Climate change impact on the discharge of the Italian river network using Convection Permitting climate models

Luiza Vargas de Oliveira Heinz

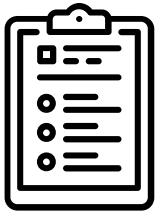
12th Workshop on the Theory and Use of Regional Climate Models

29/08/2025

UNIVERSITÀ DEGLI STUDI DI TRIESTE

The Abdus Salam International Centre for Theoretical Physics

Motivation



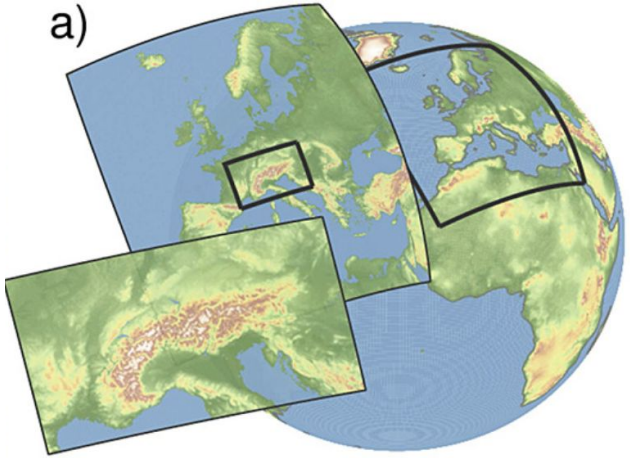
Use the CETEMPS hydrological model (CHyM) to see climate change impact on Italy's river network by way of convection permitting (CP) models

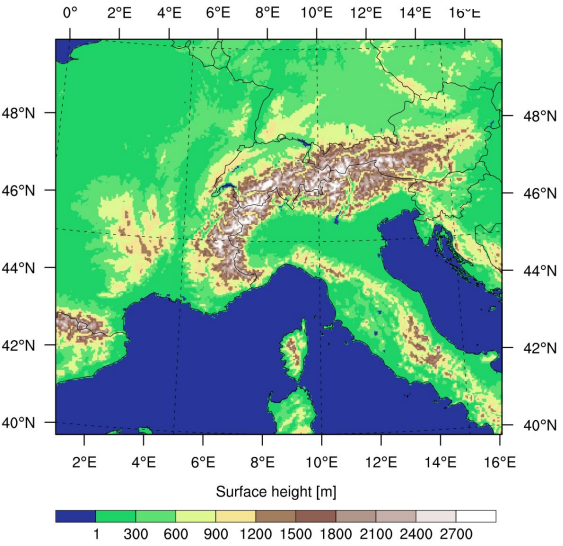
Assess if there is any improvement in the description of the hydrological cycle when using a convection permitting resolution

Use CP ensemble to

- validate the method against station data of river discharge
- analyse the climate change signal for the end of century period under the rcp85 scenario

Introduction





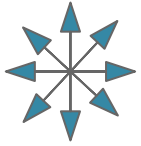
FPSCONV CORDEX

- ➔ Ensemble of convection permitting (CP) models (3km resolution, Great Alpine Domain) made available recently
- ➔ Explicit treatment of deep convection without the use of convection parameterization schemes

Ban, N., Caillaud, C., Coppola, E. *et al*. The first multi-model ensemble of regional climate simulations at kilometer-scale resolution, part I: evaluation of precipitation. *Clim Dyn* **57**, 275–302 (2021).

Introduction

CETEMPS hydrological model (CHyM)



- Grid based hydrological model developed at University of L'Aquila
- Simulates hydrological cycle with an eight-flow direction river network employing a Cellular Automata theory-based algorithm
- Hourly streamflow simulated for 7 different Italian regions (Calabria and Sicily excluded)

CHyM - TP

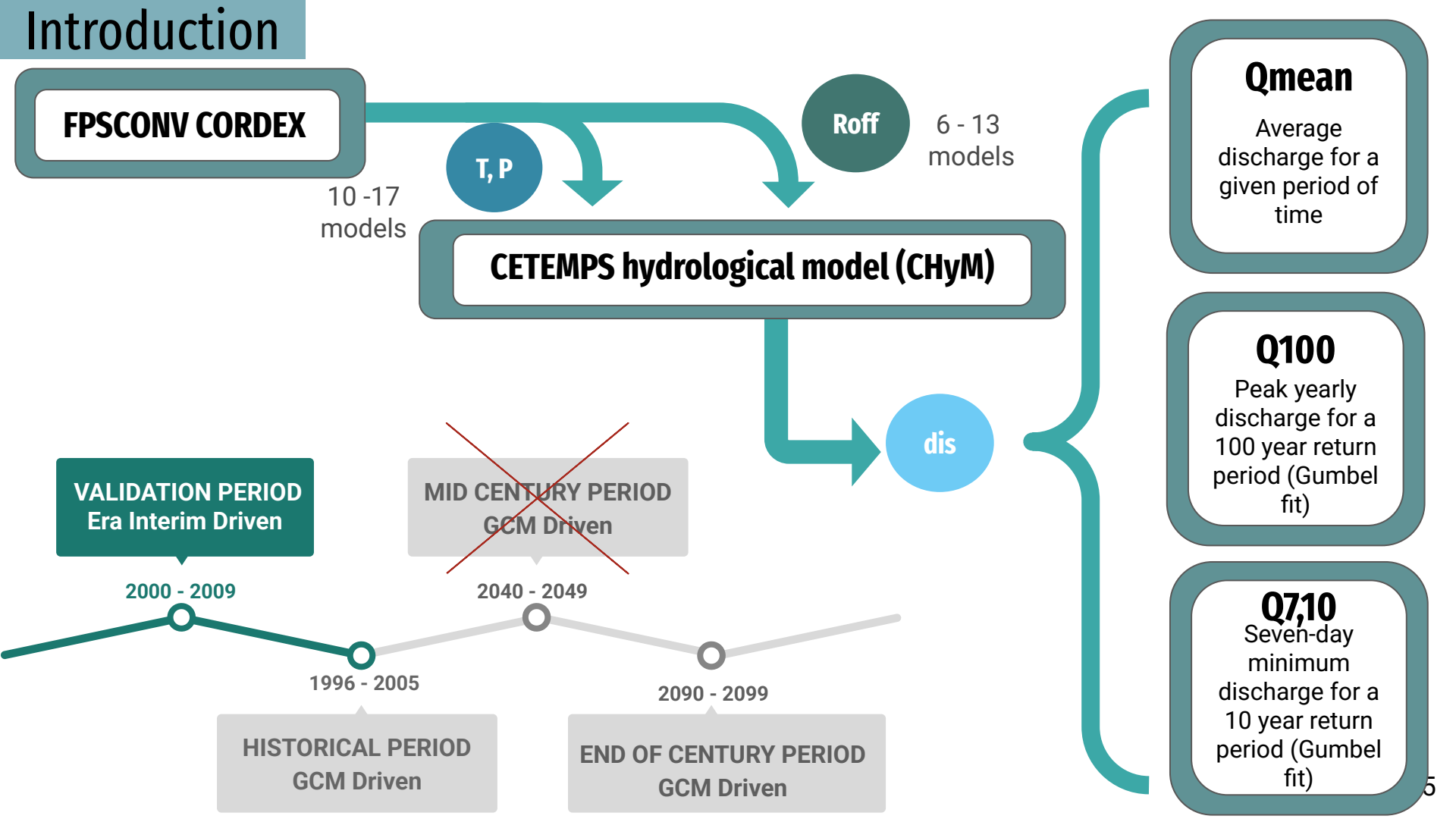
Uses temperature and precipitation to calculate the discharge

CHyM - roff

Directly routes the runoff from climate outputs

Coppola, E., Tomassetti, B., Mariotti, L., Verdecchia, M., & Visconti, G. (2007). Cellular automata algorithms for drainage network extraction and rainfall data assimilation. *Hydrological Sciences Journal*, *52*(3), 579–592.

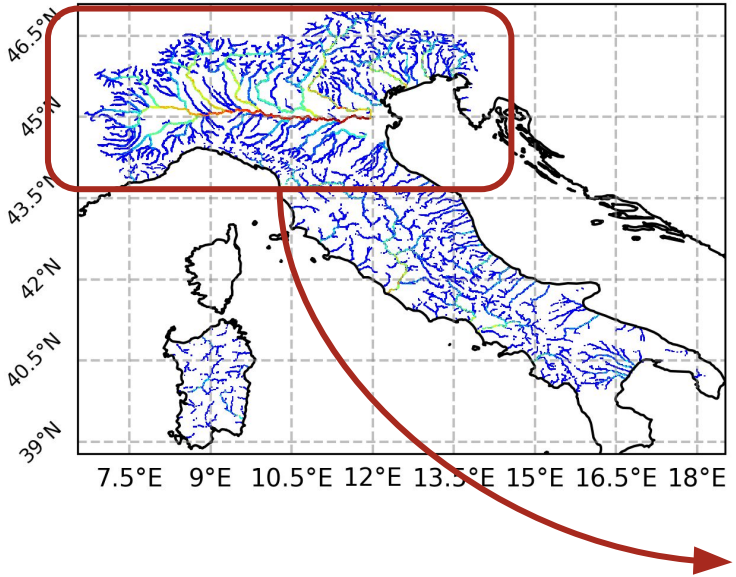
Introduction



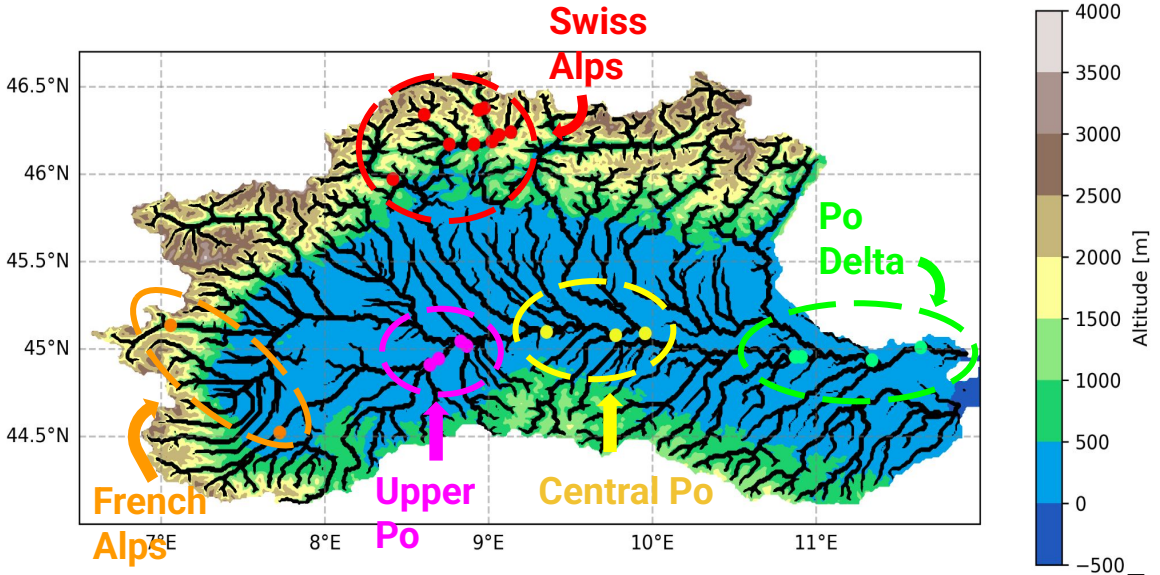
Introduction

Ensemble name	Resolution of input	Number of ensemble members	CHyM setting
CP TP	3km	10 - 17	T + P
CP Roff	3km	6 - 13	Runoff
CORDEX Roff	11km	44	Runoff
CMIP5 Roff	50km	13	Runoff

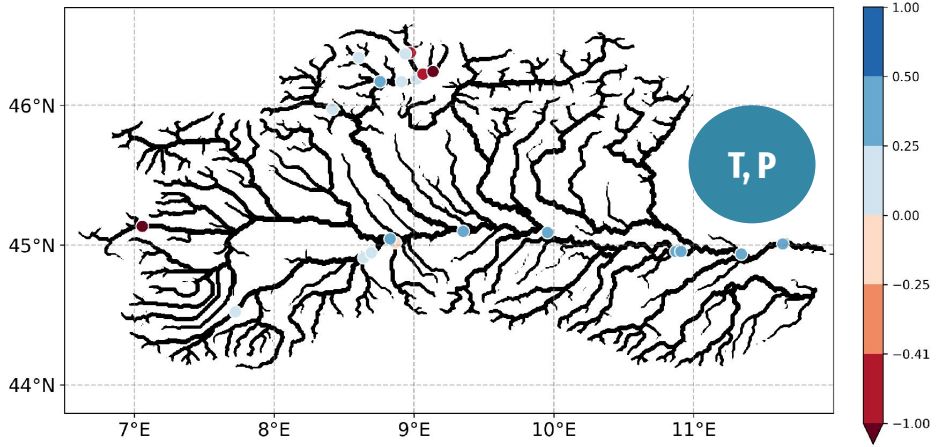
Validation

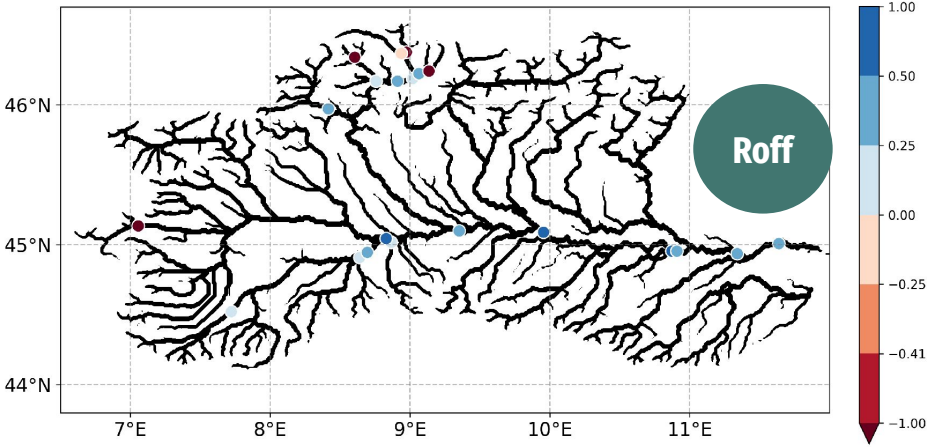


Po Valley Station Selection

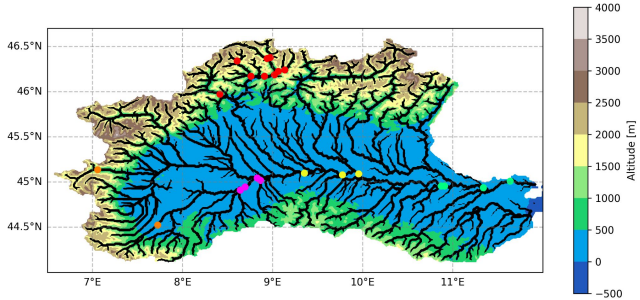


Kling-Gupta Efficiency (KGE)



