

Supplementary Information — Europe’s extreme temperatures and rainfall in finer detail: strengths and limits of downscaled models

Mira Hulkkonen^{1*}, Akash Deshmukh^{1*}, Tero Mielonen¹,
Ian G. Brosnan², Taejin Park^{2,3}, Hugo Lee⁴, Weile Wang²,
Bridget Thrasher², Jessica L. McCarty², Harri Kokkola^{1,5},
Anton Laakso¹

^{1*}Finnish Meteorological Institute, Yliopistonranta 8, Kuopio, 70210, Finland.

²NASA Ames Research Center, Moffett Field, California, 94035, USA.

³Bay Area Environmental Research Institute, Moffett Field, California, 94035, USA.

⁴Jet Propulsion Laboratory, California Institute of Technology, 4800 Oak Grove Drive, Pasadena, California, 91109, USA.

⁵University of Eastern Finland, Yliopistonranta 8, Kuopio, 70210, Finland.

*Corresponding author(s). E-mail(s): mira.hulkkonen@fmi.fi;
akash.deshmukh@fmi.fi;

Contributing authors: tero.mielonen@fmi.fi; ian.g.brosnan@nasa.gov;
taejin.park@nasa.gov; huikyo.lee@jpl.nasa.gov; weile.wang@nasa.gov;
bridget@climateanalyticsgroup.org; jessica.mccarty@nasa.gov;
harri.kokkola@fmi.fi; anton.laakso@fmi.fi;

Content: S1 Model ensemble details; S2 Supplementary Figures

S1 Model ensemble details

S1.1 CMIP5 models

Table S1: List of climate models included in the CMIP5 dataset

No.	Climate model	Realization
1	CNRM-CM5	r1i1p1
2	IPSL-CM5A-MR	r1i1p1
3	EC-EARTH	r1i1p1
4	HadGEM2-ES	r1i1p1
5	MPI-ESM-LR	r1i1p1
6	NorESM1-M	r1i1p1

S1.2 EURO-CORDEX models

Table S2: List of climate models included in the EURO-CORDEX-11 dataset

No.	CORDEX model	Driving GCM	Realization
1	CCLM4	EC-Earth	r1i1p1
2	RACMO22E	EC-Earth	r1i1p1
3	RCA4	EC-Earth	r12i1p1
4	CCLM4	HadGEM2-ES	r1i1p1
5	RACMO22E	HadGEM2-ES	r1i1p1
6	RCA4	HadGEM2-ES	r1i1p1
7	RCA4	IPSL-CM5A-MR	r1i1p1
8	WRF381P	IPSL-CM5A-MR	r1i1p1
9	ALADIN53	CNRM-CM5	r1i1p1
10	RCA4	CNRM-CM5	r1i1p1
11	CCLM4	CNRM-CM5	r1i1p1
12	HIRHAM5	NorESM1-M	r1i1p1
13	RCA4	NorESM1-M	r1i1p1
14	REMO2015	NorESM1-M	r1i1p1
15	CCLM4	MPI-ESM-LR	r1i1p1
16	RCA4	MPI-ESM-LR	r1i1p1
17	REMO2009	MPI-ESM-LR	r1i1p1

S1.3 CMIP6 models

Table S3: List of climate models included in the CMIP6 dataset

No.	Climate model	Realization
1	ACCESS-CM2	r1i1p1f1
2	ACCESS-ESM1-5	r1i1p1f1
3	BCC-CSM2-MR	r1i1p1f1
4	CMCC-ESM2	r1i1p1f1
5	CNRM-CM6-1	r1i1p1f2
6	CNRM-ESM2-1	r1i1p1f2
7	CanESM5	r1i1p1f1
8	EC-Earth3	r1i1p1f1
9	EC-Earth3-Veg-LR	r1i1p1f1
10	FGOALS-g3	r3i1p1f1
11	GFDL-CM4	r1i1p1f1
12	GFDL-ESM4	r1i1p1f1
13	GISS-E2-1-G	r1i1p1f2
14	HadGEM3-GC31-LL	r1i1p1f3
15	INM-CM4-8	r1i1p1f1
16	INM-CM5-0	r1i1p1f1
17	IPSL-CM6A-LR	r1i1p1f1
18	KACE-1-0-G	r1i1p1f1
19	KIOST-ESM	r1i1p1f1
20	MIROC-ES2L	r1i1p1f2
21	MIROC6	r1i1p1f1
22	MPI-ESM1-2-HR	r1i1p1f1
23	MPI-ESM1-2-LR	r1i1p1f1
24	MRI-ESM2-0	r1i1p1f1
25	NESM3	r1i1p1f1
26	NorESM2-LM	r1i1p1f1
27	NorESM2-MM	r1i1p1f1
28	TaiESM1	r1i1p1f1
29	UKESM1-0-LL	r1i1p1f2

S1.4 NEX-GDDP models

Table S4: List of climate models included in the NEX-GDDP dataset

No.	Climate model	Realization	Version
1	ACCESS-CM2	r1i1p1f1	v1.0
2	ACCESS-ESM1-5	r1i1p1f1	v1.0
3	BCC-CSM2-MR	r1i1p1f1	v1.0
4	CMCC-CM2-SR5	r1i1p1f1	v1.1
5	CMCC-ESM2	r1i1p1f1	v1.0
6	CNRM-CM6-1	r1i1p1f2	v1.0
7	CNRM-ESM2-1	r1i1p1f2	v1.0
8	CanESM5	r1i1p1f1	v1.0
9	EC-Earth3	r1i1p1f1	v1.1
10	EC-Earth3-Veg-LR	r1i1p1f1	v1.0
11	FGOALS-g3	r3i1p1f1	v1.0
12	GFDL-CM4	r1i1p1f1	v1.0
13	GFDL-ESM4	r1i1p1f1	v1.0
14	GISS-E2-1-G	r1i1p1f2	v1.0
15	HadGEM3-GC31-LL	r1i1p1f3	v1.0
16	INM-CM4-8	r1i1p1f1	v1.1
17	INM-CM5-0	r1i1p1f1	v1.0
18	IPSL-CM6A-LR	r1i1p1f1	v1.0
19	KACE-1-0-G	r1i1p1f1	v1.0
20	KIOST-ESM	r1i1p1f1	v1.0
21	MIROC-ES2L	r1i1p1f2	v1.0
22	MIROC6	r1i1p1f1	v1.0
23	MPI-ESM1-2-HR	r1i1p1f1	v1.0
24	MPI-ESM1-2-LR	r1i1p1f1	v1.1
25	MRI-ESM2-0	r1i1p1f1	v1.0
26	NESM3	r1i1p1f1	v1.0
27	NorESM2-LM	r1i1p1f1	v1.0
28	NorESM2-MM	r1i1p1f1	v1.0
29	TaiESM1	r1i1p1f1	v1.1
30	UKESM1-0-LL	r1i1p1f2	v1.1

