortwave (SW) and longwave (LW) components for all-sky and clear-sky conditions. Table also includes estimates for the northern and southern hemispheres.

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	SW clear	SW	LW inst. clear	LW inst.	LW adj.	NET adj.
EMAC	0.024 ± 0.002	0.036 ± 0.002	0.134 ± 0.002	0.096 ± 0.001	0.145 ± 0.002	0.180 ± 0.002
GFDL-ESM4	0.038 ± 0.002	0.054 ± 0.002	0.134 ± 0.002	0.097 ± 0.002	0.115 ± 0.002	0.170 ± 0.002
UKESM1-0-LL	0.043 ± 0.005	0.063 ± 0.006	0.138 ± 0.006	0.098 ± 0.004	0.095 ± 0.005	0.158 ± 0.006

Table S7: The radiative forcing for total ozone calculated offline using the radiative kernel for *pdClim-2050ssp370fODS-radO3* minus *pdClim-control*. The results are separated for short wave clear sky (SW clear), short wave all sky (SW), long wave instantaneous clear sky (LW inst. clear), long wave instantaneous all sky (LW inst.), long wave including stratospheric temperature adjustments (LW. adj) and the net SARF (NET adj.). The uncertainty is the standard error calculated from the interannual variability. All values are in W m^{-2}.

	SW clear	SW	LW inst. clear	LW inst.	LW adj.	NET adj.
EMAC	0.021 ± 0.000	0.030 ± 0.000	0.105 ± 0.001	0.074 ± 0.000	0.108 ± 0.001	0.138 ± 0.001
GFDL -ESM4	0.019 ± 0.000	0.028 ± 0.000	0.087 ± 0.001	0.061 ± 0.001	0.093 ± 0.001	0.121 ± 0.001
UKESM1.0 -LL	0.019 ± 0.001	0.027 ± 0.001	0.086 ± 0.002	0.060 ± 0.002	0.089 ± 0.003	0.116 ± 0.003

Table S8: The radiative forcing for tropospheric ozone calculated offline using the radiative kernel for *pdClim-2050ssp370fODS-radO3* minus *pdClim-control*. The results are separated for short wave clear sky (SW clear), short wave all sky (SW), long wave instantaneous clear sky (LW inst. clear), long wave instantaneous all sky (LW inst.), long wave including stratospheric temperature adjustments (LW. adj) and the net SARF (NET adj.). The uncertainty is the standard error calculated from the interannual variability. All values are in W m^{-2}.

Model	Cloud cover		(All-sky minus clear-sky) ERF		
	Reference [%]	Absolute Change [%]	SW ERF [W m^{-2}]	LW ERF [W m^{-2}]	Net ERF [W m^{-2}]
EMAC	62.37±0.11	-0.03±0.01	0.05±0.01	-0.09±0.03	-0.04±0.01
GFDL-ESM4	66.02±0.02	-0.08±0.03	0.10±0.03	-0.14±0.02	-0.04±0.03
UKESM1-0-LL	69.14±0.03	-0.20±0.03	0.28±0.03	-0.22±0.02	0.05±0.02
Multi-model mean	65.8±2.8	-0.10±0.07	0.14±0.10	-0.15±0.05	-0.01±0.04
EMAC		-0.01±0.005	0.03±0.01	-0.04±0.01	-0.005±0.005
GFDL-ESM4		-0.04±0.03	-0.02±0.03	-0.08±0.01	-0.10±0.03
UKESM1-0-LL		-0.10±0.05	0.08±0.03	-0.09±0.02	-0.004±0.02
Multi-model mean		-0.05±0.03	0.03±0.04	-0.07±0.02	-0.04±0.04

Table S9: Global mean cloud cover in reference simulation (*pdClim-control*), and absolute change in cloud cover and contribution of clouds to the SW, LW and net ERF for the *pdClim-2050ssp370-radO3* (top 4 rows) and *pdClim-2050ssp370fODS-radO3* (bottom 4 rows) experiments. The uncertainty for the individual models is the error on the mean, and the uncertainty on the multi-model mean is the standard deviation between the models.

