

## Supplementary Material for the article

### **Increased projected changes in quasi-resonant amplification and persistent summer weather extremes in the latest multimodel climate projections**

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**This document includes supplementary figures, tables, and information**

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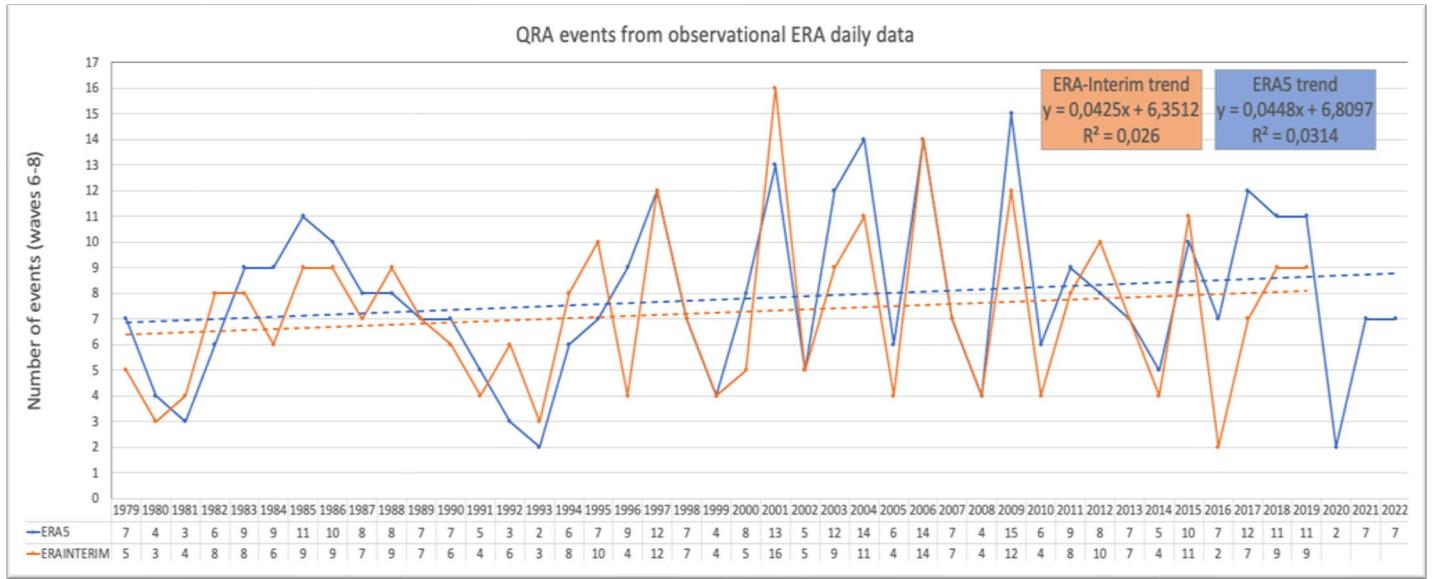
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**Figure S1:** Number of QRA events for JJA wave numbers from 6 to 8 for the ERA5 and ERA-Interim reanalysis.

### Mann-Kendall Trend Test

The Mann-Kendall Trend Test is a useful tool for identifying trends in time series data. Since it is non-parametric, no underlying assumption on the normality of the data is made ([1]).

If the **p-value** of the test is lower than some significance level (common choices are 0.10, 0.05, and 0.01), then there is statistically significant evidence that a trend is present in the time series data.

In our analysis, the trends were considered significant at significance level of 0.05.

Result for the ERA5 QRA events series (1979-2022) present in **Figure 1** and **Figure S1**:

**trend='no trend'**, **h=False**, **p=0.32732960607421324**, **z=0.9795068491984874**,  
**Tau=0.10253699788583509**, **s=97.0**, **var\_s=9605.666666666666**, **slope=0.031754032258064516**, and  
**intercept=6.317288306451613**.

Here is how to interpret the output of the test:

- **trend:** This tells the trend. Possible output includes increasing, decreasing, or no trend.
- **h:** True if trend is present. False if no trend is present.
- **p:** The p-value of the test.
- **z:** The normalized test statistic.
- **Tau:** Kendall Tau.
- **s:** Mann-Kendall's score
- **var\_s:** Variance S
- **slope:** Theil-Sen estimator/slope
- **intercept:** Intercept of Kendall-Theil Robust Line

N	M	Model (realizations)	Variant label	Nominal resolution (km)	Atm levels	Components	Institution	Experiments in this study
1	1	ACCESS-CM2 (1)	r1i1p1f1	250	85	AOGCM AER	CSIRO-ARCCSS	Historical SSP585 SSP370
2	2	ACCESS-ESM1-5 (1)	r1i1p1f1	250	38	AOGCM AER BGC	CSIRO	Historical SSP585 SSP370
3	3	AWI-CM-1-1-MR (1)	r1i1p1f1	100	95	AOGCM	AWI	Historical SSP585
4	4	AWI-ESM-1-1-LR (1)	r1i1p1f1	250	47	AOGCM	AWI	Historical
5	5	BCC-CSM2-MR (1)	r1i1p1f1	100	46	AOGCM	BCC	Historical SSP585 SSP370
6	6	BCC-ESM1 (1)	r1i1p1f1	250	26	AOGCM AER CHEM	BCC	Historical
7	7	CAMS-CSM1-0 (1)	r1i1p1f1	100	31	AOGCM	CAMS	Historical
8	8	CanESM5-CanOE (1)	r1i1p2f1	500	49	AOGCM AER BGC	CCCma	Historical SSP585
9			r1i1p1f1					Historical SSP585 SSP370
10	9	CanESM5 (3)	r1i1p2f1	500	49	AOGCM AER BGC	CCCma	Historical SSP585 SSP370
11			r2i1p1f1					Historical SSP585 SSP370
12	10	CAS-ESM2-0 (1)	r1i1p1f1	100	35	AOGCM	CAS	Historical SSP585
13	11	CESM2-FV2 (1)	r1i1p1f1	250	60	AOGCM BGC CHEM AER	NCAR	Historical
14	12	CESM2 (1)	r1i1p1f1	100	60	AOGCM BGC CHEM AER	NCAR	Historical SSP585
15	13	CESM2-WACCM-FV2 (1)	r1i1p1f1	100	70	AOGCM BGC CHEM AER	NCAR	Historical
16	14	CESM2-WACCM (1)	r1i1p1f1	100	70	AOGCM BGC CHEM AER	NCAR	Historical SSP585 SSP370
17	15	CMCC-CM2-HR4 (1)	r1i1p1f1	100	26	AOGCM	CMCC	Historical
18	16	CMCC-CM2-SR5 (1)	r1i1p1f1	100	30	AOGCM AER	CMCC	Historical SSP585
19	17	CMCC-ESM2 (1)	r1i1p1f1	100	30	AOGCM AER BGC	CMCC	Historical SSP585
20	18	CNRM-CM6-1 (1)	r1i1p1f2	250	91	AOGCM CHEM	CNRM-CERFACS	Historical SSP585 SSP370
21	19	CNRM-ESM2-1 (1)	r1i1p1f2	250	91	AOGCM BGC AER CHEM	CNRM-CERFACS	Historical SSP585 SSP370
22	20	E3SM-1-0 (1)	r1i1p1f1	100	72	AOGCM AER CHEM	E3SM-Project	Historical
23	21	E3SM-1-1-ECA (1)	r1i1p1f1	100	72	AOGCM BGC AER CHEM	E3SM-Project	Historical
24	22	E3SM-1-1 (1)	r1i1p1f1	100	72	AOGCM BGC AER CHEM	E3SM-Project	Historical SSP585
25	23	EC-Earth3-AerChem (1)	r1i1p1f1	100	91	AOGCM AER CHEM	EC-Earth-Consortium	Historical
26	24	EC-Earth3-CC (1)	r1i1p1f1	100	91	AOGCM BGC	EC-Earth-Consortium	Historical SSP585
27	25	EC-Earth3 (2)	r1i1p1f1	100	91	AOGCM	EC-Earth-Consortium	Historical SSP585 SSP370
28			r4i1p1f1					Historical SSP585 SSP370
29	26	EC-Earth3-Veg (1)	r1i1p1f1	100	91	AOGCM	EC-Earth-Consortium	Historical SSP585 SSP370
30	27	EC-Earth3-Veg-LR (1)	r1i1p1f1	250	62	AOGCM	EC-Earth-Consortium	Historical SSP585
31	28	FGOALS-f3-L (1)	r1i1p1f1	100	32	AOGCM	CAS	Historical SSP585 SSP370
32	29	FGOALS-g3 (1)	r1i1p1f1	250	26	AOGCM	CAS	Historical SSP585 SSP370
33	30	FIO-ESM-2-0 (1)	r1i1p1f1	100	26	AOGCM BGC	FIO-QLNM	Historical SSP585
34	31	GFDL-CM4 (1)	r1i1p1f1	100	33	AOGCM AER CHEM BGC	NOAA-GFDL	Historical SSP585
35	32	GFDL-ESM4 (1)	r1i1p1f1	100	49	AOGCM AER CHEM BGC	NOAA-GFDL	Historical SSP585 SSP370
36	33	GISS-E2-1-G-CC (1)	r1i1p1f1	250	40	AOGCM AER CHEM BGC	NASA-GISS	Historical
37	34	GISS-E2-1-G (2)	r1i1p3f1	250	40	AOGCM AER CHEM BGC	NASA-GISS	Historical SSP585
38			r1i1p1f1					Historical SSP585
39	35	GISS-E2-1-H (1)	r1i1p1f1	250	40	AOGCM AER CHEM BGC	NASA-GISS	Historical
40	36	HadGEM3-GC31-L1 (1)	r1i1p1f3	250	85	AOGCM AER	MOHC	Historical SSP585
41	37	HadGEM3-GC31-MM (1)	r1i1p1f3	100	85	AOGCM AER	MOHC	Historical SSP585
42	38	IITM-ESM (1)	r1i1p1f1	250	64	AOGCM BGC	CCCR-IITM	Historical
43	39	INM-CM4-8 (1)	r1i1p1f1	100	21	AOGCM AER	INM	Historical SSP585 SSP370
44	40	INM-CM5-0 (1)	r1i1p1f1	100	73	AOGCM AER	INM	Historical SSP585 SSP370
45	41	IPSL-CM5A2-INCA (1)	r1i1p1f1	500	39	AOGCM BGC AER CHEM	IPSL	Historical
46	42	IPSL-CM6A-LR (1)	r1i1p1f1	250	75	AOGCM BGC	IPSL	Historical SSP585 SSP370
47	43	IPSL-CM6A-LR-INCA (1)	r1i1p1f1	250	75	AOGCM BGC AER	IPSL	Historical
48	44	KACE-1-0-G (1)	r1i1p1f1	250	85	AOGCM AER	NIMS-KMA	Historical SSP585
49	45	KIOT-Esm (1)	r1i1p1f1	250	32	AOGCM AER BGC	KIOT	Historical SSP585
50	46	MCM-UA-1-0 (2)	r1i1p1f1	250	14	AOGCM AER	UA	Historical
51	47		r1i1p1f2					Historical SSP585 SSP370
52	48	MIROC6 (1)	r1i1p1f1	250	81	AOGCM AER BGC	MIROC	Historical SSP585 SSP370
53	49	MIROC-ES2L (1)	r1i1p1f2	500	40	AOGCM AER BGC	MIROC	Historical SSP585 SSP370
54	50	MPI-ESM-1-2-HAM (1)	r1i1p1f1	250	47	AOGCM AER CHEM BGC	HAMMOZ-Consortium	Historical
55	51	MPI-ESM1-2-HR (2)	r1i1p1f1	100	95	AOGCM BGC	MPI-M	Historical SSP585 SSP370
56			r2i1p1f1					Historical SSP585 SSP370
57	52	MPI-ESM1-2-LR (1)	r1i1p1f1	250	47	AOGCM BGC	MPI-M	Historical SSP585 SSP370
58	53	MRI-ESM2-0 (1)	r1i1p1f1	100	80	AOGCM AER CHEM BGC	MRI	Historical SSP585 SSP370
59	54	NESM3 (1)	r1i1p1f1	250	47	AOGCM	NUIST	Historical SSP585
60	55	NorCPM1 (1)	r1i1p1f1	250	26	AOGCM AER BGC	NCC	Historical
61	56	NorESM2-LM (2)	r1i1p1f1	250	32	AOGCM AER BGC CHEM	NCC	Historical SSP585 SSP370
62			r2i1p1f1					Historical
63	57	NorESM2-MM (1)	r1i1p1f1	100	32	AOGCM AER BGC CHEM	NCC	Historical SSP585 SSP370
64	58	SAMO-UNICON (1)	r1i1p1f1	100	30	AOGCM BGC AER	SNU	Historical
65	59	TaiESM1 (1)	r1i1p1f1	100	30	AOGCM AER BGC	AS-RCEC	Historical SSP585
66	60	UKESM1-0-LL (1)	r1i1p1f2	250	85	AOGCM AER BGC CHEM	MOHC	Historical SSP585 SSP370

**Table S1:** CMIP6 multimodel ensemble. Additional information was obtained from [2] and [3].

N	M	Model (realizations)	Variant label	Nominal resolution (km)	Atm levels	Components	Institution	Experiments in this study
1	1	ACCESS1-0 (2)	r1i1p1 r2i1p1	250	38	AOGCM AER CHEM BGC	CSIRO-BOM	Historical RCP85 Historical
3			r1i1p1					Historical RCP85
4	2	ACCESS1.3 (3)	r2i1p1 r3i1p1	250	38	AOGCM AER	CSIRO-BOM	Historical Historical
6			r1i1p1					Historical RCP85
7	3	bcc-csm1-1 (3)	r2i1p1 r3i1p1	500	26	AOGCM BGC	BCC	Historical Historical
9			r1i1p1					Historical RCP85
10	4	bcc-csm1-1-m (3)	r2i1p1 r3i1p1	100	26	AOGCM BGC	BCC	Historical Historical
12	5	BNU-ESM (1)	r1i1p1	500	26	AOGCM AER BGC	BNU	Historical RCP85
13			r1i1p1					Historical RCP85
14			r2i1p1					Historical RCP85
15	6	CanESM2 (5)	r3i1p1	500	35	AOGCM AER BGC	CCCma	Historical RCP85
16			r4i1p1					Historical RCP85
17			r5i1p1					Historical RCP85
18			r1i1p1					Historical RCP85
19			r1i2p1					Historical
20			r1i2p2					Historical
21	7	CCSM4 (8)	r2i1p1 r3i1p1	100	27	AOGCM AER CHEM BGC	NCAR	Historical RCP85 Historical RCP85
23			r4i1p1					Historical RCP85
24			r5i1p1					Historical RCP85
25			r6i1p1					Historical RCP85
26	8	CESM1-BGC (1)	r1i1p1	100	27	AOGCM AER BGC	NSF-DOE-NCAR	Historical RCP85
27			r1i1p1					Historical
28	9	CESM1-CAM5.1-FV2 (4)	r2i1p1 r3i1p1 r4i1p1	250	30	AOGCM AER	NSF-DOE-NCAR	Historical Historical Historical
31	10	CESM1-CAM5 (2)	r1i1p1 r2i1p1	100	27	AOGCM AER	NSF-DOE-NCAR	Historical RCP85 Historical RCP85
33			r1i1p1					Historical
34	11	CESM1-FASTCHEM (3)	r2i1p1 r3i1p1	100	27	AOGCM AER CHEM	NSF-DOE-NCAR	Historical Historical
36	12	CESM1-WACCM (1)	r1i1p1	250	66	AOGCM AER	NSF-DOE-NCAR	Historical
37	13	CMCC-CESM (1)	r1i1p1	500	39	AOGCM AER BGC	CMCC	Historical RCP85
38	14	CMCC-CM (1)	r1i1p1	100	31	AOGCM AER	CMCC	Historical RCP85
39	15	CMCC-CMS (1)	r1i1p1	250	95	AOGCM AER	CMCC	Historical RCP85
40	16	CNRM-CM5-2 (1)	r1i1p1	250	31	AOGCM AER CHEM BGC	CNRM-CERFACS	Historical
41			r1i1p1					Historical RCP85
42			r2i1p1					Historical RCP85
43			r3i1p1					Historical
44			r4i1p1					Historical RCP85
45	17	CNRM-CM5 (10)	r5i1p1 r6i1p1 r7i1p1 r8i1p1 r9i1p1 r10i1p1	250	31	AOGCM CHEM BGC	CNRM-CERFACS	Historical Historical RCP85 Historical Historical Historical Historical RCP85
51			r1i1p1					Historical RCP85
52			r2i1p1					Historical RCP85
53			r3i1p1					Historical RCP85
54			r4i1p1					Historical RCP85
55	18	CSIRO-Mk3-6-0 (10)	r5i1p1 r6i1p1 r7i1p1 r8i1p1 r9i1p1 r10i1p1	250	18	AOGCM AER	CSIRO-QCCCE	Historical RCP85 Historical RCP85 Historical RCP85 Historical RCP85 Historical RCP85 Historical RCP85
56			r7i1p1					Historical RCP85
57			r8i1p1					Historical RCP85
58			r9i1p1					Historical RCP85
59			r10i1p1					Historical RCP85
60			r10i1p1					Historical RCP85

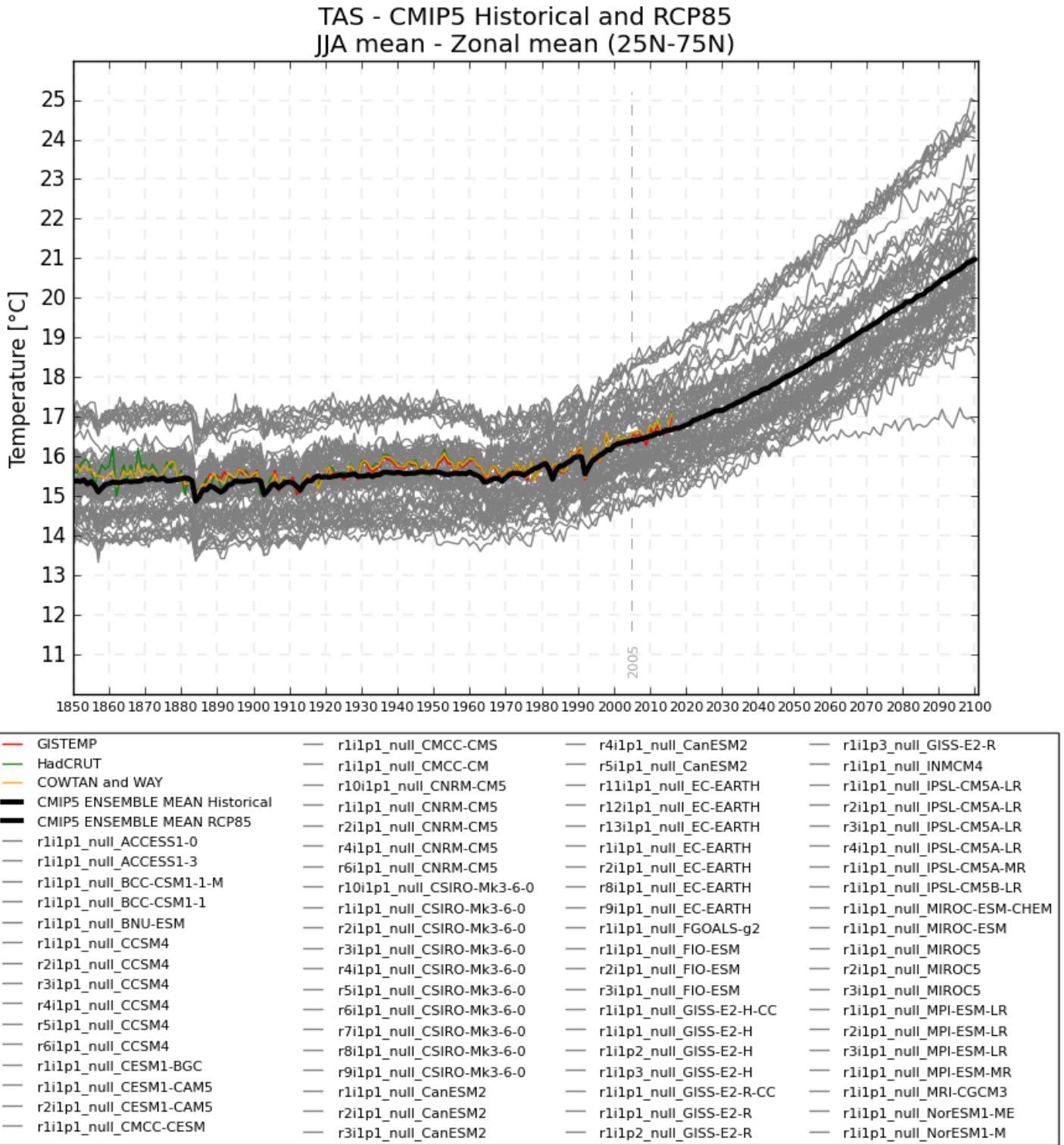
**Table S2:** CMIP5 multimodel ensemble. Additional information was obtained from [2] and [3].

N	M	Model (realizations)	Variant label	Nominal resolution (km)	Atm levels	Components	Institution	Experiments in this study
61			r1i1p1					Historical RCP85
62			r2i1p1					Historical RCP85
63			r7i1p1					Historical RCP85
64			r8i1p1					Historical
65	19	EC-EARTH (9)	r9i1p1	100	62	AOGCM	ICHEC	Historical RCP85
66			r11i1p1					Historical RCP85
67			r12i1p1					Historical
68			r13i1p1					Historical RCP85
69			r14i1p1					Historical RCP85
70			r1i1p1					Historical RCP85
71	20	FGOALS_g2 (4)	r3i1p1	500	26	AOGCM AER	LASG-CESS	Historical
72			r4i1p1					Historical
73			r5i1p1					Historical
74			r1i1p1					Historical RCP85
75	21	FIO-ESM (3)	r2i1p1	500	26	AOGCM BGC	FIO	Historical RCP85
76			r3i1p1					Historical RCP85
77	22	GISS-E2-H-CC (1)	r1i1p1	250	40	AOGCM BGC	NASA-GISS	Historical RCP85
78			r1i1p1					Historical RCP85
79			r1i1p2					Historical RCP85
80			r1i1p3					Historical RCP85
81			r2i1p1					Historical
82			r2i1p2					Historical
83			r2i1p3					Historical
84			r3i1p1					Historical
85			r3i1p2					Historical
86	23	GISS-E2-H (17)	r3i1p3	250	40	AOGCM AER CHEM	NASA-GISS	Historical
87			r4i1p1					Historical
88			r4i1p2					Historical
89			r4i1p3					Historical
90			r5i1p1					Historical
91			r5i1p2					Historical
92			r5i1p3					Historical
93			r6i1p1					Historical
94			r6i1p3					Historical
95	24	GISS-E2-R-CC (1)	r1i1p1	250	40	AOGCM BGC	NASA-GISS	Historical RCP85
96			r1i1p1					Historical RCP85
97			r1i1p2					Historical RCP85
98			r1i1p3					Historical RCP85
99			r2i1p1					Historical
100			r2i1p2					Historical
101			r2i1p3					Historical
102			r3i1p1					Historical
103			r3i1p2					Historical
104	25	GISS-E2-R (18)	r3i1p3	250	40	AOGCM AER CHEM	NASA-GISS	Historical
105			r4i1p1					Historical
106			r4i1p2					Historical
107			r4i1p3					Historical
108			r5i1p1					Historical
109			r5i1p2					Historical
110			r5i1p3					Historical
111			r6i1p1					Historical
112			r6i1p2					Historical
113			r6i1p3					Historical
114	26	inmcm4 (1)	r1i1p1	250	21	AOGCM BGC	INM	Historical RCP85
115			r1i1p1					Historical RCP85
116			r2i1p1					Historical RCP85
117	27	IPSL-CM5A-LR (6)	r3i1p1	500	39	AOGCM AER BGC	IPSL	Historical RCP85
118			r4i1p1					Historical RCP85
119			r5i1p1					Historical
120			r6i1p1					Historical

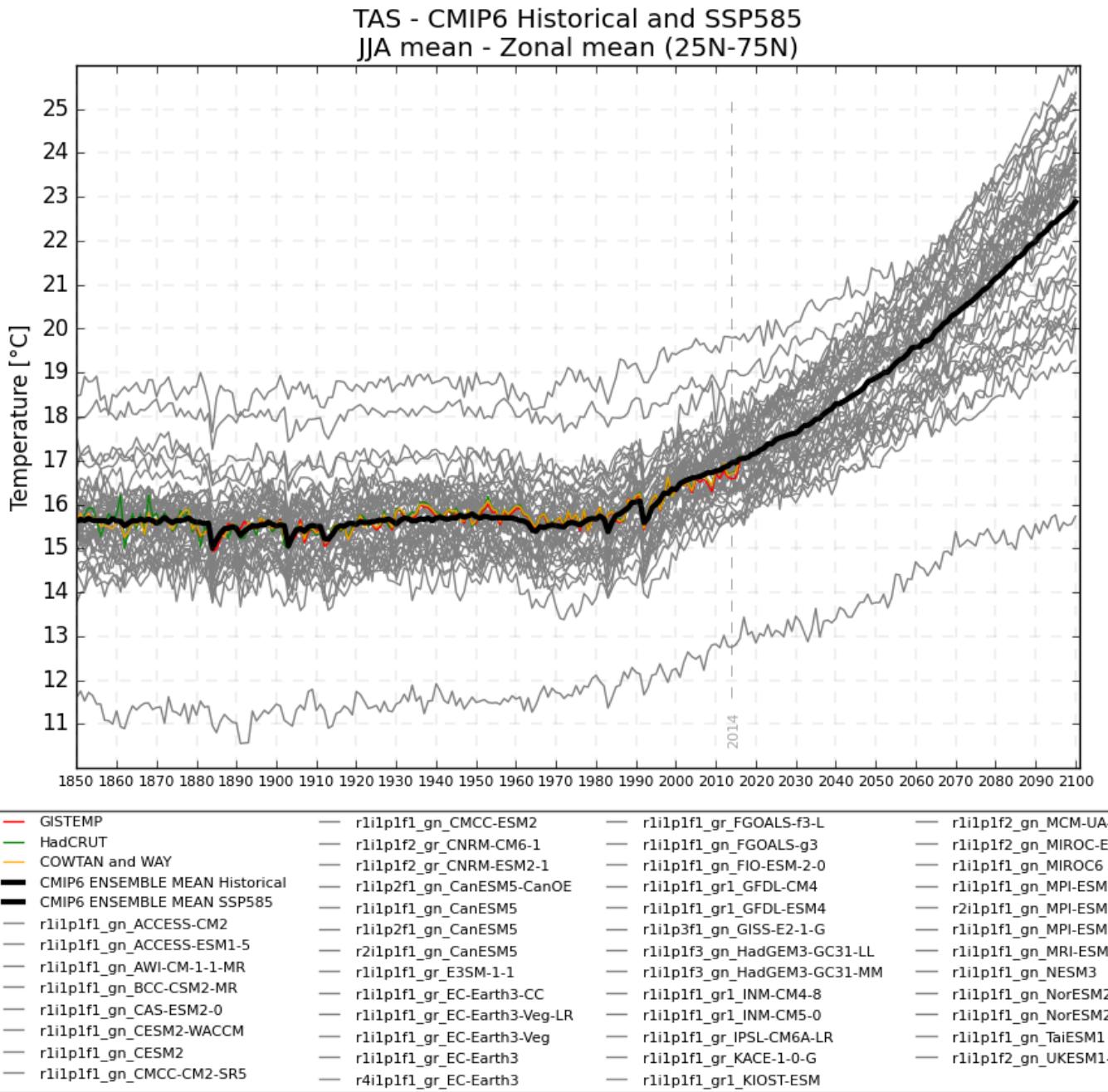
**Table S3:** CMIP5 multimodel ensemble (continuation). Additional information was obtained from [2] and [3].

