Journal of Geophysical Research: Atmospheres

Supporting Information for

Future Projections of the Large Scale Meteorology Associated with California Heat Waves in CMIP5 Models

Erool Palipane[1] and Richard Grotjahn[1*]

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Introductory text

Introduction

This supporting information is for readers who wish to see more details than are necessary to understand the results as presented in the main text of the article. For example, the LSMPs (large scale meteorological patterns) for the heat waves of the two types are shown, similar to what is shown in LG2016. The longitude by latitude regions in which the LSMPi and cluster indices are calculated are stated in the main text, but a reader wishing to visualize them can do so here. The LSMPs for the ERA-Interim data are also shown in case a reader wants to compare that (shorter period with few events) reanalysis against the NCEP-NCAR reanalysis used in data shown in the main text. As shown by LG2016, the two reanalyses match in terms of LSMP and cluster type. The differences between historical and future climate means needed to understand the preference for cluster type 2 in the future are adequately described in the text, but details are shown here for the CCSM4 model. The Generalized Pareto shape parameter is often paired with the scale parameter; the latter was shown in the text while the former was deemed inconclusive and thus not discussed in the text; shape is shown here for completeness. Trends are shown in the distributions of LSMPi values between the first and last 20 year periods for the RCP8.5 scenario which might interest some readers, but these were not discussed in the text. Historical simulation and reanalysis LSMPs of temperature anomaly at 850 hPa for readers who want a visual depiction of the LSMP metrics defined in section 2.7 and presented in section 3.1 of the main text. Only 5 of the 13 models are shown; also shown are the boundaries of the small domain for the bias and percent error calculations.

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Figures S1 to S13

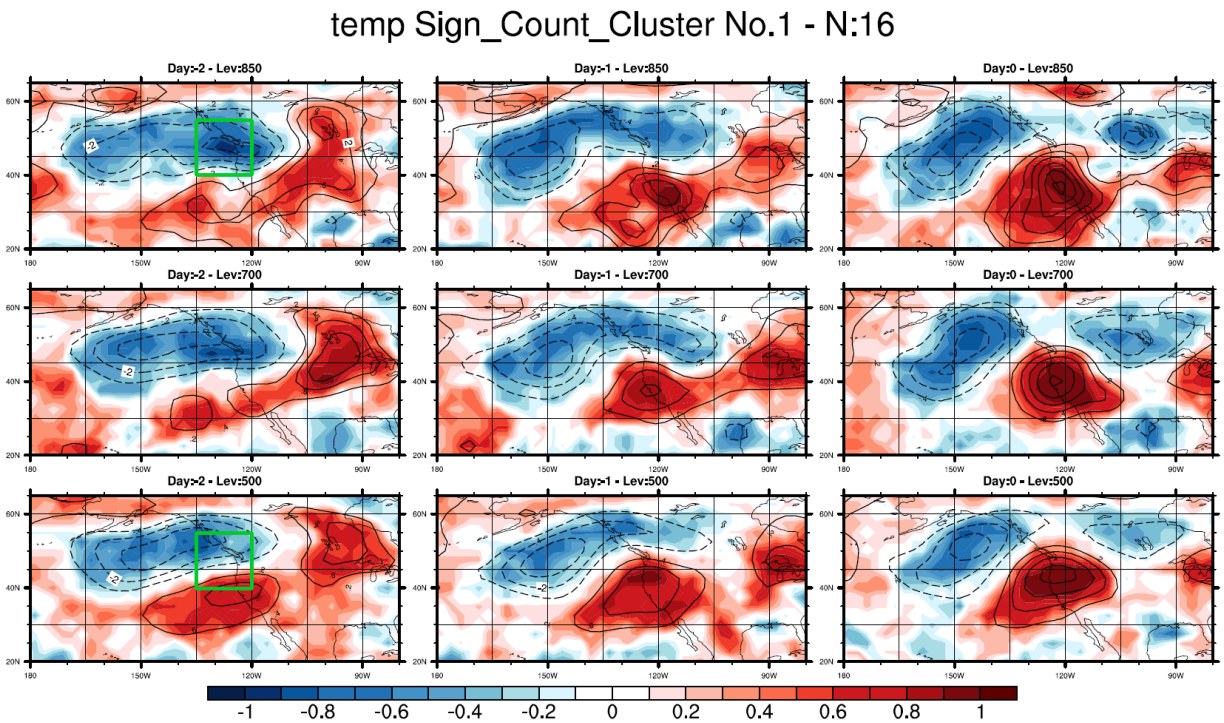

Figure S1. Temperature anomaly ensemble mean at the indicated days before the onset of the 16 Cluster type 1 events in NCEP-NCAR (1971-2010) data. Temperature sign counts are normalized and shaded while and anomalies are contoured. Green rectangle outlines the region used to determine cluster type.

