

Supplementary Information

Amplified future drying of tropical land constrained by physical theory

Andrew E. Chingos, Graeme A. MacGilchrist, Michael P. Byrne
School of Earth and Environmental Sciences, University of St Andrews

January 14, 2026

Supplementary Figures

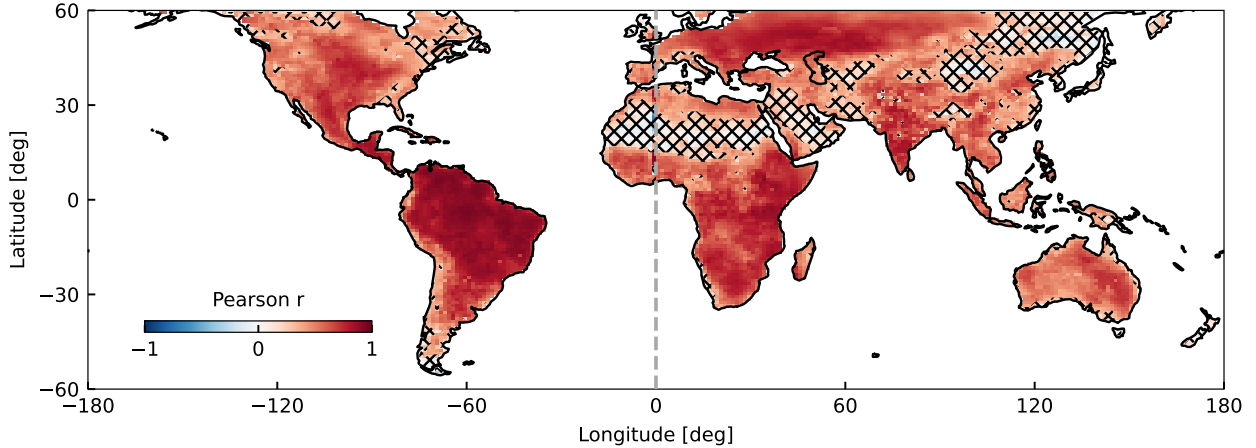
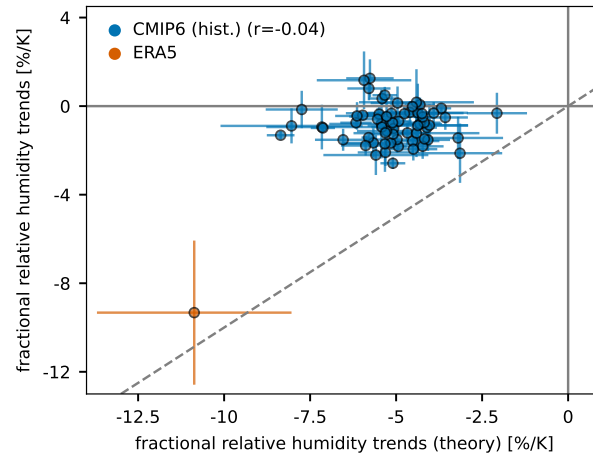


Figure S1: Pearson's correlation coefficient across CMIP6 historical simulations (1980–2014) between simulated fractional trends in near-surface land RH and estimates from the ocean-influence theory [see equation (2) in the main text]. Cross-hatched areas indicate regions where the correlation is not significant at $p < 0.01$. Outliers, defined as values with z -scores greater than 3 in either simulated or estimated fractional near-surface RH trends, are removed prior to the correlation coefficients being computed. All fields are regridded to the GFDL-CM4 model grid using bilinear interpolation prior to calculations being performed.



16

Figure S2: As for Fig. 2 in the main text, but here showing data for all land regions between 60°S
 18 and 60°N.

