Decomposing the Effective Radiative Forcing of anthropogenic aerosols based on CMIP6 Earth System Models

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Table S1. AOD differences for the piClim experiments (piClim-aer, piClim-SO₂, piClim-OC and piClim-BC), and the transient (histSST) experiment averaged over the 1995-2014 period. Global mean ΔAOD values are presented for each ESM, along with the multi-model ensemble mean and the inter-model variability (one standard deviation; SD).

Model	piClim-aer	piClim-SO₂	piClim-OC	piClim-BC	histSST (1995-2014)			
	od550aer	od550aer	od550aer	od550aer	od550aer	od550so4	od550oa	od550bc
CNRM-ESM2-1	0.0161	0.0119	0.0028	0.0017	0.0166	0.0127	0.0027	0.0013
EC-Earth3-AerChem	0.0369	-	-	-	0.0380	0.0225	0.0129	0.0016
GFDL-ESM4	0.0410	0.0173	0.0054	0.0067	0.0411	0.0301	0.0049	0.0027
MPI-ESM-1-2-HAM	0.0257	0.0186	0.0060	0.0043	0.0255	-	-	-
MRI-ESM2-0	0.0346	0.0272	0.0037	0.0057	-	-	-	-
NorESM2-LM	0.0218	0.0139	0.0050	0.0029	0.0239	0.0110	0.0089	0.0016
UKESM1-0-LL	0.0329	0.0260	0.0044	0.0029	0.0363	-	-	-
ENSEMBLE (Mean)	0.0299	0.0191	0.0046	0.0040	0.0302	0.0191	0.0073	0.0018
ENSEMBLE (SD)	0.0082	0.0057	0.0011	0.0018	0.0088	0.0077	0.0039	0.0005

Table S2. Global mean SW ERF values for the piClim experiments (piClim-aer, piClim-SO$_2$, piClim-OC and piClim-BC). ERF$_{TOTAL}$, ERF$_{ARI}$, ERF$_{ACI}$ and ERF$_{ALB}$ are presented for each ESM, along with the multi-model ensemble mean and the inter-model variability (one standard deviation; SD).

Model	piClim-aer				piClim-SO$_2$				piClim-OC				piClim-BC			
	ERF	ARI	ACI	ALB	ERF	ARI	ACI	ALB	ERF	ARI	ACI	ALB	ERF	ARI	ACI	ALB
CNRM-ESM2-1	-0.82	-0.22	-0.59	-0.01	-0.84	-0.29	-0.55	0.01	-0.23	-0.07	-0.18	0.02	0.15	0.13	-0.01	0.02
EC-Earth3-AerChem	-1.36	0.08	-1.36	-0.08	-	-	-	-	-	-	-	-	-	-	-	-
GFDL-ESM4	-0.59	0.24	-0.77	-0.06	-0.76	-0.22	-0.51	-0.02	-0.21	-0.09	-0.13	0.01	0.62	0.51	0.08	0.03
MPI-ESM-1-2-HAM	-1.53	0.19	-1.67	-0.05	-1.35	-0.20	-1.10	-0.05	-0.85	-0.04	-0.80	0.00	0.04	0.71	-0.71	0.04
MRI-ESM2-0	-2.76	-0.32	-2.49	0.05	-1.92	-0.49	-1.38	-0.05	-0.52	-0.07	-0.43	-0.02	-1.22	0.26	-1.63	0.15
NorESM2-LM	-1.63	0.00	-1.55	-0.08	-1.80	-0.22	-1.40	-0.18	-0.35	-0.08	-0.27	0.00	0.46	0.32	0.02	0.12
UKESM1-0-LL	-1.26	-0.20	-1.00	-0.06	-1.68	-0.53	-1.08	-0.07	-0.25	-0.16	-0.07	-0.03	0.51	0.36	0.15	0.00
ENSEMBLE (Mean)	-1.42	-0.03	-1.35	-0.04	-1.39	-0.33	-1.01	-0.06	-0.40	-0.09	-0.31	0.00	0.09	0.38	-0.35	0.06
ENSEMBLE (SD)	0.65	0.20	0.59	0.04	0.45	0.13	0.36	0.06	0.22	0.04	0.25	0.01	0.62	0.19	0.64	0.06

Table S3. As in Table S1, but for the global mean LW ERF values.

Model	piClim-aer				piClim-SO$_2$				piClim-OC				piClim-BC			
	ERF	ARI	ACI	ALB	ERF	ARI	ACI	ALB	ERF	ARI	ACI	ALB	ERF	ARI	ACI	ALB
CNRM-ESM2-1	0.08	0.00	-0.02	0.09	0.10	0.00	0.02	0.07	0.06	0.00	0.04	0.03	-0.03	0.00	-0.02	-0.01
EC-Earth3-AerChem	0.01	0.03	-0.17	0.15	-	-	-	-	-	-	-	-	-	-	-	-
GFDL-ESM4	-0.11	0.02	-0.15	0.02	0.08	0.01	0.00	0.08	0.00	0.00	-0.04	0.04	-0.27	0.01	-0.18	-0.11
MPI-ESM-1-2-HAM	0.27	-0.03	0.10	0.19	0.28	-0.04	0.14	0.19	0.06	0.02	0.02	0.02	-0.19	0.01	-0.16	-0.04
MRI-ESM2-0	1.52	0.00	1.49	0.03	0.52	0.00	0.42	0.09	0.18	0.00	0.21	-0.03	1.45	0.00	1.54	-0.08
NorESM2-LM	0.22	0.04	0.17	0.02	0.35	0.03	0.29	0.03	-0.02	0.00	0.00	-0.03	-0.22	0.00	-0.13	-0.10
UKESM1-0-LL	0.16	0.05	0.01	0.11	0.32	0.04	0.18	0.10	0.04	0.00	0.01	0.03	-0.15	0.01	-0.16	0.01
ENSEMBLE (Mean)	0.31	0.02	0.21	0.09	0.28	0.01	0.18	0.09	0.05	0.00	0.04	0.01	0.10	0.00	0.15	-0.06
ENSEMBLE (SD)	0.51	0.02	0.54	0.06	0.15	0.03	0.15	0.05	0.07	0.01	0.08	0.03	0.61	0.01	0.62	0.04

Table S4. Global mean SW and LW ERF values for the transient (histSST) experiment averaged over the 1995-2014 period. ERF_{TOTAL}, ERF_{ARI}, ERF_{ACI} and ERF_{ALB} are presented for each ESM, along with the multi-model ensemble mean and the inter-model variability (one standard deviation; SD).