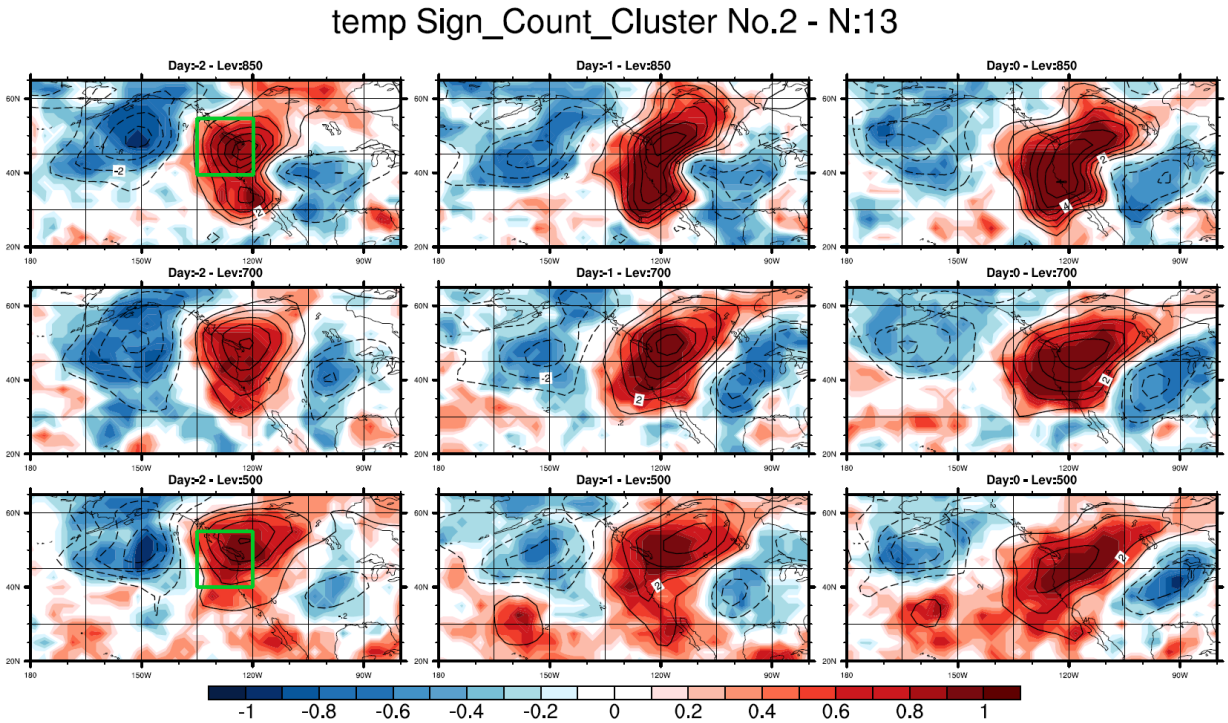

Figure S2. Similar to Figure S1 except for 13 Cluster type 2 events.

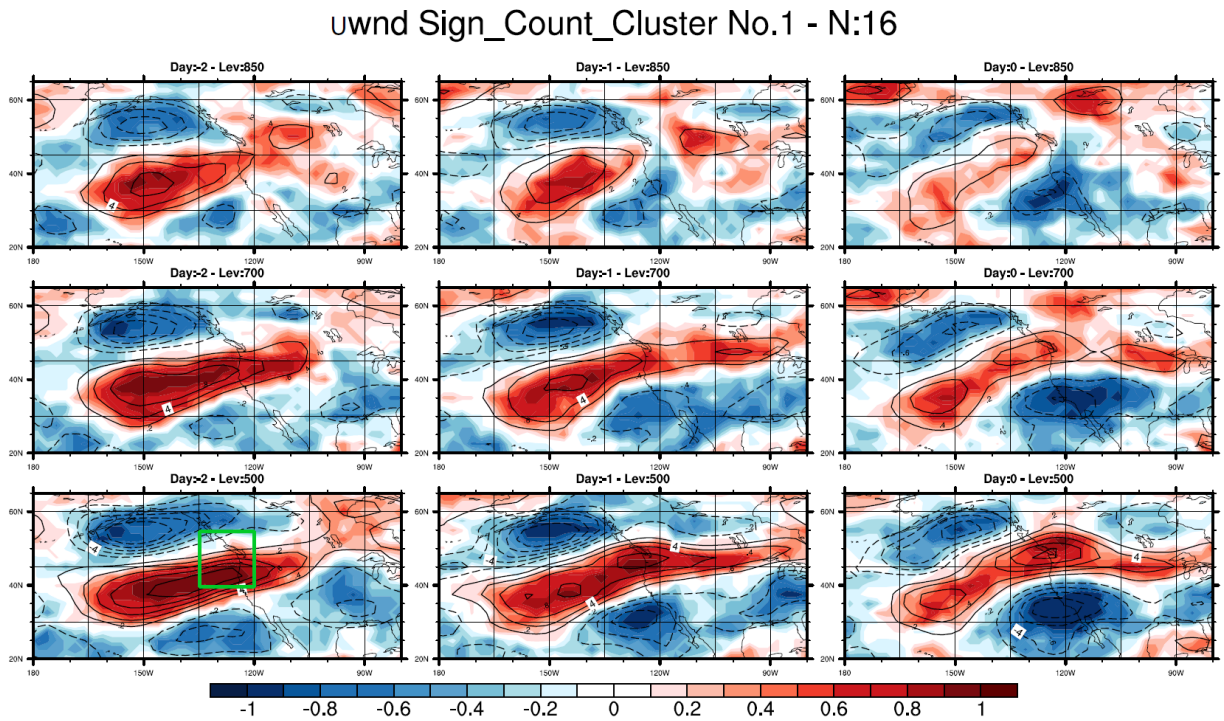

Figure S3. Similar to Figure S1 except that zonal mean wind sign counts are shaded and anomalies are contoured for Cluster type 1.

