Impact simulations of climate change on hydrological extremes in the Po basin

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Servizio Idro Meteo Clima

cmcc Centro Euro-Mediterraneo sui Cambiamenti Climatici ISC - Capua

Outline

Motivation, Aims, Actors, Methodology

Climate & Hydrological models

Case study

Preliminary results

Conclusions

Motivation

Climate natural variability influences the river flow

Short and intense precipitations and prolonged dry periods are expected to increase in frequency in Mediterranean area (IPCC 2007, WG1)

Floods and hydrological droughts are expected to increase in frequency due to variations in the precipitation partitioning in space and time (Blenkinsop and Fowler, 2007)

Global climate models resolution is to coarse (200 x 200 km) to reproduce the small-scale spatial variability of precipitation

The use of downscaling techniques provides climate data at finer spatial scale (< 50 km) comparable with the spatial scale of hydrological models

Actors

The research activity is carried on within project GEMINA (WP6.2.17) funded by MIUR (Italian Ministry of Education, University and Resarch) and MiSE (Italian Ministry of Economic Development)

Centro Euro-Mediterraneo sui Cambiamenti Climatici ISC - Capua

The expertises on climate model downscaling (dynamical and statistical) are guaranteed by CMCC-ISC (Impacts on coast and soil division of the Eurومediterranean Center on Climate Change)

agenzia regionale prevenzione e ambiente dell'emilia-romagna Servizio Idro Meteo Clima

The expertises on hydrological modelling are guaranteed by SIMC ARPA-EMR (Hydrometeoclimate Service of the Emilia Romagna region Prevention and Environment Agency)

Aims

WP 6.2.17 “Analysis of hydro-geological risk related to climate change”, i.e., the analysis of landslides, floods and low flows risks related to climate change conditions on the Mediterranean area.

To investigate climate changes on precipitation and temperature patterns over the Mediterranean region over the period 1971-2100.

Control period: 1971-2000
Prevision period: 2001-2100
Scenarios: RCP 4.5 and RCP 8.5

Aims

To evaluate, qualitative and quantitative, of the hydrogeological risk in some typical context of the Mediterranean area (e.g. Po river basin for hydrological risk).

To analyze the role of the uncertainties of the complex relationship between "climate change and hydrogeology" at regional scale on risks evaluation.

A. L. Zollo et al. (03/2012) RP0129 Architectures and tools to analyse the impact of climate change on hydrogeological risk on Mediterranean area. http://www.cmcc.it/pubblicazioni/pubblicazioni/research-papers/rp0129-isc-03-2012

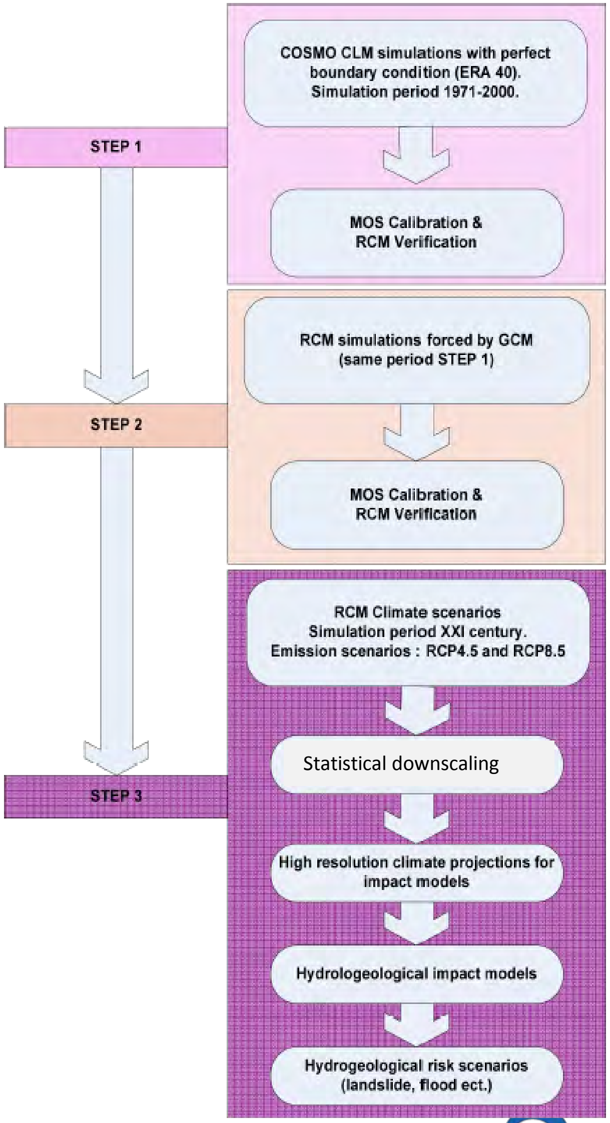
Methodology

Step 1: Hydrological and climate simulation over the control period 1971-2000 under perfect boundary condition (ERA40 Reanalysis)

Step 2: Hydrological and climate simulation over the control period 1971-2000 under GCM: CMCC-MED

Step 3: Hydrological and climate simulation for the XXI century
RCP: 4.5 and 8.5
GCM: CMCC-MED

A. L. Zollo et al. (03/2012) RP0129 Architectures and tools to analyse the impact of climate change on hydrogeological risk on Mediterranea area.
http://www.cmcc.it/pubblicazioni/pubblicazioni/research-papers/rp0129-isc-03-2012



Methodology

	Hydrological Run	RCM Run	RCM & SD Run	GCM Run	GCM & SD Run	RCP 4.5 Scenario	RCP 8.5 Scenario
Period	1971-2000	1971-2000	1971-2000	1971-2000	1971-2000	2001-2100	2001-2100
Initial and boundary conditions	NONE	ERA40 Reanalysis	ERA40 Reanalysis	CMCC-MED	CMCC-MED	CMCC-MED	CMCC-MED
RCM	Observed precipitation temperature	COSMO – CLM	COSMO – CLM	COSMO – CLM	COSMO – CLM	COSMO – CLM	COSMO – CLM
Statistical downscaling / Bias correction	NONE	NONE	MOS analog (other methods will be tested)	NONE	To be defined according to SD validation results	To be defined according to SD validation results	To be defined according to SD validation results
Hydrological Model	TOPKAPI	TOPKAPI	TOPKAPI	TOPKAPI	TOPKAPI	TOPKAPI	TOPKAPI
Hydrological balance at basin scale model	RIBASIM	RIBASIM	RIBASIM	RIBASIM	RIBASIM	RIBASIM	RIBASIM

Ensamble Approach

Forcing data

ECMWF ERA40 Reanalysis

The ECMWF (European Centre for Medium-Range Weather Forecasts) Reanalysis are used to perform simulations with "perfect boundary conditions" as forcing

horizontal resolution of 1.125° (about 128km)

49 vertical levels

3 soil levels

Uppala S.M. et al, 2006. The ERA-40 re-analysis, Quart. J. Roy. Meteor. Soc., 612: 2961-3012

Global climate model: CMCC - MED

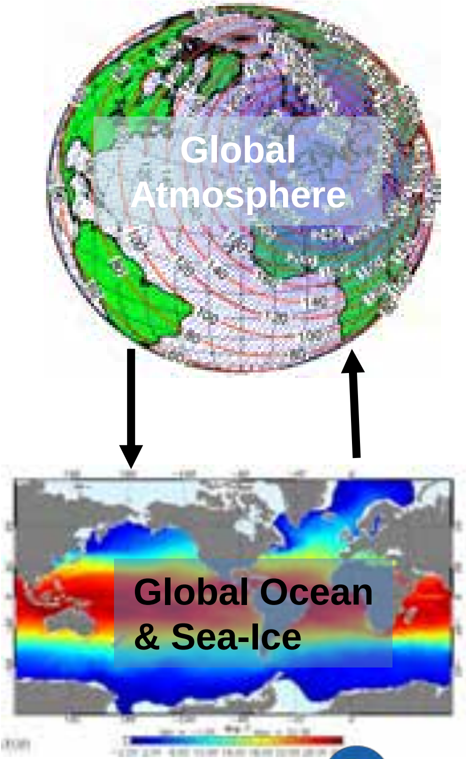
Coupled atmosphere-ocean general circulation model developed at CMCC.

- Atmospheric component: ECHAM5, Gaussian grid of about 0.75° x 0.75° .
- Global ocean component: OPA 8.2, horizontal resolution of 2° x 2° with a meridional refinement near the equator, approaching minimum 0.5° grid spacing.
- High resolution model of the Mediterranean sea: regional configuration of the NEMO model, with a 1/16° horizontal resolution and 71 levels along the vertical.
- Coupler used: OASIS3
- Coupling frequency: 160 minutes.

horizontal resolution of 0.75° (about 85km)

31 vertical levels

4 soil levels



Gualdi et. al., 2012. The CIRCE simulations: a new set of regional climate change projections performed with a realistic representation of the Mediterranean Sea. Bull. Amer. Meteor. Soc., 10.1175/BAMS-D-11-00136.1

RCM model: COSMO-CLM

COSMO-CLM is a non hydrostatic regional climate model developed by the CLM-Community where CMCC is involved in the validation WP

The non hydrostatic formulation

- better represents the convective phenomena (and the severe precipitation events)
- made it eligible for dynamical downscaling at 20 km or less (spatial resolutions between 1 and 50km) and for long simulation time scales up to centuries

The high horizontal resolution allows a better description of the terrain orography with respect to the global climate models.

It allows an improved representation of subgrid scale physical processes (clouds, aerosols, orography, land and vegetation properties).

It is continuously updated, thanks to the continuous development of the LM version.

Its range of applicability encompasses

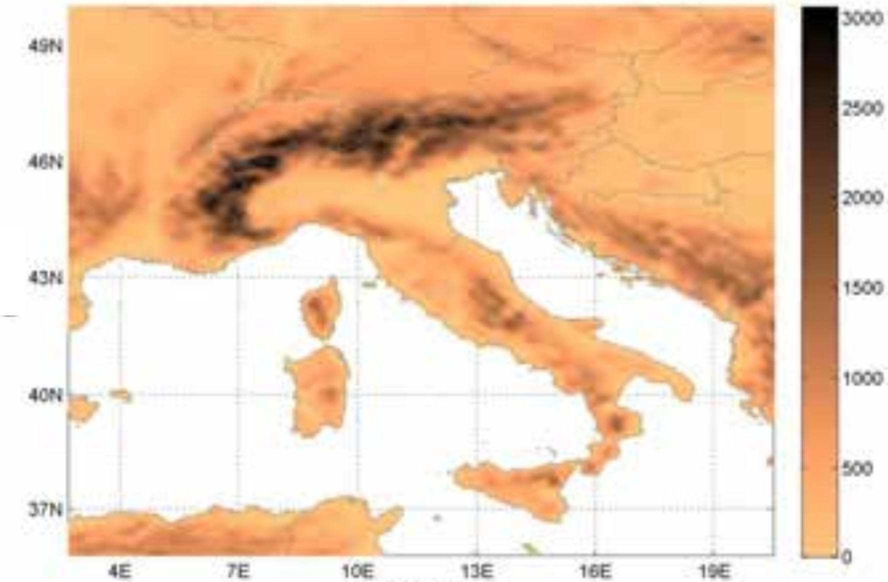
1. operational numerical weather prediction (NWP),
2. regional climate modelling of past, present and future (RCM),
3. idealized studies (ITC).