Model	SW				LW			
	ERF	ARI	ACI	ALB	ERF	ARI	ACI	ALB
CNRM-ESM2-1	-0.85	-0.26	-0.53	-0.05	-0.01	0.00	-0.06	0.04
EC-Earth3-AerChem	-1.85	-0.01	-1.78	-0.06	0.15	0.03	-0.08	0.20
GFDL-ESM4	-0.80	0.05	-0.79	-0.06	0.01	0.02	-0.08	0.08
MPI-ESM-1-2-HAM	-1.60	0.10	-1.64	-0.05	0.27	-0.02	0.13	0.16
NorESM2-LM	-2.03	-0.09	-1.76	-0.17	0.28	0.04	0.17	0.08
UKESM1-0-LL	-1.52	-0.31	-1.12	-0.09	0.24	0.04	0.03	0.17
ENSEMBLE (Mean)	-1.43	-0.10	-1.25	-0.08	0.15	0.02	0.01	0.12
ENSEMBLE (SD)	0.47	0.15	0.49	0.04	0.12	0.02	0.10	0.06

Table S5. Mean AOD changes for histSST experiment averaged over 1965-1984 and 1995-2014. Variables od550aer, od550so4, od550oa, and od550bc denote the differences in all-aerosol, sulphate, organic aerosol, and black carbon AOD, respectively. Global and regional AOD changes for the five NH regions of interest (see main text) are presented for each model and their ensemble.

Model	Region	1965-1984				1995-2014			
		od550aer	od550so4	od550oa	od550bc	od550aer	od550so4	od550oa	od550bc
CNRM-ESM2-1	ENA	0.0916	0.0935	-0.0029	0.0014	0.0520	0.0543	-0.0042	0.0009
	WCE	0.1079	0.1014	0.0028	0.0042	0.0369	0.0351	-0.0009	0.0018
	MED	0.0580	0.0526	0.0019	0.0018	0.0369	0.0329	0.0025	0.0022
	EAS	0.0639	0.0511	0.0072	0.0053	0.1547	0.1212	0.0211	0.0127
	SAS	0.0415	0.0278	0.0085	0.0046	0.1190	0.0896	0.0219	0.0108
	GLOBAL	0.0132	0.0117	0.0011	0.0007	0.0166	0.0127	0.0027	0.0013
EC-Earth3-AerChem	ENA	0.1370	0.1084	0.0187	0.0022	0.0905	0.0644	0.0150	0.0018
	WCE	0.1665	0.1218	0.0176	0.0045	0.0749	0.0482	0.0091	0.0022
	MED	0.0975	0.0754	0.0099	0.0022	0.0607	0.0455	0.0109	0.0024
	EAS	0.1216	0.0604	0.0290	0.0051	0.2866	0.1579	0.0724	0.0133
	SAS	0.0746	0.0399	0.0267	0.0037	0.2098	0.1198	0.0714	0.0101
	GLOBAL	0.0290	0.0192	0.0068	0.0009	0.0380	0.0225	0.0129	0.0016
GFDL-ESM4	ENA	0.1134	0.1103	-0.0036	0.0030	0.0855	0.0753	-0.0044	0.0026
	WCE	0.3129	0.2967	0.0041	0.0077	0.1157	0.0964	-0.0009	0.0038
	MED	0.0916	0.0906	0.0025	0.0033	0.0648	0.0579	0.0036	0.0038
	EAS	0.1323	0.1022	0.0103	0.0090	0.3343	0.2543	0.0305	0.0220
	SAS	0.0596	0.0423	0.0119	0.0057	0.2433	0.1439	0.0318	0.0135
	GLOBAL	0.0290	0.0269	0.0019	0.0015	0.0411	0.0301	0.0049	0.0027
MPI-ESM-1-2-HAM	ENA	0.2016				0.0908			
	WCE	0.4352				0.1107			
	MED	0.1309				0.0768			
	EAS	0.1502		-		0.3783		-	
	SAS	0.0416				0.1304			
	GLOBAL	0.0244				0.0255			
NorESM2-LM	ENA	0.0707	0.0545	0.0115	0.0021	0.0380	0.0298	0.0052	0.0017
	WCE	0.1031	0.0714	0.0194	0.0041	0.0377	0.0240	0.0072	0.0021
	MED	0.0688	0.0416	0.0083	0.0023	0.0404	0.0239	0.0069	0.0028
	EAS	0.0600	0.0303	0.0209	0.0054	0.1593	0.0786	0.0638	0.0133
	SAS	0.0383	0.0216	0.0147	0.0039	0.1169	0.0618	0.0469	0.0098
	GLOBAL	0.0166	0.0097	0.0045	0.0009	0.0239	0.0110	0.0089	0.0016
UKESM1-0-LL	ENA	0.1422				0.0805			
	WCE	0.2273				0.0751			
	MED	0.1198				0.0786			
	EAS	0.0925		-		0.2319		-	
	SAS	0.0497				0.1972			
	GLOBAL	0.0300				0.0363			
ENSEMBLE	ENA	0.1261	0.0917	0.0059	0.0022	0.0729	0.0560	0.0029	0.0017
	WCE	0.2255	0.1478	0.0110	0.0051	0.0752	0.0509	0.0036	0.0025
	MED	0.0944	0.0650	0.0057	0.0024	0.0597	0.0400	0.0060	0.0028
	EAS	0.1034	0.0610	0.0169	0.0062	0.2575	0.1530	0.0469	0.0153
	SAS	0.0509	0.0329	0.0154	0.0045	0.1694	0.1038	0.0430	0.0111
	GLOBAL	0.0237	0.0169	0.0036	0.0010	0.0302	0.0191	0.0073	0.0018

Table S6. Global mean total ERF values for the transient (histSST) experiment averaged over the 2005-2014 period and the year 2014. ERF$_{TOTAL}$, ERF$_{ARI}$, ERF$_{ACI}$ and ERF$_{ALB}$ are presented for each ESM, along with the multi-model ensemble mean and the inter-model variability (one standard deviation; SD).

