Introduction to Convection-Permitting Climate Modelling

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Advanced School on High-Performance Computing and Applied AI for High-Resolution Regional Climate Modeling

Ben Guerir - Morocco

OGS

ICTP The Abdus Salam International Centre for Theoretical Physics

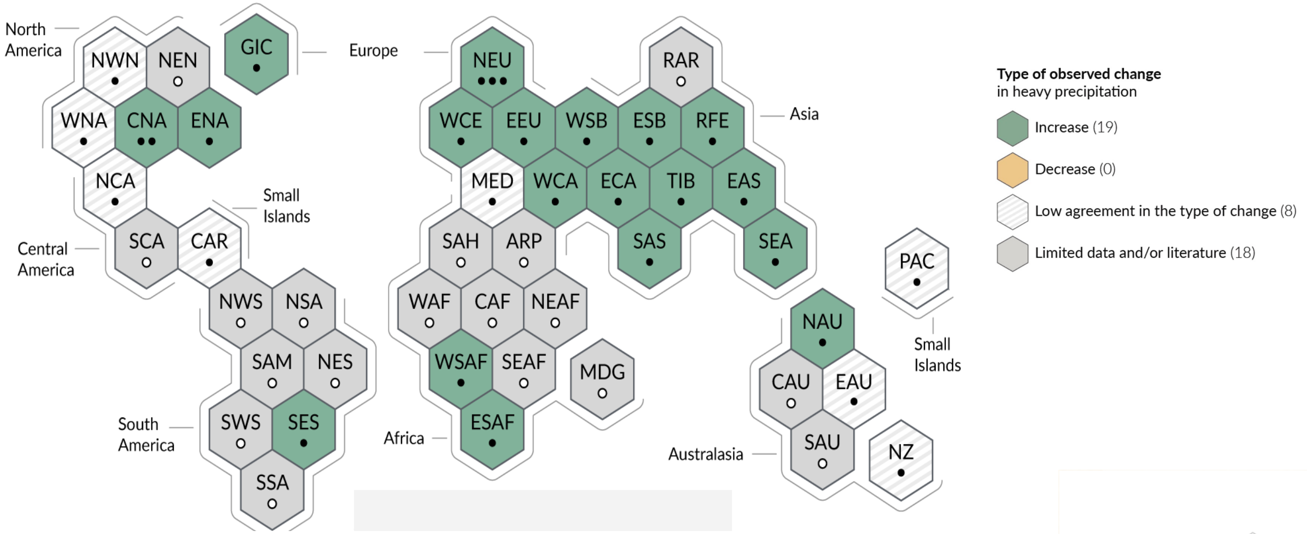
IAEA International Atomic Energy Agency

unesco United Nations Educational, Scientific and Cultural Organization

Why do we need high resolution climate simulations?

Increase on heavy precipitation is affecting many regions on Earth and is projected to continue in almost every region

Observed



Type of observed change

Colour = Increase/decrease

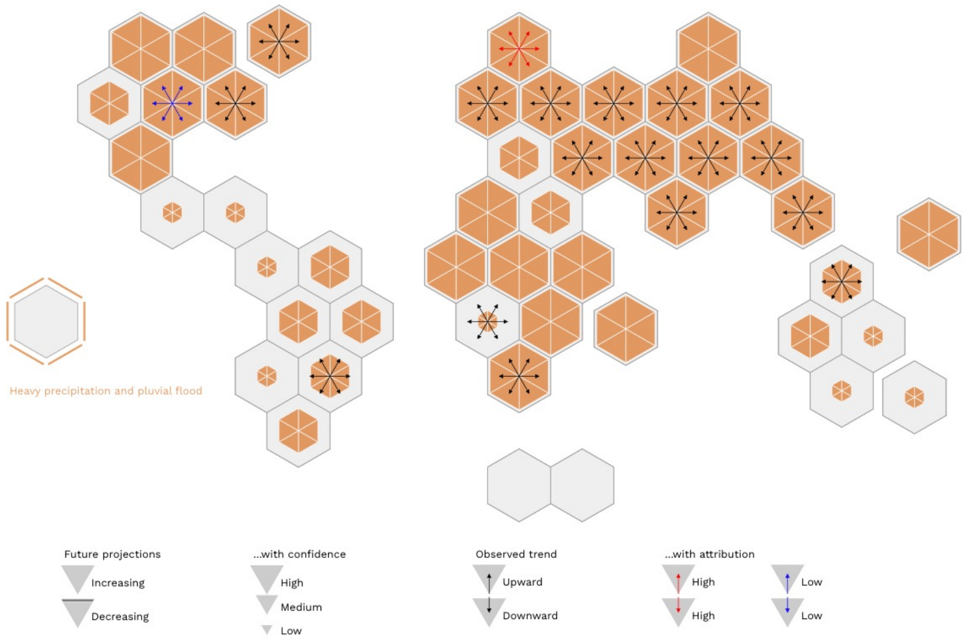
Low agreement in the type of change

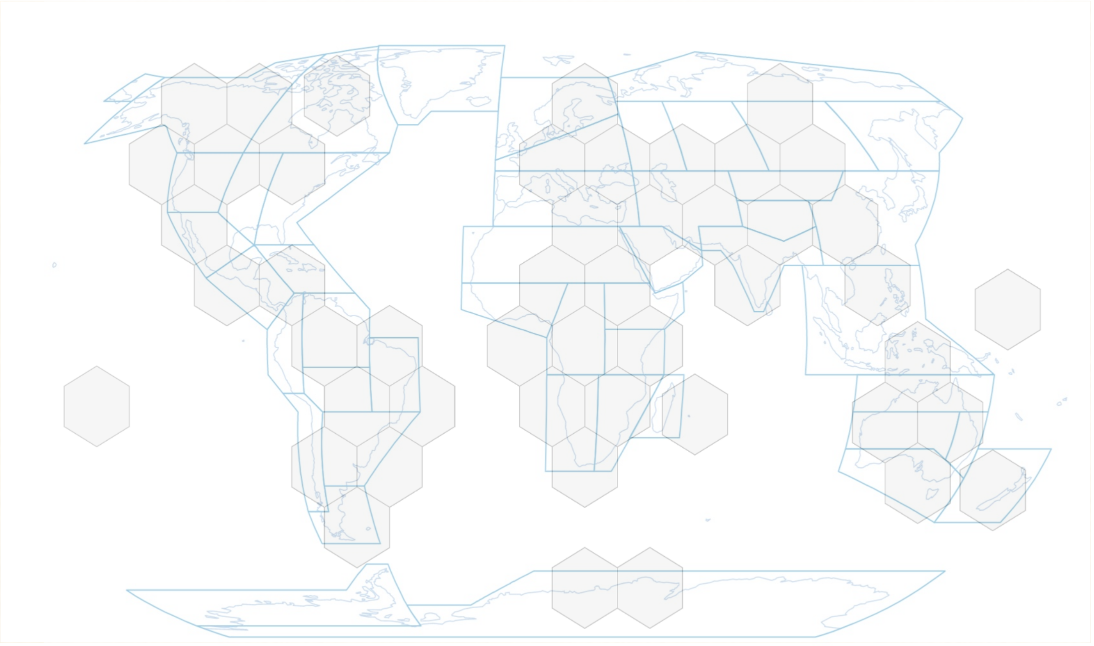
Limited data and/or literature

Confidence in human contribution to the observed change

- ●●● High
- ●● Medium
- ● Low due to limited agreement
- ○ Low due to limited evidence

Projected





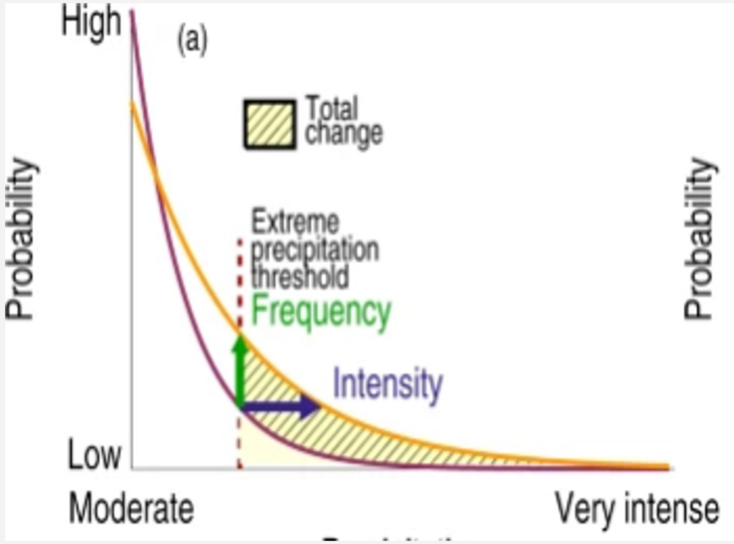
www.ipcc.ch

Interactive Atlas: interactive-atl

Definitions:
extreme precipitation

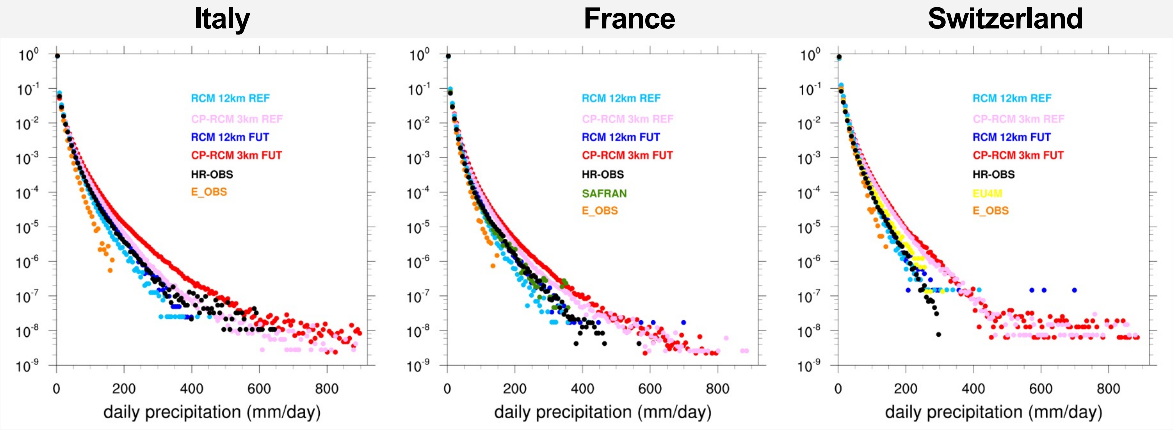
It is unusually intense or prolonged rainfall events, often linked to **convective** systems. These events can cause floods, landslides, and other socio-economic impacts.

- Heavy precipitation is an episode of abnormally high rain or snow (95th percentile). The definition of "extreme" is a statistical concept that varies depending on location, season, and length of the historical record.



Myhre et. al, 2019. https://doi.org/10.1038/s41598-019-52277-4

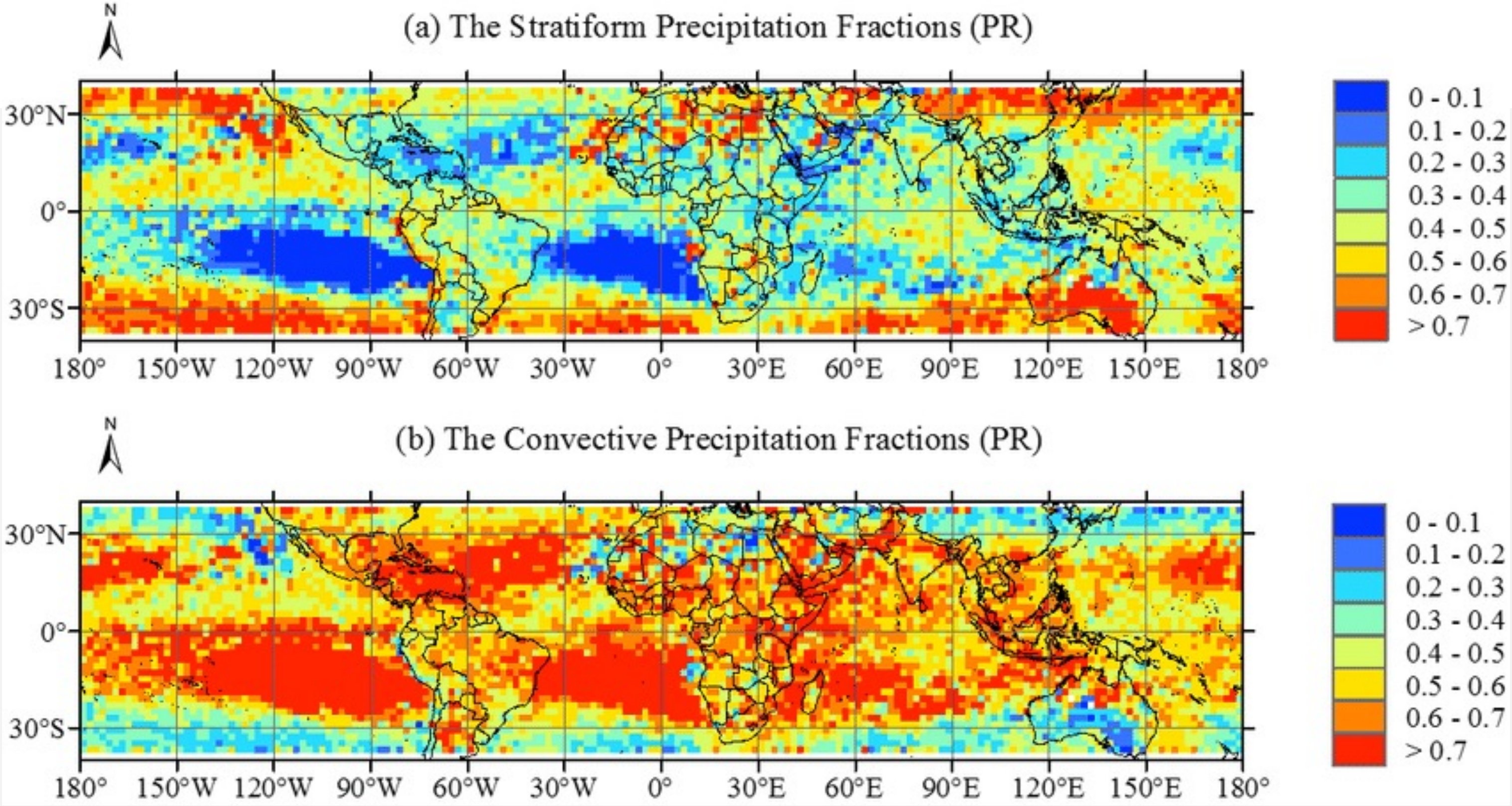
- The mechanisms (perturbation, air mass water content and stability, interaction with local forcings, persistence, etc.) that generate an heavy/extreme event can be very different among different regions.
- Same amount of heavy/extreme precipitation over different areas can lead to different response at ground (in terms of floods).



Pichelli et al. (2021)

Definitions: convection

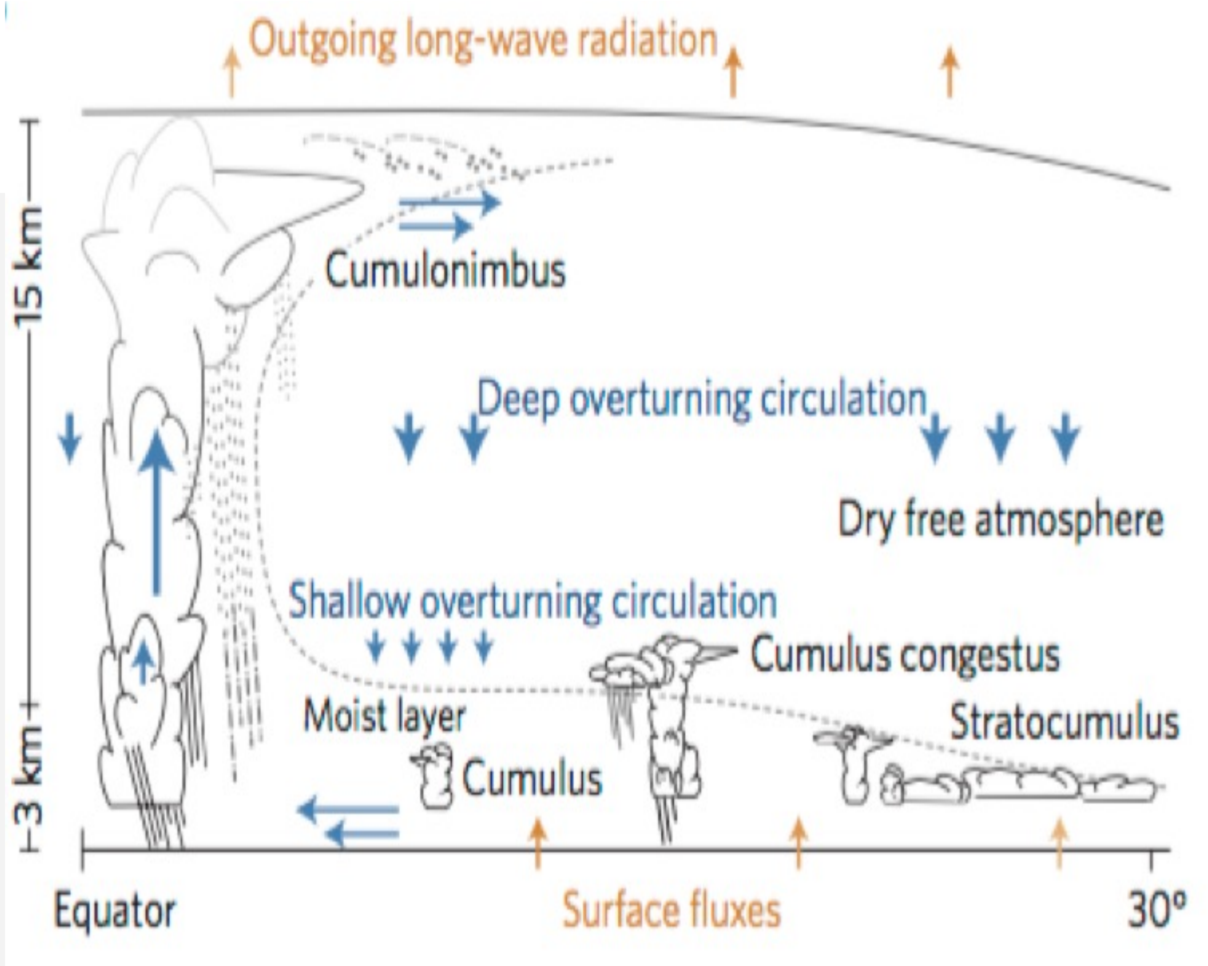
It is a fundamental atmospheric process where warm, moist air rises, cools as it ascends, and may lead to cloud formation and precipitation. It's responsible for many types of weather phenomena, including thunderstorms and **extreme precipitation**.



In the tropics most of the rainfall is convective, while in the mid-latitudes about 40 per cent of precipitation occurs in areas with convective instability

Definitions: convection

it is the rising of plumes of moist air in response to instability in the atmosphere



The instability can be caused by cooling at the top or heating at the bottom. **Either process creates deviations from stable conditions in the vertical temperature profile.** This instability trigger an updraft and downdraft in the atmosphere thus a mixing of the troposphere: the result is that convection is the main process of vertical exchange between the lower and the upper troposphere of energy and mass, in particular of water vapour, heat and chemical species.

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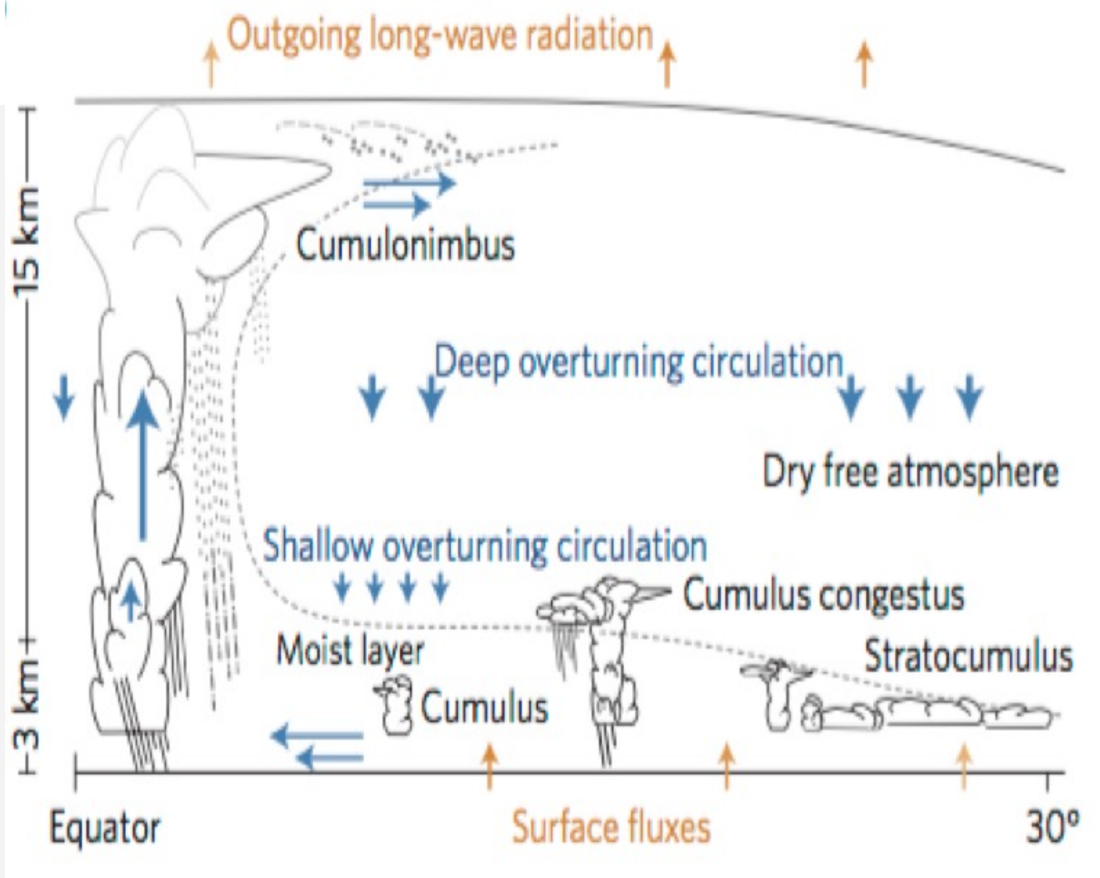


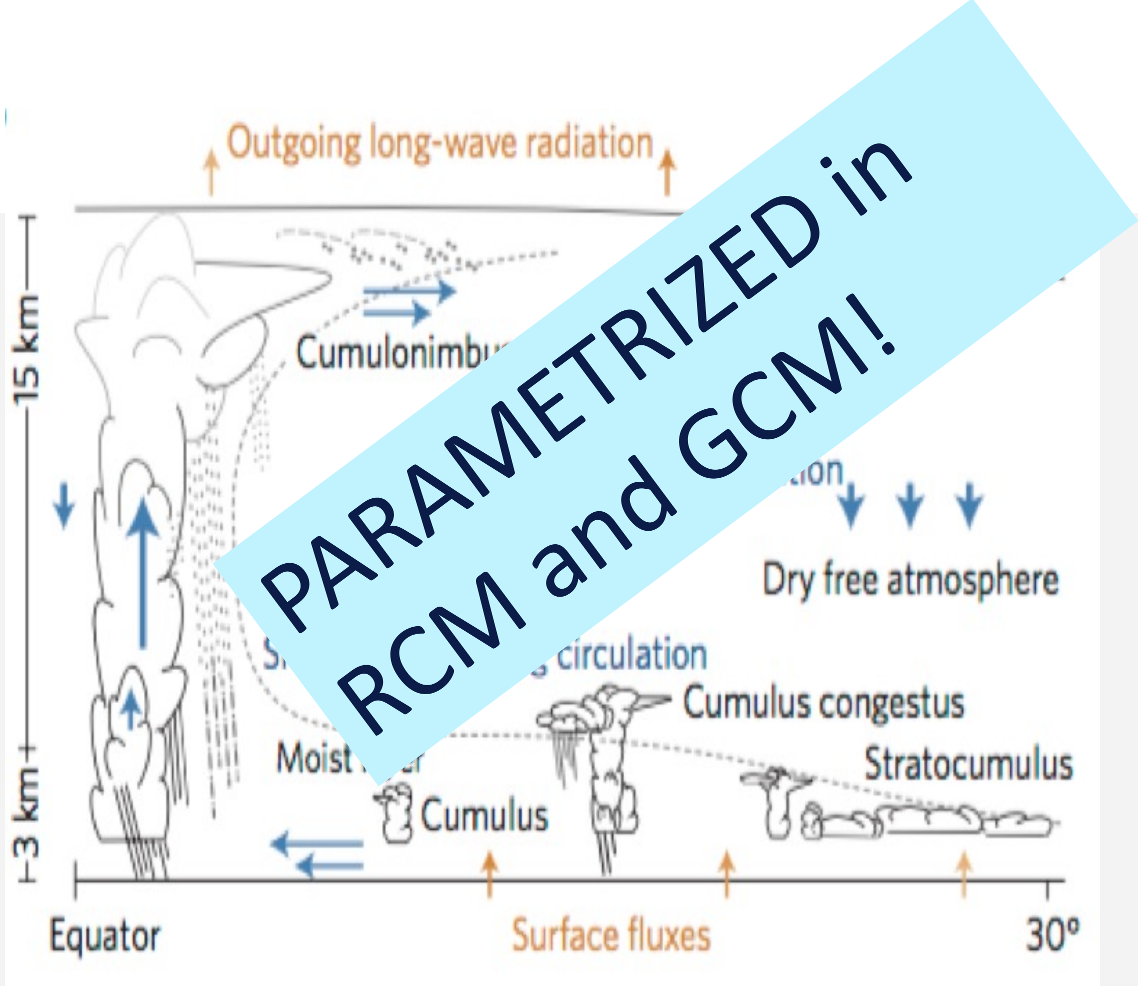
Deep convection penetrates to altitudes of about 10 to 15 km at the top of the troposphere and even into the lower stratosphere. The clouds it produces can be towering structures taller than the highest mountains.