S1.5 CIL GDPCIR models

Table S5: List of climate models included in the CIL GDPCIR dataset

No.	Climate model	Realization
1	INM-CM5-0	r1i1p1f1
2	FGOALS-g3	r1i1p1f1
3	CanESM5	r1i1p1f1
4	ACCESS-CM2	r1i1p1f1
5	EC-Earth3	r1i1p1f1
6	GFDL-ESM4	r1i1p1f1
7	NorESM2-MM	r1i1p1f1
8	NESM3	r1i1p1f1
9	MIROC6	r1i1p1f1
10	UKESM1-0-LL	r1i1p1f2
11	BCC-CSM2-MR	r1i1p1f1
12	CMCC-CM2-SR5	r1i1p1f1
13	CMCC-ESM2	r1i1p1f1
14	ACCESS-ESM1-5	r1i1p1f1
15	MIROC-ES2L	r1i1p1f1
16	HadGEM3-GC31-LL	r1i1p1f3
17	MPI-ESM1-2-HR	r1i1p1f1

S2 Supplementary Figures

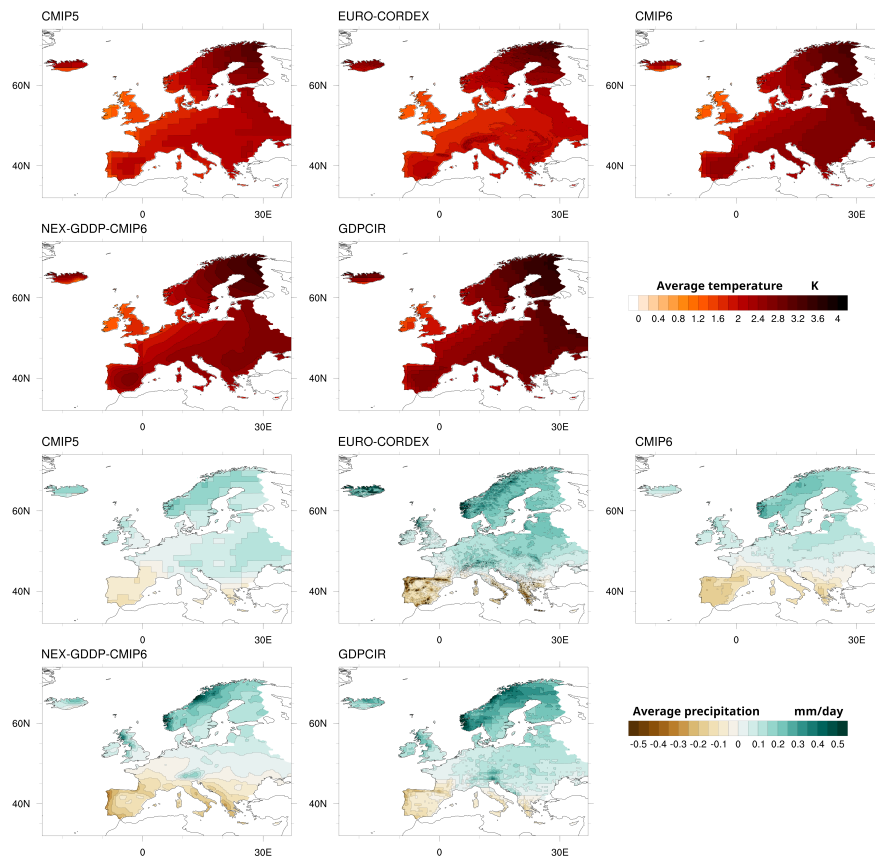


Fig. S1 Change in average temperature and precipitation projected by different climate model ensembles for future climate (2071-2100) in comparison to 1990-2019 using the scenario SSP2-4.5.

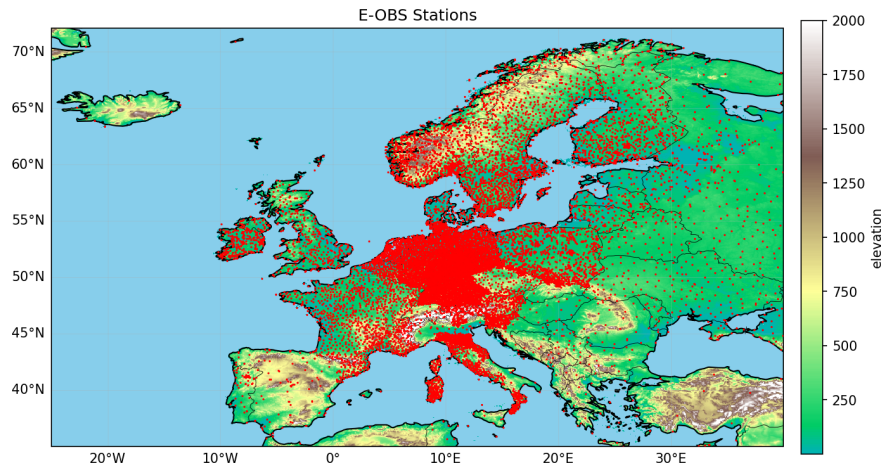


Fig. S2 Weather measurement stations (red points) and geographic altitude across Europe.