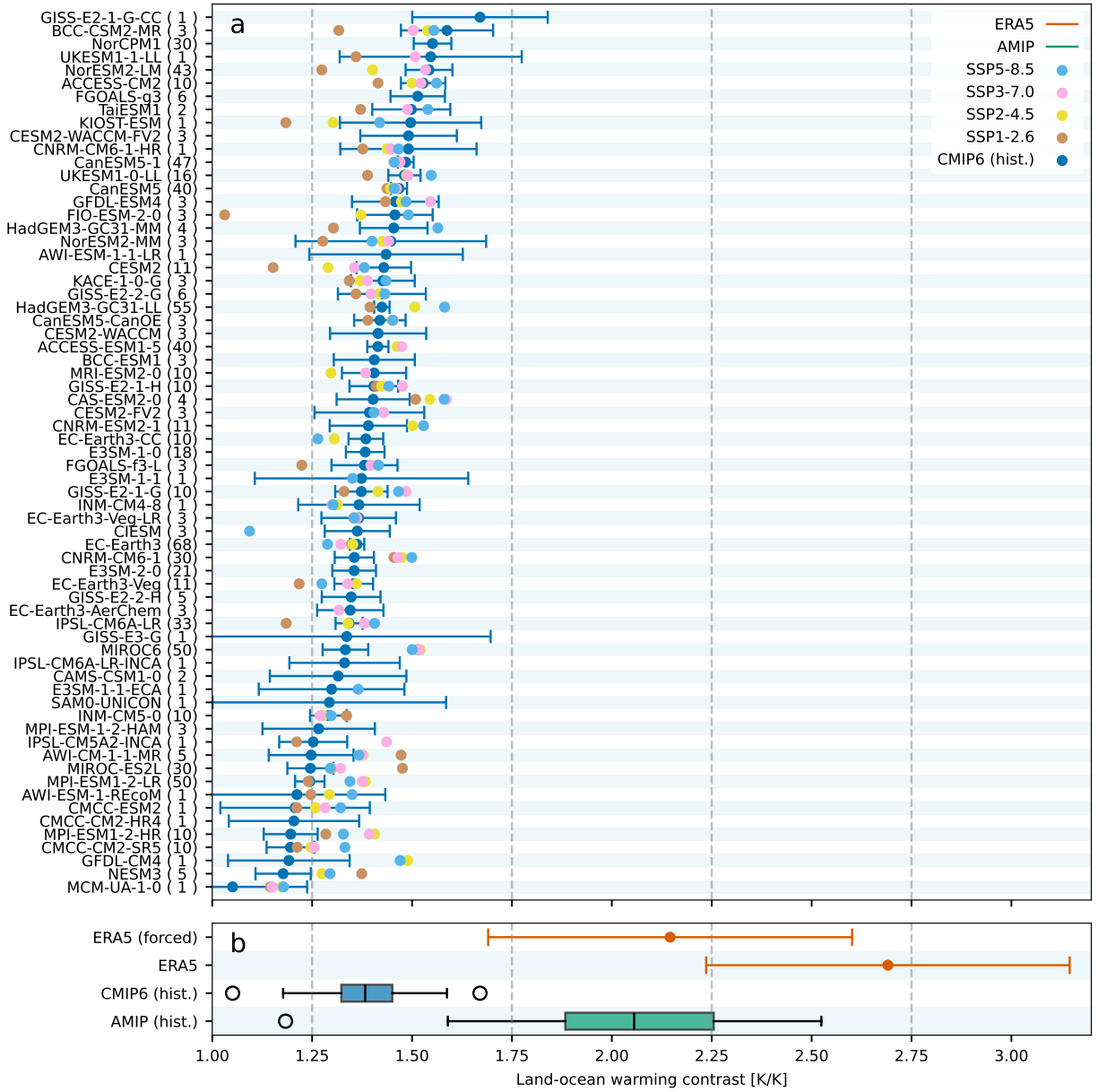


Figure S3: (a) Land-ocean warming contrasts in historical (1980–2014; dark blue) and future CMIP6 simulations (brown corresponds to SSP1-2.6 [2015–2100]; yellow to SSP2-4.5 [2015–2100]; pink to SSP3-7.0 [2015–2100]; light blue to SSP5-8.5 [2015–2100]). Numbers adjacent to model names on the y -axis indicate the number of ensemble members analysed for the historical simulations. Error bars on historical points indicate 95% confidence intervals on each model's ensemble mean (note that error bars on the SSP simulations are not shown). Models are sorted vertically by the magnitude of the ensemble-mean warming contrast for the historical simulations. (b) Boxplots of the land-ocean warming contrasts for the CMIP6 historical simulations (blue) and AMIP historical simulations (green). Also plotted are the ERA5 warming contrast and an estimate of its forced component (both orange), with whiskers indicating the 95% confidence intervals.

