Supplementary maps and graphs:

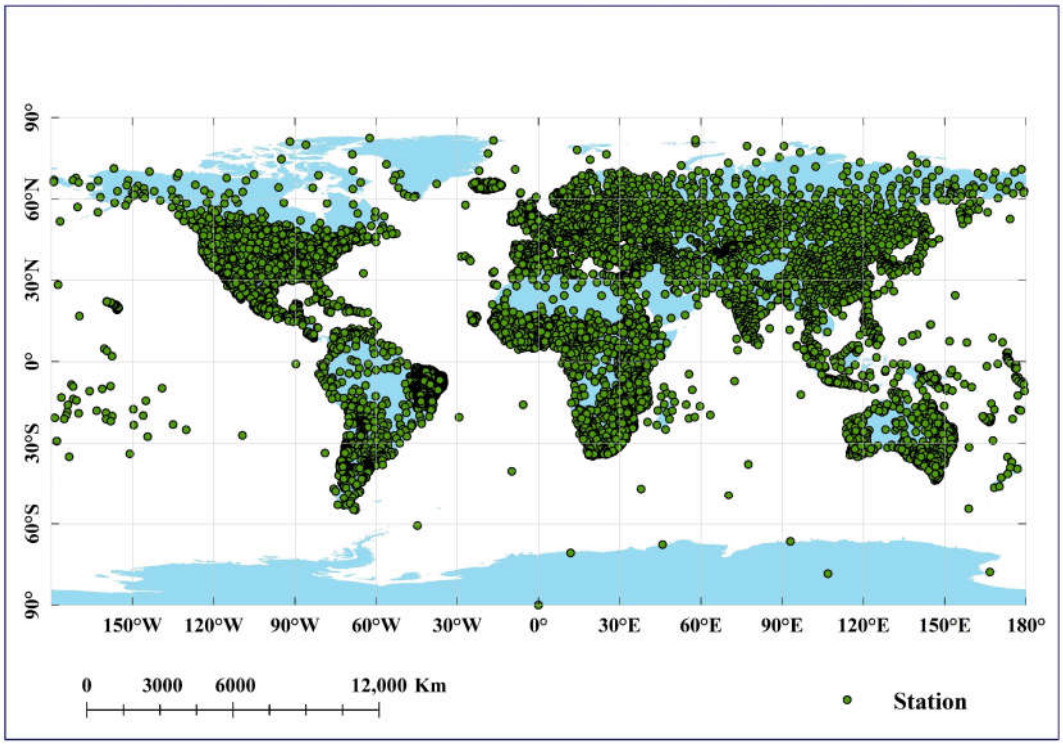

Figure S1. Map of CRU data site locations.

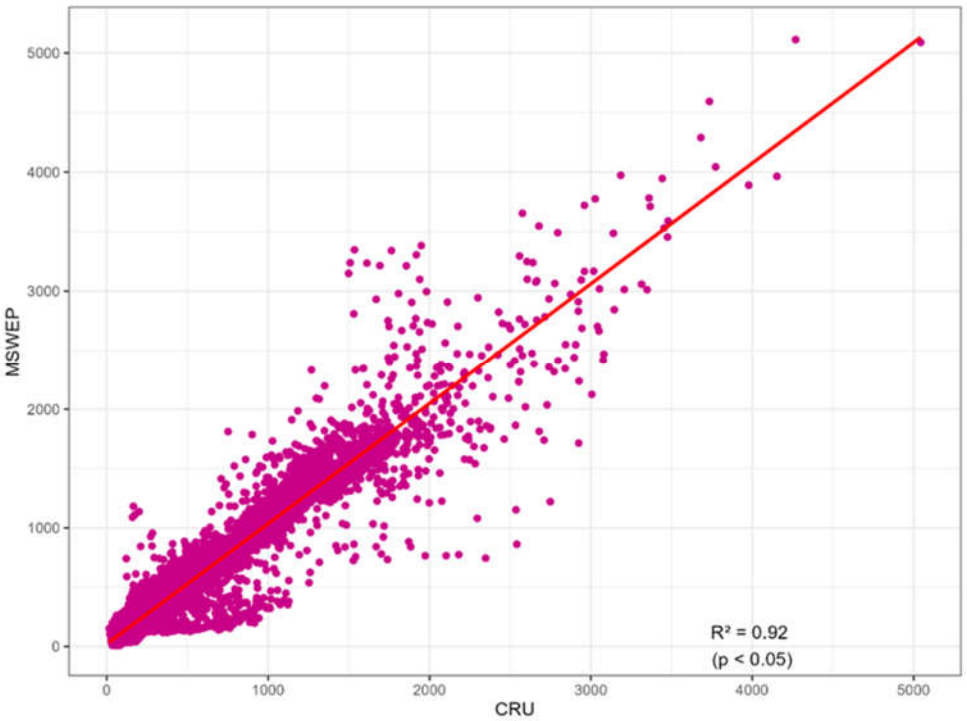

Figure S2. Fitted plot between CRU data and MSWEP data.