Simulations performed with COSMO-CLM

Simulations performed for the period 1971-2000:
- driven by ERA40 Reanalysis;
- driven by the global climate model CMCC-MED

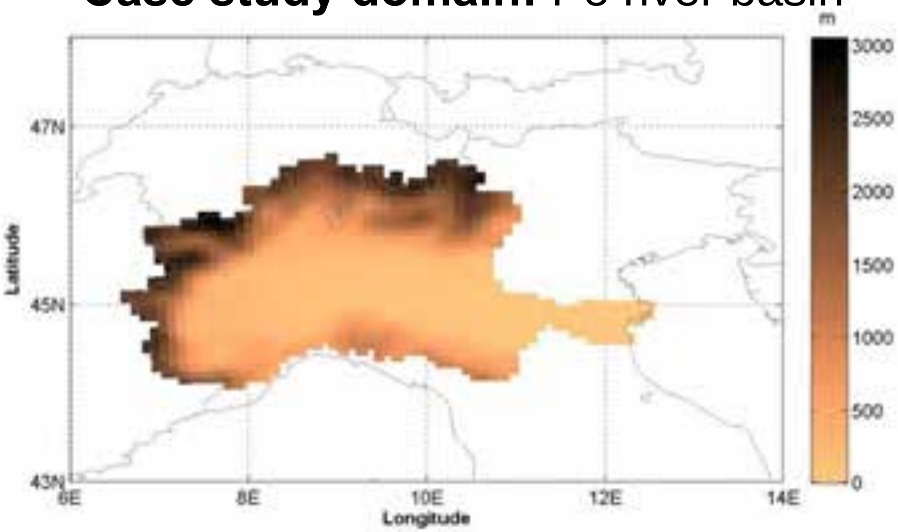
Simulations performed for the period 2001-2100
- RCP 4.5 scenario: Running;
- RCP 8.5 scenario: Running

Simulated domain: (3-20E; 36-50N)



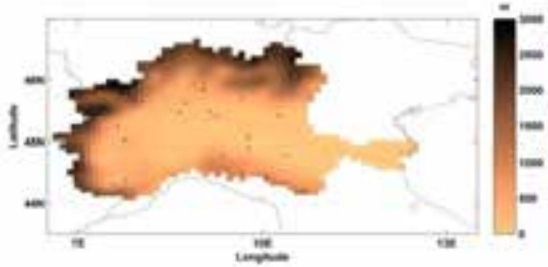
Driving data	ERA40 Reanalysis CMCC-MED model
Horizontal resolution	0.0715° (about 8km)
Num. of grid points	224 x 230
Num. of vertical levels in the atm.	40
Num. of soil levels	7
Soil scheme	TERRA_ML
Time step	40 s
Melting processes	yes
Convection scheme	TIEDTKE
Frequency of radiation computation	1 hour
Time integration	Runge-Kutta (3rd ord.)
Frequency update boundary cond.	6 hours

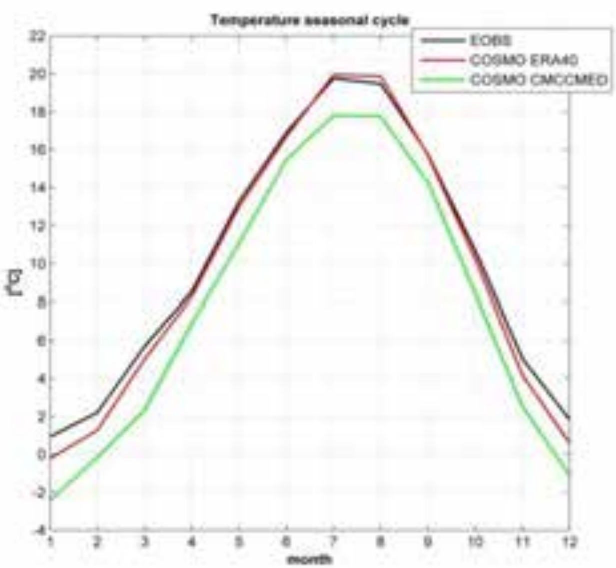
Case study domain: Po river basin



Characterization of the error of COSMO-CLM on the Po river basin: Temperature (EOBS dataset)

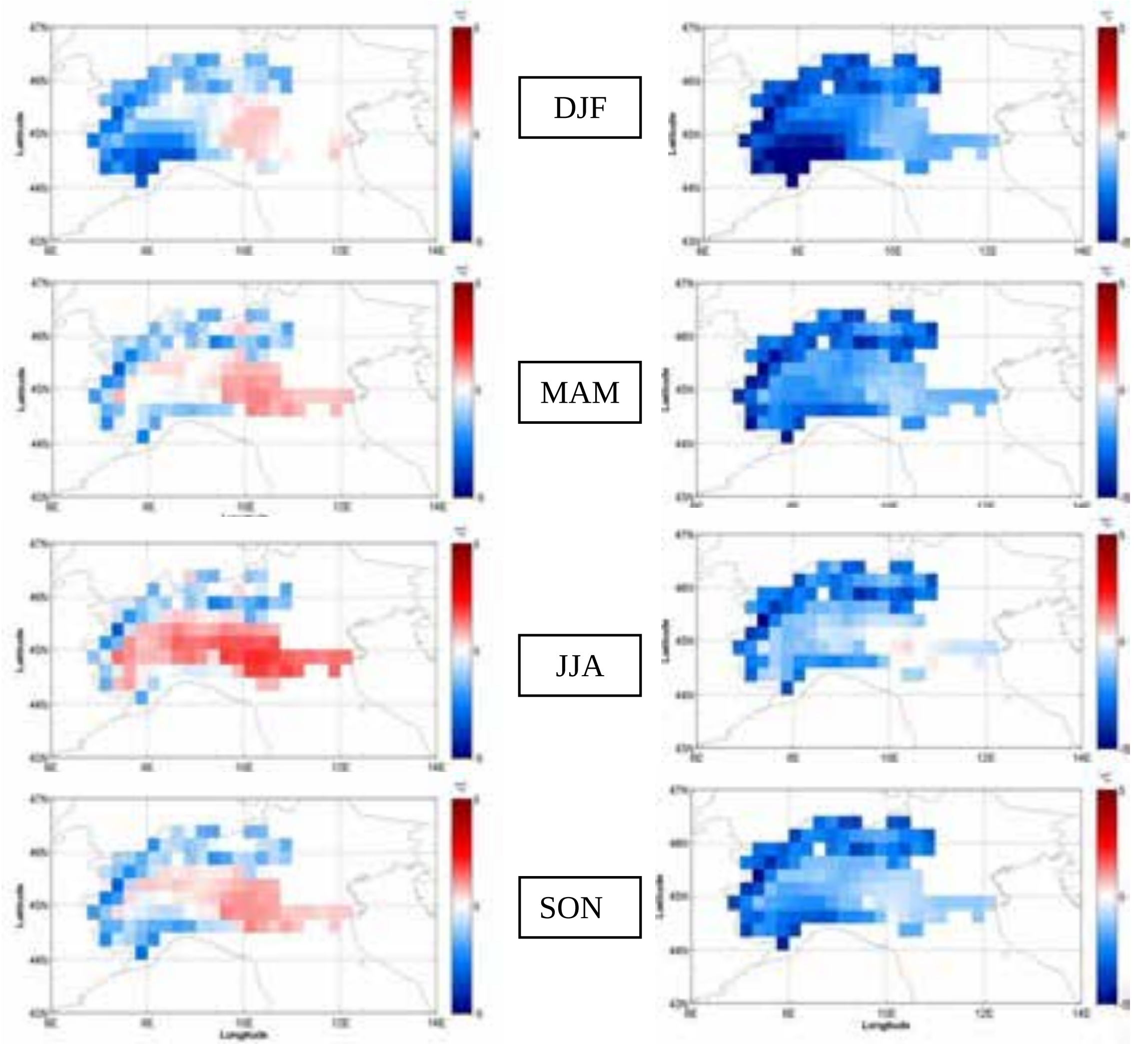
http://eca.knmi.nl/





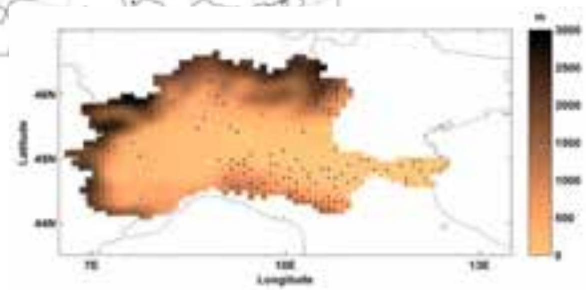
COSMO-CLM forced by ERA40

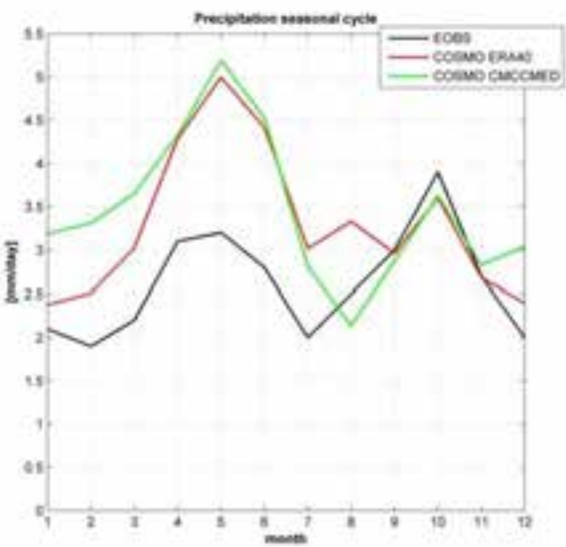
COSMO-CLM forced by CMCC-MED



Characterization of the error of COSMO-CLM on the Po river basin: Precipitation (EOBS dataset)

