Supplementary Materials for

Improve the projection of East China summer precipitation with emergent constraints

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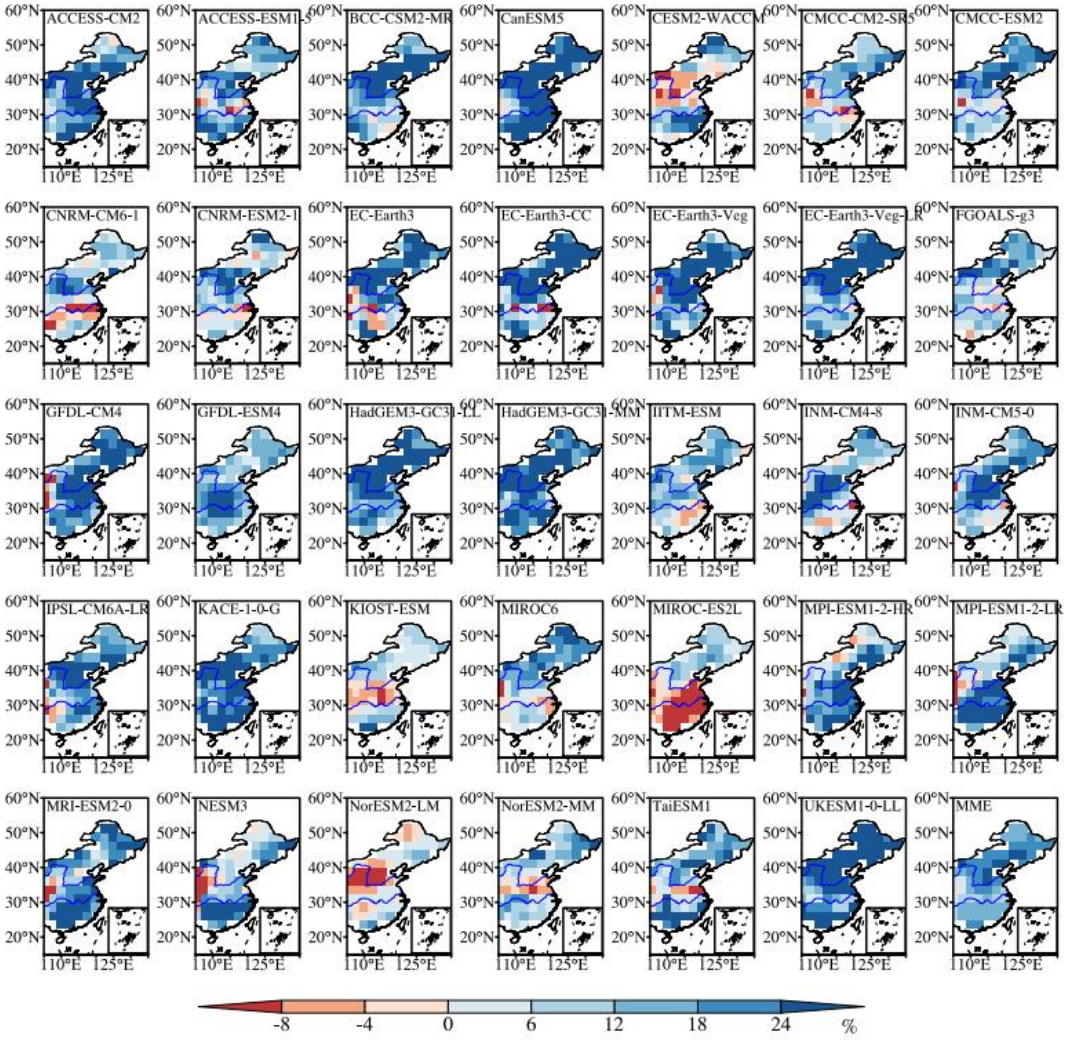
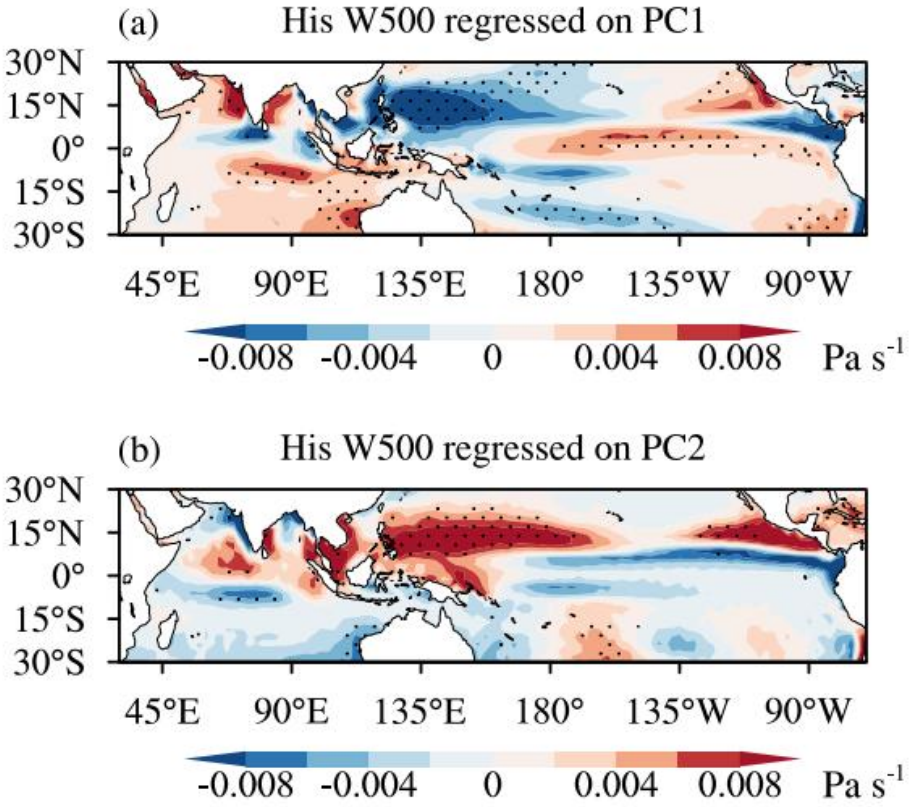
Table S1. Model numbers, model names, modeling centers and countries, as well as the atmospheric resolutions, of 34 CMIP6 global climate models.