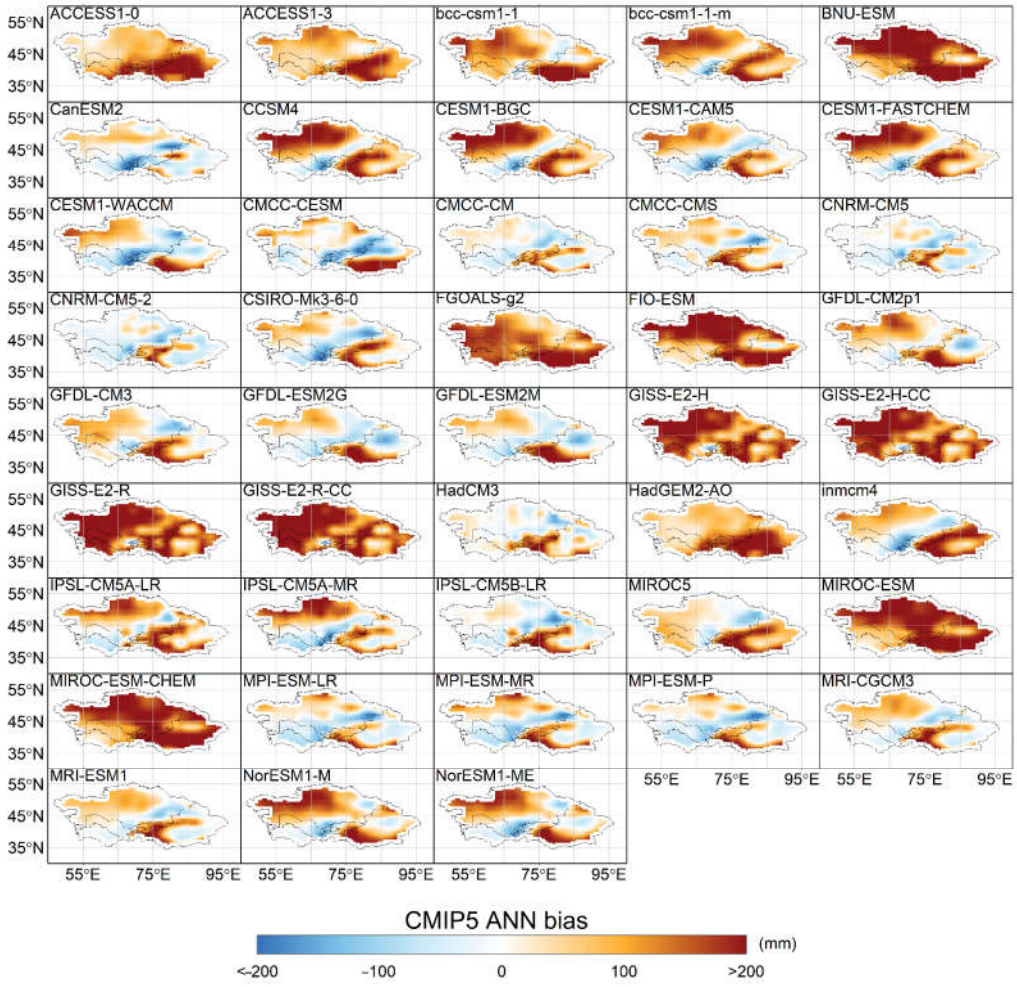

Figure S3. Spatial distribution of precipitation bias between CRU observations and CMIP5 models for ANN from 1959 to 2005.

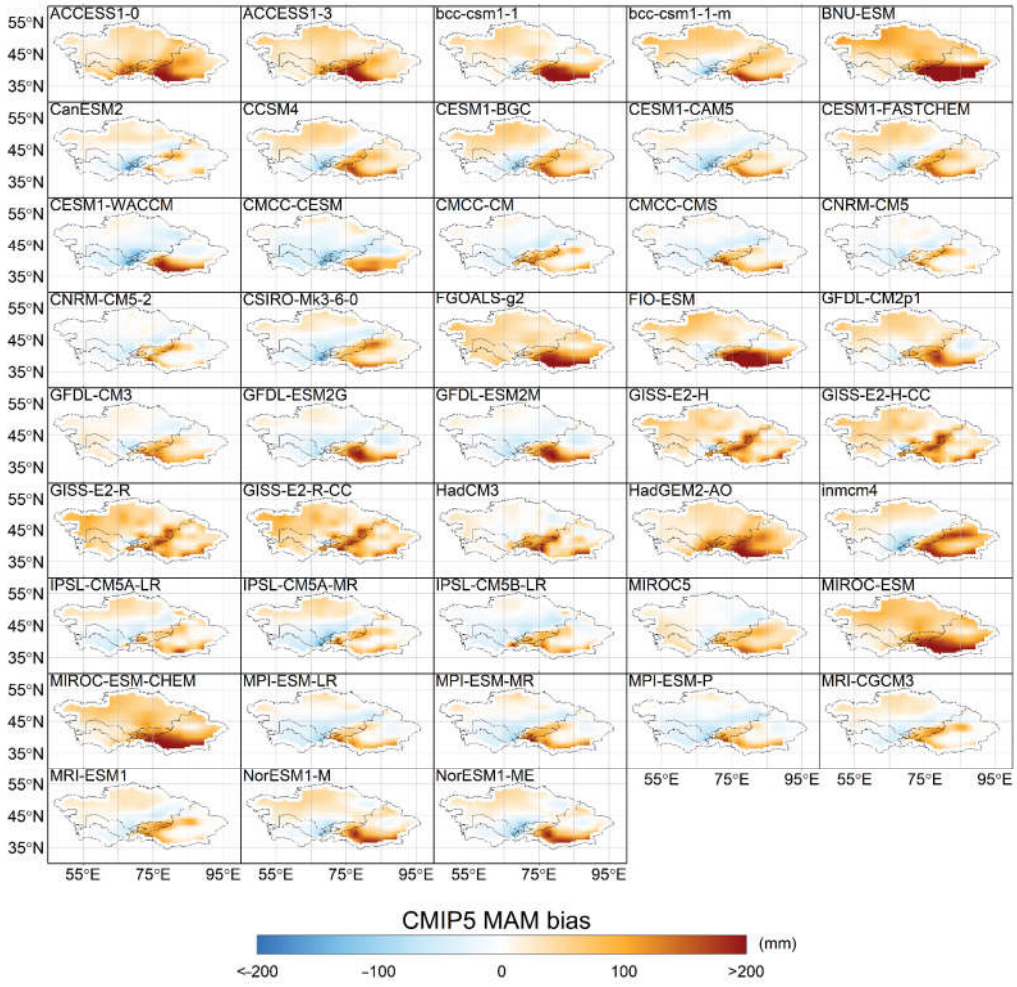

Figure S4. Same as Figure S3 but for MAM.

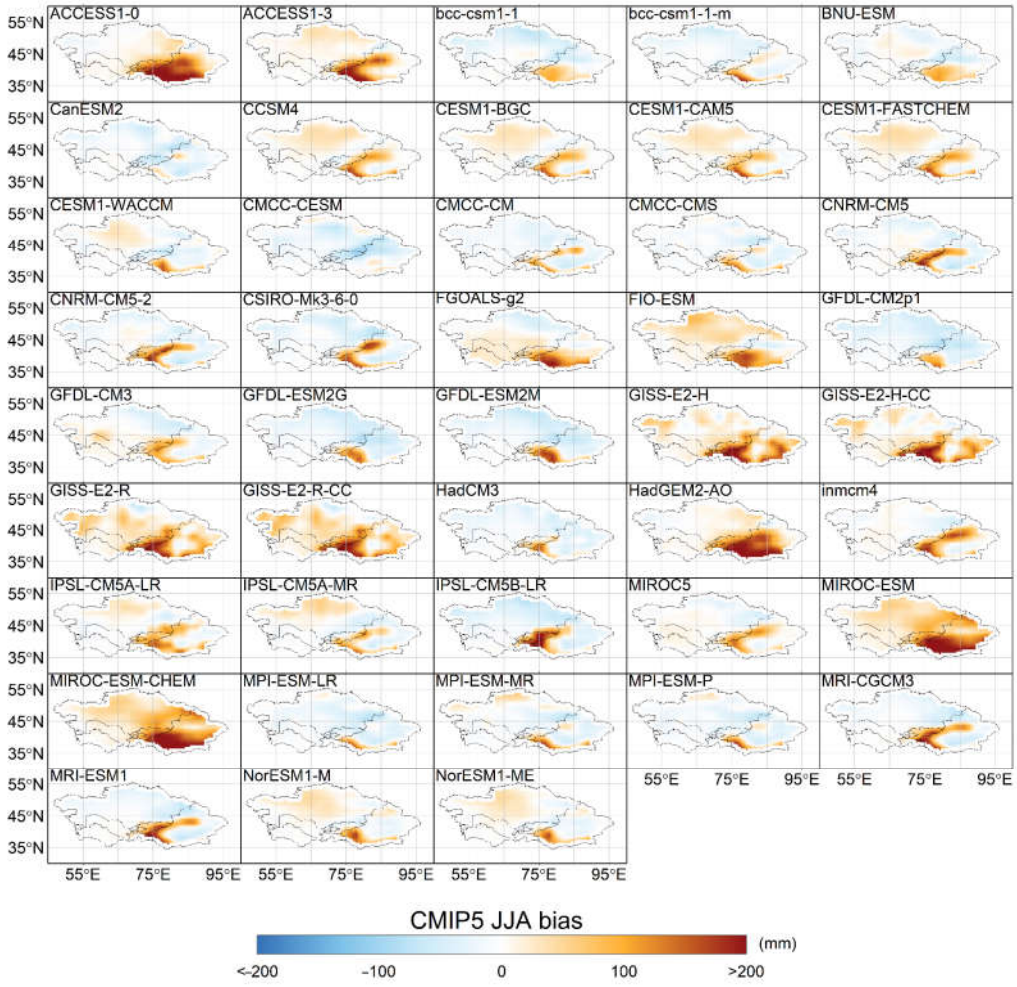

Figure S5. Same as Figure S3 but for JJA.