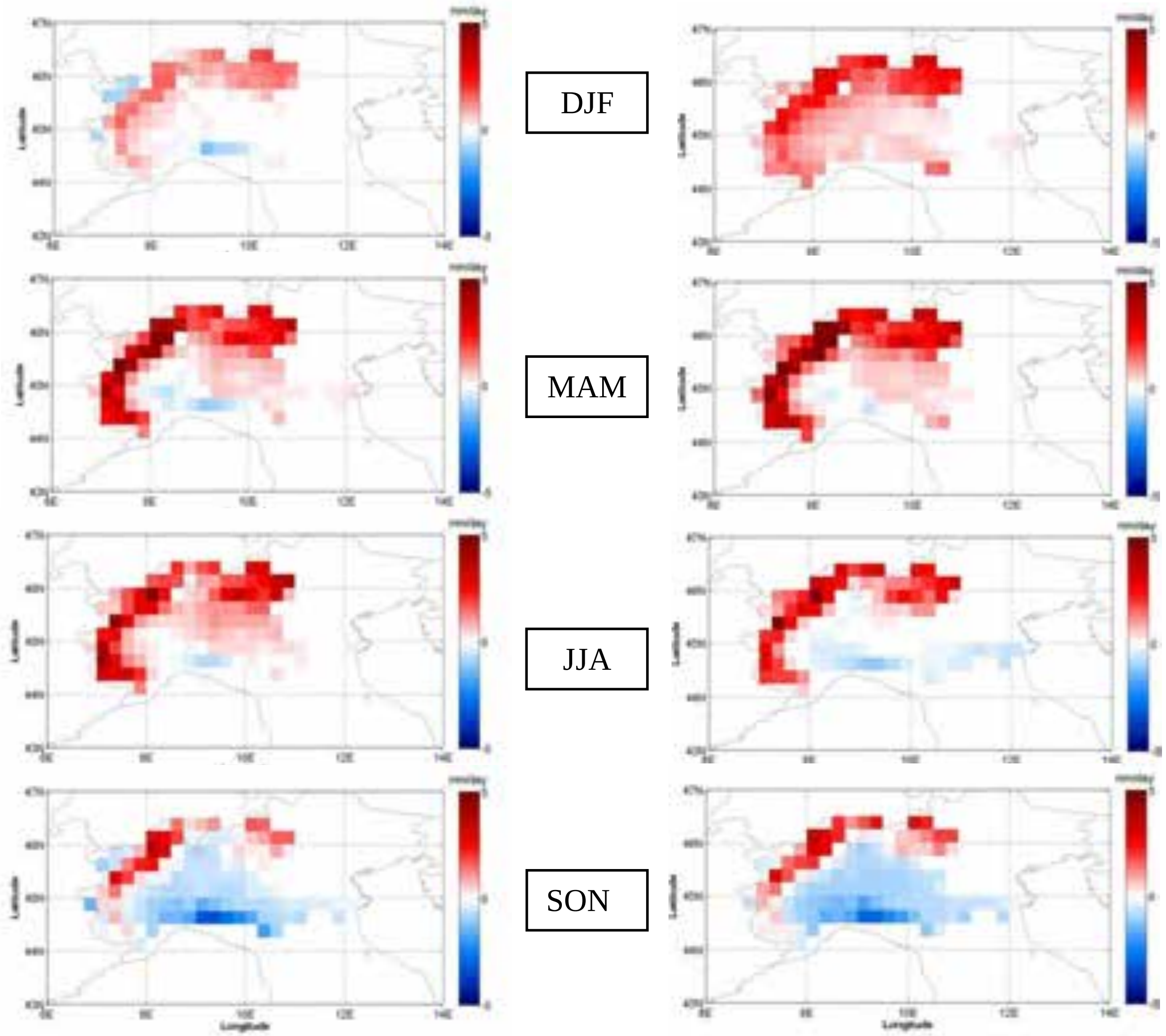
http://eca.knmi.nl/





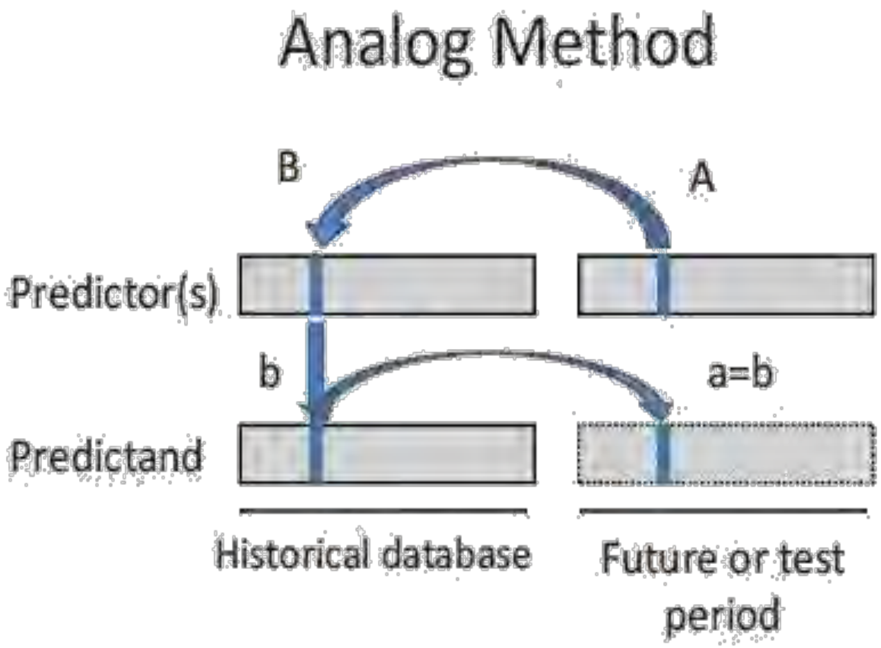
COSMO-CLM forced by ERA40

COSMO-CLM forced by CMCC-MED



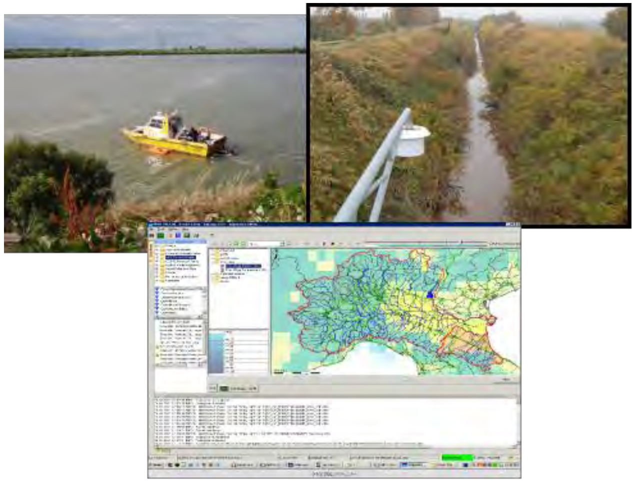
MOS (Model Output Statistics) correction: Analog method

The closest historical predictor B (the analog) considering the Euclidean distance between the two raw predictor fields is found, then, the local precipitation observed, b, correspondent to the analog day B, is used as the downscaled precipitation of the day A (i.e. a=b).



Turco et al. (2011)

DEWS – Drought Early Warning System



PRECIPITATION
TEMPERATURE
LEVEL/DISCHARGES

Observed/Telemeasure

METEOROLOGICAL
MODELS

LM + 15 days/Seasonal Forecasts + 3 months

VALIDATION,
INTERPOLATION
AND DATA
TRANSFORMATION
(DEWS)

TOPKAPI

Rainfall-runoff model

RIBASIM

For simulation of river basin management

Hydrological model: TOPKAPI

Distributed and physically based

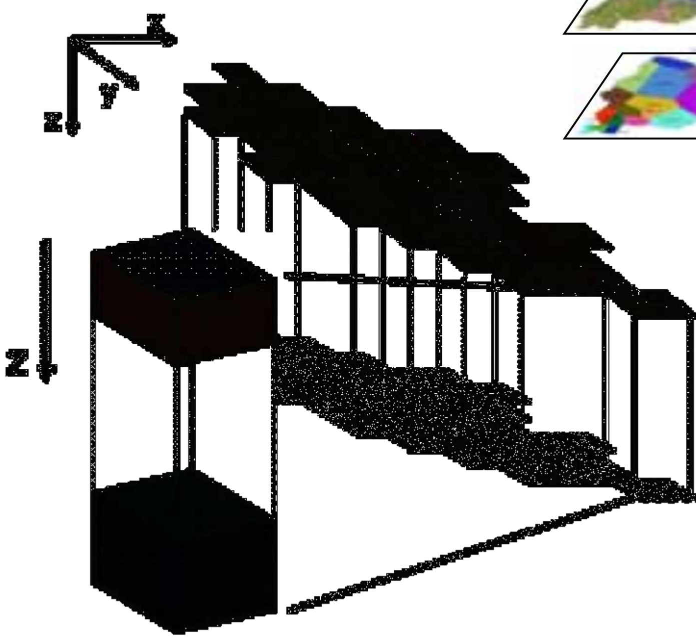
Hydrographs are obtained from:

-climate (weather) inputs

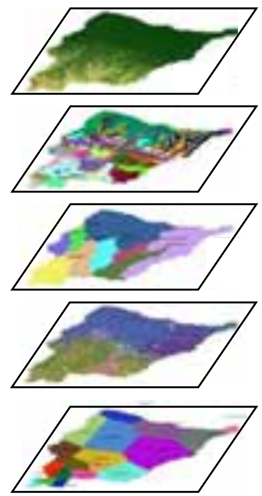
-basin features (morphology)

-land use

-etc



Thematic Maps:



DEM

Soil type

Drainage coefficients

Land use and vegetation type

Climate

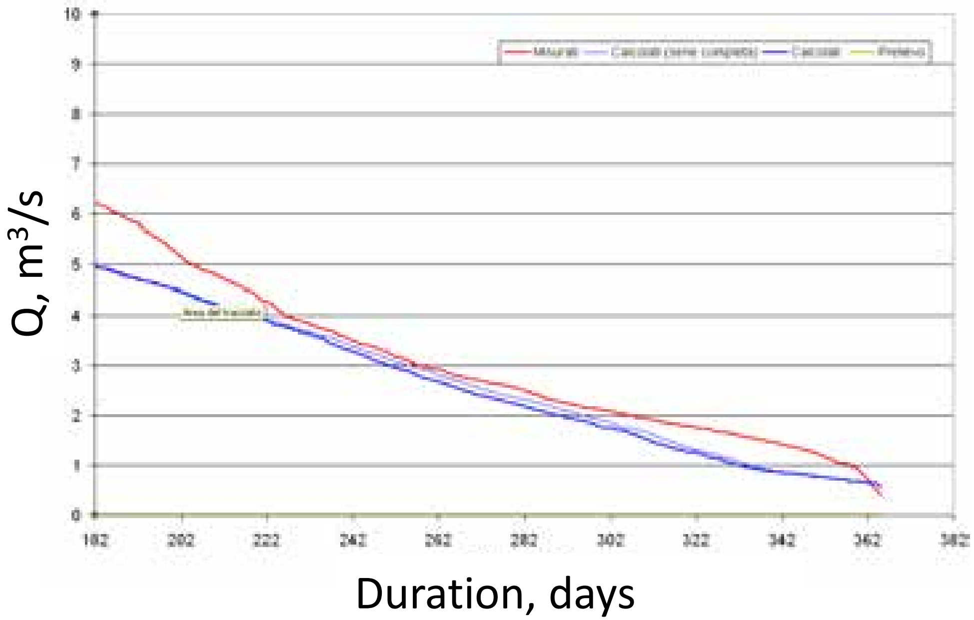
Hydrological model: TOPKAPI

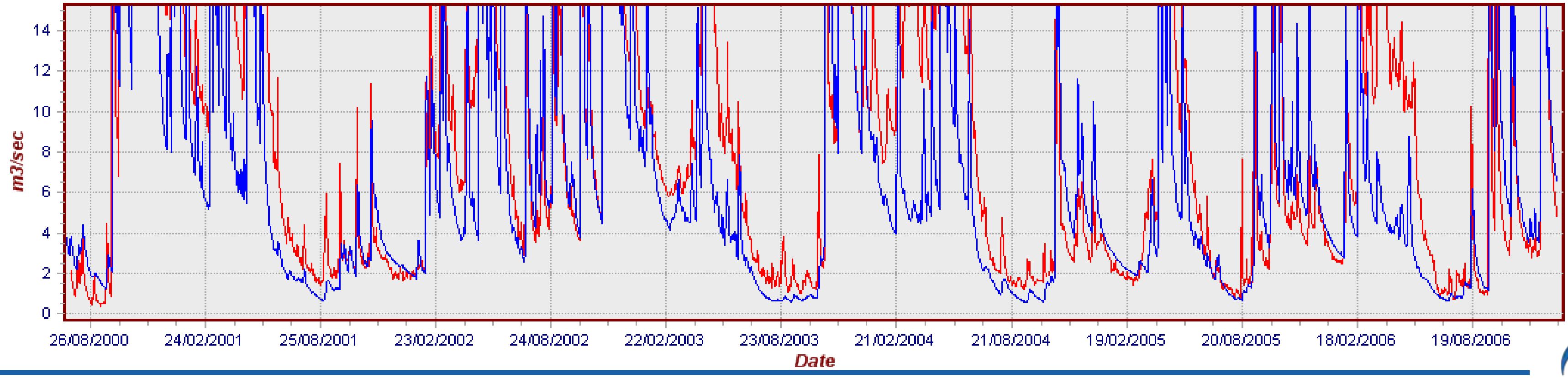
TOPKAPI calibration: Tanaro river at Pian Torre