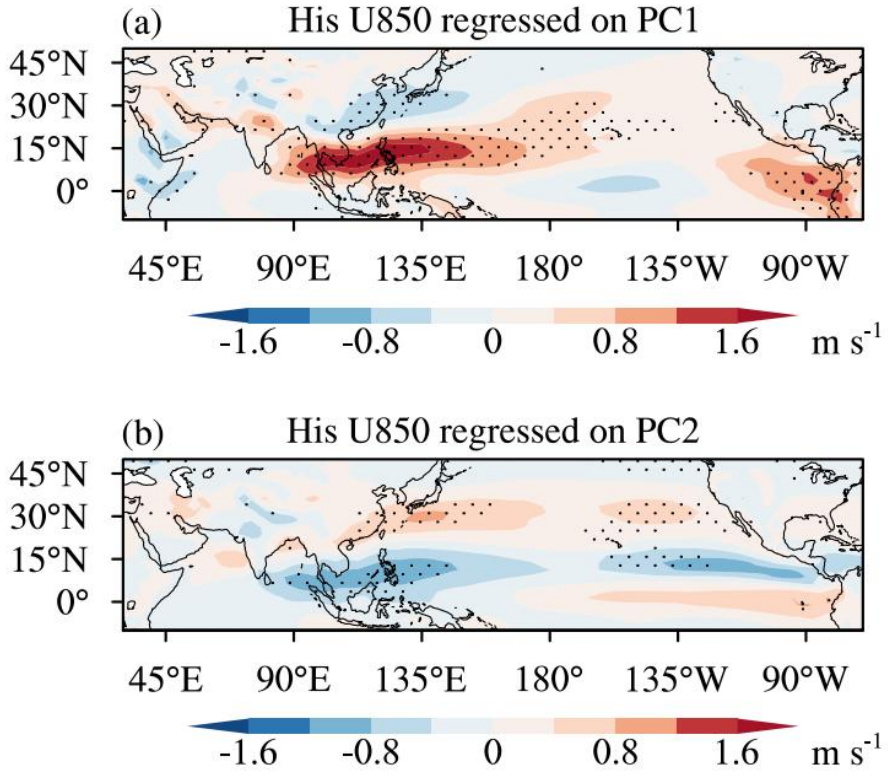
Number	Model	Institute/Country	lat×lon	SSP2-4.5	SSP5-8.5
1	ACCESS-CM2	CSIRO/Australia	144×192	✓	✓
2	ACCESS-ESM1-5		145×192	✓	✓
3	BCC-CSM2-MR	BCC-CMA/China	160×320	✓	✓
4	CanESM5	CCCMA/Canada	64×128	✓	✓
5	CESM2-WACCM	NCAR/USA	192×288	✓	✓
6	CMCC-CM2-SR5	CMCC/Italy	192×288	✓	✓
7	CMCC-ESM2		192×288	✓	✓
8	CNRM-CM6-1	CNRM-CERFACS/France	128×256	✓	✓
9	CNRM-ESM2-1		128×256	✓	✓
10	EC-Earth3	EC-Earth-Consortium	256×512	✓	✓
11	EC-Earth3-CC		256×512	✓	✓
12	EC-Earth3-Veg		256×512	✓	✓
13	EC-Earth3-Veg-LR		160×320	✓	✓
14	FGOALS-g3	LASG-IAP/China	90×180	✓	✓
15	GFDL-CM4	NOAA-GFDL/USA	180×360	✓	✓
16	GFDL-ESM4		180×360	✓	✓
17	HadGEM3-GC31-LL	MOHC/UK	144×192	✓	✓
18	HadGEM3-GC31-MM		324×432		✓
19	IITM-ESM	CCCR-IITM/India	94×192	✓	✓
20	INM-CM4-8	INM/Russia	120×180	✓	✓
21	INM-CM5-0		120×180	✓	✓
22	IPSL-CM6A-LR	IPSL/France	143×144	✓	✓
23	KACE-1-0-G	NIMS-KMA/Korea	144×192	✓	✓
24	KIOST-ESM	KIOST/Korea	96×192	✓	✓
25	MIROC6	MIROC/Japan	128×256	✓	✓
26	MIROC-ES2L		64×128	✓	✓
27	MPI-ESM-1-2-HR	MPI-M/Germany	192×384	✓	✓
28	MPI-ESM-1-2-LR		96×192	✓	✓
29	MRI-ESM2-0	MRI/Japan	160×320	✓	✓
30	NESM3	NUIST/China	96×192	✓	✓
31	NorESM2-LM	NCC/Norway	96×144	✓	✓
32	NorESM2-MM		192×288	✓	✓
33	TaiESM1	AS-RCEC/Taiwan	192×288	✓	✓
34	UKESM1-0-LL	MOHC/UK	144×192	✓	✓



