East Asian aerosol cleanup has likely contributed to the recent acceleration in global warming

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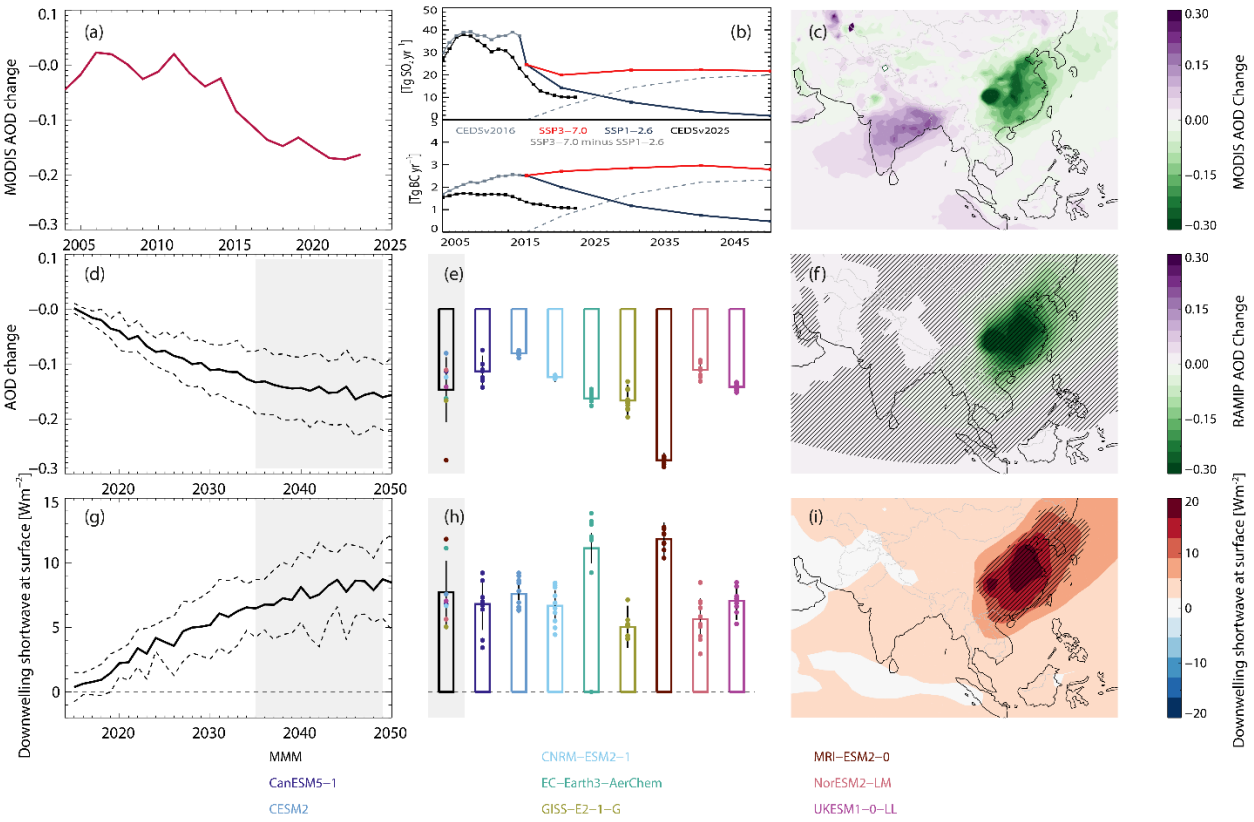
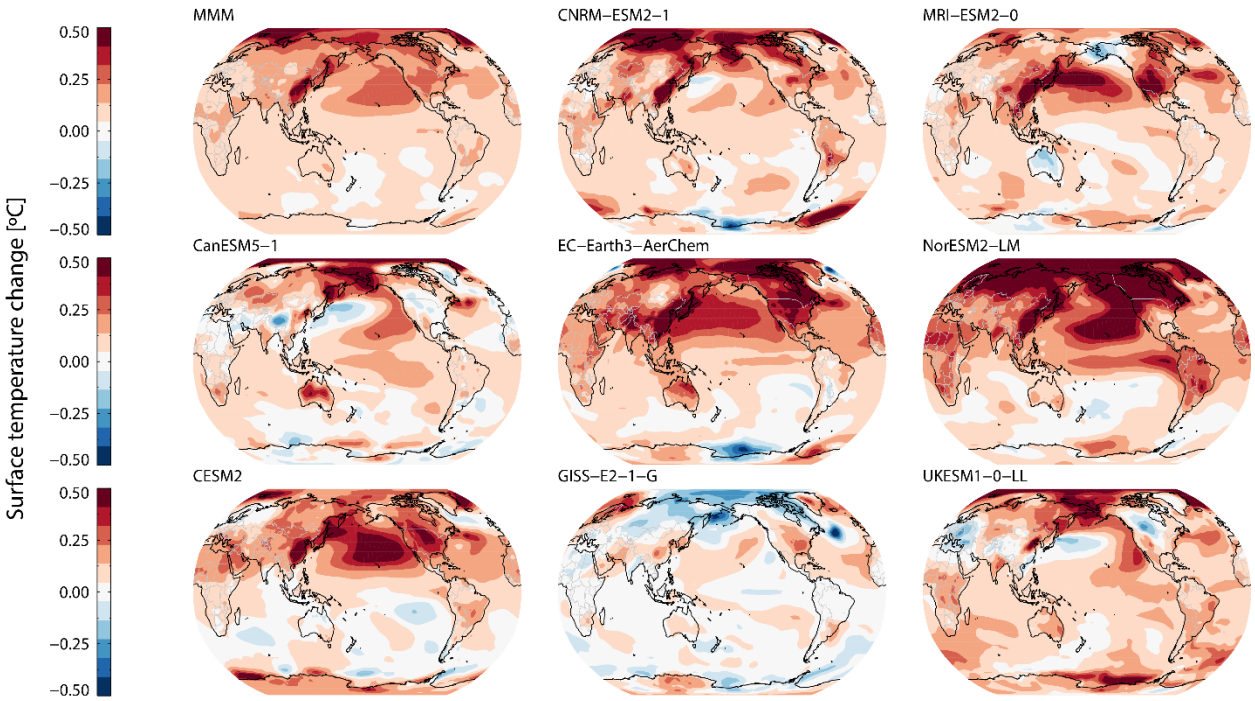
Supplementary Materials

