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Descripción y análisis de técnicas de regionalización estadística para la proyección local de extremos

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UNIVERSIDAD DE CANTABRIA
CSIC

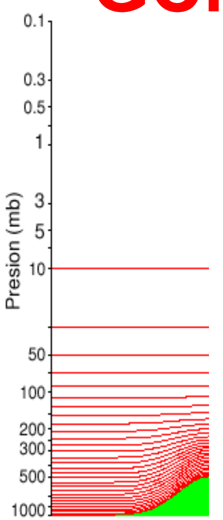
VALUE

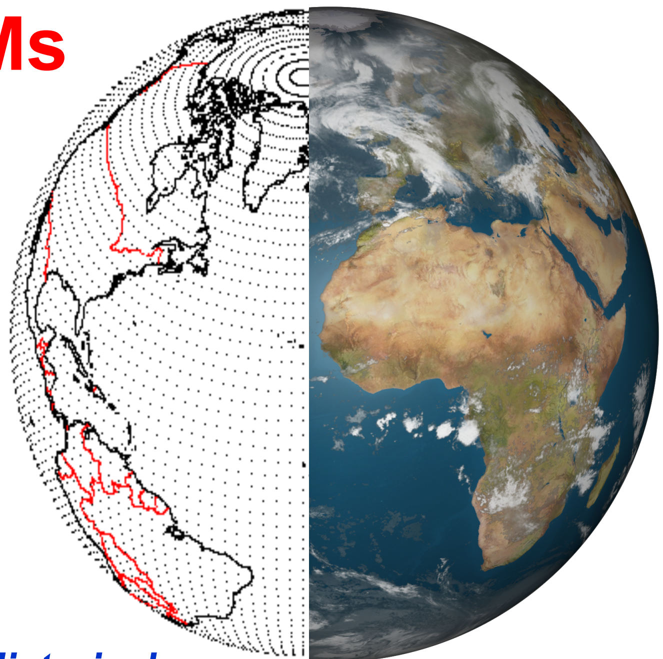
WCRP
World Climate Research Programme
CORDEX

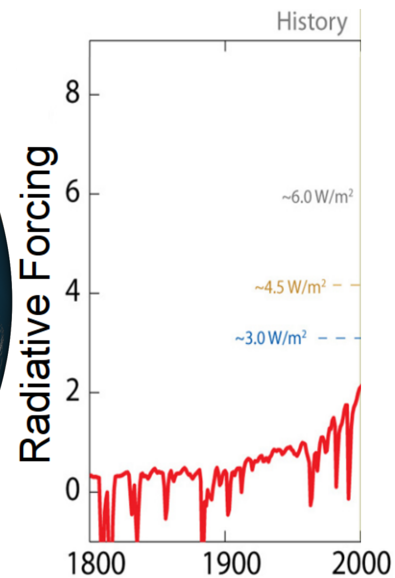
TALLER SOBRE INUNDACIONES Y CAMBIO CLIMÁTICO. Madrid, 21/6/2017

Global Climate Models (GCMs)

GCMs







Equations of conservation (mass,momentum,energy,water vapour) and gas state

$\boldsymbol{v}$ = (u, v, w), T, p, $\rho = 1/\alpha$ and q

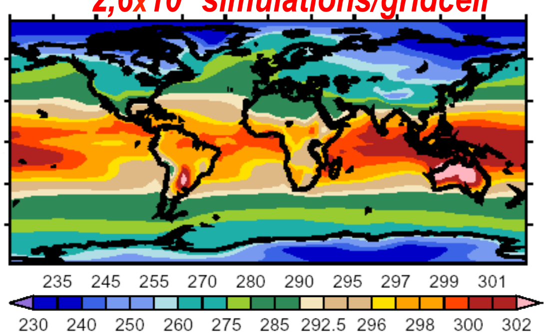
$$\left\{\begin{aligned} \frac{d\boldsymbol{v}}{dt} &= -\alpha\nabla p - \nabla\phi + \boldsymbol{F} - 2\boldsymbol{\Omega}\times\boldsymbol{v} \\ \frac{\partial\rho}{\partial t} &= -\nabla\cdot(\rho\,\boldsymbol{v}) \\ p\,\alpha &= RT \\ Q &= C_p\frac{dT}{dt} - \alpha\frac{dp}{dt} \\ \frac{\partial\rho\,q}{\partial t} &= -\nabla\cdot(\rho\,\boldsymbol{v}\,q) + \rho\,(E-C) \end{aligned}\right.$$

Historical simulations

1980	1990	2000

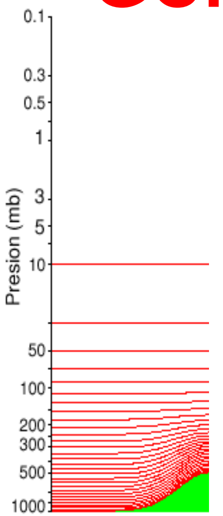
1h integration step x 30 years

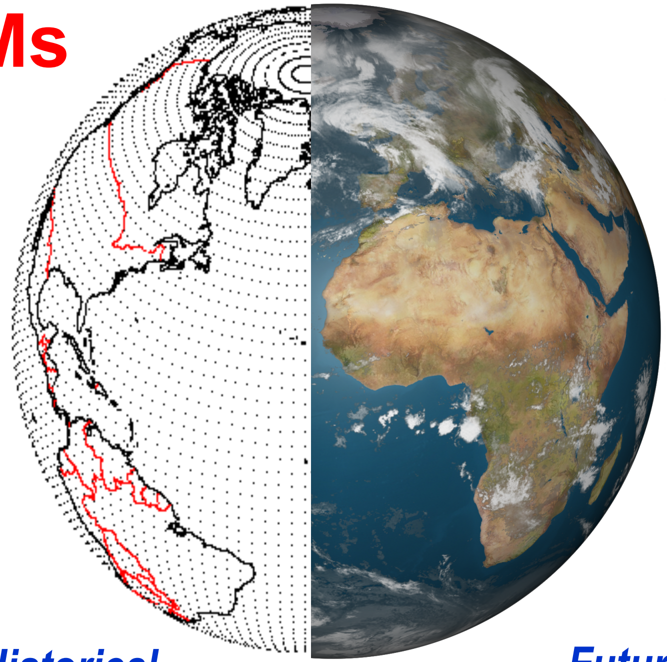
2,6x10⁵ simulations/gridcell

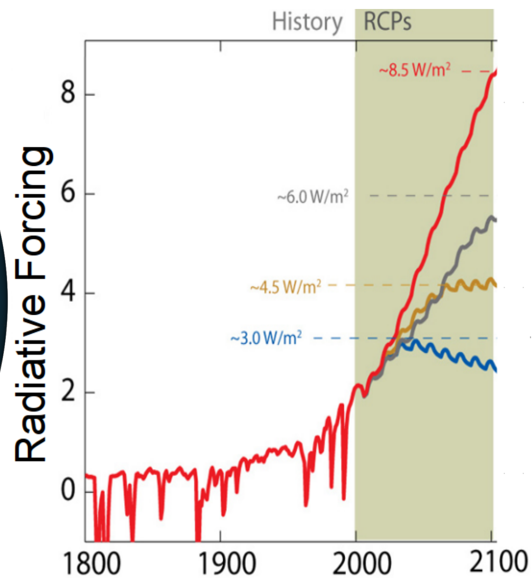


Global Climate Models (GCMs)

GCMs







Equations of conservation (mass,momentum,energy,water vapour) and gas state

$\boldsymbol{v} = (u, v, w), T, p, \rho = 1/\alpha$ and q

$$
\left\{
\begin{aligned}
\frac{d\boldsymbol{v}}{dt} &= -\alpha\nabla p - \nabla\phi + \boldsymbol{F} - 2\boldsymbol{\Omega}\times\boldsymbol{v} \\
\frac{\partial\rho}{\partial t} &= -\nabla\cdot(\rho\,\boldsymbol{v}) \\
p\,\alpha &= RT \\
Q &= C_p\frac{dT}{dt} - \alpha\frac{dp}{dt} \\
\frac{\partial\rho\,q}{\partial t} &= -\nabla\cdot(\rho\,\boldsymbol{v}\,q) + \rho\,(E - C)
\end{aligned}
\right.
$$

Historical simulations

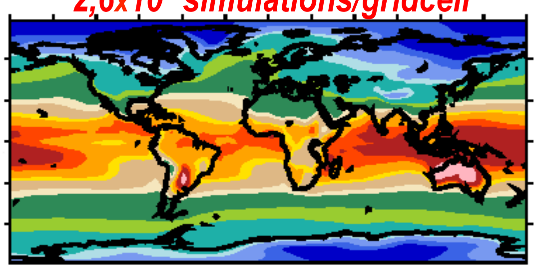
1980	1990	2000

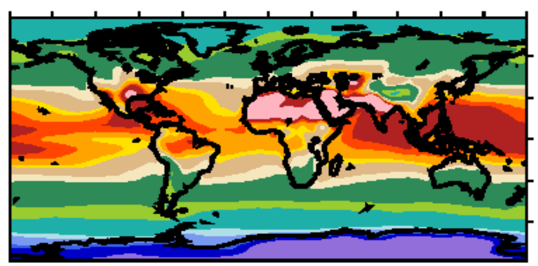
Future projections (scenarios)

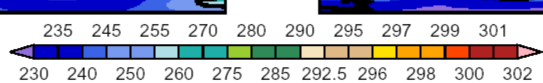
2010	2020	2030	2040	2050	2060	2070	2080	2090

1h step x 30 years

2,6x10^5 simulations/gridcell





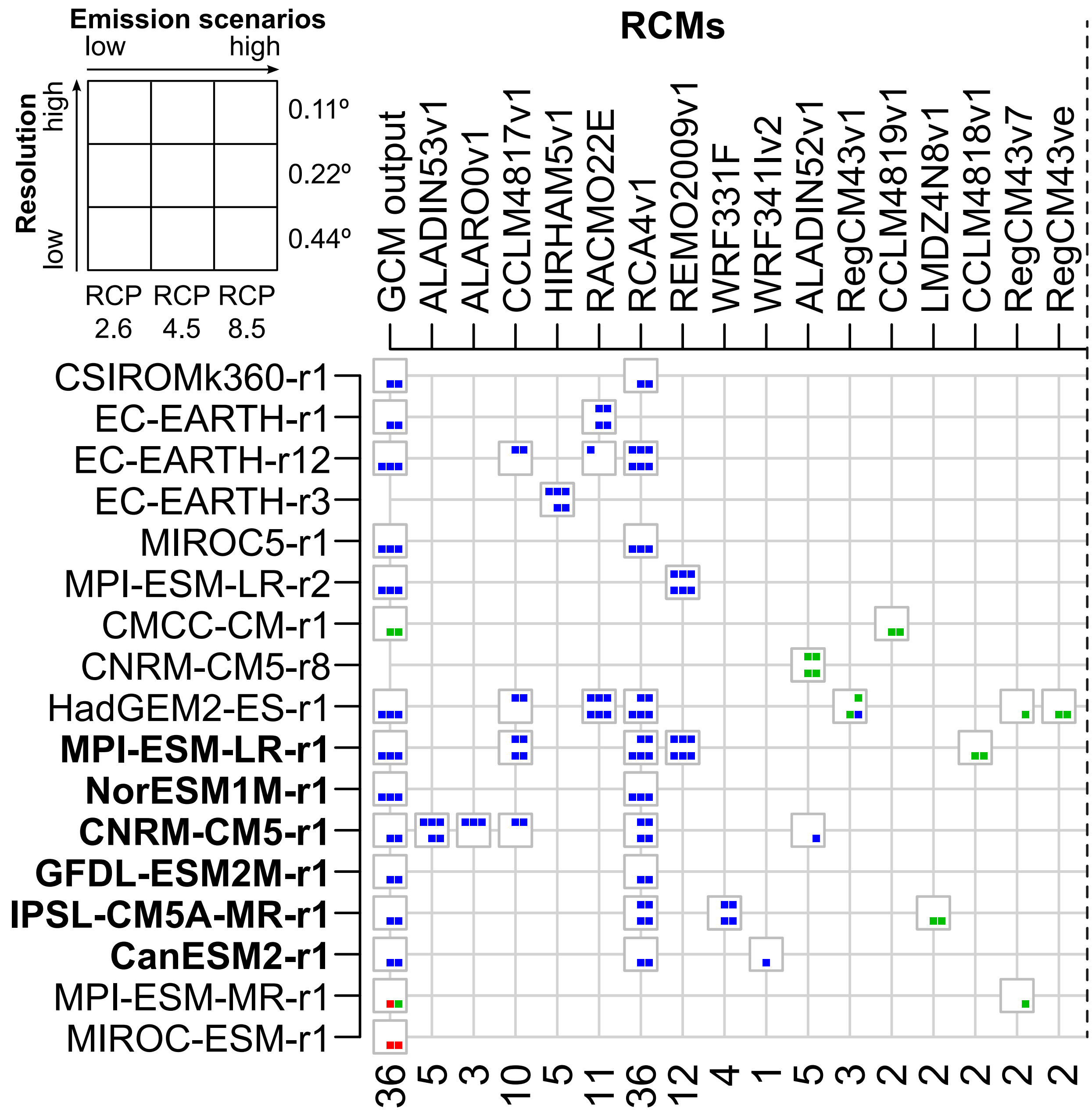


Computational (and physical) constraints limit the resolution (~100-200 Km)

Regional Climate Models (RCMs)

Euro-CORDEX is the last of a series of international initiatives for regional climate change projection over Europe.

