

***From convection-permitting coupled modeling to
large scale circulation and carbon sink in the
Mediterranean Sea: a small journey with a lot of
great friends***

M. Reale

with contributions from

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- ***Convection-permitting coupled modeling over Northern Italy***
- ***Response of large scale circulation at mid-latitudes to the Indian Ocean SST variability***
- ***Links between CO₂ sink in the Mediterranean region and synoptic features crossing the region***

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Importance of simulating precipitation patterns and extremes : Convection-permitting (CP) simulations

Precipitation are the result of several processes ...some of them are not resolved with grid spacings of climate models and must be parameterised (Deep Convection, Microphysics, Planetary Boundary Layer , Urban physics, Land surface, Air-Sea interactions, etc..)

Parameterisations are a major source for model errors:

Convection parameterisation schemes produce some of the largest uncertainties and model errors in future climate projections (Sherwood et al., 2014)

Parameterising deep convection is challenging :

- Interplay of processes acting at scales from the microscale to the synoptic scale**
- Convection parameterisation schemes interact with many other parameterisation schemes**

Importance of simulating precipitation patterns and extremes: Convection-permitting (CP) simulations

Precipitation intensity DJF

Precipitation intensity SON

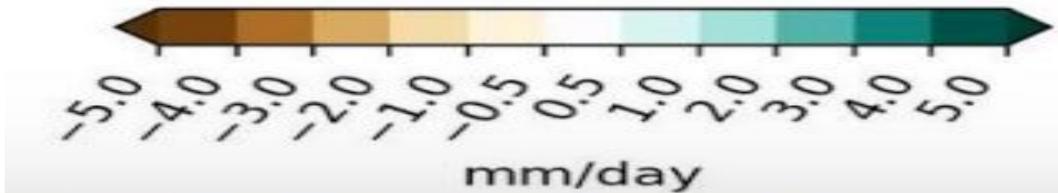
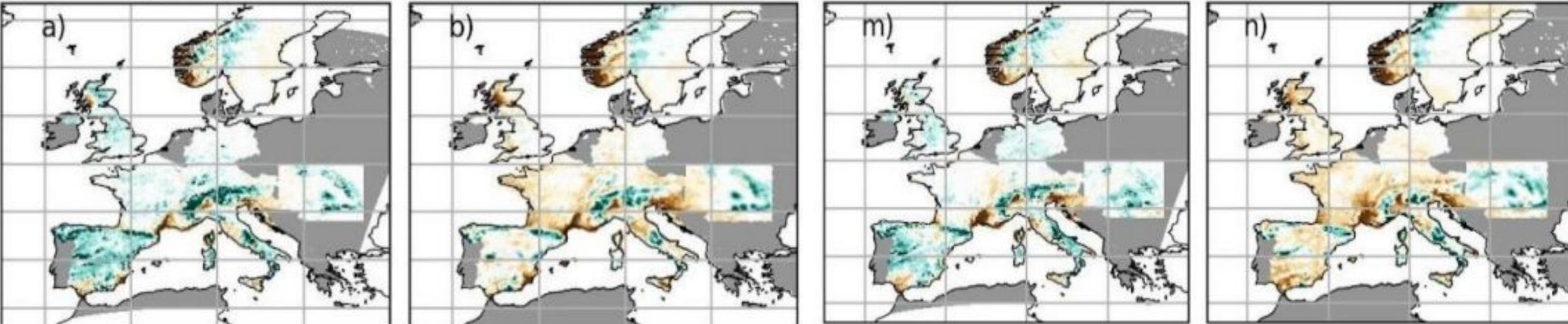
RegCM5 CP

RegCM5 12km

RegCM5 CP

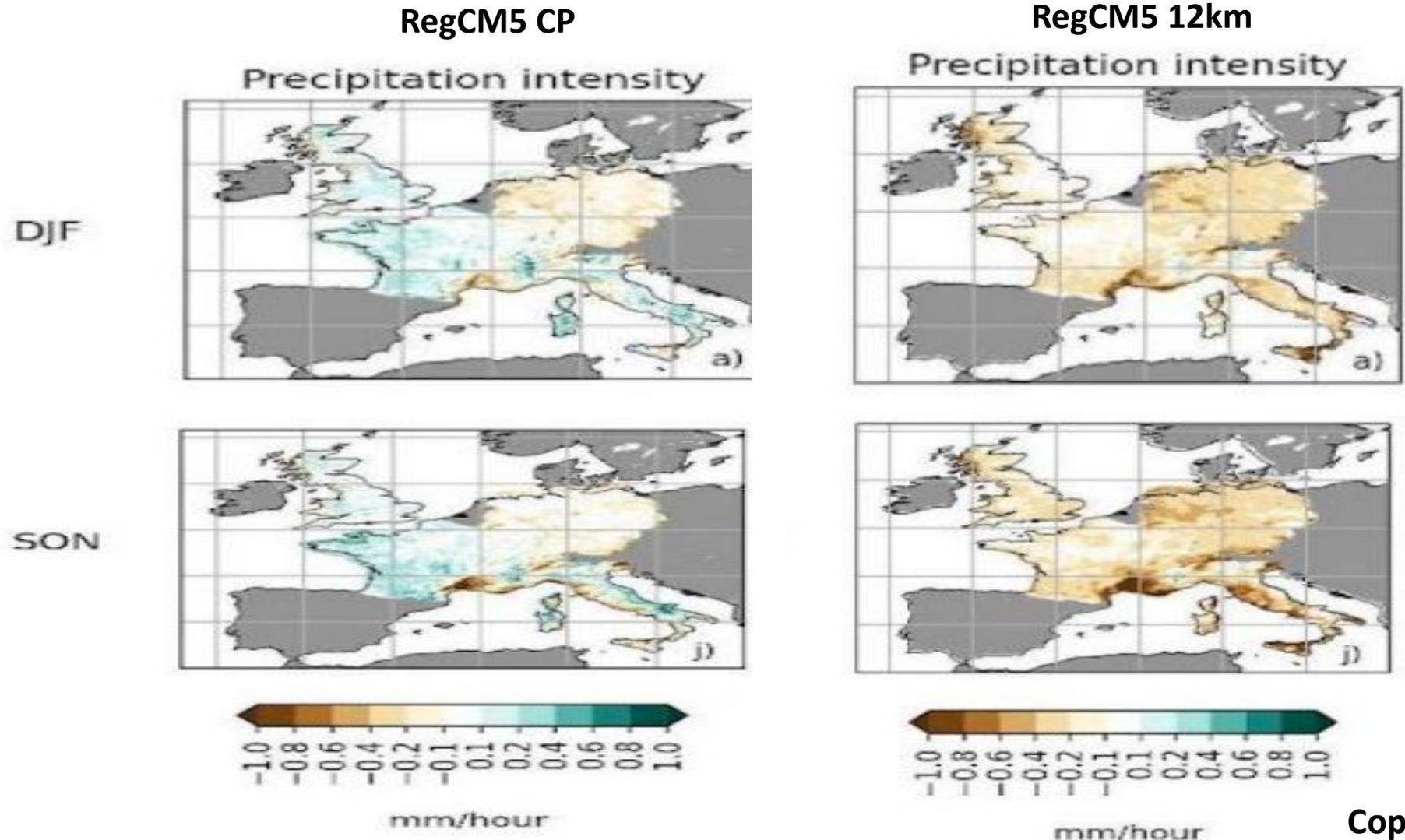
RegCM5 12km

DJF

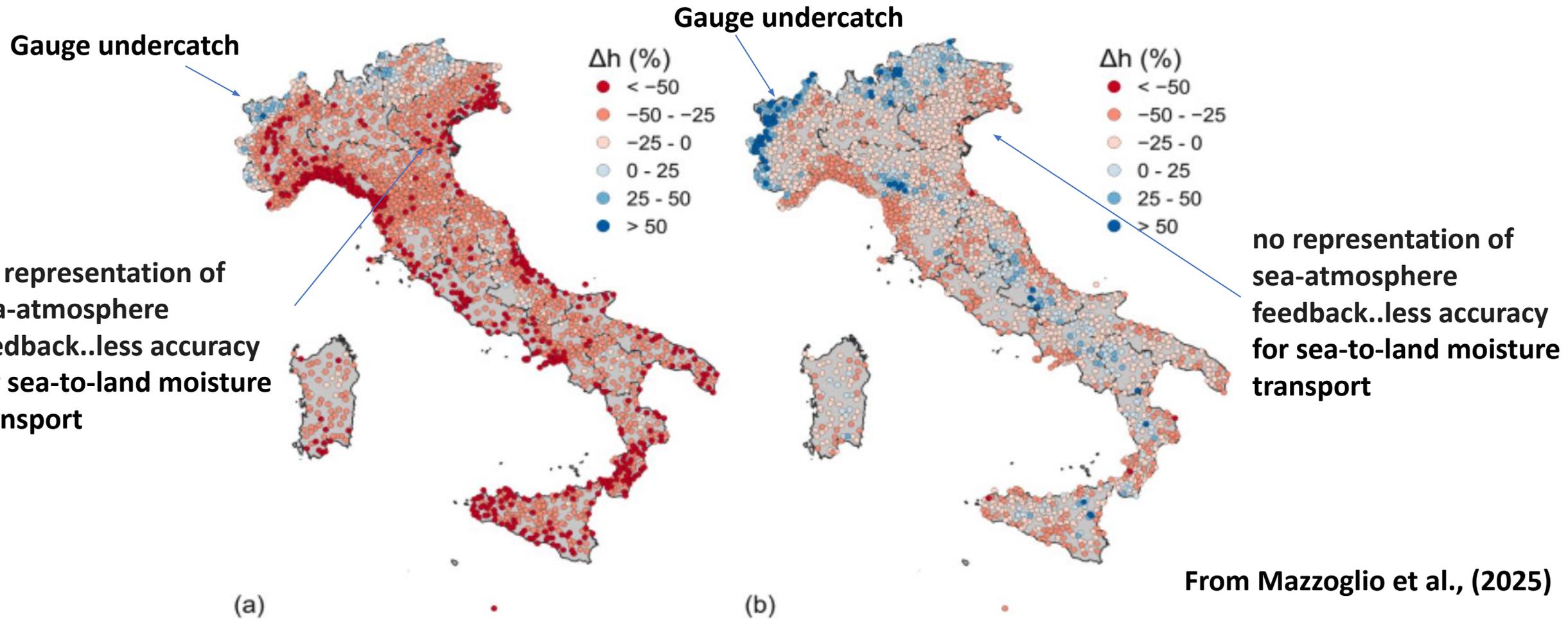


Importance of simulating precipitation patterns and extremes: Convection-permitting (CP) simulations

Hourly precipitation

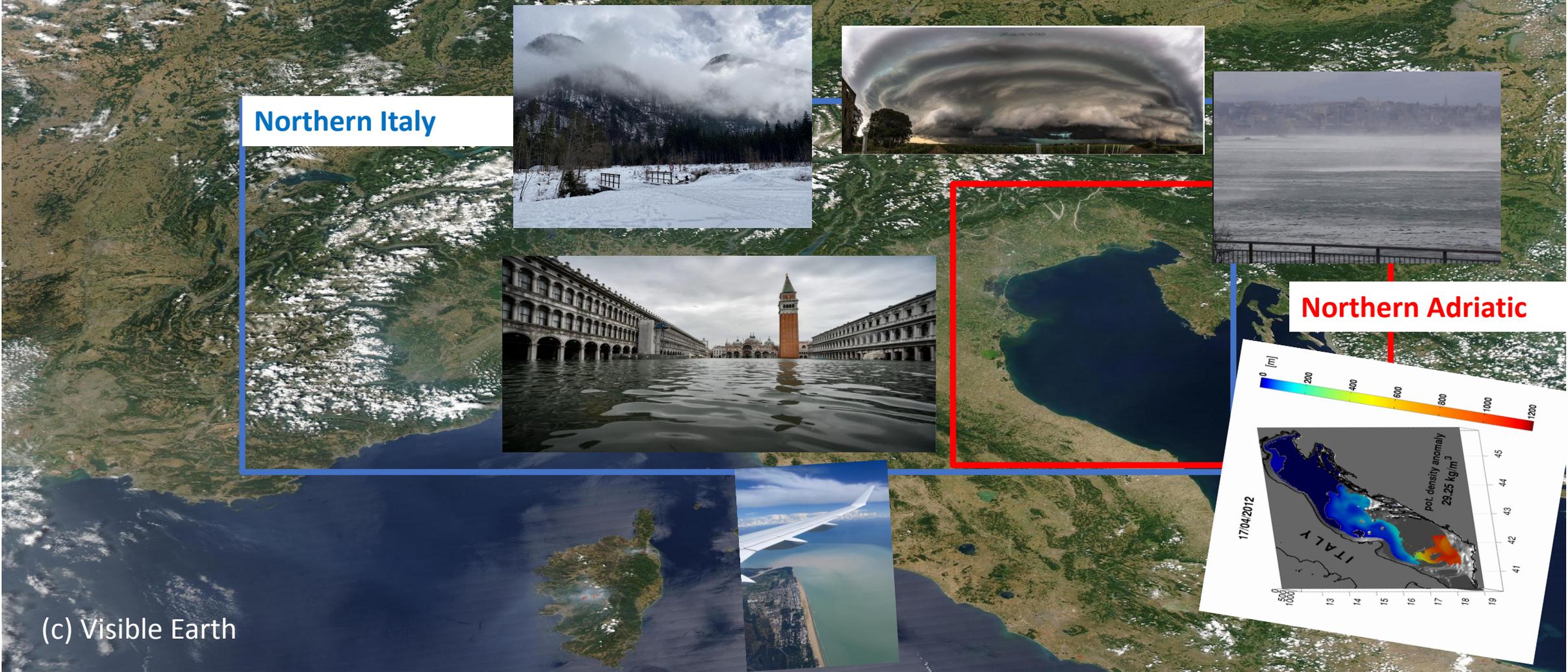


Importance of simulating precipitation patterns and extremes : Convection permitting (CP) simulations



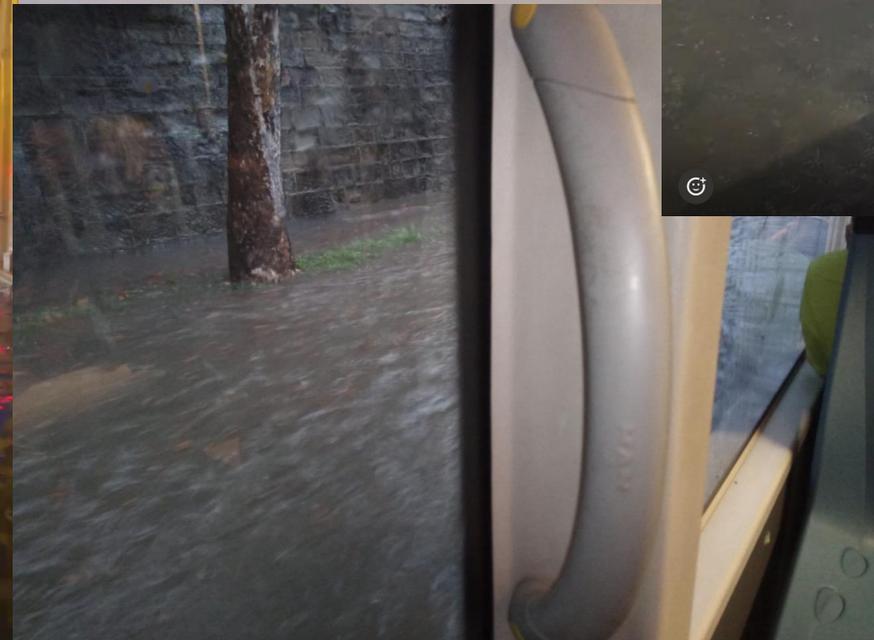
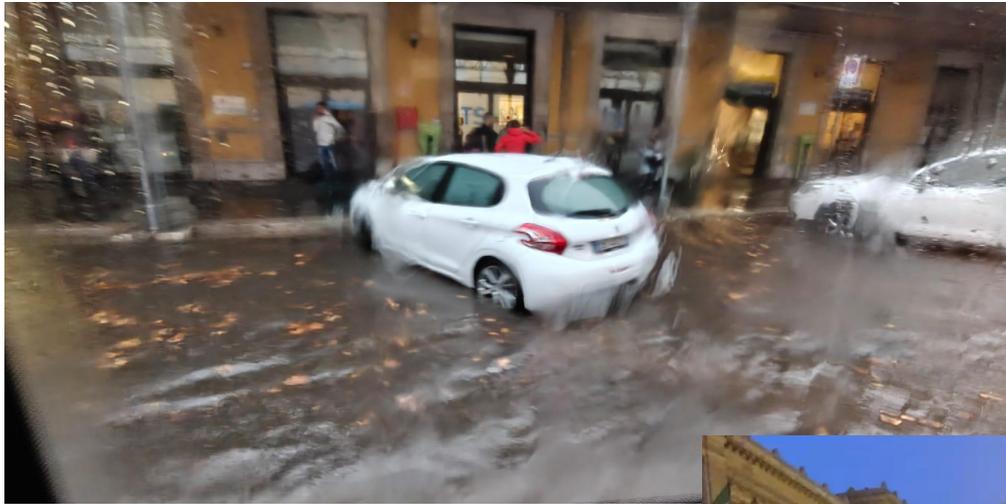
Relative differences between the median values of the two datasets (VHR-PRO_IT and I²-RED) for the 1 (a) and 24 (b) hour durations. Negative values (in red) indicate locations where the CPM underestimates the median annual maxima, while positive values (in blue) indicate overestimation.

Domain of interest



Multiple environmental gradients and processes involved in the dynamics of the area

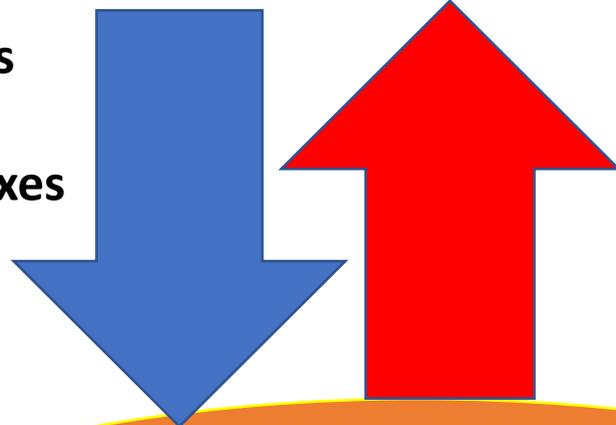
Importance of simulating precipitation patterns and extremes



RegCM-ES

Atmosphere/Land/Urban
RegCM5/CLM4.5/CLMU

- Net Heat Fluxes
- Wind Speed
- Freshwater Fluxes
- Atmospheric pressure
- Short wave radiation