Supplementary Figures

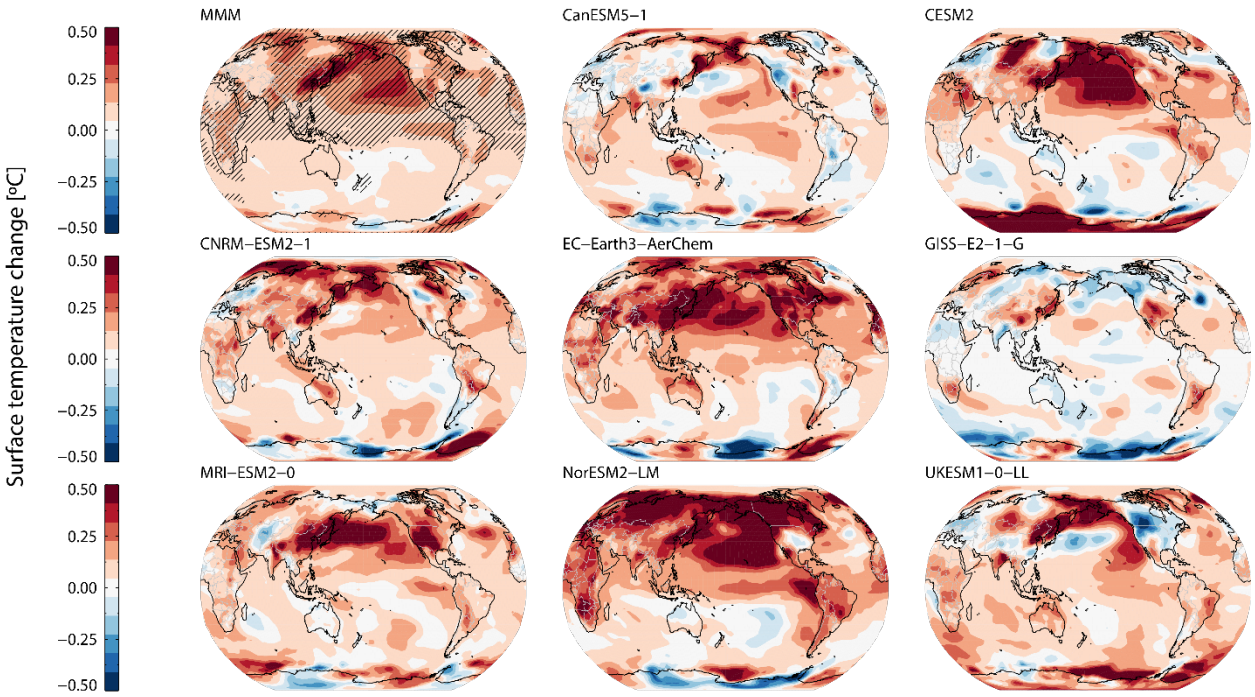


Supplementary Figure 1: Observed changes in aerosol optical depth since 2010, and the corresponding changes in the RAMIP model simulations. (a) Reduction in