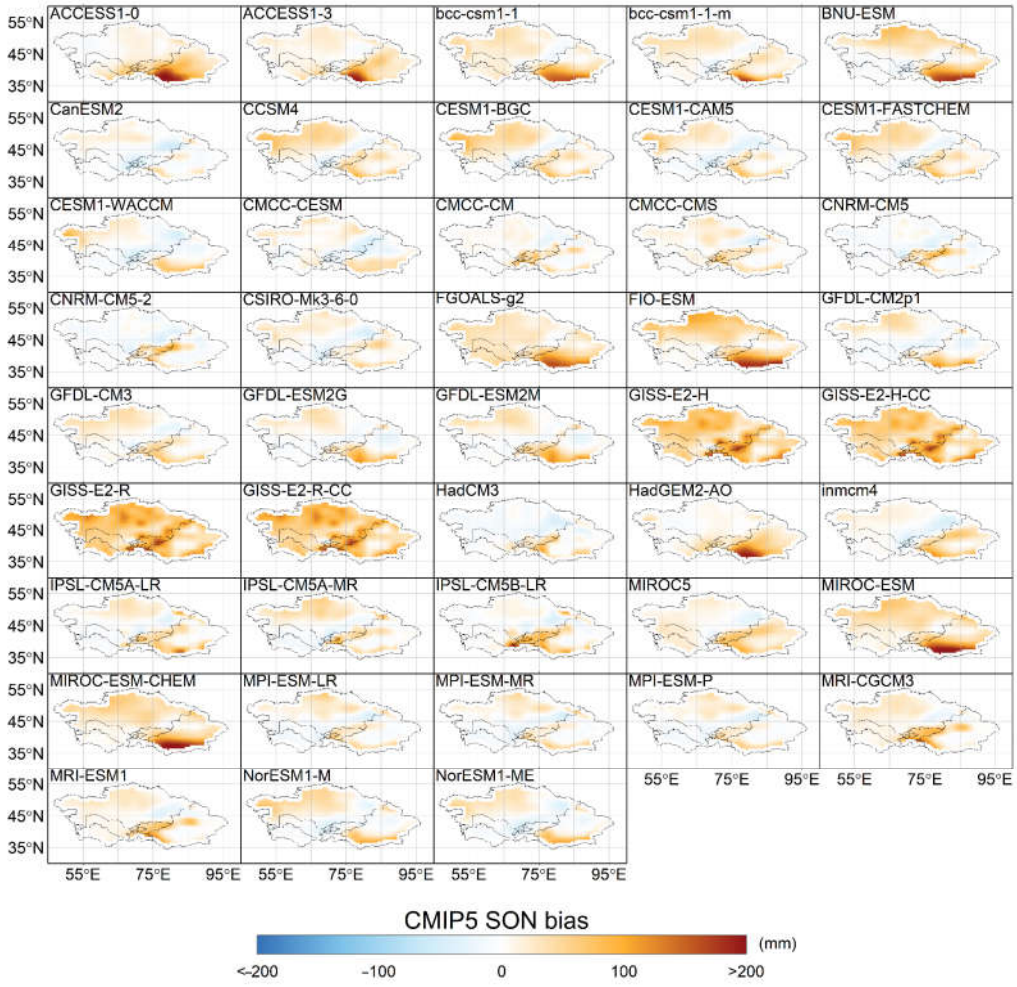

Figure S6. Same as Figure S3 but for SON.

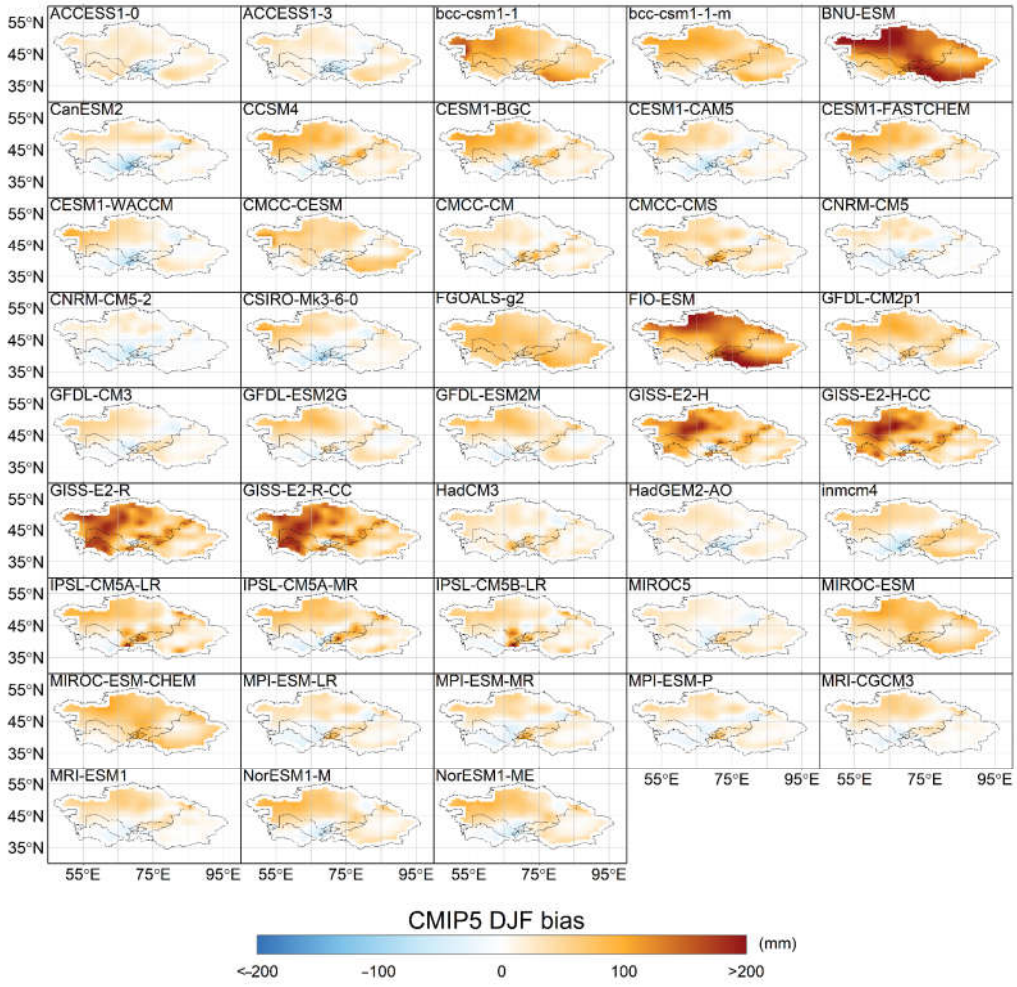

Figure S7. Same as Figure S3 but for DJF.