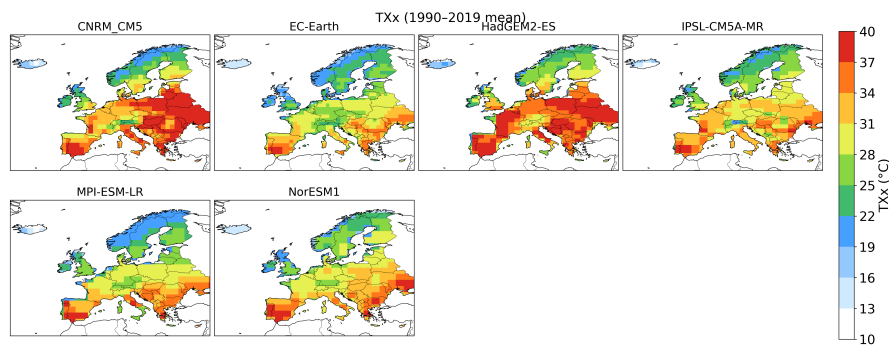


Fig. S3 TXx by each CMIP5 model ensemble member used in this study

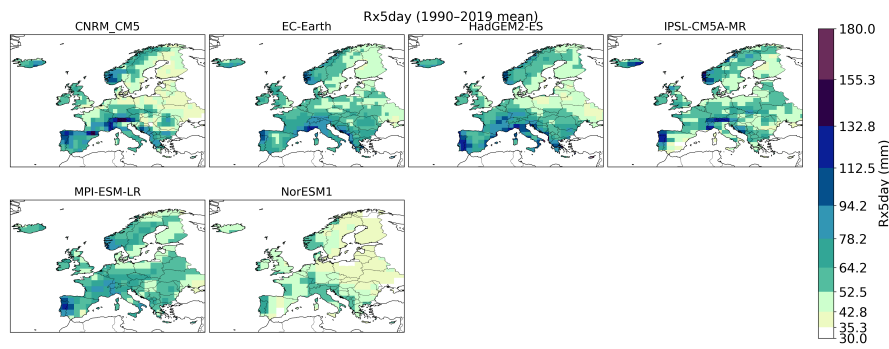


Fig. S4 Rx5day by each CMIP5 model ensemble member used in this study

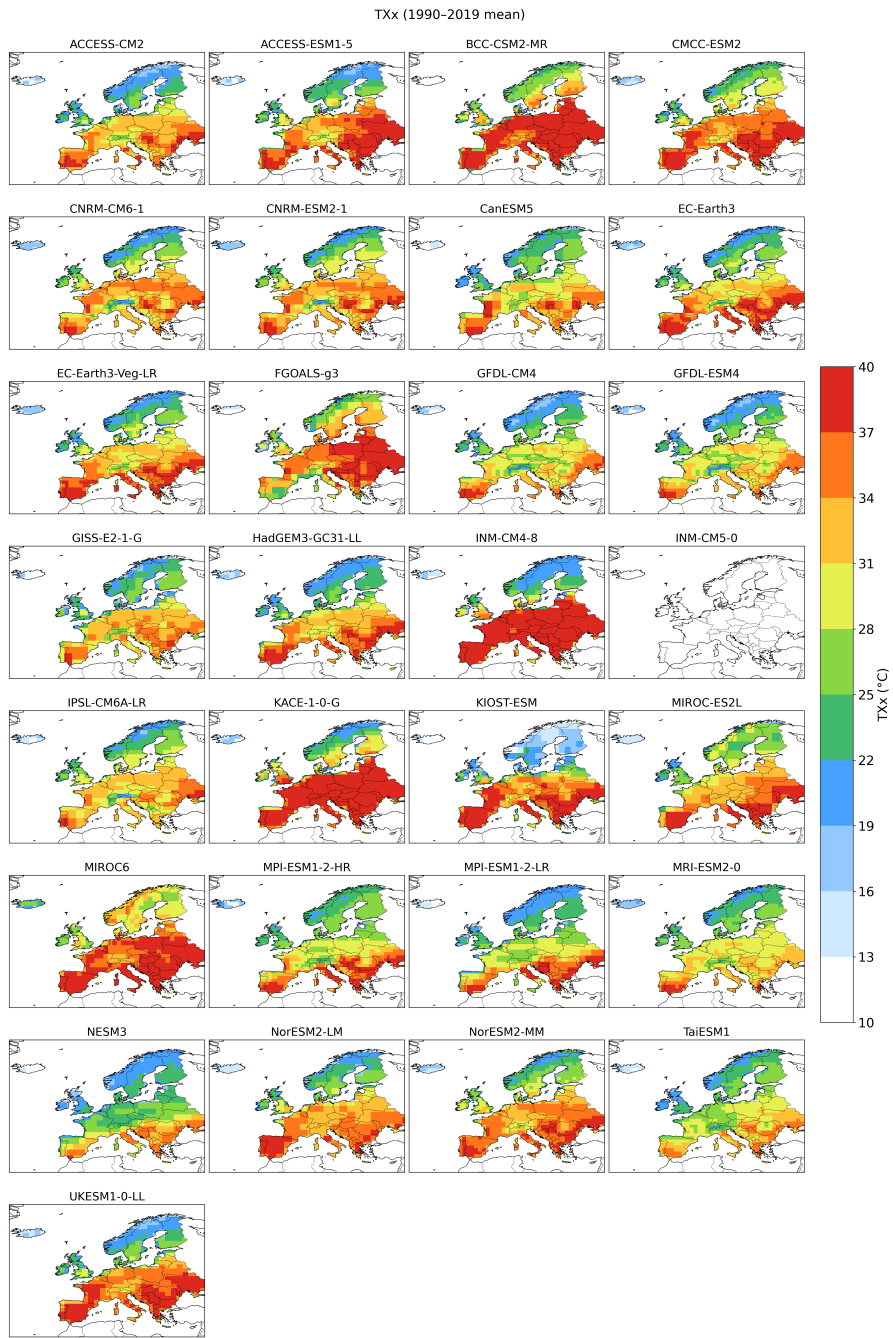