N	M	Model (realizations)	Variant label	Nominal resolution (km)	Atm levels	Components	Institution	Experiments in this study
121			r1i1p1					Historical RCP85
122	28	IPSL-CM5A-MR (3)	r2i1p1	250	39	AOGCM AER BGC	IPSL	Historical
123			r3i1p1					Historical
124	29	IPSL-CM5B-LR (1)	r1i1p1	500	39	AOGCM AER BGC	IPSL	Historical RCP85
125			r1i1p1					Historical RCP85
126			r2i1p1					Historical RCP85
127	30	MIROC5 (5)	r3i1p1	250	40	AOGCM AER	MIROC	Historical RCP85
128			r4i1p1					Historical
129			r5i1p1					Historical
130	31	MIROC-ESM-CHEM (1)	r1i1p1	500	80	AOGCM AER CHEM BGC	MIROC	Historical RCP85
131			r1i1p1					Historical RCP85
132	32	MIROC-ESM (3)	r2i1p1	500	38	AOGCM AER BGC	MIROC	Historical
133			r3i1p1					Historical
134			r1i1p1					Historical RCP85
135	33	MPI-ESM-LR (3)	r2i1p1	250	47	AOGCM BGC	MPI-M	Historical RCP85
136			r3i1p1					Historical RCP85
137			r1i1p1					Historical RCP85
138	34	MPI-ESM-MR (3)	r2i1p1	250	95	AOGCM BGC	MPI-M	Historical
139			r3i1p1					Historical
140	35	MPI-ESM-P (2)	r1i1p1					Historical
141			r2i1p1	250	47	AOGCM BGC	MPI-M	Historical
142			r1i1p1					Historical RCP85
143			r2i1p1					Historical
144	36	MRI-CGCM3 (5)	r3i1p1	100	48	AOGCM AER	MRI	Historical
145			r4i1p2					Historical
146			r5i1p2					Historical
147	37	NorESM1-ME (1)	r1i1p1	250	26	AOGCM AER CHEM BGC	NCC	Historical RCP85
148			r1i1p1					Historical RCP85
149	38	NorESM1-M (3)	r2i1p1	250	26	AOGCM AER CHEM	NCC	Historical
150			r3i1p1					Historical

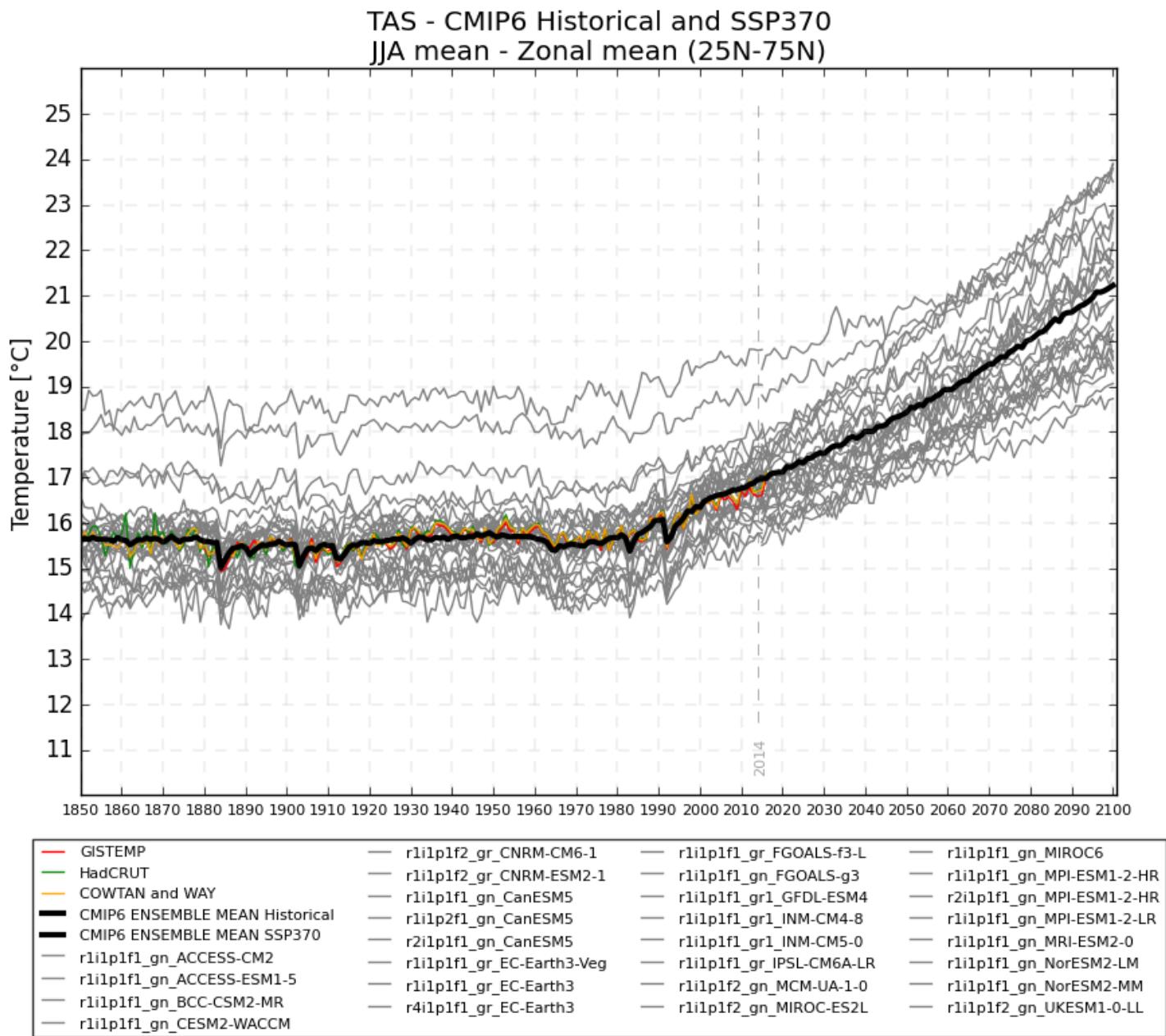
**Table S4:** CMIP5 multimodel ensemble (continuation). Additional information was obtained from [2] and [3].



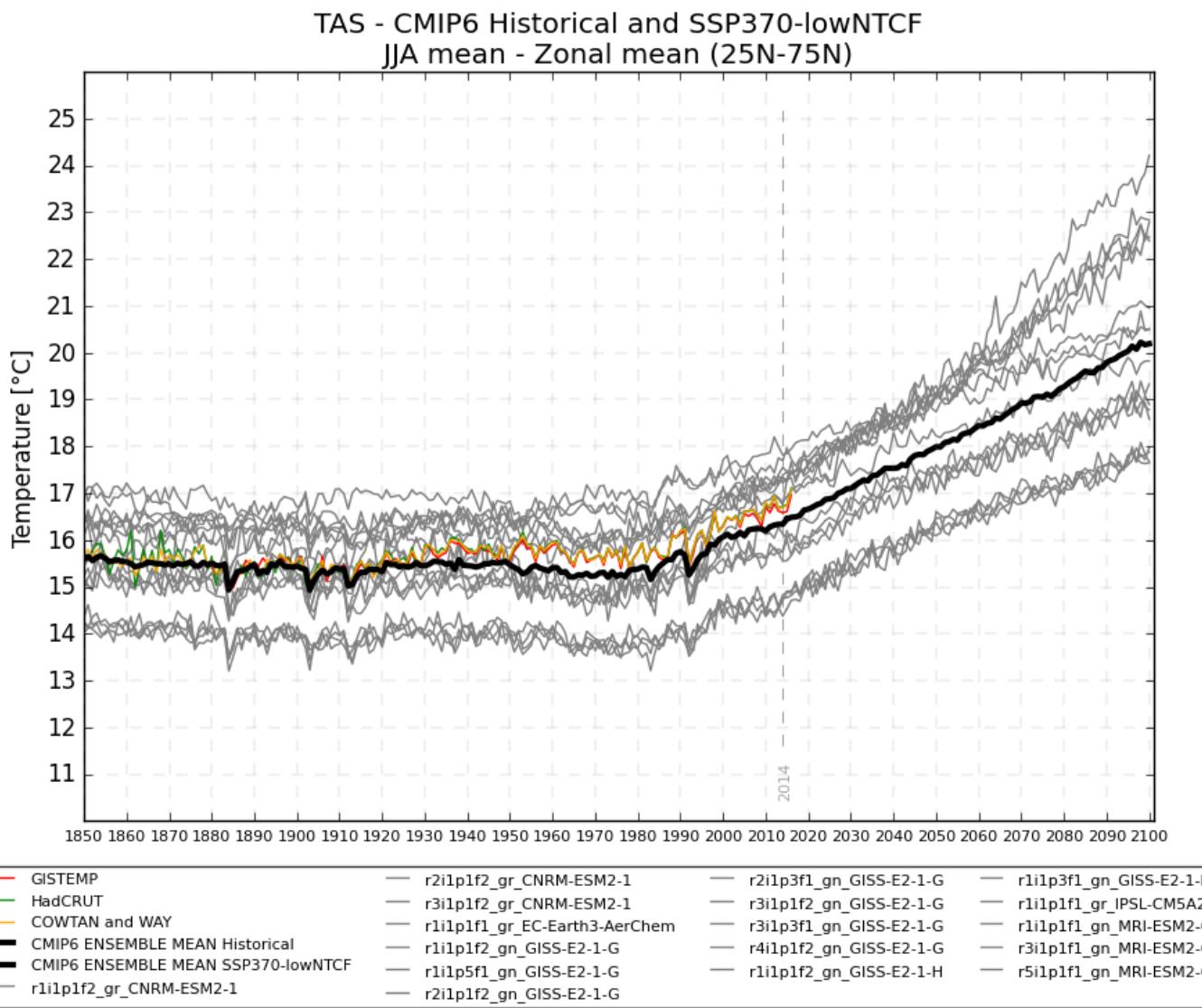
**Figure S2:** Temperature JJA seasonal means for CMIP5 Historical and RCP85 simulations.



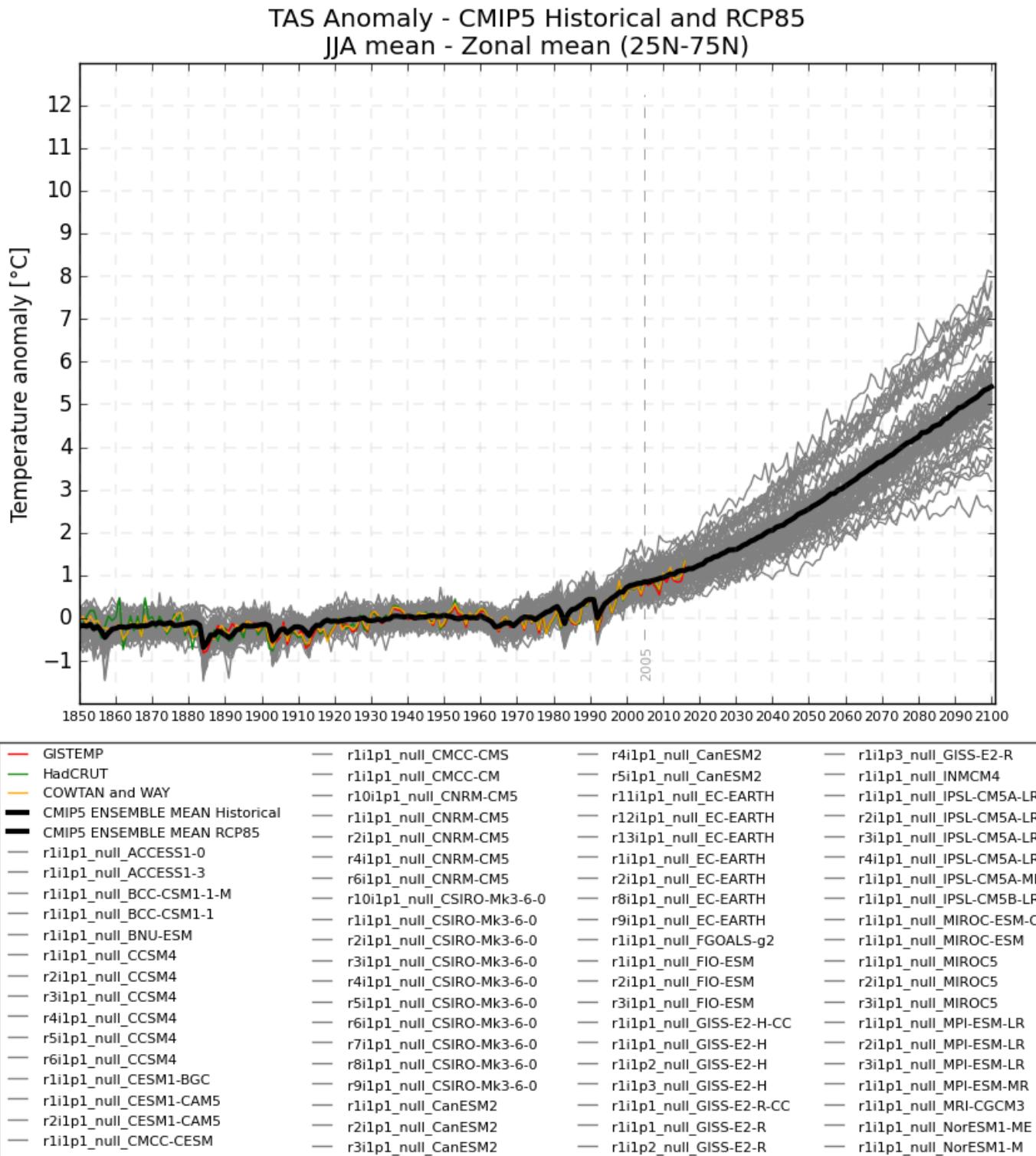
**Figure S3:** Temperature JJA seasonal means for CMIP6 Historical and SSP585 simulations.



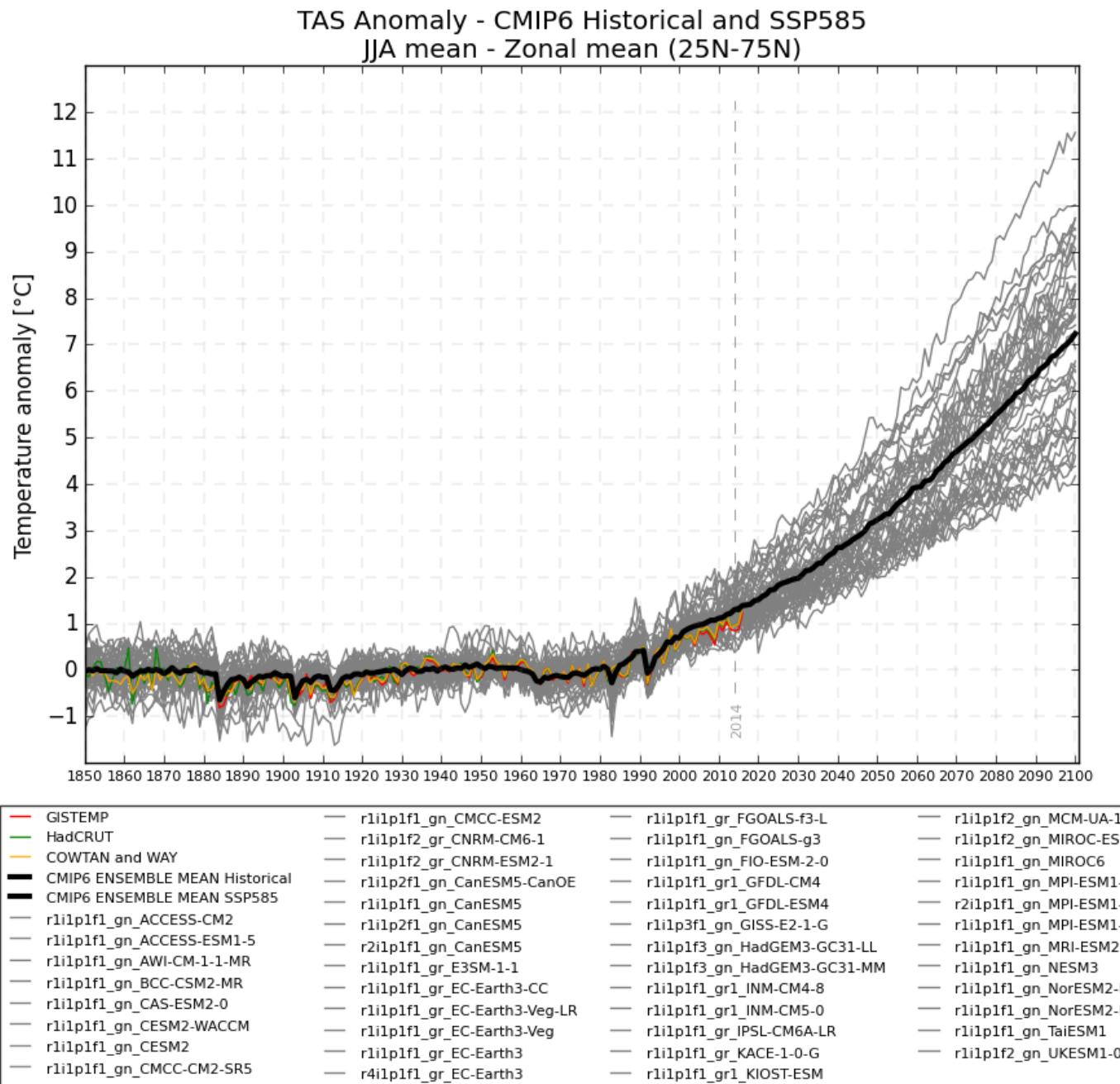
**Figure S4:** Temperature JJA seasonal means for CMIP6 Historical and SSP370 simulations.



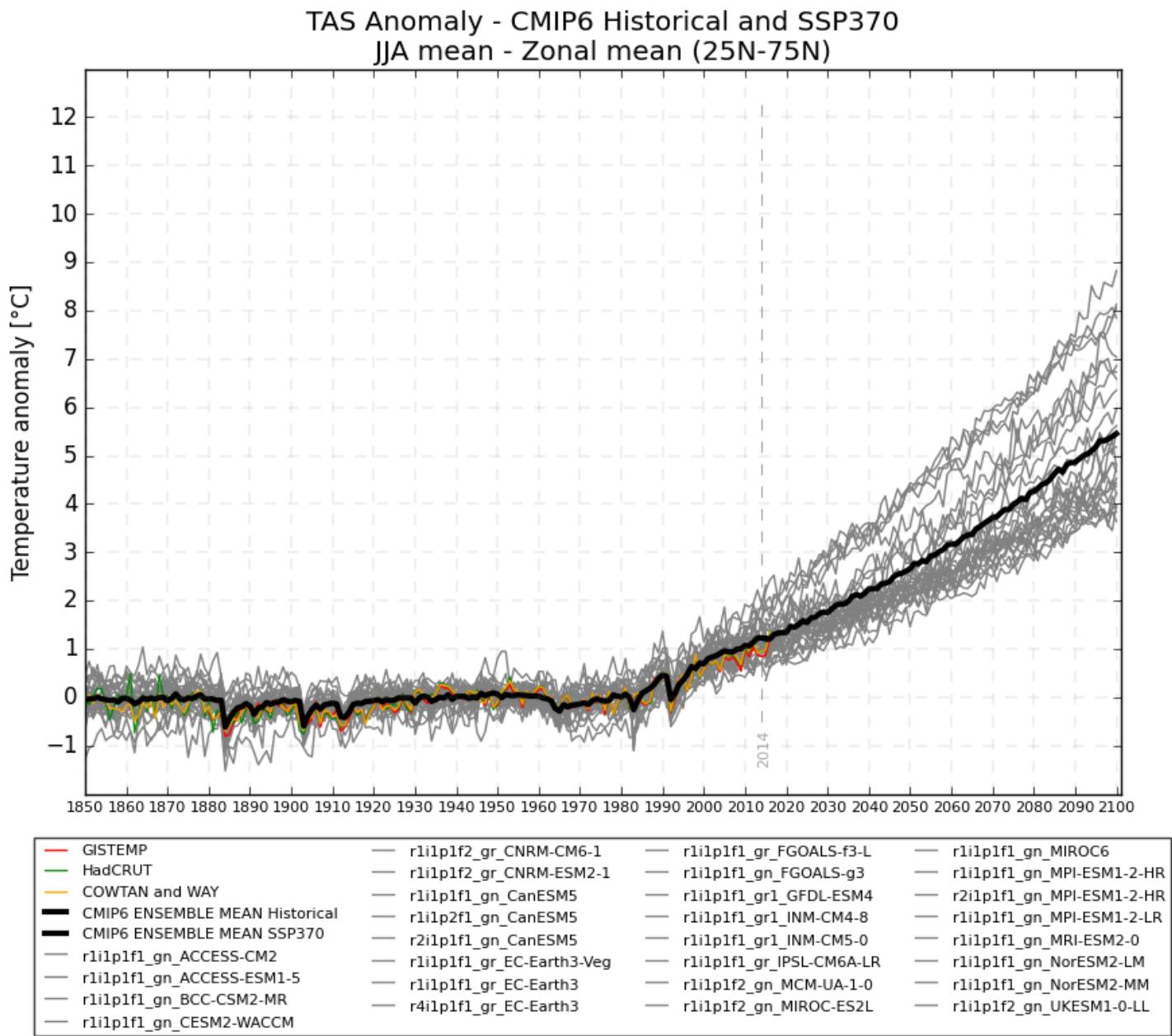
**Figure S5:** Temperature JJA seasonal means for CMIP6 Historical and SSP370-lowNTCF simulations.



