Regional Climate simulations over multiple domains with COSMO-CLM: Status of CORDEX simulations and lessons learned

Silje Lund Sørland[1], Roman Brogli[1], Praveen Kumar[2], Emmanuele Russo[3], Jonas Van de Walle[4], Ivonne Anders[5], Edoardo Bucchignan[6], Marie-Estelle Demory[1], Alessandro Dosio[7], Hendrik Feldman[8], Barbara Früh[9], Beate Geyer[10], Klaus Keuler[11], Donghyun Lee[12], Delei Li[13], Nicole van Lipzig[4], Seung-Ki Min[12], Hans-Jürgen Paniz[8], Burkhardt Rockel[10], Christoph Schär[1], Christian Steger[9], and Wim Thiery[14]

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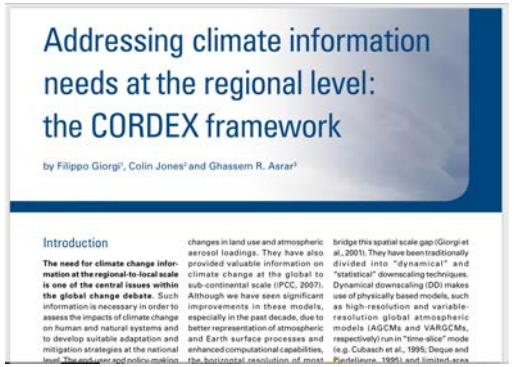
[13]CAS Key Laboratory of Ocean Circulation and Waves, Institute of Oceanology, Chinese Academy of Sciences, Qingdao, China
[14]University of Brussels, Belgium

COSMO-CLM Climate Limited-area Modelling Community



Addressing climate information needs at the regional level: the CORDEX framework

by Filippo Giorgi[1], Colin Jones[2] and Ghassem R. Asrar[3]

Introduction

The need for climate change information at the regional-to-local scale is one of the central issues within the global change debate. Such information is necessary in order to assess the impacts of climate change on human and natural systems and to develop suitable adaptation and mitigation strategies at the national

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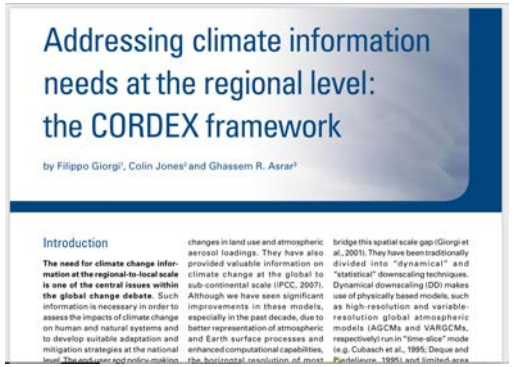
CORDEX was officially designed and endorsed by the World Climate Research Programme (WCRP)

CORDEX to coordinate the downscaling of CMIP5



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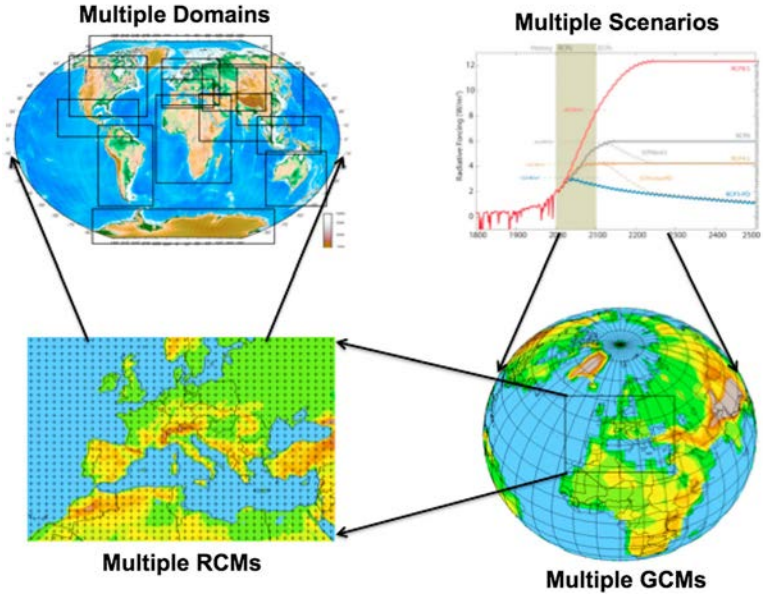

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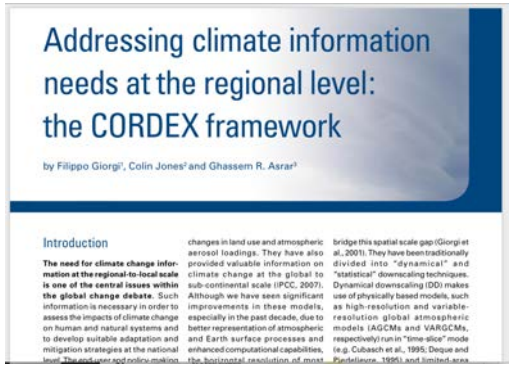
CORDEX to coordinate the downscaling of CMIP5

RCMs Δx 50-12km
Which GCMs?
Which RCPs?

Africa (AFR)
South Asia (WAS)
Central America (CAM)
Southeast Asia (SEA)
South America (SAM)
Middle East North Africa (MNA)
East Asia (EAS)
Antarctica (ART)
Mediterranean (MED)
Arctic (ARC)
Europe (EUR)
North America (NAM)
Australia (AUS)
Central Asia (CAS)



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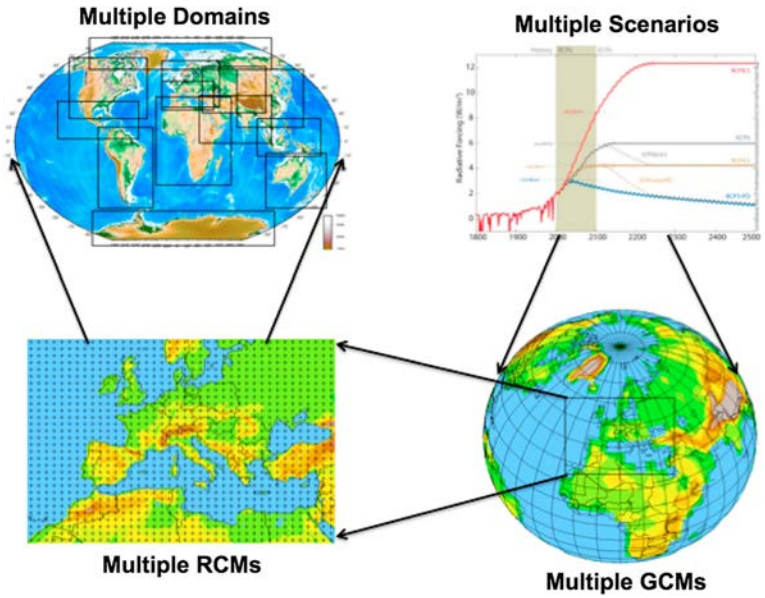
Giorgi et al. 2009 in WMO Bulletin



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2016

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CORDEX-CORE

RCMs Δx 25km
3 GCMs (HadGEM,MPI-ESM, Nor-ESM)
2 RCPs (RCP2.6 and RCP8.5)

Africa (AFR)
South Asia (WAS)
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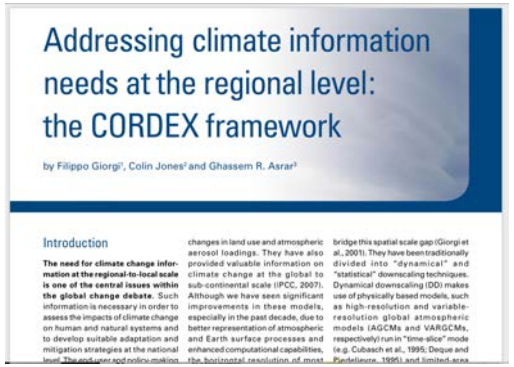
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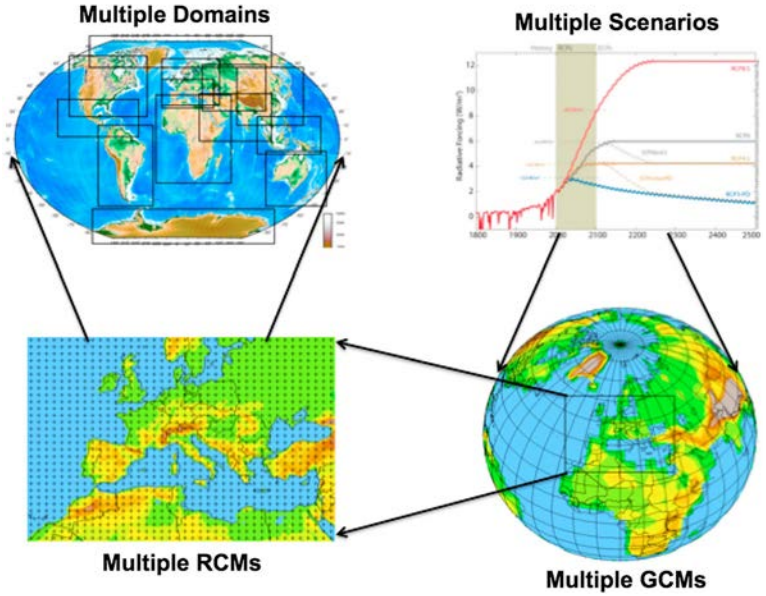



To produce CORDEX simulations requires a lot of computing time and storage.