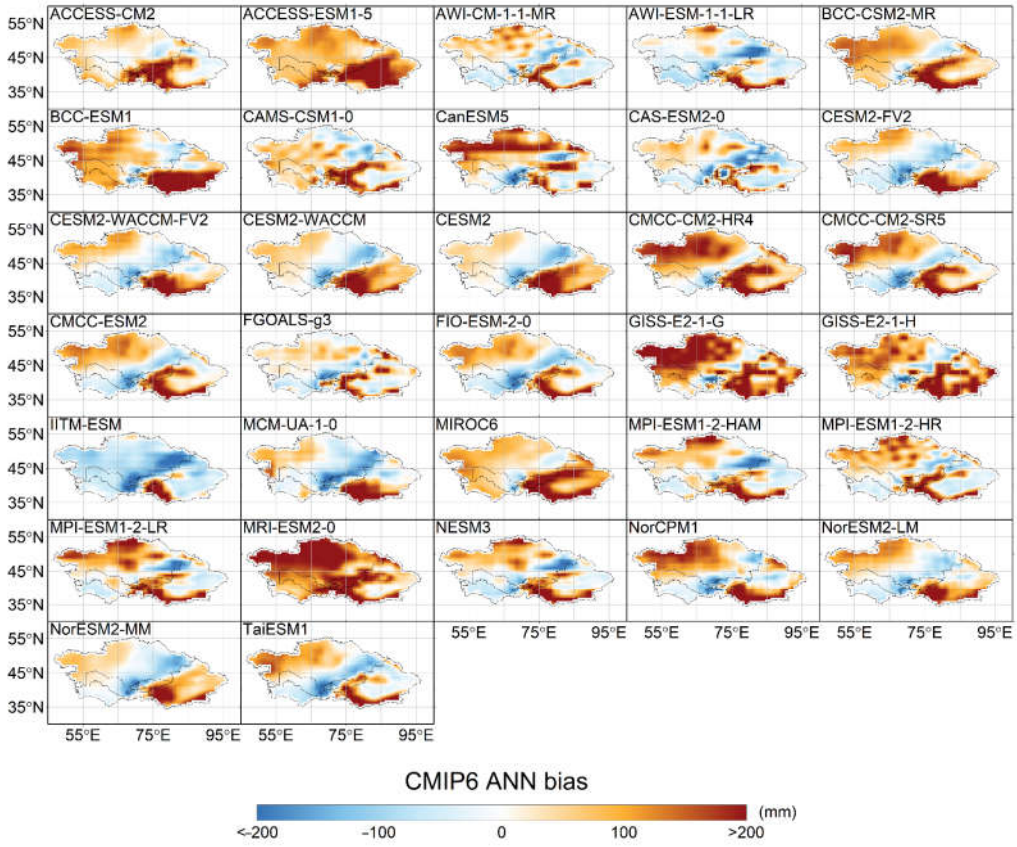

Figure S8. Spatial distribution of precipitation bias between CRU observations and CMIP6 models for ANN from 1959 to 2005.

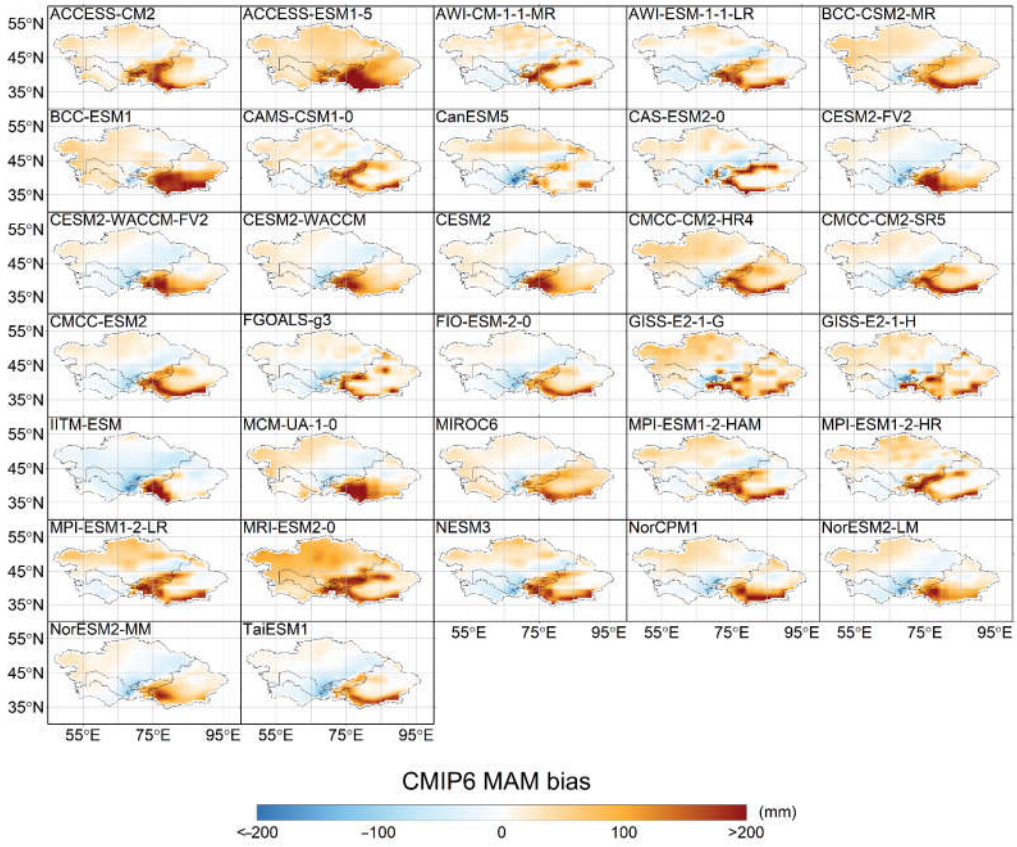

Figure S9. Same as Figure S8 but for MAM.