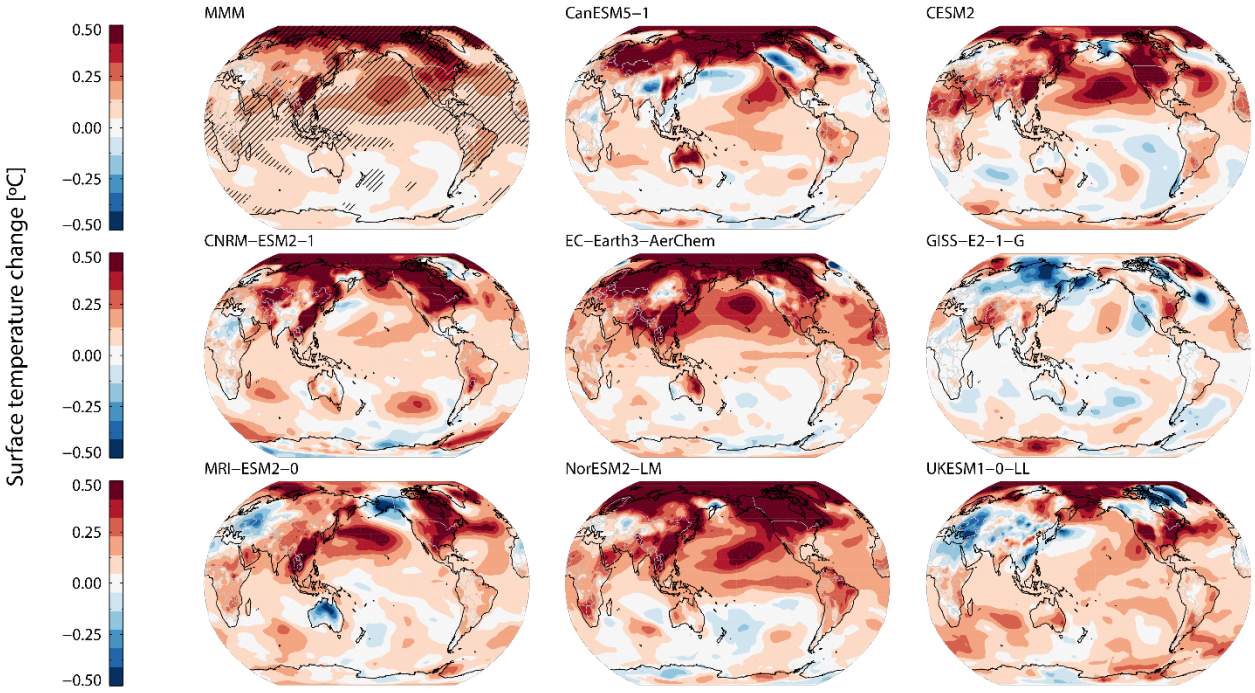
annual mean Aerosol Optical Depth (AOD) over East Asia, relative to 2005-2010. Mean of MODIS Aqua and Terra. (b) Annual emissions of SO2 (top) and BC aerosols (bottom) from CEDSv2025 (black), and the two scenarios used by RAMIP (red, blue). The older CEDSv2016 used by CMIP6 is also shown. Dashed line shows the emissions perturbation simulated by RAMIP. (c) As (a), spatially resolved, difference between 2014-2023 and 2005-2014. (d) AOD change in the RAMIP simulations, multi-model mean and ±1 standard deviation range. (e) Individual ensemble member (dots), model means (colored boxes) and multi-model mean (black box) AOD difference in RAMIP, for 2035-2049. (f) Spatial distribution of AOD change in RAMIP, multi-model mean. Hatching indicates statistical significance (see Methods). (g-i) As d-f, for downwelling shortwave radiation at the surface.



