Reducing hydrological budget modeling uncertainty related to climate induced change

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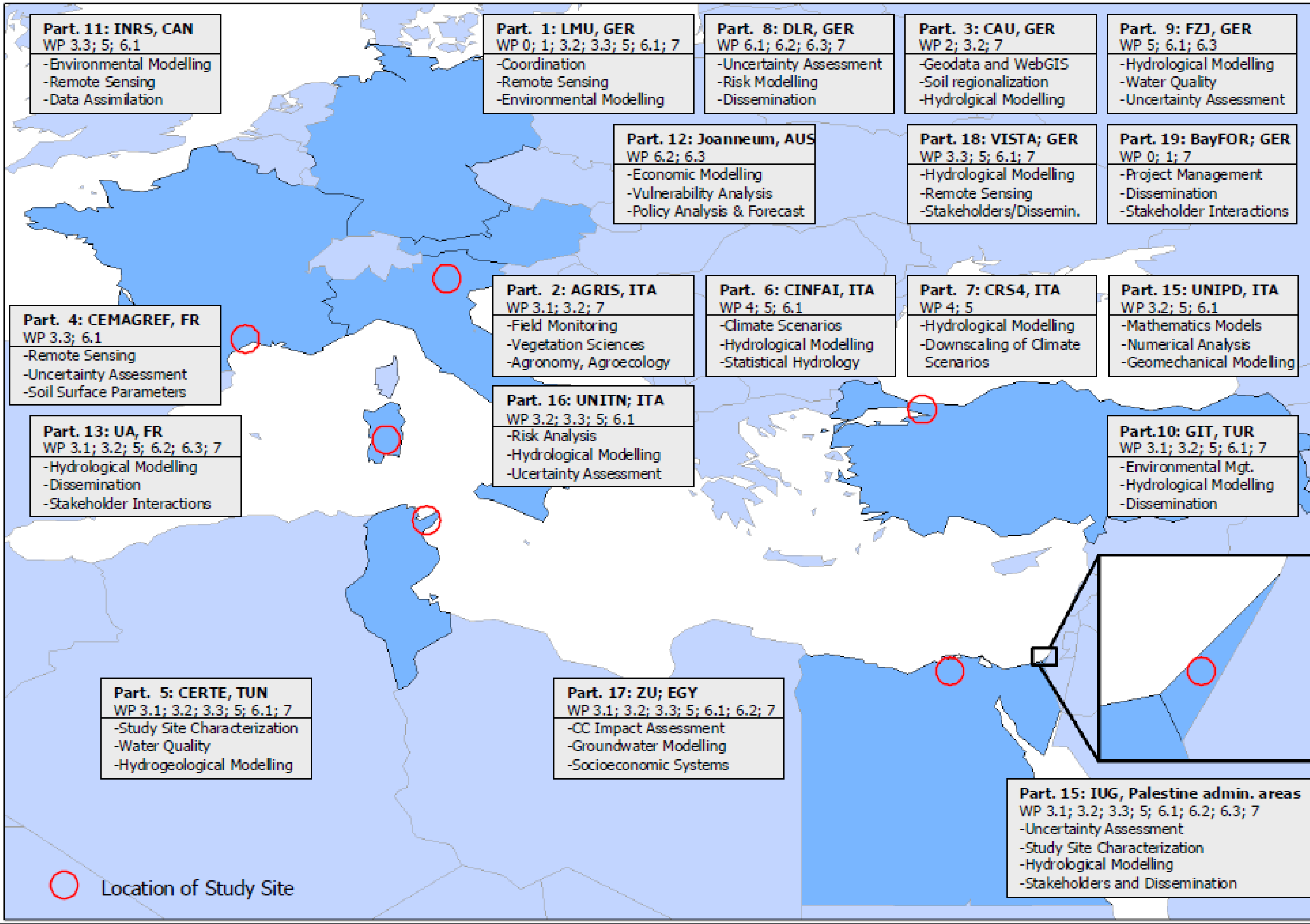
Motivations and abstract

- Issues related to the use of Climate Model Scenarios (CMS) as BC for hydrological modeling:
  - Climate models are in general biased
  - Spatio-temporal resolution of CMS is insuffcient for hydrological modeling studies at basin scale
- CLIMB project (http://www.climb-fp7.eu), funded by the EU-FP7, address some some of these issues
  - Aim: reducing the uncertainty and quantifying risks related to climate induced changes on the hydrological cycle of Mediterranean basins.
  - The output of 4 different RCMs have been post-processed for the period 1951-2100, using the QQ methodology, for the Riu Mannu basin located in the southern part of Sardinia (Italy).
  - The resulting data sets have been used to model the hydrological cycle with SWAT for two different periods (REF: 1971 -2000 and Fut 2041 – 2070).
- As a follow up we developed a methodology of precipitation downscaling for CMS data named QQS:
  - combines a distribution mapping technique (QQ) to calibrate pdf and the Shackle-Shuffling methodology to improve spatial correlation of precipitation field within the catchment

CLIMB EU fp7 project



Map with participant countries (9) to the CLIMB project and location of study sites (7).
In each study site at least two hydrological models were used to estimate uncertainty due to HM

Climate projections: www.ensembles.eu

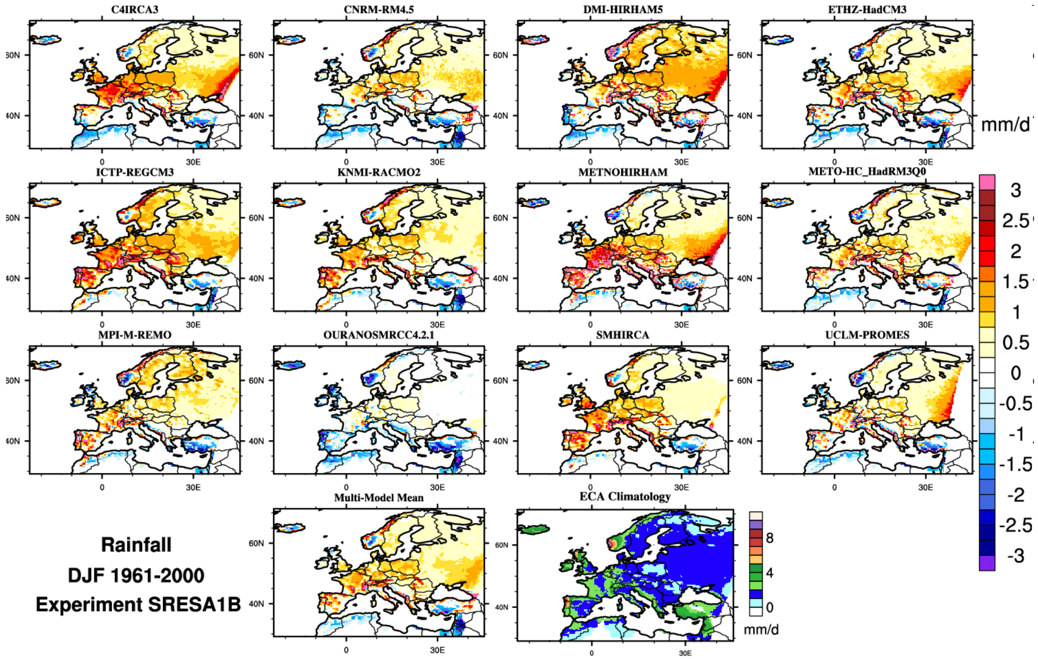
- RMC ENSEMBLES project data (ΔX~22km)
- 14 models. Data from 1951 to 2100 at daily scale.
- A1 scenarios are devised to describe a more integrated world and are characterized by:
  - Rapid economic growth.
  - A global population that reaches 9 billion in 2050 and then gradually declines.
  - The quick spread of new and efficient technologies.
  - convergent world - income and way of life converge between regions. Extensive social and cultural interactions worldwide.
- Moreover the A1B scenario try give a balanced emphasis on the use of all energy sources.