Calibration period 2000 -2011

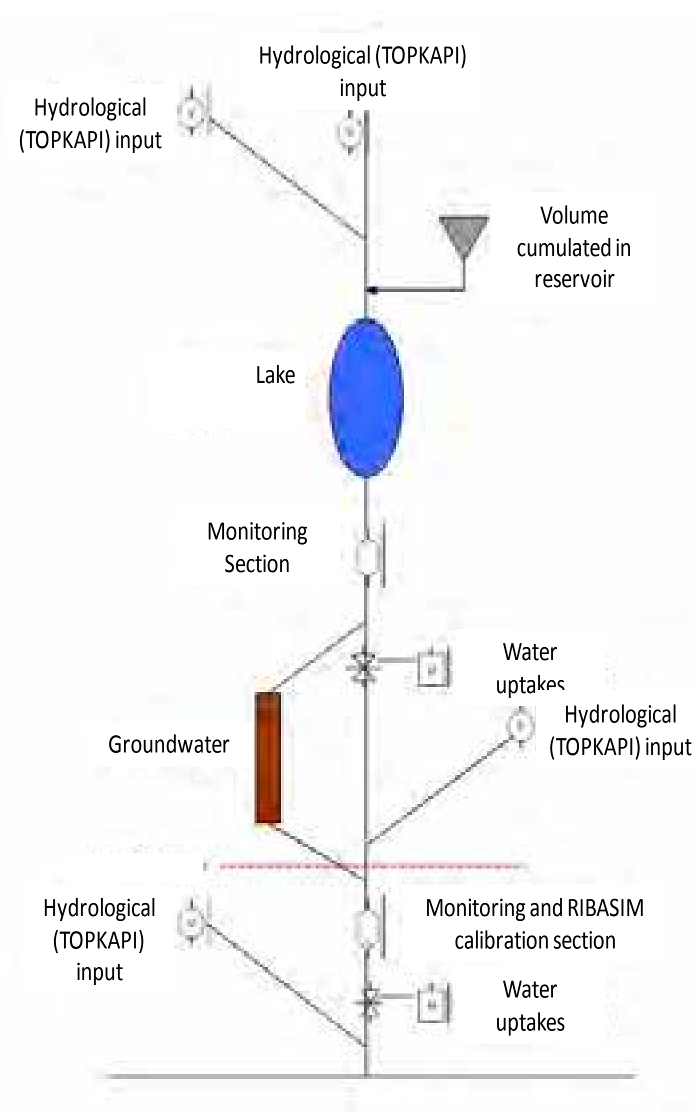
Pian Torre – Tanaro river	
Area (km^2)	500
Mean altitudine (m)	103
Annual withdrawal (m^3/s)	0
Summer withdrawal (m^3/s)	0
Winter withdrawal (m^3/s)	0

Flow – Duration Curve





River basin balance: RIBASIM



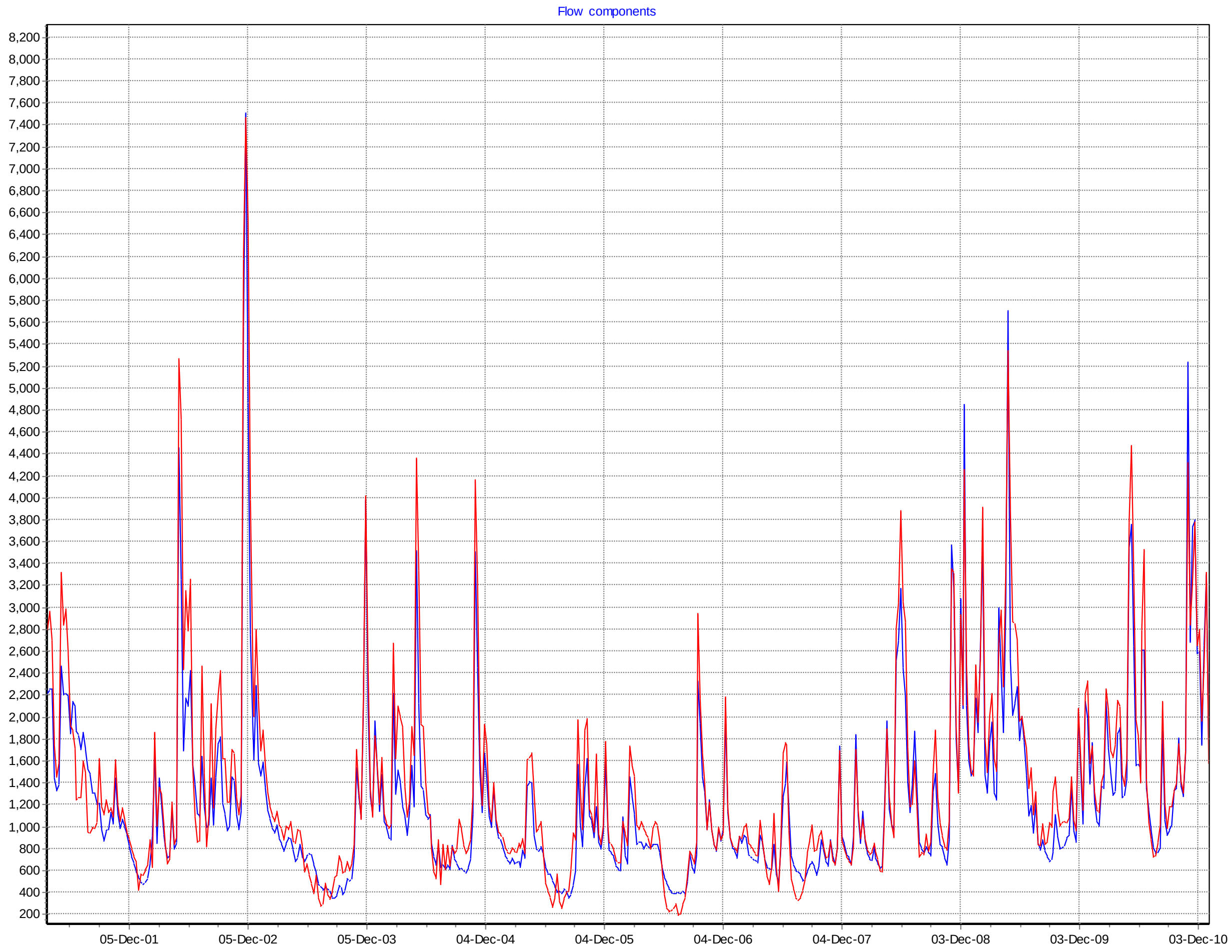
RIBASIM (RIver Basin SIMulation) is a water balance model developed by DELTARES on the basis of MITSIM model from MIT

The hydrological network is defined by links and nodes and water is distributed through links according to schematization and water demand at the nodes.

Nodes represent flow input sites (coupling between TOPKAPI and RIBASIM), groundwater and surface water reservoirs, irrigation areas, pubblic water supply points, control/ calibration section where verify the model performances

Links represent spatially homogenous river or channels, recharge, abstraction and outflow of groundwater diverted flow, backwater flow of the surface reservoir to end users

River Basin Balance: RIBASIM



Po at Pontelagoscuro

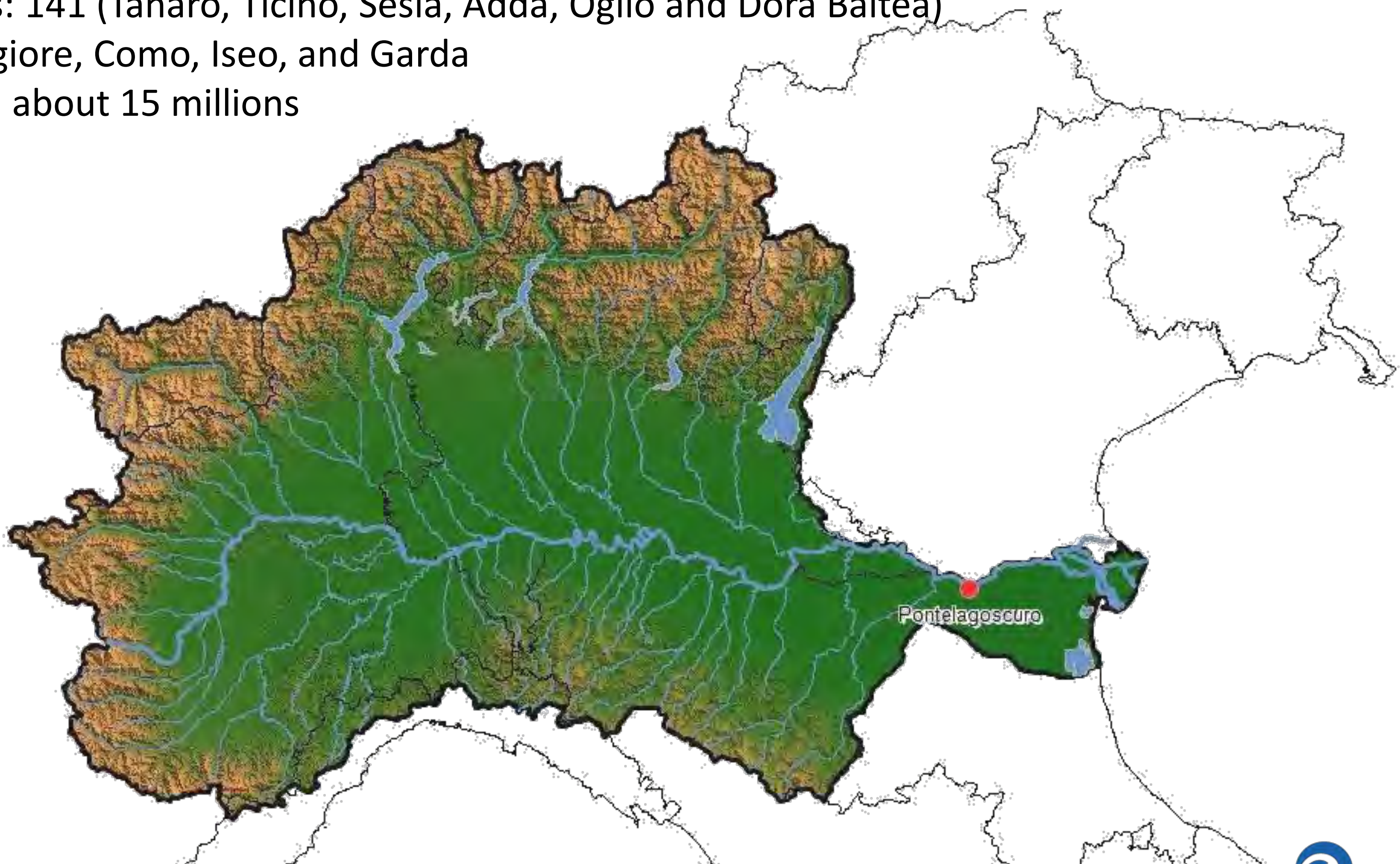
Calibration period 2000-2011

Observed mean 1453 m^3/s

Simulated mean 1386 m^3/s

Case Study: Po river basin

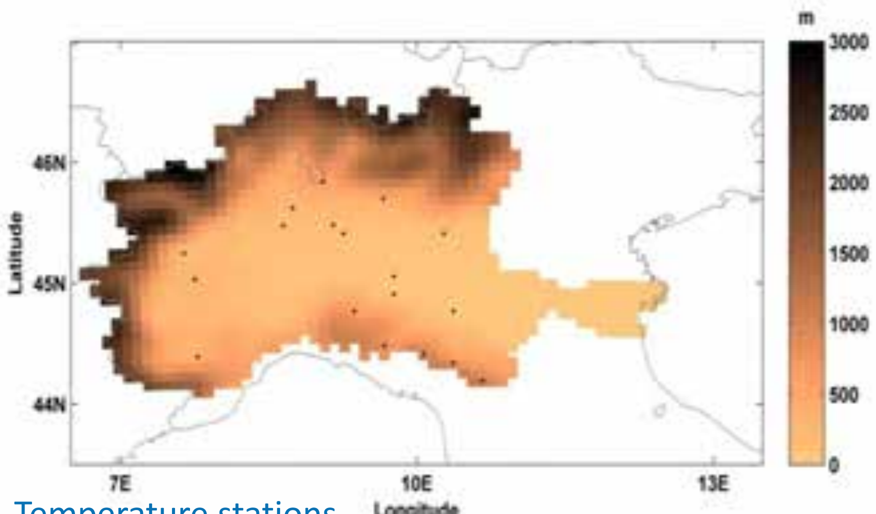
Area: about 74.000 km^2
Total length: 650 km
Tributarities: 141 (Tanaro, Ticino, Sesia, Adda, Oglio and Dora Baltea)
Lakes: Maggiore, Como, Iseo, and Garda
Inhabitants: about 15 millions



