Setting an E-Flow regime under climate change

Leone M.[1,2], Gentile F.[2], Lo Porto A.[1], Ricci G.F.[2], Schürz C.[3], Strauch M.[3], Volk M.[3], De Girolamo A.M.[1]

1. Water Research Institute, National Research Council
2. Department of Soil, Plant and Food Sciences, University of Bari Aldo Moro
3. Helmholtz Centre for Environmental Research GmbH-UFZ, Department of Computational Landscape Ecology

Introduction

The **E-Flow regime** has been **defined** as “quantity, quality, and timing of flow necessary to support aquatic ecosystems, which in turn support crops, the economy, sustainable livelihoods, and human well-being” (Brisbane Declaration, 2012). The **Water Framework Directive** (EC, 2000) requires Member States to set an E-Flow regime.

There are over 200 methods in the literature to set up the E-Flow regime, but they have been validated for perennial rivers.
The watercourses of the **Mediterranean** regions are mostly **non-perennial**. Given the scarcity of data that characterizes non-perennial rivers, **hydrological methods** are the most applied because they require as input data **long-term time series of measured or estimated streamflow under natural conditions (at least 20 years).**

The Mediterranean area is a **hotspot** for climate change. The warmer climate of the 21st century has led to **decrease in water resources.** Therefore, **climate change must be included when setting an E-Flows.**

Objectives

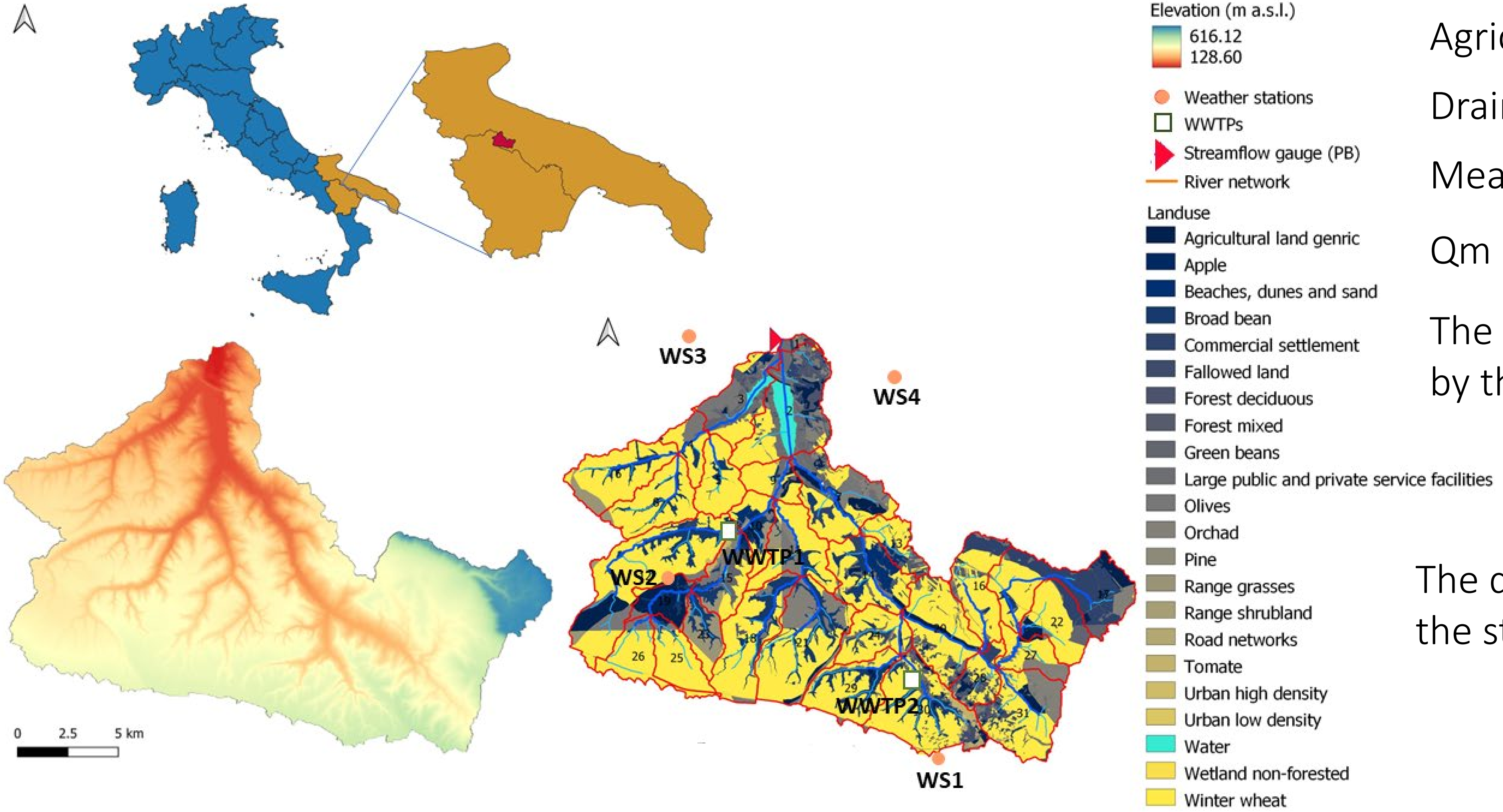
General objective

To propose a methodological approach for setting an E-Flow regime for temporary rivers under climate change.

