Effects of climate change on the Nossana karst spring (northern Italy): future discharge projections and water distribution system sustainability

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Open Access Article

Nossana Spring (Northern Italy) under Climate Change: Projections of Future Discharge Rates and Water Availability

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water

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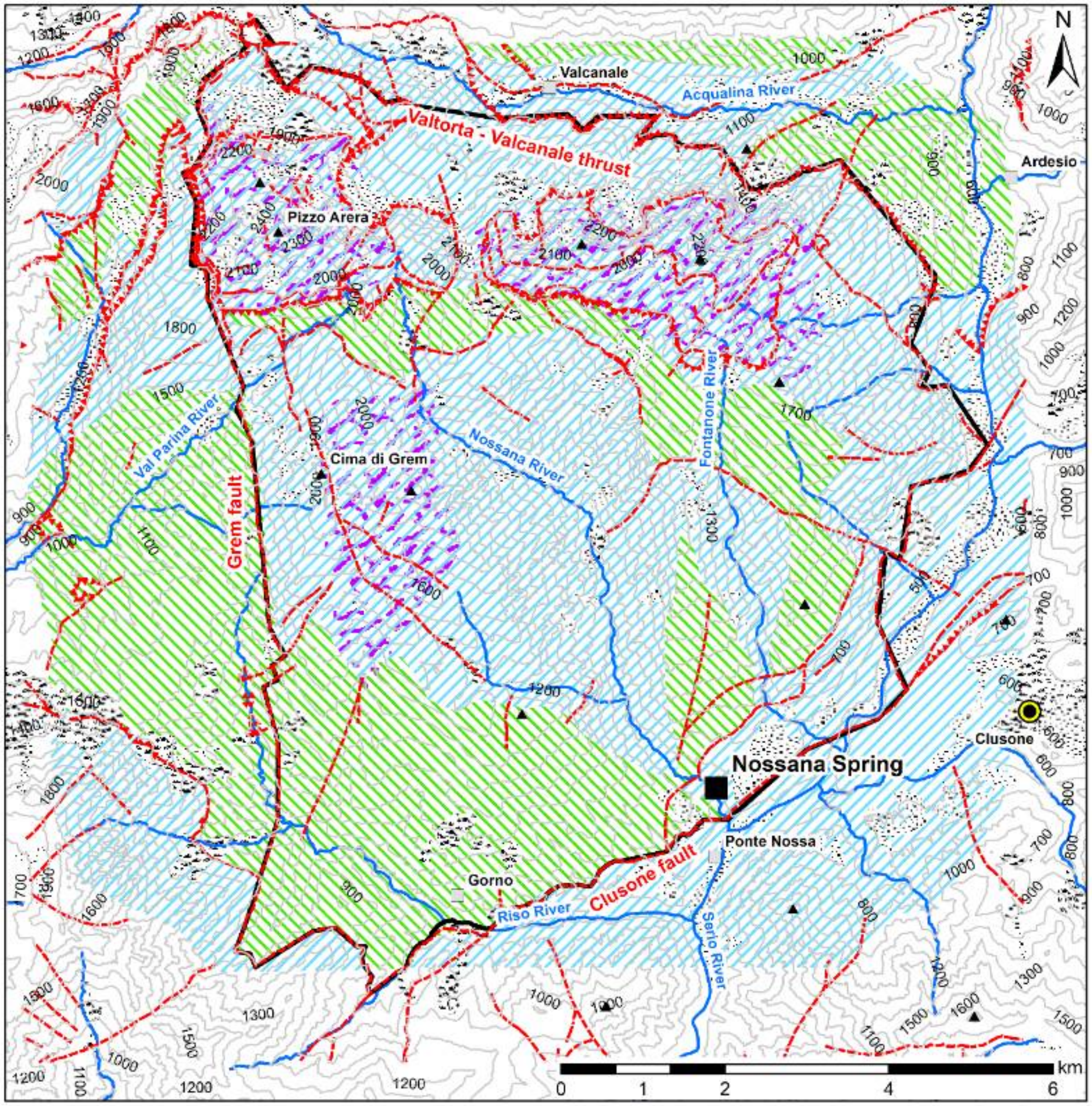
Objectives

- Quantification of the expected changes in precipitation and temperature in the study area (reference period 1998-2017)
- Calibration and validation of a hydrological lumped-parameter model based on observed data
- Recognition of possible limits in the future utilization of the spring as a drinking supply (2021-2100)

Study Area



Legend

- Nossana Spring
- Main town
- Meteorological station
- Mountain peak
- Fault
- Thrust
- Nossana catchment
- Main rivers
- Slope deposit
- Alluvial deposit
- Low permeable unit
- High permeable unit
- Intense karst area