Hydrological run

Application to the period 1971-2000 of the TOPKAPI/RIBASIM chain calibrated to the period 2000-2011 driven by observed T and P

Aim:
estimate the error introduced by the use of 2000-2011 calibration in simulating the 1971-2000 discharge

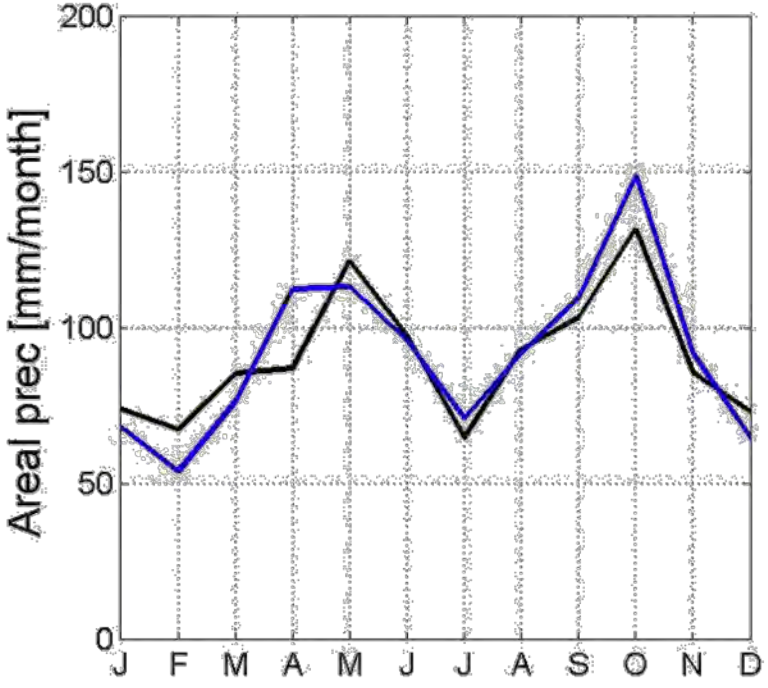


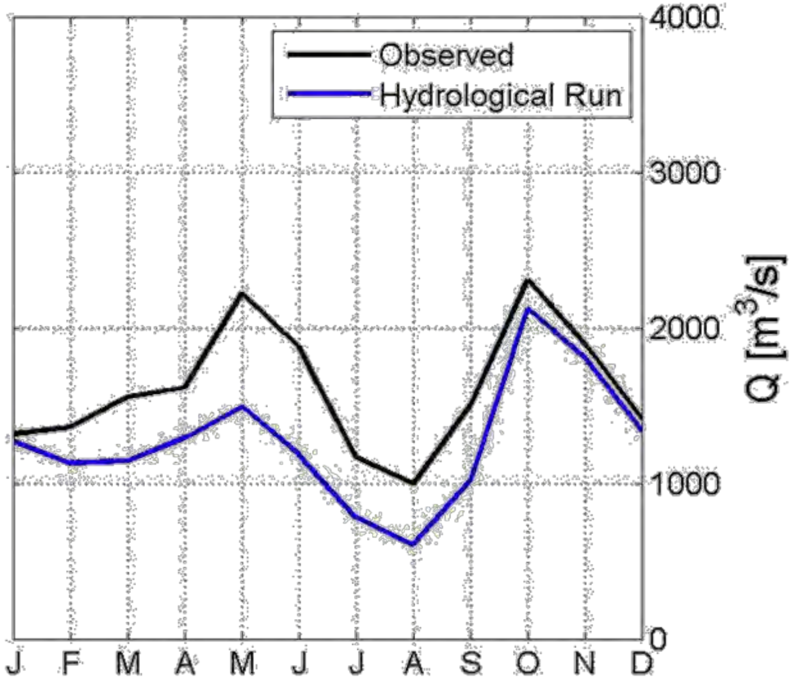
Temperature stations of EOBS dataset in Po river basin

1100 raingauge stations within Po river basin & Emilia Romagna region

Hydrological run 1971-2000: TOPKAPI/RIBASIM driven by P, T observed

The use of 2000-2011 calibration for TOPKAPI and RIBASIM causes a understimation in simulated discharge in 1971-2000,
In the next the outputs of the simulation runs will be compared with this run as representative of the period 1971-2000

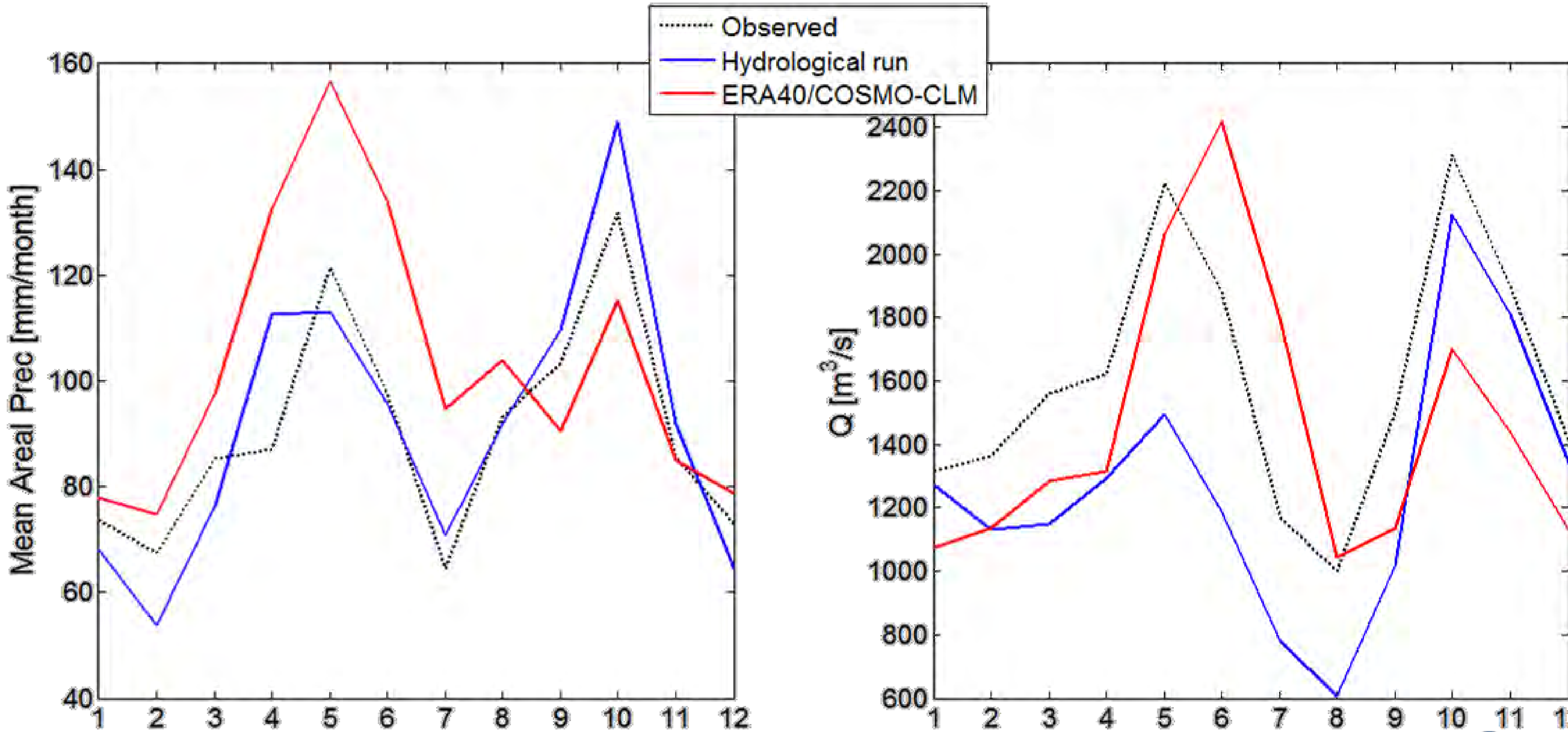




RCM run (perfect boundary conditions): COSMO-CLM driven by ERA40 Reanalysis

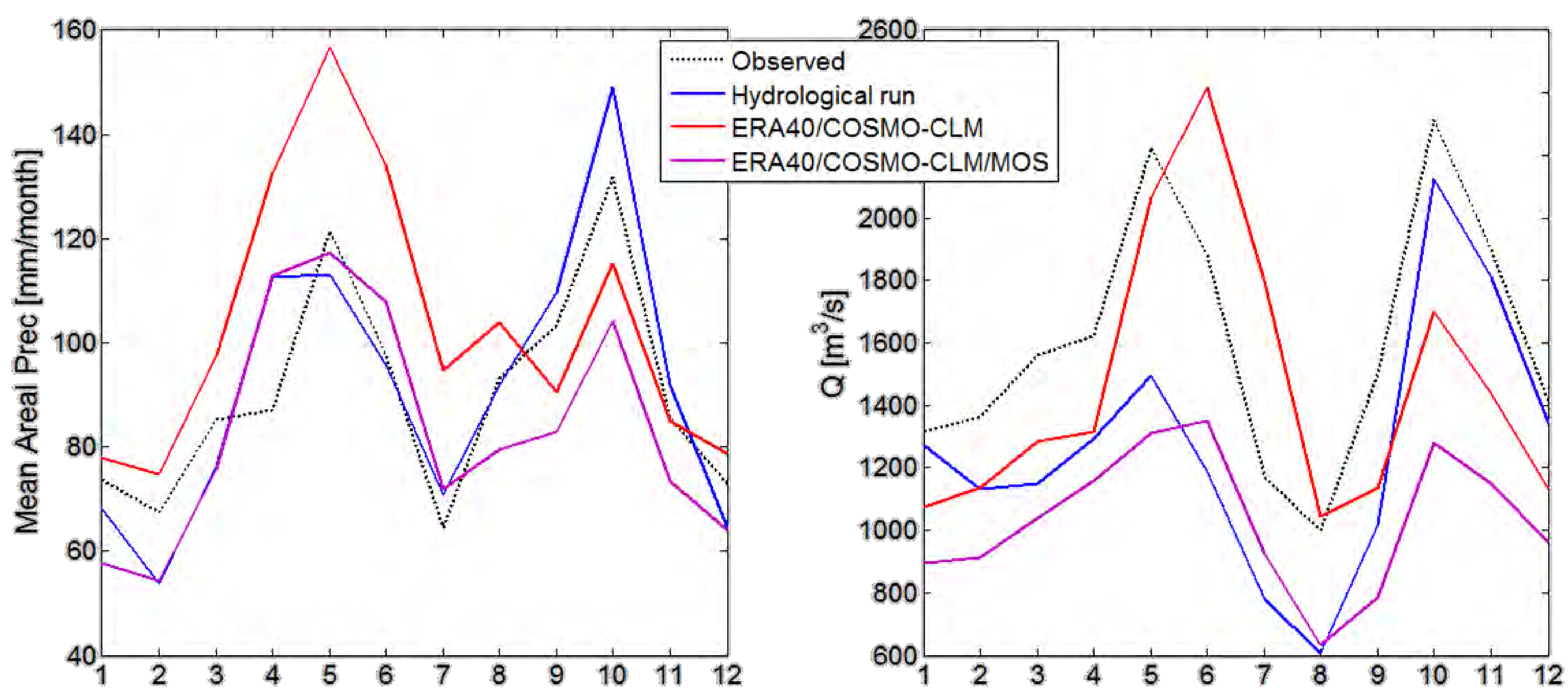
Aim:

estimate the additional error introduced by COSMO-CLM



RCM & SD run (under perfect boundary conditions): COSMO-CLM driven by ERA40 Reanalysis + MOS Analog