Such clouds are typical of the tropics but they are also common in the mid-latitudes. They can produce large amounts of precipitation.

If temperature inversion layers are present lower down in the atmosphere, they give rise to shallower convective clouds, commonly found in the sub-tropics.

Definitions: convection

it is the rising of plumes of moist air in response to instability in the atmosphere



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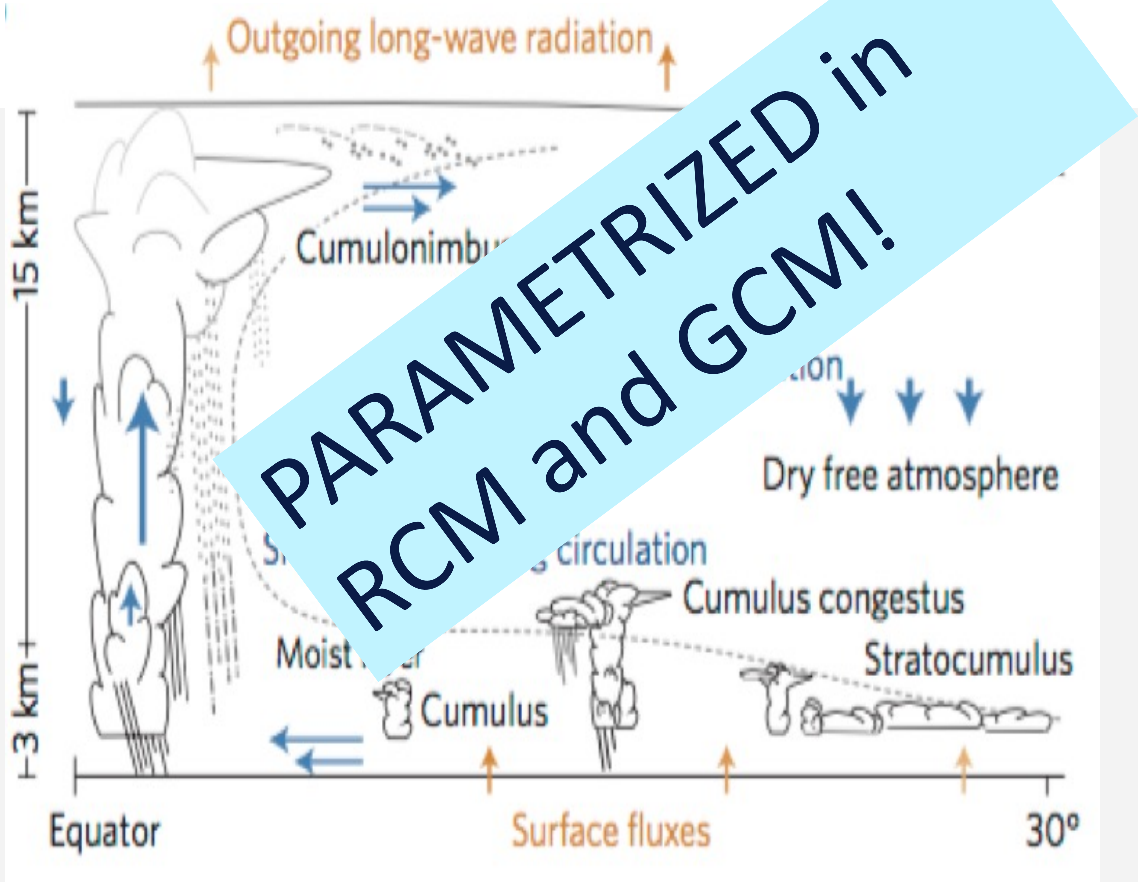
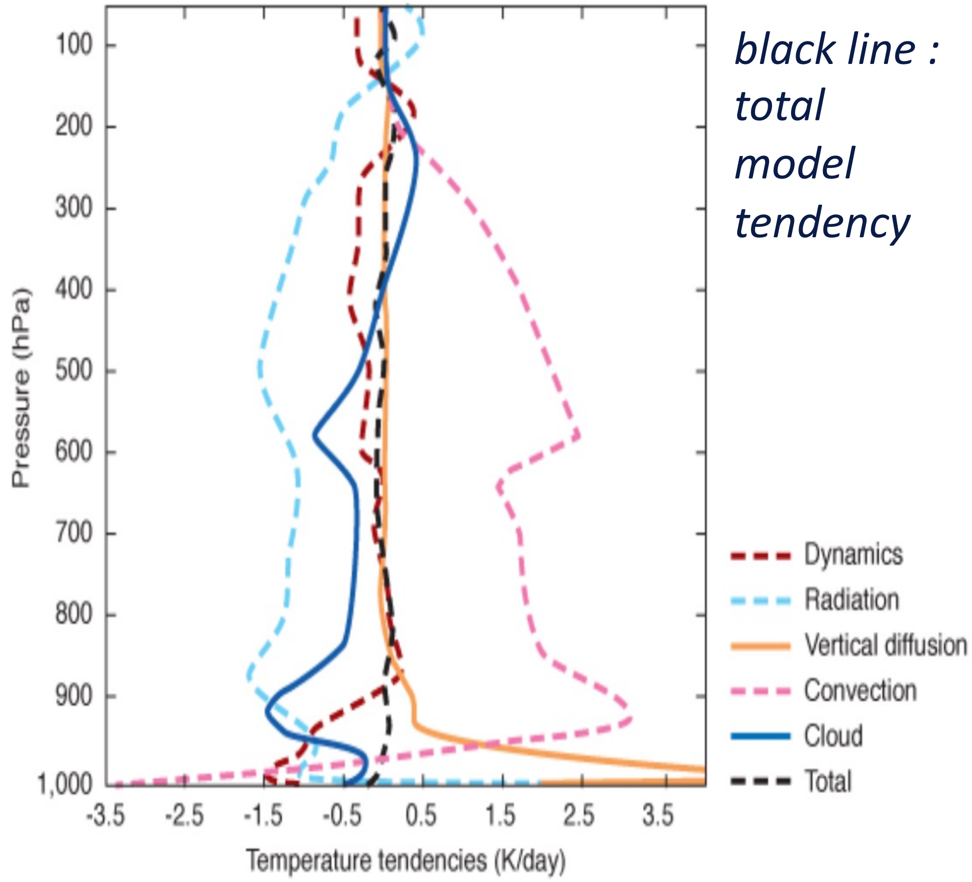
If temperature inversion layers are present lower down in the atmosphere, they give rise to shallower convective clouds, commonly found in the sub-tropics.

Definitions: convection

- **In ECMWF's Integrated Forecasting System (IFS), convection accounts for about 50 % of the total forecast tendencies above the boundary-layer**



Contribution of the different physical parametrization schemes for temperature in the IFS (averaged over the tropics)



black line : total model tendency

Modelling convection ..

- **Parameterization** are considerated as a major source for errors and uncertanty in future climate projections.
- **Parameterization of deep convective** clouds produces the largest uncertainties of projected (GCM or RCM) large-scale parameters such as the climate sensitivity [Knight et al., 2007; Sanderson et al., 2008; Sherwood et al., 2014; and many others ...].
- **In addition**, convection parameterization schemes interact with many other parameterization schemes, such as microphysics, radiation, and planetary boundary layer schemes, such that weaknesses in convection parameterization schemes can imply far-reaching consequences through nonlinearities.

Modelling convection ..

FAQ 7.2 | What Is the Role of Clouds in a Warming Climate?

One of the biggest challenges in climate science has been to predict how clouds will change in a warming world and whether those changes will amplify or partially offset the warming caused by increasing concentrations of greenhouse gases and other human activities. Scientists have made significant progress over the past decade and are now more confident that changes in clouds will amplify, rather than offset, global warming in the future.

Forster, P., T. et al., 2021: The Earth's Energy Budget, Climate Feedbacks, and Climate Sensitivity. In Climate Change 2021: **The Physical Science Basis. Contribution of Working Group I to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change** [Masson-Delmotte, V., P. Zhai, A. Pirani, S.L. Connors, C. Péan, S. Berger, N. Caud, Y. Chen, L. Goldfarb, M.I. Gomis, M. Huang, K. Leitzell, E. Lonnoy, J.B.R. Matthews, T.K. Maycock, T. Waterfield, O. Yelekçi, R. Yu, and B. Zhou (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, pp. 923–1054, doi:10.1017/9781009157896.009.

Role of clouds in a warmer climate: IPCC AR6 WGI

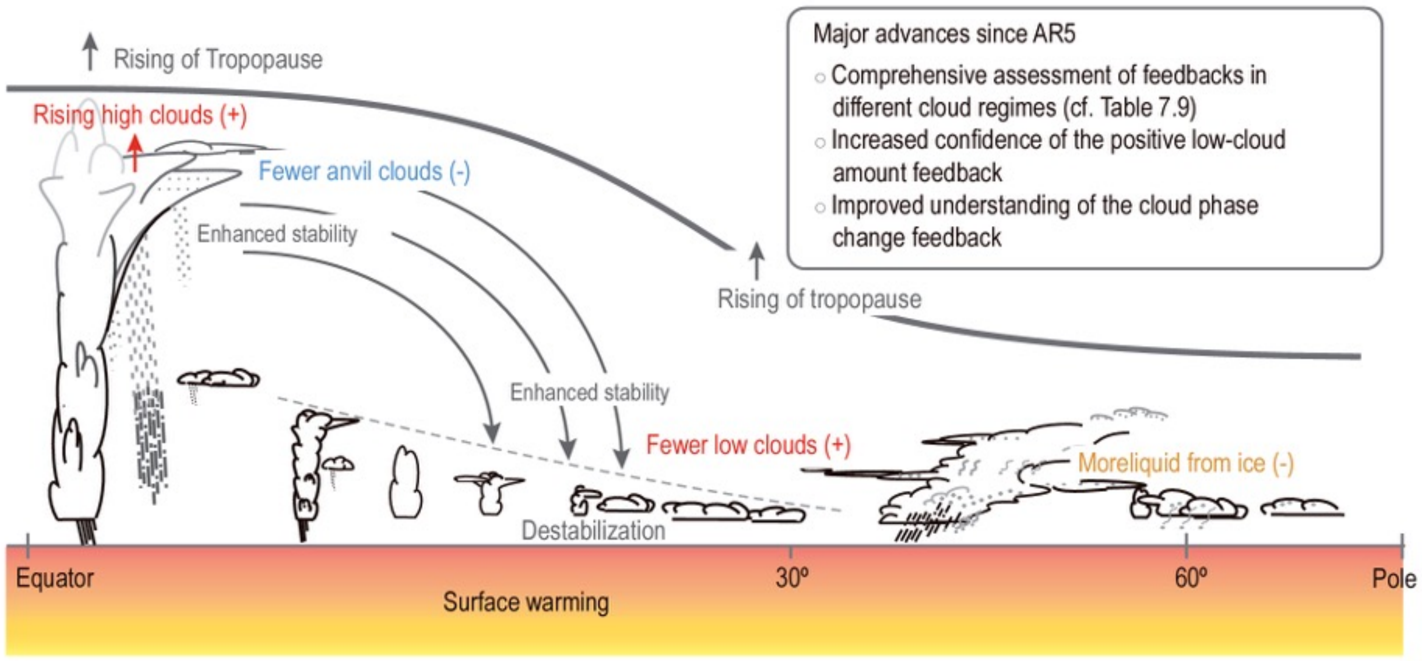


Figure 7.9 | Schematic cross section of diverse cloud responses to surface warming from the tropics to polar regions. Thick solid and dashed curves indicate the

- the amount of **low-clouds** will reduce over the subtropical ocean, leading to less reflection of incoming solar energy → **warming** effect
- the altitude of **high-clouds** will rise, making them more prone to trapping outgoing energy → **warming** effect
- clouds in **high latitudes** will be increasingly made of water droplets rather than ice crystals. This shift from fewer, larger ice crystals to smaller but more numerous water droplets will result in more of the incoming solar energy being reflected back to space → **cooling** effect.

Better understanding of how clouds respond to warming has led to more confidence than before that future changes in clouds will, overall, cause additional warming (i.e., by weakening the current cooling effect of clouds). This is called a positive net cloud feedback.

Why do we need high resolution climate simulations?

- **Investigate the Earth System:**
  Studying how relevant climate parameters change in the future
- **Provide information to impact researchers, stakeholders, and policy makers**
  Scale difference between available climate information provided by climate models (>100km) and information needed (~1km)

How do we bridge this gap?

RCMs as a suitable way to produce high-resolution climate information that is computationally affordable and suitable for end users.

What do we need for CP climate modelling?

- **Non-Hydrostatic Dynamical core** RegCM5 NH-MOLOCH core (Giorgi et al, 2023)

$$\Theta_v = \frac{T_v}{\Pi}$$

$$\Pi = \left(\frac{P}{P_0}\right)^{\frac{R_d}{C_{p_d}}}$$

Horizontal momentum

$$\frac{du}{dt} = mc_{p_d}\Theta_v \frac{\partial \Pi}{\partial x} - mG(\zeta)\frac{\partial h}{\partial x}\left(g + \frac{dw}{dt}\right) + f_v + K_u$$

$$\frac{dv}{dt} = mc_{p_d}\Theta_v \frac{\partial \Pi}{\partial y} - mG(\zeta)\frac{\partial h}{\partial y}\left(g + \frac{dw}{dt}\right) - f_u + K_v$$

Vertical momentum

$$\frac{dw}{dt} = -F_z c_{p_d}\Theta_v \frac{\partial \Pi}{\partial z} - g + K_w$$

Temperature

$$\frac{d\Theta_v}{dt} \approx K_{\Theta_v}$$

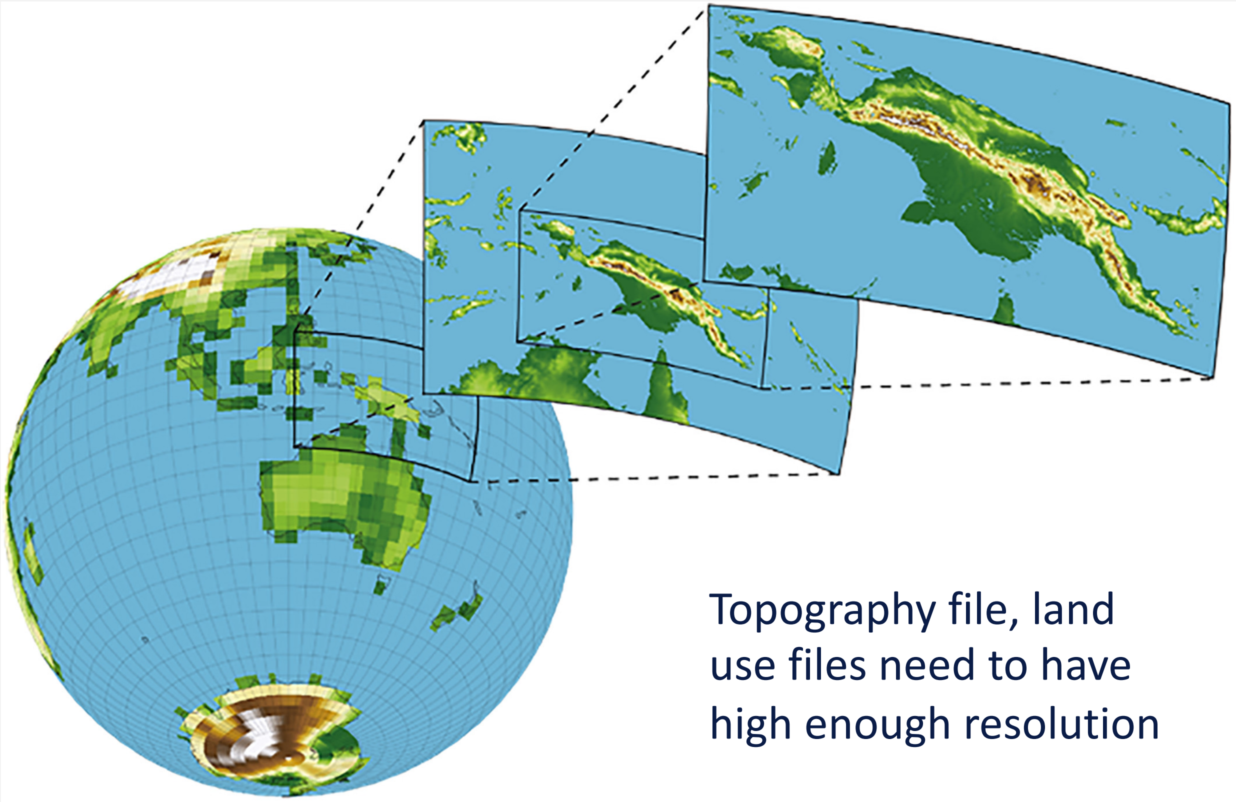
Pressure

$$\frac{d\Pi}{dt} \approx -\Pi \frac{R_d}{C_{v_d}} m^2 \left\{ F_z \left[\frac{\partial\left(\frac{u}{mF_z}\right)}{\partial x} + \frac{\partial\left(\frac{v}{mF_z}\right)}{\partial y} \right] + \frac{\partial\left(\frac{s}{F_z}\right)}{\partial \zeta} \right\}$$

What do we need for CP climate modelling?

Boundary conditions

Generally, the maximum step in resolution between nests should be <12 for CPRCMs (Berthou et al., 2020; Chawla et al., 2018).



Topography file, land use files need to have high enough resolution

Lucas-Picher et al. 2021

Telescopic nesting

Most common:
(two-step nesting strategy)

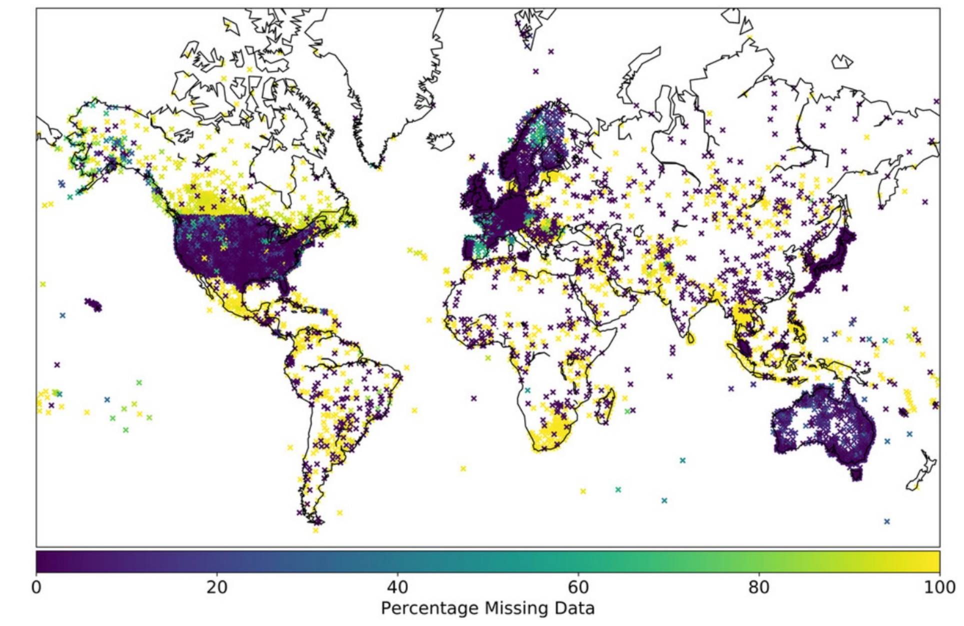
GCM (~100 km)
RCM (~12 km)
CPRCM (~ 3km)

Bigger resolution step is possible, but larger buffer zone at the boundaries is then essential

What do we need for CP climate modelling?

Observations to evaluate the results

- Evaluation of climate simulations becomes a challenge due to the lack of high-quality high-resolution observational gridded datasets (Piazza et al., 2019; Prein & Gobiet, 2017).
- Sub-daily data that is available only from a subset of weather stations (Lewis et al., 2019).
- Precipitation extremes are possibly underestimated in the gridded observations due to the localized nature of these events (Piazza et al., 2019). Also regions with orography are underpresented in gridded observations.
- Alternatively, some regions have high spatio-temporal resolution radar data that are adjusted with gauges from weather stations:
    - France (Tabary et al., 2012)
    - Germany (Winterrath et al., 2018)
    - the UK (Yu, Li, et al., 2020)
    - the United States (Lin & Mitchell, 2005)
    - Netherlands (Overeem et al., 2009)
    - Sweden (Berg et al., 2016)
    - Switzerland (Wüest et al., 2010).



From Lewis et al., 2019

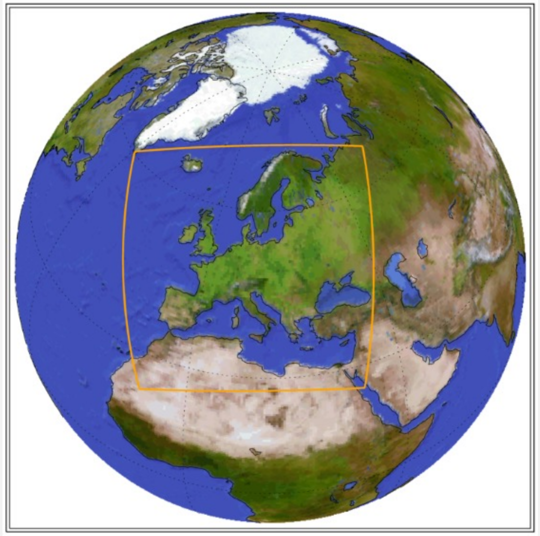
>>>> Observations are also not perfect!

What do we need for CP climate modelling?

