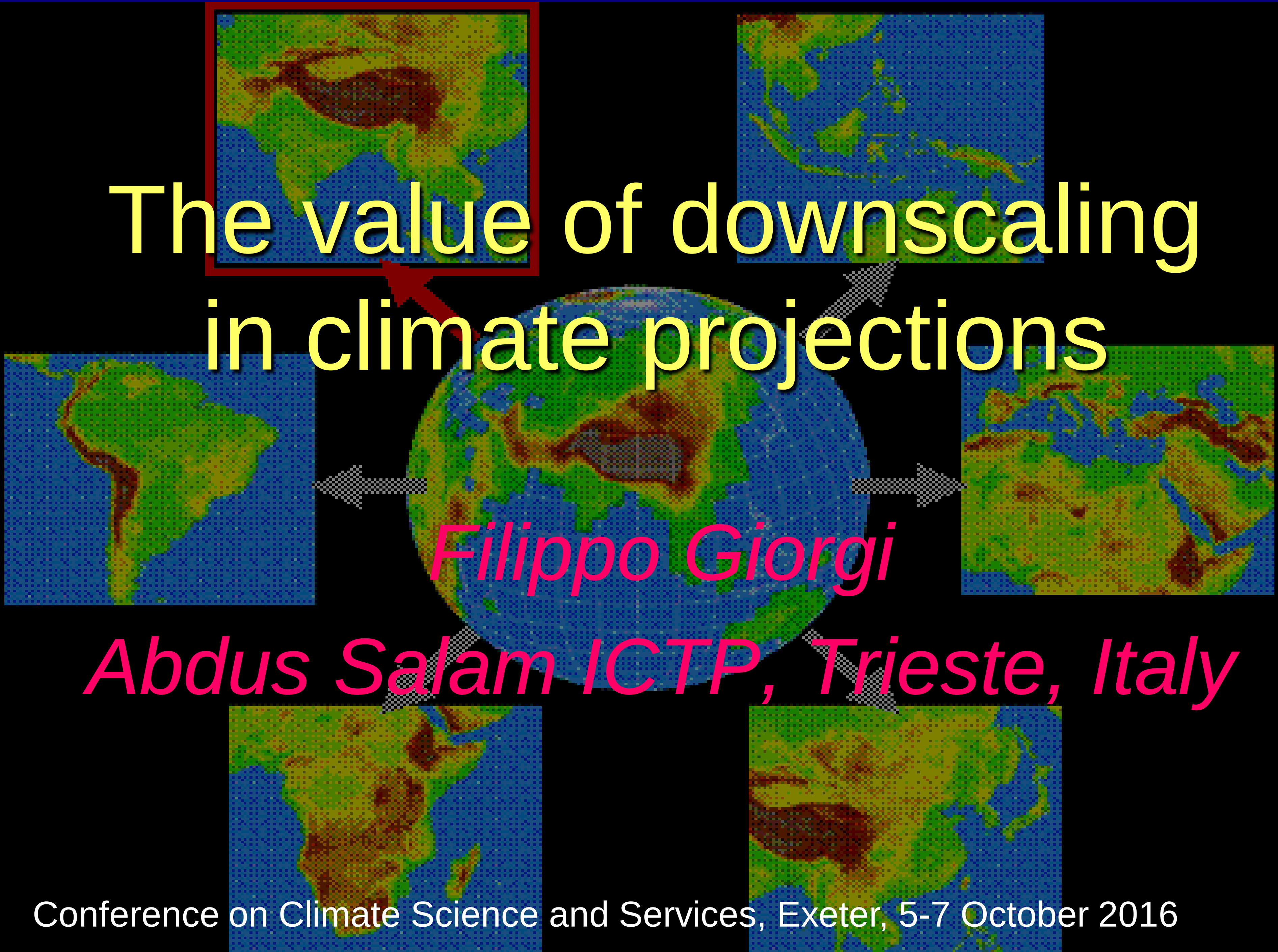
The value of downscaling in climate projections