GCM	Description	RCM	Description
HCH	Hadley Centre for Climate Prediction, Met Office, UK, HadCM3 Model(high sensitivity)	**RCA**	RCA Sweden
HCS	Hadley Centre for Climate Prediction, Met Office, UK, HadCM3 Model(normal sensitivity)	**HIR**	HIRAM5 Denmark
HCL	Hadley Centre for Climate Prediction, Met Office, UK, HadCM3 Model(low sensitivity)	**CLM**	CLM Switzerland
ARP	Meteo-France, Centre National de Recherches Meteorologiques, CM3 Model Arpege	**HRM**	HadRM3Q3 UK
ECH	Max Planck Institute for Meteorology, Germany, ECHAM5 / MPI OM	**RMO**	RACMO2 Netherlands
BCM	Bjerknes Centre for Climate Research, Norway, BCM2.0	**REM**	REMO Germany

GCM / RCM	HadleyC, Std.	HadleyC, Low	HadleyC, High	ECHam 5	ARPege	BCM
HadRM ●	HCS_HRM ●	HCL_HRM ●	HCH_HRM ●			
REMo ◆				ECH_REM ◆		
HIRham ■	HCS_HIR ■			ECH_HIR ■	ARP_HIR ■	BCM_HIR ■
CLM ▲	HCS_CLM ▲					
RacMO ▼				ECH_RMO ▼		
RCA 3 ►		HCL_RCA ►	HCH_RCA ►	ECH_RCA ►		BCM_RCA ►

E-obs verification data set

- Gridded observational datasets of daily precipitation and temperature
- Based on a European network of high-quality station series.
- The datasets cover the period from 1950 to 2011.
- They are made available on 0.22 and 0.22 degree rotated pole grid.
- The grid is the same as the Climatic Research Unit monthly datasets for the globe.
- The rotated grid is the same as used in many ENSEMBLES Regional Climate Models.
- Haylock, M. R., N. Hofstra, A. M. G. Klein Tank, E. J. Klok, P. D. Jones, and M. New, 2008: A European daily high-resolution gridded data set of surface temperature and precipitation for 1950–2006, *J. Geophys. Res.*, 113, D20119, doi:10.1029/2008JD010201.



Bias of climate projections

$$\mu^{M}_{ijym} = \frac{1}{nd}\sum_{d=1}^{nd} X^{M}_{ijymd}$$

$$\mu^{M}_{ijm} = \frac{1}{30}\sum_{y=yi}^{yi+30-1} \mu^{M}_{ijym}$$

$$AE^{M}_{ij} = \frac{1}{12}\sum_{m=1}^{12} |\mu^{M}_{ijm} - \mu^{0}_{ijm}|$$

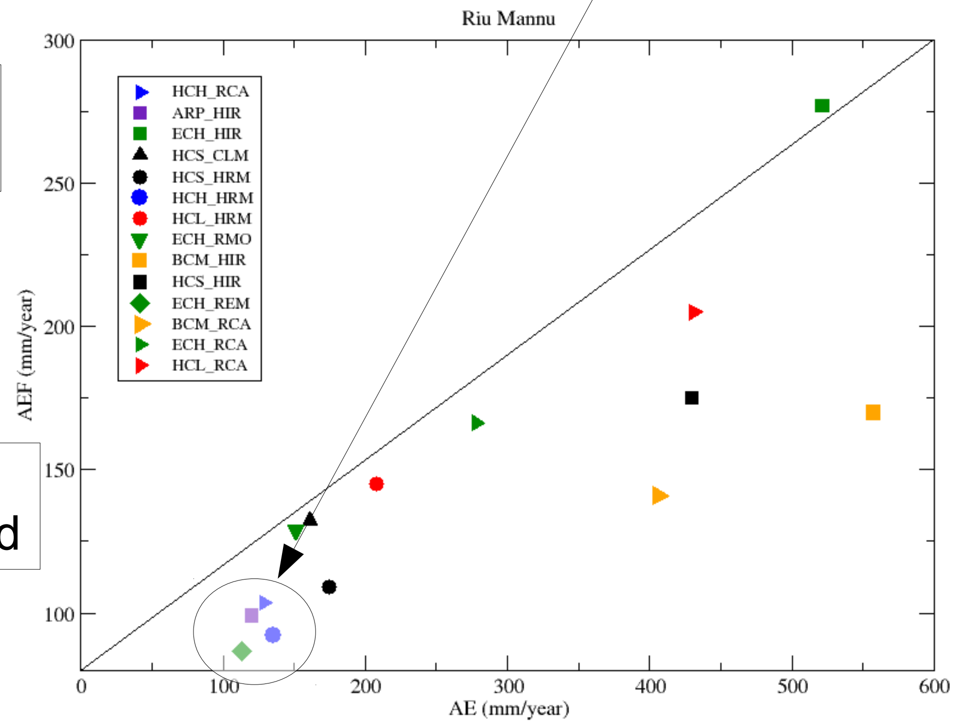
Absolute mean error

$$\sigma^{M}_{ijym} = \sqrt{\frac{1}{30-1}\sum_{y=yi}^{yi+30-1}\left(\mu^{M}_{ijym} - \mu^{M}_{ijm}\right)^2}$$

$$AEF^{M}_{ij} = \frac{1}{12}\sum_{m=1}^{12} |\sigma^{M}_{ijm} - \sigma^{0}_{ijm}|$$

Fluctuations error on mothly cumulated

The 4 best models

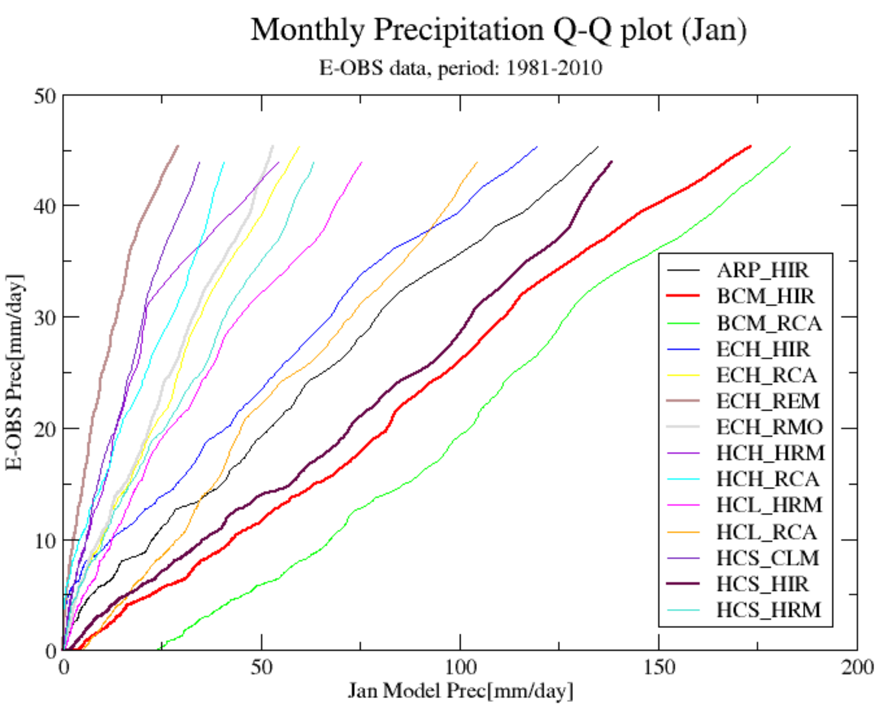


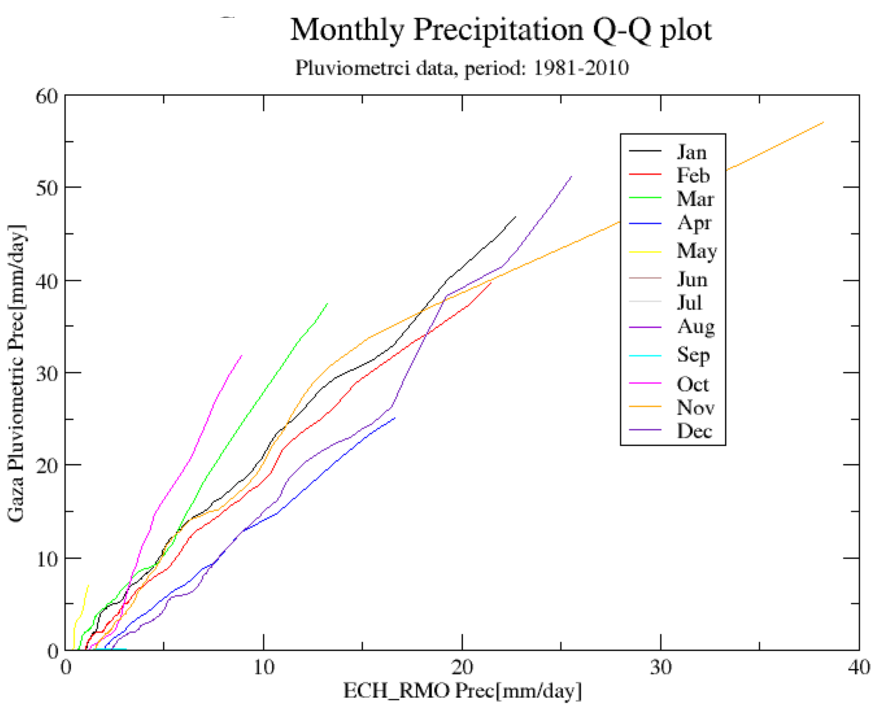
AE-AEF skill scores plot for each of the 14 RCM models (see color and symbol legend within the box plot) for climatic period 1951-2010, for precipitation. Verification was done using the E-obs data set as verification

