

Supporting Information for "Testing linearity and comparing linear response models for global surface temperatures"

Hege-Beate Fredriksen^{1,2}, Kai-Uwe Eiselt¹ and Peter Good³

¹UiT the Arctic University of Norway, Tromsø, Norway

²Norwegian Polar Institute, Tromsø, Norway

³Met Office Hadley Centre, Exeter, United Kingdom

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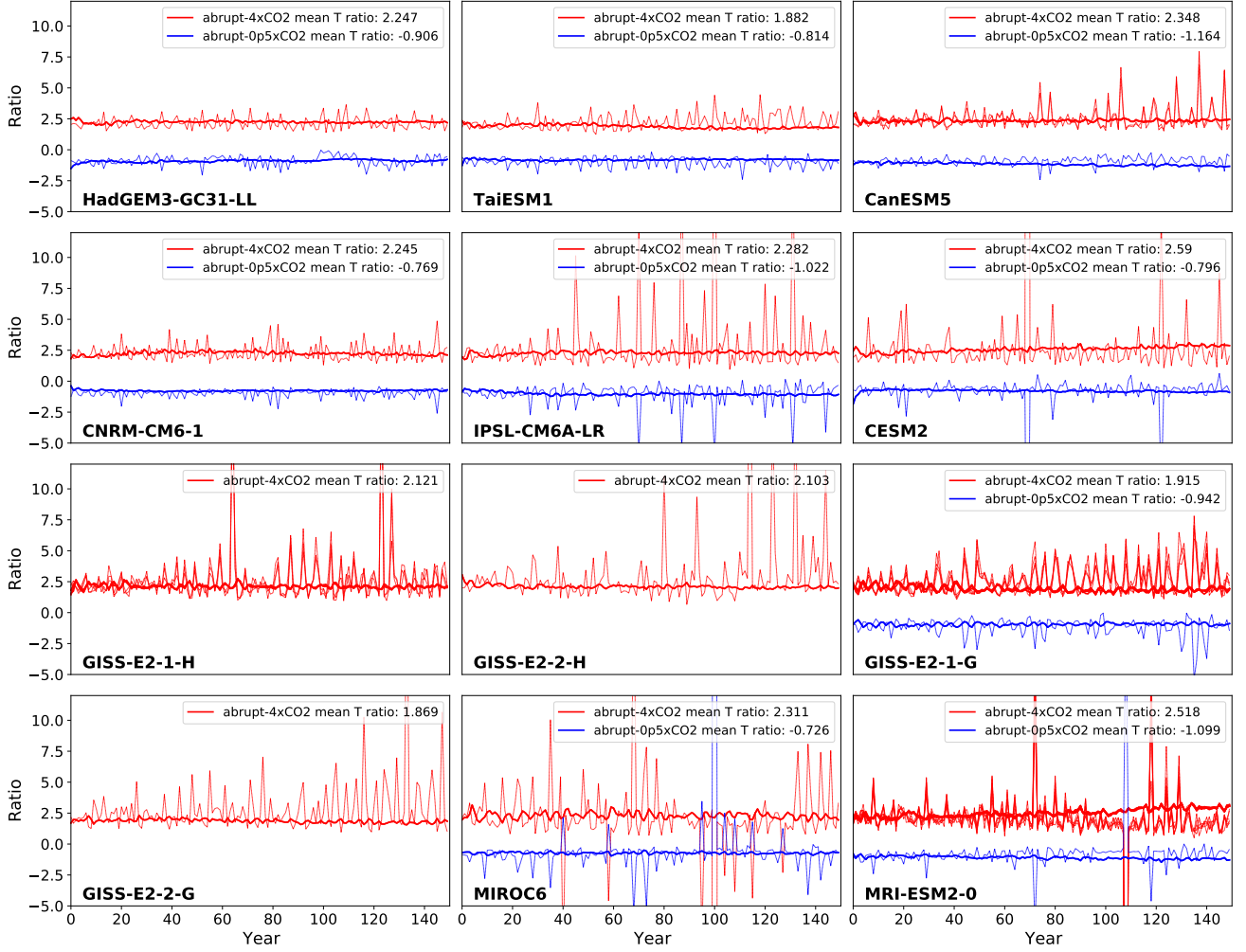


Figure S1. Ratios of T and N between abrupt-4xCO₂ (red)/abrupt-0p5xCO₂ (blue) experiments and abrupt-2xCO₂ experiments. Solid curves are T ratios and noisy thinner curves are N ratios.

