

Supplementary Material: Evaluation of Historical CMIP5 GCM Simulation Results Based on Detected Atmospheric Teleconnections

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Table S1. Comparison of stability patterns by RMSE values computed in the entire Northern Hemisphere (NH) and minimum (abbreviated as min.), 1st, 5th, 25th, 50th, 75th, 95th 99th percentiles (abbreviated as p.) and maximum (abbreviated as max.) of the RMSE values obtained from 500,000 Monte Carlo simulations. The range is the difference between the maximum and the minimum values. In (a-d) the GCMs are listed in alphabetical order.

(a) Analysis of 30-year-long periods in which the ERA-20C is used as a reference dataset.

Reanalysis / GCM name	RMSE NH	min.	1 st p.	5 th p.	25 th p.	50 th p.	75 th p.	95 th p.	99 th p.	max.	range
NCEP-NCAR R1	0.82	0.00	0.32	0.43	0.62	0.77	0.94	1.17	1.33	1.79	1.79
ACCESS1-0	1.84	0.37	1.04	1.27	1.60	1.82	2.03	2.33	2.54	3.14	2.77
ACCESS1-3	1.95	0.50	1.14	1.38	1.71	1.93	2.15	2.45	2.65	3.23	2.73
CCSM4	2.14	0.54	1.29	1.54	1.88	2.12	2.34	2.65	2.86	3.49	2.95
CMCC-CM	1.76	0.32	0.95	1.18	1.51	1.73	1.95	2.25	2.45	3.08	2.77
CMCC-CMS	1.85	0.51	1.07	1.30	1.62	1.83	2.04	2.32	2.52	3.09	2.58
CNRM-CM5	2.03	0.41	1.16	1.42	1.77	2.01	2.23	2.55	2.76	3.37	2.96
GFDL-CM3	2.17	0.52	1.31	1.57	1.92	2.15	2.37	2.68	2.90	3.41	2.89
GFDL-ESM2G	2.12	0.49	1.25	1.51	1.87	2.10	2.32	2.63	2.84	3.40	2.91
GFDL-ESM2M	1.87	0.44	1.06	1.30	1.63	1.85	2.06	2.36	2.56	3.11	2.67
HadGEM2-AO	1.91	0.85	1.29	1.46	1.71	1.89	2.07	2.32	2.49	2.98	2.14
HadGEM2-CC	1.75	0.29	0.96	1.19	1.51	1.73	1.93	2.23	2.42	2.92	2.64
IPSL-CM5A-MR	2.05	0.51	1.21	1.46	1.81	2.03	2.25	2.56	2.77	3.35	2.84
MIROC5	2.04	0.51	1.25	1.48	1.81	2.03	2.24	2.53	2.73	3.30	2.80
MPI-ESM-LR	1.81	0.29	0.97	1.22	1.56	1.79	2.01	2.31	2.52	3.14	2.85
MPI-ESM-MR	2.03	0.47	1.21	1.45	1.79	2.01	2.23	2.52	2.72	3.33	2.86
MPI-ESM-P	1.98	0.51	1.15	1.40	1.74	1.96	2.18	2.49	2.69	3.25	2.74
MRI-CGCM3	2.33	0.53	1.49	1.74	2.08	2.31	2.53	2.83	3.04	3.58	3.05
MRI-ESM1	2.41	0.38	1.55	1.81	2.16	2.39	2.62	2.93	3.15	3.75	3.37
NorESM1-M	2.31	0.74	1.44	1.71	2.06	2.29	2.51	2.82	3.04	3.60	2.87

(b) Analysis of 30-year-long periods in which the NCEP-NCAR R1 is used as a reference dataset.

Reanalysis / GCM name	RMSE NH	min.	1 st p.	5 th p.	25 th p.	50 th p.	75 th p.	95 th p.	99 th p.	max.	range
ERA-20C	0.82	0.00	0.32	0.43	0.62	0.77	0.94	1.17	1.33	1.79	1.79
ACCESS1-0	1.93	0.45	1.11	1.35	1.68	1.91	2.12	2.42	2.63	3.20	2.75
ACCESS1-3	2.03	0.56	1.22	1.46	1.79	2.01	2.23	2.52	2.73	3.29	2.72
CCSM4	2.10	0.47	1.26	1.51	1.85	2.08	2.30	2.61	2.81	3.50	3.03
CMCC-CM	1.79	0.26	0.99	1.22	1.54	1.76	1.97	2.27	2.47	3.04	2.78
CMCC-CMS	1.71	0.25	0.95	1.17	1.48	1.69	1.89	2.17	2.36	2.92	2.67
CNRM-CM5	2.07	0.39	1.21	1.47	1.82	2.05	2.27	2.58	2.79	3.52	3.13
GFDL-CM3	2.01	0.48	1.16	1.41	1.76	1.98	2.21	2.52	2.72	3.30	2.82
GFDL-ESM2G	2.19	0.56	1.34	1.60	1.94	2.17	2.39	2.70	2.91	3.40	2.84
GFDL-ESM2M	1.91	0.47	1.09	1.33	1.67	1.89	2.11	2.41	2.62	3.22	2.75
HadGEM2-AO	1.99	0.86	1.34	1.53	1.79	1.97	2.15	2.40	2.58	3.12	2.26
HadGEM2-CC	1.93	0.39	1.11	1.36	1.69	1.91	2.12	2.42	2.62	3.20	2.81
IPSL-CM5A-MR	2.02	0.45	1.20	1.44	1.78	2.01	2.22	2.53	2.73	3.25	2.80
MIROC5	1.94	0.47	1.15	1.38	1.70	1.92	2.13	2.42	2.62	3.19	2.72
MPI-ESM-LR	1.76	0.30	0.95	1.19	1.52	1.74	1.95	2.25	2.46	3.13	2.83
MPI-ESM-MR	2.03	0.42	1.23	1.47	1.79	2.01	2.22	2.51	2.71	3.35	2.92
MPI-ESM-P	1.92	0.43	1.09	1.34	1.67	1.90	2.11	2.42	2.62	3.23	2.80
MRI-CGCM3	2.27	0.68	1.44	1.68	2.03	2.25	2.47	2.78	2.99	3.68	3.00
MRI-ESM1	2.30	0.32	1.44	1.69	2.05	2.28	2.50	2.82	3.03	3.78	3.45
NorESM1-M	2.21	0.53	1.35	1.61	1.96	2.19	2.42	2.73	2.94	3.49	2.96

(c) Analysis of 10-year-long periods in which the ERA-20C is used as a reference dataset.

Reanalysis / GCM name	RMSE NH	min.	1 st p.	5 th p.	25 th p.	50 th p.	75 th p.	95 th p.	99 th p.	max.	range
NCEP-NCAR R1	1.00	0.39	0.64	0.73	0.88	0.99	1.10	1.26	1.37	1.73	1.35
ACCESS1-0	2.19	0.81	1.48	1.68	1.97	2.17	2.37	2.66	2.87	3.52	2.71
ACCESS1-3	2.61	1.19	1.80	2.03	2.36	2.59	2.81	3.14	3.36	4.02	2.83
CCSM4	2.70	1.34	1.91	2.13	2.45	2.68	2.91	3.25	3.49	4.24	2.89
CMCC-CM	2.09	0.85	1.34	1.54	1.84	2.06	2.29	2.62	2.87	3.58	2.73
CMCC-CMS	2.03	0.97	1.39	1.57	1.83	2.02	2.20	2.47	2.67	3.30	2.33
CNRM-CM5	2.49	1.17	1.66	1.88	2.22	2.46	2.70	3.05	3.30	4.07	2.90
GFDL-CM3	2.74	1.18	1.93	2.16	2.49	2.72	2.95	3.27	3.49	4.04	2.86
GFDL-ESM2G	2.62	1.01	1.73	1.97	2.34	2.60	2.85	3.23	3.50	4.25	3.23
GFDL-ESM2M	2.36	1.07	1.63	1.83	2.13	2.34	2.55	2.86	3.08	3.76	2.69
HadGEM2-AO	2.73	1.62	2.05	2.24	2.52	2.71	2.91	3.20	3.40	3.91	2.29
HadGEM2-CC	2.36	1.03	1.63	1.83	2.13	2.34	2.56	2.87	3.09	3.76	2.72
IPSL-CM5A-MR	2.55	1.02	1.69	1.93	2.28	2.52	2.77	3.13	3.39	4.15	3.13
MIROC5	2.67	1.23	1.90	2.12	2.43	2.65	2.86	3.17	3.38	3.96	2.73
MPI-ESM-LR	2.05	1.00	1.39	1.56	1.83	2.02	2.22	2.51	2.72	3.33	2.33
MPI-ESM-MR	2.42	1.15	1.69	1.89	2.18	2.40	2.61	2.93	3.16	3.76	2.61
MPI-ESM-P	2.20	1.05	1.50	1.68	1.97	2.17	2.39	2.70	2.92	3.78	2.73
MRI-CGCM3	3.01	1.41	2.15	2.39	2.74	2.99	3.24	3.59	3.84	4.56	3.16
MRI-ESM1	3.01	1.27	2.10	2.36	2.73	2.98	3.24	3.61	3.86	4.73	3.46
NorESM1-M	2.80	1.19	1.92	2.18	2.53	2.78	3.02	3.37	3.61	4.17	2.98

(d) Analysis of 10-year-long periods in which the NCEP-NCAR R1 is used as a reference dataset.

Reanalysis / GCM name	RMSE NH	min.	1 st p.	5 th p.	25 th p.	50 th p.	75 th p.	95 th p.	99 th p.	max.	range
ERA-20C	1.00	0.39	0.64	0.73	0.88	0.99	1.10	1.26	1.37	1.73	1.35
ACCESS1-0	2.22	0.94	1.48	1.69	1.99	2.20	2.41	2.71	2.91	3.49	2.55
ACCESS1-3	2.70	1.15	1.85	2.09	2.43	2.67	2.91	3.25	3.49	4.20	3.05
CCSM4	2.63	1.13	1.84	2.06	2.38	2.60	2.83	3.16	3.39	4.02	2.89
CMCC-CM	2.07	0.87	1.34	1.53	1.83	2.04	2.26	2.57	2.80	3.43	2.56
CMCC-CMS	1.97	0.90	1.35	1.52	1.77	1.95	2.13	2.40	2.59	3.13	2.23
CNRM-CM5	2.55	1.15	1.70	1.94	2.28	2.52	2.76	3.11	3.35	4.13	2.97
GFDL-CM3	2.55	1.09	1.78	2.00	2.31	2.53	2.74	3.05	3.26	3.99	2.90
GFDL-ESM2G	2.67	1.07	1.79	2.04	2.40	2.65	2.89	3.25	3.51	4.25	3.17
GFDL-ESM2M	2.43	1.16	1.67	1.88	2.19	2.41	2.63	2.96	3.19	3.92	2.76
HadGEM2-AO	2.83	1.53	2.13	2.32	2.61	2.81	3.01	3.31	3.51	4.07	2.54
HadGEM2-CC	2.49	1.17	1.69	1.92	2.24	2.47	2.69	3.02	3.25	4.11	2.93
IPSL-CM5A-MR	2.50	1.06	1.67	1.89	2.23	2.47	2.72	3.08	3.32	4.12	3.06
MIROC5	2.66	1.27	1.89	2.11	2.42	2.64	2.86	3.18	3.39	4.01	2.74
MPI-ESM-LR	1.99	0.89	1.38	1.54	1.79	1.97	2.15	2.43	2.62	3.23	2.34
MPI-ESM-MR	2.47	1.03	1.72	1.93	2.24	2.45	2.66	2.97	3.19	3.67	2.64
MPI-ESM-P	2.20	1.04	1.49	1.68	1.96	2.17	2.39	2.69	2.91	3.67	2.63
MRI-CGCM3	2.95	1.42	2.09	2.33	2.68	2.92	3.17	3.53	3.79	4.53	3.11
MRI-ESM1	2.90	1.27	2.01	2.25	2.62	2.87	3.12	3.50	3.74	4.46	3.19
NorESM1-M	2.72	1.20	1.88	2.12	2.46	2.70	2.94	3.28	3.52	4.13	2.93

Table S2. Span parameter (span), explained variance (EV, expressed in %) and residual sum of squares (RSS) of the loess model fitting on the southerly and northerly located potential action centers, respectively. The models are fitted on Atlantic and Pacific views (abbreviated as Atlantic and Pacific, respectively). The GCMs are listed in alphabetical order.

a) Parameters of loess models fitted on the southerly located potential action centers.