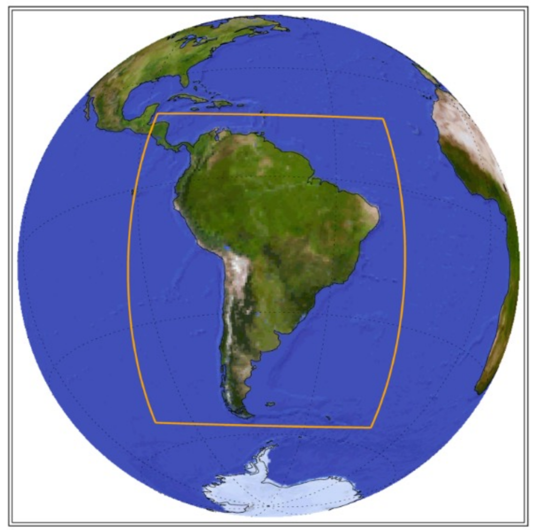
Computational Resources

Performing decadal-long CPRCM climate change projections is computationally demanding and also requires huge data storage capabilities (Schar et al 2020)

Transient climate simulation



EURO-CORDEX 12 km



South America-CORDEX 12 km

Time needed to run: Months
Storage needed: 1TB per year

https://cordex.org

What do we need for CP climate modelling?

Computational Resources

Performing decadal-long CPRCM climate change projections is computationally demanding and also requires huge data storage capabilities (Schar et al 2020)

Transient climate simulation

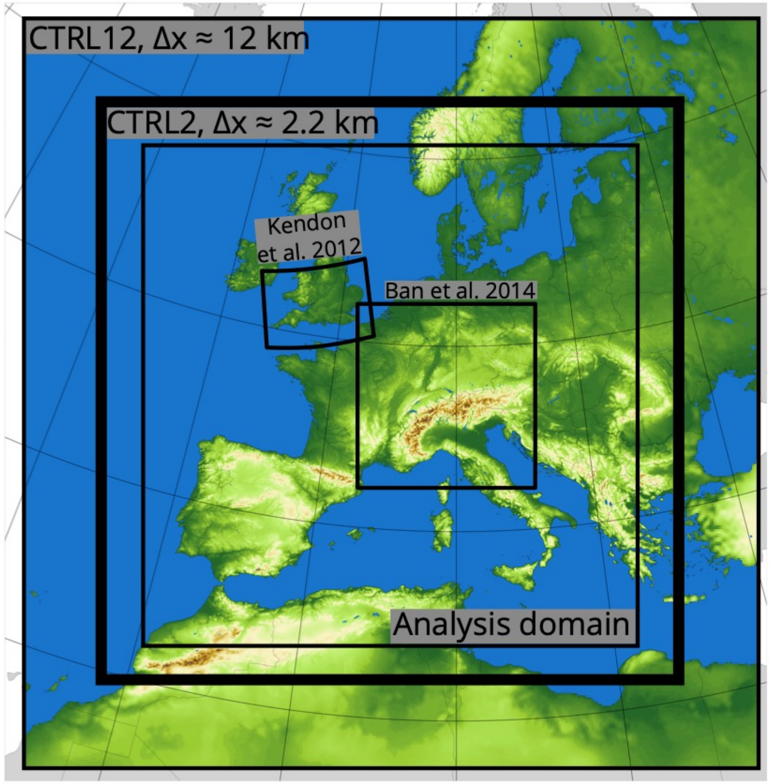
CP-CORDEX 3 km

✗

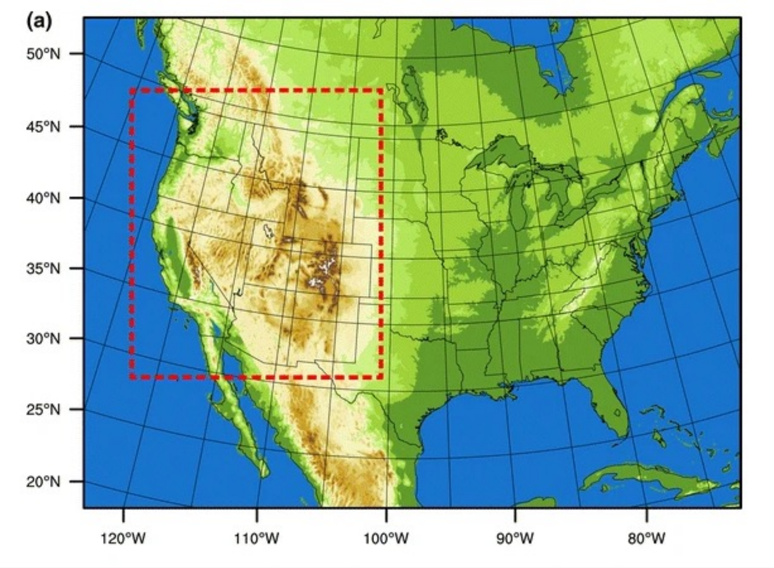
Time needed to run: Years-Decades
Storage space needed: >10TB per year

Where are we now?

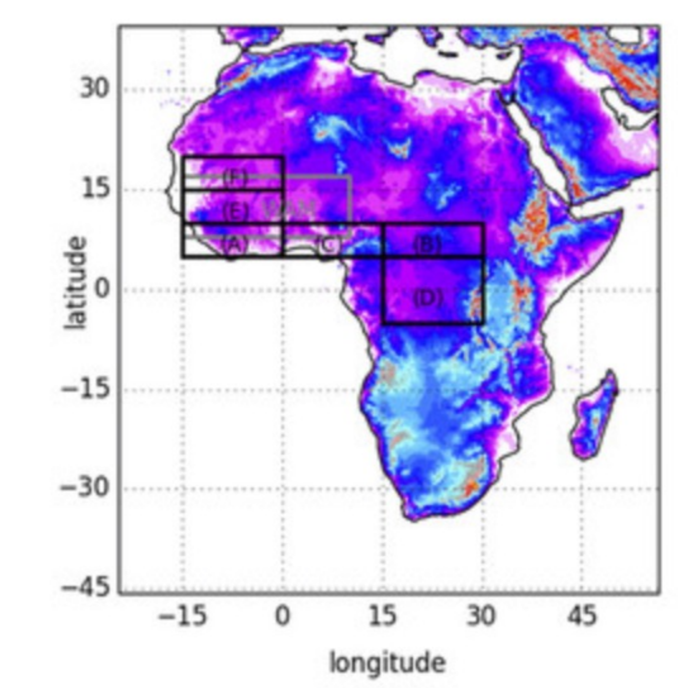
CPRCMs have been used widely over many regions of the globe <u>for single model studies</u> (Europe: Leutwyler et al., 2016; North America: Liu et al., 2017; Africa: Stratton et al., 2018)



Leutwyler et al., 2016



Liu et al., 2017



Stratton et al., 2018

Still need very large supercomputers to run these simulations, which most of us don't have access to.

Recent Climate Projects at CP scale

Due to the complexity, scientific projects were launched to better coordinate CPRCM research activities and increase the amount of CPRCM simulations with similar experimental configurations to explore uncertainties and robustness in CPRCM climate change projections.

CORDEX Flagship Pilot Studies

URB-RCC

ELVIC

IMPETUS 4CHANGE

- **FPS-CPS** (**ELVIC** – Climate Extremes in the Lake Victoria Basin)
- **FPS-CPS** (Euro-Mediterranean)
- **FPS URB-RCC** (URBan environments and Regional Climate Change)
- **FPS-SESA** (Southeastern South America)

EUCP European Climate Prediction system

CP models validation

❖ **FPS-Convection:** Ensembles are essential to get any robust signal from your CPRCM!

Group	Group Name	Model	Grid Spacing	Intermediate step grid spacing/ Model/Domain
IPSL	Institut Pierre-Simon-Laplace (FR)	WRF381BE	3	15/WRF/EURO-CORDEX
BCCR	The Bjerknes Centre for Climate Research (NO)	WRF381BF	3	15/WRF/EURO-CORDEX
AUTH	Aristotle University of Thessaloniki (GR)	WRF381BG	3	15/WRF/EURO-CORDEX
CICERO	Climate and Environmental Research (NO)	WRF381BJ	3	15/WRF/EURO-CORDEX
FZJ	Research Centre Jülich (DE)	WRF381BB	3	15/WRF/EURO-CORDEX
IDL	Instituto Dom Luiz (PT)	WRF381BH	3	15/WRF/EURO-CORDEX
UCAN	Universidad de Cantabria (ES)	WRF381BI	3	15/WRF/EURO-CORDEX
UHOH	University of Hohenheim (DE)	WRF381BD	3	15/WRF/EURO-CORDEX
WEGC	University of Graz (AT)	WRF381BL	3	15/WRF/EURO-CORDEX
ICTP	International Centre for Theoretical Physics (IT)	RegCM4	3	12/RegCM4/Europe
DHMZ	Meteorological and Hydrological Service (HR)	RegCM4	4	12/RegCM4/Europe
KNMI	Royal Netherlands Meteorological Inst. (NL)	HCLIM38-AROME	2.5	12/RACMO/Europe
HCLIMcom	HARMONIE-Climate community (DK, NO, SE)	HCLIM38-AROME	3	12/ALADIN/Europe
CNRM	Centre National de Recherches Meteorologiques (FR)	CNRM-AROME41t1	2.5	12/ALADIN/Med-CORDEX
GERICS	Climate Service Center (DE)	REMO	3	12/REMO/Europe
UKMO	Met Office Hadley Centre Exeter (UK)	UM	2.2	No*
ETHZ	ETH Zürich (CH)	COSMO-CLM	2.2	12/COSMO-CLM/Europe
CMCC	Centro Euro-Mediterraneo sui Cambiamenti Climatici (IT)	COSMO-CLM	3	12/COSMO-CLM/Euro-CORDEX
KIT	Karlsruhe Institute of Technology (DE)	COSMO-CLM	3	25/COSMO-CLM/Europe
GUF	Goethe University Frankfurt (DE)	COSMO-CLM	3	12/COSMO-CLM/Euro-CORDEX
BTU	Brandenburg University of Technology (DE)	COSMO-CLM	3	12/COSMO-CLM/Euro-CORDEX
JLU	Justus-Liebig-University Giessen (DE)	COSMO-CLM	3	No

*UKMO does not use an intermediate nesting step, but provide the simulation data at the 12 km grid spacing for comparison

In total, we analyze **23** simulations with ~3km grid spacing (no deep convection parametrization, CPMs) and 22 simulation with > 12 km grid spacing (parametrized convection, RCMs).

6 different regional climate models are represented in the ensemble.

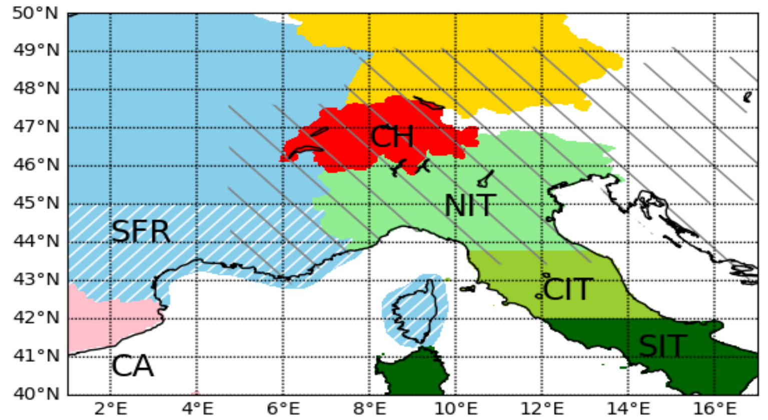
10-year long simulations (2000-2009) driven by ERA-Interim reanalysis.

(Ban, N., et al. 2021)

Observations and Analysis

Observations used in this work

Observations	Area	Grid Resolution	Time Resolution	Period
EURO4M-APGD	Alpine region	5 km	Daily	1971-2008
RdisaggH	Switzerland	1 km	Hourly	2003-2010
COMEPHORE	France	1 km	Hourly	
GRIPHO	Italy	3 km	Hourly	2001-20016



Analyzed indices

Mean	Mean Precipitation	mm/d
Freq	Wet day/hour[a] frequency	[fraction]
Int	Wet day/ hour[a] intensity	[mm/d] / [mm/h]
pXX	XX percentile[b] of daily/hourly precipitation	[mm/d] / [mm/h]

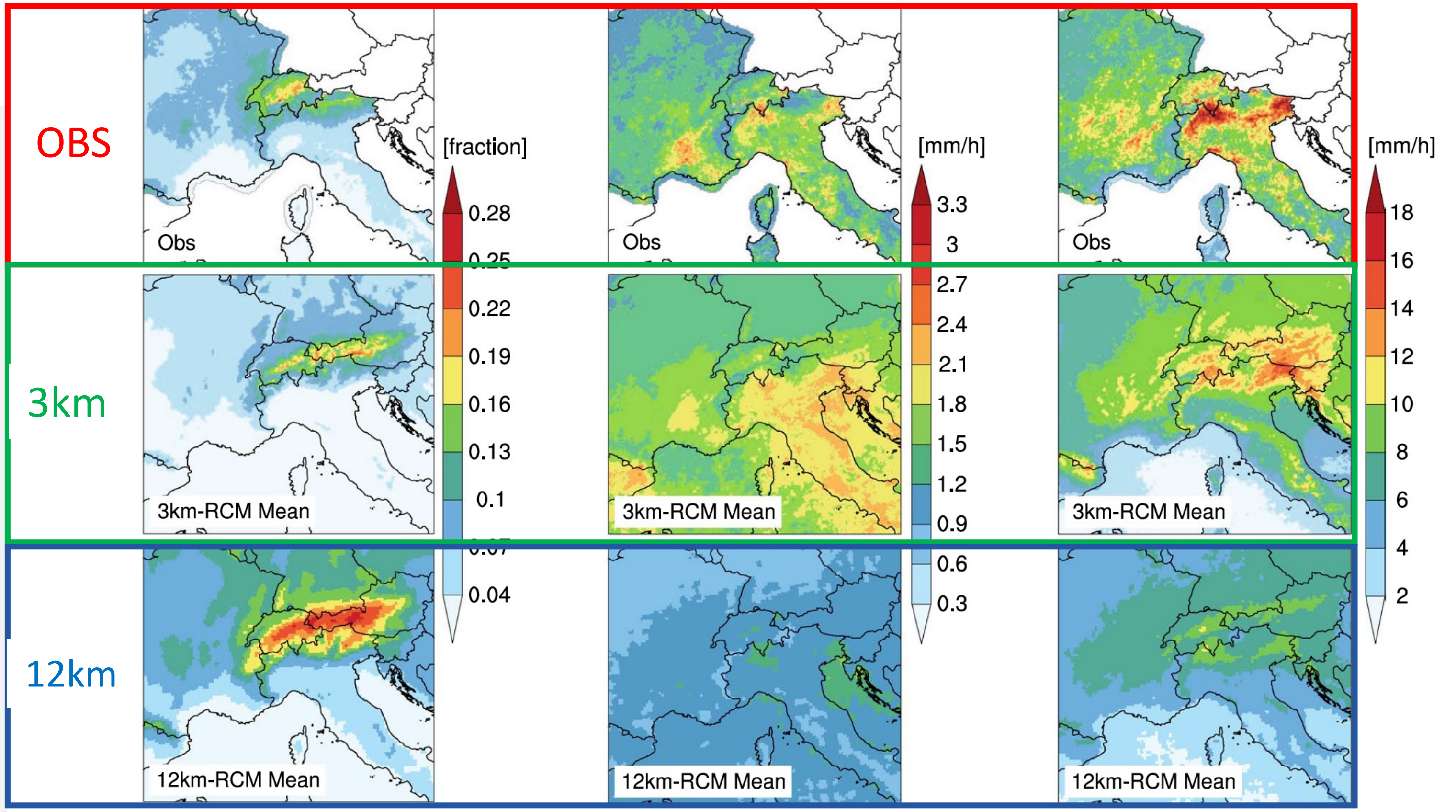
[a] A wet day (hour) is defined as a day (hour) with precipitation ≥ 1 *mm/d* (0.1 *mm/h*)

[b] Percentiles are calculated using all events (wet and dry) following Schär et al., 2016

- Prior to the analysis, all high-resolution simulations have been interpolated to the common 3 km grid, while the intermediate simulations have been interpolated to the common 12 km grid.

Multi-model mean of hourly precipitation in the summer season

Frequency | Intensity | Heavy precipitation(p99.9)

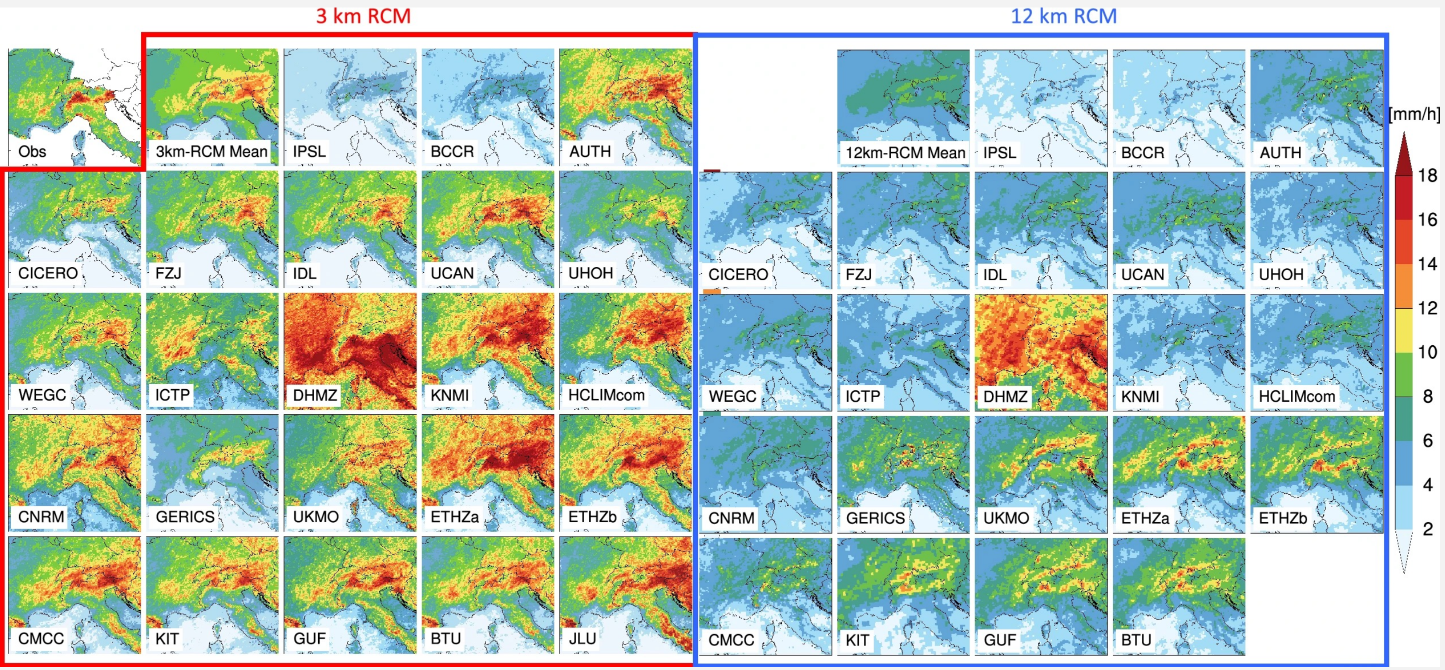


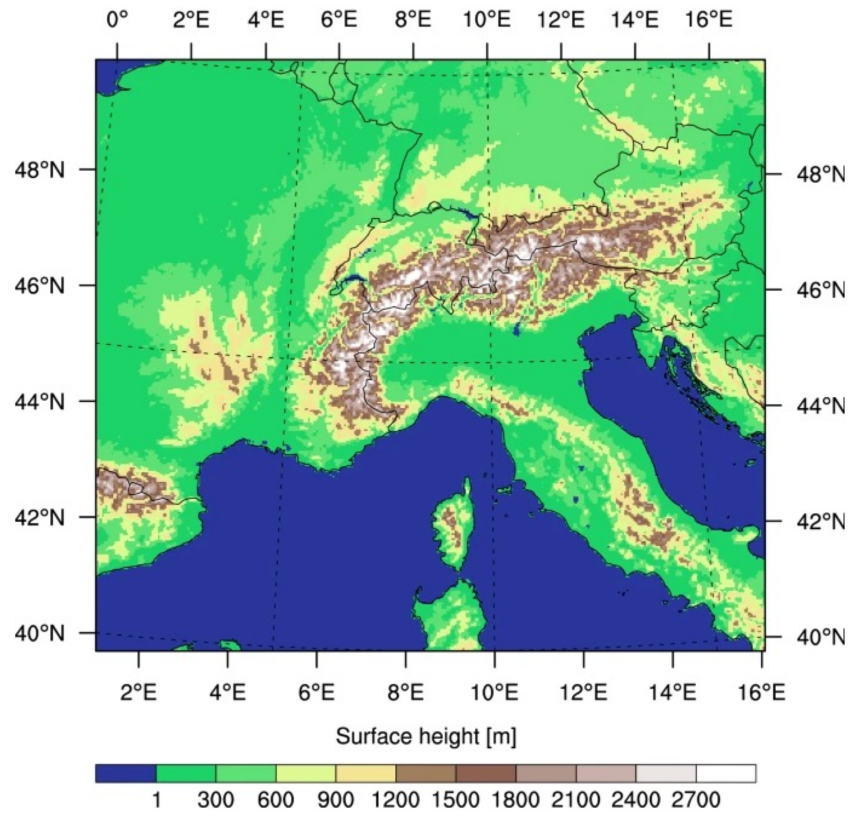
→ 12 km RCM mean shows a large **underestimation** of precipitation **intensity**, and **overestimation** of precipitation **frequency**

→ 3 km CPM mean show better performance in reproducing the spatial patterns of precipitation, driving toward an improvement of the long-standing "*drizzle problem*" with coarse resolution models

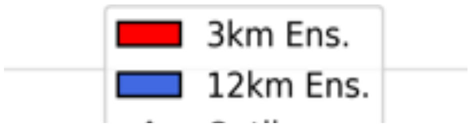
Multi-model mean of hourly precipitation in the summer season

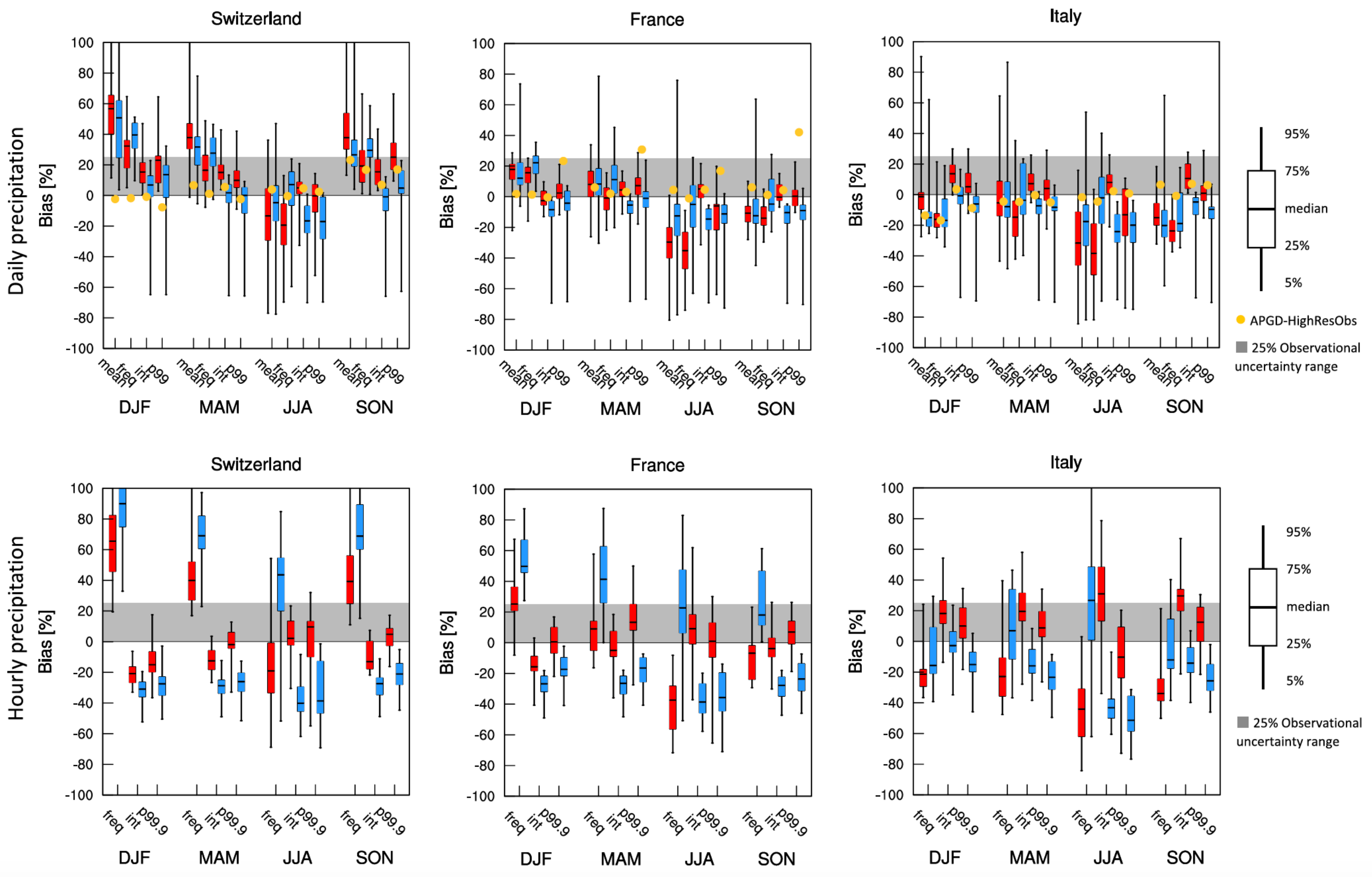
Heavy hourly precipitation (p99.9) in the summer season (Ban et al., 2021)