- **0.11º** and **0.44º** resolution.



Jaccob, D. et al. 2014. EURO-CORDEX: new high-resolution climate change projections for European impact research. Regional Environmental Change, 4, 563-578.

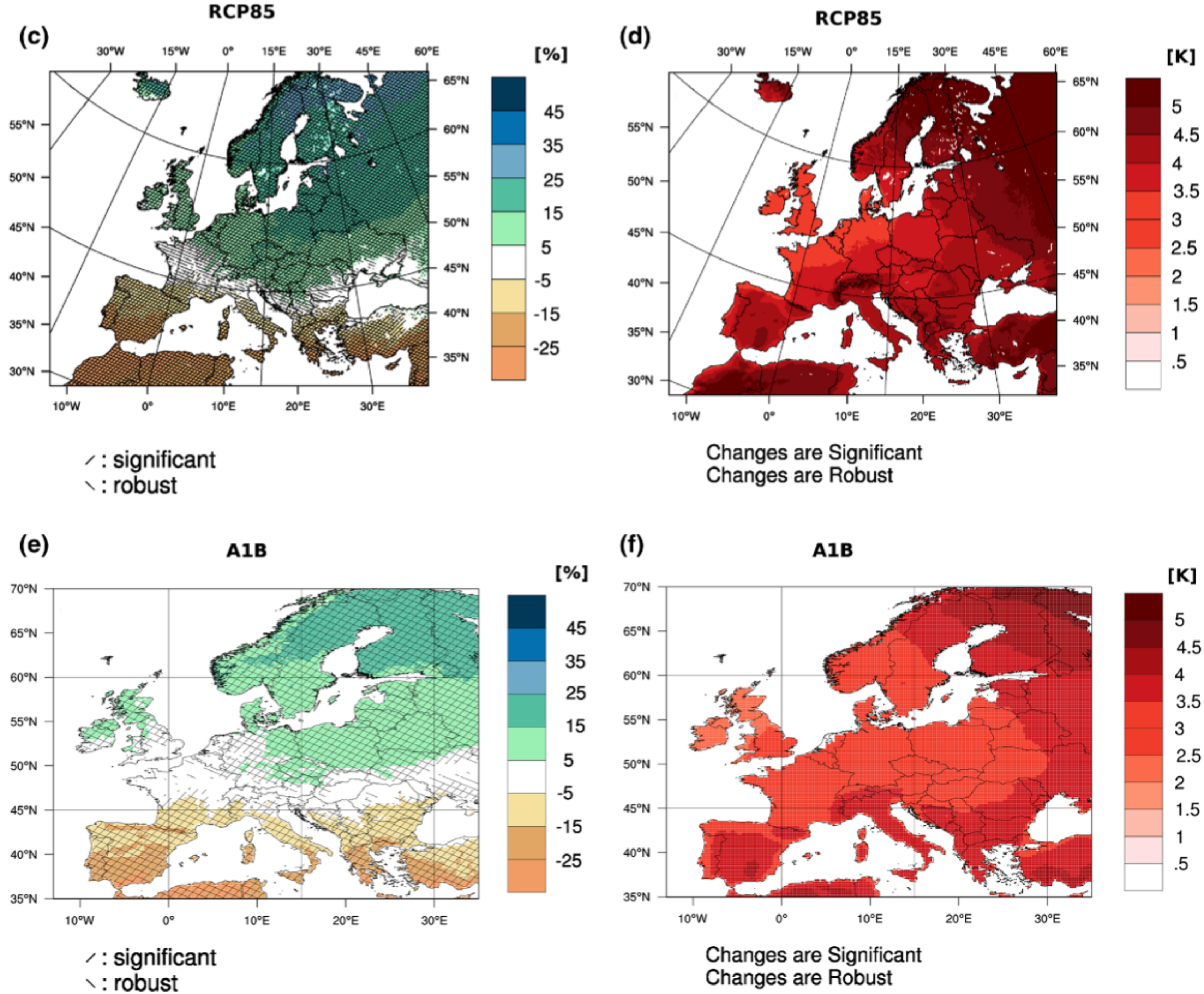


Fig. 1 Projected changes of total annual precipitation (%) (*left*) and annual mean temperature [K] (*right*) for 2071–2100 compared to 1971–2000, for A1B (**e**, **f**), RCP8.5 (**c**, **d**) and RCP4.5 (**a**, **b**) scenarios. *Hatched areas* indicate regions with robust and/or statistical significant change (**a**, **c**, **e**). Changes are robust and significant across the entire European continent (**b**, **d**, **f**)

"Heavy precipitation" is defined as the intensity of the heavy precipitation events defined as the 95th percentile of daily precipitation (only days with precipitation >1 mm/day are considered).

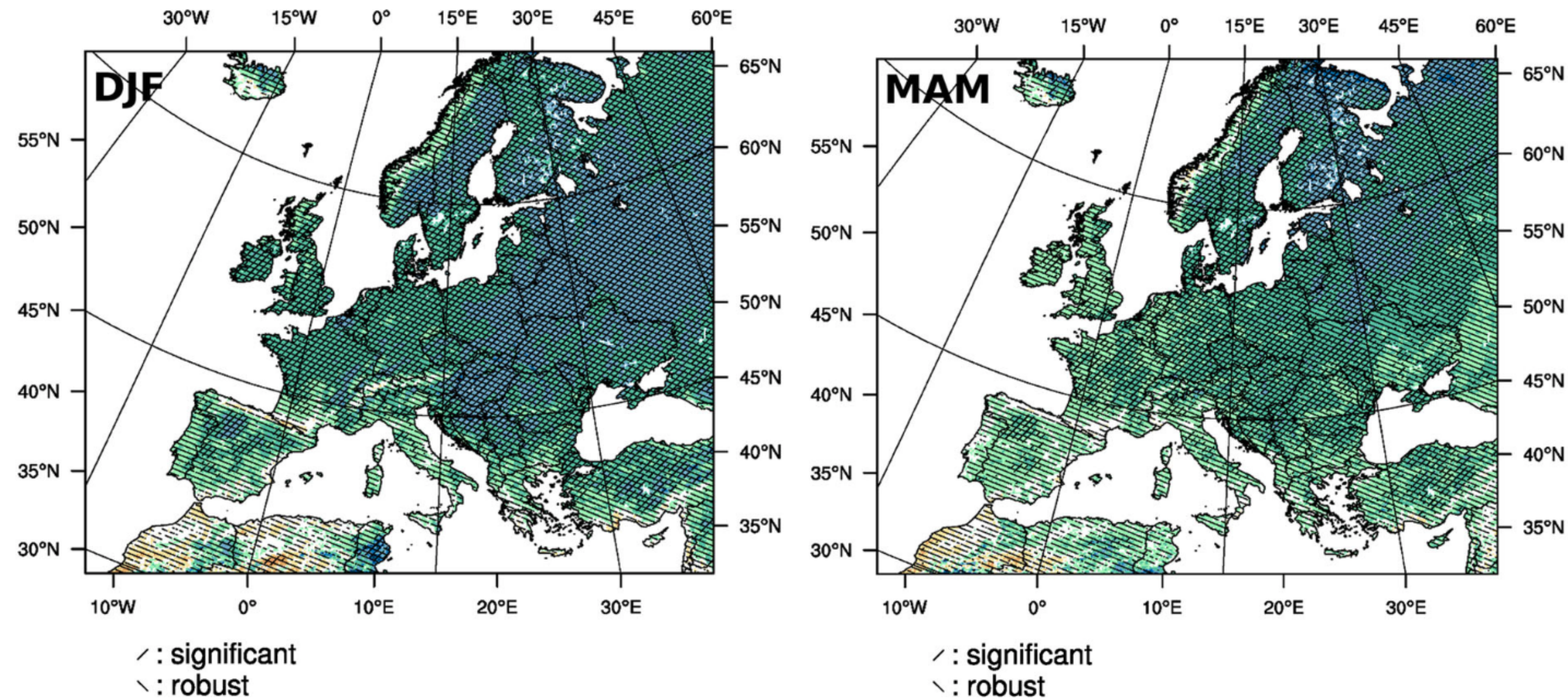
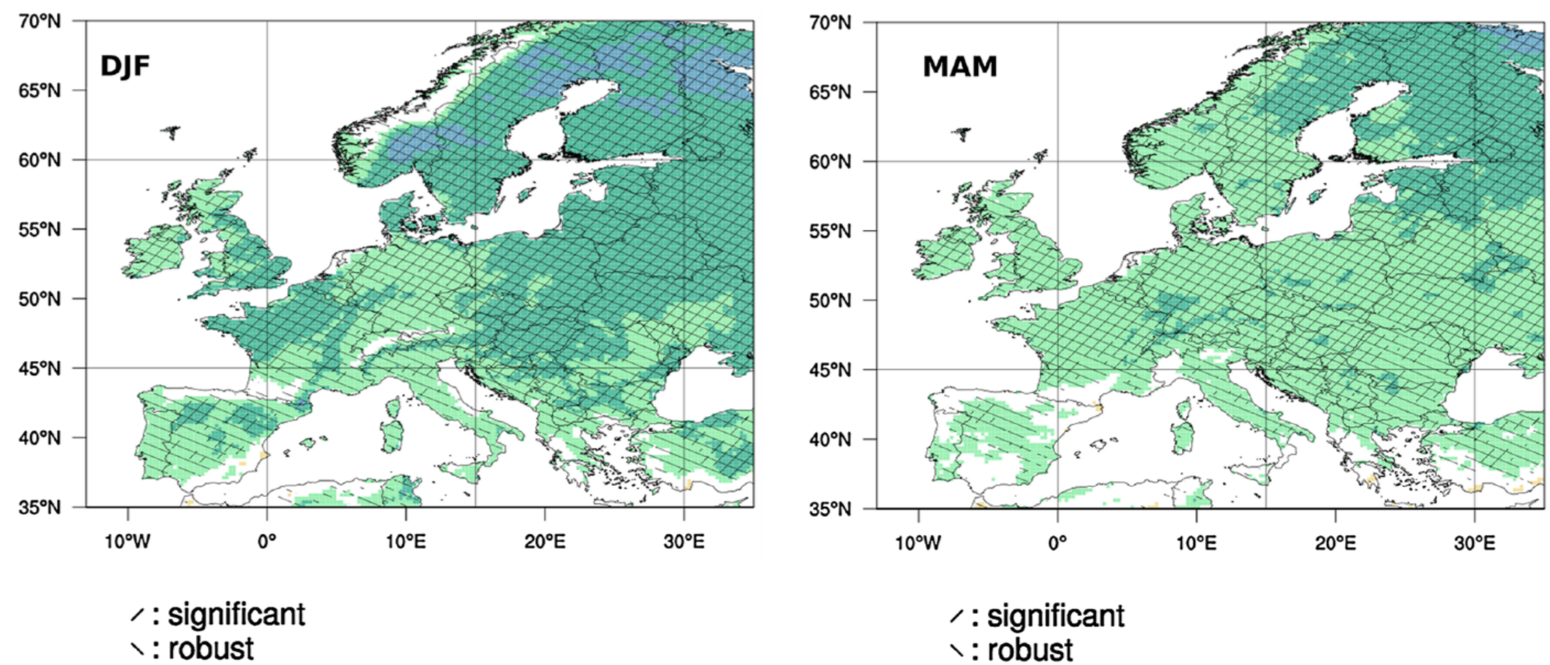
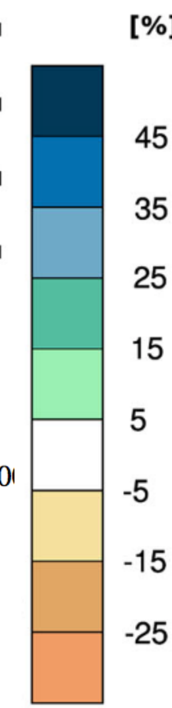
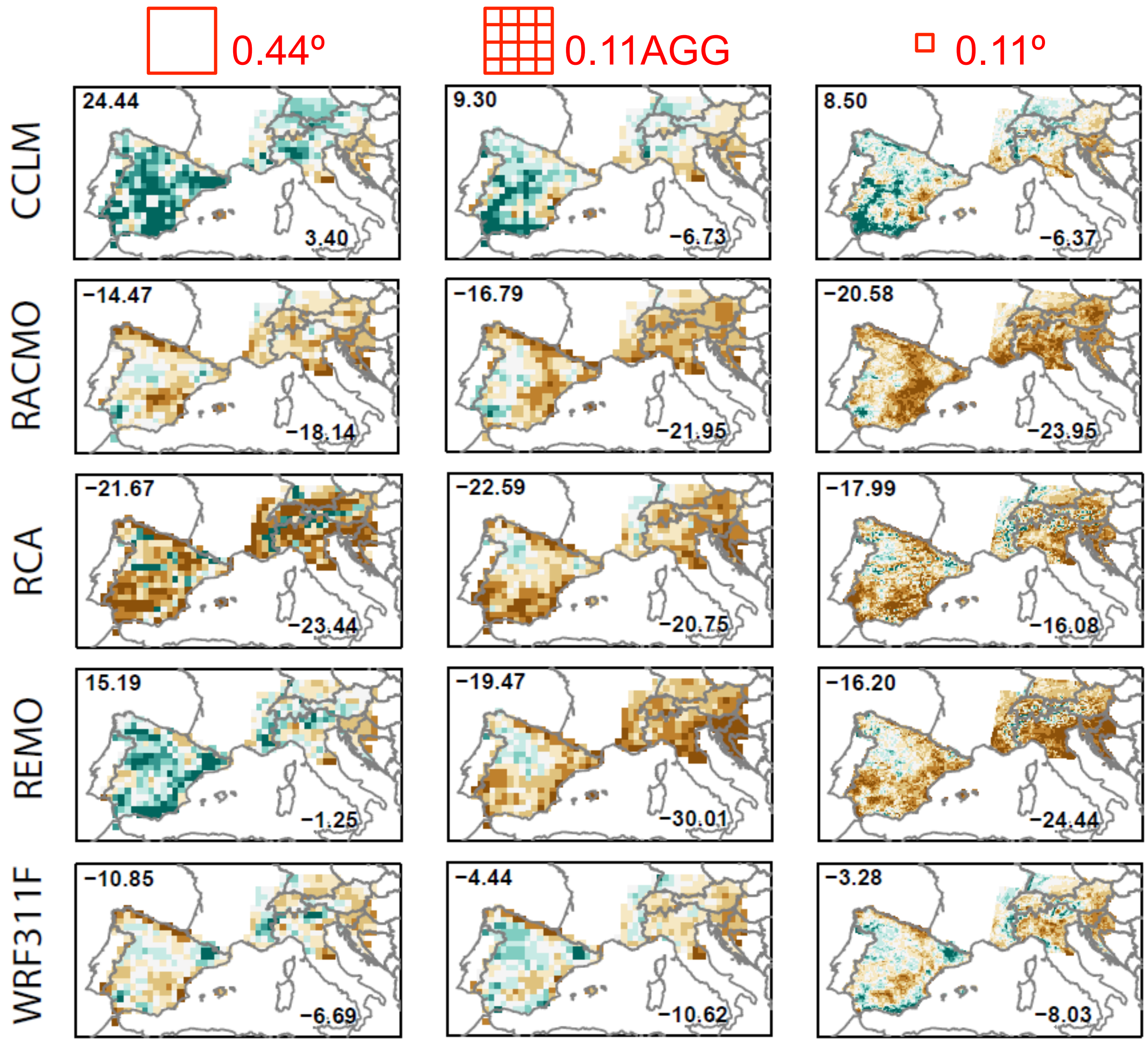