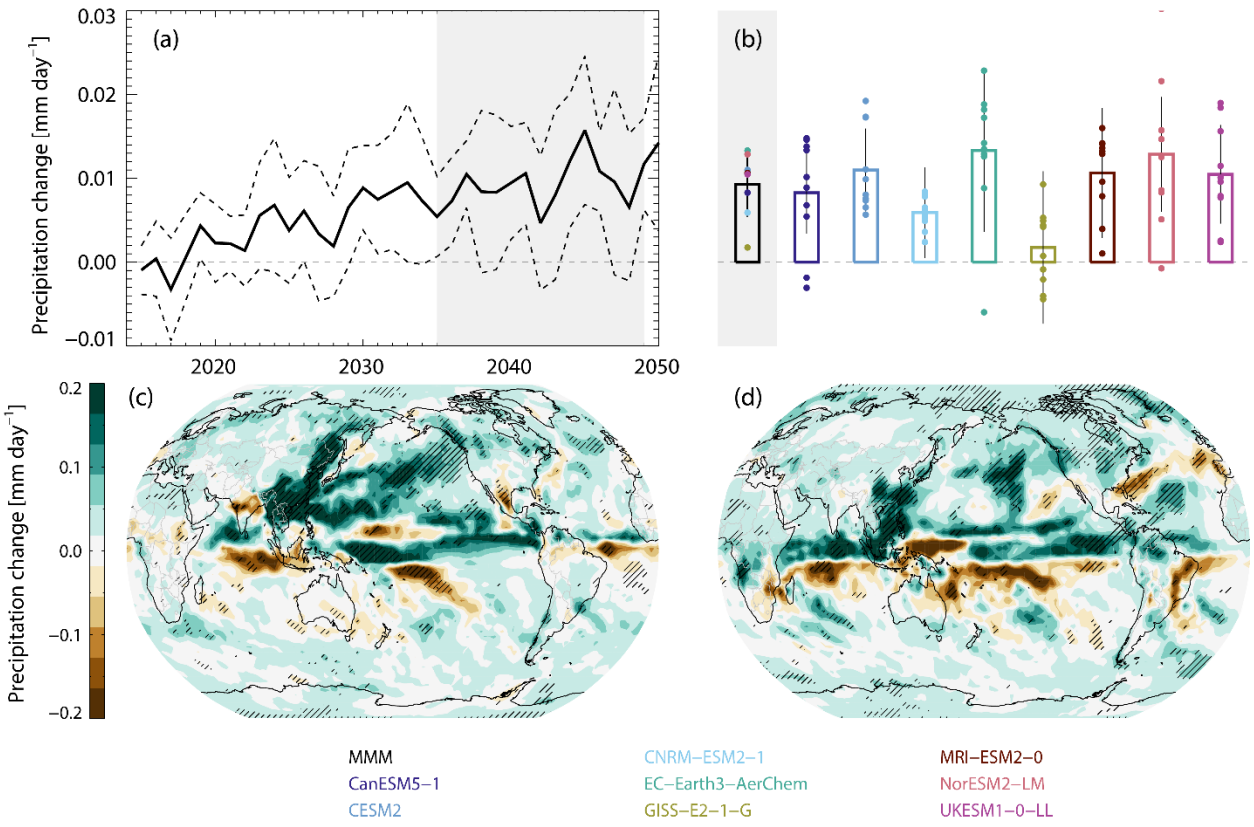
Supplementary Figure 2: RAMIP annual mean surface temperature response to East Asian aerosol emissions reductions. Multi-model mean (MMM) and individual model annual mean temperature change for the 2035-2049 period, difference between the *East Asia* and *baseline* simulations. Each model result is the mean of 10 ensemble members.



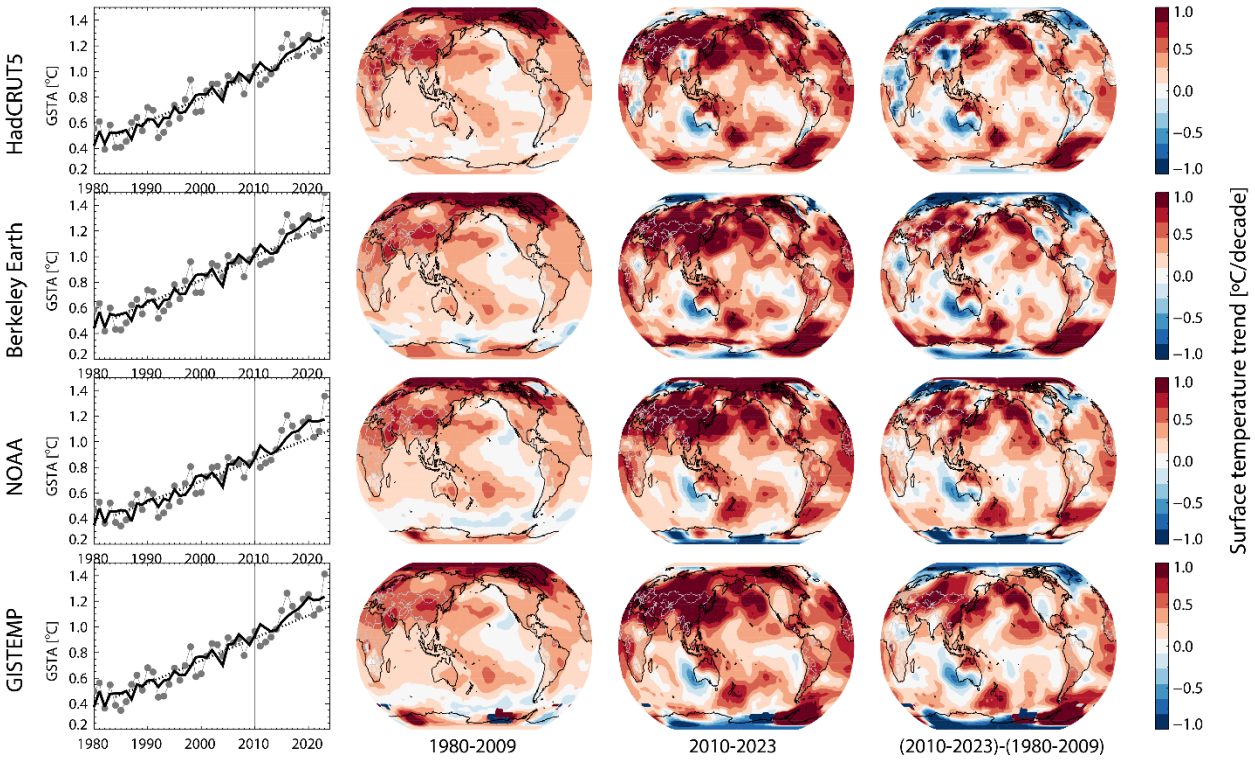
Supplementary Figure 3: RAMIP JJA surface temperature response to East Asian aerosol emissions reductions. Multi-model mean (MMM) and individual model JJA temperature change for the 2035-2049 period, difference between the *East Asia* and *baseline* simulations. Each model result is the mean of 10 ensemble members.