The objectives of this work are:

1. To simulate daily streamflow in natural conditions over 30 years with SWAT+,
2. to improve the calibration of the SWAT+ model for the low flow period using swatplusR,
3. to evaluate the alterations induced by climate change on the hydrological regime,
4. to set E-Flow components

Study area
Locone river basin (S-E Italy)



Agricultural watershed

Drainage area: 228 km^2

Mean rainfall: 584 mm

Qm (PB) = 0.45 m^{3}s^{-1}

The river is classified as **temporary** by the Basin Authority

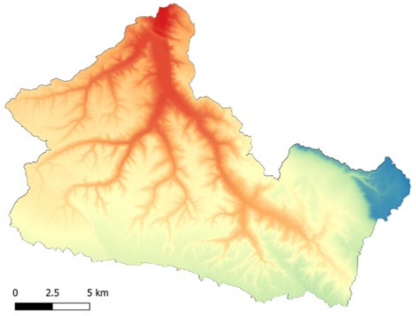
The dam was built downstream the streamflow gauge.

Methodology (1)

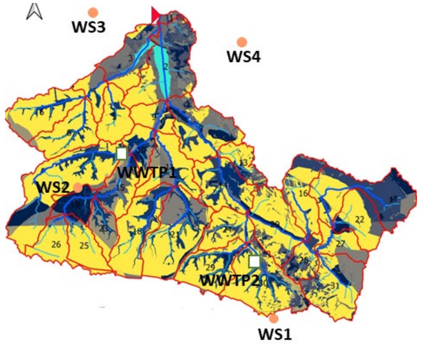
Setting up of SWAT+

Input

DTM (spatial resolution 10m x 10m)
SOIL MAP (spatial resolution 10m x 10m; 12 soil profiles)
LAND USE MAP (spatial resolution 100m; 16 land use type)
RIVER NETWORK



CLIMATE data (1971-2020) Daily scale
Precipitation (WS1, WS2, WS3, WS4),
Temperature (WS1, WS4)
Relative humidity (sim)
Wind speed (sim)
Solar radiation (sim)



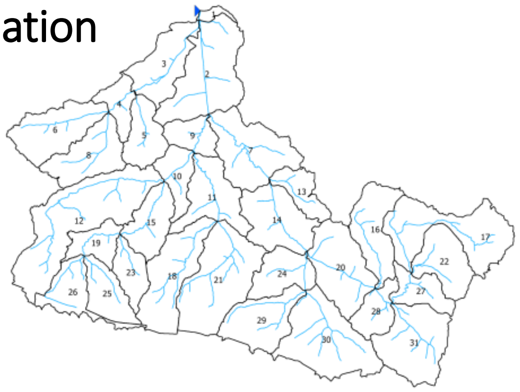
Crop management operation

Additional point sources **WWTP1** and **WWTP2**

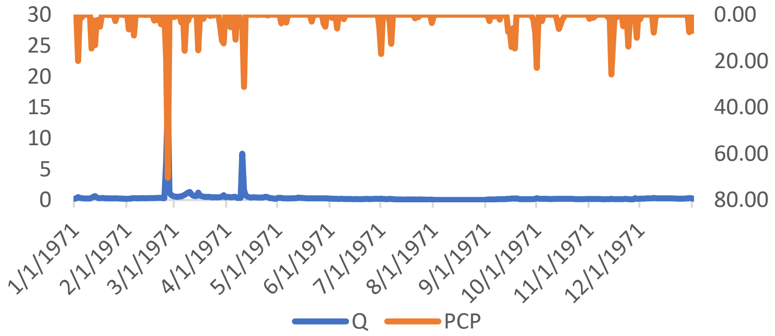
Potential evapotranspiration was calculated with the Hargreaves-Samani formula.
Surface runoff was calculated with SCS Curve Number method.

Output

Watershed delineation
739 HRUs
31 sub-basins,
183 LSUs.