Precipitation uncertainty





→ Larger differences between RCMs and CPMs at sub-daily scale;

→ Smaller biases for CPMs at the hourly scale;

→ **Smaller uncertainties** for CPMs at the hourly scale (all regions, most indices and seasons);

→ side note: differences between the two observations can be larger than 20%

CP models projections

INSTITUTE	CP-RCM	Resolution (km)	Driving RCM	Resolution (km)	GCM
KNMI (**) The Royal Netherlands Meteorological Institute	HCLIM38-AROME	2.5	RACMO	12	EC-Earth
DMI- MET Norway- SMHI (**) HARMONIE-Climate community	HCLIM38-AROME	3	HCLIM38-ALADIN	12	EC-EARTH
CNRM (**) Centre National de Recherches Meteorologique	CNRM-AROME41t1	2.5	CNRM-ALADIN63	12	CNRM-CM5
ICTP (**) Abdus Salam Internatinal Centre for Theoretical Physics	RegCM4	3	RegCM4	12	HadGEM
KIT Karlsruhe Institute of Technology	CCLM5	3	CCLM4	12	MPI-ESM-LR
BTU Brandenburg University of Technology	CCLM5	3	CCLM4	12	CNRM-CM5
ETHZ (**) Federal Institute of Technology, Institute for Atmospheric and Climate Science	CCLM	2.2	CCLM	12	MPI
ETHZ (**) Federal Institute of Technology	CCLM	2.2	CCLM	12	pgw
UNIGRAZ-WEGC Wegener Center for Climate and Global Change, University of Graz	WEGC-CCLM5	3	WEGC-CCLM5	12	MPI-ESM-LR
UK Met OFFICE (**) Met Office Hadley Centre Exeter	UM	2.2	No intermediate RCM (*)		HadGEM
FZJ-IBG3-IDL Research Centre Julich Institute Dom Luis	WRF3.8	3	WRF3.8.1CA	15	EC-EARTH
BCCR The Bjerknes Centre for Climate Research	WRF3.8	3	WRF3.8.1CA	15	NorESM1

CORDEX-FPS Convection Community model members + (**) EUCP (European Climate Prediction system) model members

12 CPMs ~3km grid spacing

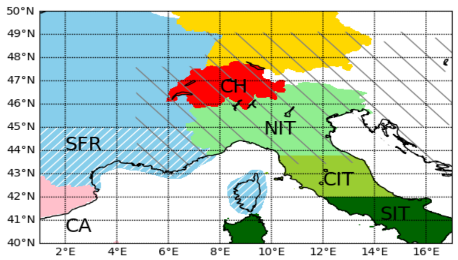
11 RCMs (*) ~ 12/15 km

5 different regional climate models are represented in the ensemble.

10-year long simulations (Historical period: 1996-2005; Future projection: 2090-2099) driven by CMIP5 GCMs.

(Pichelli, E., et al. 2021)

CP models projections: hourly precipitation change

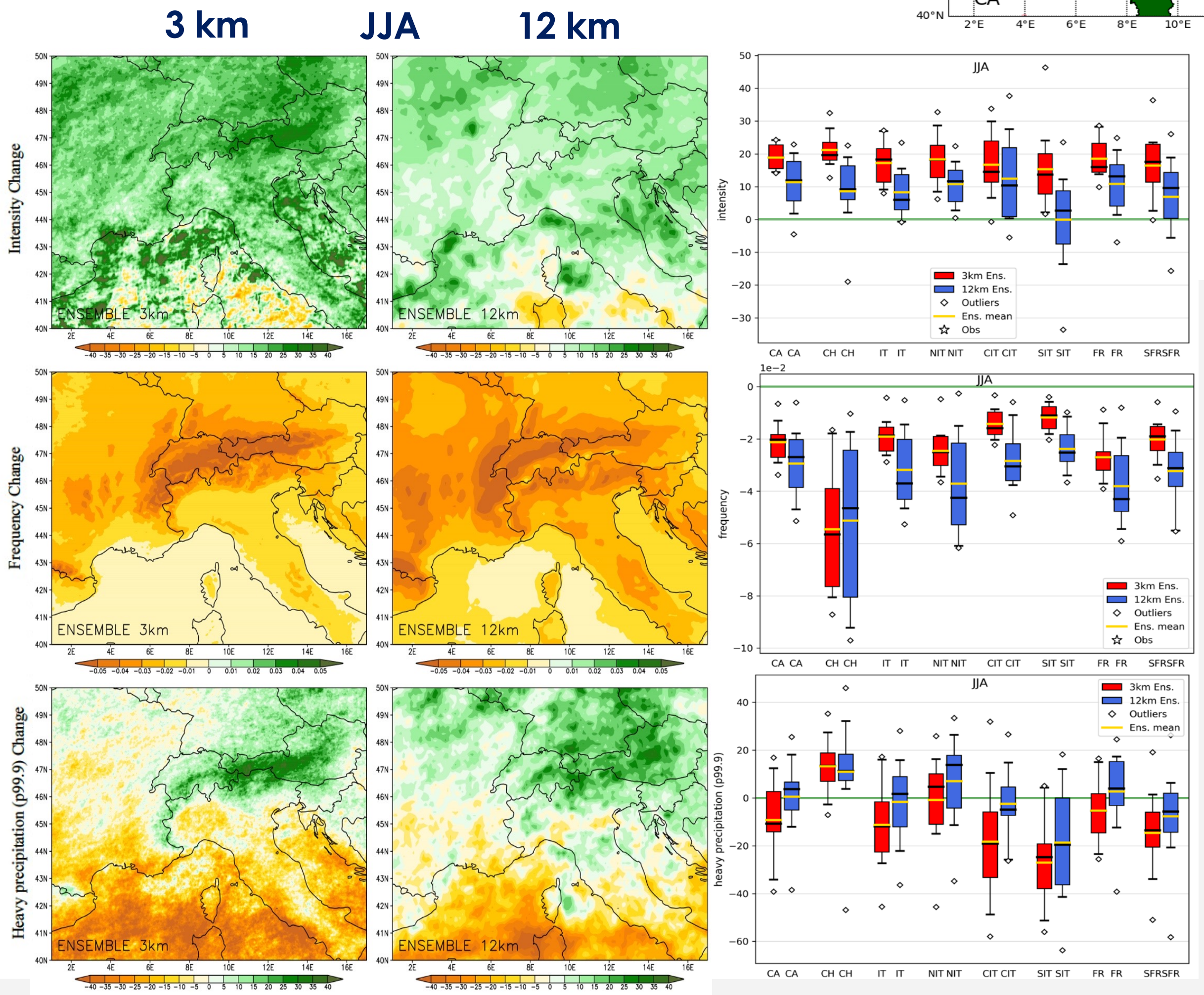


- At the hourly time scale the patterns of change is in agreement between CPM-e and RCM-e

- CPM-e shows an intensification of its response mainly across the orography in JJA

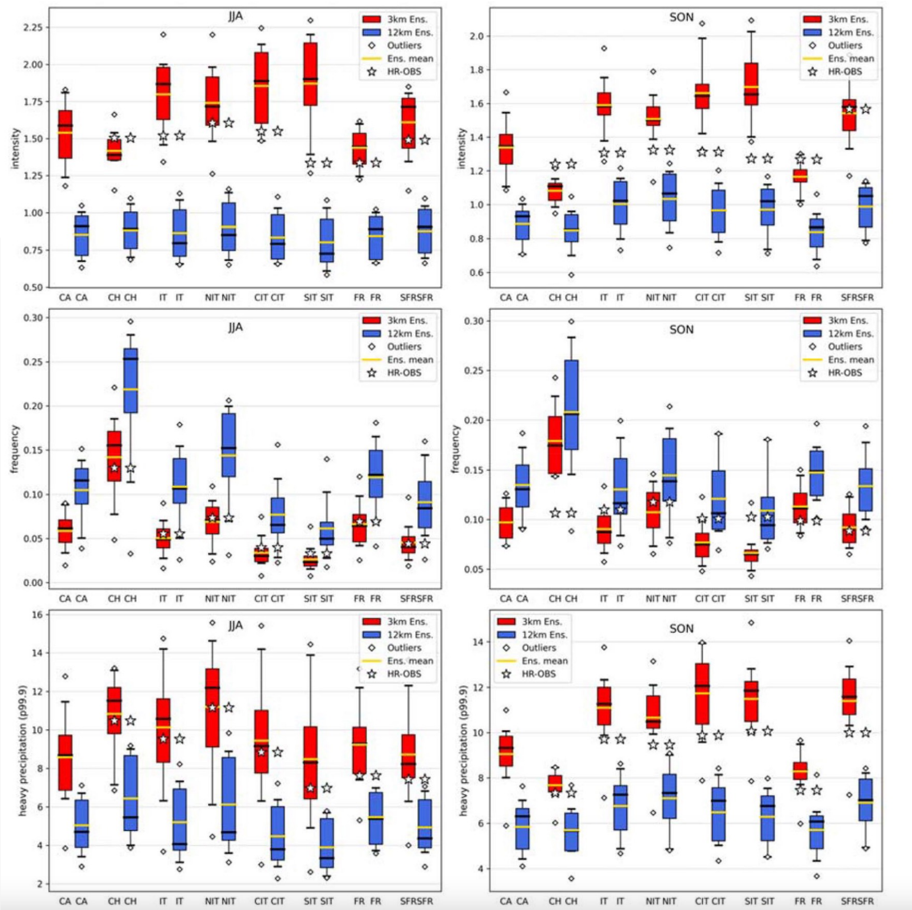
- for HPE largest changes over the Alps and western Mediterranean; switch of sign compared to the RCMs over part of northern Italy (subalpine region) and central-northern France

- smaller uncertainty for frequency and intensity; agreement in sign (int., P99.9) among CPMs over SIT and SFR (not for RCMs)

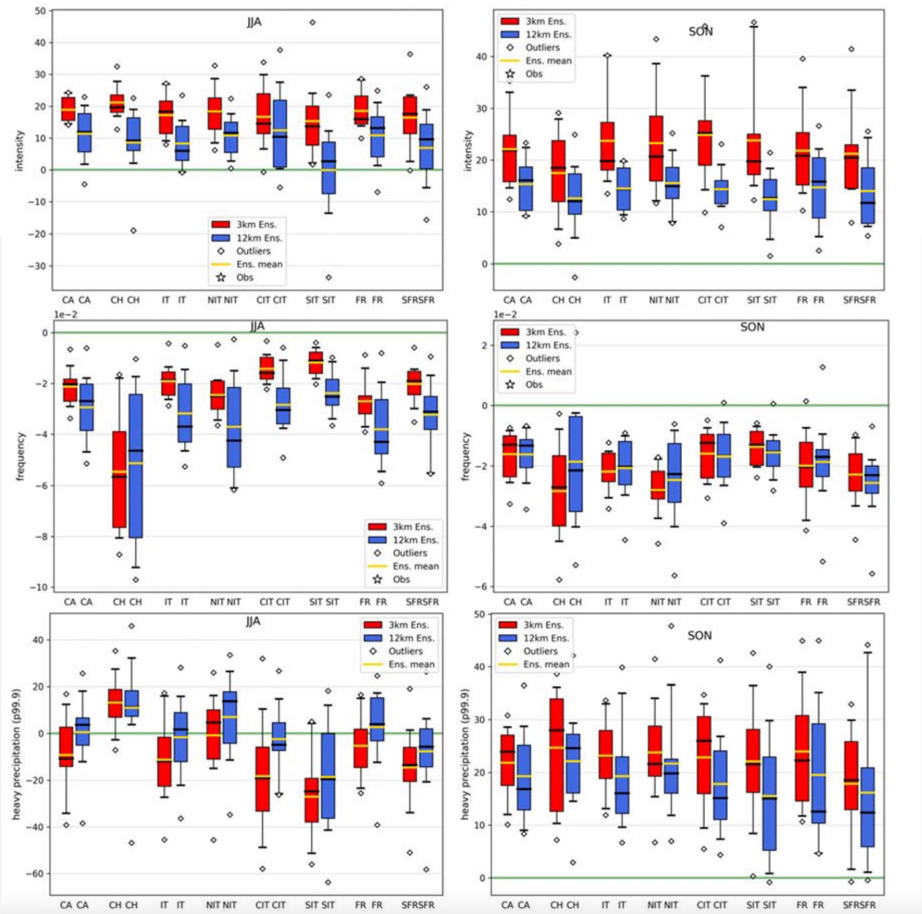


CP models projections: less uncertainty!

Present Hourly Precipitation



Future Hourly Pr. change

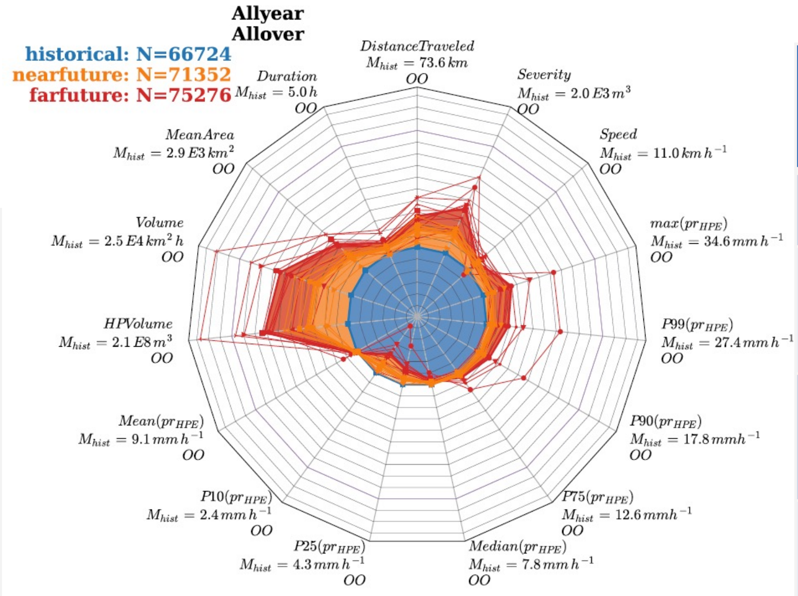


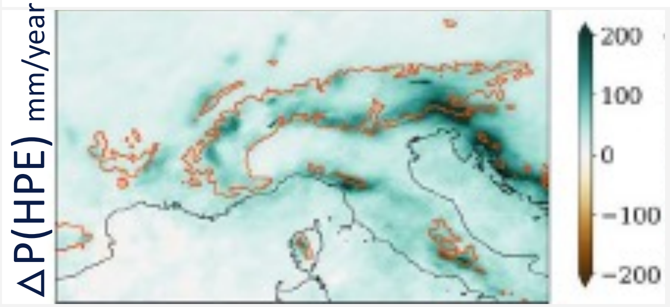
Smaller uncertainties for CPMs at the hourly scale in all regions for most indices and seasons

Pichelli, E., Coppola, E., Sobolowski, S., Ban, N., Giorgi, F., Stocchi, P., ... & Vergara-Temprado, J. (2021). The first multi-model ensemble of regional climate simulations at kilometer-scale resolution part 2: historical and future simulations of precipitation. *Climate Dynamics*, *56*(11), https://doi.org/10.1007/s00382-021-05657-4, 3581-3602.

Ban, N., Caillaud, C., Coppola, E., Pichelli, E., Sobolowski, S., Adinolfi, M., ... & Zander, M. J. (2021). The first multi-model ensemble of regional climate simulations at kilometer-scale resolution, part I: evaluation of precipitation. *Climate Dynamics*, https://doi.org/10.1007/s00382-021-05708-w, 1-28.

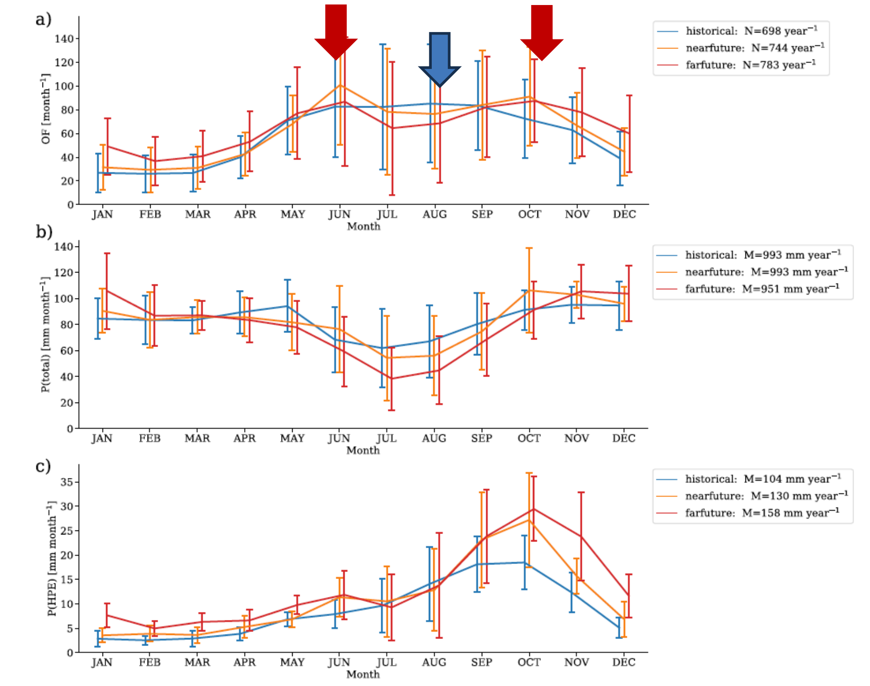
CP models projections: impact on HPE using a tracking algorithm





Results:

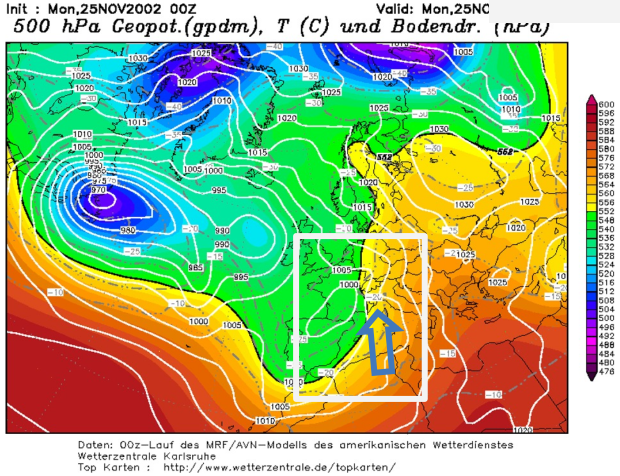
HPE property	Percent of change %
Duration	5
Distance traveled	15
Propagation speed	13
Geometrical volume	30
Mean P	3
HPVolume	35
Severity	21

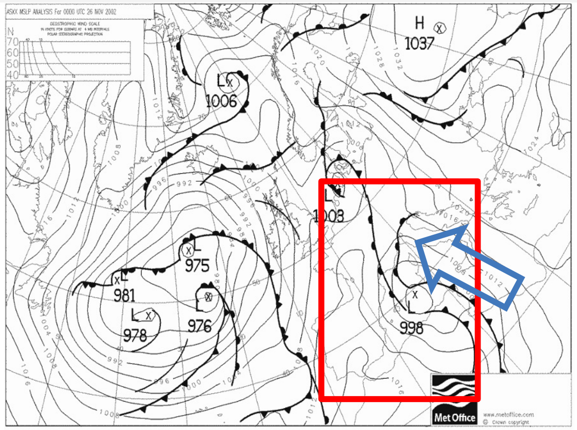


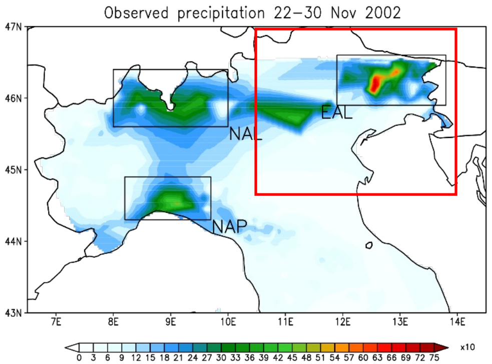
Frequency of the HPE change distribution shape from unimodal to bimodal

Müller, S.K., Pichelli, E., Coppola, E., et al. (2023). The climate change response of alpine-mediterranean heavy precipitation events. *Climate Dynamics*, https://doi.org/10.1007/s00382-023-06901-9.