Fig. 2 Projected seasonal changes of heavy precipitation (%) based on the RCP8.5 scenario for 2071–2100 compared to 1971–200





EURO-CORDEX

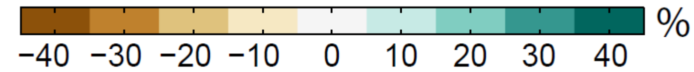


Important biases at both resolutions in SDII and RR1.

Hi-res 0.11º Euro-CORDEX simulations took ~100x the computing power of the standard 0.44º CORDEX resolution.

Where should we look for added value in hi-res simulations?

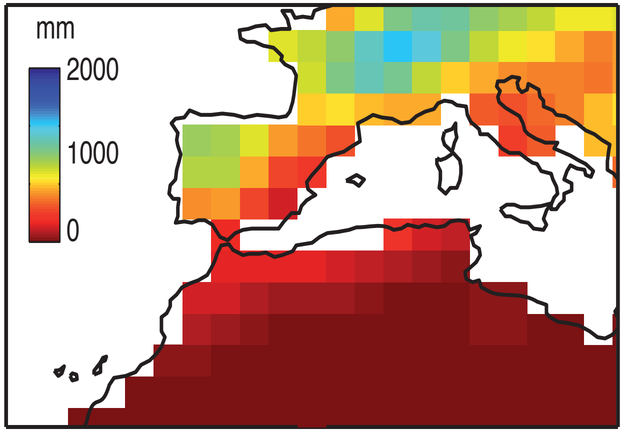
JJA SDII relative bias



Casanueva et al. (2015) "Daily pr statistics in the EURO-CORDEX … ", Cliimate Dynamics.

Downscaling

MODEL SPACE



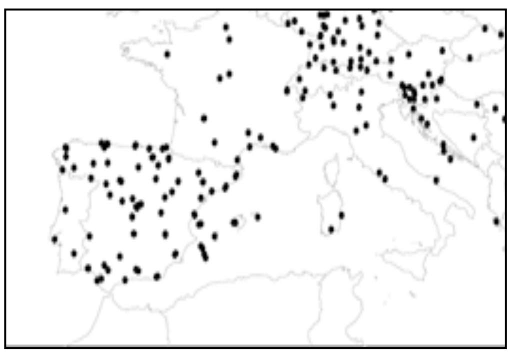
GCM outputs (**~200 km**)

Variables	Description	Units
tas	2-meter temperature	K
tasmax	Daily maximum 2-m temperature	K
tasmin	Daily minimum 2-m temperature	K
wss	10-meter wind speed	m/s
huss	2-meter specific humidity	Kg/kg
hurs	2-meter relative humidity	%
tdps	2-meter dew point temperature	K
psl	Mean sea level pressure	Pa
pr	Precipitation	Mm
evspsbl	Evaporation	Mm
evspsblpot	Potential Evapotranspiration	Mm
rss	Net SW surface radiation	W/m^2
rls	Net LW surface radiation	W/m^2
rsds	Downward SW surface radiation	W/m^2
rlds	Downward LW surface radiation	W/m^2

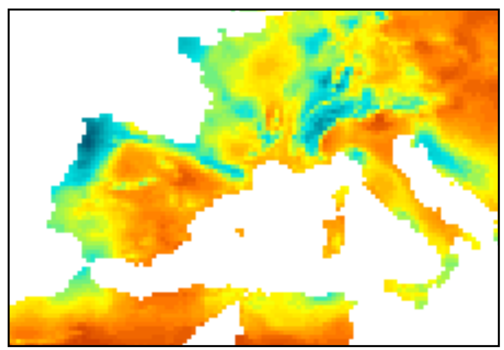
MODEL BIASES

RESOLUTION

REAL WORLD



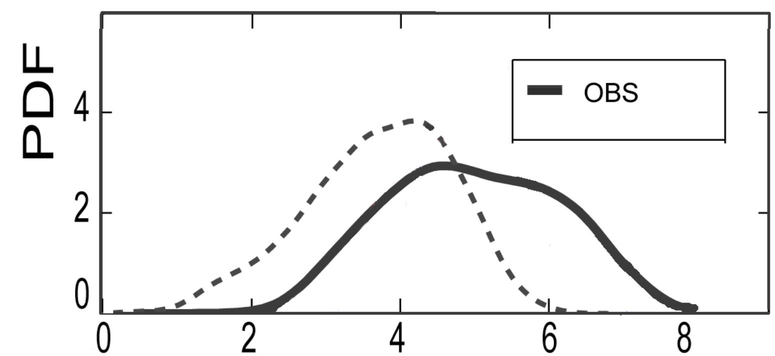
Local data (**points**)



Gridded data (**~10 km**)

[subdaily, daily temporal scale]

– Hydrology - Energy
– Agriculture - Health



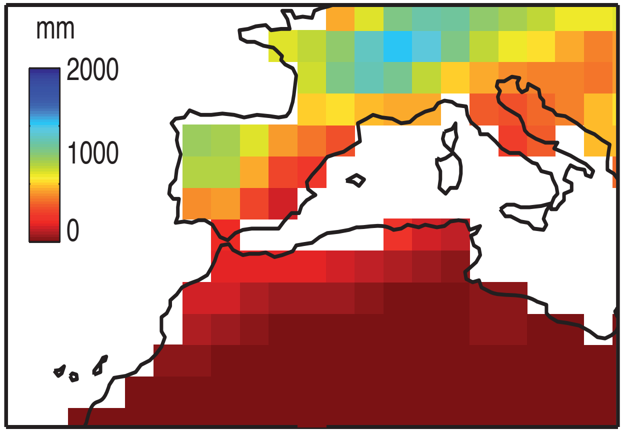
Models exhibit biases when compared with observations:

1. Systematic model biases

2. Different resolutions

Delta method (change factors)

MODEL SPACE



GCM outputs (**~200 km**)

Variables	Description	Units
tas	2-meter temperature	K
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huss	2-meter specific humidity	Kg/kg
hurs	2-meter relative humidity	%
tdps	2-meter dew point temperature	K
psl	Mean sea level pressure	Pa
pr	Precipitation	Mm
evspsbl	Evaporation	Mm
evspsblpot	Potential Evapotranspiration	Mm
rss	Net SW surface radiation	W/m^2
rls	Net LW surface radiation	W/m^2
rsds	Downward SW surface radiation	W/m^2
rlds	Downward LW surface radiation	W/m^2

MODEL BIASES

RESOLUTION

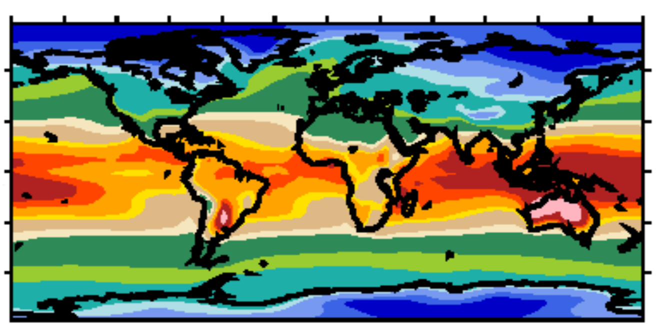
Historical simulations

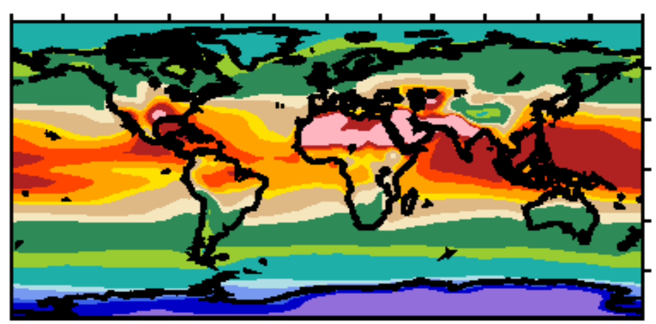
1980 | 1990 | 2000

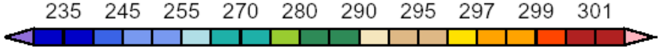
Future projections (scenarios)

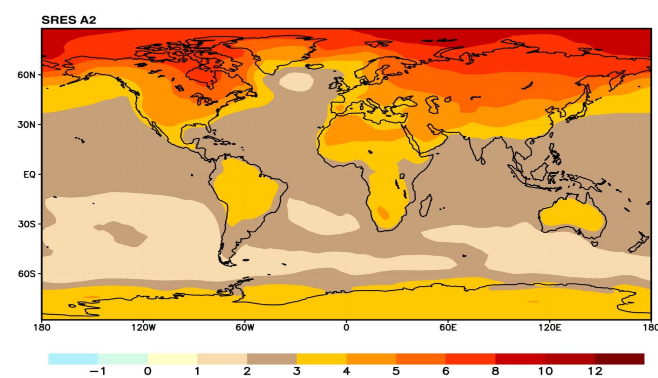
2010 | 2020 | 2030 | 2040 | 2050 | 2060 | 2070 | 2080 | 2090