Today Earth System Grid Federation (ESGF) servers contains more than 370 GCM-RCM model chain simulations, and the number of simulations has increased substantially the last years.

2009 2016 2020

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CORDEX to coordinate the downscaling of CMIP5

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CORDEX-CORE

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To follow CORDEX-CORE: Each RCM needs to be run for more than 6000 model years, producing over 400 TB of data.



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2020

, Nor-ESM)

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The CLM-Community's contribution to CORDEX simulations

		EUR	
		0.11	0.44
MPI-ESM-r1	CCLM4-8-17	✓	✓
	CCLM4-8-17-CLM3-5		
	CCLM5-0-2		
	CCLM5-0-6		✓
	CCLM-5-0-9		
	CCLM-5-0-15		
	CcrCLIM-v1-1	✓	
MPI-ESM-r2	CcrCLIM-v1-1	✓	
MPI-ESM-r3	CcrCLIM-v1-1	✓	
HadGEM2-ES-r1	CCLM4-8-17	✓	
	CCLM5-0-2		
	CCLM5-0-6		✓
	CCLM5-0-15		
HadGEM2-AO-r1	CCLM-5-0-9		
CNRM-CM5-r1	CCLM4-8-17	✓	
	CCLM5-0-2		
	CCLM5-0-6		✓
EC-EARTH-r12	CCLM4-8-17	✓	
	CCLM4-8-17-CLM3-5		
	CCLM5-0-2		
	CCLM5-0-6		✓
	CcrCLIM-v1-1	✓	
CanESM2-r1	CCLM4-8-17	✓	
NorESM-r1	CCLM5-0-15		
	CcrCLIM-v1-1	✓	
MIROC5-r1	CCLM4-8-17	✓	
	CCLM5-0-6		✓
Sum RCP8.5	38	11	6
Sum RCP4.5	16	4	1
Sum RCP2.6	14	4	0

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	CCLM5-0-2		
	CCLM5-0-6		✓
	CCLM-5-0-9		
	CCLM-5-0-15		
	CcrCLIM-v1-1	✓	
MPI-ESM-r2	CcrCLIM-v1-1	✓	
MPI-ESM-r3	CcrCLIM-v1-1	✓	
HadGEM2-ES-r1	CCLM4-8-17	✓	
	CCLM5-0-2		
	CCLM5-0-6		✓
	CCLM5-0-15		
HadGEM2-AO-r1	CCLM-5-0-9		
CNRM-CM5-r1	CCLM4-8-17	✓	
	CCLM5-0-2		
	CCLM5-0-6		✓
EC-EARTH-r12	CCLM4-8-17	✓	
	CCLM4-8-17-CLM3-5		
	CCLM5-0-2		
	CCLM5-0-6		✓
	CcrCLIM-v1-1	✓	
CanESM2-r1	CCLM4-8-17	✓	
NorESM-r1	CCLM5-0-15		
	CcrCLIM-v1-1	✓	
MIROC5-r1	CCLM4-8-17	✓	
	CCLM5-0-6		✓
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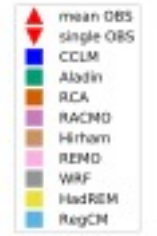

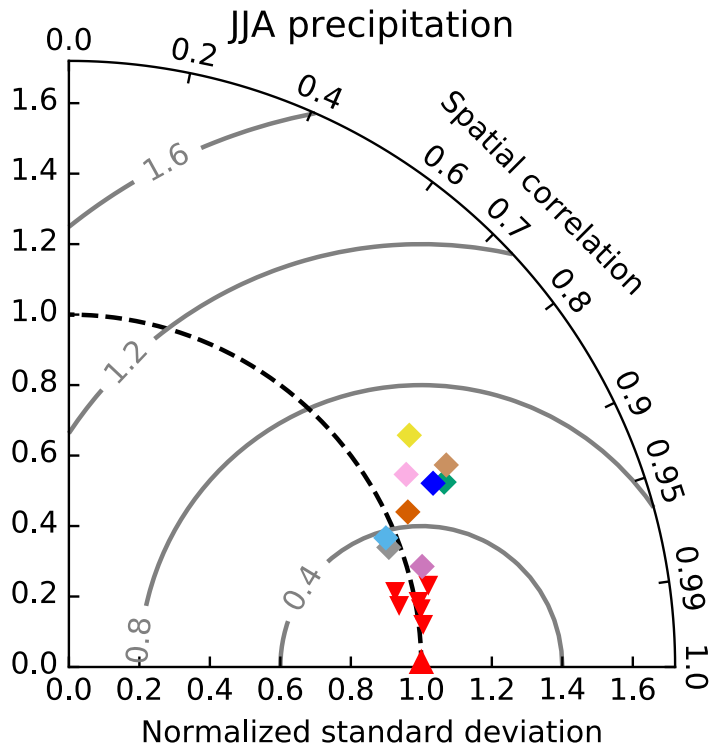



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2020

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The CLM-Community's contribution to CORDEX simulations

		EUR		AFR		EAS		AUS		WAS	
		0.11	0.44	0.22	0.44	0.22	0.44	0.22	0.44	0.22	0.44
MPI-ESM-r1	CCLM4-8-17	✓	✓		✓						(✓)
	CCLM4-8-17-CLM3-5								✓		
	CCLM5-0-2						✓				
	CCLM5-0-6		✓								
	CCLM-5-0-9					✓					
	CCLM-5-0-15			✓				✓			
	CcrCLIM-v1-1	✓								✓	
MPI-ESM-r2	CcrCLIM-v1-1	✓									
MPI-ESM-r3	CcrCLIM-v1-1	✓									
HadGEM2-ES-r1	CCLM4-8-17	✓			✓						
	CCLM5-0-2						✓				
	CCLM5-0-6		✓								
	CCLM5-0-15			✓				✓			
HadGEM2-AO-r1	CCLM-5-0-9					✓					
CNRM-CM5-r1	CCLM4-8-17	✓			✓						
	CCLM5-0-2						✓				
	CCLM5-0-6		✓								
EC-EARTH-r12	CCLM4-8-17	✓			✓						
	CCLM4-8-17-CLM3-5								✓		
	CCLM5-0-2						✓				
	CCLM5-0-6		✓								
	CcrCLIM-v1-1	✓								✓	
CanESM2-r1	CCLM4-8-17	✓									
NorESM-r1	CCLM5-0-15			✓				✓			
	CcrCLIM-v1-1	✓								✓	
MIROC5-r1	CCLM4-8-17	✓									
	CCLM5-0-6		✓								
Sum RCP8.5	38	11	6	3	4	2	4	3	2	3	0
Sum RCP4.5	16	4	1	0	4	0	4	0	2	0	1
Sum RCP2.6	14	4	0	3	0	2	0	3	0	2	0
Sum all RCPs	68 (80 incl ERA-I)										

What can we learn from this set of simulation?



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2020

, Nor-ESM)

CORDEX phase 2? CMIP6?