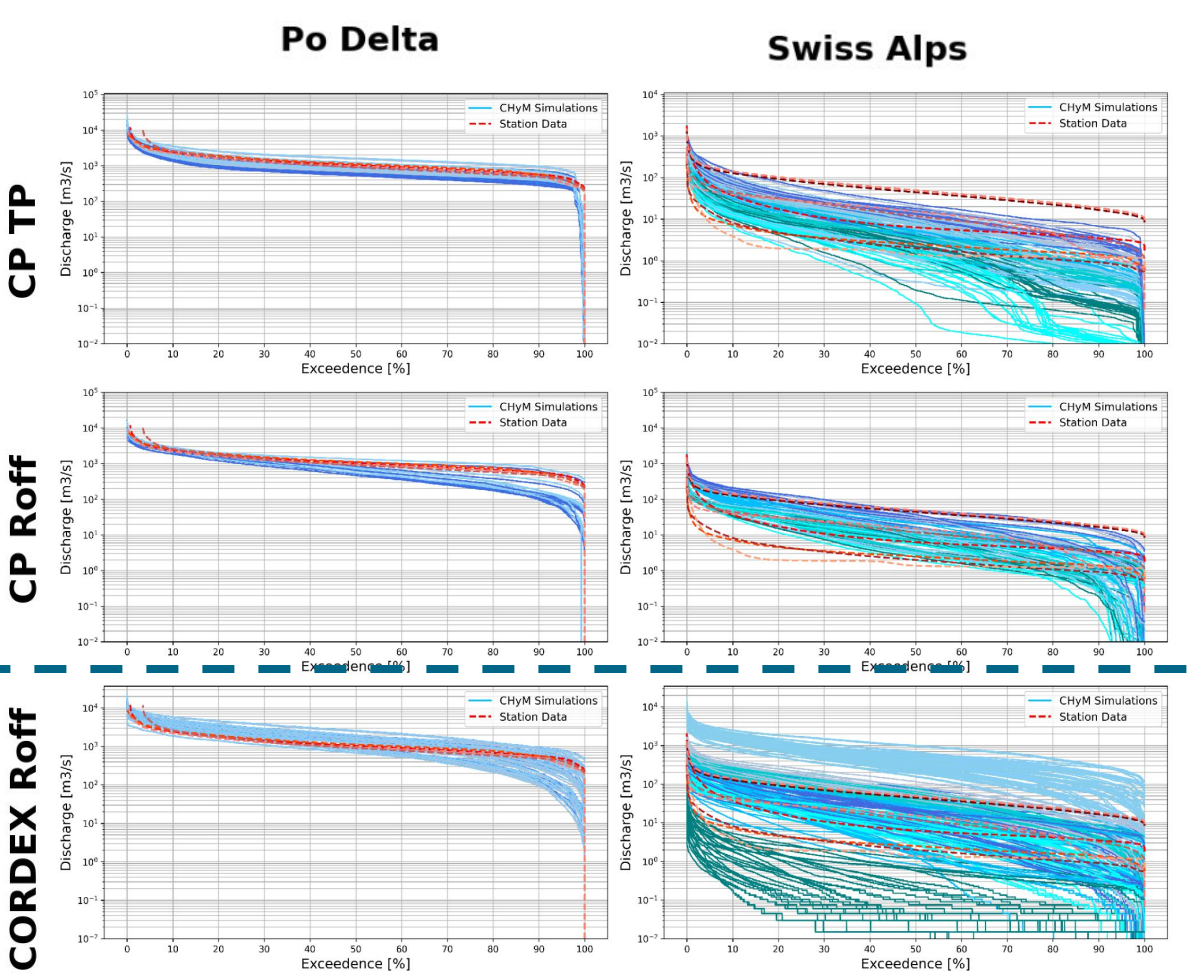


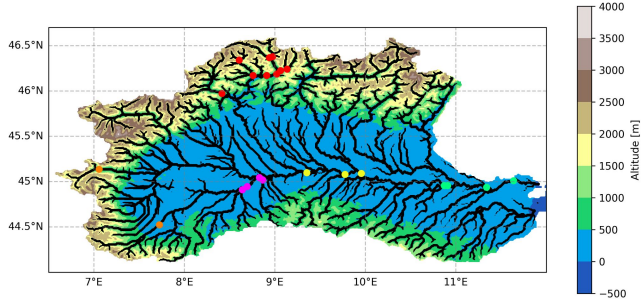
Skill Score	Equation	Range
Kling-Gupta Efficiency (KGE)	$1 - \sqrt{(r-1)^2 + (\beta-1)^2 + (\alpha-1)^2}$	$(-\infty, 1]$
Correlation term of the KGE (r)	$\frac{\sum_{i=1}^{n}(Q_{sim}(i) - \bar{Q}_{sim})(Q_{obs}(i) - \bar{Q}_{obs})}{\sqrt{\sum_{i=1}^{n}(Q_{sim}(i) - \bar{Q}_{sim})^2 \sum_{i=1}^{n}(Q_{obs}(i) - \bar{Q}_{obs})^2}}$	$[-1, 1]$
Bias term of the KGE (β)	$\frac{\bar{Q}_{sim}}{\bar{Q}_{obs}}$	$[0, \infty)$
Variability term of the KGE (α)	$\frac{\sigma_{sim}}{\sigma_{obs}}$	$[0, \infty)$



García-Valdecasas Ojeda, M., Di Sante, F., Coppola, E., Fantini, A., Nogherotto, R., Raffaele, F., & Giorgi, F. (2022). Climate change impact on flood hazard over Italy. *Journal of Hydrology*, *615*, 128628.

Validation





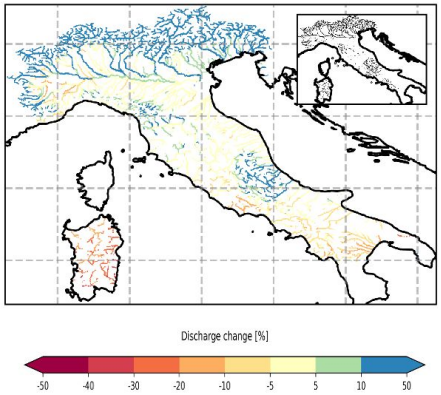
3km

11km

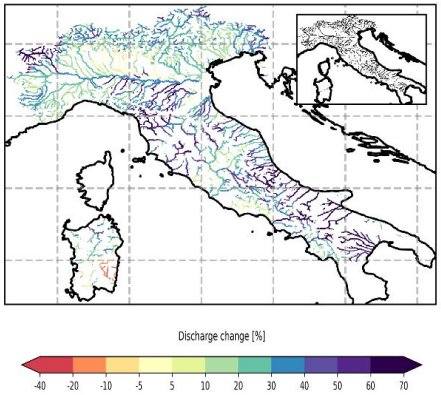
Smaller range of outputs and closer to station data for higher resolution

(End-of-century signal) - (Historical signal)

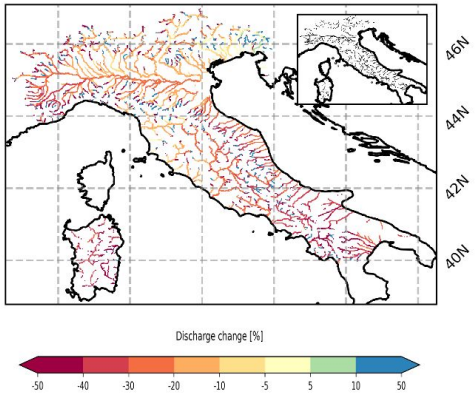
Qmean



Q100

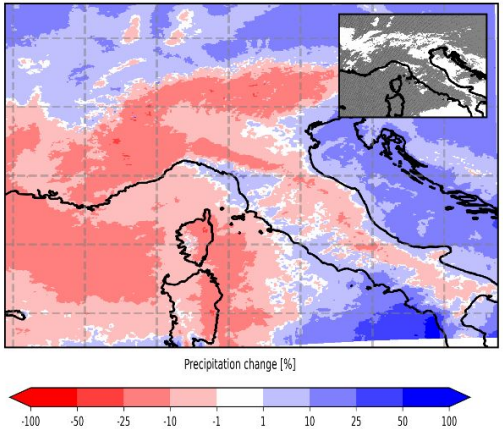


Q710

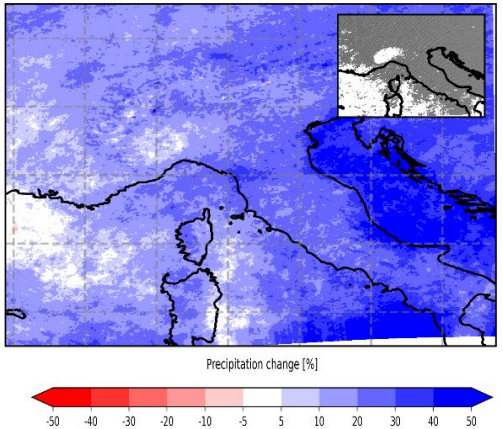


Average value and droughts governed by average precipitation; Floods and Alpine signal governed by extreme precipitation;

Average PR

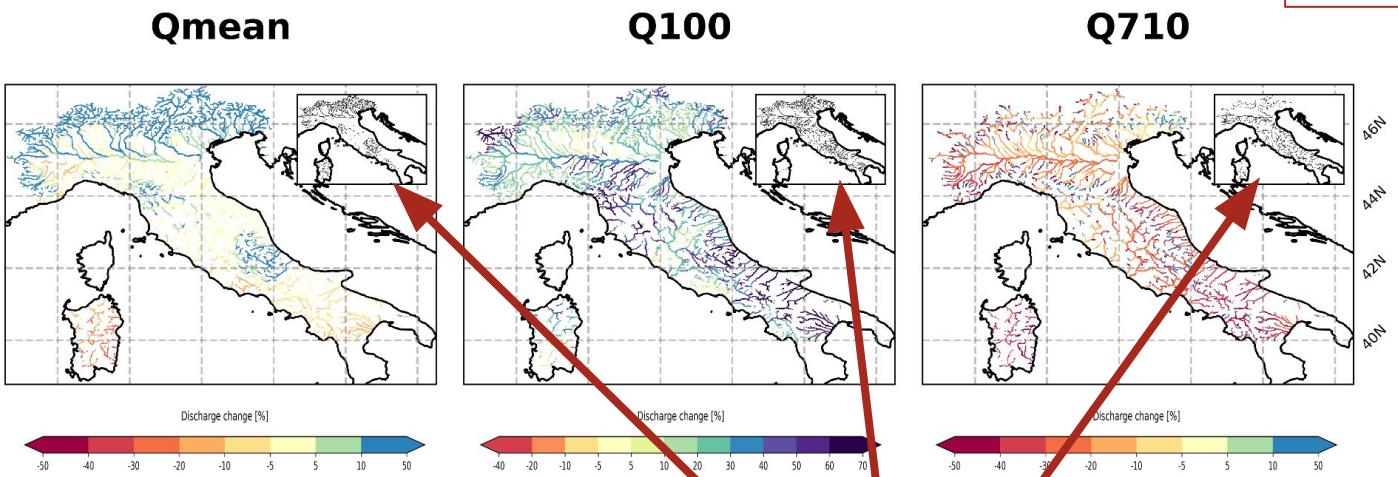


P99.9th

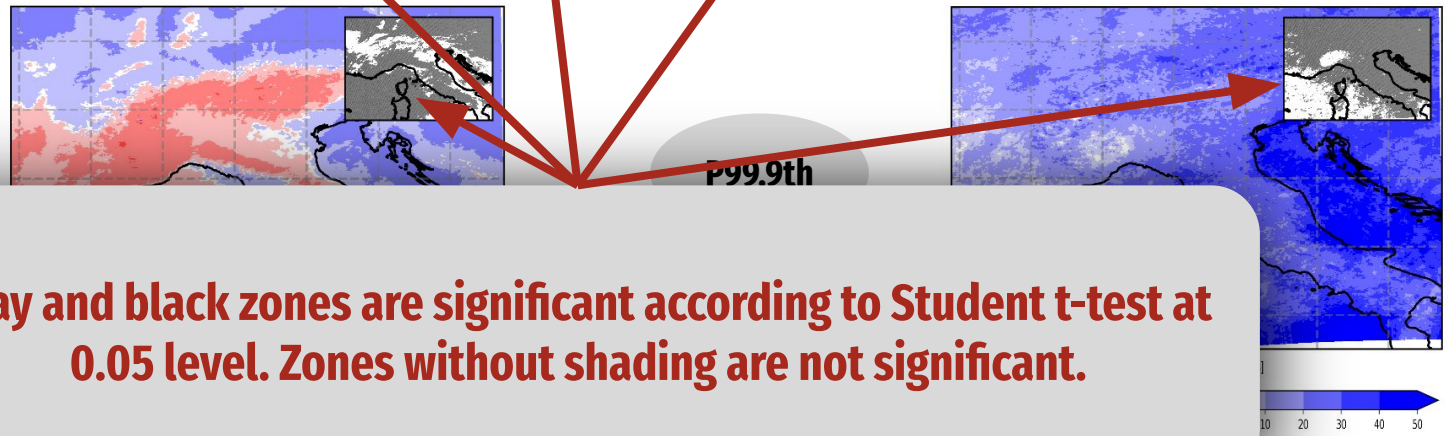


Climate change signal SSP585

(End-of-century signal) - (Historical signal)