Reanalysis / GCM name	Span (Atlantic)	EV (Atlantic)	RSS (Atlantic)	Span (Pacific)	EV (Pacific)	RSS (Pacific)
ERA-20C	0.31	50	4657	0.38	58	4649
NCEP-NCAR R1	0.23	65	2617	0.40	48	6156
ACCESS1-0	0.25	45	4404	0.37	27	10064
ACCESS1-3	0.21	69	2800	0.27	56	6832
CCSM4	0.38	52	4694	0.49	37	8542
CMCC-CM	0.27	67	2599	0.52	34	6392
CMCC-CMS	0.32	58	3178	0.37	61	5843
CNRM-CM5	0.25	71	2314	0.26	54	5169
GFDL-CM3	0.31	48	4782	0.47	26	11250
GFDL-ESM2G	0.26	51	2832	0.39	34	8223
GFDL-ESM2M	0.60	31	4542	0.57	32	12566
HadGEM2-AO	0.53	12	6224	0.94	2	9826
HadGEM2-CC	0.24	47	2407	0.14	68	3906
IPSL-CM5A-MR	0.14	77	849	0.36	53	5777
MIROC5	0.29	57	2806	0.42	41	4969
MPI-ESM-LR	0.53	17	6894	0.50	34	9748
MPI-ESM-MR	0.18	75	1179	0.41	63	3802
MPI-ESM-P	0.35	24	8282	0.39	54	5268
MRI-CGCM3	0.22	64	3877	0.94	9	17902
MRI-ESM1	0.26	55	5434	0.92	6	20178
NorESM1-M	0.38	44	5955	0.40	34	9157

b) Parameters of loess models fitted on the northerly located potential action centers.

Reanalysis / GCM name	Span (Atlantic)	EV (Atlantic)	RSS (Atlantic)	Span (Pacific)	EV (Pacific)	RSS (Pacific)
ERA-20C	0.30	55	4751	0.31	58	4525
NCEP-NCAR R1	0.21	72	2332	0.45	49	6389
ACCESS1-0	0.24	47	4024	0.79	18	13033
ACCESS1-3	0.25	64	3189	0.57	33	11181
CCSM4	0.28	58	4519	0.39	41	8713
CMCC-CM	0.29	63	2655	0.74	26	6876
CMCC-CMS	0.42	53	3384	0.39	59	5930
CNRM-CM5	0.26	71	2393	0.70	27	8180
GFDL-CM3	0.36	42	4868	0.48	26	11382
GFDL-ESM2G	0.26	50	2861	0.79	23	10111
GFDL-ESM2M	0.62	37	4630	0.83	23	13643
HadGEM2-AO	0.37	21	5619	0.94	2	9799
HadGEM2-CC	0.30	41	2831	0.79	33	10697
IPSL-CM5A-MR	0.26	58	1569	0.33	51	5916
MIROC5	0.26	58	2551	0.57	34	5513
MPI-ESM-LR	0.43	23	6540	0.49	34	9754
MPI-ESM-MR	0.18	77	1112	0.46	64	3922
MPI-ESM-P	0.33	27	8115	0.52	49	5640
MRI-CGCM3	0.24	59	4177	0.82	10	17301
MRI-ESM1	0.26	53	5473	0.67	8	19308
NorESM1-M	0.40	47	6223	0.47	34	9456

Table S3. Comparison of the GCM loess regression curves against the reanalysis loess regression curves by calculating root-mean-square error (RMSE; expressed in degrees). The fitted loess models are the followings: (1) loess model fitted on the southerly located potential action centers (PotACs; abbreviated as S) on Atlantic view, (2) loess model fitted on the northerly located PotACs (abbreviated as N) on Atlantic view, (3) loess model fitted on the southerly located PotACs on Pacific view, (4) loess model fitted on the northerly located PotACs on Pacific view. GCMs are listed in alphabetical order.

Reanalysis / GCM name	Atlantic view				Pacific view			
	Ref. dataset: ERA-20C		Ref. dataset: NCEP-NCAR R1		Ref. dataset: ERA-20C		Ref. dataset: NCEP-NCAR R1	
	(1) RMSE, S	(2) RMSE, N	(1) RMSE, S	(2) RMSE, N	(3) RMSE, S	(4) RMSE, N	(3) RMSE, S	(4) RMSE, N
ERA-20C	0	0	3.6	2.9	0	0	4.4	3.1
NCEP-NCAR R1	3.6	2.9	0	0	4.4	3.1	0	0
ACCESS1-0	6.5	9.2	8.7	10	6.9	8.9	9.7	9.5
ACCESS1-3	5.9	8.3	7.4	9.6	5.9	7.1	7.9	7.8
CCSM4	6.9	4.5	7.4	3.2	7.7	4.8	8.4	3.3
CMCC-CM	5.7	3	5.4	2.2	5.9	4.2	5.9	3.2
CMCC-CMS	6.3	3.9	6.5	4.4	6.7	4	7.1	4.2
CNRM-CM5	5	5.8	5.7	4.6	5.1	4.5	6.3	2.6
GFDL-CM3	5.2	5	6.3	4.9	5.7	5.2	7.3	4.8
GFDL-ESM2G	5	4.5	5.9	3.8	5.9	4.4	7.2	2.9
GFDL-ESM2M	8.1	4.9	8.4	5.3	8.3	5.1	8.5	5.1
HadGEM2-AO	5.5	8.5	6.6	6.8	4.9	8.3	6.7	6.7
HadGEM2-CC	7	6.5	8.7	7.1	7.1	4.1	9.2	4.3
IPSL-CM5A-MR	7.6	4.1	8.5	5.6	7.2	4.1	8.8	5.1
MIROC5	6.7	4.5	7.7	5.2	6.7	5.3	8.1	5.4
MPI-ESM-LR	6.7	4.6	7.2	3	6.8	4.4	7.6	2.9
MPI-ESM-MR	5.1	3.6	6.1	3.1	5.2	3.8	6.7	3
MPI-ESM-P	4.1	3.8	5.2	3	4.7	3.8	6	2.3
MRI-CGCM3	8.3	8.2	7.9	7.5	7.9	7	7.9	6.4
MRI-ESM1	6.4	9.1	6.3	8.3	6.2	9.5	6.7	9
NorESM1-M	7.1	7.4	7.5	6.3	7	7	8	5.6

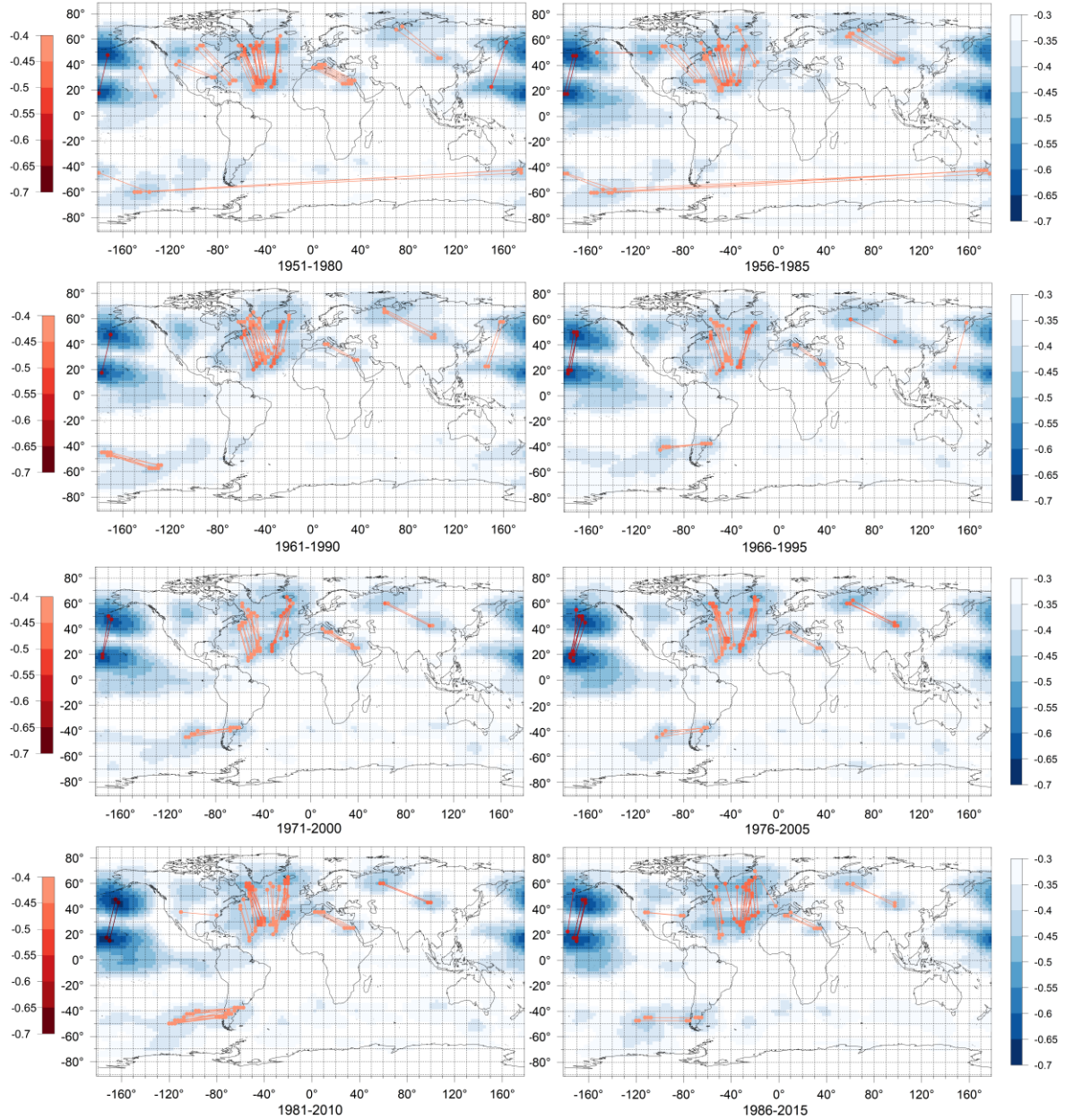


Figure S1. Global correlation maps obtained from the Z500 field of the NCEP-NCAR R1 for 30-year-long periods. Strongest negative correlations associated with the grid cells are denoted with blue-shaded dots. PotACs are denoted with red circles and those are connected with red lines. Brighter/darker colours indicate weaker/stronger correlations.