Driver ESMF

Total runoff

River
CHyM

River Discharge

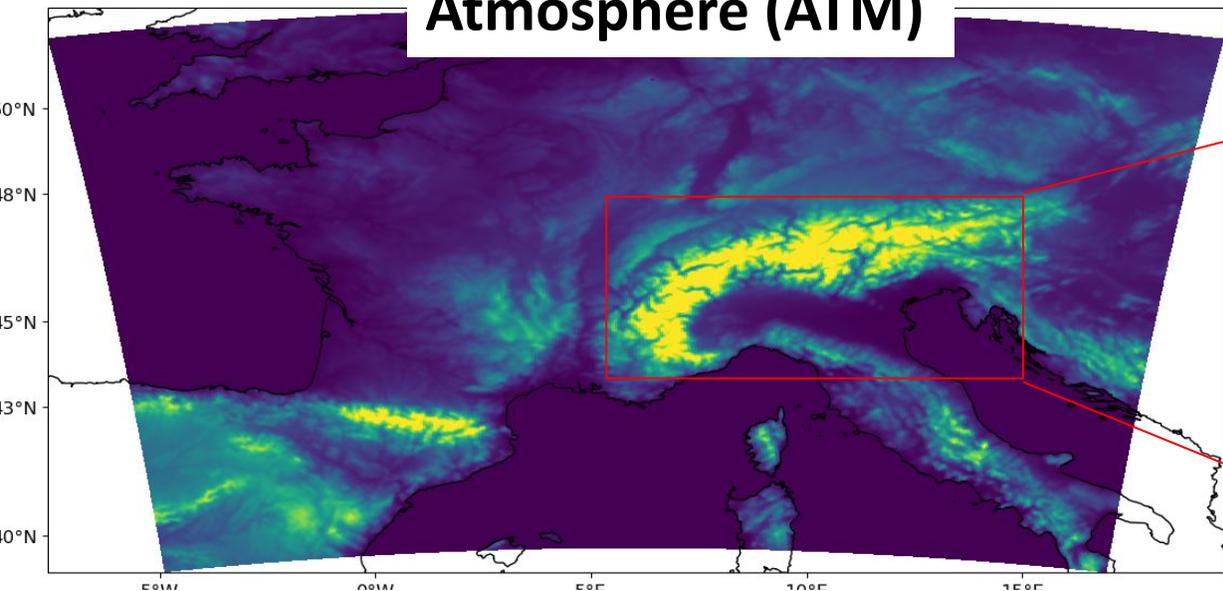
Sea Surface Temperature

Ocean

MITgcm c65

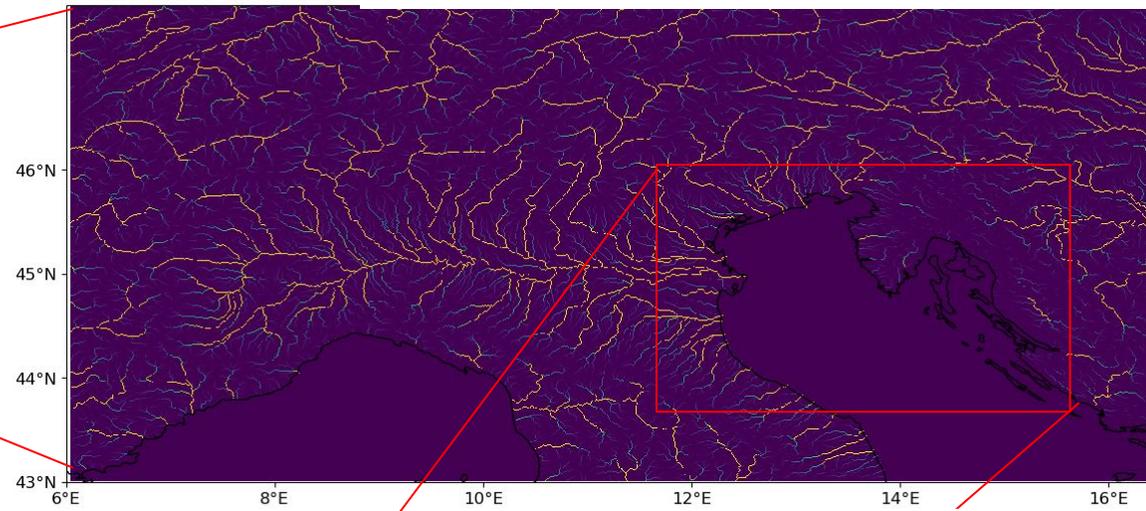
Redrawn from Reale
et al., 2020

Atmosphere (ATM)



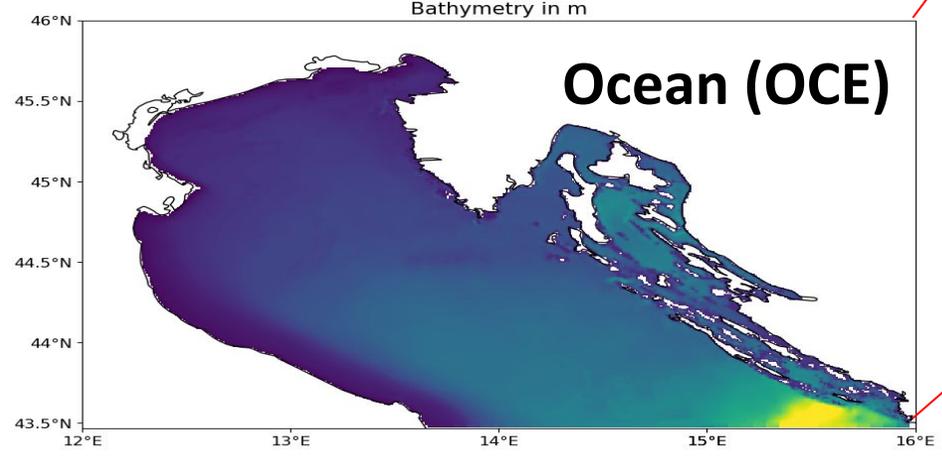
3 km CP*/ 41 Z vertical levels [m]

River

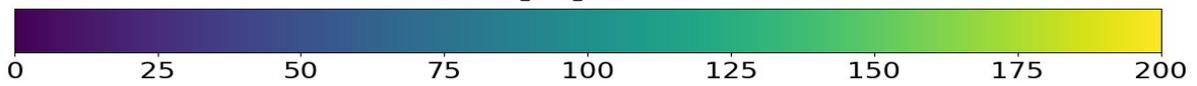


[km²] approximately 1 km

700 m NH**
59 Z vertical levels



[m]



*Convection permitting
**Non Hydrostatic

Settings for the coupler, ATM and OCN (EVALUATION RUN)

- August, 1st 1987-December, 31st 2020** (EVALUATION RUN)
- 3 hours between ATM and OCEAN, 1 day with ATM/OCEAN/RIVER
- ICs/BCs: ERA5 (Hersbach et al., 2020)
- Convection: Explicitly resolved
- Microphysics: Nogherotto/Tompkins
- Air-Sea Fluxes : Zeng
- PBL: Holtslag
- Aerosol : MERRA2
- Timestep: 30s
- ICs/BCs (Temperature and Salinity, Zonal and Meridional Velocity): Copernicus Marine Service (CMS, Escudier et al., 2021)
- Timestep: 50s
- Settings based on Bruschi et al. (2021)*

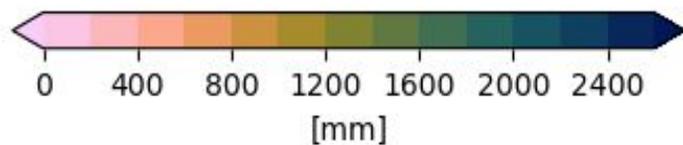
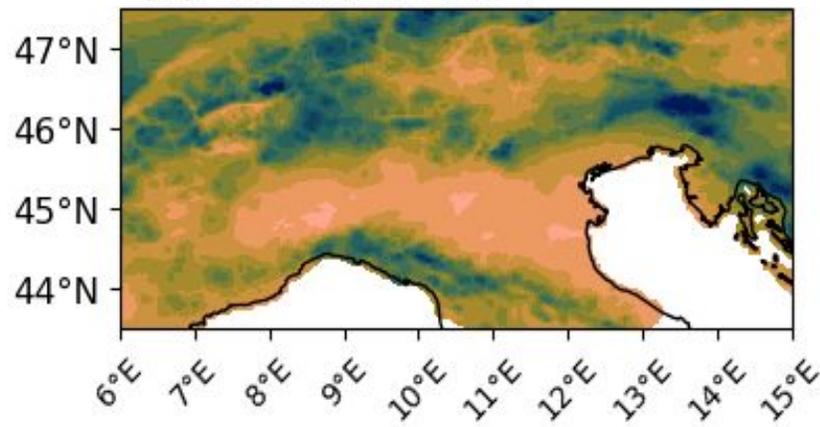
**We run the fully coupled system and only atmosphere, only-river and only ocean models (STANDALONE). Currently the RegCM-ES run covers ONLY the period 1987/08-2003/12

*Bruschi, A., Lisi, I., De Angelis, R., Querin, S., Cossarini, G., Di Biagio, V., ... & Silvestri, C. (2021). Indexes for the assessment of bacterial pollution in bathing waters from point sources: The northern Adriatic Sea CADEAU service. *Journal of Environmental Management*, 293, 112878.

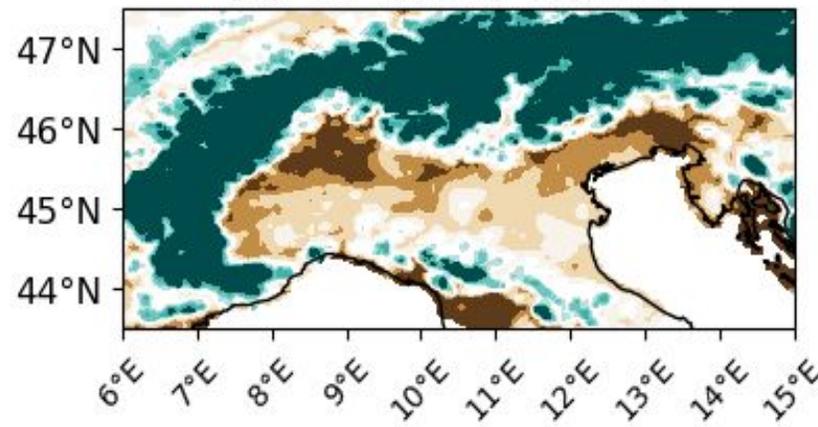
Total Precipitation during wet days

$$\text{ADDED VALUE (AV)} = 100 * (\text{abs}(\text{BIAS}_{\text{RegCM5}}) - \text{abs}(\text{BIAS}_{\text{RegCM-ES}})) / \text{abs}(\text{BIAS}_{\text{RegCM5}})$$

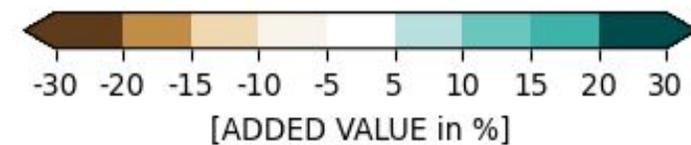
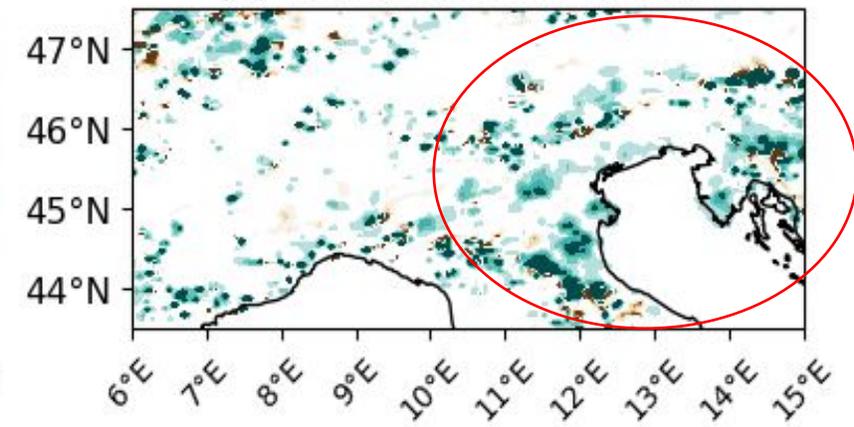
(a) YEAR PRECTOT EURO4M



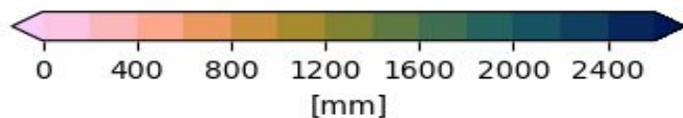
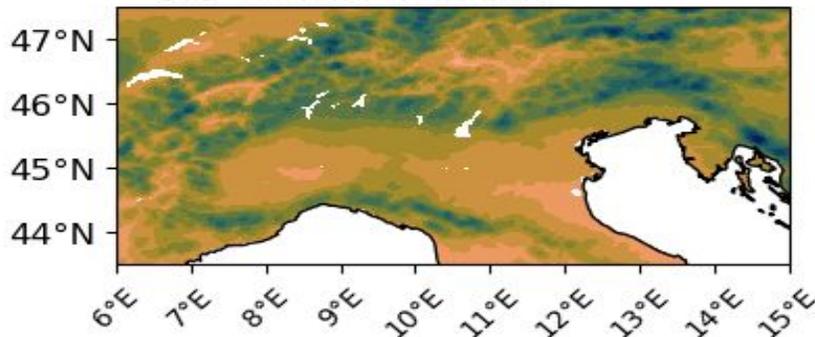
(b) YEAR MIN BIASES



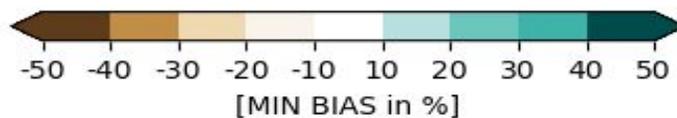
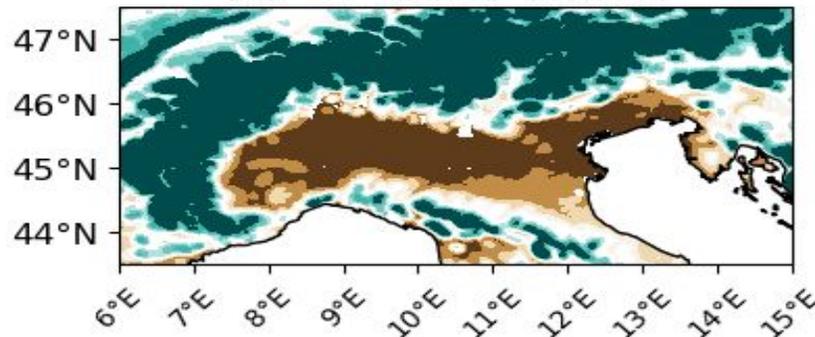
(c) YEAR ADDED VALUE



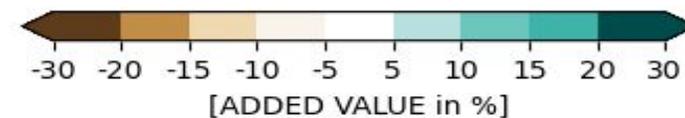
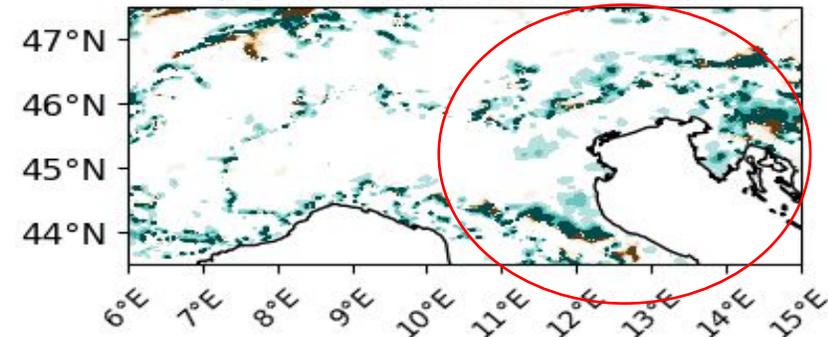
(a) YEAR PRECTOT SPHERA



(b) YEAR MIN BIASES

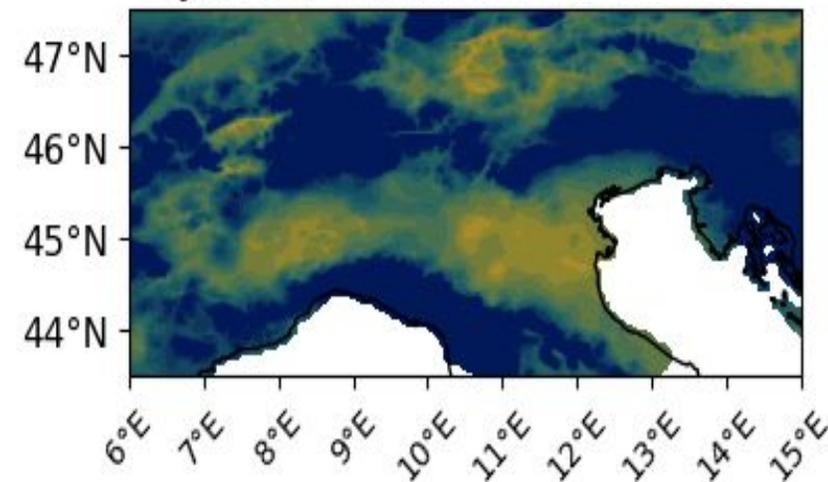


(c) YEAR ADDED VALUE

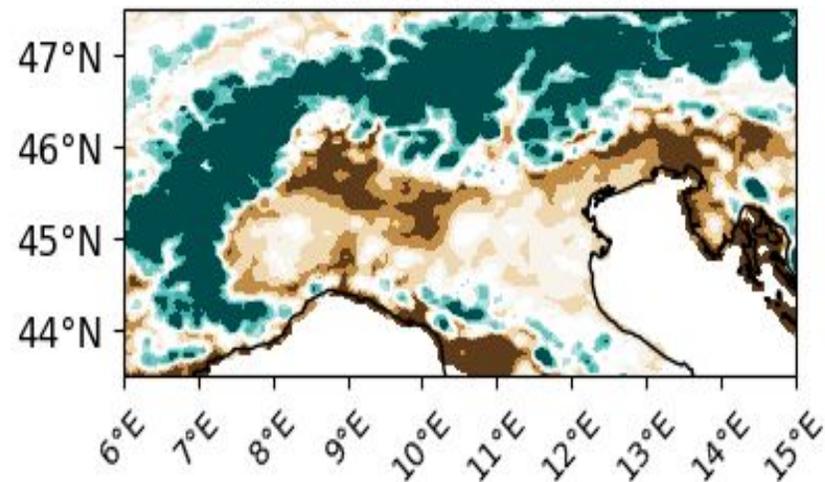


Total Precipitation during wet days : Autumn

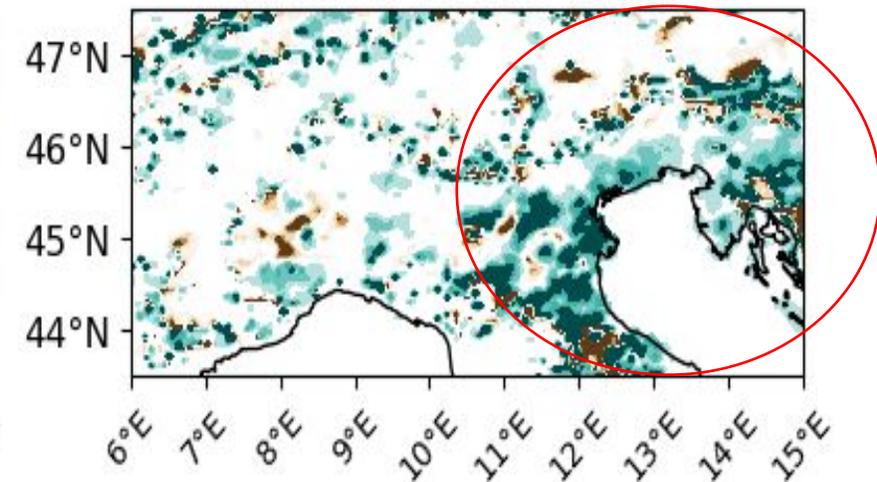
(j) SON PRECTOT EURO4AM



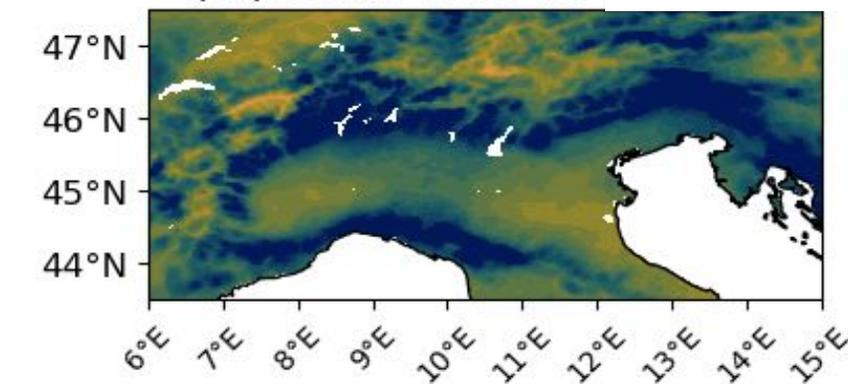
(k) SON MIN BIASES



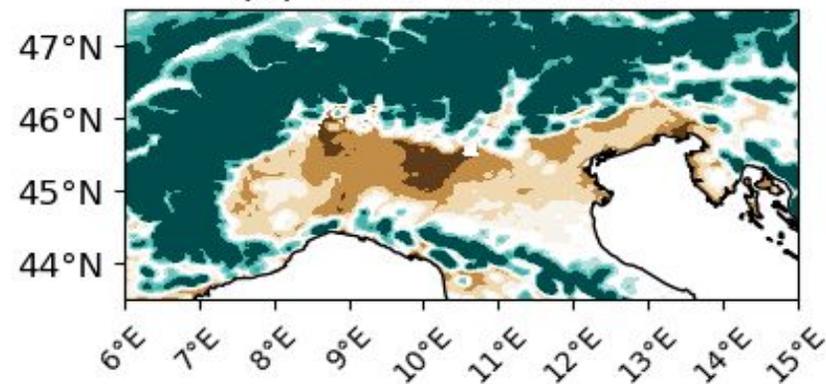
(l) SON ADDED VALUE



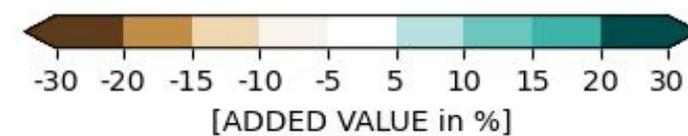
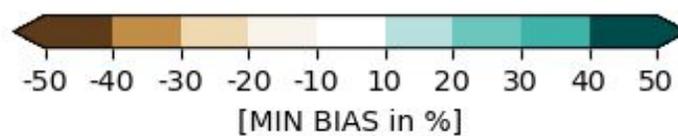
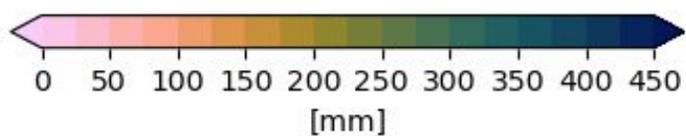
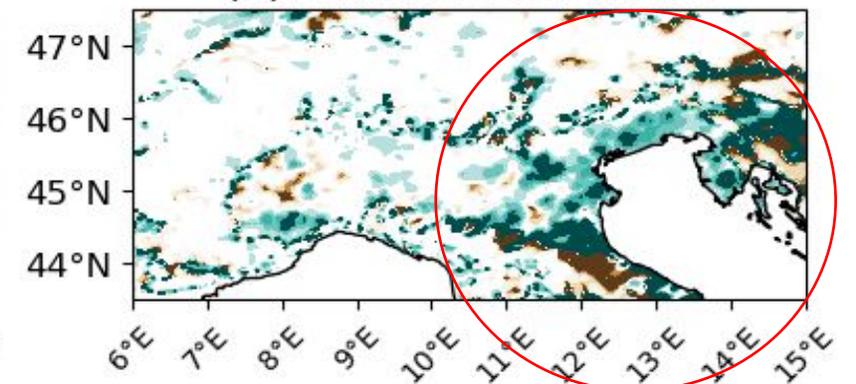
(m) SON PRECTOT SPHERA



