



Supplement of

Impact of increased resolution on long-standing biases in HighResMIP-PRIMAVERA climate models

Eduardo Moreno-Chamarro et al.

Correspondence to: Eduardo Moreno-Chamarro (eduardo.moreno@bsc.es)

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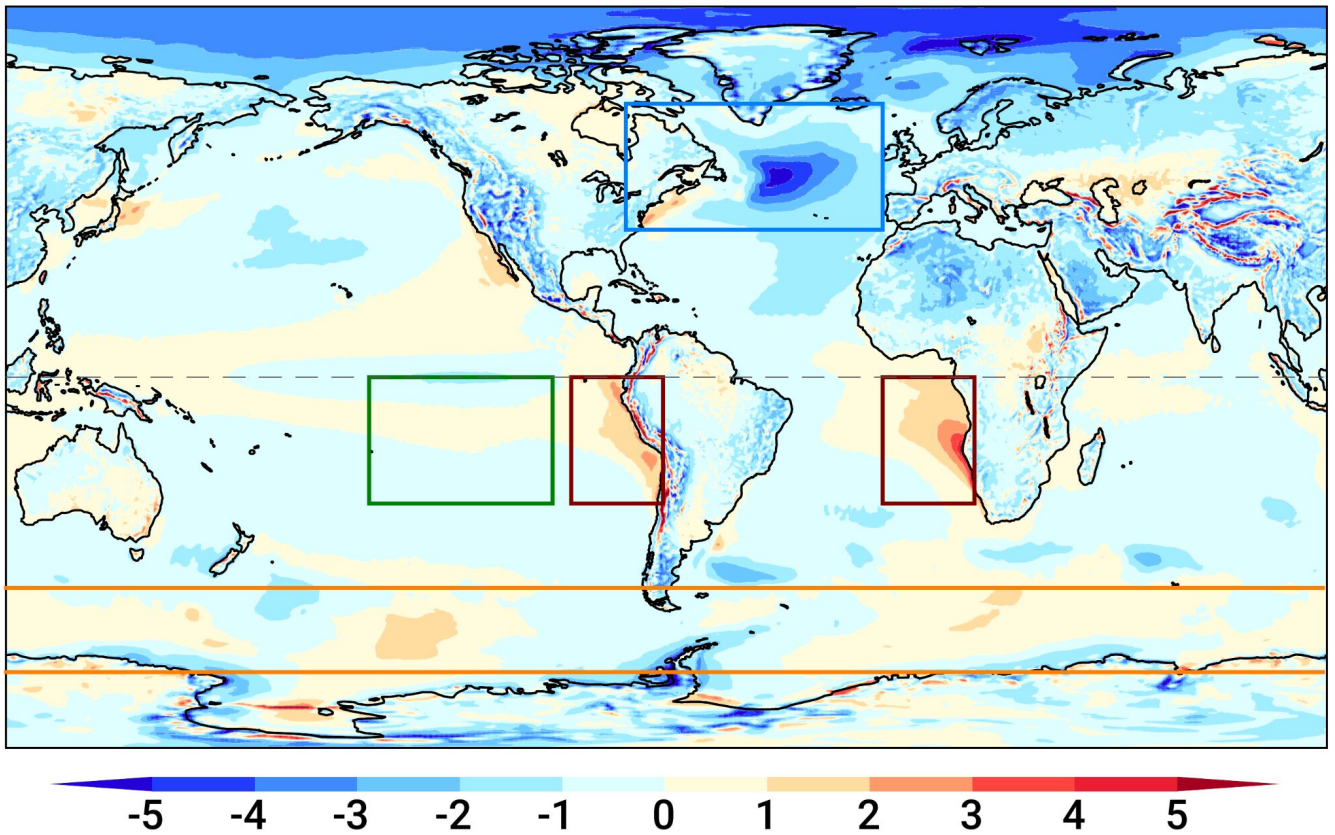


Figure S1. Areas where regional biases are calculated for biases in Tables S1–S4: upwelling regions over the SH Pacific and Atlantic (red boxes; 105–70° W for the Pacific and 30° W–15° E for the Atlantic, both between 0–30° S), Pacific ITCZ (green box; 100–150° W and 0–30° S; as in Tian and Dong, 2020), SO (orange box; 0–360° E and 50–70° S), and North Atlantic (blue box; 80–10° W and 35–65° N). Shading is for the SAT bias with respect to ERA5 of the ensemble mean of LR coupled models from Fig. 1b.