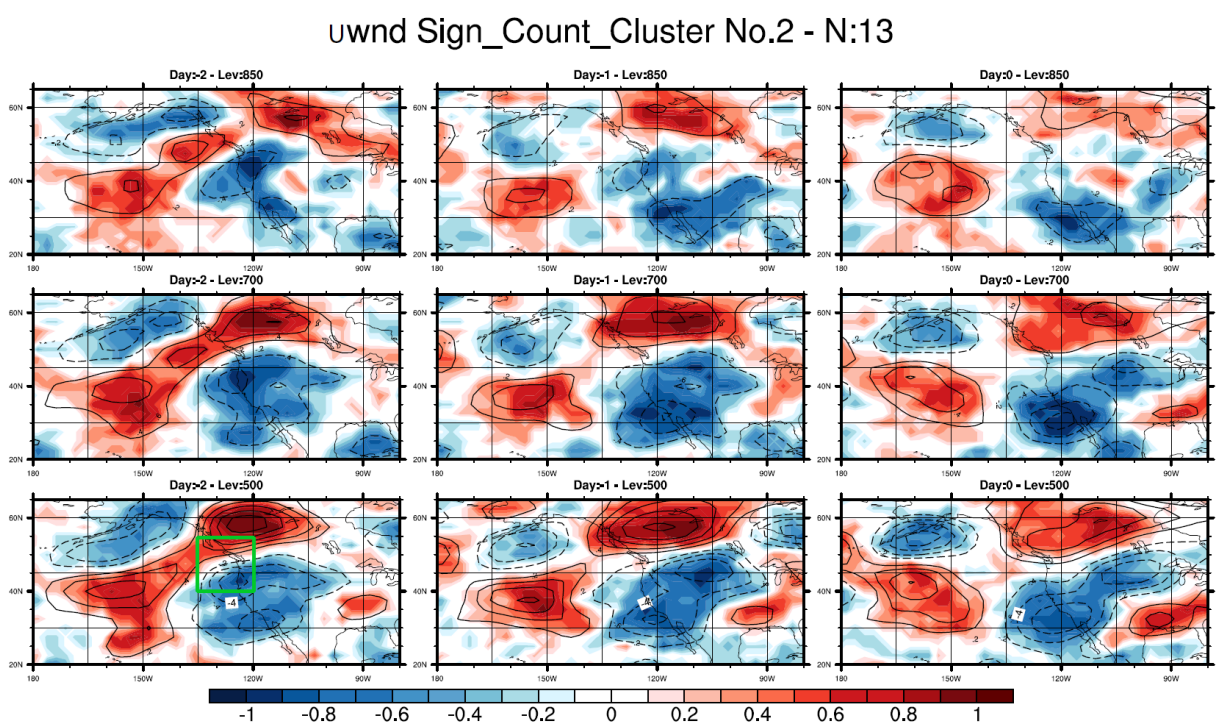

Figure S4. Similar to Figure S3 except for Cluster type 2.

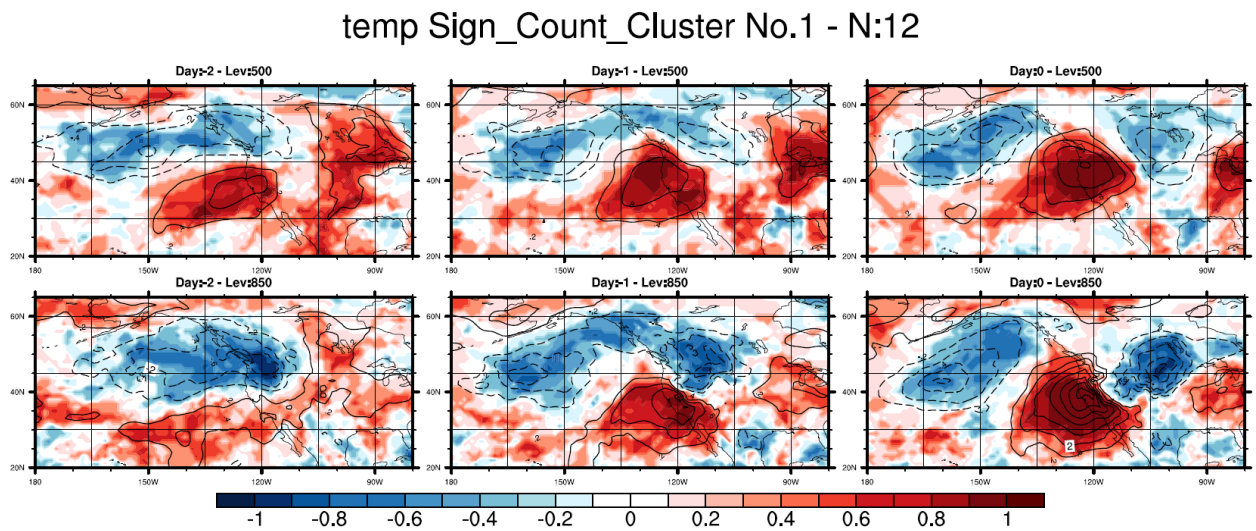

Figure S5. Similar to Figure S1 except for ERA-interim temperature anomalies only from 1979-2010 (a total of 12 heat events).

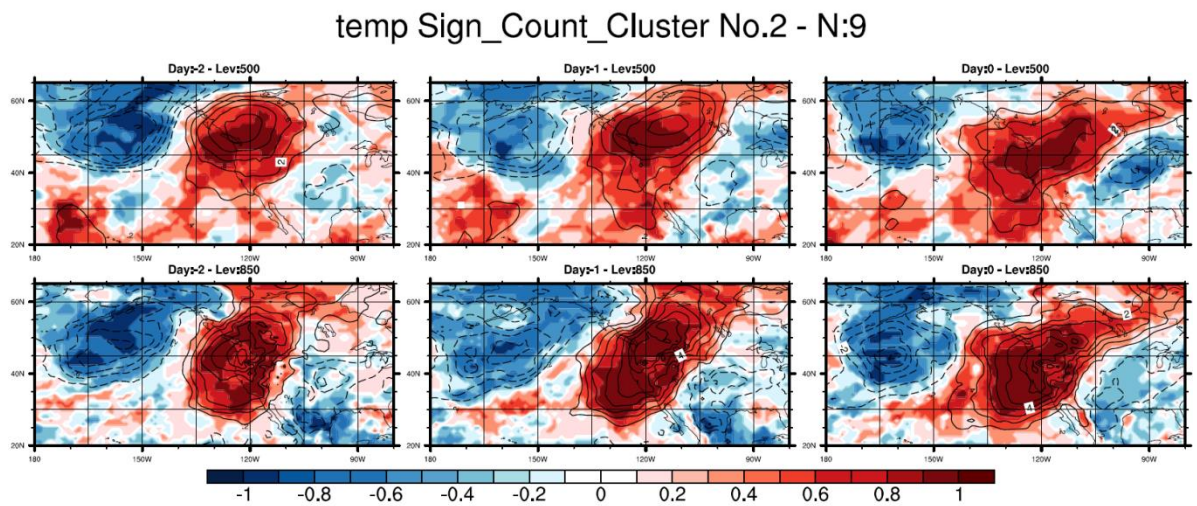

Figure S6. Similar to Figure S2 except for ERA-interim temperature anomalies only from 1979-2010 (a total of 9 heat events).