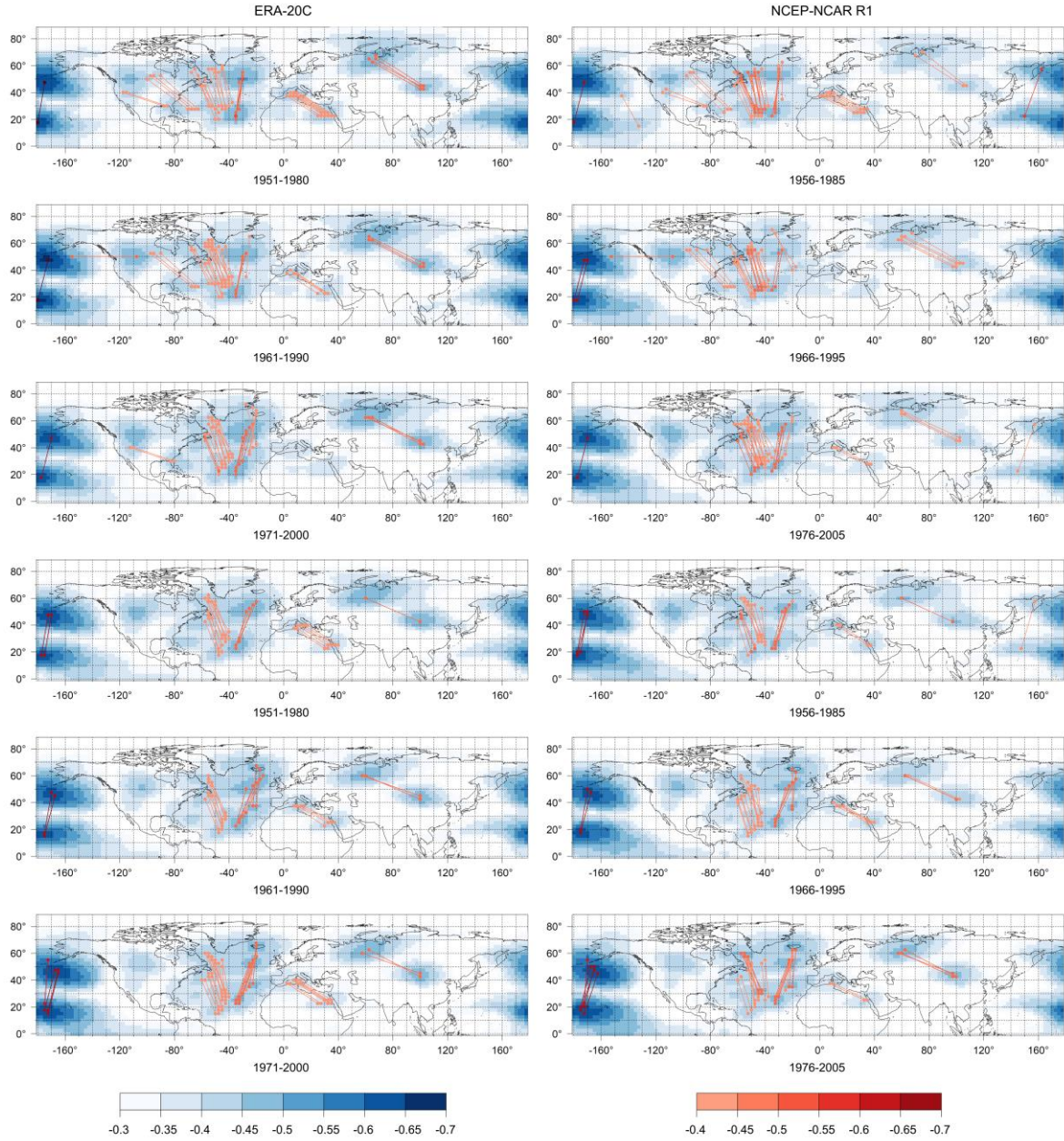
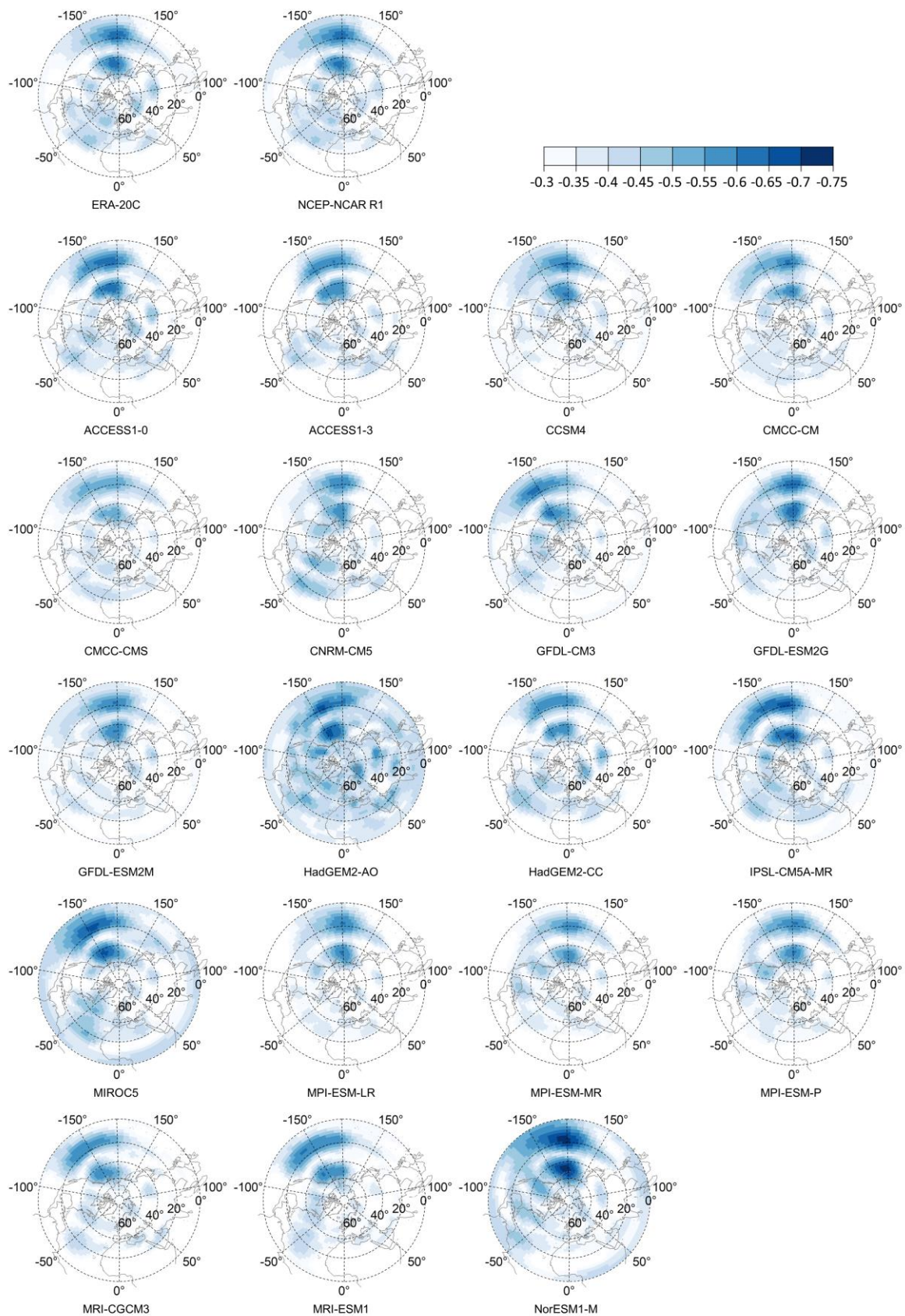


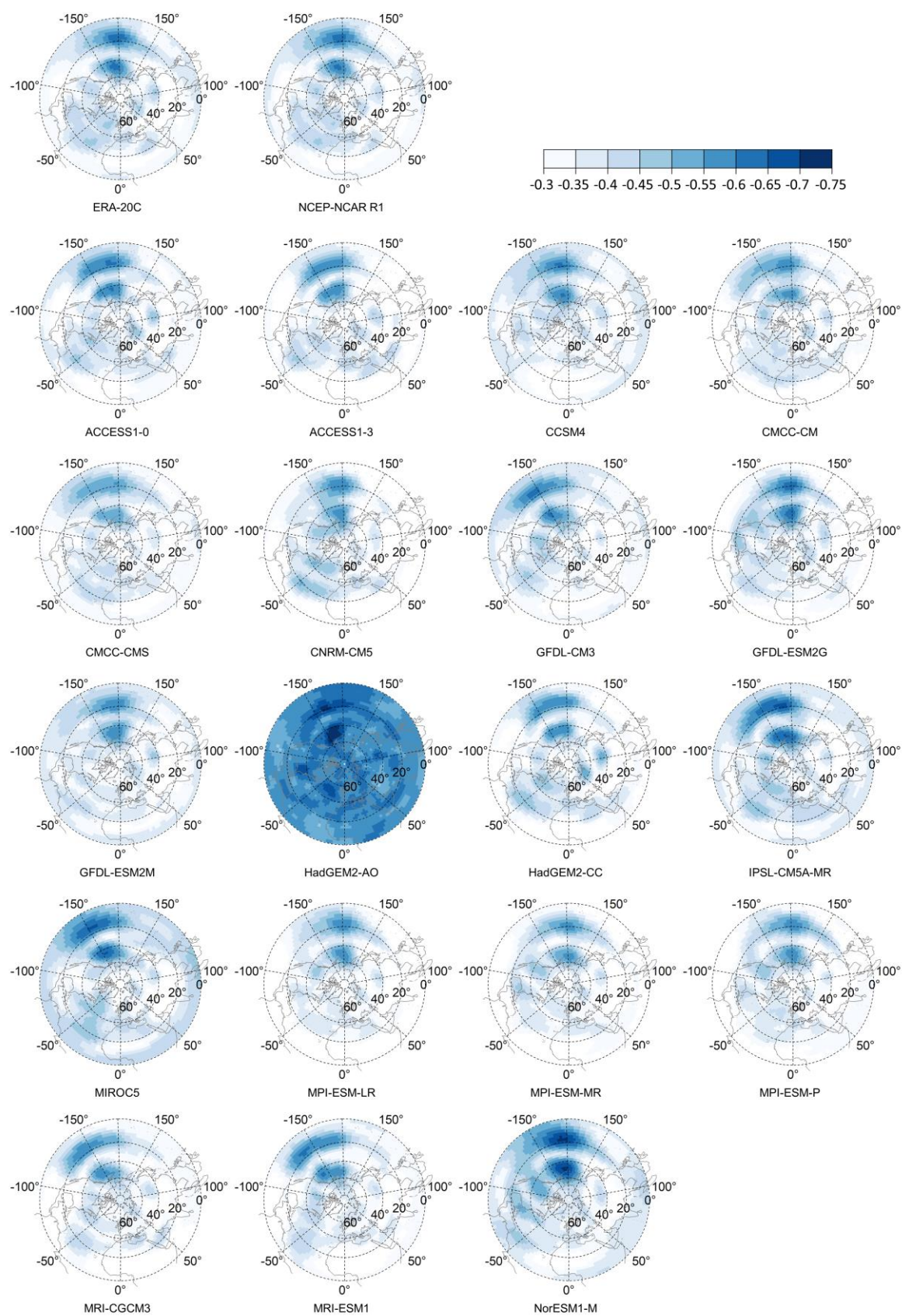
Figure S2. Hemispherical correlation maps of the Z500 fields obtained from the ERA-20C (first column) and the NCEP-NCAR R1 (second column) in cases of 30-year-long periods. The period of 1951-2005 is covered for which historical GCM outputs are available. Strongest negative correlations associated with the grid cells are denoted with blue-shaded dots. Potential action centers are represented with red circles and those are connected with red lines. Brighter/darker colours are associated with weaker/stronger correlations.



(a)

Figure S3. Average value of the strongest negative correlations in each grid cell obtained from the Z500 in case of each reanalysis/GCM based on (a) the 30-year-long periods and (b) the 10-year-long periods.

Figure S3 continued.



(b)

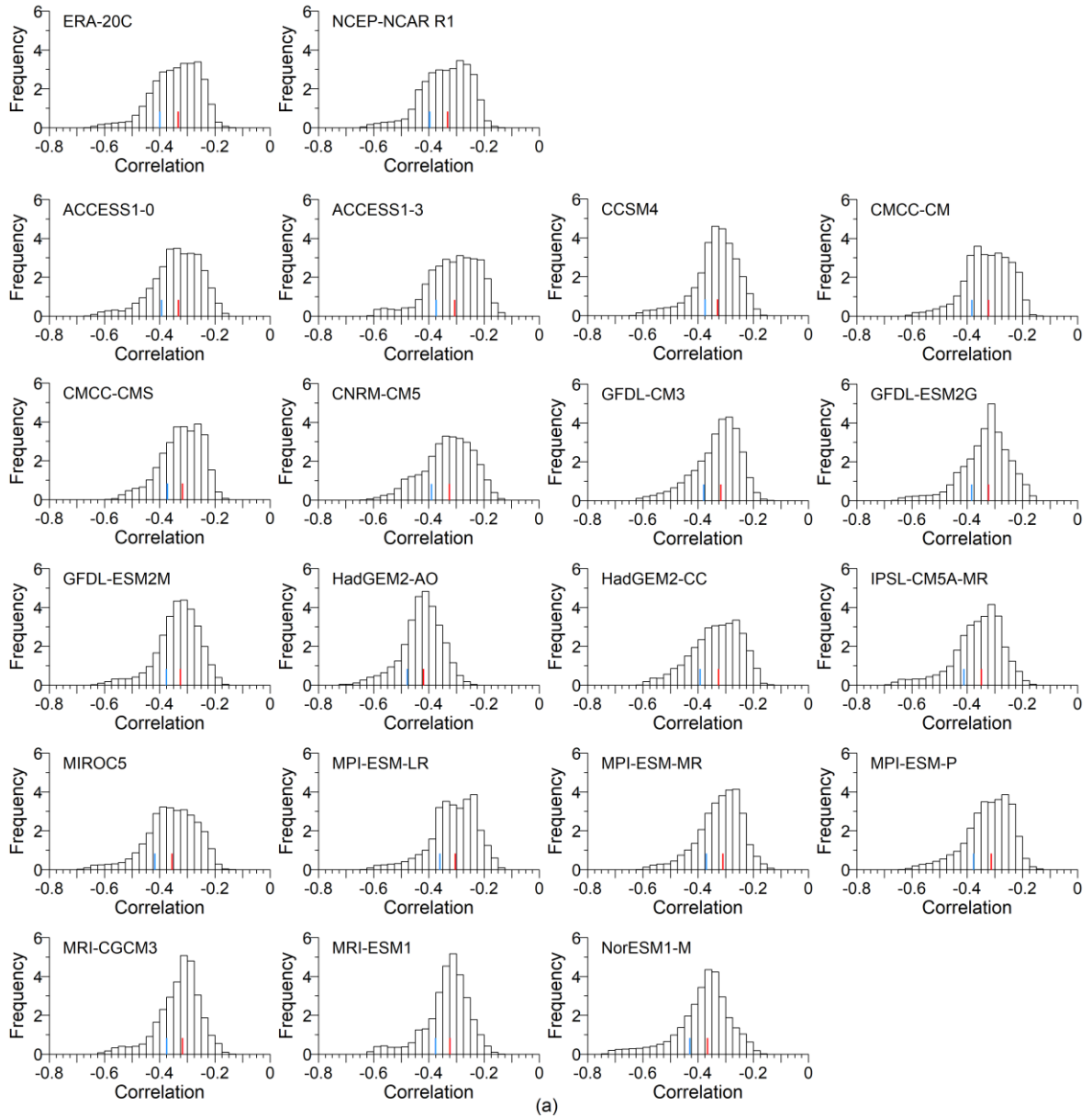
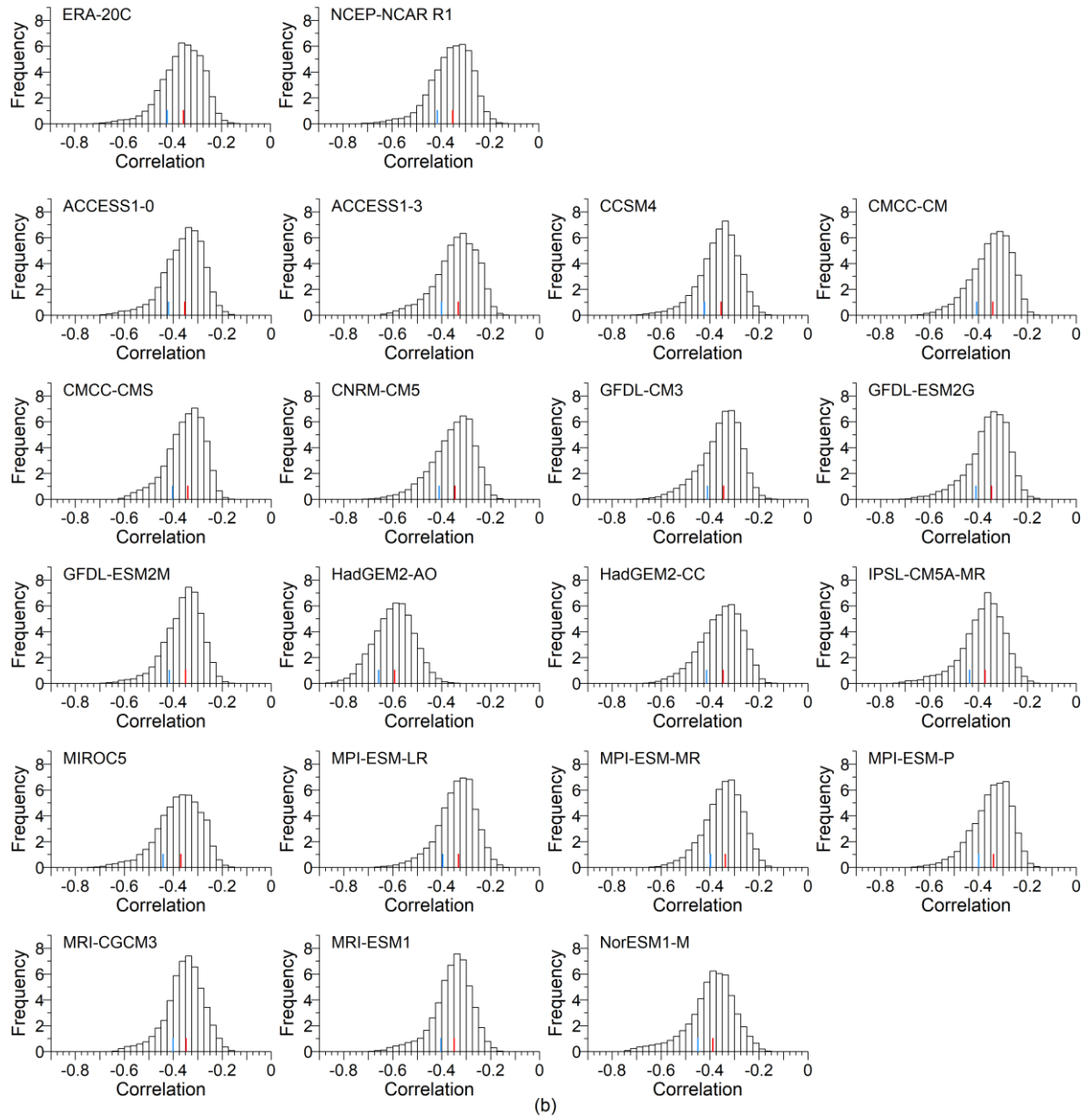


