

## **Supplement of**

Are we using the right fuel to drive hydrological  
models? A climate impact study in the Upper  
Blue Nile

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August 17, 2016

Table S 1: RCMs

Driving ESM	RCM			
	SMHI-RCA4	CanRCM4	KNMI-RACMO22T	DMI-HIRHAM4
CanESM2	x	x		
CNRM-CM5	x			
EC-EARTH	x		x	x
GFDL-ESM2M	x			
MIROC5	x			
MPI-ESM-LR	x			
NorESM1-M	x			

Table S 2: Model IDs

ID	Model
1	GFDL
2	HadGEM
3	IPSL
4	MIROC
5	NorESM
6	CanESM2-RCM4
7	CanESM2-RCA4
8	CNRM-CM5-RCA4
9	GFDL-RCA4
10	EC-EARTH-Hirham5
11	EC-EARTH-RACMO
12	EC-EARTH-RCA4
13	MIROC-RCA4
14	MPI-M-ESM-LR-RCA4
15	NorESM1-RCA4

Table S 3: Daily precipitation parameters in [mm]

Model	nDays>1mm	ave	max	SD	ave (JAS)	SD (JAS)
WFD	164.1	3.9	63.4	6.9	9.1	9.6
UC						
GFDL	188.4	3.8	49.5	4.7	7.6	3.8
HadGEM	228.1	3.6	21.9	3.6	7.5	2.8
IPSL	134.4	1.7	28.4	2.8	5.2	3.2
MIROC	194.2	3.7	66.2	5.5	7.8	7.3
NorESM	204.8	3.5	28.5	4.5	5.4	4.1
CanESM2-RCM4	250.1	4.4	57.7	4.4	8.6	3.7
CanESM2-RCA4	130.4	1.8	39.6	3.1	5.3	3.9
CNRM-CM5-RCA4	180.6	2.6	30.3	3.4	6.5	3.2
GFDL-RCA4	183.8	3.4	40.4	4.5	8.5	4.0
EC-EARTH-Hirham5	177.8	3.7	40.7	5.2	9.0	5.5
EC-EARTH-RACMO	213.6	3.8	52.3	4.5	7.8	4.7
EC-EARTH-RCA4	197.4	4.2	44.9	5.3	10.1	4.5
MIROC-RCA4	191.8	3.4	38.6	4.6	8.8	4.3
MPI-M-ESM-LR-RCA4	177.0	3.7	42.9	5.1	9.7	4.9
NorESM1-RCA4	157.3	2.9	41.0	4.4	8.1	5.0
BC						
GFDL	220.7	3.9	30.4	4.3	8.6	4.0
HadGEM	180.7	3.9	73.5	5.2	8.4	4.9
IPSL	153.1	3.7	65.8	6.5	8.9	6.8
MIROC	192.9	3.9	90.8	6.4	8.7	9.1
NorESM	187.1	3.9	51.0	5.5	8.5	6.4
CanESM2-RCM4	174.2	3.8	305.8	8.3	8.8	13.4
CanESM2-RCA4	130.4	3.2	142.0	7	8.6	10.5
CNRM-CM5-RCA4	161.6	3.7	117.3	6.9	8.5	9.4
GFDL-RCA4	159.8	3.9	133.6	7.6	9.2	10.8
EC-EARTH-Hirham5	159.6	4.0	85.1	7.3	8.8	10.5
EC-EARTH-RACMO	155.1	3.8	210.8	8.8	9.0	13.7
EC-EARTH-RCA4	164.2	3.8	155.1	7.4	9.0	10.7
MIROC-RCA4	158.7	3.6	107.5	7.1	8.5	9.6
MPI-M-ESM-LR-RCA4	153.8	3.7	108.0	7.8	8.8	11.5
NorESM1-RCA4	146.2	3.5	144.5	7.5	8.9	11.2

Table S 4: Daily precipitation parameters in [mm], differences to WFD

Model	nDays>1mm	ave	max	SD	ave (JAS)	SD (JAS)
UC						
GFDL	24.3	-0.1	-13.9	0.7	-1.5	0.4
HadGEM	63.9	-0.4	-41.5	0.5	-1.6	0.3
IPSL	-29.7	-2.2	-35	0.4	-3.9	0.3
MIROC	30.1	-0.2	2.7	0.8	-1.3	0.8
NorESM	40.6	-0.4	-34.9	0.7	-3.7	0.4
CanESM2-RCM4	86.0	0.5	-5.8	0.6	-0.5	0.4
CanESM2-RCA4	-33.8	-2.1	-23.8	0.4	-3.8	0.4
CNRM-CM5-RCA4	16.5	-1.3	-33.1	0.5	-2.5	0.3
GFDL-RCA4	19.7	-0.5	-23.0	0.6	-0.5	0.4
EC-EARTH-Hirham5	13.6	-0.3	-22.8	0.8	-0.1	0.6
EC-EARTH-RACMO	49.5	-0.1	-11.1	0.6	-1.3	0.5
EC-EARTH-RCA4	33.3	0.3	-18.6	0.8	1.0	0.5
MIROC-RCA4	27.6	-0.5	-24.9	0.7	-0.2	0.4
MPI-M-ESM-LR-RCA4	12.9	-0.2	-20.6	0.7	0.6	0.5
NorESM1-RCA4	-6.8	-1.1	-22.4	0.6	-1.0	0.5
BC						
GFDL	56.6	0.0	-33	0.6	-0.5	0.4
HadGEM	16.6	0.0	10.1	0.7	-0.7	0.5
IPSL	-11.0	-0.2	2.4	0.9	-0.2	0.7
MIROC	28.8	0.0	27.4	0.9	-0.4	1.0
NorESM	22.9	0.0	-12.4	0.8	-0.6	0.7
CanESM2-RCM4	10.1	-0.1	242.3	1.2	-0.3	1.4
CanESM2-RCA4	-33.7	-0.7	78.6	1.0	-0.5	1.1
CNRM-CM5-RCA4	-2.5	-0.2	53.8	1.0	-0.6	1.0
GFDL-RCA4	-4.4	-0.1	70.2	1.1	0.1	1.1
EC-EARTH-Hirham5	-4.6	0.1	21.7	1.1	-0.3	1.1
EC-EARTH-RACMO	-9.1	-0.1	147.3	1.3	-0.1	1.4
EC-EARTH-RCA4	0.1	-0.1	91.6	1.1	-0.1	1.1
MIROC-RCA4	-5.4	-0.3	44.0	1.0	-0.6	1.0
MPI-M-ESM-LR-RCA4	-10.3	-0.2	44.5	1.1	-0.3	1.2
NorESM1-RCA4	-17.9	-0.4	81.0	1.1	-0.1	1.2

Table S 5: Relative deviation [%] of FDC values between UC ESMs and WFD in the period 1970-1999.  $Q_{pt}$  = percentile of discharge.