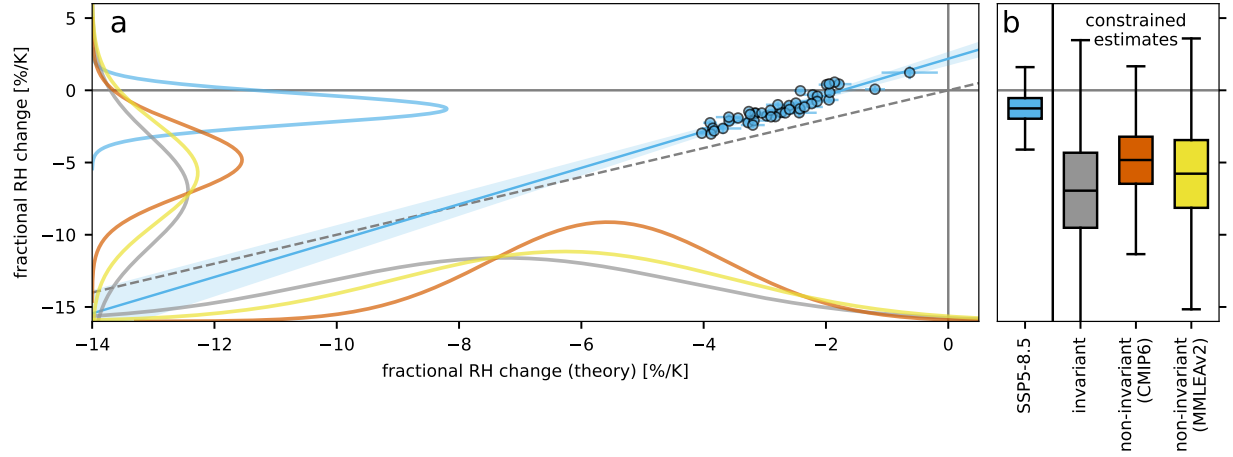


Figure S4: As for Fig. 3 in the main text, but here showing data for the SSP5-8.5 simulations. The constrained land RH changes are summarised in Table S2.

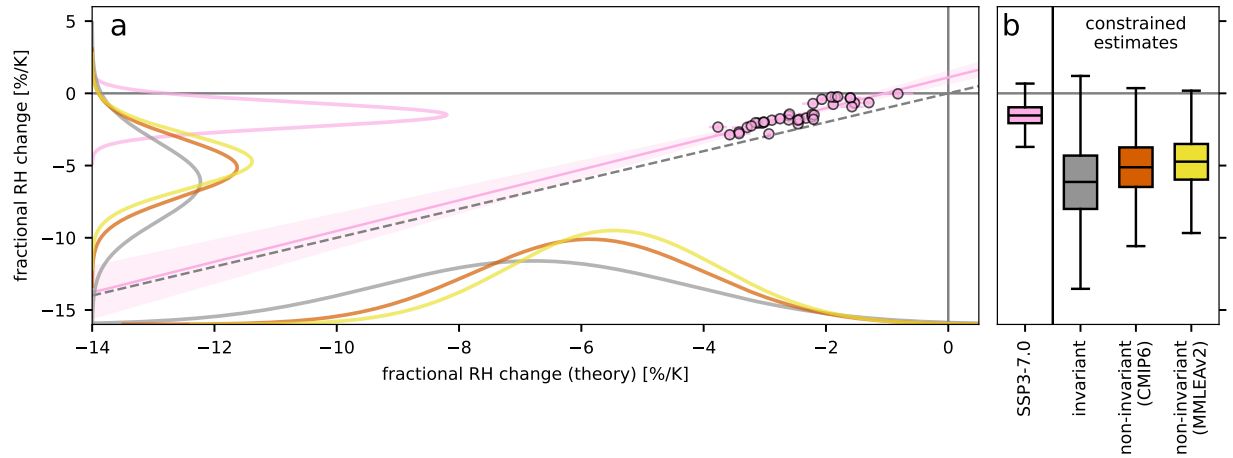


Figure S5: As for Fig. 3 in the main text, but here showing data for climatologically humid land regions only. The constrained land RH changes are summarised in Table S3.

