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

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Table S 1: Regional Climate Models (RCM) and driving Earth System Models (ESM)

| 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] in the period 1970–1999

| Model | nDays>1mm | ave | max | SD | ave (JAS) | SD (JAS) |
|---|---|---|---|---|---|---|
| WATCH Forcing Data (WFD) | 164.1 | 3.9 | 63.4 | 6.9 | 9.1 | 9.6 |
| Uncorrected (UC) model runs | | | | | | |
| 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 |
| Bias-corrected (BC) model runs | | | | | | |
| 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 |

$nDays > 1mm$=Average number of days with precipitation $> 1\,mm$ per annum;
$ave$=average daily precipitation; $max$=maximum daily precipitation
$SD$=standard deviation; $ave(JAS)$=average precipitation in July, August, and September
$SD(JAS)$=standard deviation of daily precipitation in July, August, and September

Table S 4: Daily precipitation parameters in [mm] in the period 1970–1999, absolute differences to WATCH Forcing Data (WFD)

| Model | nDays>1mm | ave | max | SD | ave (JAS) | SD (JAS) |
|---|---|---|---|---|---|---|
| | | | Uncorrected (UC) model runs | | | |
| 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 |
| | | | Bias-corrected (BC) model runs | | | |
| 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 |

$nDays > 1mm$=Average number of days with precipitation $> 1\,mm$ per annum;
$ave$=average daily precipitation; $max$=maximum daily precipitation
$SD$=standard deviation; $ave(JAS)$=average precipitation in July, August, and September
$SD(JAS)$=standard deviation of daily precipitation in July, August, and September

Table S 5: Relative deviation [%] of Flow Duration Curve (FDC) values between uncorrected (UC) Earth System Models (ESMs) and WATCH Forcing Data (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 Flow Duration Curve (FDC) values between bias-corrected (BC) Earth System Models (ESMs) and WATCH Forcing Data (WFD) in the period 1970–1999. $Q_{pt}$ = percentile of discharge.

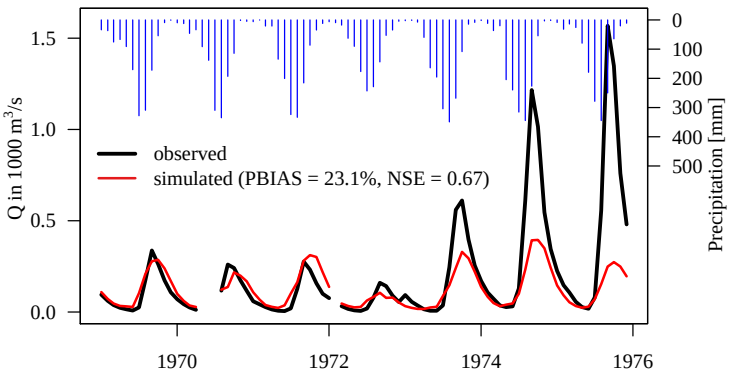
| $Q_{pt}$ | GFDL | HadGEM | IPSL | MIROC | NorESM |
|---|---|---|---|---|---|
| 99.99 | -3.4 | 36.5 | -107.0 | -93.4 | -70.7 |
| 99.9 | -3.5 | 63.4 | -106.6 | -5.6 | -9.6 |
| 99 | -66.8 | 55.6 | -101.1 | -33.6 | -68.8 |
| 95 | -33.7 | 36.1 | -73.4 | 2.6 | -12.7 |
| 90 | 1.4 | 26.3 | -27.6 | 8.6 | 14.5 |
| 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 Flow Duration Curve (FDC) values between uncorrected (UC) Regional Climate Models (RCMs) and WATCH Forcing Data (WFD) in the period 1970–1999. $Q_{pt}$ = percentile of discharge.