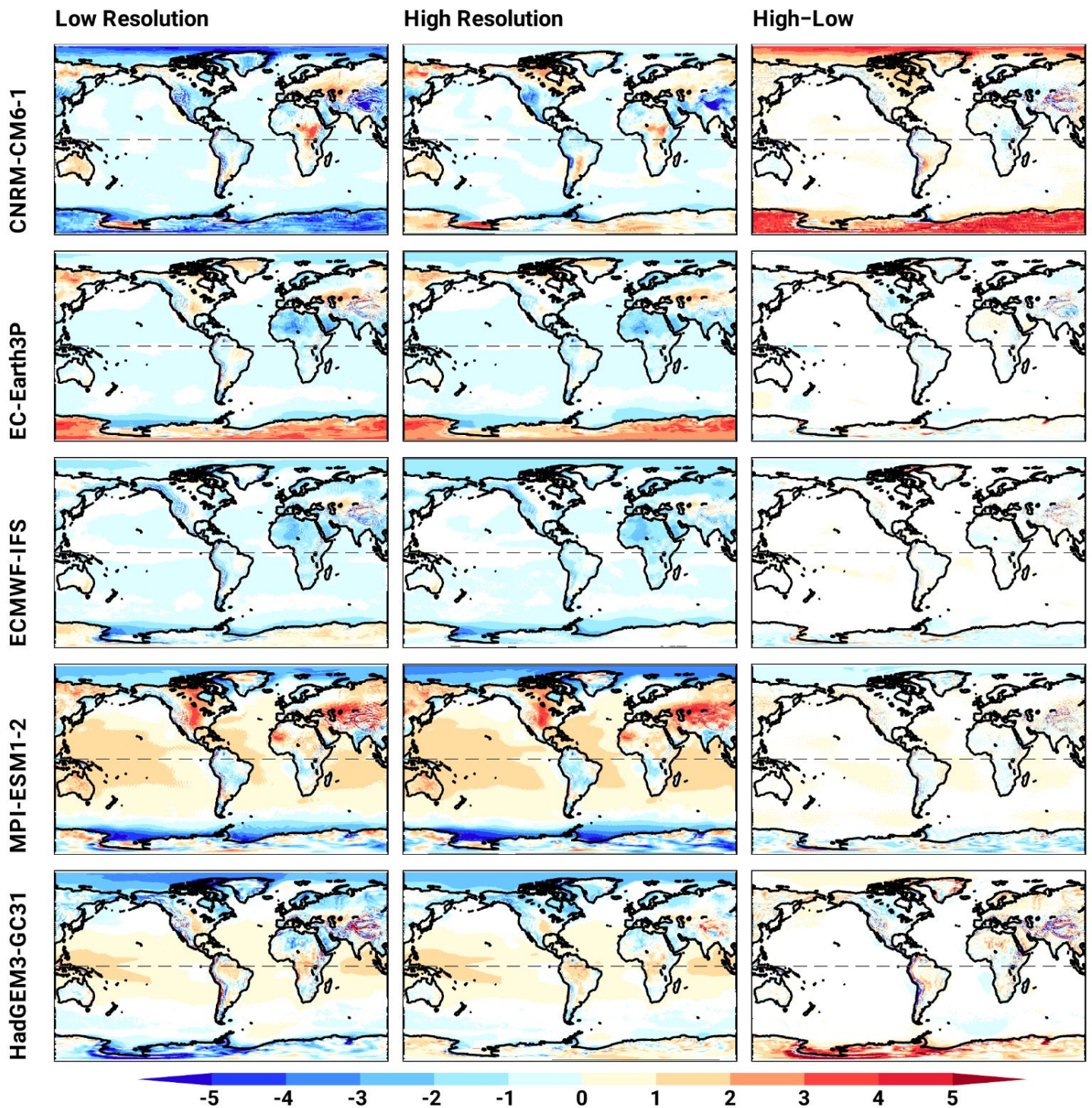


Figure S2. Mean bias in near-surface (2 m) air temperature (SAT; in °C) in each individual atmosphere-only simulation of the ensemble at low (*left*), high (*middle*) resolutions, and as the difference between the two (*right*). Biases are with respect to ERA5. Non-significant anomalies at the 5 % level are masked white. The Equator is a dashed line.

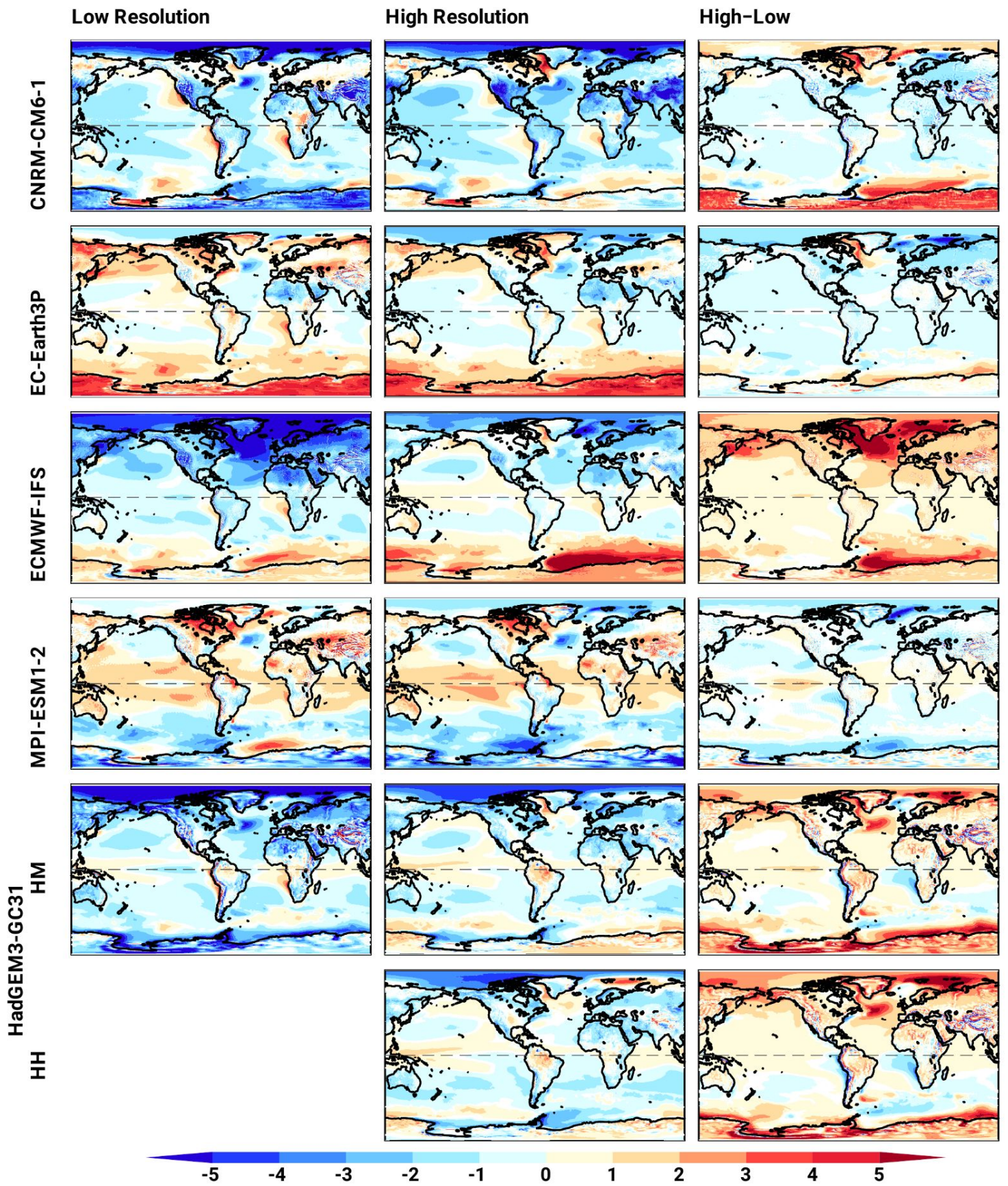


Figure S3. As in Fig. S2 but for the coupled simulations.