Fig. S5 TXx by each CMIP6 model ensemble member used in this study

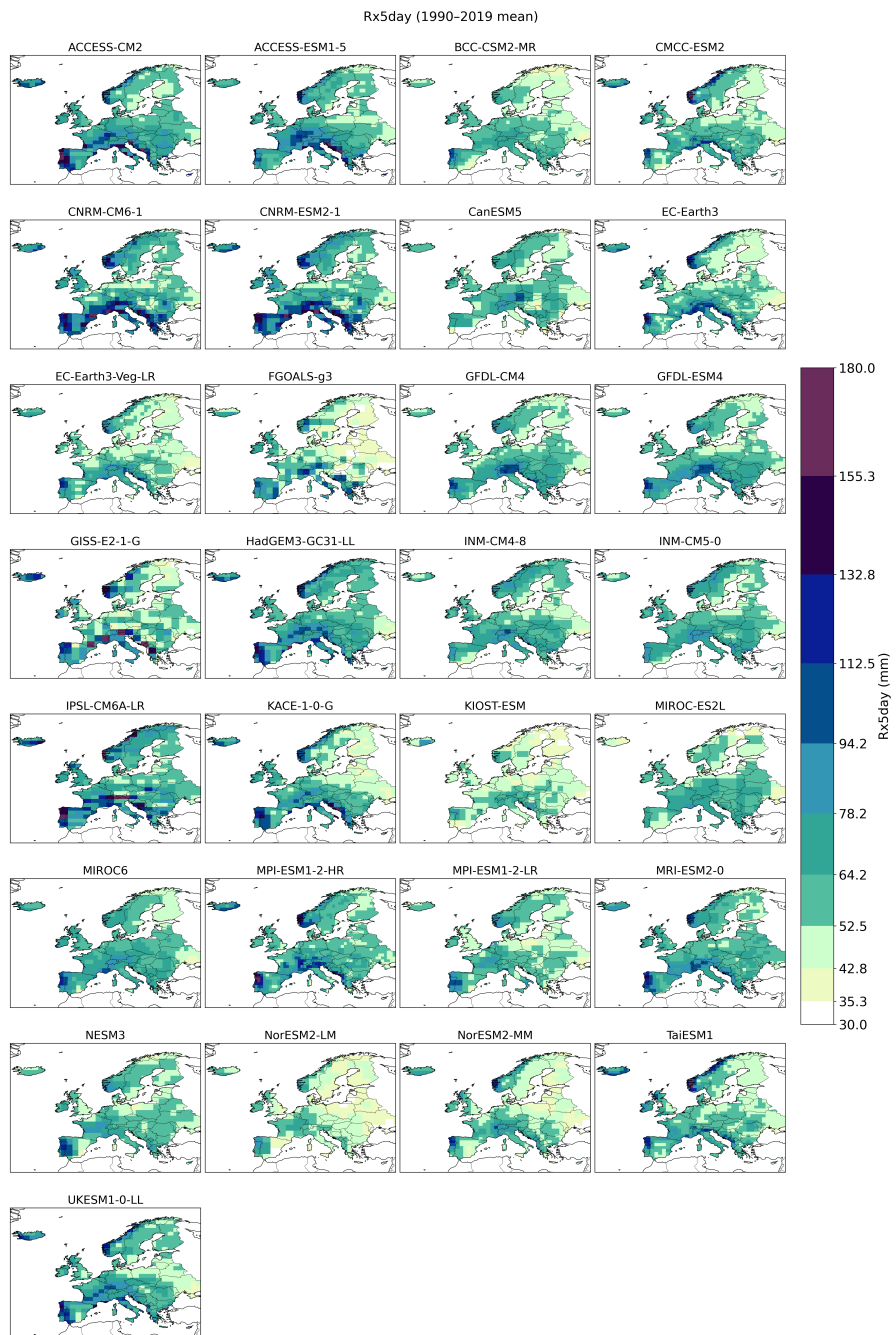


Fig. S6 Rx5day by each CMIP6 model ensemble member used in this study

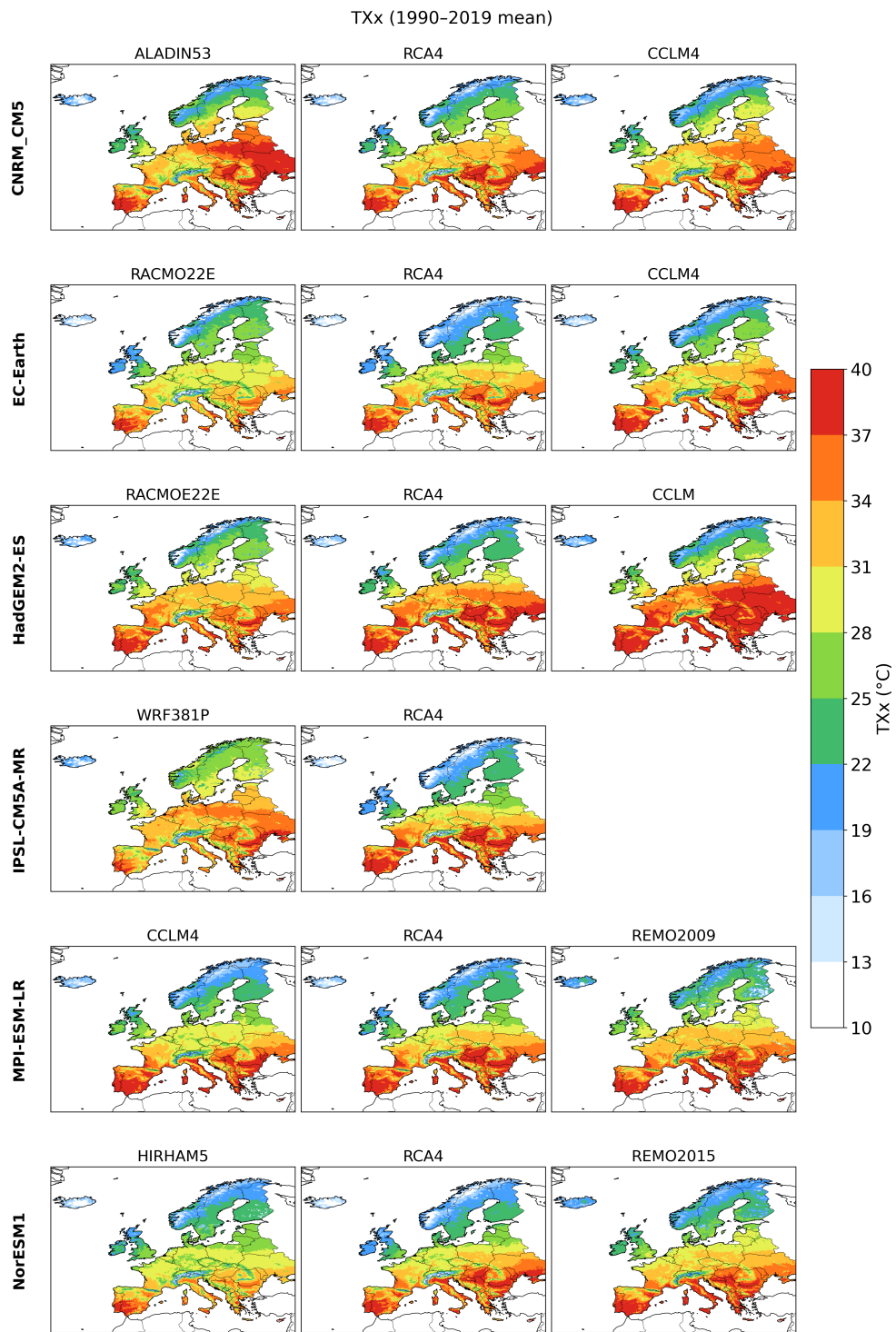


Fig. S7 TXx by each EURO-CORDEX ensemble member used in this study

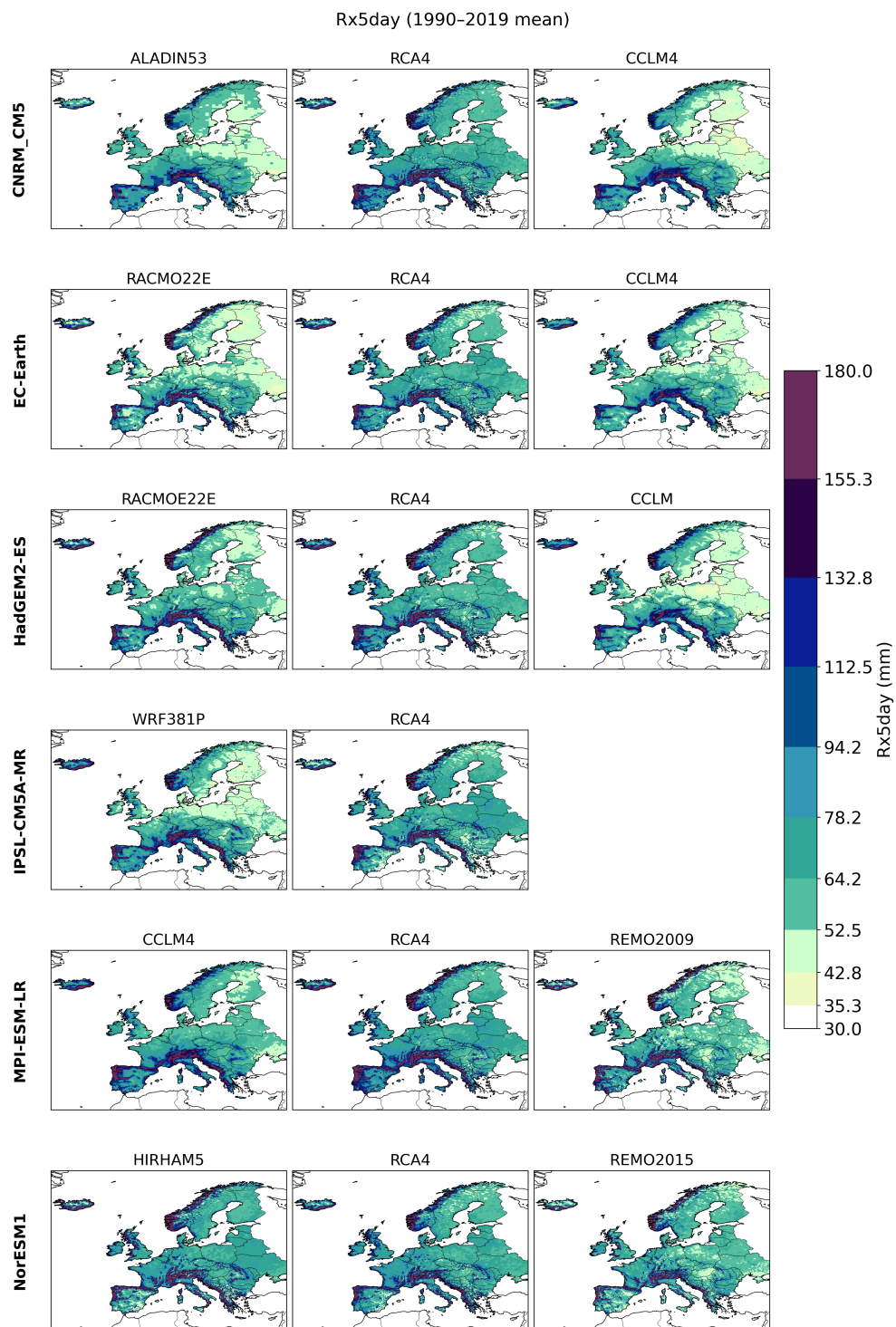