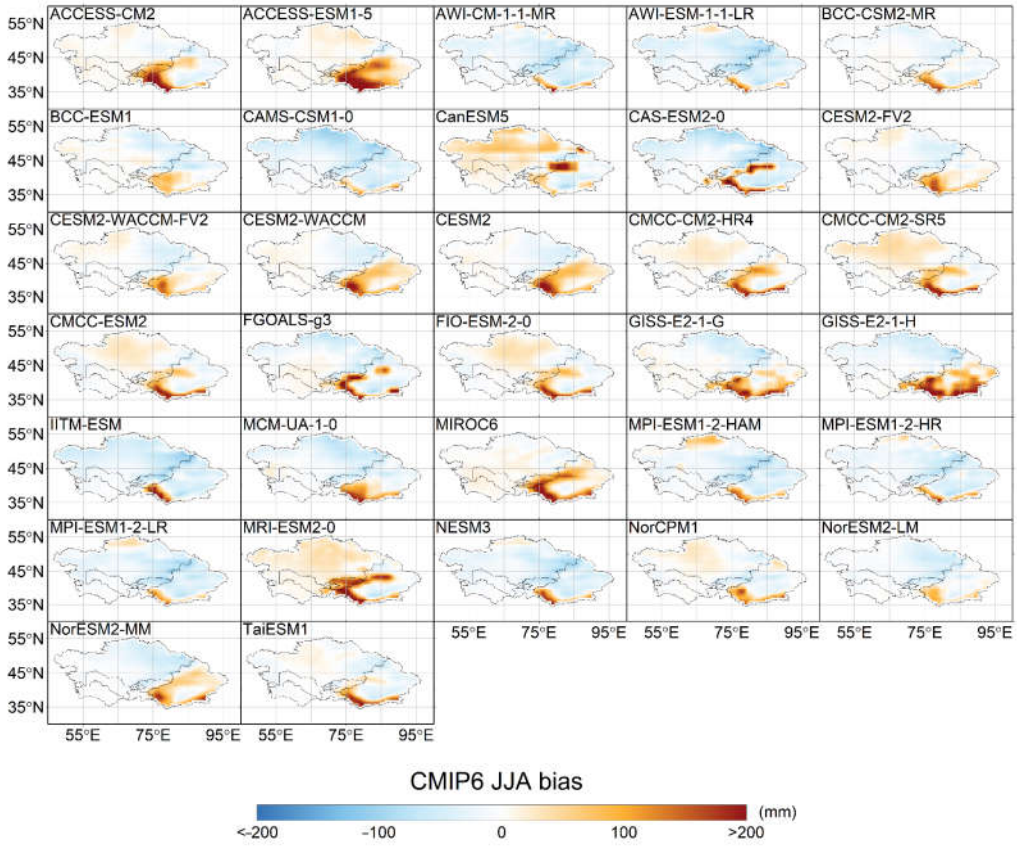

Figure S10. Same as Figure S8 but for JJA.

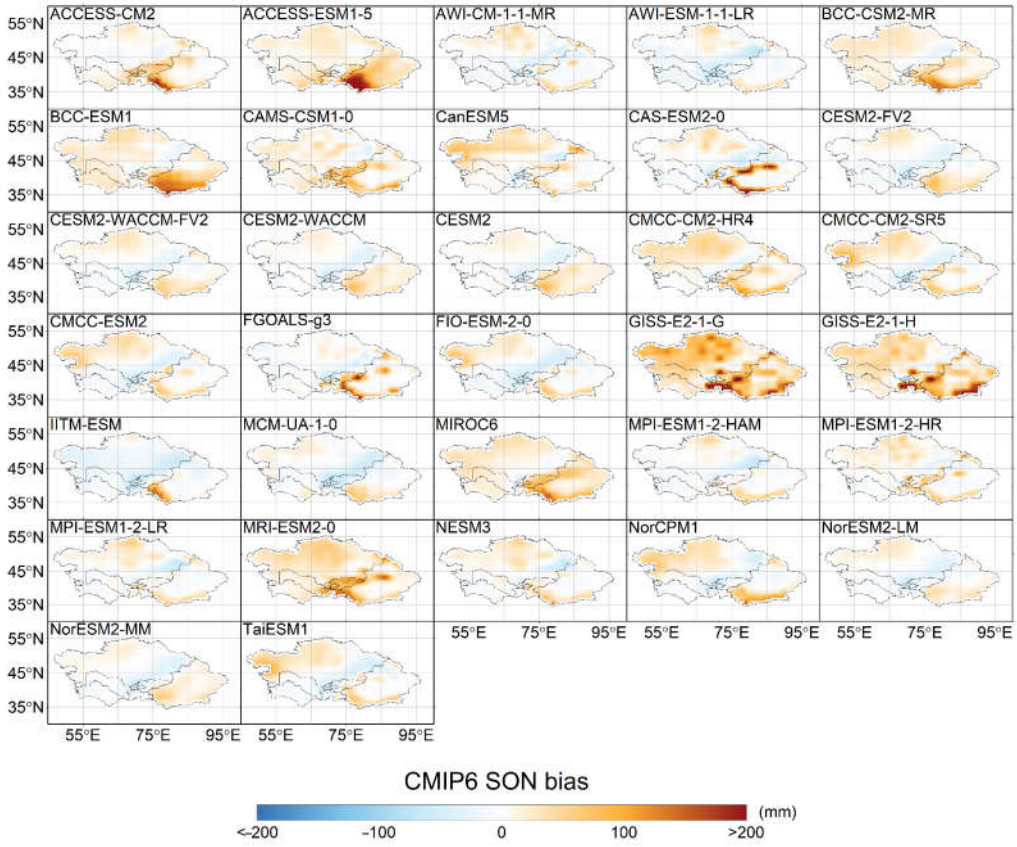

Figure S11. Same as Figure S8 but for SON.

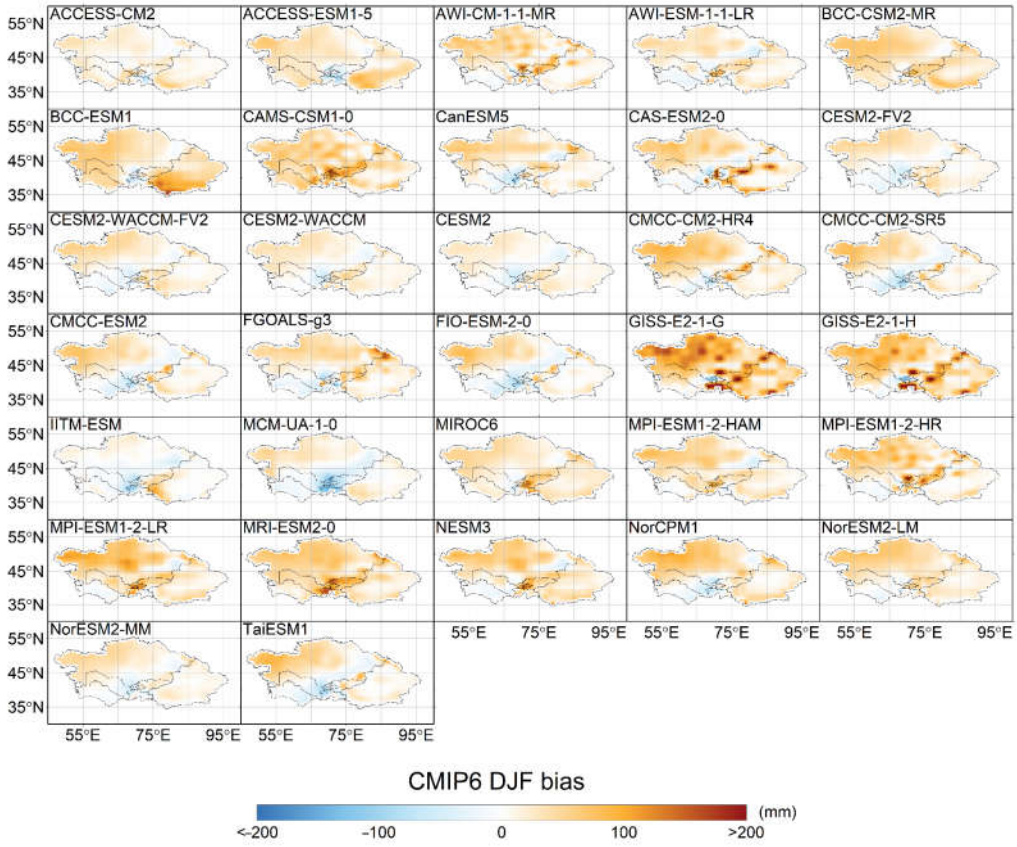

Figure S12. Same as Figure S8 but for DJF.