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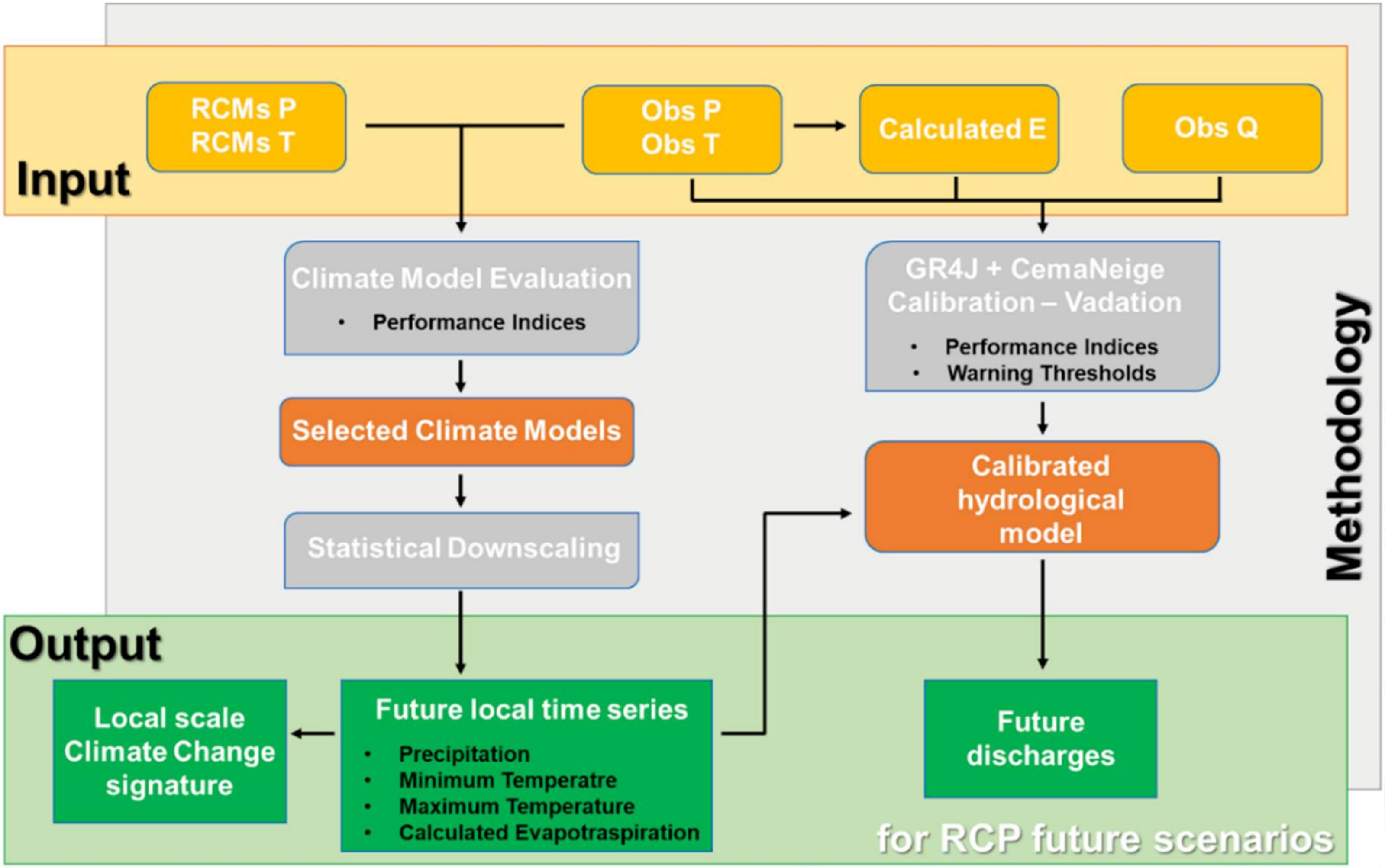
Methods



RCP 2.6 → 3 models

RCP 4.5 → 3 models

RCP 8.5 → 3 models

Reference 1998-2017

p1 2021-2040

p2 2041-2060

p3 2061-2080

p4 2081-2100

Step 1 – Climate Model Evaluation

Precipitation → NSE > 0.0; MAE < 20%

Temperature → NSE > 0.8; MAE < 20%

Reference → 1998-2017

	Precipitation			Tmin			Tmax		
Model	NSE	MAE (mm)	%MAE	NSE	MAE (° C)	%MAE	NSE	MAE (° C)	%MAE
Mod_1 RCP 2.6	0.79	12.35	10.71	0.96	1.10	17.69	0.97	1.18	7.09
Mod_1 RCP 4.5	0.66	14.97	12.97	0.97	1.00	17.19	0.97	1.08	6.48
Mod_1 RCP 8.5	0.76	12.71	11.20	0.97	1.00	15.96	0.98	0.90	5.43
Mod_2 RCP 2.6	0.31	19.81	17.16	0.97	0.90	14.20	0.97	0.99	5.95
Mod_2 RCP 4.5	0.52	17.44	15.12	0.97	1.00	16.13	0.96	1.27	7.65
Mod_2 RCP 8.5	0.31	22.90	19.85	0.97	0.90	15.42	0.96	1.28	7.66
Mod_3 RCP 2.6	0.23	20.53	17.79	0.97	1.00	15.96	0.96	1.19	7.14
Mod_3 RCP 4.5	0.37	17.17	14.88	0.98	0.80	12.79	0.97	0.99	5.95
Mod_3 RCP 8.5	0.52	17.78	15.41	0.98	0.80	12.69	0.97	0.98	5.88