Filippo Giorgi

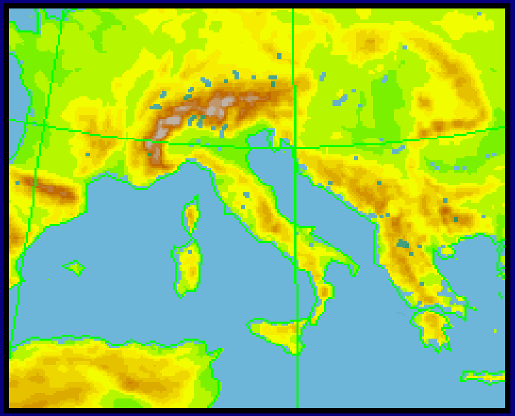
Abdus Salam ICTP, Trieste, Italy



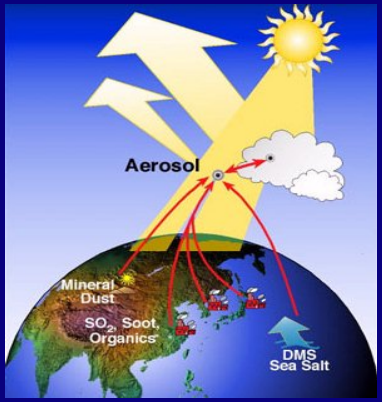
Conference on Climate Science and Services, Exeter, 5-7 October 2016

Regionalization techniques have been developed to account for regional climatic forcings and to produce fine scale climate information for application to impact assessment studies