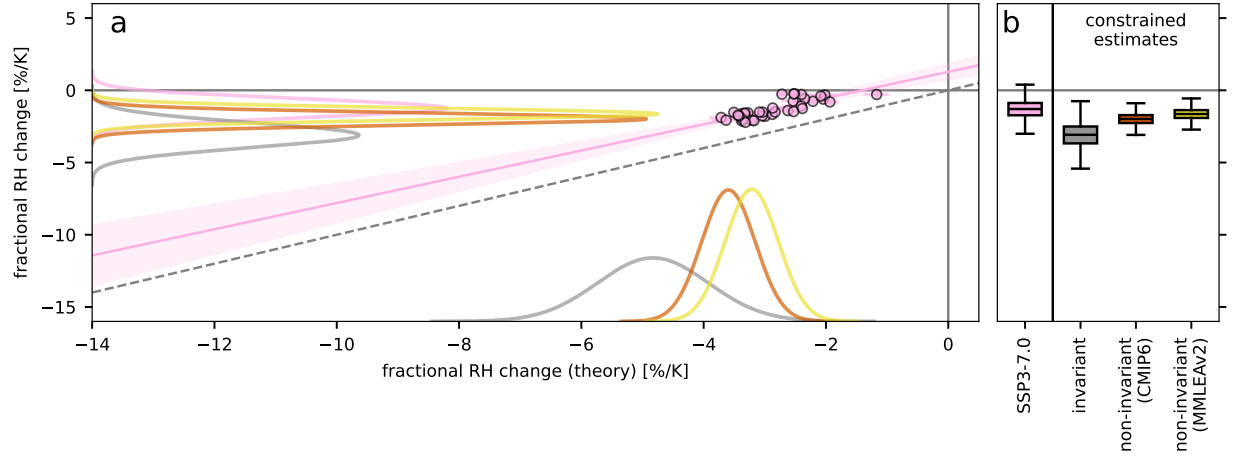


Figure S6: As for Fig. 3 in the main text, but here expanding the analysis area to include subtropical humid regions (40°S to 40°N). The constrained land RH changes are summarised in Table S4.