Fig. S8 Rx5day by each EURO-CORDEX model ensemble member used in this study

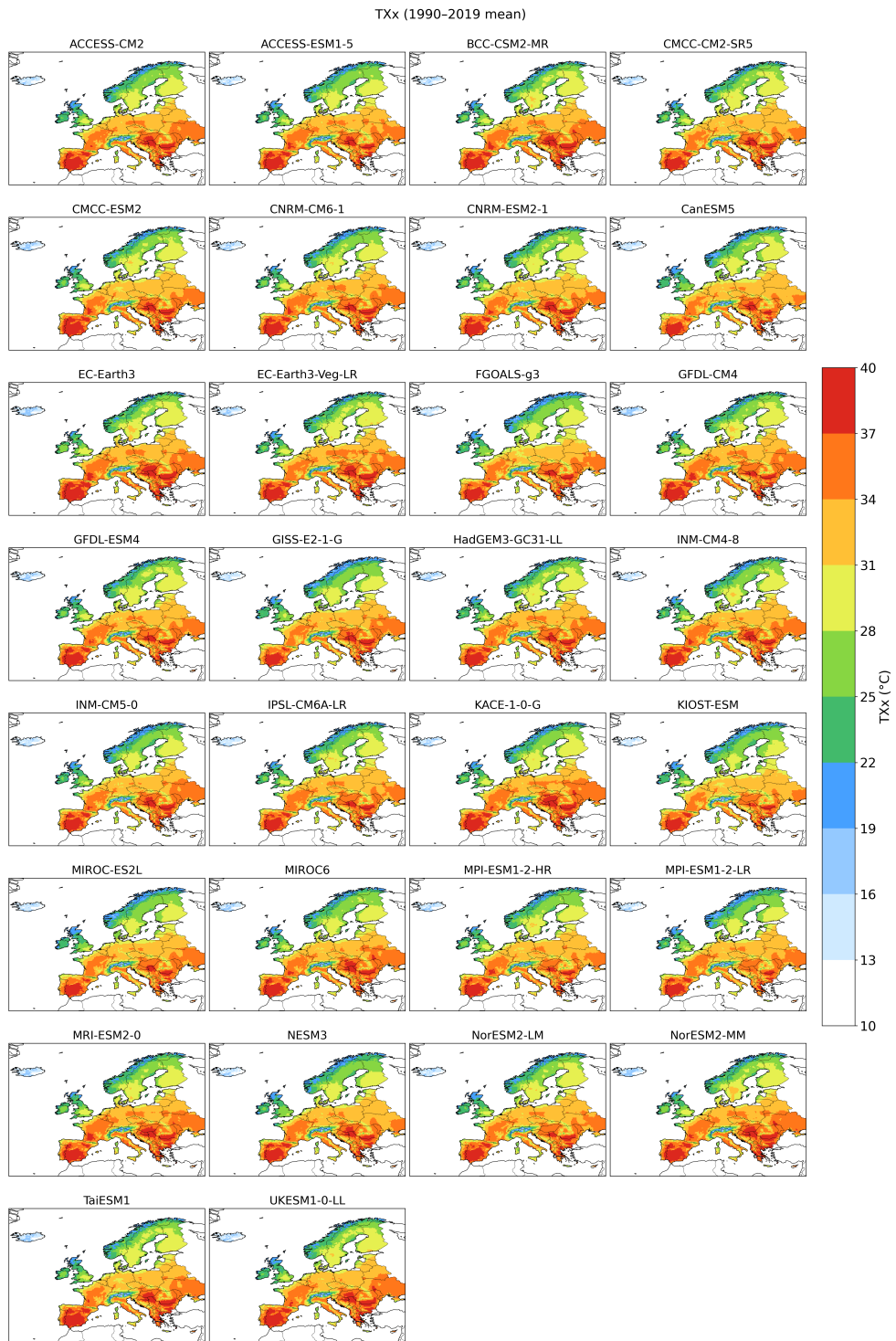


Fig. S9 TXx by each NEX-GDDP-CMIP6 model ensemble member used in this study

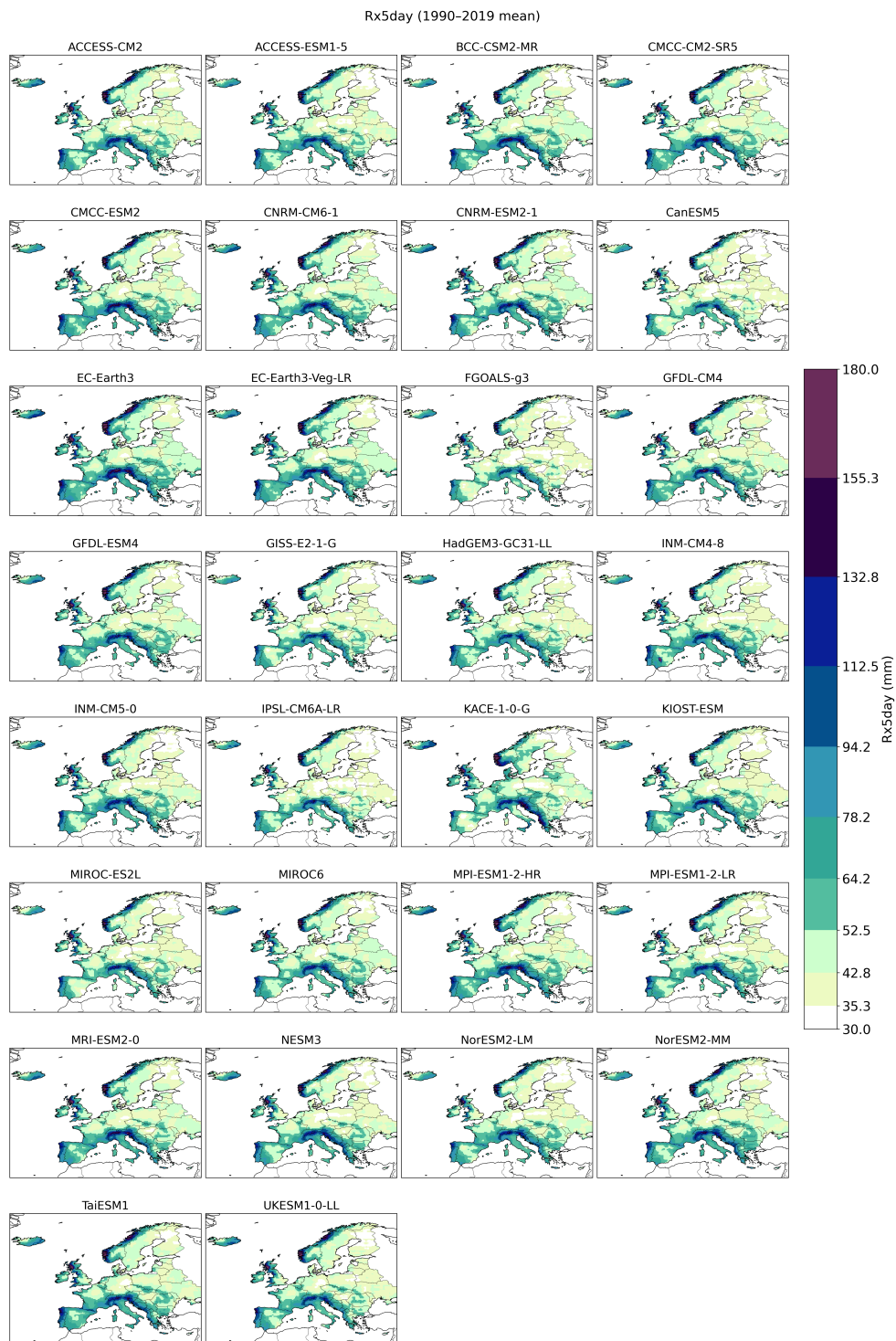


Fig. S10 Rx5day by each NEX-GDDP-CMIP6 model ensemble member used in this study