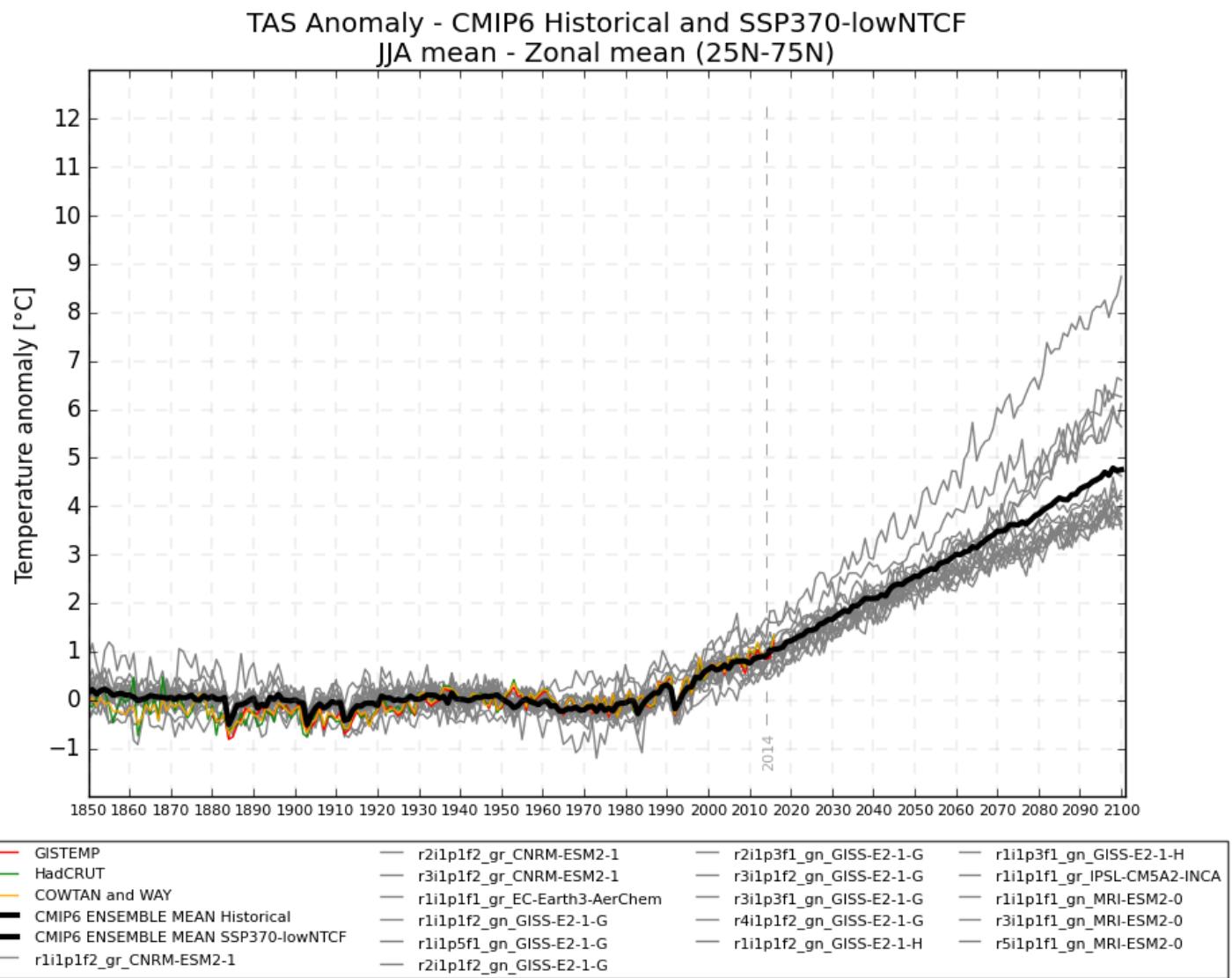
**Figure S6:** Temperature anomaly JJA seasonal means for CMIP5 Historical and RCP85 simulations. This anomaly follows [4].



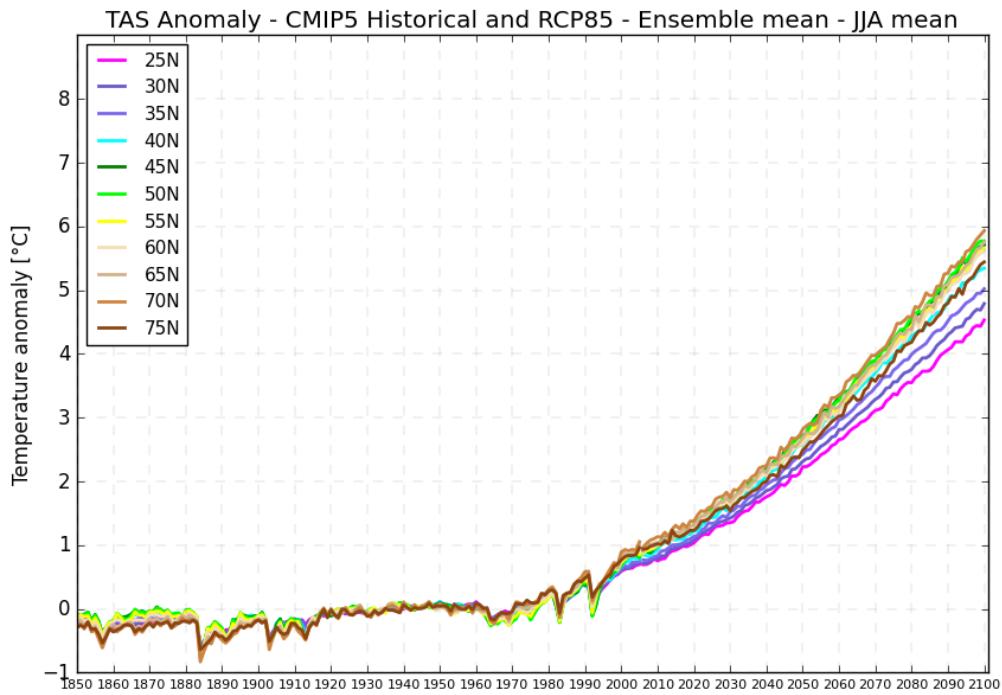
**Figure S7:** Temperature anomaly JJA seasonal means for CMIP6 Historical and SSP585 simulations. This anomaly follows [4].



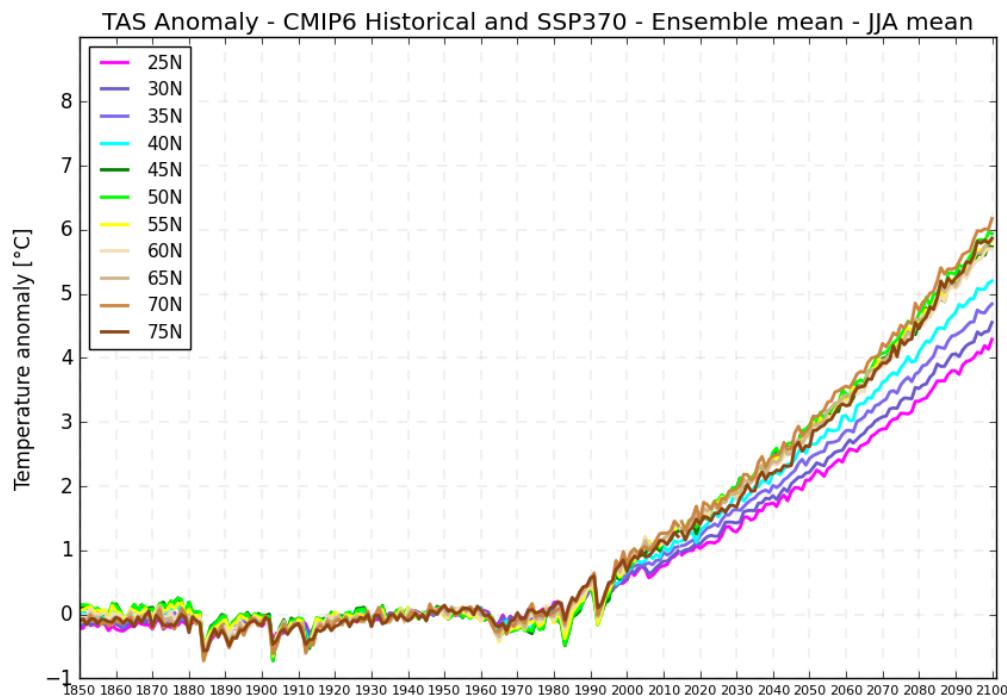
**Figure S8:** Temperature anomaly JJA seasonal means for CMIP6 Historical and SSP370 simulations. This anomaly follows [4].



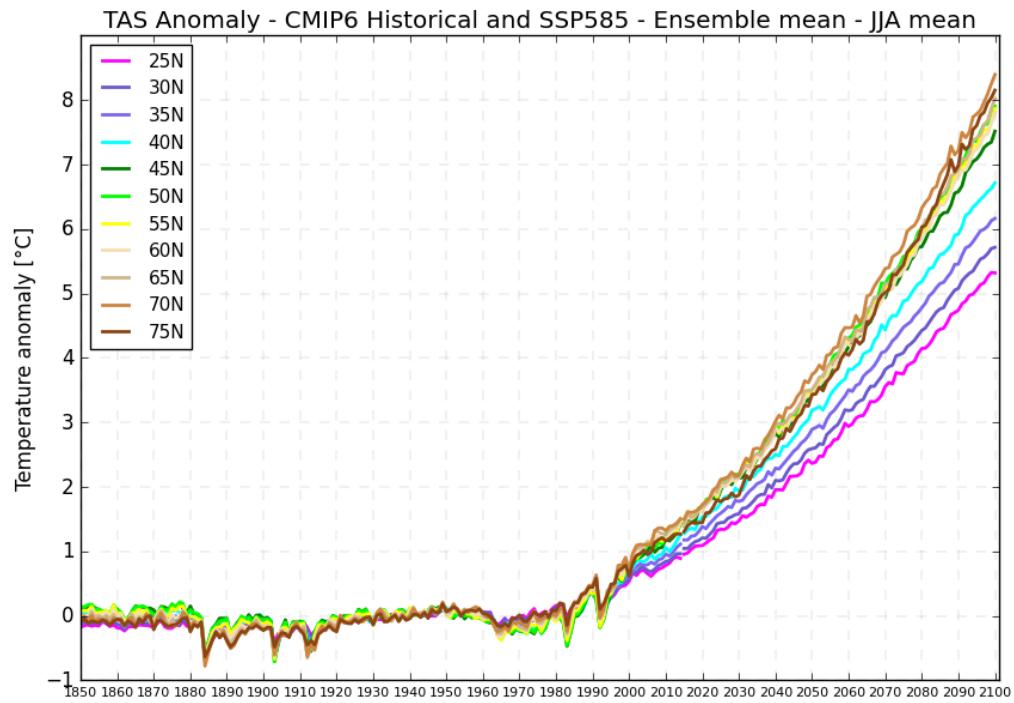
**Figure S9:** Temperature anomaly JJA seasonal means for CMIP6 Historical and SSP370-lowNTCF simulations. This anomaly follows [4].



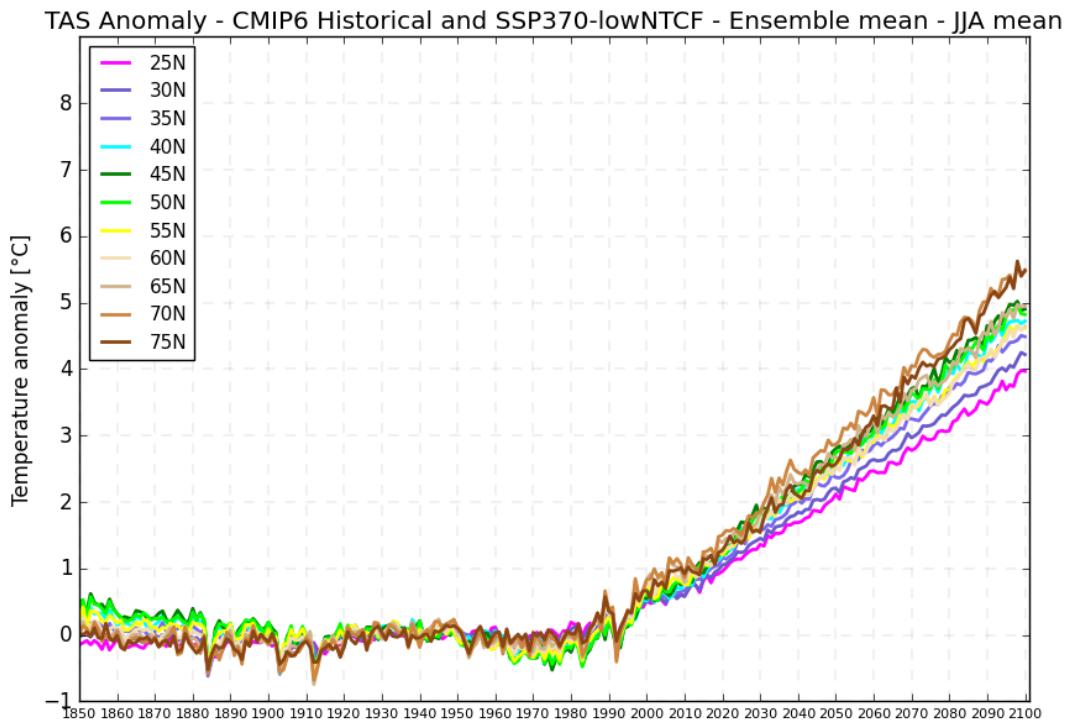
**Figure S10:** Temperature anomaly JJA seasonal means for CMIP5 Historical and RCP85. This anomaly follows [4].



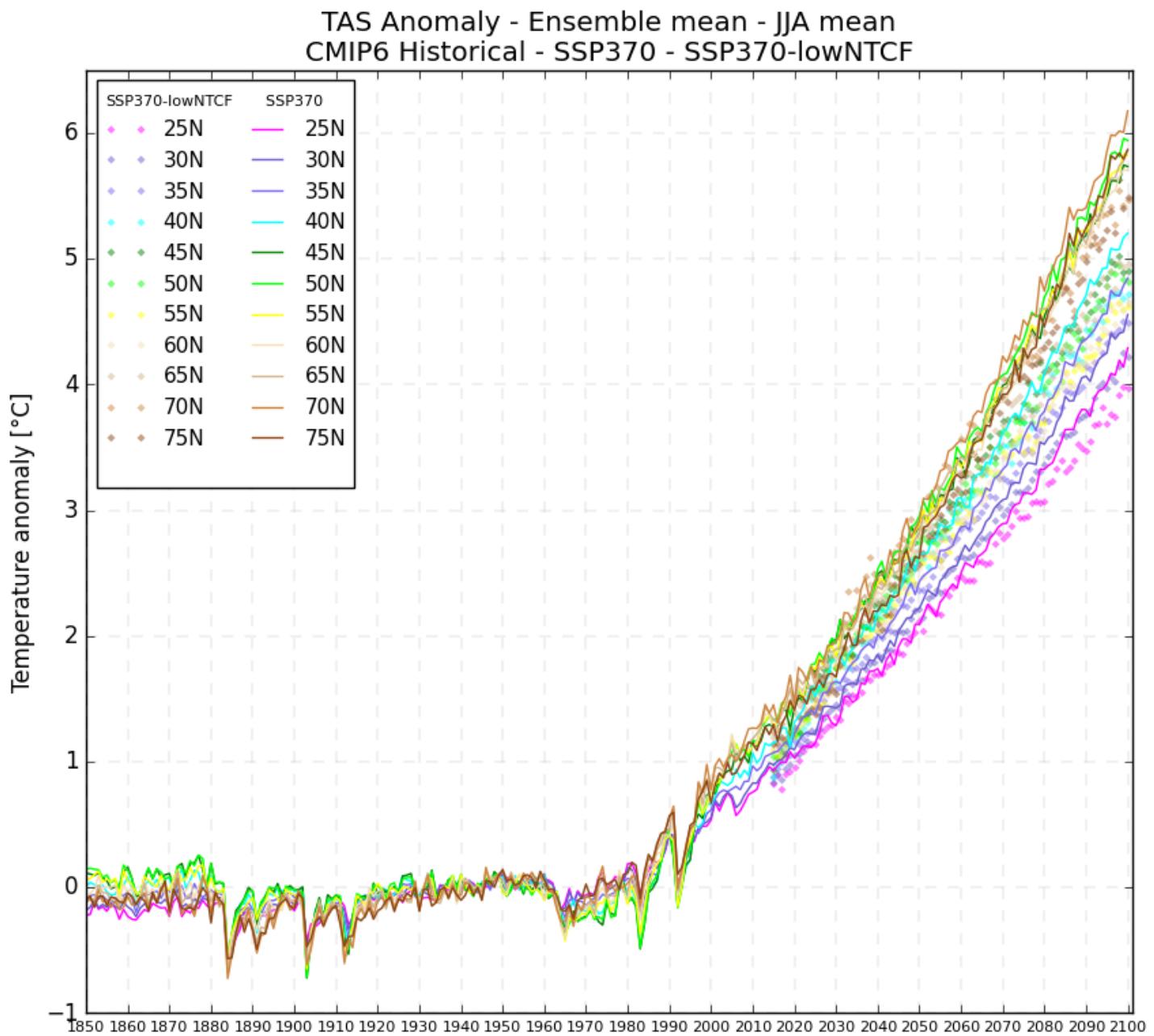
**Figure S11:** Temperature anomaly JJA seasonal means for CMIP6 Historical and SSP370. This anomaly follows [4].



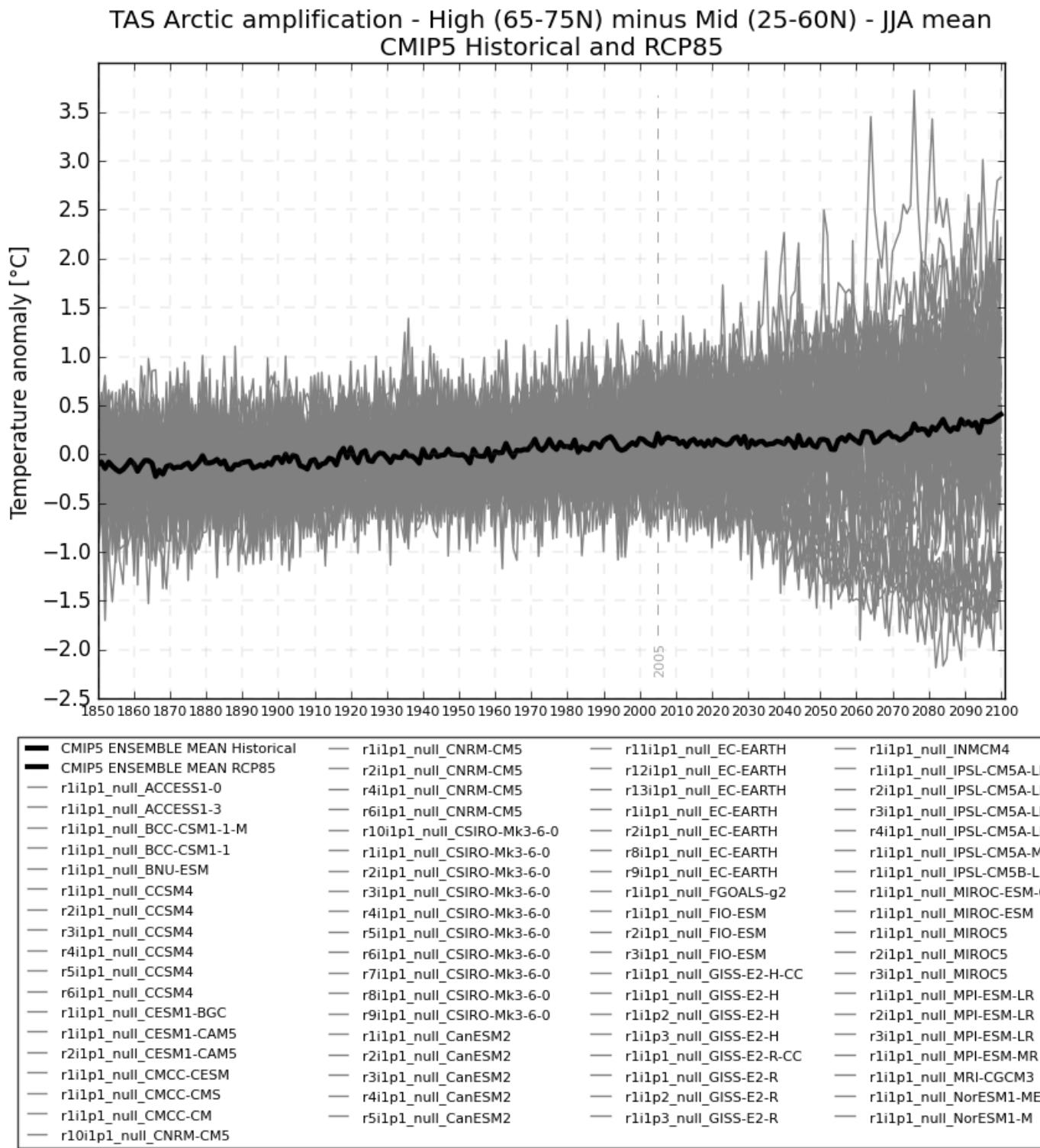
**Figure S12:** Temperature anomaly JJA seasonal means for CMIP6 Historical and SSP585. This anomaly follows [4].



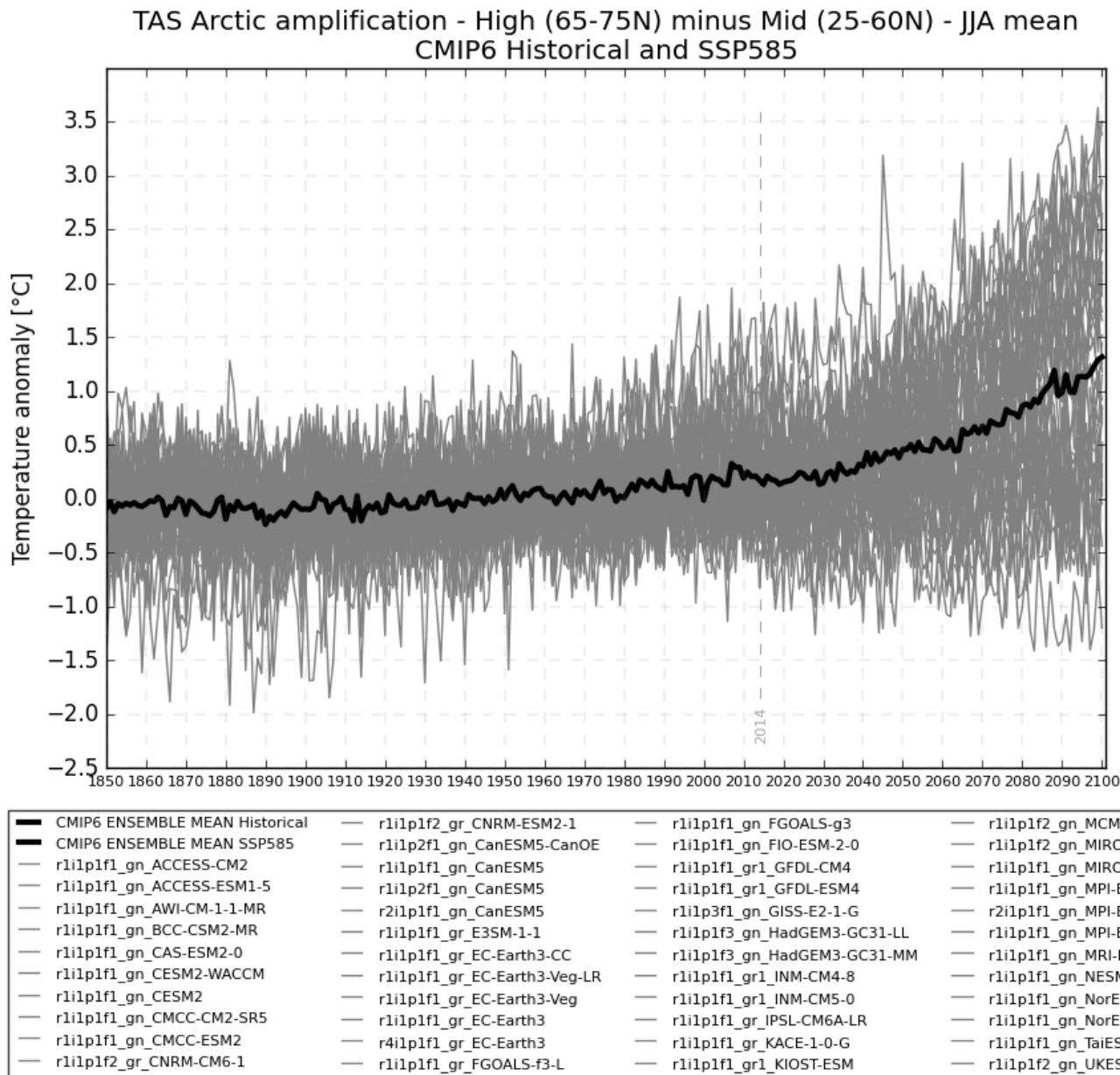
**Figure S13:** Temperature anomaly JJA seasonal means for CMIP6 Historical and SSP370-lowNTCF. This anomaly follows [4].