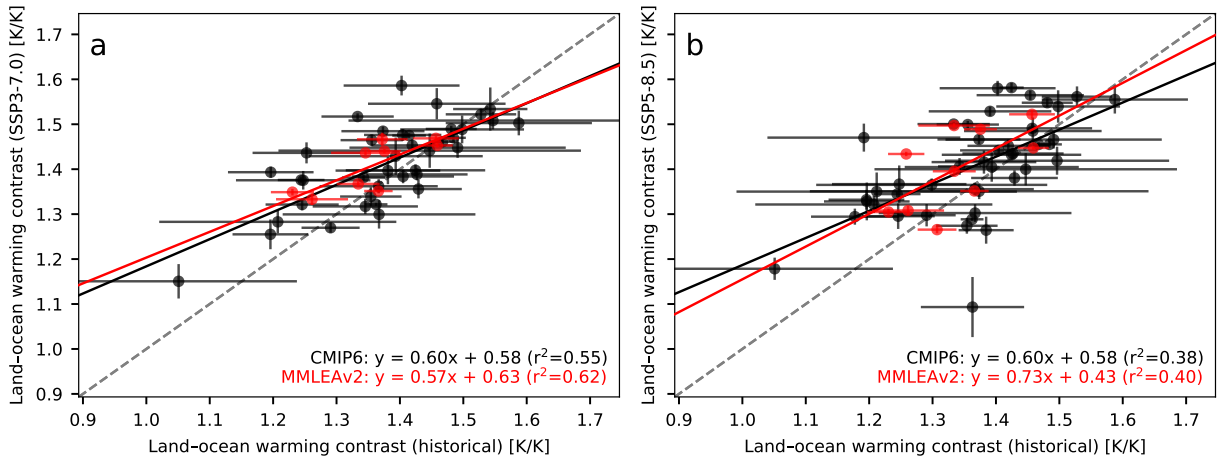


Figure S7: Tropical land-ocean warming contrasts in: (a) SSP3-7.0 (2015–2100) and (b) SSP5-8.5 simulations (2015–2100) vs in historical simulations (1980–2014). Error bars indicate the 95% confidence intervals on each model's ensemble mean. The red markers correspond to large ensembles in the MMLEAv2 archive (see Table S6), and the black markers correspond to (a) SSP3-7.0 and (b) SSP5-8.5 simulations from the CMIP6 archive. Ordinary least squares regressions for the MMLEAv2 and CMIP6 data are shown as red and black lines, respectively, along with the 1:1 line (dashed grey). The equations and r^2 values for each regression line are displayed in the panels.

Supplemental Tables

Table S1: Summary of the constrained estimates of fractional land RH changes for the SSP3-7.0 simulations using the invariant and non-invariant methods, along with the 95% and 66% confidence intervals. Averaged over all land regions from 20°S to 20°N.

Method	RH Change (%/K)	95% CI	66% CI
invariant	-6.42	[-13.17 – 0.34]	[-9.88 – -2.95]
non-invariant (CMIP6)	-4.49	[-8.74 – -0.24]	[-6.67 – -2.31]
non-invariant (MMLEAv2)	-4.37	[-8.74 – -0.01]	[-6.61 – -2.14]

Table S2: Summary of the constrained estimates of fractional land RH changes for the SSP5-8.5 simulations using the invariant and non-invariant methods, along with the 95% and 66% confidence intervals. Averaged over all land regions from 20°S to 20°N.

Method	RH Change (%/K)	95% CI	66% CI
invariant	-6.97	[-14.45 – 0.51]	[-10.80 – -3.13]
non-invariant (CMIP6)	-4.82	[-9.61 – -0.04]	[-7.28 – -2.37]
non-invariant (MMLEAv2)	-5.72	[-12.51 – 1.07]	[-9.20 – -2.24]

Table S3: Summary of the constrained estimates of fractional land RH changes for the SSP3-7.0 simulations using the invariant and non-invariant methods, along with the 95% and 66% confidence intervals. Averaged over humid land regions from 20°S to 20°N.

Method	RH Change (%/K)	95% CI	66% CI
invariant	-6.11	[-11.49 – -0.73]	[-8.87 – -3.35]
non-invariant (CMIP6)	-5.14	[-9.16 – -1.12]	[-7.20 – -3.08]
non-invariant (MMLEAv2)	-4.71	[-8.35 – -1.07]	[-6.58 – -2.84]

Table S4: Summary of the constrained estimates of fractional land RH changes for the SSP3-7.0 simulations using the invariant and non-invariant methods, along with the 95% and 66% confidence intervals. Averaged over humid land regions from 40°S to 40°N.

Method	RH Change (%/K)	95% CI	66% CI
invariant	-3.11	[-4.78 – -1.43]	[-3.96 – -2.25]
non-invariant (CMIP6)	-1.99	[-2.79 – -1.18]	[-2.40 – -1.57]
non-invariant (MMLEAv2)	-1.64	[-2.43 – -0.85]	[-2.04 – -1.23]

Table S5: Models, institutions, simulations, and ensemble sizes (n) used in analyses of data from the CMIP6 and AMIP archives. Also shown in brackets are the numbers of additional ensemble members used in analyses where only near-surface temperature data are needed (e.g., for the analysis of land-ocean warming contrasts across simulations; see Fig. S3).