Table S1. Summary of CMIP5 models used in this study.

Models	Institution	Resolution (°)
ACCESS1-0	CSIRO-BOM, Australia	1.875° × 1.25°
ACCESS1-3	CSIRO-BOM, Australia	1.875° × 1.25°
bcc-csm1-1	BCC, China	1.1° × 1.1°
bcc-csm1-1-m	BCC, China	2.8° × 2.8°
BNU-ESM	GCESS, China	2.8° × 2.8°
CanESM2	CCCMA, Canada	2.8° × 2.8°
CCSM4	NCAR, USA	1.25° × 0.9°
CESM1-BGC	NCAR, USA	1.25° × 0.9°
CESM1-CAM5	NCAR, USA	1.25° × 0.9°
CESM1-FASTCHEM	NCAR, USA	1.3° × 0.9°
CESM1-WACCM	NCAR, USA	2.5° × 1.9°
CMCC-CESM	CMCC, Italy	3.75° × 3.75°
CMCC-CM	CMCC, Italy	0.75° × 0.75°
CMCC-CMS	CMCC, Italy	1.875° × 1.875°
CNRM-CM5	CNRM-CERFACS, France	1.4° × 1.4°
CNRM-CM5-2	CNRM-CERFACS, France	1.4° × 1.4°
CSIRO-Mk3-6-0	CSIRO-QCCCE, Australia	1.875° × 1.875°
FGOALS-g2	LASG-CESS, China	2.8125° × 3°
FIO-ESM	FIO, China	2.8° × 2.8°
GFDL-CM2p1	NOAA GFDL, USA	2.5° × 2.0°
GFDL-CM3	NOAA GFDL, USA	2.5° × 2.0°
GFDL-ESM2G	NOAA GFDL, USA	2.5° × 2.0°
GFDL-ESM2M	NOAA GFDL, USA	2.5° × 2.0°
GISS-E2-H	NASA GISS, USA	2.5° × 2.0°
GISS-E2-H-CC	NASA GISS, USA	2.5° × 2.0°
GISS-E2-R	NASA GISS, USA	2.5° × 2.0°

GISS-E2-R-CC	NASA GISS, USA	2.5° × 2.0°
HadCM3	MOHC, UK	3.8° × 2.5°
HadGEM2-AO	NIMR/KMA, Korea/UK	1.875° × 1.24°
inmcm4	UNM, Russia	1.4° × 1.4°
IPSL-CM5A-LR	IPSL, France	3.75° × 1.875°
IPSL-CM5A-MR	IPSL, France	2.5° × 1.25°
IPSL-CM5B-LR	IPSL, France	3.75° × 1.875°
MIROC5	MIROC, Japan	1.4° × 1.4°
MIROC-ESM	MIROC, Japan	2.8° × 2.8°
MIROC-ESM-CHEM	MIROC, Japan	2.8° × 2.8°
MPI-ESM-LR	MPI-M, Germany	1.875° × 1.875°
MPI-ESM-MR	MPI-M, Germany	1.875° × 1.875°
MPI-ESM-P	MPI-M, Germany	1.875° × 1.875°
MRI-CGCM3	MRI, Japan	1.125° × 1.125°
MRI-ESM1	MRI, Japan	1.125° × 1.125°
NorESM1-M	NCC, Norway	2.5° × 1.875°
NorESM1-ME	NCC, Norway	2.5° × 1.875°

Table S2. Summary of CMIP6 models used in this study.

Models	Institution	Resolution (°)
ACCESS-CM2	CSIRO, Australia	1.875° × 1.25°
ACCESS-ESM1-5	CSIRO, Australia	1.875° × 1.24°
AWI-CM-1-1-MR	AWI, Germany	0.9° × 0.9°
AWI-ESM-1-1-LR	AWI, Germany	1.875° × 1.875°
BCC-CSM2-MR	BCC, China	1.125° × 1.1°
BCC-ESM1	BCC, China	2.8125° × 2.8°
CAMS-CSM1-0	CAMS, China	1.125° × 1.1°
CanESM5	CCCMA, Canada	2.8125° × 2.8°
CAS-ESM2-0	CAS, China	1.4° × 1.4°
CESM2	NCAR, USA	1.25° × 0.9°
CESM2-FV2	NCAR, USA	2.5° × 1.875°
CESM2-WACCM	NCAR, USA	1.25° × 0.9°
CESM2-WACCM-FV2	NCAR, USA	2.5° × 1.875°
CMCC-CM2-HR4	CMCC, Italy	1.25° × 0.9°
CMCC-CM2-SR5	CMCC, Italy	1.25° × 0.9°
CMCC-ESM2	CMCC, Italy	1.25° × 0.9°
FGOALS-g3	CAS, China	2° × 2.5°
FIO-ESM-2-0	FIO-QLNM, China	1.25° × 0.9°
GISS-E2-1-G	NASA-GISS, USA	2.5° × 2°
GISS-E2-1-H	NASA-GISS, USA	2.5° × 2°
IITM-ESM	CCCR-IITM, India	1.875° × 1.9°
MCM-UA-1-0	UA, USA	3.75° × 2.2°
MIROC6	MIROC, Japan	1.4° × 1.4°
MPI-ESM-1-2-HAM	MPI-M, Germany	1.875° × 2°
MPI-ESM-1-2-HR	MPI-M, Germany	0.9° × 0.9°
MPI-ESM-1-2-LR	MPI-M, Germany	1.875° × 2°
MRI-ESM2-0	MRI, Japan	1.125° × 1.1°
NESM3	NUIST, China	1.875° × 1.9°
NorCPM1	NCC, Norway	2.5° × 1.9°
NorESM2-LM	NCC, Norway	2.5° × 1.9°
NorESM2-MM	NCC, Norway	1.25° × 0.9°
TaiESM1	AS-RCEC, China	1.25° × 0.9°

Table S3. TSS of MME and each model under CMIP5. ALL, CA, and XJ represent the entire study area, the five Central Asian countries, and the Xinjiang region, respectively. ANN, MAM, JJA, SON, and DJF represent the annual average, spring, summer, autumn, and winter precipitation, respectively. The highest and lowest TSS values for MME and each GCM are shown in bold and underlined, respectively.