"delta" method
Warming signal
2070-2100 – 1970-2000



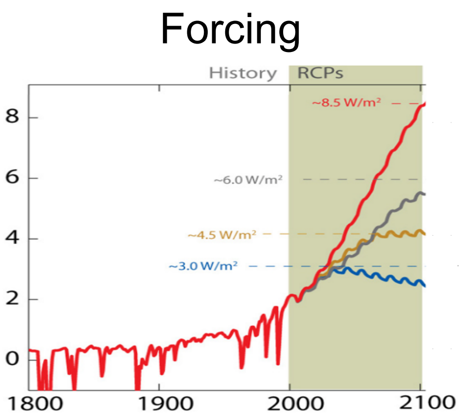


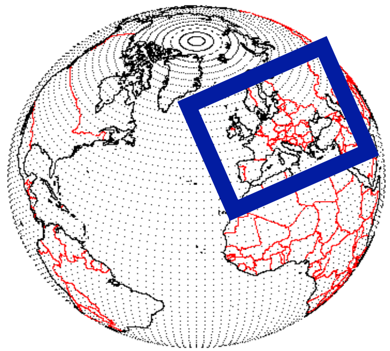


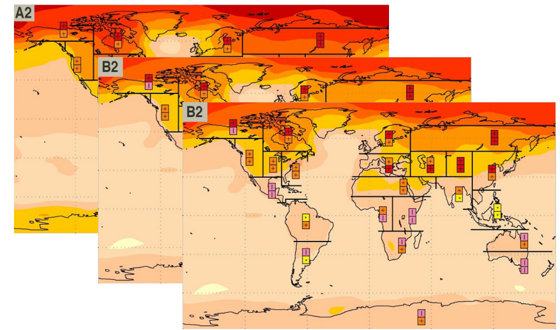


Statistical Downscaling (SDM)

GCMs

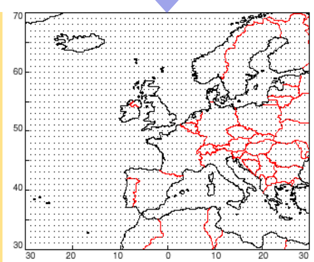


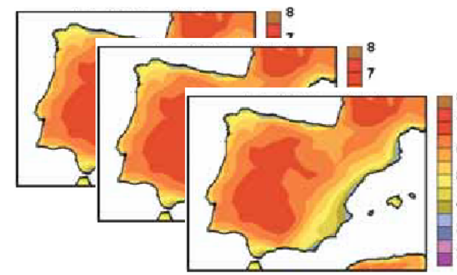




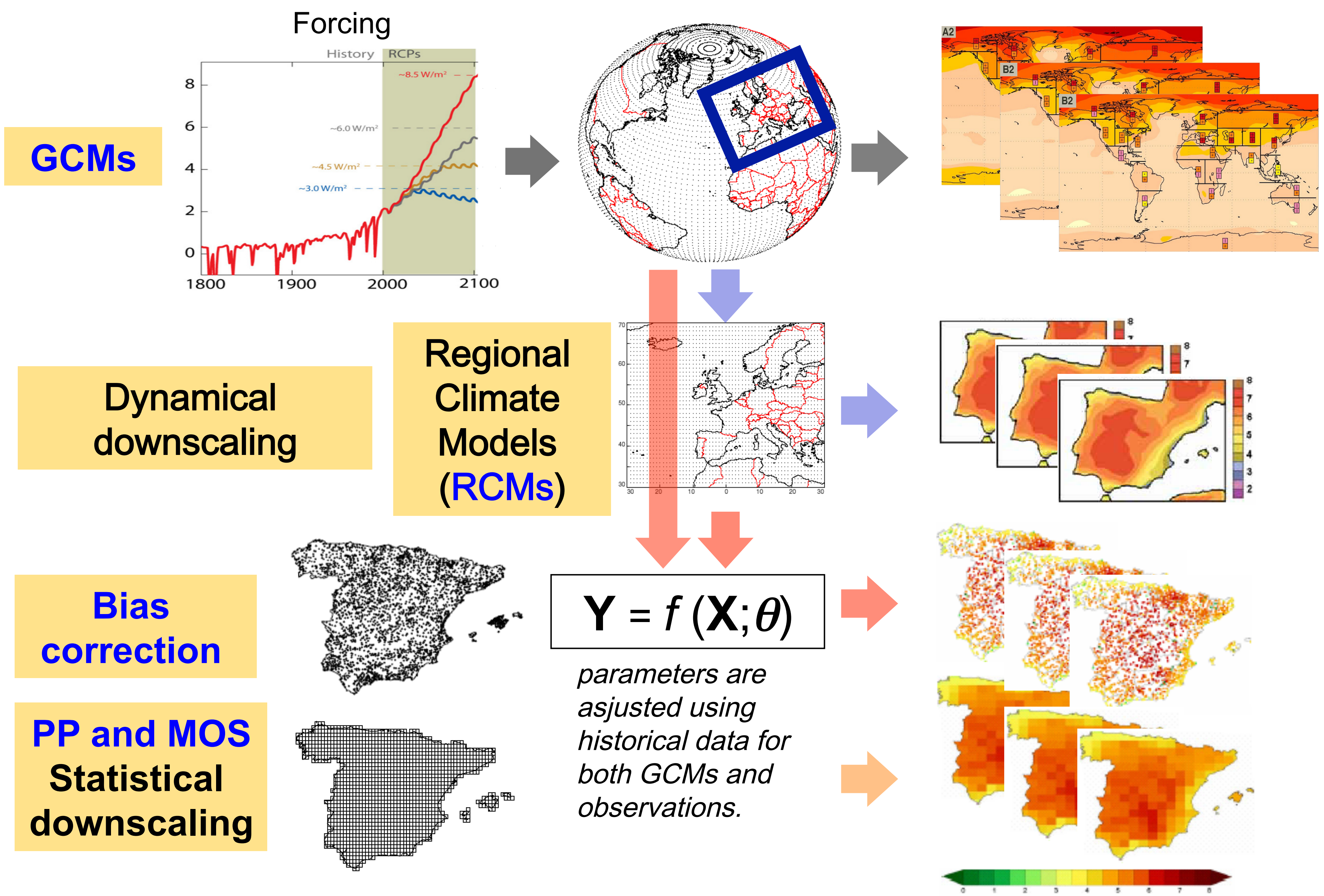
Dynamical downscaling

Regional Climate Models (RCMs)





Statistical Downscaling (SDM)



- **Model Output Statistics (MOS):** The model is trained using observations and GCM outputs (which include biases/errors).

BIASES

RESOLUTION

$$\mathbf{precip}_{\mathbf{obs}}[d] = \mathbf{f}\,(\mathbf{precip}_{\mathbf{gcm}}[d])$$

First introduced in weather forecast (Glahn and Lowry, 1972),
but problematic for climate projection.

Approaches: MOS & PP

- **Model Output Statistics (MOS):** The model is trained using observations and GCM outputs (which include biases/errors).

$$\mathbf{precip_{obs}}[d] = \mathbf{f}\ (\mathbf{precip_{gcm}}[d])$$

First introduced in weather forecast (Glahn and Lowry, 1972),
but problematic for climate projection.

BIASES

RESOLUTION

Adapted for climate projection under the name **"bias-correction"** in a PDF-wise approach:

$$\mathbf{PDF(precip_{obs})} = \mathbf{F}\ (\mathbf{PDF(precip_{gcm})})$$

BIASES

RCMs

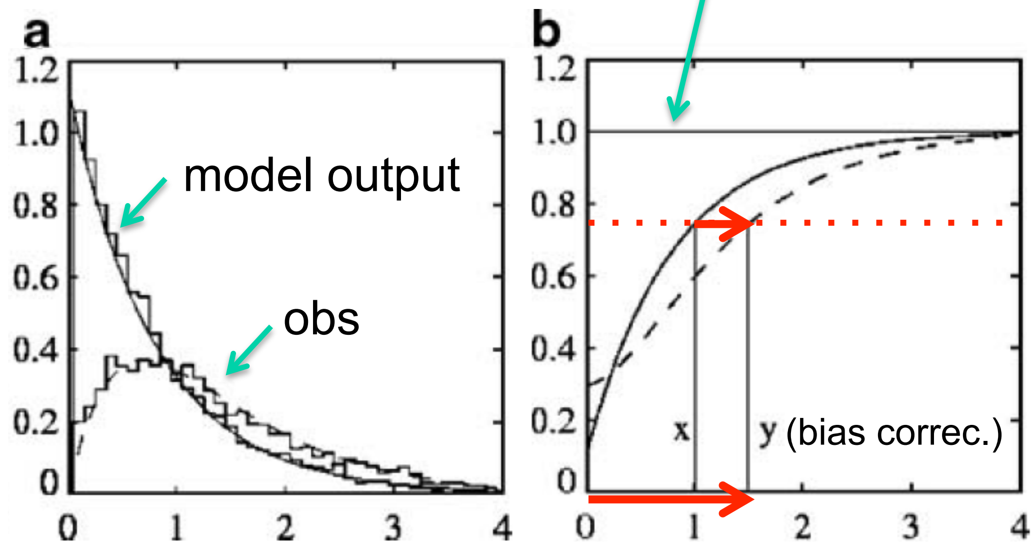
Bias correction: QQ Mapping

Fig. 1 Statistical correction applied to a synthetic dataset. **a** Synthetic pdf of simulated daily precipitation (*solid line*), synthetic pdf of observed daily precipitation (*dashed line*). **b** cdfs obtained by integrating the corresponding pdfs in **a**. **c** Transfer function obtained graphically from **b** by solving: $cdf_{obs}(y)=cdf_{sim}(x)$ (*thick solid line*). **d**

Source Piani et al. 2010

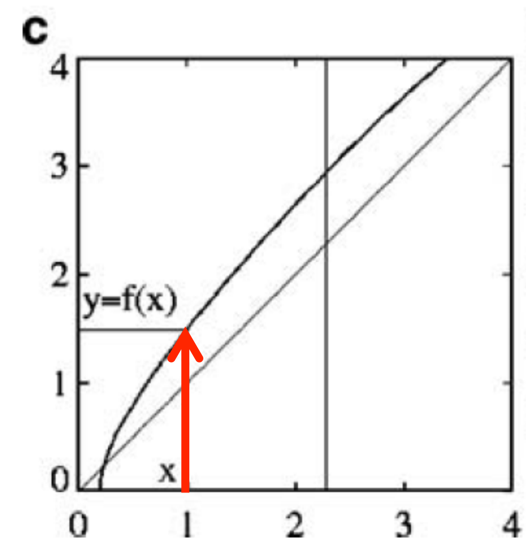
$$cdf(x) = \int_0^x \frac{e^{\left(-\frac{x}{\theta}\right)} x'^{(k-1)}}{\Gamma(k)\theta^k} dx' + cdf(0)$$

$$pdf(x) = \frac{e^{\left(-\frac{x}{\theta}\right)} x^{(k-1)}}{\Gamma(k)\theta^k}$$



Requires a "reference" PDF !!!!