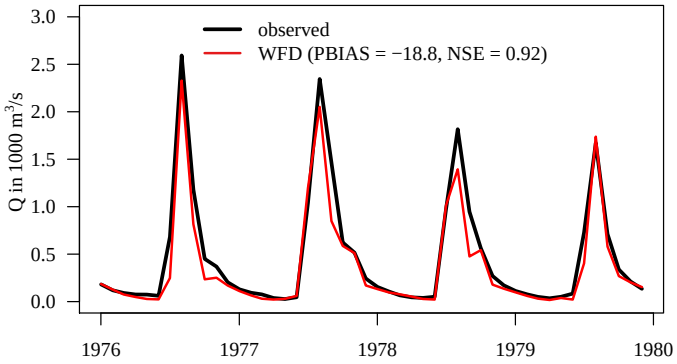
| | Model ID | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| $Q_{pt}$ | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 |
| 99.99 | 611.8 | -107.0 | -106.1 | 1016.3 | 314.6 | 551.8 | 3048.1 | 736.0 | 433.3 | 2.2 |
| 99.9 | 721.9 | -106.6 | -96.1 | 1103.3 | 476.5 | 820.7 | 3208.3 | 1184.7 | 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 Flow Duration Curve (FDC) values between bias-corrected (BC) Regional Climate Models (RCMs) and WATCH Forcing Data (WFD) in the period 1970–1999. $Q_{pt}$ = percentile of discharge.

| | Model ID | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| $Q_{pt}$ | 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 |




(a) downstream Tana




(b) Kessie

Figure S 1: Monthly observed and simulated discharges at gauges downstream Lake Tana and Kessie both upstream El Diem. Blue bars in top figure show monthly precipitation amounts. Y-axes indicate the year.