(n) SON MIN BIASES

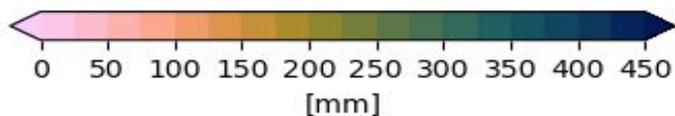
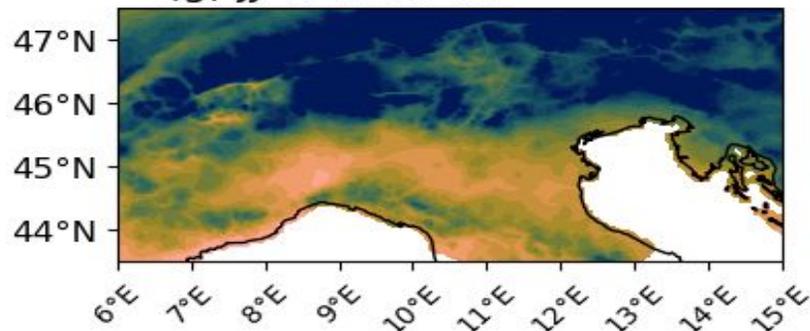


(o) SON ADDED VALUE

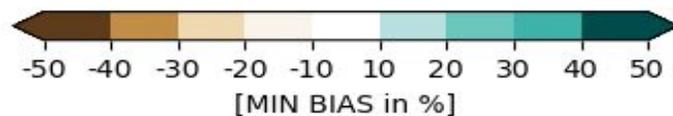
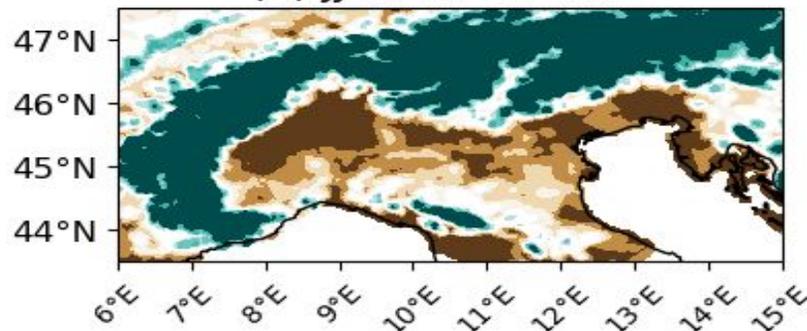


Total Precipitation during wet days : JJA

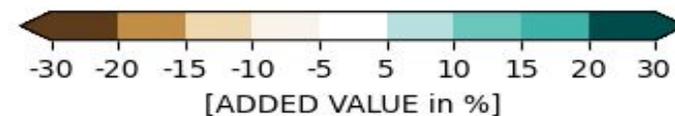
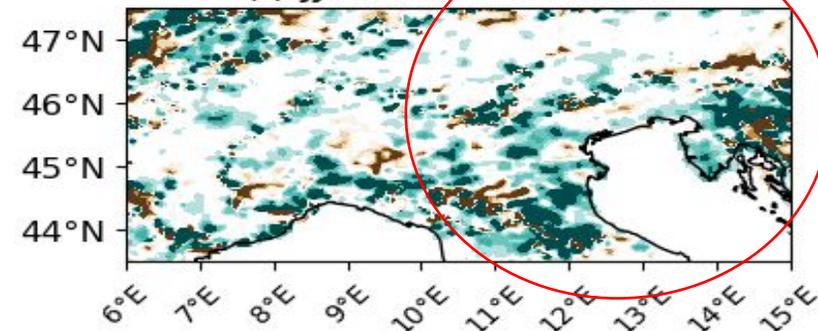
(g) JJA PRECTOT EURO4AM



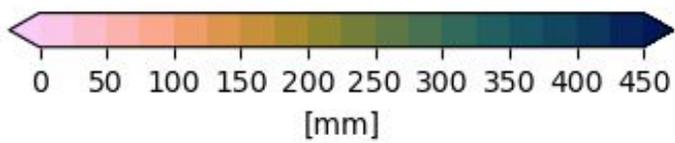
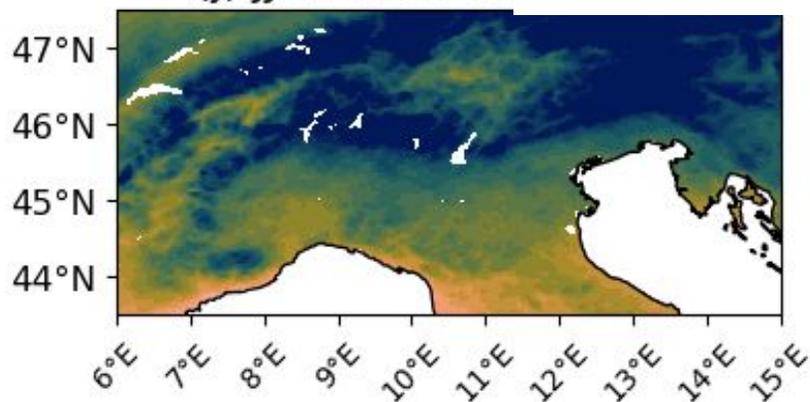
(h) JJA MIN BIASES



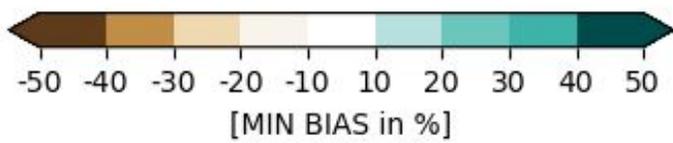
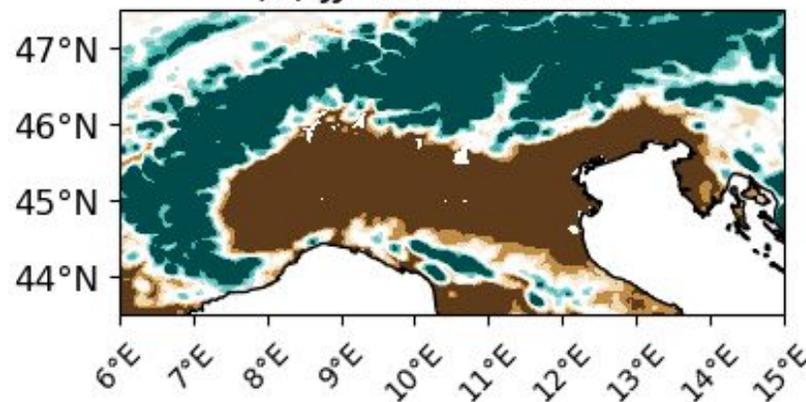
(i) JJA ADDED VALUE



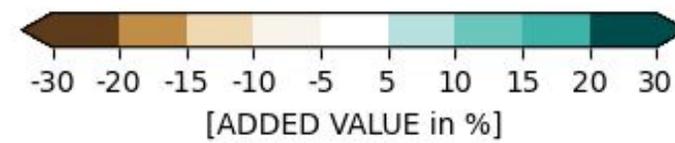
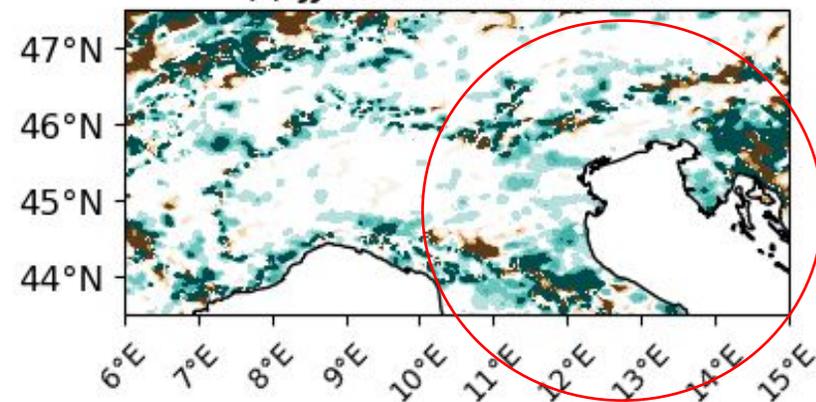
(j) JJA PRECTOT SPHERA



(k) JJA MIN BIASES



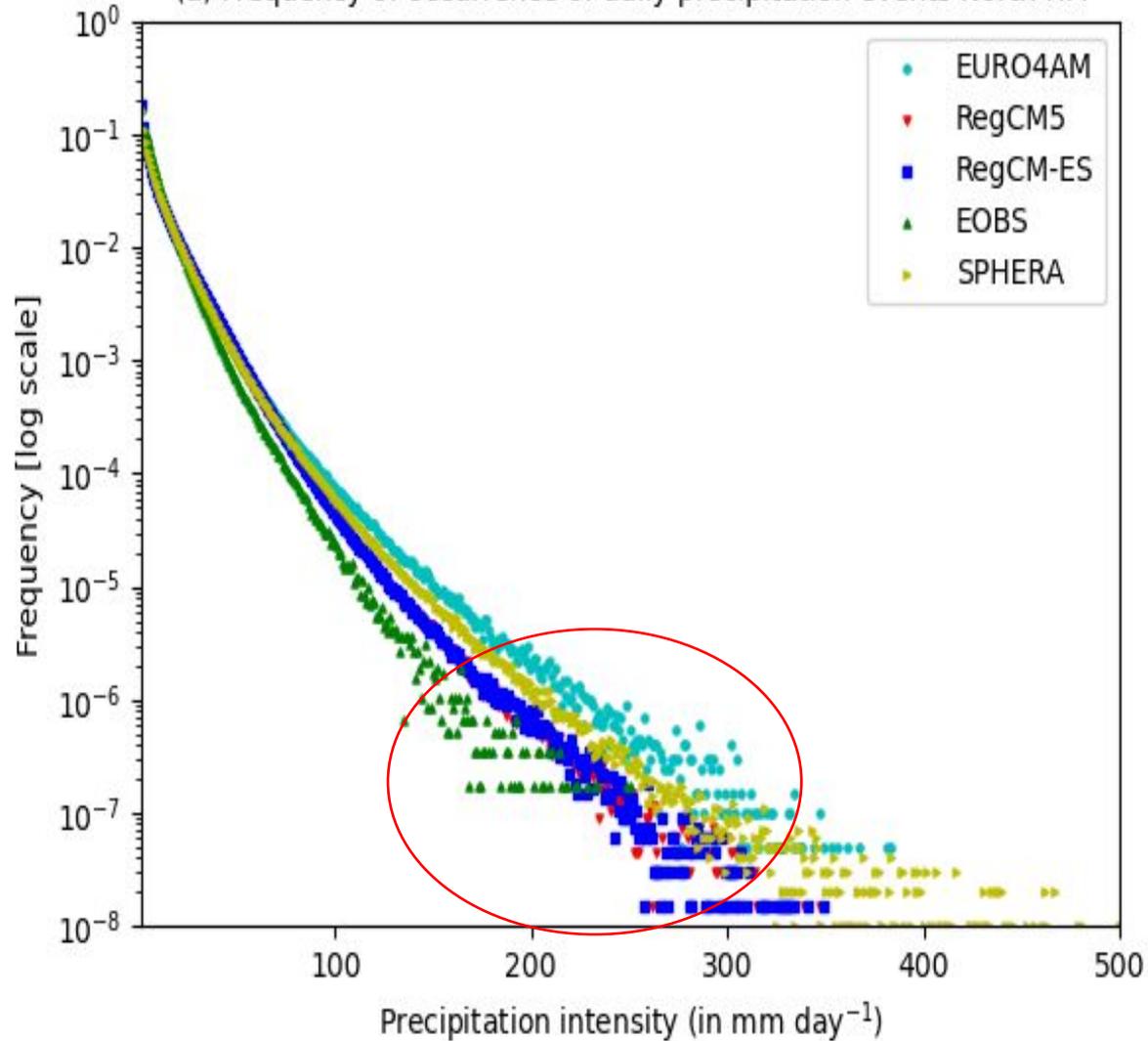
(l) JJA ADDED VALUE



Relative frequency of daily precipitation

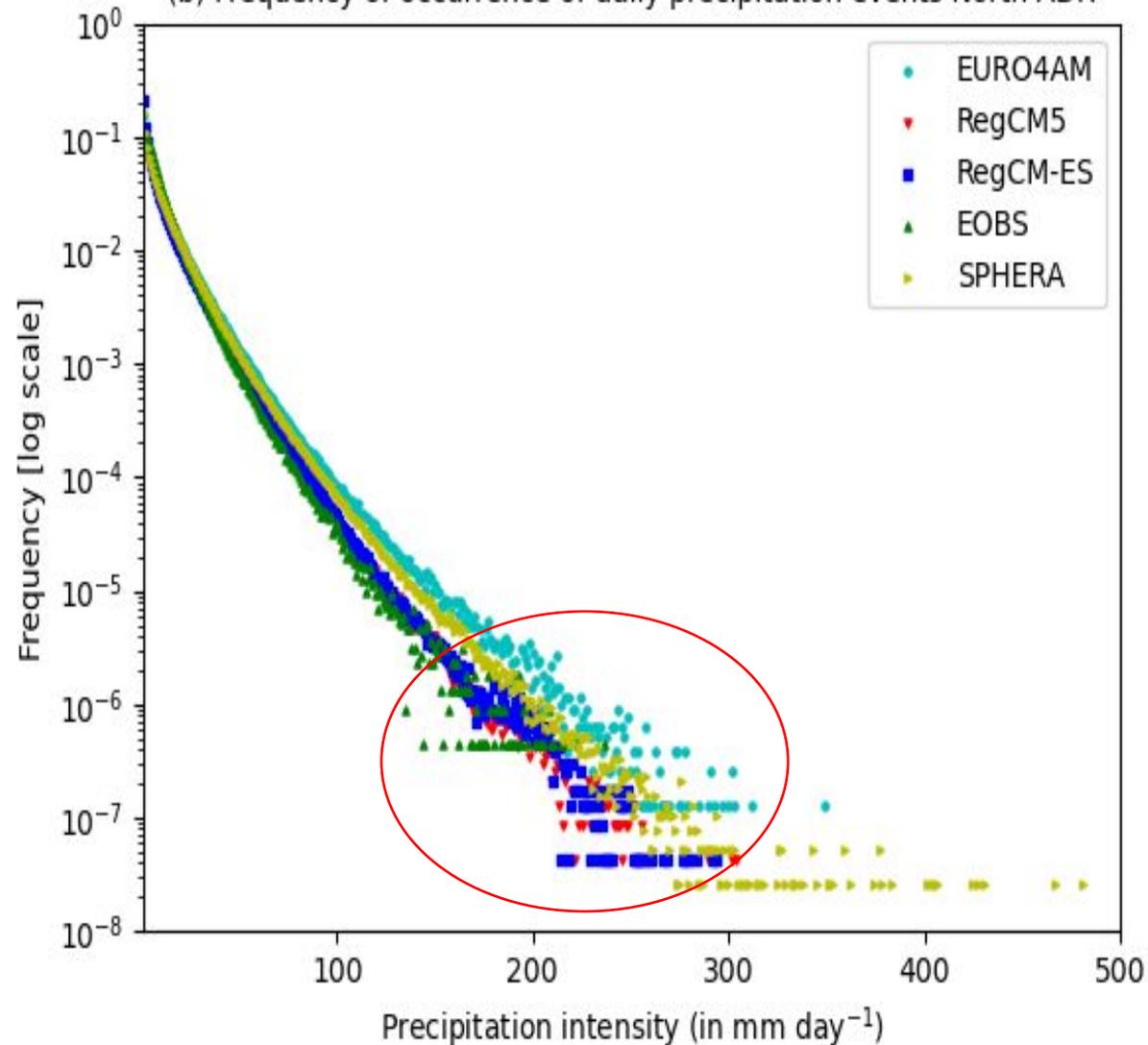
Northern Italy

(a) Frequency of occurrence of daily precipitation events North ITA



Northern Adriatic

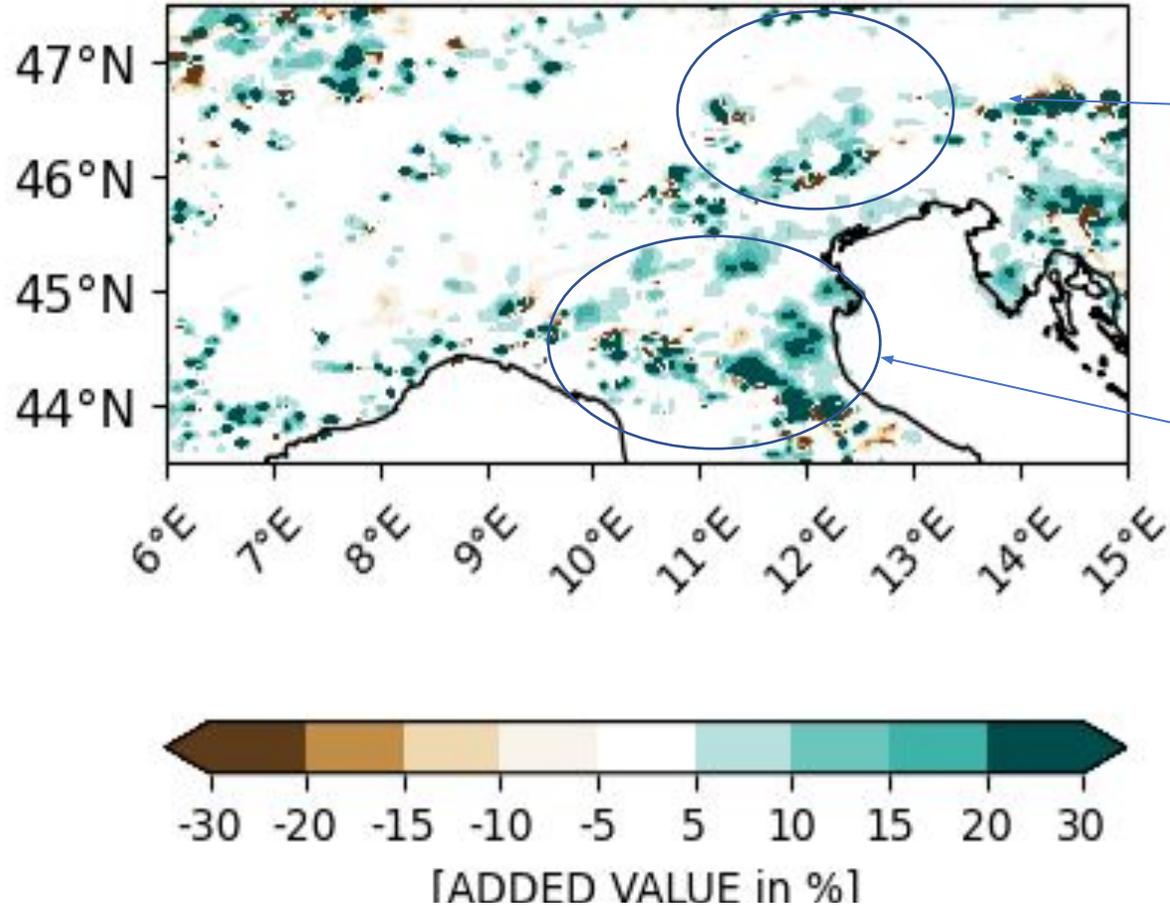
(b) Frequency of occurrence of daily precipitation events North ADR