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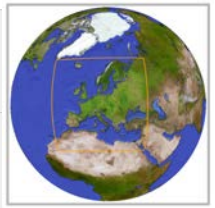
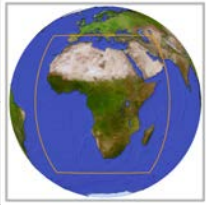
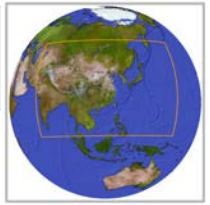
		0.11	0.44	0.22	0.44	0.22	0.44	0.22	0.44	0.22	0.44
MPI-ESM-r1	CCLM4-8-17	✓	✓		✓						(✓)
	CCLM4-8-17-CLM3-5								✓		
	CCLM5-0-2						✓				
	CCLM5-0-6		✓								
	CCLM-5-0-9					✓					
	CCLM-5-0-15			✓				✓			
	CcrCLIM-v1-1	✓								✓	
MPI-ESM-r2	CcrCLIM-v1-1	✓									
MPI-ESM-r3	CcrCLIM-v1-1	✓									
HadGEM2-ES-r1	CCLM4-8-17	✓			✓						
	CCLM5-0-2						✓				
	CCLM5-0-6		✓								
	CCLM5-0-15			✓				✓			
HadGEM2-AO-r1	CCLM-5-0-9					✓					
CNRM-CM5-r1	CCLM4-8-17	✓			✓						
	CCLM5-0-2						✓				
	CCLM5-0-6		✓								
EC-EARTH-r12	CCLM4-8-17	✓			✓						
	CCLM4-8-17-CLM3-5								✓		
	CCLM5-0-2						✓				
	CCLM5-0-6		✓								
	CcrCLIM-v1-1	✓								✓	
CanESM2-r1	CCLM4-8-17	✓									
NorESM-r1	CCLM5-0-15			✓				✓			
	CcrCLIM-v1-1	✓								✓	
MIROC5-r1	CCLM4-8-17	✓									
	CCLM5-0-6		✓								
Sum RCP8.5	38	11	6	3	4	2	4	3	2	3	0
Sum RCP4.5	16	4	1	0	4	0	4	0	2	0	1
Sum RCP2.6	14	4	0	3	0	2	0	3	0	2	0
Sum all RCPs	68 (80 incl ERA-I)										

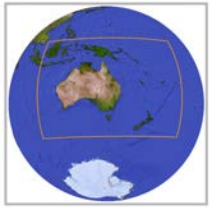
What can we learn from this set of simulation?

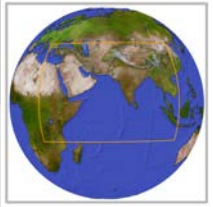
		Model version	Institute	Vertical levels Model top	Time step (s)	Aerosol	Tuning param	Other	Reference
Europe (EUR)	EUR-11	CCLM4-8-17	BTU, DWD, ETH	40/22.7km	100	Tanre	Default		Kotlarski et al. (2014); Keuler et al. (2016); Dalelane et al. (2018); Bülow et al. (2019).
		COSMO-crCLIM-v1-1	ETH	40/22.7km	90	Aerocom	Default, except a some changed due to past experience and sensistivity runs (tkhmin, tkmmin,		Leutwyler et al. (2017) Vautard et al. (2020)
	EUR-44	CCLM4-8-17	BTU	40/22.7km	300	Tanre	Default		
		CCLM5-0-6	ETH	40/22.7km	300	Tanre	Objective Calibration	The recommended version from the CLM-Community (from year 2015)	Sørland et al. (2018)
Africa (AFR)	AFR-22	CCLM4-8-17	KIT	35/30km	120	Tanre	Default	Used to investigate the added value of increasing the horizontal resolution. Thus, only one evaluation run (1989-2000).	Panitz et al. (2014)
		CCLM-5-0-15	KIT	57/30km	150	Tegen	Default, except q_crit, rlam_heat, uc1, following Bucchignani et al. (2016)	CORDEX-CORE framework	
	AFR-44	CCLM4-8-17	KIT	35/30km	240	Tanre	Default	Tropical setup, and lower height of damping changed to 18 km.	Panitz et al. (2014) Dosio and Panitz (2016) Dosio et al. (2015)
East Asia (EAS)	EAS-22	CCLM5-0-9	POSTECH	45/30km	150	Type 2 (Tegen or Aerocom)	Default except tkhmin, rlam_heat, entr_sc, uc1, fac_rootdp2, soilhyd	Spectral nudging on. CORDEX-CORE framework	
	EAS-44	CCLM-5-0-2	HZG	40/22.7km	300	Tanre	Default		Li et al. (2018, 2019)
Australasia (AUS)	AUS-22	CCLM-5-0-15	HZG	57/30km	150	Tanre	Default (except rat_sea which is decreased)	Tropical setup, and lower height of damping changed to 18 km. Bechthold et al. (2008) convection scheme. CORDEX-CORE framework.	
	AUS-44	CCLM4-8-17-CLM3-5	HZG	35/30km	360	Tanre	Default	Tropical setup, and lower height of damping changed to 18 km Bechthold et al. (2008) convection scheme. Coupled to the Community Land Model	Di Virgilio et al. (2019) Hirsch et al. (2019)
South Asia (WAS)	WAS-22	COSMO-crCLIM-v1-1	ETH/GUF	57/30km	150	Aerocom	Default, except a couple changed due to sensitivity runs: rlam_heat, radfac, l_g	Tropical setup, and lower height of damping changed to 18 km. CORDEX-CORE framework.	Leutwyler et al. (2017); Pothapakula et al. in prep.
	WAS-44	CCLM4-8-17	GUF	35/?				Kessler (1969) microphysics scheme. No ERA-Interim simulation is performed, but the MPI-ESM-LR has been downscaled for the historical period and RCP4.5 scenario.	Asharaf and Ahrens (2015)











Official CORDEX-simulations

Focusing on simulations that are published on the ESGF-node

Evaluation runs (ERA-Interim) (12 simulations)
The GCM historical simulations (38 simulations)
Time period:
Historical: 1981-2010 (from 2006-2010 RCP85 is used)

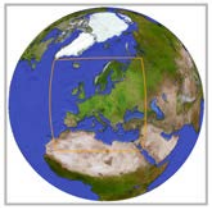
Sharing data

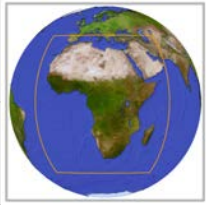
The simulations are collected and placed on an FTP-server as monthly mean.

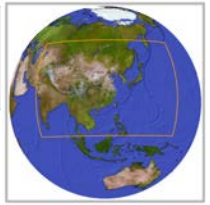
Analyzing

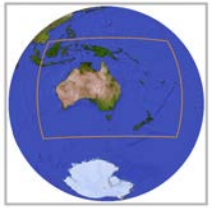
Seasonal means of T2M and PR (focusing on JJA and DJF)

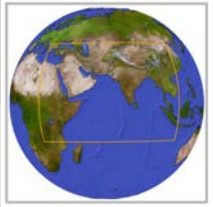
		Model version	Institute	Vertical levels Model top	Time step (s)	Aerosol	Tuning param	Other	Reference
Europe (EUR)	**EUR-11**	CCLM4-8-17	BTU, DWD, ETH	40/22.7km	100	Tanre	Default		Kotlarski et al. (2014); Keuler et al. (2016); Dalelane et al. (2018); Bülow et al. (2019).
		COSMO-crCLIM-v1-1	ETH	40/22.7km	90	Aerocom	Default, except a some changed due to past experience and sensistivity runs (tkhmin, tkmmin,		Leutwyler et al. (2017) Vautard et al. (2020)
	EUR-44	CCLM4-8-17	BTU	40/22.7km	300	Tanre	Default		
		CCLM5-0-6	ETH	40/22.7km	300	Tanre	Objective Calibration	The recommended version from the CLM-Community (from year 2015)	Sørland et al. (2018)
Africa (AFR)	**AFR-22**	CCLM4-8-17	KIT	35/30km	120	Tanre	Default	Used to investigate the added value of increasing the horizontal resolution. Thus, only one evaluation run (1989-2000).	Panitz et al. (2014)
		CCLM-5-0-15	KIT	57/30km	150	Tegen	Default, except q_crit, rlam_heat, uc1, following Bucchignani et al. (2016)	CORDEX-CORE framework	
	AFR-44	CCLM4-8-17	KIT	35/30km	240	Tanre	Default	Tropical setup, and lower height of damping changed to 18 km.	Panitz et al. (2014) Dosio and Panitz (2016) Dosio et al. (2015)
East Asia (EAS)	**EAS-22**	CCLM5-0-9	POSTECH	45/30km	150	Type 2 (Tegen or Aerocom)	Default except tkhmin, rlam_heat, entr_sc, uc1, fac_rootdp2, soilhyd	Spectral nudging on. CORDEX-CORE framework	
	EAS-44	CCLM-5-0-2	HZG	40/22.7km	300	Tanre	Default		Li et al. (2018, 2019)
Australasia (AUS)	**AUS-22**	CCLM-5-0-15	HZG	57/30km	150	Tanre	Default (except rat_sea which is decreased)	Tropical setup, and lower height of damping changed to 18 km. Bechthold et al. (2008) convection scheme. CORDEX-CORE framework.	
	AUS-44	CCLM4-8-17-CLM3-5	HZG	35/30km	360	Tanre	Default	Tropical setup, and lower height of damping changed to 18 km Bechthold et al. (2008) convection scheme. Coupled to the Community Land Model	Di Virgilio et al. (2019) Hirsch et al. (2019)
South Asia (WAS)	**WAS-22**	COSMO-crCLIM-v1-1	ETH/GUF	57/30km	150	Aerocom	Default, except a couple changed due to sensitivity runs: rlam_heat, radfac, l_g	Tropical setup, and lower height of damping changed to 18 km. CORDEX-CORE framework.	Leutwyler et al. (2017); Pothapakula et al. in prep.
	WAS-44	CCLM4-8-17	GUF	35/?				Kessler (1969) microphysics scheme. No ERA-Interim simulation is performed, but the MPI-ESM-LR has been downscaled for the historical period and RCP4.5 scenario.	Asharaf and Ahrens (2015)