CLIMB approach: bias removal then downscaling

- Model skill evaluation and intercomparison allowed to choose the "4 best RCM" models. See: *Deidda, R., M. Marrocu, G. Caroletti, G. Pusceddu, A. Langousis, V. Lucarini, M. Puliga and A. Speranza (2013)* Regional climate models' performance in representing precipitation and temperature over selected Mediterranean areas, *Hydrol. Earth Syst. Sci.*, **17**, 5041-5059, doi:10.5194/hess-17-5041-2013
- We then removed seasonal bias of climate model outputs before applying a downscaling procedure and using them as input for hydrological models
- A conservative approach has been used, correcting climate models at the same scale they were run (~22km).
- A spatial-temporal statistical (multi-fractal) downscaling procedure have been applied to calculate BC for the hydrological model at the spatial resolution of 1km
- For bias removal we used the daily translation method, or QQ mapping, that has been shown to be skillful in many hydrologic impact studies [see for example Wood et al., 2004; Maurer and Hidalgo, 2008]

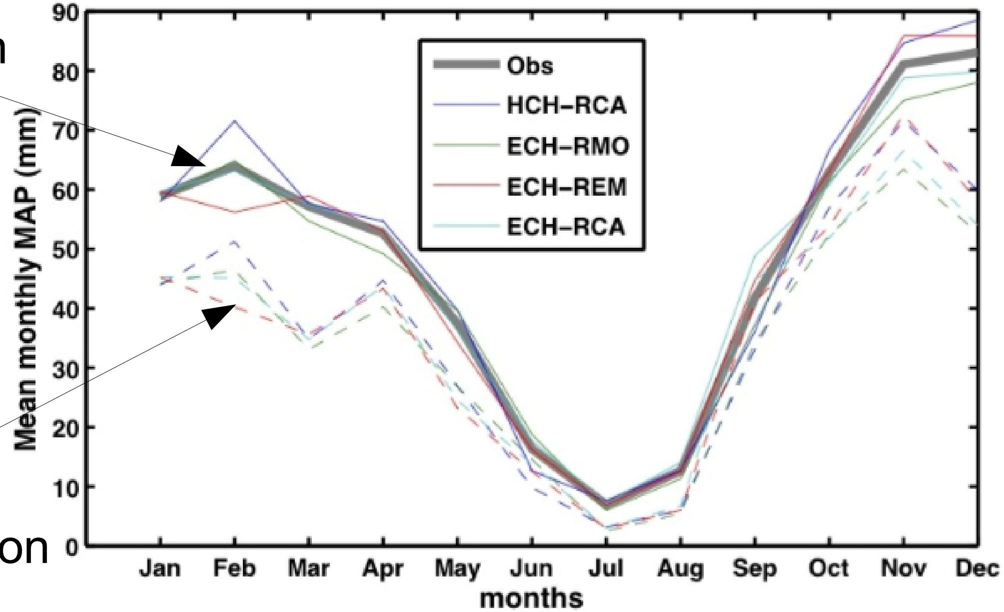
Q-Q calibration curves





Distribution mapping using Q-Q calibration plots, known also as daily translation method, obtained plotting ranked CM daily precipitation against rancke E-OBS.

After QQ correcton



Before QQ correction

Fig. 7: Local scale bias corrections.

Comparison of mean monthly observed MAP (mean areal precipitation; grey thick line) and mean monthly RCMs MAP, before correction (dashed lines) and after correction (continuous line). Catchment: Rio Mannu, Sardinia (Italy).

CLIMB results

http://cordis.europa.eu/docs/results/244/244151/final1-final-summary-report-climb-formatted.pdf

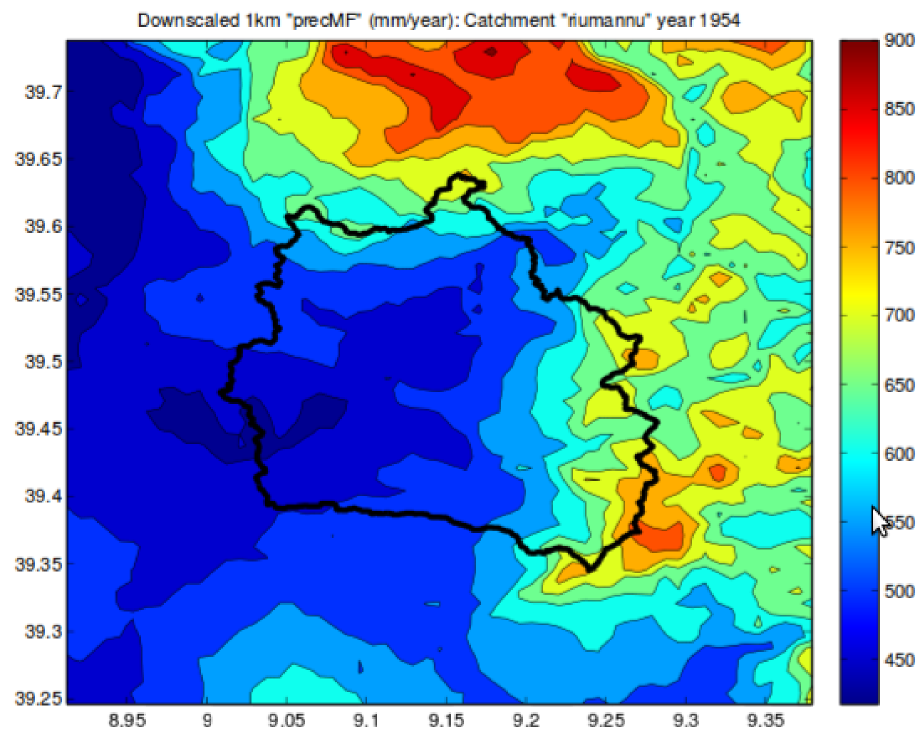


Fig. 8: Small scale interpolation and downscaling.

Annual mean of high resolution precipitation field (about 1 km) after bias correction and application of a space-time rainfall downscaling model.

CLIMB results: quantifying uncertainties

4 RCMs and 2 HMs

Water Supply

Hydrological parameters quantified in CLIMB		Unit	Trend	Risk Level	Multi-Model Average: 1970-2000	Multi-Model Average: 2041-2070	Multi-Model Average: Trend	Multi-Model Average: Trend [%]	Climate Signal Uncertainty: CUS Error [%]	Climate Signal Uncertainty: Impact	Model Structure Uncertainty: Description	Model Structure Uncertainty: Impact
Precipitation (PRC)	**WASIM**	mm/a	↓	+	560.03 +/- 20.08	491.59 +/- 27.27	-68.44 +/- 3.11	-12.22 +/- 0.56	4.58	**Low**	Both hydrological impact models show a decrease trend. WaSiM and SWAT project similar absolute and percentual change values.	**Low**
	SWAT		↓	+	474.23 +/- 18.91	406.05 +/- 29.6	-68.18 +/- 3.85	-14.38 +/- 0.81	5.62			
Potential Evapotranspiration (ETP)	**WASIM**	mm/a	↑	+	1425.43 +/- 137.06	1651 +/- 162.93	225.57 +/- 21.99	15.82 +/- 1.54	9.73	**Low/ Medium**	Both hydrological impact models show an increase trend. WaSiM and SWAT project very different absolute and percentual change values.	**Medium /High**
	SWAT		↑	+	992.08 +/- 8.07	1006.95 +/- 8.08	14.87 +/- 0.12	1.5 +/- 0.01	0.67			
Actual Evapotranspiration (ETR)	**WASIM**	mm/a	↑	+	474.37 +/- 16.14	423.33 +/- 28.43	-51.04 +/- 2.58	-10.76 +/- 0.54	5.02	**Low**	Both hydrological impact models show a decrease trend. WaSiM and SWAT project very different absolute change values. The percentual change is roughly in the same magnitude.	**Medium /High**
	SWAT		↑	+	264.2 +/- 6.16	226.07 +/- 17.13	-38.13 +/- 1.89	-14.43 +/- 0.72	5			
Discharge (DIS)	**WASIM**	m³/s	↓	+	1.4 +/- 0.21	1.13 +/- 0.14	-0.27 +/- 0.04	-19.29 +/- 2.86	14.83	**Low/ Medium**	Both hydrological impact models show a decrease trend. WaSiM and SWAT project different absolute values for both time periods as well as different absolute change. The percentual change is roughly in the same magnitude.	**Low/ Medium**
	SWAT		↓	+	3.12 +/- 0.25	2.65 +/- 0.19	-0.47 +/- 0.04	-15.06 +/- 1.28	8.48			
Σ Total Available water (TAW: PRC-ETR)	**WASIM**	mm/a	↓	+	85.66 +/- 15.6	68.26 +/- 10.4	-17.4 +/- 3.17	-20.31 +/- 3.7	18.22	**Low/ Medium**	Both hydrological impact models show a decrease trend. WaSiM and SWAT project different absolute and percentual change values. SWAT features a lot more TAW in the system, although PRC is lower compared to WaSiM. This is possible due to much lower losses in ETR.	**Medium /High**
	SWAT		↓	+	210.03 +/- 17.58	179.97 +/- 14.79	-30.06 +/- 2.53	-14.31 +/- 1.2	8.39			
Percolati	**WASIM**	mm/a	↓	+	12.35 +/- 2.23	10.38 +/- 1.72	-1.97 +/- 0.34	-16 +/- 2.8	17.5	**Low/ Medium**	Both hydrological impact models show a decrease trend. Absolute values of SWAT are much higher than in WaSiM. The percentual change in both models is roughly in the same magnitude.	**Medium /High**
	SWAT		↓	+	84.88 +/- 5.26	74.55 +/- 7.5	-10.33 +/- 0.84	-12.2 +/- 1	8.2			