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Experiment set

Derived output

Prognostic ozone

pdClim-2050ssp370-radO3 minus pdClim-control → O_3 ERF

Radiative and microphysical impact of 2050 aerosols

Radiative impact of CH_4 driven changes in H_2O

minus

Fixed ozone

pdClim-2050ssp370fixO3-radO3 minus pdClim-fixO3 →

Radiative and microphysical impact of 2050 aerosols

Radiative impact of CH_4 driven changes in H_2O

= O_3 ERF

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Figure S1: Schematic of the method to derive O_3 ERF with CESM2.
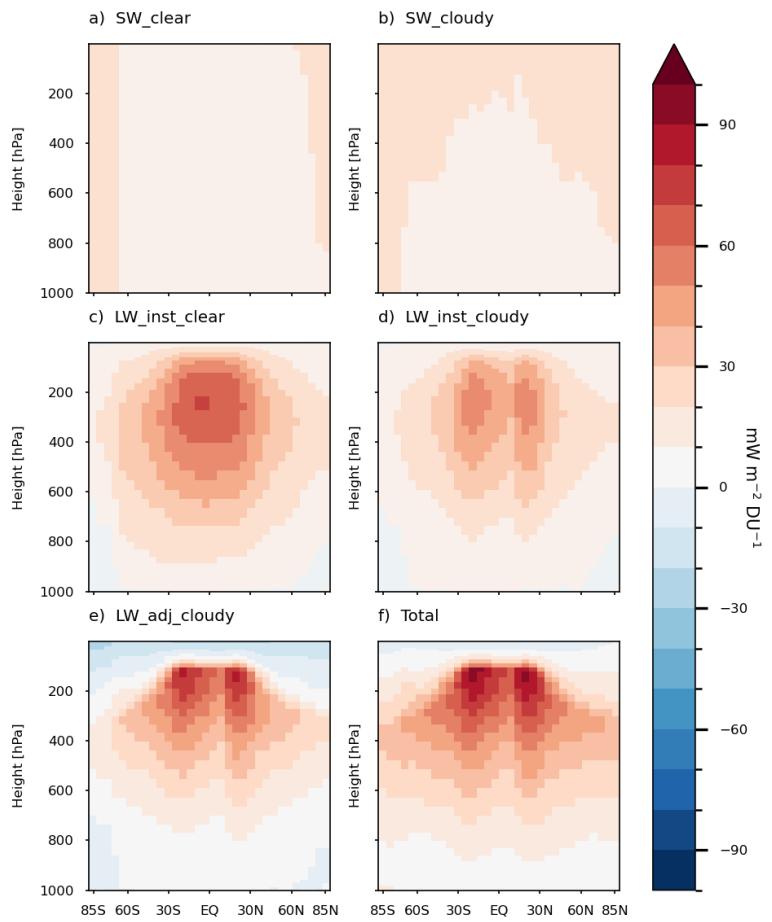
Figure S2: Annual zonal mean values of the TOA radiative kernel (mW m⁻² per DU). In a) instantaneous radiative forcing (IRF) shortwave (SW) clear sky, b) IRF SW all sky, c) IRF longwave (LW) clear sky, d) IRF LW all sky, e) LW all sky with stratospheric adjustment and d) net forcing (LW all sky adjusted + SW all sky). The vertical coordinates are sigma hybrid-pressure levels and approximate pressure levels are used on the y-axis.
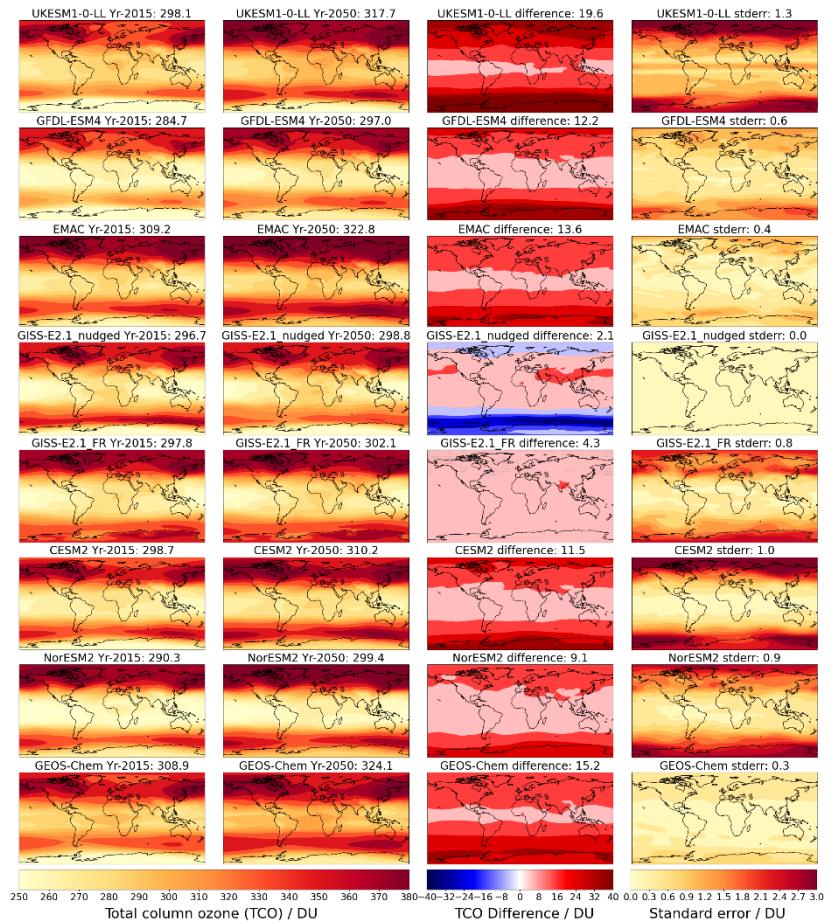
Figure S3: Year-2015 (1st column) and year-2050 (2nd column) climatologies for the global distribution of total column ozone (TCO), the difference between the two climatologies (3rd column; year-2050 minus year-2015), and the standard error in the difference (4th column) simulated by the models: UKESM1-0-LL, GFDL-ESM4, EMAC, GISS-E2.1_nudged, GISS-E2.1_FR, CESM2, NorESM2 and GEOS-Chem. The units for TCO are in Dobson Units (DU). Global mean values are shown above each panel.