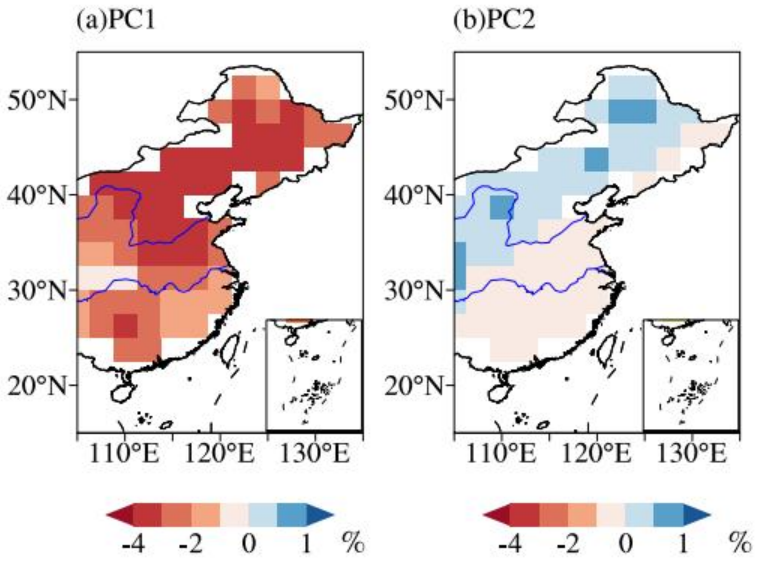
Supplementary Fig. S1 Spatial distributions of projected changes for East China summer precipitation during 2070-2099 relative to 1985-2014 (unit: %).



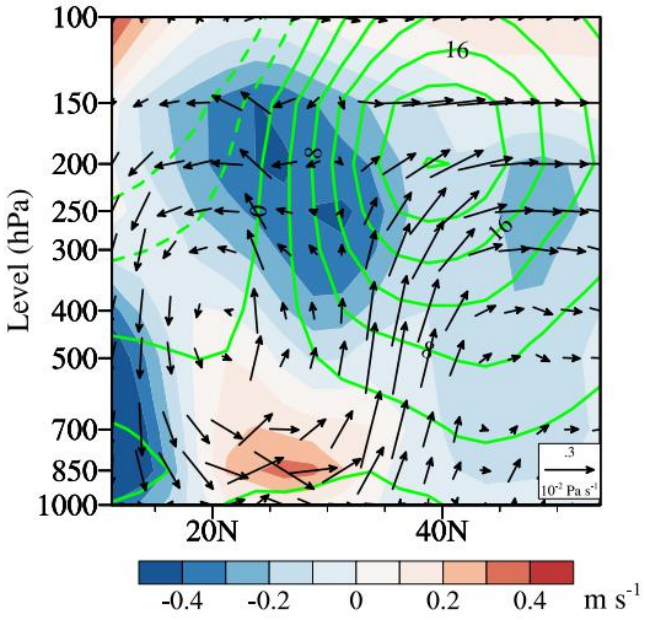
Supplementary Fig. S2 As in **Fig. 2**, but for vertical velocity at 500 hPa.