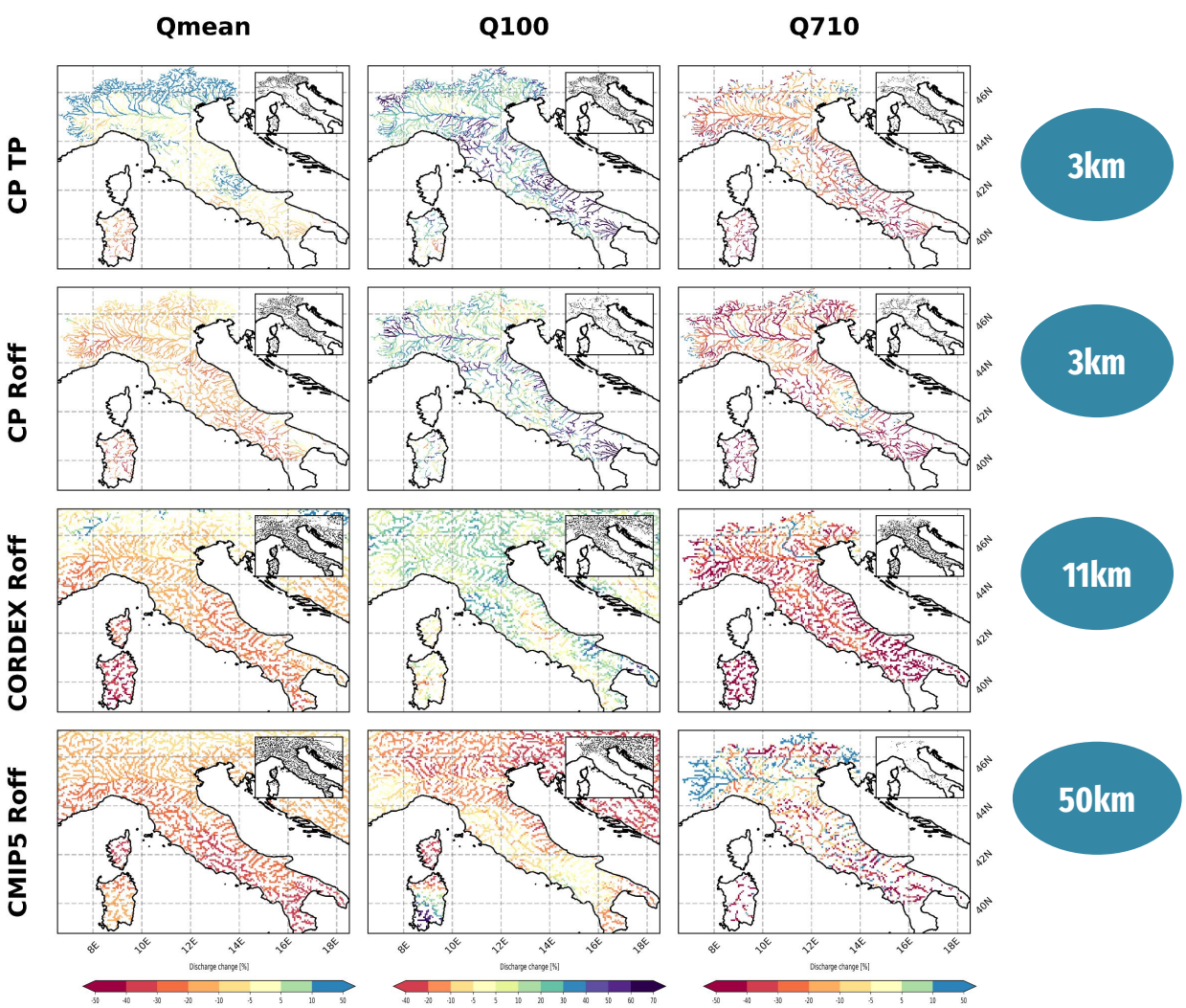


Average value and droughts governed by average precipitation; Floods and Alpine signal governed by extreme precipitation;



Gray and black zones are significant according to Student t-test at 0.05 level. Zones without shading are not significant.

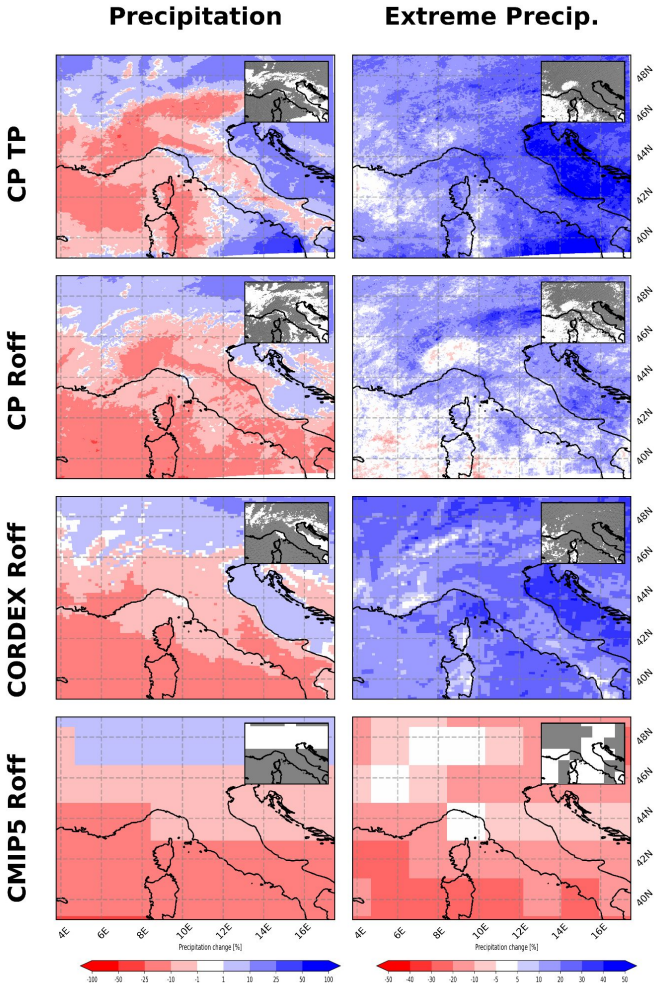
Climate change signal SSP 585



Change in yearly values

More floods and more droughts;
Average discharge decrease with varying signal in the Alps;

(End-of-century signal) - (Historical signal)



3km

3km

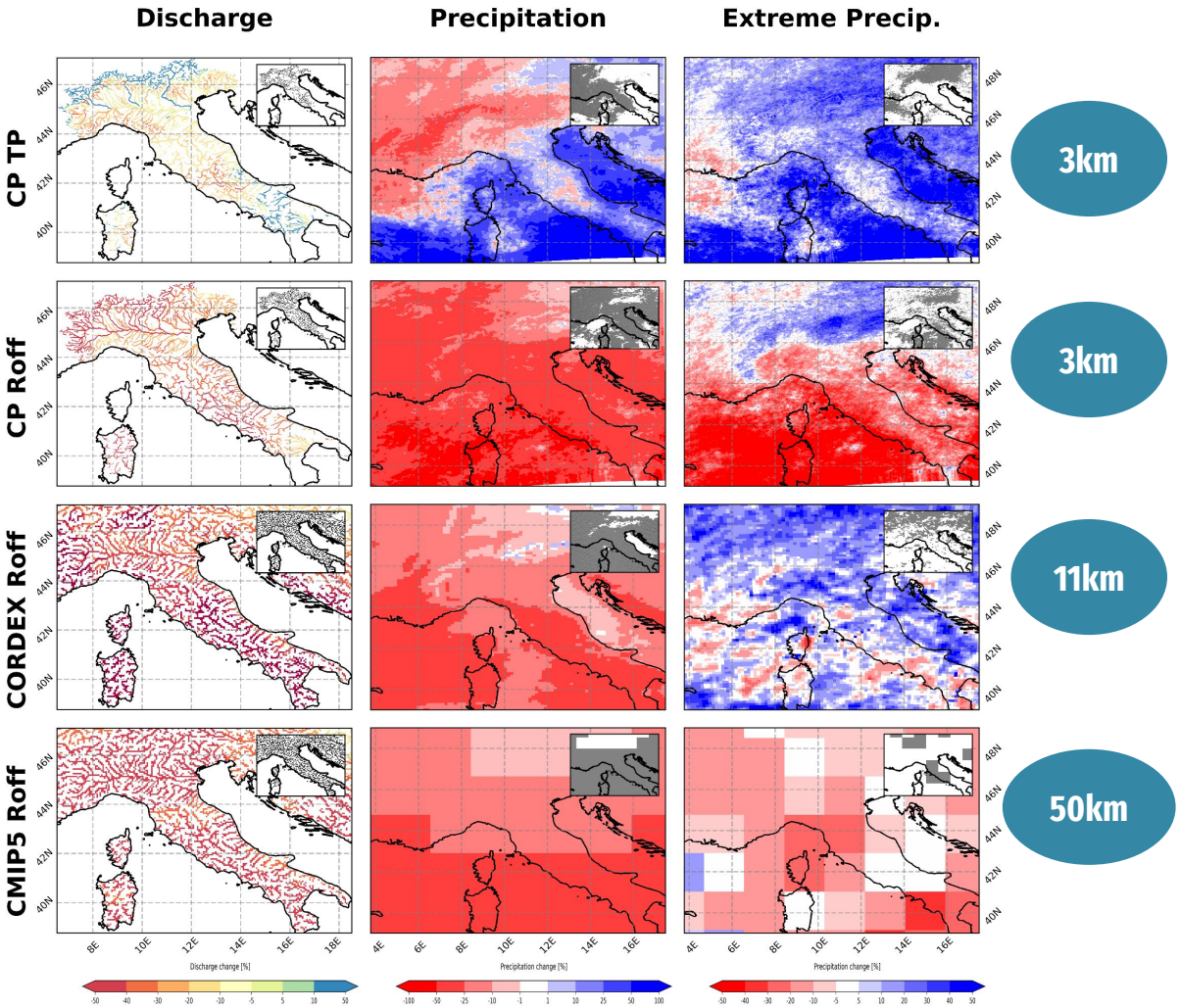
11km

50km

Change in yearly values

Floods modulated by extreme precipitation and droughts by average precipitation;

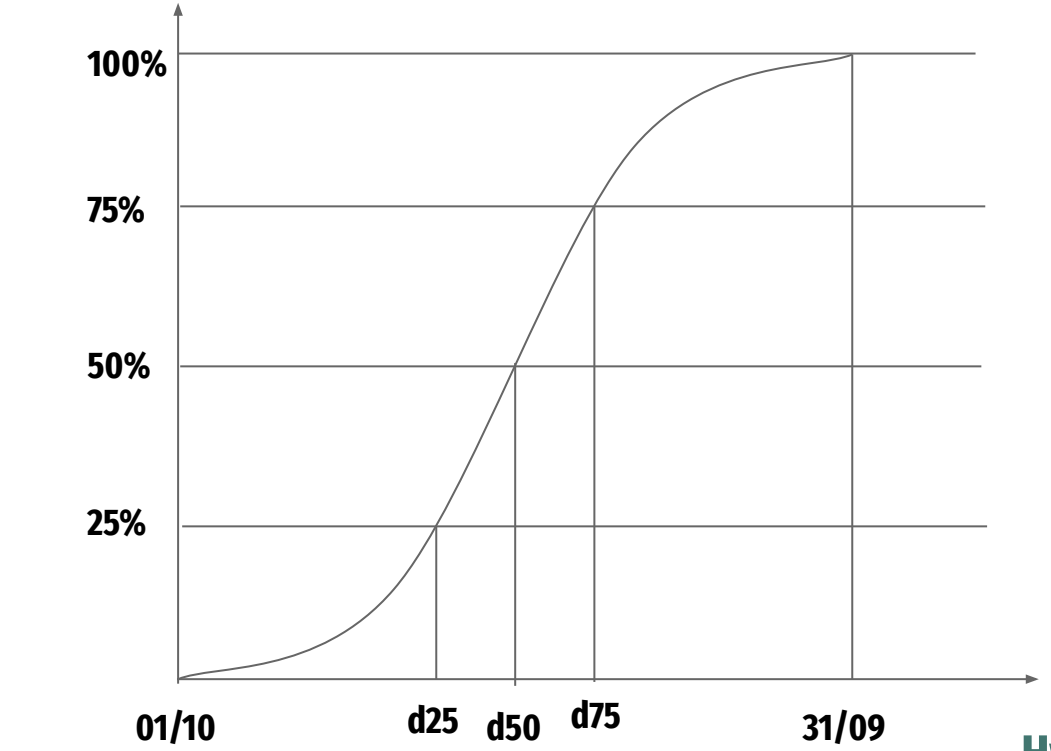
(End-of-century signal) - (Historical signal)

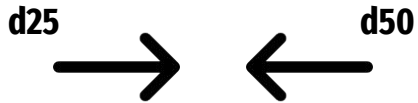


Change in summer months JJA

Clear effect of resolution in extreme precipitation projection;
Modulating effect of JJA and MAM in low discharge changes → more intense decrease in CP Roff and CORDEX Roff;
Effect of extreme precipitation in Alpine discharge in CP TP;

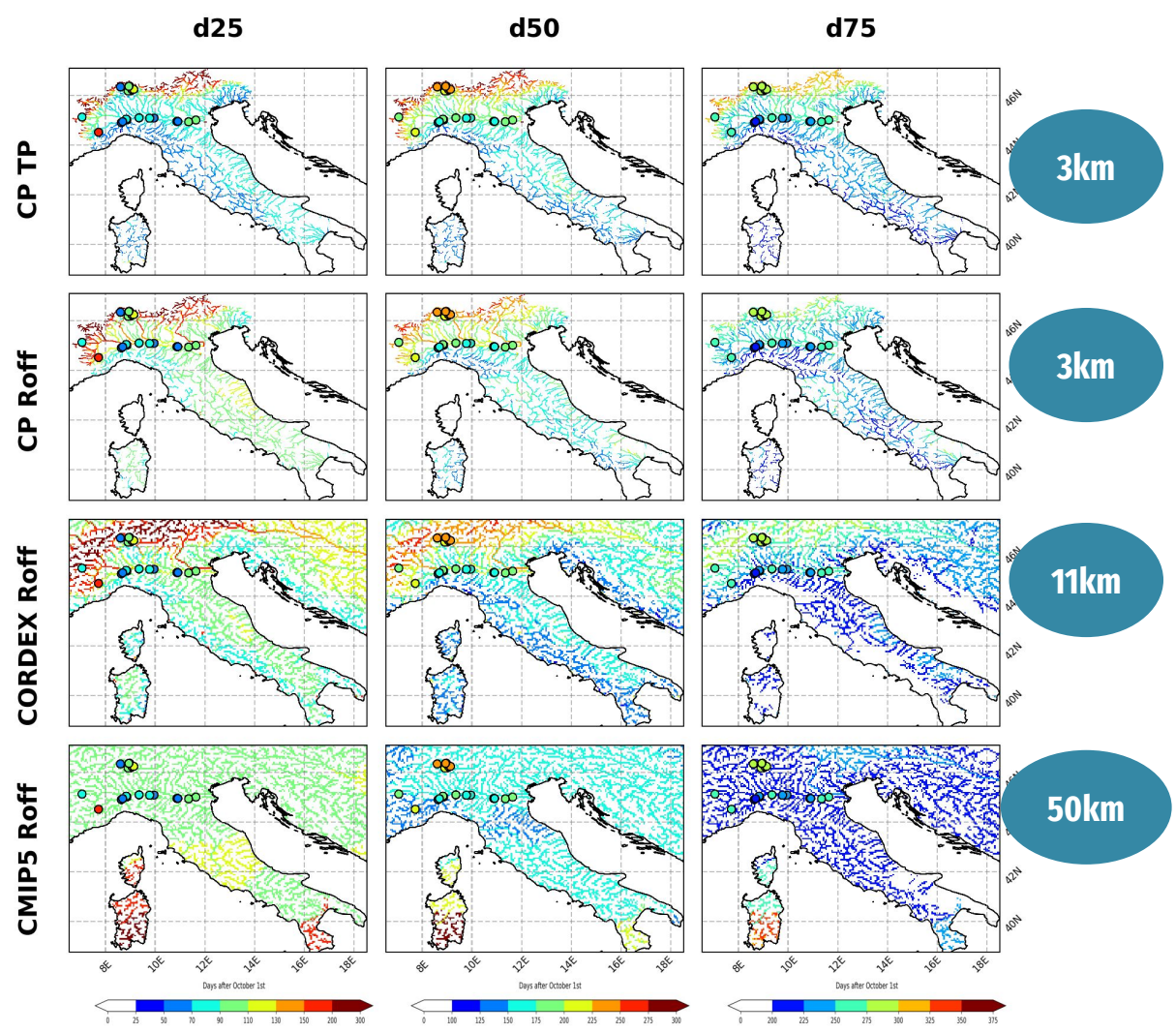
(End-of-century signal) - (Historical signal)