$Q_{pt}$	GFDL	HadGEM	IPSL	MIROC	NorESM
99.99	3.0	37.9	-107.0	-106.7	-106.8
99.9	3.3	55.9	-106.6	-103.0	-106.2
99	-63.8	-37.5	-101.6	-36.7	-98.7
95	-37.0	-21.8	-100.4	15.2	-38.2
90	9.8	-22.5	-100.2	16.1	-10.3
80	49.1	-26.8	-100.1	5.1	-7.4
70	53.8	-20.3	-99.9	4.1	12.2
60	49.5	-19.2	-98.5	1.8	14.6
50	55.9	-18.9	-96.2	0.8	14.1
40	67.1	-17.9	-94.6	-1.1	4.1
30	45.4	-19.2	-93.1	-9.8	-18.6
20	0.7	-24.1	-89.3	-13.7	-42.6
10	-12.6	-29.3	-81.3	-15.1	-42.5
5	-11.9	-33.5	-75.6	-11.5	-34.4
1	-15.3	-38.3	-69.1	-4.3	-17.4
0.1	-13.6	-42.4	-59.3	14.2	-11.1
0.01	-2.5	-43.0	-49.6	42.8	-13.2

Table S 6: Relative deviation [%] of FDC values between BC ESMs and WFD in the period 1970-1999.  $Q_{pt}$  = percentile of discharge.

$Q_{pt}$	GFDL	HadGEM	IPSL	MIROC	NorESM
99.99	-3.4	36.5	-107.0	-93.4	-70.7
99.9	-3.5	63.4	-106.6	-5.6	-9.6
99	-66.8	55.6	-101.1	-33.6	-68.8
95	-33.7	36.1	-73.4	2.6	-12.7
90	1.4	26.3	-27.6	8.6	14.5
80	25.9	14.4	-6.6	-3.0	5.4
70	31.8	10.5	7.8	2.3	18.6
60	28.4	3.0	9.8	0.5	20.3
50	29.5	0.4	9.1	-0.4	17.1
40	24.9	-5.3	7.7	-4.4	9.3
30	15.3	-12.1	1.9	-11.5	2.8
20	-8.3	-10.1	-10.7	-20.5	-16.8
10	-7.5	-15.3	-5.2	-15.1	-17.9
5	-11.1	-17.0	8.3	-5.8	-14.3
1	-10.1	-20.9	45.3	20.2	-1.2
0.1	26.6	-23.8	76.7	54.5	33.5
0.01	77.1	-24.7	142.0	66.1	41.4

Table S 7: Relative deviation [%] of FDC values between UC RCMs and WFD in the period 1970-1999.  $Q_{pt}$  = percentile of discharge.

$Q_{pt}$	Model ID									
	6	7	8	9	10	11	12	13	14	15
99.99	611.8	-107.0	-106.1	1016.3	314.6	551.8	3048.1	736.0	433.3	2.2
99.9	721.9	-106.6	-96.1	1103.3	476.5	820.7	3208.3	1184.7	478.4	-1.4
99	836.5	-101.6	-50.7	475.9	360.7	518.2	1104.2	803.1	377.2	-33.5
95	325.3	-100.4	-44.2	124.8	124.2	231.9	416.3	217.2	174.8	-15.9
90	217.2	-100.0	-44.5	69.6	101.2	159.0	296.0	121.8	128.9	-21.1
80	139.7	-96.8	-52.5	30.4	79.8	104.0	187.2	56.3	85.3	-30.6
70	122.4	-92.7	-50.5	27.5	74.6	96.4	169.0	42.0	76.6	-30.7
60	111.5	-89.8	-48.0	23.4	76.8	95.9	157.0	32.6	71.6	-29.6
50	120.8	-87.9	-43.7	29.8	88.1	104.7	157.7	26.5	74.1	-28.2
40	119.0	-87.4	-42.9	28.9	82.7	105.6	142.2	14.7	62.7	-29.6
30	71.4	-86.4	-48.2	14.4	63.3	79.1	115.3	-8.1	42.1	-39.3
20	12.3	-86.2	-54.8	-3.3	41.1	32.3	77.2	-11.7	47.7	-40.2
10	-2.9	-74.3	-45.9	-9.6	35.1	9.0	56.1	-1.5	32.8	-15.0
5	-7.4	-65.1	-43.6	-6.8	35.6	2.7	50.0	1.0	24.1	-4.8
1	-5.5	-53.6	-44.4	-3.2	32.5	-1.3	46.1	6.2	21.6	12.1
0.1	6.5	-36.4	-42.8	6.8	25.2	5.5	50.8	17.2	36.5	12.7
0.01	15.8	-15.6	-41.6	17.3	31.9	16.8	60.7	31.1	36.0	21.7

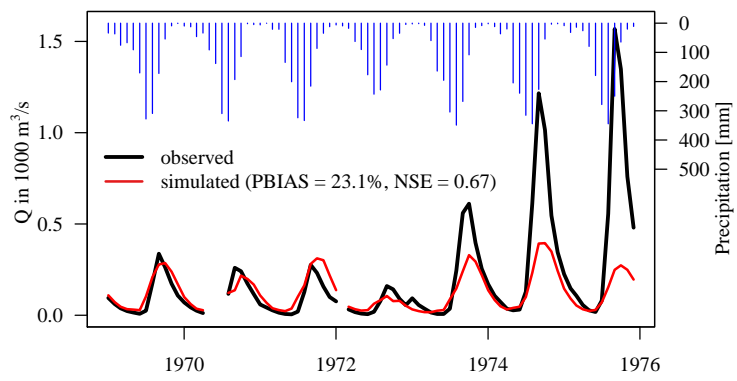
Table S 8: Relative deviation [%] of FDC values between BC RCMs and WFD in the period 1970-1999.  $Q_{pt}$  = percentile of discharge.