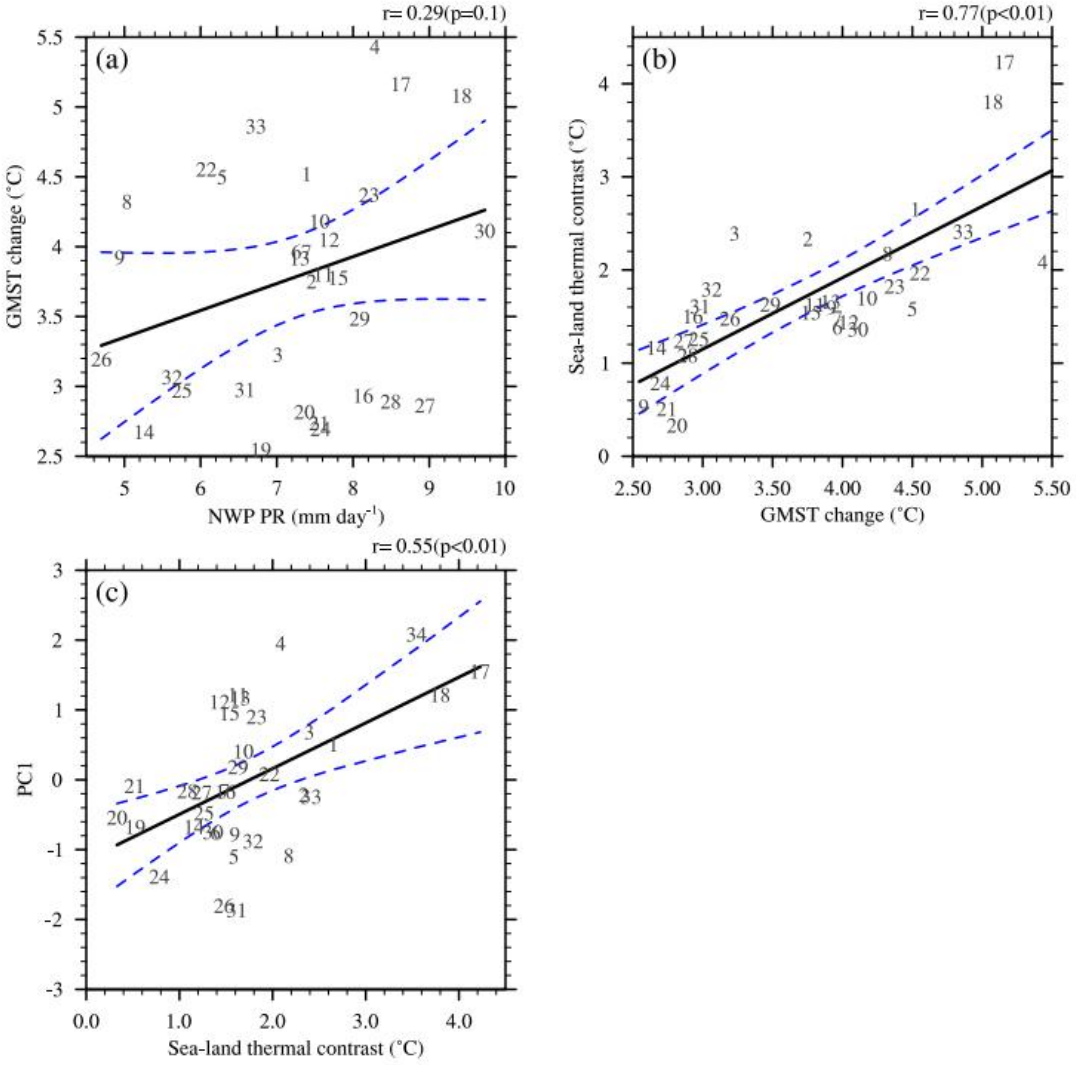
Supplementary Fig. S3 As in **Fig. 2**, but for zonal wind at 850 hPa.



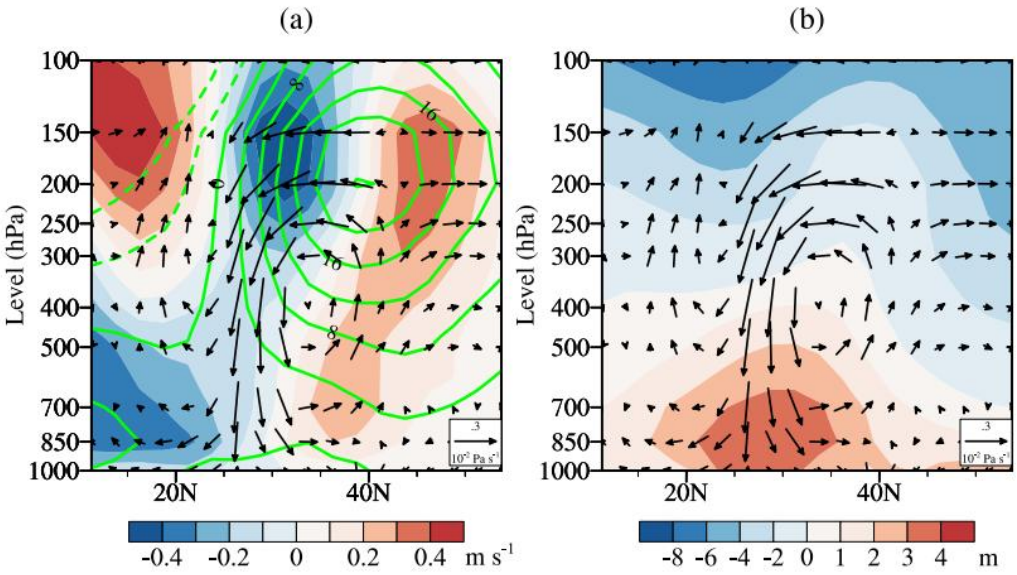
Supplementary Fig. S4 Constrained leading modes of the inter-model spread. Panels a and b are the two constrained leading EOF modes of the inter-model ECSP changes, based on the optimal first and second Principal Components (*PC1* and *PC2*).