Hydrology
Streamflow at daily scale



Methodology (2)

General Circulation Models and Regional Circulation Models

Climate models
- CMCC-CM-COSMO-CLM model (**CMCC**)
- MPI-ESM 1.2 -LR (**MPI**)

Climatic variables at daily scale:
- Precipitation (PCP);
- Temperature (TMP)

Experiment:
- Historical (1971-2005)
- Near future (2020-2049) under SSP2 4.5 (MPI) and RCP 4.5 (CMCC) scenarios

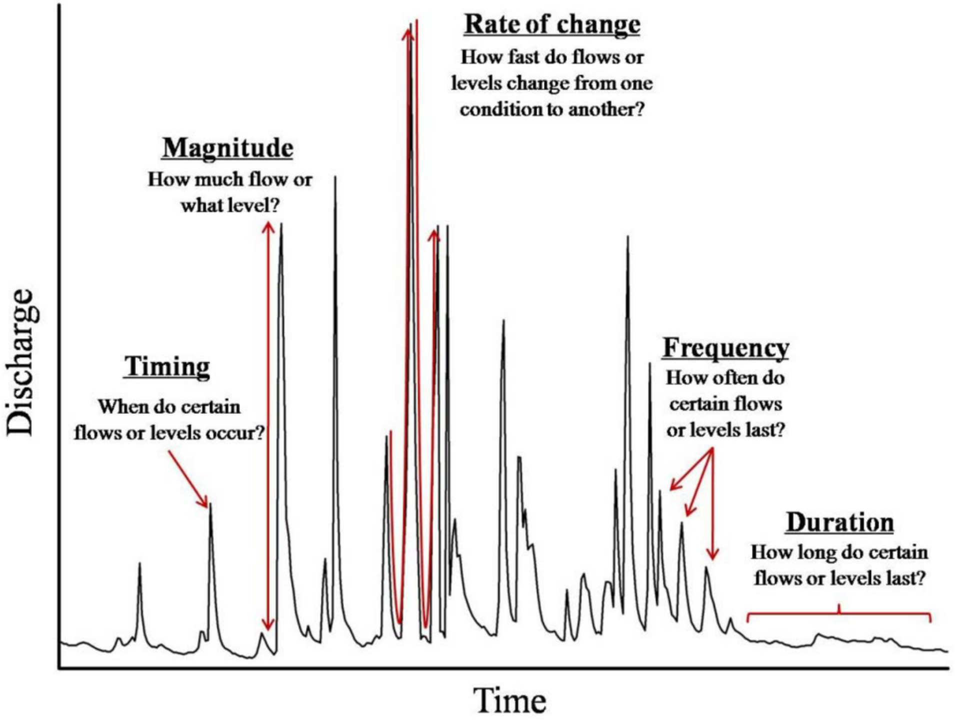
In the near future, both models show a **statistically significant positive trend** (p-value between 0.00047 and 0.0035; Mann-Kendall test) of the **minimum and maximum temperatures** for both stations. Conversely, **no trends for precipitation emerged**.

Methodology (3)

Range of Variability Approach- hydrological method

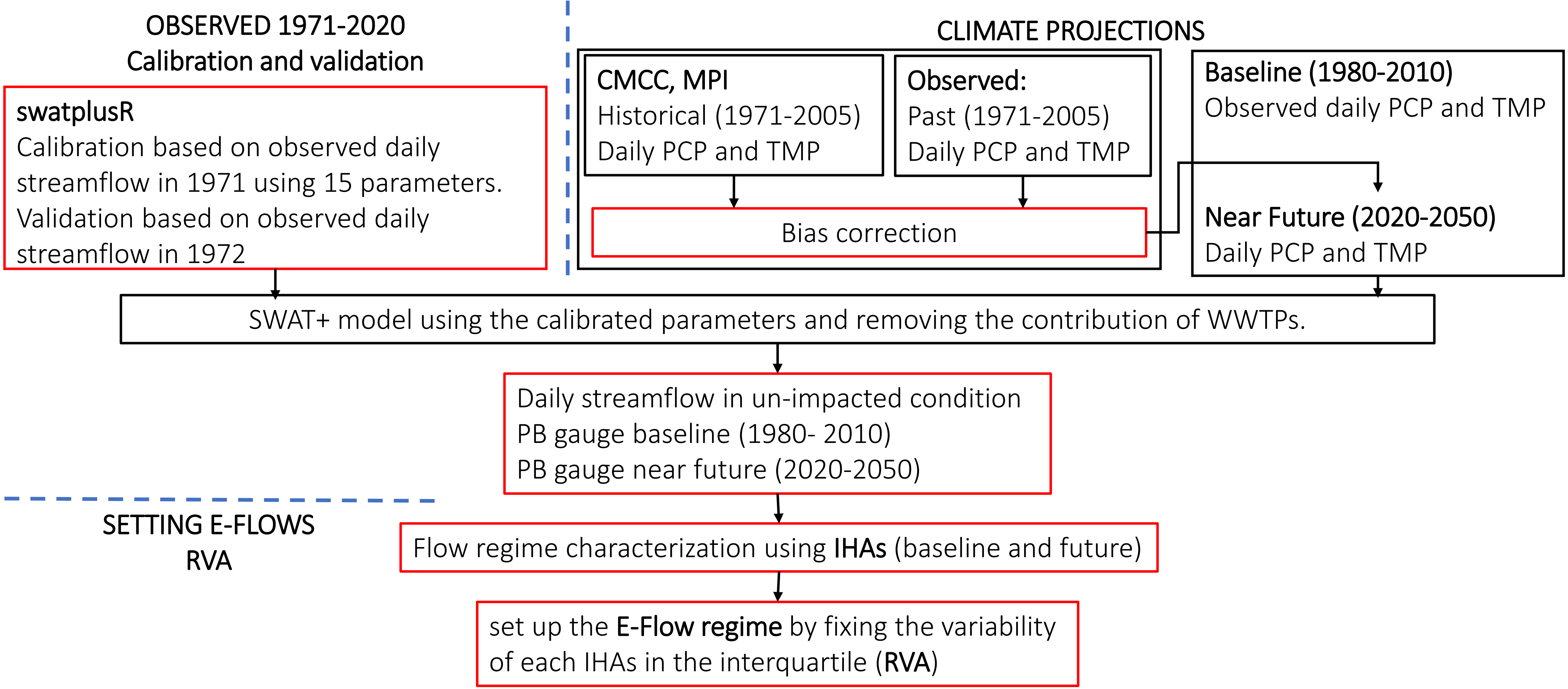
The **RVA** uses 32 Indicators of Hydrological Alterations (IHAs) to describe the hydrological components that have a direct influence on ecosystems. When ecological data are not available, an **acceptable range** of indicators variation can be between the **25th and 75th percentiles** (non-parametric analysis).