Step 2 – Statistical Downscaling

USING

$$\frac{P^{Fut}}{P^{Obs}} = \frac{P^{RCMFut}}{P^{RCMCon}} \quad \text{where} \quad \frac{P^{RCMFut}}{P^{RCMCon}} = \alpha$$

$$P^{Fut} = \alpha \cdot P^{Obs}$$

P = any variable

MODEL PARAMETERS

Storm origin time	(λ)	$[h^{-1}]$
Number of raincells	(ν)	[-]
Raincell origin delay	(β)	$[h^{-1}]$
Raincell intensity	(ξ)	[h/mm]
Raincell duration	(η)	$[h^{-1}]$

RainSim V3.0 (Burton et al., 2008),

Stochastic rainfall model
Neyman-Scott Rectangular Pulses (NSRP) model

RAINFALL GENERATOR

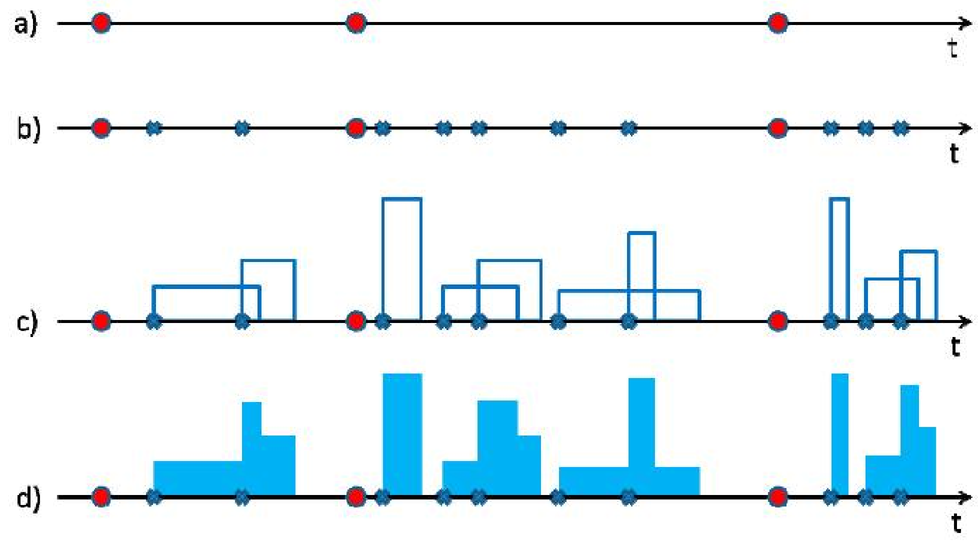
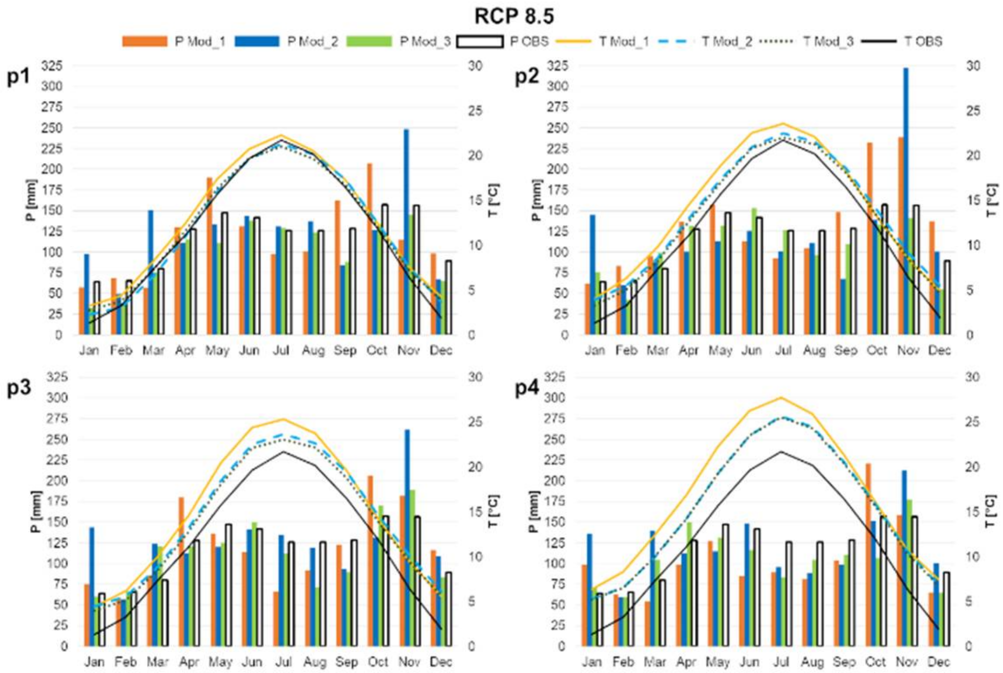


image by De Luca and Galasso (2019)

Burton, A., C. G. Kilsby, H. J. Fowler, P. S. P. Cowpertwait, and P. E. O'Connell (2008), RainSim: A spatial-temporal stochastic rainfall modelling system, *Environmental Modelling & Software*, *23*, 1356-1369.