Increased chance of floods

Increased chance of droughts

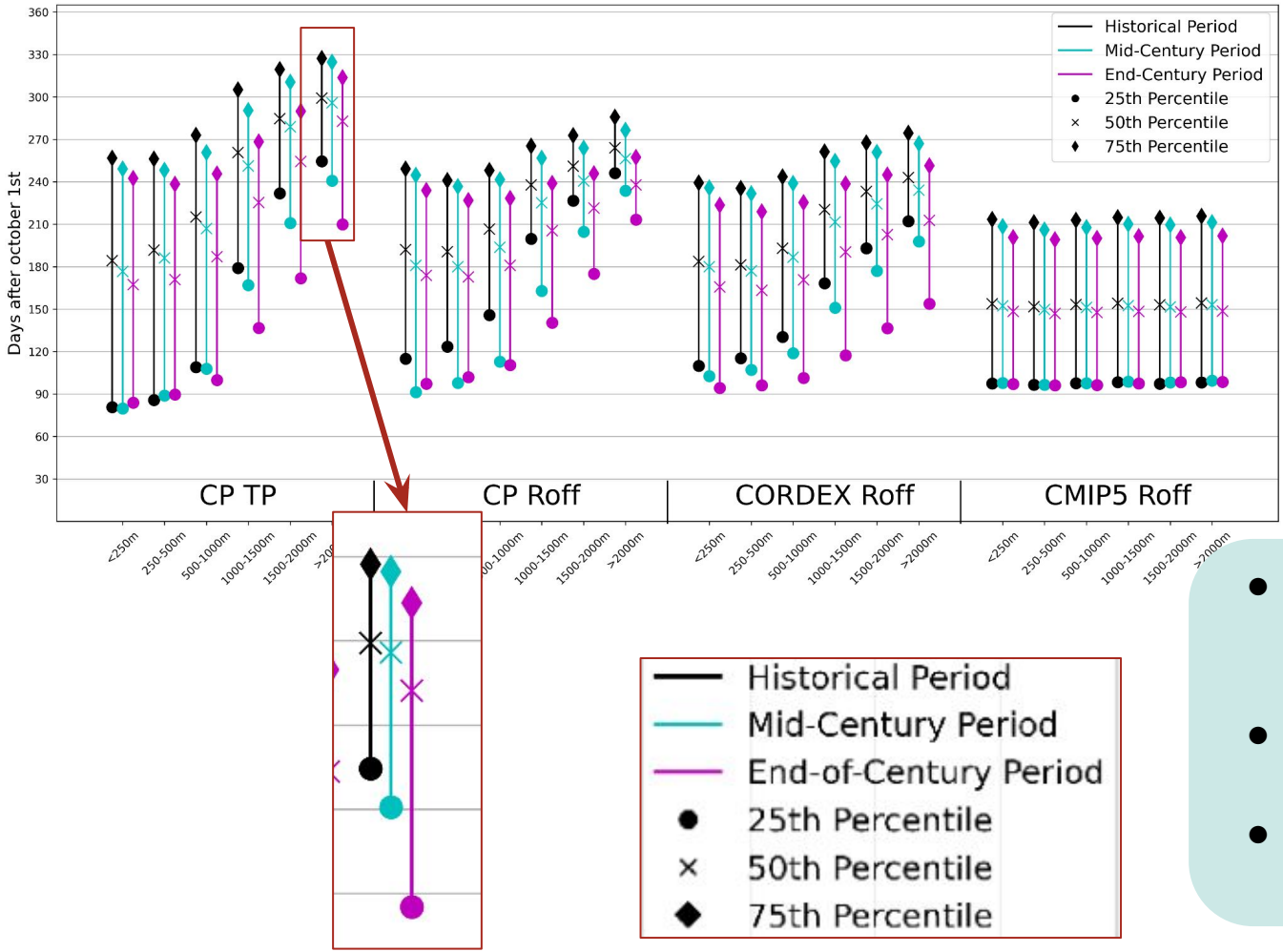


Climate change signal SSP585

Overall consistent with station data, with overestimation over high altitudes;

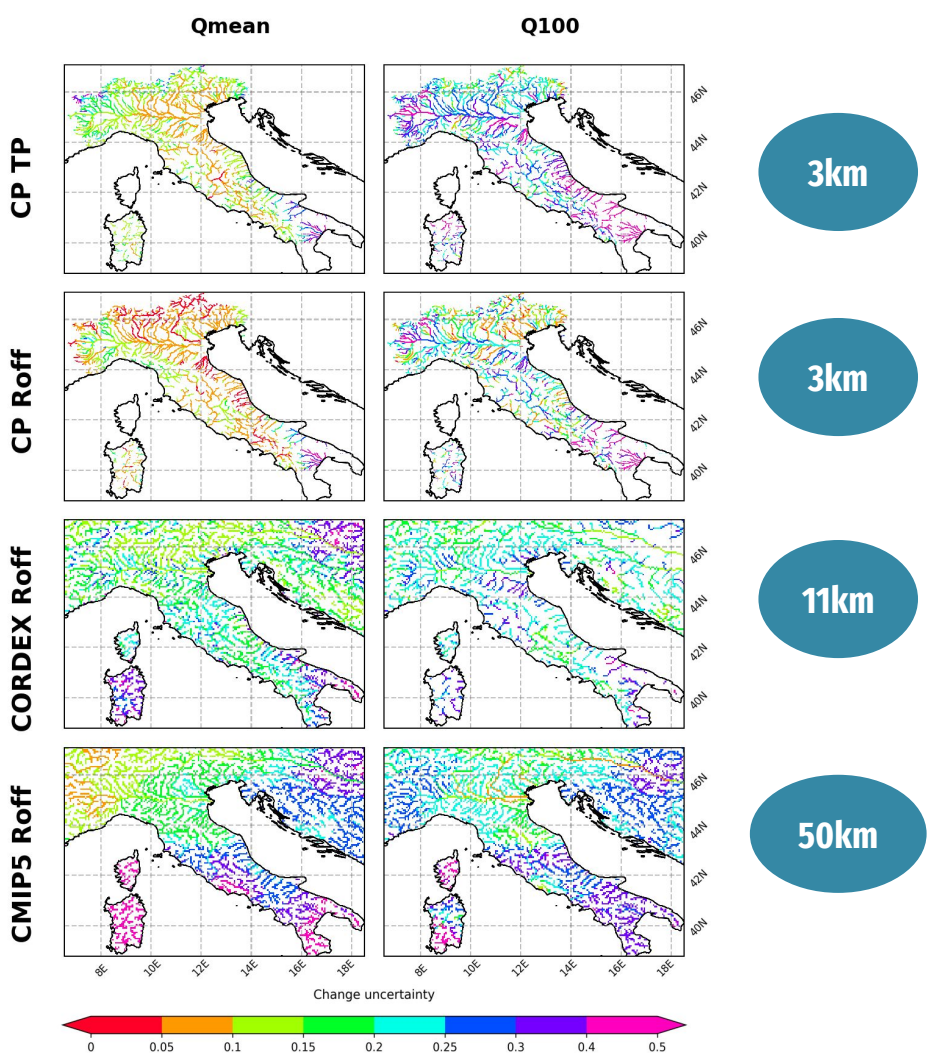
Days at which hydrological year percentiles are reached in the historical period

Climate change signal SSP585



- Earlier d25 in high altitudes → wetter winter/earlier snowmelt
- Increased distance between d25 and d50 → drier springs
- Less clear pattern for low resolutions;

Model uncertainty



3km

3km

11km

50km

Spread of the mean change is lower in the CP driven simulation in average;

$$u = \frac{\sigma_{\Delta Q_i}}{Q_{his}}$$

Conclusions

High resolution **kilometer scale projection** are **suitable** to represent the **hydrological cycle** in the **Italian river basin** when coupled with a hydrological model

Change in mean and **low discharge** are modulated by the **precipitation mean change**

Change in very **high discharge** values are modulated by **extreme precipitation**

Modulating effect of **JJA and MAM in low discharge changes**

Summer season is projected to experience an i**ncrease of discharge over the Alpine** chain and a **decreased elsewhere** driven by the **change extreme** and **mean precipitation** respectively for the CP TP simulations. Other ensembles have a **decrease** everywhere in **summer** consistent with **more intense decreases** of precipitation.

The **high resolution** driven **hydrological** simulation ensemble shows a **reduced** climate change **signal spread** for the mean discharge change

Changes in the **hydrological year** length for high resolution simulations show earlier shift of the 25th percentile due to wetter winter and earlier snowmelt, with an increase distance between the 25th and 50th percentile projecting in a **drier springer to summer period**

Any questions?

Climate change impact on the discharge of the Italian river network using Convection Permitting climate models

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Extra Slides

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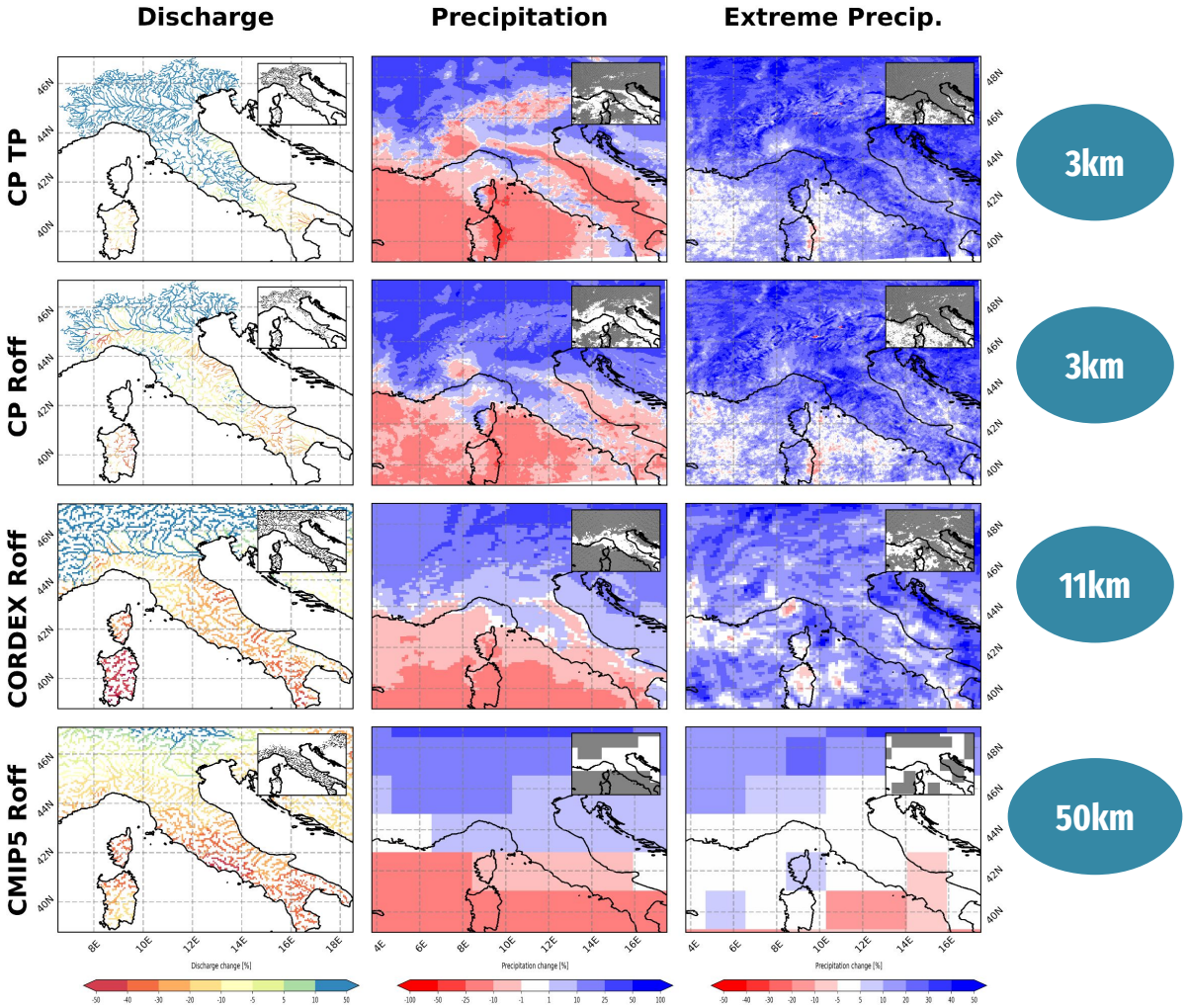
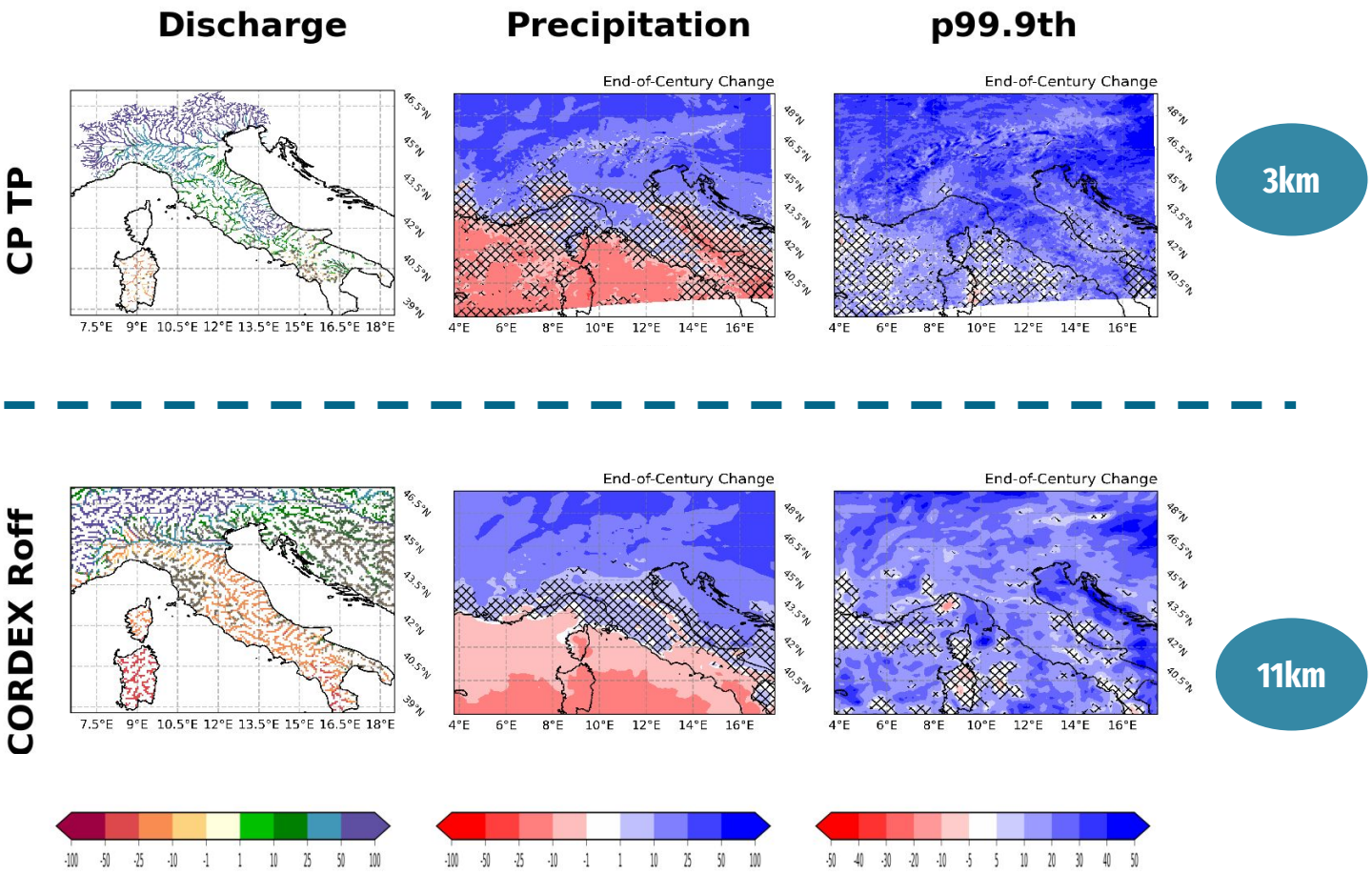
Luiza Vargas de Oliveira Heinz,
Supervisor : Erika Coppola