Model	2005-2014				2014 (Jan-Dec)			
	ERF	ARI	ACI	ALB	ERF	ARI	ACI	ALB
CNRM-ESM2-1	-0.92	-0.25	-0.59	-0.07	-1.12	-0.26	-0.72	-0.15
EC-Earth3-AerChem	-1.52	0.04	-1.81	0.25	-1.63	0.08	-1.99	0.28
GFDL-ESM4	-0.69	0.10	-0.82	0.03	-0.47	0.11	-0.78	0.20
MPI-ESM-1-2-HAM	-1.29	0.11	-1.57	0.16	0.00	0.00	0.00	0.00
NorESM2-LM	-1.80	-0.03	-1.67	-0.10	-1.53	0.03	-1.49	-0.07
UKESM1-0-LL	-1.21	-0.25	-1.08	0.11	-0.77	-0.22	-1.05	0.51
ENSEMBLE (Mean)	-1.23	-0.06	-1.22	0.06	-1.10	-0.05	-1.21	0.16
ENSEMBLE (SD)	0.36	0.15	0.45	0.12	0.44	0.16	0.48	0.24

All Aerosols SW ERF (ENSEMBLE)
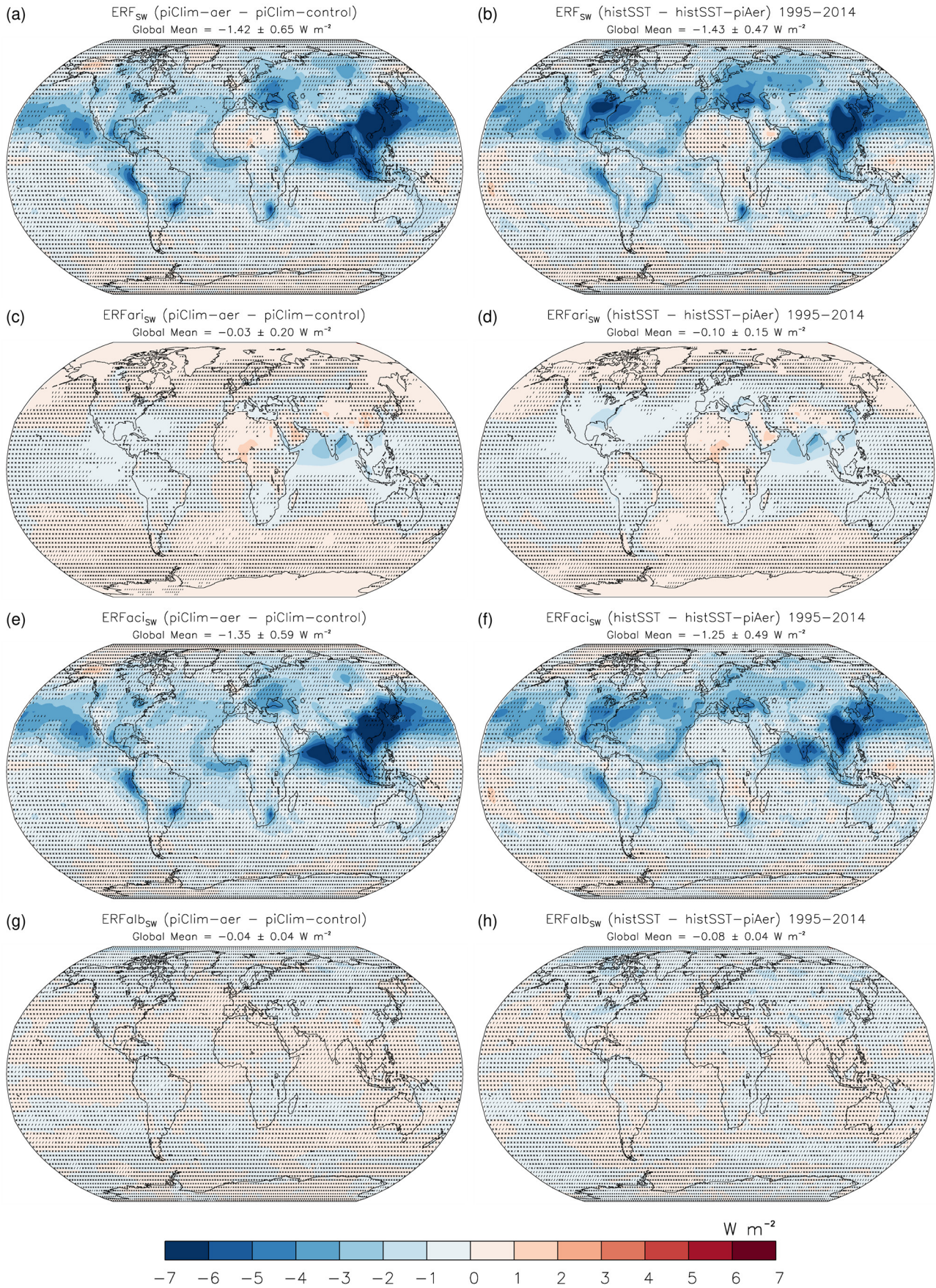
Figure S1. The SW ERF due to all anthropogenic aerosols relative to the pre-industrial era. The TOA spatial distribution is presented for the multi-model ensembles of piClim (left column) and histSST (averaged over 1995-2014; right column) experiments, respectively. The global mean SW ERF (1st row), ERF_{ARI} (2nd row), ERF_{ACI} (3rd row), and ERF_{ALB} (4th row) are shown along with the inter-model variability (one standard deviation). Colored areas devoid of markings indicate robust changes, while hatched (/) and cross-hatched (X) areas indicate non-robust changes and conflicting signals, respectively.