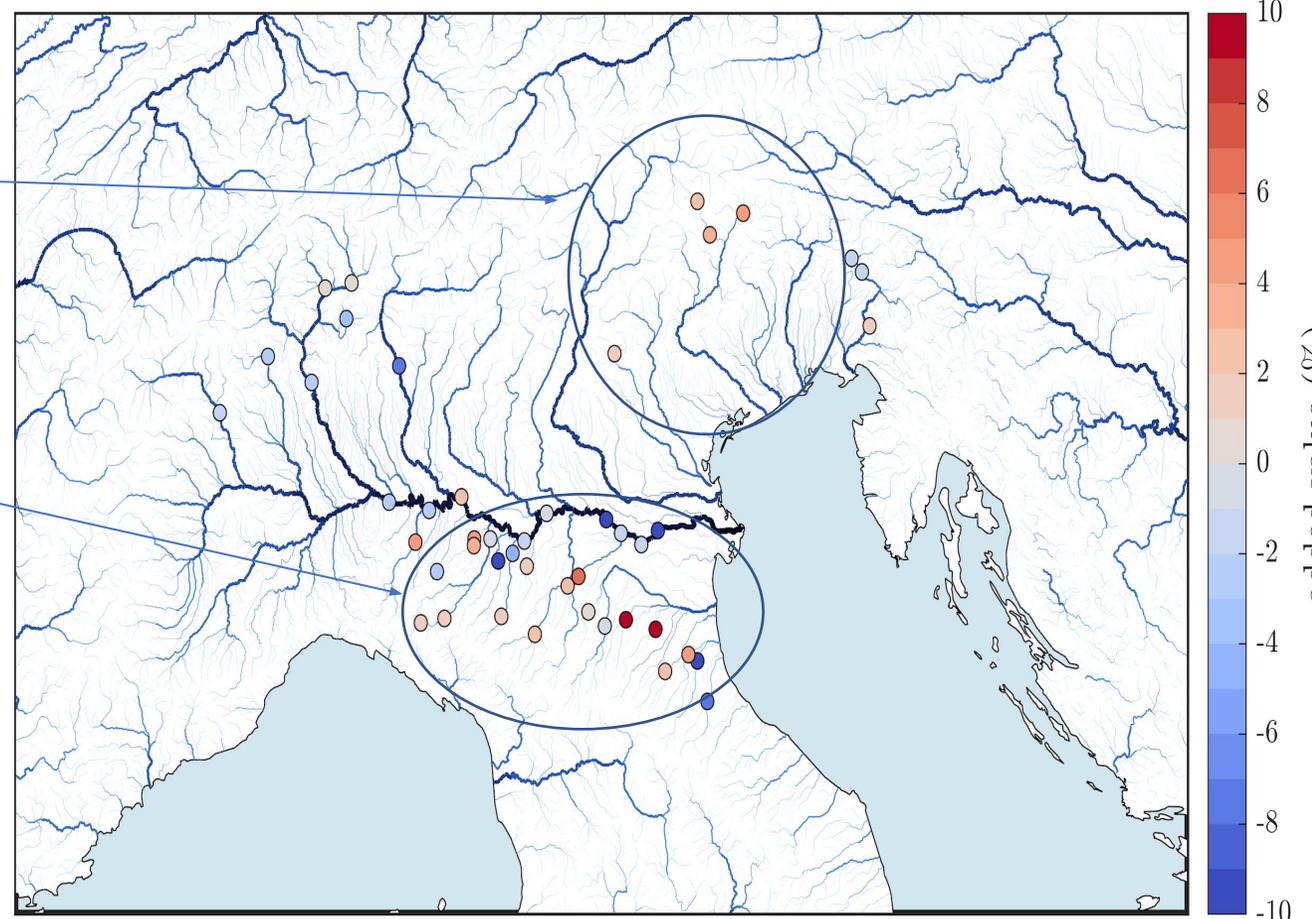
River discharge simulation

Precipitation (AV)

(c) YEAR ADDED VALUE



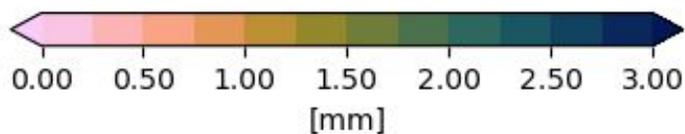
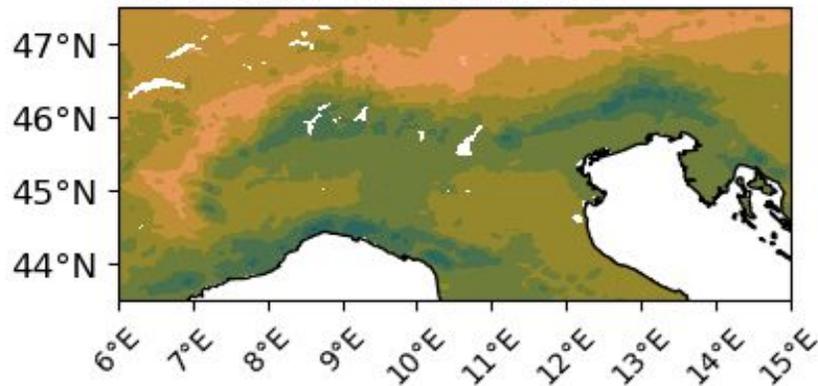
River Discharge (AV)



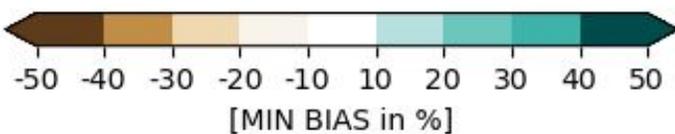
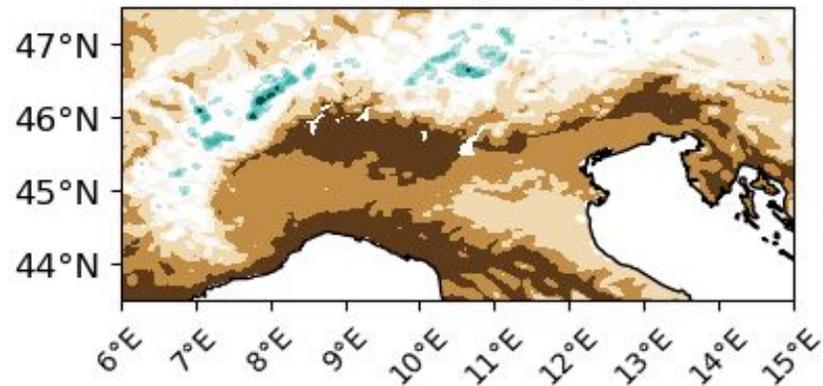
Measuring station

Hourly Precipitation

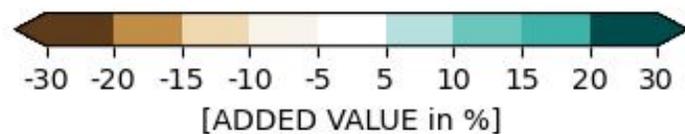
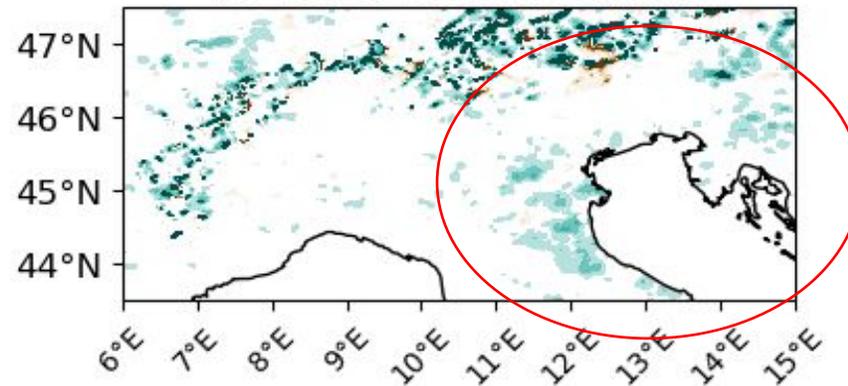
(a) YEAR PREC HOURLY SPHERA



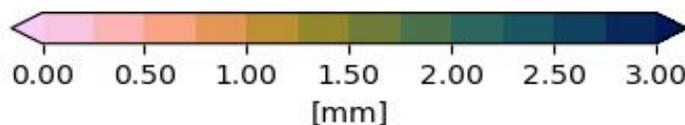
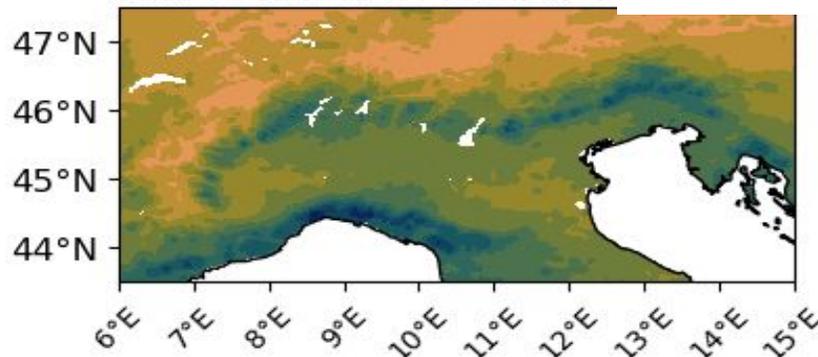
(b) YEAR MIN BIASES



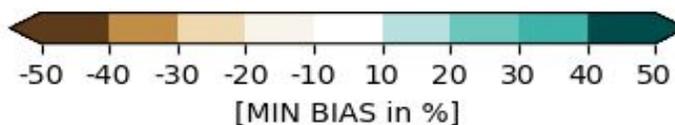
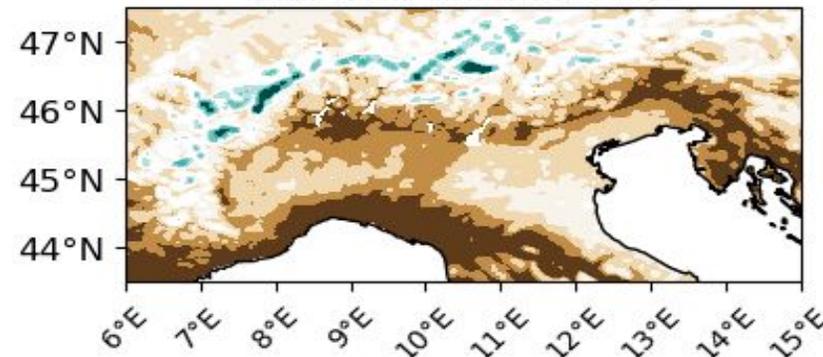
(c) YEAR ADDED VALUE



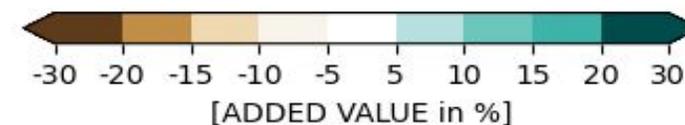
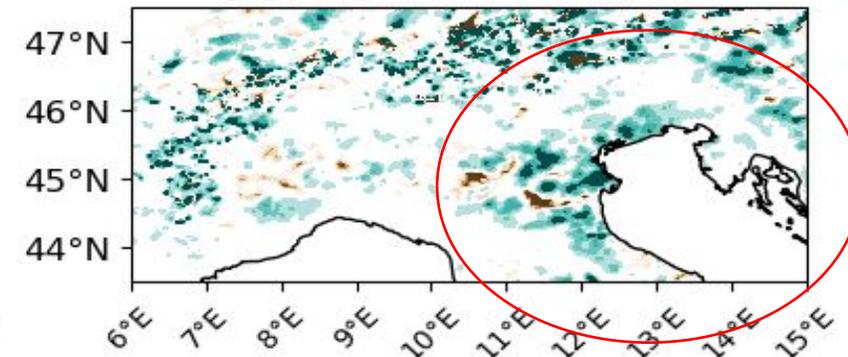
(m) SON PREC HOURLY SPHERA



(n) SON MIN BIASES

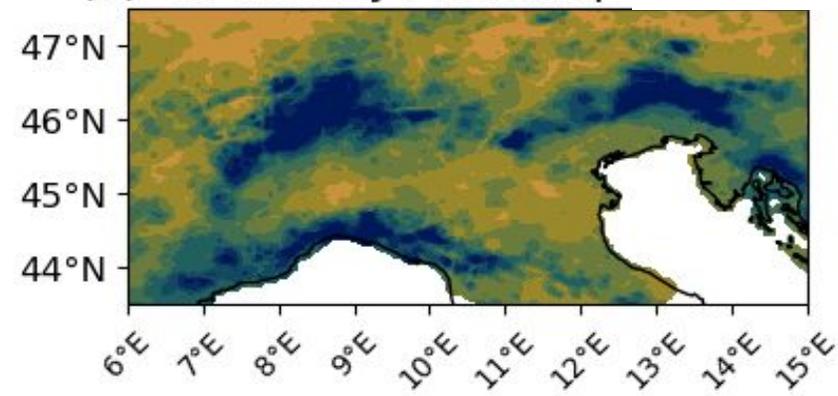


(o) SON ADDED VALUE

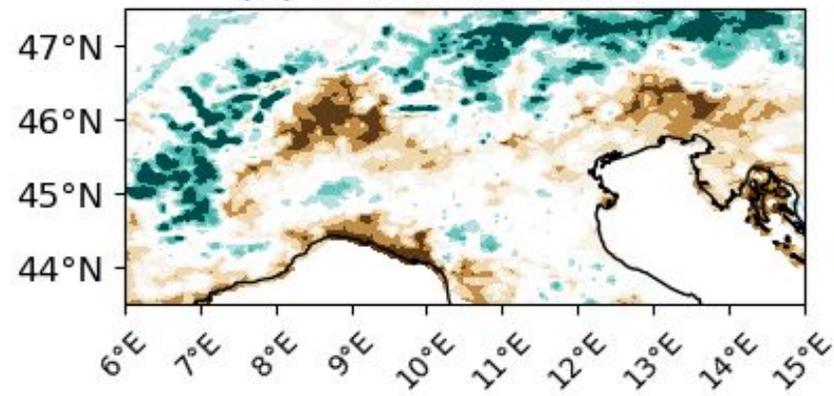


Extreme daily precipitation : 99p

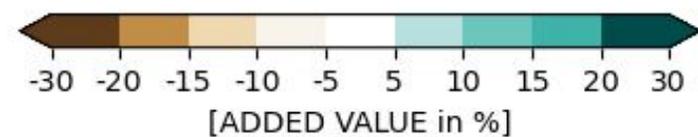
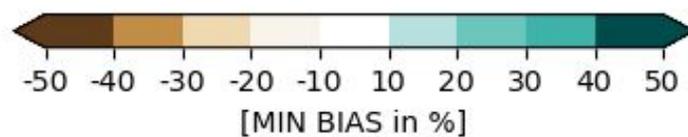
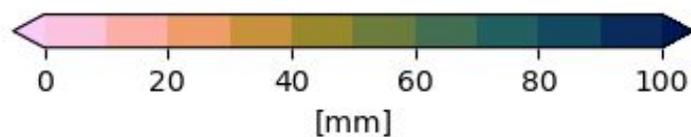
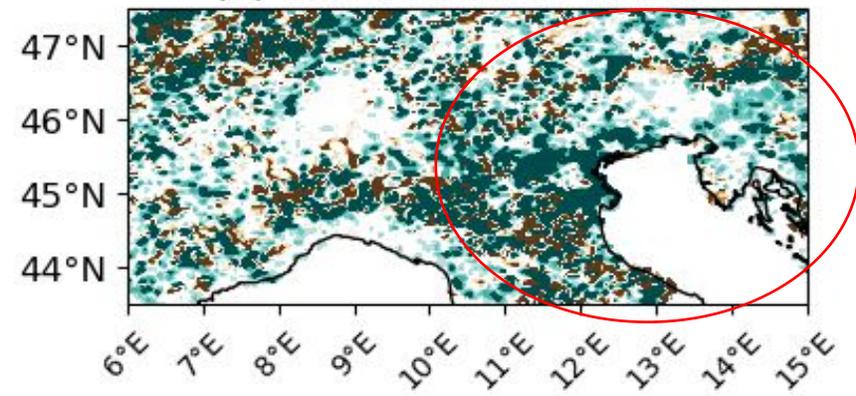
(a) YEAR Daily PREC 99p **EURO4M**



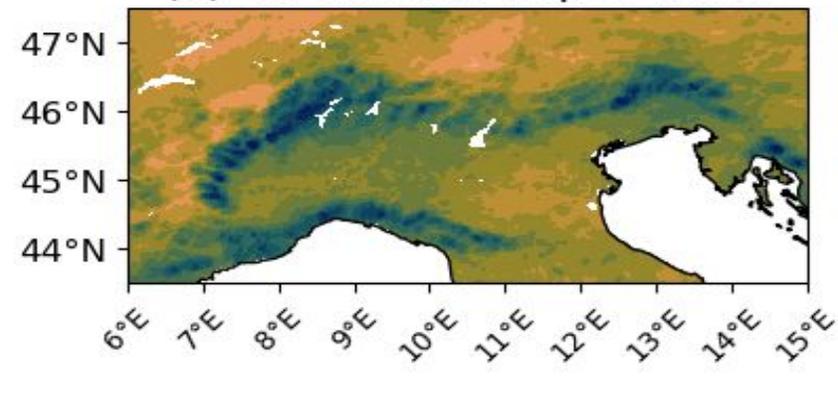
(b) YEAR MIN BIASES



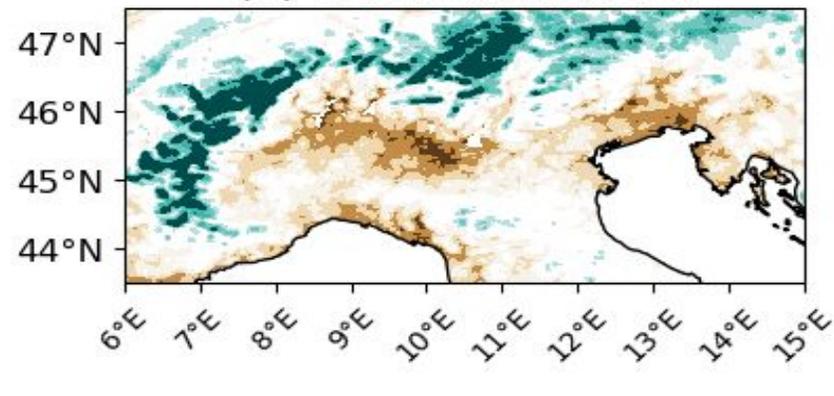
(c) YEAR ADDED VALUE



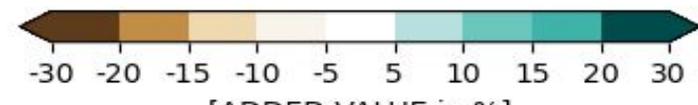
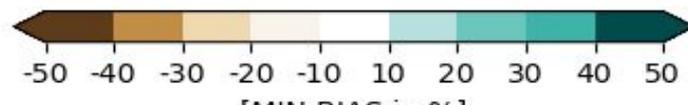
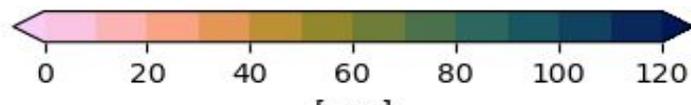
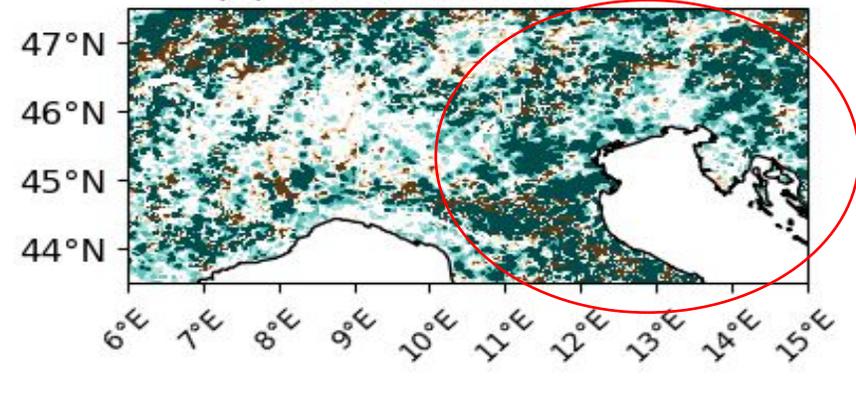
(a) YEAR DAILY 99p **SPHERA**