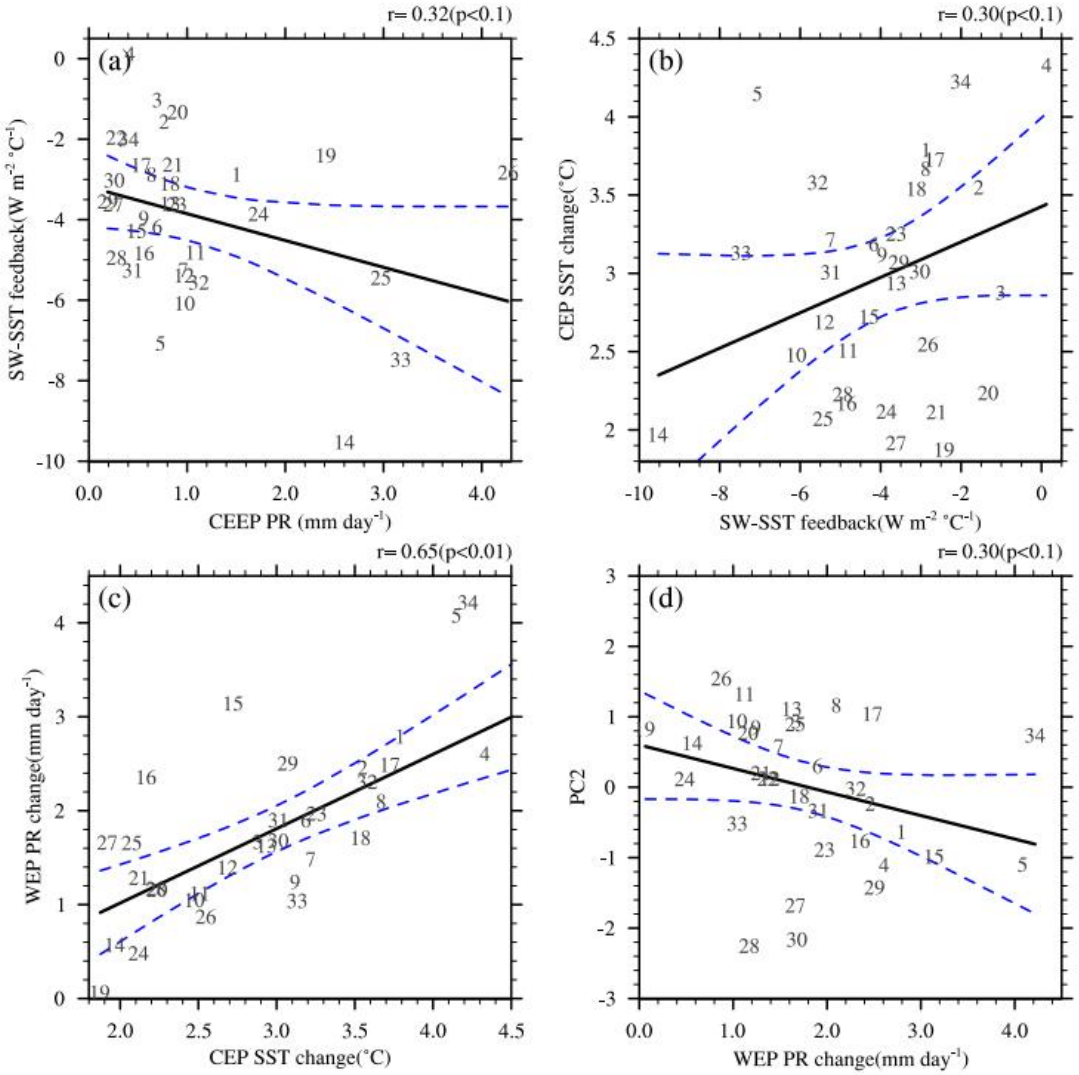
Supplementary Fig. S5 Inter-model regressions of meridional circulation (vectors) and zonal wind (shadings) changes zonally averaged within105°E–123°E onto *PC1* in summer. The green contour lines represent the climatological zonal wind.



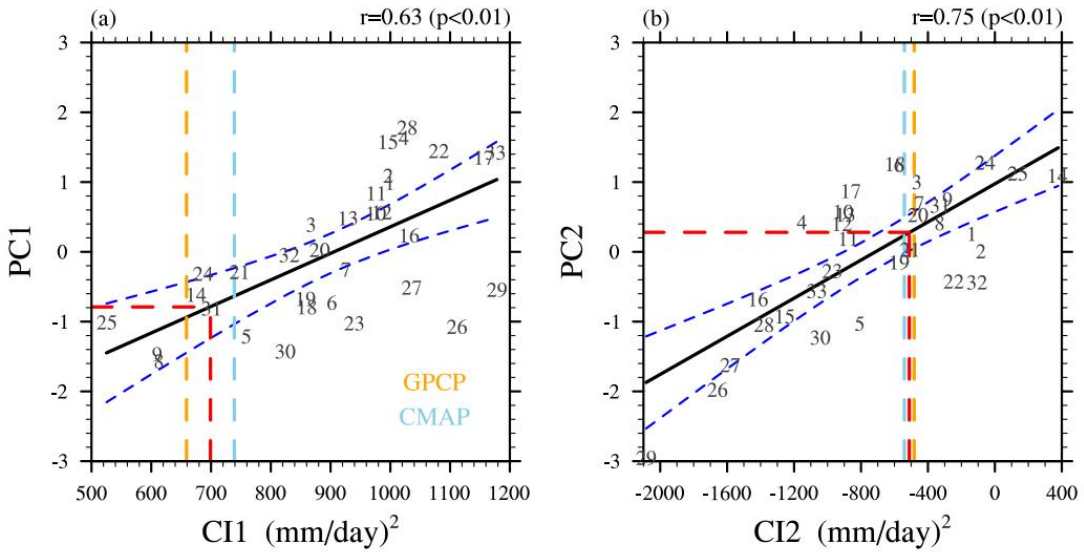
Supplementary Fig. S6 Inter-model physical relationship between historical and projected spreads. Intermodel relationship among the northwest Pacific (NWP, 8°N–25°N, 120°E–180°E) precipitation (PR), global mean surface air temperature (GMST) change, Sea-land thermal contrast, and the first principal component (*PC1*). Blue dashed curves denote the 95% confidence range of the linear regression. Value on the top-right corner of each subplot is correlation coefficient and significance level. Each number represents an individual model listed in Table S1. Sea-land thermal contrast is defined as the projected change of surface temperature difference between the East China land area (22–40°N, 105–120°E) and the subtropical Northwest Pacific (10–25°N, 120°–160°E).