$Q_{pt}$	Model ID									
	6	7	8	9	10	11	12	13	14	15
99.99	-101.4	-107.0	-106.9	-106.9	-106.4	-106.9	-3.4	-106.8	-107.0	-106.8
99.9	-33.8	-106.6	-104.4	-103.3	-95.4	-106.4	-7.7	-103.9	-105.9	-103.7
99	-10.8	-101.6	-67.4	-41.7	-74.2	-50.2	-71.8	-73.1	-67.9	-68.5
95	-3.4	-93.6	-46.6	-15.7	-60.2	-17.4	-6.4	-67.8	-42.6	-43.4
90	-7.4	-86.8	-32.5	-15.7	-42.5	-5.3	0.1	-51.0	-12.2	-34.3
80	-16.8	-65.7	-24.4	-9.7	-13.7	-9.6	-7.6	-35.3	-3.9	-24.9
70	-14.0	-46.3	-10.7	-1.6	1.4	-5.4	2.0	-23.1	4.2	-15.9
60	-11.7	-35.1	-6.2	6.0	9.9	4.8	7.8	-17.3	6.8	-10.7
50	-1.8	-20.1	0.3	16.7	15.9	9.3	12.3	-6.4	9.8	1.9
40	5.7	-14.8	2.1	18.1	11.0	3.4	4.9	-6.5	8.6	5.2
30	10.1	-30.4	-6.9	0.4	2.7	-7.7	-11.1	-18.0	-1.5	-6.6
20	-6.2	-40.6	-13.2	-11.2	-6.6	-16.4	-11.4	-23.3	-10.8	-17.9
10	8.9	-16.3	-0.9	11.0	9.9	-1.1	3.3	-9.0	1.0	7.1
5	37.2	24.5	15.3	39.6	22.8	23.3	26.9	17.7	21.4	43.9
1	140.5	120.3	53.0	109.5	52.4	116.0	98.4	86.2	67.5	146.8
0.1	327.6	279.1	132.9	242.5	71.3	260.0	213.5	245.8	185.8	246.9
0.01	656.9	593.0	146.7	411.2	100.4	418.2	233.8	313.5	217.3	401.0

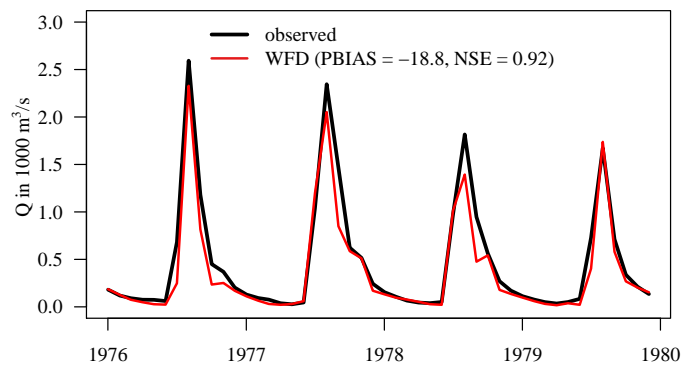
Table S 9: Projected changes in average annual discharges (recent studies) in [%]

Study	Catchment	Models	Reference	Scenario	Future	Pcp change	Q change
Dile et al. (2013)	Gilgel Abay (Lake Tana)	1 GCM & stat. downsc.	1990-2001	A2a, B2a	2020	-10%, -13%	-46% <sup>1)</sup>
					2050	3.8%, 2.2%	+135% <sup>1)</sup>
					2080	19.3%, 12%	+136% <sup>1)</sup>
Setegn et al. (2011)	Gilgel Abay (Lake Tana)	9 downsc. CMIP3 GCMs	1980-2000	B2, A1B, A2	2046-2065		-45% to +10%
Mengistu & Sorteberg (2012)	Blue Nile	Pcp change assumptions CMIP3 GCMs			2080-2100		-52% to +5%
						±10%	±19%
						±20%	±40%
Conway & Schipper (2011)	Ethiopia	CMIP3 GCMs	1981-2000	lin. interpol. A2	2081-2100		+5%
			1995-2008		2020s	-19% to +19%	
					2050s	-16% to +25%	
					2080s	-22% to +21%	