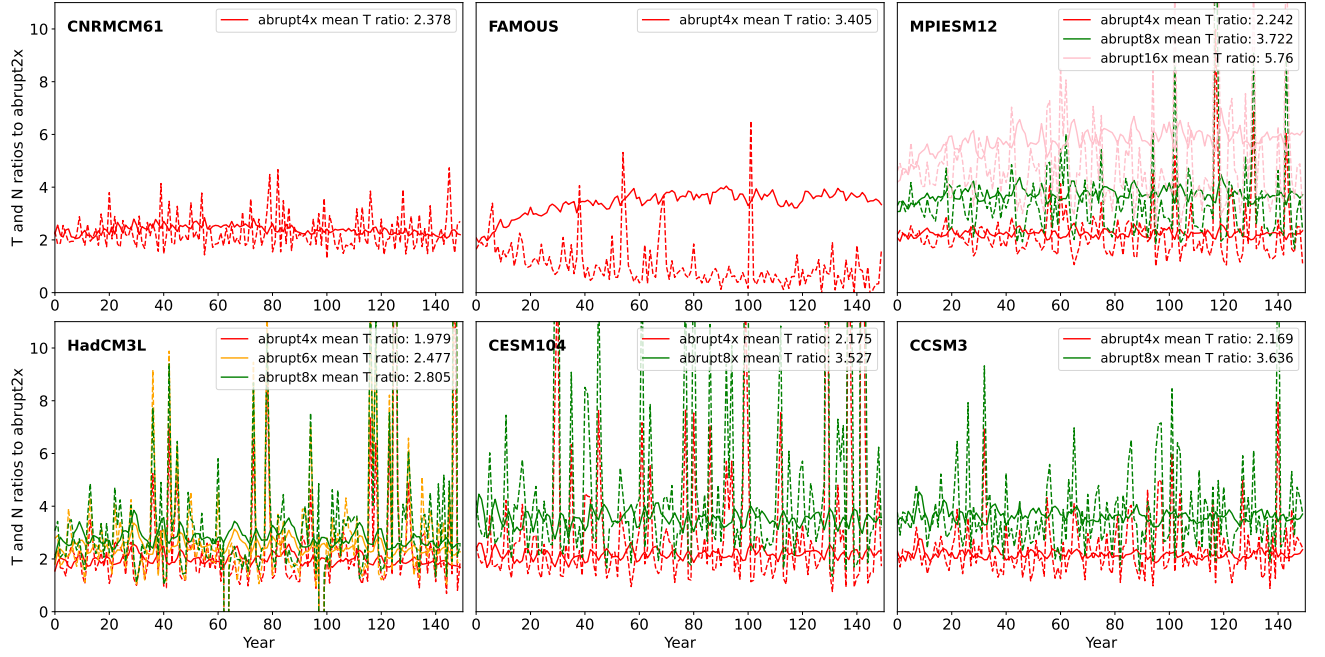


Figure S2. Ratios of T and N between abrupt4x (red)/abrupt6x (yellow)/abrupt8x (green)/abrupt16x (pink) experiments and abrupt2x experiments. Solid curves are T ratios and the dashed curves are N ratios. Only the first 150 years are used.