CMIP5	ALL					CA					XJ				
Model/ensemble	**ANN**	**MAM**	**JJA**	**SON**	**DJF**	**ANN**	**MAM**	**JJA**	**SON**	**DJF**	**ANN**	**MAM**	**JJA**	**SON**	**DJF**
MME	0.641	0.659	0.617	0.647	0.784	0.802	0.830	0.891	0.792	0.734	0.225	0.308	0.162	0.182	0.631
ACCESS1-0	0.348	0.519	0.208	0.264	0.791	0.738	0.707	0.654	0.683	0.715	0.072	0.172	0.037	0.041	0.284
ACCESS1-3	0.352	0.424	0.257	0.342	0.699	0.718	0.684	0.663	0.730	0.606	0.066	0.111	0.026	0.056	0.414
bcc-csm1-1	0.388	0.344	0.552	0.345	0.536	0.682	0.761	0.654	0.723	0.438	0.077	0.080	0.220	0.042	0.255
bcc-csm1-1-m	0.522	0.506	0.515	0.467	0.655	0.728	0.587	0.809	0.765	0.553	0.158	0.254	0.108	0.087	0.393
BNU-ESM	0.303	0.225	0.683	0.281	0.330	0.582	0.671	0.881	0.552	0.319	0.046	0.042	0.221	0.033	0.114
CanESM2	0.690	0.643	0.726	0.711	0.624	0.667	0.617	0.829	0.698	0.420	0.387	0.420	0.327	0.365	0.735
CCSM4	0.548	0.546	0.580	0.565	0.534	0.603	0.663	0.904	0.562	0.377	0.225	0.278	0.134	0.212	0.412
CESM1-BGC	0.564	0.567	0.607	0.559	0.547	0.603	0.654	0.915	0.546	0.399	0.237	0.301	0.148	0.213	0.449
CESM1-CAM5	0.583	0.582	0.563	0.589	0.637	0.671	0.717	0.910	0.571	0.478	0.219	0.300	0.105	0.234	0.529
CESM1-FASTCHEM	0.556	0.573	0.585	0.580	0.522	0.605	0.678	0.907	0.588	0.354	0.230	0.296	0.137	0.210	0.437
CESM1-WACCM	0.460	0.340	0.655	0.514	0.577	0.600	0.649	0.873	0.545	0.370	0.133	0.107	0.165	0.139	0.591
CMCC-CESM	0.561	0.413	0.741	0.668	0.583	0.664	0.605	0.839	0.692	0.481	0.136	0.164	0.303	0.162	0.292
CMCC-CM	0.516	0.553	0.560	0.536	0.635	0.565	0.585	0.865	0.543	0.576	0.177	0.283	0.120	0.174	0.340
CMCC-CMS	0.593	0.574	0.627	0.660	0.725	0.658	0.682	0.857	0.654	0.673	0.201	0.224	0.152	0.278	0.538
CNRM-CM5	0.528	0.654	0.345	0.566	0.727	0.570	0.698	0.524	0.555	0.613	0.198	0.360	0.083	0.243	0.677
CNRM-CM5-2	0.526	0.657	0.347	0.552	0.724	0.575	0.703	0.525	0.558	0.599	0.196	0.357	0.084	0.215	0.683
CSIRO-Mk3-6-0	0.489	0.471	0.365	0.666	0.535	0.647	0.643	0.765	0.695	0.311	0.169	0.218	0.075	0.297	0.678
FGOALS-g2	0.420	0.461	0.432	0.391	0.785	0.746	0.848	0.599	0.763	0.776	0.092	0.122	0.122	0.056	0.541
FIO-ESM	0.261	0.246	0.617	0.255	0.306	0.514	0.664	0.837	0.505	0.359	0.038	0.051	0.154	0.025	0.070
GFDL-CM2p1	0.618	0.620	0.576	0.474	0.604	0.753	0.766	0.785	0.634	0.539	0.161	0.192	0.127	0.072	0.336
GFDL-CM3	0.618	0.654	0.564	0.609	0.779	0.679	0.732	0.701	0.655	0.714	0.240	0.329	0.205	0.186	0.618
GFDL-ESM2G	0.589	0.534	0.554	0.541	0.670	0.770	0.784	0.741	0.701	0.573	0.140	0.149	0.132	0.091	0.409
GFDL-ESM2M	0.535	0.501	0.469	0.495	0.632	0.751	0.770	0.686	0.656	0.520	0.116	0.134	0.101	0.081	0.386

GISS-E2-H	0.252	0.347	0.238	0.241	0.290	0.231	0.345	0.450	0.200	0.222	0.095	0.164	0.043	0.081	0.188
GISS-E2-H-CC	0.232	0.373	0.205	0.205	0.260	0.204	0.377	0.338	0.162	0.202	0.092	0.172	0.040	0.073	0.170
GISS-E2-R	0.250	0.348	0.313	0.239	0.244	0.217	0.340	0.449	0.198	0.195	0.107	0.174	0.086	0.087	0.145
GISS-E2-R-CC	0.244	0.340	0.297	0.259	0.225	0.210	0.336	0.419	0.221	0.176	0.105	0.160	0.082	0.089	0.147
HadCM3	0.580	0.545	0.667	0.566	0.761	0.663	0.662	0.840	0.651	0.731	0.195	0.203	0.183	0.175	0.451
HadGEM2-AO	0.354	0.506	0.194	0.330	0.785	0.783	0.703	0.703	0.758	0.655	0.072	0.166	0.034	0.051	0.454
inmcm4	0.430	0.380	0.545	0.475	0.586	0.630	0.600	0.844	0.682	0.491	0.209	0.264	0.165	0.177	0.487
IPSL-CM5A-LR	0.483	0.547	0.599	0.467	0.470	0.519	0.637	0.782	0.502	0.398	0.170	0.240	0.208	0.138	0.231
IPSL-CM5A-MR	0.439	0.476	0.612	0.472	0.379	0.384	0.449	0.797	0.386	0.278	0.246	0.362	0.166	0.296	0.340
IPSL-CM5B-LR	0.436	0.527	0.351	0.364	0.474	0.432	0.604	0.423	0.339	0.386	0.173	0.226	0.129	0.123	0.308
MIROC5	0.649	0.673	0.661	0.631	0.848	0.722	0.763	0.812	0.687	0.808	0.382	0.438	0.298	0.369	0.740
MIROC-ESM	0.318	0.466	0.301	0.262	0.641	0.668	0.723	0.760	0.671	0.630	0.058	0.143	0.065	0.026	0.280
MIROC-ESM-CHEM	0.336	0.494	0.298	0.265	0.669	0.676	0.738	0.720	0.677	0.660	0.062	0.150	0.065	0.026	0.313
MPI-ESM-LR	0.583	0.602	0.571	0.600	0.749	0.652	0.678	0.865	0.577	0.682	0.195	0.288	0.106	0.244	0.565
MPI-ESM-MR	0.526	0.535	0.544	0.581	0.688	0.571	0.594	0.802	0.572	0.604	0.175	0.246	0.101	0.218	0.548
MPI-ESM-P	0.570	0.607	0.543	0.605	0.753	0.657	0.689	0.845	0.621	0.688	0.182	0.290	0.098	0.209	0.558
MRI-CGCM3	0.502	0.708	0.235	0.534	0.758	0.595	0.725	0.509	0.538	0.654	0.154	0.445	0.038	0.185	0.712
MRI-ESM1	0.500	0.694	0.231	0.559	0.752	0.592	0.711	0.486	0.587	0.654	0.153	0.436	0.037	0.181	0.677
NorESM1-M	0.510	0.475	0.664	0.480	0.592	0.621	0.712	0.891	0.571	0.407	0.153	0.156	0.180	0.100	0.429
NorESM1-ME	0.501	0.450	0.679	0.463	0.578	0.626	0.675	0.891	0.629	0.405	0.148	0.160	0.190	0.088	0.406
TSS MIN	0.23	0.23	0.19	0.20	0.22	0.20	0.34	0.34	0.16	0.18	0.04	0.04	0.03	0.02	0.07
TSS MAX	0.69	0.70	0.74	0.71	0.85	0.80	0.85	0.92	0.79	0.81	0.39	0.45	0.33	0.37	0.74

Table S4. TSS of MME and each model under CMIP6. ALL, CA, and XJ represent the entire study area, the five Central Asian countries, and the Xinjiang region, respectively. ANN, MAM, JJA, SON, and DJF represent the annual average, spring, summer, autumn, and winter precipitation, respectively. The highest and lowest TSS values for MME and each GCM are shown in bold and underlined, respectively.