The IHAs are classified into five groups representing the components that characterize the entire range of flows.



- **magnitude**: volume of water that moves with respect to a fixed section in the unit of time,
- **frequency**: it is the frequency with which a flow of a certain entity recurs in a certain period of time,
- **duration**: it is the time period associated with a given flow condition (sec),
- **timing**: is the regularity with which flows of a certain entity occur (Julian date),
- **rate of change**: it is the speed with which the flow passes from one quantity to another.

Methodology



OBSERVED 1971-2020
Calibration and validation

swatplusR
Calibration based on observed daily streamflow in 1971 using 15 parameters.
Validation based on observed daily streamflow in 1972

CLIMATE PROJECTIONS

CMCC, MPI
Historical (1971-2005)
Daily PCP and TMP

Observed:
Past (1971-2005)
Daily PCP and TMP

Bias correction

Baseline (1980-2010)
Observed daily PCP and TMP

Near Future (2020-2050)
Daily PCP and TMP

SWAT+ model using the calibrated parameters and removing the contribution of WWTPs.

Daily streamflow in un-impacted condition
PB gauge baseline (1980- 2010)
PB gauge near future (2020-2050)

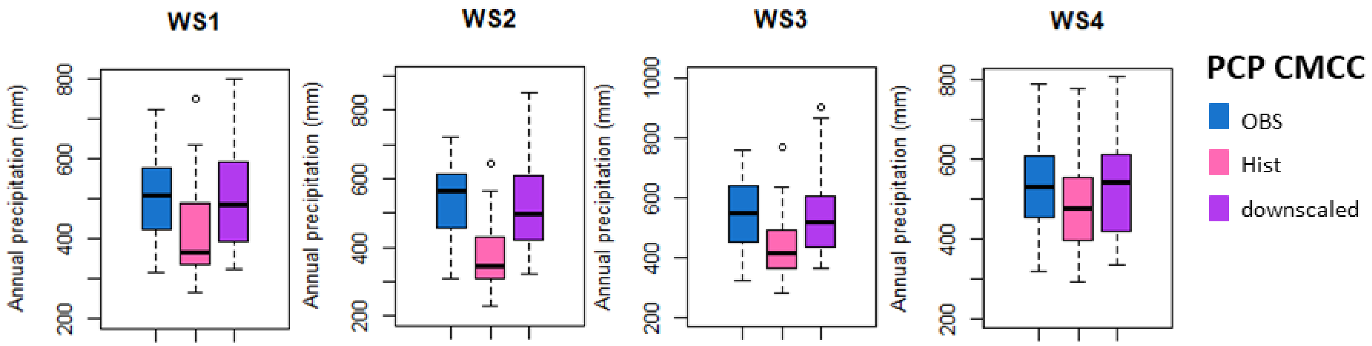
SETTING E-FLOWS
RVA

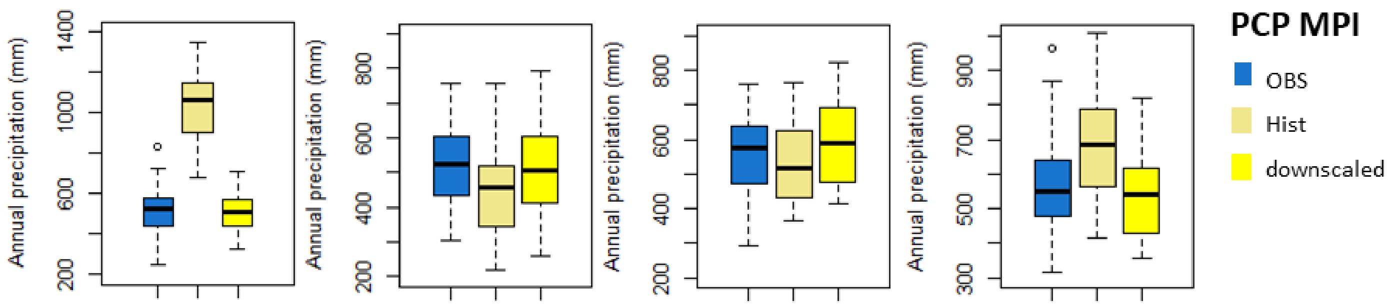
Flow regime characterization using **IHAs** (baseline and future)

set up the **E-Flow regime** by fixing the variability of each IHAs in the interquartile (**RVA**)

Results
Bias correction- Precipitation

1971- 2005





↓ 100 mm

↑ 100 mm

At basin scale

- The average annual rainfall was underestimated by about 100 mm by CMCC model,

- The average annual rainfall was overestimated by about 100 mm by MPI model

Simple ratio method

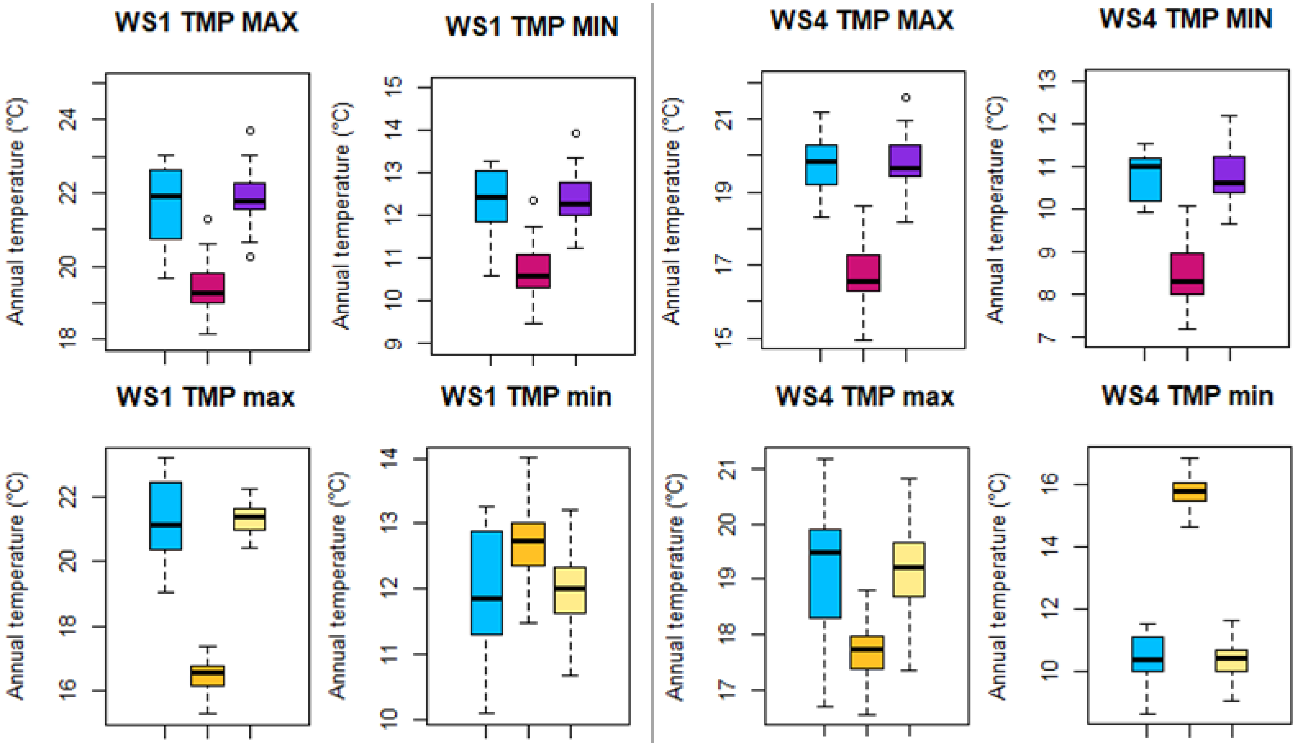
$$\text{monthly factor} = \frac{AVRGmonth(i)Hist\_OBS}{AVRGmonth(i)Hist\_SIM} \cdot daily\ PCP\ SIM$$

The monthly factor is then multiplied by the daily value of the models for each month, obtaining climatic series in the near future of daily precipitation downscaled as a function of the local climate.