Figure S4. Distribution of the strongest negative correlations obtained from the Z500 in case of each reanalysis/GCM based on (a) the 30-year-long periods and (b) the 10-year-long periods. Frequencies are given in thousands. The median values and the 25th percentiles of the distributions are denoted by red and blue tick marks, subsequently.

Figure S4 continued.



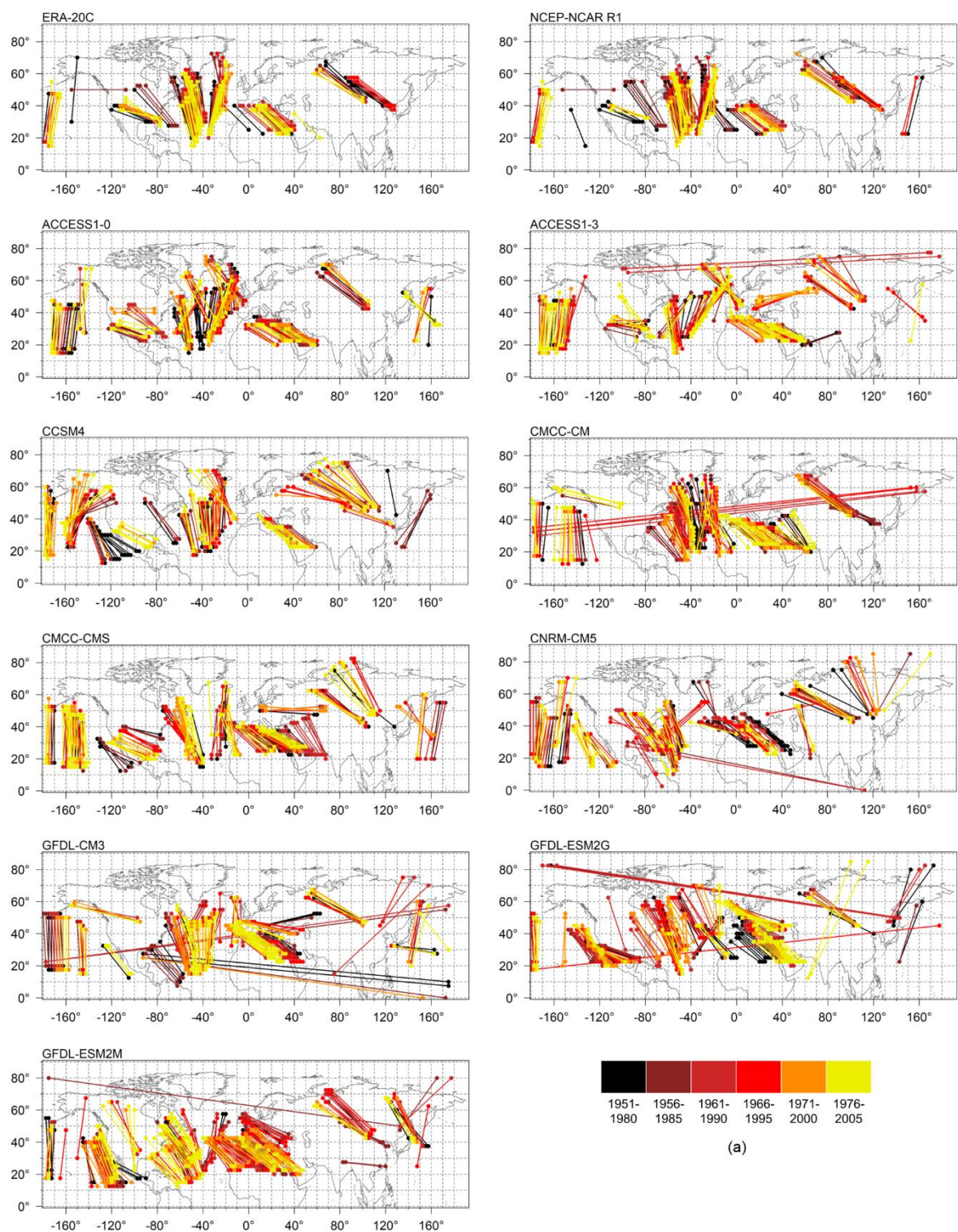
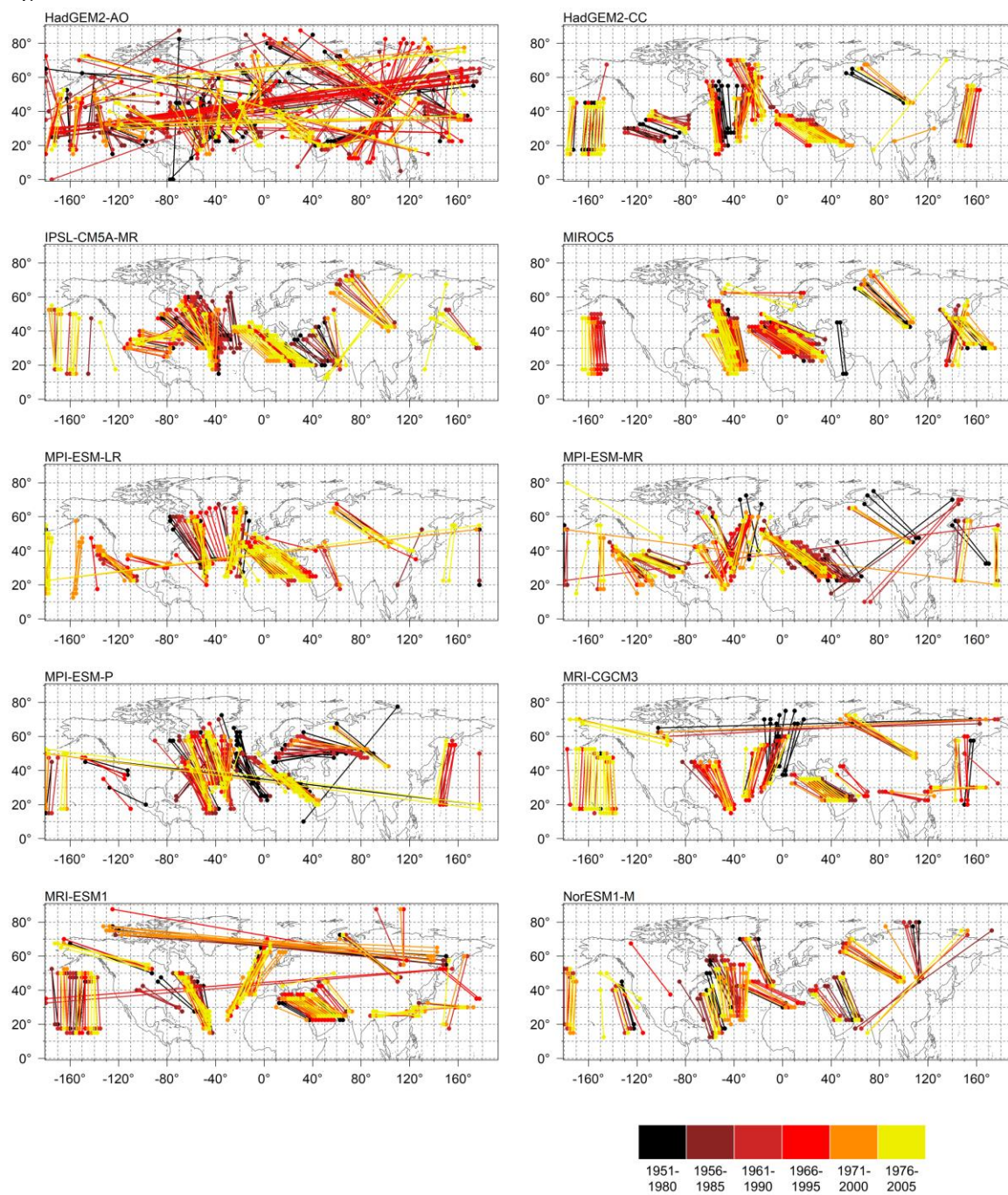


Figure S5. PotACs obtained from the analysis of correlation maps in case of (a) all 30-year-long periods, (b) all 10-year-long periods. PotACs are represented with coloured circles which are connected with lines with the same colour. Brighter colours indicate periods closer to the year 2000. PotACs are associated with correlation values below the median of the strongest negative correlations.

Figure S5 continued.



(a)

Figure S5 continued.