Supplementary Figure 4: RAMIP DJF surface temperature response to East Asian aerosol emissions reductions. Multi-model mean (MMM) and individual model DJF temperature change for the 2035-2049 period, difference between the *East Asia* and *baseline* simulations. Each model result is the mean of 10 ensemble members.

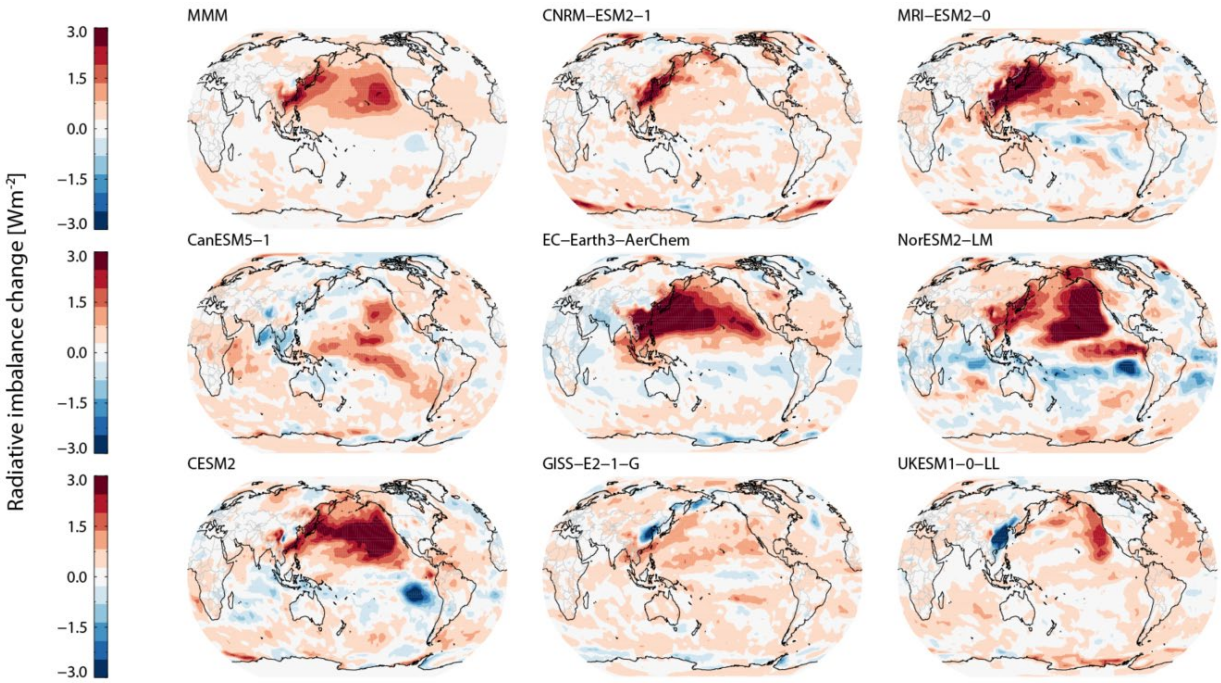


Supplementary Figure 5: Precipitation responses to reductions in East Asian aerosol emissions. (a) Global, annual mean precipitation response to the RAMIP East Asian aerosol emissions perturbations, multi-model mean (MMM) and ±1 standard deviation range. (b) Ensemble member, model mean and multi-model mean precipitation response for 2035-2049. (c) Multi-model spatial response, for June-July-August. (d) As c, for December-January-February.