Results

Bias correction- Temperature maxima and minima

1971- 2005



CMCC
TMP 1979 2005

🟦 OBS
🟥 Hist
🟪 downscaled

↓ 3°C

MPI
TMP 1971 2005

🟦 OBS
🟧 Hist
🟨 downscaled

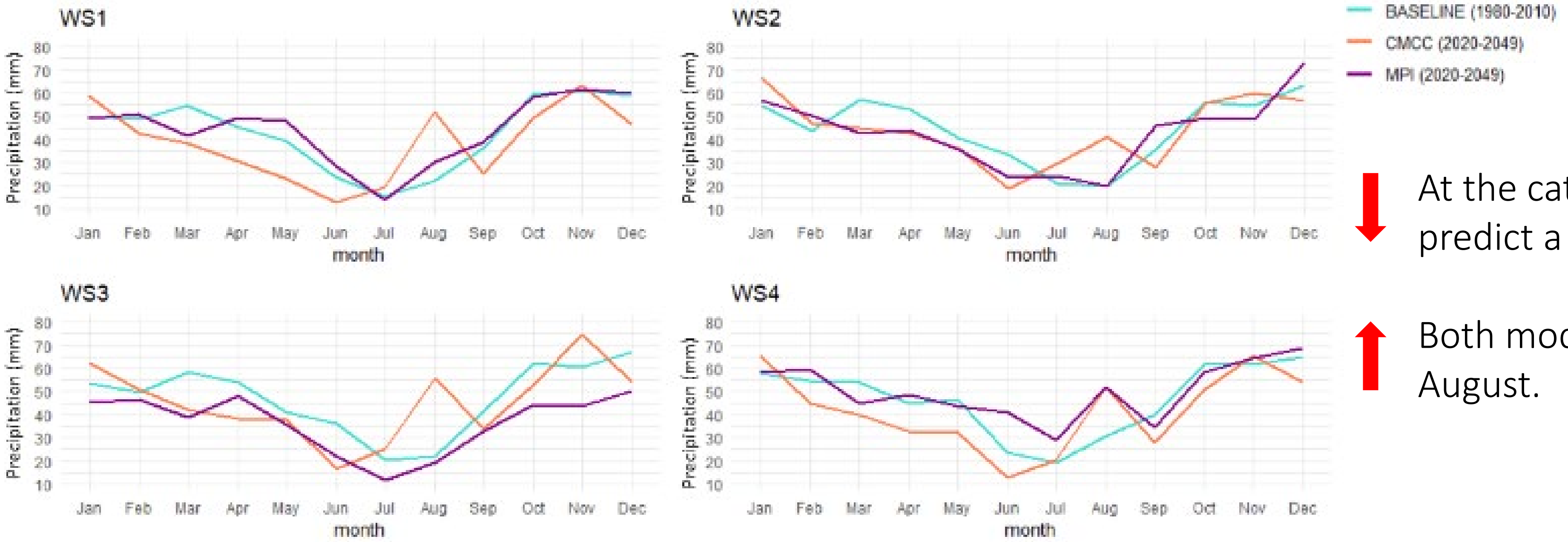
≈

At basin scale,
the mean annual temperature was underestimated by about 3°C by the CMCC model.
Fairly close to the temperatures observed for the MPI model.

Method used: **quantile mapping** (qmap v package. 1.0-4 R environment). We applied the same parameters to maximum and minimum temperature of the near future scenario.

Results

Baseline - future climate projections



At the catchment scale, both models predict a reduction in rainfall (-6% and -4%).

Both models predict increased rainfall in August.

	Baseline (1980- 2010)		CMCC (2020-2049)		MPI (2020-2049)	
	T max	T min	T max	T min	T max	T min
WS1	22.19	12.57	23.23	13.64	23.13	13.26
WS4	19.87	10.67	21.12	11.97	21.30	11.90

Global increase in average annual temperatures, especially the maximum, for which the expected increase is between +1°C and +1.5°C.