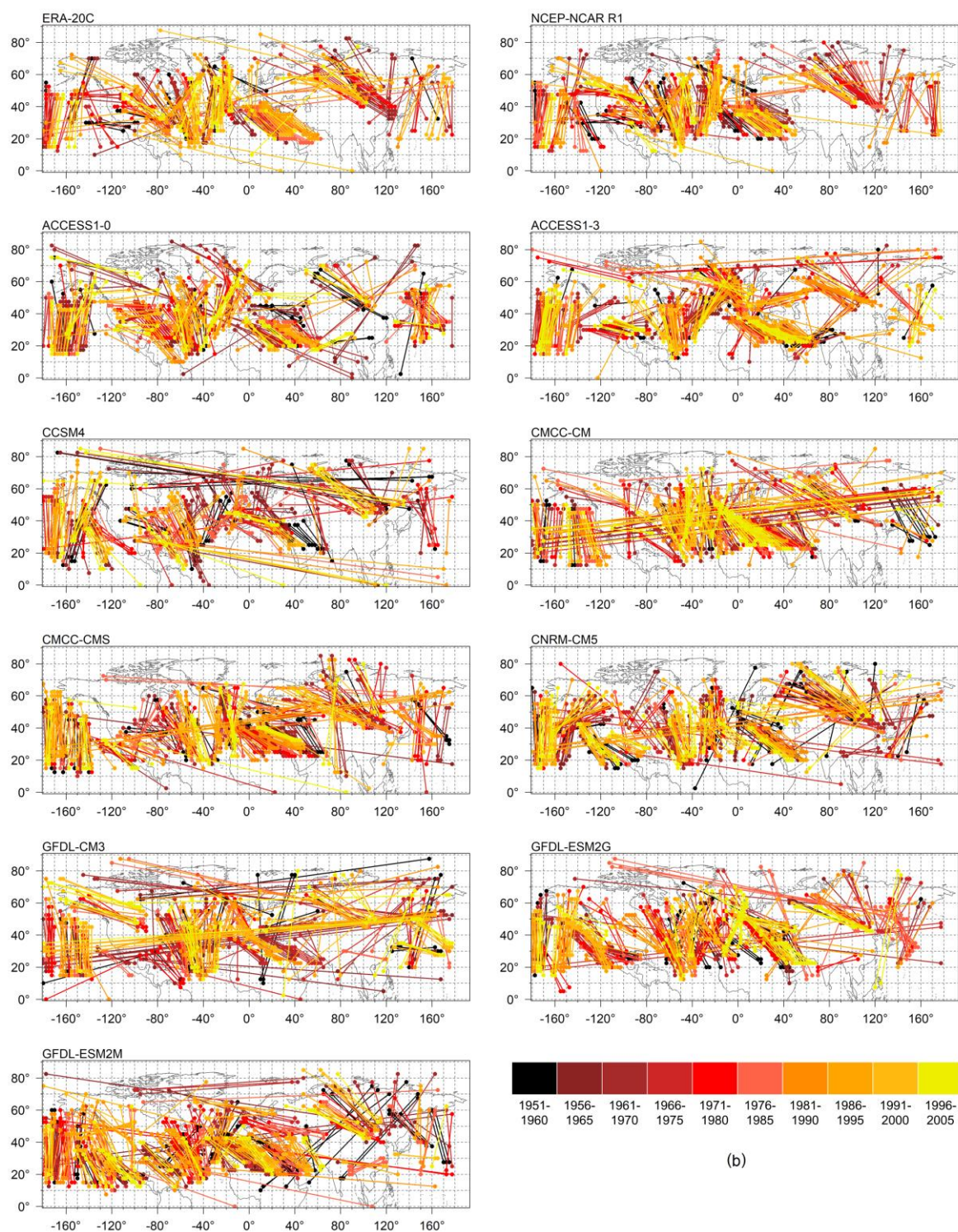
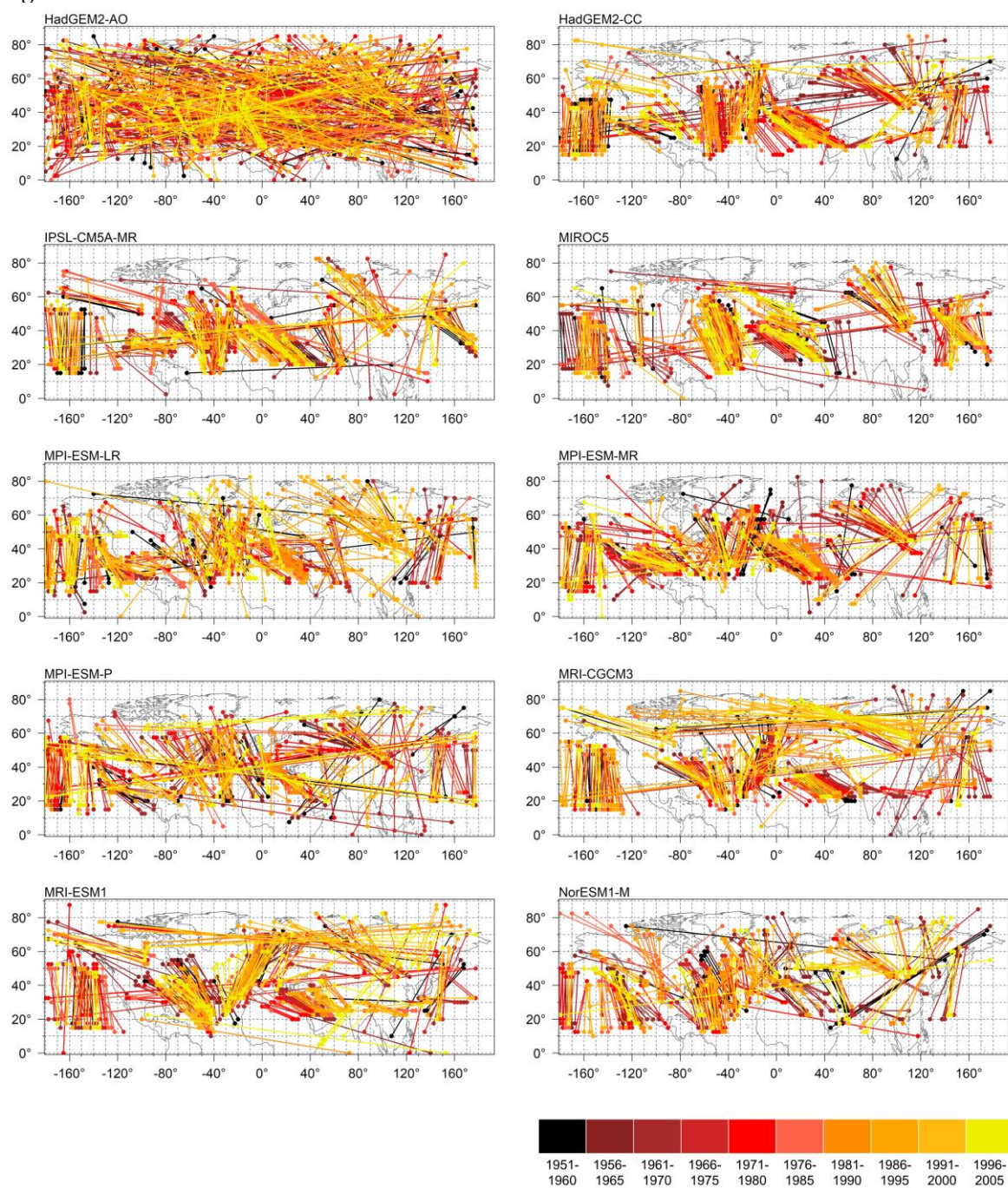
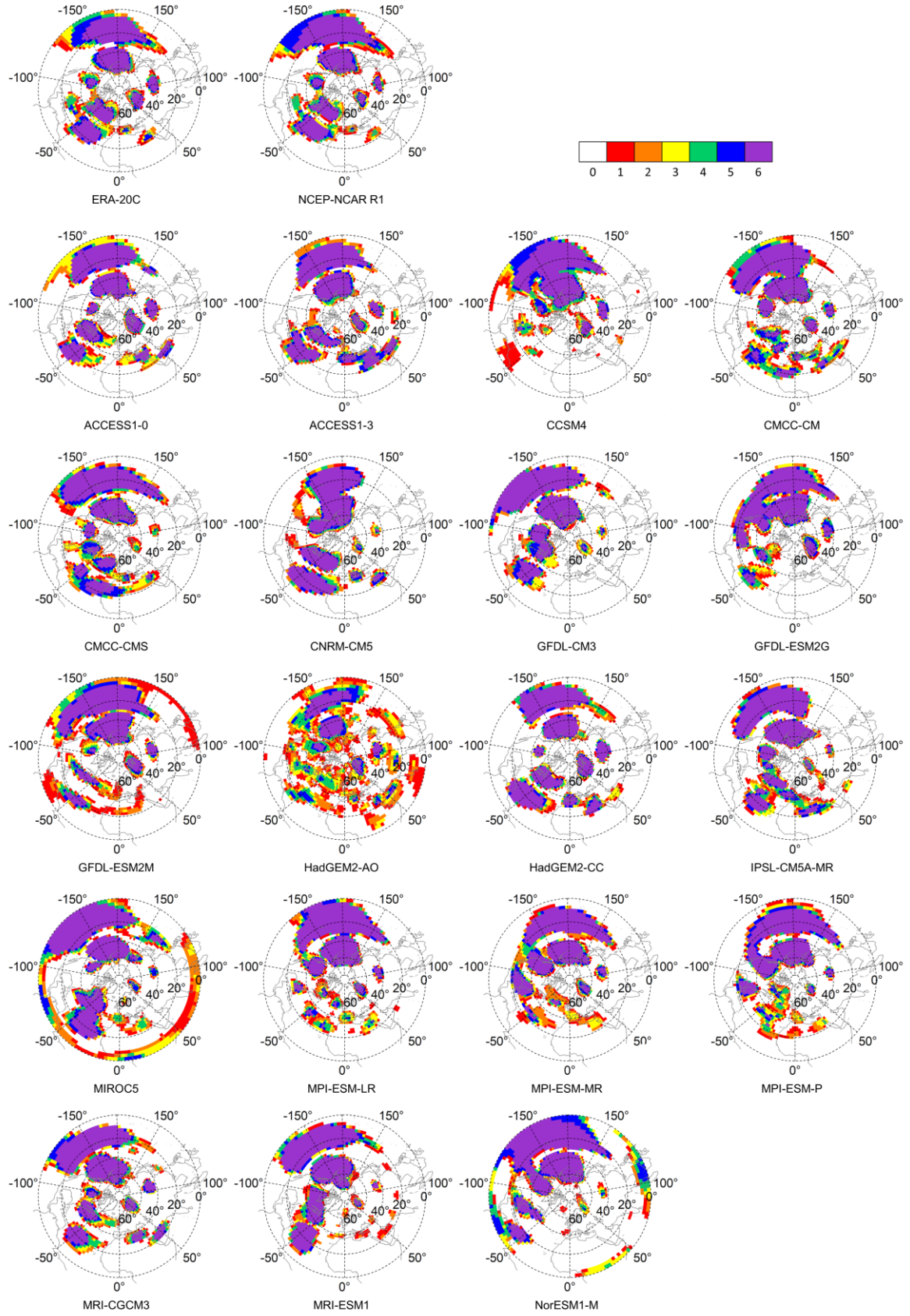


Figure S5 continued.



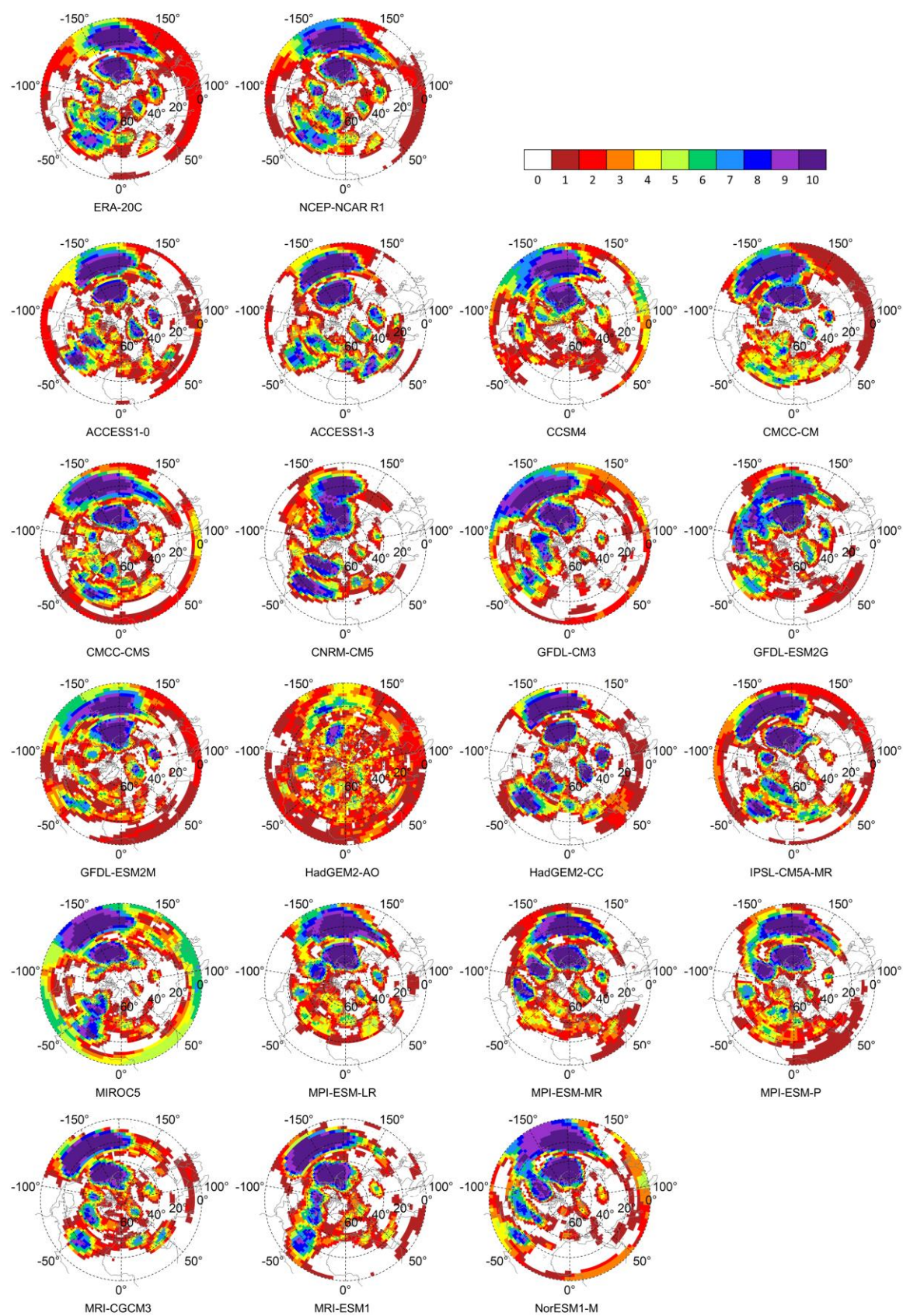
(b)



(a)

Figure S6. Stability pattern of each reanalysis/GCM. (a) The number of the 30-year-long periods, (b) the number of the 10-year-long periods with strongest negative correlation below the 25th percentiles of all correlations are shown in each grid cell.