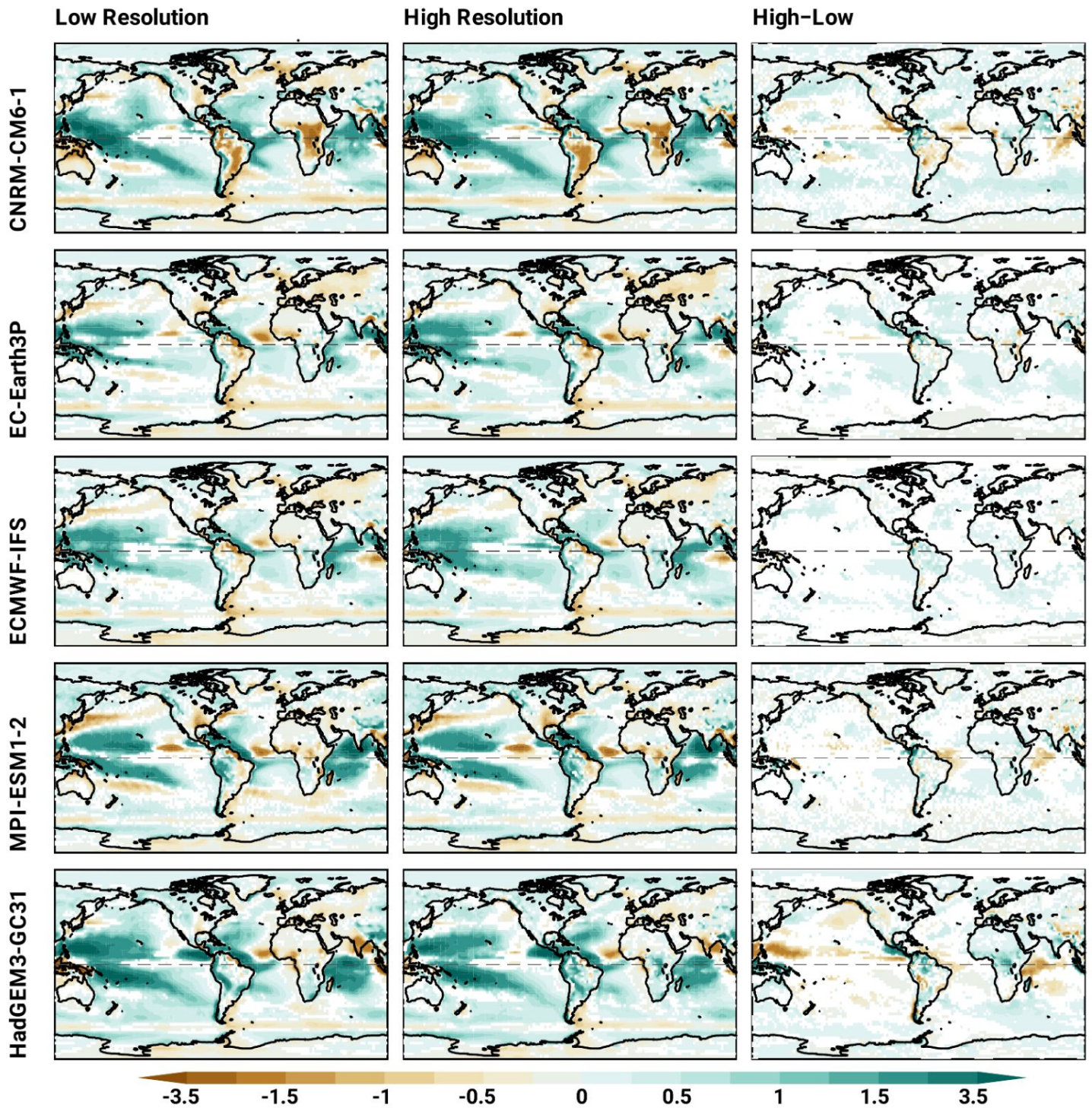


Figure S4. Mean bias in the precipitation rate (in mm d^{-1}) in each individual atmosphere-only simulation of the ensemble at low (*left*), high (*middle*) resolutions, and as the difference between the two (*right*). Biases are with respect to the GPCP precipitation. Non-significant anomalies at the 5 % level are masked white. The Equator is a dashed line.

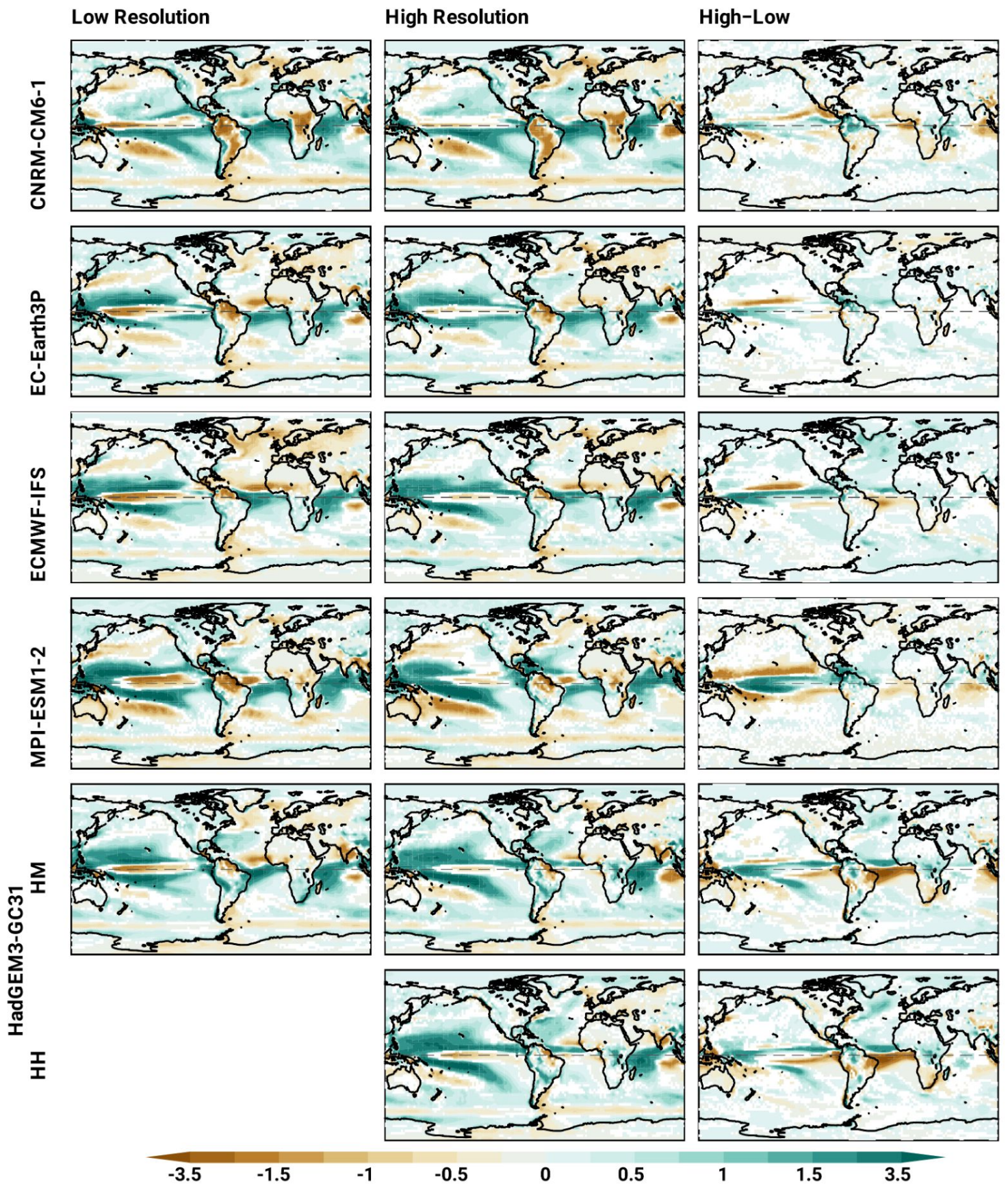


Figure S5. As in Fig. S4 but for the coupled simulations.