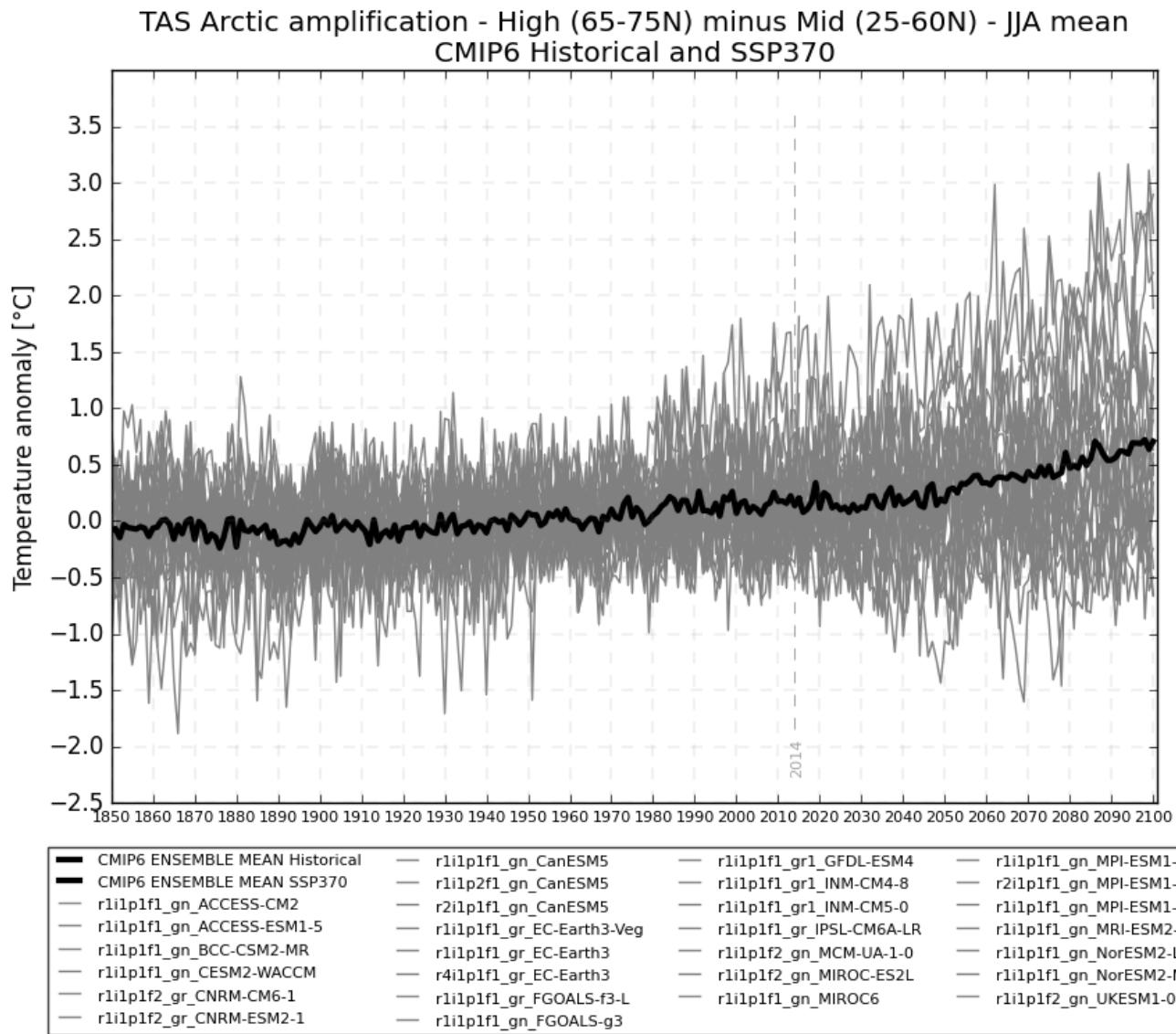
**Figure S14:** Temperature anomaly JJA seasonal means for CMIP6 Historical, SSP370, and SSP370-lowNTCF. This anomaly follows [4].



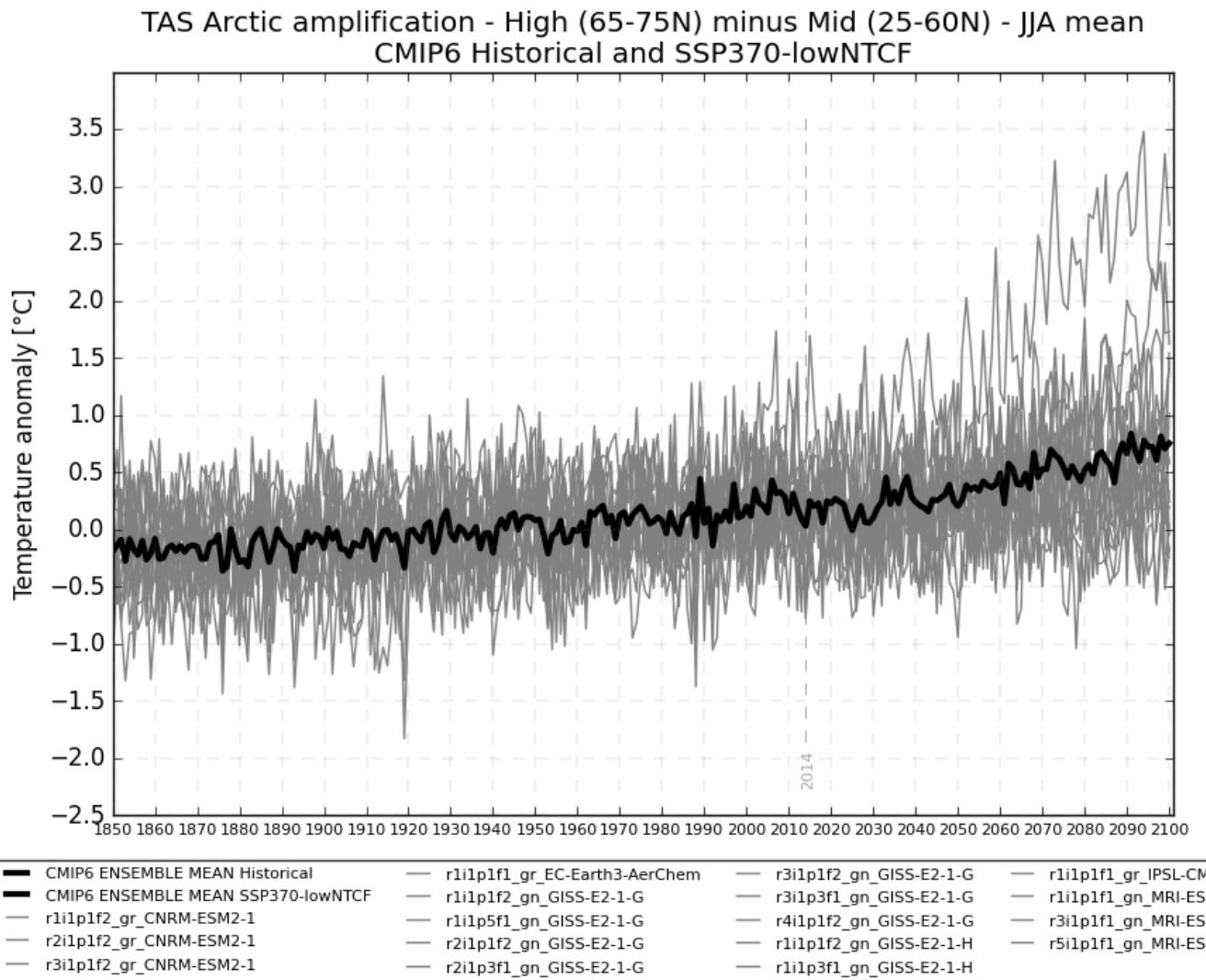
**Figure S15:** Arctic amplification from Temperature anomaly JJA seasonal means for CMIP5 Historical and RCP85. This anomaly follows [4].



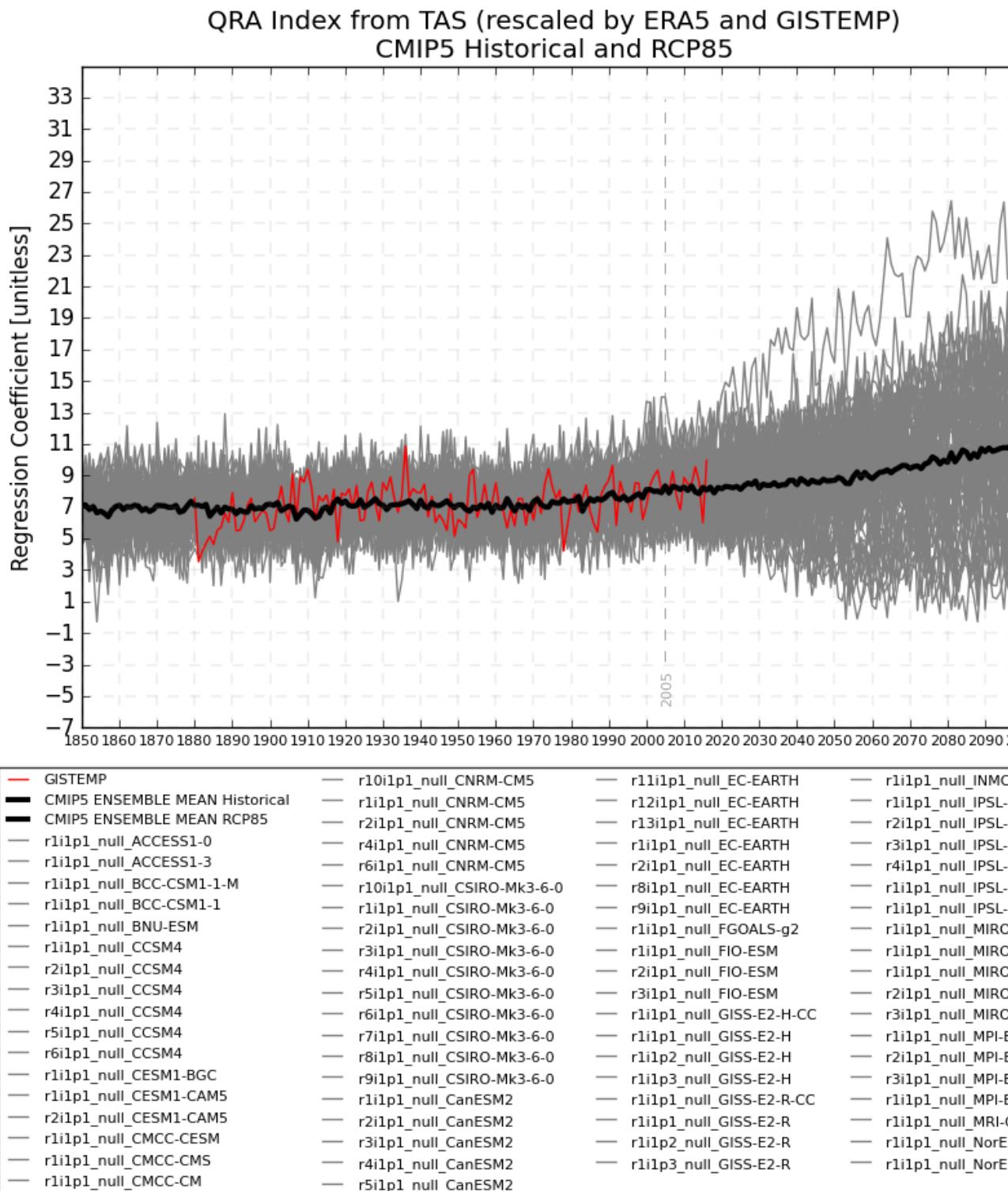
**Figure S16:** Arctic amplification from Temperature anomaly JJA seasonal means for CMIP6 Historical and SSP585. This anomaly follows [4].



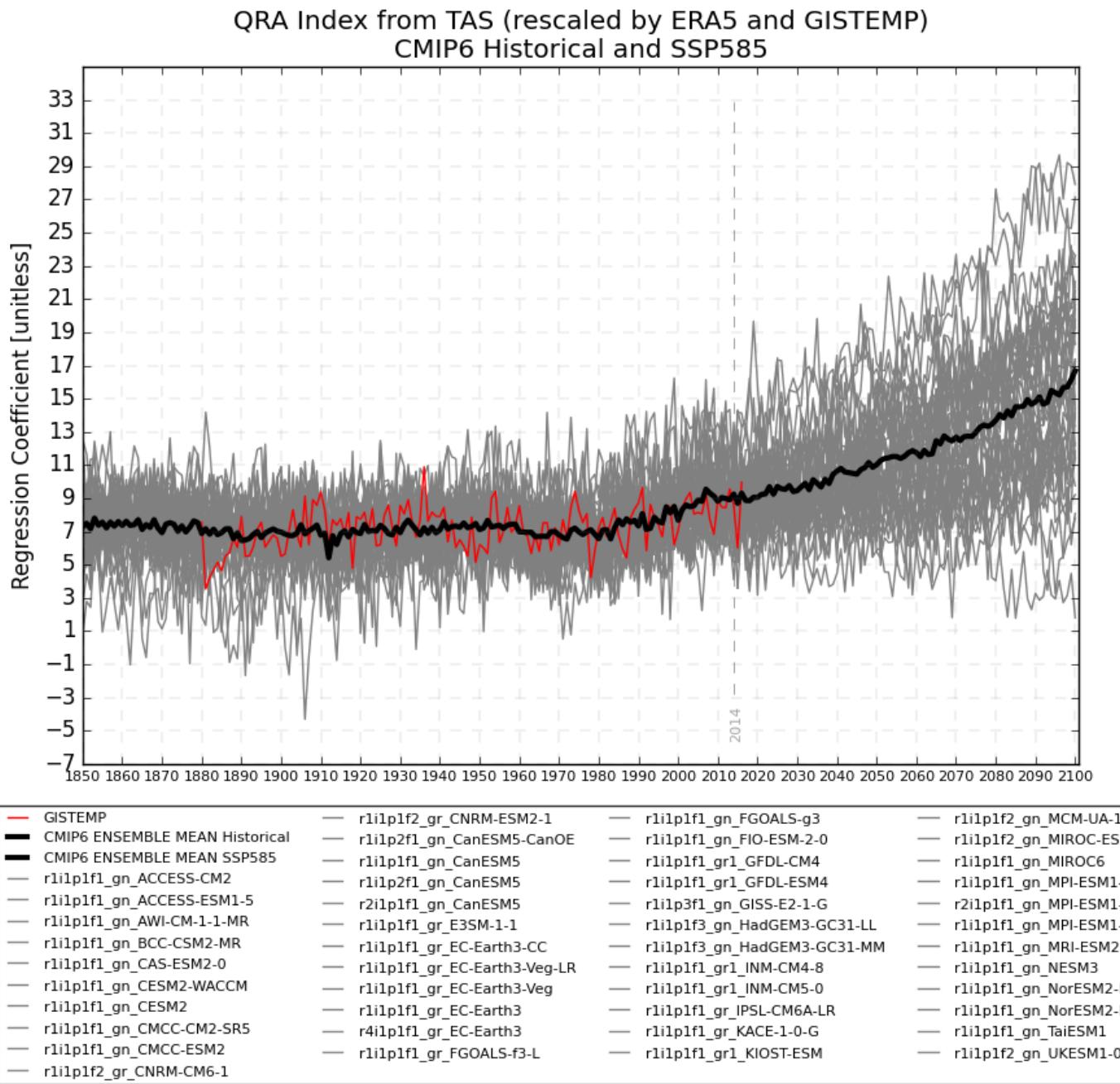
**Figure S17:** Arctic amplification from Temperature anomaly JJA seasonal means for CMIP6 Historical and SSP370. This anomaly follows [4].



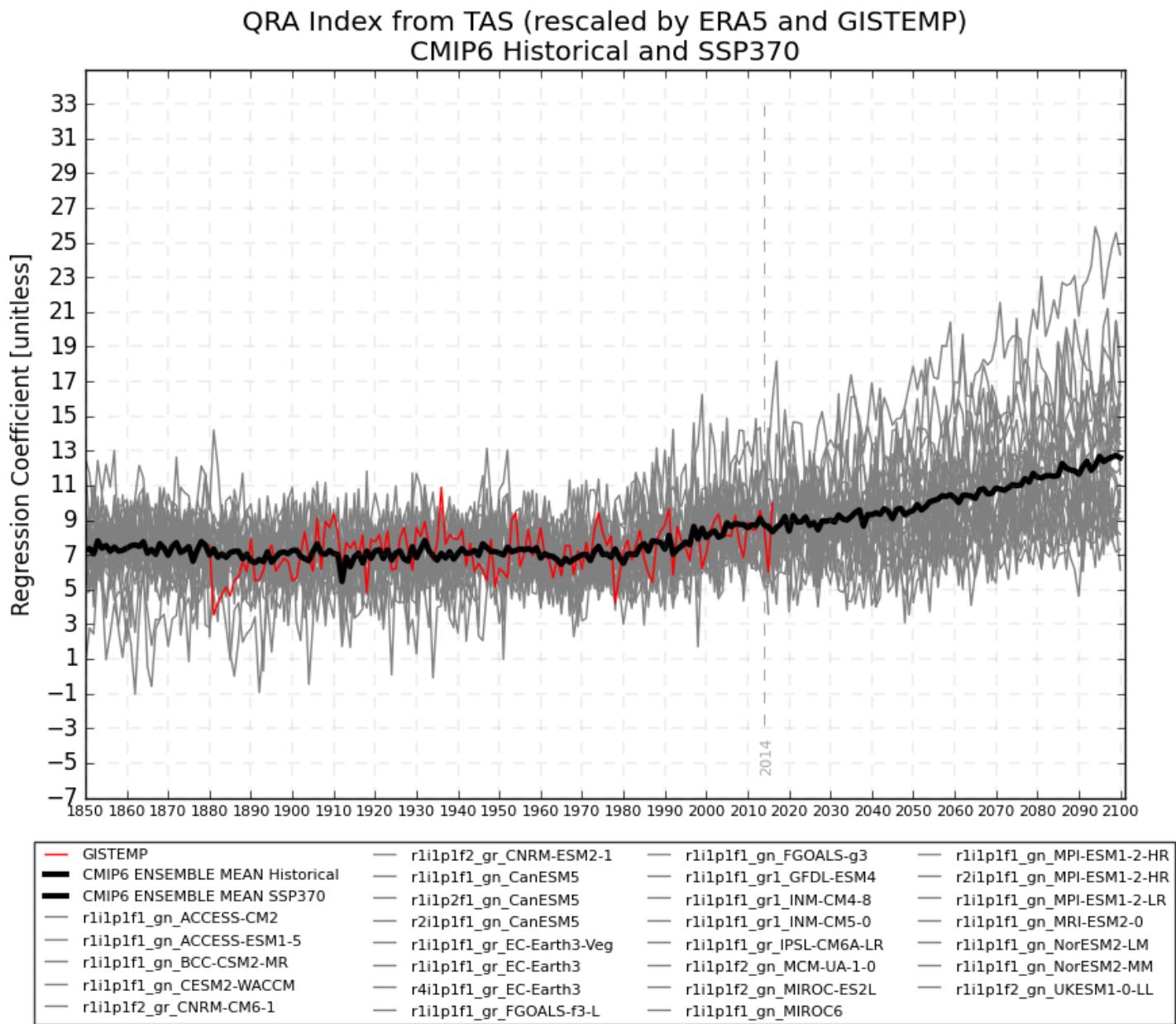
**Figure S18:** Arctic amplification from Temperature anomaly JJA seasonal means for CMIP6 Historical and SSP370-lowNTCF. This anomaly follows [4].



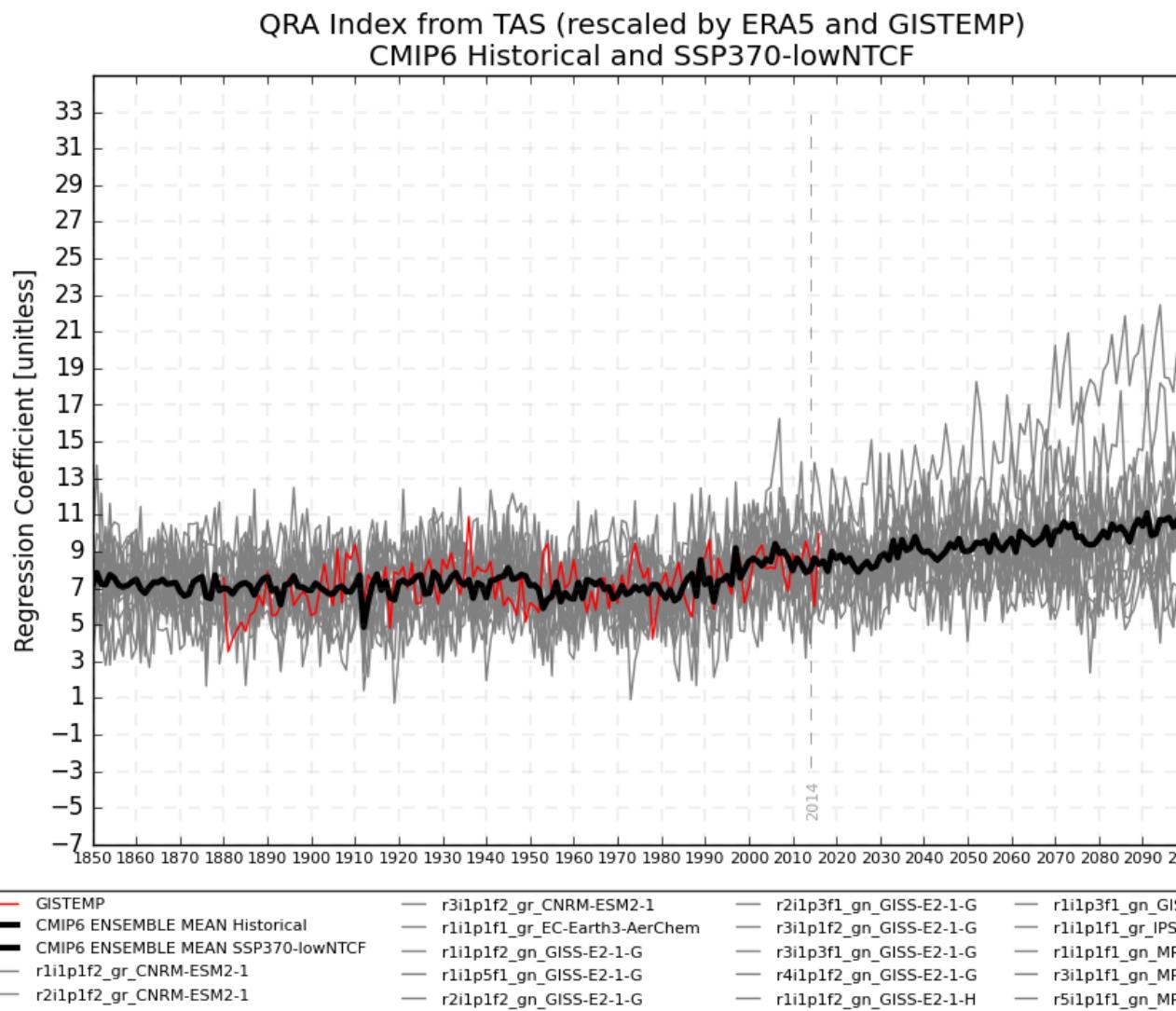
**Figure S19:** QRA index from Temperature JJA seasonal means for CMIP5 Historical and RCP85.



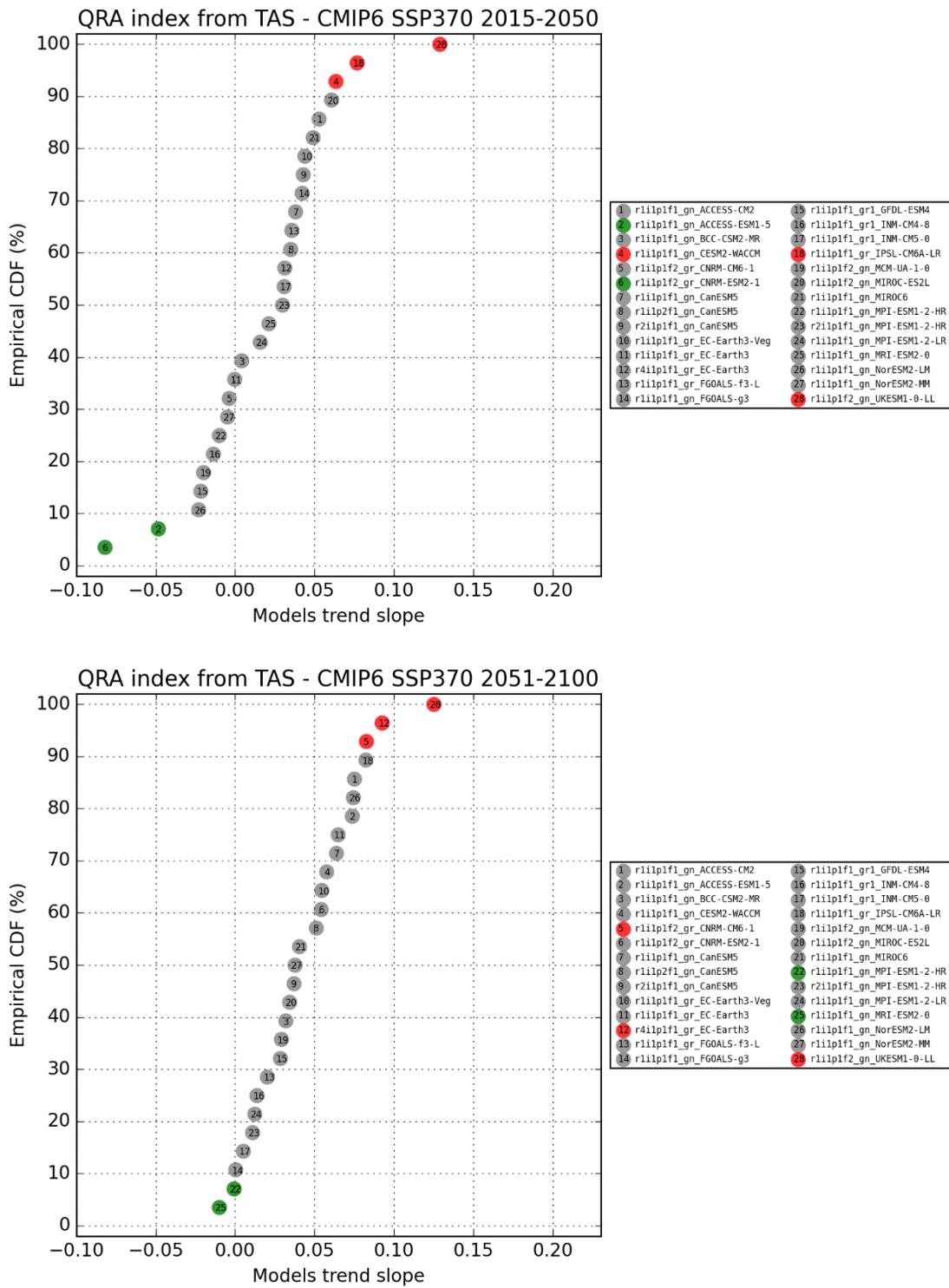
**Figure S20:** QRA index from Temperature JJA seasonal means for CMIP6 Historical and SSP585.