Step 2 – Local Scale Climate Change



Changes in monthly climatology (precipitation and temperature) for twenty-year periods

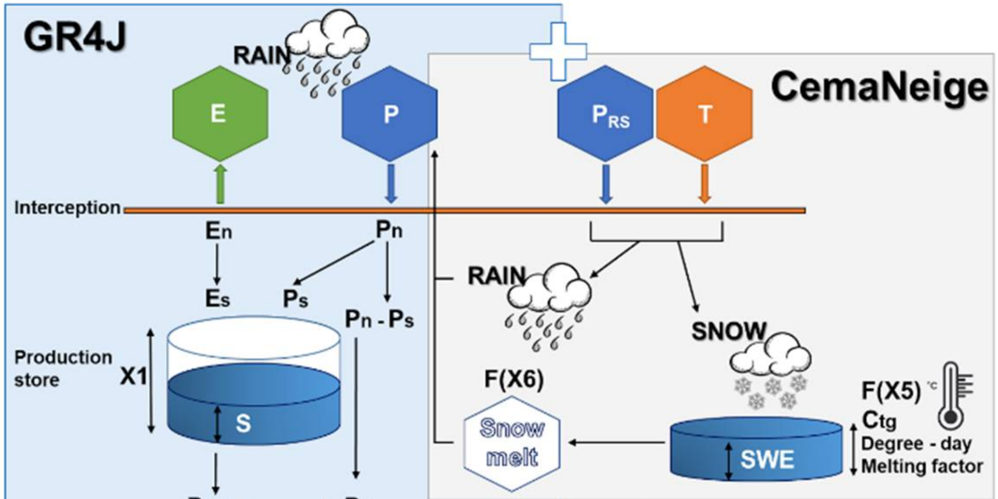
Summary

- **Not all models agrees regarding mean annual prcp trends in different periods**
- **General prcp decrease in summer**
- **Temperature increases up to ≈ 5 °C**

Relative changes (%) in mean annual precipitation

	RCP2.6			RCP4.5			RCP8.5		
Period	Mod_1 [%]	Mod_2 [%]	Mod_3 [%]	Mod_1 [%]	Mod_2 [%]	Mod_3 [%]	Mod_1 [%]	Mod_2 [%]	Mod_3 [%]
p1	−3.8	2.7	2.4	1.6	9.4	7.1	1.7	6.3	−14.1
p2	6.6	−5.2	0.7	−18.5	3.4	6.8	15.1	5.9	−6.9
p3	−4.4	5.4	−13.4	−3.0	0.9	−0.7	2.5	11.0	−2.4
p4	−4.4	8.3	−2.0	2.2	9.7	−8.4	−10.4	4.8	−7.9