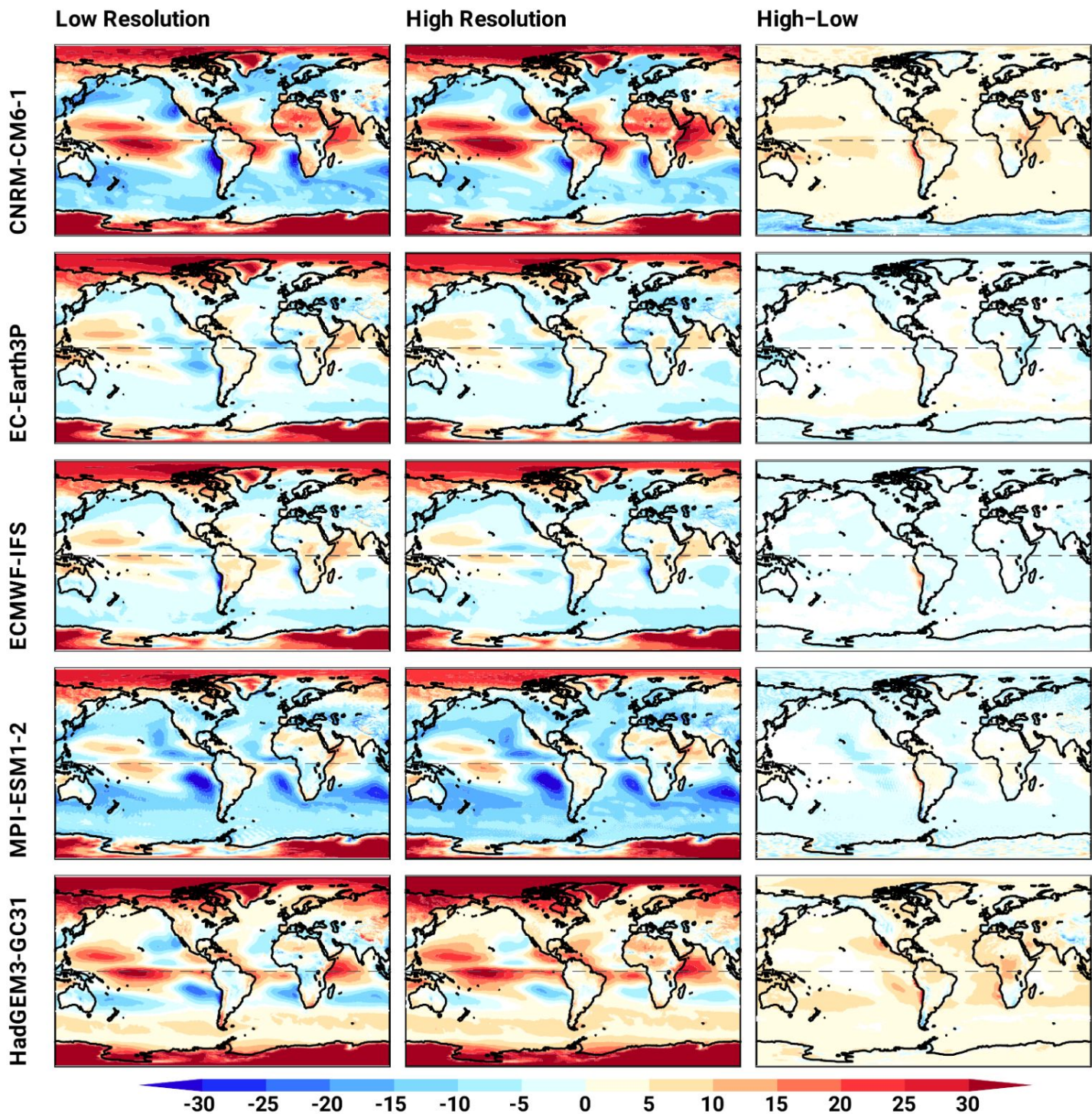


Figure S6. Mean bias in the net cloud cover (in %) in each individual atmosphere-only simulation of the ensemble at low (*left*), high (*middle*) resolutions, and as the difference between the two (*right*). Biases are with respect to ESACCI-CLOUD. Non-significant anomalies at the 5% level are masked white. The Equator is a dashed line.

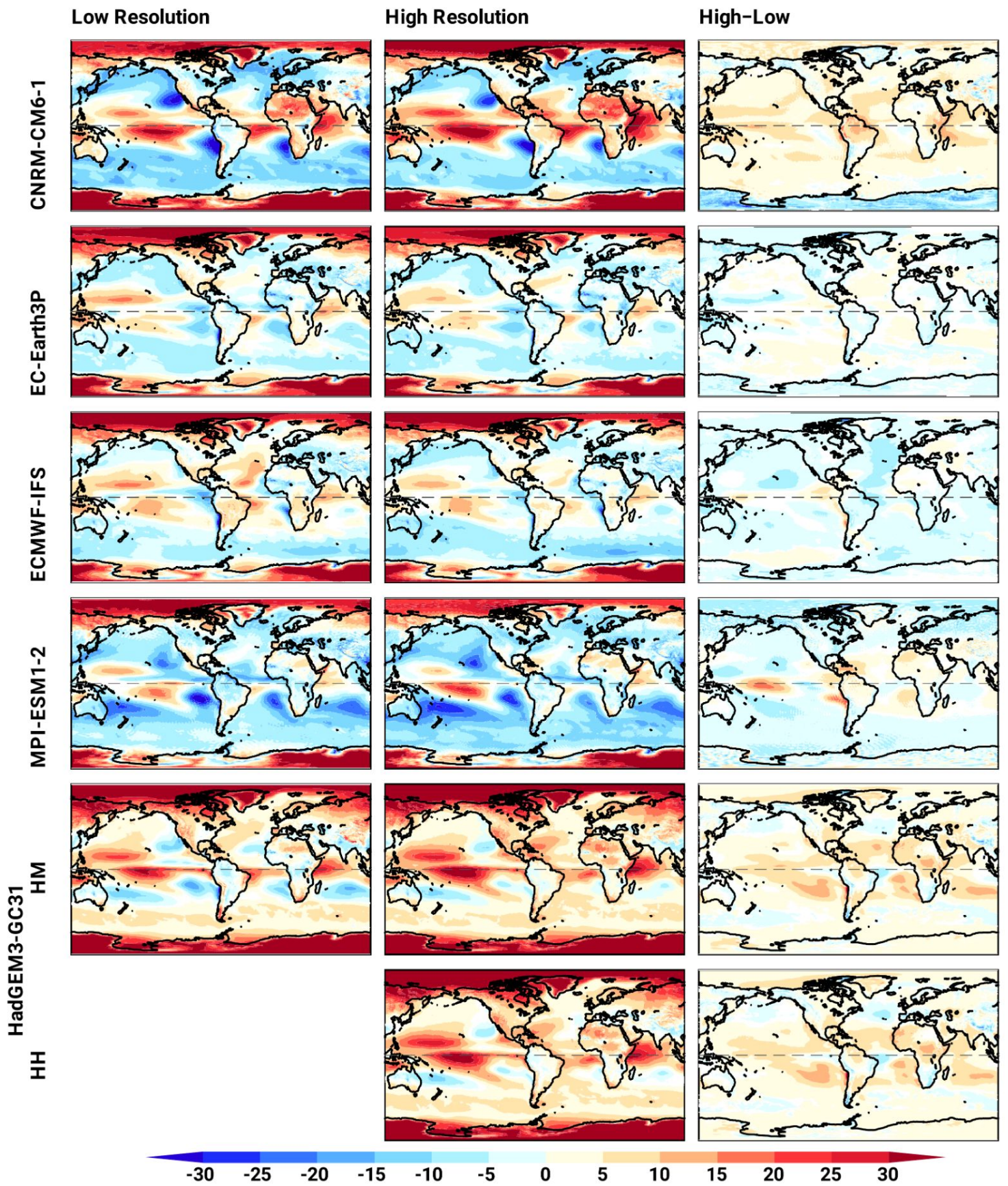


Figure S7. As in Fig. S6 but for the coupled simulations.