Figure S6 continued.



(b)

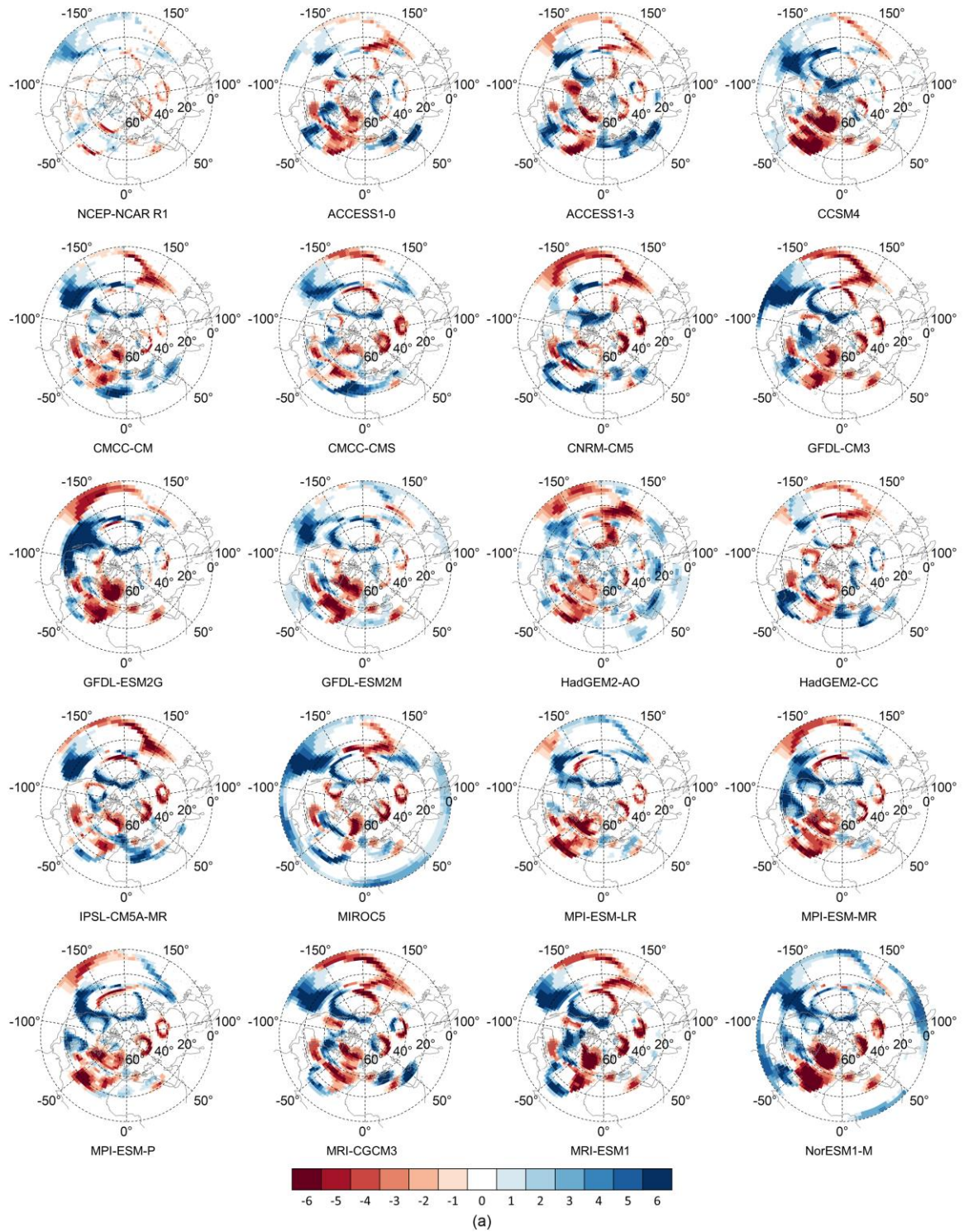


Figure S7. Difference map of each reanalysis/GCM relative to the ERA-20C (a, c) and the NCEP-NCAR R1 (b, d). Difference of number of periods with strongest negative correlation below the 25th percentile of all correlations relative to the selected reanalysis is given per each grid cell in case of (a, b) the 30-year-long periods and in case of (c, d) the 10-year-long periods.

Figure S7 continued.

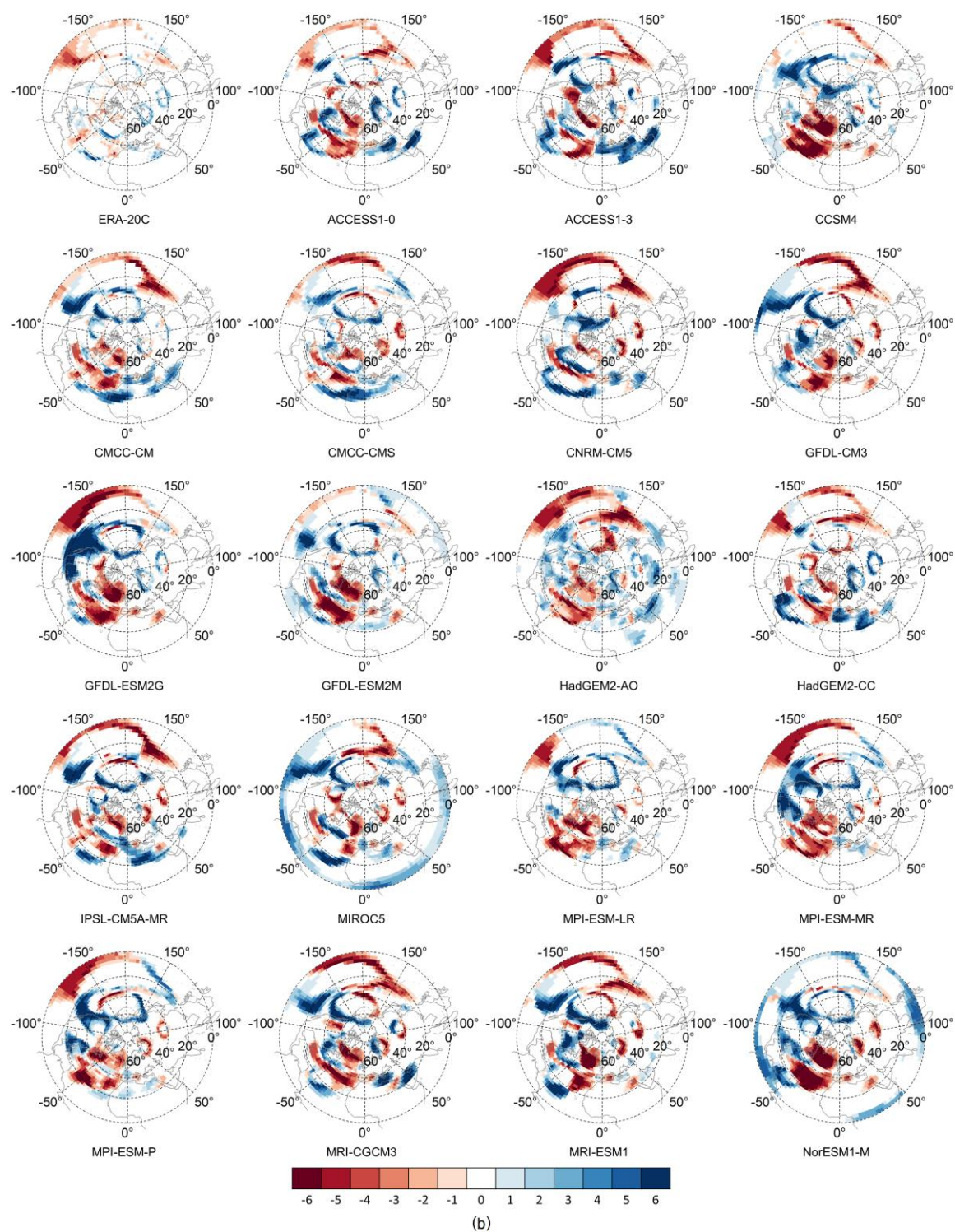


Figure S7 continued.

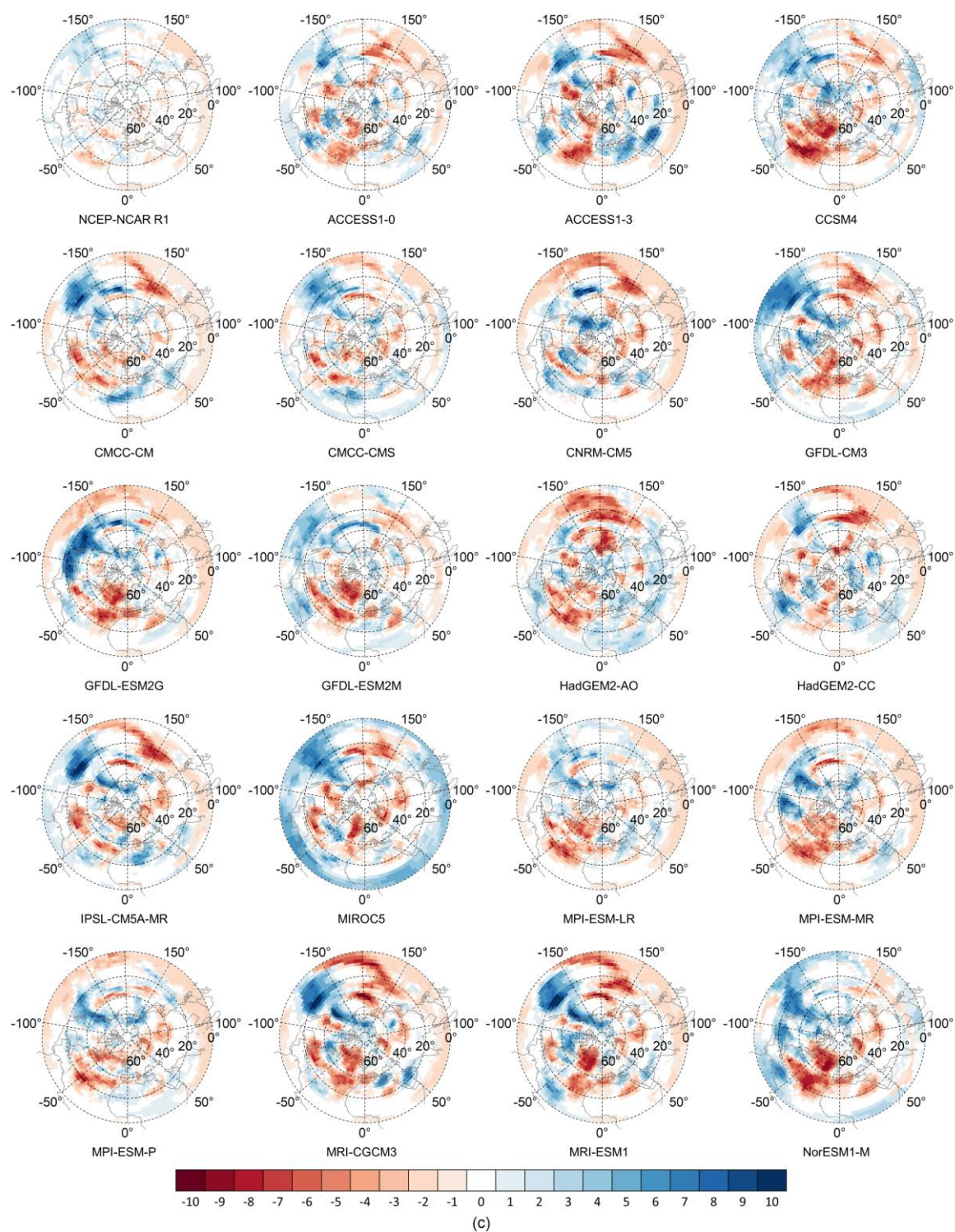
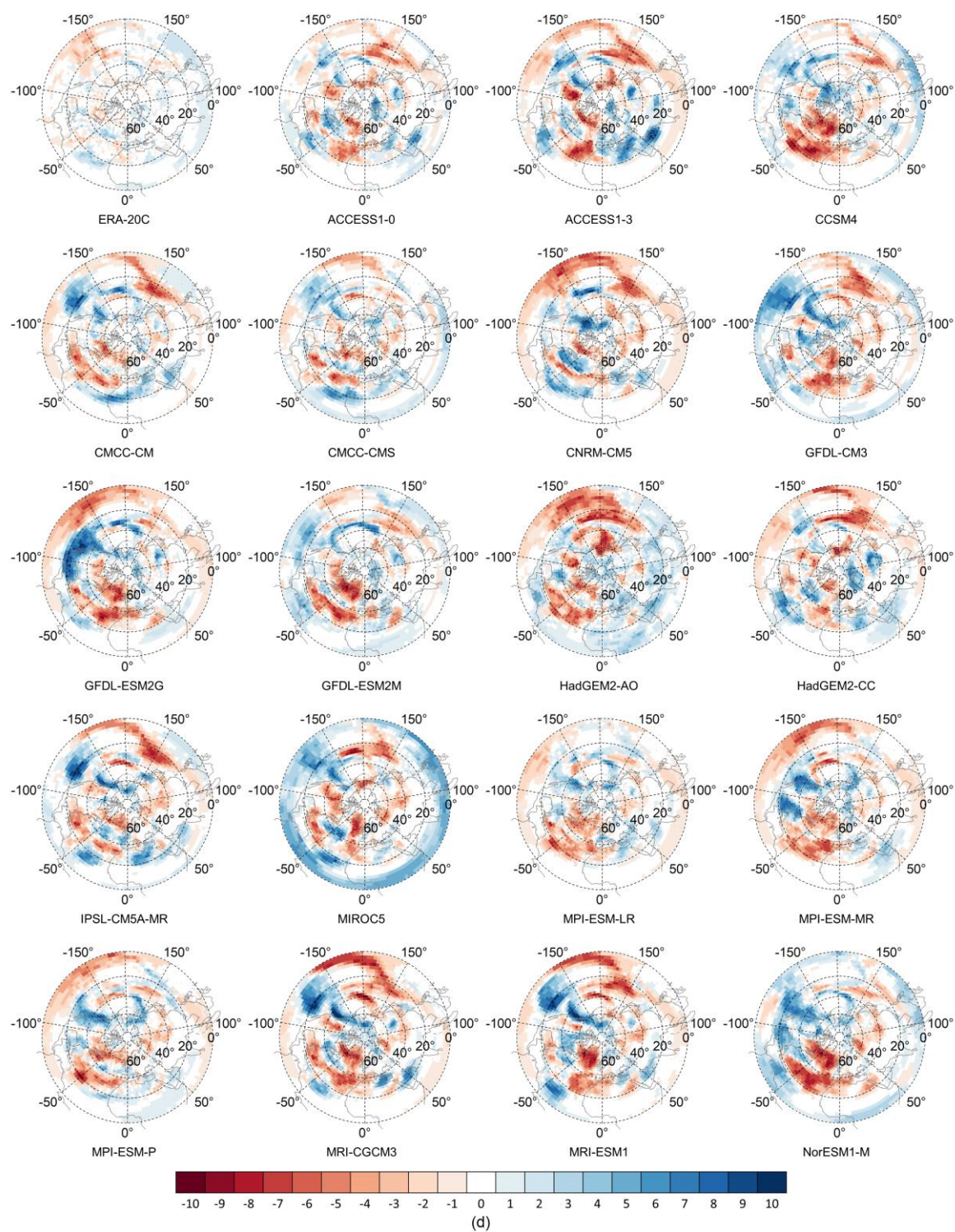