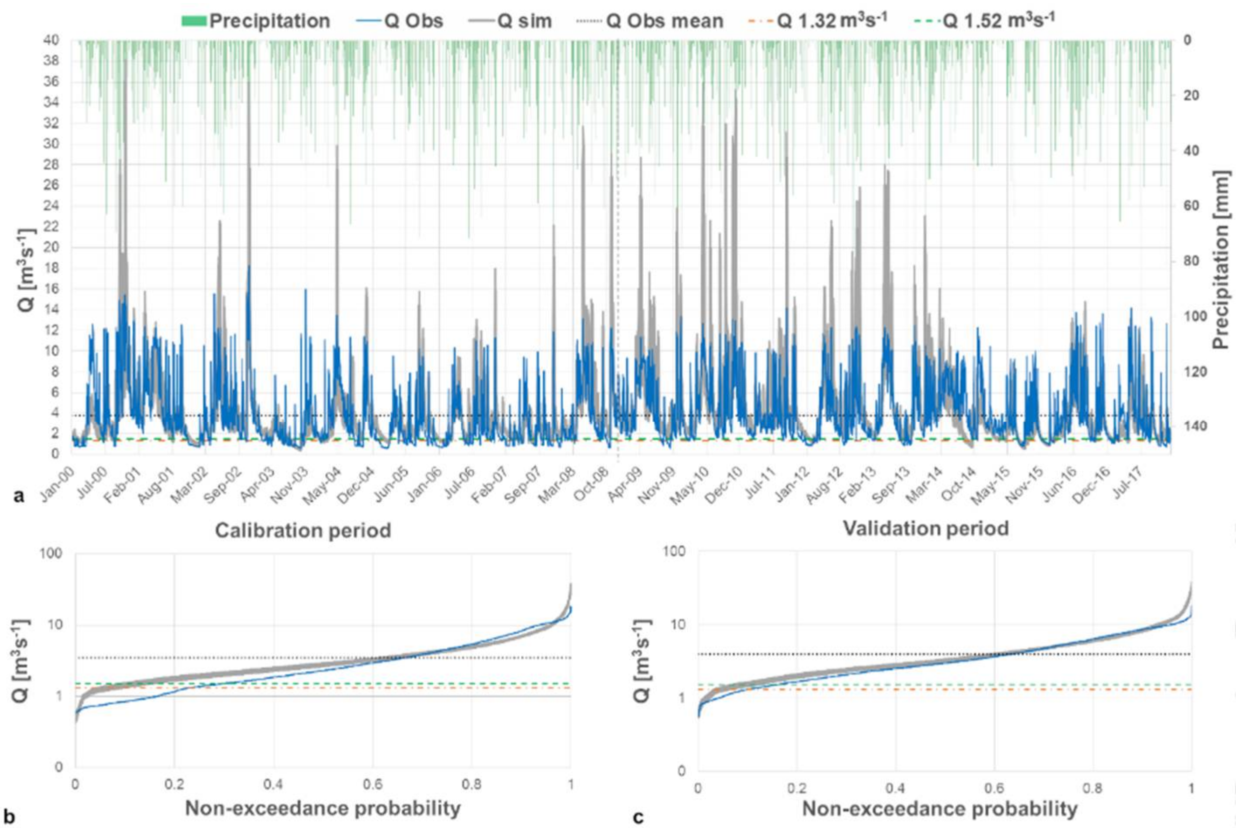
Step 3 – Hydrologic Model Calibration



Parameter	Definition
Es	Actual evaporation rate
P	Areal catchment rainfall
P_{RS}	Rain/Snow precipitation
T	Temperature
Perc	Percolation leakage
Pn	Net rainfall
Pr	Total quantity of water to reach routing functions
Pn - Ps	Amount of net rainfall that goes directly to the routing functions
Ps	Amount of net rainfall that goes directly to the production store
Q	Total stream flow
Q1	Output of UH2
Q9	Output of UH1
Qd	Direct flow component
Qr	Routed flow component
R	Water content in the routing store
S	Water content in the production store
UH1, UH2	Unit hydrographs
SWE	Snow Water Equivalent
X1	Capacity of the production soil (SMA) store (mm)
X2	Water exchange coefficient (mm)
X3	Capacity of the routing store (mm)
X4	Time parameter (days) for unit hydrographs
X5 - Ctg	Weighting coefficient for snow pack thermal state ($mm °C^{-1} day^{-1}$)
X6 - Kf	Degree-day melt coefficient (-)

- **Random generation of 10,000 model parameter sets**
- **Model spin-up: 1998-1999**
- **Calibration: 2000-2008**
- **Validation: 2009-2017**
- **Criteria 1: KGE > 0.70; lNSE > 0.5**
- **Criteria 2: number of days and consecutive with discharge below warning thresholds**

Step 3 – Hydrologic Model Calibration

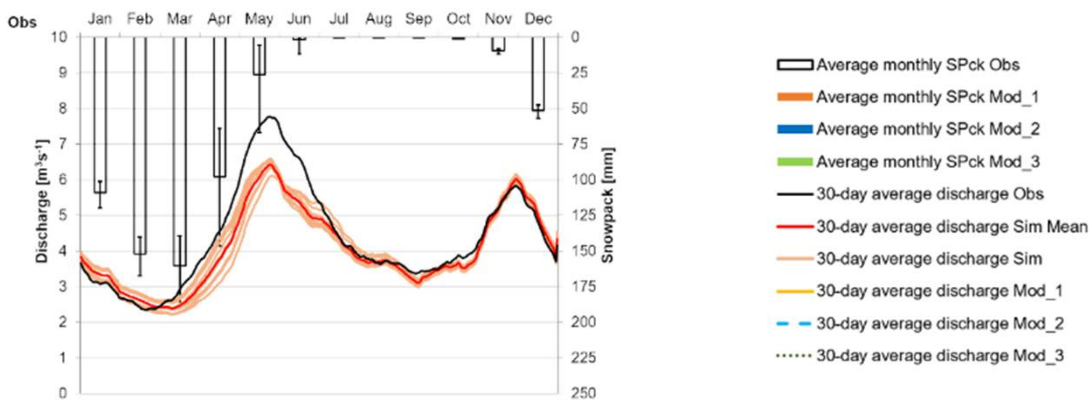


- **10 parameter sets**
- **Underestimation number of days below warning thresholds**
- **Maximum number of days below the warning threshold best indicator**

n. days	Obs_Cal	Obs_Val	Mod_Cal	Mod_Val
Q 1.32	758	335	141-310	102-207
Q 1.52	992	522	307-513	219-391