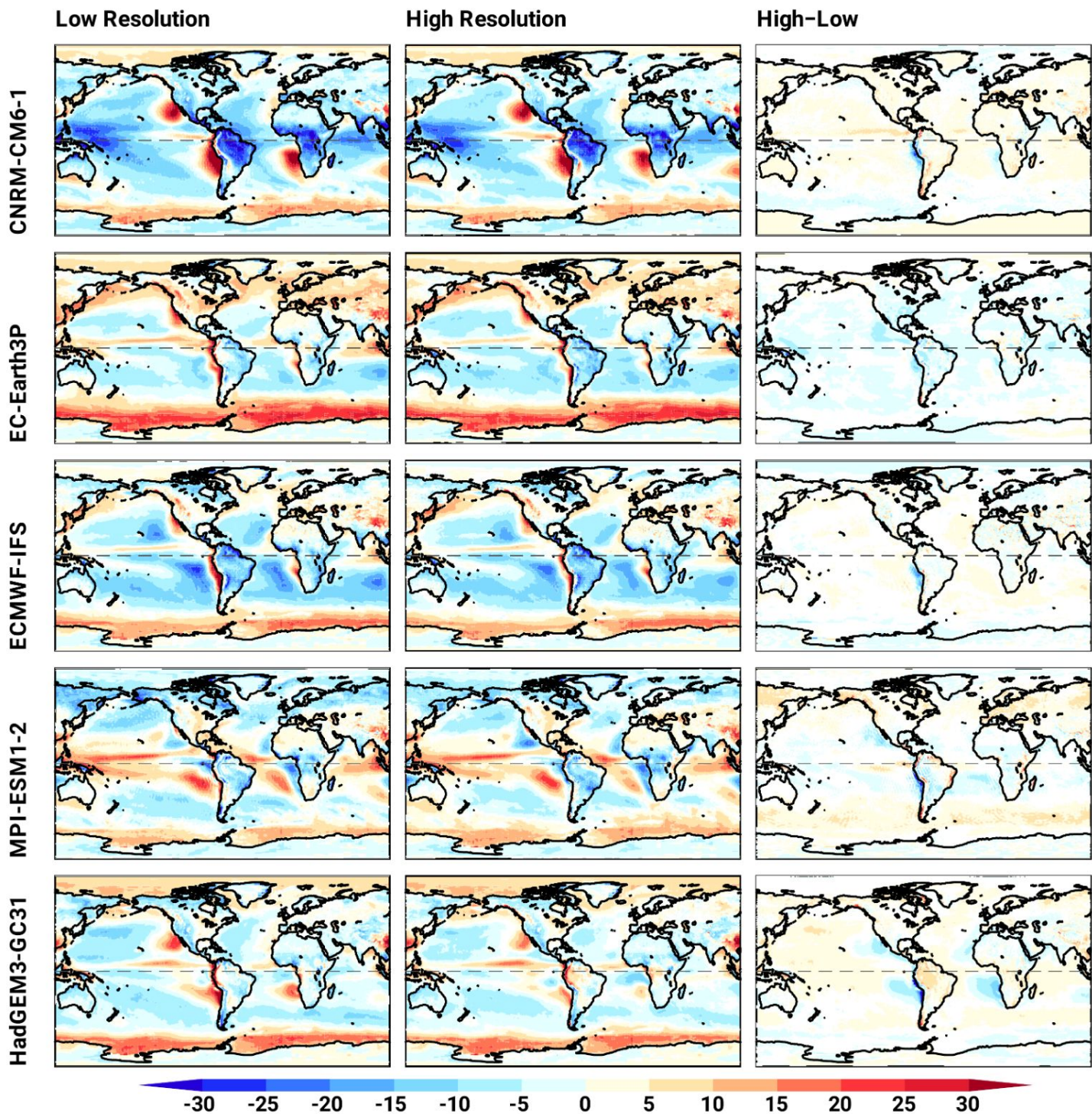


Figure S8. Mean bias in the net cloud radiative effect (in Wm^{-2}) in each individual atmosphere-only simulation of the ensemble at low (*left*), high (*middle*) resolutions, and as the difference between the two (*right*). Biases are with respect to CERES-EBAF. Non-significant anomalies at the 5 % level are masked white. The Equator is a dashed line.

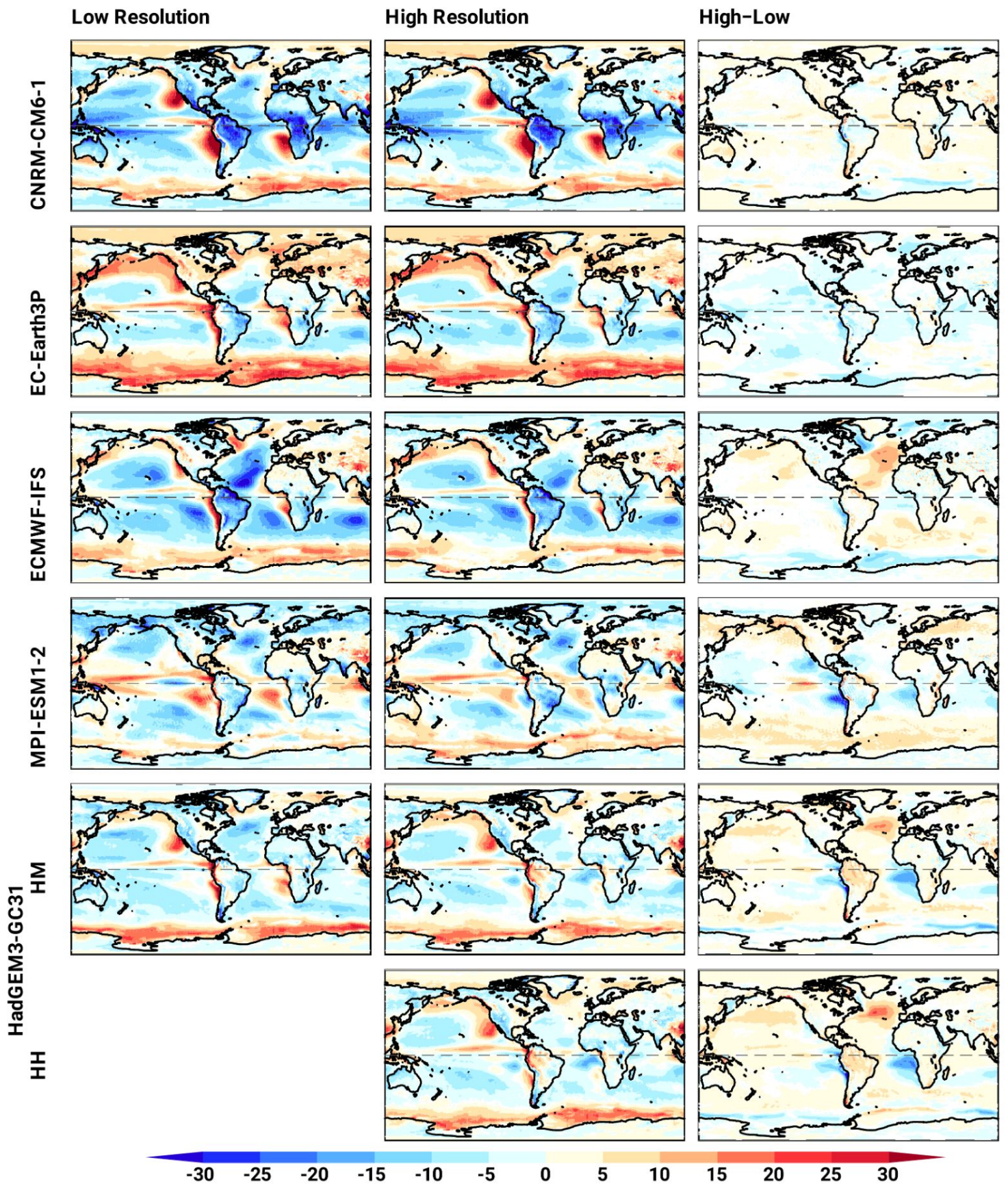


Figure S9. As in Fig. S8 but for the coupled simulations.