Change in winter months DJF

Clear effect of resolution in extreme precipitation projection;
Possible effect on local discharge;

(End-of-century signal) - (Historical signal)



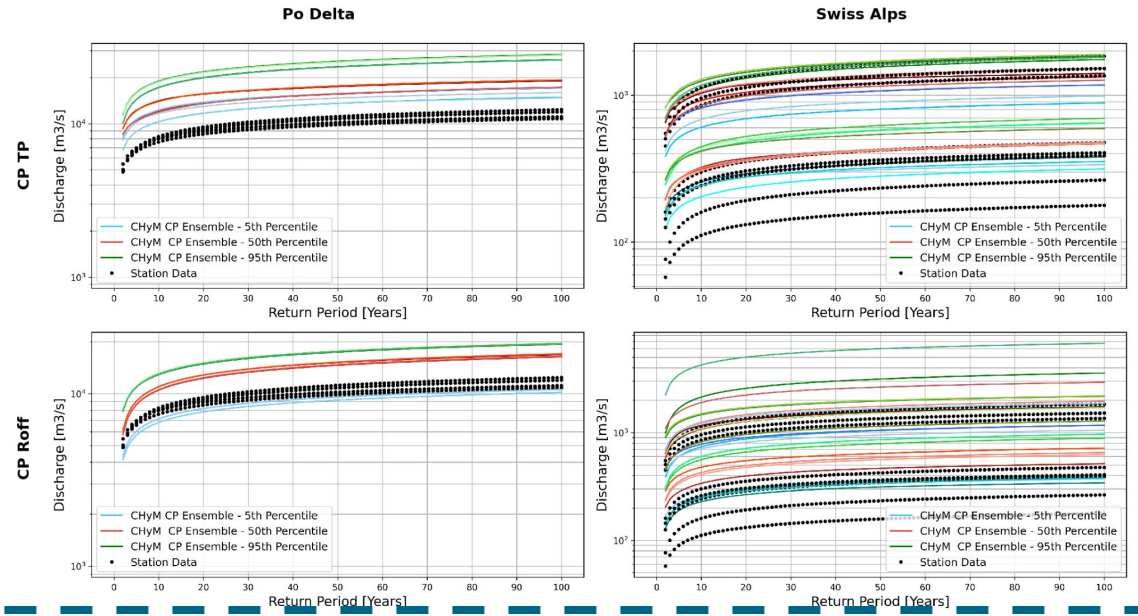
3km

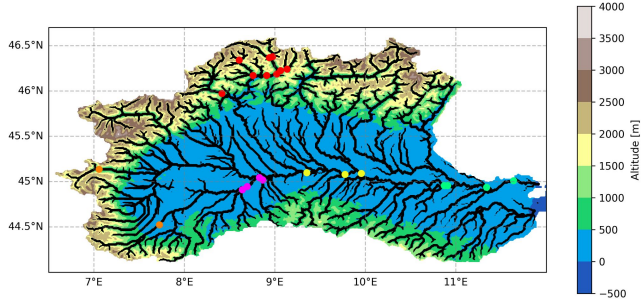
11km

Change in winter months

Precipitation signal consistent for different resolutions;
CHyM TP more susceptible to extreme precipitation than CHyM Roff;

Validation



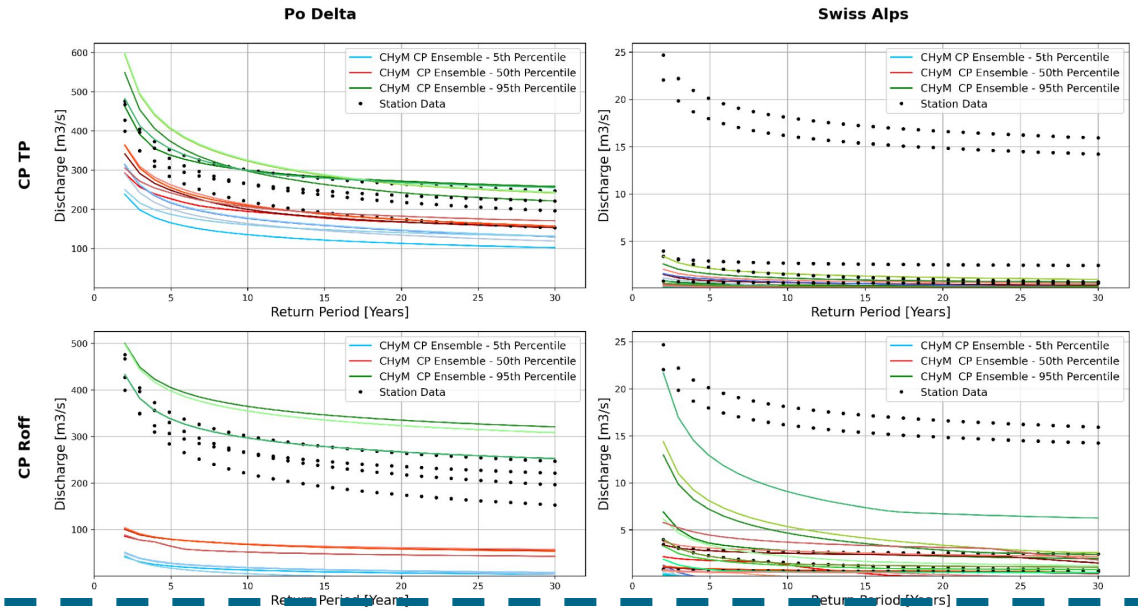


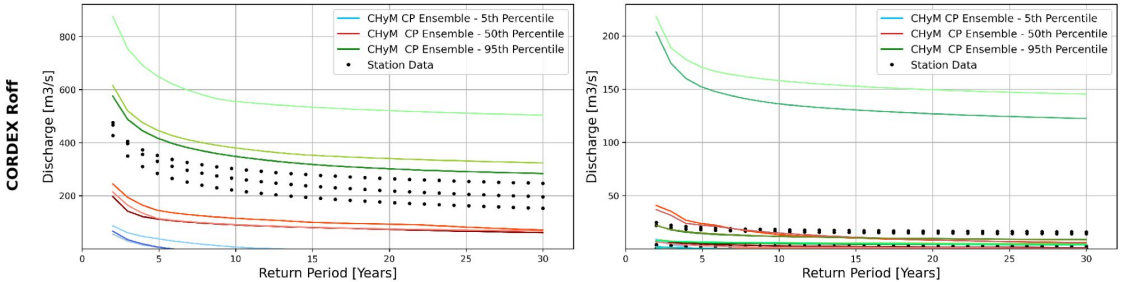
3km

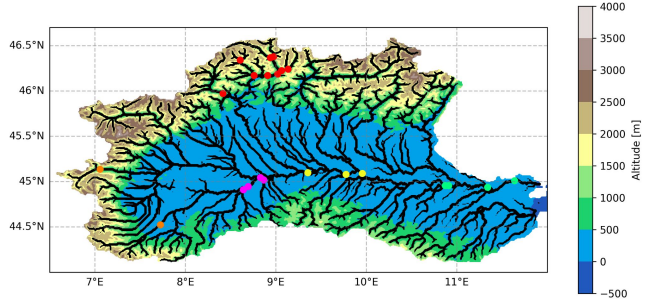
11km

Overestimation for higher resolution and underrestimation for lower

Validation







3km

11km

Good match for Po Delta and over/under estimation for Swiss Alps

Models used

Table 1: Ensemble of models used for the validation period for CP TP driven by Era-Interim data (CPRCMs and driving intermediate RCMs)

Institute	CPRCM	RCM
Aristotle University of Thessaloniki	WRF381BF	WRF
BCCR The Bjerknes Centre for Climate Research	WRF3.8	WRF3.8.1CA
Center for International Climate and Environmental	WRF381BJ	WRF
BTU Brandenburg University of Technology	CCLM5	CCLM4
ETHZ Federal Institute of Technology	CCLM	CCLM
Justus-Liebig-University Giessen	CCLM	-
KIT Karlsruhe Institute of Technology	CCLM5	CCLM4
Centro Euro-Mediterraneo sui Cambiamenti Climatici	CCLM	CCLM
Centre National de Recherches Meteorologique	CNRM-AROME41t1	CNRM-ALADIN63
Research Centre Jülich	WRF381BB	WRF
Climate Service Center Germany	REMO	REMO
HARMONIE-Climate community	HCLIM38-AROME	HCLIMcom
ICTP Abdus Salam Internatinal Centre for Theoretical Physics	RegCM4	RegCM4
KNMI The Royal Netherlands Meteorological Institute	HCLIM38-AROME	RACMO
Institut Pierre-Simon-Laplace	WRF381BE	WRF
University of Hohenheim	WRF381BD	WRF
Wegener Center for Climate and Global Change, University of Graz	WRF381BL	WRF

Table 2: Ensemble of models used for the validation period for CP Roff driven by Era-Interim data (CPRCMs and driving intermediate RCMs)

Institute	CPRCM	RCM
BCCR The Bjerknes Centre for Climate Research	WRF3.8	WRF3.8.1CA
Center for International Climate and Environmental	WRF381BJ	WRF
BTU Brandenburg University of Technology	CCLM5	CCLM4
ETHZ Federal Institute of Technology	CCLM	CCLM
Justus-Liebig-University Giessen	CCLM	-
KIT Karlsruhe Institute of Technology	CCLM5	CCLM4
HARMONIE-Climate community	HCLIM38-AROME	HCLIMcom
ICTP Abdus Salam Internatinal Centre for Theoretical Physics	RegCM4	RegCM4
Instituto Dom Luiz	WRF381BH	WRF
KNMI The Royal Netherlands Meteorological Institute	HCLIM38-AROME	RACMO
Institut Pierre-Simon-Laplace	WRF381BE	WRF
University of Hohenheim	WRF381BD	WRF
Wegener Center for Climate and Global Change, University of Graz	WRF381BL	WRF

Table 3: Ensemble of models CP Roff - Mid and End of Century (CPRCMs, driving intermediate RCMs and driving GCMs)

Institude	CPRCM	RCM	GCM
BTU Brandenburg University of Technology	CCLM5	CCLM4	CNRM-CM5
Justus-Liebig-University Giessen	CCLM	-	MPI
KIT Karlsruhe Institute of Technology	CCLM5	CCLM4	MPI-ESM-LR
HARMONIE Climate Modelling Community	HCLIM38-AROME	HCLIMcom	EC-Earth
ICTP Abdus Salam Internatinal Centre for Theoretical Physicss	RegCM4	RegCM4	HadGEM
ETHZ Federal Institute of Technology	CCLM	CCLM	MPI

Table 4: Ensemble of models CP TP - Mid Century (CPRCMs, driving intermediate RCMs and driving GCMs)

Institude	CPRCM	RCM	GCM
BTU Brandenburg University of Technology	CCLM5	CCLM4	CNRM-CM5
KNMI The Royal Netherlands Meteorological Institute	HCLIM38-AROME	RACMO	EC-Earth
Climate Service Center Germany	REMO	REMO	MPI
Justus-Liebig-University Giessen	CCLM	-	MPI
Institut Pierre-Simon-Laplace	WRF381BE	WRF	IPSL-CM5
KIT Karlsruhe Institute of Technology	CCLM5	CCLM4	MPI-ESM-LR
HARMONIE Climate Modelling Community	HCLIM38-AROME	HCLIMcom	EC-Earth
ICTP Abdus Salam Internatinal Centre for Theoretical Physicss	RegCM4	RegCM4	HadGEM
Centro Euro-Mediterraneo sui Cambiamenti Climatici	CCLM	CCLM	EC-Earth
ETHZ Federal Institute of Technology	CCLM	CCLM	MPI