Interactive Stressors	Trend	Risk Level	Reference Conditions	Likelihood of the projected trend
Water Reserves to Cope with Drought Events	↓	+	Water management in Sardinia is centralized, which has led to the construction of interconnected structures between dams and basins. Sardinia is currently (2012) equipped with 32 reservoirs/dams, exhibiting a storage capacity of 1,865 Mm³. Authorities estimate, that their multi-annual water storage policy is able to cope with three consecutive years of drought (given current water resource uses).	With the increase in severity, intensity and duration of drought events, the decrease in precipitation and discharge, the pressure on the reservoirs is likely to increase.
Use of reclaimed wastewater			In 2011, only three out of 465 wastewater treament plants in Sardinia were equipped with recycling facilities to produce treated water for agricultural uses.	
Groundwater Resources			The volume of available and renewable groundwater in Sardinia is estimated at about 380 Mm³. Groundwater is heavily exploited: 111 Mm³ for domestic use, 76 Mm³ for industry, 64 Mm³ for irrigation. Another estimated 100 Mm³ are additionally exploted by numerous wells.	

Water Demand

Hydrological parameters quantified in CLIMB		Unit	Trend	Risk Level	Multi-Model Average: 1970-2000	Multi-Model Average: 2041-2070	Multi-Model Average: Trend	Multi-Model Average: Trend [%]	Climate Signal Uncertainty: CUS Error [%]	Climate Signal Uncertainty: Impact	Model Structure Uncertainty: Description	Model Structure Uncertainty: Impact
Soil Water Content (SWC)	**WASIM**	[%]	↓	+	16.56 +/- 0.55	14.97 +/- 0.82	-1.59 +/- 0.07	-9.6 +/- 0.42	4.38	**Low**	Both hydrological impact models show a decrease trend. Absolute and percentual values are very similar in both models.	**Low**
	SWAT		↓	+	17.57 +/- 0.76	15.47 +/- 1.19	-2.1 +/- 0.13	-11.95 +/- 0.74	6.17			
Agriculture Water Demand Lettuce (Oct. planting)	**AQUA CROP**	mm/a	↑	+					4.96	**Low**	The values shown assume that irrigation use is optimised. The value for 2041-2070 does not assume any water restrictions. This is unrealistic since hydrological modelling finds that TAW will decrease by 14 - 20 % (see above)	**Low**
Agriculture Water Demand Lettuce (Mar. planting)	**AQUA CROP**		↑	+					2.81			

Interactive Stressors	Trend	Risk Level	Reference Conditions	Likelihood of the projected trend
				Projections from the Italian National Institut of Statistics (ISTAT) assume a decreasing trend for the population in Sardinia, i.e. -14% between 2012

hrc_prc_ref / hrc_prc_monthly / hrc_run_daily / hrc_dis_daily_ref / Supply_DEMAND

http://www.climb-fp7.eu/dissemination/dokumente/Supply_demand_Rio_Mannu_FINAL.xlsx

CLIMB results: quantifying uncertainties

Hydrological parameters quantified in CLIMB		Unit	Trend	Risk Level	Multi-Model Average 1970-2000	Multi-Model Average 2041-2070	Multi-Model Average Trend	Multi-Model Average Trend [%]
Precipitation (PRC)	WASIM	mm/a	↓	+	560.03 +/- 20.08	491.59 +/- 27.27	-68.44 +/- 3.11	-12.22 +/- 0.56
	SWAT		↓	+	474.23 +/- 18.91	406.05 +/- 29.6	-68.18 +/- 3.85	-14.38 +/- 0.81
Potential Evapotranspiration (ETP)	WASIM	mm/a	↑	+	1425.43 +/- 137.06	1651 +/- 162.93	225.57 +/- 21.99	15.82 +/- 1.54
	SWAT		↑	+	992.08 +/- 8.07	1006.95 +/- 8.08	14.87 +/- 0.12	1.5 +/- 0.01
Actual Evapotranspiration (ETR)	WASIM	mm/a	↑	+	474.37 +/- 16.14	423.33 +/- 28.43	-51.04 +/- 2.58	-10.76 +/- 0.54
	SWAT		↑	+	264.2 +/- 6.16	226.07 +/- 17.13	-38.13 +/- 1.89	-14.43 +/- 0.72
Discharge (DIS)	WASIM	m^3/s	↓	+	1.4 +/- 0.21	1.13 +/- 0.14	-0.27 +/- 0.04	-19.29 +/- 2.86
	SWAT		↓	+	3.12 +/- 0.25	2.65 +/- 0.19	-0.47 +/- 0.04	-15.06 +/- 1.28
Σ Total Available water (TAW: PRC-ETR)	WASIM	mm/a	↓	+	85.66 +/- 15.6	68.26 +/- 10.4	-17.4 +/- 3.17	-20.31 +/- 3.7
	SWAT		↓	+	210.03 +/- 17.58	179.97 +/- 14.79	-30.06 +/- 2.53	-14.31 +/- 1.2
Percolati Slide 22	WASIM	mm/a	↓	+	12.35 +/- 2.23	10.38 +/- 1.72	-1.97 +/- 0.34	-16 +/- 2.8
	SWAT		↓	+	84.88 +/- 5.26	74.55 +/- 7.5	-10.33 +/- 0.84	-12.2 +/- 1

6 different hydrological parameters were compared

Trend due to the two HMs is the same for both and for all the 6 parameters

Risk level may increase for all

CLIMB results: quantifying uncertainties

Hydrological parameters quantified in CLIMB		Multi-Model Average				Climate Signal Uncertainty	
		1970-2000	2041-2070	Trend	Trend [%]	CUS Error [%]	Impact
Precipitation (PRC)	WASIM	560.03 +/- 20.08	491.59 +/- 27.27	-68.44 +/- 3.11	-12.22 +/- 0.56	4.58	Low
	SWAT	474.23 +/- 18.91	406.05 +/- 29.6	-68.18 +/- 3.85	-14.38 +/- 0.81	5.62	
Potential Evapotranspiration (ETP)	WASIM	1425.43 +/- 137.06	1651 +/- 162.93	225.57 +/- 21.99	15.82 +/- 1.54	9.73	Low/ Medium
	SWAT	992.08 +/- 8.07	1006.95 +/- 8.08	14.87 +/- 0.12	1.5 +/- 0.01	0.67	
Actual Evapotranspiration (ETR)	WASIM	474.37 +/- 16.14	423.33 +/- 28.43	-51.04 +/- 2.58	-10.76 +/- 0.54	5.02	Low
	SWAT	264.2 +/- 6.16	226.07 +/- 17.13	-38.13 +/- 1.89	-14.43 +/- 0.72	5	
Discharge (DIS)	WASIM	1.4 +/- 0.21	1.13 +/- 0.14	-0.27 +/- 0.04	-19.29 +/- 2.86	14.83	Low/ Medium
	SWAT	3.12 +/- 0.25	2.65 +/- 0.19	-0.47 +/- 0.04	-15.06 +/- 1.28	8.48	
Σ Total Available water (TAW: PRC-ETR)	WASIM	85.66 +/- 15.6	68.26 +/- 10.4	-17.4 +/- 3.17	-20.31 +/- 3.7	18.22	Low/ Medium
	SWAT	210.03 +/- 17.58	179.97 +/- 14.79	-30.06 +/- 2.53	-14.31 +/- 1.2	8.39	
Percolati	WASIM	12.35 +/- 2.23	10.38 +/- 1.72	-1.97 +/- 0.34	-16 +/- 2.8	17.5	Low/ Medium
	SWAT	84.88 +/- 5.26	74.55 +/- 7.5	-10.33 +/- 0.84	-12.2 +/- 1	8.2	

Climate signal uncertainty, estimated comparing HM outputs from the 4 different CMs, suggests a level of impact from low to low-medium