Figure S7 continued.



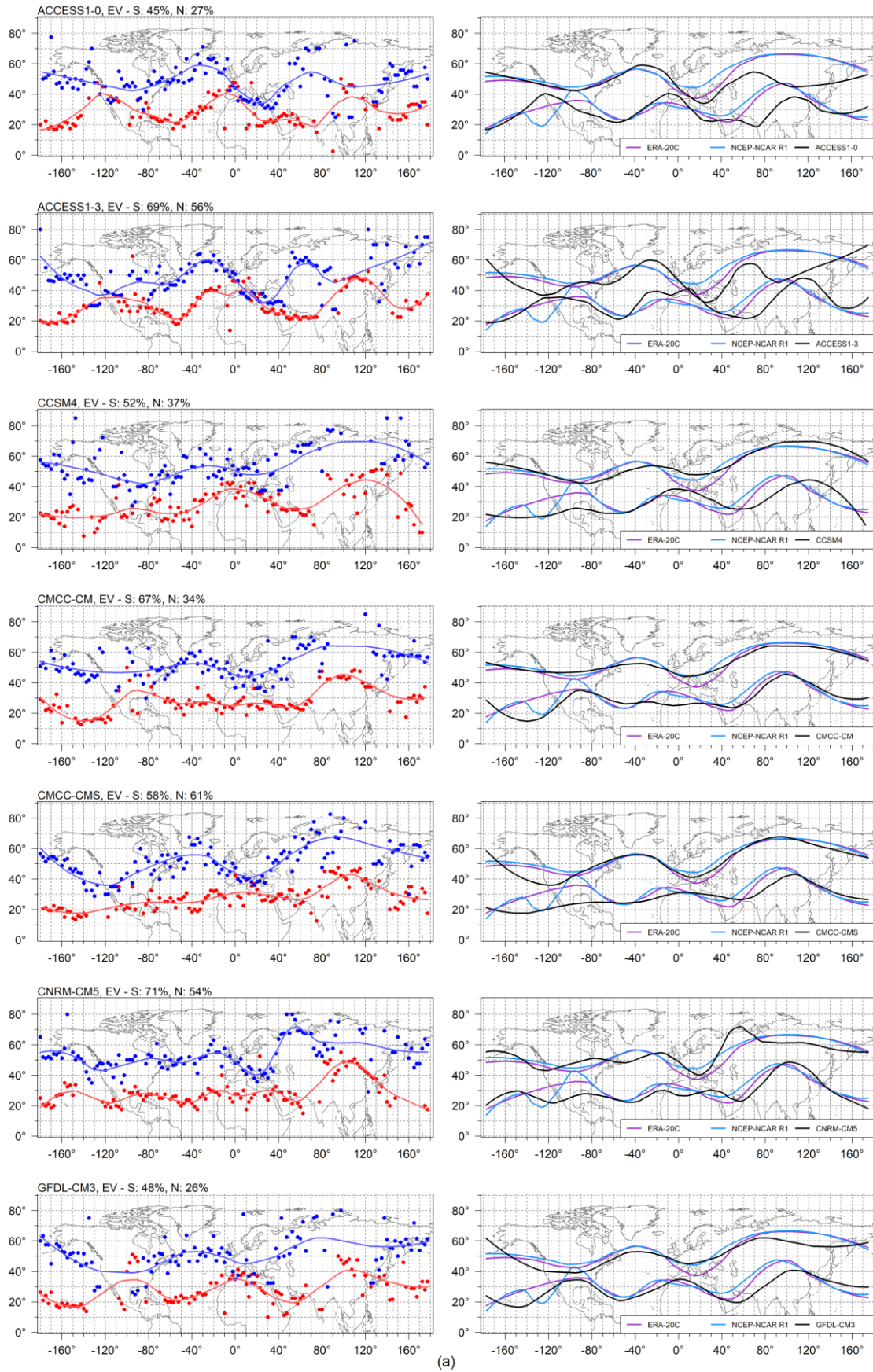
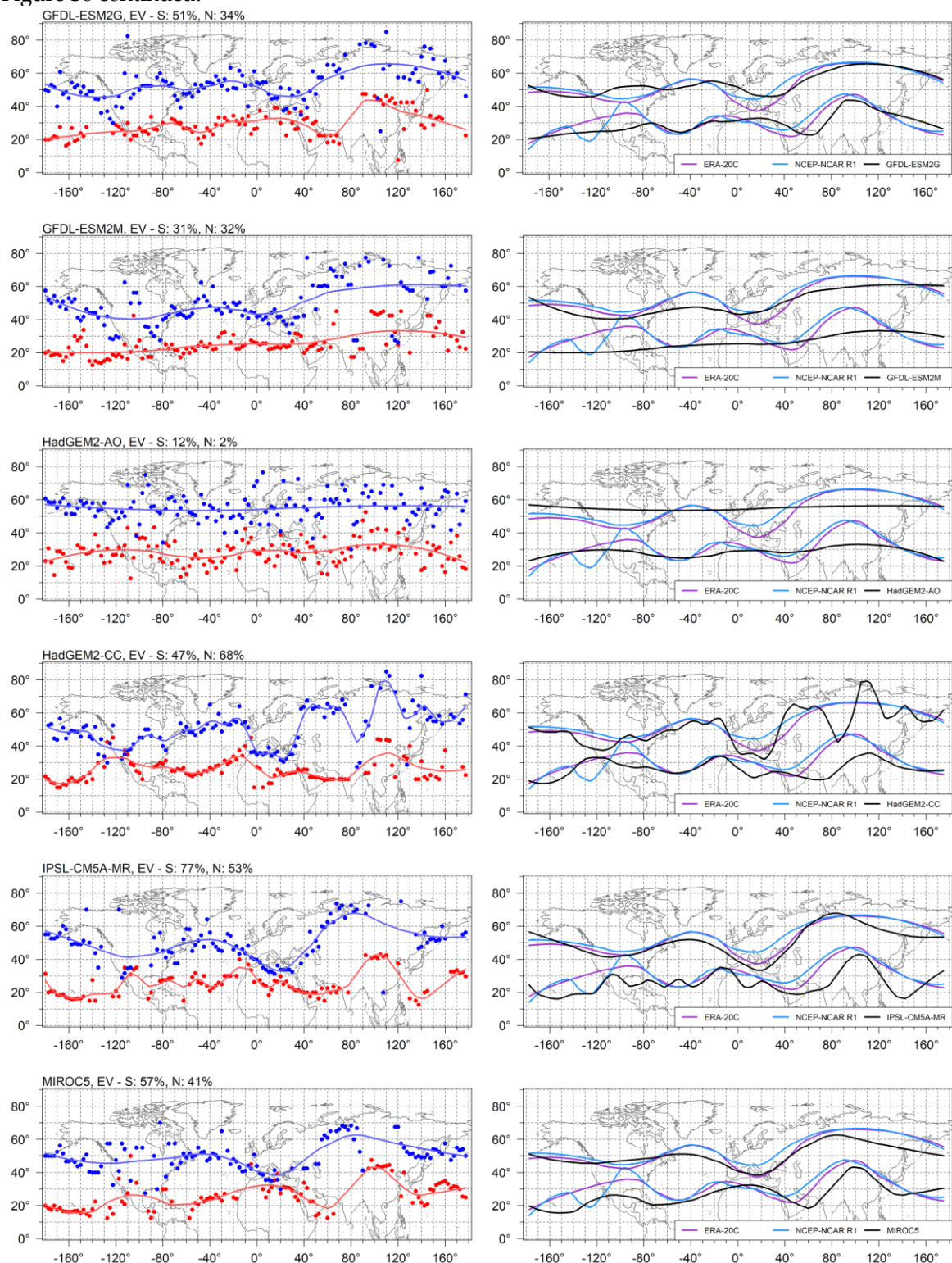


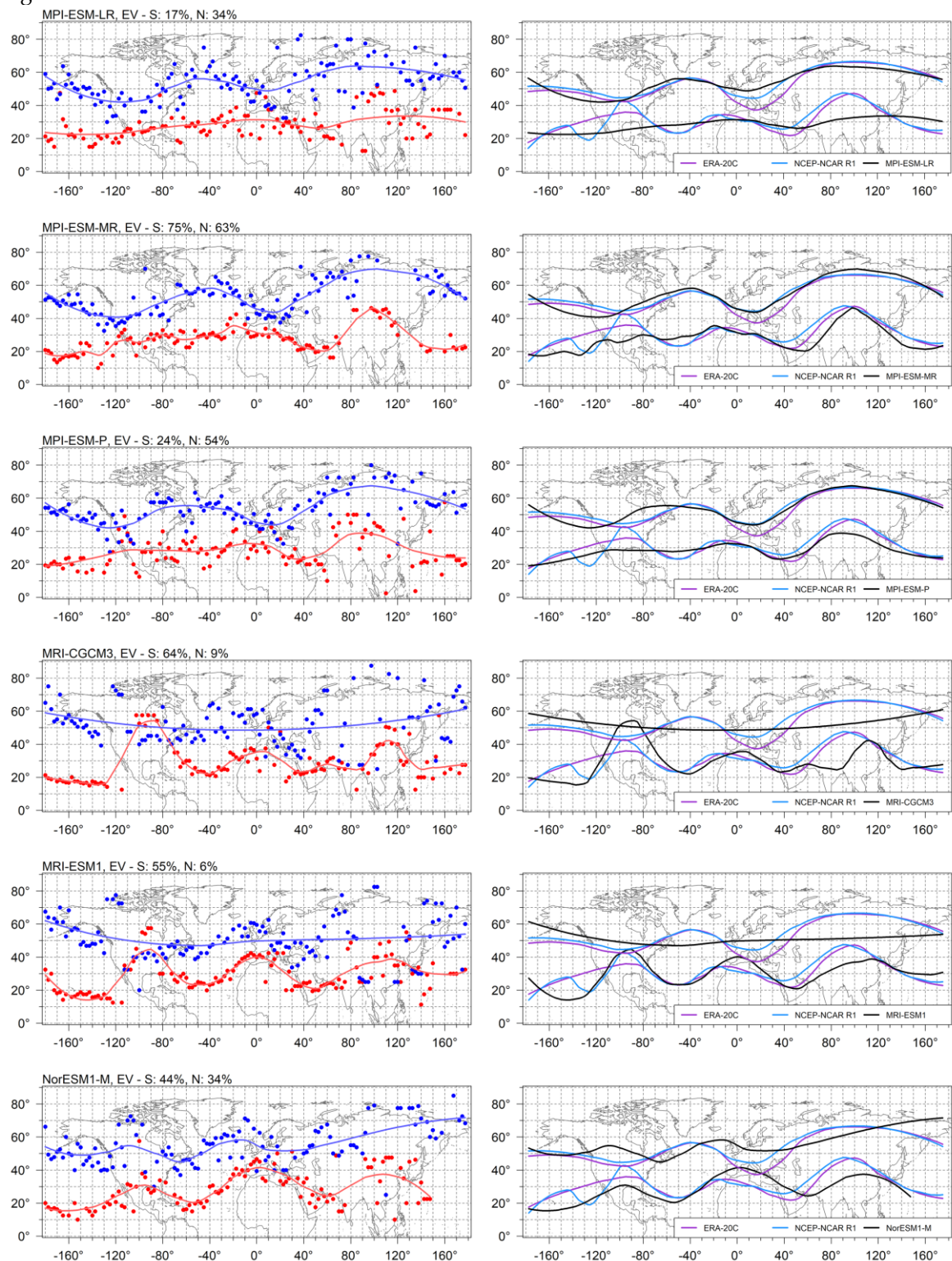
Figure S8. First column: loess regression curves fitted on the southerly and northerly located PotACs (denoted with red and blue circles, respectively) of each GCM (a) on maps with Atlantic view and (b) on maps with Pacific view. Explained variance (EV) of loess models in cases of southerly located PotACs (abbreviated as S) and northerly located PotACs (abbreviated with N) are indicated above the maps. Second column: Comparison of the GCM loess regression curves (denoted with black lines) against the reanalysis regression curves (the purple curve is for the ERA-20C while the blue curve is for the NCEP-NCAR R1).