Table 5: Ensemble of models CP TP - End Century (CPRCMs, driving intermediate RCMs and driving GCMs)

Institude	CPRCM	RCM	GCM
BTU Brandenburg University of Technology	CCLM5	CCLM4	CNRM-CM5
Justus-Liebig-University Giessen	CCLM	-	MPI
Institut Pierre-Simon-Laplace	WRF381BE	WRF	IPSL-CM5
KIT Karlsruhe Institute of Technology	CCLM5	CCLM4	MPI-ESM-LR
HARMONIE Climate Modelling Community	HCLIM38-AROME	HCLIMcom	EC-Earth
Centre National de Recherches Meteorologique	CNRM-AROME41t1	CNRM-ALADIN63	CNRM-CM5
ICTP Abdus Salam Internatinal Centre for Theoretical Physicss	RegCM4	RegCM4	HadGEM
Centro Euro-Mediterraneo sui Cambiamenti Climatici	CCLM	CCLM	EC-Earth
Wegener Center for Climate and Global Change, University of Graz	WRF381BL	WRF	IPSL-CM5
ETHZ Federal Institute of Technology	CCLM	CCLM	MPI

Models used

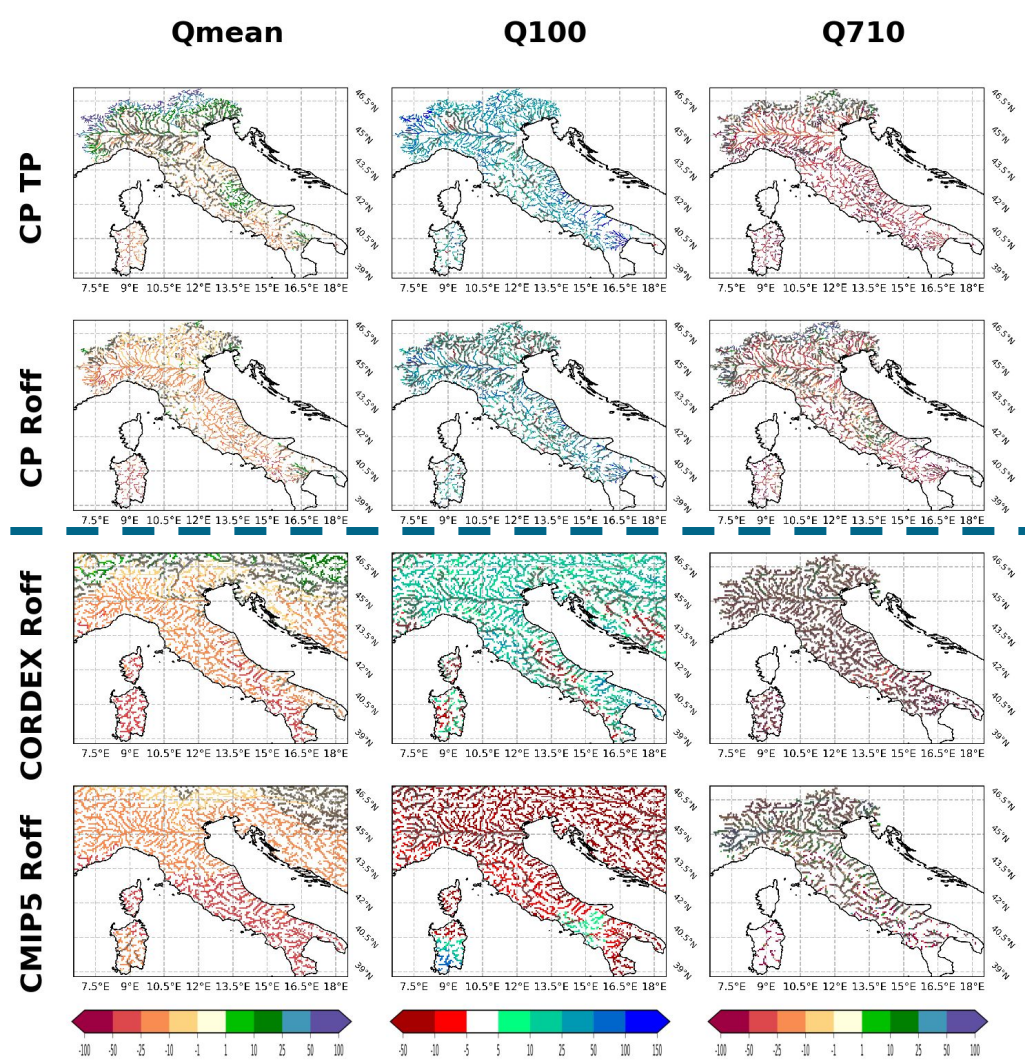
Table S1: Ensemble of models used for the CORDEX Roff ensemble (RCMs and driving GCMs)

RCM	Driving Model	Ensembles
CLMcom-CCLM4-8-17	CCCma-CanESM2	r1
CLMcom-CCLM4-8-17	CNRM-CERFACS-CNRM-CM5	r1
CLMcom-CCLM4-8-17	ICHEC-EC-EARTH	r12
CLMcom-CCLM4-8-17	MIROC-MIROC5	r1
CLMcom-CCLM4-8-17	MOHC-HadGEM2-ES	r1
CLMcom-CCLM4-8-17	MPI-M-MPI-ESM-LR	r1
CLMcom-ETH-COSMO-crCLIM-v1-1	MPI-M-MPI-ESM-LR	r1
CNRM-ALADIN63	CNRM-CERFACS-CNRM-CM5	r1
CNRM-ALADIN63	MOHC-HadGEM2-ES	r1
DMI-HIRHAM5	CNRM-CERFACS-CNRM-CM5	r1
DMI-HIRHAM5	ICHEC-EC-EARTH	r12
DMI-HIRHAM5	ICHEC-EC-EARTH	r1
DMI-HIRHAM5	ICHEC-EC-EARTH	r3
DMI-HIRHAM5	MOHC-HadGEM2-ES	r1
DMI-HIRHAM5	NCC-NorESM1-M	r1
GERICS-REMO2015	CCCma-CanESM2	r1
GERICS-REMO2015	CNRM-CERFACS-CNRM-CM5	r1
GERICS-REMO2015	ICHEC-EC-EARTH	r12
GERICS-REMO2015	MIROC-MIROC5	r1
GERICS-REMO2015	MOHC-HadGEM2-ES	r1
GERICS-REMO2015	MPI-M-MPI-ESM-LR	r3
GERICS-REMO2015	NCC-NorESM1-M	r1
ICTP-RegCM4-6	MOHC-HadGEM2-ES	r1
ICTP-RegCM4-6	MPI-M-MPI-ESM-LR	r1
IPSL-WRF381P	CNRM-CERFACS-CNRM-CM5	r1
IPSL-WRF381P	NCC-NorESM1-M	r1
KNMI-RACMO22E	CNRM-CERFACS-CNRM-CM5	r1
KNMI-RACMO22E	ICHEC-EC-EARTH	r12
KNMI-RACMO22E	ICHEC-EC-EARTH	r1
KNMI-RACMO22E	ICHEC-EC-EARTH	r3
KNMI-RACMO22E	MOHC-HadGEM2-ES	r1
KNMI-RACMO22E	MPI-M-MPI-ESM-LR	r1
KNMI-RACMO22E	NCC-NorESM1-M	r1
MPI-CSC-REMO2009	MPI-M-MPI-ESM-LR	r1
MPI-CSC-REMO2009	MPI-M-MPI-ESM-LR	r2
SMHI-RCA4	CNRM-CERFACS-CNRM-CM5	r1
SMHI-RCA4	ICHEC-EC-EARTH	r12
SMHI-RCA4	ICHEC-EC-EARTH	r1
SMHI-RCA4	IPSL-IPSL-CM5A-MR	r1
SMHI-RCA4	MOHC-HadGEM2-ES	r1
SMHI-RCA4	MPI-M-MPI-ESM-LR	r1
SMHI-RCA4	MPI-M-MPI-ESM-LR	r3
SMHI-RCA4	NCC-NorESM1-M	r1
UHOH-WRF361H	ICHEC-EC-EARTH	r12

Models used

Table S2: Ensemble of models used for the CMIP5 Roff ensemble

GCM	Realizations
CNRM-CM5	r1
CanESM2	r1,r2,r3,r4,r5
MIROC-ESM	r1
MIROC5	r1
MPI-ESM-LR	r1,r2,r3
MPI-ESM-MR	r1
NorESM1-M	r1



Climate change signal SSP585

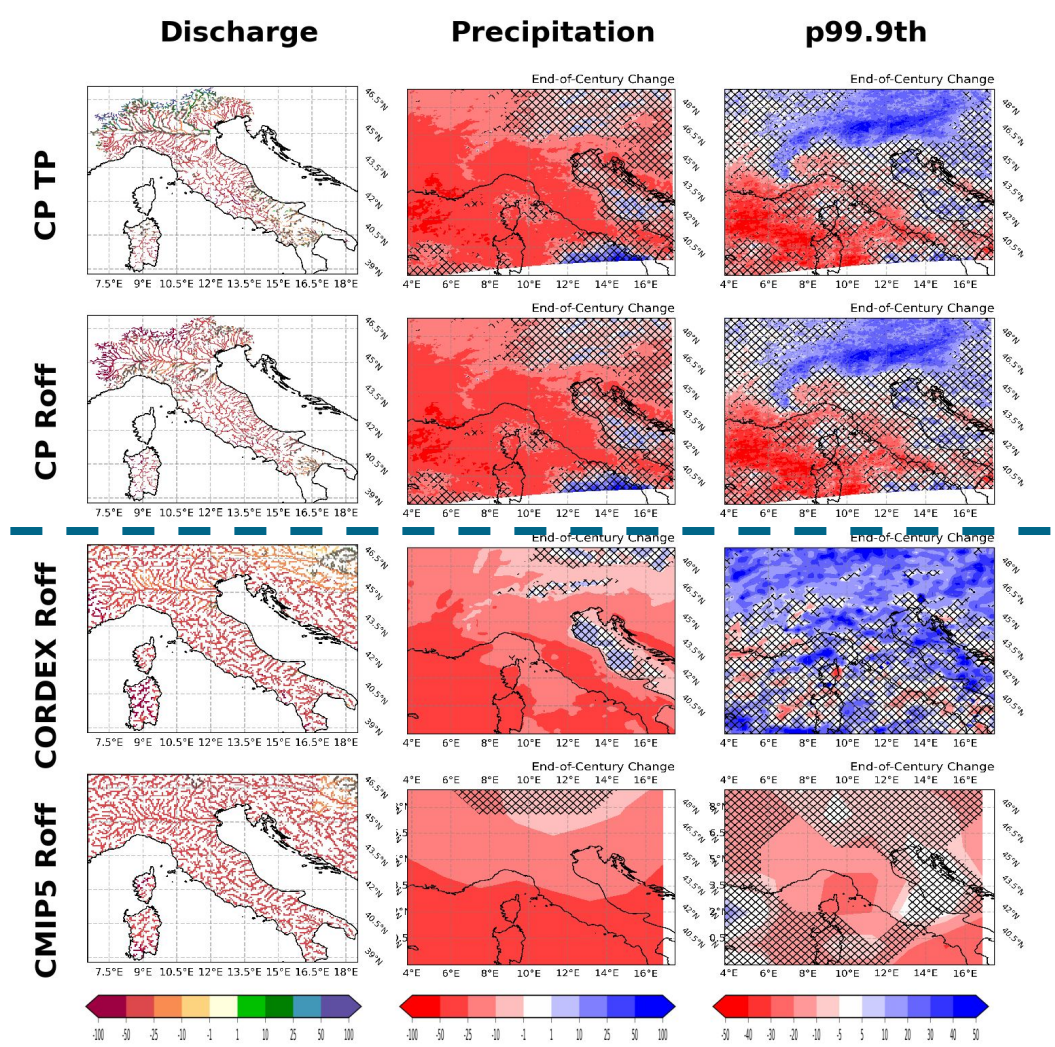
3km

11km

50km

Change in yearly values

More floods and more droughts;
Average discharge decrease with possible increase in the Alps;



Climate change signal SSP585

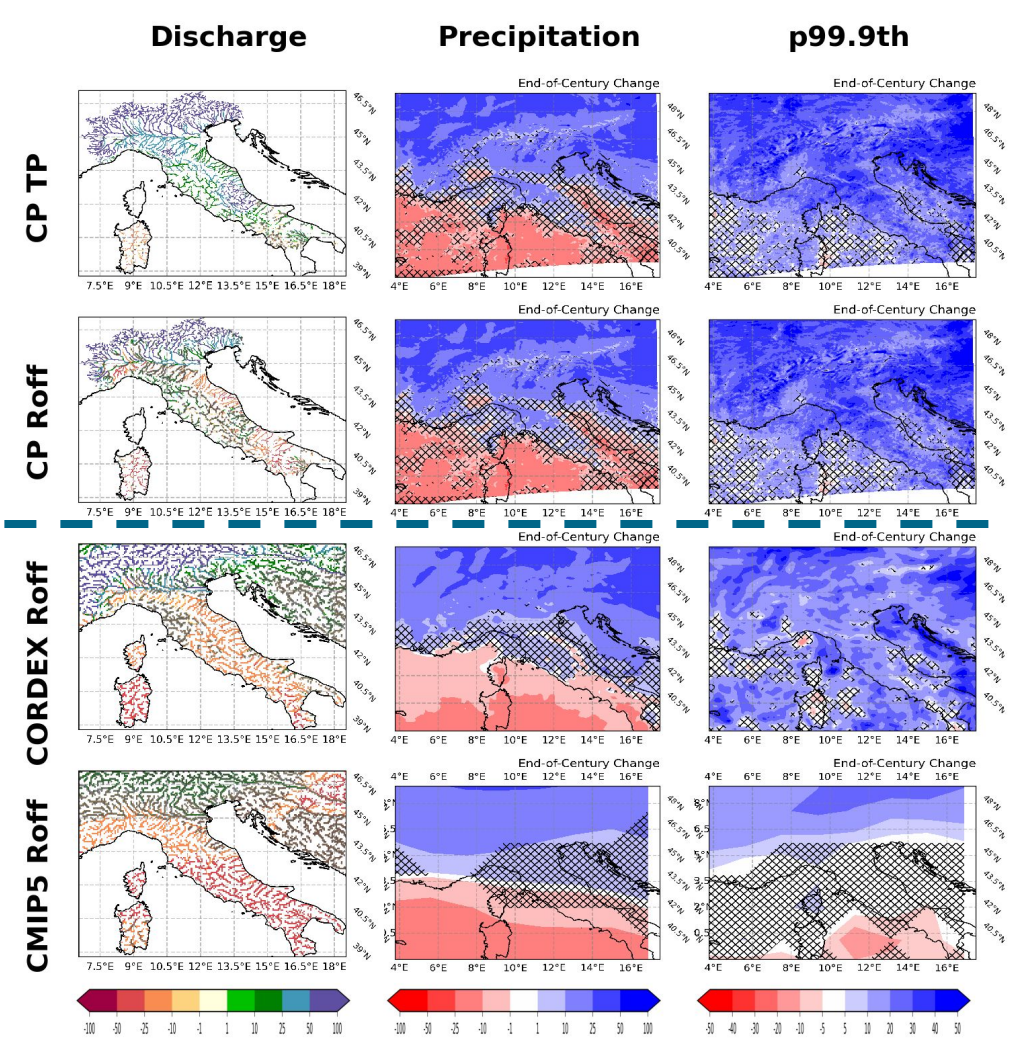
3km

11km

50km

Change in summer months

Clear effect of resolution in extreme precipitation projection;
Possible effect on local discharge;