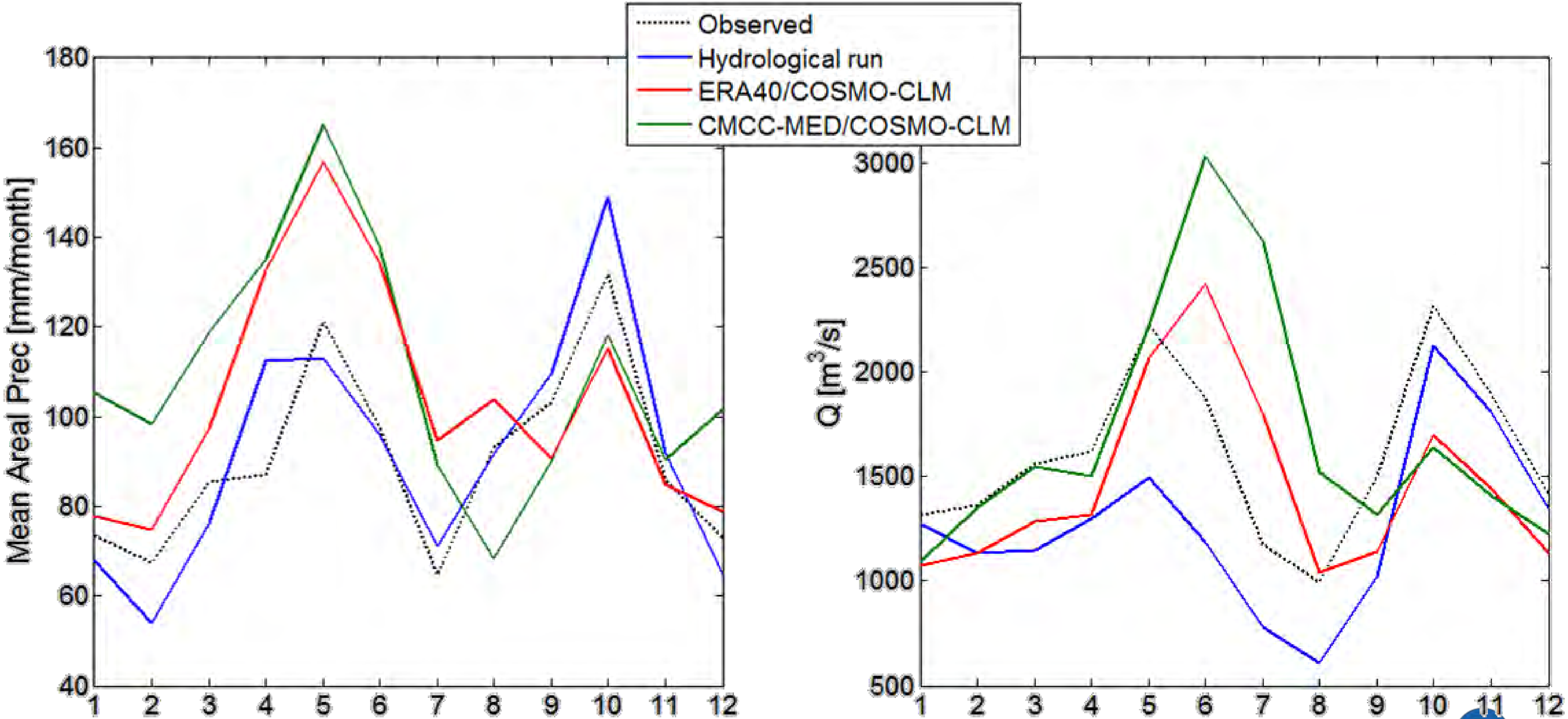
Aim:
estimate if MOS analog technique is sufficient to "correct" COSMO-CLM error in precipitation



GCM & RCM run:
COSMO-CLM driven by CMCC-MED

Aim:

estimate the error introduced by CMCC-MED and COSMO-CLM in the precipitation



Preliminary Conclusions

The simulation driven by ERA40 (perfect boundary conditions) overestimates precipitation and discharge in Spring and understimates in Autumn,

The application of a statistical downscaling techniques based on analogs improves the reproduction of precipitation variability and Spring precipitation, while precipitation (discharge) in Autumn is still understimated

The CMCC-MED/COSMO-CLM overestimates preciptation from January to August this is reflected in the discharge behaviour

Further Developments

To test bias correction tecniques or mixed statistical downscaling and bias correction tecniques to correct the COSMO-CLM precipitation and temperature fields

To evaluate the possibility of applying bias correction directly on the hydrological simulations outputs (discharge) e.g. quantile-quantile mapping

To consider more RCP scenarios and/or more GCM / RCM tecnique for ensamble approach

To apply weather generator based techniques to temporally downscale RCM outputs (flood generation processes)

Use hydrological simulation outputs to droughts/flood risk analysis

Thank you
for the attention

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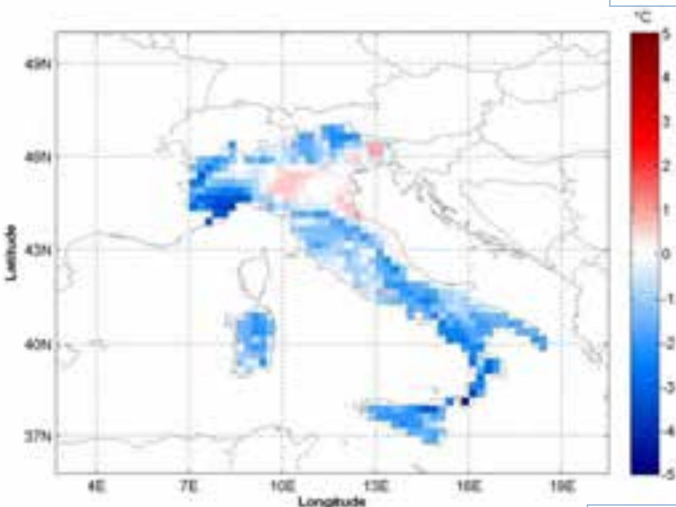
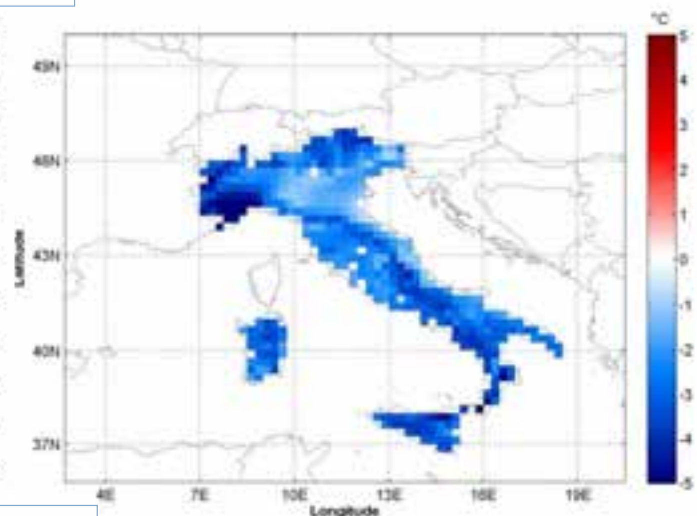
Bias of temperature (COSMO-EOBS) (° C): 1972-2000

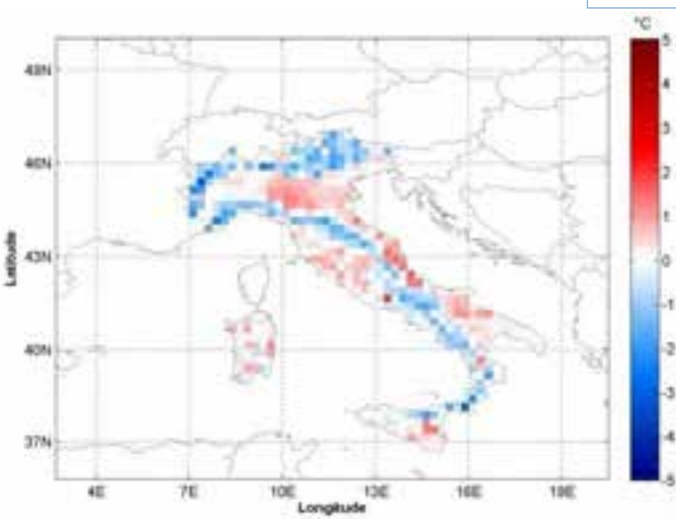
ERA40 driven | **CMCC-MED driven**

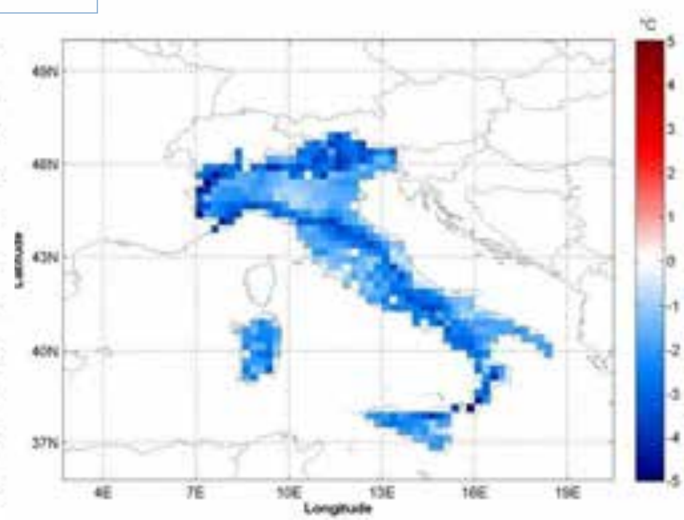
DJF





MAM





Apennines and Alps are characterized by a higher underestimation than other regions, especially in DJF.

In the ERA40 driven simulation, the spring temperature is well reproduced (bias less than 1.5° C).