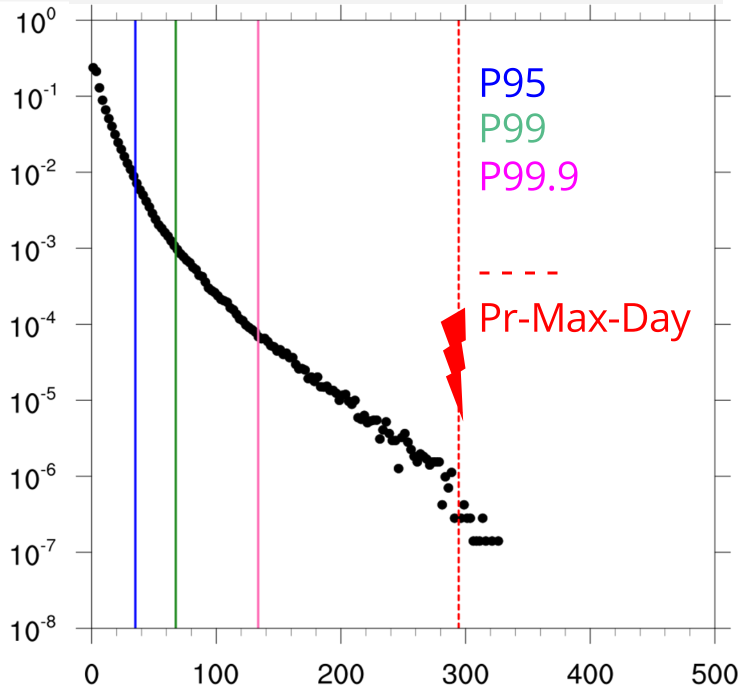
CASE STUDY: 22-30 Nov. 2002 Northern Italy







OBS daily precipitation distribution over Friuli (NE-Italy)



2002	22NOV	23NOV	24NOV	25NOV	26NOV	27NOV	28NOV	29NOV	30NOV	P99.9	TOT EVENT
OBS max	214.5	14.4	75.9	294.5	261.3	26.1	1.7	101.7	7.7	133.6	705.5

Key factors:

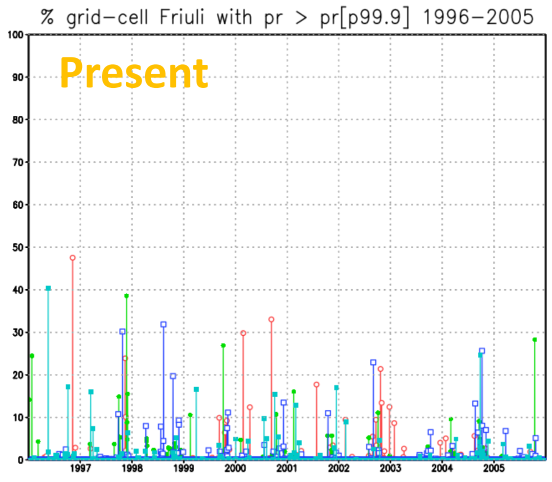
Persistent south-westerly **unstable** and **wet** flow upstream the Alps

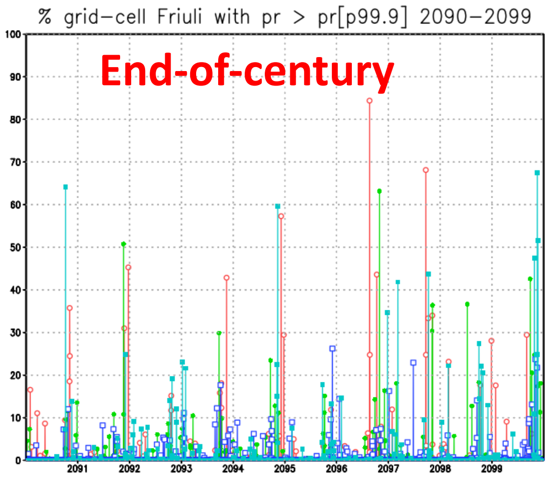
The precipitation event in the CP-models world: projections

Institute	cpRCM	dx(cpRCM) [km]	RCM	dx(RCM) [km]	GCM
CMCC	CLMcom-CMCC-CCLM5-0-9 (E)	3	CCLM (E1)	12	ICHEC-EC-EARTH
CNRM	AROME41t1 (B)	2.5	ALADIN63 (B1)	12	CNRM-CERFACS-CNRM-CM5
DWD	CLMcom-DWD-CCLM5-0-15 (E)	3	CCLM4 (E1)	12	MOHC-HadGEM2-ES
ETHZ	COSMO-crCLIM (F)	2.2	COSMO-crCLIM (F)	12	MPI-M-MPI-ESM-LR
HCLIMcom	HCLIM38-AROME (D)	3	HCLIM38-ALADIN (D)	12	ICHEC-EC-EARTH
ICTP	RegCM4-7-0 (A)	3	RegCM4-7-0 (A)	12	MOHC-HadGEM2-ES
JLU	CLMcom-JLU-CCLM5-0-15 (E)	3	–	–	MPI-M-MPI-ESM-LR
KIT	CLMcom-KIT-CCLM5-0-14 (E)	3	CCLM4 (E1)	25	MPI-M-MPI-ESM-LR
KNMI	HCLIM38h1-AROME (D)	2.5	RACMO (D1)	12	EC-Earth23 (D2)
MOHC	HadREM3-RA-UM10.1 (C)	2.2	–	–	MOHC-HadGEM2-ES

Mueller et al. (2023, their Table 1) https://doi.org/10.1007/s00382-023-06901-9

SON	CNRM	ETHZ	HCLIMcom	ICTP
HIST	45	47	40	32
RCP85	83	68	52	43





More HPEs hitting **larger areas**

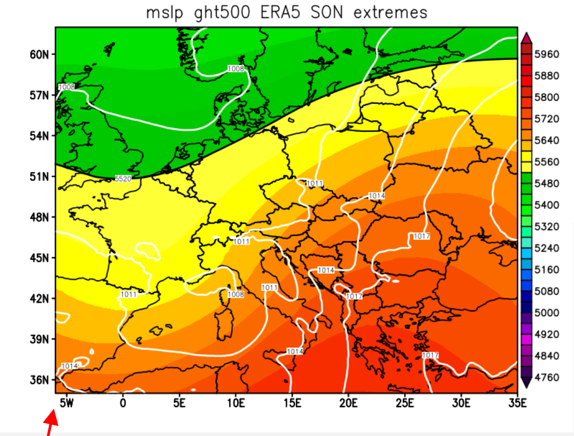
The precipitation event in the CP-models world: projections

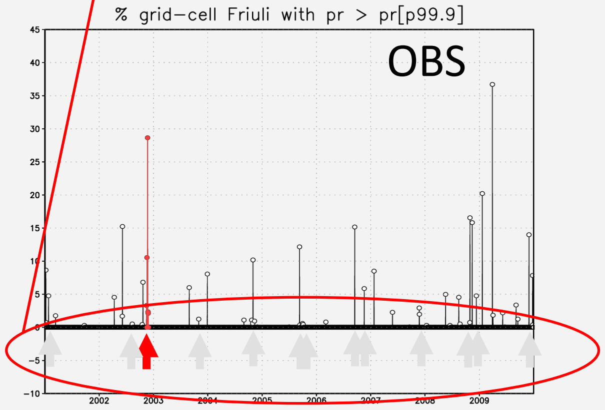
Driving conditions: mean large scale dynamical signature of the events

Mean sea level pressure (hPa, contours)

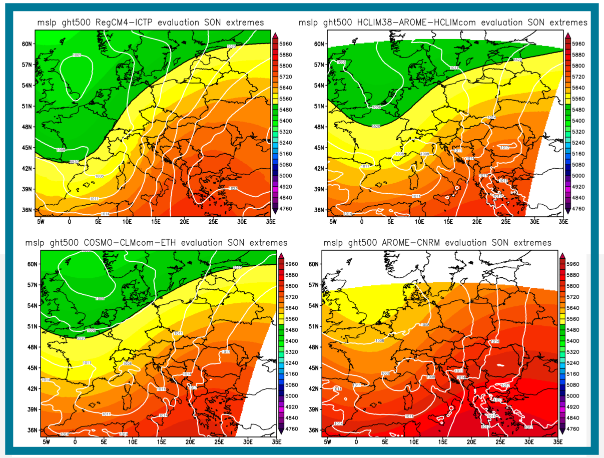
500 hPa geopotential height (m, colors)

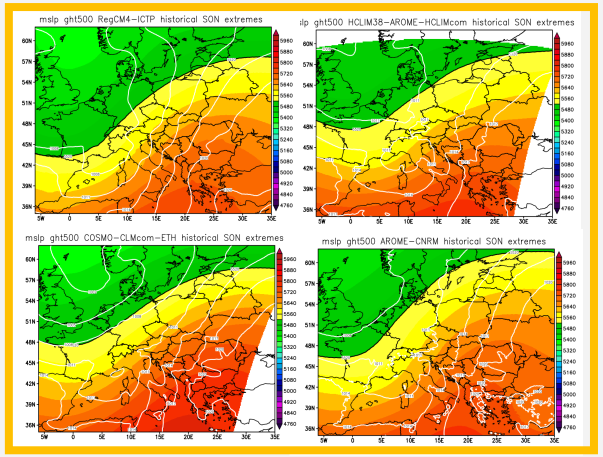
ERA5





Evaluation run





Historical run

ICTP-RegCM4

HCLIMcom-HCLIM38-AROME

ETHZ-COSMO

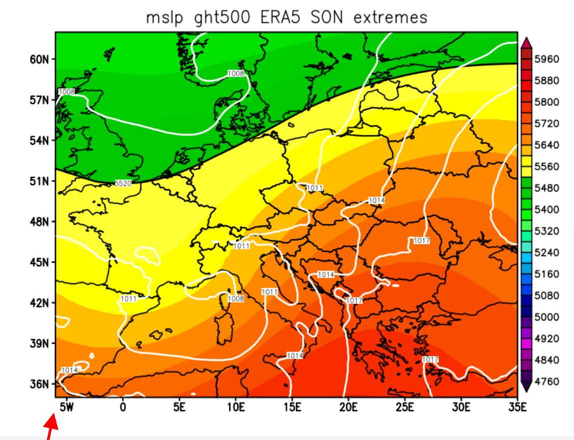
CNRM-AROME

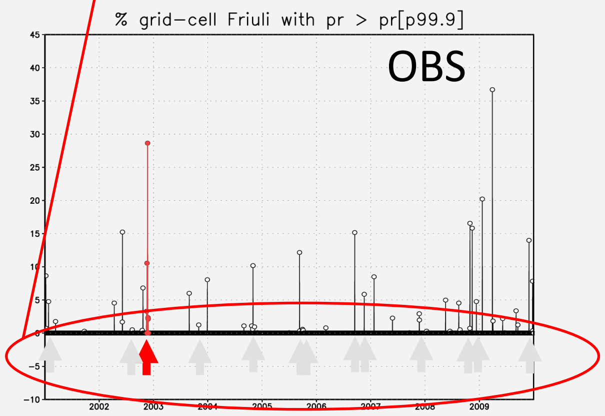
The precipitation event in the CP-models world: projections

Driving conditions: mean large scale dynamical signature of the events

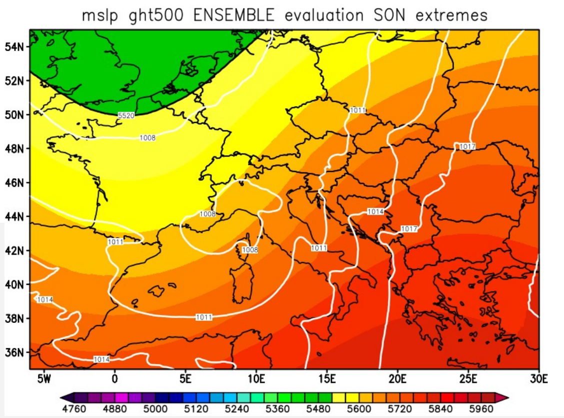
Mean sea level pressure
(hPa, contours)
500 hPa geopotential height (m, colors)

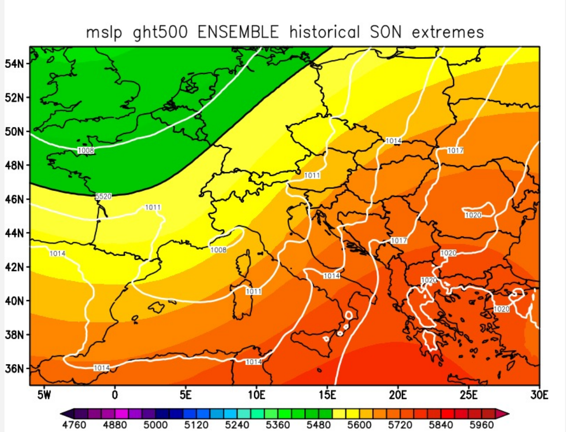
ERA5





Evaluation run





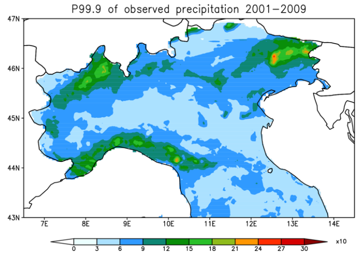
Historical run

ICTP-RegCM4

HCLIMcom-HCLIM38-AROME

ETHZ-COSMO

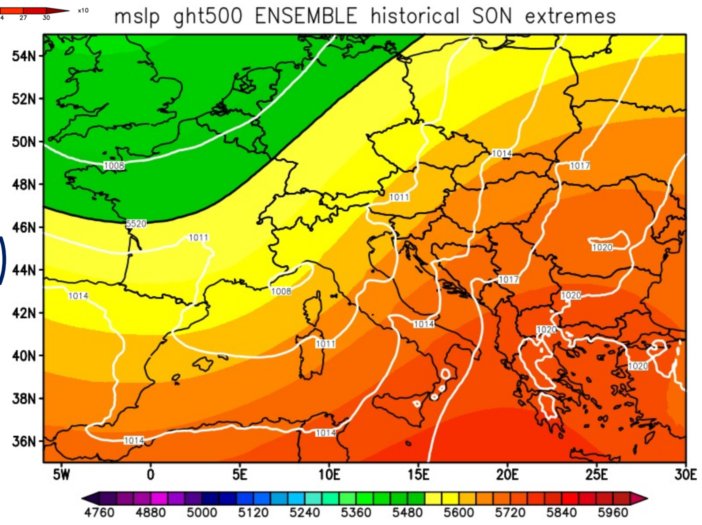
CNRM-AROME

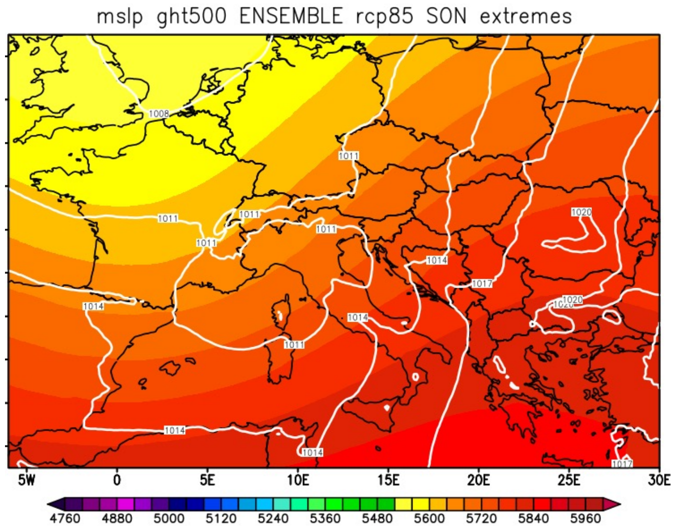


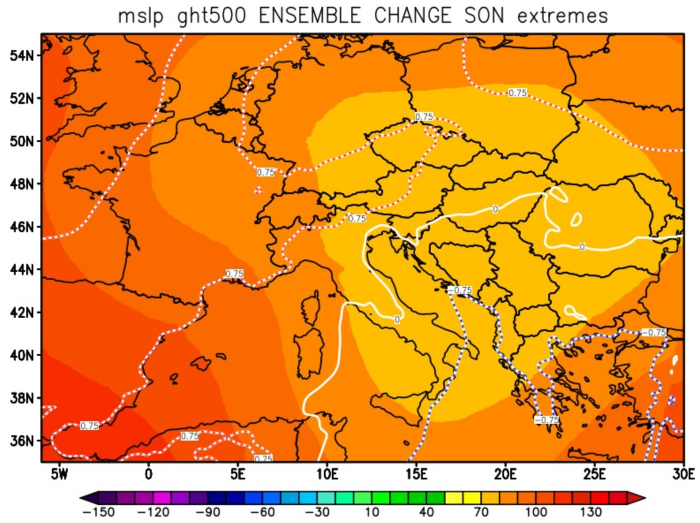
Driving conditions: mean large scale dynamical signature of the events

	Historical period	End of Century	Change

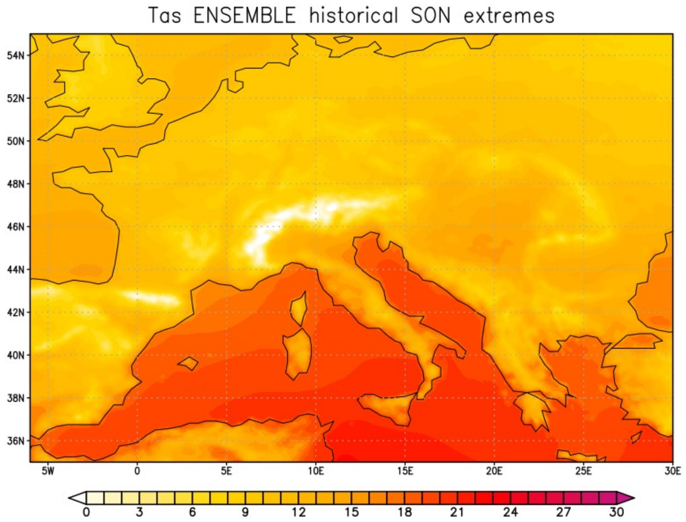
Mslp (hPa)
Ght (m)

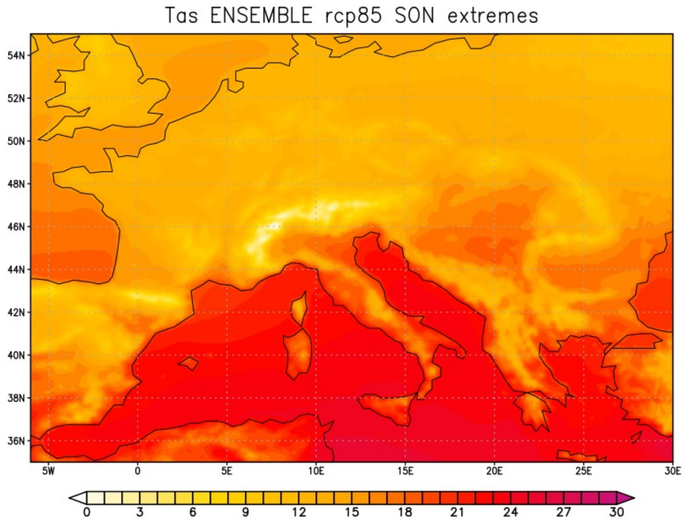


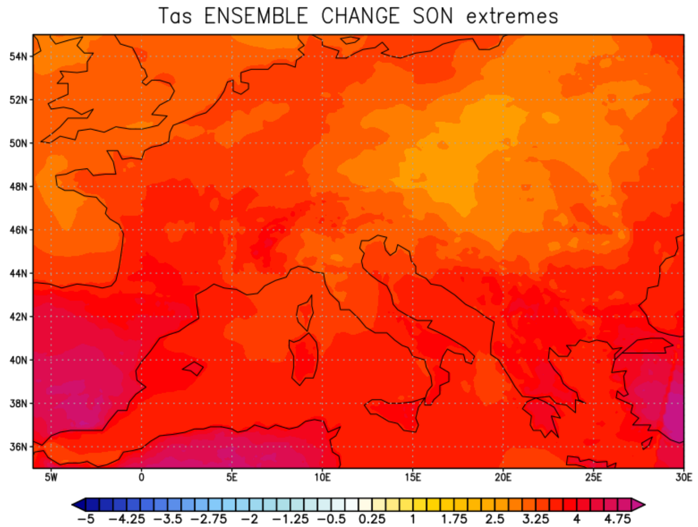




Tas (C)







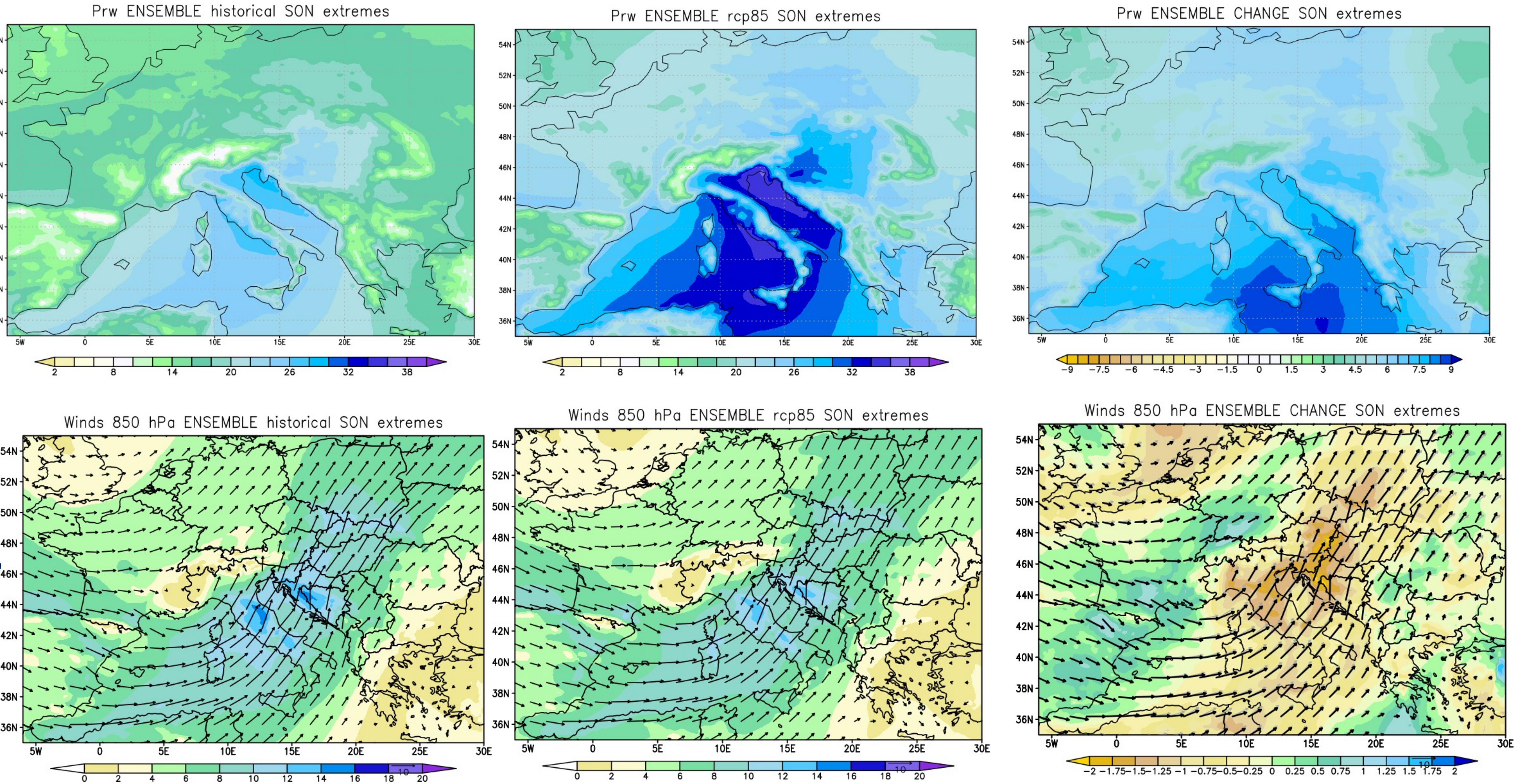
The Abdus Salam International Centre for Theoretical Physics

Driving conditions: mean large scale dynamical signature of the events

Historical period | End of Century | Change

PWV (mm)

Winds 850mb (m/s)



Pichelli, E., Coppola, E., et al., in Preparation

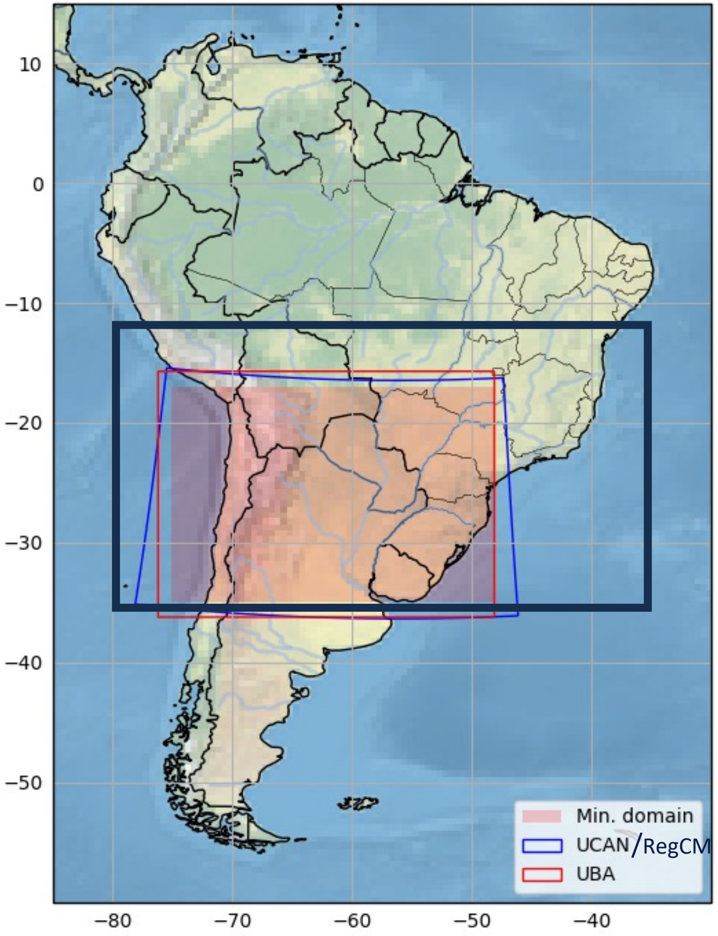
Convection-Permitting simulations over South America: a look at the uncertainty sources at the sub-daily time scale

Erika Coppola[1], Francesca Raffaele[1], Leidinice Silva[1] Maria L. Bettolli[2], Josefina Blazquez[3], Jesús Fernández[4], Josipa Milovac[4], Rosmeri P. da Rocha[5], Silvina Solman[6]

[1]International Centre for Theoretical Physics, Trieste, Italy
[2]University of Buenos Aires-CONICET, Buenos Aires, Argentina
[3]UNational University of La Plata-CIMA/CONICET, La PlataBuenos Aires, Argentina
[4]Instituto de Física de Cantabria (IFCA), CSIC-Universidad de Cantabria, Santander, Spain
[5]Universidade de São Paulo, São Paulo, Brazil
[6]University of Buenos Aires-CIMA/CONICET, Buenos Aires, Argentina

The FPS-SESA ensemble

- The multi-model ensemble was developed as part of the CORDEX Flagship Pilot Study on Extreme Precipitation Events in Southeastern South America (FPS-SESA)(1).
- This ensemble consists of four coordinated simulations produced by convection-permitting regional climate models (CPRCMs) at a 4 km resolution + one uncoordinated simulation covering the entire South American continent, by the NCAR South America Affinity Group, also at a 4 km resolution.
- An additional simulation at 3 km resolution and for a bigger domain (Fig.1) has been performed at ICTP.
- Each simulation covers a three-year period (from June 2018 to June 2021).