100
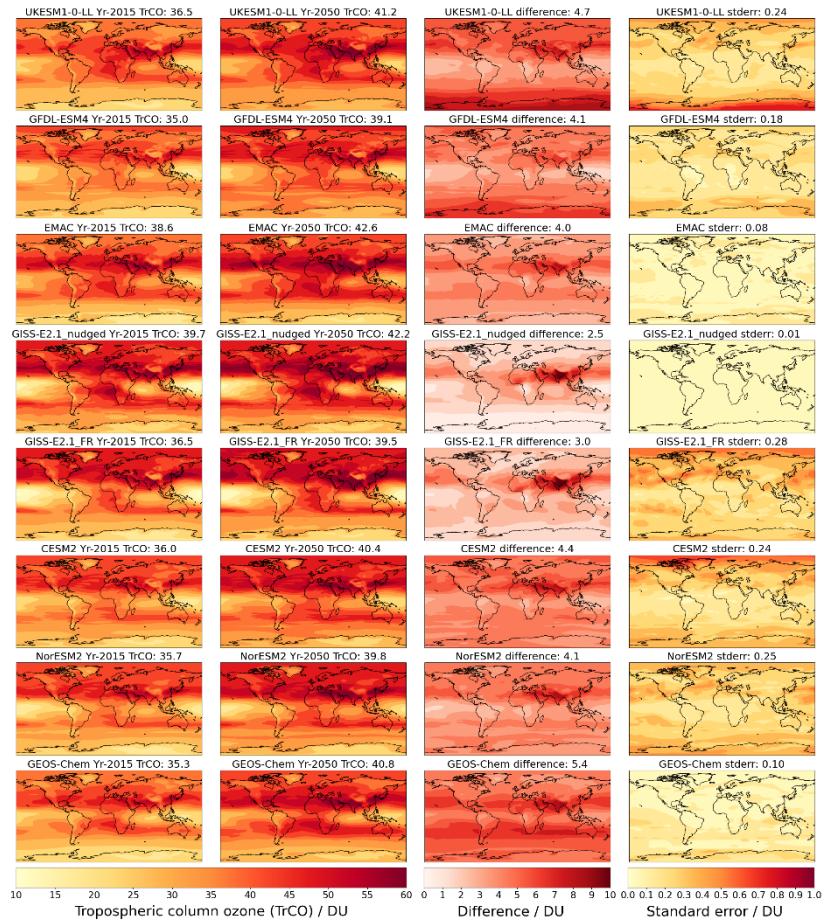
Figure S4: Year-2015 (1st column) and Year-2050 (2nd column) climatologies for the global distribution of tropospheric column ozone (TrCO), the difference between the two climatologies (3rd column; Year-2050 minus Year-2015), and the standard error in the difference (4th column) simulated by the models: UKESM1-0-LL, GFDL-ESM4, EMAC, GISS-E2.1_nudged, GISS-E2.1_FR, CESM2, NorESM2 and GEOS-Chem. The units for TrCO are in Dobson Units (DU).