**Figure S21:** QRA index from Temperature JJA seasonal means for CMIP6 Historical and SSP370.

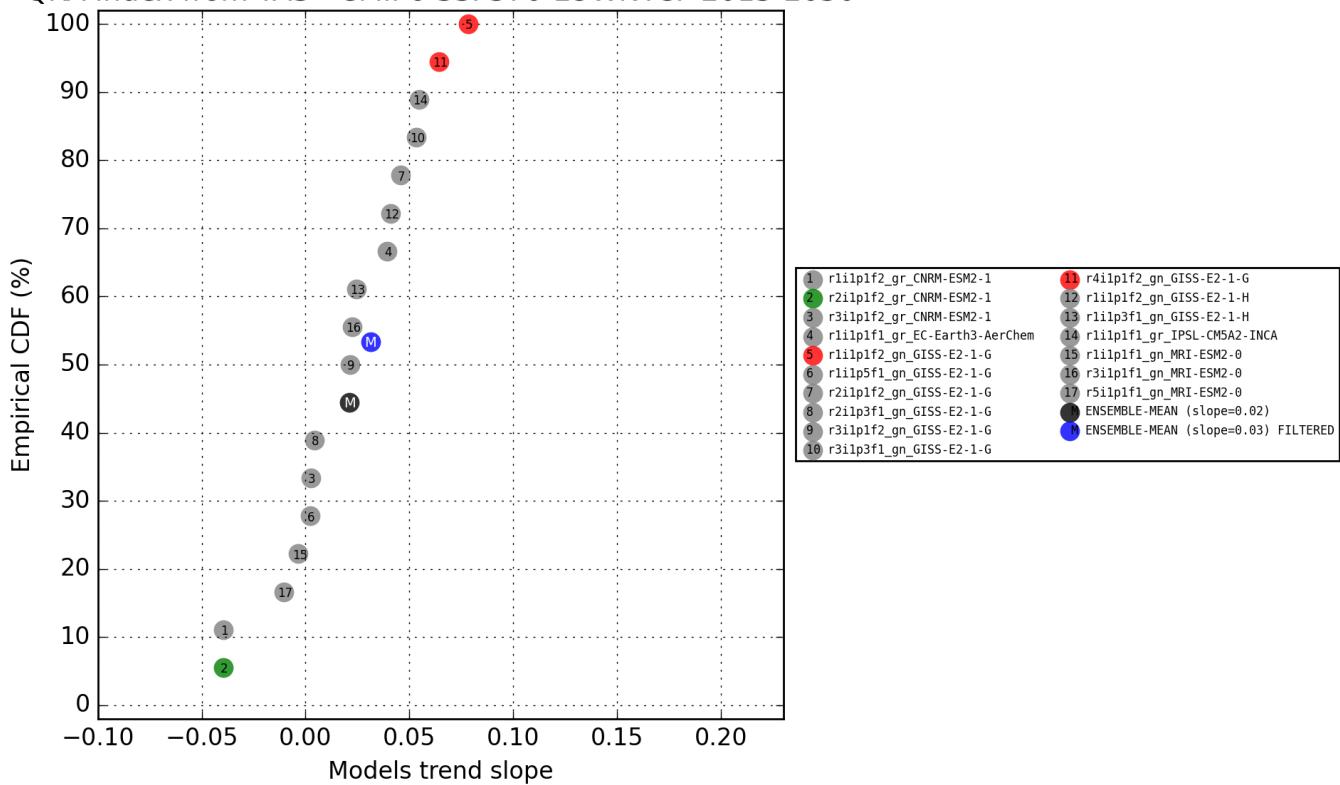


**Figure S22:** QRA index from Temperature JJA seasonal means for CMIP6 Historical and SSP370-lowNTCF.

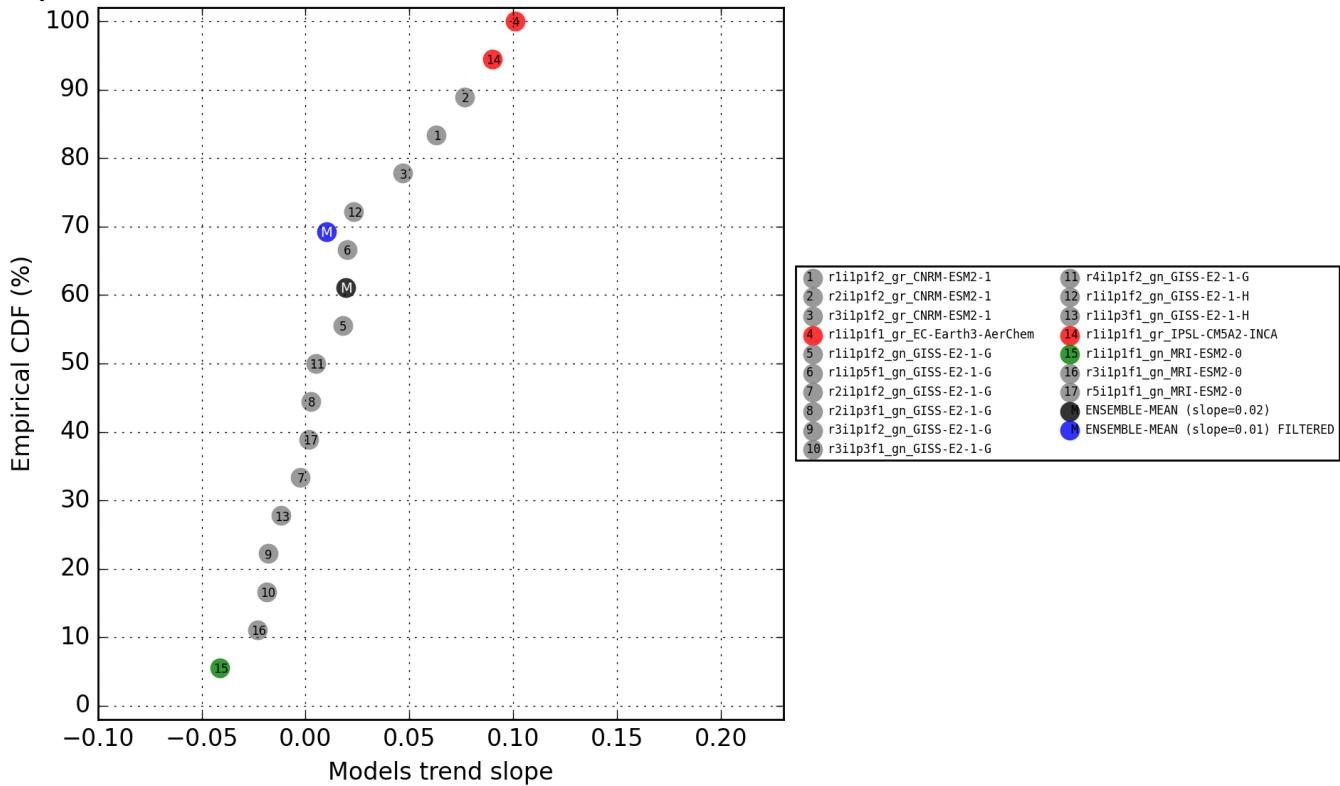


**Figure S23:** Average QRA index from Temperature JJA seasonal means for CMIP6 SSP370.

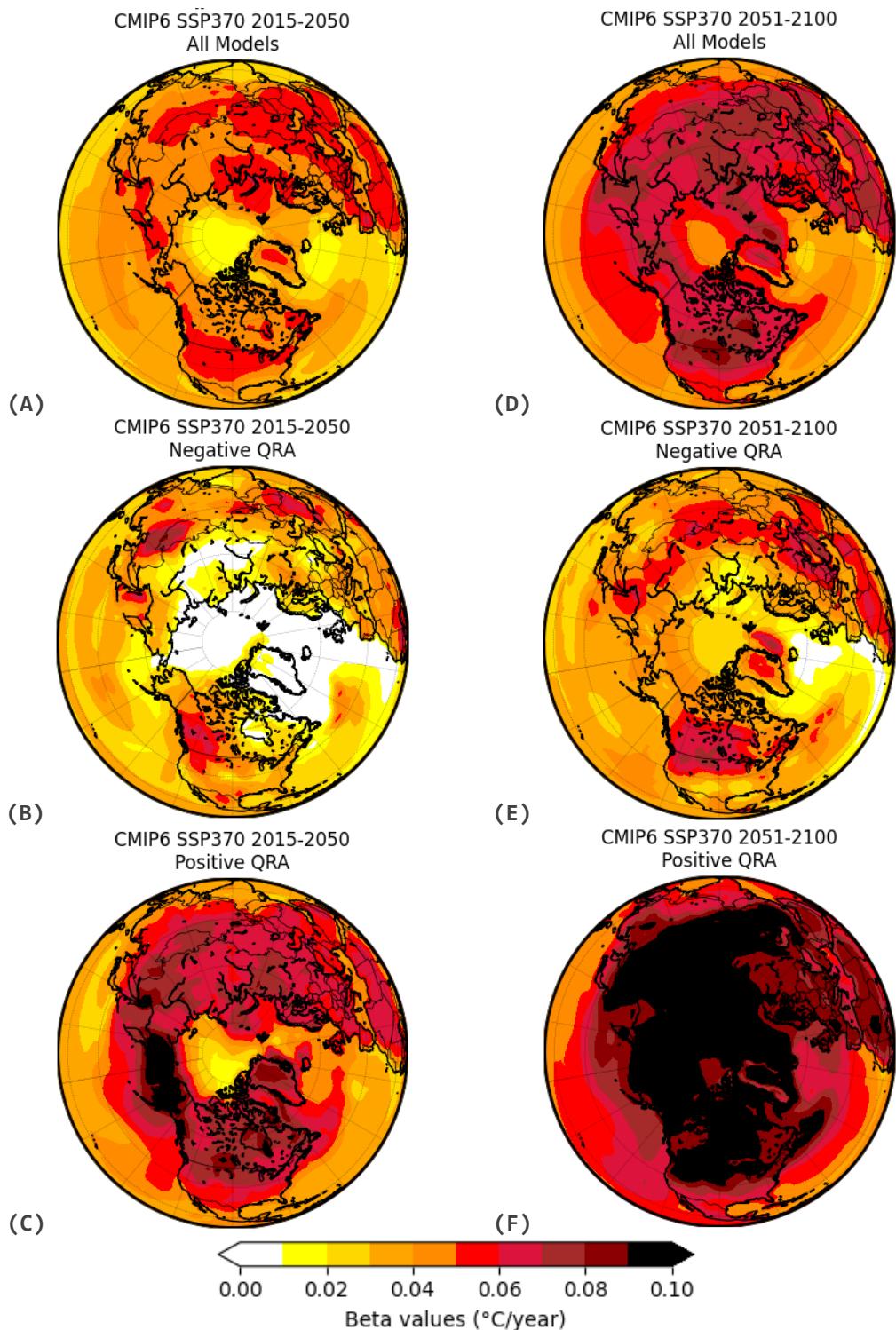
### QRA index from TAS - CMIP6 SSP370-LOWNTCF 2015-2050



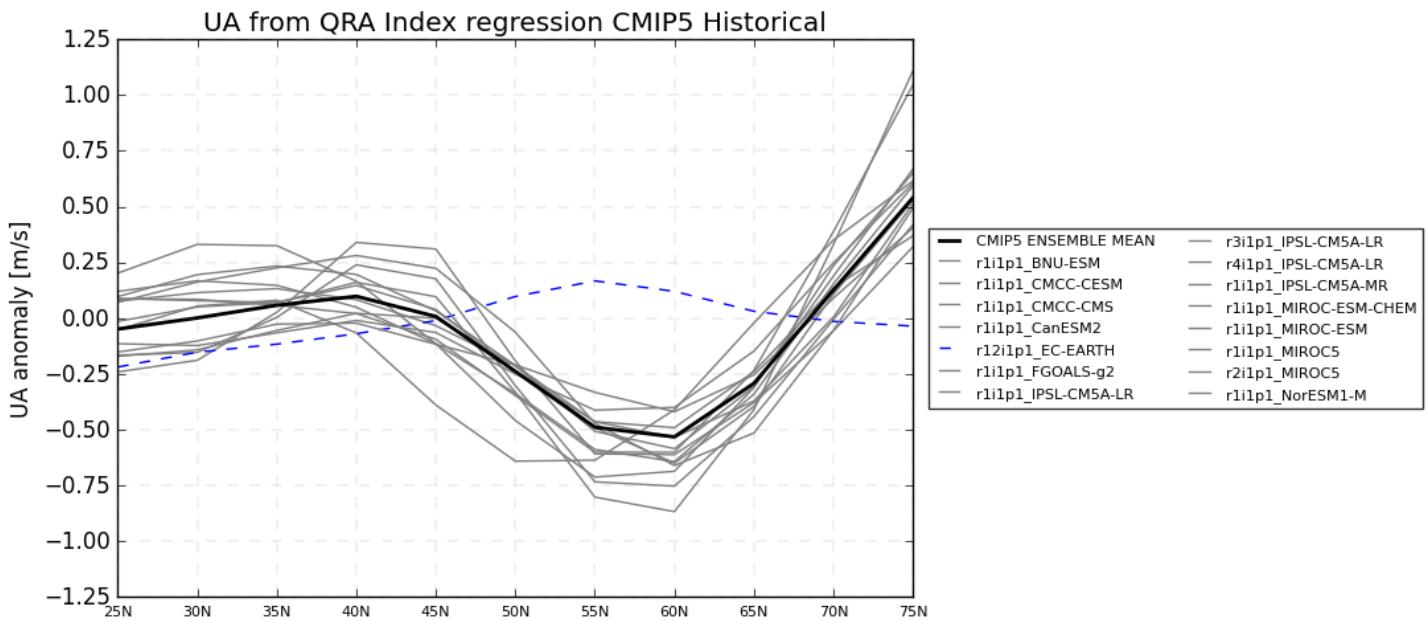
### QRA index from TAS - CMIP6 SSP370-LOWNTCF 2051-2100



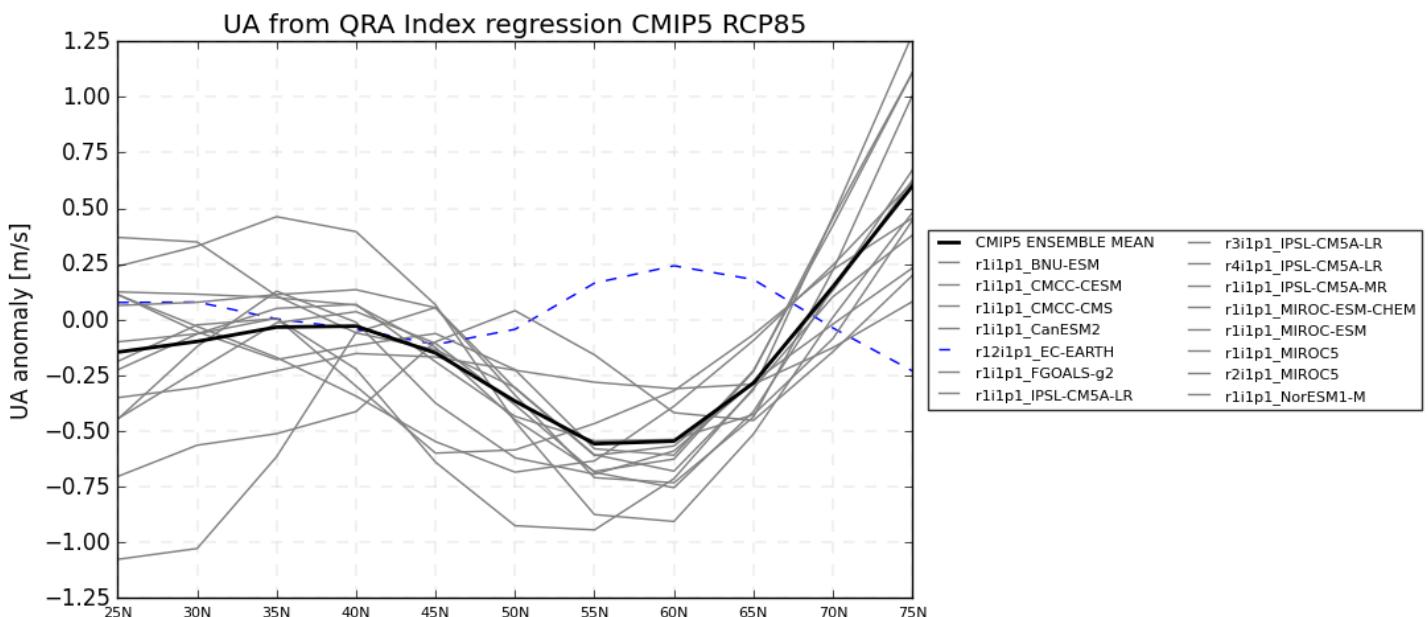
**Figure S24:** Average QRA index from Temperature JJA seasonal means for CMIP6 SSP370-lowNTCF.



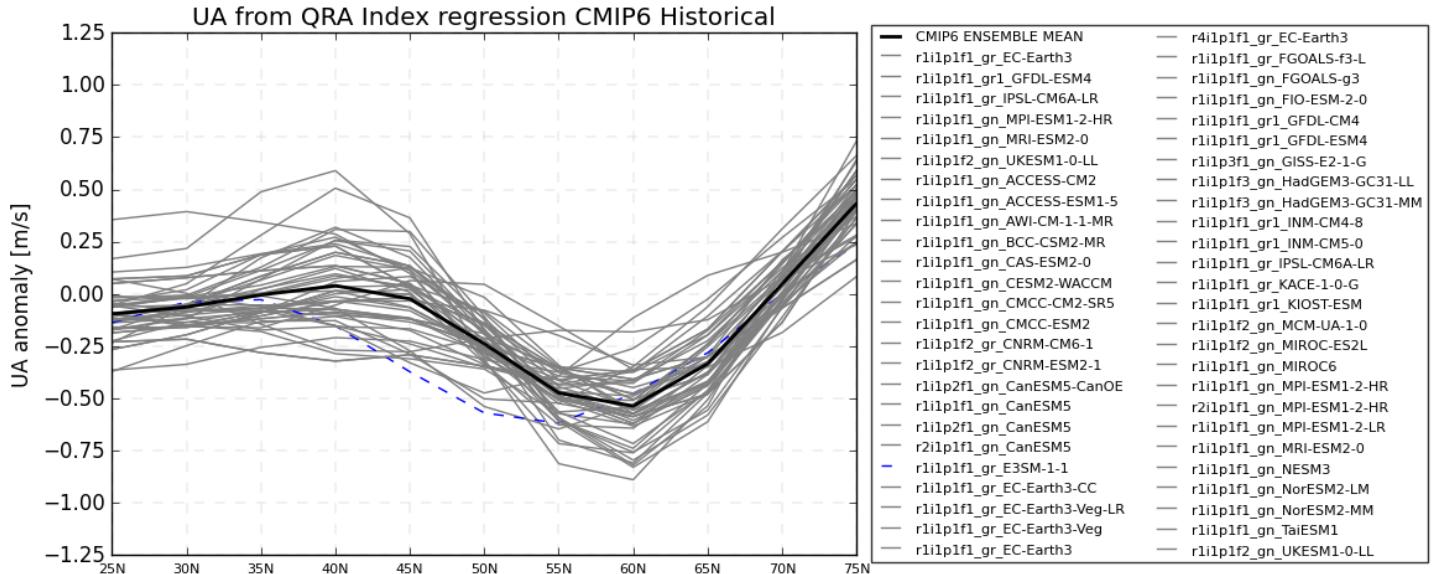
**Figure S25:** Mean surface temperature trend patterns (JJA seasonal means) for CMIP6 SSP370. (A,D) multimodel ensemble, (B,E) most negative QRA-trending ensemble members, and (C,F) most positive QRA-trending ensemble members (“most” is defined as upper 10th percentile of multimodel ensemble).



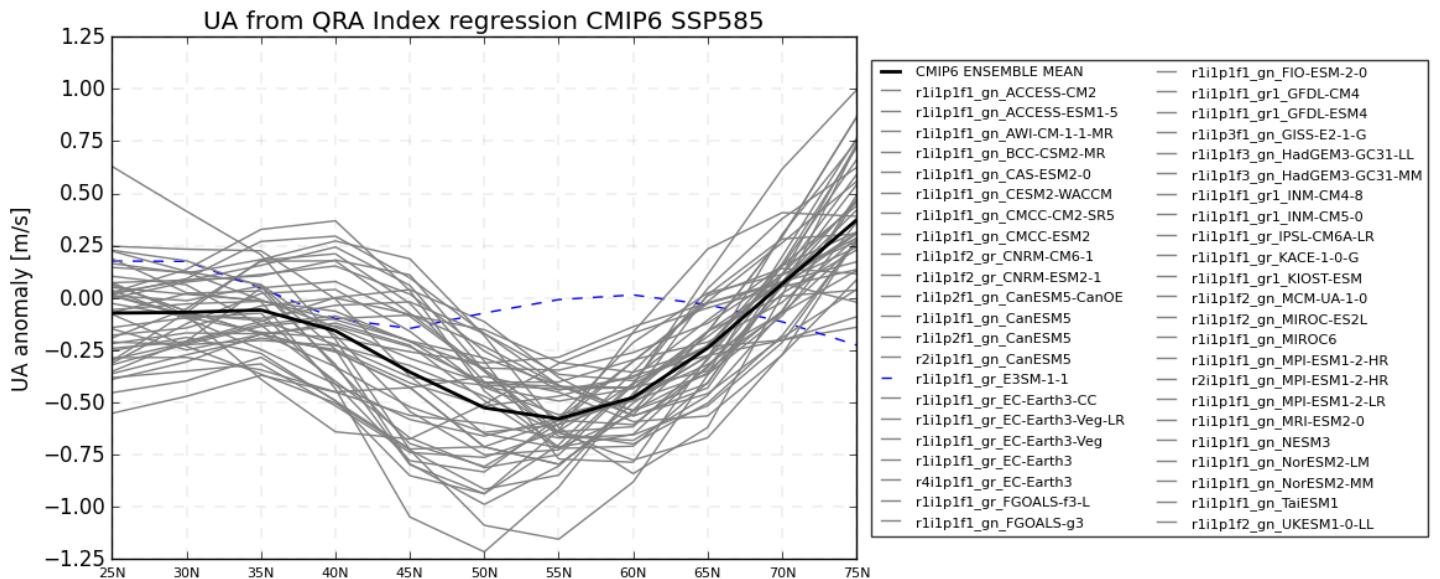
**Figure S26:** Projection of QRA index from Temperature JJA seasonal means onto zonal wind anomalies for CMIP5 Historical.



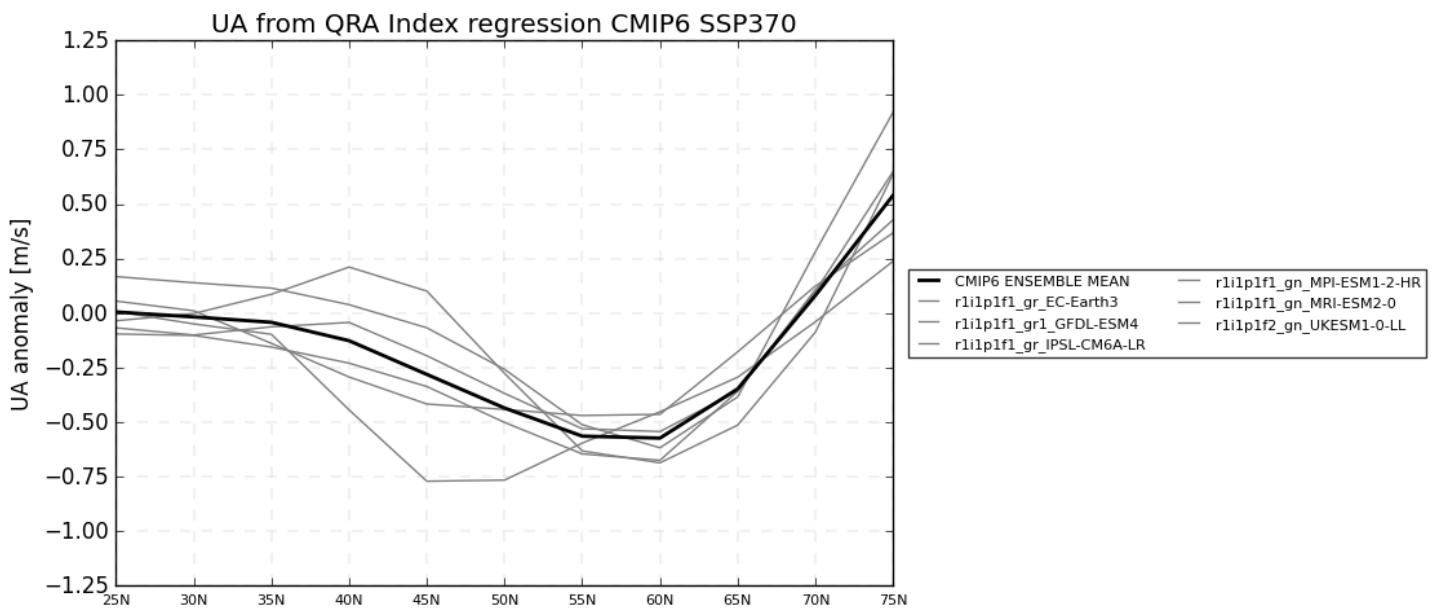
**Figure S27:** Projection of QRA index from Temperature JJA seasonal means onto zonal wind anomalies for CMIP5 RCP85.