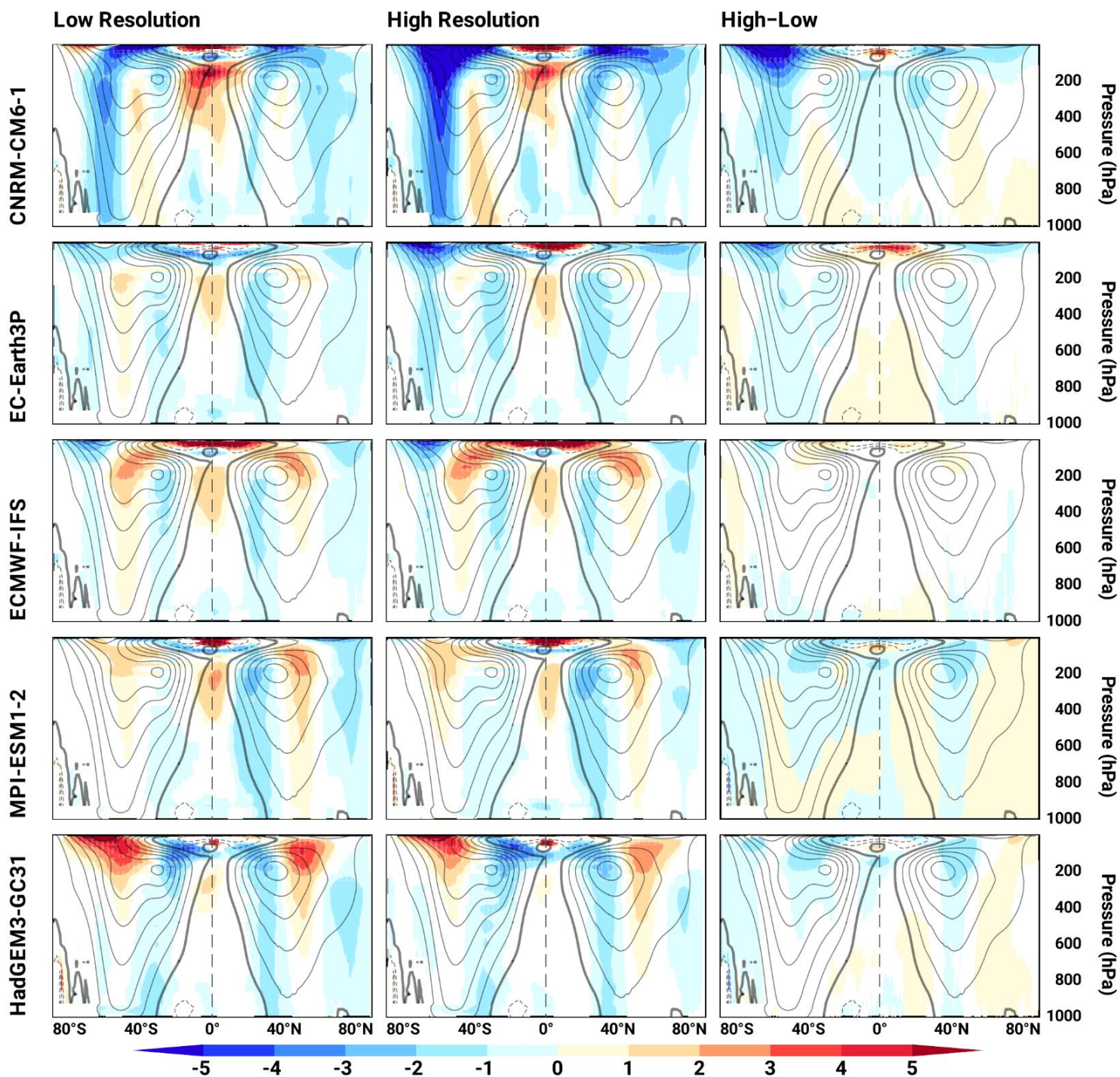


Figure S10. Mean bias in the zonally averaged zonal wind (in ms^{-1}) in each individual atmosphere-only simulation of the ensemble at low (left), high (middle) resolutions, and as the difference between the two (right). Biases are with respect to ERA5. Non-significant anomalies at the 5% level are masked white. The Equator is a vertical dashed line. Contours represent the ERA5 climatology (every 5 ms^{-1} ; negative values, which are for easterlies, are dashed lines, and positive values, for westerlies, are solid lines).