(a) downstream Tana



(b) Kessi

Figure S 1: Monthly observed and simulated discharges

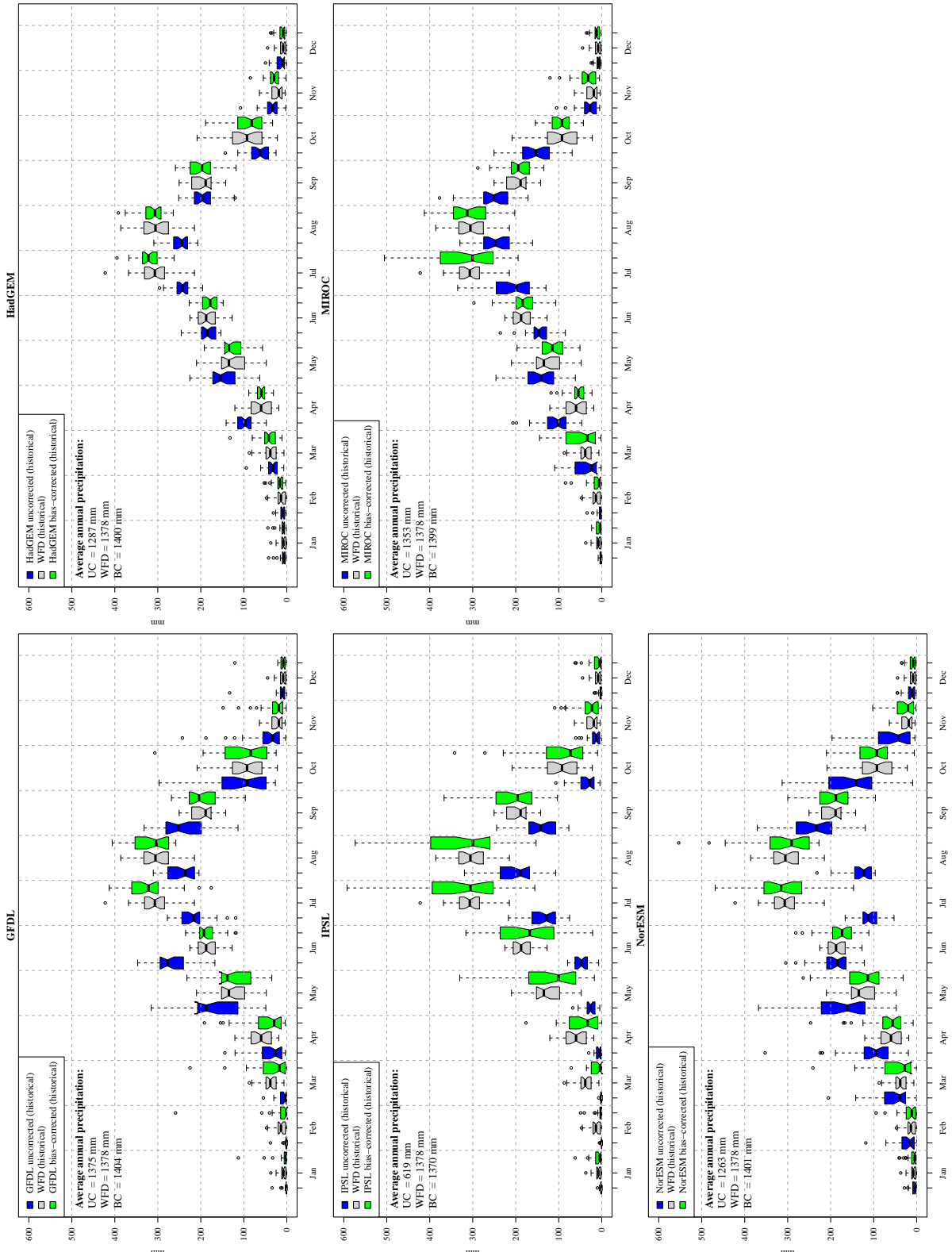


Figure S 2: Monthly precipitation of WFD and uncorrected and bias-corrected ISI-MIP ESMs in the historical period (1970-1999).

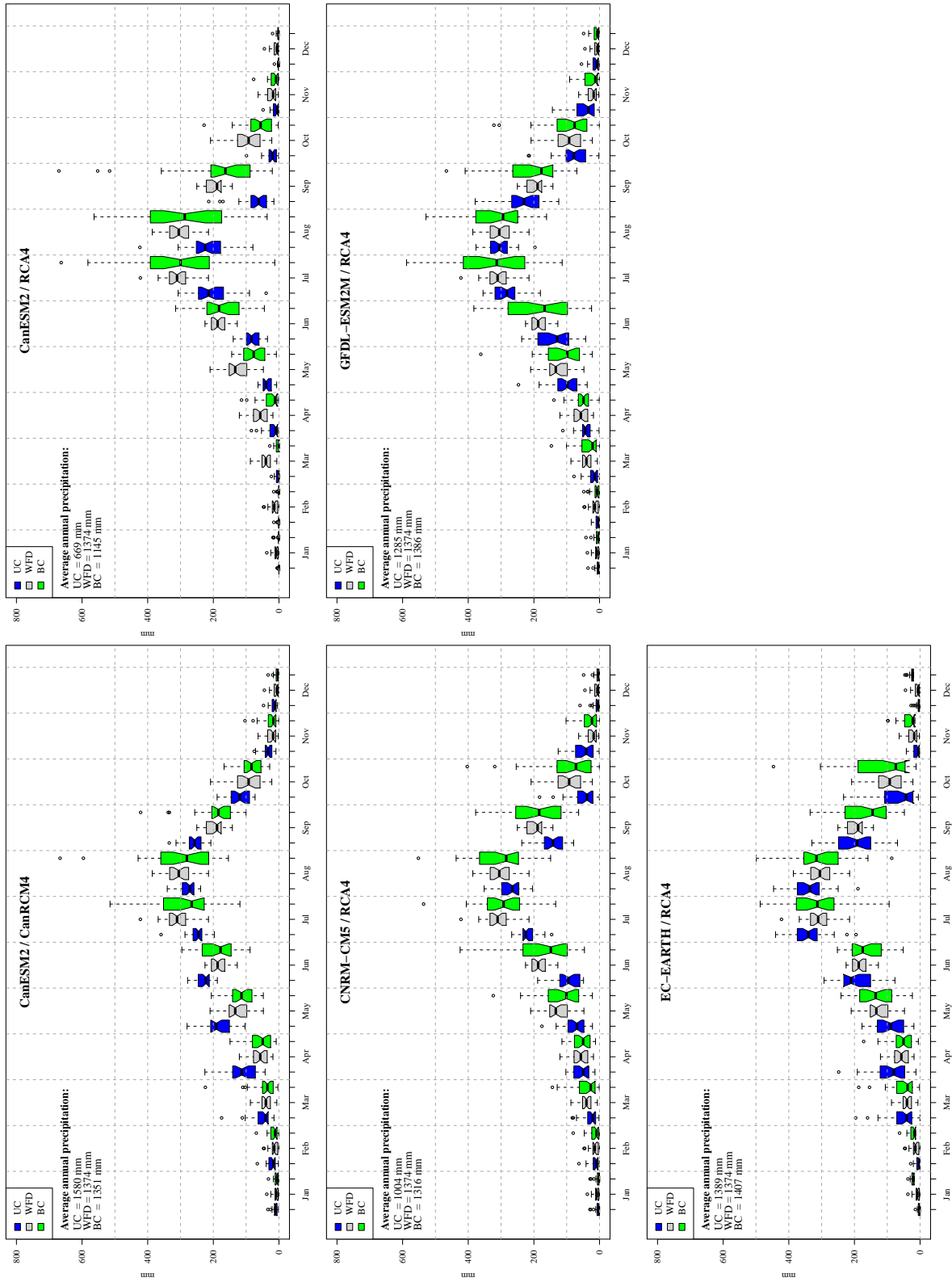


Figure S 3: Monthly precipitation of WFD and uncorrected and bias-corrected CORDEX RCMs (models 1-5) in the historical period (1970-1999).