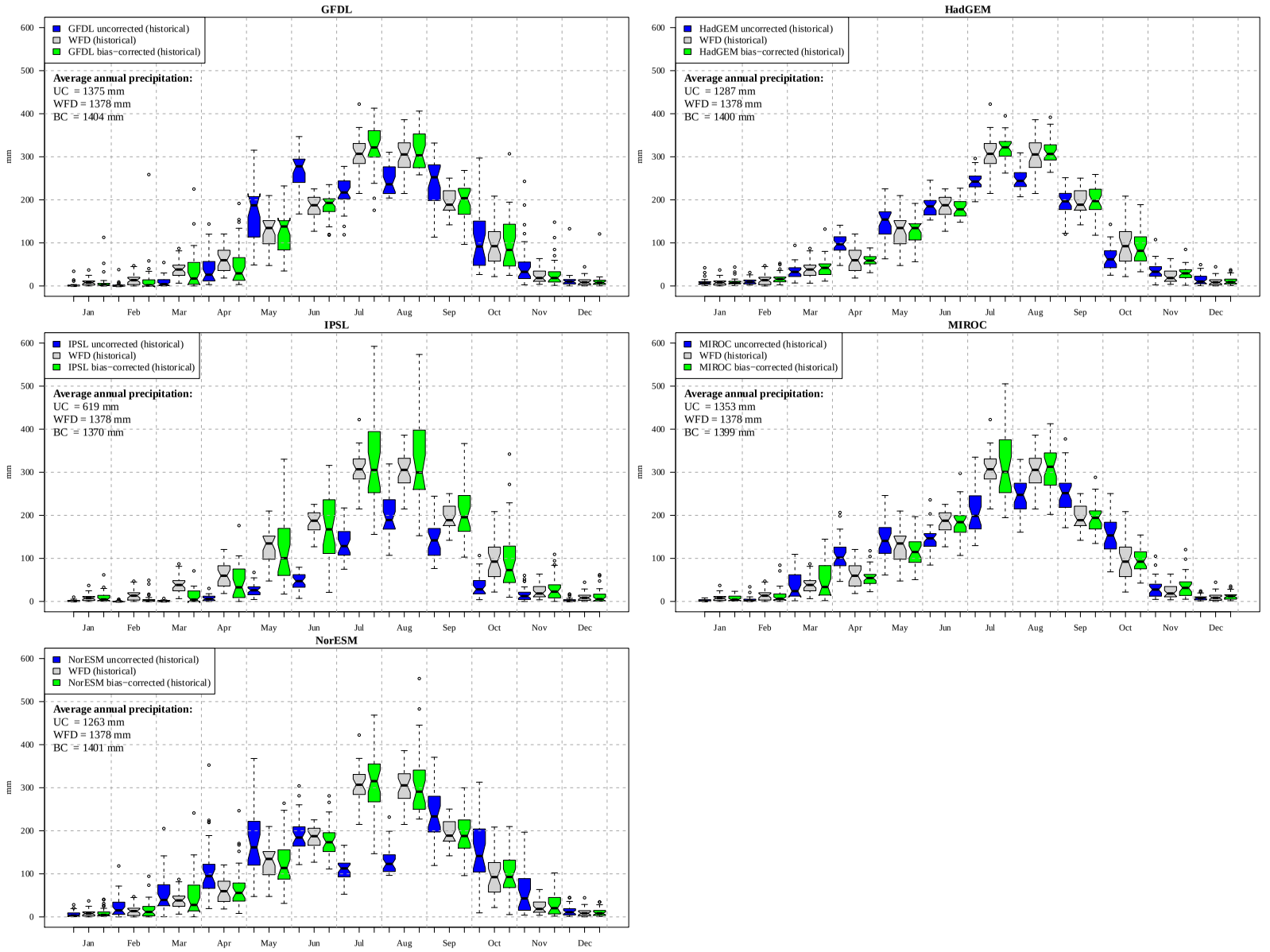



Figure S 2: Monthly precipitation of WATCH Forcing Data (WFD) and uncorrected and bias-corrected ISIMIP Earth System Models (ESMs) in the historical period (1970–1999) in the Upper Blue Nile catchment.