All Aerosols LW ERF (ENSEMBLE)
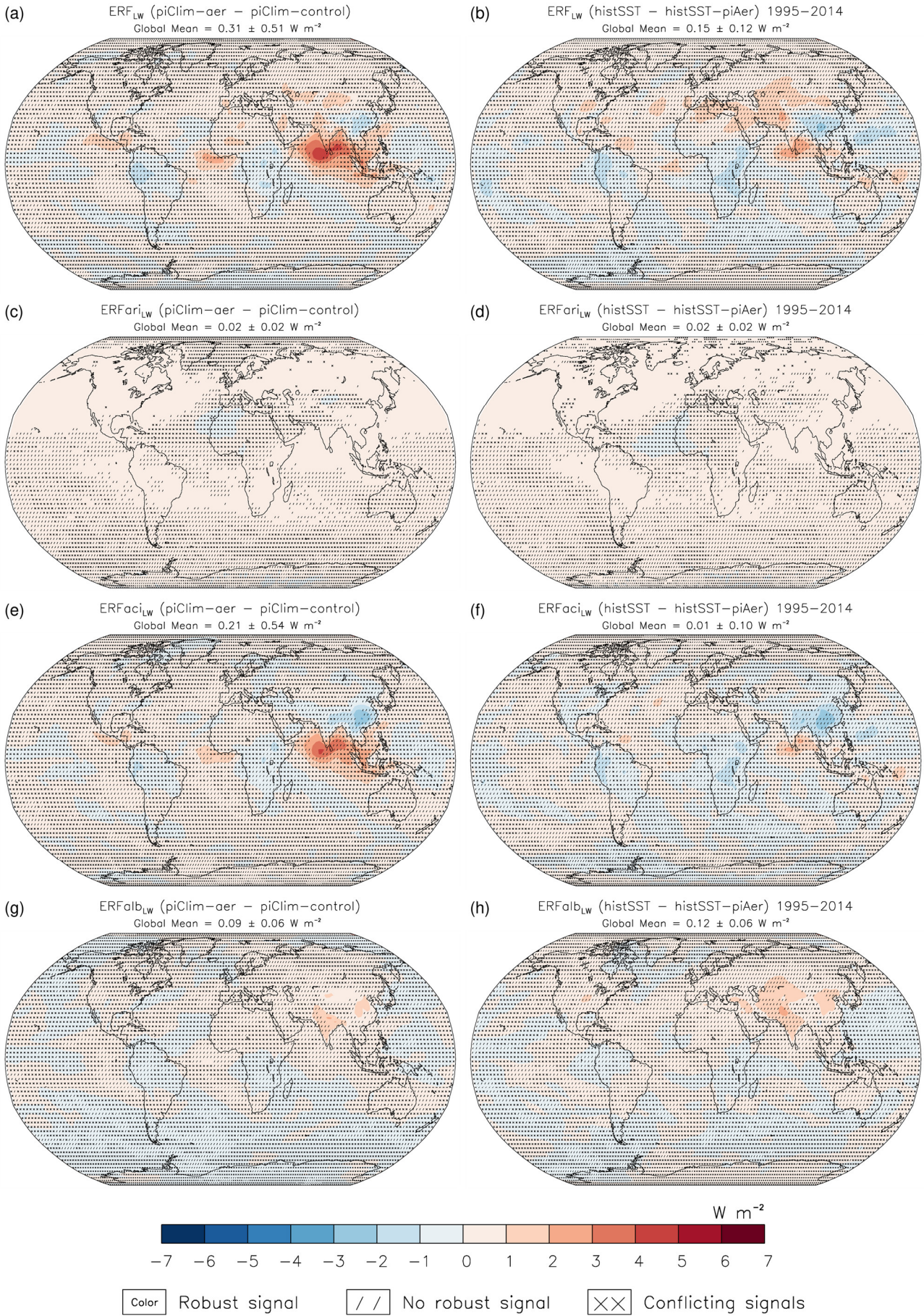
Figure S2. As in Figure S1, but for the LW.

All Aerosols Total ERF (piClim-aer - piClim-control)
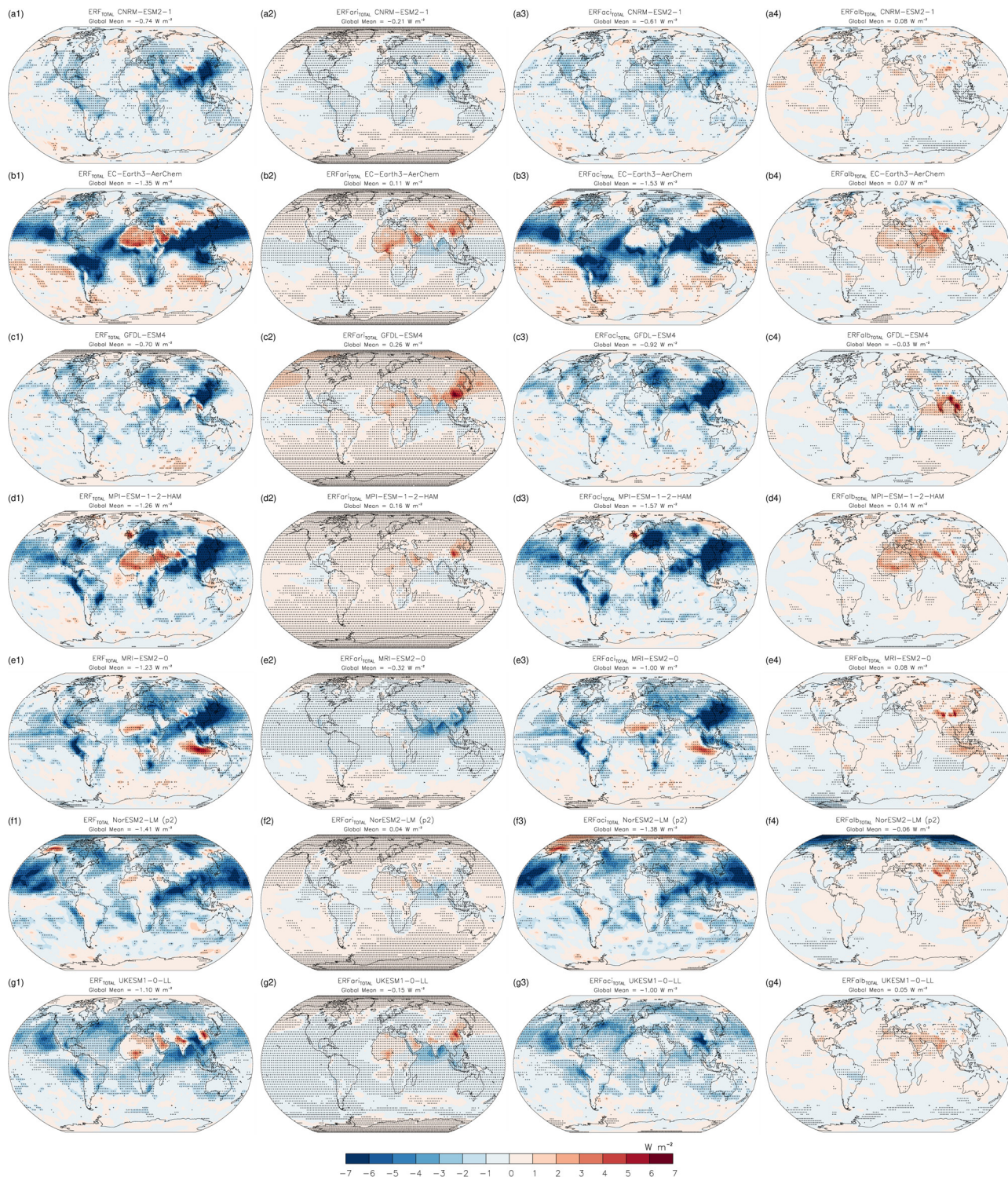
Figure S3. The total (SW+LW) ERF due to all anthropogenic aerosols relative to the pre-industrial era for each climate model. The TOA spatial distribution is presented only for the piClim-aer experiment. The global mean total ERF (1st column), ERF$_{ARI}$ (2nd column), ERF$_{ACI}$ (3rd column), and ERF$_{ALB}$ (4th column) are shown. Black crosses indicate statistically significant results.