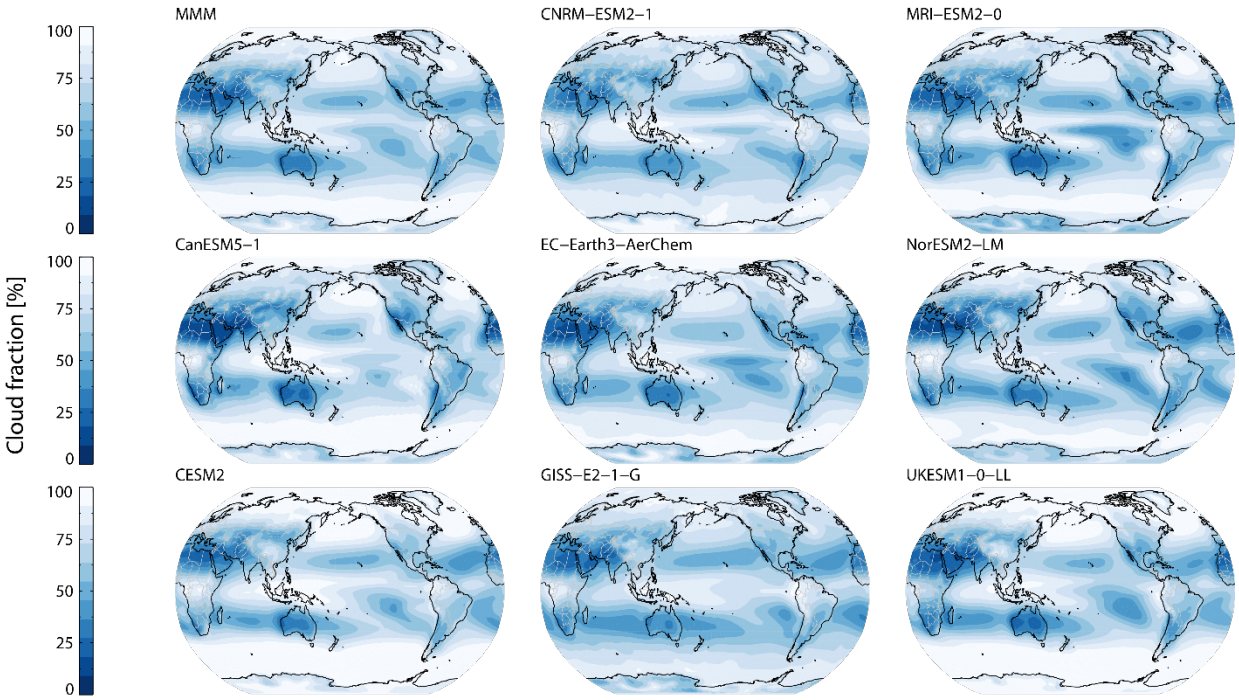


Supplementary Figure 6: Global and regional surface temperature trends from individual reconstructions.

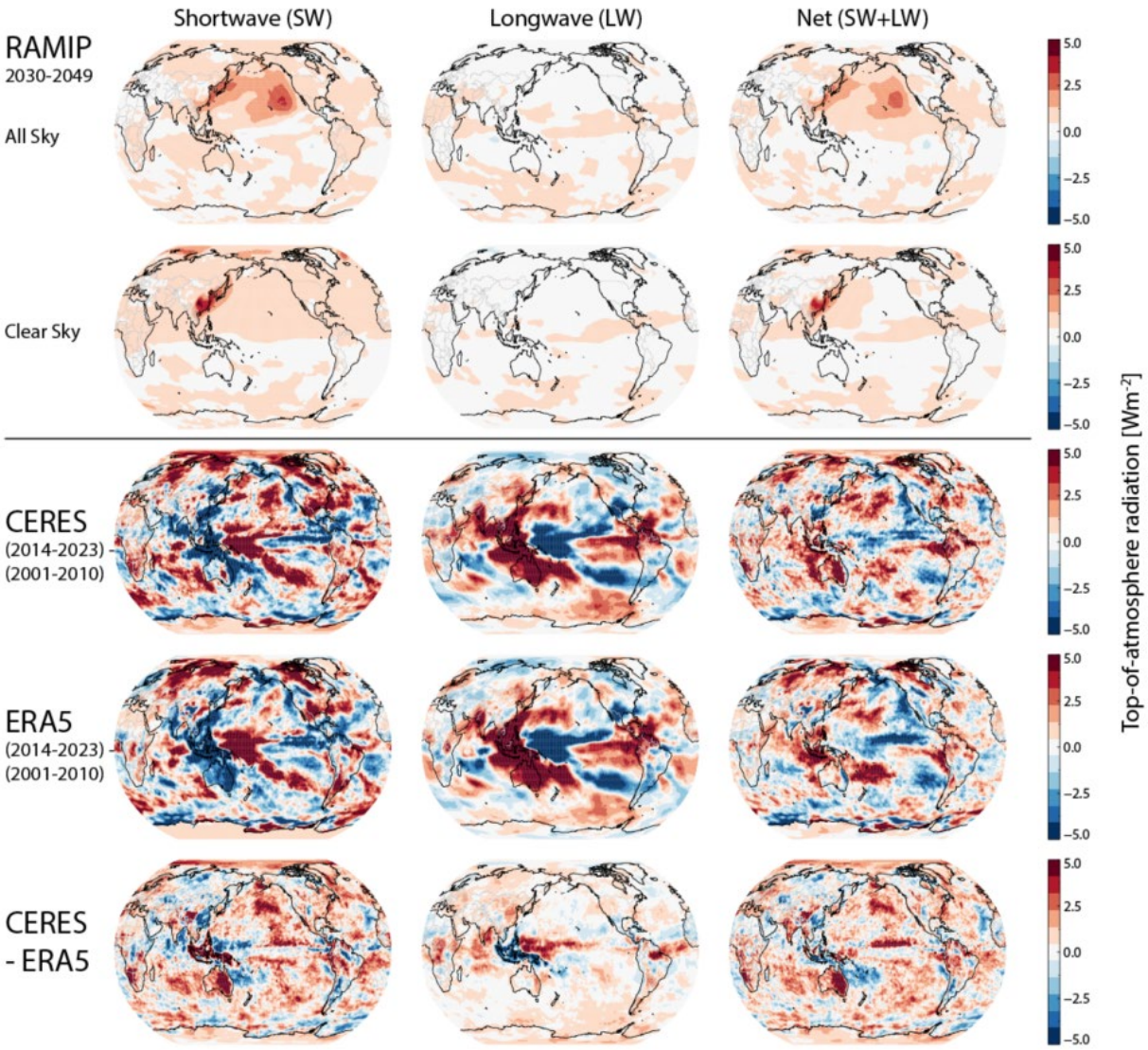
Left: Global, annual mean surface temperature anomalies, relative to 1850-1900 (1880-1900 for GISTEMP) for four reconstructions: HadCRUT5, Berkeley Earth, NOAA and GISTEMP. As in Figure 3, the dashed line shows the 1980-2009 trend, and its continuation through 2023. Subsequent columns show regional trends for 1980-2009 and 2010-2023. The right column shows the difference between the two trend periods.