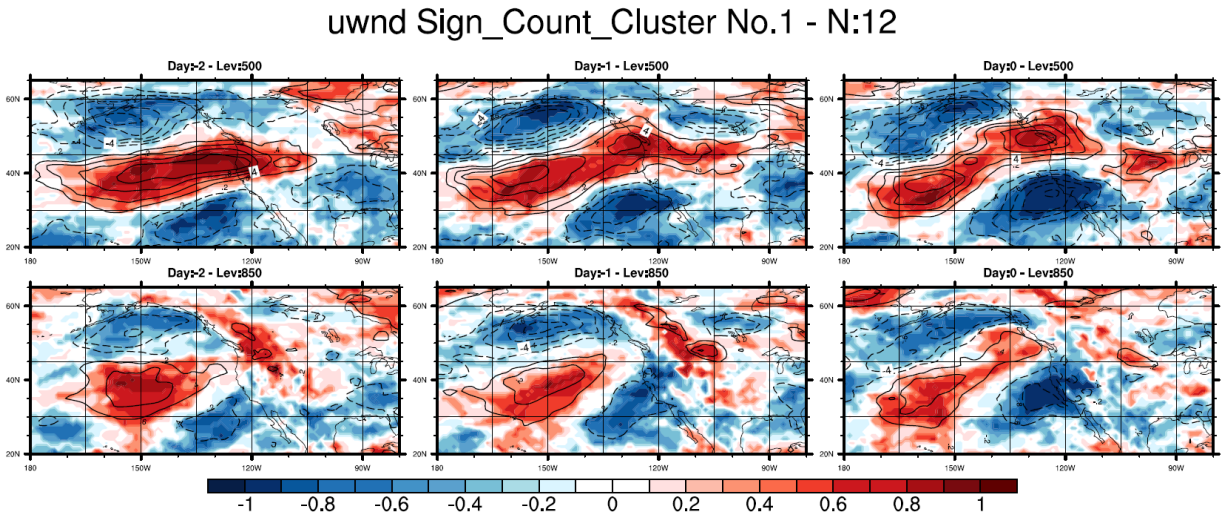

Figure S7. ERA-interim Zonal wind anomaly 1979-2010 cluster 1. (From a total of 24 heat events)

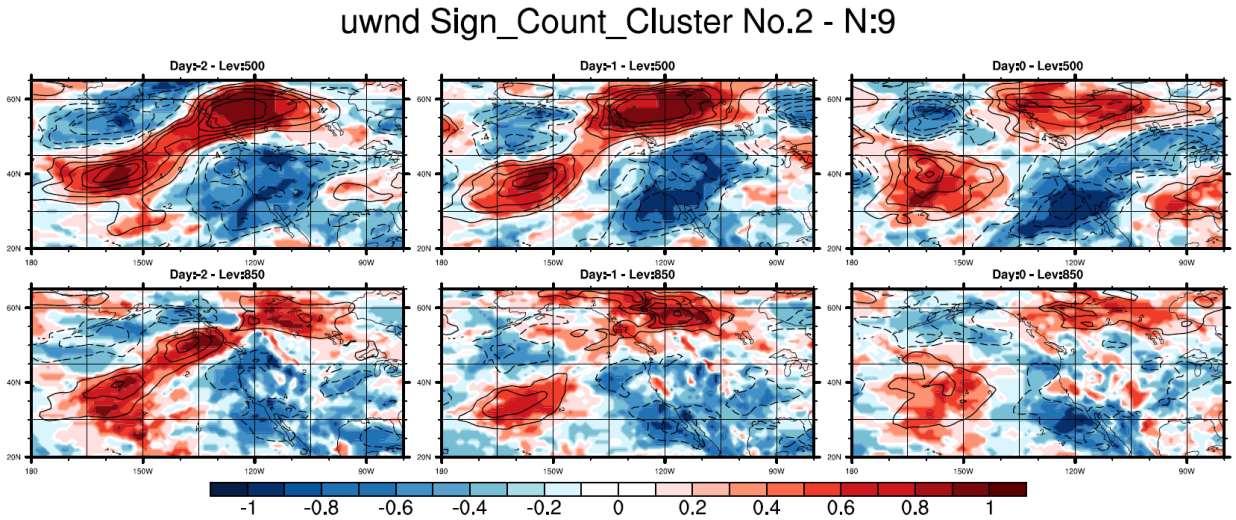

Figure S8. ERA-interim Zonal wind anomaly 1979-2010 cluster 2. (From a total of 24 heat events)