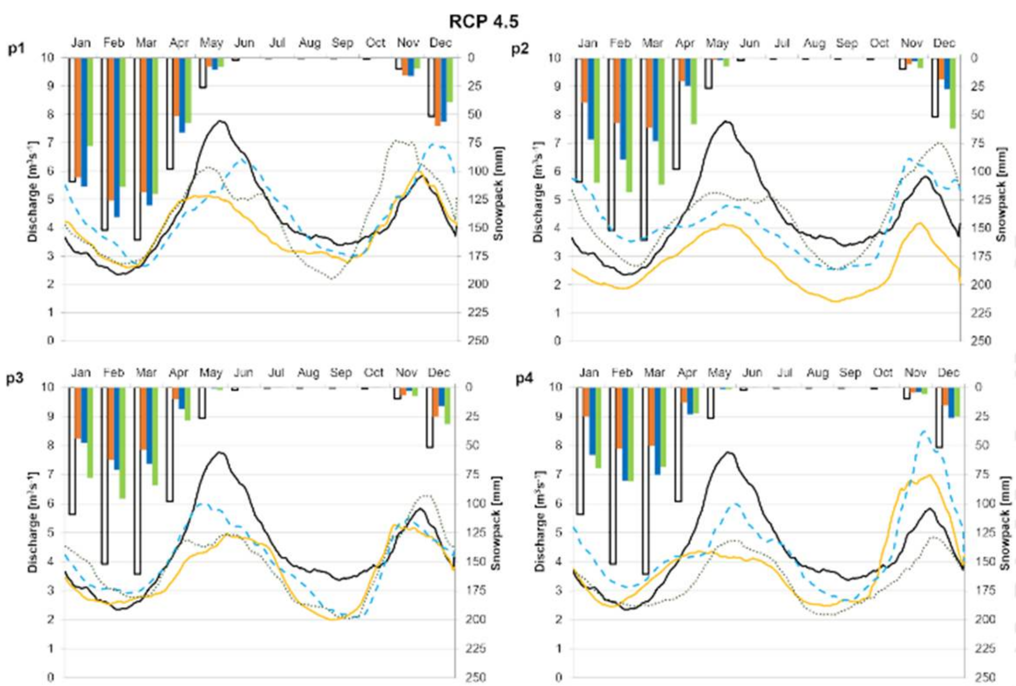
Max days	Obs_Cal	Obs_Val	Mod_Cal	Mod_Val
Q 1.32	71	47	57-63	33-44
Q 1.52	74	59	63-66	44-53

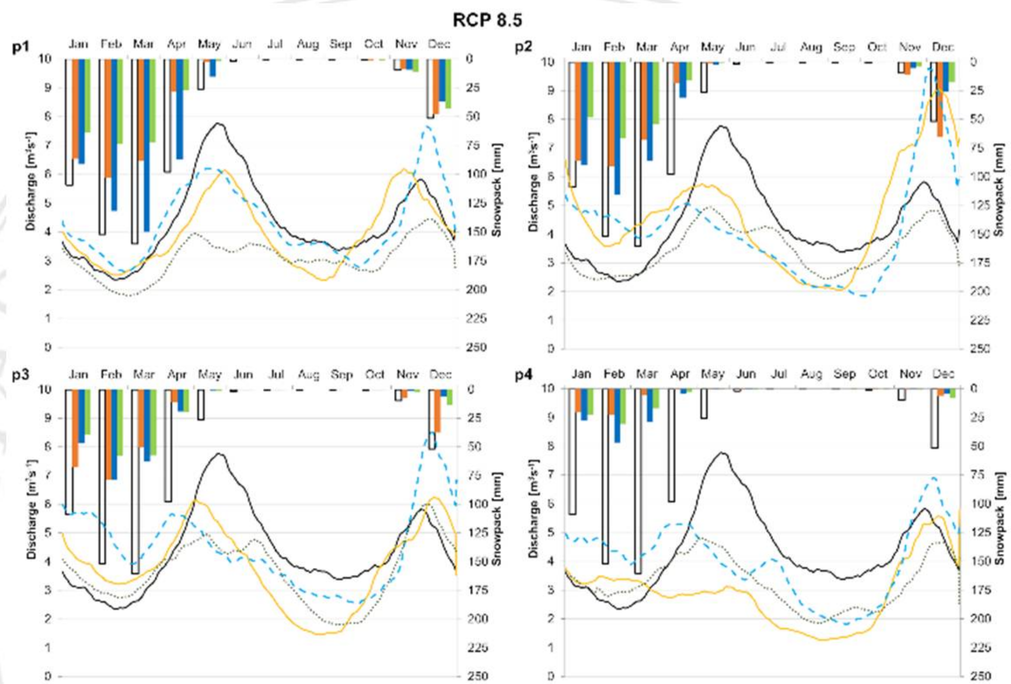
Step 4 – Future discharges



SUMMARY

- **Variation of recharge periods**
- **Variation of annual cycle trend**
- **Decrease in mean discharge**