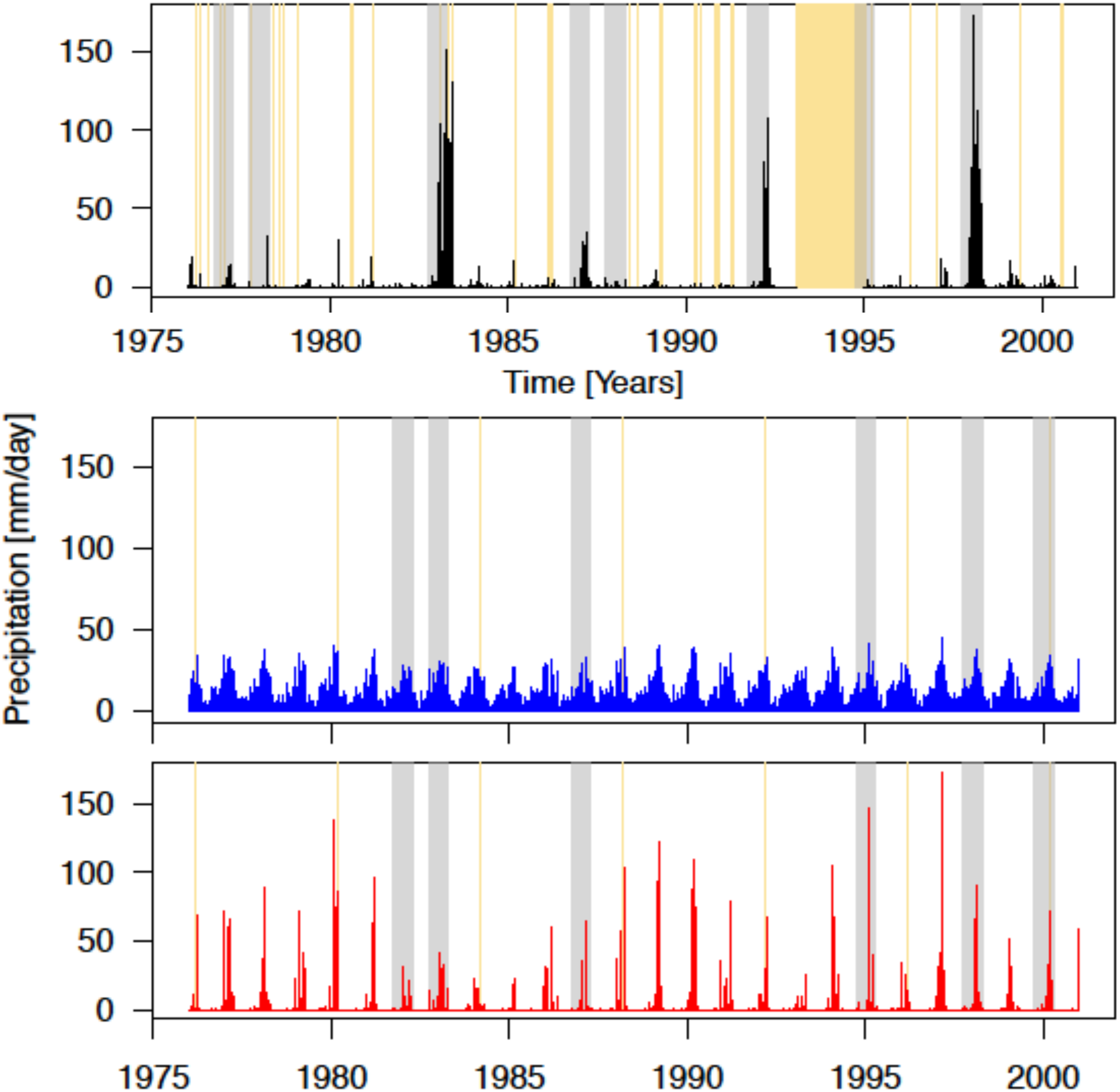
$$cdf_{obs}(f(x))=cdf_{sim}(x)$$

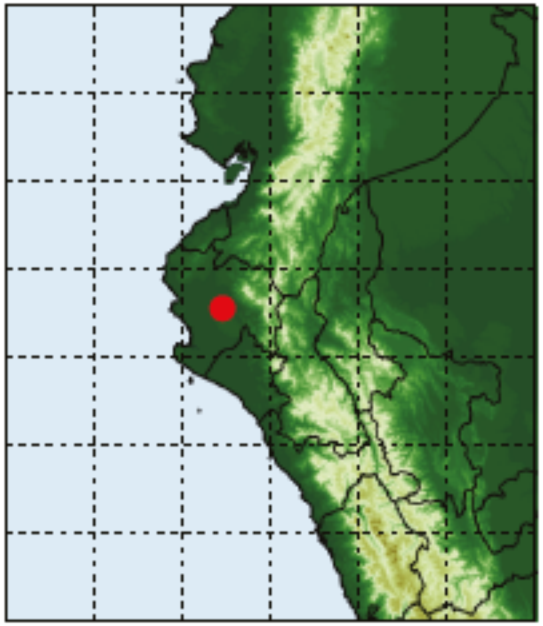


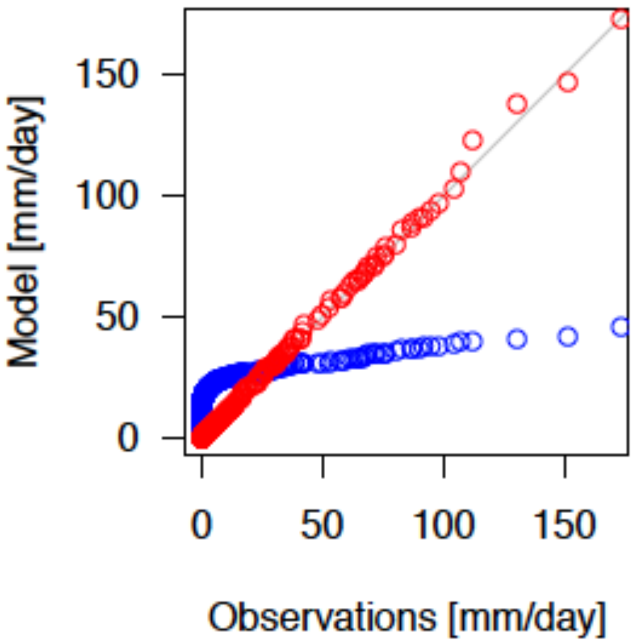
More sensitive to non-stationarity issues !!!!

$$y = f(x) = cdf_{obs}^{-1}(cdf_{prd}(X))$$

Requires cross-validation (e.g. Gutiérrez et al. 2013)


150
100
50
0
1975
1980
1985
1990
1995
2000
Time [Years]
Precipitation [mm/day]




150
100
50
0
Model [mm/day]
0
50
100
150
Observations [mm/day]

Approaches: MOS & PP

BIASES ↓ RESOLUTION ↓

- **Model Output Statistics (MOS):** The model is trained using observations and GCM outputs (which include biases/errors).

$$\mathbf{precip}_{obs}[d] = \mathbf{f}\,(\mathbf{precip}_{gcm}[d])$$

First introduced in weather forecast (Glahn and Lowry, 1972),
but problematic for climate projection.

BIASES ↓

Adapted for climate projection under the name **"bias-correction"** in a PDF-wise approach:

$$\mathbf{PDF}(\mathbf{precip}_{obs}) = \mathbf{F}\,(\mathbf{PDF}(\mathbf{precip}_{gcm}))$$

RCMs

RESOLUTION ↓

- **Perfect Prognosis (PP):** The model is trained using observations and reanalysis (quasi-observations)**. Predictors are large-scale variables well represented by GCMs**.

$$\mathbf{preci}_{obs}[d] = \mathbf{f}\,(\mathbf{SLP}_{rea}[d], \mathbf{Q850}_{rea}[d])$$

GCMs

Typical predictors

ELSEVIER
Journal of Hydrology 225 (1999) 67–91
Journal of Hydrology
www.elsevier.com/locate/jhydrol

A comparison of downscaled and raw GCM output: implications for climate change scenarios in the San Juan River basin, Colorado

R.L. Wilby[a,b,*], L.E. Hay[c], G.H. Leavesley[c]
[a]National Center for Atmospheric Research, Boulder, CO 80307, USA
[b]Division of Geography, University of Derby, Kedleston Road, Derby DE22 1GB, UK
[c]Water Resources Division, US Geological Survey, Denver Federal Center, Denver, CO 80225, USA

Received 2 November 1998; received in revised form 23 April 1999; accepted 1 September 1999

Predictor variable	Abbrevation
Surface variables	
*Mean sea level pressure	mslp
Zonal velocity component	Us
Meridional velocity component	Vs
Strength of the resultant flow (hPa)	Fs
Vorticity (hPa)	Zs
Divergence (hPa)	Ds
2 m temperatures (°C)	T2m
Relative humidities (%)	RH
*Specific humidity (gm/kg)	SH
Upper-atmosphere variables (500 hPa)	
*500 hPa geopotential heights (m)	H
Zonal velocity component	Uu
Meridional velocity component	Vu
Strength of the resultant flow (hPa)	Fu
Vorticity (hPa)	Zu
Divergence (hPa)	Du

ELSEVIER
Available online at www.sciencedirect.com
ScienceDirect
Environmental Modelling & Software 23 (2008) 813e834
Environmental Modelling & Software
www.elsevier.com/locate/envsoft

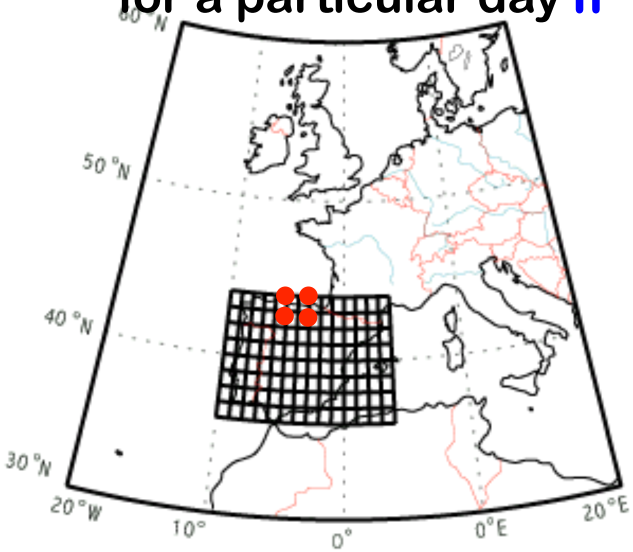
Automated regression-based statistical downscaling tool

Masoud Hessami[a,*], Philippe Gachon[b,c], Taha B.M.J. Ouarda[d], André St-Hilaire[d]

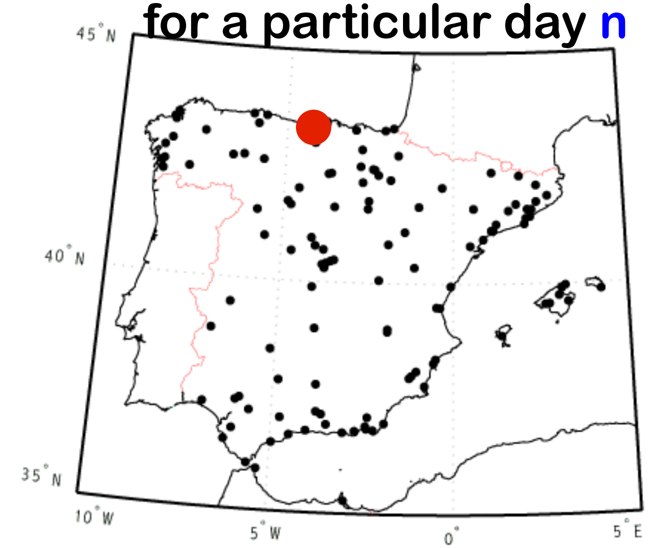
No.	Predictors	No.	Predictors
1	Mean sea level pressure	14	500 hPa divergence
2	Surface airflow strength	15	850 hPa airflow strength
3	Surface zonal velocity	16	850 hPa zonal velocity
4	Surface meridional velocity	17	850 hPa meridional velocity
5	Surface vorticity	18	850 hPa vorticity
6	Surface wind direction	19	850 hPa geopotential height
7	Surface divergence	20	850 hPa wind direction
8	500 hPa airflow strength	21	850 hPa divergence
9	500 hPa zonal velocity	22	Relative humidity at 500 hPa
10	500 hPa meridional velocity	23	Relative humidity at 850 hPa
11	500 hPa vorticity	24	Near surface relative humidity
12	500 hPa geopotential height	25	Surface specific humidity
13	500 hPa wind direction	26	Mean temperature at 2 m

Technique: Rregression

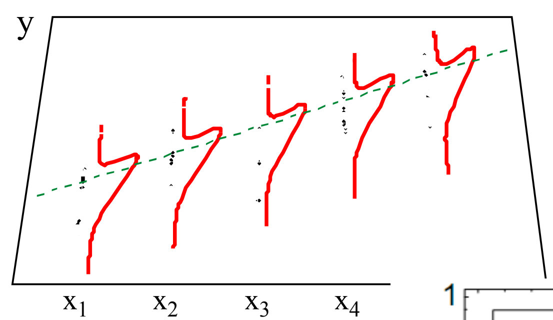
Large scale atmospheric drivers for a particular day n



Predictands: *precip*., etc. for a particular day n



(T(1000 mb),..., **T**(500 mb);
Z(1000 mb),..., **Z**(500 mb);
.......;
H(1000 mb),..., **H**(500 mb)) = X_n