To evaluate the simulations

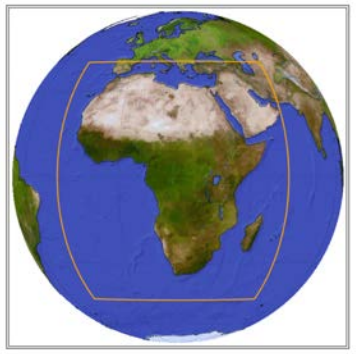
Global observation datasets

Precipitation

CRU v3.24 (0.5°,monthly)
UDEL v4.01 (0.5°, monthly)
GPCC (0.25°, monthly)
GPCP (2.5°, monthly)
MSWEP v2.2 (0.1° daily -> monthly)

Temperature

CRU v3.24 (0.5° monthly)
UDEL v4.01 (0.5° monthly)
GHCN_CAMS (0.5° monthly)



		Model version	Institute	Vertical levels Model top	Time step (s)	Aerosol	Tuning param	Other	Reference
Africa (AFR)	AFR-22	CCLM4-8-17	KIT	35/30km	120	Tanre	Default	Used to investigate the added value of increasing the horizontal resolution. Thus, only one evaluation run (1989-2000).	Panitz et al. (2014)
		CCLM-5-0-15	KIT	57/30km	150	Tegen	Default, except q_crit, rlam_heat, uc1, following Bucchignani et al. (2016)	CORDEX-CORE framework	
	AFR-44	CCLM4-8-17	KIT	35/30km	240	Tanre	Default	Tropical setup, and lower height of damping changed to 18 km.	Panitz et al. (2014) Dosio and Panitz (2016) Dosio et al. (2015)

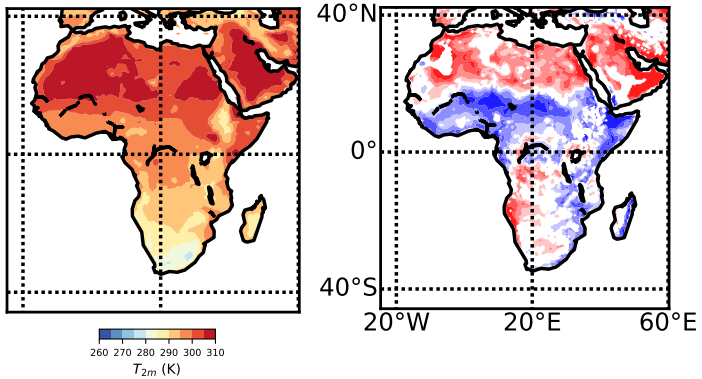
Two model-versions
CCLM4-8-17 vs CCLM5-0-15

Two resolutions
AFR-44 vs AFR-22

June-July-August

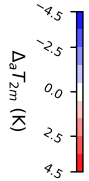
AFR-44
CCLM4-8-17

GHNC

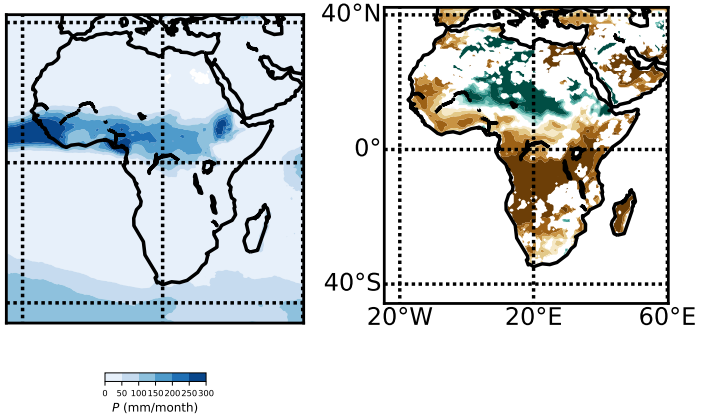


Summer hemisphere

Winter hemisphere

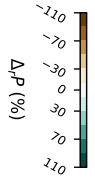


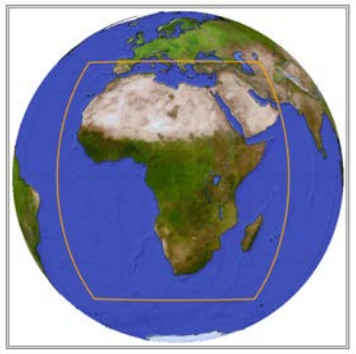
MSWEP



Summer hemisphere

Winter hemisphere





		Model version	Institute	Vertical levels Model top	Time step (s)	Aerosol	Tuning param	Other	Reference
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		CCLM-5-0-15	KIT	57/30km	150	Tegen	Default, except q_crit, rlam_heat, uc1, following Bucchignani et al. (2016)	CORDEX-CORE framework	
	AFR-44	CCLM4-8-17	KIT	35/30km	240	Tanre	Default	Tropical setup, and lower height of damping changed to 18 km.	Panitz et al. (2014) Dosio and Panitz (2016) Dosio et al. (2015)

Two model-versions
CCLM4-8-17 vs CCLM5-0-15

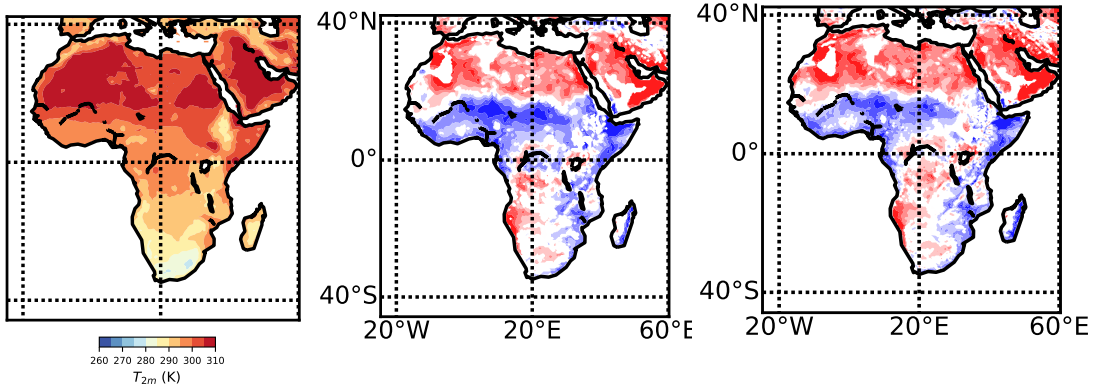
Two resolutions
AFR-44 vs AFR-22

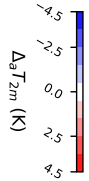
June-July-August

AFR-44
CCLM4-8-17

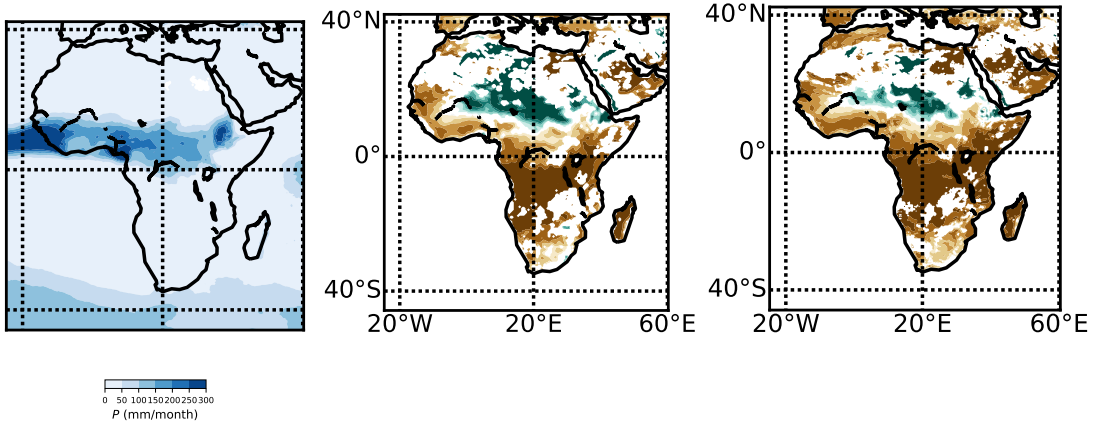
AFR-22
CCLM4-8-17

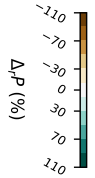
GHNC



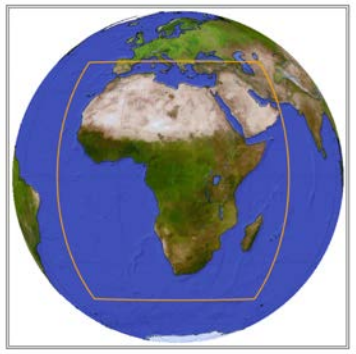


MSWEP





The model performance is very little influenced when using the same model version but different horizontal resolution