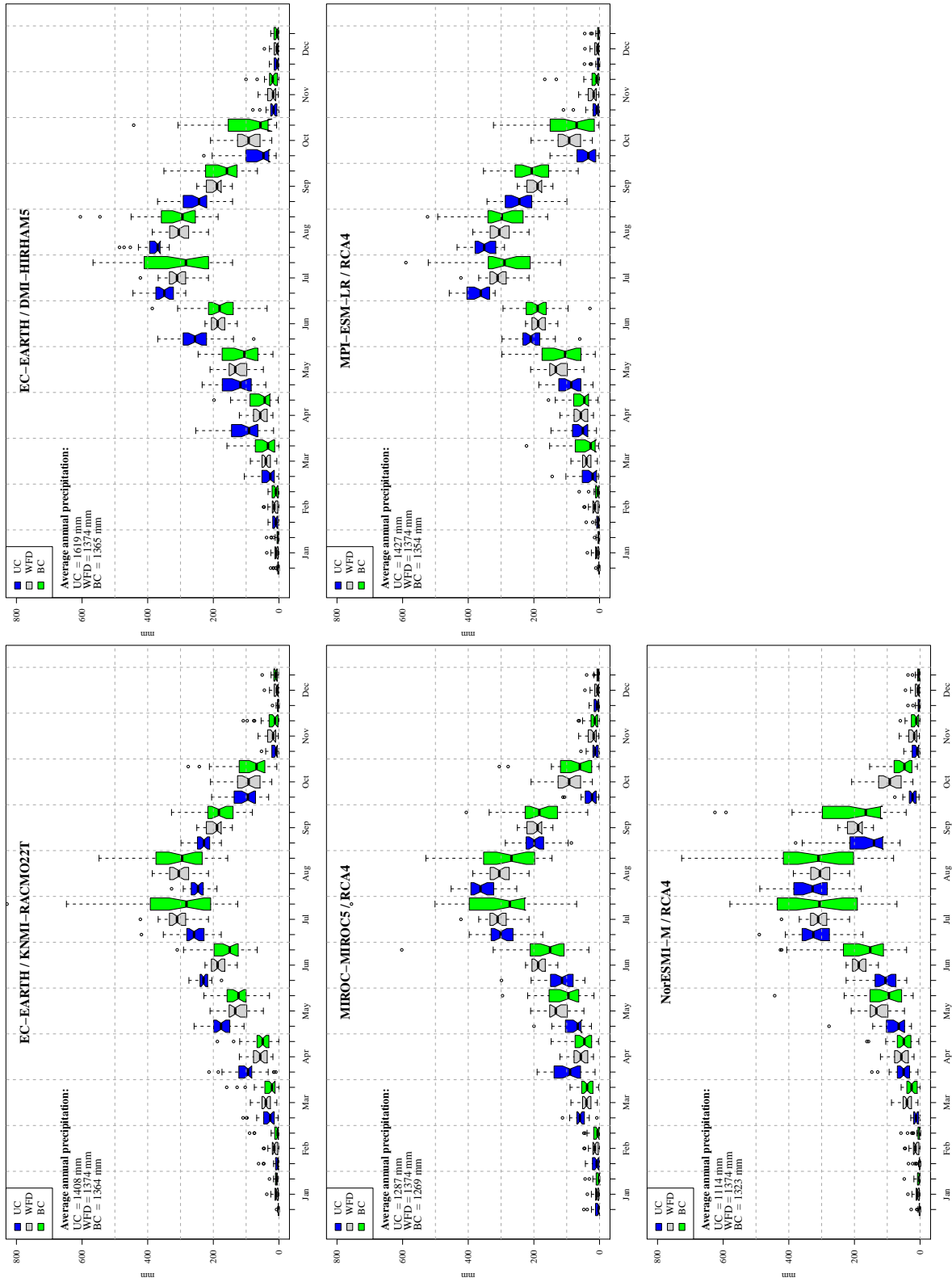


Figure S 4: Monthly precipitation of WFD and uncorrected and bias-corrected CORDEX RCMs (models 6-10) in the historical period (1970-1999).

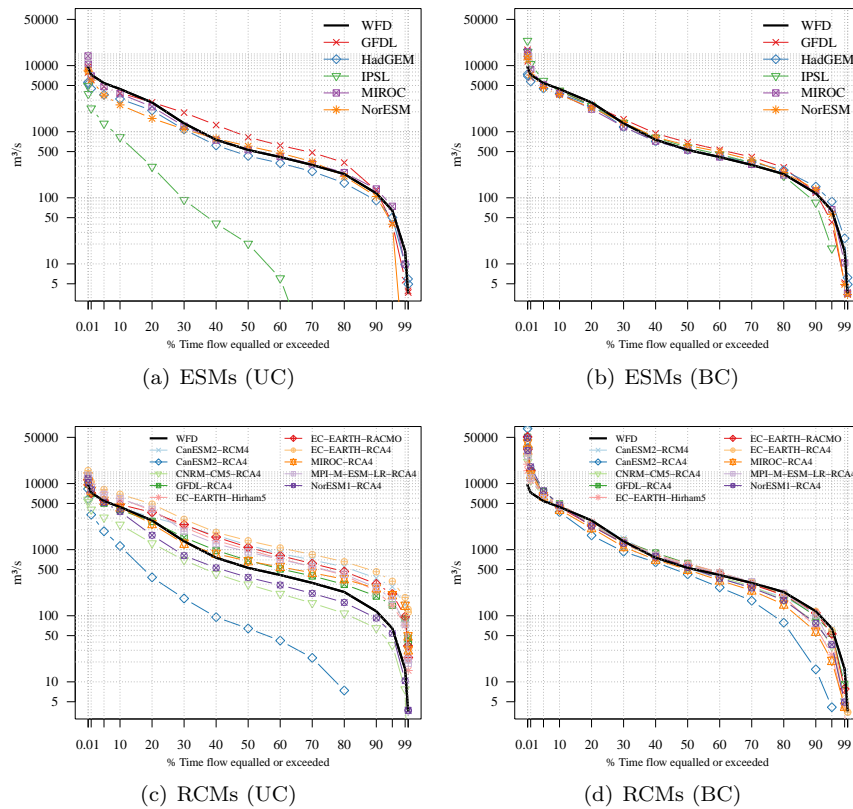


Figure S 5: FDCs of average daily discharge using WFD and ESM and RCM climate input in the reference period (1970-1999).