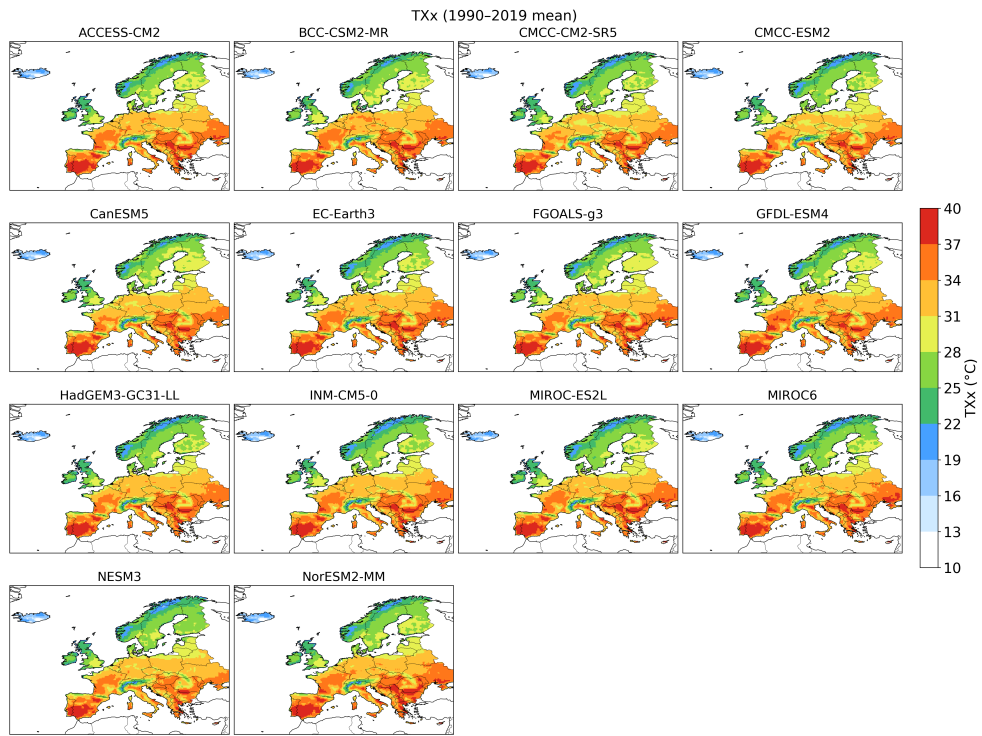


Fig. S11 TXx by each GDPCIR model ensemble member used in this study

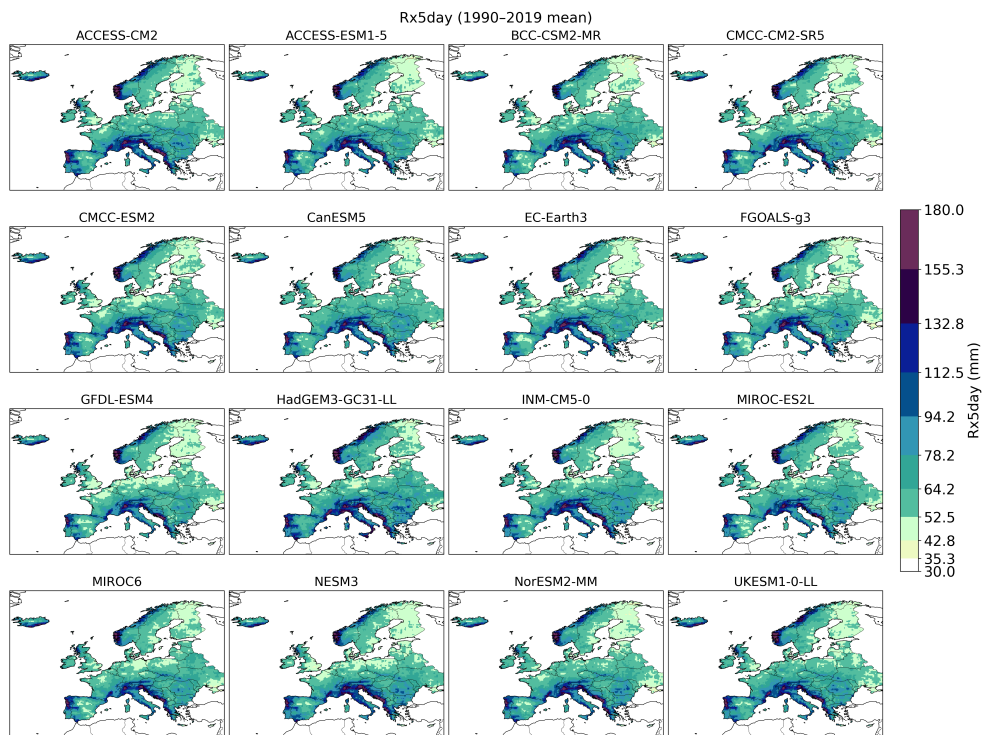


Fig. S12 Rx5day by each GPCIR model ensemble member used in this study

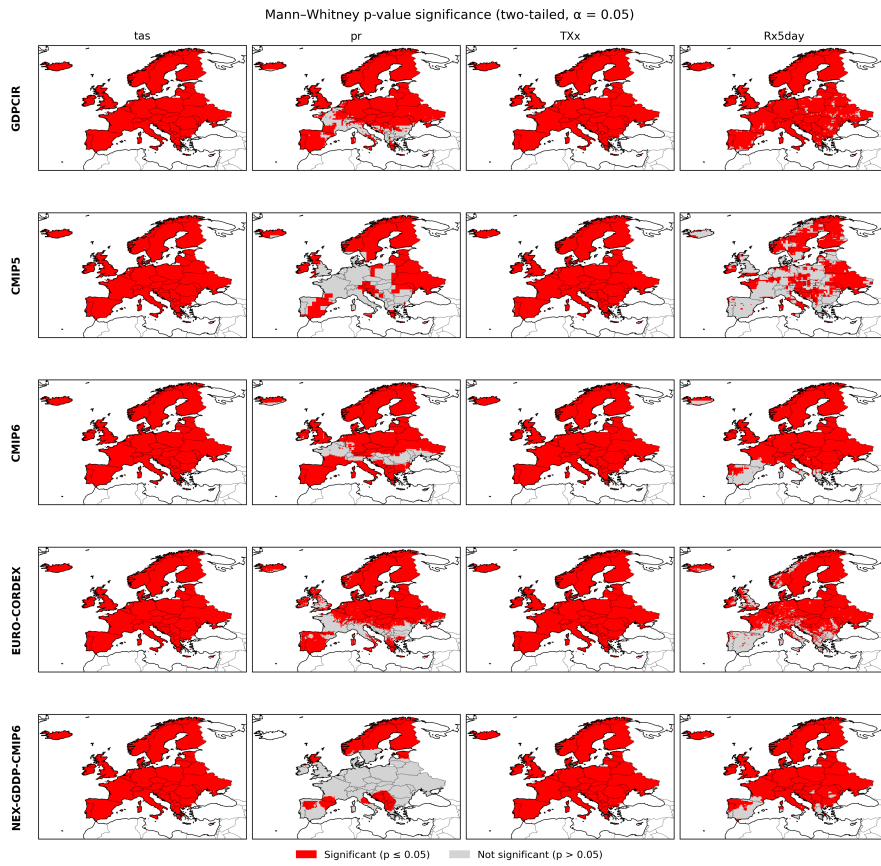


Fig. S13 Statistical significance of the differences between the historical (1990-2019) and future (2071-2100) climate variables (tas, pr, TXx, Rx5day) based on different climate model ensemble outputs. The Mann-Whitney U-test was applied to determine the statistical significance.