		Model version	Institute	Vertical levels Model top	Time step (s)	Aerosol	Tuning param	Other	Reference
Africa (AFR)	AFR-22	CCLM4-8-17	KIT	35/30km	120	Tanre	Default	Used to investigate the added value of increasing the horizontal resolution. Thus, only one evaluation run (1989-2000).	Panitz et al. (2014)
		CCLM-5-0-15	KIT	57/30km	150	Tegen	Default, except q_crit, rlam_heat, uc1, following Bucchignani et al. (2016)	CORDEX-CORE framework	
	AFR-44	CCLM4-8-17	KIT	35/30km	240	Tanre	Default	Tropical setup, and lower height of damping changed to 18 km.	Panitz et al. (2014) Dosio and Panitz (2016) Dosio et al. (2015)

Two model-versions
CCLM4-8-17 vs CCLM5-0-15

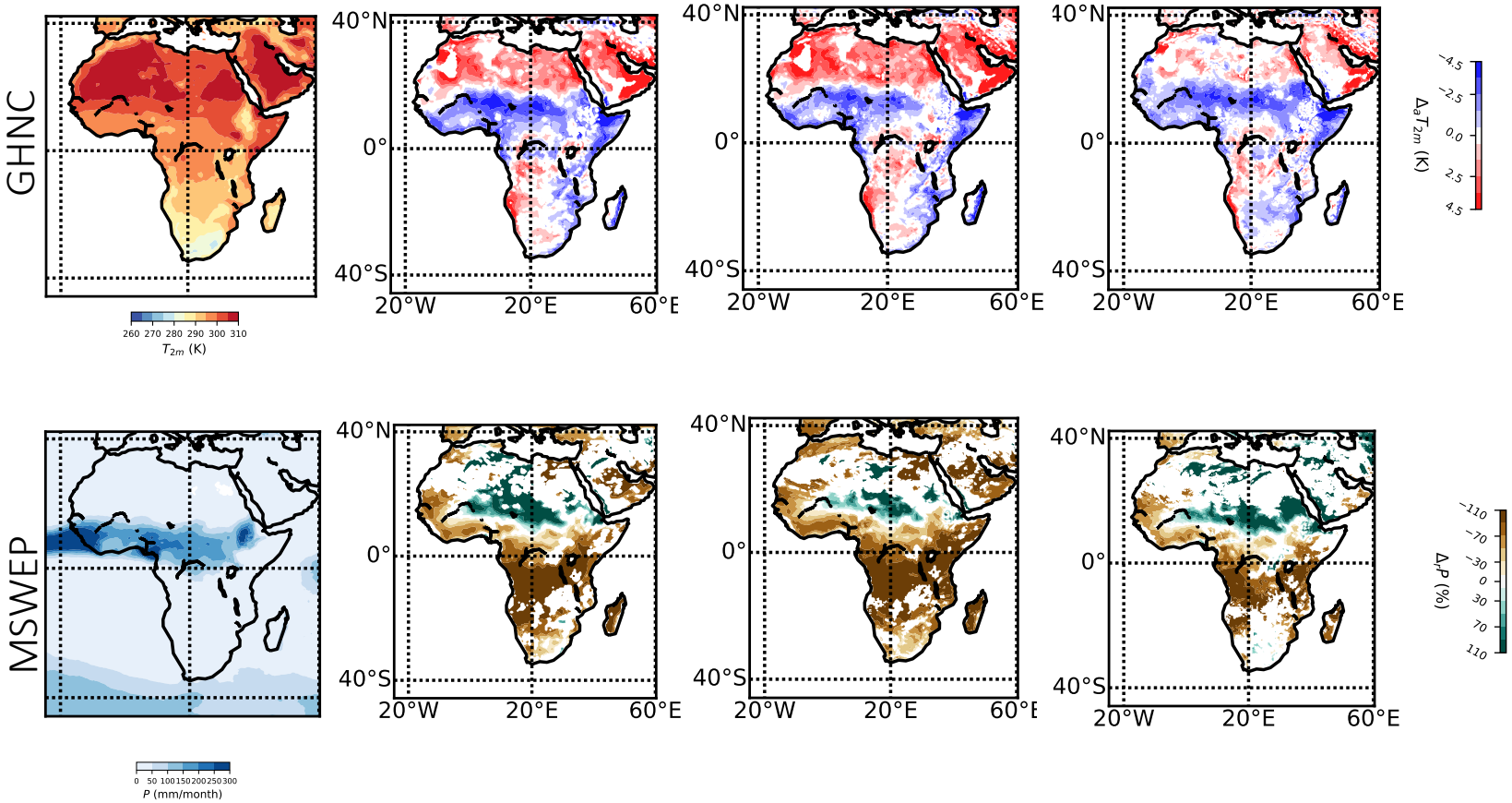
Two resolutions
AFR-44 vs AFR-22

June-July-August

AFR-44
CCLM4-8-17

AFR-22
CCLM4-8-17

AFR-22
CCLM5-8-15



When changing the model version, model configuration and horizontal resolution, the biases are reduced, in particular for precipitation and summer temperature.

These results suggest that it is not enough to only change the horizontal resolution, but it is important to re-adjust the model configuration to the new resolution employed.

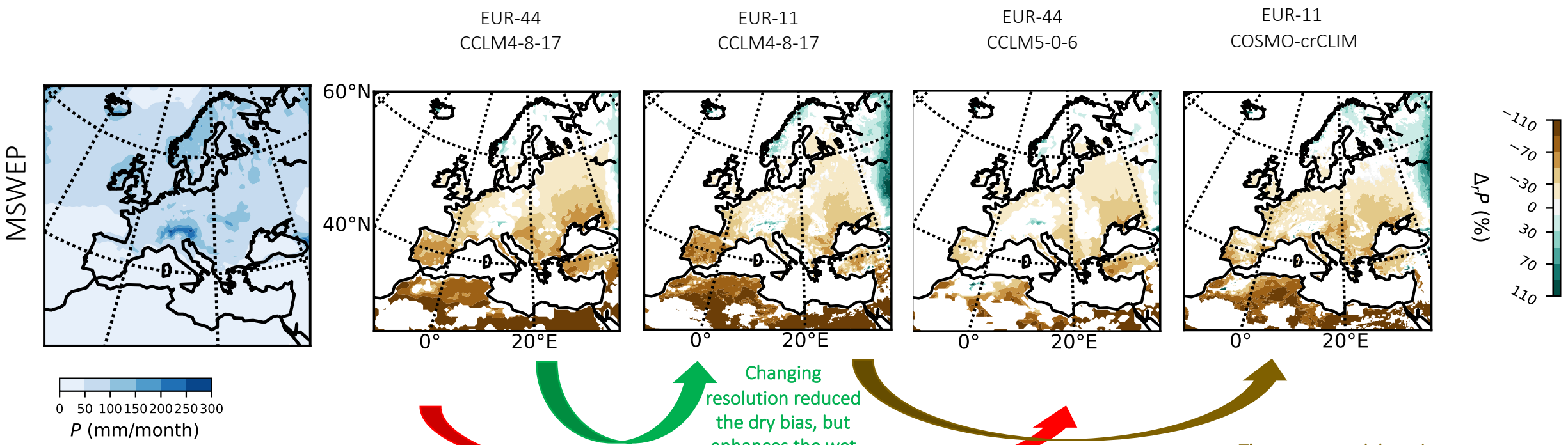


		Model version	Institute	Vertical levels Model top	Time step (s)	Aerosol	Tuning param	Other	Reference
Europe (EUR)	EUR-11	CCLM4-8-17	BTU, DWD, ETH	40/22.7km	100	Tanre	Default		Kotlarski et al. (2014); Keuler et al. (2016); Dalelane et al. (2018); Bülow et al. (2019).
		COSMO-crCLIM-v1-1	ETH	40/22.7km	90	Aerocom	Default, except a some changed due to past experience and sensistivity runs (tkhmin, tkmmin,		Leutwyler et al. (2017) Vautard et al. (2020)
	EUR-44	CCLM4-8-17	BTU	40/22.7km	300	Tanre	Default		
		CCLM5-0-6	ETH	40/22.7km	300	Tanre	Objective Calibration	The recommended version from the CLM-Community (from year 2015)	Sørland et al. (2018)