(b) YEAR MIN BIASES



(c) YEAR ADDED VALUE



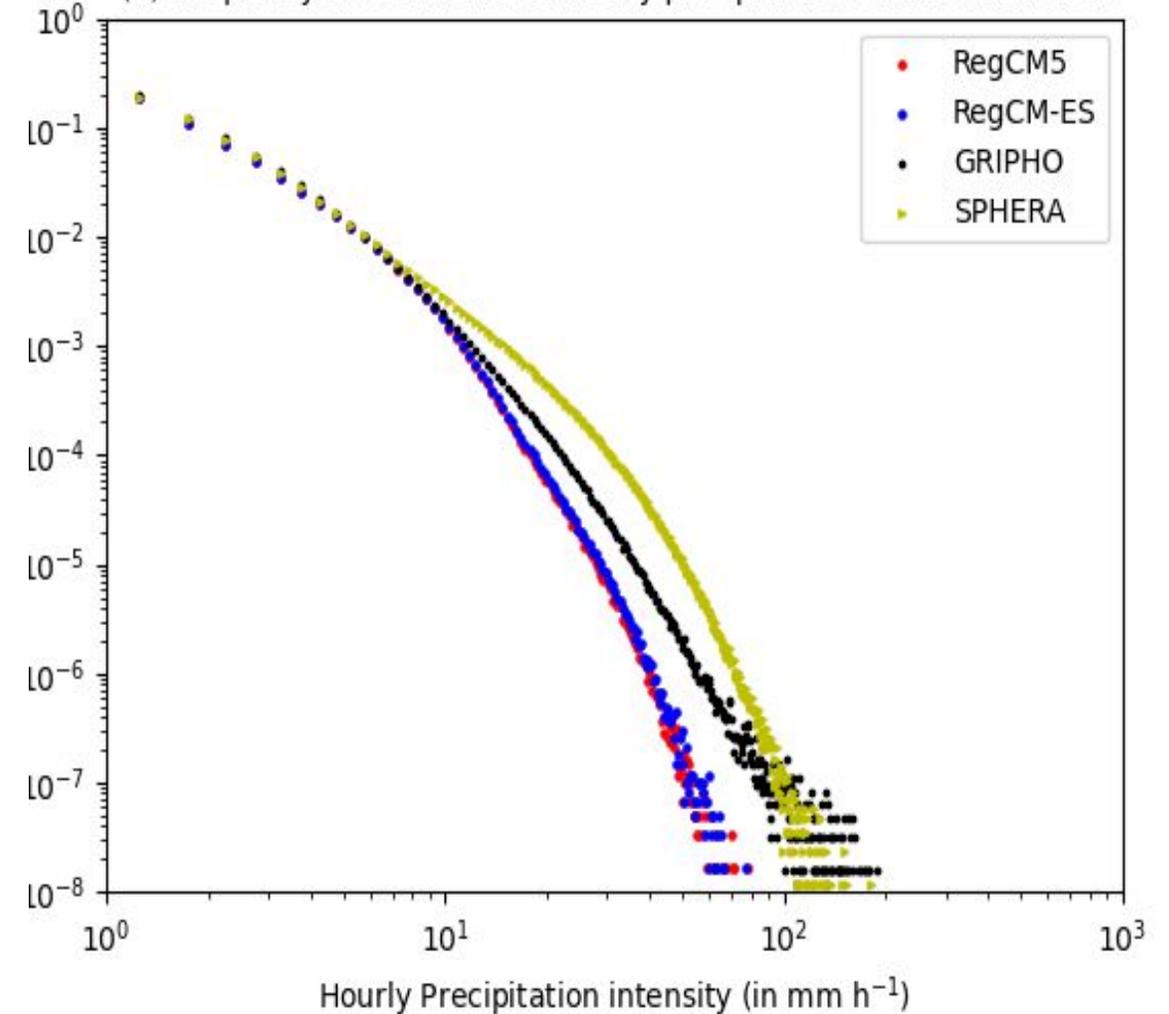
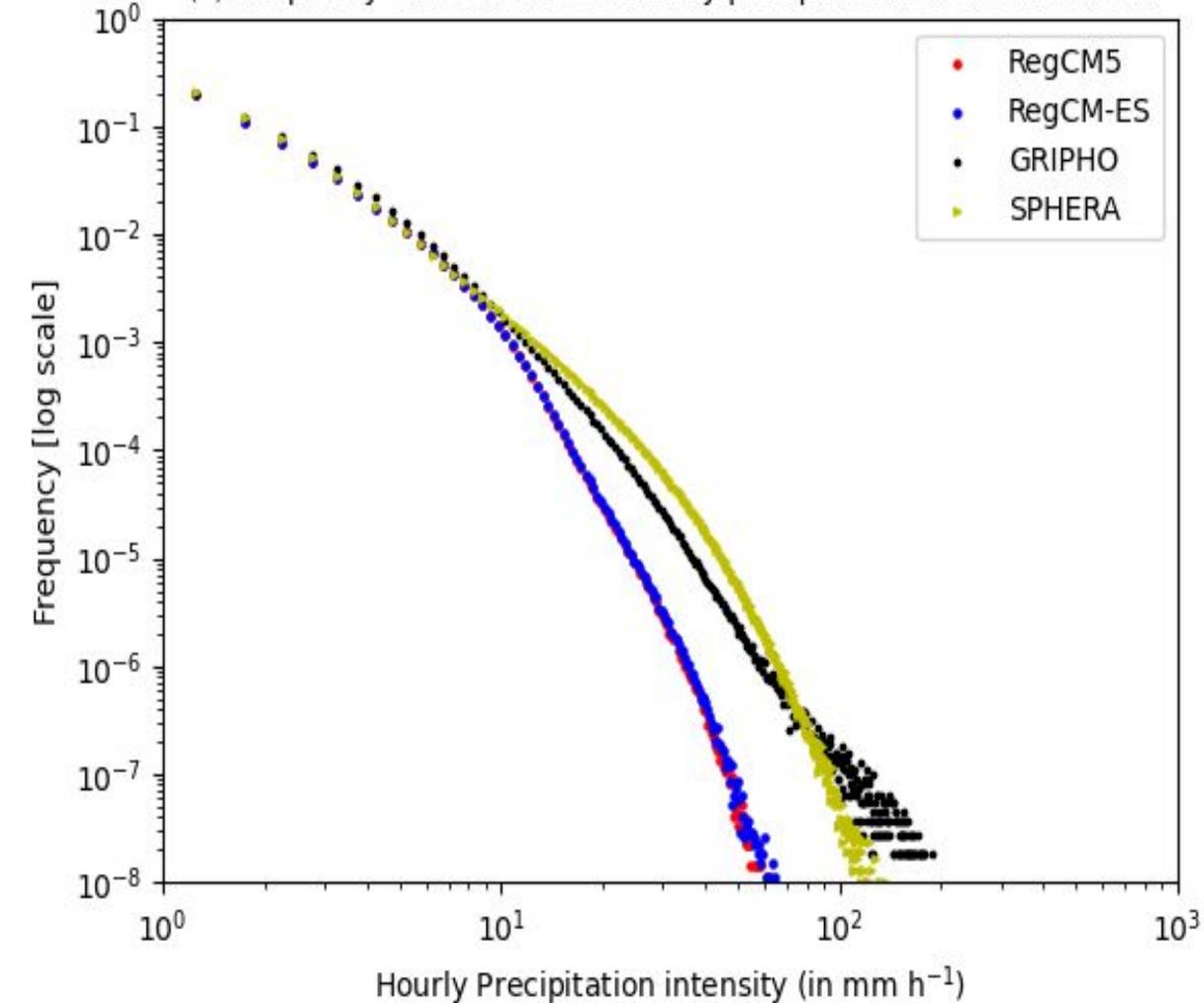
Relative frequency of hourly precipitation

Northern Italy

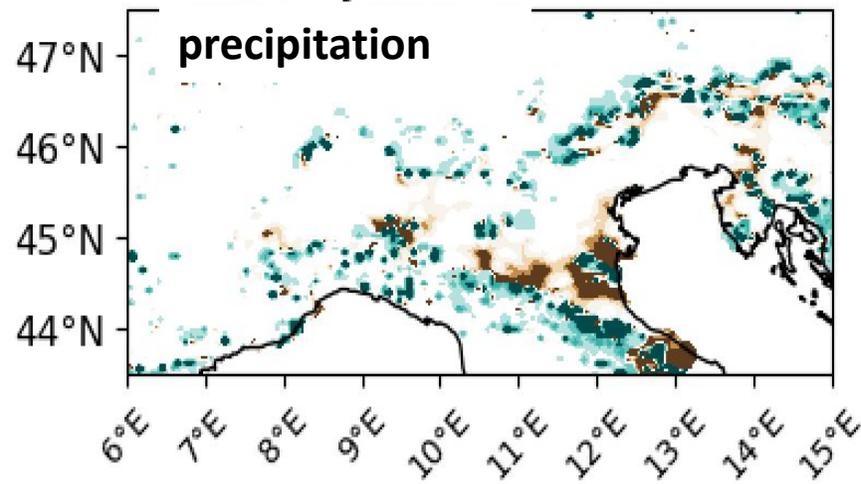
Northern Adriatic

(c) Frequency of occurrence of hourly precipitation events North ITA

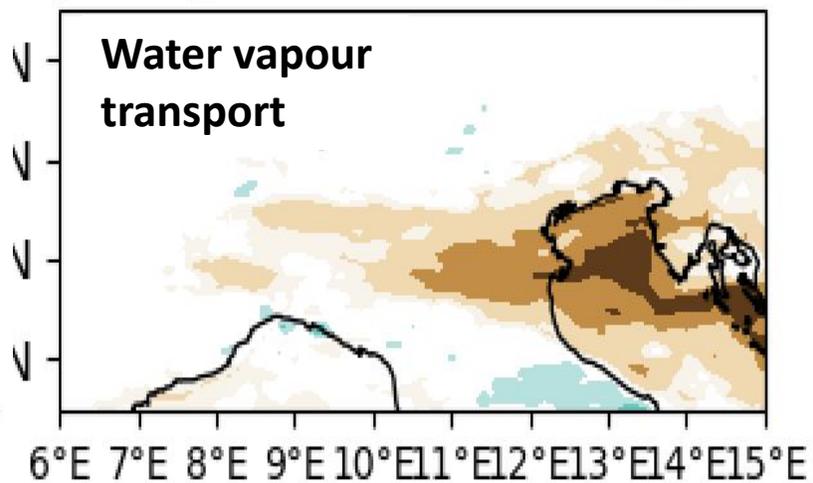
(d) Frequency of occurrence of hourly precipitation events North ADR



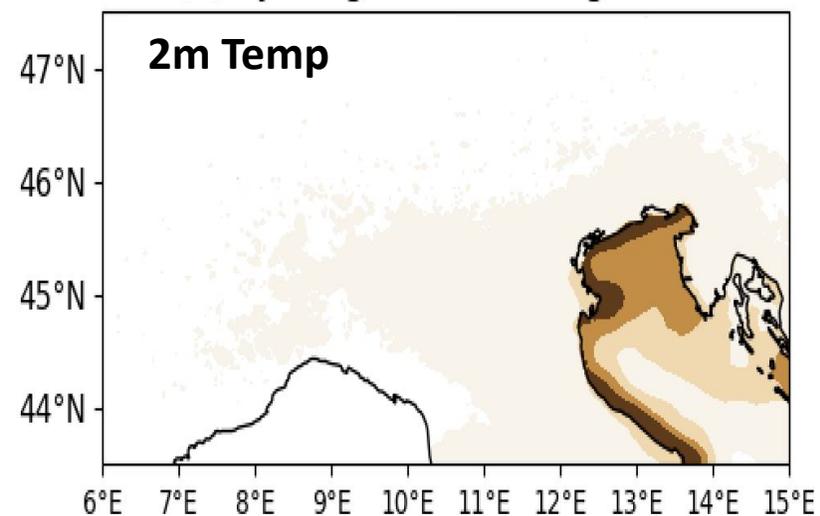
(c) DJF ADDED VALUE



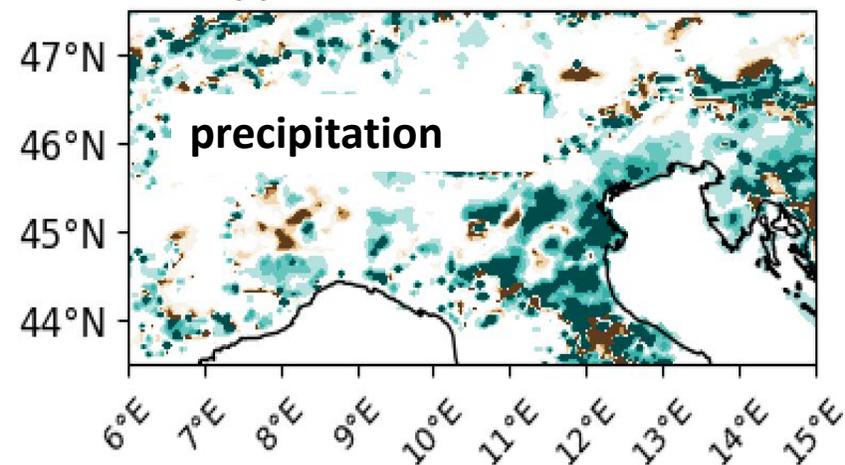
DJF RegCM-ES minus RegCM5



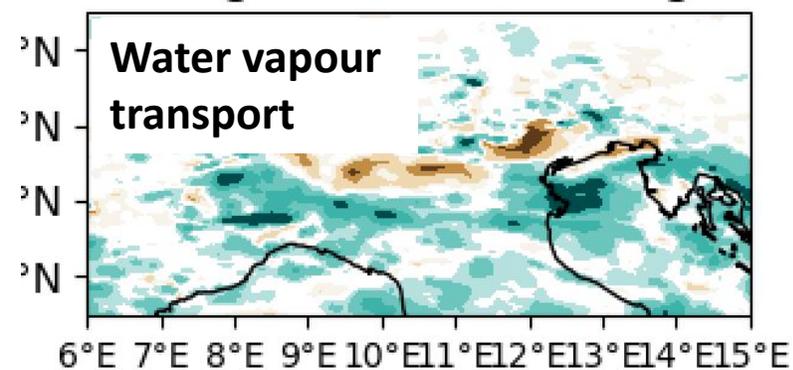
(d) DJF RegCM5minusRegCM-ES



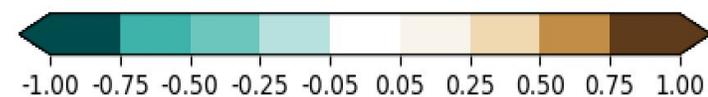
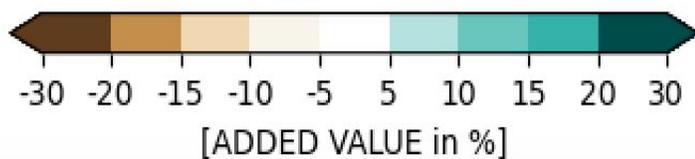
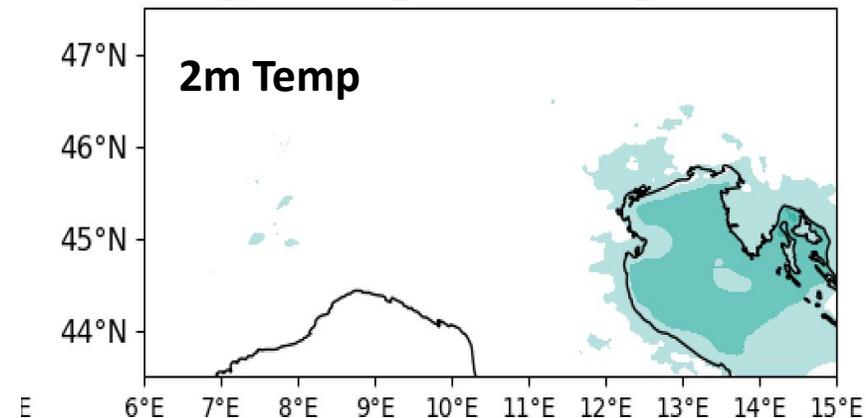
(I) SON ADDED VALUE



SON RegCM-ES minus RegCM5



(j) SON RegCM5minusRegCM-ES



Conclusions (part 1)

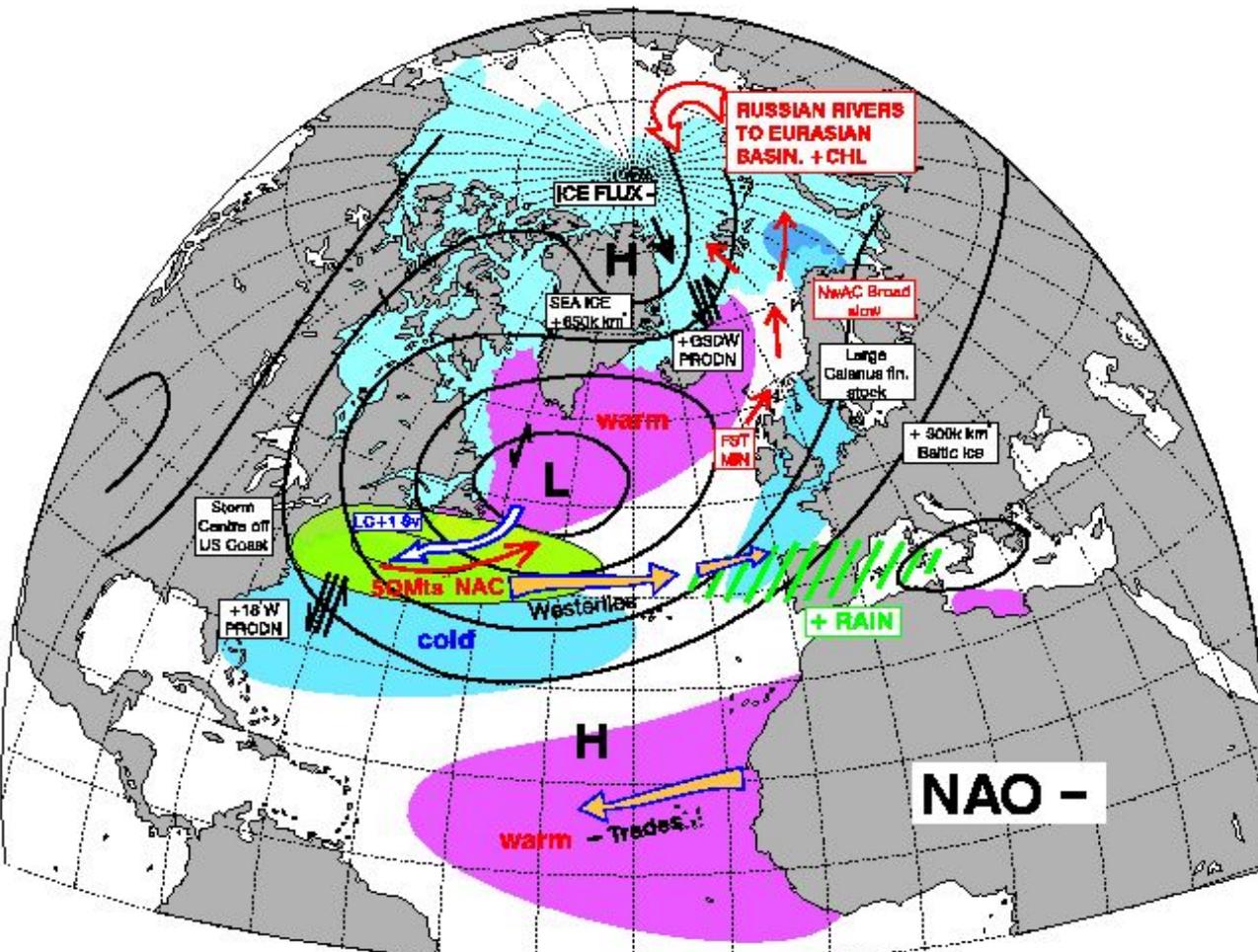
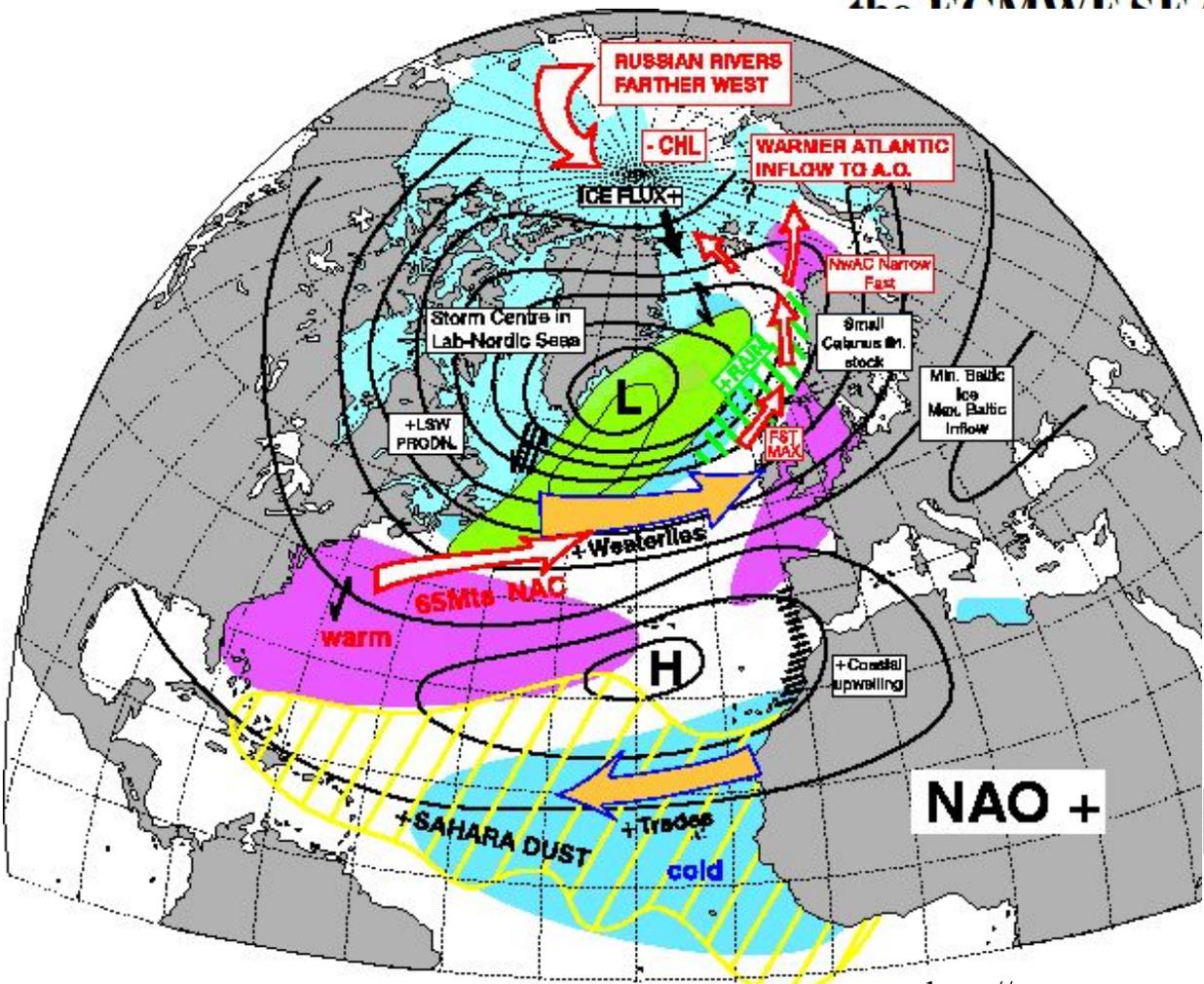
- A improvement in the simulation of the precipitation regime and related extreme is observed mainly in Autumn over the area the closest to the active coupling region
- This affects also the river discharge over the region (and thus potentially also the biogeochemistry of the coastal region)
- The added value in simulating the precipitation regime and related extremes relies on the active interactions and feedbacks between atmosphere and ocean in the coupled system which affects the local circulation of moisture