Supplementary Figure 7: RAMIP TOA all sky radiative imbalance response to East Asian aerosol emissions reductions. Multi-model mean and individual model annual mean radiative imbalance (shortwave + longwave) change for the 2035-2049 period, difference between the *East Asia* and *baseline* simulations. Each model result is the mean of 10 ensemble members.



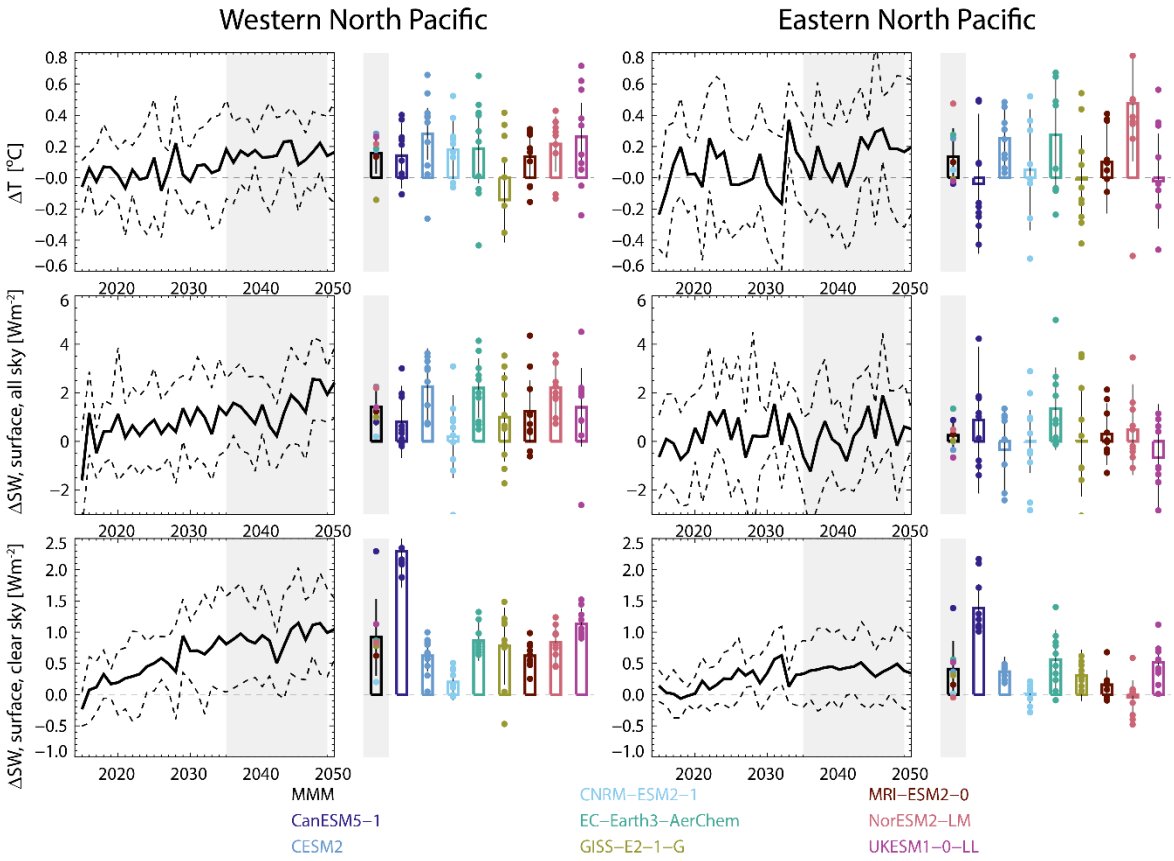
Supplementary Figure 8: RAMIP model cloud climatologies. Multi-model mean (MMM) and individual model annual mean total cloud fraction for the 2035-2049 period, in the *ssp370* baseline simulation. Each model result is the mean of 10 ensemble members.