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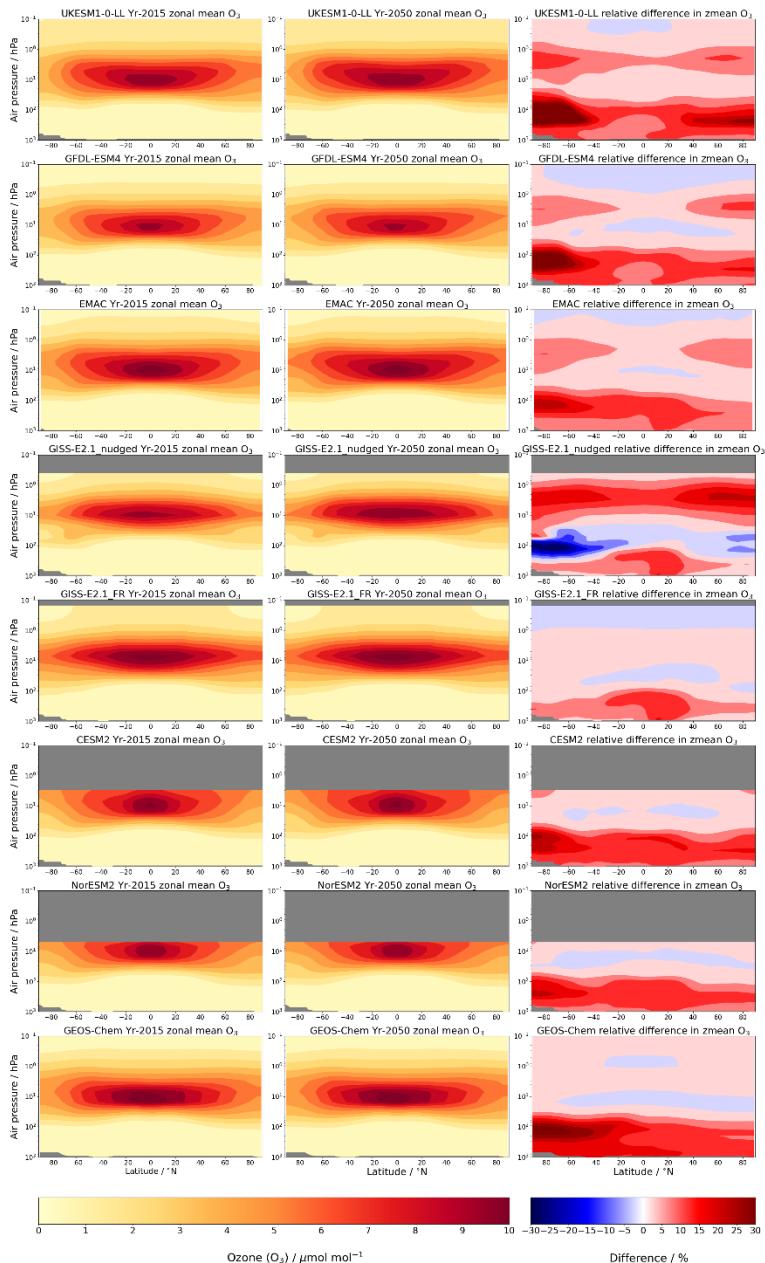
Figure S5: Year-2015 (1st column) and Year-2050 (2nd column) climatologies for the zonal mean distribution of ozone and the relative difference between the two climatologies (3rd column) from the TOAR simulations for the models: UKESM1-0-LL, GFDL-ESM4, EMAC, GISS-E2.1_nudged, GISS-E2.1_FR, CESM2, NorESM and GEOS-Chem. The units for ozone are in µmol mol^{-1} and the relative differences are in %. Pressure levels that are above the model top or pressure levels below the surface are greyed out.