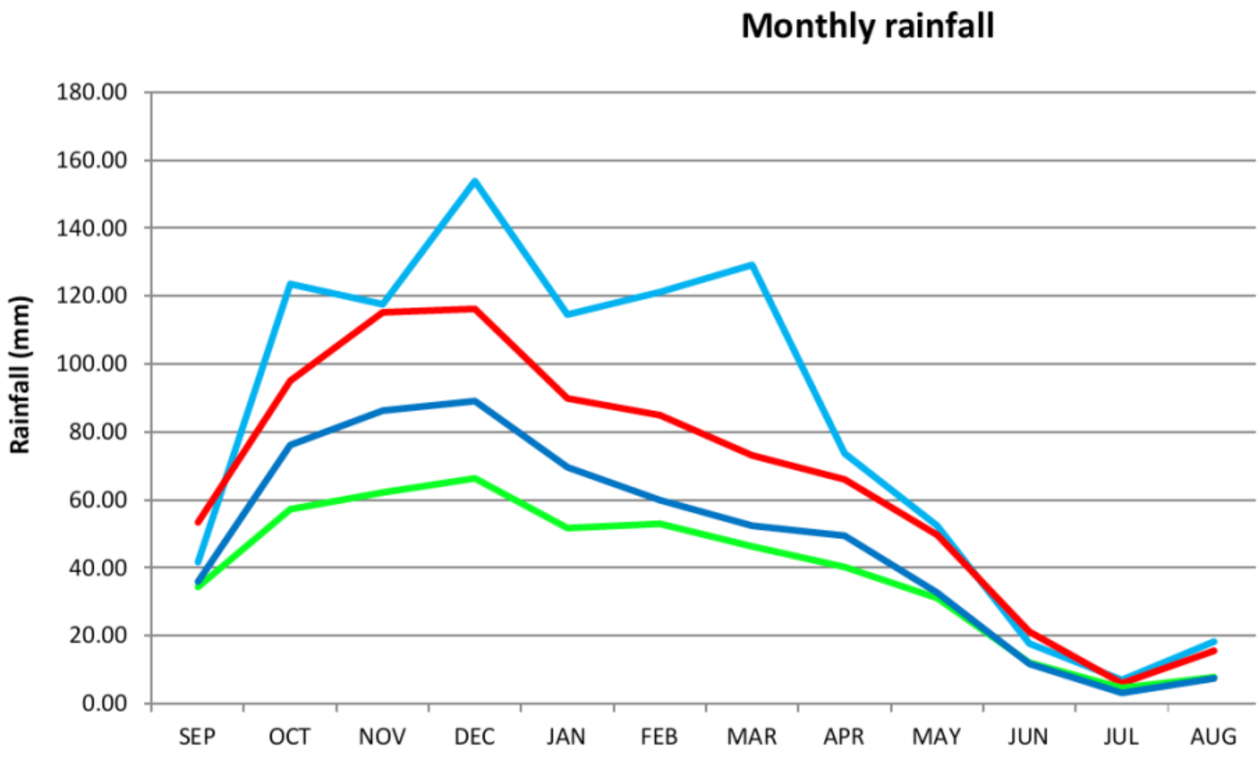
CLIMB results: quantifying uncertainties

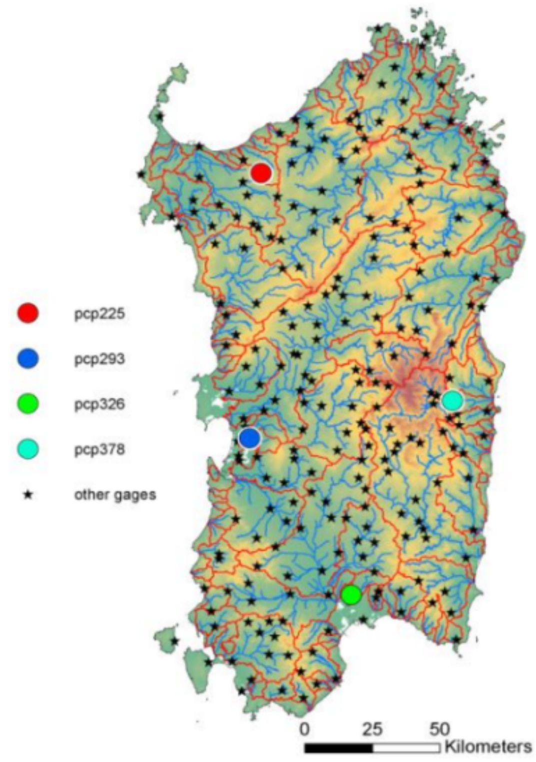
Hydrological parameters quantified in CLIMB		Climate Signal Uncertainty		Model Structure Uncertainty	
		CUS Error [%]	**Impact**	**Description**	**Impact**
Precipitation (PRC)	**WASIM**	4.58	**Low**	Both hydrological impact models show a decrease trend. WaSiM and SWAT project similar absolute and percentual change values.	**Low**
	SWAT	5.62			
Potential Evapotranspiration (ETP)	**WASIM**	9.73	**Low/ Medium**	Both hydrological impact models show an increase trend. WaSiM and SWAT project very different absolute and percentual change values.	**Medium /High**
	SWAT	0.67			
Actual Evapotranspiration (ETR)	**WASIM**	5.02	**Low**	Both hydrological impact models show a decrease trend. WaSiM and SWAT project very different absolute change values. The percentual change is roughly in the same magnitude.	**Medium /High**
	SWAT	5			
Discharge (DIS)	**WASIM**	14.83	**Low/ Medium**	Both hydrological impact models show a decrease trend. WaSiM and SWAT project different absolute values for both time periods as well as different absolute change. The percentual change is roughly in the same magnitude.	**Low/ Medium**
	SWAT	8.48			
Σ Total Available water (TAW: PRC-ETR)	**WASIM**	18.22	**Low/ Medium**	Both hydrological impact models show a decrease trend. WaSiM and SWAT project different absolute and percentual change values. SWAT features a lot more TAW in the system, although PRC is lower compared to WaSiM. This is possible due to much lower losses in ETR.	**Medium /High**
	SWAT	8.39			
Percolati Slide 22	**WASIM**	17.5	**Low/ Medium**	Both hydrological impact models show a decrease trend. Absolute values of SWAT are much higher than in WaSiM. The percentual change in both models is roughly in the same magnitude.	**Medium /High**
	SWAT	8.2			

HM structure uncertainty, estimated comparing outputs from the 2 different HMs, suggests a level of impact medium-high indicating that in this case the major source of uncertaiinty come from the HM structure.
The lower impact of climate signal can be related also to the procedures applied to reduce climate model uncertainty.

Pluviometric data

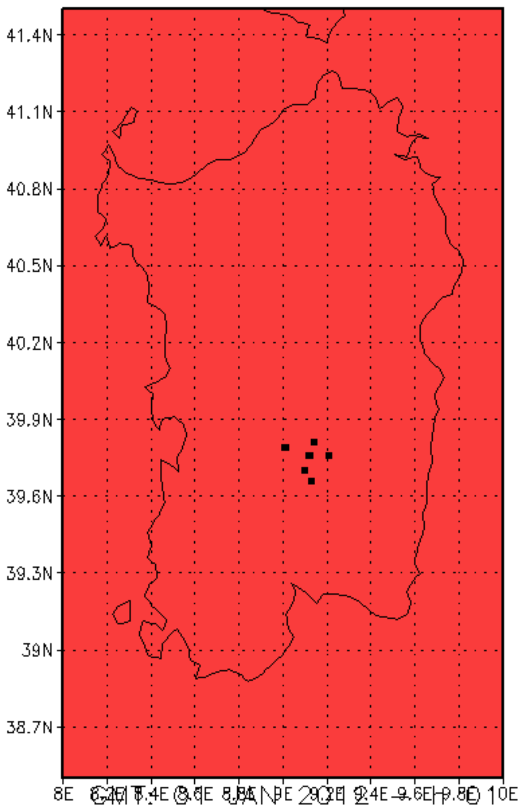
A further reduction of the CM signal uncertainty can be, at least in principle, obtained calibrating pluviometric data exactly were they were observed instead of using a gridded dataset





439 pluviometric stations, From 1 Jan 1922 to 31 Dec 2008, 6 rain gauges contribute to Riu Mannu outflow

QQS: **a method to dowscale RCM output using time series of daily cumulated precipitation**



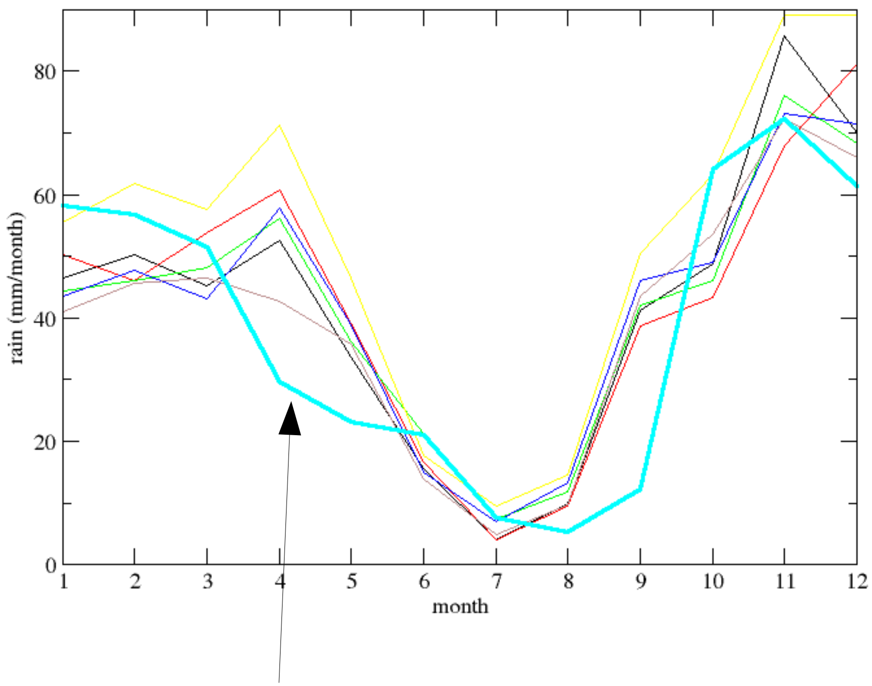
Geographical location of the 6 pluviometers