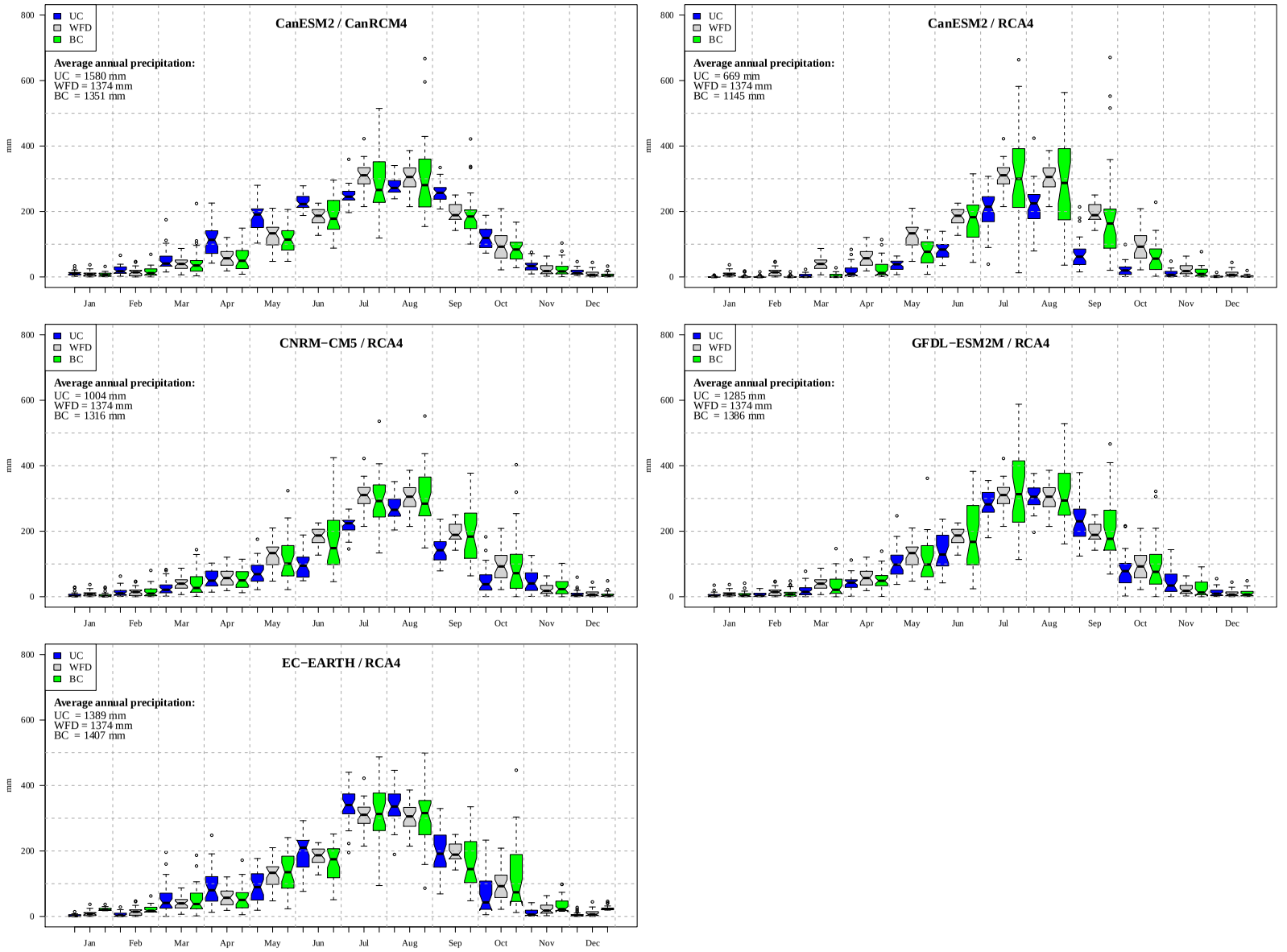



Figure S 3: Monthly precipitation of WATCH Forcing Data (WFD) and uncorrected and bias-corrected CORDEX Regional Climate Models (RCMs) in the historical period (1970–1999) in the Upper Blue Nile catchment, models 1–5.

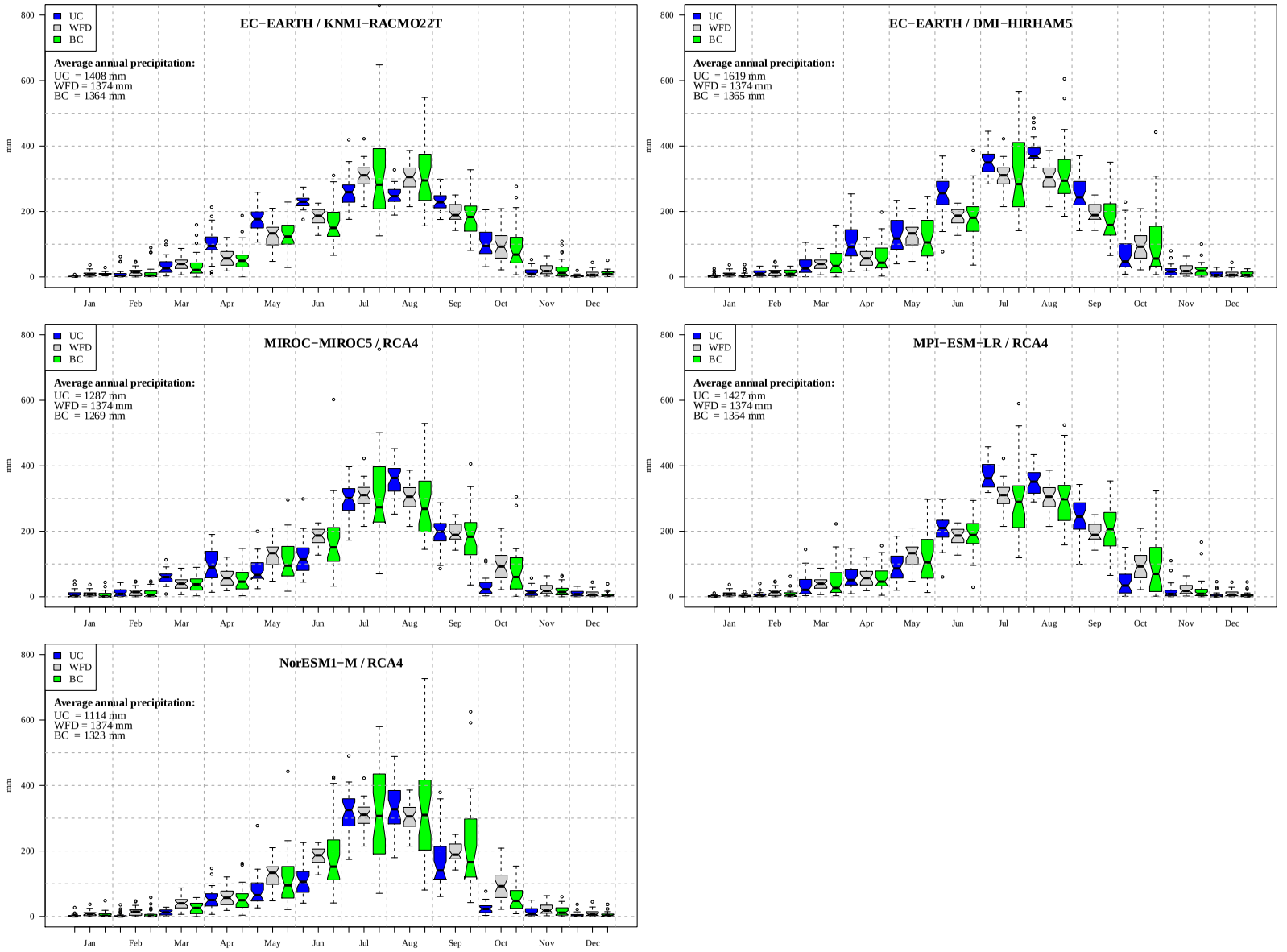
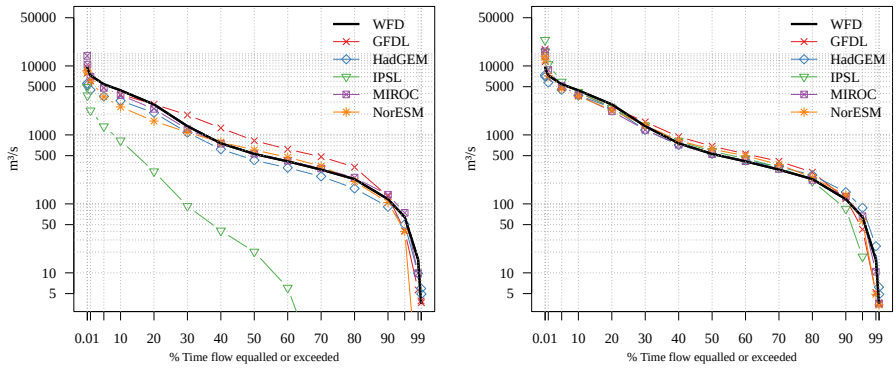