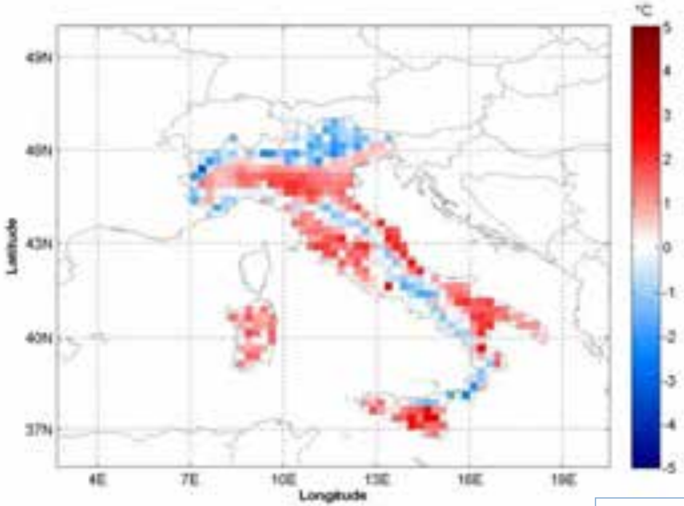
The simulation driven by CMCC-MED is strongly colder than the one driven by ERA40.

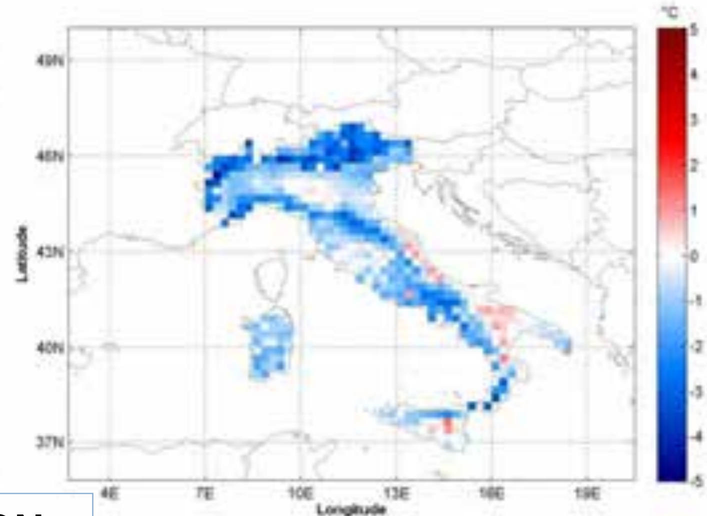
Bias of temperature (COSMO-EOBS) (° C): 1972-2000

ERA40 driven

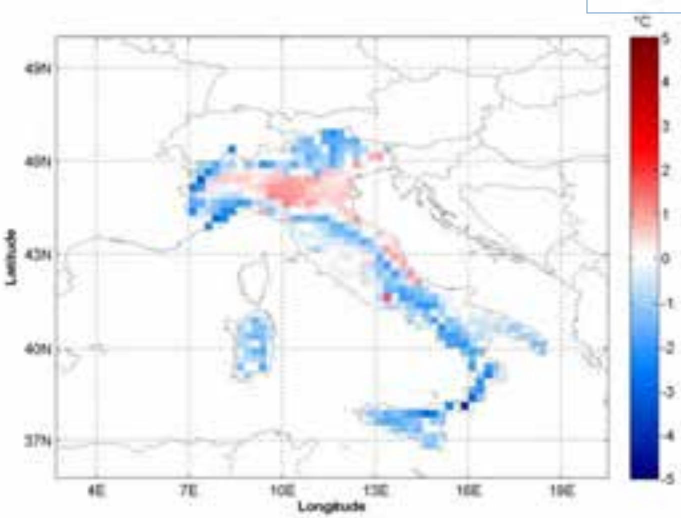
CMCC-MED driven

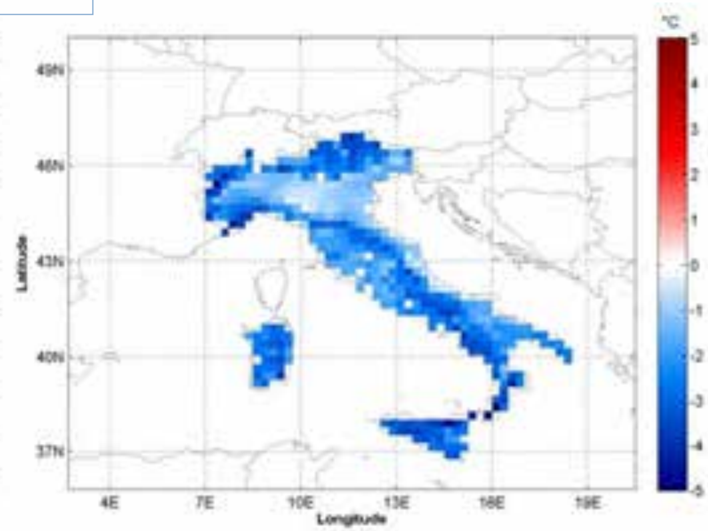
JJA





SON





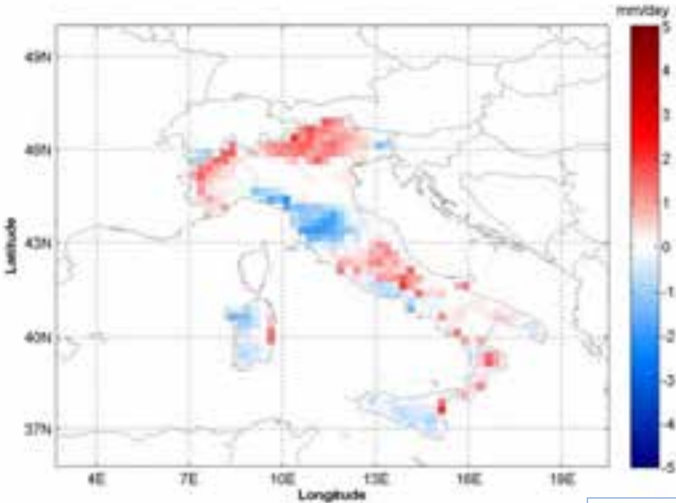
In JJA, the ERA40 driven simulation generally overestimates the temperature. The cold bias of the CMCC-MED driven simulation, instead, is lower with respect to the other seasons.

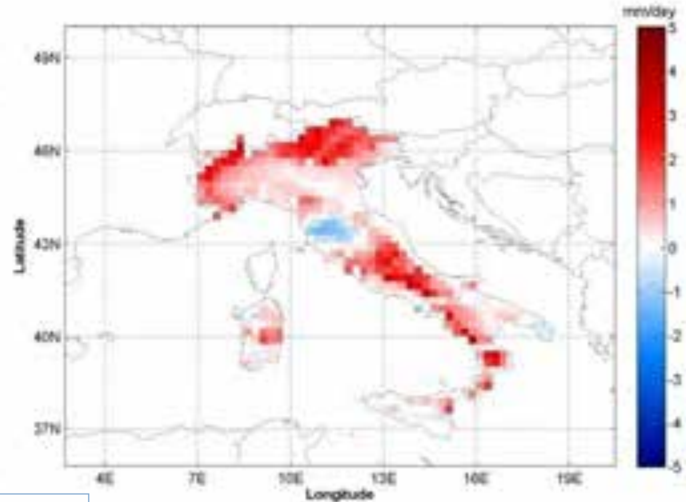
The temperature in SON is well reproduced by the ERA40 forced simulation.

Bias of precipitation (COSMO-EOBS) (mm/day): 1972-2000

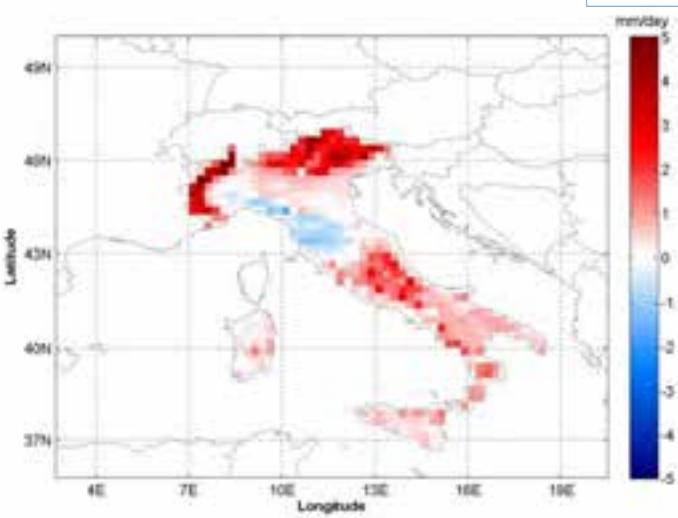
ERA40 driven | **CMCC-MED driven**

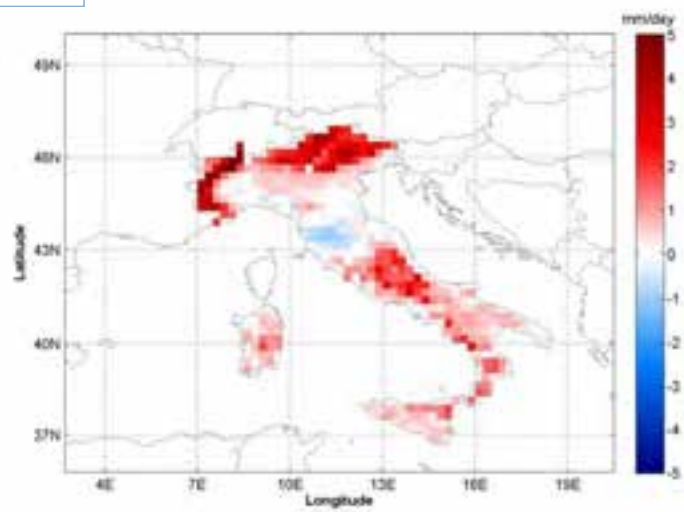
DJF





MAM





The difference between the results of the two simulations is less evident with respect to what observed for the temperature.

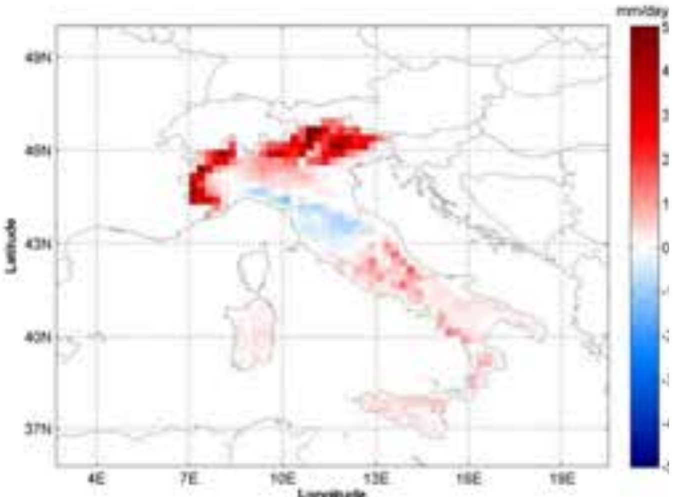
In DJF, the simulation driven by CMCC-MED shows a higher over-estimation than the one driven by ERA40, where the bias does not exceed 1.5 mm/day.