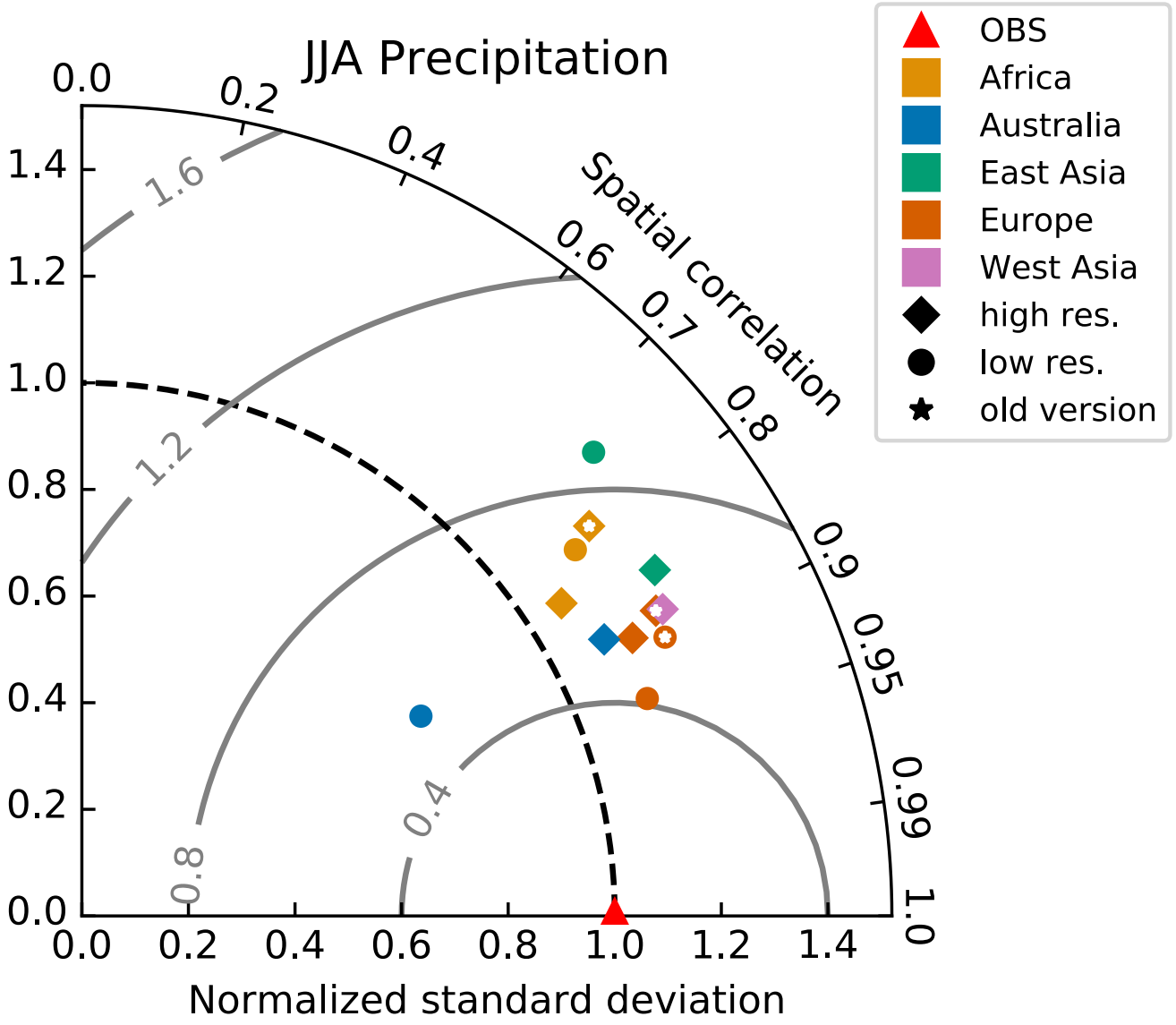
Two resolutions EUR-44 vs EUR-11

Three model versions:
CCLM4-8-17
CCLM5-0-6
COSMO-crCLIM

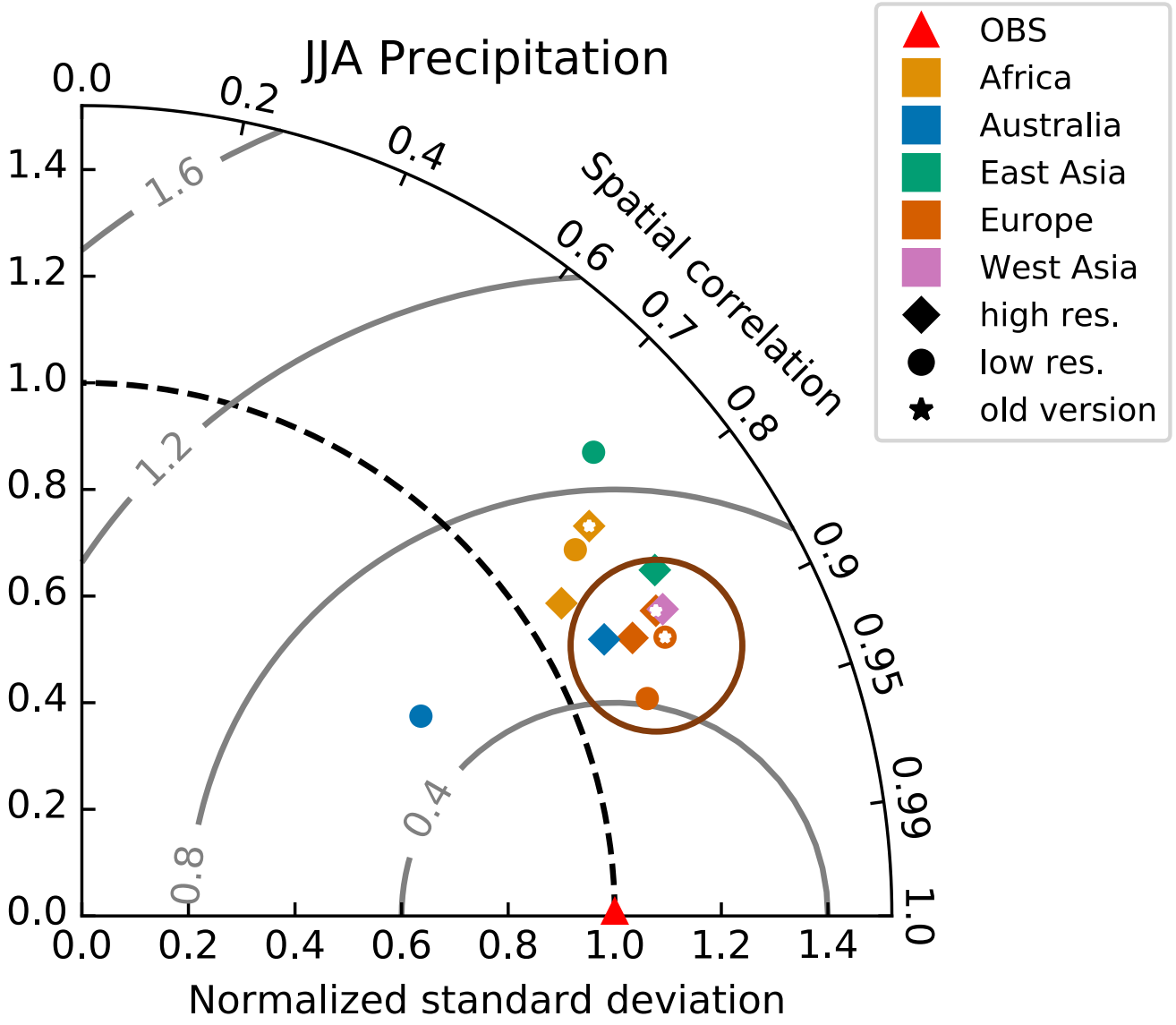
June-July-August



Summarizing the model performance with Taylor diagram

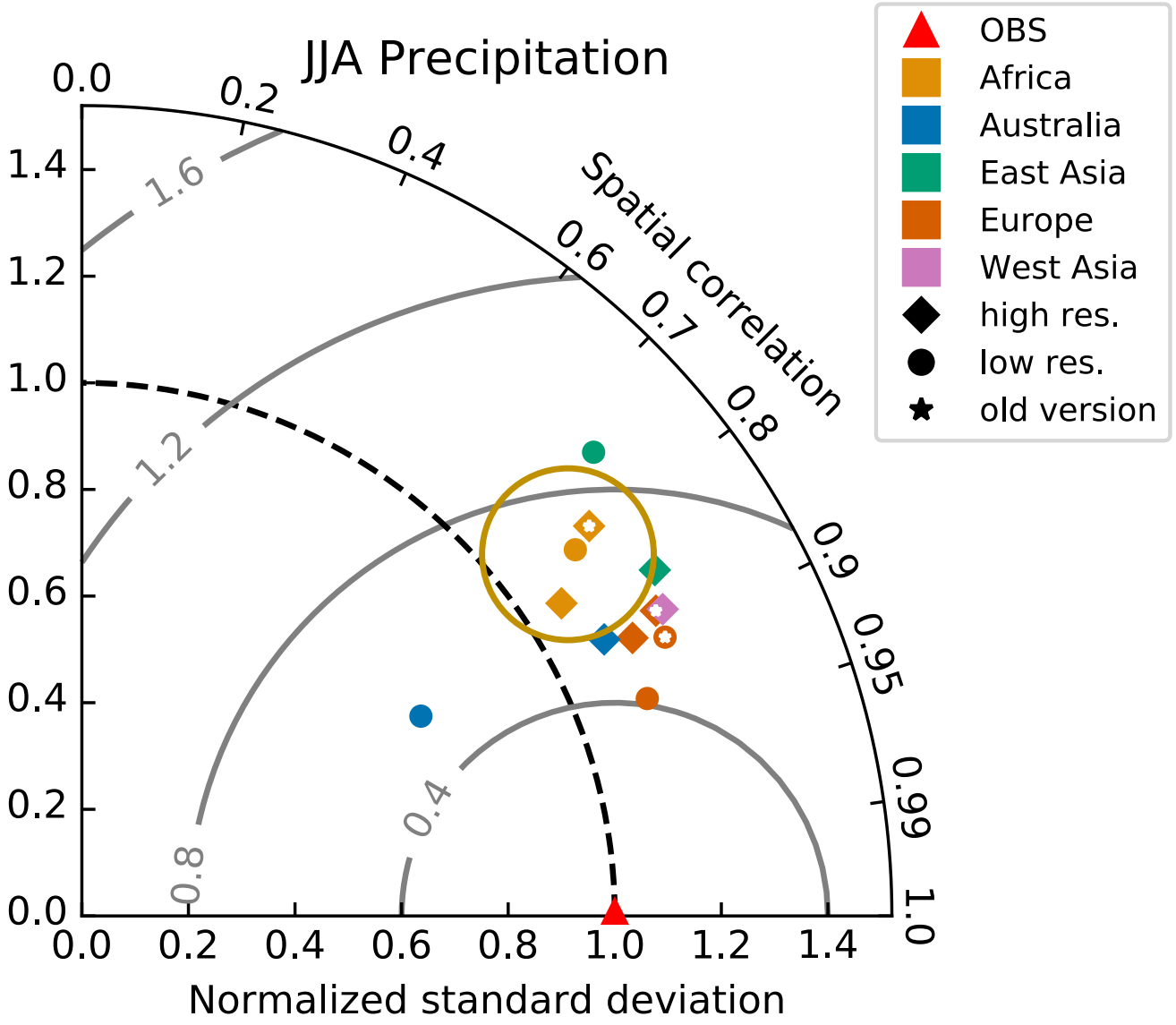