Model	Institution	Simulation	n
ACCESS-CM2	CSIRO-ARCCSS	historical	10
		ssp370	7
		ssp585	1 (4)
		amip	7
ACCESS-ESM1-5	CSIRO	historical	40
		ssp370	40
		ssp585	40
		amip	10
AWI-CM-1-1-MR	AWI	historical	5
		ssp370	5
		ssp585	1 (4)
AWI-ESM-1-1-LR	AWI	historical	1
AWI-ESM-1-REcoM	AWI	historical	1
		ssp370	1
		ssp585	1
BCC-CSM2-MR	BCC	historical	3
		ssp370	1
		ssp585	1
BCC-ESM1	BCC	historical	3
CAMS-CSM1-0	CAMS	historical	2
CAS-ESM2-0	CAS	historical	4
		ssp370	2
		ssp585	2
		amip	2
CESM2	NCAR	historical	11
		ssp370	6
		ssp585	3
		amip	10
CESM2-FV2	NCAR	historical	4
		ssp370	1
		ssp585	1
		amip	4
CESM2-WACCM	NCAR	historical	3
		ssp370	1
		ssp585	3

Continued on next page

Table S5

Model	Institution	Simulation	n
CESM2-WACCM-FV2	NCAR	amip	3
		historical	3
CIESM	THU	amip	3
		historical	3
		ssp370	1
		ssp585	1
		amip	3
CMCC-CM2-HR4	CMCC	historical	1
CMCC-CM2-SR5	CMCC	historical	11
		ssp370	1
		ssp585	1
CMCC-ESM2	CMCC	amip	1
		historical	1
		ssp370	1
CNRM-CM6-1	CNRM-CERFACS	ssp585	1
		historical	29 (1)
		ssp370	6
CNRM-CM6-1-HR	CNRM-CERFACS	ssp585	6
		amip	1
		historical	1
CNRM-ESM2-1	CNRM-CERFACS	ssp370	1
		ssp585	1
		amip	1
CanESM5	CCCma	historical	11
		ssp370	10
		ssp585	5
CanESM5-1	CCCma	amip	1
		historical	65
		ssp370	50
CanESM5-CanOE	CCCma	ssp585	44
		amip	7
		historical	72
E3SM-1-0	E3SM-Project	ssp370	20
		ssp585	20
		historical	3
		ssp370	3
		ssp585	3
		historical	3

Continued on next page

Table S5

Model	Institution	Simulation	n
E3SM-1-1	E3SM-Project	amip	3
		historical	1
		ssp585	1
E3SM-1-1-ECA	E3SM-Project	historical	1
		ssp585	1
E3SM-2-0	E3SM-Project	historical	21
		amip	3
EC-Earth3	EC-Earth-Consortium	historical	4 (64)
		ssp370	8 (60)
		ssp585	4 (54)
		amip	6
EC-Earth3-AerChem	EC-Earth-Consortium	historical	2 (1)
		ssp370	1
		ssp585	2
EC-Earth3-CC	EC-Earth-Consortium	amip	1
		historical	10
		ssp370	2
		ssp585	1
EC-Earth3-Veg	EC-Earth-Consortium	amip	5
		historical	9 (2)
		ssp370	2
		ssp585	2
EC-Earth3-Veg-LR	EC-Earth-Consortium	amip	2
		historical	3
		ssp370	3
		ssp585	3
FGOALS-f3-L	CAS	amip	1
		historical	3
		ssp370	1
		ssp585	1
FGOALS-g3	CAS	amip	3
		historical	6
FIO-ESM-2-0	FIO-QLNM	amip	1
		historical	3
		ssp370	3
GFDL-CM4	NOAA-GFDL	ssp585	3
		historical	1
		ssp370	1
Continued on next page			