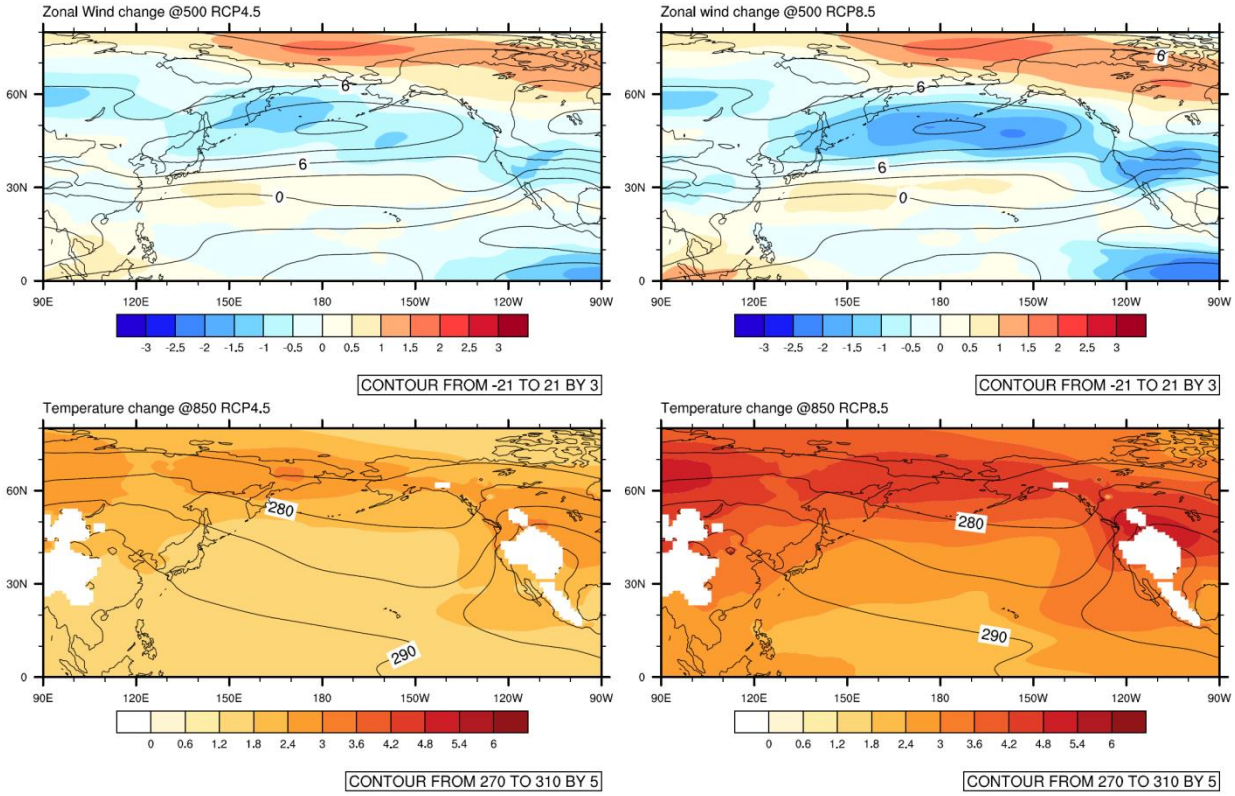

Figure S9. The panels show the change of summer climatology (averaged over June-September) from historical to future simulations by CCSM4 at the 500 hPa level of: zonal mean wind (top) and the 850hPa temperature (bottom). The difference is future summer minus historical summer averages. The shading varies between upper and lower panels. The historical climatology is from 1951-2000 data and future climatology is from 2051-2100 for two RCP scenarios. The left side panels are the RCP4.5 changes and right side panels are the RCP8.5 changes. These plots help interpret changes to the cluster strengths and the number of heat waves in 'Fh' simulations. For example, where these climatological mean changes match up well with the anomaly patterns of a particular cluster, that cluster would occur more frequently in the future. The patterns of the lower row have a warm anomaly over Canada that more closely matches the key region for cluster 2 (figures S2 and S6) than cluster 1 (figures S1 and S5).

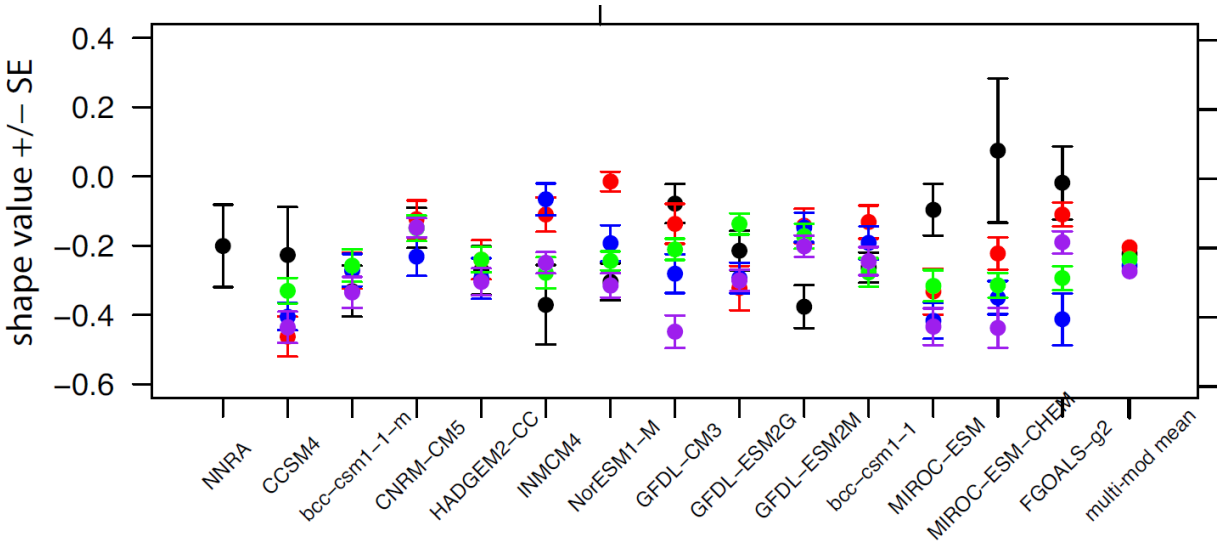

Figure S10. Generalized Pareto shape parameter values for model and reanalysis data LSMPi >1. The black dots are Hh, red dots are Ff (RCP4.5), blue dots are Ff (RCP8.5), green dots are Fh (RCP4.5) and purple dots are Fh (RCP8.5). The dots are the mean and the range shown is the 95% confidence interval.