******PAPER IN PREPARATION**

- ***Convection-permitting coupled modeling over Northern Italy***
- ***Response of large scale circulation at mid-latitudes to the Indian ocean SST variability***
- ***Links between CO₂ sink in the Mediterranean region and synoptic features crossing the region***

The Combined Link of the Indian Ocean Dipole and ENSO with the North Atlantic–European Circulation during Early Boreal Winter in Reanalysis and

45 ECMWF SEAS5 Hindcast



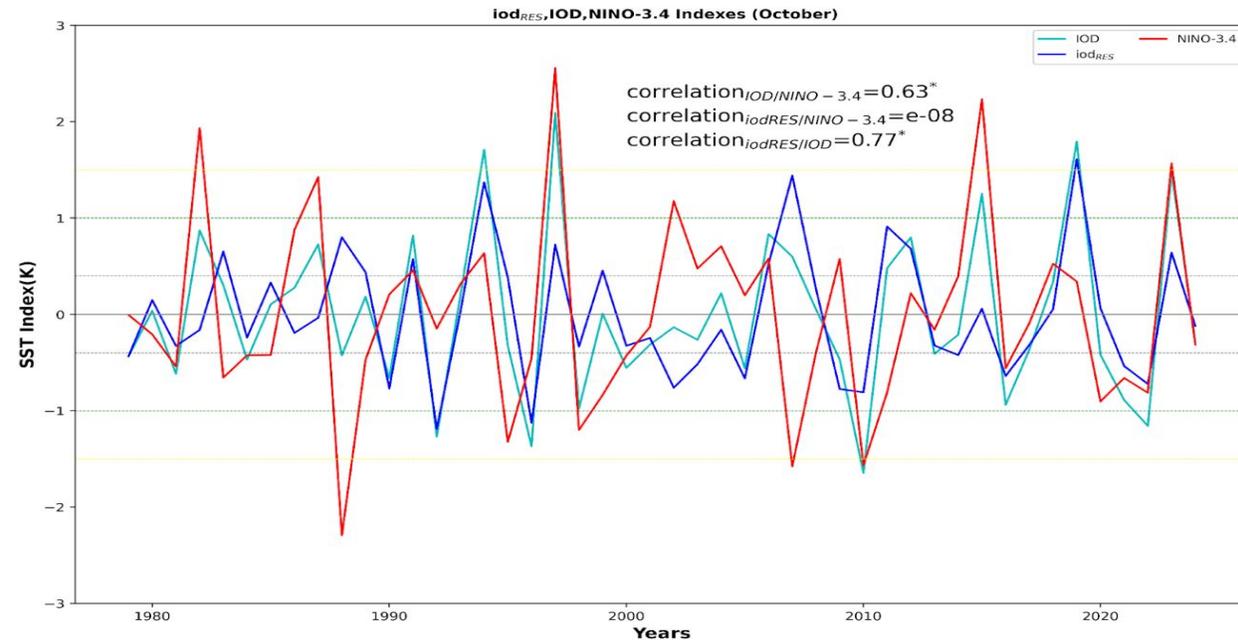
Seasonal forecast based on simple linear regression between a physical variable Y and a standardized index X

$$Y = \text{slope} * X + \text{intercept}$$

Y (ERA5 1979-2020)

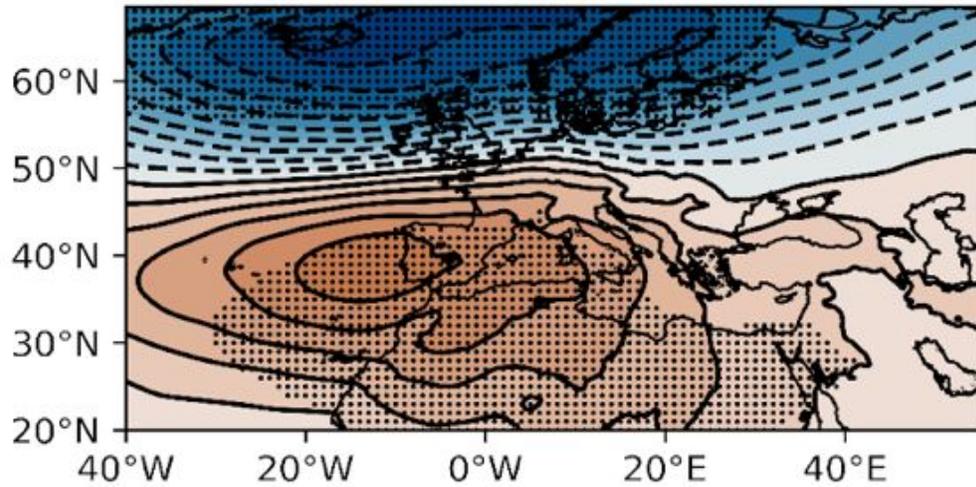
- MSLP
- Total precipitation
- Density of tracks
- Temperature
- Eady growth rate..

X

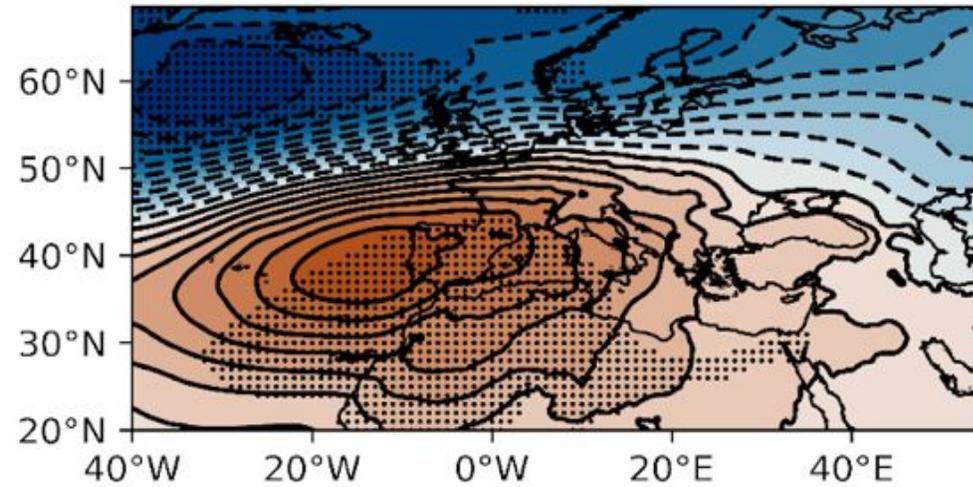


Seasonal forecast based on simple linear regression between a physical variable Y and a standardized index X

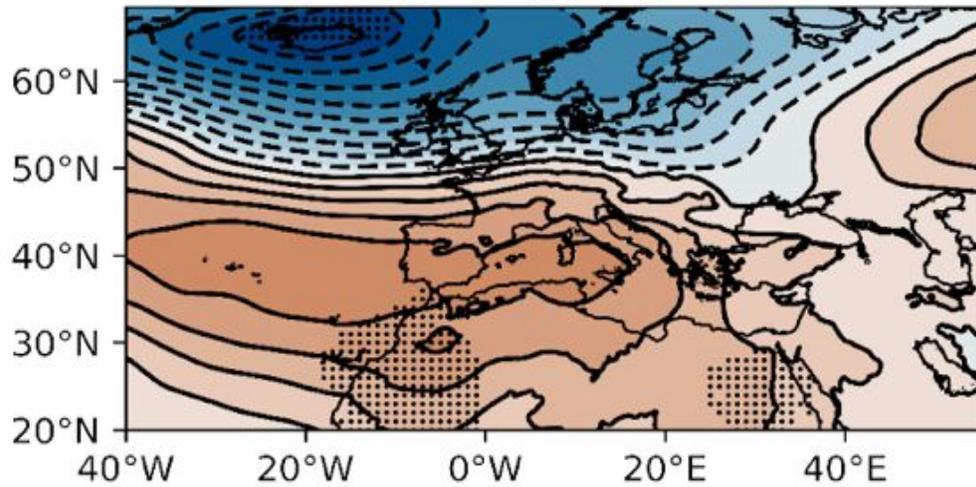
(a) $\text{Reg}(\text{MSLP}_{DJF}, \text{iod_RES}_{OCT})$



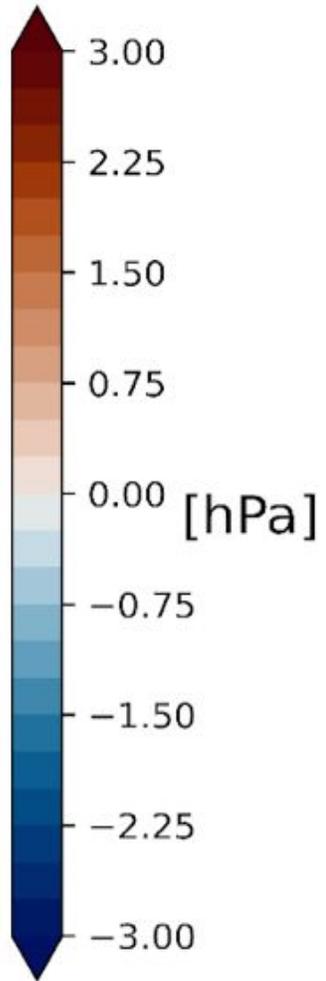
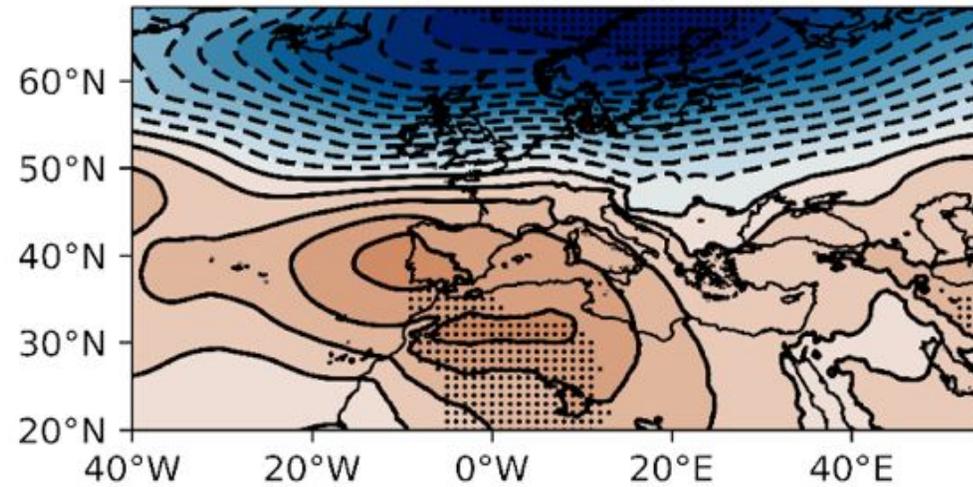
(b) $\text{Reg}(\text{MSLP}_{DEC}, \text{iod_RES}_{OCT})$



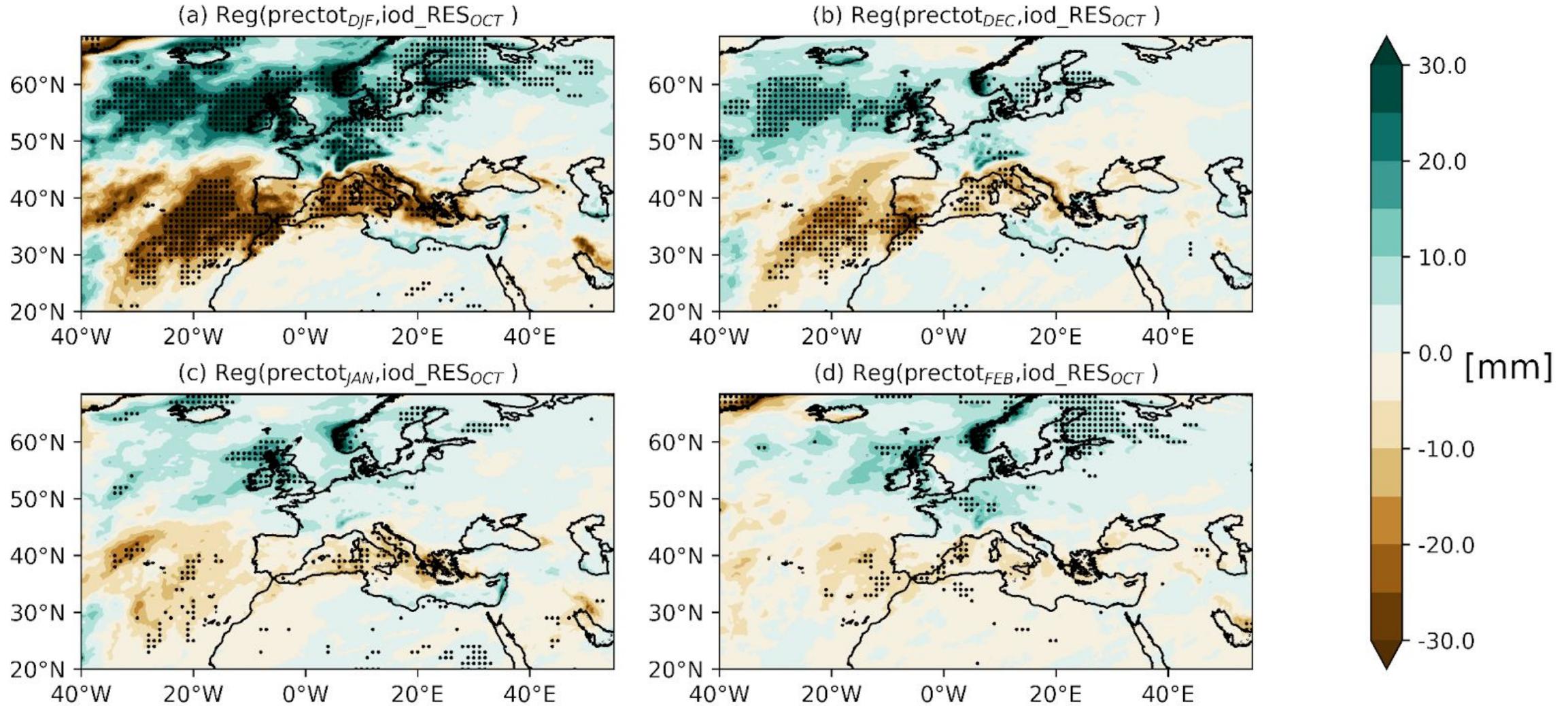
(c) $\text{Reg}(\text{MSLP}_{JAN}, \text{iod_RES}_{OCT})$



(d) $\text{Reg}(\text{MSLP}_{FEB}, \text{iod_RES}_{OCT})$

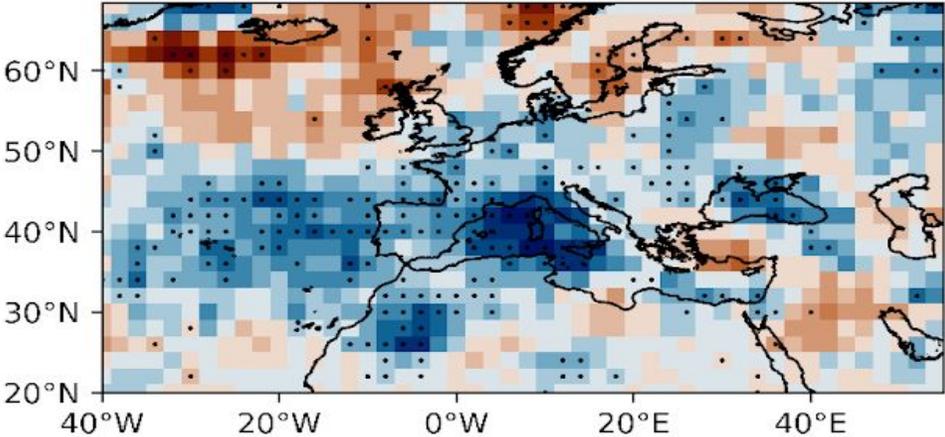


Seasonal forecast based on simple linear regression between a physical variable Y and a standardized index X