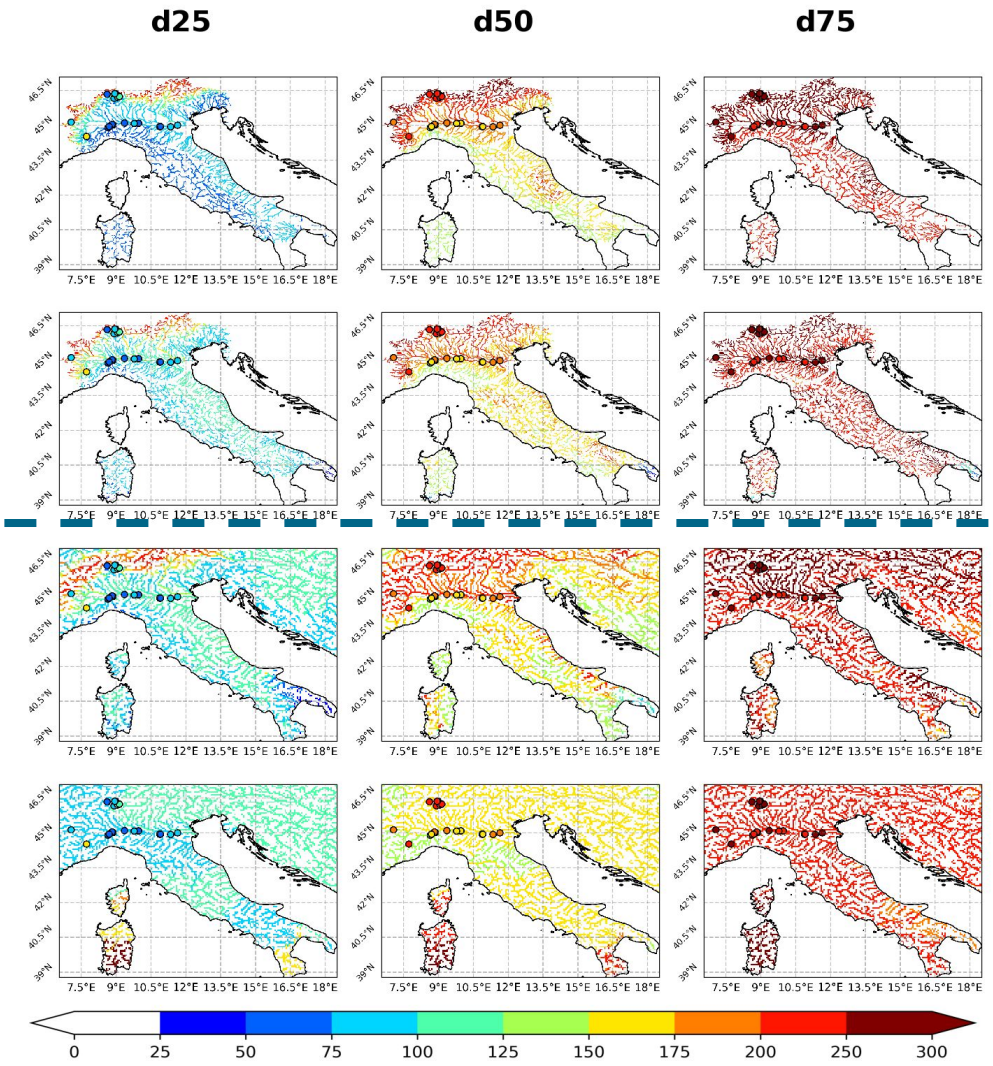
3km

11km

50km

Change in winter months

Precipitation signal consistent for different resolutions;
CHyM TP more susceptible to extreme precipitation than CHyM Roff



3km

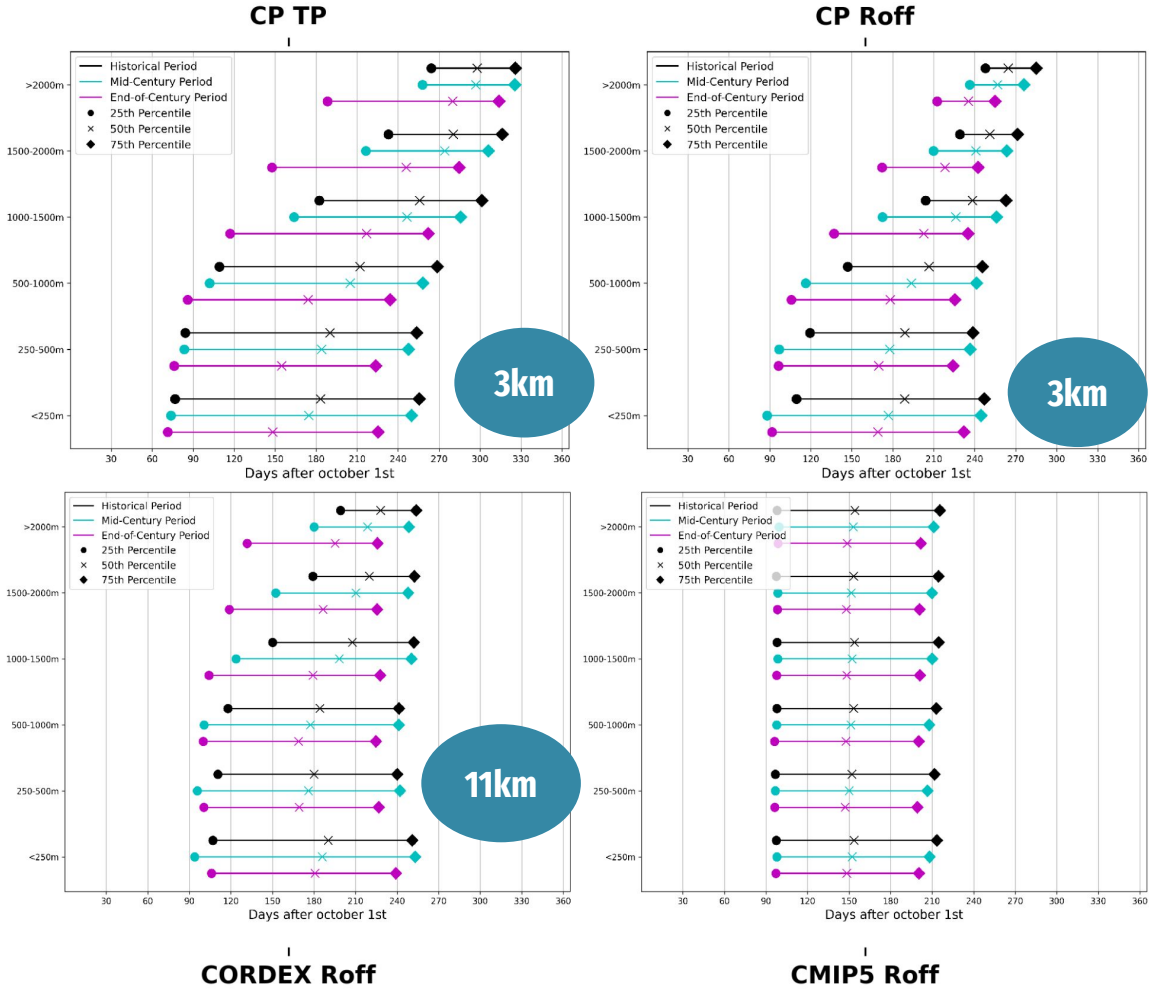
11km

50km

Days at which hydrological year percentiles are reached

Overall consistent with station data, with overestimation over high altitudes;
No altitude signal for low resolutions;

Climate change signal SSP585



Earlier d25 in high altitudes → wetter winter/earlier snowmelt
Increased distance between d25 and d50 → drier springs
No altitude signal for low resolutions;

Conclusions

CHyM shows overestimation of high discharge values when comparing to station data, but with good description of mean flow and timing

Decrease of average/drought flow by end of century and increase of high flow rates

Impact of extreme precipitation events on discharge change, specially over the Alps and in the summer months

More detailed signal with CP resolution

Perspectives

Expand on the uncertainty analysis as CP resolution can decrease model uncertainty

Possible to reproduce analysis in other regions if/when other CP ensembles become available

Possible to reproduce analysis in other parts of the Great Alpine Domain

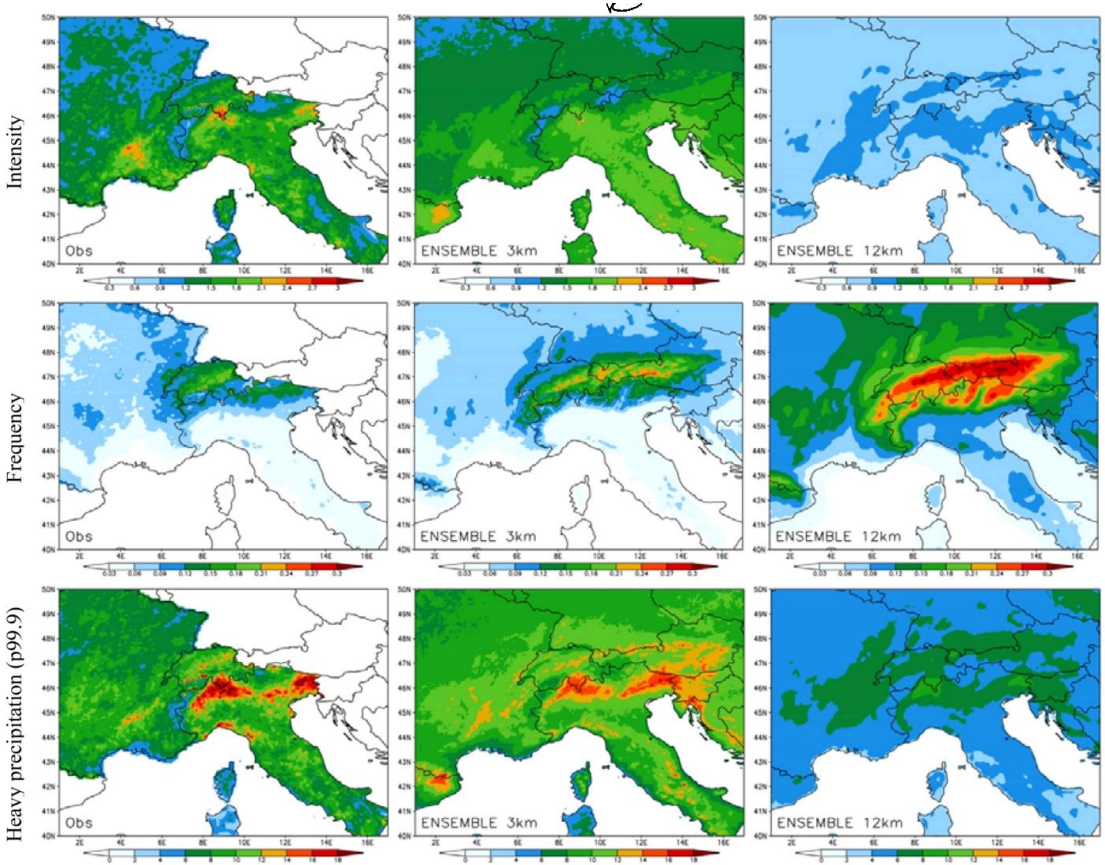


Fig. 2 Summer hourly indices over the Alpine region. From top to bottom: intensity of hourly precipitation (mm/h), wet-hour frequency, heavy hourly precipitation (mm/h) events (p99.9). Results are obtained (from left to right) by a combination of high resolution observations over different areas (see Sect. 3 for details and considered periods), the ensemble of CPRCMs and the ensemble of the corresponding driving RCMs. The model results are averaged over the period 1996-2005

Pichelli, E., Coppola, E., Sobolowski, S. et al. The first multi-model ensemble of regional climate simulations at kilometer-scale resolution part 2: historical and future simulations of precipitation. Clim Dyn 56, 3581–3602 (2021). https://doi.org/10.1007/s00382-021-05657-4

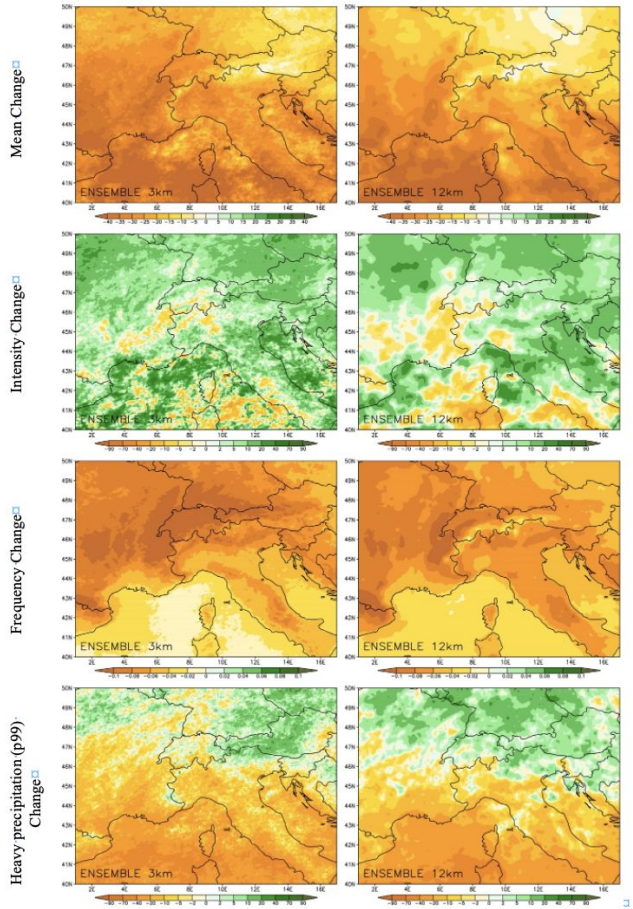


Figure S5 Ensemble mean percent change of the indices analysed over 2090-2099 for the summer daily precipitation (historical simulation is the reference, 1996-2005). From top to bottom: mean precipitation, intensity , frequency (change) and heavy precipitation (p99). The results are obtained from the CPRCM ensemble (left) and the driving RCM ensemble (right).¶