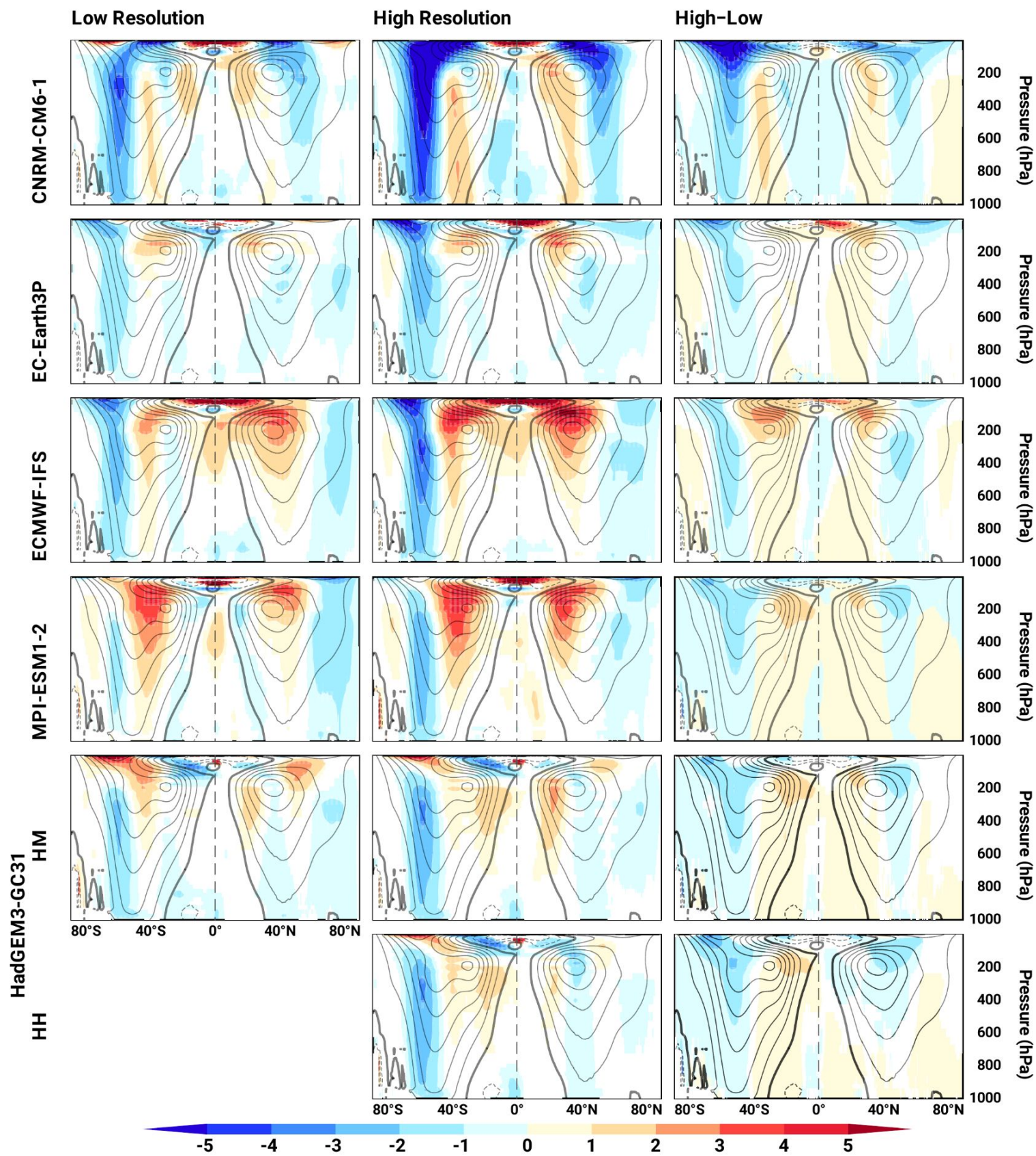


Figure S11. As in Fig. S10 but for the coupled simulations.

		SAT (°C)				Precipitation (mm/d)				Cloud Cover (%)				Net cloud radiative effect (W/m ²)			
		RMSD		Bias		RMSD		Bias		RMSD		Bias		RMSD		Bias	
		Atm.	Coup.	Atm.	Coup.	Atm.	Coup.	Atm.	Coup.	Atm.	Coup.	Atm.	Coup.	Atm.	Coup.	Atm.	Coup.
Ensemble Mean	LR	0.68	1.19	-0.06	0.46	0.62	1.20	0.29	0.78	11.45	10.67	-8.15	-6.79	10.76	11.57	2.43	4.53
	HR	0.37	0.60	-0.09	0.11	0.56	0.78	0.32	0.55	9.07	7.80	-5.71	-4.19	7.56	7.91	0.39	1.11
CNRM-CM6	LR	0.83	1.50	-0.29	0.59	1.47	2.15	0.29	1.20	17.29	19.21	-9.82	-8.60	21.47	21.35	9.95	10.17
	HR	0.62	1.19	-0.37	0.11	0.85	1.56	0.34	0.97	13.50	16.92	-5.67	-5.55	18.40	20.28	8.99	11.08
EC-Earth3P	LR	0.66	1.18	-0.34	0.66	0.59	1.22	0.34	0.80	9.87	9.89	-7.46	-6.85	11.34	13.56	-0.31	4.90
	HR	0.51	0.83	-0.37	0.36	0.57	1.07	0.36	0.74	8.85	8.98	-6.58	-6.16	10.54	12.14	-2.13	2.03
ECMWF-IFS	LR	0.65	1.14	-0.29	-0.12	0.48	0.74	0.28	0.49	8.40	8.98	-3.58	-2.99	17.14	17.58	-6.37	-4.56
	HR	0.46	0.69	-0.25	0.09	0.55	0.61	0.35	0.39	7.50	7.87	-4.44	-3.93	14.54	15.20	-5.83	-5.39
HadGEM3-GC31	LR	1.16	1.67	0.29	0.09	0.80	1.47	0.27	0.65	13.32	10.28	-5.50	-1.90	12.89	11.27	5.87	4.92
	HR (HM)	0.46	0.77	0.16	-0.54	0.78	0.62	0.22	0.05	10.19	8.77	2.17	4.72	8.98	9.46	0.46	-1.71
	HR (HH)	0.46	0.90	0.16	-0.74	0.78	0.62	0.22	0.02	10.19	8.71	2.17	4.73	8.98	9.73	0.46	-2.36
MPI-ESM1-2	LR	0.90	1.52	0.30	1.07	0.59	1.23	0.27	0.75	18.62	16.75	-14.36	-13.63	13.64	12.10	3.01	7.22
	HR	0.81	1.07	0.37	0.53	0.71	1.02	0.35	0.58	19.25	13.46	-14.05	-10.03	12.82	10.11	0.48	-0.45

Table S1. As in Table 1 but for the mean bias over the SH Pacific and Atlantic upwelling regions (area shown in Fig. S1), root-mean-square deviation (RMSD) and mean bias (Bias) of the variables in Figs. 1,2,4,5 in the atmosphere-only (Atm.) and coupled (Coup.) models at LR and HR, including the eddy-rich coupled model HadGEM3-GC3-HH. The white-to-yellow shading reflects the RMSD gradient between its minimum (white) and maximum (yellow) values of each variable. The red-to-blue shading, centered around the zero value, represents the bias values of each variable, blue meaning an excessively cold and wet model with negative biases in the cloud cover and net cloud radiative effect compared to observations (and vice versa).

		SAT (°C)				Precipitation (mm/d)				Cloud Cover (%)				Net cloud radiative effect (W/m ²)			
		RMSD		Bias		RMSD		Bias		RMSD		Bias		RMSD		Bias	
		Atm.	Coup.	Atm.	Coup.	Atm.	Coup.	Atm.	Coup.	Atm.	Coup.	Atm.	Coup.	Atm.	Coup.	Atm.	Coup.
Ensemble Mean	LR	0.18	0.48	0.14	-0.28	0.84	1.31	0.66	0.90	7.51	8.75	1.14	3.71	4.83	6.67	-4.23	-5.97
	HR	0.24	0.50	0.21	-0.07	0.86	1.42	0.71	0.98	7.61	10.27	1.31	5.21	4.62	6.46	-3.86	-5.69
CNRM-CM6	LR	0.33	1.03	-0.30	-0.81	1.09	1.81	0.83	1.28	13.79	16.83	9.24	10.86	9.18	10.33	-8.18	-8.58
	HR	0.26	1.16	-0.22	-0.97	1.20	1.86	1.00	1.33	17.87	20.21	13.32	14.40	7.95	8.82	-6.69	-6.61
EC-Earth3P	LR	0.30	0.28	-0.27	-0.12	0.50	0.85	0.37	0.48	5.85	5.05	-2.09	0.20	5.57	6.15	-4.78	-4.97
	HR	0.31	0.43	-0.29	-0.34	0.61	0.92	0.53	0.64	5.93	5.47	-2.67	0.35	6.88	7.45	-6.34	-6.72
ECMWF-IFS	LR	0.21	0.90	-0.19	-0.85	0.62	1.06	0.52	0.63	4.02	5.97	0.58	4.07	11.35	12.55	-9.89	-11.49
	HR	0.13	0.40	-0.11	-0.19	0.66	1.10	0.59	0.70	4.51	5.04	-1.50	2.54	10.03	12.20	-8.86	-11.36
HadGEM3-GC31	LR	0.54	0.75	0.49	-0.62	1.18	1.26	0.97	0.90	12.04	11.48	3.02	3.59	5.04	4.82	-1.82	-3.23
	HR (HM)	0.56	0.62	0.52	-0.20	1.01	1.74	0.81	1.11	11.89	14.96	6.24	10.94	3.98	5.49	-0.78	-3.47
	HR (HH)	0.56	0.67	0.52	-0.40	1.01	2.17	0.81	0.90	11.89	13.78	6.24	10.21	3.98	5.37	-0.78	-3.68
MPI-ESM1-2	LR	0.97	1.33	0.95	1.01	1.03	1.54	0.62	1.20	10.91	11.35	-5.04	-0.15	7.17	9.15	3.51	-1.60
	HR	1.19	1.64	1.17	1.32	1.01	1.94	0.61	1.10	13.44	13.11	-8.81	-2.17	7.47	8.44	3.35	-0.32