Supplementary Figure 9: Top-of-atmosphere radiative imbalance in RAMIP, observations and reanalysis.

Breakdown of top-of-atmosphere radiative imbalances into shortwave (left), longwave (middle), and net (right) radiation. Two top rows show RAMIP multi-model results for all-sky (i.e. including cloud contributions) and clear sky conditions. Difference between the *East Asia* and *baseline* simulations, 2035-2049. Subsequent rows show

results from CERES and ERA5, as the difference between two recent decades (see main text). The last row shows the difference between CERES and ERA5.



Supplementary Figure 10: RAMIP North Pacific responses

Multi-model and individual model responses in the Western (left) and Eastern (right) North Pacific. Domains used are 120W-180W (West Pacific), 120E-180E (East Pacific), and 25N-52N (both), with an ocean mask applied. Top row: Surface temperature change, as the difference between the *East Asia* and *baseline* simulations for 2035-2049. Middle row: Change in downwelling shortwave radiation for all sky conditions. Bottom row: Same, but for clear sky conditions.

Supplementary Tables

Supplementary Table 1: Simulation details

Simulations used in this analysis. For further documentation, see [1]. SSP3-7.0 and SSP1-2.6 aerosol emissions are documented in [2].

Simulation name	**RAMIP name**	**Aerosol emissions**		**Time period**	**Ensemble members**	
		East Asia	Elsewhere			
Baseline	SSP370	SSP370	SSP370	2015-2050	10	
East Asia	SSP370-eas126aer	SSP126	SSP370	2015-2050	10	

Supplementary Table 2: RAMIP participating models

Technical details and key reference for RAMIP models included in this analysis

Centre	**Model**	**Model construction**			**Resolution**				
		Atmosphere	**Aerosol**	**Chemistry**	**Lon**	**Lan**	**Lev**	**Model top**	**Documentation**
CCCma	CanESM5-1	CanAM5	Interactive	Specified oxidants	128	64	49	1hPa	[3]
NCAR	CESM2	CAM6	MAM4	MAM4	288	192	32	2.25hPa	[4]
CNRM-CERFACS	CNRM-ESM2-1	Arpege 6.3	TACTIC_v2	REPROBUS-C_v2	256	128	91	78.4km	[5]
EC-Earth-Consortium	EC-Earth3-AerChem	IFS cy36r4	TM5	TM5	512	256	91	0.01hPa	[6]
NASA-GISS	GISS-E2-1-G (p3)	GISS-E2.1	OMA	GPUCCINI	144	90	40	0.1hPa	[7]
MRI	MRI-ESM2-0	MRI-AGCM3.5	MASINGAR mk2r4	MRI-CCM2.1	320	160	80	0.01hPa	[8]

NCC	NorESM2-LM	CAM-OSLO	OsloAero	OsloChemSimp	144	96	32	3mb	[9]
MOHC	UKESM1-0-LL	MetUM-HadGEM3-GA7.1	UKCA-GLOMAP-mode	UKCA-StratTrop	192	144	85	85km	[10]

Supplementary Table 3: RAMIP model and dataset references

Key reference for CMIP6 and RAMIP datasets included in this analysis

Model	Data reference (historical)	Data reference (RAMIP)
CanESM5-1	https://doi.org/10.22033/ESGF/CMIP6.3610	
CESM2	https://doi.org/10.22033/ESGF/CMIP6.7627	
CNRM-ESM2-1	https://doi.org/10.22033/ESGF/CMIP6.4068	https://doi.org/10.22033/ESGF/CMIP6.3924
EC-Earth3-AerChem	https://doi.org/10.22033/ESGF/CMIP6.4701	https://doi.org/10.22033/ESGF/CMIP6.4530
GISS-E2-1-G (p3)	https://doi.org/10.22033/ESGF/CMIP6.7127	https://doi.org/10.22033/ESGF/CMIP6.6984
MRI-ESM2-0	https://doi.org/10.22033/ESGF/CMIP6.6842	
NorESM2-LM	https://doi.org/10.22033/ESGF/CMIP6.8036	https://doi.org/10.22033/ESGF/CMIP6.7848
UKESM1-0-LL	https://doi.org/10.22033/ESGF/CMIP6.6113	https://doi.org/10.22033/ESGF/CMIP6.5857

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