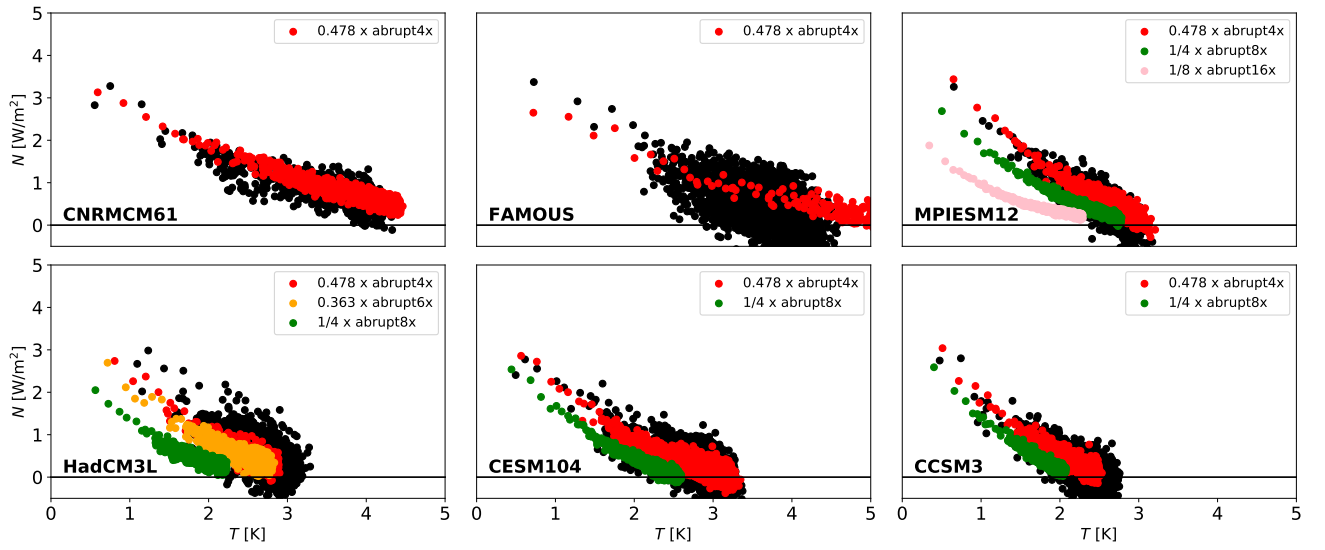


Figure S3. N and T both scaled to correspond to abrupt2x, using the scaling factors in the legends. Black dots are from the abrupt2x experiment, red is scaled abrupt4x, yellow is scaled abrupt6x, green is scaled abrupt8x, and pink is scaled abrupt16x.