Summarizing the model performance with Taylor diagram



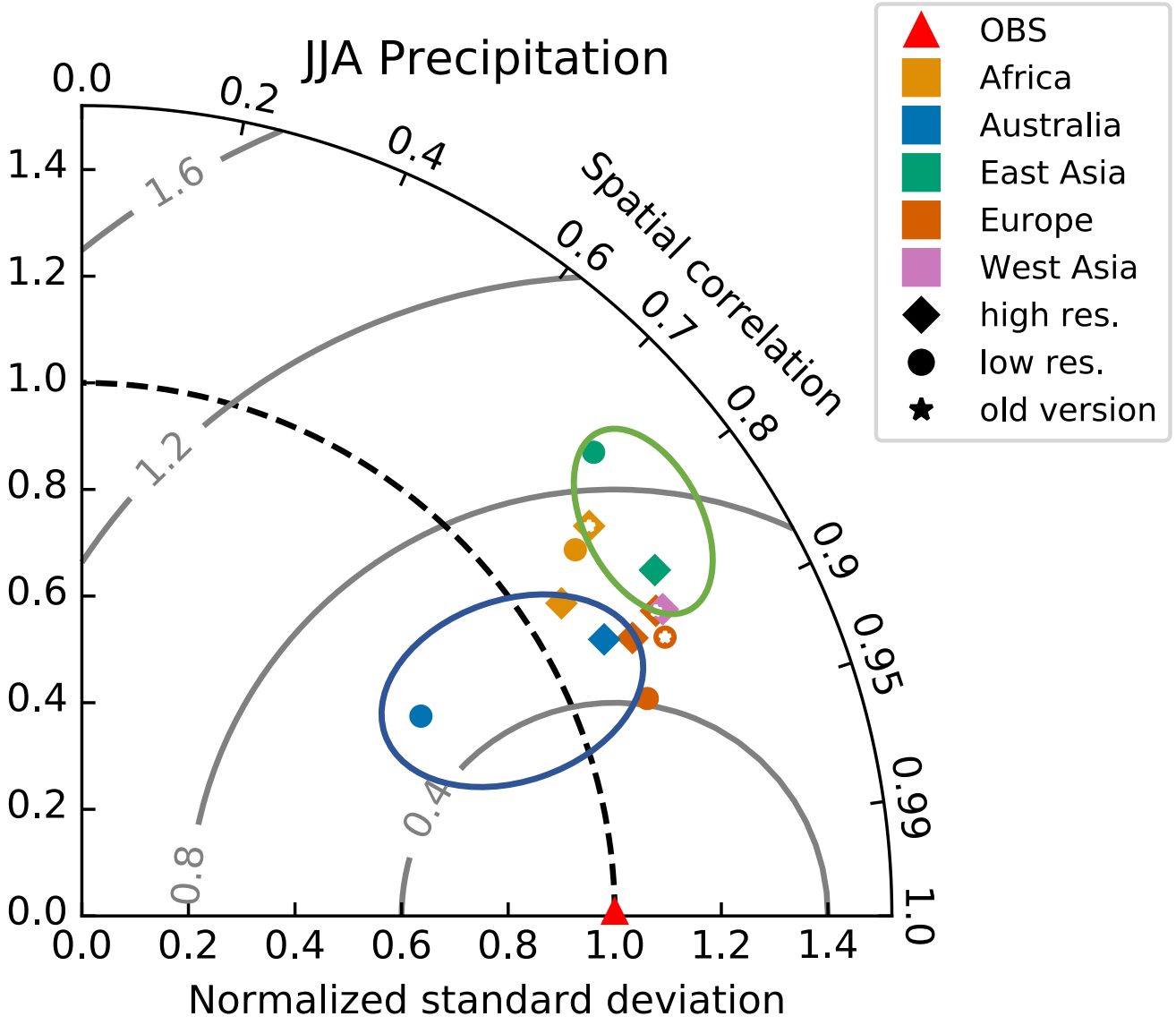
- Europe:
  - Has in general the best performance (as expected?)
  - The newer model versions have a better performance
  - The recommended version CCLM5-0-6 at EUR-44 outperforms the older and higher resolution simulations.