(1) Bettolli et al. (2021): DOI: 10.1007/s00382-020-05549-z

Convection-Permitting simulations over South America: a look at the uncertainty sources at the sub-daily time scale

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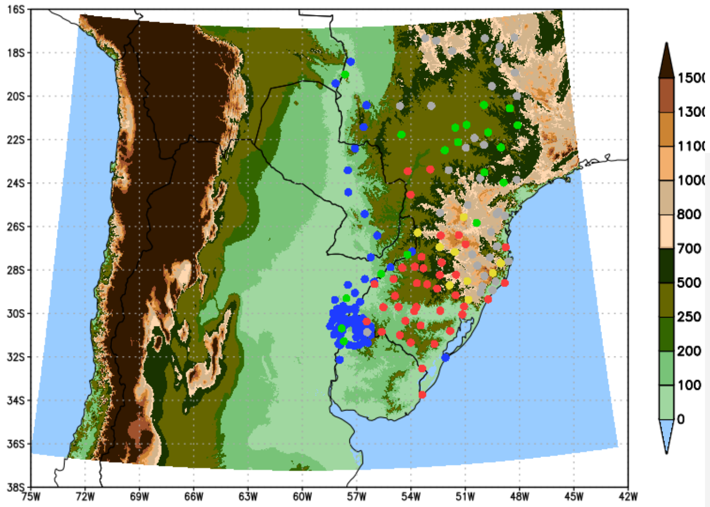
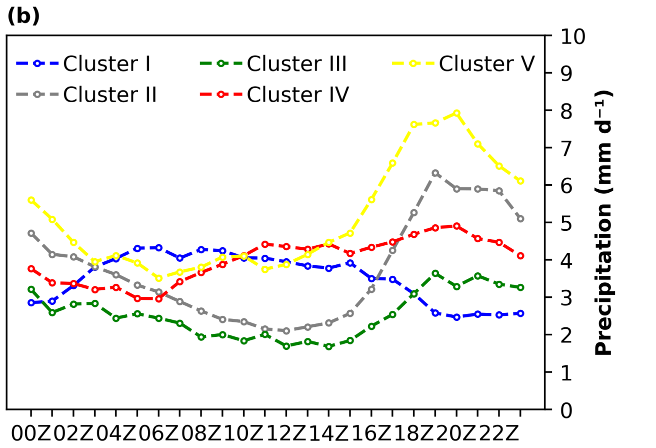
Validation data:

- Hourly Satellite datasets: CMORPH[2] (8km), GPM-IMERG[3] (0.1°), PERSIANN (0.25°)[4]
- Hourly stations[5]: 99 stations from Brazil (INMet) and 71 stations from Argentina, Uruguay and Paraguay (SMN –only rainfall).





The stations location. The colors represent the 5 clusters identified by the "Ward" hierarchical method based on the minimum variance between clusters, is applied to define the ideal number of clusters (5 in this case). The resulting dendrogram is shown in panel a; the diurnal cycle of precipitation for each clusters is shown in panel b.

Convection-Permitting simulations over South America: a look at the uncertainty sources at the sub-daily time scale

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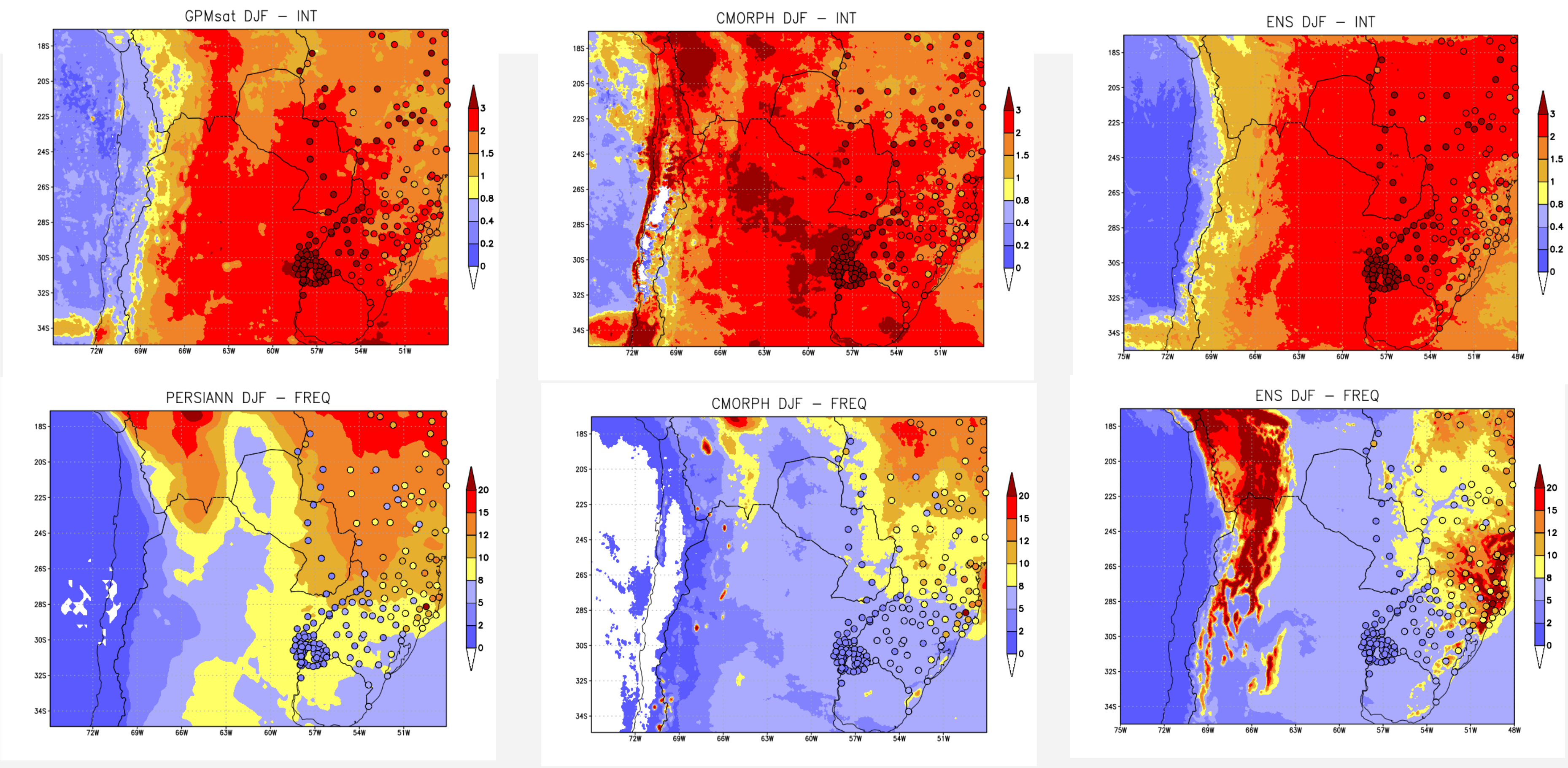
The Hourly Analysis: Spatial distribution



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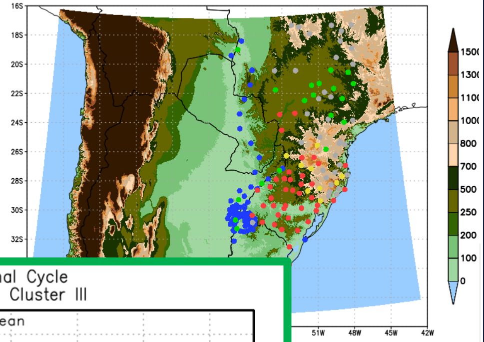
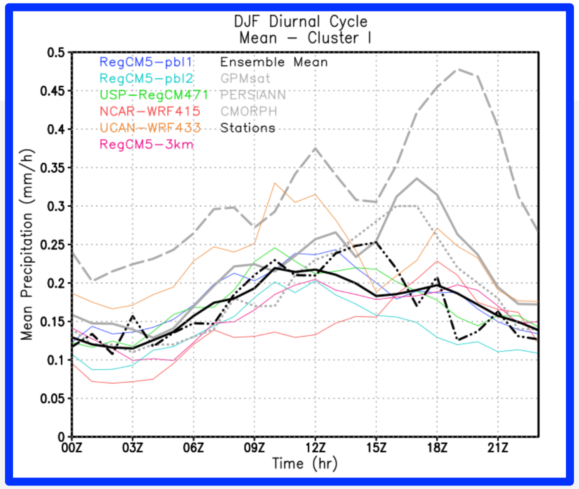
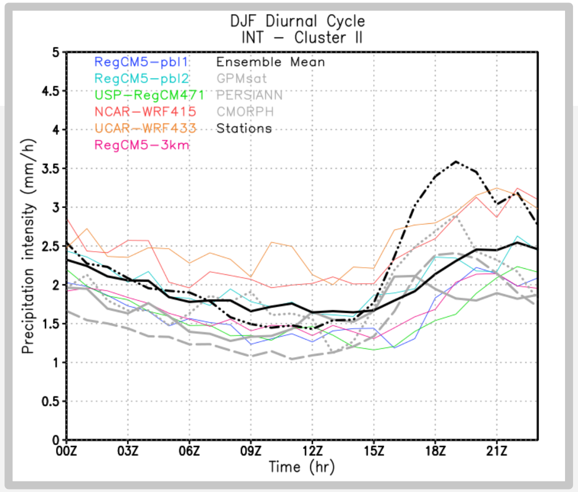
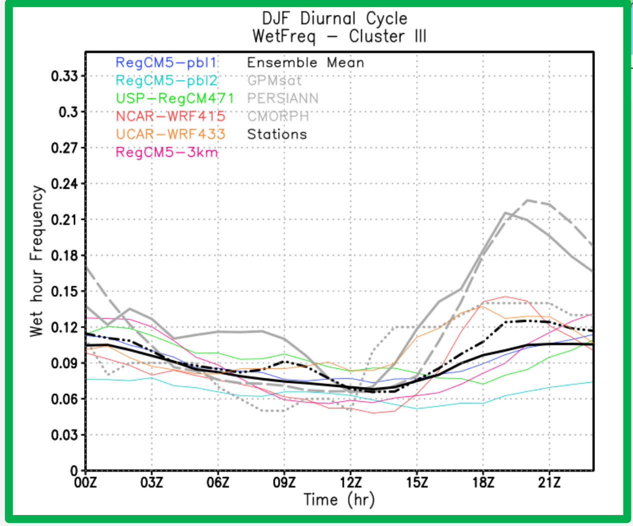
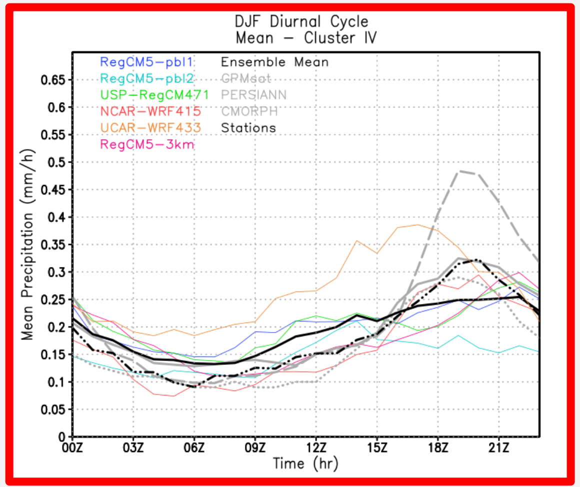


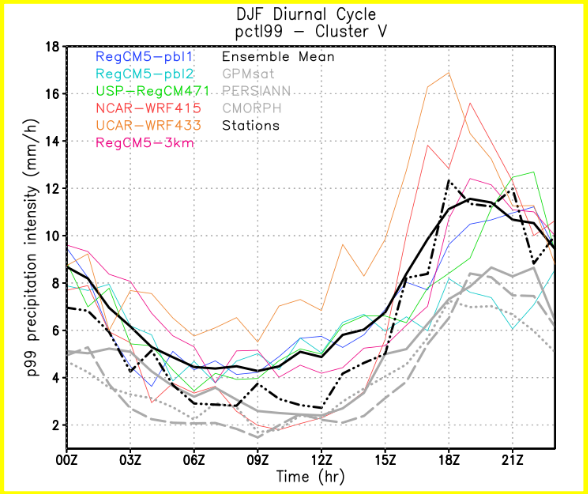
The Hourly Analysis: Diurnal cycles





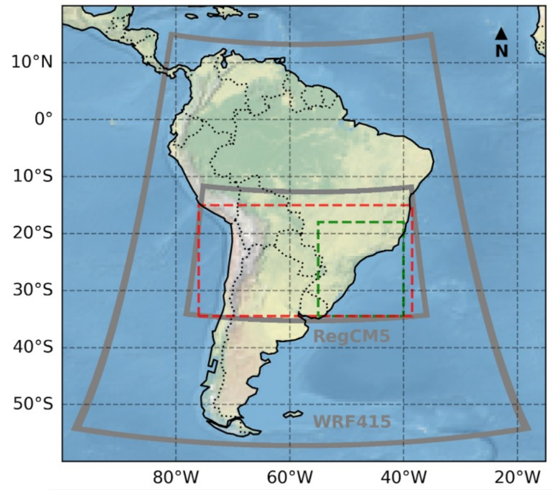




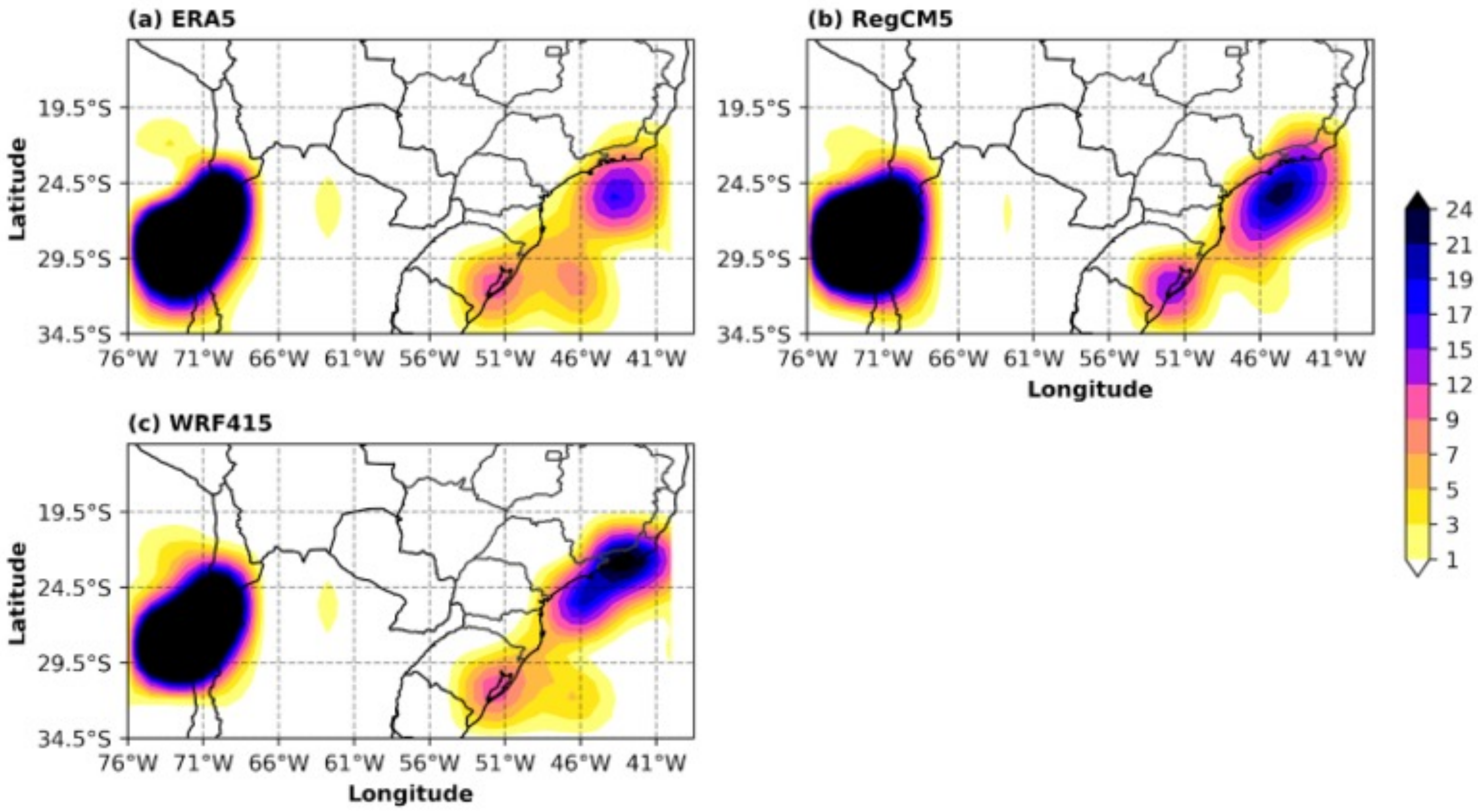


Stations
Ensemble
GPMsat
PERSIANN
CMORPH ....

CP models projections: synoptic-scale cyclones over South Atlantic

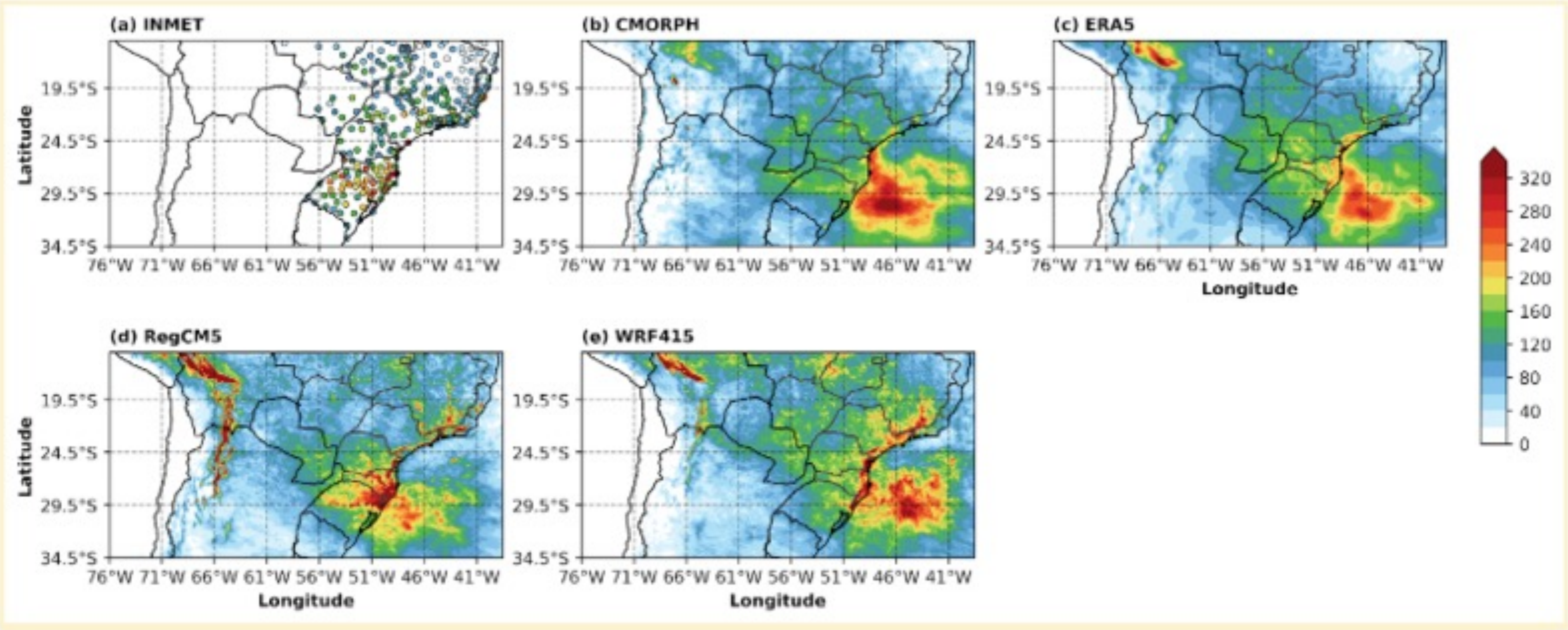


Annual average of cyclogenesis density



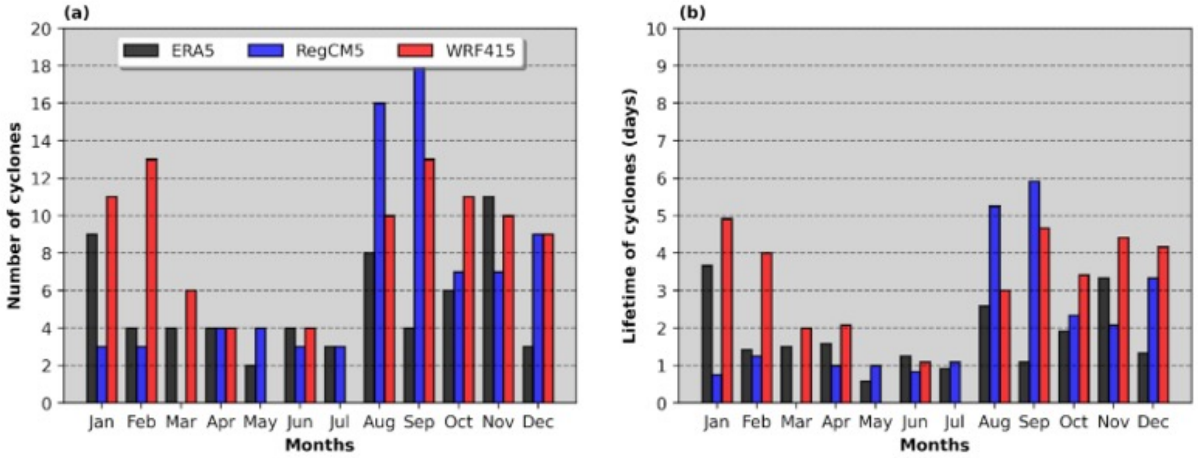
CP models projections: synoptic-scale cyclones over South Atlantic