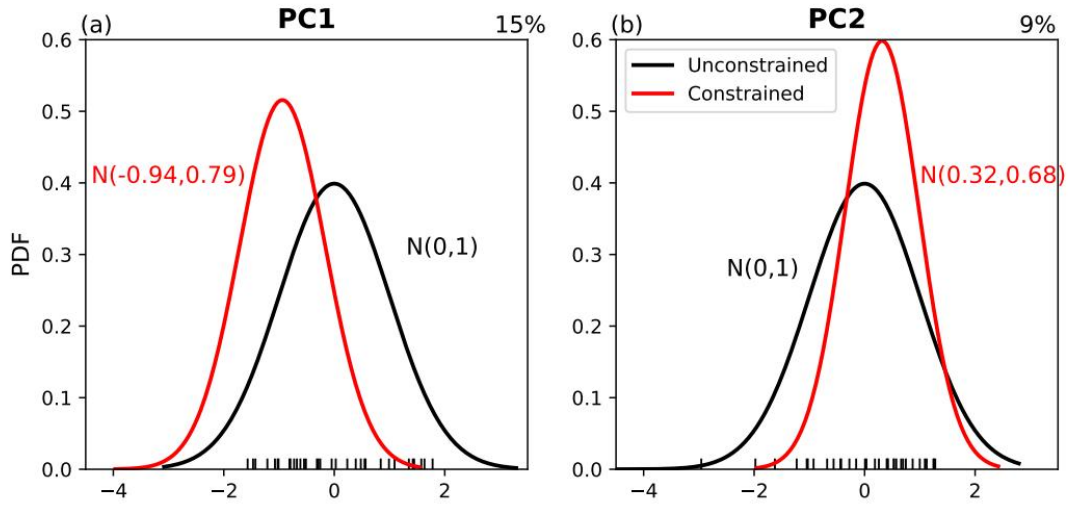
Supplementary Fig. S7 Inter-model regressions of meridional circulation (vectors), (a) zonal wind (shadings) and (b) geopotential height (shadings) changes zonally averaged within105°E–123°E onto *PC2* in summer. The green contour lines (a) represent the climatological zonal wind.



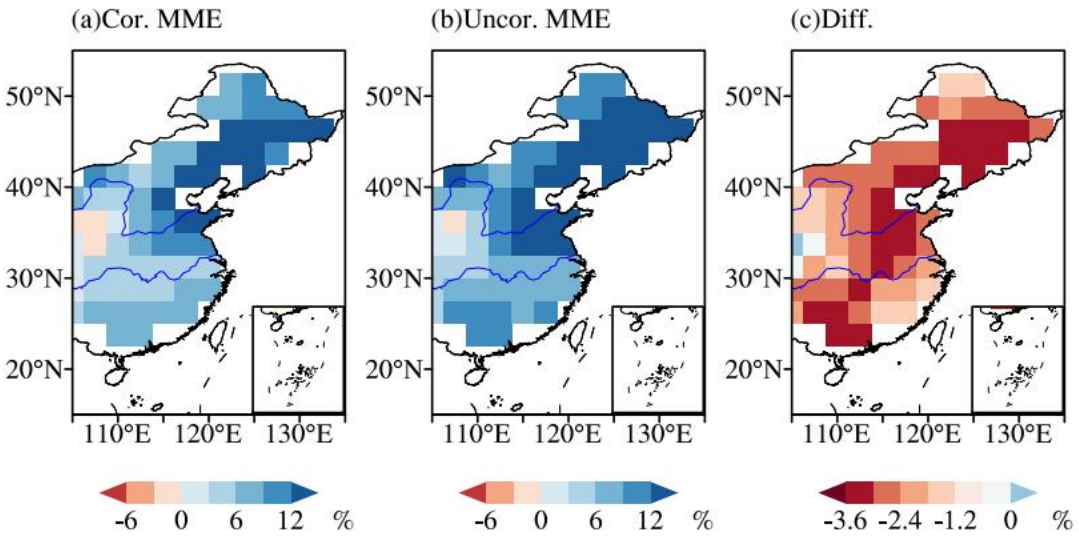
Supplementary Fig. S8 Inter-model physical relationship between historical and projected spreads. Intermodel relationship among the central-eastern Equatorial Pacific (CEEP, 5°S–5°N, 180°W–90°W) precipitation (PR), cloud shortwave-SST (SW-SST) feedback, central Equatorial Pacific (CEP, 5°S–5°N, 170°E–145°W) sea surface temperature (SST), western Equatorial Pacific (WEP, 10°S–2°N, 160°E–170°W) precipitation change, and the second principal component (*PC2*). Blue dashed curves denote the 95% confidence range of the linear regression. Value on the top-right corner of each subplot is correlation coefficient and significance level. Each number represents an individual model listed in Table S1.