All Aerosols Total ERF (histSST - histSST-piAer) 1995-2014
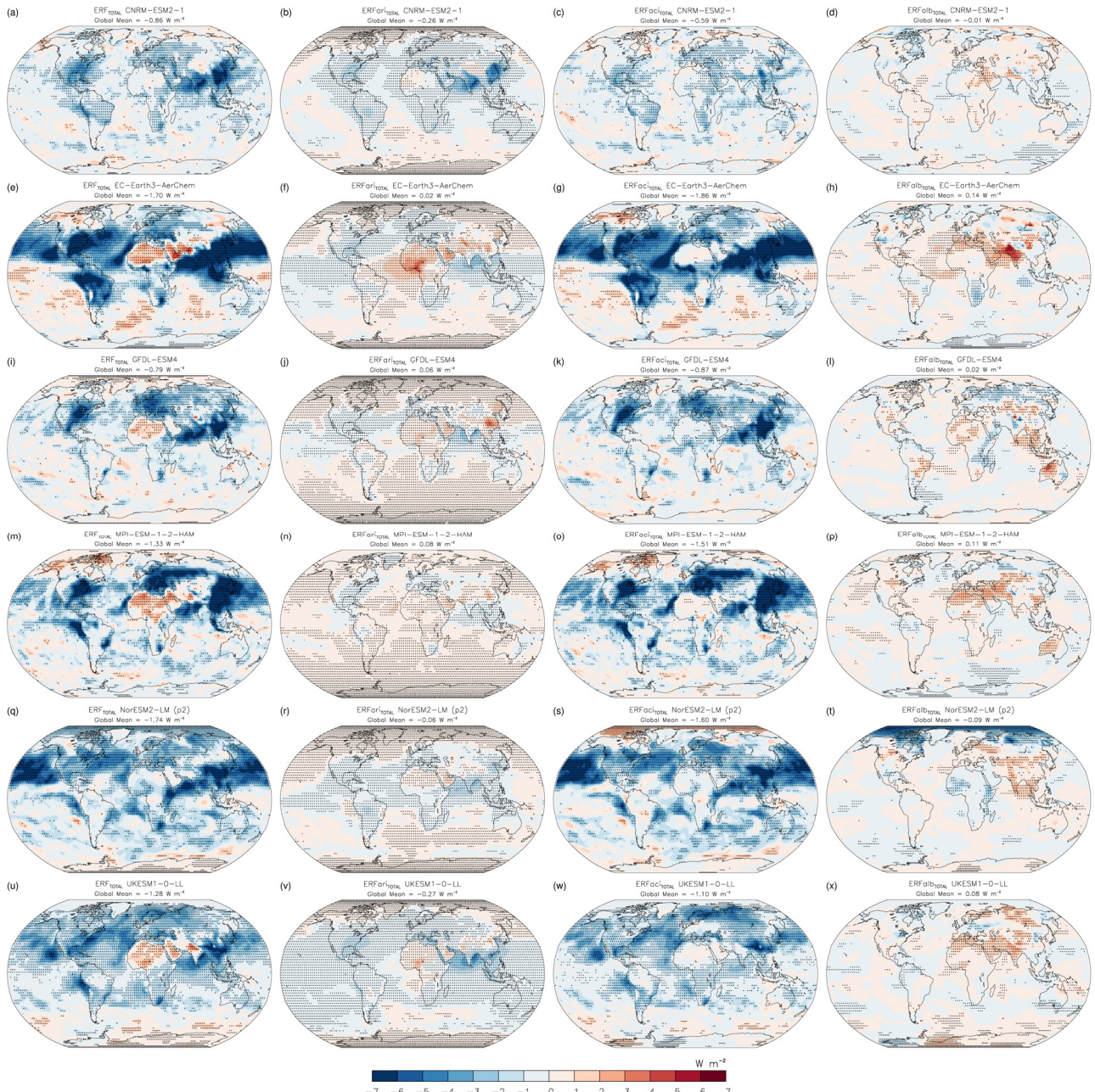
Figure S4. As in Fig. S3, but for the histSST experiment averaged over the 1995-2014 period.

Figure S5. The SW ERF due to different anthropogenic aerosol subtype relative to the pre-industrial era. The TOA spatial distribution is presented for the multi-model ensembles piClim-SO$_2$ (left column), piClim-OC (middle column), and piClim-BC (right column) experiments, respectively. The global mean SW ERF (1st row), ERF$_{ARI}$ (2nd row), ERF$_{ACI}$ (3rd row), and ERF$_{ALB}$ (4th row) are shown along with the inter-model variability (one standard deviation). Colored areas devoid of markings indicate robust changes, while hatched (/) and cross-hatched (X) areas indicate non-robust changes and conflicting signals, respectively.