12
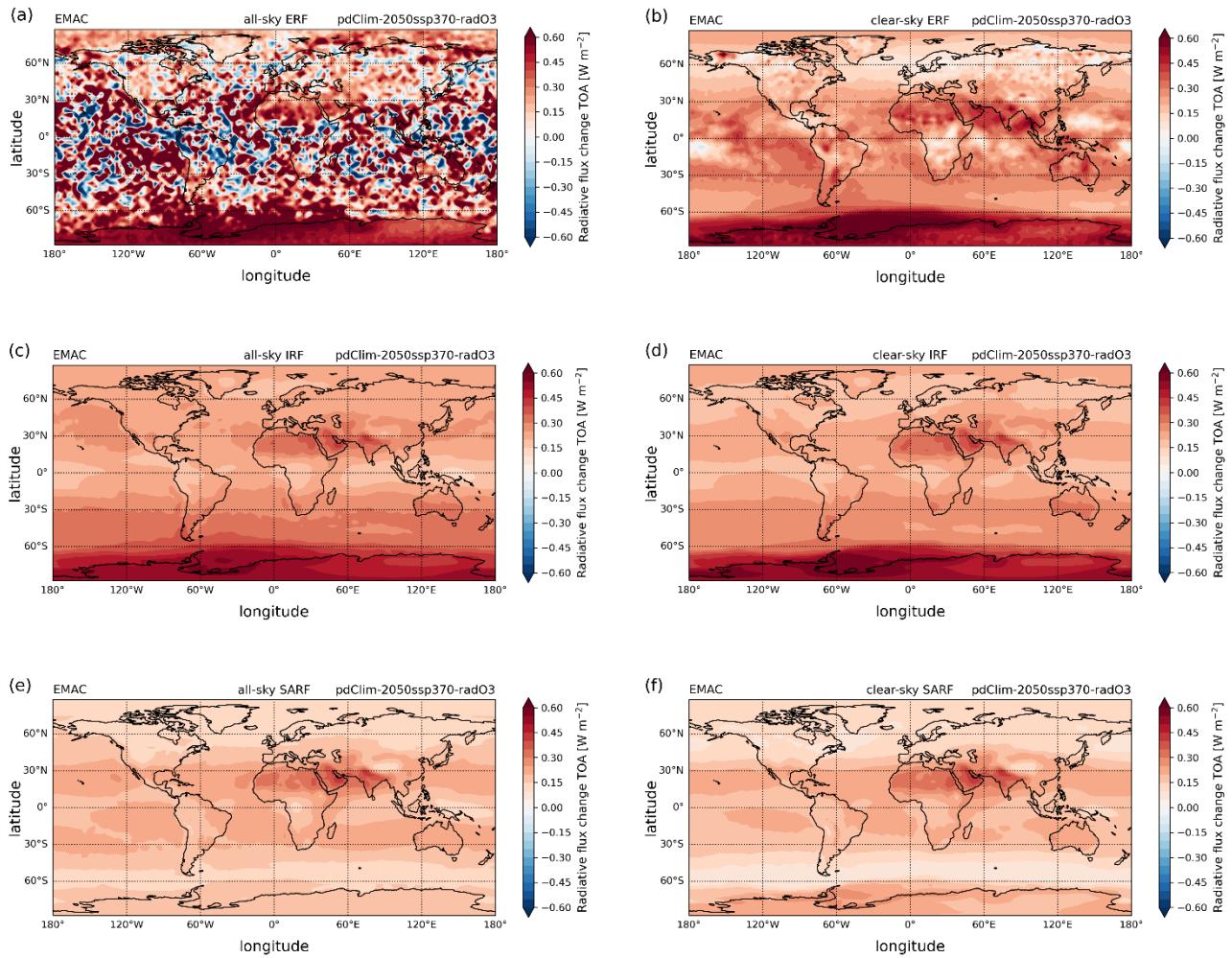
Figure S6: Spatial distribution of radiative flux changes from EMAC. Left column shows all-sky values for ERF (a), IRF (c) and SARF (e), whereas the right column shows the respective clear-sky values (b,d,f). ERF is calculated from pdClim-ssp370-radO3 minus pdClim-control. IRF and SARF are determined from multiple radiation call diagnostics in the EMAC pdClim-ssp370-radO3 simulation.