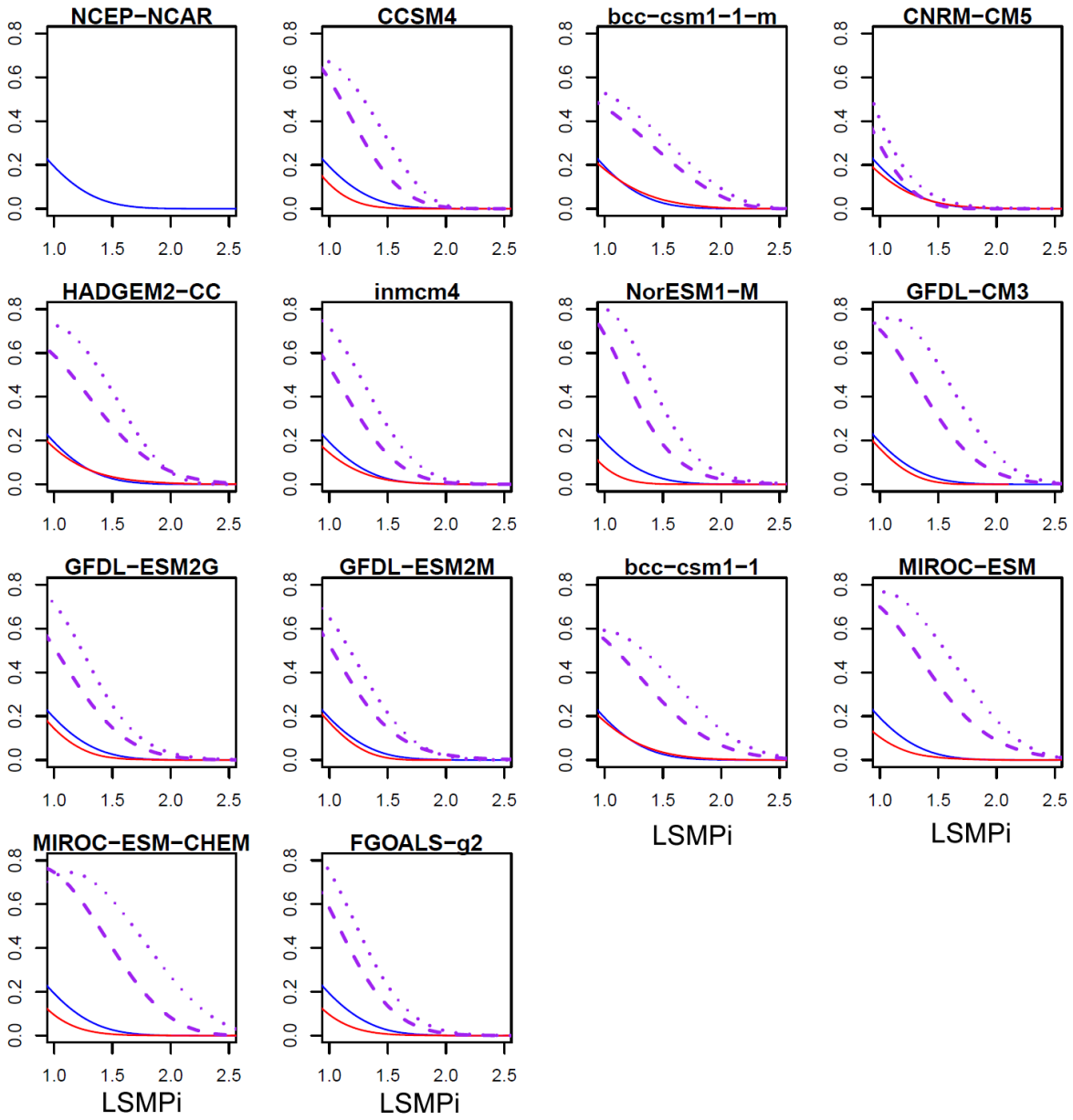

Figure S11. Distribution of the summer days for abscissa values LSMPi >1. The blue line indicates the NCEP-NCAR reanalysis. The red curve indicates the CMIP5_Hh model simulations. The dashed purple curve indicates the 2061-2080 distribution of the CMIP5_Fh for RCP8.5 and the purple dotted curve indicates the 2081-2100 distribution of the CMIP5_Fh for RCP 8.5.