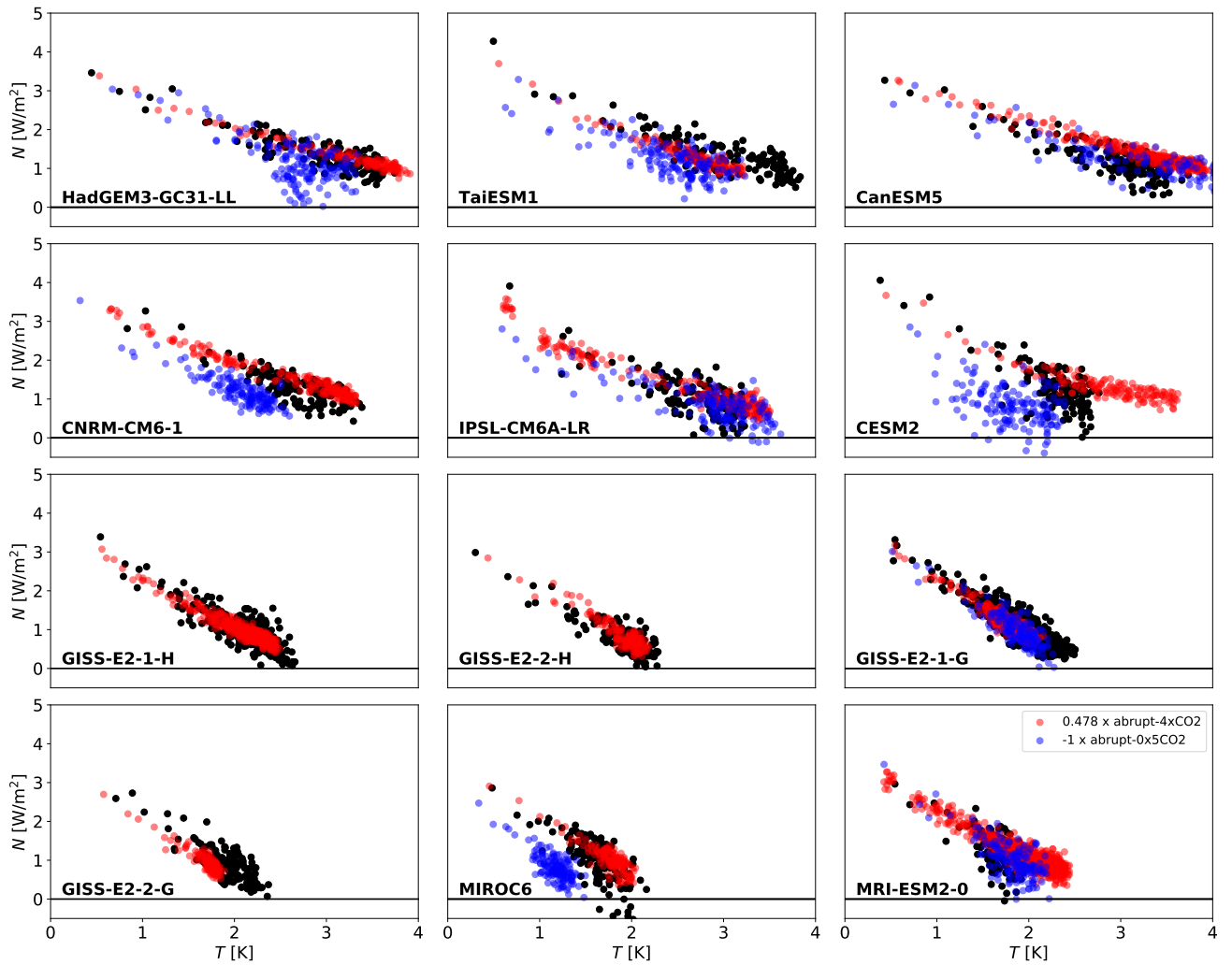


Figure S4. N and T both scaled to correspond to abrupt-2xCO₂, using the same scaling factors for all models (see legend in the bottom right). The black circles are from the abrupt-2xCO₂ experiment, red is the scaled abrupt-4xCO₂ experiment and blue the scaled abrupt-0p5xCO₂ experiment.

Table S1. Forcing ratios of abrupt-2xCO₂ to abrupt-4xCO₂ experiments, estimated from Gregory regressions of the first 5, 10, 20 and 30 years. The ensemble mean is the result of first averaging all model data for each year, and then perform regressions.

	5	10	20	30	Mean
CESM2	0.50	0.54	0.54	0.55	0.53
CNRM-CM6-1	0.51	0.50	0.50	0.54	0.51
CanESM5	0.48	0.48	0.49	0.49	0.49
GISS-E2-1-G	0.49	0.49	0.48	0.49	0.49
GISS-E2-1-H	0.49	0.51	0.49	0.52	0.50
GISS-E2-2-G	0.53	0.53	0.56	0.57	0.55
GISS-E2-2-H	0.48	0.51	0.49	0.45	0.48
IPSL-CM6A-LR	0.64	0.54	0.52	0.53	0.56
MIROC6	0.53	0.44	0.42	0.45	0.46
MRI-ESM2-0	0.50	0.49	0.46	0.47	0.48
TaiESM1	0.50	0.49	0.51	0.52	0.51
HadGEM3-GC31-LL	0.43	0.48	0.48	0.49	0.47
Ensemble mean	0.50	0.50	0.49	0.50	0.50
Mean of model results	0.51	0.50	0.50	0.51	0.50

Table S2. Forcing ratios of abrupt-2xCO₂ to abrupt-0p5xCO₂ experiments, estimated from Gregory regressions of the first 5, 10, 20 and 30 years. The ensemble mean is the result of first averaging all model data for each year, and then perform regressions.