Results
Calibration and validation

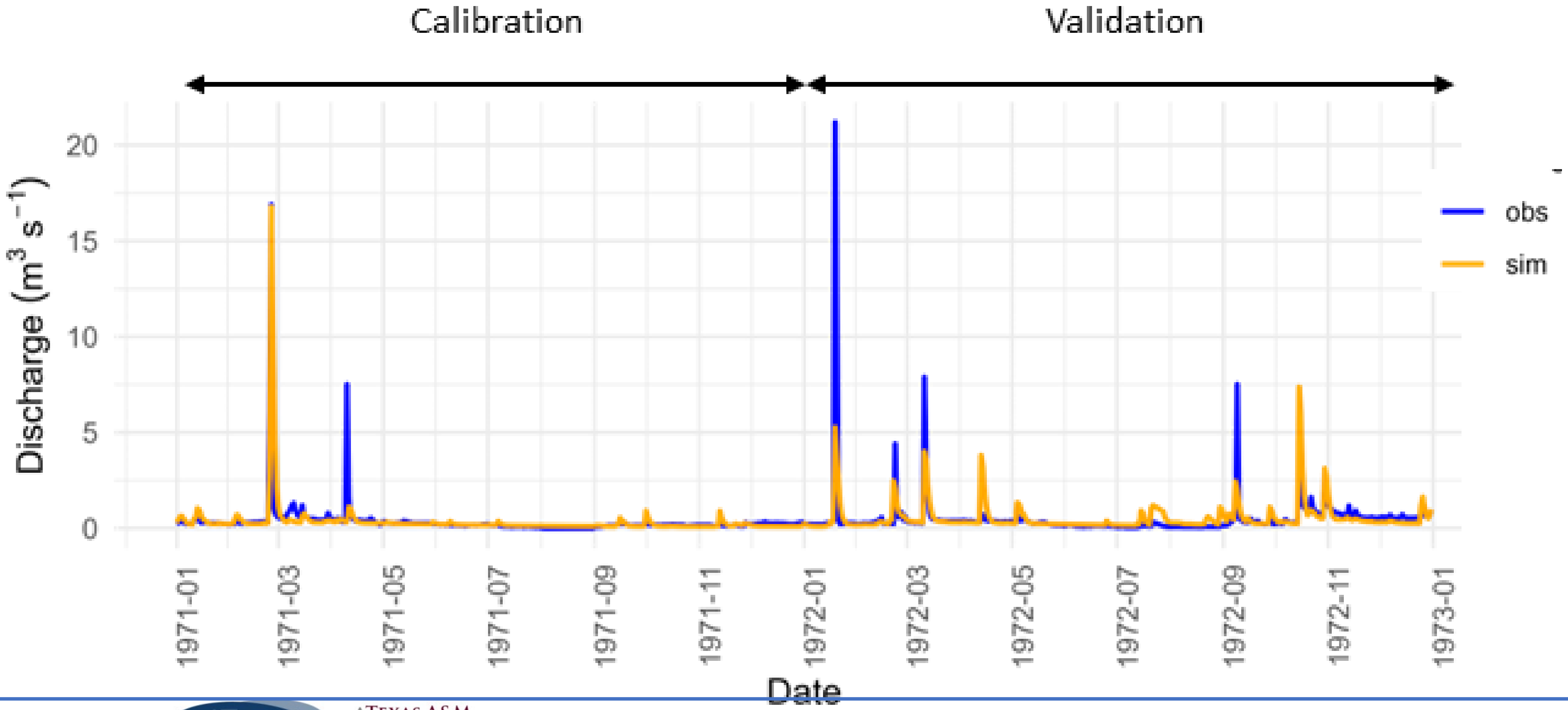
The calibration was performed including 15 parameters.

Parameter	Description	Range of variability	Type of change	Value
ESCO	Soil evaporation compensation factor	0.15 ÷ 0.35	Absval	0.302
PERCO	Percolation coefficient	-0.3 ÷ 0.3	Abschg	0.195
CN3_SFW	Soil water factor for CNIII	-0.3 ÷ 0.3	Abschg	0.0599
LATQ_CO	Lateral flow coefficient	-0.3 ÷ 0.3	Abschg	-0.12
AWC	Available Water Capacity of the soil layer (mm H2O/mm soil)	-0.5 ÷ 0.5	Relchg	-0.483
BD	Moist Builk Density (Mg/m^3)	-0.5 ÷ 0.5	Relchg	-0.115
K	Saturated hydraulic conductivity (mm/hr)	-0.5 ÷ 2	Relchg	1.91
SURLAG	Surface runoff coefficient	0.01 ÷ 2	Absval	0.0249
CN2	Initial SCS runoff CNII	-0.15 ÷ 0.10	Relchg	20 ^{A} ÷ 91 ^{B}
LAT_TTIME	Lateral flow travel time (days)	0.1 ÷ 100	Absval	89.5
LAT_LEN	Slope length for lateral subsurface flow (m)	1 ÷ 100	Absval	17.3
ALPHA	Baseflow alpha factor	0 ÷ 0.2	Abschg	0.163
DEEP_SEEP	Deep aquifer percolation fraction	-0.9 ÷ 1	Relchg	-0.373
SP_YLD	Specific yield of the shallow aquifer (m^3/m^3)	-0.9 ÷ 1	Relchg	0.587
REVAP_CO	Groundwater “revap” coefficient.	0 ÷ 10	Relchg	1.38

Previous work: Leone et al., 2023 https://doi.org/10.1016/j.ecohyd.2023.03.005

Results
Calibration and validation - swatplusR package

The calibration was carried out based on the daily streamflows observed in 1971. The simulation selection criterion was:
KGE_cal > 0.75, |pbias_low flow| < 5%, mae_low flow < sd(qobs_low flow)
low flow from 1971-05-01 to 1971-12-31.
The validation, conducted based on the flows observed in the year 1972, returned good KGE values for the selected runs between 0.46 and 0.67.