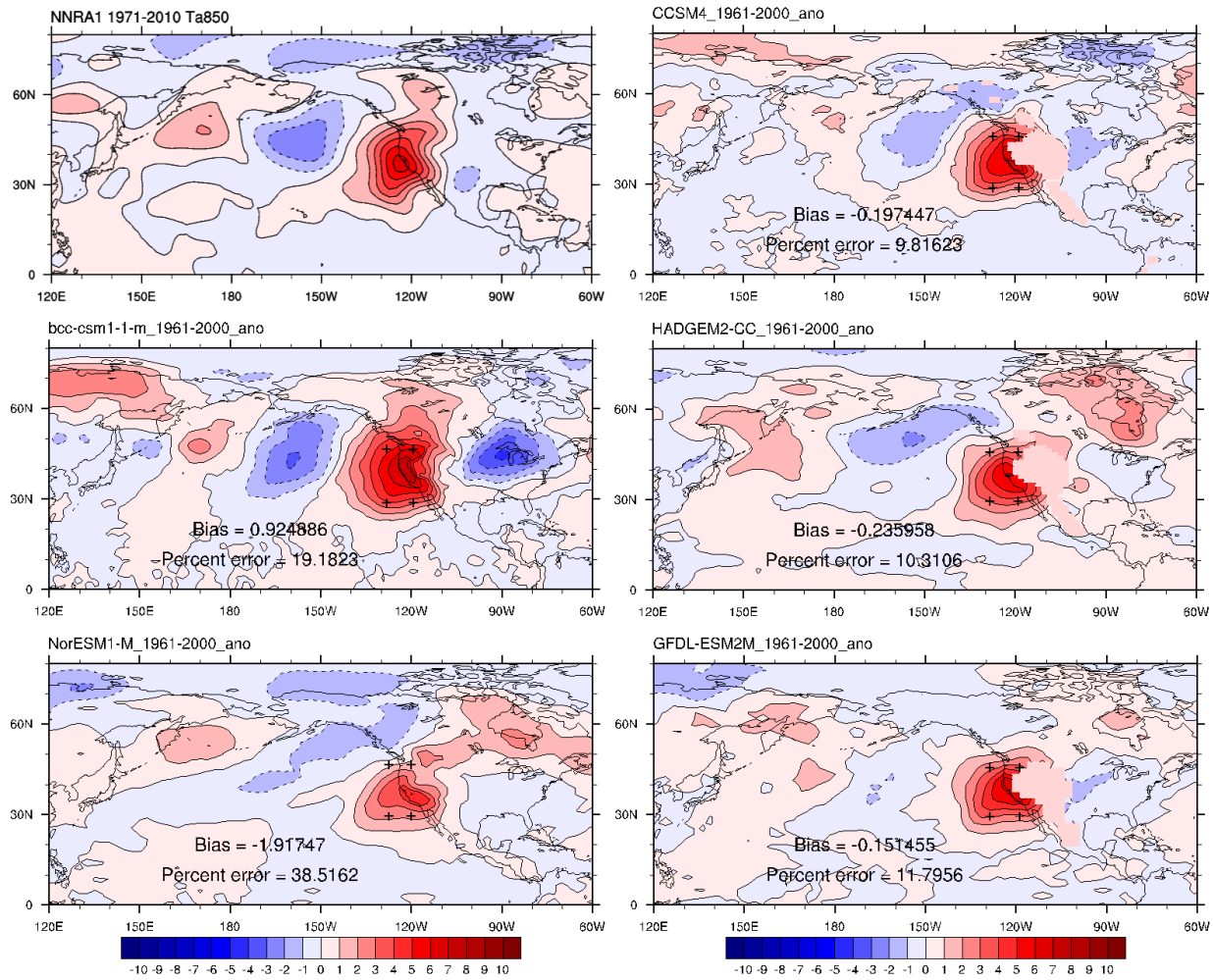

Figure S12. Comparisons of the LSMP of temperature anomaly at 850hPa for the NCEP-NCAR reanalysis (upper left panel) and five of the models. The model plots include the bias and percent error information from the region bounded by the '+' symbols when compared with this reanalysis ensemble mean. The error metrics are not calculated where a model does not have data (seen over the Rocky Mountains for the three models on the right column).

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Tables S1 to S5

Table S1. The models used in the analysis, their corresponding horizontal resolution, availability of ensembles, the number of grid points designated as being within the CCV, and the minimum number of those grid points that must exceed a threshold simultaneously to qualify as a heat wave evet. The first value in columns 3 and 4 are the number of ensembles having tasmax (non-normalized surface max temperature) and 6hrly ua,va,ta data respectively All these are from the r1i1p1 ensemble runs (except CCSM4 which uses r6i1p1 ensemble)

Table S1. *Models' resolution, number of ensembles, and number of California Central Valley (CCV) grid points.*

Model	**Horizontal Resolution (lonxlat)**	**Historical (tasmax, 6hrly) ensembles**	**RCP 4.5 (tasmax, 6hrly) ensembles**	**RCP8.5 (tasmax, 6hrly) ensembles**	**CCV grid #**	**Min grid#**
CCSM4	288x192	6,1	6,1	6,1	4	2
bcc-csm1-1-m	320x160	3,3	1,1	1,1	5	3
CNRM-CM5	256x128	6,3	1,1	1,1	3	2
HADGEM2-CC	192x144	3,2	1,1	3,1	4	2
Inmcm4	180x120	1,1	1,1	1,1	2	1
NorESM1-M	144x96	3,3	1,1	1,1	2	1
GFDL-CM3	144x90	3,3	3,1	1,1	3	2
GFDL-ESM2G	144x90	3,3	1,1	1,1	3	2
GFDL-ESM2M	144x90	3,3	1,1	1,1	3	2
bcc-csm1-1	128x64	3,3	1,1	1,1	1	1
MIROC-ESM	128x64	3,3	1,1	1,1	1	1
MIROC-ESM-CHEM	128x64	1,1	1,1	1,1	1	1
FGOALS-g2	128x64	2,2	1,1	1,1	1	1

Table S2. This table displays the number of events for the CMIP5_Hh, CMIP5_Ff (RCP4.5) and CMIP5_Fh (RCP4.5) simulations including separate totals for cluster types one and two. The sum of clusters one and two may be less than the total number due to those events determined to be type mixed. (See the main text for information about the mixed designation.) Unlike the main text, this table only uses one simulation even when a model has multiple members of their ensemble simulations. Red color indicates results where the RCP4.5 total number of events exceeds the corresponding number for RCP8.5.

Table S2. *Heat wave events for Hh and RCP4.5 simulations*

Model	CMIP5_Hh			CMIP5_Fh(RCP4.5)			CMIP5_Ff (RCP4.5)		
Event types	#evnt	Clust1	Clust2	#evnt	Clust1	Clust2	#evnt	Clust1	Clust2
NCEP-NCAR	32	16	15				32	16	15
CCSM4	34	15	14	133	15	92	37	11	21
bcc-csm1-1-m	39	14	21	104	22	63	41	19	19
CNRM-CM5	32	17	8	124	43	58	33	15	14
HadGEM2-CC	42	19	17	171	28	110	39	16	10
inmcm4	58	23	26	141	51	59	55	24	17
NorESM1-M	59	28	21	170	27	117	65	28	30
GFDL-CM3	34	14	18	170	33	119	32	16	13
GFDL-ESM2G	33	14	14	122	35	71	29	9	13
GFDL-ESM2M	33	13	13	130	51	62	31	16	11
bcc-csm1-1	39	15	18	127	29	73	41	12	21
MIROC-ESM	32	18	10	169	9	129	31	9	11
MIROC-ESM-CHEM	31	15	8	174	19	123	28	7	14
FGOALS-g2	42	17	17	166	63	71	41	16	16