Figure S8 continued.



(a)

Figure S8 continued.



(a)

Figure S8 continued.

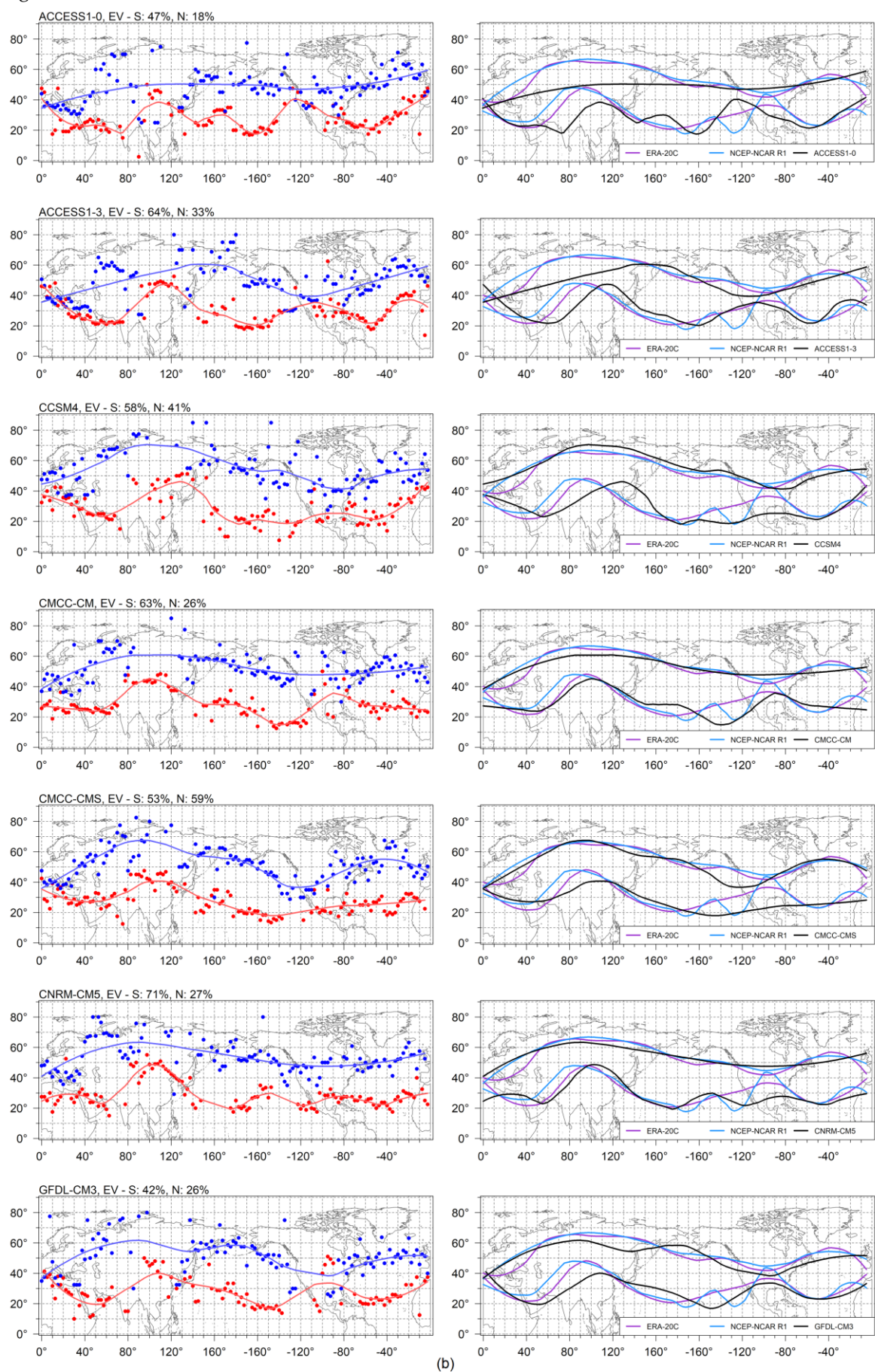
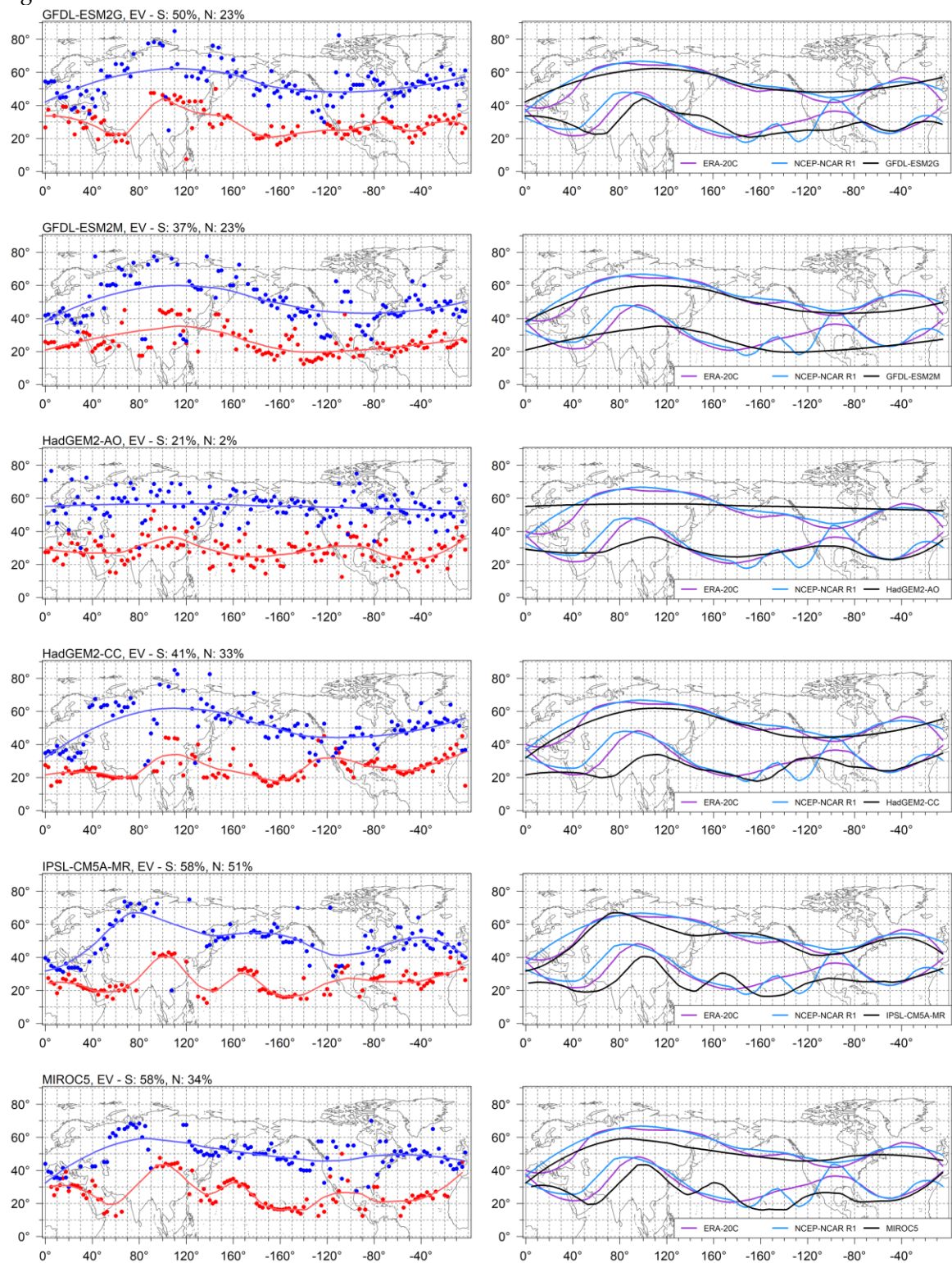
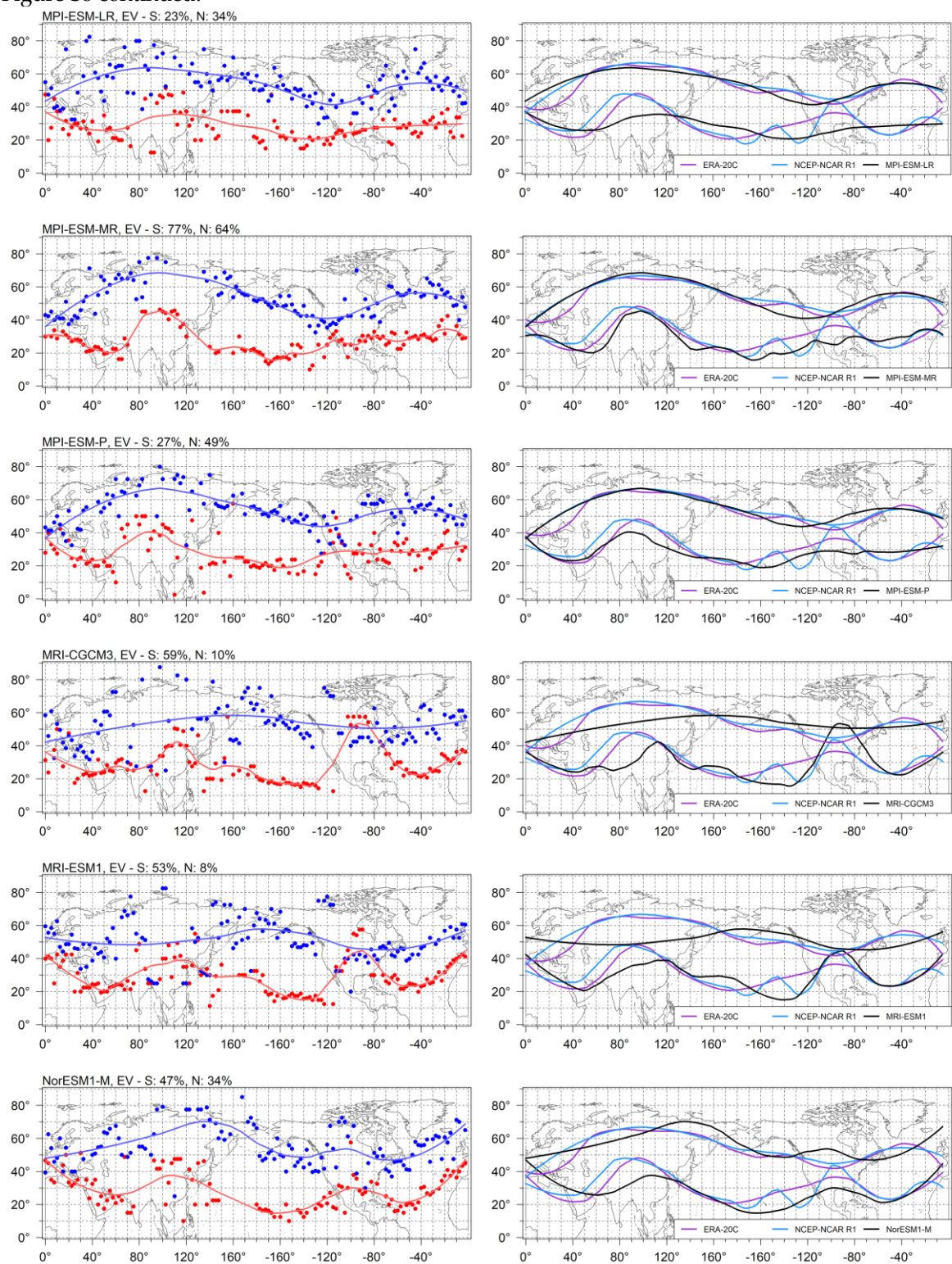


Figure S8 continued.



(b)

Figure S8 continued.



(b)