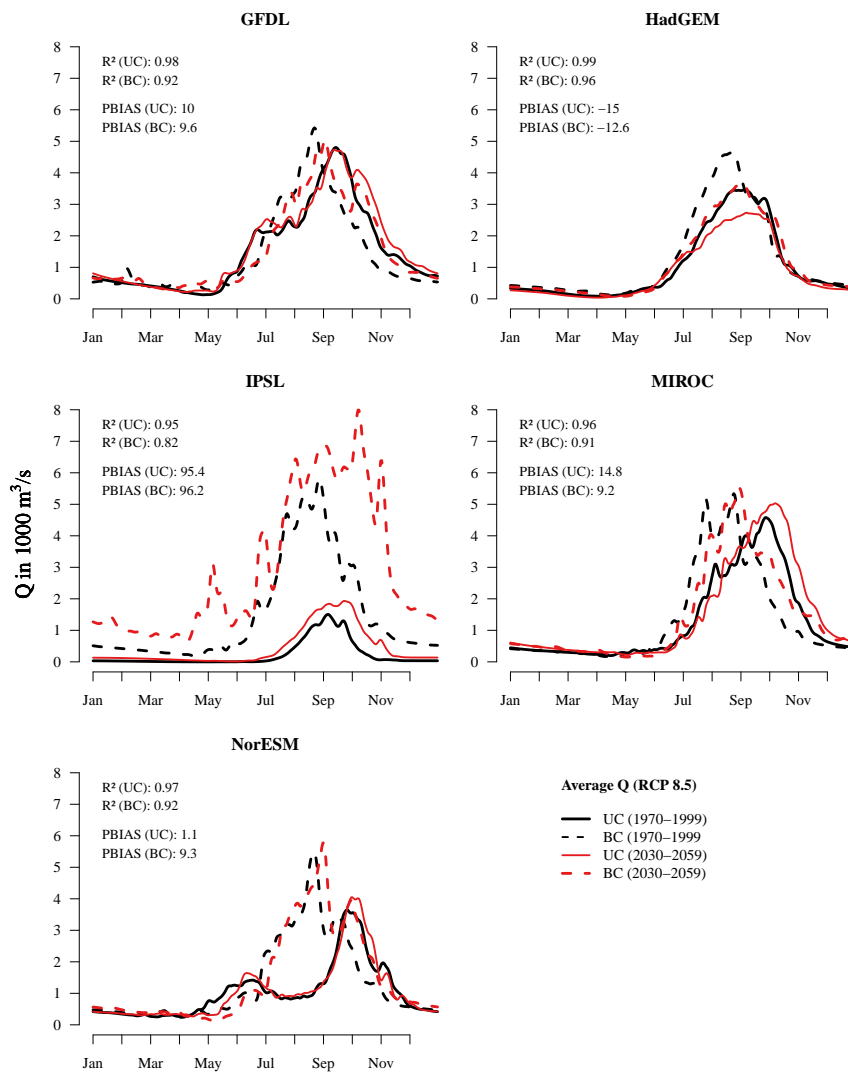


Figure S 6: Changes of average daily discharges (ESMs) in the period (2030-2059) under RCP 8.5 relative to the models' reference period (1970-1999).  $R^2$  and PBIAS values are computed to show the differences between projection period and reference period.

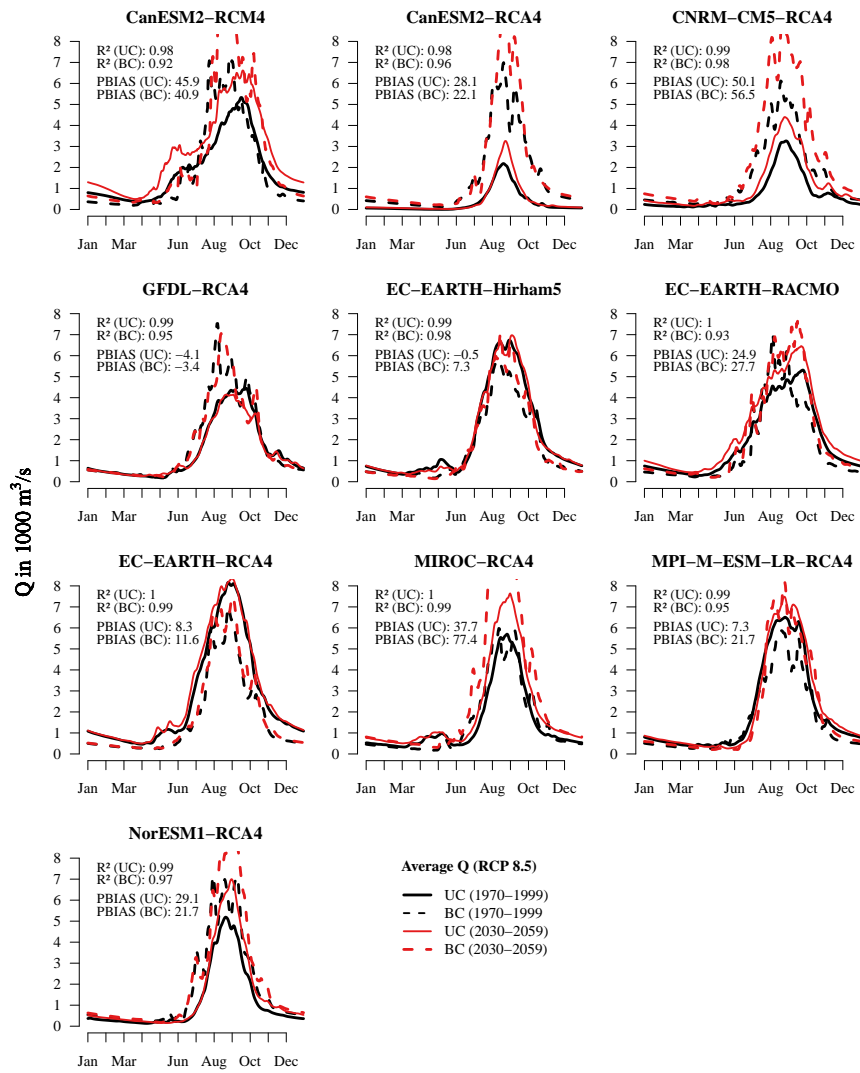


Figure S 7: Changes of average daily discharges (RCMs) in the period (2030-2059) under RCP 8.5 relative to the models' reference period (1970-1999).  $R^2$  and PBIAS values are computed to show the differences between projection period and reference period.