Figure S13. Stations used in this study are shown in the map below, reproduced from LG2016:

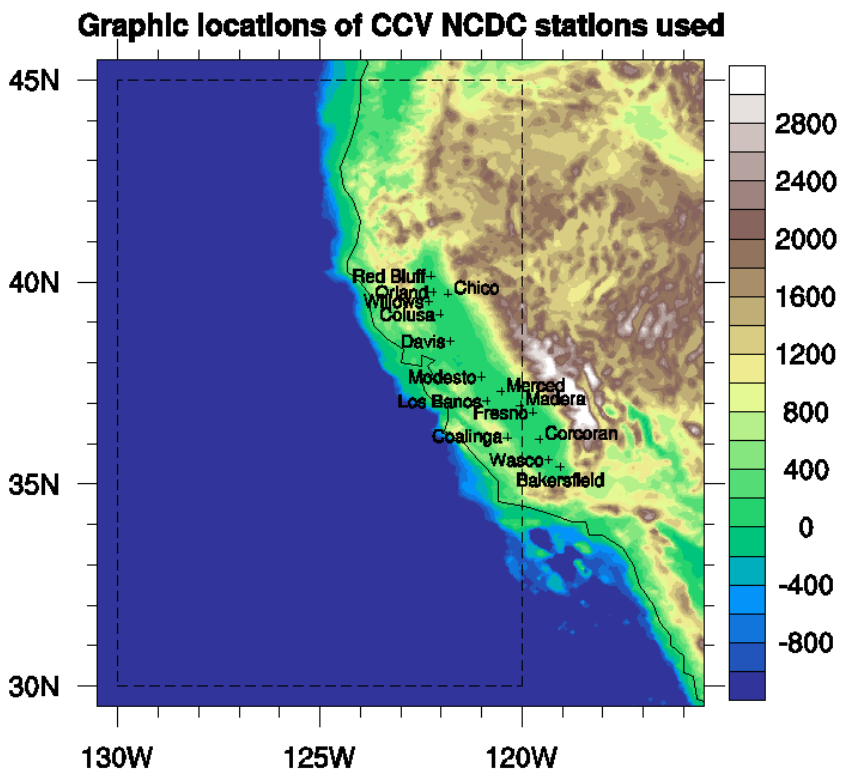

Table S3. The station names and elevations

Station	Elevation/m
Red bluff	107.6
Chico	63.7
Orland	77.4
Willows	42.1
Colusa	15.0
Davis	18.3
Modesto	27.7
Merced	46.6
Los Banos	36.6
Fresno	101.5
Coalinga	204.2
Corcoran	61.0
Madera	82.3
Wasco	105.2
Bakersfield	149.0

Note: The elevation data was taken from http://ipm.ucanr.edu/WEATHER/wxactstnames.html

The values used are the daily surface level maximum temperatures and from 1961-2000.

Table S4 shows the number of percentage of the summer that have 'heat event days'. Heat event days are those days having sufficient temperature anomaly and duration to satisfy the heat wave criteria.

Table S4. Percentage of heat event days (heat event days/days)*100%

Model	CMIP5_hh	CMIP5_ff RCP4.5	CMIP5_fh RCP4.5	CMIP5_ff RCP8.5	CMIP5_fh RCP8.5
CCSM4	3.26	3.42	14.19	3.49	23.28
Bcc-csm1-1-m	3.29	3.44	10.51	2.99	17.95
CNRM-CM5	2.88	2.64	12.36	3.07	21.02
HADGEM2-CC	3.60	3.11	22.30	3.52	24.51
INMCM4	4.60	4.60	17.40	4.50	23.75
NorESM1-M	4.70	4.71	20.29	4.65	26.80
GFDL-CM3	2.75	2.56	22.58	2.97	26.15
GFDL-ESM2G	3.10	2.90	14.29	3.00	27.41
GFDL-ESM2M	3.10	3.0	14.54	2.85	26.46
Bcc-csm1-1	3.75	3.67	14.93	2.99	26.89
MIROC-ESM	2.62	2.46	27.19	2.72	26.75
MIROC-ESM-CHEM	2.77	2.39	24.42	3.15	26.78
FGOALS-G2	3.80	3.56	19.22	3.42	23.62
Multi-model Weighted Ave.	3.13	2.98	17.96	3.13	25.00

Table S5: Distances between the centroids for cluster types one and two for the reanalysis, individual models, and the multi-model mean. For comparison, the corresponding centroid distances shown by GL2016 are also included.

Table S5.	Distance between centroids for cluster types one and two.					
	New values	GL2016 values	Weights	Weighted distance		% change vs GL2016 values
NNRA1	2.502	1.77				41.36
CCSM4	2.305	1.48	0.1109	0.2556245		55.74
bcc-csm1-1-m	2.637	1.62	0.0534	0.1408158		62.78
CNRM-CM5	2.816	1.5	0.0935	0.263296		87.73
HadGEM2-CC	2.595	1.53	0.0947	0.2457465		69.61
inmcm4	2.145	1.24	0.0168	0.036036		72.98
NorESM1-M	2.213	1.21	0.0125	0.0276625		82.89
GFDL-CM3	2.33	1	0.2076	0.483708		133.00
GFDL-ESM2G	2.404	1.51	0.1059	0.2545836		59.21
GFDL-ESM2M	2.164	1.49	0.1047	0.2265708		45.23
bcc-csm1-1	2.315	1.57	0.0754	0.174551		47.45
MIROC-ESM	1.815	1.25	0.0578	0.104907		45.20
MIROC-ESM-CHEM	1.405	1.28	0.0595	0.0835975		9.77
FGOALS-g2	1.977	1.01	0.0072	0.0142344		95.74
					Average change in models	66.72
Multi-model Weighted average				2.311	Multi-model weighted change	72.67