Anthropogenic Aerosols LW ERF (ENSEMBLE)
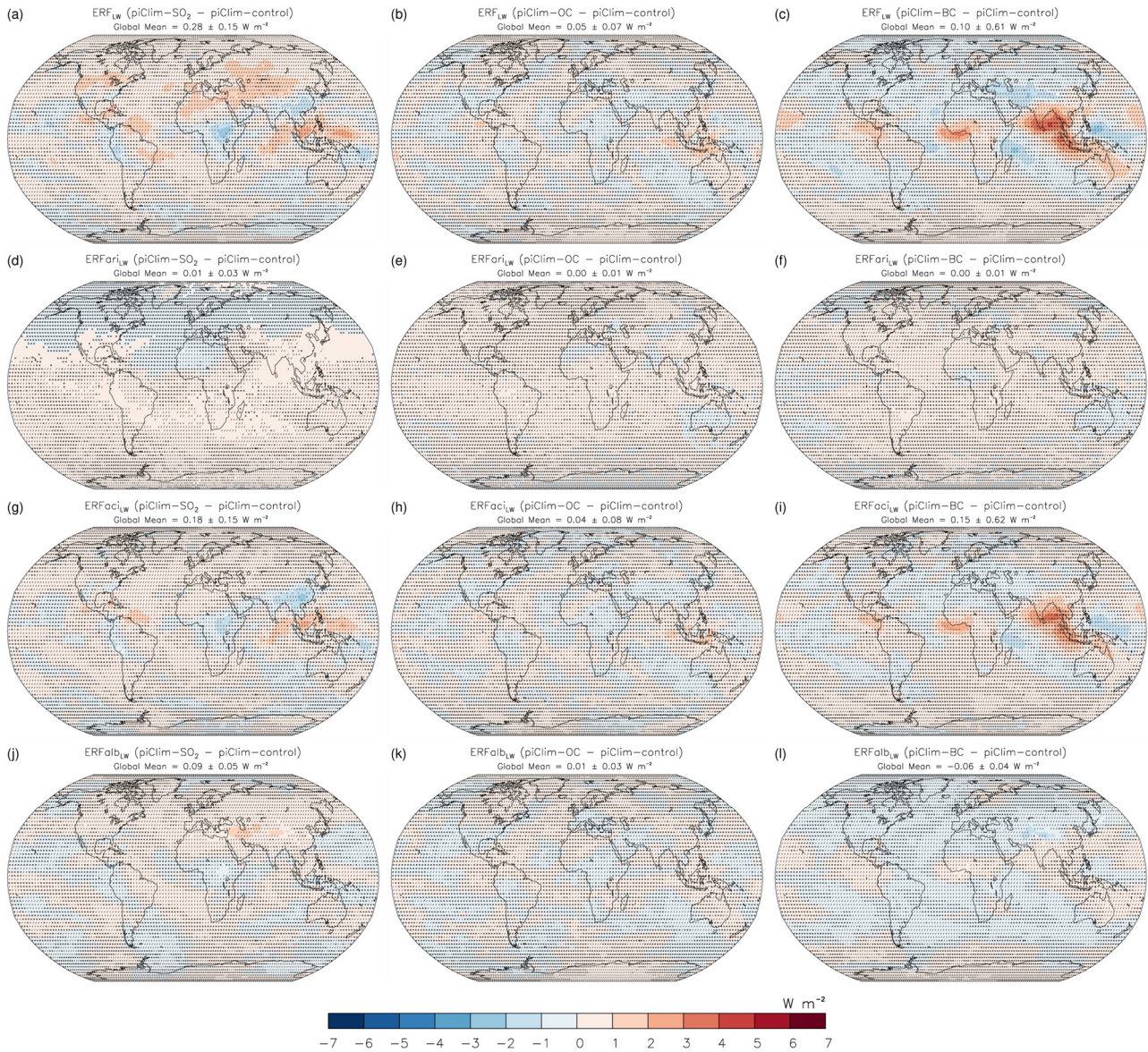
Figure S6. As in Figure S5, but for the LW ERFs.

Sulphates Total ERF (piClim-SO2 - piClim-control)
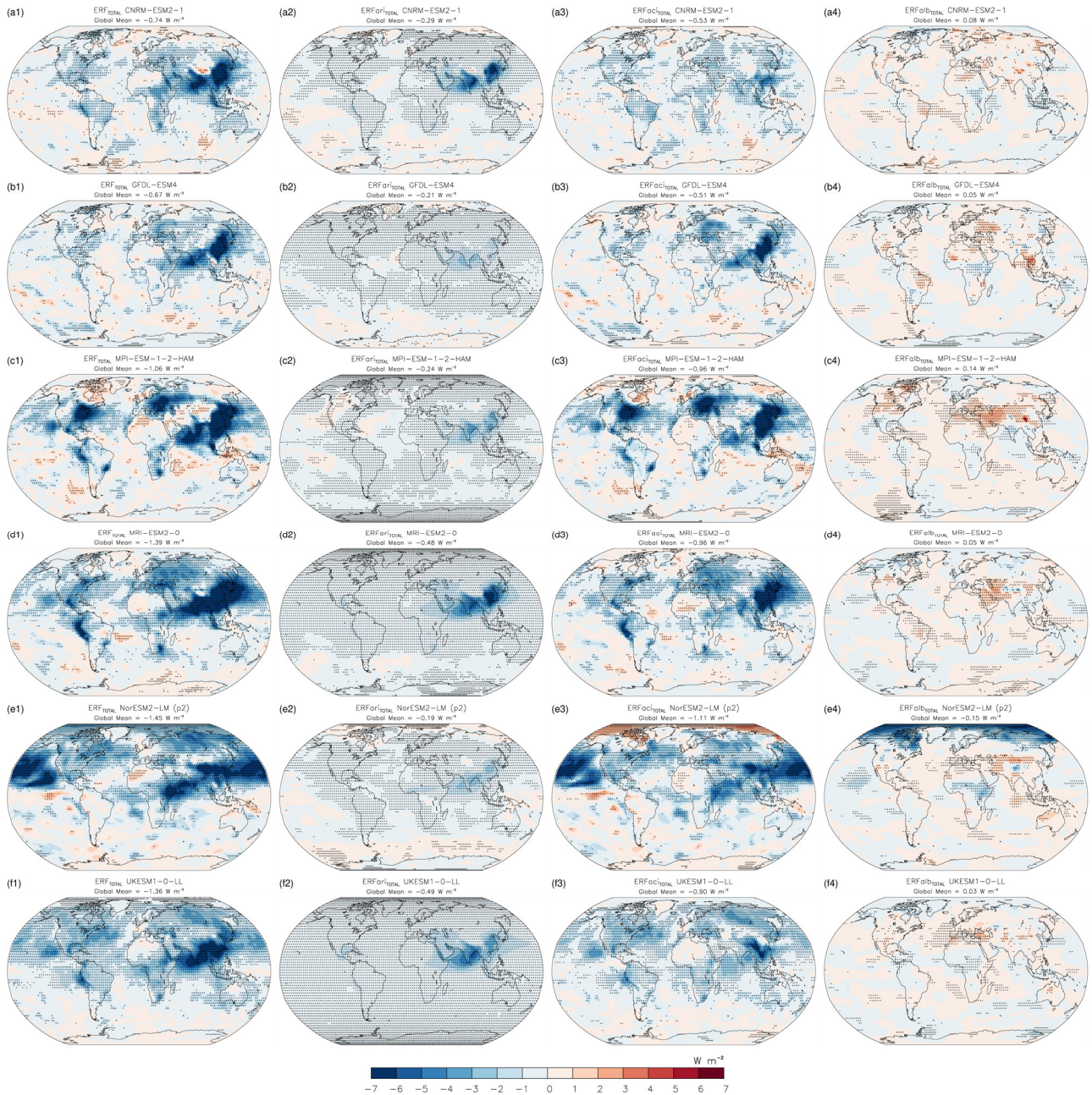
Figure S7. The total (SW+LW) ERF due to sulphate aerosols relative to the pre-industrial era for each climate model. The TOA spatial distribution is presented only for the piClim-SO$_2$ experiment. The global mean total ERF (1st column), ERF$_{ARI}$ (2nd column), ERF$_{ACI}$ (3rd column), and ERF$_{ALB}$ (4th column) are shown. Black crosses indicate statistically significant results.