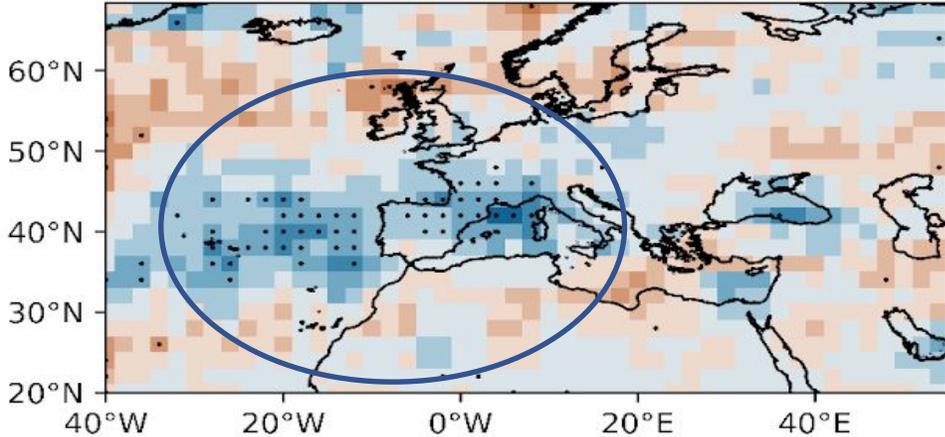


Density of tracks

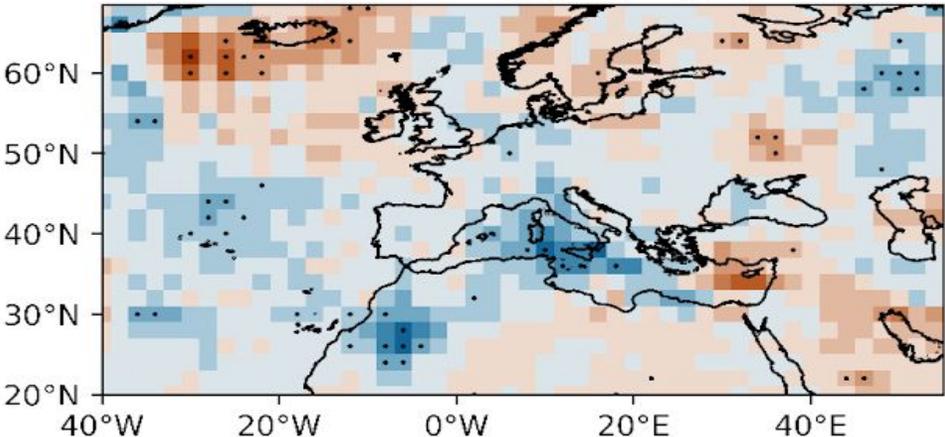
(a) $\text{Reg}(\text{tracks}_{DJF}, \text{iod_RES}_{OCT})$



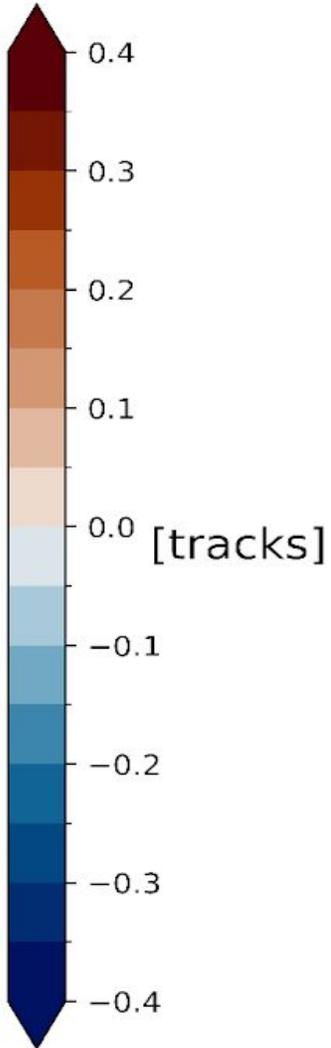
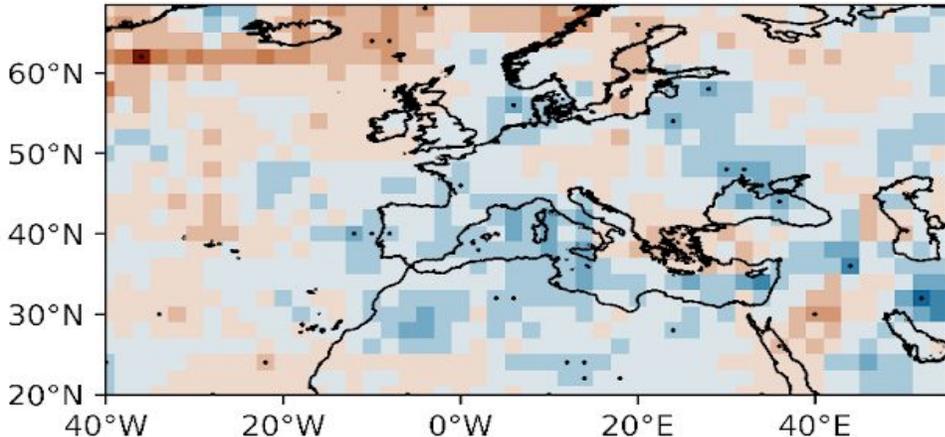
(b) $\text{Reg}(\text{tracks}_{DEC}, \text{iod_RES}_{OCT})$



(c) $\text{Reg}(\text{tracks}_{JAN}, \text{iod_RES}_{OCT})$

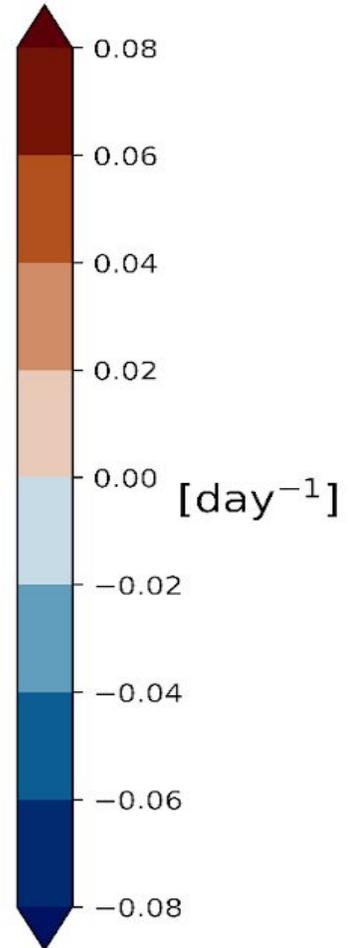
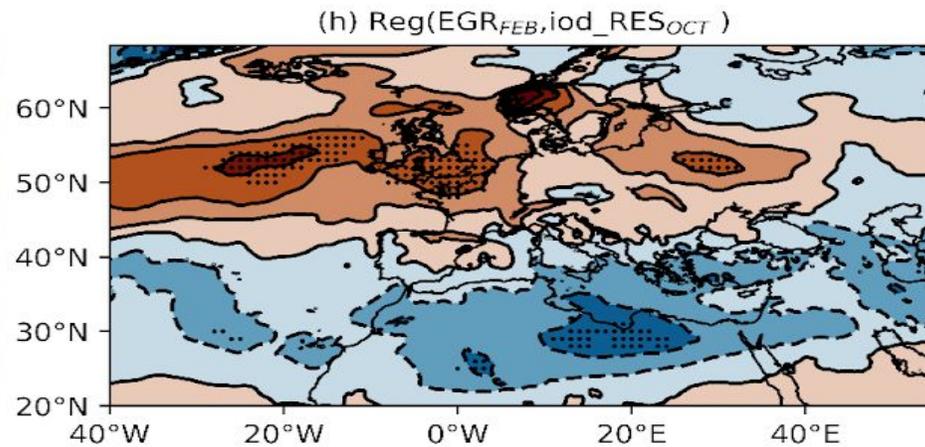
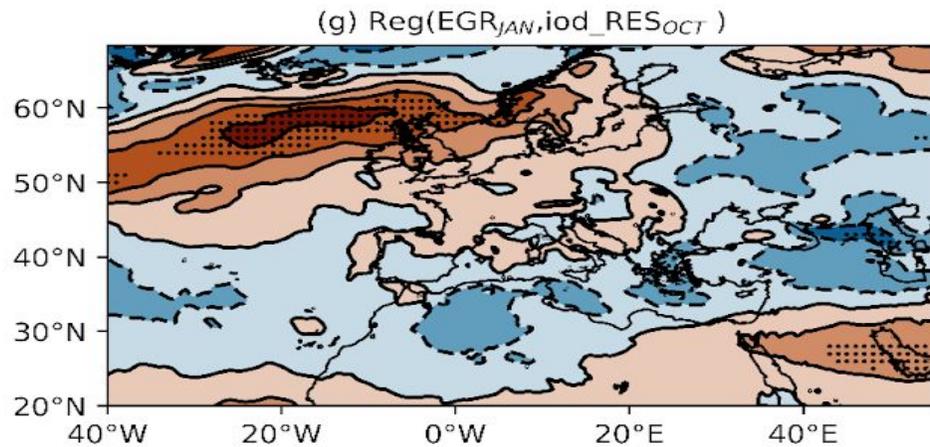
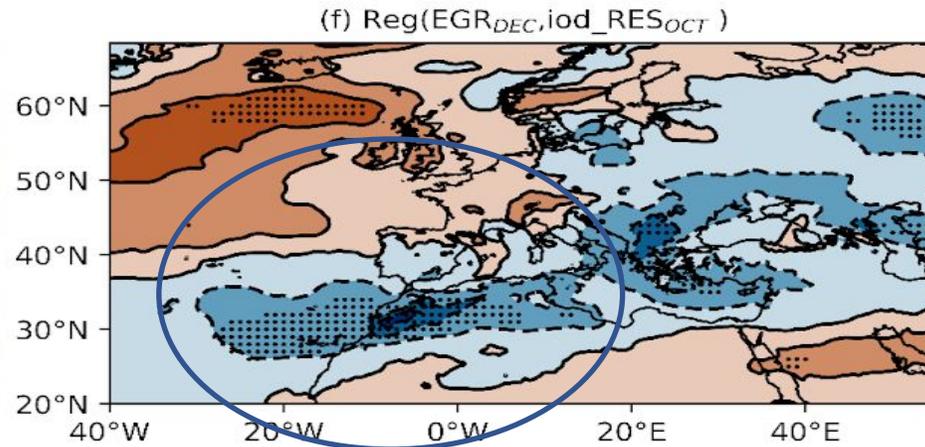
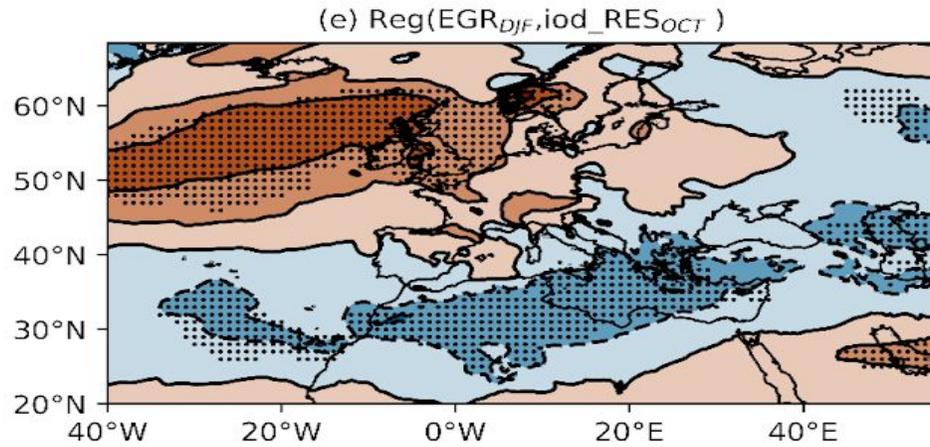


(d) $\text{Reg}(\text{tracks}_{FEB}, \text{iod_RES}_{OCT})$

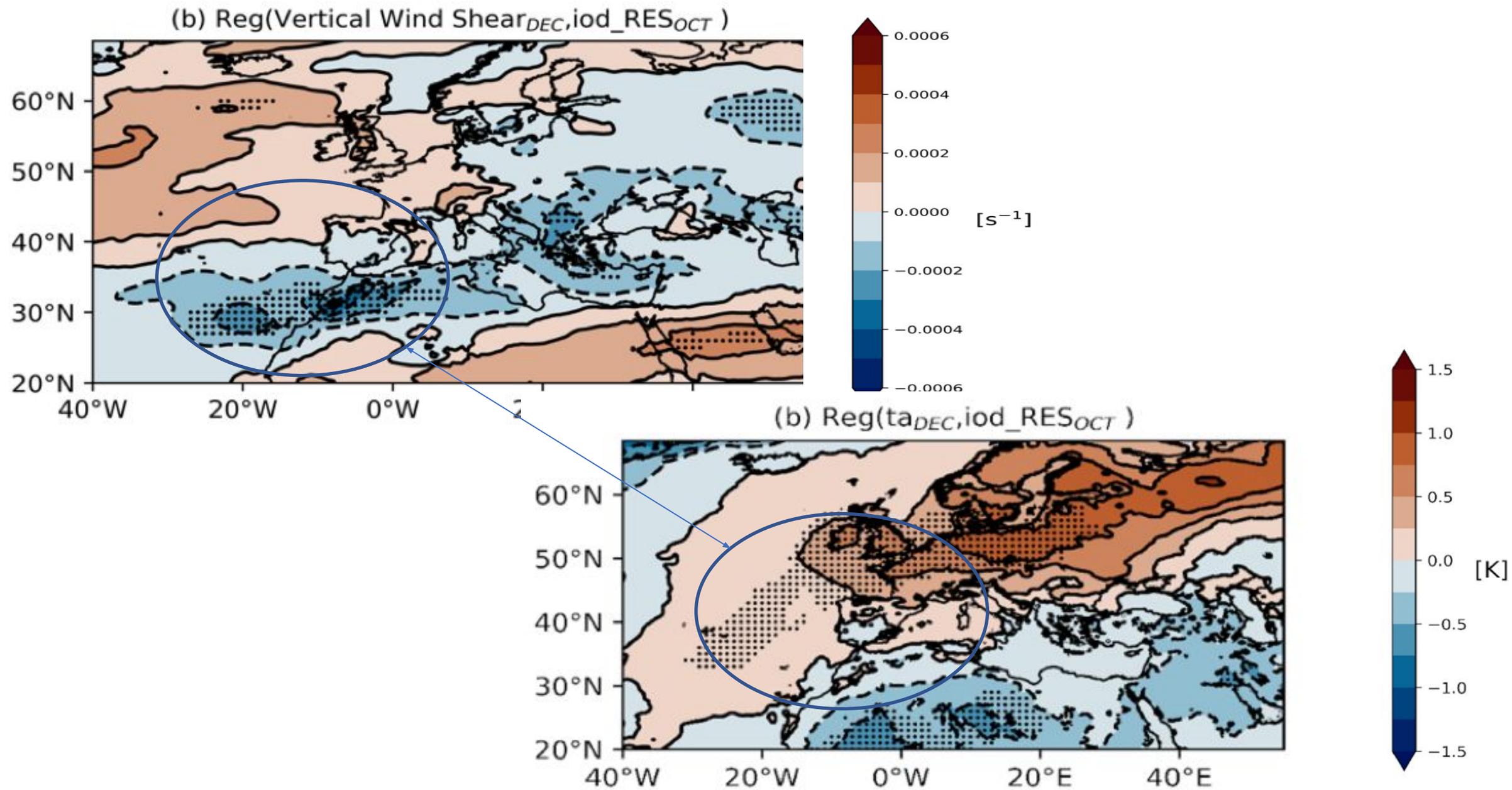


The mechanisms

$$EGR = \alpha f (\partial u / \partial z) N^{-1}$$



The mechanisms



Conclusions (part 2)

Winter precipitation and storm activity shows mainly in

Geophysical Research Letters®



RESEARCH LETTER

10.1029/2025GL116732

Key Points:

- Winter precipitation and storm activity shows mainly in December a long-term significant response to the Indian Ocean Dipole
- Spatial changes in the environmental baroclinicity drive the observed changes in the storm activity in December
- Latitudinal variations of baroclinicity are linked to stronger vertical wind shear driven by an enhanced meridional temperature gradient

Response of Early Winter Precipitation and Storm Activity in the North Atlantic–European–Mediterranean Region to Indian Ocean SST Variability

M. Reale¹ , **A. Raganato**² , **F. D'Andrea**³, **M. Adnan Abid**^{4,5} , **A. Hochman**⁶ ,
N. R. Chowdhury^{7,8} , **S. Salon**¹, and **F. Kucharski**⁸ 

¹National Institute of Oceanography and Applied Geophysics—OGS, Trieste, Italy, ²School of Earth and Atmospheric Sciences, Georgia Institute of Technology, Atlanta, GA, USA, ³Laboratoire de Météorologie Dynamique, IPSL, ENS, PSL Research University, École Polytechnique, Institut Polytechnique de Paris, Sorbonne Université, CNRS, Paris, France, ⁴Department of Physics, Atmospheric, Oceanic and Planetary Physics (AOPP), University of Oxford, Oxford, UK, ⁵National Centre for Atmospheric Science (NCAS), Oxford, UK, ⁶Fredy and Nadine Herrmann Institute of Earth Sciences, The Hebrew University of Jerusalem (HUJI), Jerusalem, Israel, ⁷Department of Mathematics, Informatics and Geosciences, University of Trieste, Trieste, Italy, ⁸Earth System Physics, The Abdus Salam International Centre for Theoretical Physics, Trieste, Italy

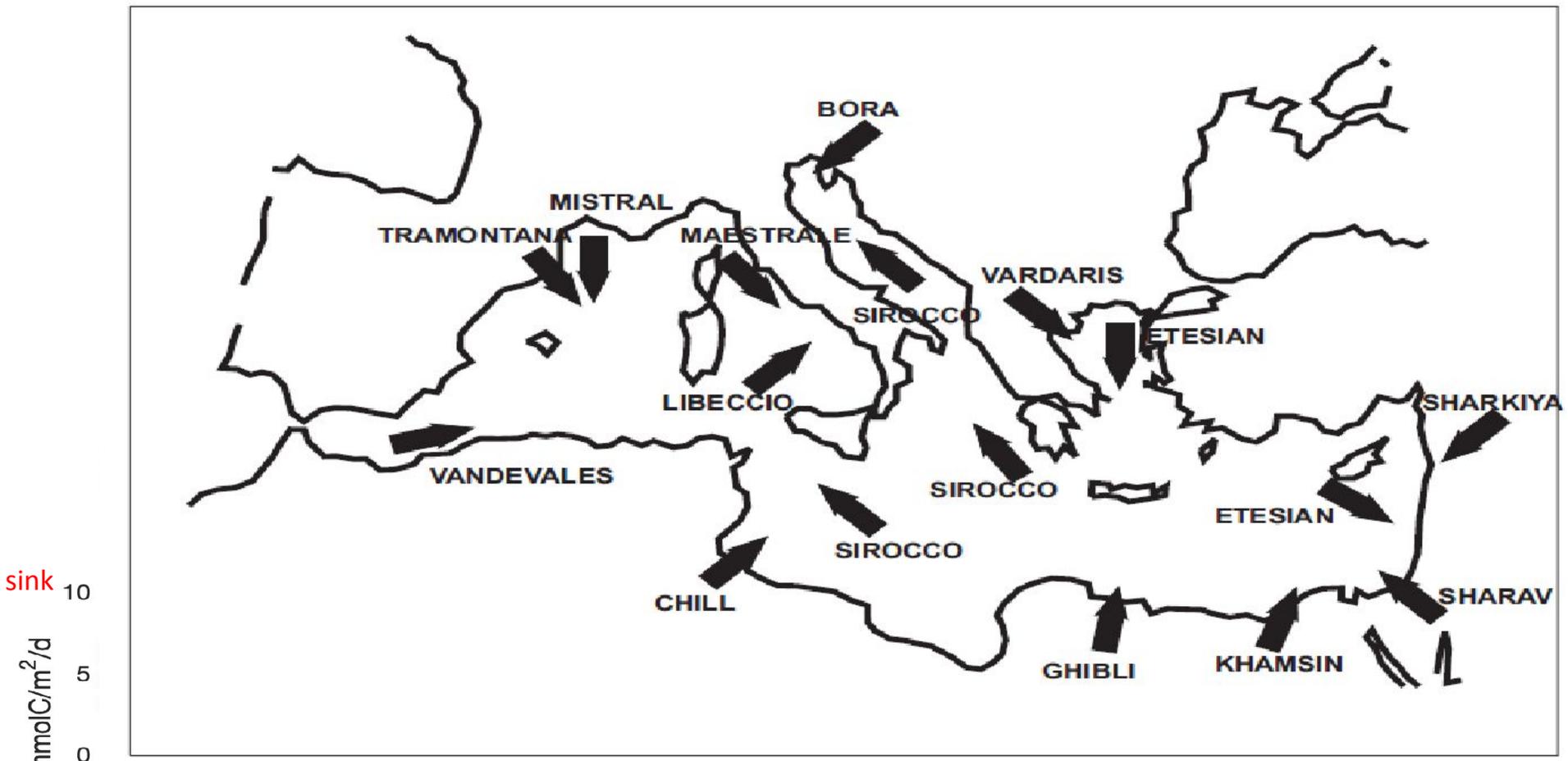
- ***Convection-permitting coupled modeling over Northern Italy***
- ***Response of large scale circulation at mid-latitudes to the Indian ocean SST variability***
- ***Links between CO₂ sink in the Mediterranean region and synoptic features crossing the region***