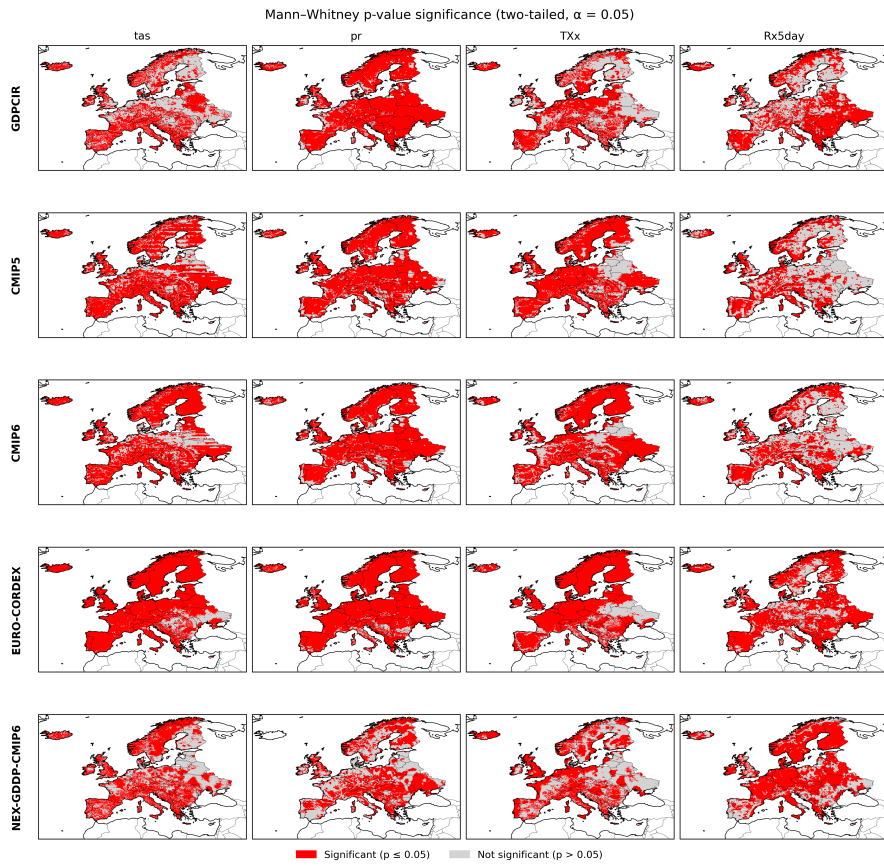


Fig. S14 Statistical significance of how much each climate variable (tas, pr, TXx, Rx5day) calculated based on historical climate model data sets (1990-2019) differs from those calculated based on the observational reference E-OBS (1990-2019). The Mann-Whitney U-test was applied to determine the statistical significance.

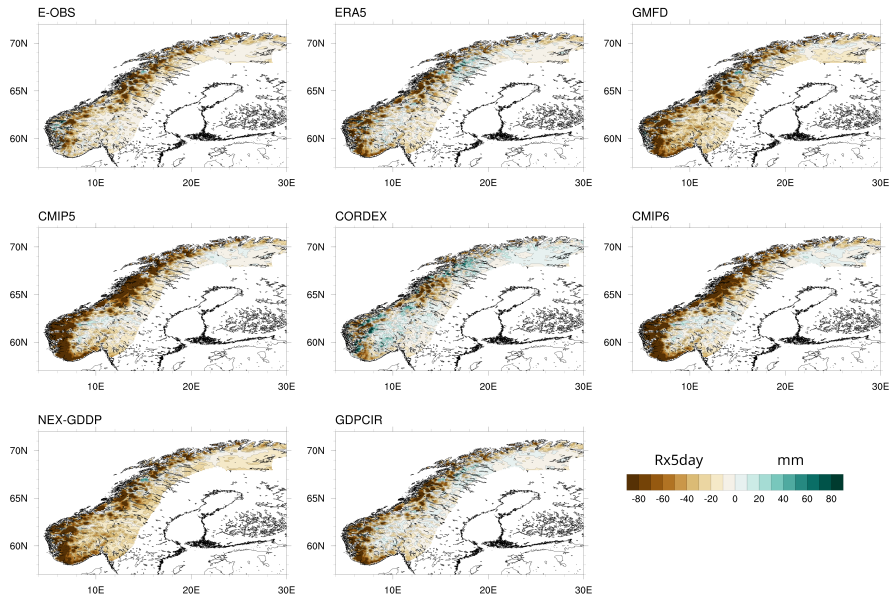


Fig. S15 Average Rx5day based on the historical climate model datasets (1990-2019) compared to an observational gridded dataset for Norway, seNorge.

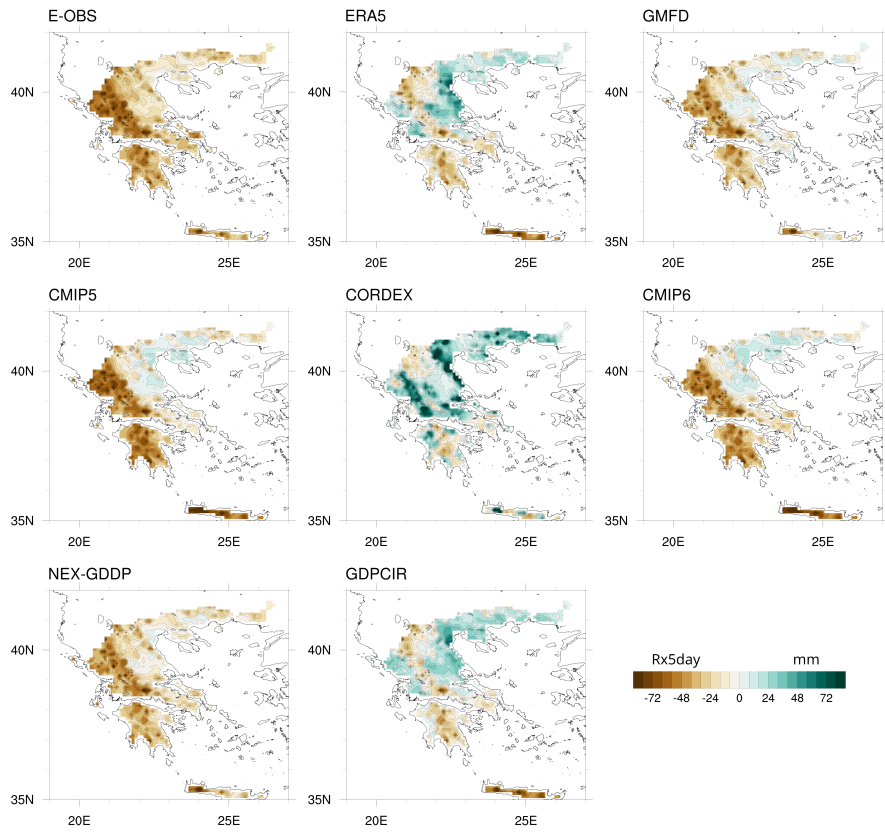


Fig. S16 Average Rx5day based on the historical climate model datasets (1990-2019) compared to a high-resolution gridded precipitation dataset for Greece, CLIMADAT-GRid