Y_n

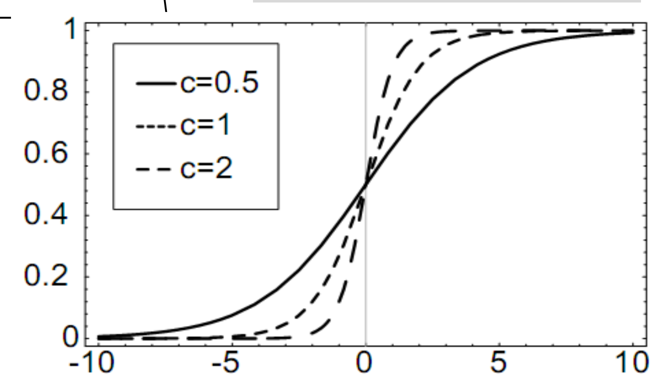
Linear regression:

$$\hat{Y}_n = a\, X_n + b$$

Logistic regression

Probabilistic prediction

$$\hat{Y}_n = F(a\, X_n + b)$$



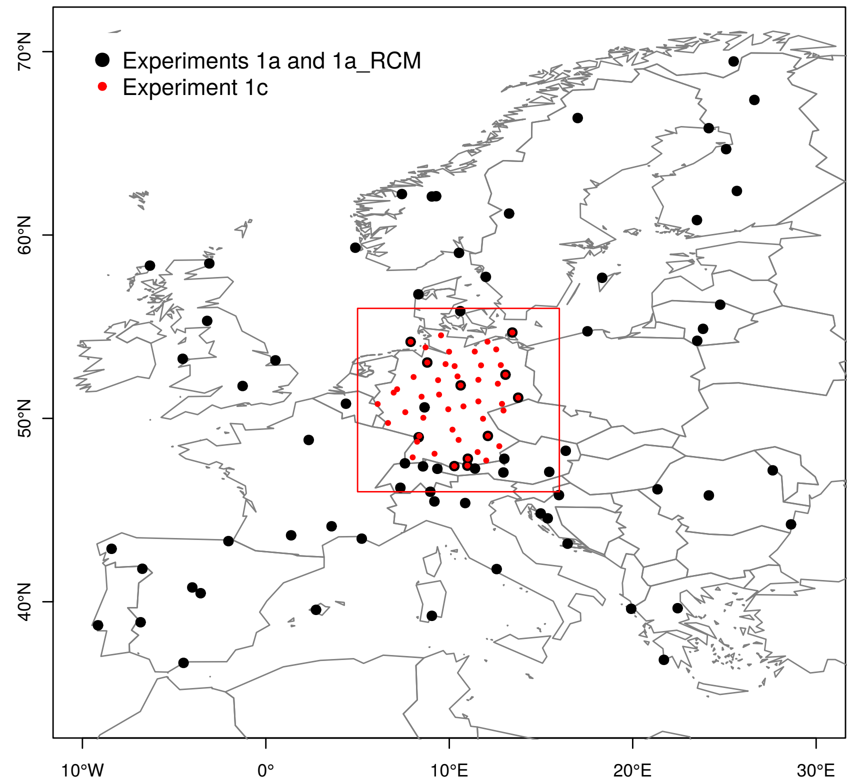
VALUE (20012-2016)

VALUE is an open European network to Systematically **validate and compare (dynamical and statistical) downscaling methods for climate change**.

Different (**cross-validation**) experiments:

- **Perfect (*ERA-Interim*) Predictor**
- **GCM (*CMIP5*) Predictor**
- **Pseudo Reality (*RCM as predictand*).**

86 (53) stations:
Over Europe (Germany)



RESEARCH ARTICLE

VALUE: A framework to validate downscaling approaches for climate change studies

OPEN

Douglas Maraun[1,*], Martin Widmann[2], José M. Gutiérrez[3], Sven Kotlarski[4], Richard E. Chandler[5], Elke Hertig[6], Joanna Wibig[7], Radan Huth[8] and Renate A.I. Wilcke[9]

Article first published online: 7 JAN 2015

Issue

Earth's Future
Early View (Online Version of Record published before inclusion in an issue)

Validation framework

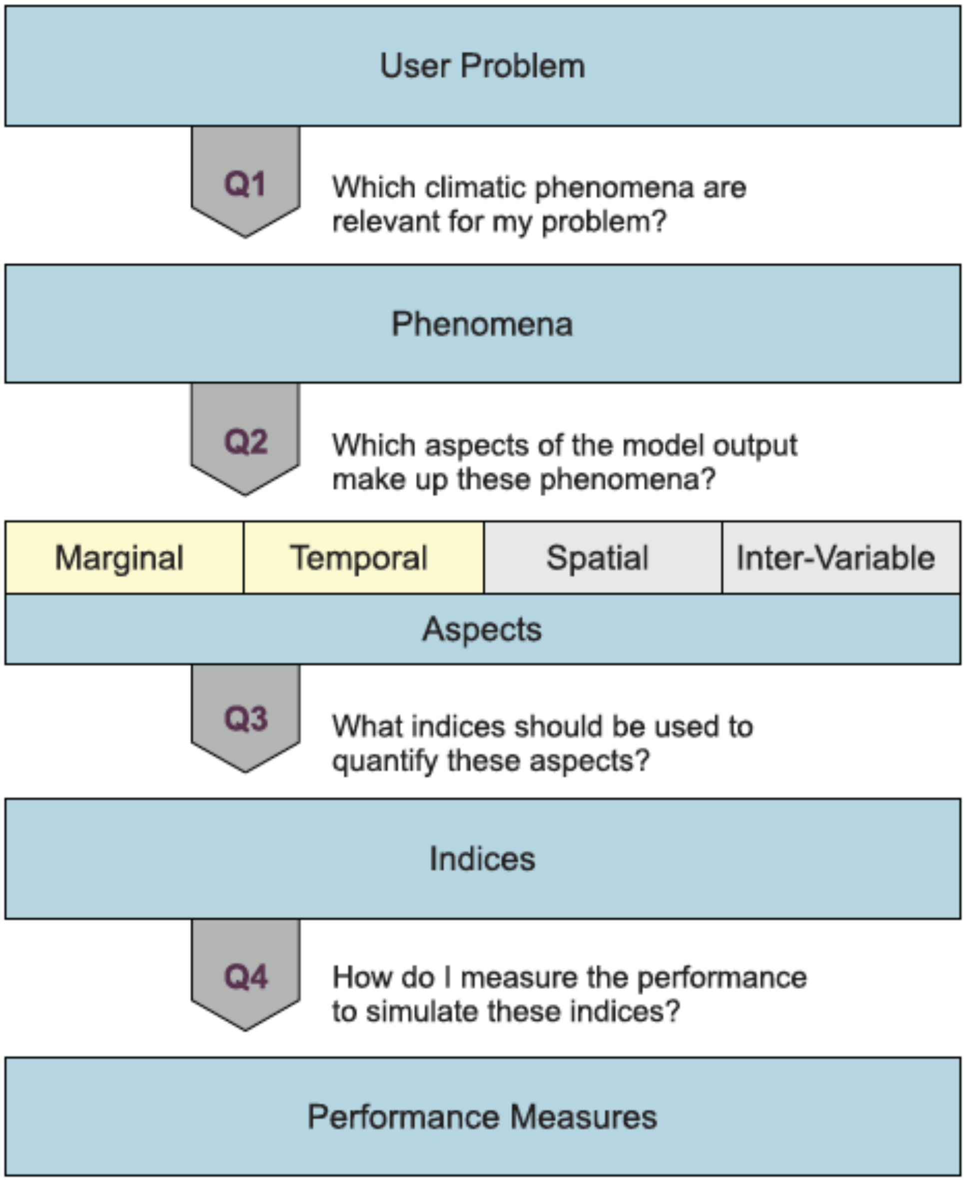
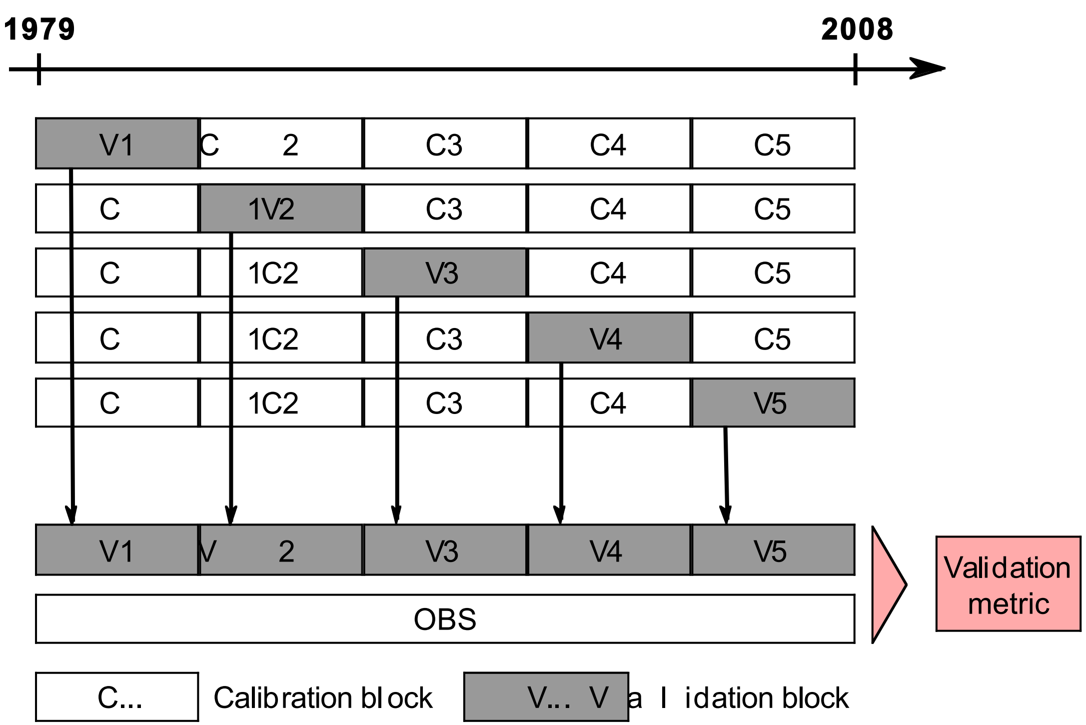


Figure 1. Validation Tree. Grey arrows: selection questions. Beige: tier I aspects; gray: tier II aspects.

The validation period is **1979-2008** and the indices and performance measures are obtained:

- **Unconditionally (for the whole period)**
- **Conditioned to several processes** (NAO, Blocking, Lamb weather types, given by 0/1 binary series).

Cross-validation (k-fold approach, k=5):



Experiment 1 ... Completed

A web portal has been developed to **collect**, **validate**, **visuallize** and **publish** the validation results (and data) in a user-friendly way.

Precipitation

#	R	INSTITUTION	CODE	APPRO.	TECH.	ST	MS	MV	SE	AC
1	-	ECMWF	ERAINT-200	RAW	-	-	-	-	-	-
2	-	ECMWF	ERAINT-075	RAW	-	-	-	-	-	-
3	X	KNMI	RACMO22E	RAW	-	-	-	-	-	-
4	X	UHEL	Ratyetal-M6	MOS	S	no	no	no	yes	no
5	X	UHEL	Ratyetal-M7	MOS	S	no	no	no	yes	no
6	X	UCAN-CSIC	ISI-MIP	MOS	S|PM	no	no	no	yes	no
7	X	SMHI	DBS	MOS	PM	no	no	yes	yes	no
8	X	UHEL	Ratyetal-M9	MOS	PM	no	no	no	yes	no
9	X	FIC	BC	MOS	PM	no	no	no	yes	no
10	X	UCAN-CSIC	GQM	MOS	PM	no	no	no	no	no
11	X	UCAN-CSIC	GPQM	MOS	PM	no	no	no	no	no
12	X	UCAN-CSIC	EQM	MOS	QM	no	no	no	no	no
13	X	UCAN-CSIC	EQMs	MOS	QM	no	no	no	yes	no
14	X	UCAN-CSIC	EQM-WT	MOS	QM|WT	no	no	no	no	no
15	X	IDL	QMm	MOS	QM	no	no	no	yes	no
16	X	ELU	QMBC-BJ-PR	MOS	QM	no	no	no	yes	no
17	X	LSCE/IPSL	CDFt	MOS	QM	no	no	no	yes	no
18	X	GCRI-CAS	QM-DAP	MOS	QM	no	no	no	yes	no
19	X	SMHI	EQM-WIC658	MOS	QM	no	no	no	yes	no
20	X	UHEL	Ratyetal-M8	MOS	QM	no	no	no	yes	no
21	X	UB	MOS-AN	MOS	A	no	yes	no	no	no
22	X	UCAN-CSIC	MOS-GLM	MOS	TF	yes	no	no	no	no
23	-	UNIGRAZ	VGLMGAMMA	MOS	TF	yes	no	no	yes	no
24	-	FIC	FIC02P	MOS|PP	PM|A|TF	no	no	no	yes	no
25	-	FIC	FIC04P	MOS|PP	PM|A|TF	no	no	no	yes	no
26	-	FIC	FIC01P	PP	A|TF	no	yes	no	yes	no
27	-	FIC	FIC03P	PP	A|TF	no	yes	no	yes	no
28	-	LSCE/IPSL	ANALOG-ANOM	PP	A	no	yes	yes	yes	no
29	-	UCAN-CSIC	ANALOG	PP	A	no	yes	yes	no	no
30	-	CNRS/IGE	ANALOG-MP	PP	A	yes	yes	yes	yes	no
31	-	CNRS/IGE	ANALOG-SP	PP	A	yes	yes	yes	yes	no
32	-	MIUB	MO-GP	PP	TF	no	no	no	no	no
33	-	AEMET	GLM-P	PP	TF	yes	no	no	no	no
34	-	CUNI	MLR-RAN	PP	TF	no	no	no	no	no
35	-	CUNI	MLR-RSN	PP	TF	no	no	no	yes	no
36	-	CUNI	MLR-ASW	PP	TF	yes	no	no	yes	no
37	-	CUNI	MLR- ASI	PP	TF	no	no	no	yes	no
38	-	UCAN-CSIC	GLM-DET	PP	TF	no	*yes*	no	no	no
39	-	UCAN-CSIC	GLM	PP	TF	yes	*yes*	no	no	no
40	-	UCAN-CSIC	GLM-WT	PP	TF|WT	yes	*yes*	no	no	no
41	-	UCAN-CSIC	WT-WG	PP	WT	yes	no	no	no	no
42	-	LSCE/IPSL	SWG	PP	TF	yes	*yes*	no	yes	no
43	-	METEOSWISS	SS-WG	WG	WG	yes	no	yes	yes	yes
44	-	IAP-CAS	MARFI-BASIC	WG	WG	yes	no	yes	yes	yes
45	-	IAP-CAS	MARFI-TAD	WG	WG	yes	no	yes	yes	yes
46	-	IAP-CAS	MARFI-M3	WG	WG	yes	no	yes	yes	yes
47	-	IAP-CAS	GOMEZ-BASIC	WG	WG	yes	no	yes	yes	yes
48	-	IAP-CAS	GOMEZ-TAD	WG	WG	yes	no	yes	yes	yes