Id st.	1	2	3	4	5	6
1	1.00	0.46	0.65	0.66	0.69	0.66
2		1.00	0.53	0.57	0.51	0.47
3			1.00	0.68	0.64	0.65
4				1.00	0.75	0.66
5					1.00	0.65
6						1.00

Spatial correlation between daily cumulated values in each of the six stations (period 1979-2008)

RCM (~22 km): bias issue

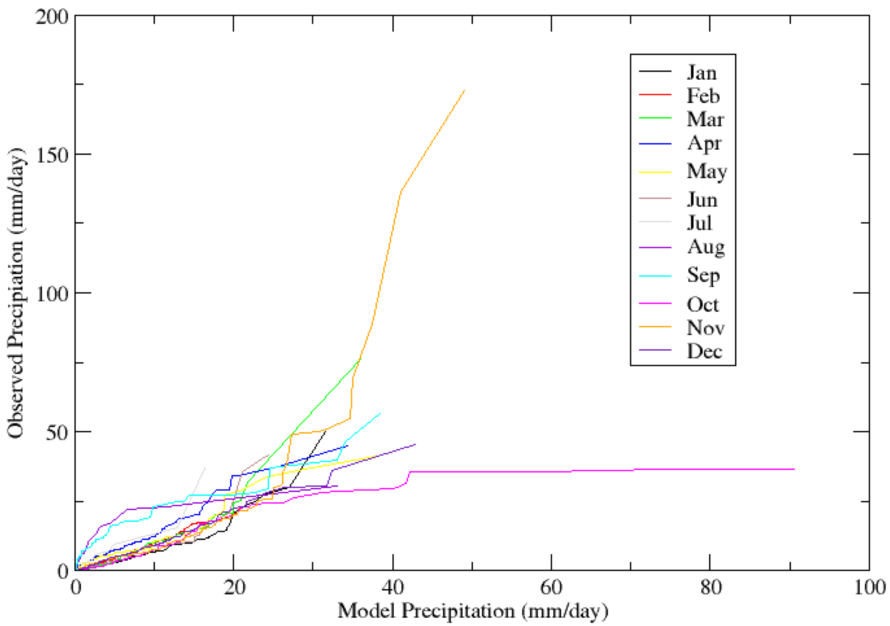
month	st1	st2	st3	st4	st5	st6
gen	58.2	58.2	58.2	58.2	58.2	58.2
feb	56.9	56.9	56.9	56.9	56.9	56.9
mar	51.6	51.6	51.6	51.6	51.6	51.6
apr	29.7	29.7	29.7	29.7	29.7	29.7
mag	23.1	23.1	23.1	23.1	23.1	23.1
giu	21.0	21.0	21.0	21.0	21.0	21.0
lug	7.6	7.6	7.6	7.6	7.6	7.6
ago	5.4	5.4	5.4	5.4	5.4	5.4
set	12.3	12.3	12.3	12.3	12.3	12.3
ott	64.2	64.2	64.2	64.2	64.2	64.2
nov	72.3	72.3	72.3	72.3	72.3	72.3
dic	61.4	61.4	61.4	61.4	61.4	61.4



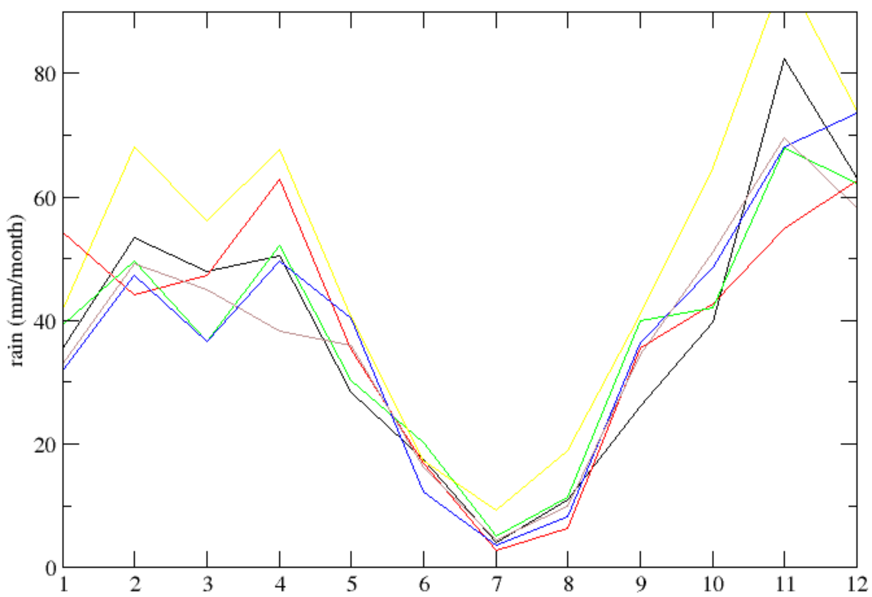
Average cumulated monthly values for each of the 6 pluviometers and corresponding RCM output (thick line)

Seasonal cycle is not well represented

RCM (~22 km): bias removal



Quantile-Quantile calibration plot of RCM against measuered data



Average cumulated monthly values after QQ correction for each of the 6 pluviometers after QQ correction

QQ corrected: correlation issues

Id st.	1	2	3	4	5	6
1	1.00	0.98	0.95	0.97	0.96	0.92
2		1.00	0.97	0.97	0.96	0.94
3			1.00	0.96	0.93	0.95
4				1.00	0.95	0.96
5					1.00	0.94
6						1.00

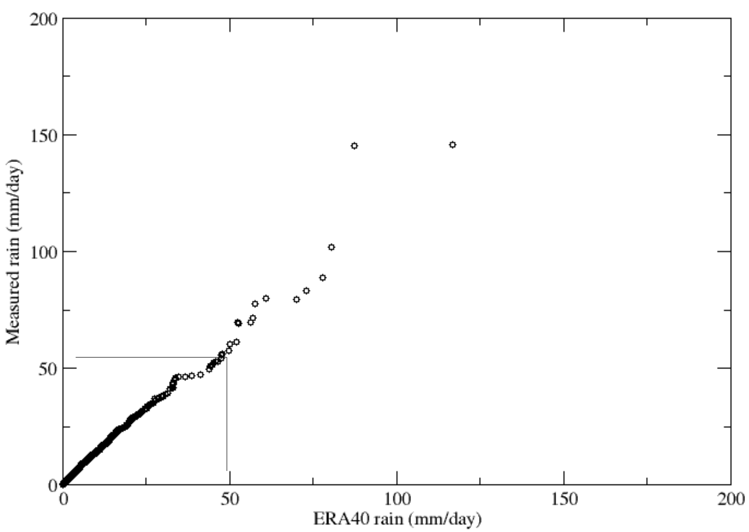
Spatial correlation between daiily cumulated values in each of the six stations (period 1979-2008) after deterministic QQ correction

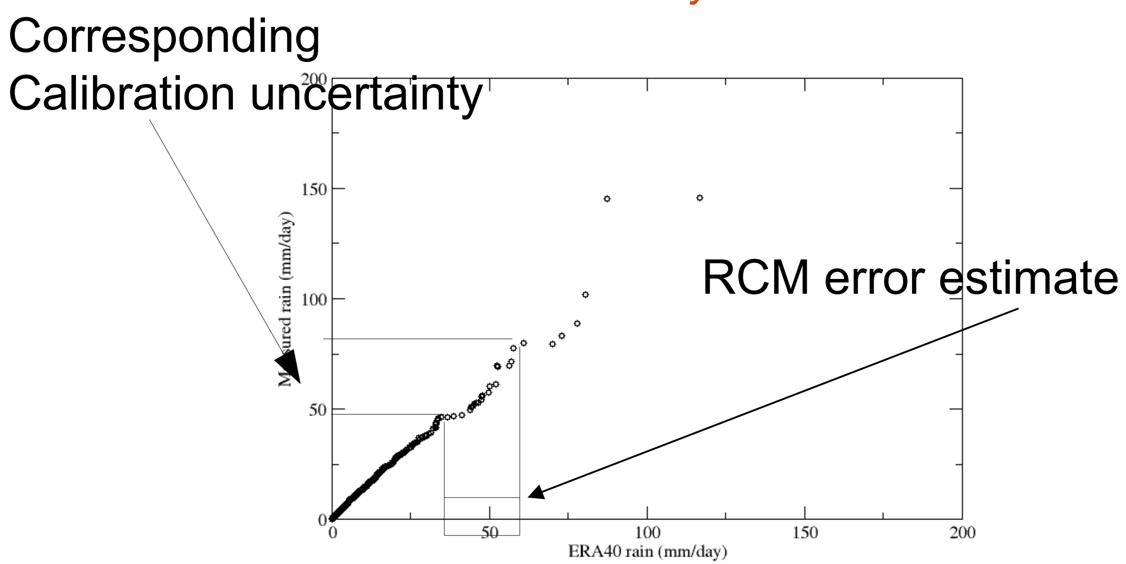
Unrealistically too high

Id st.	1	2	3	4	5	6
1	1.00	0..38	0.38	0.39	0.40	0.42
2		1.00	0.35	0.40	0.39	0.36
3			1.00	0.41	0.43	0.41
4				1.00	0.45	0.40
5					1.00	0.40
6						1.00