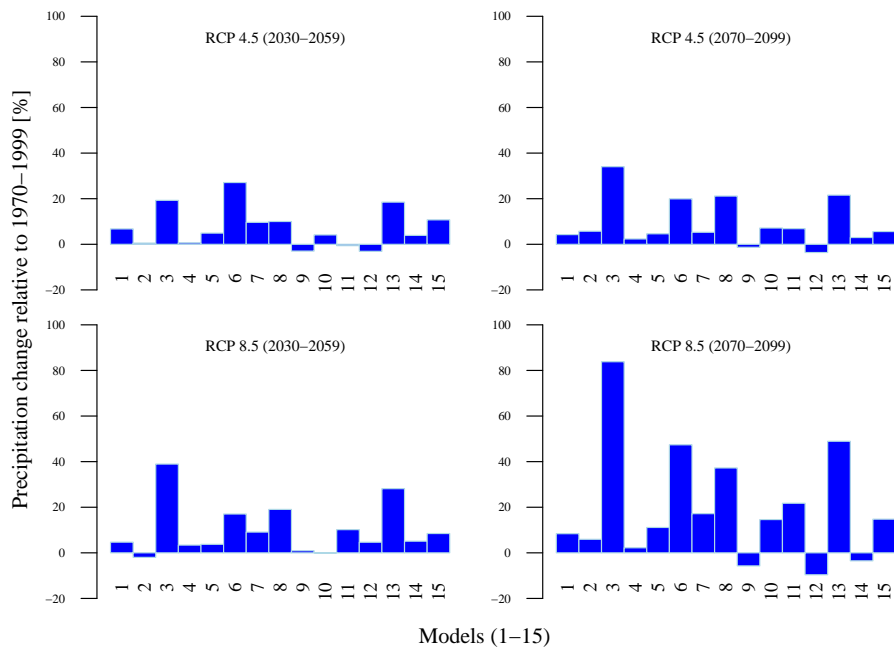


Figure S 8: Relative annual precipitation changes of UC climate models

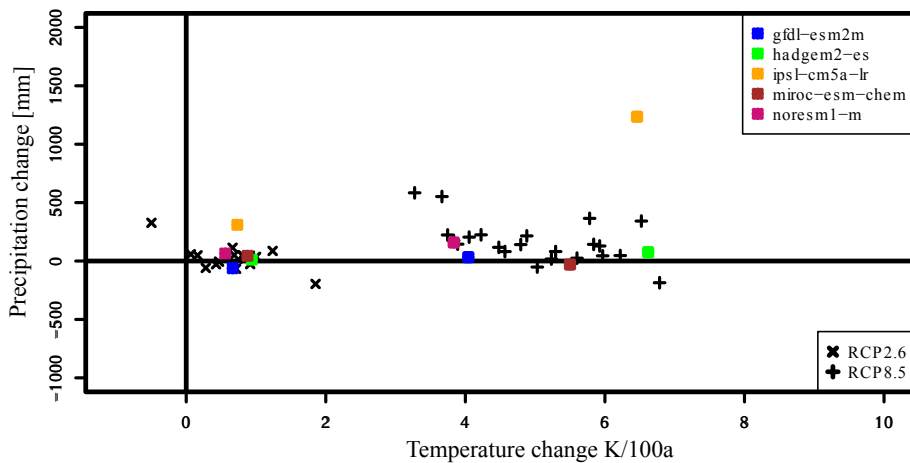


Figure S 9: Precipitation and temperature changes in the UBN catchment (CMIP5 ESM ensemble). ESMs used in this study are highlighted in colours.



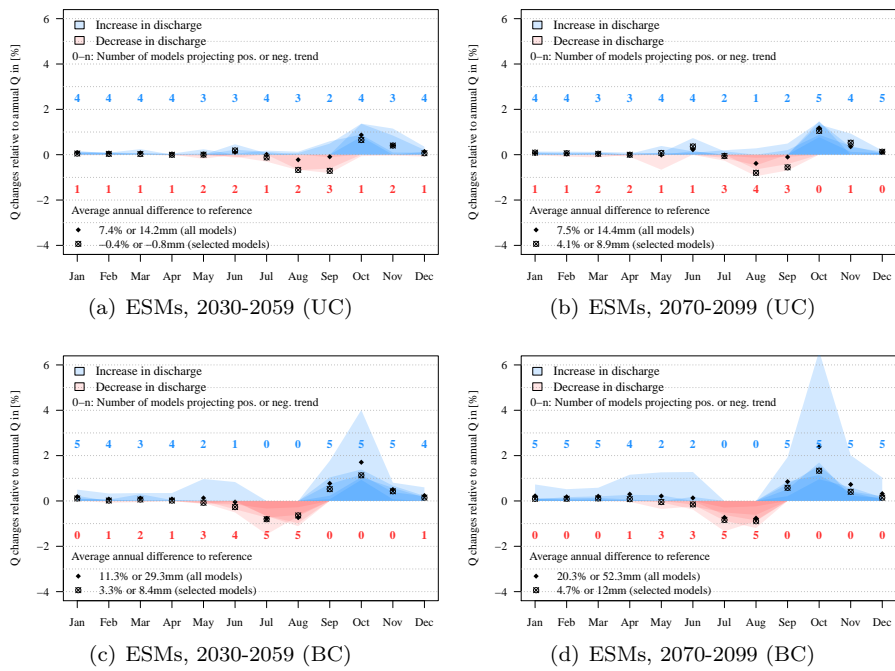


Figure S 10: Monthly discharge changes of uncorrected (UC) and bias-corrected (BC) ESM simulations in [%] under RCP 4.5. Changes are relative to average annual discharge in the reference period (1970-1999) at gauge El Diem.