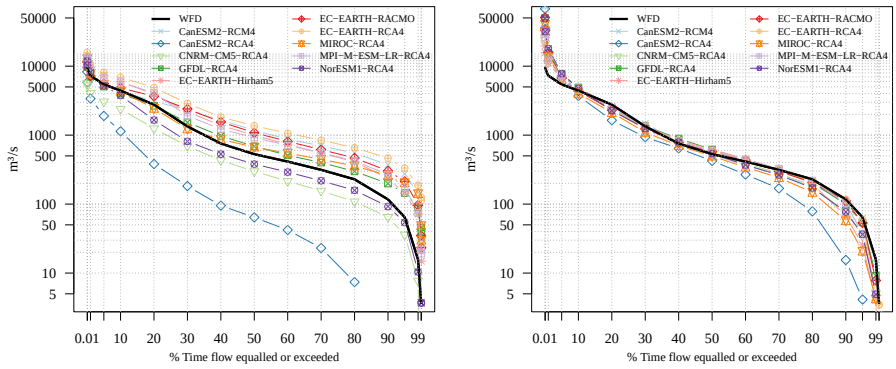

Figure S 4: Monthly precipitation of WATCH Forcing Data (WFD) and uncorrected and bias-corrected CORDEX Regional Climate Models (RCMs) in the historical period (1970–1999) in the Upper Blue Nile catchment, models 6–10.




(a) ESMs (UC)




(b) ESMs (BC)




(c) RCMs (UC)




(d) RCMs (BC)

Figure S 5: Flow Duration Curves (FDCs) of average daily discharge at gauge El Diem using WATCH Forcing Data (WFD), uncorrected (UC) and bias-corrected (BC) Earth System Model (ESM) and Regional Climate Model (RCM) climate input in the reference period (1970–1999).