Annual average of precipitation related to synoptic-scale cyclones

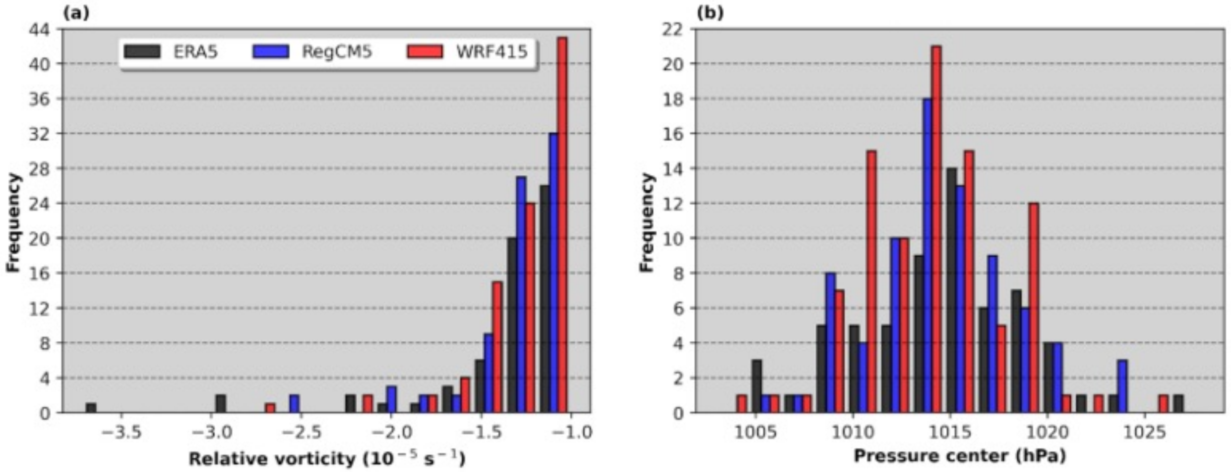


CP models projections: synoptic-scale cyclones over South Atlantic

Annual cycle of number of cyclones and lifetime



Relative vorticity and mean sea level pressure in the cyclogenesis

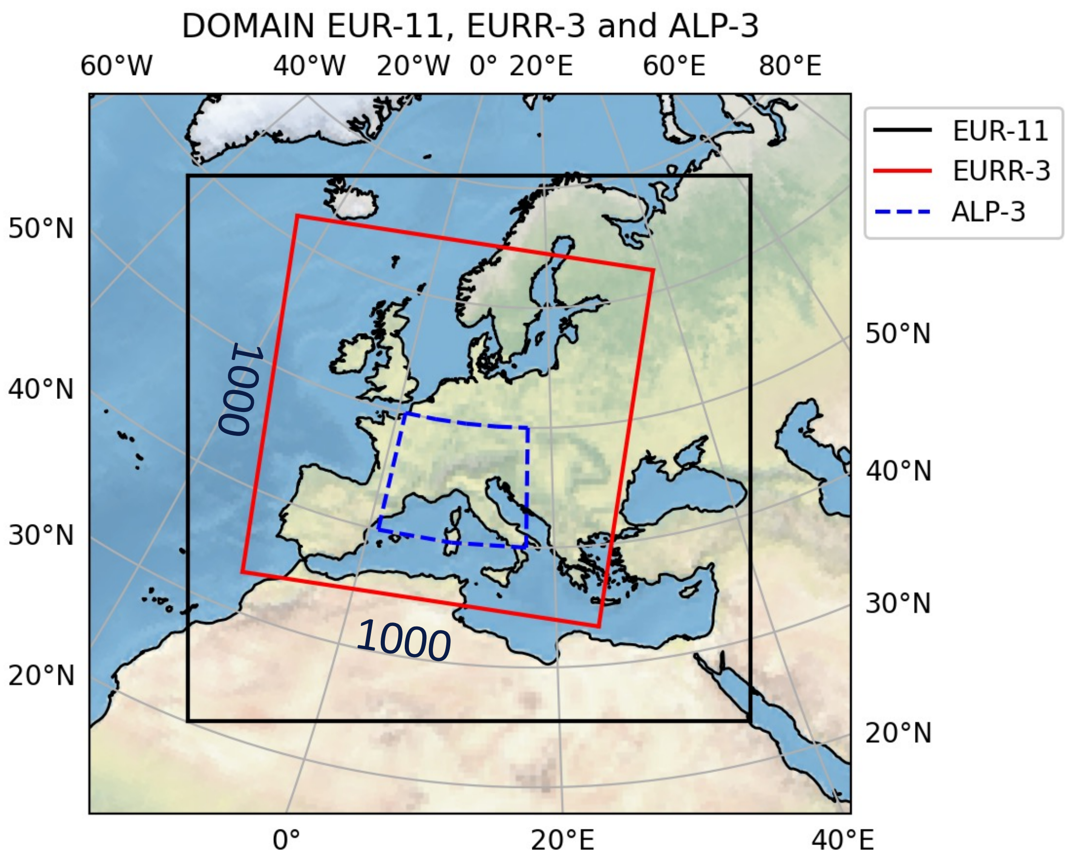


RegCM5 EURR-3 CP simulation
ICTP nesting strategy

The European **CP domain EURR-3** (red outline) has been simulated with RegCM5 using:

- **ERA5 boundary conditions** for the evaluation period **1999-2009**
- GW level scenarios by nesting the EURR-3 domain on the output from the EUR-12 simulations driven by **EC-Earth3-Veg GCM boundary conditions.**

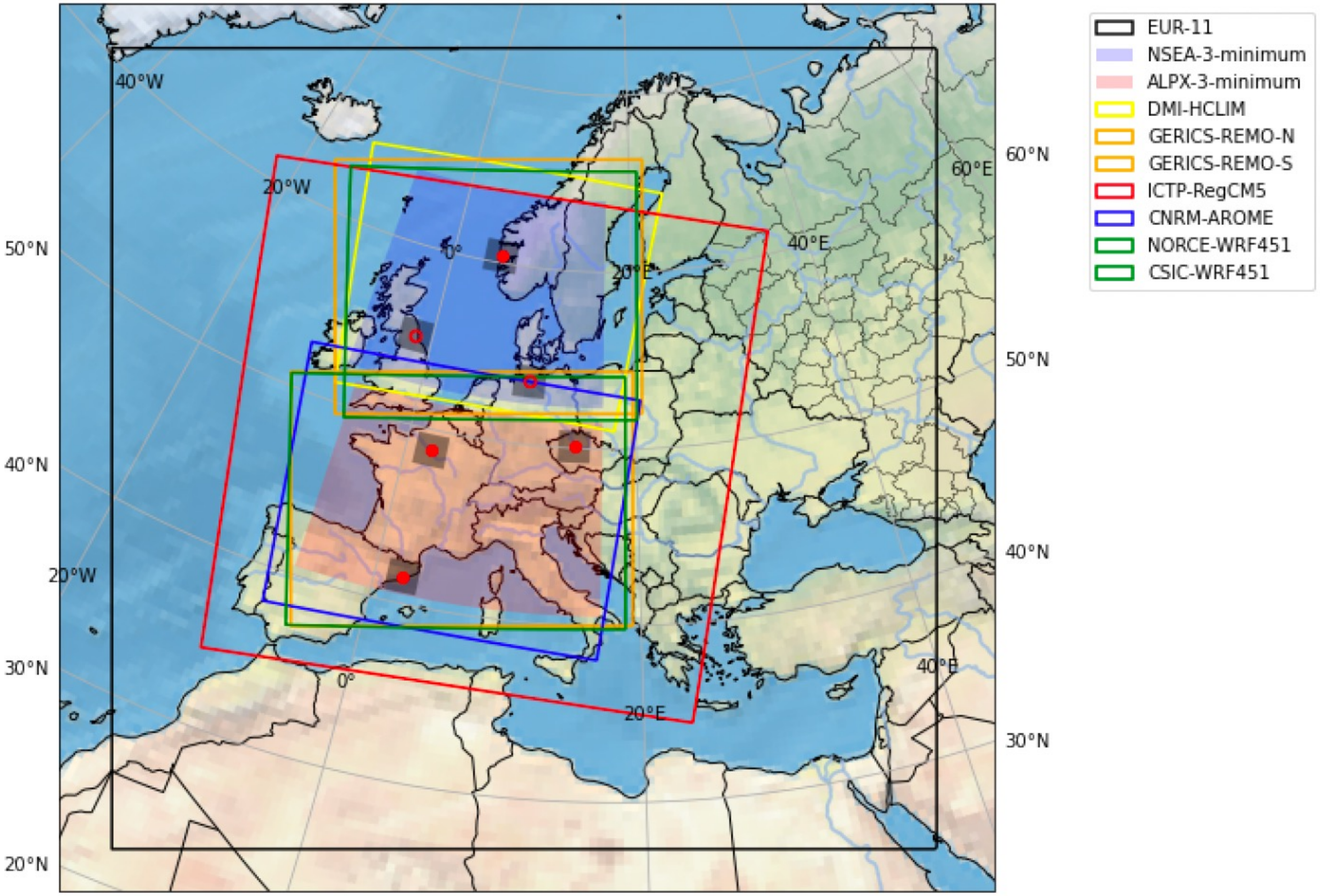
Cost: (~200.000 CPU core hours/year)
Storage space needed: 9TB per year



Domain size for CP simulations

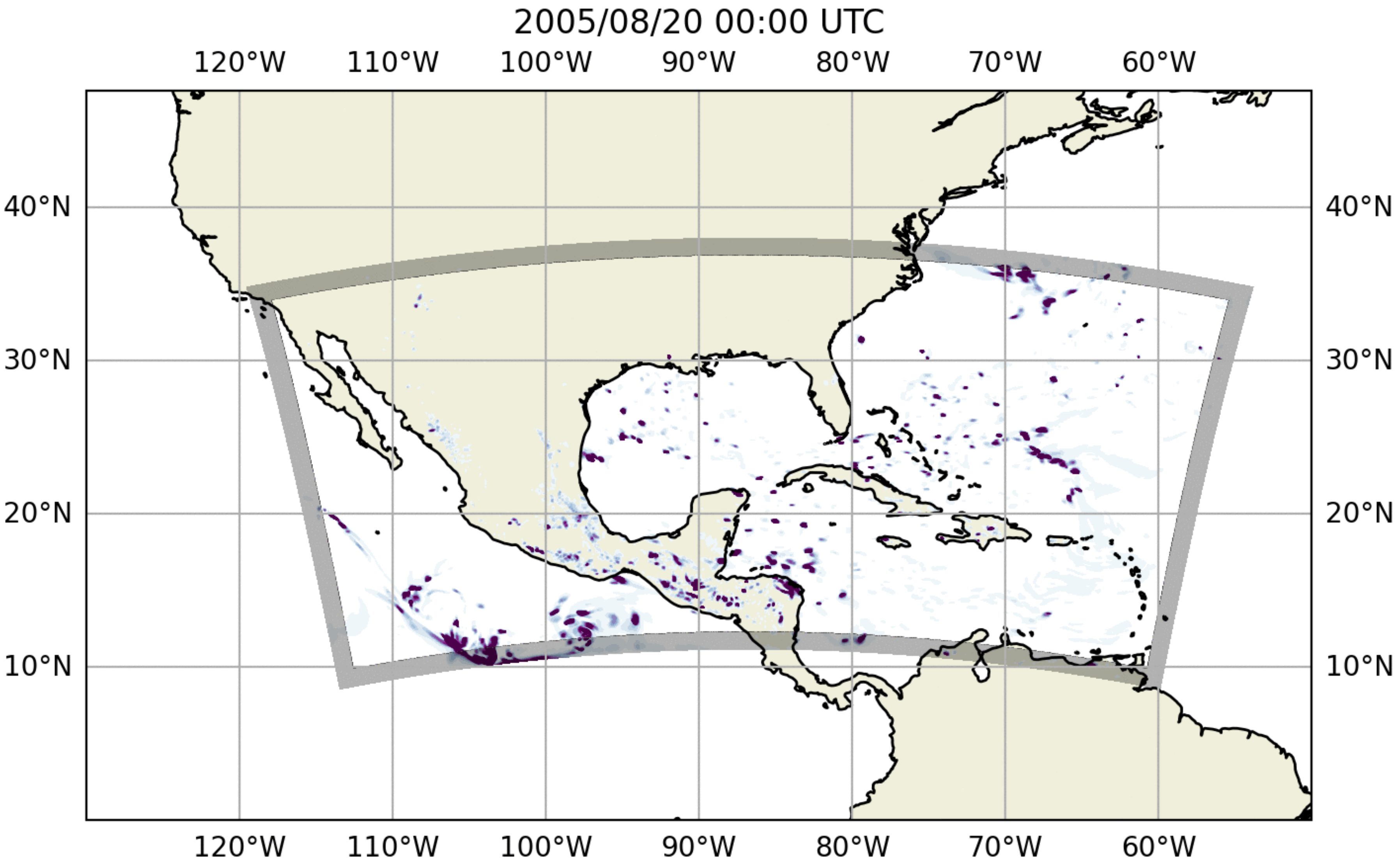
CPRCM I4C simulations

CPRCM (Group)	GCM CMIP6 scenarioMIP
CNRS-MF-AROME46t1	CNRM-ESM2-1, r1i1p1f2
UNESCO-ICTP-RegCM5 DMI-HCLIM43-AROME	EC-Earth3-Veg, r1i1p1f1
Hereon-GERICS-REMO2020	MPI-ESM1-2-HR, r1i1p1f1
CSIC-WRF451 NORCE-WRF451	NorESM2-MM, r1i1p1f1

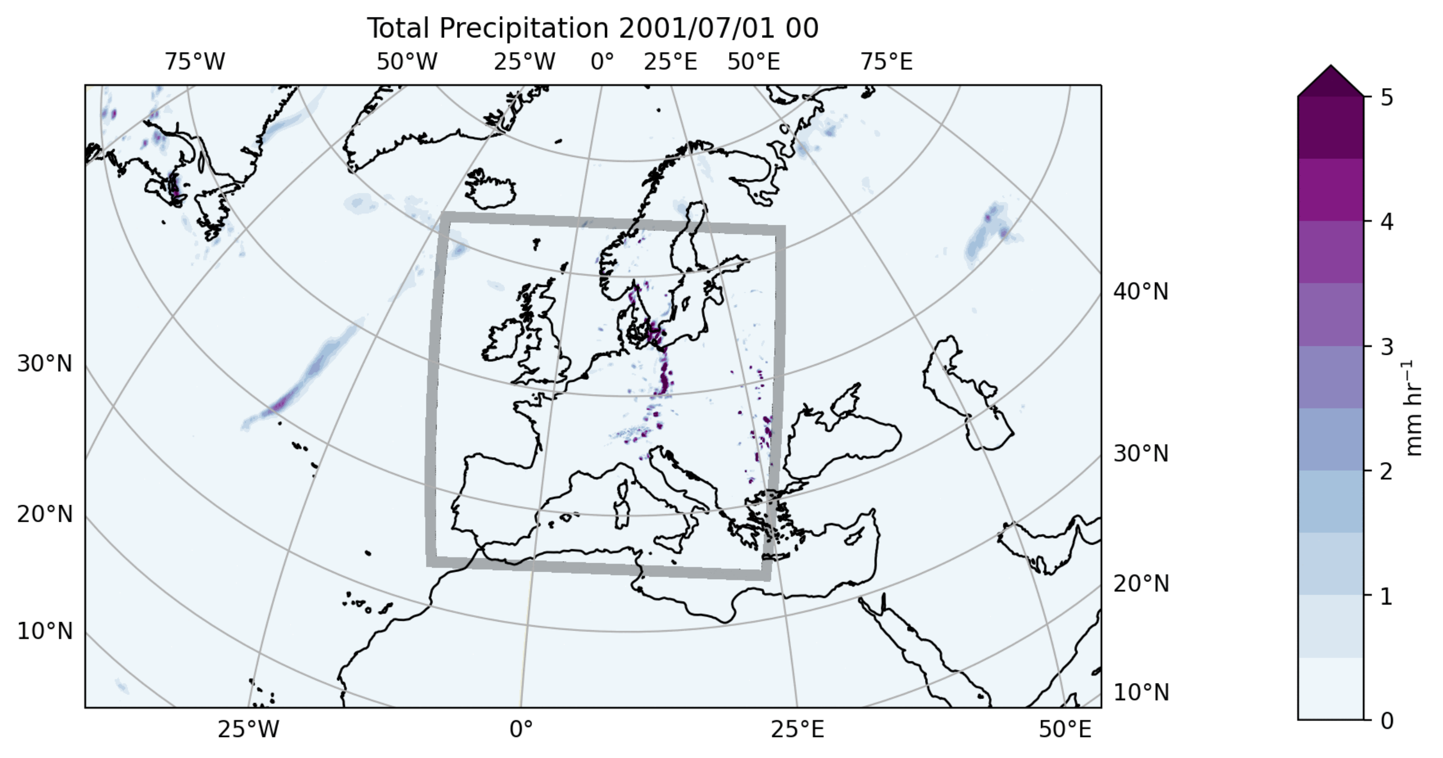


https://impetus4change.eu

Domain size for CP simulations



How to deal with the evaluation of the high resolution models?



RegCM5 EURR-3 CP simulation
How to evaluate the results

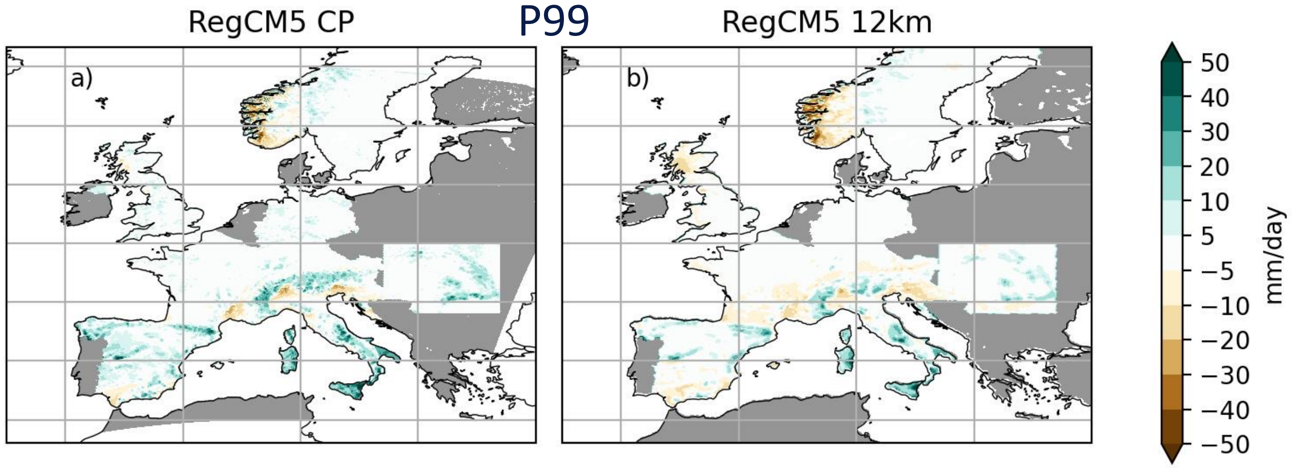
RADKLIM	Germany	PRECIP	Radar based (rain gauges calibration)	1 km	HOURLY	2001-2009	Kreklow et al. (2020)
SPAIN02	Spain	PRECIP	Station based	0.11 degrees	DAILY	1971-2010	Herrera et al. (2010)
CARPATCLIM	Carpatians	PRECIP	Station based	0.1 degrees	DAILY	1961-2010	Szalai et al. (2013)
ENG_REGR	Great Britain	PRECIP	Station based	5 km	DAILY	1990-2010	http://www.precisrcm.com/Erasmo/ncic.uk.11.tgz
COMEPHORE	France	PRECIP	Reanalysis based on radar and rain gauges	1 km	HOURLY	1997-2017	Tabary et al. (2012)
GRIPHO	Italy	PRECIP	Station based gridded dataset	3 km	HOURLY	2001-2016	Fantini (2019)
EURO4M	Alps	PRECIP	Station based gridded dataset	5 km	DAILY	1971-2008	Isotta et al. (2014a)
PTHBV	Sweden	PRECIP	Station based gridded dataset	4 km	DAILY	1961-2011	https://opendata-download-metanalys.smhi.se Johansson (2000)
METNO	Norway	PRECIP	Station based gridded dataset	1 km	DAILY	1980-2008	Mohr et al. (2009)
RdisaggH	Switzerland	PRECIP	Combination of rain-gauge data and radar measurements	1 km	HOURLY	2003-2010	Wüest et al. (2010)
CEH-GEAR	Great Britain	PRECIP	Rain-gauge based gridded dataset	1 km	HOURLY	1990-2016	Lewis et al. (2022)

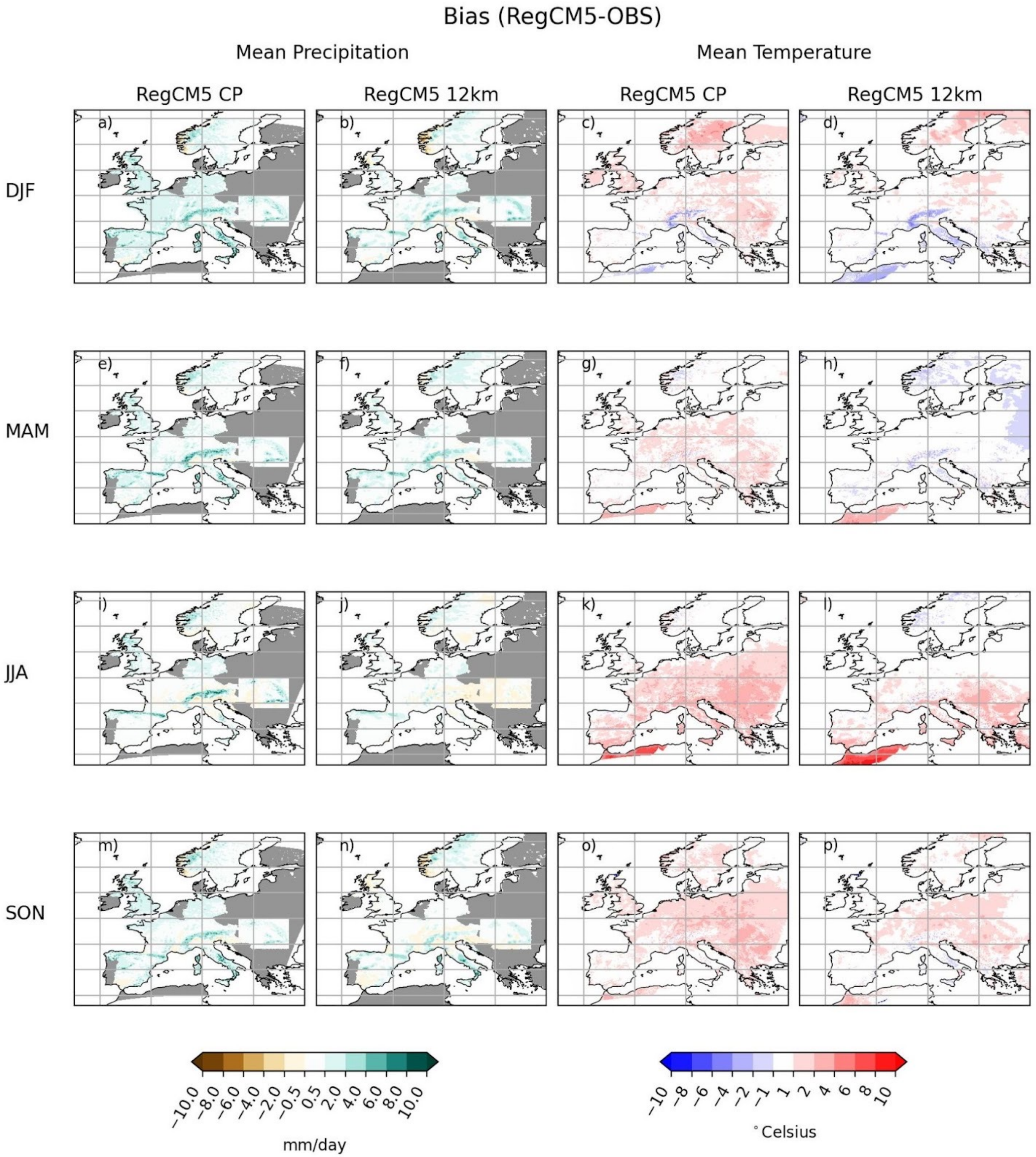
- To validate the results, you need to use observations.
- Parameters most investigated are **temperature** and **precipitation**
- The higher the resolution of the model, the more detailed observations are needed for the evaluation.
- Model output: hourly at 3km resolution
- **What observations are available?**