Summarizing the model performance with Taylor diagram



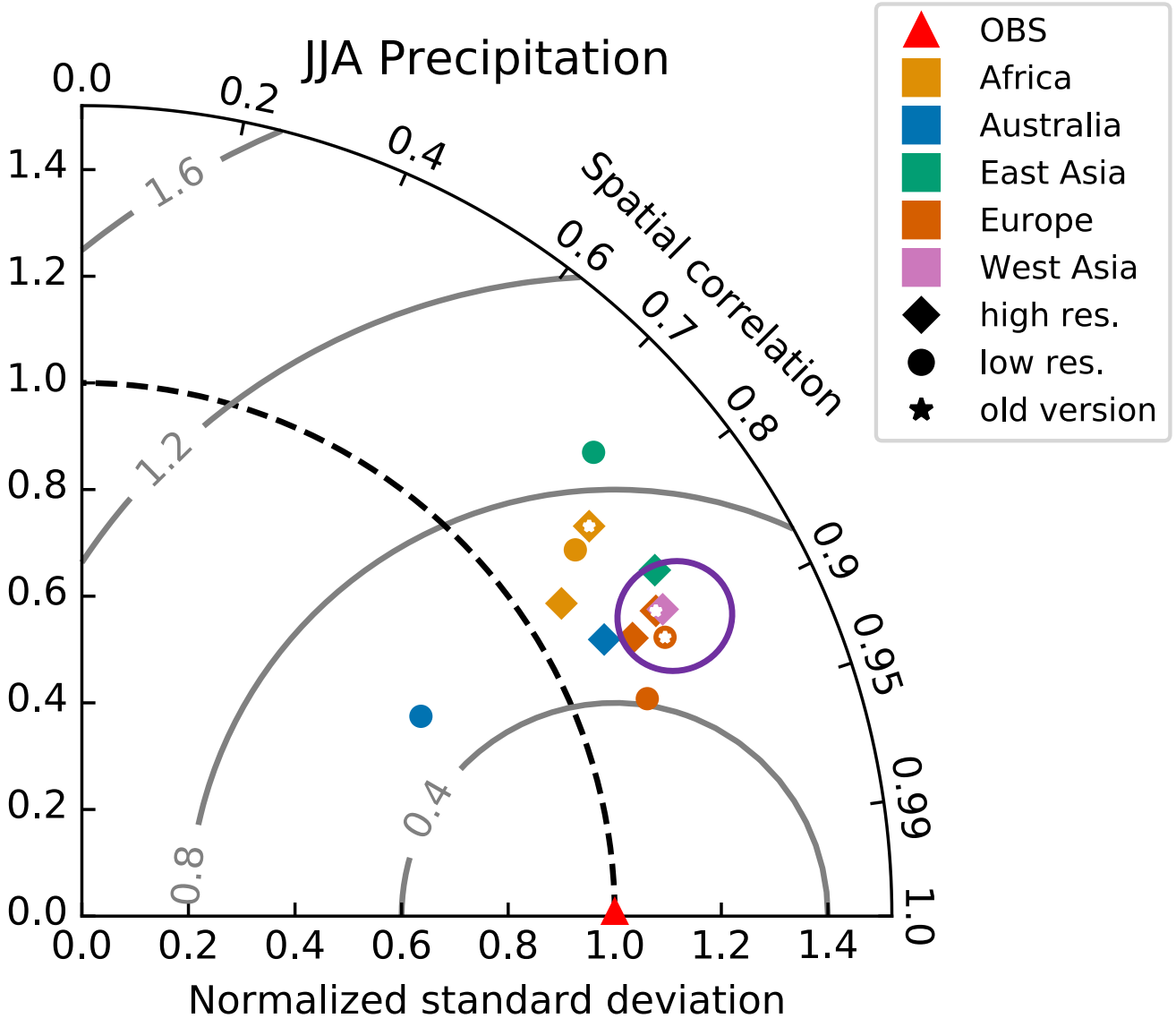
- Europe:
  - Has in general the best performance (as expected?)
  - The newer model versions have a better performance
  - The recommended version CCLM5-0-6 at EUR-44 outperforms the older and higher resolution simulations.
- Africa:
  - The newer and higher resolution seems to be better

Summarizing the model performance with Taylor diagram



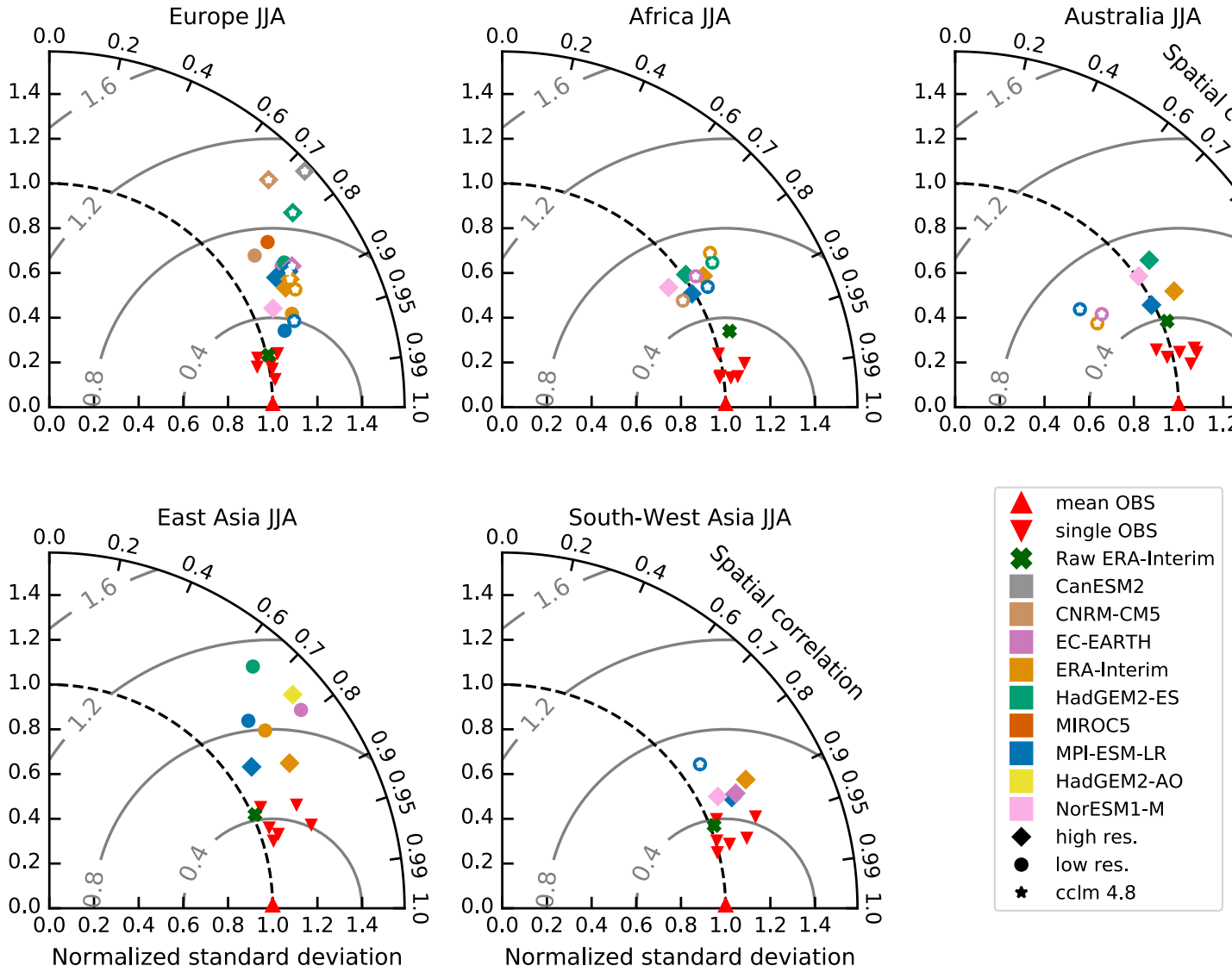
- Europe:
  - Has in general the best performance (as expected?)
  - The newer model versions have a better performance
  - The recommended version CCLM5-0-6 at EUR-44 outperforms the older and higher resolution simulations.
- Africa:
  - The newer and higher resolution seems to be better
- Australia and East-Asia
  - The two evaluation runs are very different
  - Australia: AUS-44 simulation is coupled to the land model
  - East-Asia: EAS-22 is using spectral nudging

Summarizing the model performance with Taylor diagram



- Europe:
  - Has in general the best performance (as expected?)
  - The newer model versions have a better performance
  - The recommended version CCLM5-0-6 at EUR-44 outperforms the older and higher resolution simulations.
- Africa:
  - The newer and higher resolution seems to be better
- Australia and East-Asia
  - The two evaluation runs are very different
  - Australia: AUS-44 simulation is coupled to the land model
  - East-Asia: EAS-22 is using spectral nudging
- South Asia
  - Only contain one evaluation simulation

Evaluating the GCM driven simulations



In general:

- The choice of the driving data is the main controller of the performance of the simulation. Model version and resolution is only changing this performance slightly, but not in the same magnitude as when changing the driving data.
- There is a tendency that the higher resolution simulations are performing better.

Summary and next step

- Summary:
  - We are currently doing a systematic assessment of the CORDEX simulations performed with different versions and resolutions of the COSMO-CLM model over the domains Europe, Africa, Australasia, East-Asia and South-Asia.
  - In general, the model performance seems to not be improved by only changing the horizontal resolution, but model development, model tuning (i.e. testing model parameters, physical paramterization and/or performing objective calibration) is also important.
  - By changing the GCM forcing data, has a larger impact on the model performance, than changing e.g. the model configuration or resolution.
- Next step:
  - Comparing the ERA-Interim simulations with the raw ERA-Interim
  - Discuss how to finalize the manuscript in the WG CP on Wednesday 10:00-12:00
- If anyone wants to contribute, or feel they they should be included in this study, just send me an email!