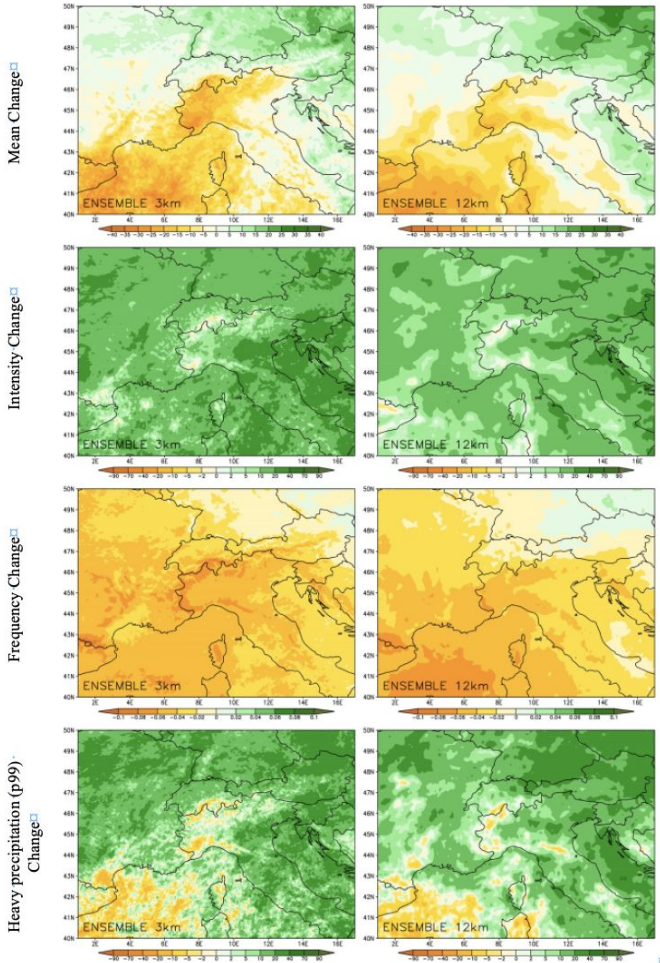


Figure S6 Same as Fig. S5 but for autumn daily precipitation mean change.¶

Pichelli, E., Coppola, E., Sobolowski, S. et al. The first multi-model ensemble of regional climate simulations at kilometer-scale resolution part 2: historical and future simulations of precipitation. Clim Dyn 56, 3581–3602 (2021). https://doi.org/10.1007/s00382-021-05657-4

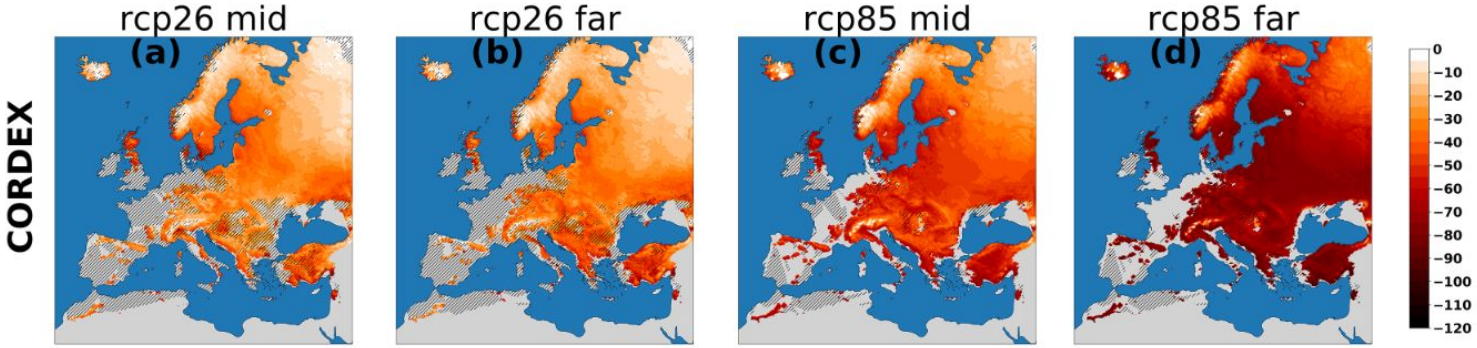


FIGURE 12 JFMA mean snow change. Areas where the change is not statistically significant at .05 level are crossed out [Colour figure can be viewed at wileyonlinelibrary.com]

Di Sante, F., Coppola, E., & Giorgi, F. (2021). Projections of river floods in Europe using euro-cordex, cmip5 and cmip6 simulations. *International Journal of Climatology*, *41*(5), 3203–3221. doi:10.1002/joc.7014

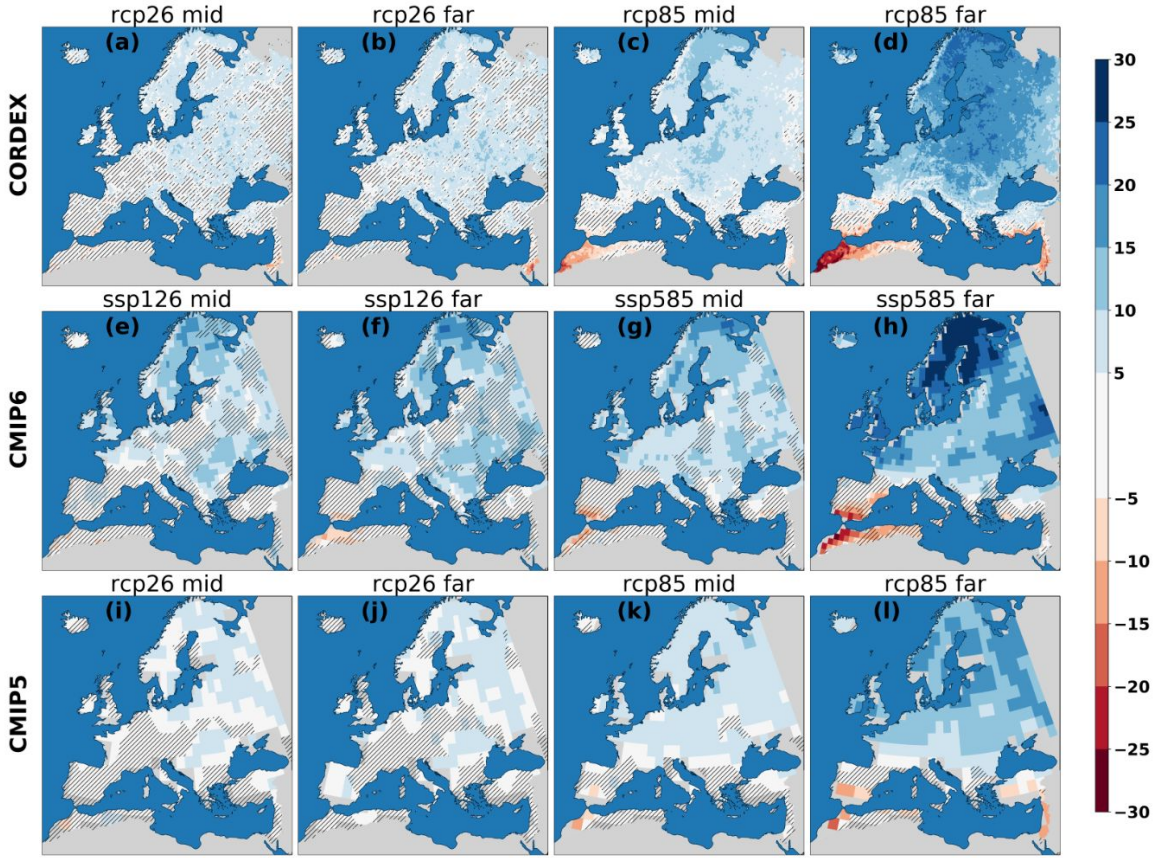


FIGURE 10 7 day maximum-precipitation. Areas where the change is not statistically significant at .05 level are crossed out [Colour figure can be viewed at wileyonlinelibrary.com]

Di Sante, F., Coppola, E., & Giorgi, F. (2021). Projections of river floods in Europe using euro-cordex, cmip5 and cmip6 simulations. *International Journal of Climatology*, *41*(5), 3203–3221. doi:10.1002/joc.7014

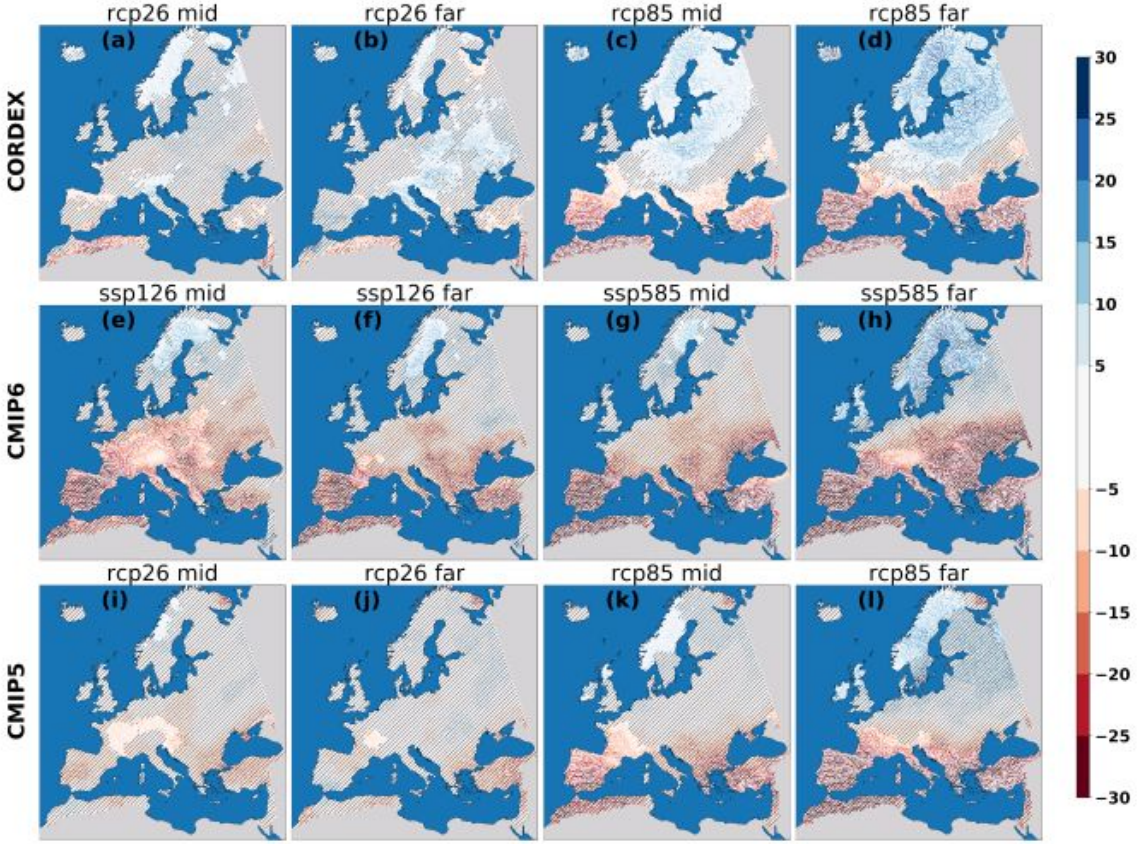
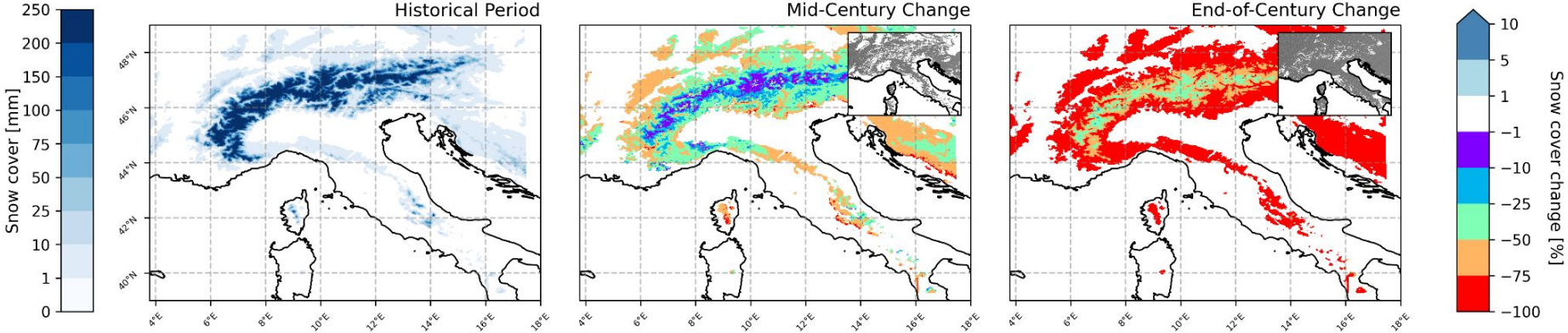


FIGURE 7 Relative changes of multi-model ensemble mean of mean flow for different scenarios and time slices. Areas where the change is not statistically significant at .05 level are crossed out [Colour figure can be viewed at wileyonlinelibrary.com]

Di Sante, F., Coppola, E., & Giorgi, F. (2021). Projections of river floods in Europe using euro-cordex, cmip5 and cmip6 simulations. *International Journal of Climatology*, *41*(5), 3203–3221. doi:10.1002/joc.7014


Historical Period
Mid-Century Change
End-of-Century Change
Snow cover [mm]
250
200
150
100
75
50
25
10
1
0
Snow cover change [%]
10
5
1
−1
−10
−25
−50
−75
−100
48°N
46°N
44°N
42°N
40°N
4°E
6°E
8°E
10°E
12°E
14°E
16°E
18°E