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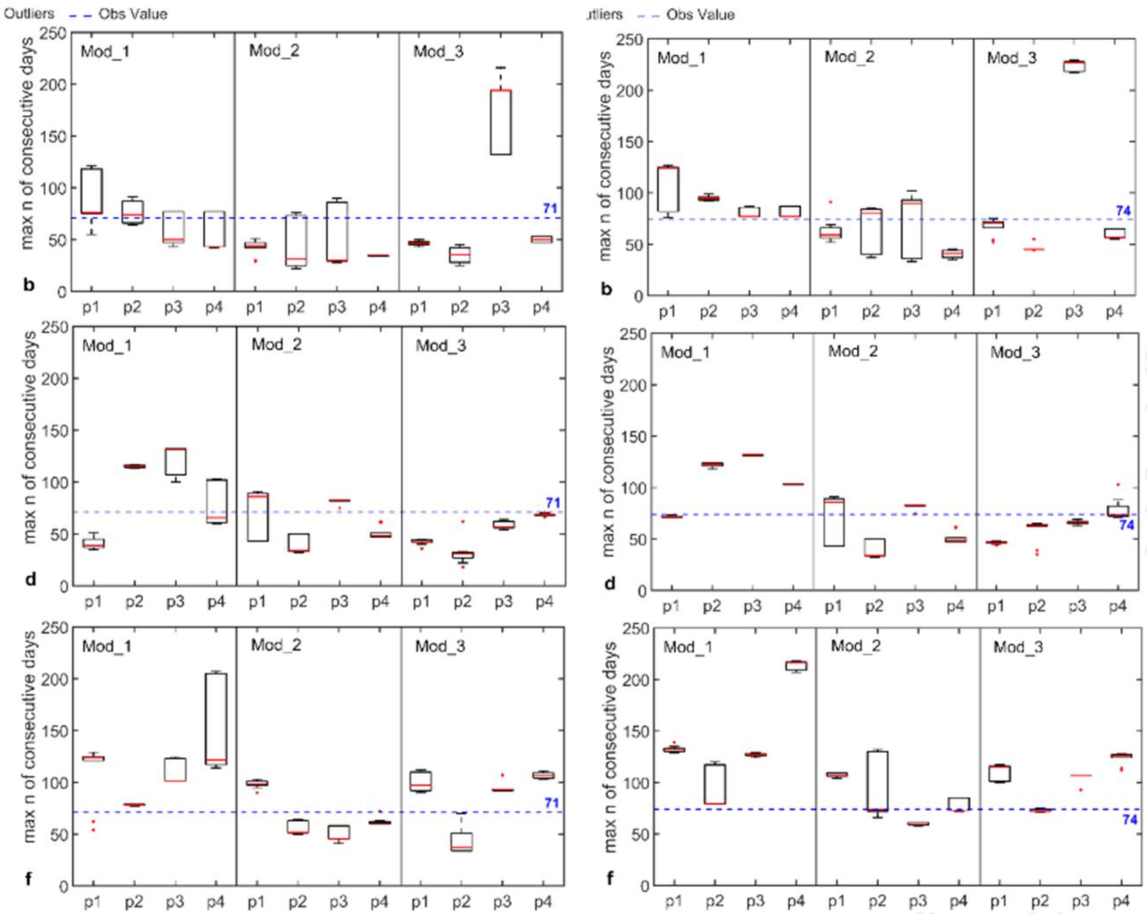
Step 4 – Future discharges

1.32 m³/s threshold | 1.52 m³/s threshold



RCP 2.6

RCP 4.5

RCP 8.5

AFTER 2060

- Longest period below the 1.32 m³/s warning threshold 36 extra days
- Longest period below the 1.52 m³/s warning threshold 64 extra days.