Organic Carbon Total ERF (piClim-OC - piClim-control)
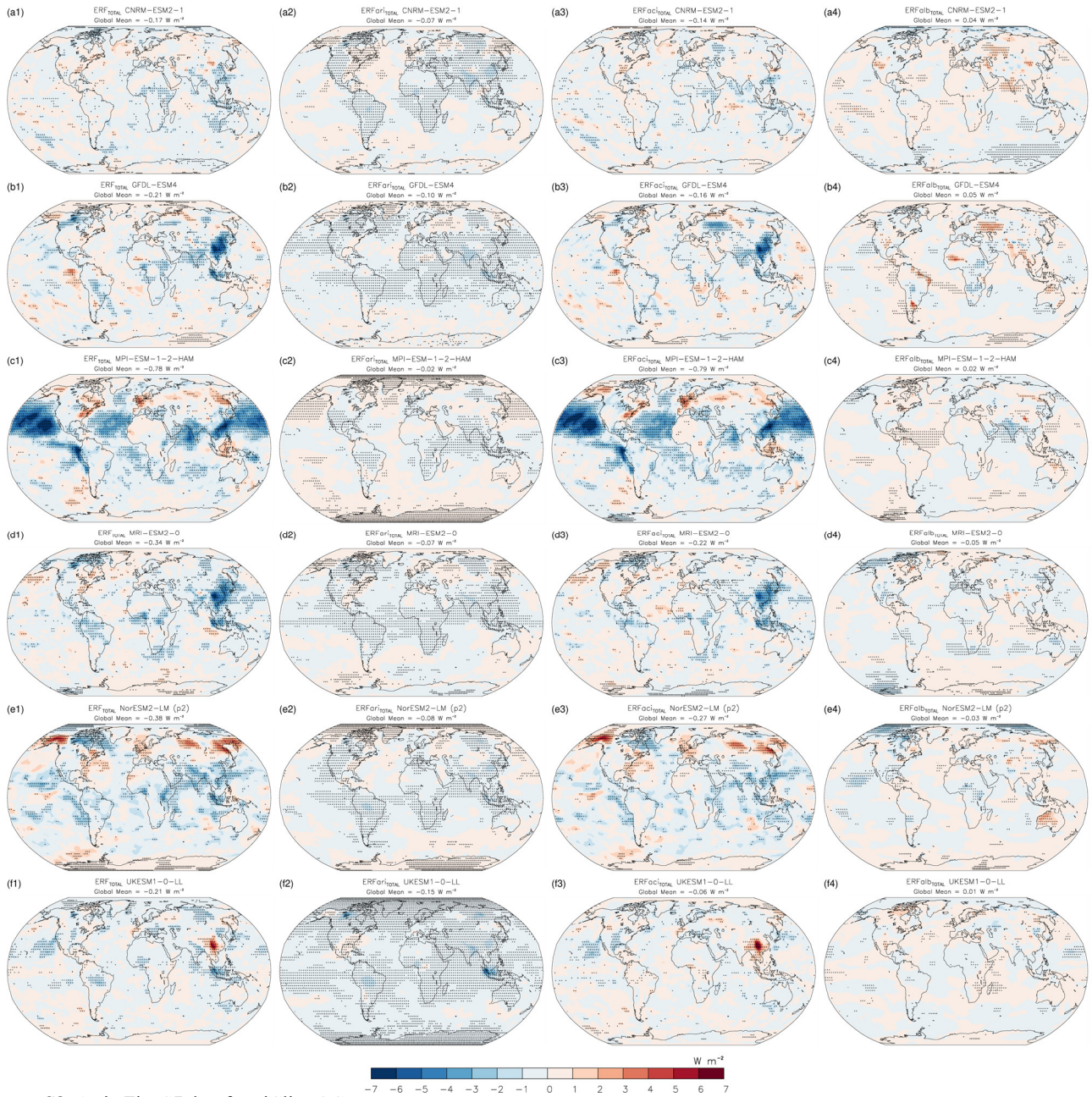
Figure S8. As in Fig. S7, but for piClim-OC.