	5	10	20	30	Mean
CESM2	-0.75	-1.11	-1.18	-1.28	-1.08
CNRM-CM6-1	-1.11	-1.16	-1.13	-1.22	-1.15
CanESM5	-1.06	-1.16	-1.11	-1.08	-1.10
GISS-E2-1-G	-1.03	-0.99	-1.00	-1.02	-1.01
IPSL-CM6A-LR	-1.53	-1.32	-1.40	-1.37	-1.41
MIROC6	-1.33	-1.14	-1.07	-1.14	-1.17
MRI-ESM2-0	-0.94	-0.95	-0.87	-0.86	-0.90
TaiESM1	-1.26	-1.28	-1.34	-1.36	-1.31
HadGEM3-GC31-LL	-1.05	-1.02	-0.98	-0.99	-1.01
Ensemble mean	-1.16	-1.15	-1.12	-1.15	-1.15
Mean of model results	-1.12	-1.12	-1.12	-1.15	-1.13

Table S3. Forcing ratios of longrunmip abrupt-2x to abrupt-Nx experiments, estimated from Gregory regressions of the first 5, 10, 20 and 30 years. The ensemble mean is the result of first averaging all model data for each year, and then perform regressions. If excluding FAMOUS for N=4, the model mean result is reduced to 0.46.

N = 4	5	10	20	30	Mean
MPIESM12	0.44	0.45	0.45	0.46	0.45
HadCM3L	0.31	0.54	0.55	0.52	0.48
FAMOUS	0.60	0.65	0.66	0.67	0.64
CNRMCM61	0.49	0.48	0.48	0.52	0.49
CESM104	0.38	0.41	0.45	0.45	0.42
CCSM3	0.48	0.49	0.41	0.43	0.45
Ensemble mean	0.46	0.50	0.51	0.53	0.50
Mean of model results	0.45	0.50	0.50	0.51	0.49
N = 6	5	10	20	30	Mean
HadCM3L	0.22	0.41	0.40	0.38	0.35
N = 8	5	10	20	30	Mean
MPIESM12	0.30	0.32	0.33	0.33	0.32
HadCM3L	0.22	0.41	0.40	0.38	0.35
CESM104	0.23	0.26	0.27	0.27	0.26
CCSM3	0.29	0.30	0.26	0.26	0.28
Ensemble mean	0.26	0.32	0.31	0.32	0.30
Mean of model results	0.26	0.32	0.31	0.31	0.30
N = 16	5	10	20	30	Mean
MPIESM12	0.22	0.24	0.24	0.25	0.24

	T_{4x}/T_{2x}	$(T_{4x}/T_{2x}) / (F_{4x}/F_{2x})$	T_{0p5x}/T_{2x}	$(T_{0p5x}/T_{2x}) / (F_{0p5x}/F_{2x})$
CESM2	2.57	1.37	-0.78	0.85
CNRM-CM6-1	2.23	1.15	-0.76	0.88
CanESM5	2.34	1.14	-1.15	1.27
GISS-E2-1-G	2.10	1.02	-0.95	0.96
GISS-E2-1-H	2.08	1.05	nan	nan
GISS-E2-2-G	1.86	1.01	nan	nan
GISS-E2-2-H	2.09	1.01	nan	nan
IPSL-CM6A-LR	2.27	1.26	-1.00	1.41
MIROC6	2.28	1.05	-0.72	0.84
MRI-ESM2-0	2.48	1.18	-1.08	0.98
TaiESM1	1.87	0.95	-0.81	1.06
HadGEM3-GC31-LL	2.24	1.05	-0.90	0.90
Mean	2.20	1.10	-0.91	1.02

Table S4. Mean ratios for CMIP6 models. The mean over 150 years are used, and the forcing ratios used are taken from the Mean columns in Tables S1 and S2.

	T_{4x}/T_{2x}	$(T_{4x}/T_{2x}) / (F_{4x}/F_{2x})$
MPIESM12	2.23	1.00
HadCM3L	1.96	0.94
FAMOUS	3.33	2.14
CNRMCM61	2.37	1.17
CESM104	2.16	0.91
CCSM3	2.16	0.98
Mean	2.18	1.00

Table S5. Mean ratios for LongRunMIP, using the first 150 years for estimation. The anomalous values for FAMOUS are omitted when computing the mean values. The forcing ratios are taken from the Mean column in Table S3.