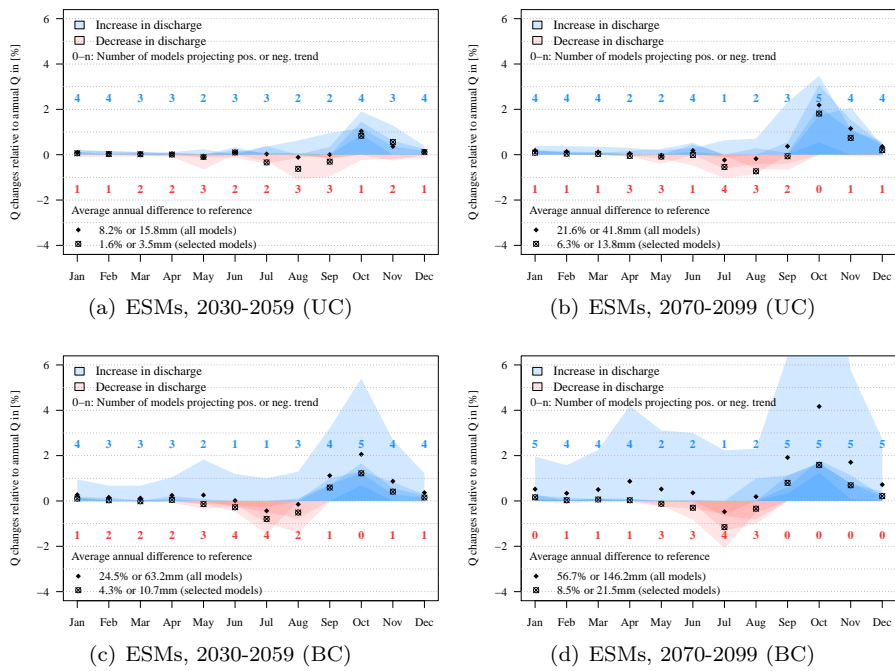


Figure S 11: Monthly discharge changes of uncorrected (UC) and bias-corrected (BC) ESM simulations in [%] under RCP 8.5. Changes are relative to average annual discharge in the reference period (1970-1999) at gauge El Diem.

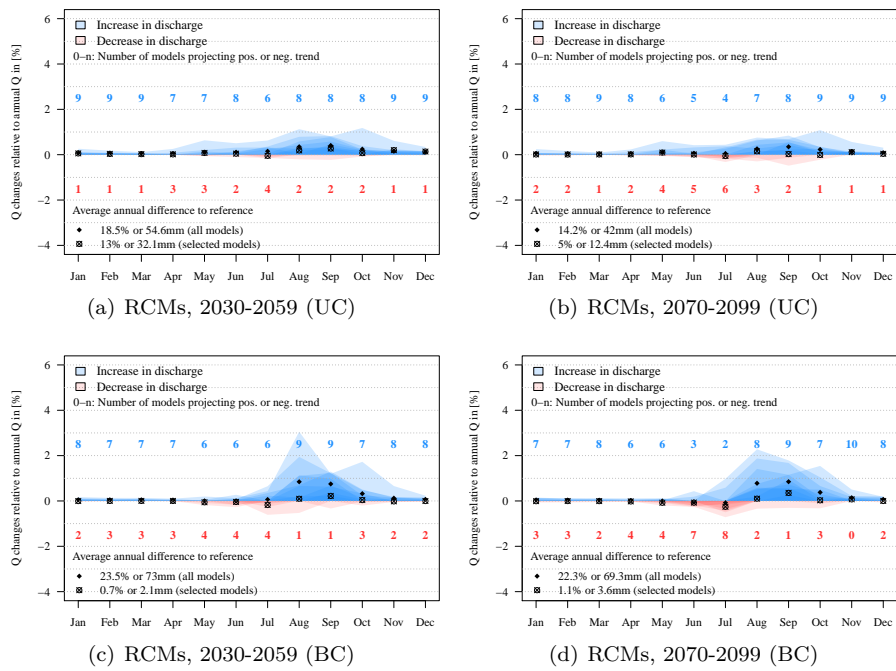
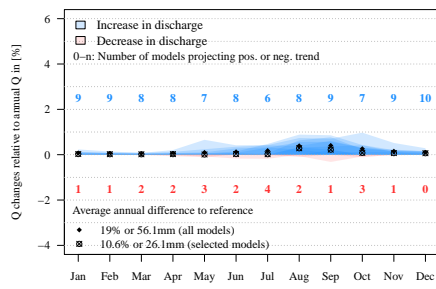
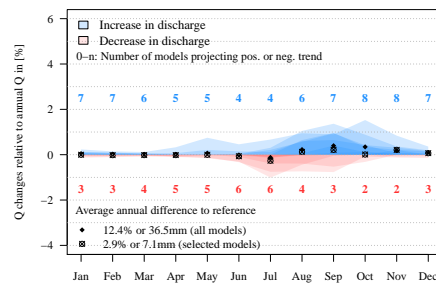


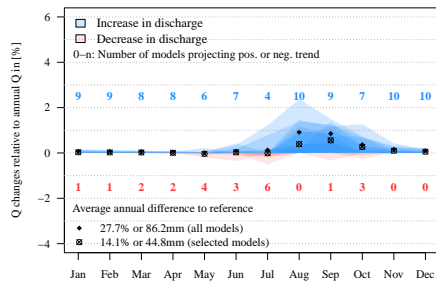
Figure S 12: Monthly discharge changes of uncorrected (UC) and bias-corrected (BC) RCM simulations in [mm] under RCP 4.5. Changes are relative to the reference period (1970-1999) at gauge El Diem.



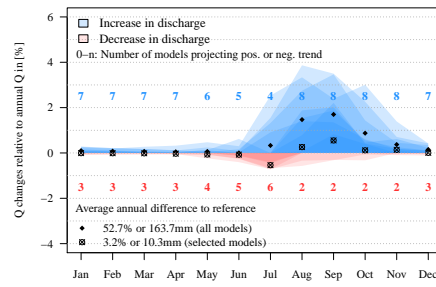
(a) RCMs, 2030-2059 (UC)



(b) RCMs, 2070-2099 (UC)



(c) RCMs, 2030-2059 (BC)



(d) RCMs, 2070-2099 (BC)

Figure S 13: Monthly discharge changes of uncorrected (UC) and bias-corrected (BC) RCM simulations in [mm] under RCP 8.5. Changes are relative to the reference period (1970-1999) at gauge El Diem.