Black Carbon Total ERF (piClim-BC - piClim-control)
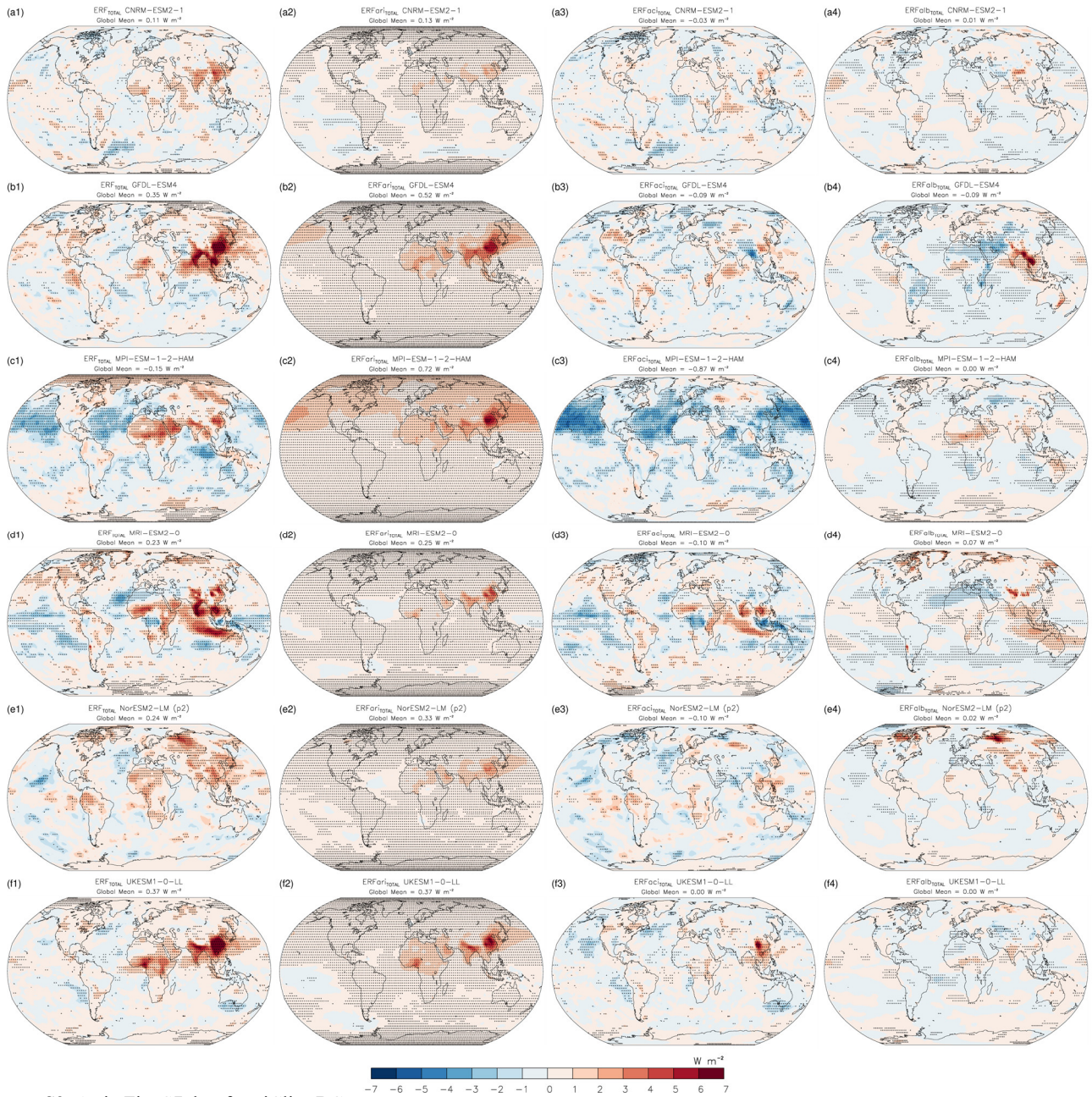
Figure S9. As in Fig. S7, but for piClim-BC.

ENSEMBLE (histSST - histSST-piAer)
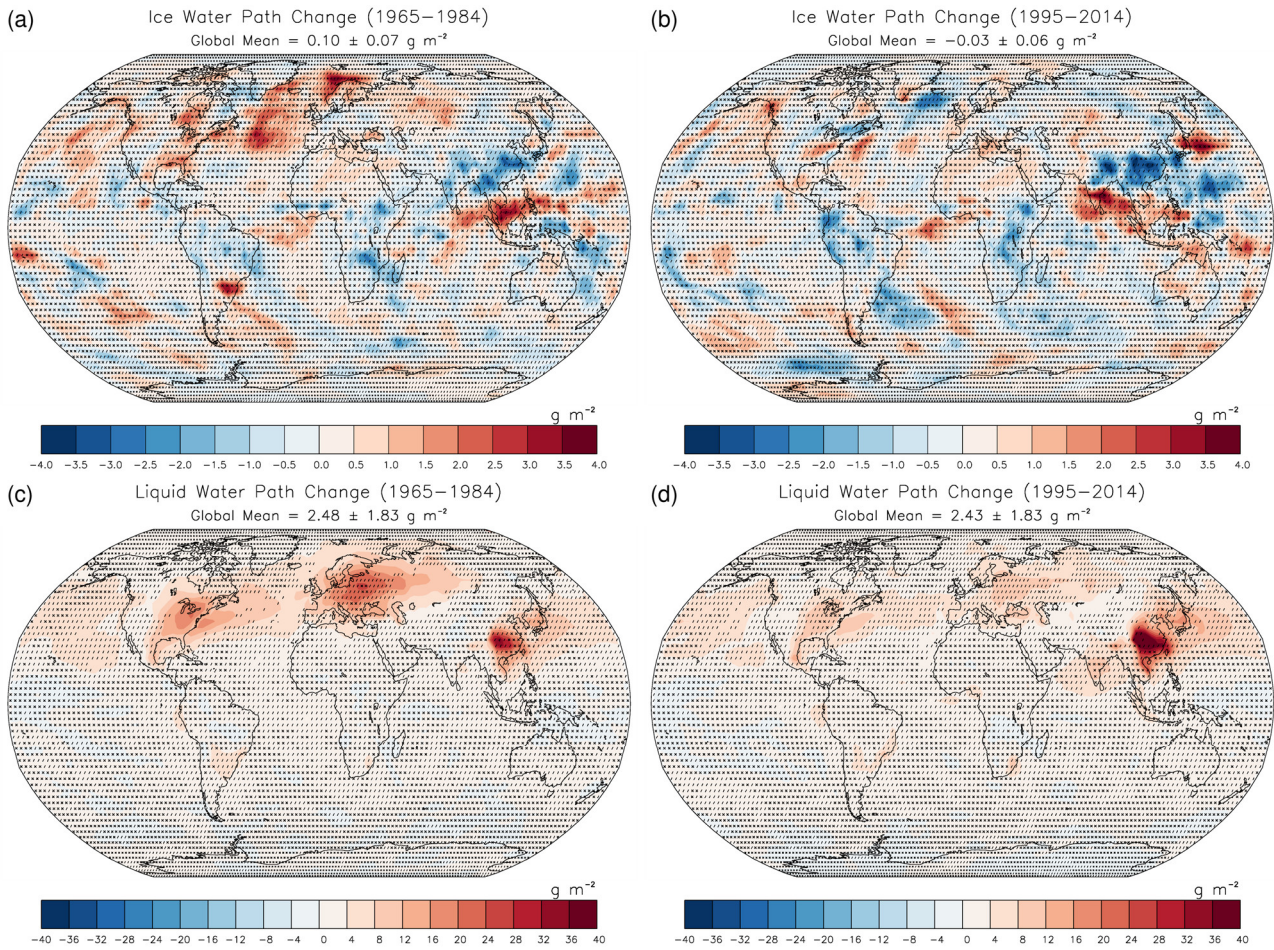
Figure S10. Spatial distribution of ice water path changes (top row) and liquid water path changes (bottom row) averaged over 1965-1984 (left column) and 1995-2014 (right column) using the histSST experiment. Global means are shown along with the inter-model variability (one standard deviation). Colored areas devoid of markings indicate robust changes, while hatched (/) and cross-hatched (X) areas indicate non-robust changes and conflicting signals, respectively.