Table S6. RMSE values for CMIP6 abrupt-4xCO2 experiments, part I.

model	member	two-exp	three-exp	two-exp + osc	% change1	% change2
ACCESS-CM2	r1ilp1f1	0.096	0.096	0.089	0.000	-7.261
ACCESS-ESM1-5	r1ilp1f1	0.127	0.114	0.111	-10.392	-2.389
ACCESS-ESM1-5	r2ilp1f1	0.104	0.101	0.102	-3.036	0.872
AWI-CM-1-1-MR	r1ilp1f1	0.125	0.118	0.118	-5.490	0.188
BCC-CSM2-MR	r1ilp1f1	0.092	0.076	0.078	-17.366	1.891
BCC-ESM1	r1ilp1f1	0.075	0.064	0.067	-13.916	4.082
CAMS-CSM1-0	r1ilp1f1	0.083	0.071	0.071	-13.784	0.015
CAMS-CSM1-0	r2ilp1f1	0.087	0.084	0.084	-3.756	0.620
CAS-ESM2-0	r1ilp1f1	0.097	0.088	0.085	-9.554	-3.548
CESM2	r1ilp1f1	0.088	0.075	0.078	-14.594	4.346
CESM2-FV2	r1ilp1f1	0.131	0.122	0.116	-7.310	-4.958
CESM2-WACCM	r1ilp1f1	0.086	0.081	0.079	-6.122	-3.109
CESM2-WACCM-FV2	r1ilp1f1	0.118	0.115	0.108	-2.287	-6.181
CIesm	r1ilp1f1	0.111	0.096	0.091	-13.337	-5.750
CMCC-CM2-SR5	r1ilp1f1	0.153	0.152	0.153	-0.812	0.661
CMCC-ESM2	r1ilp1f1	0.167	0.162	0.165	-3.219	2.117
CNRM-CM6-1	r1ilp1f2	0.111	0.097	0.097	-13.008	-0.048
CNRM-CM6-1-HR	r1ilp1f2	0.111	0.079	0.076	-28.670	-3.629
CNRM-ESM2-1	r1ilp1f2	0.120	0.120	0.115	0.000	-4.169
CNRM-ESM2-1	r2ilp1f2	0.101	0.101	0.096	0.000	-4.404
CNRM-ESM2-1	r3ilp1f2	0.096	0.096	0.094	0.000	-2.530
CanESM5	r1ilp1f1	0.113	0.093	0.096	-17.727	4.128
CanESM5	r1ilp2f1	0.117	0.092	0.092	-21.178	-0.593
E3SM-1-0	r1ilp1f1	0.144	0.125	0.140	-13.432	12.680
EC-Earth3	r3ilp1f1	0.153	0.147	0.141	-4.366	-3.906
EC-Earth3	r8ilp1f1	0.134	0.134	0.133	-0.136	-1.099
EC-Earth3-AerChem	r1ilp1f1	0.138	0.137	0.134	-0.844	-2.366
EC-Earth3-CC	r1ilp1f1	0.142	0.139	0.142	-2.506	2.150
EC-Earth3-Veg	r1ilp1f1	0.138	0.134	0.136	-2.425	1.091
FGOALS-f3-L	r1ilp1f1	0.129	0.121	0.125	-6.581	3.522
FGOALS-f3-L	r2ilp1f1	0.128	0.122	0.126	-4.244	3.469
FGOALS-f3-L	r3ilp1f1	0.115	0.108	0.109	-6.213	0.413
FGOALS-g3	r1ilp1f1	0.073	0.072	0.072	-1.265	0.290
GFDL-CM4	r1ilp1f1	0.113	0.108	0.107	-4.819	-0.520
GFDL-ESM4	r1ilp1f1	0.090	0.084	0.090	-5.993	6.326

Table S7. RMSE values for CMIP6 abrupt-4xCO2 experiments, part II.