Table S5

Model	Institution	Simulation	n
GFDL-ESM4	NOAA-GFDL	ssp585	1
		amip	1
		historical	1 (2)
		ssp370	1 (2)
GISS-E2-1-G	NASA-GISS	ssp585	1
		historical	45
		ssp370	23
		ssp585	14
GISS-E2-1-G-CC	NASA-GISS	amip	20
		historical	1
GISS-E2-1-H	NASA-GISS	historical	25
		ssp370	6
		ssp585	10
		historical	11
GISS-E2-2-G	NASA-GISS	ssp370	5
		ssp585	5
		amip	5
		historical	5
GISS-E2-2-H	NASA-GISS	historical	2
		amip	1
GISS-E3-G	NASA-GISS	historical	55
		ssp370	5
		ssp585	4
		amip	5
HadGEM3-GC31-LL	MOHC	historical	4
		ssp585	4
		amip	4
		historical	4
HadGEM3-GC31-MM	MOHC	ssp585	4
		amip	4
		historical	1
		ssp370	1
INM-CM4-8	INM	ssp585	1
		amip	1
		historical	10
		ssp370	5
INM-CM5-0	INM	ssp585	1 (4)
		amip	1
		historical	1
		ssp585	1
IPSL-CM5A2-INCA	IPSL	historical	33
		ssp585	33
IPSL-CM6A-LR	IPSL	historical	33

Continued on next page

Table S5

Model	Institution	Simulation	n
IPSL-CM6A-LR-INCA	IPSL	ssp370	11
		ssp585	1 (10)
		amip	22
		historical	1
		historical	3
KACE-1-0-G	NIMS-KMA	ssp370	3
		ssp585	3
		amip	1
KIOST-ESM	KIOST	historical	1
		ssp370	1
MCM-UA-1-0	UA	historical	2
		ssp370	1
		ssp585	1
MIROC-ES2L	MIROC	historical	31
		ssp370	10 (20)
		ssp585	1 (9)
		amip	3
MIROC6	MIROC	historical	50
		ssp370	41 (9)
		ssp585	34 (16)
		amip	10
MPI-ESM-1-2-HAM	HAMMOZ-Consortium	historical	3
		amip	3
MPI-ESM1-2-HR	MPI-M	historical	10
		ssp370	10
		ssp585	1 (9)
		amip	3
MPI-ESM1-2-LR	MPI-M	historical	51
		ssp370	44 (6)
		ssp585	32 (18)
		amip	3
MRI-ESM2-0	MRI	historical	12
		ssp370	5
		ssp585	5
		amip	3
NESM3	NUIST	historical	5
		ssp370	2
NorCPM1	NCC	historical	30

Continued on next page

Table S5

Model	Institution	Simulation	n
NorESM2-LM	NCC	amip	10
		historical	44
		ssp370	1 (2)
		ssp585	1
NorESM2-MM	NCC	amip	3
		historical	3
		ssp370	1 (1)
SAM0-UNICON	SNU	ssp585	1
		historical	1
TaiESM1	AS-RCEC	amip	1
		historical	2
		ssp370	1
UKESM1-0-LL	MOHC	ssp585	1
		amip	1
		historical	19
		ssp370	14
UKESM1-1-LL	MOHC	ssp585	5 (7)
		amip	2
		historical	1
		ssp370	1
		ssp585	1
		amip	1

Table S6: Models, institutions, simulations, and ensemble sizes (n) used in analyses of data from the Multi-Model Large Ensemble Archive version 2 (MMLEAv2).

Model	Institution	Simulation	n
ACCESS-ESM1-5	CSIRO	historical	40
		ssp370	40
		ssp585	40
CESM2	NCAR	historical	100
		ssp370	100
		ssp585	100
CanESM5	CCCma	historical	25
		ssp370	25
		ssp585	25
E3SM-1-0	E3SM-Project	historical	14

Continued on next page

Table S6

Model	Institution	Simulation	n
E3SMv2	E3SM-Project	historical	21
		ssp370	21
EC-Earth3	EC-Earth-Consortium	historical	23
		ssp585	8
GFDL-SPEAR-MED	NOAA-GFDL	historical	30
		ssp585	30
GISS-E2-1-G	NASA-GISS	historical	28
		ssp370	5
IPSL-CM6A-LR	IPSL	historical	33
		ssp370	11
		ssp585	7
MIROC-ES2L	MIROC	historical	31
		ssp370	10
		ssp585	10
MIROC6	MIROC	historical	50
		ssp585	50
MPI-ESM1-2-LR	MPI-M	historical	50
		ssp370	30
		ssp585	30
UKESM1-0-LL	MOHC	historical	19
		ssp370	13
		ssp585	5