**Figure S28:** Projection of QRA index from Temperature JJA seasonal means onto zonal wind anomalies for CMIP6 Historical.



**Figure S29:** Projection of QRA index from Temperature JJA seasonal means onto zonal wind anomalies for CMIP6 SSP585.



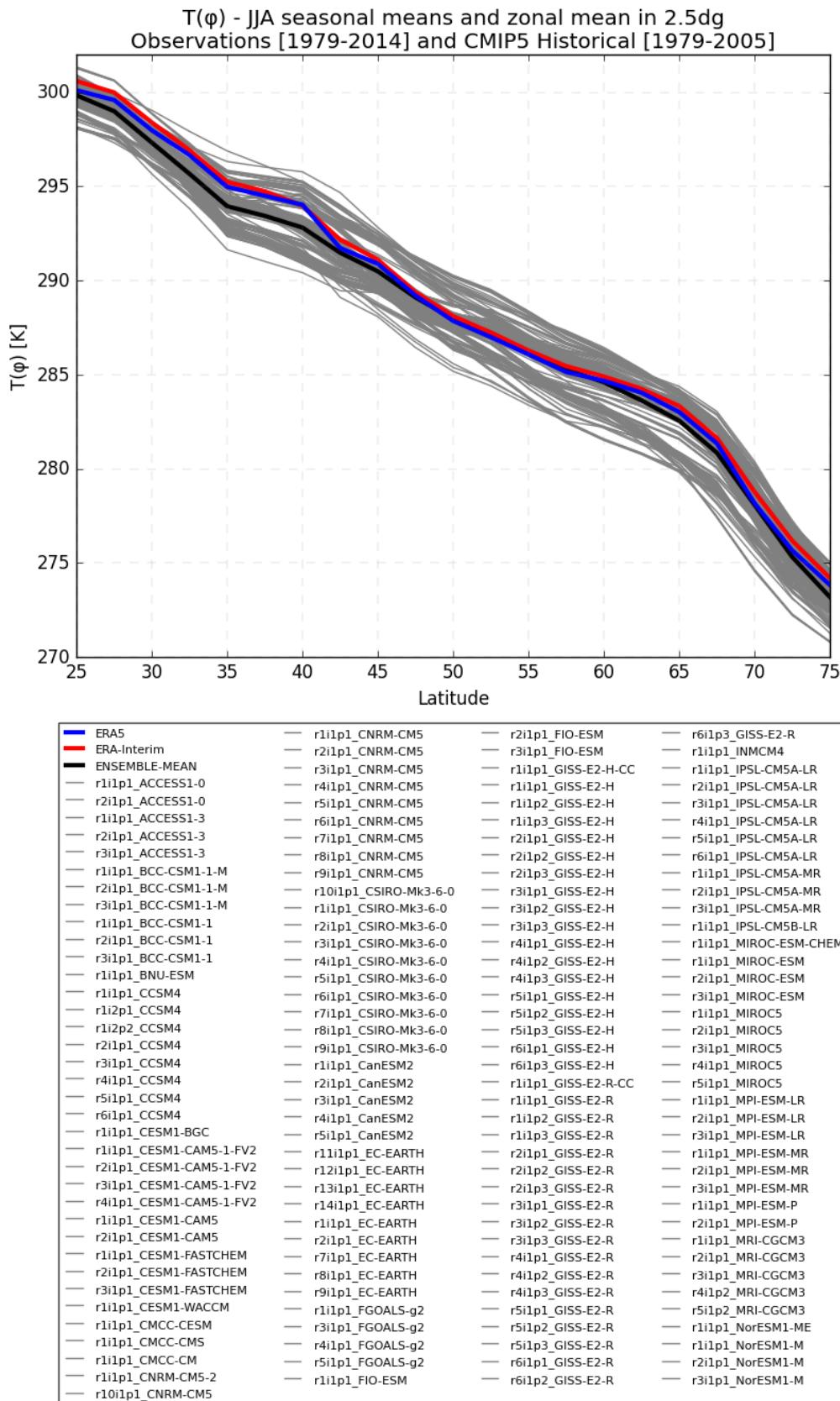
**Figure S30:** Projection of QRA index from Temperature JJA seasonal means onto zonal wind anomalies for CMIP6 SSP370.

RMSE related to ERA-Interim	Mean error for Ensemble Members		Error for Ensemble Mean	
	CMIP5	CMIP6	CMIP5	CMIP6
$T(\varphi)$	0.5% (150)	0.5% (66)	0.3% (150)	0.3% (66)
$dT(\varphi)/d\varphi$	-28.8% (150)	-26.4% (66)	-15.1% (150)	-13.6% (66)
$\bar{u}(\varphi)$	28.0% (74)	17.6% (66)	19.1% (74)	10.8% (66)
$d\bar{u}(\varphi)/d\varphi$	188.8% (74)	169.3% (66)	91.3% (74)	118.0% (66)
$d^2\bar{u}(\varphi)/d\varphi^2$	-324.1% (74)	-271.5% (66)	-148.8% (74)	-194.6% (66)

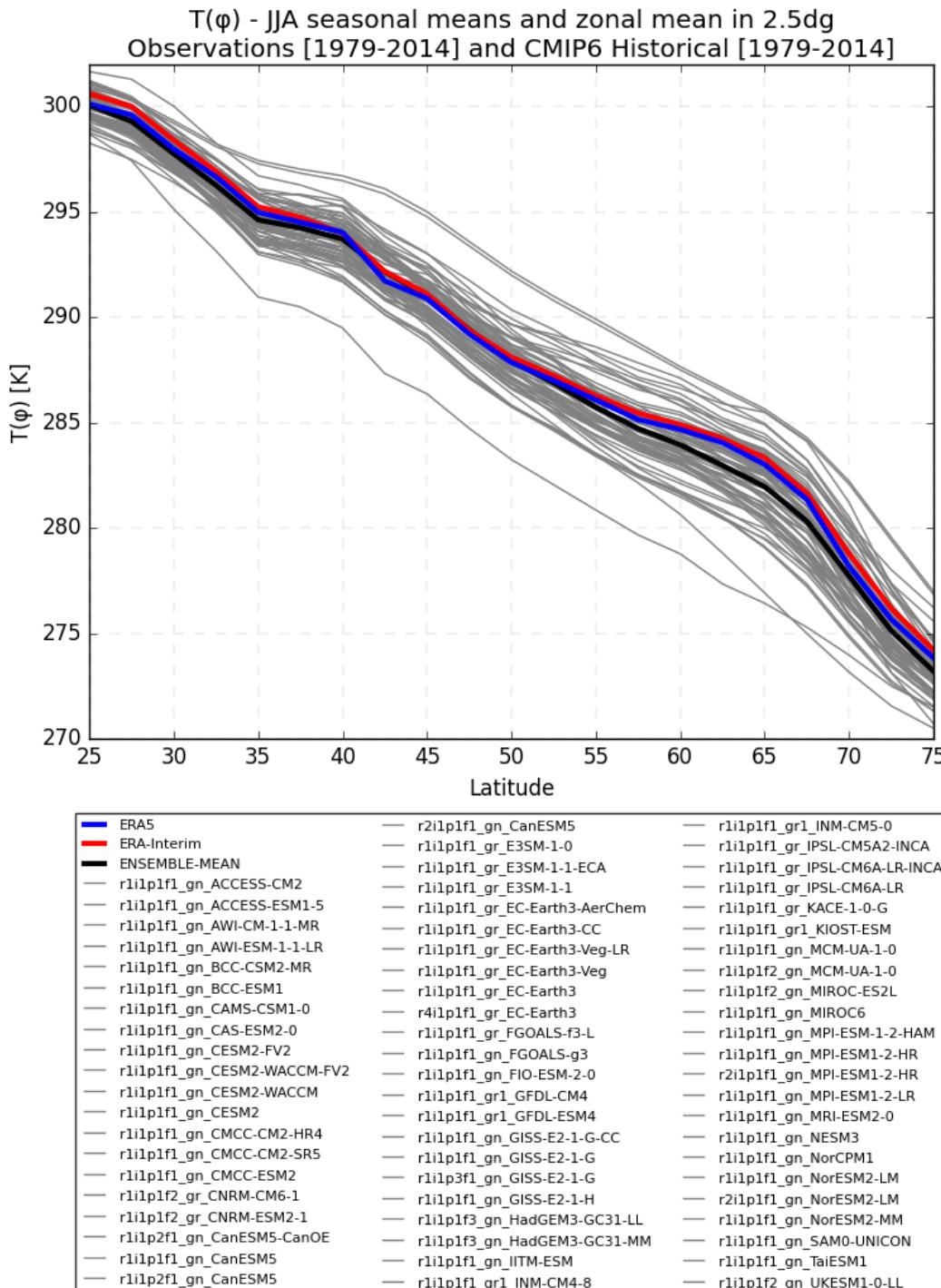
**Table S5:** Temperature  $T(\varphi)$  and zonal wind  $\bar{u}(\varphi)$  RMSE for CMIP5 (1979-2005) and CMIP6 (1979-2014) Historical multimodel ensemble over 25N-75N (2.5 degrees) JJA seasonal means compared to ERA-Interim (1979-2014).

RMSE related to ERA5	Mean error for Ensemble Members		Error for Ensemble Mean	
	CMIP5	CMIP6	CMIP5	CMIP6
$T(\varphi)$	0.4% (150)	0.5% (66)	0.2% (150)	0.2% (66)
$dT(\varphi)/d\varphi$	-33.8% (150)	-30.6% (66)	-23.3% (150)	-20.6% (66)
$\bar{u}(\varphi)$	28.0% (74)	17.6% (66)	19.0% (74)	10.7% (66)
$d\bar{u}(\varphi)/d\varphi$	192.4% (74)	172.8% (66)	93.4% (74)	120.8% (66)
$d^2\bar{u}(\varphi)/d\varphi^2$	-341.3% (74)	-285.3% (66)	-160.0% (74)	-205.2% (66)

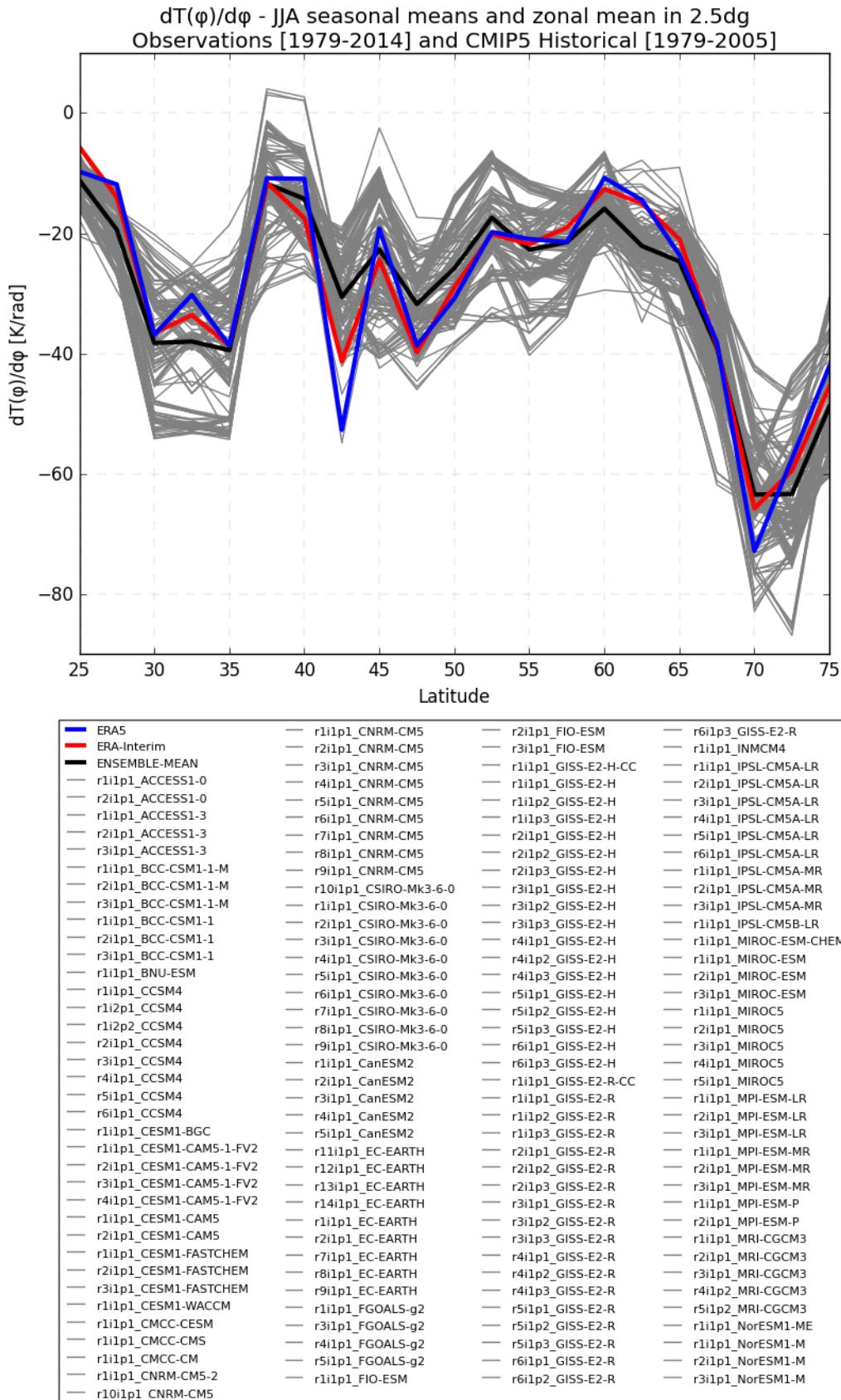
**Table S6:** Temperature  $T(\varphi)$  and zonal wind  $\bar{u}(\varphi)$  RMSE for CMIP5 (1979-2005) and CMIP6 (1979-2014) Historical multimodel ensemble over 25N-75N (2.5 degrees) JJA seasonal means compared to ERA5 (1979-2014).



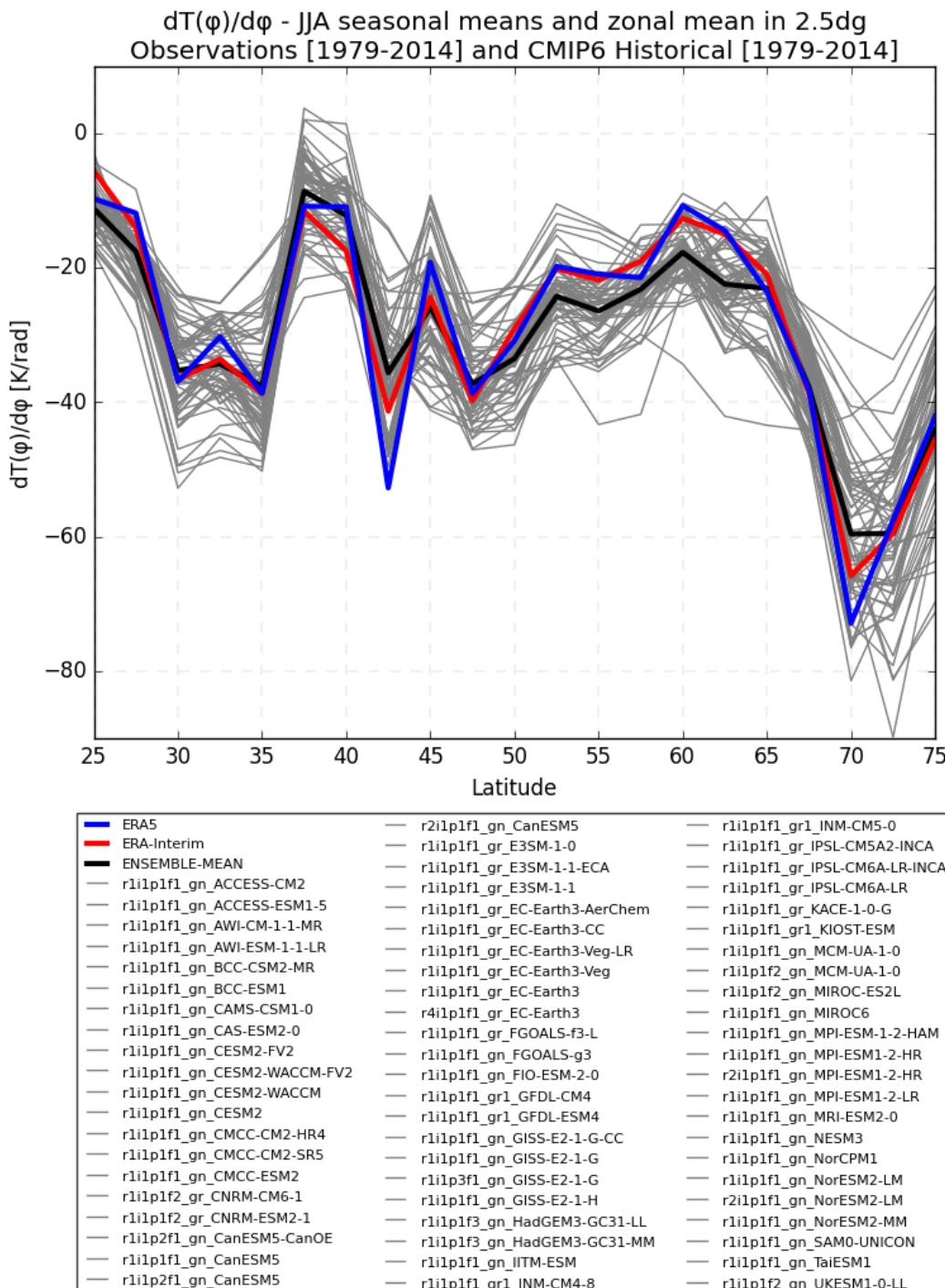
**Figure S31:** Temperature  $T(\phi)$  for CMIP5 (1979-2005) Historical multimodel ensemble over 25N-75N (2.5 degrees) JJA seasonal means compared to observations.



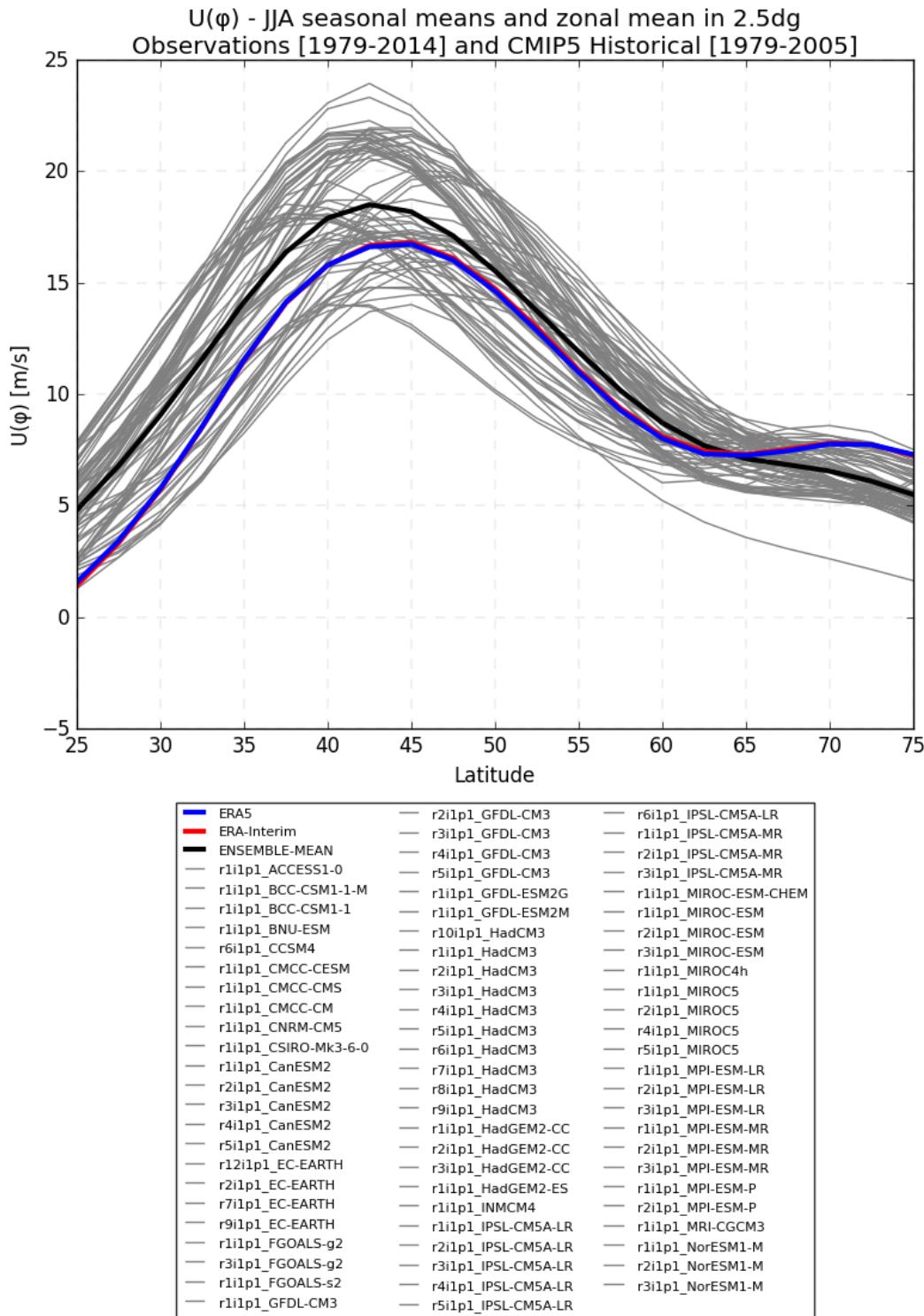
**Figure S32:** Temperature  $T(\phi)$  for CMIP6 (1979-2014) Historical multimodel ensemble over 25N-75N (2.5 degrees) JJA seasonal means compared to observations.



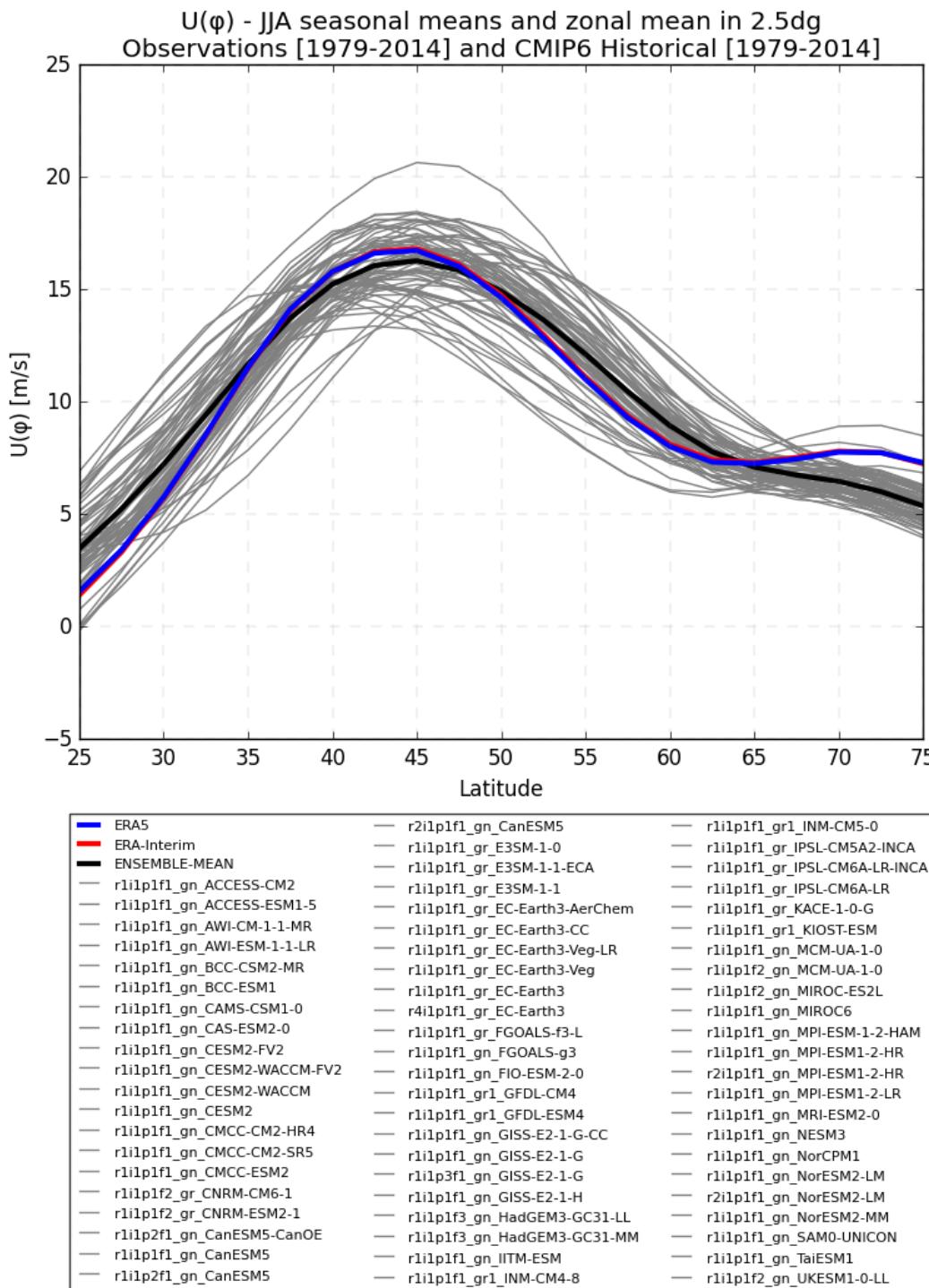
**Figure S33:** Temperature  $dT(\phi)/d\phi$  for CMIP5 (1979-2005) Historical multimodel ensemble over 25N-75N (2.5 degrees) JJA seasonal means compared to observations.