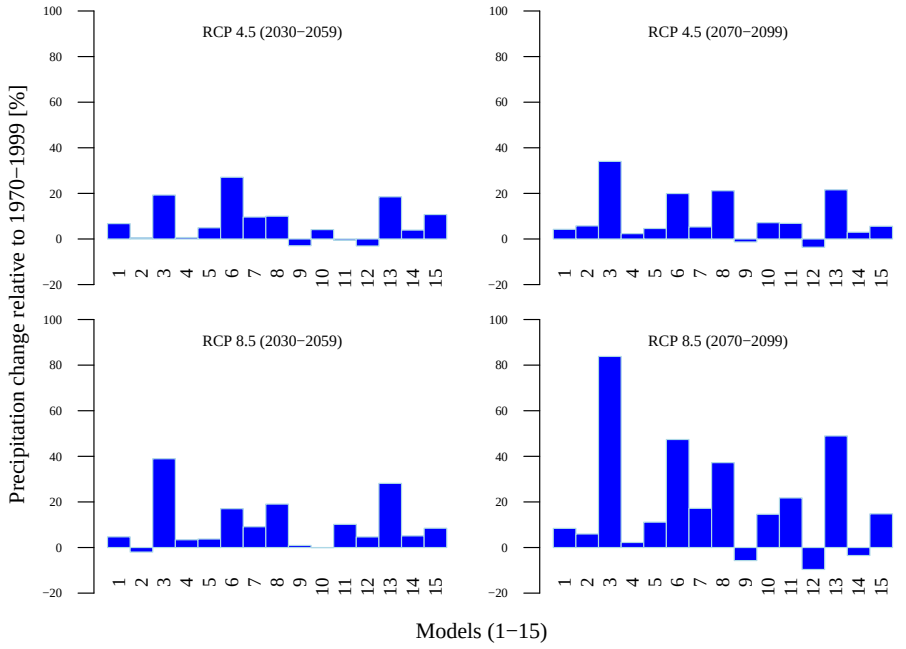



Figure S 6: Relative annual precipitation changes of uncorrected (UC) climate models in the Upper Blue Nile catchment

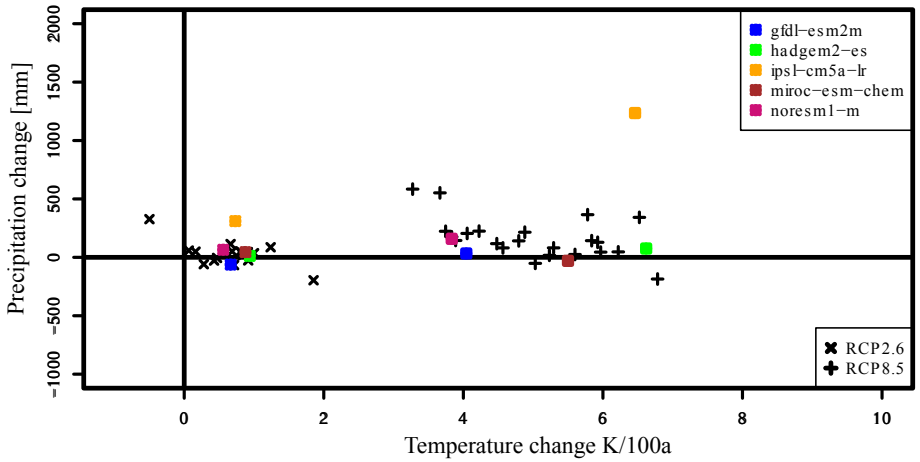
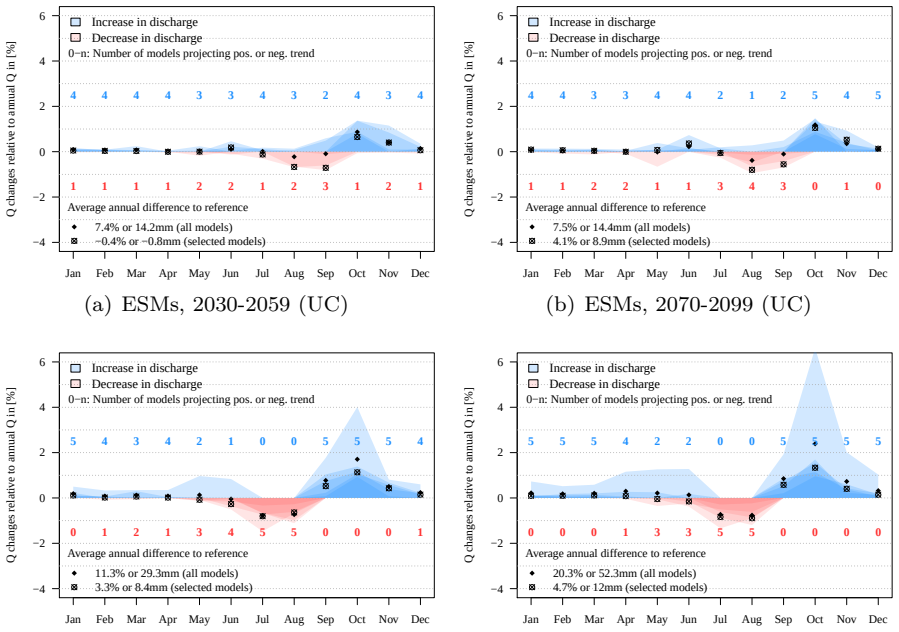