115
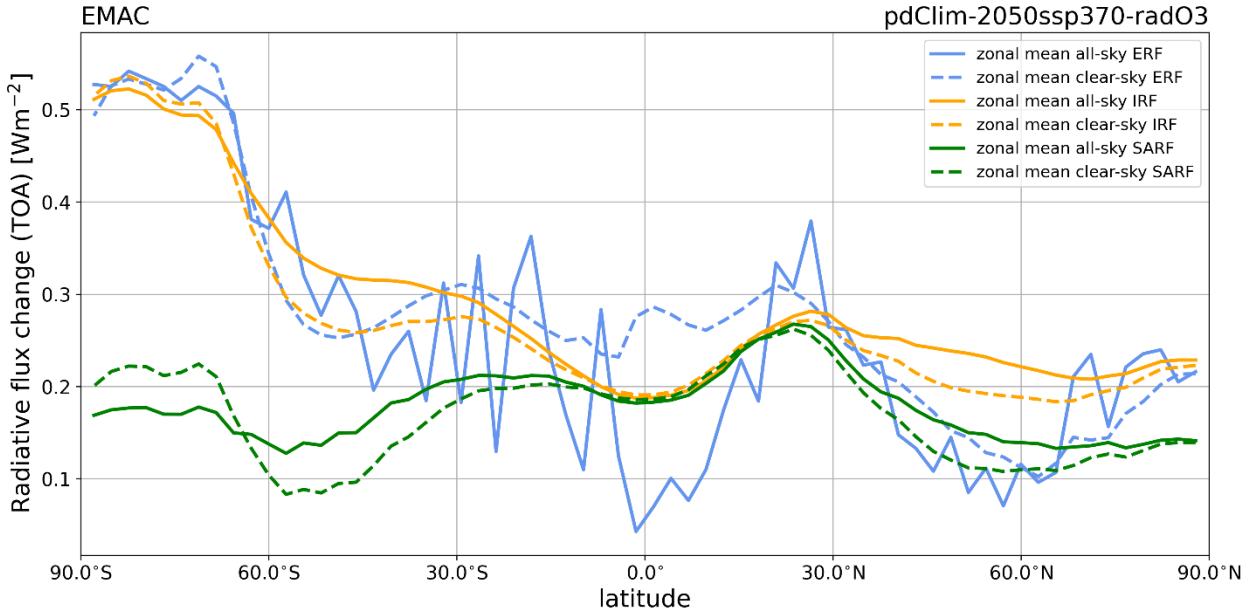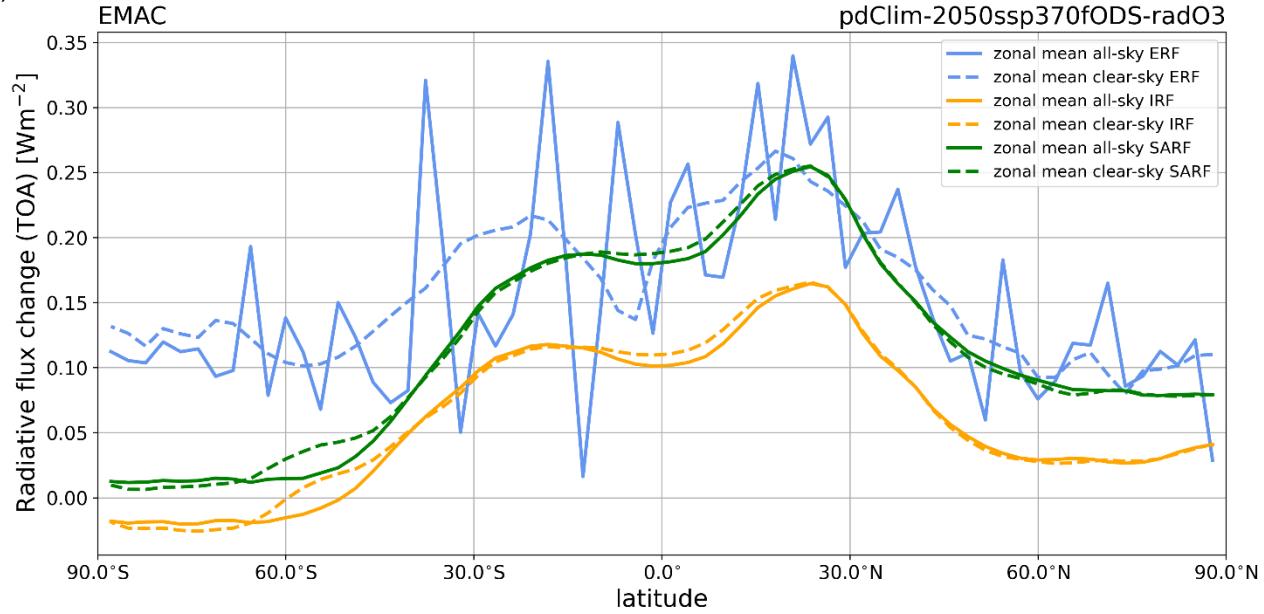
Figure S7: Zonal mean radiative flux changes for the EMAC pdClim-2050ssp370-radO3 simulation (a) and the EMAC pdClim-2050ssp370fODS-radO3 simulation (b). As in Fig. S6 the ERF values are calculated using the EMAC pdClim-control simulations, whereas IRF and SARF values are calculated using multiple radiation calls.

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