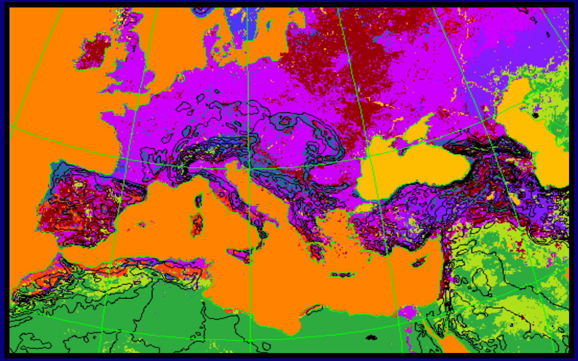
Complex topography



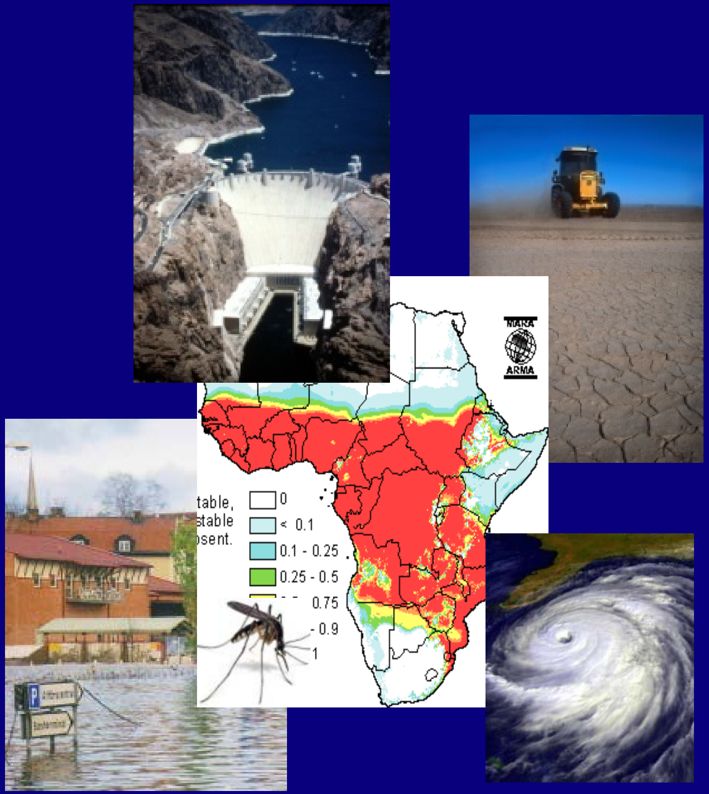
Aerosol effects