RegCM5 CP simulation
Latest results

Evaluation simulation results (2000-2009):

- Mean **daily** precipitation compares well with observations for all seasons. General results between the two datasets is similar for **mean precipitation, precipitation frequency and P99**

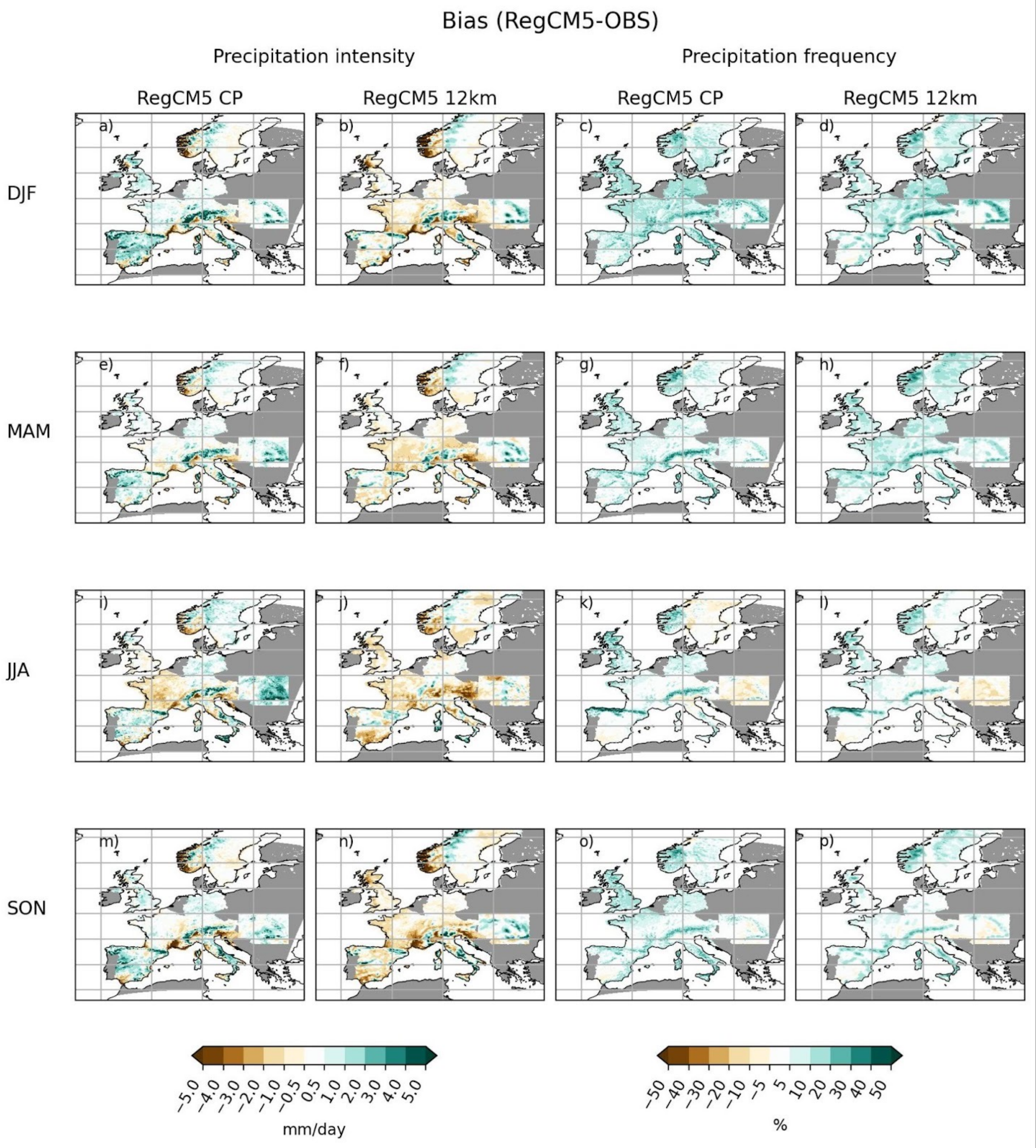




RegCM5 CP simulation
Latest results

Evaluation simulation results (2000-2009):

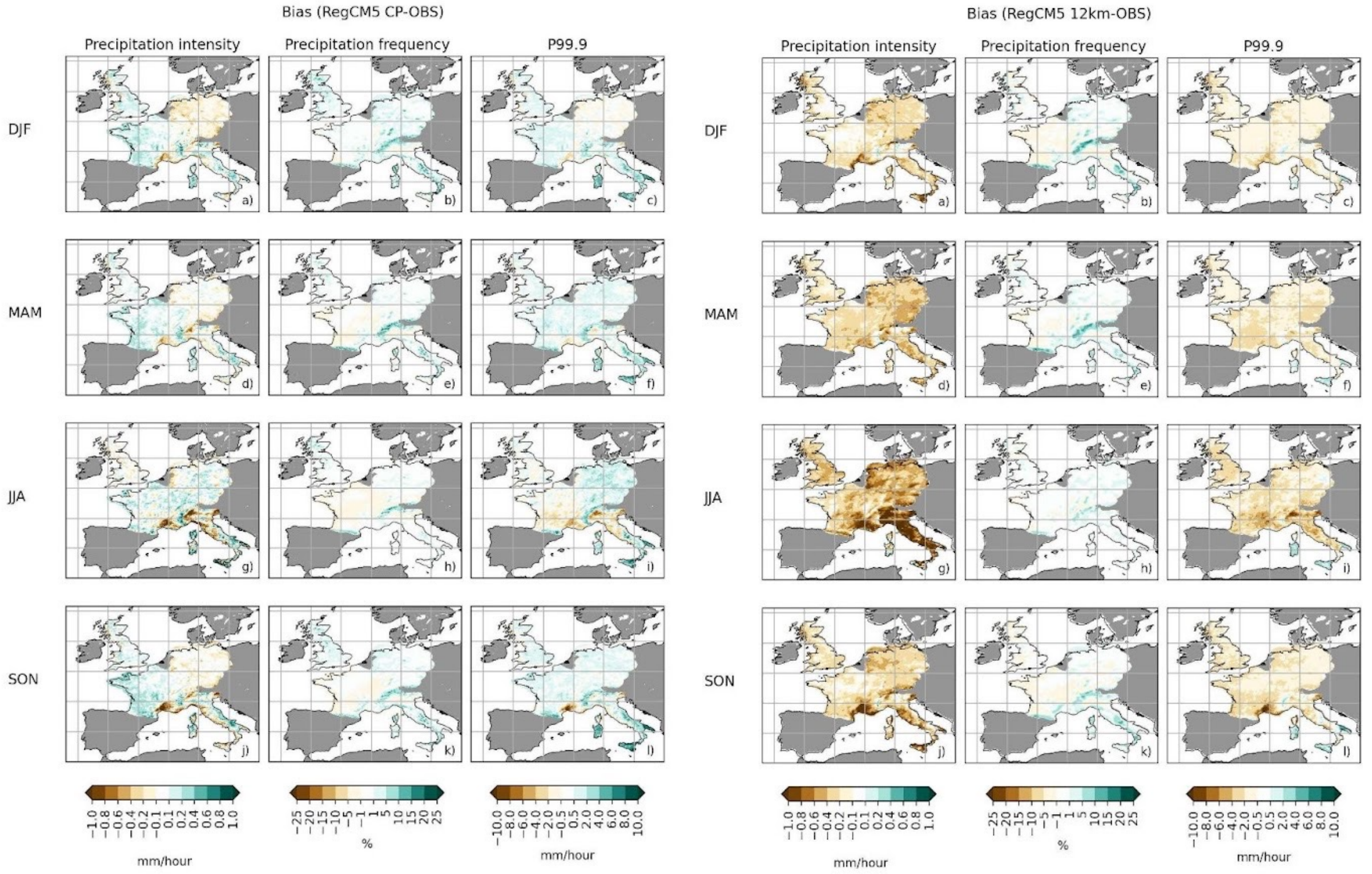
- Clear improvement in the **daily** precipitation intensity signal



RegCM5 CP simulation
Latest results

First evaluation simulation results (2000-2009):

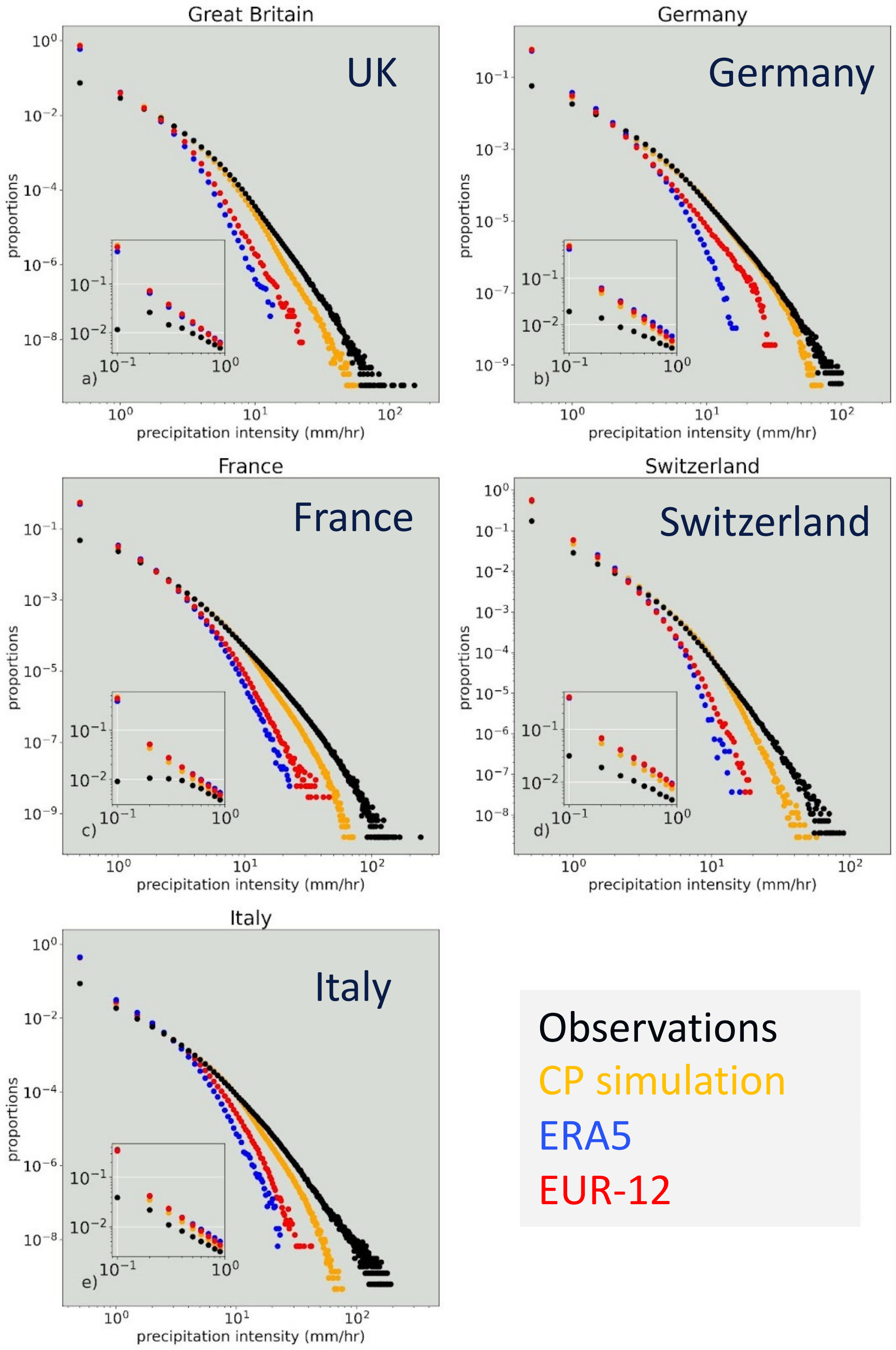
- **Hourly** Precipitation intensity, frequency and P99 compare well with high resolution observations over Europe for all seasons.
- Results are generally better than for the EUR-12 simulation (12km)



RegCM5 CP simulation
Latest results

First evaluation simulation results (2000-2009):

- Extreme **hourly** precipitation events are captured well by the simulation, as shown by the good comparison between the simulated precipitation PDF (orange points) and the hourly precipitation observations (black points) for 5 regions selected in the EURR-3 domain.

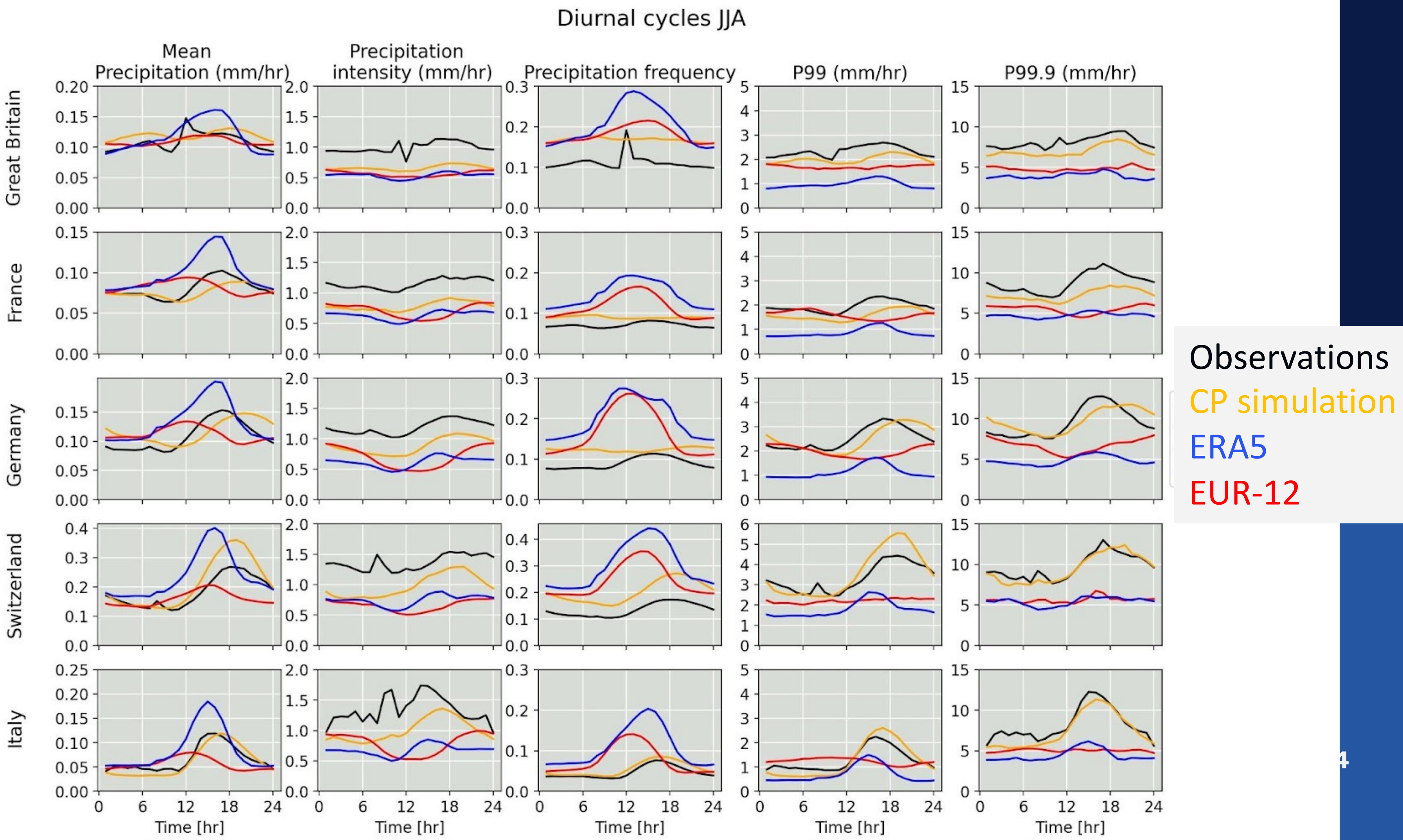


RegCM5 CP simulation

Latest results

First evaluation simulation results (2000-2009):

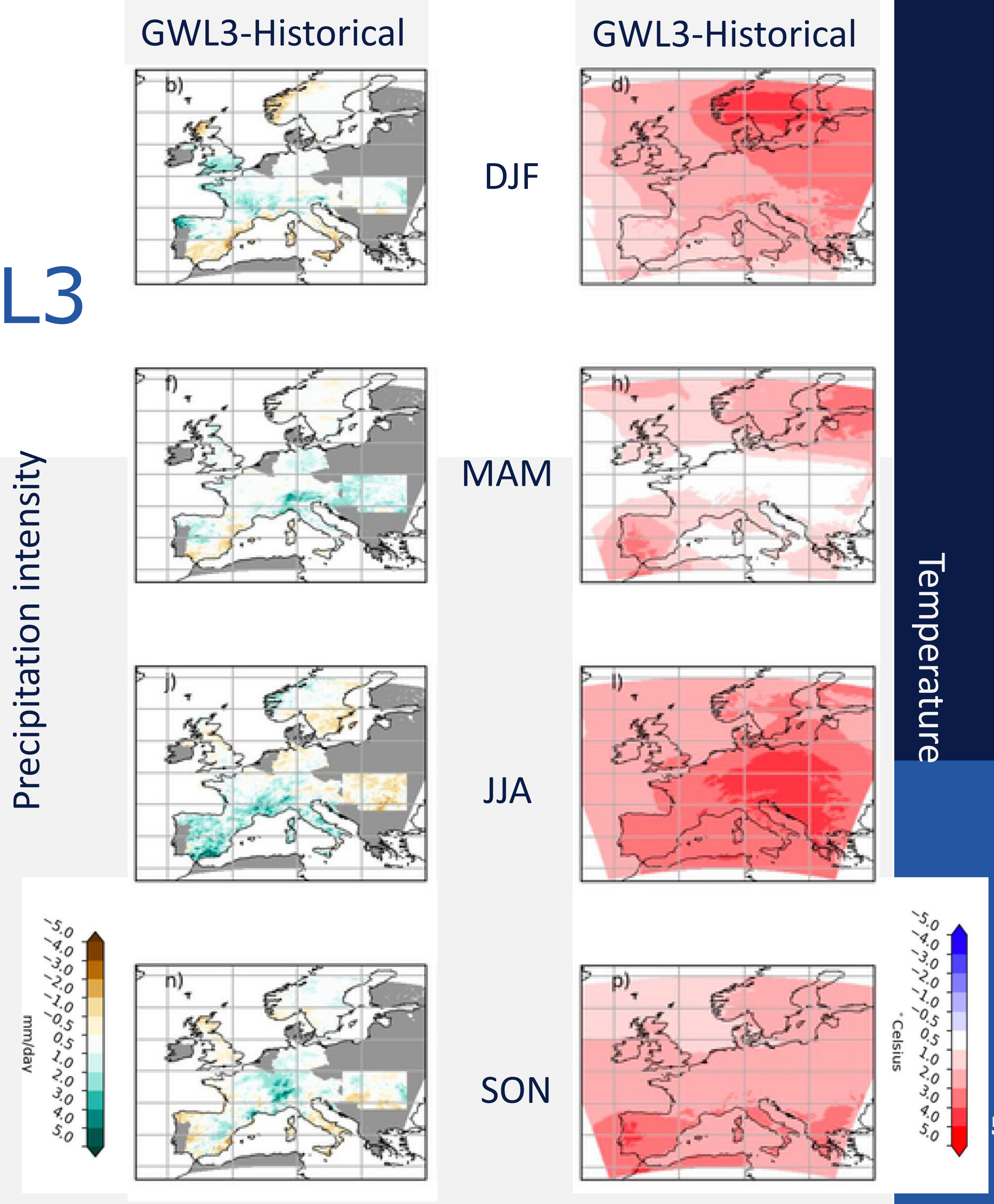
- Better representation of the diurnal cycle of precipitation variables



RegCM5 CP simulation
Latest results for the GWL3

Simulation results for future climate scenarios.

Seasonal differences in daily precipitation intensity and surface temperature between the historical simulation (1995-2014) and the GWL3 simulation (2048-2062)

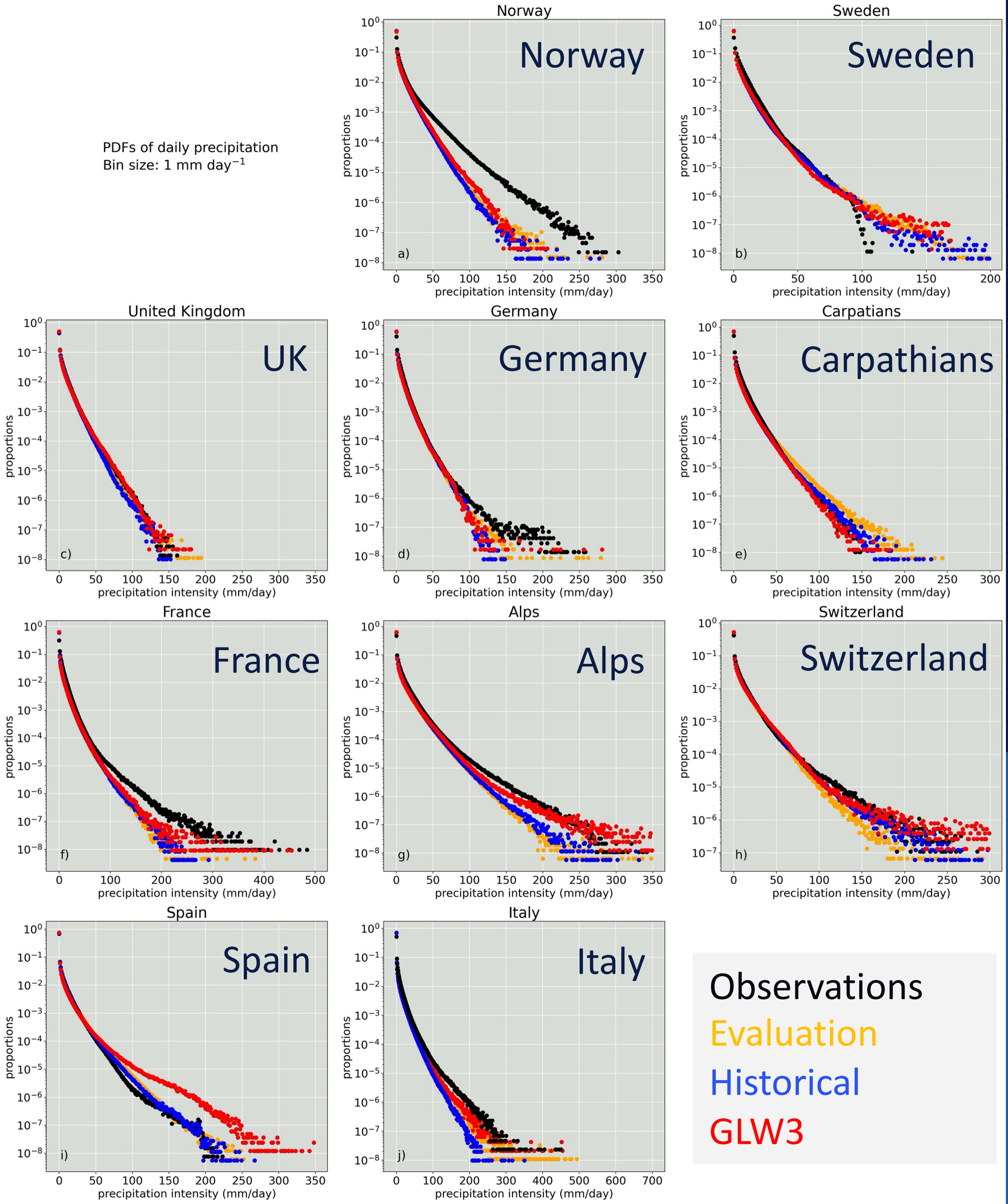


RegCM5 CP simulation
Latest results for the GWL3

Simulation results for future climate scenarios

Daily precipitation PDFs for 10 regions within the simulated domain for:

1) Observations (2000-2009)
2) Evaluation period (2000-2009)
3) Historical simulation (1995-2005)
4) GLW3 scenario (2048-2057)



Thank you

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