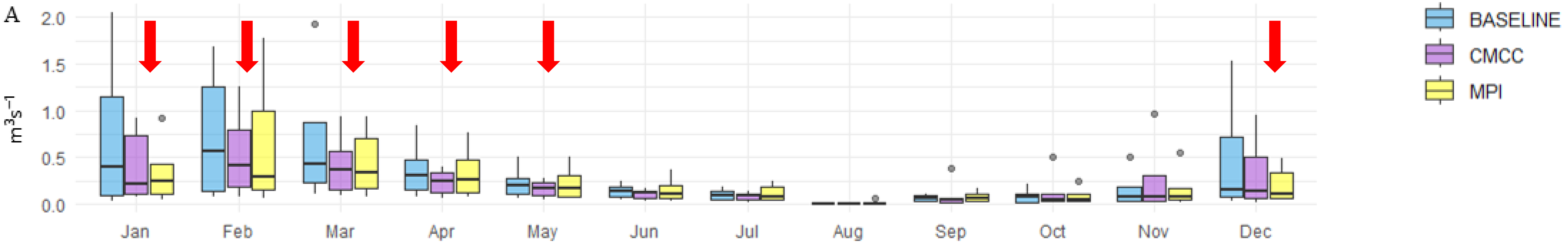


Statistical results
Calibration
r = 0.80, MAE= 0.16, pBias =0.29, NSE = 0.65, KGE = 0.75.
Low flow period:
MAE=0.08, pBias = -4.53.

Validation
pBias = -1.05, KGE =0.46, NSE =0.40

Results

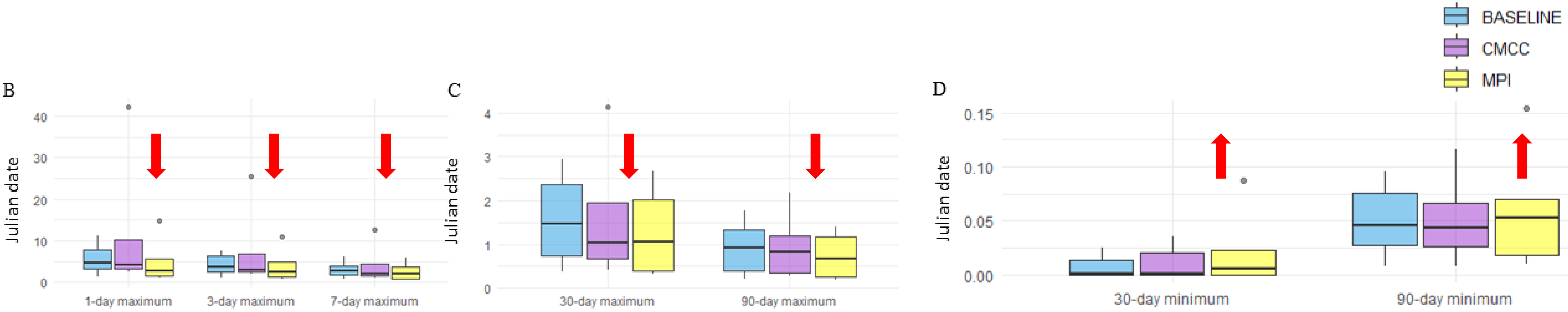
Setting E-Flow Regime (IHA and RVA)



Mean monthly flows which represent **magnitude** and **duration** of streamflow.

In the future scenarios it is observed that the **greatest impacts** induced by climate change could occur in the **winter months** (DJF) and in the **spring months** (MAM).
The **increase** in the **May** and **June** interquartile variability (MPI) could be due to the occurrence of **small floods**.

Results
Setting E-Flow Regime (IHA and RVA)



Magnitude of the maximum and minimum **extreme annual flow** of different durations.

Significant **decreasing** is predicted for the **1-day, 3-day, 7-day, 30-day and 90-day maximum**. The number of **outliers** tends to increase, probably due to an expected **increase** in extreme events of minimum magnitude.

Discussion and conclusion

SWAT is widely used model also in the Mediterranean environment. However, getting a good low flow simulation is a common problem. The main difficulties of this work are the result of a **lack of quantitative and qualitative input data** (WWTPs, climate variable, only two years of observed streamflow, ..). An improvement in the low flow simulation could be achieved by making **changes to the groundwater parameters.**

swatplusR (Schürz C., 2019) allows us to **run simulations in parallel** by setting up multiple threads. In this work, 5000 iterations were processed in an extremely short time. Furthermore, it is possible to adopt a **multi-criteria approach** in the definition of **the objective function**.

Discussion and conclusion

The outputs of climate models are often affected by systematic errors. It is extremely important to resort to **bias correction** procedures so that the outputs of climate models are modified based on local conditions.

In the near future scenario, a reduction of streamflow is expected which could cause the aggravation of the **water scarcity** condition in the Mediterranean areas. Therefore, **climate change must be analyzed before setting an E-Flow regime.**

THANK YOU