CMIP6	ALL					CA					XJ				
Model/ensemble	**ANN**	**MAM**	**JJA**	**SON**	**DJF**	**ANN**	**MAM**	**JJA**	**SON**	**DJF**	**ANN**	**MAM**	**JJA**	**SON**	**DJF**
MME	0.658	0.635	0.633	0.711	0.828	0.798	0.783	0.898	0.797	0.773	0.250	0.304	0.150	0.286	0.719
ACCESS-CM2	0.509	0.579	0.336	0.550	0.876	0.705	0.693	0.703	0.700	0.859	0.115	0.205	0.034	0.130	0.608
ACCESS-ESM1-5	0.309	0.372	0.263	0.295	0.704	0.769	0.729	0.736	0.726	0.653	0.056	0.090	0.032	0.045	0.277
AWI-CM-1-1-MR	0.646	0.560	0.643	0.678	0.655	0.695	0.620	0.853	0.648	0.591	0.244	0.255	0.143	0.321	0.445
AWI-ESM-1-1-LR	0.644	0.513	0.599	0.682	0.803	0.747	0.644	0.807	0.655	0.748	0.222	0.197	0.125	0.386	0.624
BCC-CSM2-MR	0.624	0.608	0.695	0.539	0.791	0.786	0.787	0.882	0.742	0.770	0.213	0.260	0.195	0.123	0.480
BCC-ESM1	0.420	0.419	0.694	0.363	0.594	0.676	0.779	0.808	0.734	0.584	0.099	0.118	0.260	0.052	0.250
CAMS-CSM1-0	0.619	0.592	0.450	0.564	0.686	0.663	0.676	0.420	0.585	0.671	0.249	0.269	0.217	0.194	0.411
CanESM5	0.590	0.615	0.537	0.620	0.707	0.575	0.605	0.757	0.555	0.579	0.281	0.385	0.158	0.368	0.647
CAS-ESM2-0	0.129	0.227	0.072	0.165	0.491	0.201	0.343	0.170	0.261	0.439	0.029	0.069	0.012	0.029	0.193
CESM2	0.599	0.579	0.558	0.722	0.865	0.747	0.668	0.890	0.817	0.825	0.275	0.310	0.153	0.491	0.728
CESM2-FV2	0.581	0.482	0.707	0.671	0.789	0.736	0.701	0.907	0.765	0.716	0.200	0.185	0.205	0.268	0.588
CESM2-WACCM	0.628	0.604	0.585	0.709	0.856	0.764	0.704	0.886	0.808	0.805	0.303	0.319	0.171	0.498	0.765
CESM2-WACCM-FV2	0.630	0.525	0.726	0.747	0.787	0.746	0.710	0.898	0.791	0.720	0.239	0.215	0.226	0.376	0.576
CMCC-CM2-HR4	0.585	0.570	0.602	0.608	0.639	0.677	0.691	0.938	0.666	0.512	0.231	0.280	0.152	0.201	0.502
CMCC-CM2-SR5	0.549	0.486	0.590	0.613	0.625	0.639	0.680	0.902	0.549	0.475	0.185	0.179	0.111	0.330	0.518
CMCC-ESM2	0.574	0.486	0.591	0.660	0.673	0.692	0.677	0.917	0.606	0.547	0.191	0.178	0.113	0.362	0.526
FGOALS-g3	0.432	0.485	0.320	0.428	0.647	0.595	0.652	0.544	0.594	0.546	0.124	0.191	0.070	0.106	0.396
FIO-ESM-2-0	0.605	0.579	0.614	0.632	0.632	0.697	0.754	0.913	0.590	0.493	0.222	0.245	0.126	0.308	0.523
GISS-E2-1-G	0.275	0.383	0.389	0.221	0.264	0.274	0.399	0.649	0.206	0.210	0.093	0.181	0.103	0.055	0.124
GISS-E2-1-H	0.251	0.362	0.265	0.203	0.299	0.282	0.385	0.629	0.228	0.237	0.078	0.160	0.066	0.039	0.148
IITM-ESM	0.469	0.422	0.480	0.545	0.759	0.671	0.616	0.696	0.704	0.719	0.124	0.149	0.073	0.167	0.448
MCM-UA-1-0	0.456	0.466	0.432	0.592	0.484	0.618	0.707	0.613	0.611	0.274	0.139	0.144	0.094	0.269	0.639
MIROC6	0.577	0.643	0.498	0.617	0.792	0.712	0.784	0.816	0.719	0.746	0.253	0.401	0.124	0.257	0.628

MPI-ESM-1-2-HAM	0.610	0.526	0.593	0.707	0.755	0.689	0.638	0.779	0.738	0.703	0.188	0.183	0.115	0.275	0.575
MPI-ESM-1-2-HR	0.599	0.531	0.661	0.641	0.599	0.629	0.576	0.871	0.627	0.534	0.226	0.238	0.146	0.267	0.431
MPI-ESM-1-2-LR	0.622	0.518	0.669	0.719	0.632	0.644	0.580	0.835	0.689	0.560	0.241	0.210	0.160	0.366	0.554
MRI-ESM2-0	0.465	0.591	0.329	0.529	0.681	0.544	0.673	0.654	0.534	0.671	0.142	0.268	0.052	0.196	0.508
NESM3	0.562	0.452	0.585	0.681	0.684	0.673	0.588	0.842	0.708	0.625	0.167	0.181	0.103	0.249	0.425
NorCPM1	0.513	0.471	0.706	0.484	0.573	0.625	0.720	0.904	0.570	0.394	0.155	0.156	0.214	0.108	0.366
NorESM2-LM	0.698	0.527	0.749	0.769	0.761	0.751	0.665	0.872	0.773	0.693	0.355	0.272	0.301	0.498	0.614
NorESM2-MM	0.659	0.640	0.569	0.753	0.823	0.788	0.765	0.810	0.819	0.732	0.362	0.342	0.229	0.592	0.710
TaiESM1	0.596	0.572	0.602	0.611	0.615	0.669	0.735	0.929	0.546	0.456	0.220	0.263	0.110	0.302	0.555
TSS MIN	0.13	0.23	0.07	0.16	0.26	0.20	0.34	0.17	0.21	0.21	0.03	0.07	0.01	0.03	0.12
TSS MAX	0.70	0.64	0.75	0.77	0.88	0.80	0.79	0.94	0.82	0.86	0.36	0.40	0.30	0.59	0.76