Figure S 7: Precipitation and temperature changes in the UBN catchment (CMIP5 ensemble). Earth System Models (ESMs) used in this study are highlighted in colours.



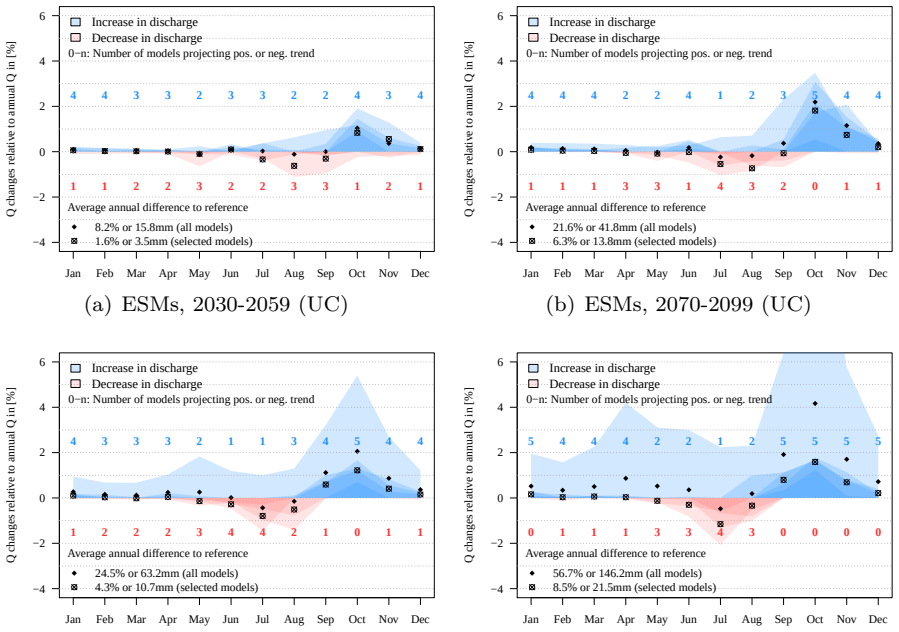

(a) ESMs, 2030-2059 (UC)

(b) ESMs, 2070-2099 (UC)

(c) ESMs, 2030-2059 (BC)

(d) ESMs, 2070-2099 (BC)

Figure S 8: Monthly discharge changes of uncorrected (UC) and bias-corrected (BC) Earth System Model (ESM) simulations in [%] under RCP 4.5. Changes are relative to average annual discharge in the reference period (1970–1999) at gauge El Diem.