model	member	two-exp	three-exp	two-exp + osc	% change1	% change2
GISS-E2-1-G	r102i1p1f1	0.147	0.146	0.134	-0.275	-8.424
GISS-E2-1-G	r1i1p1f1	0.129	0.129	0.119	-0.239	-7.836
GISS-E2-1-G	r1i1p3f1	0.158	0.157	0.150	-0.306	-4.785
GISS-E2-1-G	r1i1p5f1	0.185	0.179	0.171	-3.199	-4.465
GISS-E2-1-H	r1i1p1f1	0.122	0.112	0.112	-7.558	-0.109
GISS-E2-1-H	r1i1p3f1	0.123	0.121	0.123	-1.764	1.795
GISS-E2-1-H	r1i1p5f1	0.141	0.129	0.131	-8.242	0.850
GISS-E2-2-G	r1i1p1f1	0.103	0.101	0.101	-2.055	-0.028
GISS-E2-2-H	r1i1p1f1	0.094	0.087	0.086	-7.596	-0.242
HadGEM3-GC31-LL	r1i1p1f3	0.109	0.098	0.099	-9.806	0.502
HadGEM3-GC31-MM	r1i1p1f3	0.143	0.092	0.089	-35.752	-3.257
ICON-ESM-LR	r1i1p1f1	0.158	0.140	0.130	-11.601	-6.992
IITM-ESM	r1i1p1f1	0.106	0.099	0.102	-5.885	2.634
INM-CM4-8	r1i1p1f1	0.068	0.057	0.063	-15.632	10.321
INM-CM5-0	r1i1p1f1	0.087	0.077	0.079	-11.543	1.974
IPSL-CM5A2-INCA	r1i1p1f1	0.123	0.114	0.114	-7.165	-0.060
IPSL-CM6A-LR	r1i1p1f1	0.150	0.122	0.119	-18.672	-2.691
KIOST-ESM	r1i1p1f1	0.115	0.108	0.092	-6.742	-14.876
MIROC-ES2L	r1i1p1f2	0.159	0.155	0.156	-2.856	0.730
MIROC6	r1i1p1f1	0.167	0.164	0.163	-1.915	-0.269
MPI-ESM-1-2-HAM	r1i1p1f1	0.108	0.089	0.089	-17.801	0.455
MPI-ESM1-2-HR	r1i1p1f1	0.079	0.076	0.078	-3.200	2.185
MPI-ESM1-2-LR	r1i1p1f1	0.129	0.119	0.118	-7.906	-1.435
MRI-ESM2-0	r10i1p1f1	0.118	0.116	0.099	-1.781	-14.644
MRI-ESM2-0	r13i1p1f1	0.101	0.099	0.088	-2.800	-10.852
MRI-ESM2-0	r1i1p1f1	0.103	0.102	0.085	-0.614	-16.470
MRI-ESM2-0	r1i2p1f1	0.111	0.109	0.083	-2.222	-23.718
MRI-ESM2-0	r4i1p1f1	0.104	0.101	0.097	-2.958	-4.137
MRI-ESM2-0	r7i1p1f1	0.111	0.101	0.094	-9.111	-7.172
NESM3	r1i1p1f1	0.104	0.088	0.088	-14.984	0.006
NorCPM1	r1i1p1f1	0.091	0.091	0.090	0.000	-0.935
NorESM2-LM	r1i1p1f1	0.175	0.175	0.162	0.000	-7.727
NorESM2-MM	r1i1p1f1	0.172	0.172	0.172	-0.000	-0.197
SAM0-UNICON	r1i1p1f1	0.127	0.127	0.111	0.000	-13.109
TaiESM1	r1i1p1f1	0.145	0.117	0.103	-19.762	-11.485
UKESM1-0-LL	r1i1p1f2	0.111	0.102	0.108	-8.126	5.738