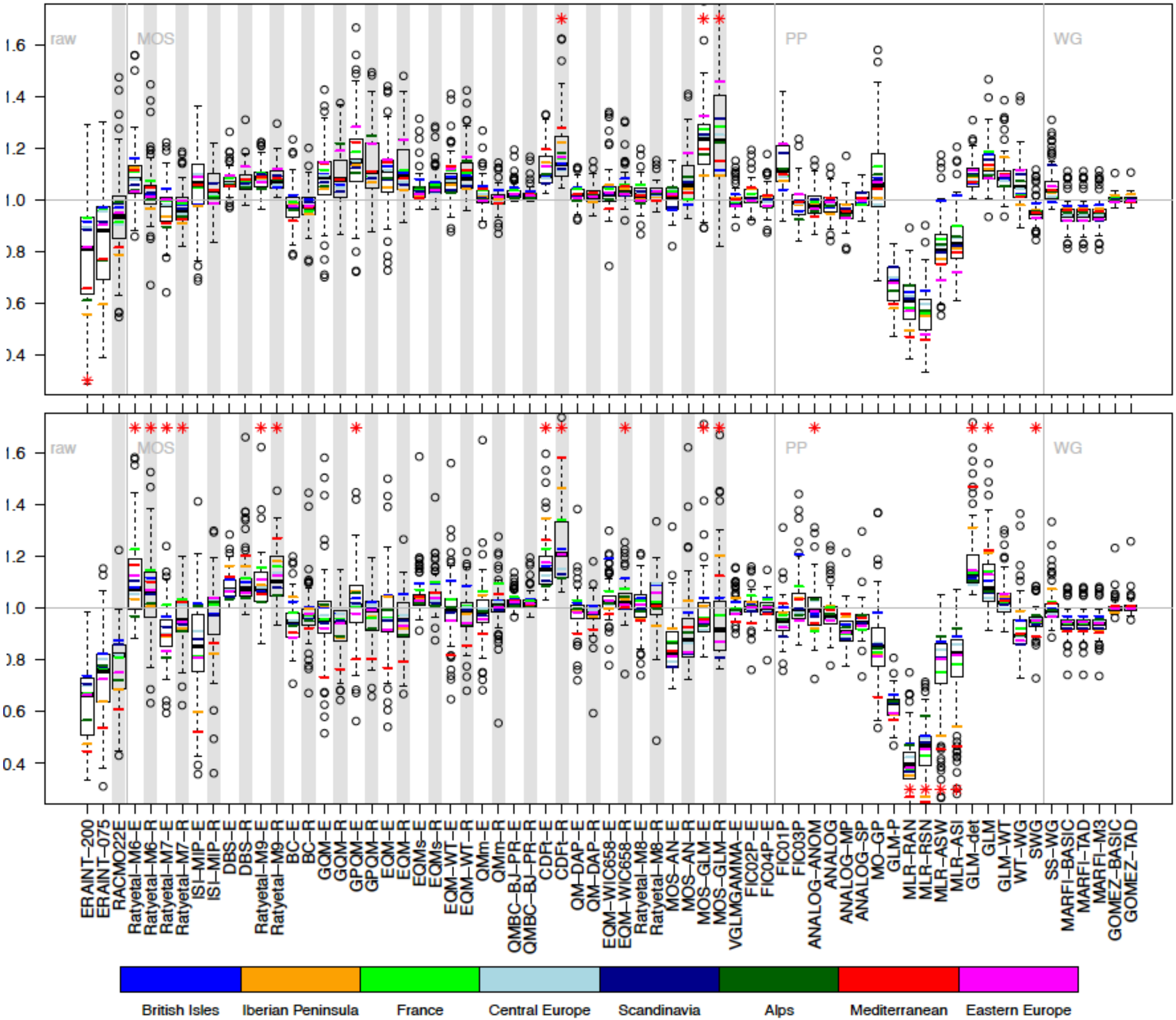
MOS, PP and WG approaches:
S (additive/mult. scaling),
QM (quantile mapping),
WT (weather types),
A (analogs),
TF (transfer function),
WG (weather generators),

Metadata:

- **stochastic** nature,
- **multi-site**
- **multi-variable**
- **seasonality**
- **autocorrelation**

Shading indicates methods applied also for temperatures (30 methods).

Mean wet-day precipitation biases of the downscaling methods for winter and summer, respectively. For each method, the box-whisker-plot summarizes the results of the 86 stations. Boxes span the 25-75% range and the whiskers the maximum value (within 1.5 times the interquartile range); outliers are plotted individually. A red asterisk indicates values outside the plotted range. Average results over the different Prudence regions are indicated for each method. Shades indicate the MOS results using RACMO predictors (all others use ERA-Interim).



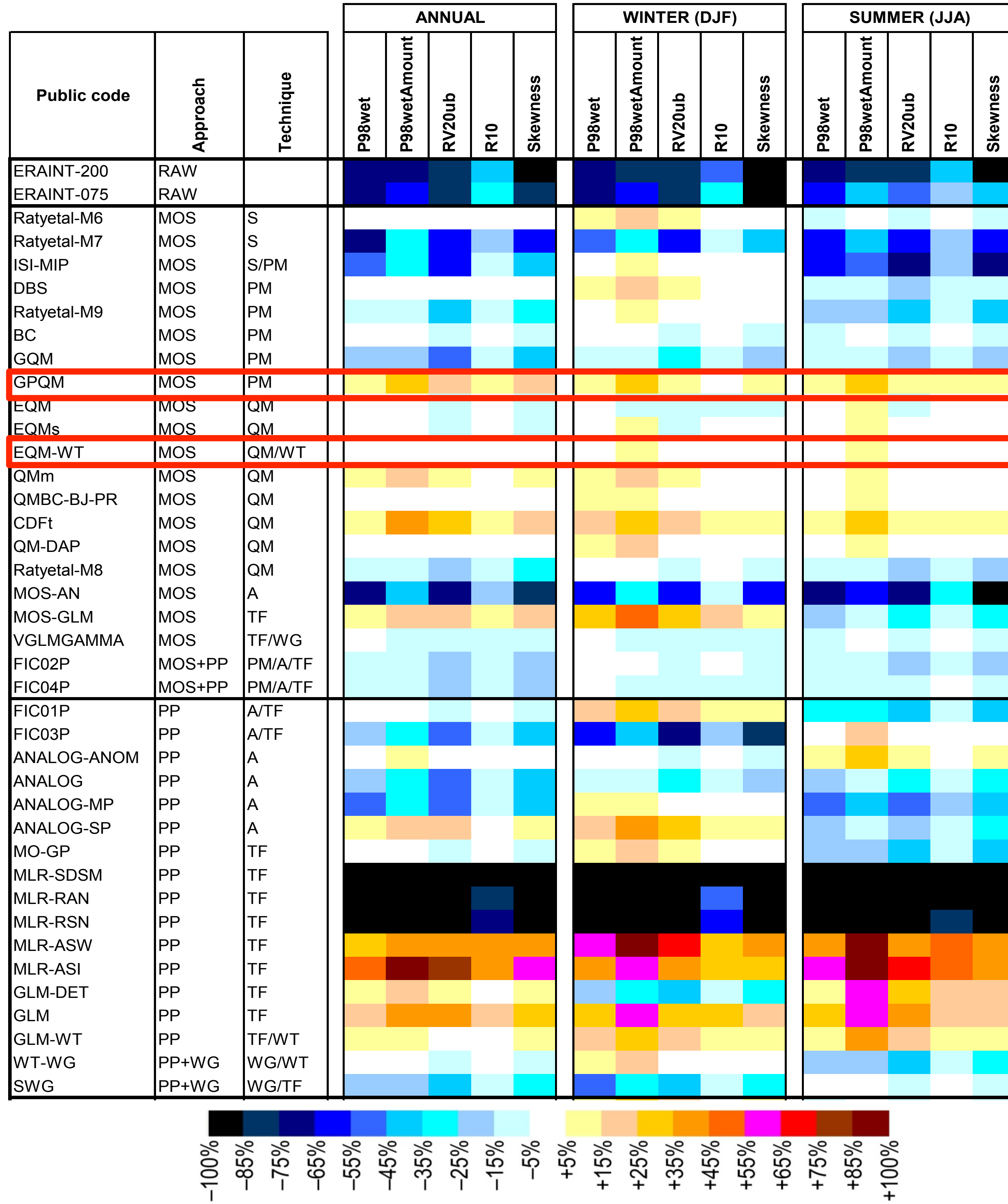
E. Hertig et al. (2017) *Comparison of statistical downscaling methods with respect to extreme events over Europe. Validation results from the Perfect-Predictor Experiment of the COST Action VALUE.* **International Journal of Climatology. In press.**

precipitation	**Marginal aspects**
	Skewness
	Relative frequency of days with precip. >= 10mm
	98th percentile of wet (>=1 mm) days
	Total amount above 98th percentile of wet (>=1 mm) days
	20-years return value (max values, right tail)
	90%, 95%, 99% quantiles
	Temporal aspects
	Median of the annual dry (<1mm) spell maxima
	Median of the annual wet (>=1mm) spell maxima
temperatures	**Marginal aspects**
	Skewness (Tmin, Tmax)
	98th percentile Tmax
	20-years return value Tmax (max values, right tail)
	2nd percentile Tmin
	20-years return value Tmin (min values, left tail)
	90%, 95%, 99% quantiles Tmax
	10%, 5%, 1% quantiles Tmin

EQM: **Empirical** Quantile Mapping with frequency adaptation adjusting 99 perc. and linearly interpolating betwen them; constant Extrapolation is used outside this range.

EQM-WT is a state-dependent version of EQM, conditioning the training to 12 **Weather Types** defined using daily SLP Over Europe.

GPQM: Parametric **Gamma** (Gaussian) Quantile Mapping with frequency adaptation for precipitation. A **Generalized Pareto Distribution** is used to adjust separately the extremes values (over the 95th percentile).



WorldClim

Very high resolution interpolated climate surfaces for global land areas

Robert J. Hijmans[1,*], Susan E. Cameron[1,2], Juan L. Parra[1], Peter G. Jones[3], Andy Jarvis[3,4]

Article first published online: 30 NOV 2005

DOI: 10.1002/joc.1276

Issue

International Journal of Climatology

Volume 25, Issue 15, pages 1965–1978, December 2005

Global ***monthly*** *hires (1km) grids*

CMIP5

Downscaled IPPC5 (CMIP5) data

The data available here are climate projections from global climate models (GCMs) for four representative concentration pathways (RCPs). These are the most recent GCM climate projections that are used in the Fifth Assessment IPCC report. The GCM output was downscaled and calibrated (bias corrected) using WorldClim 1.4 as baseline 'current' climate.

The data are available at different spatial resolutions (expressed as minutes or seconds of a degree of longitude and latitude): **10 minutes, 5 minutes, 2.5 minutes, 30 seconds**. The variables included are monthly minimum and maximum temperature, precipitation, and 'bioclimatic' variables.