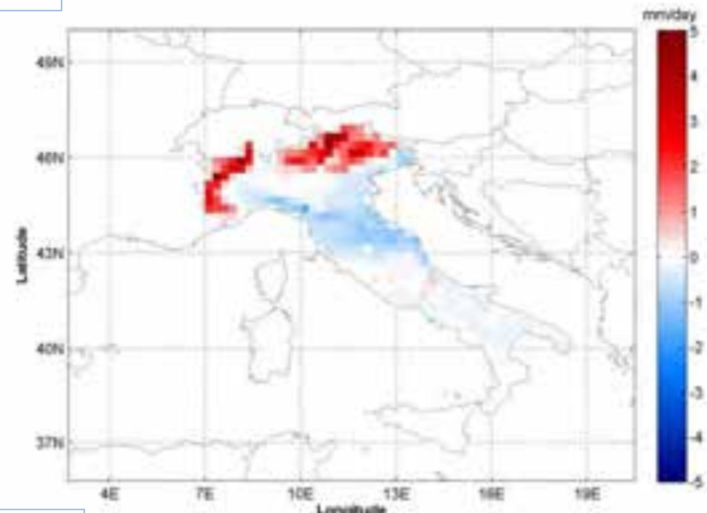
In MAM, the strongest overestimation occurs, especially over the Alps (5 mm/day).

Bias of precipitation (COSMO-EOBS) (mm/day): 1972-2000

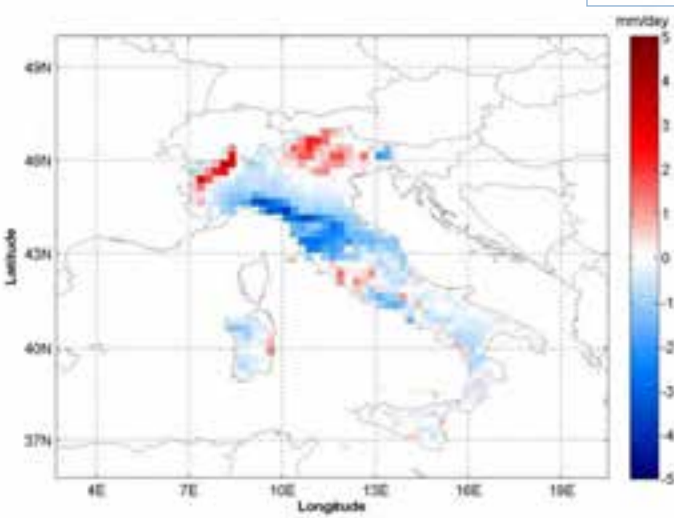
ERA40 driven | **CMCC-MED driven**

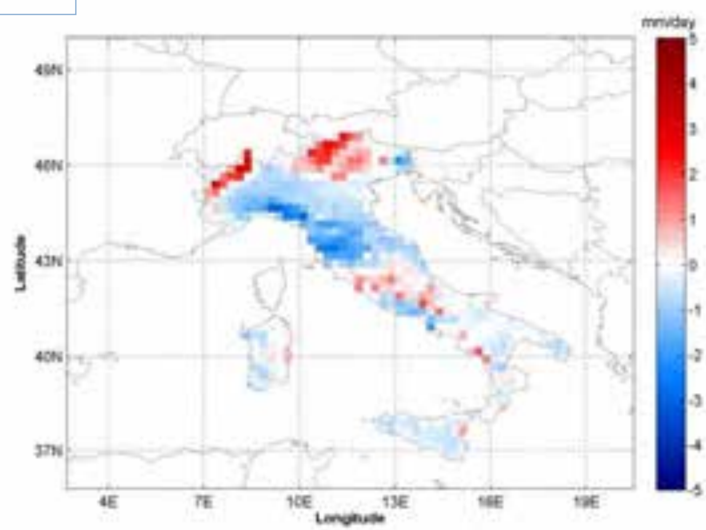
JJA





SON

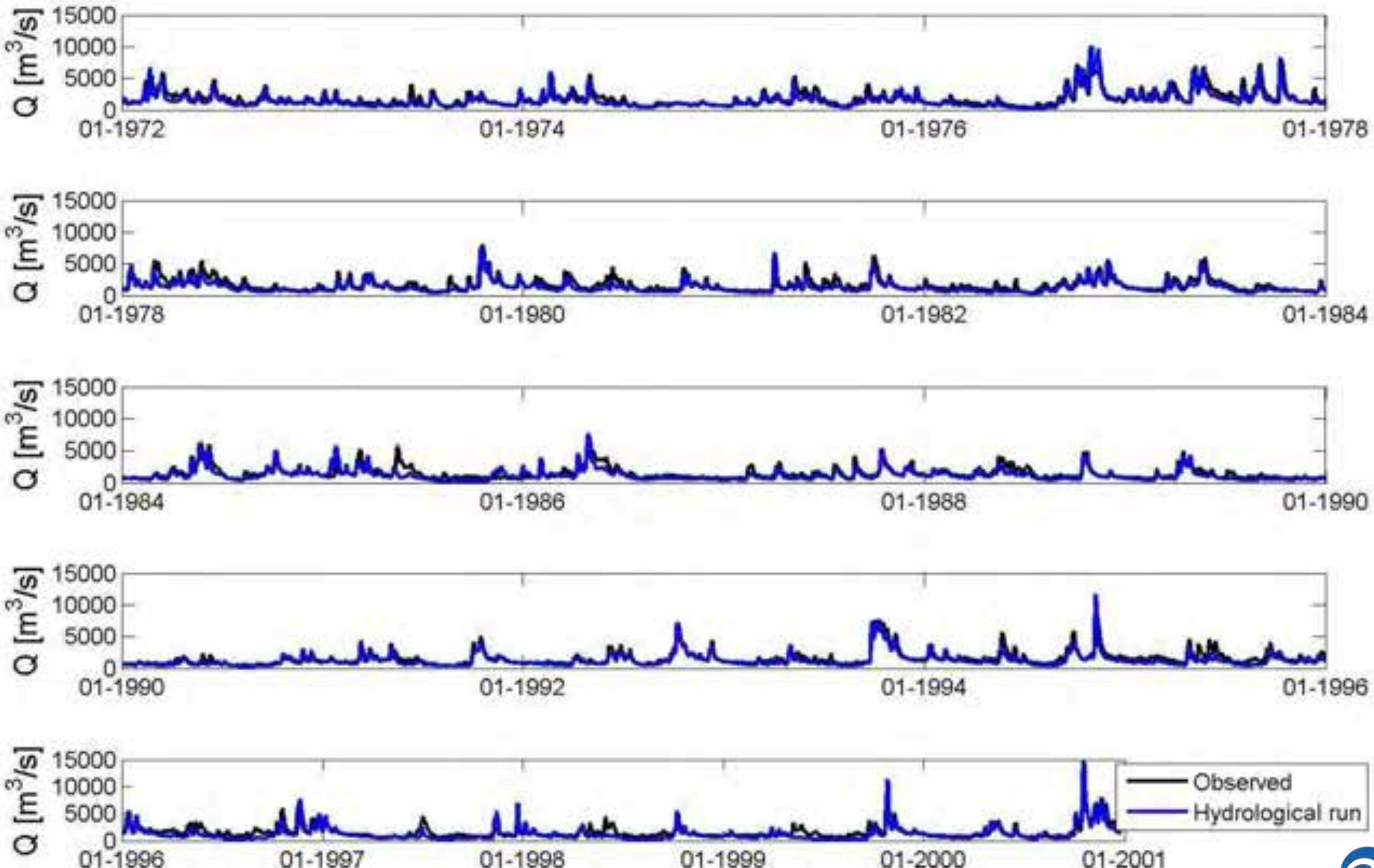




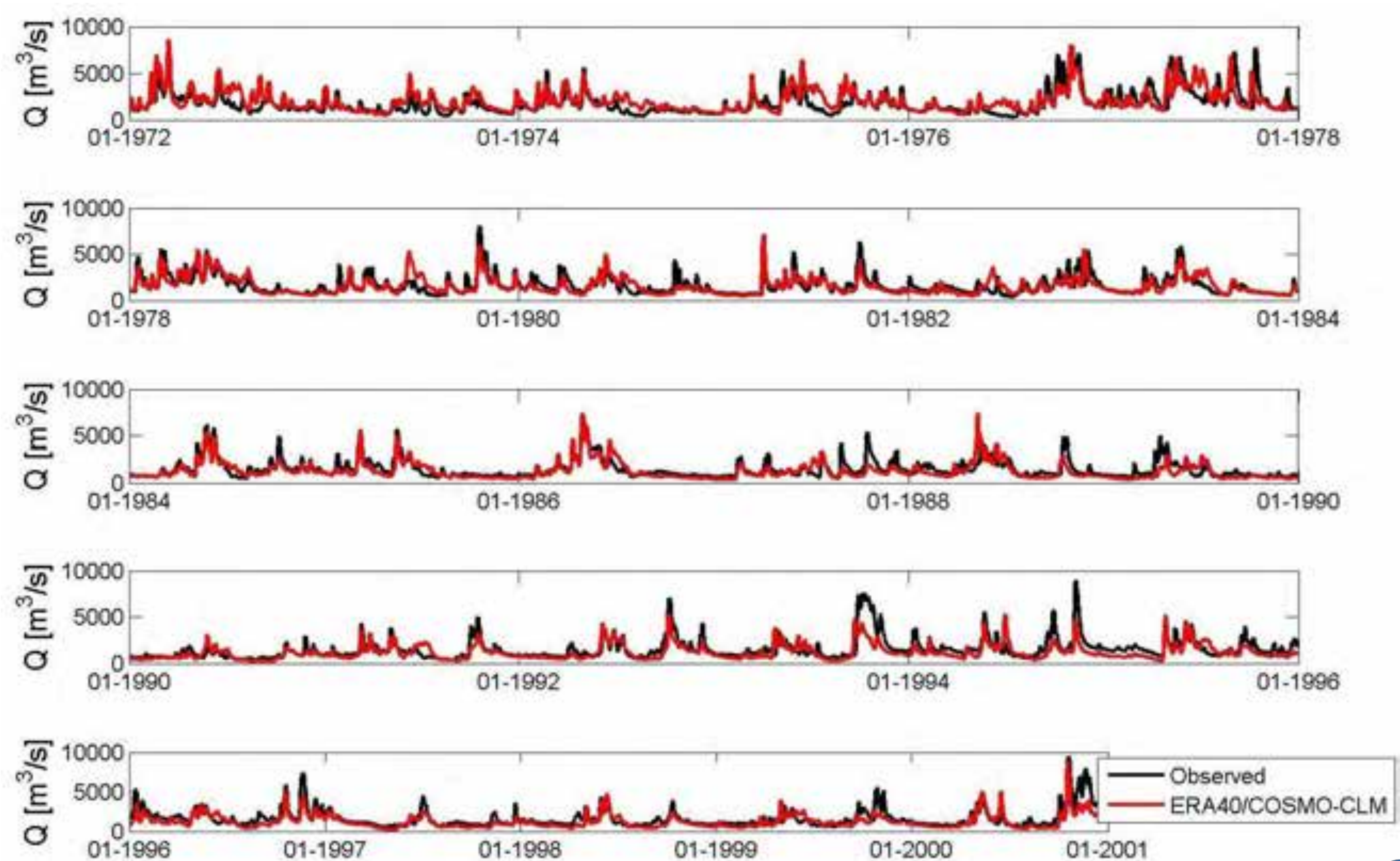
In JJA there is a very good agreement (±0.5 mm/day), except over the Alps. In the simulation driven by CMCC-MED, the bias is close to 0 mm/day in the central and south regions.

In SON the results of the two simulations are very similar, with a high underestimation on Tuscany (-3 mm/day)

Hydrological run: TOPKAPI/RIBASIM driven by P, T observed



RCM run (perfect boundary conditions): COSMO-CLM driven by ERA40 Reanalysis



RCM & SD run (perfect boundary conditions): COSMO-CLM driven by ERA40 Reanalysis + MOS Analog