Table S2. As in Table S1 but for the bias for the ITCZ region over the southern central Pacific, averaged between 100–150° W and 0–30° S (area shown in Fig. S1).

		SAT (°C)				Precipitation (mm/d)				Cloud Cover (%)				Net cloud radiative effect (W/m ²)			
		RMSD		Bias		RMSD		Bias		RMSD		Bias		RMSD		Bias	
		Atm.	Coup.	Atm.	Coup.	Atm.	Coup.	Atm.	Coup.	Atm.	Coup.	Atm.	Coup.	Atm.	Coup.	Atm.	Coup.
Ensemble Mean	LR	0.90	0.76	-0.55	-0.05	0.46	0.47	-0.04	-0.08	5.10	5.69	-3.85	-3.98	9.54	9.00	7.18	7.18
	HR	0.74	1.12	-0.46	0.55	0.55	0.56	-0.01	-0.04	5.08	6.18	-3.94	-4.69	9.35	8.99	7.23	7.60
CNRM-CM6	LR	1.31	1.63	-0.83	-0.70	0.52	0.53	-0.20	-0.24	10.09	11.13	-8.51	-9.40	7.56	8.71	4.16	5.64
	HR	0.77	1.24	-0.52	-0.07	0.57	0.58	-0.12	-0.20	8.13	9.99	-6.67	-8.41	6.76	8.26	2.97	5.55
EC-Earth3P	LR	0.78	1.54	-0.38	1.36	0.51	0.52	-0.06	0.04	4.77	6.03	-3.39	-3.82	16.39	15.47	15.05	14.49
	HR	0.78	1.80	-0.39	1.55	0.55	0.57	-0.07	0.02	4.46	5.91	-3.29	-3.99	16.08	14.87	14.42	13.77
ECMWF-IFS	LR	0.72	1.27	-0.42	0.88	0.50	0.52	-0.08	-0.08	5.97	7.35	-5.09	-5.95	10.06	9.41	7.78	7.64
	HR	0.72	3.06	-0.46	2.44	0.55	0.59	-0.05	0.06	6.36	8.97	-5.58	-7.44	9.31	8.64	7.13	6.17
HadGEM3-GC31	LR	0.92	1.87	-0.29	-1.09	0.47	0.47	0.09	-0.02	6.40	6.78	4.95	5.32	10.21	10.74	6.39	7.02
	HR (HM)	0.45	1.12	-0.17	0.14	0.71	0.69	0.17	0.07	7.35	7.28	6.00	5.79	9.32	9.22	5.93	6.76
	HR (HH)	0.45	1.13	-0.17	-0.27	0.71	0.70	0.17	0.03	7.35	7.47	6.00	5.96	9.32	9.54	5.93	6.93
MPI-ESM1-2	LR	1.43	1.63	-0.81	-0.69	0.45	0.48	0.04	-0.07	7.84	6.94	-7.19	-6.05	6.38	5.48	2.53	1.10
	HR	1.47	1.83	-0.75	-1.32	0.53	0.54	0.03	-0.15	10.62	9.95	-10.18	-9.37	7.65	7.91	-3.42	5.78

Table S3. As in Table S1 but for the bias over the SO, averaged between 0–360° E and 50–70° S (area shown in Fig. S1).

		SAT (°C)				Precipitation (mm/d)				Cloud Cover (%)				Net cloud radiative effect (W/m ²)			
		RMSD		Bias		RMSD		Bias		RMSD		Bias		RMSD		Bias	
		Atm.	Coup.	Atm.	Coup.	Atm.	Coup.	Atm.	Coup.	Atm.	Coup.	Atm.	Coup.	Atm.	Coup.	Atm.	Coup.
Ensemble Mean	LR	0.51	1.85	-0.16	-1.35	0.43	0.50	0.01	-0.13	5.12	4.18	-3.39	-1.25	4.96	7.93	-1.15	-3.44
	HR	0.42	1.27	-0.12	-0.53	0.46	0.47	0.10	0.01	4.71	4.37	-3.21	-2.13	4.75	6.26	-0.62	-2.02
CNRM-CM6	LR	0.59	1.69	-0.23	-0.80	0.60	0.69	0.06	-0.12	10.53	10.37	-8.99	-8.74	6.48	8.84	-3.42	-4.17
	HR	0.54	2.08	0.06	-0.83	0.65	0.76	0.24	-0.06	8.41	8.38	-6.66	-6.20	5.90	8.49	-3.04	-4.18
EC-Earth3P	LR	0.41	1.38	-0.15	0.14	0.45	0.47	-0.12	-0.10	4.32	4.31	-1.62	-1.04	7.37	7.44	4.66	4.06
	HR	0.41	1.40	-0.23	-0.10	0.43	0.47	-0.02	-0.07	4.00	4.25	-2.16	-1.49	6.63	7.47	3.11	2.61
ECMWF-IFS	LR	0.62	5.10	-0.36	-4.61	0.37	0.63	-0.04	-0.41	4.50	4.99	-2.27	2.89	5.67	11.63	-0.06	-4.55
	HR	0.54	1.28	-0.33	-0.92	0.41	0.41	0.03	0.02	4.94	4.41	-3.39	-1.77	6.13	6.65	0.53	-1.39
HadGEM3-GC31	LR	0.88	2.19	-0.31	-1.90	0.48	0.53	0.16	-0.04	5.29	7.12	2.83	5.94	5.42	8.74	-1.45	-4.68
	HR (HM)	0.88	1.14	-0.41	-0.61	0.55	0.58	0.24	0.24	6.44	7.17	5.04	5.85	4.71	5.14	0.16	0.21
	HR (HH)	0.88	1.05	-0.41	-0.24	0.55	0.70	0.24	0.24	6.44	6.69	5.04	4.89	4.71	5.11	0.16	1.64
MPI-ESM1-2	LR	0.82	1.77	0.26	0.40	0.59	0.60	-0.02	0.01	7.96	6.83	-6.93	-5.29	8.14	11.21	-5.50	-7.88
	HR	0.85	1.71	0.32	-0.21	0.57	0.55	0.01	-0.05	9.52	8.02	-8.89	-7.02	6.69	10.46	-3.85	-7.37

Table S4. As in Table S1 but for the bias over the North Atlantic, averaged between 80–10° W and 35–65° N (area shown in Fig. S1).