The carbon sink of the Mediterranean Sea

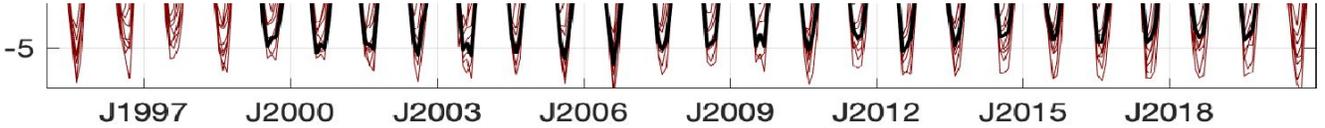
B

annual CO₂airflux Layer 0 m

Sink



sink
10
5
0

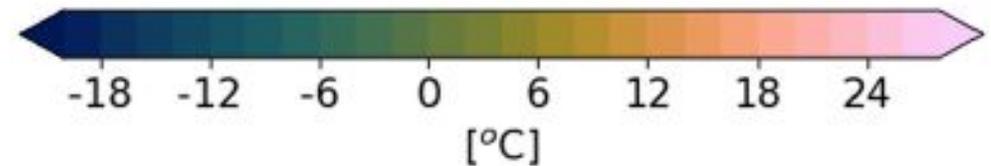
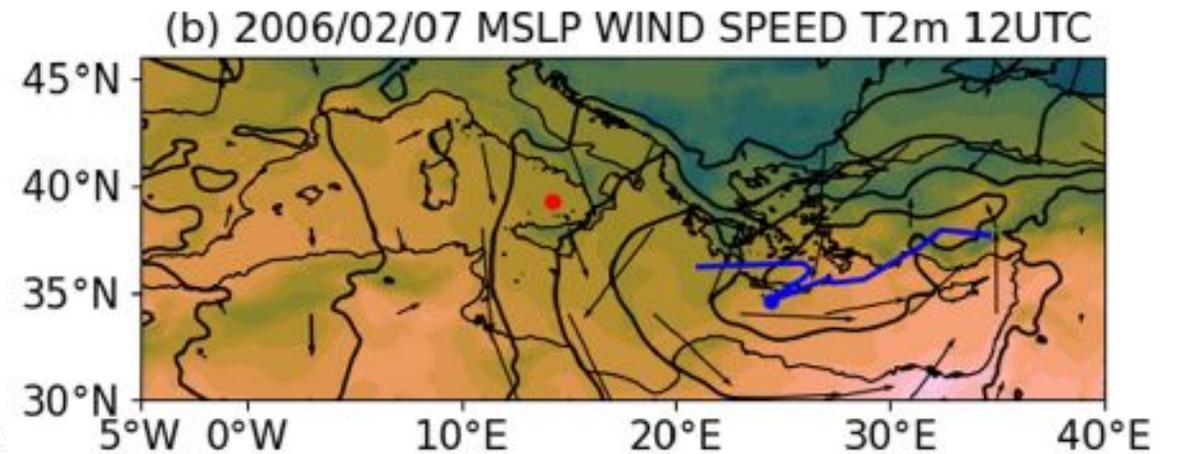
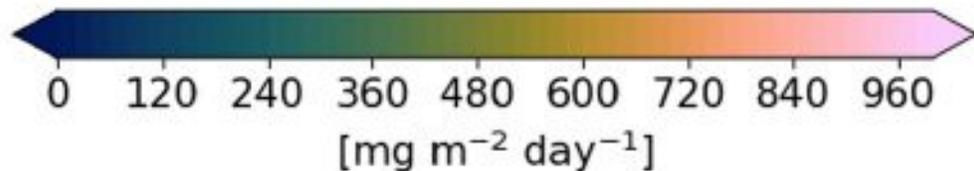
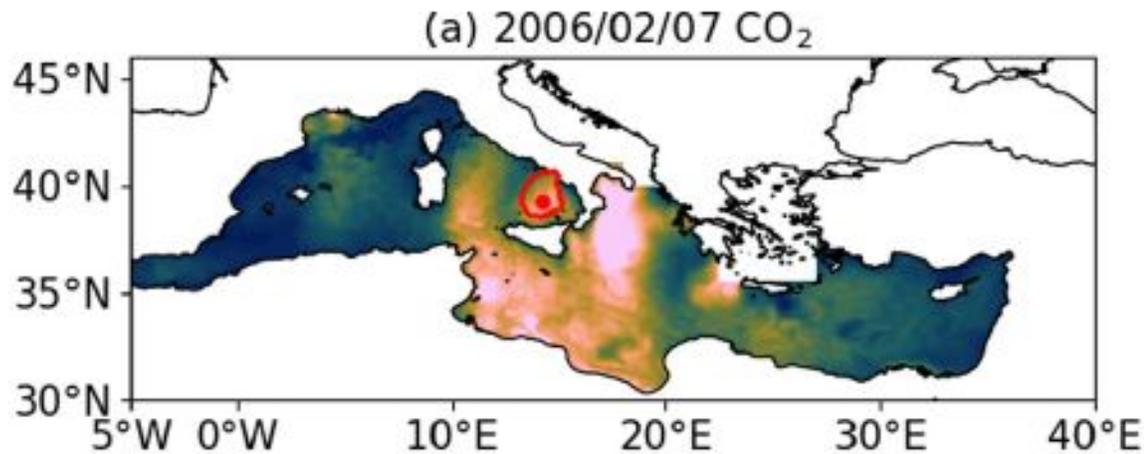


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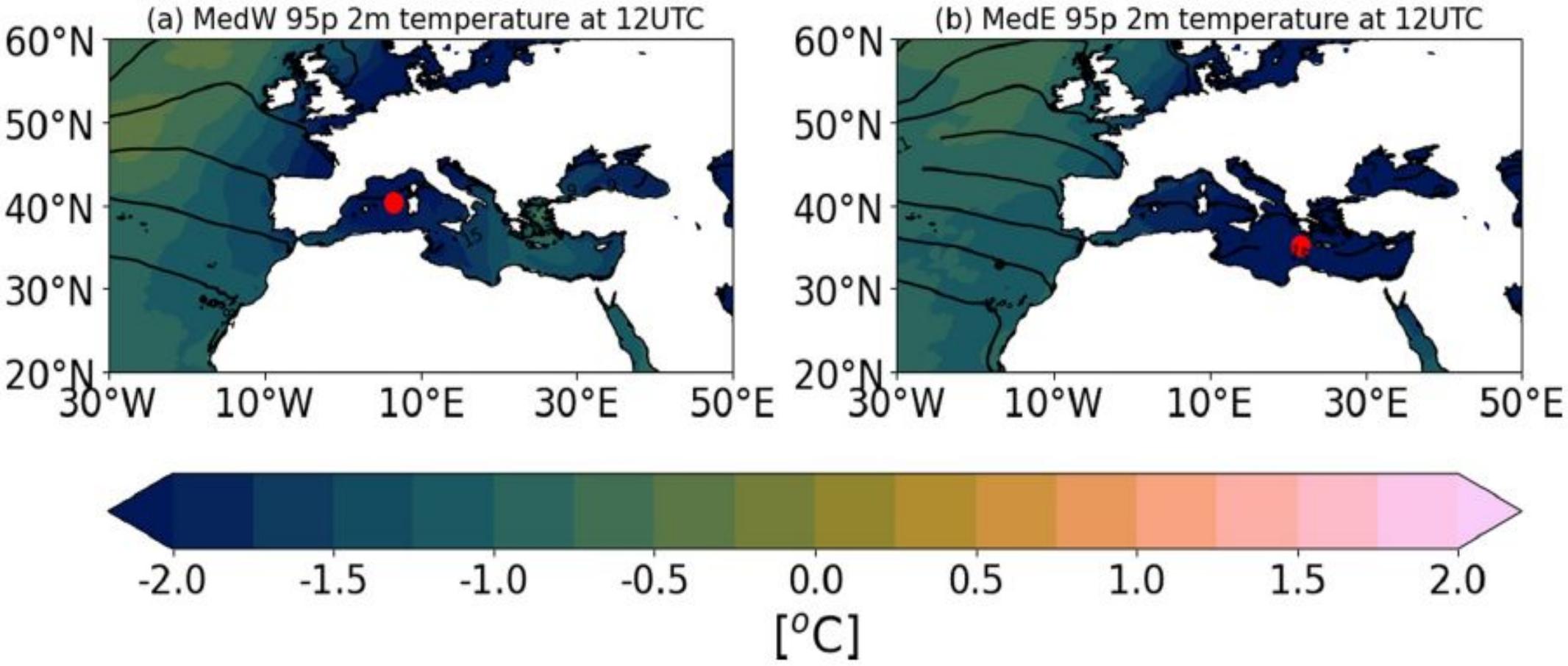
The analysis is based on Copernicus Marine Service Biogeochemical Reanalysis

The data

- Daily CO₂ air-sea fluxes 1999-2020 (from Copernicus Marine Service Reanalysis, Cossarini et al., 2021)
- Tracks of cyclones (Reale et Lionello, 2013)
- MSLP, 2m Temperature, Wind Speed (from ERA5)

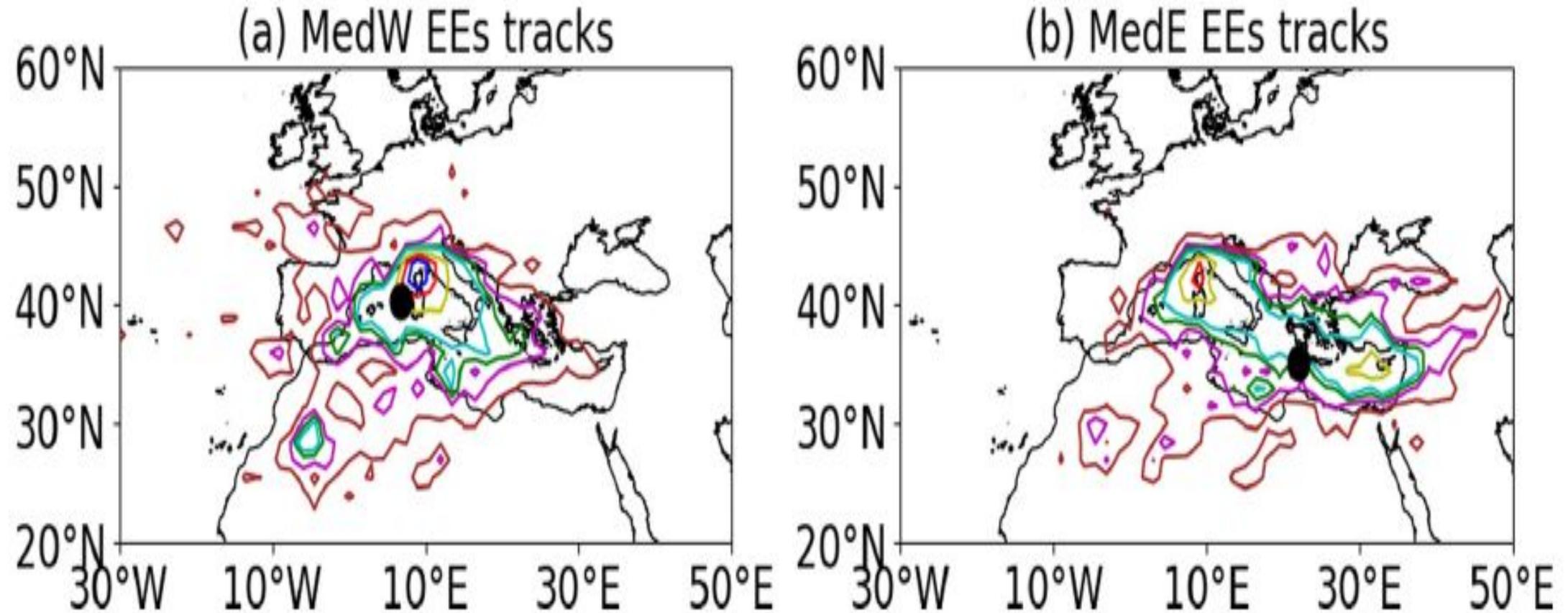


Large Scale circulation patterns

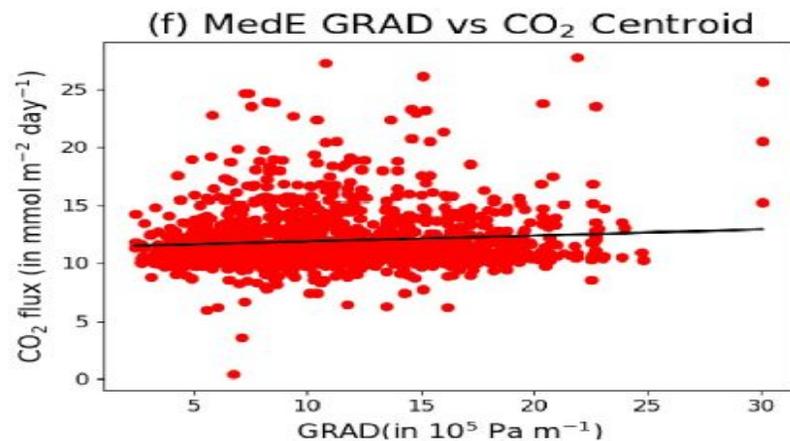
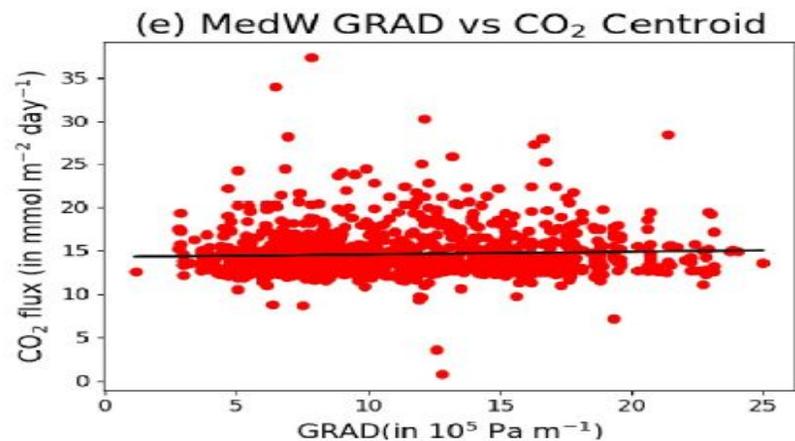
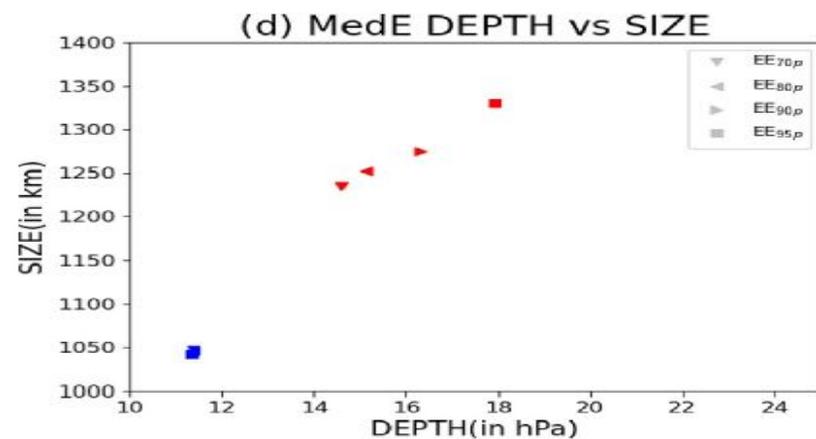
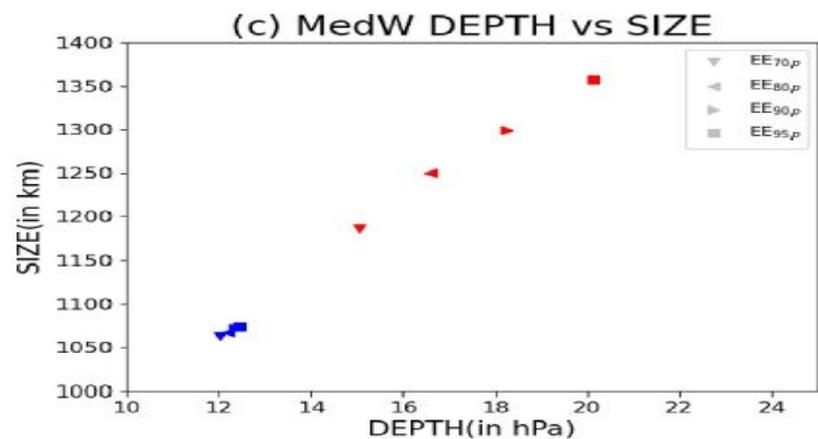
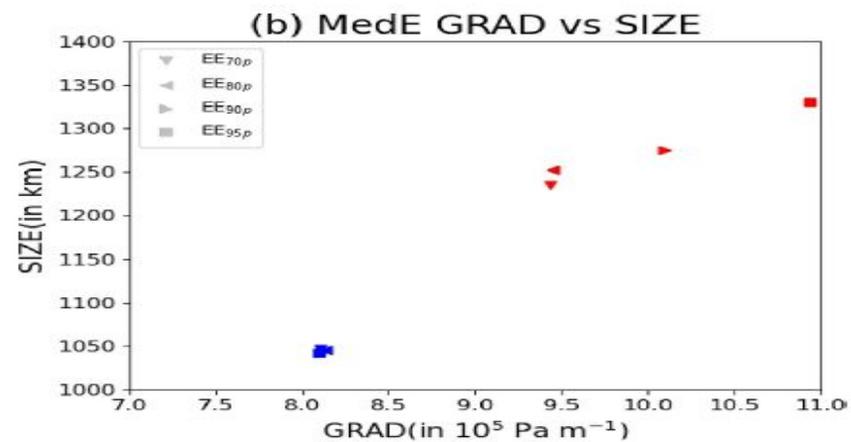
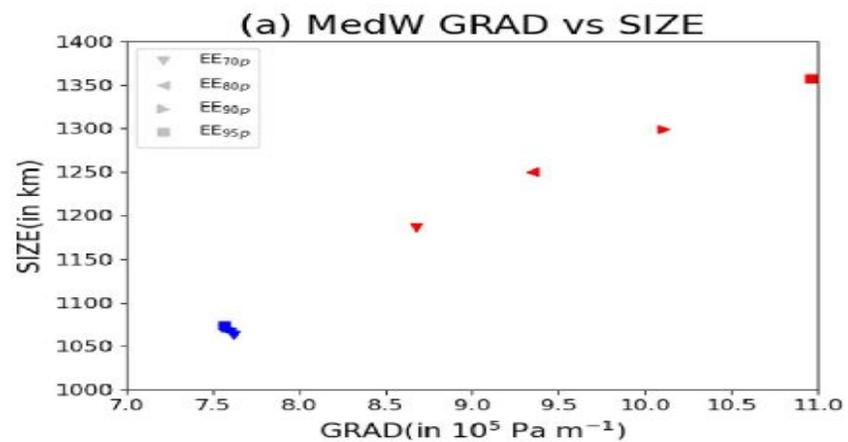


Large Scale circulation patterns

85% of the events there is a cyclone nearby



Density of tracks of cyclones associated with EEs in MedW(a) and MedE(b). Black dots represent the mean location of the centroids in each sub.basin. Contour lines are drawn at 0.25 (brown), 0.5 (magenta), 0.75 (green), 1 (cyan), 2 (yellow), 3 (red), and 4 (blue). The units used are relative frequency in % in each cell of 1.5°.



Conclusions (part 3)

- High CO₂ sink events in the Mediterranean take place in presence of specific large-scale configurations

JGR Atmospheres

RESEARCH ARTICLE

10.1029/2025JD044310

Key Points:

- High CO₂ sink events in the Mediterranean take place in presence of specific large-scale configurations
- These synoptic configurations are responsible for stronger (colder)-than-average wind (temperature) patterns in the region
- The larger the intensity of the CO₂ sink event, the higher the probability of detecting a cyclone nearby

Correspondence to:

M. Reale,
mreale@ogs.it

Synoptic Features Driving the CO₂ Sink in the Mediterranean Sea in Winter

M. Reale¹ , F. Giordano^{1,2} , V. Di Biagio¹ , G. Cossarini¹ , and S. Salon¹ 

¹National Institute of Oceanography and Applied Geophysics–OGS, Trieste, Italy, ²University of Trieste, Trieste, Italy

Abstract The Mediterranean Sea is a weak sink for the atmospheric CO₂ with the October–March extended winter season characterized by the occurrence of high CO₂ sink events. Here, we analyzed state-of-the-art ocean and atmospheric reanalyses and observational data sets to investigate the variability of the winter sink and its relation with synoptic atmospheric features crossing the region in the period 1999–2020. High CO₂ sink events are identified using classical extreme event approach with fixed threshold (95p) based on the CO₂ daily flux distribution. First, we showed that these events are driven by large-scale atmospheric configurations that produce stronger-than-average wind speed and colder-than-average 2 m and sea surface temperature patterns in the region. Second, a co-location analysis was applied to assess the probability to detect an extra-tropical cyclone at a fixed distance from the location of the events showing that the larger the event's magnitude, the





Thank a lot for your attention!!!!