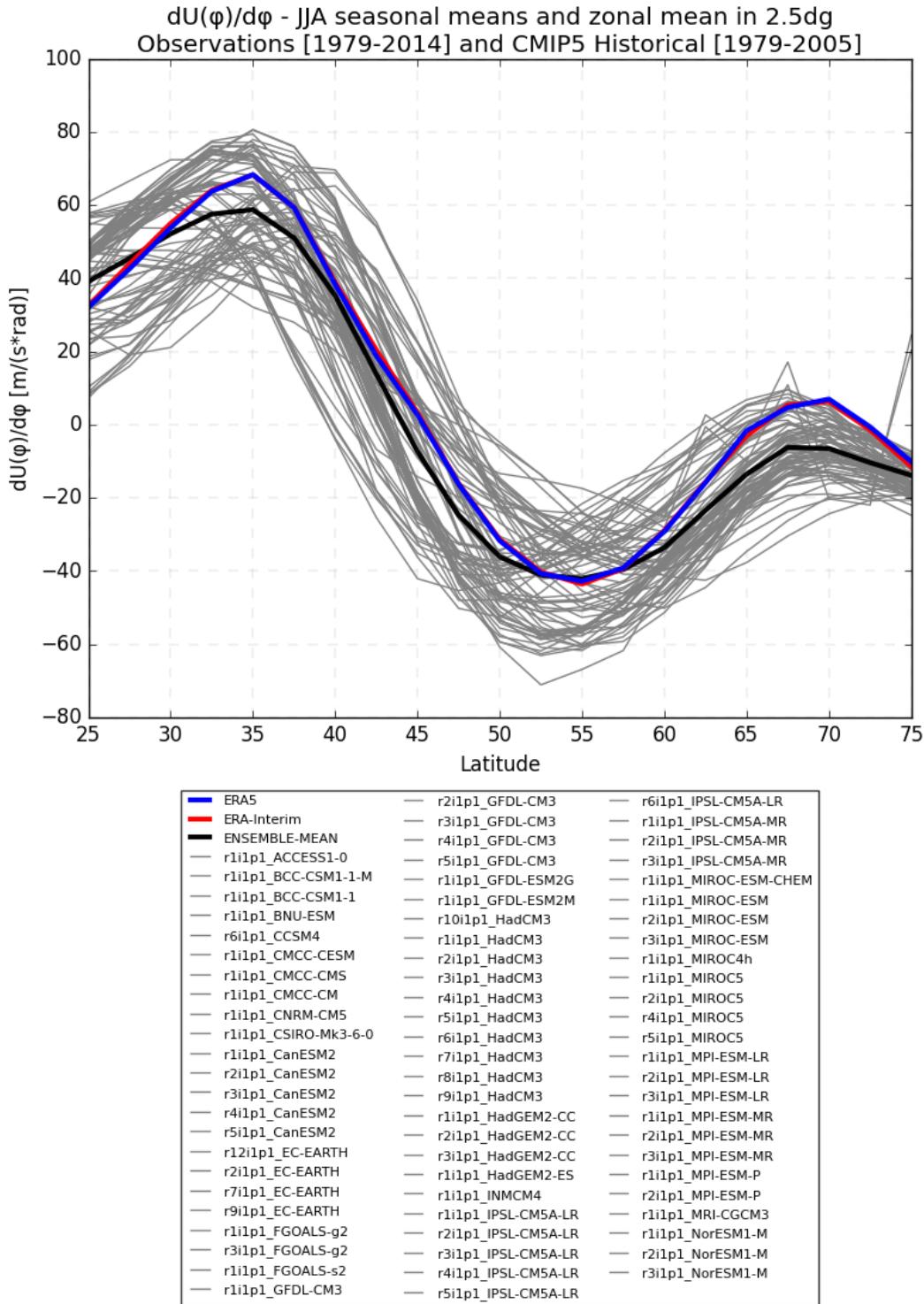
**Figure S34:** Temperature  $dT(\phi)/d\phi$  for CMIP6 (1979-2014) Historical multimodel ensemble over 25N-75N (2.5 degrees) JJA seasonal means compared to observations.



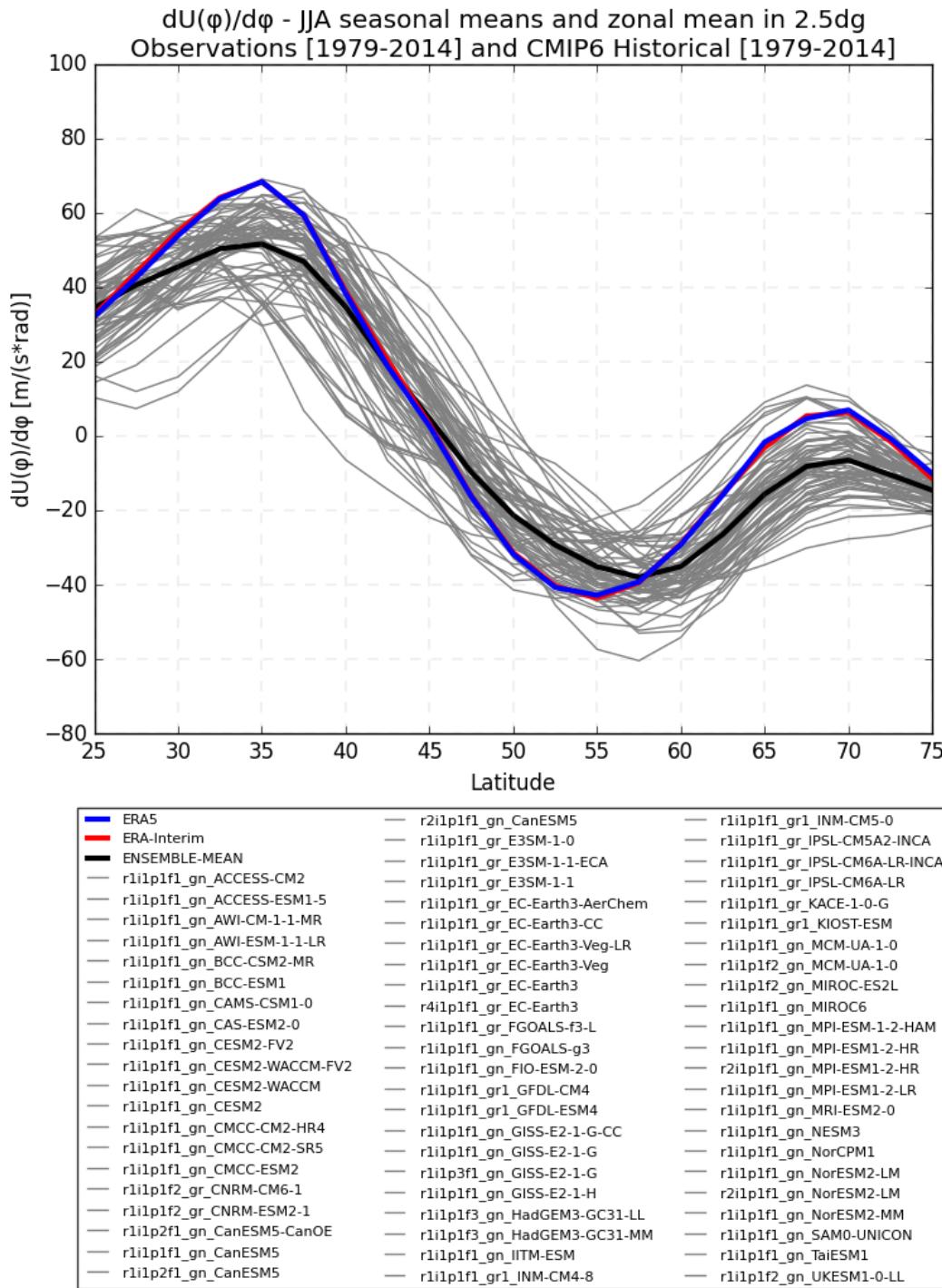
**Figure S35:** Zonal wind  $\bar{u}(\phi)$  for CMIP5 (1979-2005) Historical multimodel ensemble over 25N-75N (2.5 degrees) JJA seasonal means compared to observations.



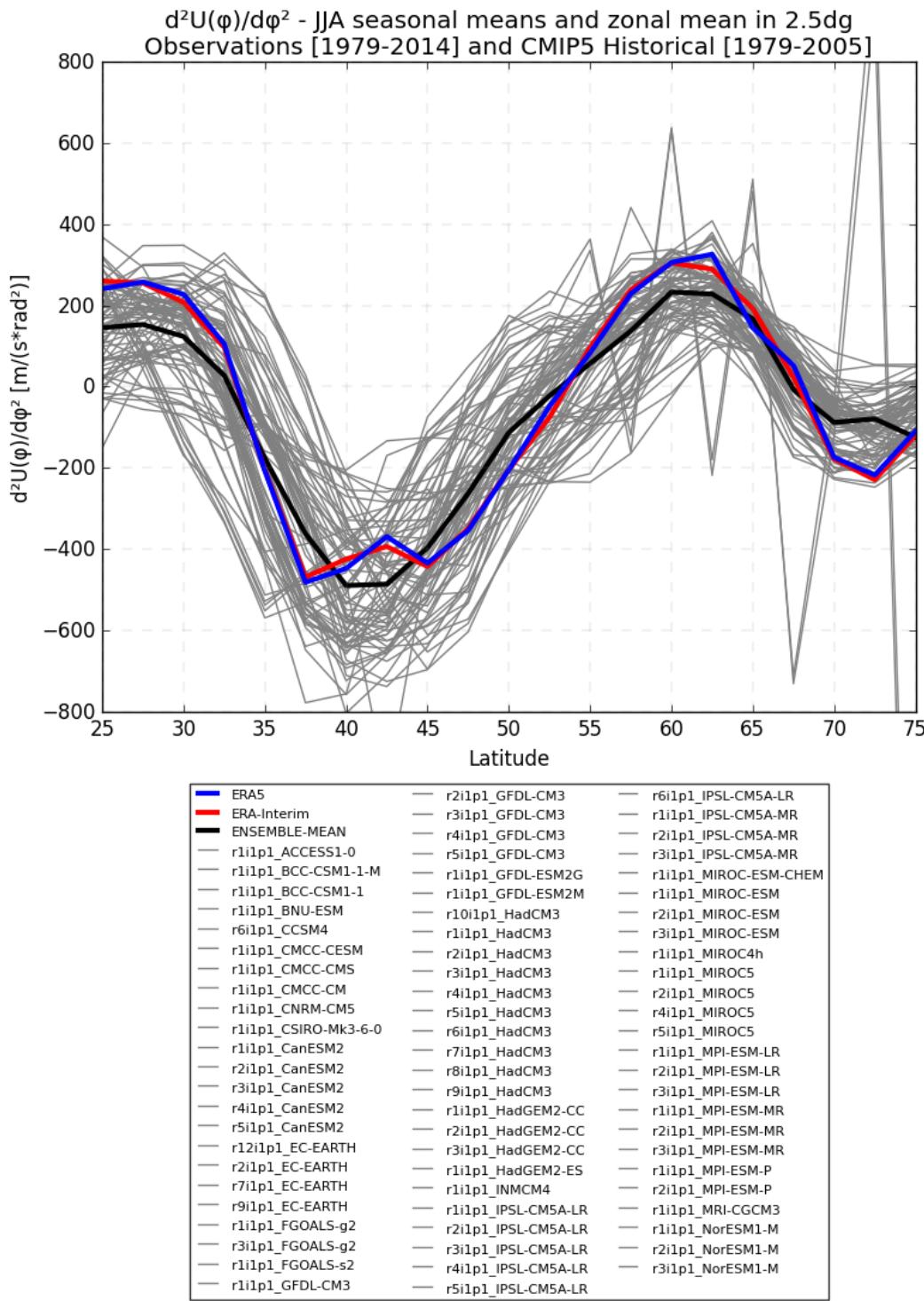
**Figure S36:** Zonal wind  $\bar{u}(\phi)$  for CMIP6 (1979-2014) Historical multimodel ensemble over 25N-75N (2.5 degrees) JJA seasonal means compared to observations.



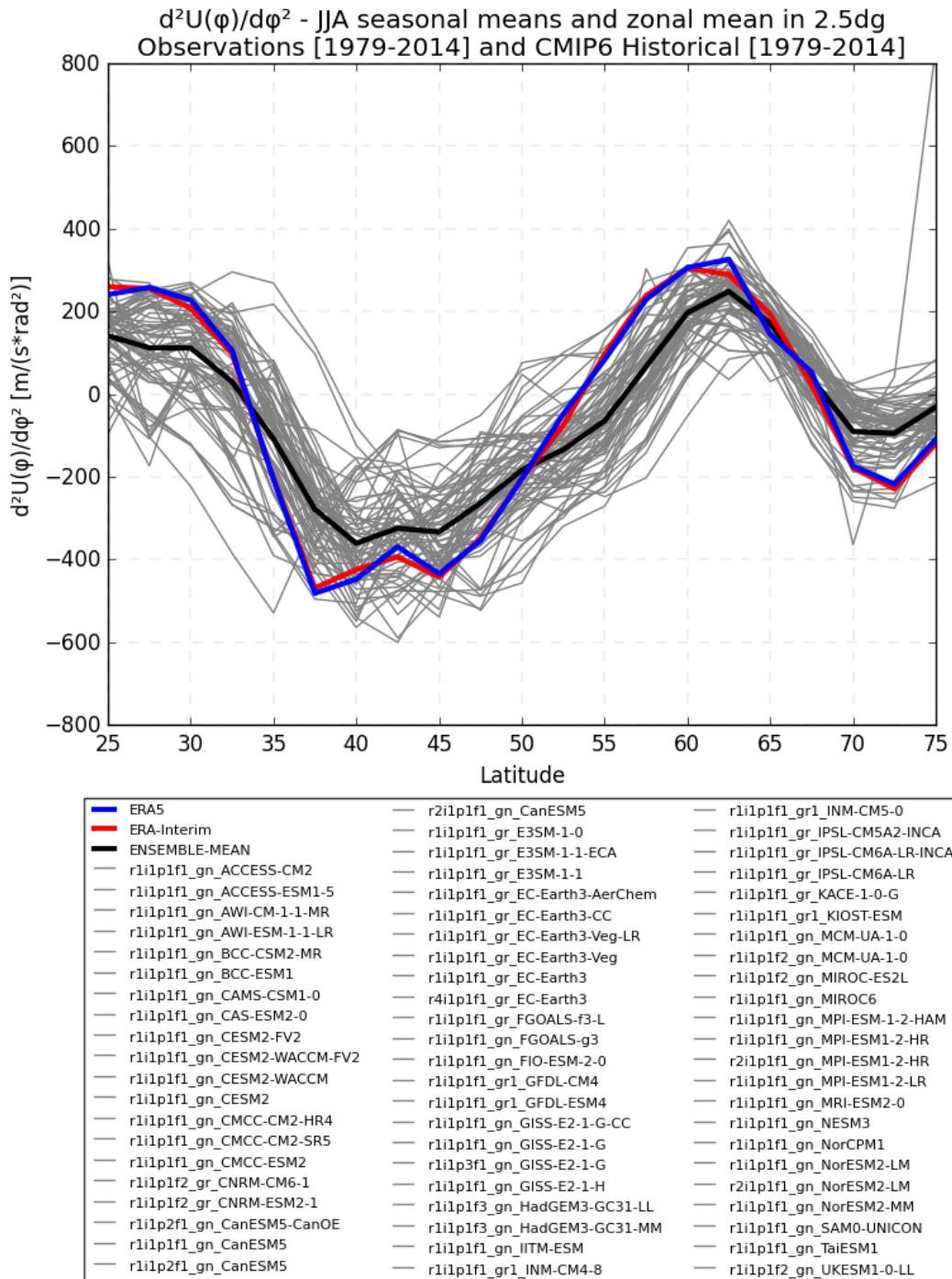
**Figure S37:** Zonal wind  $d\bar{u}(\phi)/d\phi$  for CMIP5 (1979-2005) Historical multimodel ensemble over 25N-75N (2.5 degrees) JJA seasonal means compared to observations.



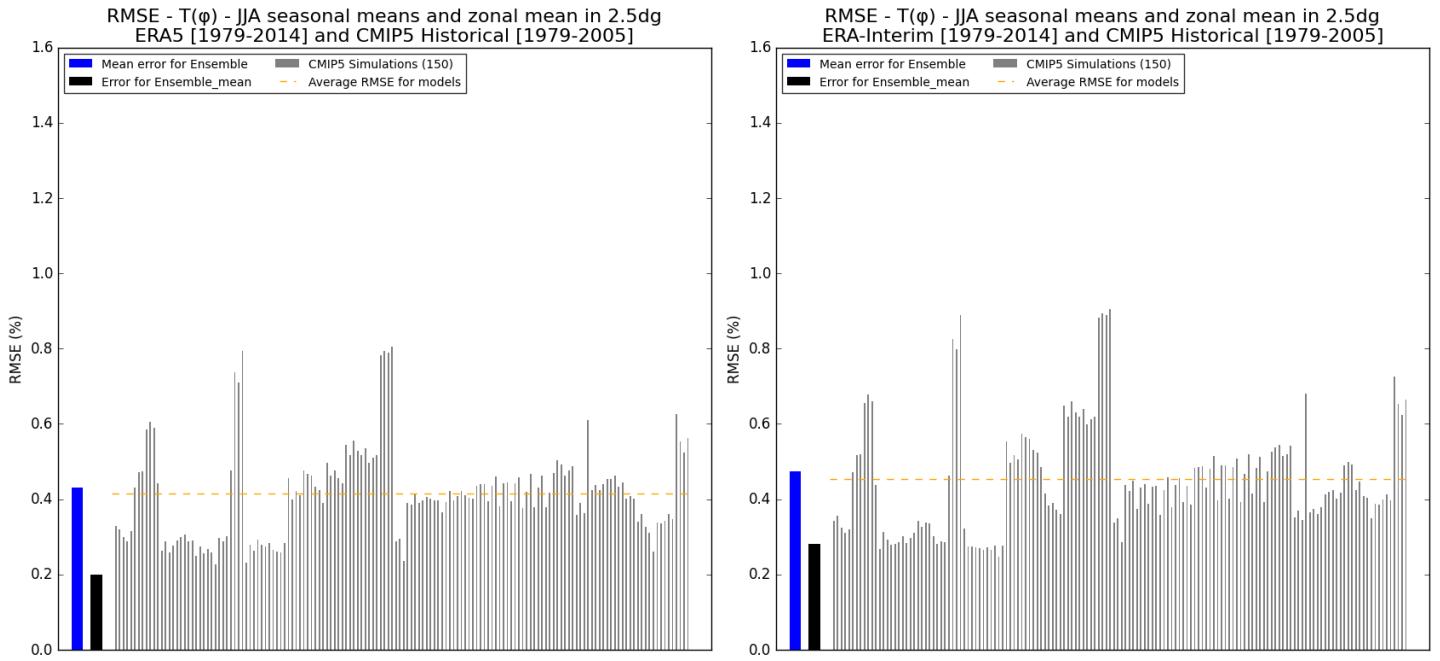
**Figure S38:** Zonal wind  $d\bar{u}(\phi)/d\phi$  for CMIP6 (1979-2014) Historical multimodel ensemble over 25N-75N (2.5 degrees) JJA seasonal means compared to observations.



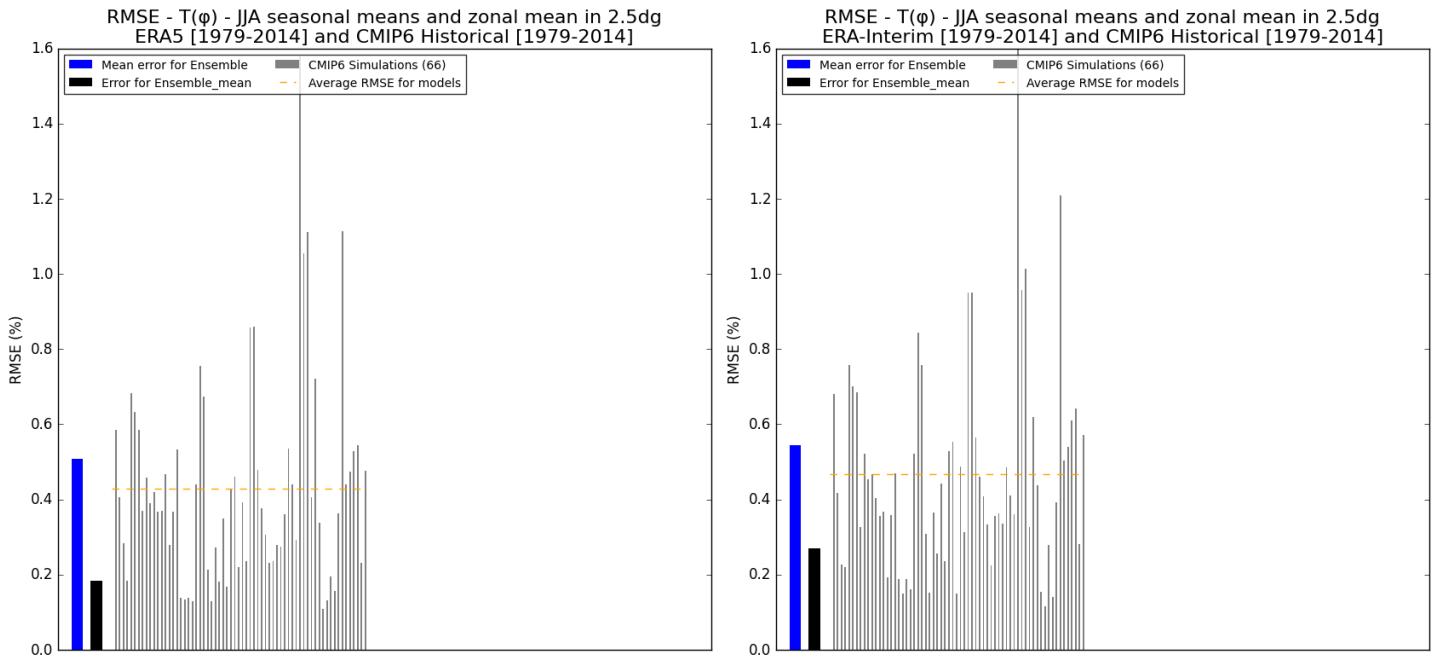
**Figure S39:** Zonal wind  $d^2\bar{u}(\phi)/d\phi^2$  for CMIP5 (1979-2005) Historical multimodel ensemble over 25N-75N (2.5 degrees) JJA seasonal means compared to observations.