Spatial correlation between daiily cumulated values in each of the six stations (period 1979-2008) after stochastic QQ correction

Unrealistically too low





QQS

An ensemble of measured data is built for each month using all the measured data with the same number of members of the QQ ensemble (~10)

For each day and station the QQ ensemble members are shuffled in such a way to have the same relative rank of the observed ensemble:

For example if for day 1 and station 1 the order of measured data for the 10 members is (7,4,8,2,6,5,9,1,3,10) the members of the cooresponding QQ ensemble are shuffled in such a way that the higher member value is assigned to the 7.th member the second higher to the 4.th stations.....

Id st.	1	2	3	4	5	6
1	1.00	0..38	0.38	0.39	0.40	0.42
2		1.00	0.35	0.40	0.39	0.36
3			1.00	0.41	0.43	0.41
4				1.00	0.45	0.40
5					1.00	0.40
6						1.00

Spatial correlation between daiily cumulated values in each of the six stations (period 1979-2008) after stochastic QQ correction

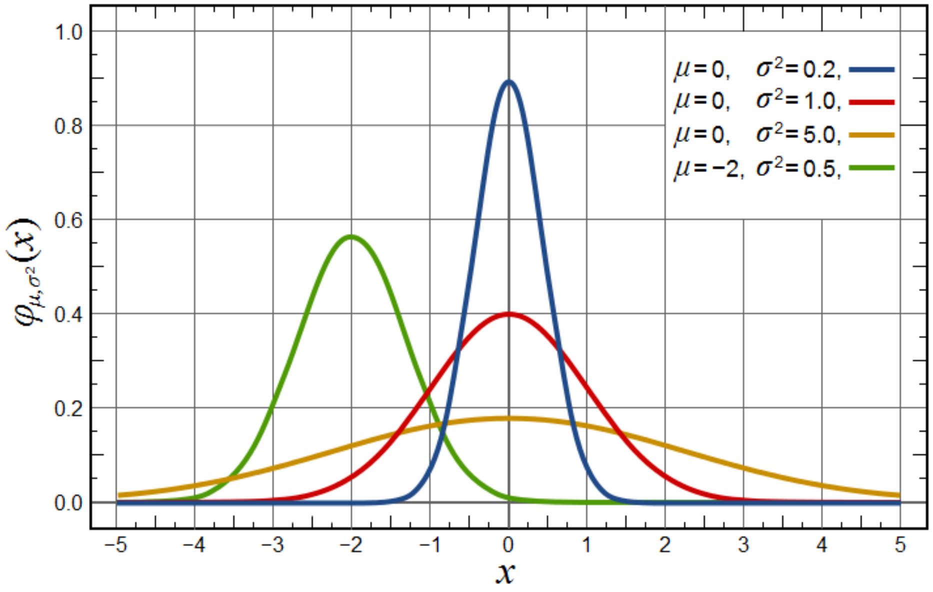
Id st.	1	2	3	4	5	6
1	1.00	0.51	0.66	0.67	0.68	0.64
2		1.00	0.47	0.48	0.48	0.46
3			1.00	0.63	0.67	0.61
4				1.00	0.65	0.63
5					1.00	0.61
6						1.00

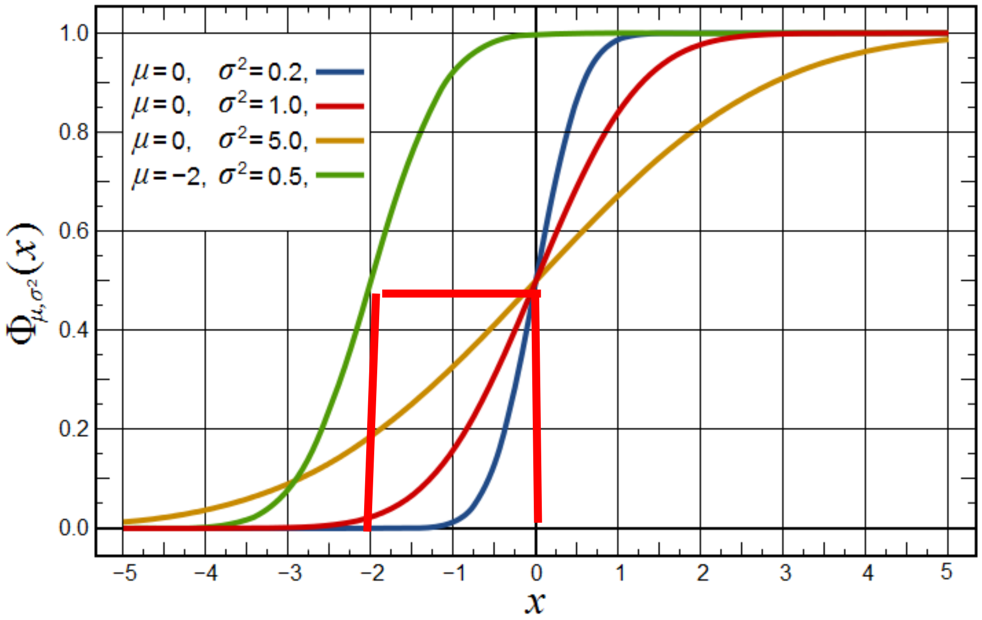
Spatial correlation between daiily cumulated values in each of the six stations (period 1979-2008) after stochastic QQ correction and shuffling of members

In conclusion..

- Diifferent approaches can be used to reduce CM uncertainty and fill the gap between CM scales and HM at catchment scale
- Within SWAT a weather generator appproach is embedded and can be used.
- In CLIMB project we coupled a bias removal distribution mapping method and a spatio-temporal statistical downscaling techinique with SWAT, strongly reducing uncertainty related to CM signal
- We then developed a new method named QQS to simultaneuosly reconstruct a realistic spatial correlation within the catchment (bias removall+downscaling) that we are currently using for the assesment of regional hydrological budget with SWAT (see presentations of Pierluigi Cau and Pier Andrea Marras)
- At the same time a different approach has also been studied in collaboration with Patras University in Greece and the University of Cagliari: using a statistical framework for simulation of daily rainfall intensities conditional on upper air variables that are much less biased than precipitation. ------> *Andreas Langousis, Antonis Mamalakis, Roberto Deidda, and Marino Marrocu*. **Assessing the relative effectiveness of statistical downscaling and distribution mapping in reproducing rainfall statistics based on climate model results.** Submitted to Water Resouce Research 2015.

Daily translation method





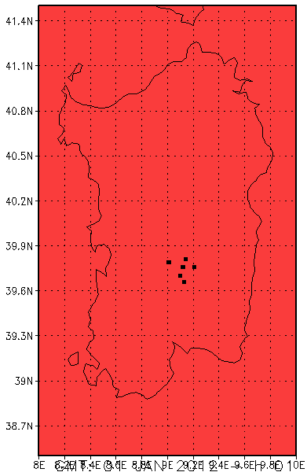
This explain also because it is named daily translation method.
Since we want to establish a correspondence between modelled and measured values linked by the same value of th cdf we can eliminate the cdf variable abd obtain directly a QQ calibration plot as this one

Reducing hydrological budget modeling uncertainty related to climate induced change

Marino Marrocu, PierLuigi Cau, Gabriella Pusceddu, Dino Soru, Davide Muroni, PierAndrrea Marras

Envinronmental Sciences Research Program, CRS4, Pula, (CA), Italy.
Email: marino.marrocu@crs4.it

QQS: a method to dowscale RCM output using time series of daily cumulated precipitation



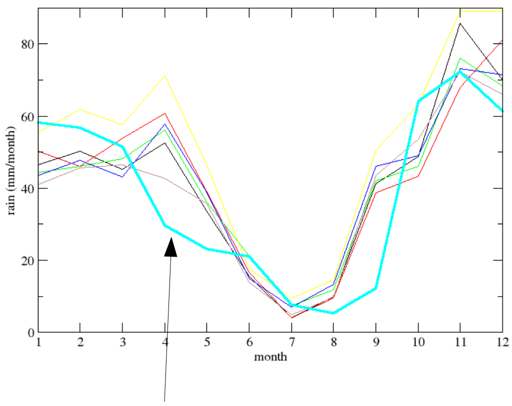
Geographical location of the 6 pluviometers