Supplementary Fig. S9 Same as **Fig. 3** but for the results under the SSP2-4.5 scenario.



Supplementary Fig. S10 Same as **Fig. 4** but for the results under the SSP2-4.5 scenario.



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92 **Supplementary Fig. S11** Same as **Fig. 5** but for the results under the SSP2-4.5
93 scenario.

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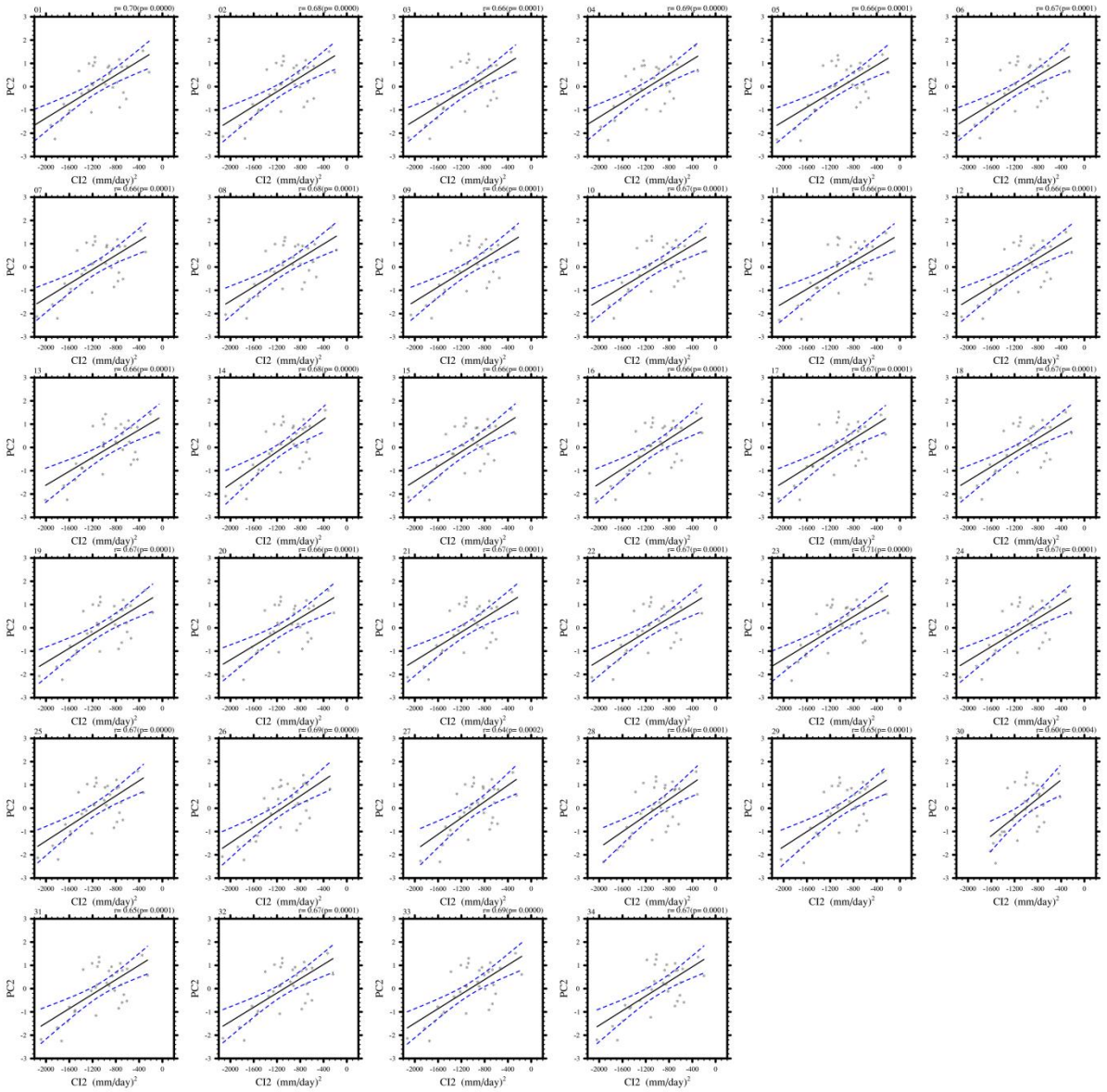
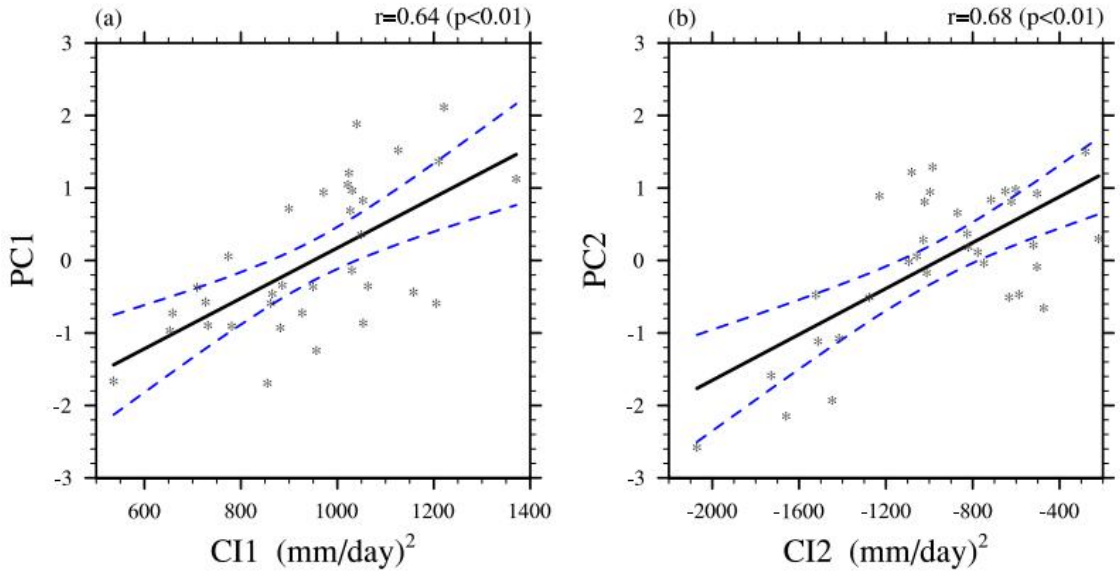
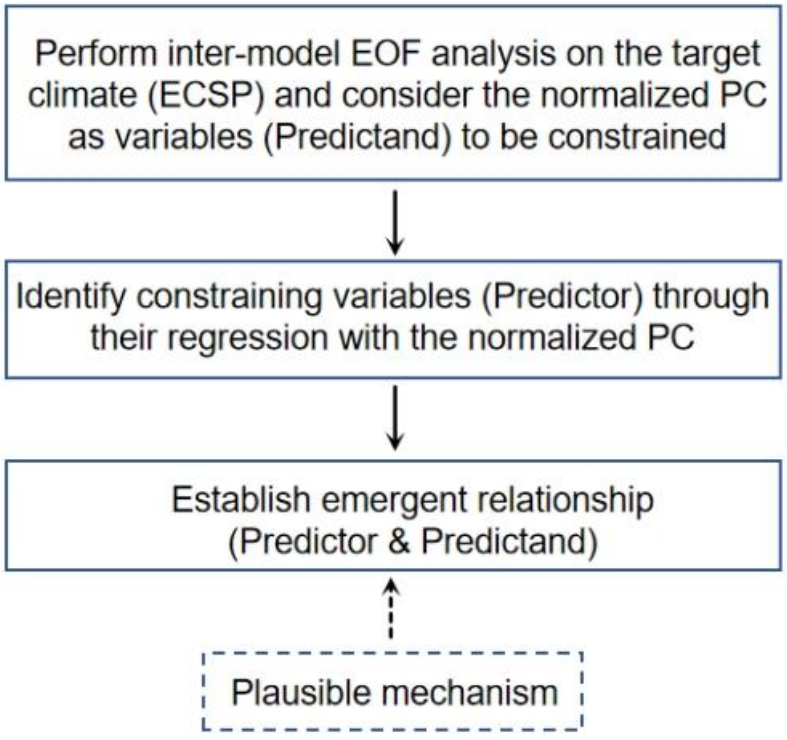
Supplementary Fig. S12 The leave-one-out test for inter-model emergent relationship between *PC1* and *CI1*. We remove one model and then build the emergent relationship based on the other 33 models ecah time. The number on the top left corner is the individual model we removed (Model numbers are listed in Table S1). Each * represents an individual model. Correlation coefficients (statistically significant at the 1% level with a Student t-test) are displayed on the top right corner.



Supplementary Fig. S13 As in **Supplementary Fig. S12,** but for the leave-one-out test for inter-model emergent relationship between *PC2* and *CI2*.



Supplementary Fig. S14 Inter-model emergent relationship between the summer precipitation projection (represented by *PC1* and *PC2*) in East China and the historical precipitation patterns in the tropical Pacific (represented by *CI1* and *CI2*). *CI1* in (a) and *CI2* in (b) measure how the precipitation patterns in black boxes in **Fig. 2** are simulated in the historical simulation. Correlation coefficients (statistically significant at the 1% level with a Student t-test) are displayed on the top right corner. Each * represents an individual model. The historical and future periods are 1965-2014 and 2050-2099.



Supplementary Fig. S15 A flowchart of the emergent constraint procedure.