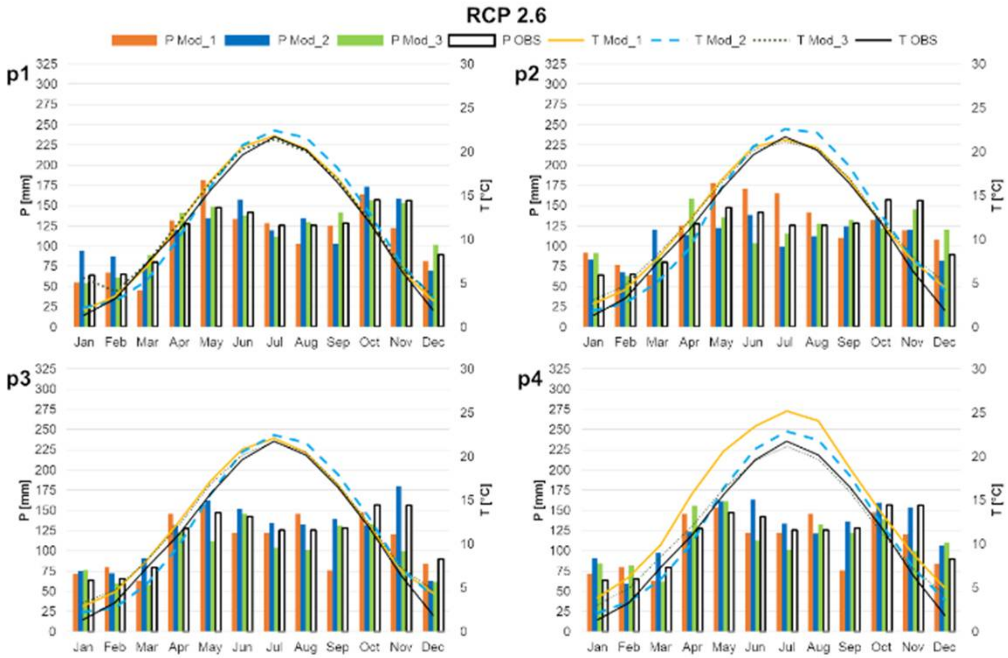
Conclusion

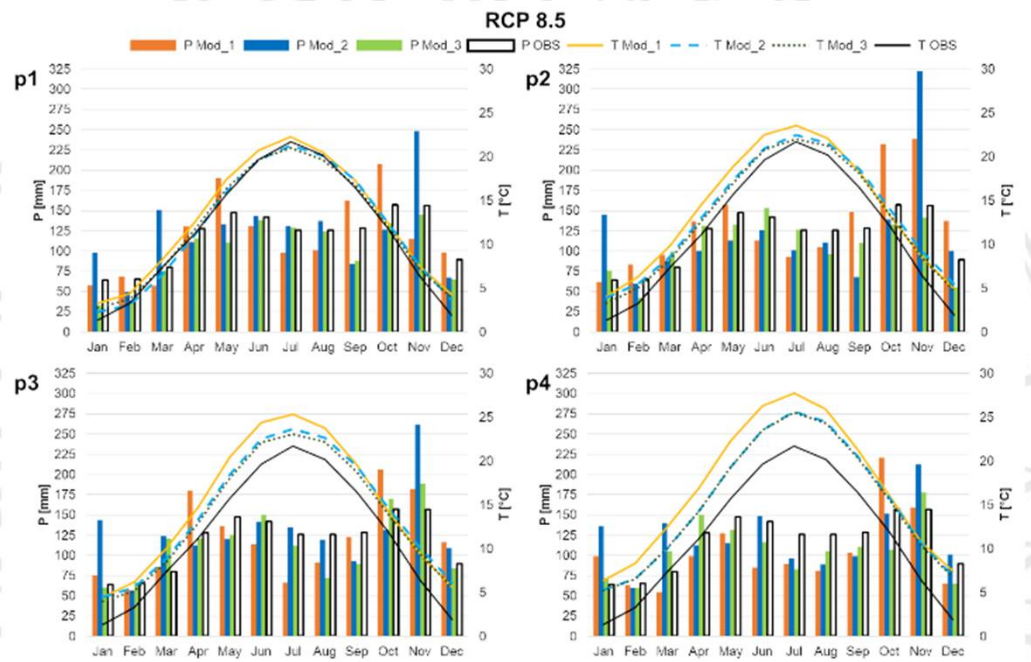
- Considered **bias-corrected EURO-CORDEX RCMs** have very **good skills** in reproducing observed **temperature** climatology while larger **errors** persist regarding **precipitation**
- Mean **temperature** will likely **increase** throughout the rest of the XXI century, **from 0.7 ° C in 2021–2040** (RCP4.5, Mod_2) **to 5.8 ° C in 2081–2100** (RCP8.5, Mod_1)
- **No clear trend for precipitation**, changes in mean annual rainfall varies between −18.5% (2041–2060, RCP4.5, Mod_2) and 15.1% (2041–2060, RCP8.5, Mod_2)
- Pronounced **decrease of precipitation** is expected in the **summer** period after 2060
- **Mean discharges** are generally projected to **decrease** in comparison to observed flow
- After 2060, the length of the periods with **discharge lower than the warning thresholds** is expected to increase. These periods could last up to **64 days (86%) longer** than in 1998–2017
- **Additional water resources might be needed to satisfy the population water demand in the Nossana Spring area, especially after 2060**

THANK YOU

Contacts: corrado.camera@unimi.it

Extras


RCP 2.6
P Mod_1
P Mod_2
P Mod_3
P OBS
T Mod_1
T Mod_2
T Mod_3
T OBS
p1
p2
p3
p4
P [mm]
T [°C]
Jan Feb Mar Apr May Jun Jul Aug Sep Oct Nov Dec


RCP 8.5
P Mod_1
P Mod_2
P Mod_3
P OBS
T Mod_1
T Mod_2
T Mod_3
T OBS
p1
p2
p3
p4
P [mm]
T [°C]
Jan Feb Mar Apr May Jun Jul Aug Sep Oct Nov Dec

Extras

Average monthly SPck Obs
Average monthly SPck Mod_1
Average monthly SPck Mod_2
Average monthly SPck Mod_3
30-day average discharge Obs
30-day average discharge Sim Mean
30-day average discharge Sim
30-day average discharge Mod_1
30-day average discharge Mod_2
30-day average discharge Mod_3