Id st.	1	2	3	4	5	6
1	1.00	0.46	0.65	0.66	0.69	0.66
2		1.00	0.53	0.57	0.51	0.47
3			1.00	0.68	0.64	0.65
4				1.00	0.75	0.66
5					1.00	0.65
6						1.00

Spatial correlation between daily cumulated values in each of the six stations (period 1979-2008)

RCM (~22 km): bias issue

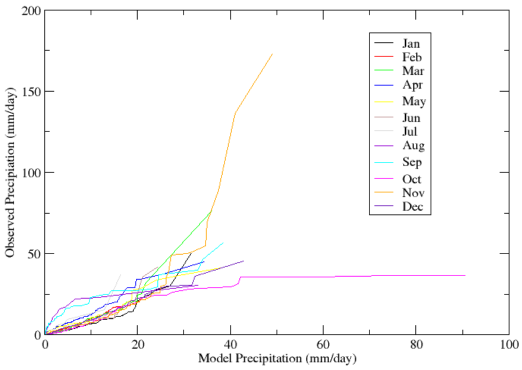
month	st1	st2	st3	st4	st5	st6
gen	58.2	58.2	58.2	58.2	58.2	58.2
feb	56.9	56.9	56.9	56.9	56.9	56.9
mar	51.6	51.6	51.6	51.6	51.6	51.6
apr	29.7	29.7	29.7	29.7	29.7	29.7
mag	23.1	23.1	23.1	23.1	23.1	23.1
giu	21.0	21.0	21.0	21.0	21.0	21.0
lug	7.6	7.6	7.6	7.6	7.6	7.6
ago	5.4	5.4	5.4	5.4	5.4	5.4
set	12.3	12.3	12.3	12.3	12.3	12.3
ott	64.2	64.2	64.2	64.2	64.2	64.2
nov	72.3	72.3	72.3	72.3	72.3	72.3
dic	61.4	61.4	61.4	61.4	61.4	61.4



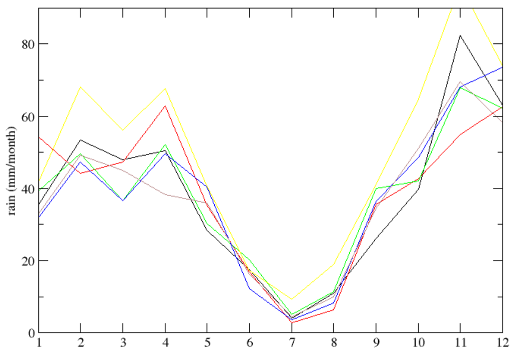
Seasonal cycle is not well represented

Average cumulated monthly values for each of the 6 pluviometers and corresponding RCM output (thick line)

RCM (~22 km): bias removal



Quantile-Quantile calibration plot of RCM against measuered data



Average cumulated monthly values after QQ correction for each of the 6 pluviometers after QQ correction

QQ corrected: correlation issues

Id st.	1	2	3	4	5	6
1	1.00	0.98	0.95	0.97	0.96	0.92
2		1.00	0.97	0.97	0.96	0.94
3			1.00	0.96	0.93	0.95
4				1.00	0.95	0.96
5					1.00	0.94
6						1.00

Spatial correlation between dailiy cumulated values in each of the six stations (period 1979-2008) after deterministic QQ correction
Unrealistically too high

Id st.	1	2	3	4	5	6
1	1.00	0..38	0.38	0.39	0.40	0.42
2		1.00	0.35	0.40	0.39	0.36
3			1.00	0.41	0.43	0.41
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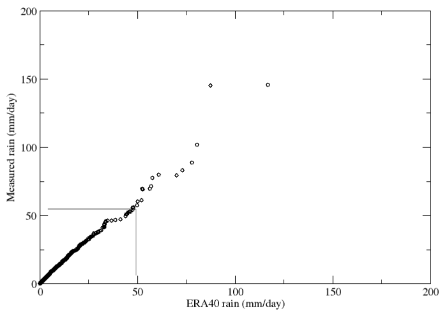
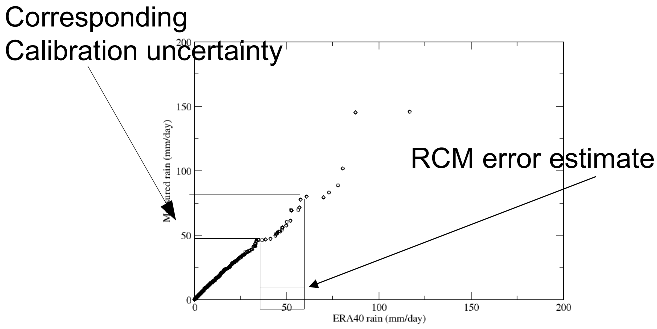
Spatial correlation between dailiy cumulated values in each of the six stations (period 1979-2008) after stochastic QQ correction
Unrealistically too low





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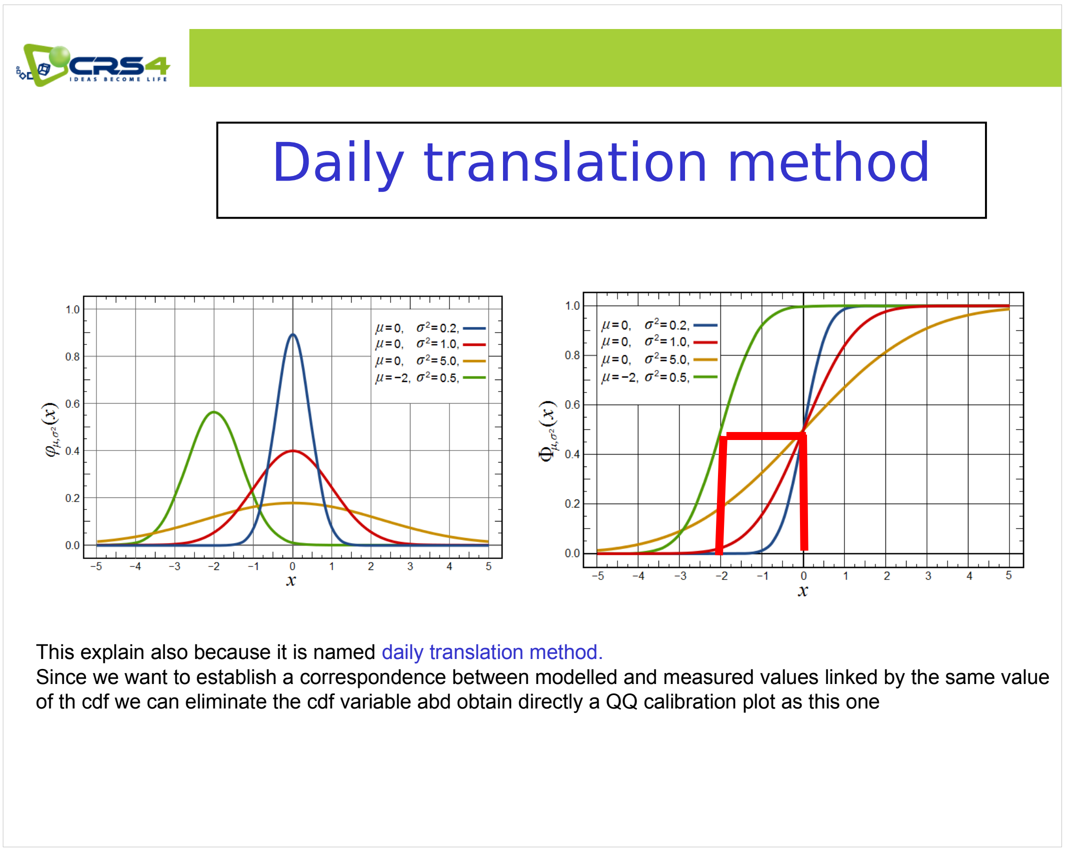
Spatial correlation between daiily cumulated values in each of the six stations (period 1979-2008) after stochastic QQ correction and shuffling of members



Here is a very very short summary an one important note to better understand the results I'll show you in the next slides.

First of all there will be a couple of slides summarizing scores of the RCM at synoptic scale on the Mediterranean area

Obtained within the ENSEMBLES projects that is our climatic models data-provider.

Then I'll show results obtained, by us, doing a systematic verification, relatively to the mean states and

their fluctuations, of the same RCM outputs, over the 6 study sites. Only Riu Mannu results, and only for precipitation,

will be shown here for reasons of time, but data of all the other study sites have been elaborated with the same procedures.

Scores are evaluated comparing model data with the ECA&D dataset (we will use the acronym **CRU**) also produced within

ENSEMBLES RT5 for two, 30 years long, climatic periods of the past. The 1951-1980 climate and the 1981-2010 climate.