Table S8. RMSE values for CMIP6 abrupt-2xCO2 experiments

model	member	two-exp	three-exp	two-exp + osc	% change1	% change2
CESM2	r1i1p1f1	0.096	0.096	0.096	0.000	-0.029
CNRM-CM6-1	r1i1p1f2	0.106	0.106	0.104	-0.046	-1.814
CanESM5	r1i1p2f1	0.117	0.115	0.113	-1.786	-1.919
GISS-E2-1-G	r102i1p1f1	0.144	0.144	0.143	0.000	-0.376
GISS-E2-1-G	r1i1p1f1	0.140	0.140	0.136	0.000	-3.105
GISS-E2-1-G	r1i1p3f1	0.164	0.158	0.153	-3.483	-3.061
GISS-E2-1-G	r1i1p5f1	0.180	0.180	0.179	-0.167	-0.606
GISS-E2-1-H	r1i1p1f1	0.121	0.120	0.119	-0.310	-0.914
GISS-E2-1-H	r1i1p5f1	0.143	0.139	0.139	-2.329	0.022
GISS-E2-2-G	r1i1p1f1	0.116	0.116	0.112	-0.219	-3.268
GISS-E2-2-H	r1i1p1f1	0.085	0.081	0.080	-4.737	-1.617
HadGEM3-GC31-LL	r1i1p1f3	0.094	0.094	0.094	-0.000	-0.095
IPSL-CM6A-LR	r1i1p1f1	0.132	0.127	0.132	-3.902	3.989
MIROC6	r1i1p1f1	0.158	0.158	0.158	-0.049	-0.151
MRI-ESM2-0	r1i1p1f1	0.105	0.105	0.103	0.000	-1.220
TaiESM1	r1i1p1f1	0.111	0.111	0.097	-0.000	-12.556

Table S9. RMSE values for CMIP6 abrupt-0p5xCO2 experiments

model	member	two-exp	three-exp	two-exp + osc	% change1	% change2
CESM2	r1i1p1f1	0.108	0.107	0.107	-1.232	-0.015
CNRM-CM6-1	r1i1p1f2	0.099	0.098	0.092	-1.013	-6.314
CanESM5	r1i1p2f1	0.104	0.104	0.099	-0.085	-4.829
GISS-E2-1-G	r1i1p1f1	0.120	0.119	0.119	-0.775	-0.067
HadGEM3-GC31-LL	r1i1p1f3	0.174	0.166	0.103	-4.880	-37.868
IPSL-CM6A-LR	r1i1p1f1	0.137	0.119	0.109	-13.440	-7.981
MIROC6	r1i1p1f1	0.074	0.074	0.070	-0.012	-4.546
MRI-ESM2-0	r1i1p1f1	0.100	0.100	0.098	-0.000	-1.767
TaiESM1	r1i1p1f1	0.100	0.094	0.098	-5.397	3.457

Table S10. RMSE values for LongRunMIP experiments

model	exp	two-exp	three-exp	two-exp + osc	% change1	% change2
MPIESM12	abrupt2x	0.124	0.119	0.119	-4.066	0.012
MPIESM12	abrupt4x	0.143	0.132	0.132	-8.095	0.026
MPIESM12	abrupt8x	0.146	0.114	0.114	-22.206	0.188
MPIESM12	abrupt16x	0.171	0.097	0.123	-43.441	27.638
HadCM3L	abrupt2x	0.179	0.175	0.174	-2.113	-0.403
HadCM3L	abrupt4x	0.125	0.117	0.118	-6.782	0.811
HadCM3L	abrupt6x	0.123	0.117	0.116	-5.587	-0.104
HadCM3L	abrupt8x	0.128	0.124	0.125	-3.127	1.440
FAMOUS	abrupt2x	0.180	0.177	0.177	-1.652	-0.171
FAMOUS	abrupt4x	0.215	0.142	0.143	-33.919	0.778
CNRMCM61	abrupt2x	0.111	0.107	0.106	-3.359	-1.105
CNRMCM61	abrupt4x	0.117	0.100	0.100	-14.394	0.002
CESM104	abrupt2x	0.153	0.145	0.134	-4.755	-7.499
CESM104	abrupt4x	0.168	0.133	0.132	-20.924	-0.396
CESM104	abrupt8x	0.222	0.168	0.156	-24.219	-7.707
CCSM3	abrupt2x	0.092	0.091	0.091	-1.229	-0.452
CCSM3	abrupt4x	0.102	0.096	0.094	-5.082	-2.096
CCSM3	abrupt8x	0.111	0.086	0.086	-22.644	0.028
IPSLCM5A	abrupt4x	0.132	0.107	0.107	-18.925	0.007
HadGEM2	abrupt4x	0.133	0.104	0.104	-21.529	0.357
GISSE2R	abrupt4x	0.093	0.080	0.079	-13.923	-0.800
ECHAM5MPIOM	abrupt4x	0.195	0.180	0.178	-7.719	-1.045