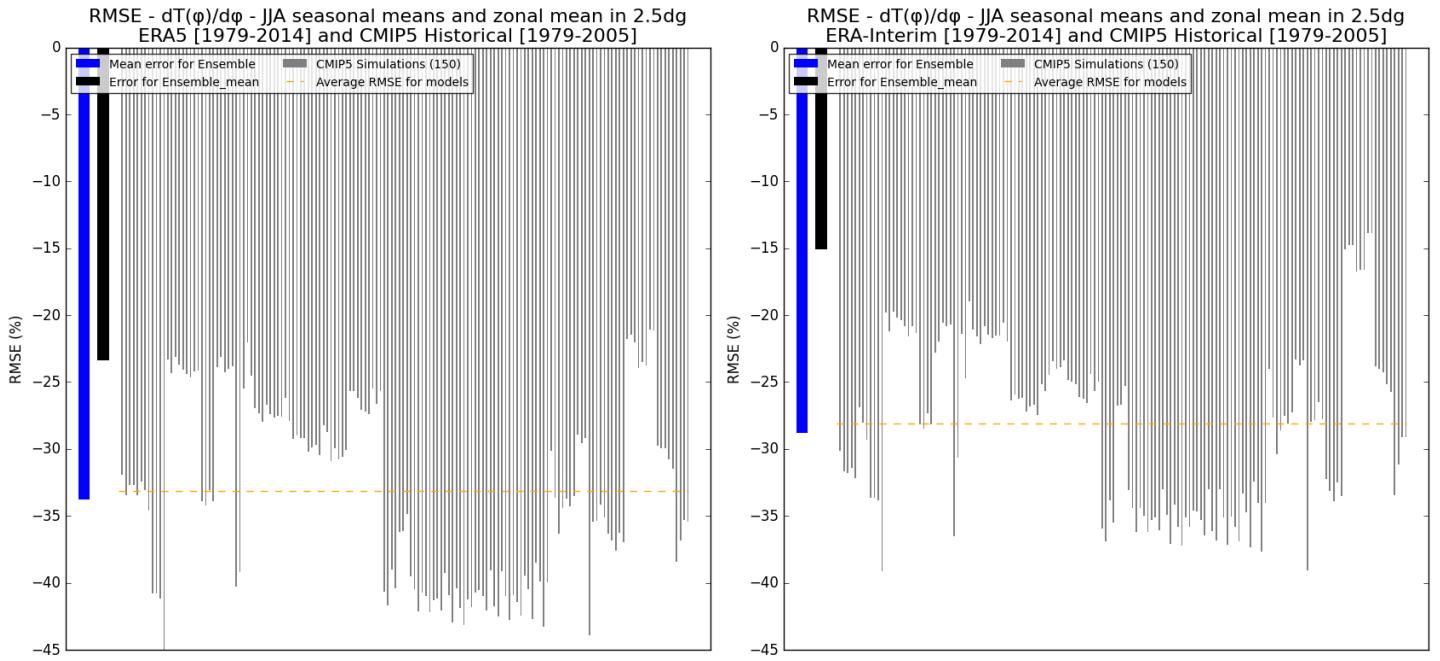
**Figure S40:** Zonal wind  $d^2\bar{u}(\phi)/d\phi^2$  for CMIP6 (1979-2014) Historical multimodel ensemble over 25N-75N (2.5 degrees) JJA seasonal means compared to observations.



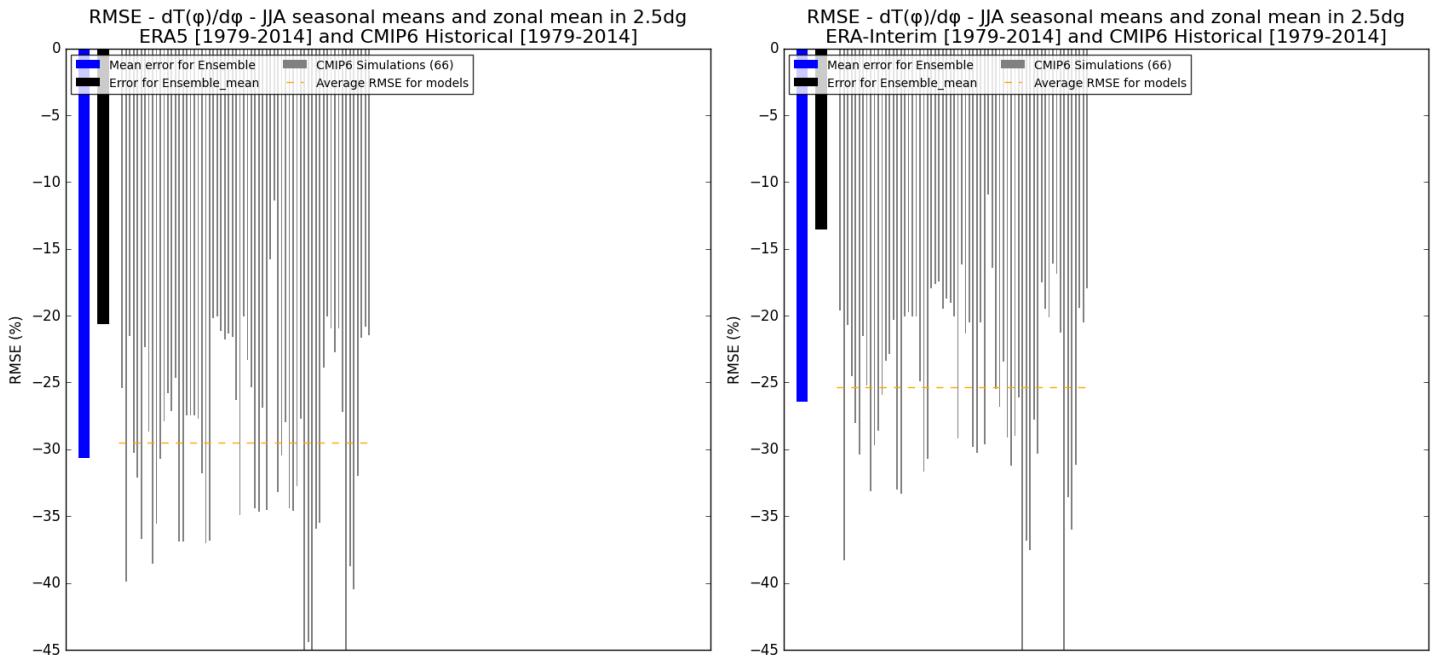
**Figure S41:** Temperature  $T(\phi)$  RMSE for CMIP5 (1979-2005) Historical multimodel ensemble over 25N-75N (2.5 degrees) JJA seasonal means compared to ERA5 and ERA-Interim.



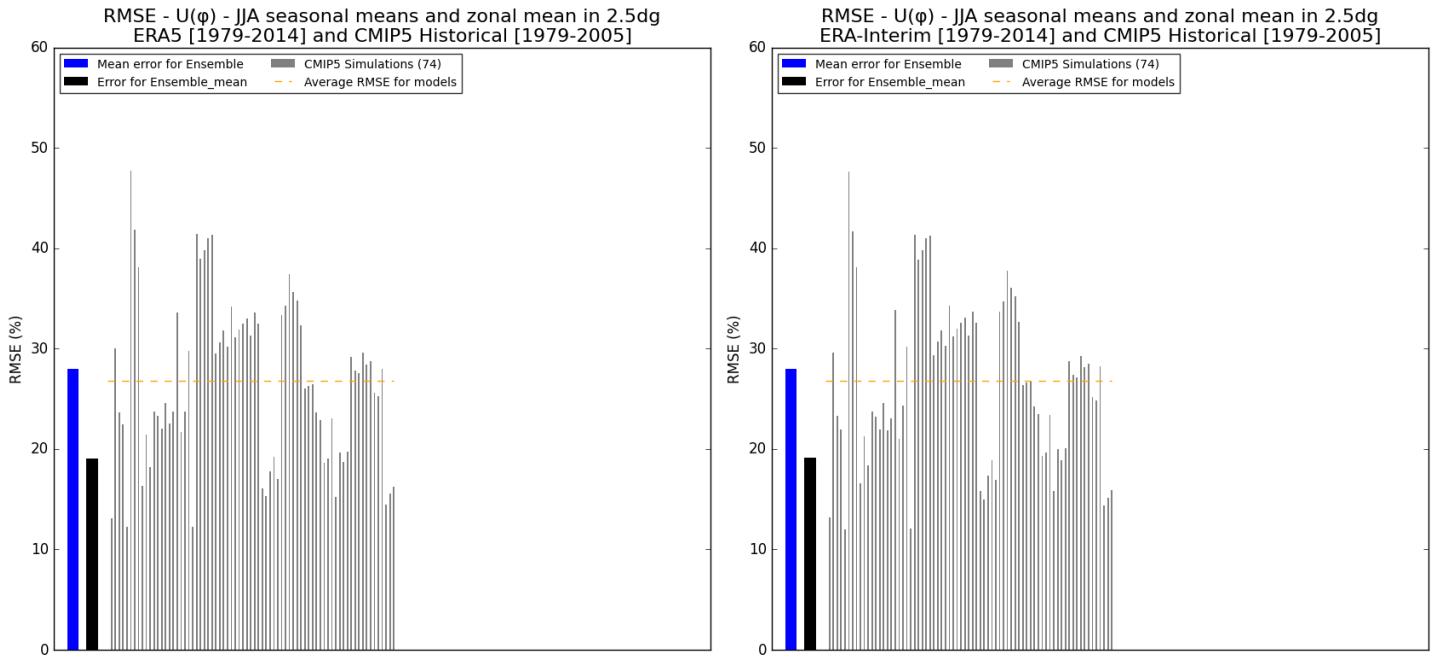
**Figure S42:** Temperature  $T(\phi)$  RMSE for CMIP6 (1979-2014) Historical multimodel ensemble over 25N-75N (2.5 degrees) JJA seasonal means compared to ERA5 and ERA-Interim.



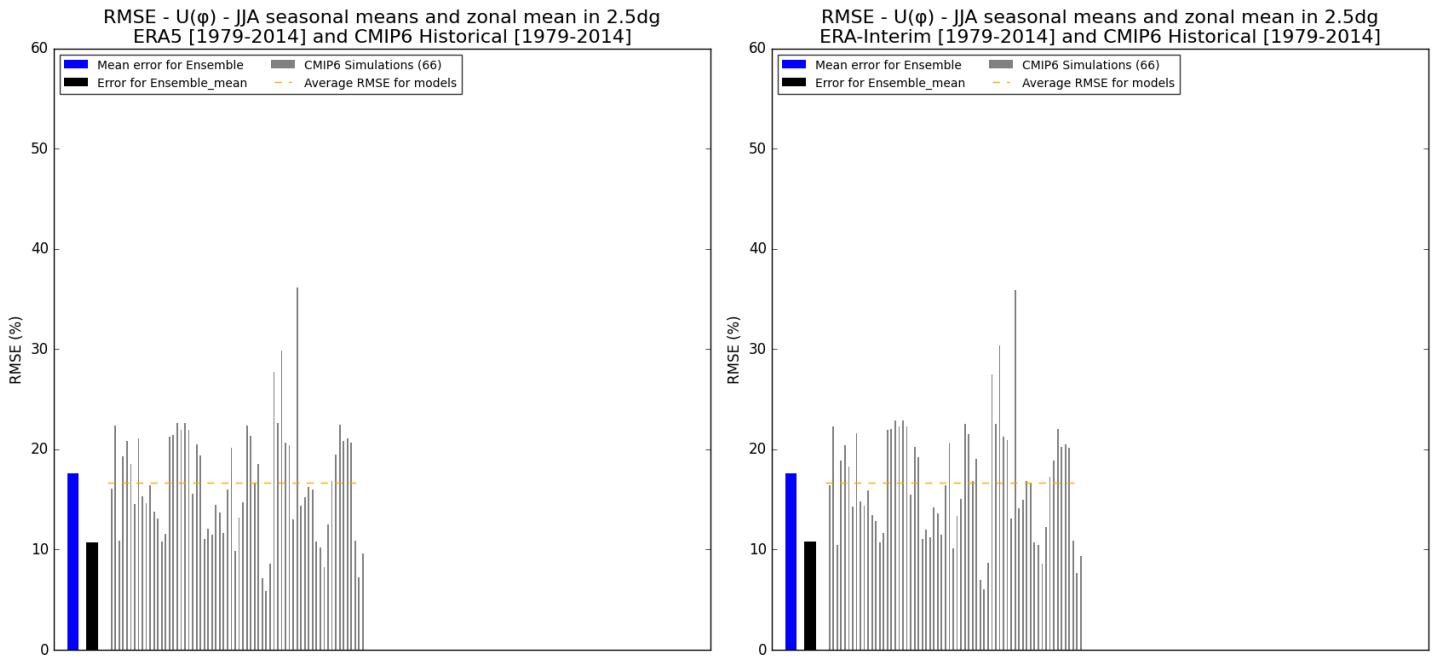
**Figure S43:** Temperature  $dT(\phi)/d\phi$  RMSE for CMIP5 (1979-2005) Historical multimodel ensemble over 25N-75N (2.5 degrees) JJA seasonal means compared to ERA5 and ERA-Interim.



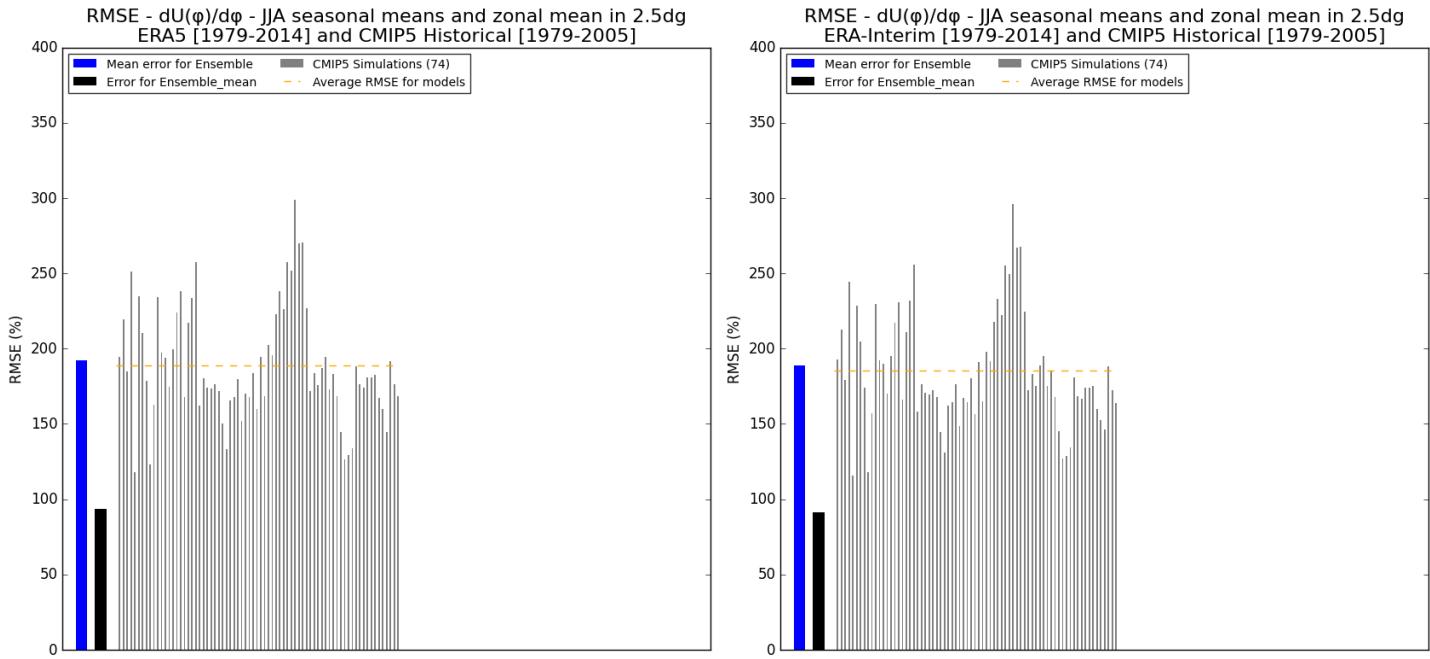
**Figure S44:** Temperature  $dT(\phi)/d\phi$  RMSE for CMIP6 (1979-2014) Historical multimodel ensemble over 25N-75N (2.5 degrees) JJA seasonal means compared to ERA5 and ERA-Interim.



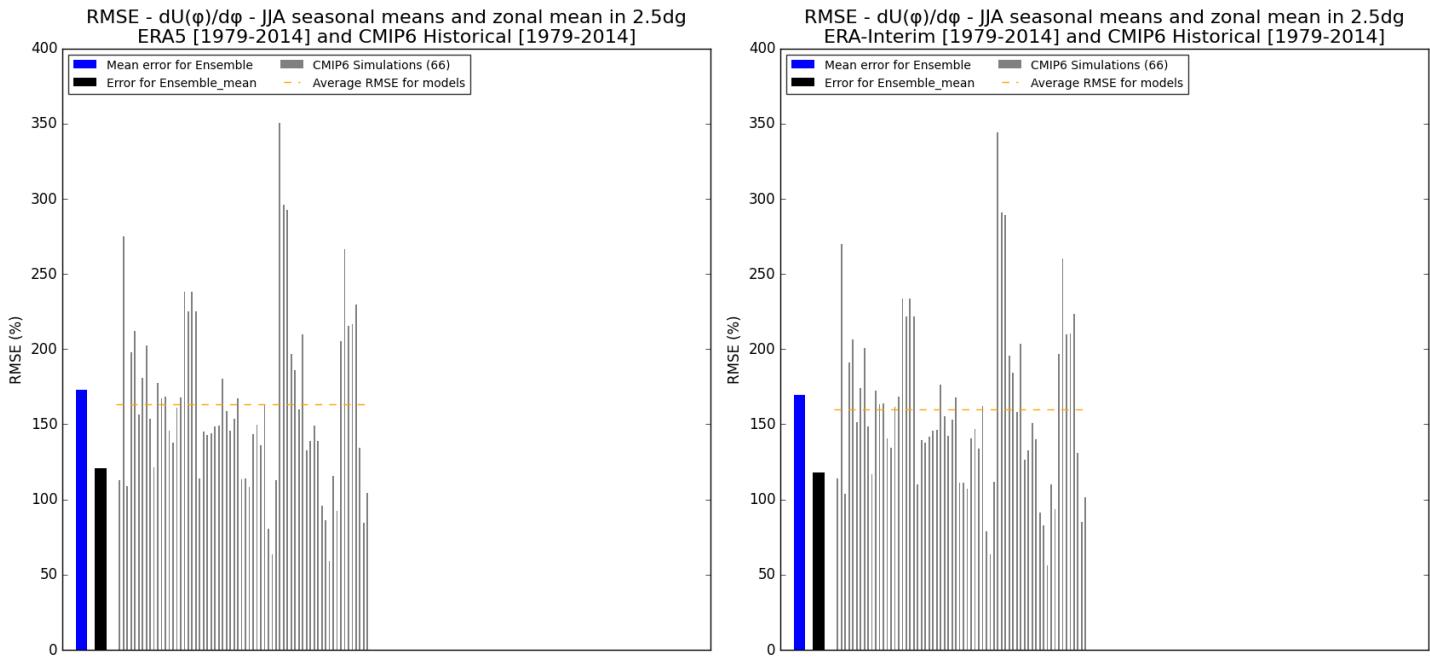
**Figure S45:** Zonal wind  $\bar{u}(\phi)$  RMSE for CMIP5 (1979-2005) Historical multimodel ensemble over 25N-75N (2.5 degrees) JJA seasonal means compared to ERA5 and ERA-Interim.



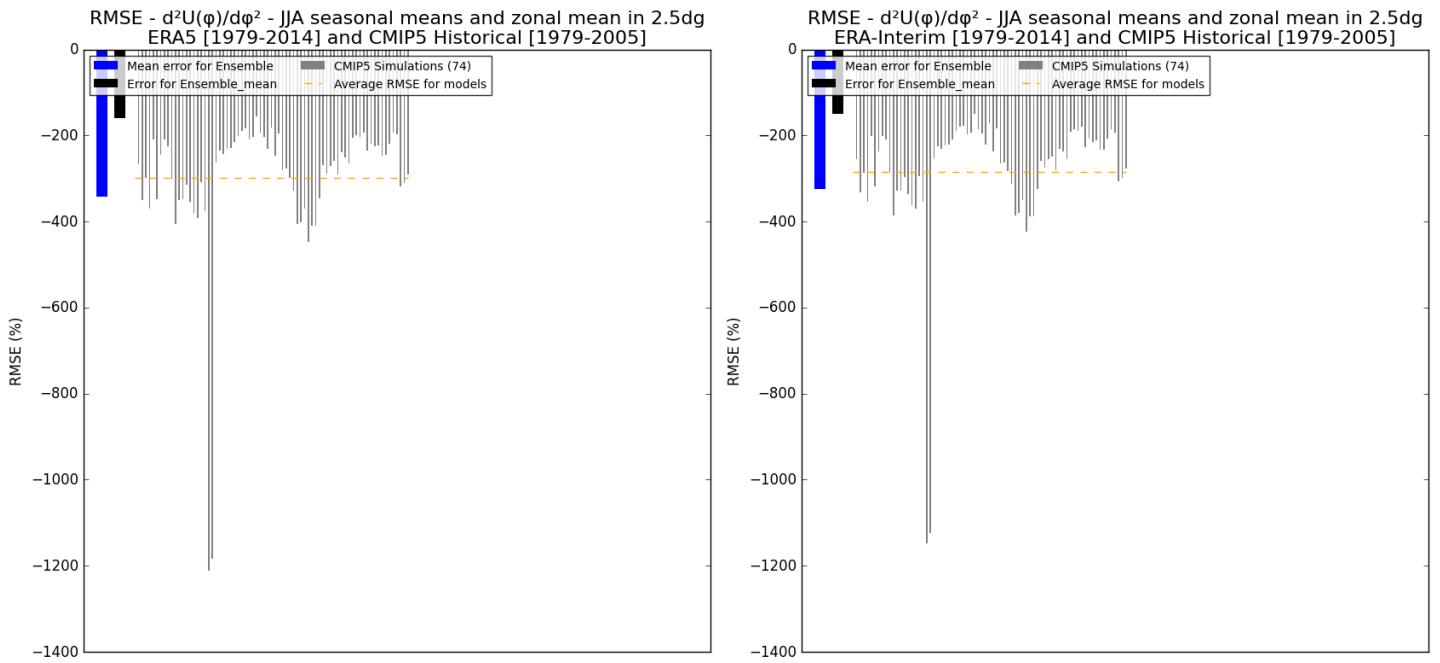
**Figure S46:** Zonal wind  $\bar{u}(\phi)$  RMSE for CMIP6 (1979-2014) Historical multimodel ensemble over 25N-75N (2.5 degrees) JJA seasonal means compared to ERA5 and ERA-Interim.



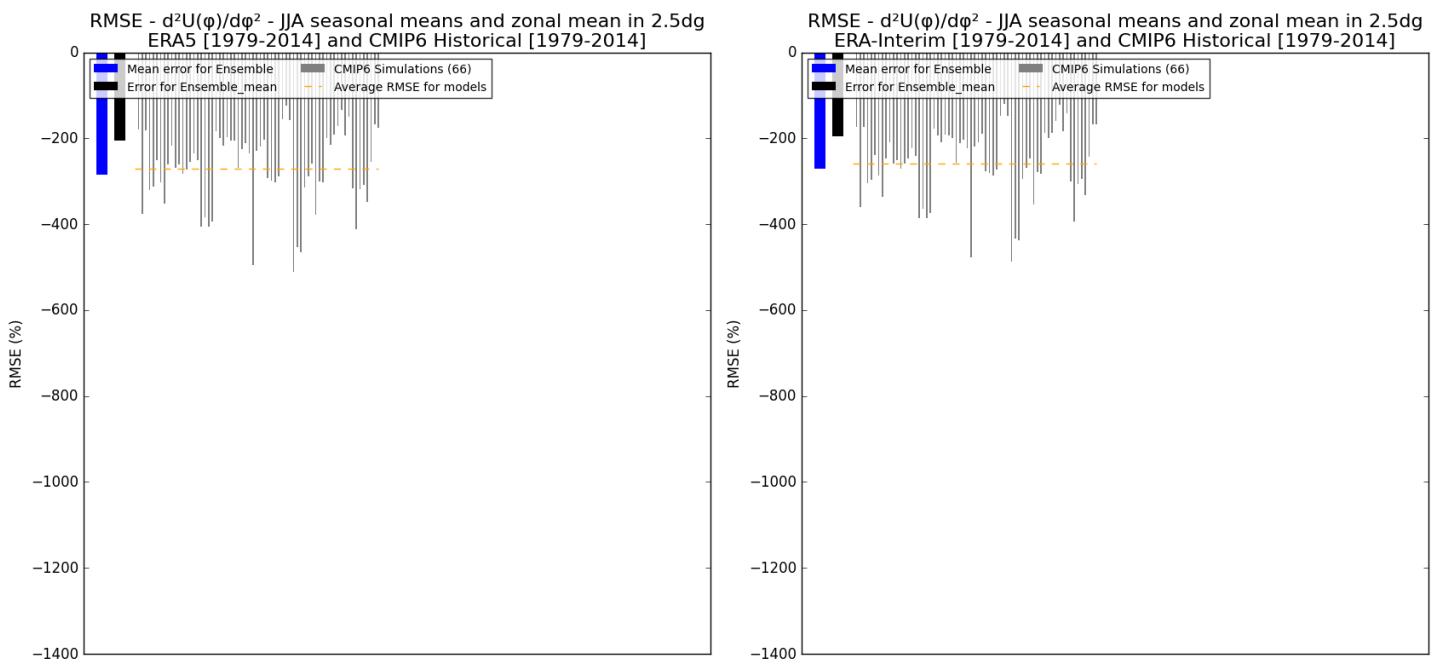
**Figure S47:** Zonal wind  $d\bar{u}(\varphi)/d\varphi$  RMSE for CMIP5 (1979-2005) Historical multimodel ensemble over 25N-75N (2.5 degrees) JJA seasonal means compared to ERA5 and ERA-Interim.



**Figure S48:** Zonal wind  $d\bar{u}(\varphi)/d\varphi$  RMSE for CMIP6 (1979-2014) Historical multimodel ensemble over 25N-75N (2.5 degrees) JJA seasonal means compared to ERA5 and ERA-Interim.



**Figure S49:** Zonal wind  $d^2\bar{u}(\phi)/d\phi^2$  RMSE for CMIP5 (1979-2005) Historical multimodel ensemble over 25N-75N (2.5 degrees) JJA seasonal means compared to ERA5 and ERA-Interim.



**Figure S50:** Zonal wind  $d^2\bar{u}(\phi)/d\phi^2$  RMSE for CMIP6 (1979-2014) Historical multimodel ensemble over 25N-75N (2.5 degrees) JJA seasonal means compared to ERA5 and ERA-Interim.

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