Towards Escenarios-PNACC 2012

PNACC Plan Nacional de Adaptación al Cambio Climático

ESCENARIOS-PNAC 2012

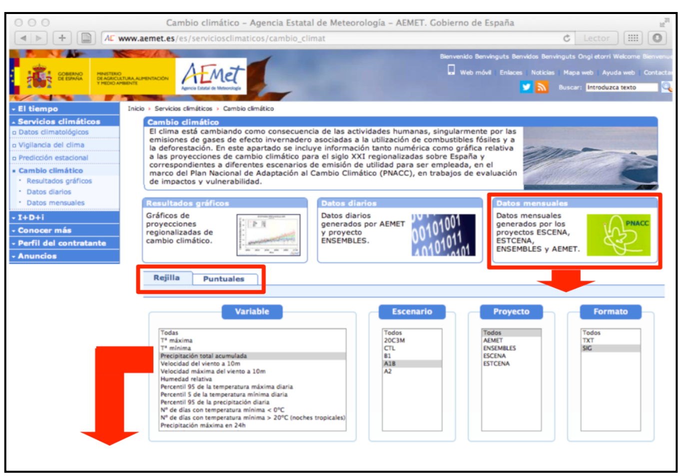
ESTCENA Escenarios regionales de cambio climático: Downscaling estadístico

AEMet Agencia Estatal de Meteorología

ESCENA

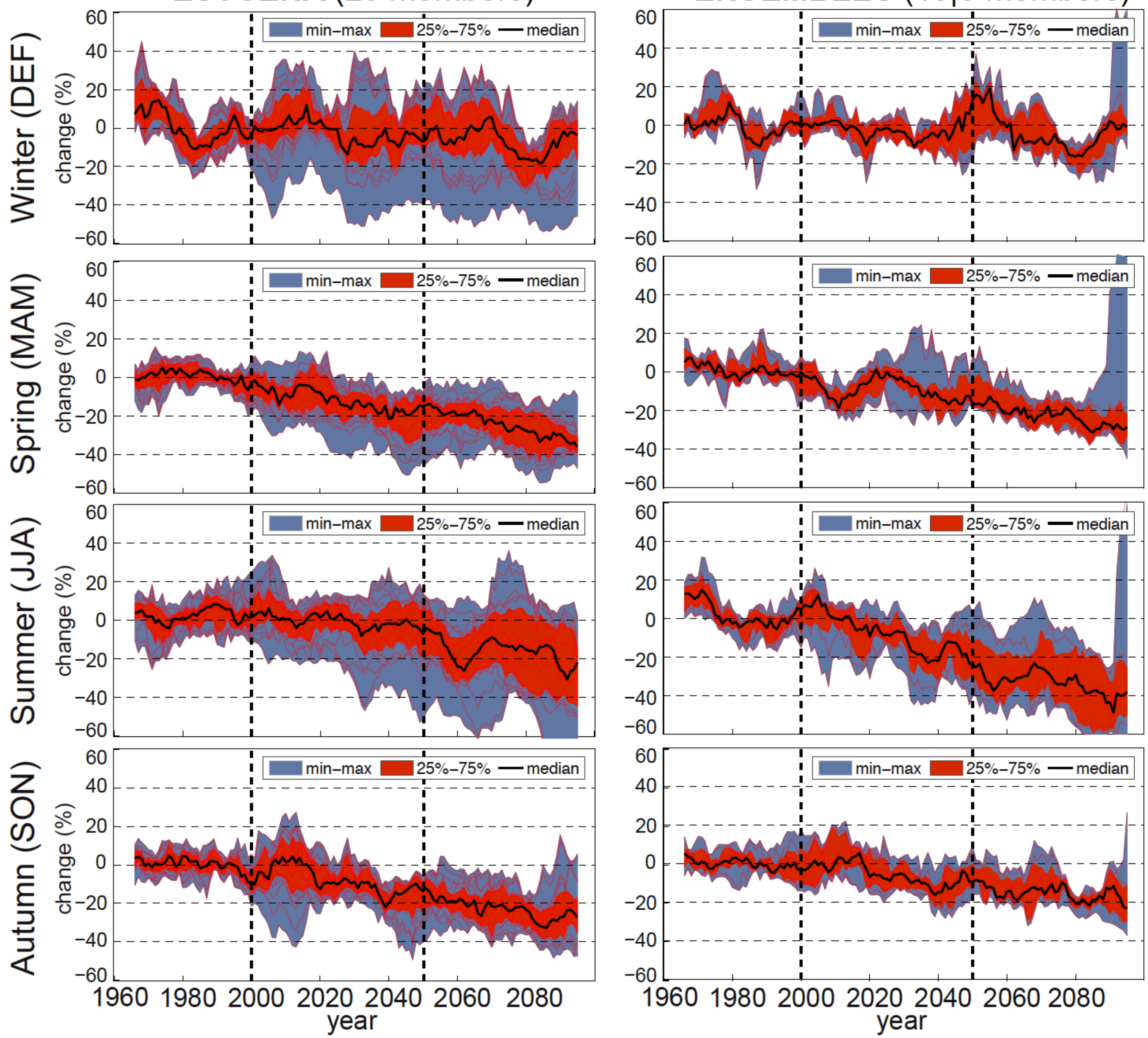
ENSEMBLES

Distribuido por AEMET y UC.

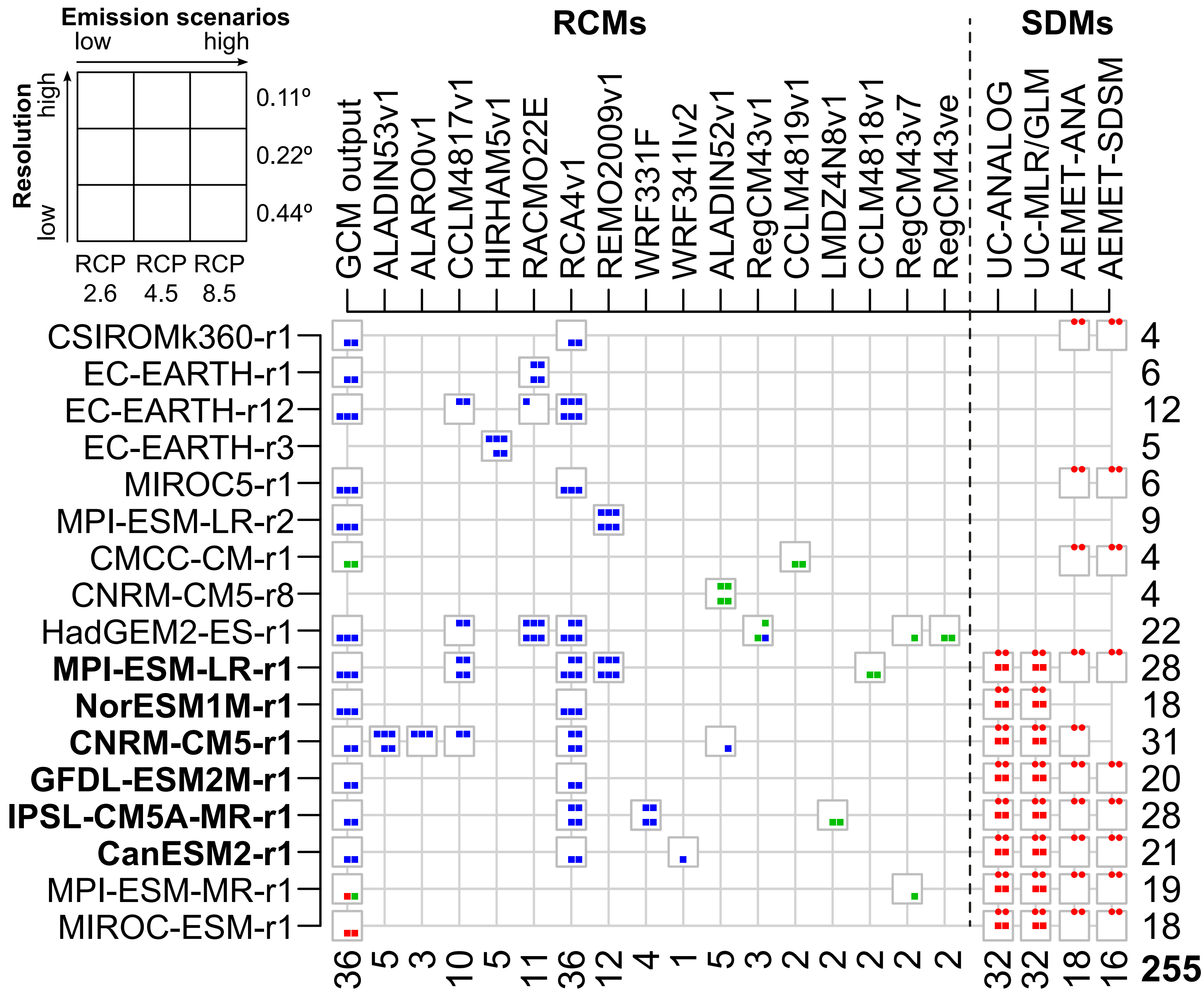


Statistical Downscaling: ESTCENA (20 members)

Dynamical Downscaling: ENSEMBLES (10|8 members)



Towards Escenarios-PNACC 2017



Plan Nacional de Adaptación al Cambio Climático

PNACC

ESCENARIOS-PNAC 2017

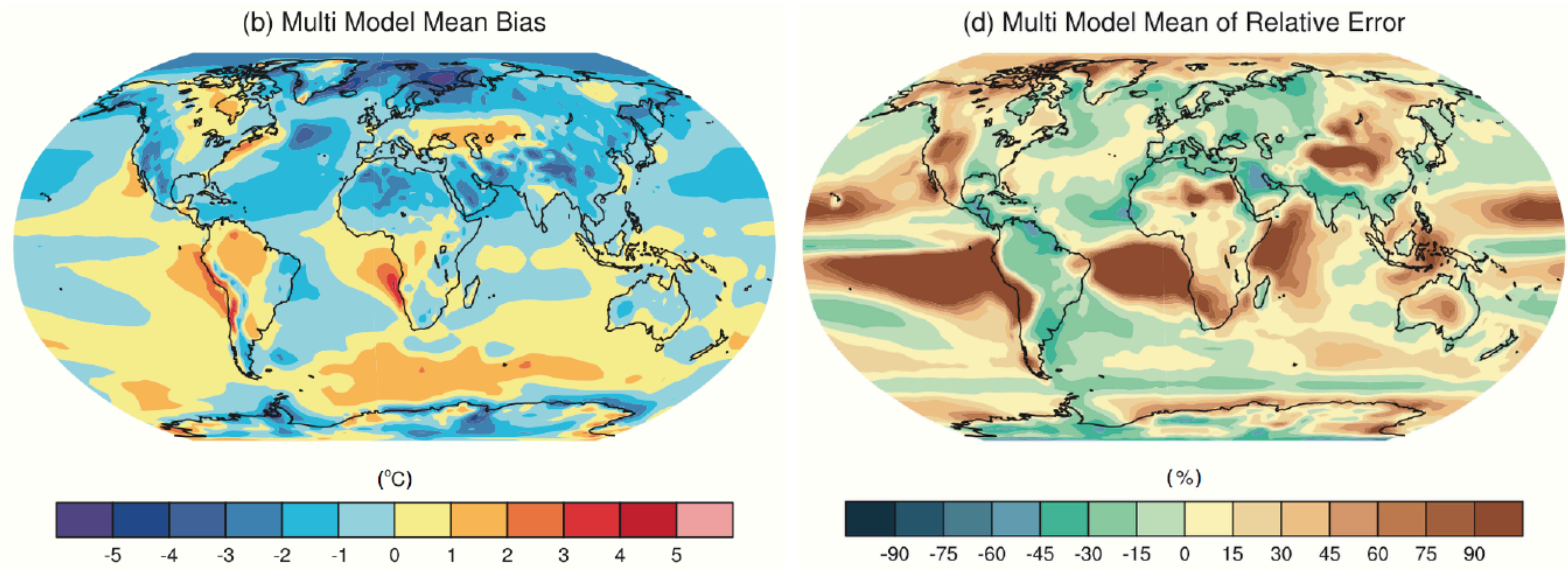
Conclusions

In order to work with extremes, two different approaches are advised in order to adjust model biases:

- For GCMs and RCMs: The “delta” method, which provides climate information about parameters of interest (e.g. change in the mean).
- For RCMs: Bias adjustment techniques, exploring different versions modeling the extremes.

In any case, there are unavoidable deficiencies which have to be estimated from a pragmatic way using ensembles.

GCM biases



CMIP5 Multi-model mean biases. Flato et al., IPCC AR5, 2013

Some of these biases are a consequence of the bad representation of key dynamical processes. **These are difficult to correct/adjust.**