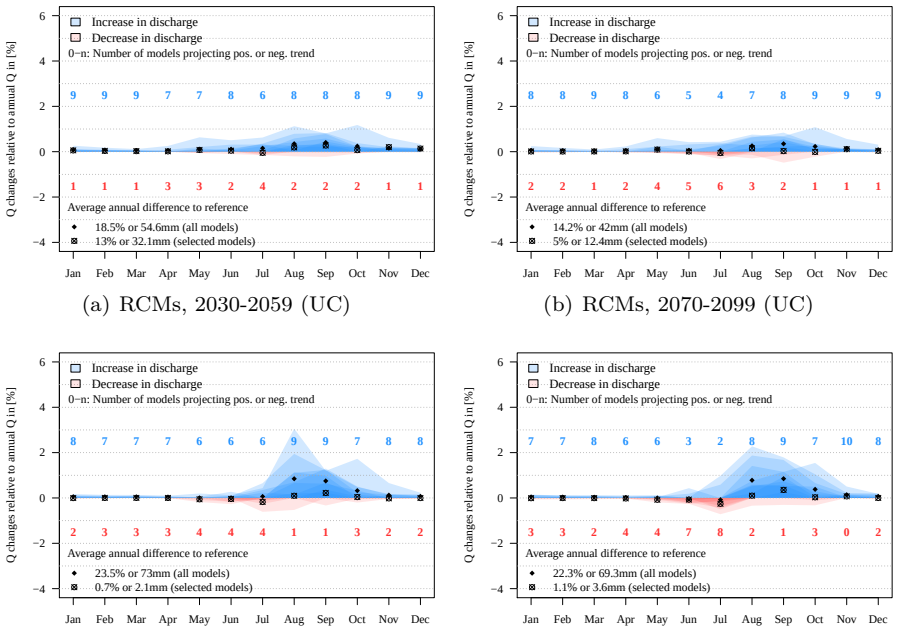

(a) ESMs, 2030-2059 (UC)

(b) ESMs, 2070-2099 (UC)

(c) ESMs, 2030-2059 (BC)

(d) ESMs, 2070-2099 (BC)

Figure S 9: 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.



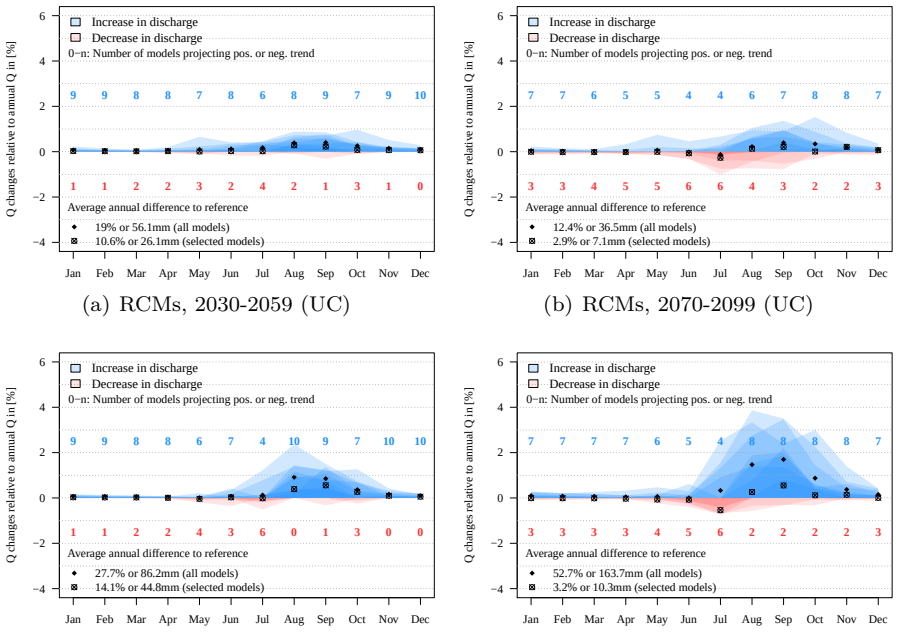

(a) RCMs, 2030-2059 (UC)

(b) RCMs, 2070-2099 (UC)

(c) RCMs, 2030-2059 (BC)

(d) RCMs, 2070-2099 (BC)

Figure S 10: 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 11: 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.