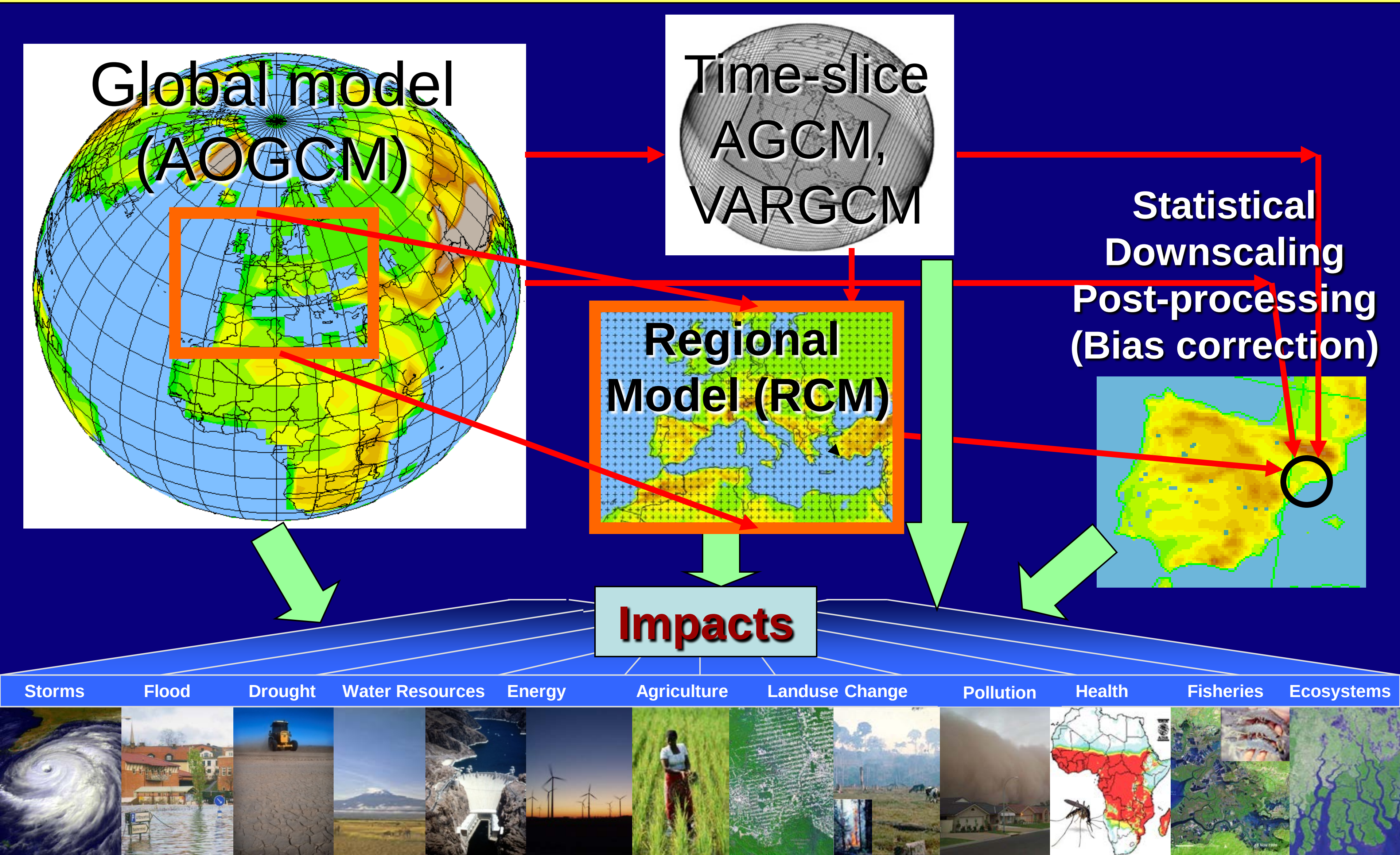
Complex landuse



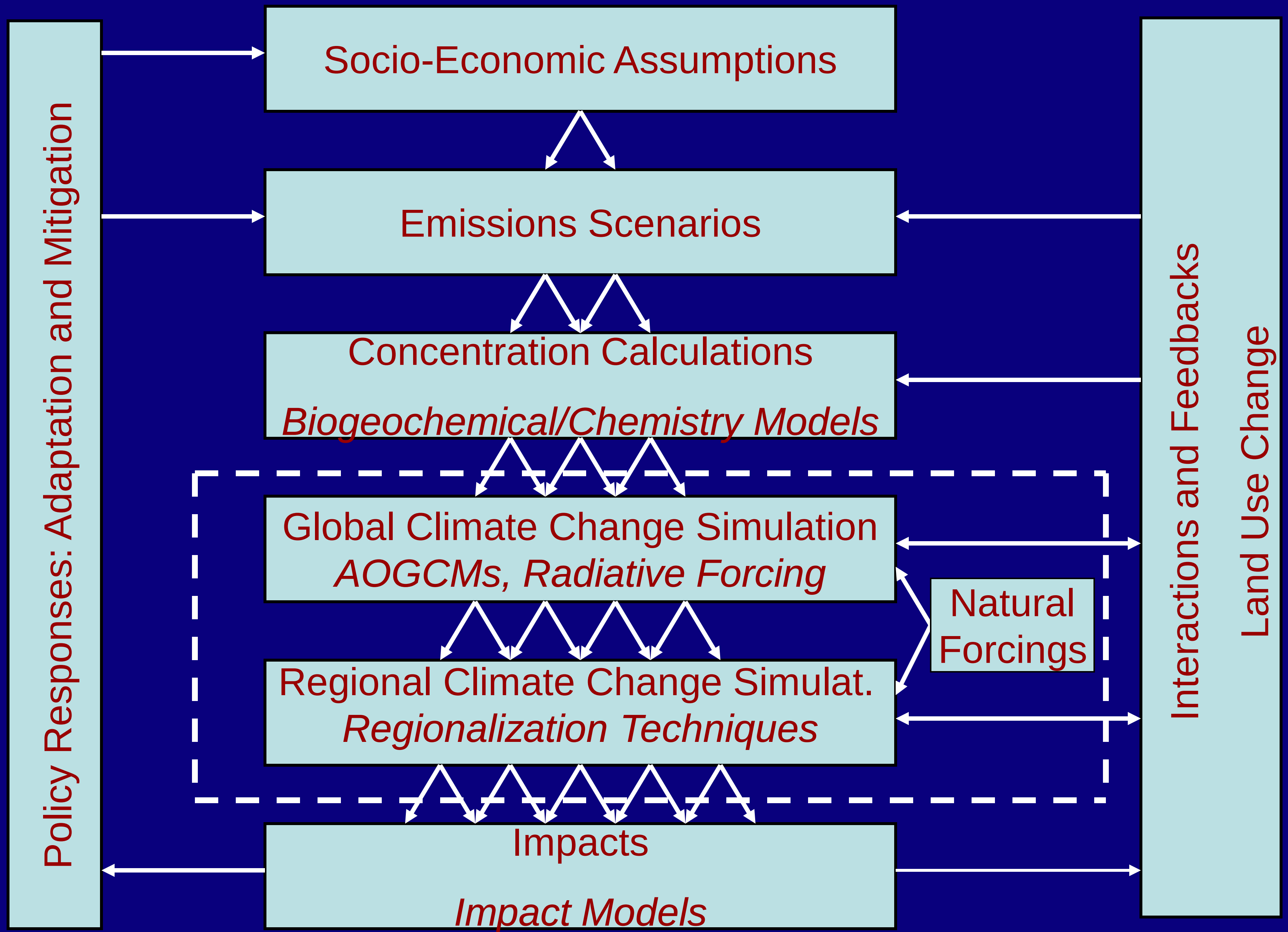
Impacts



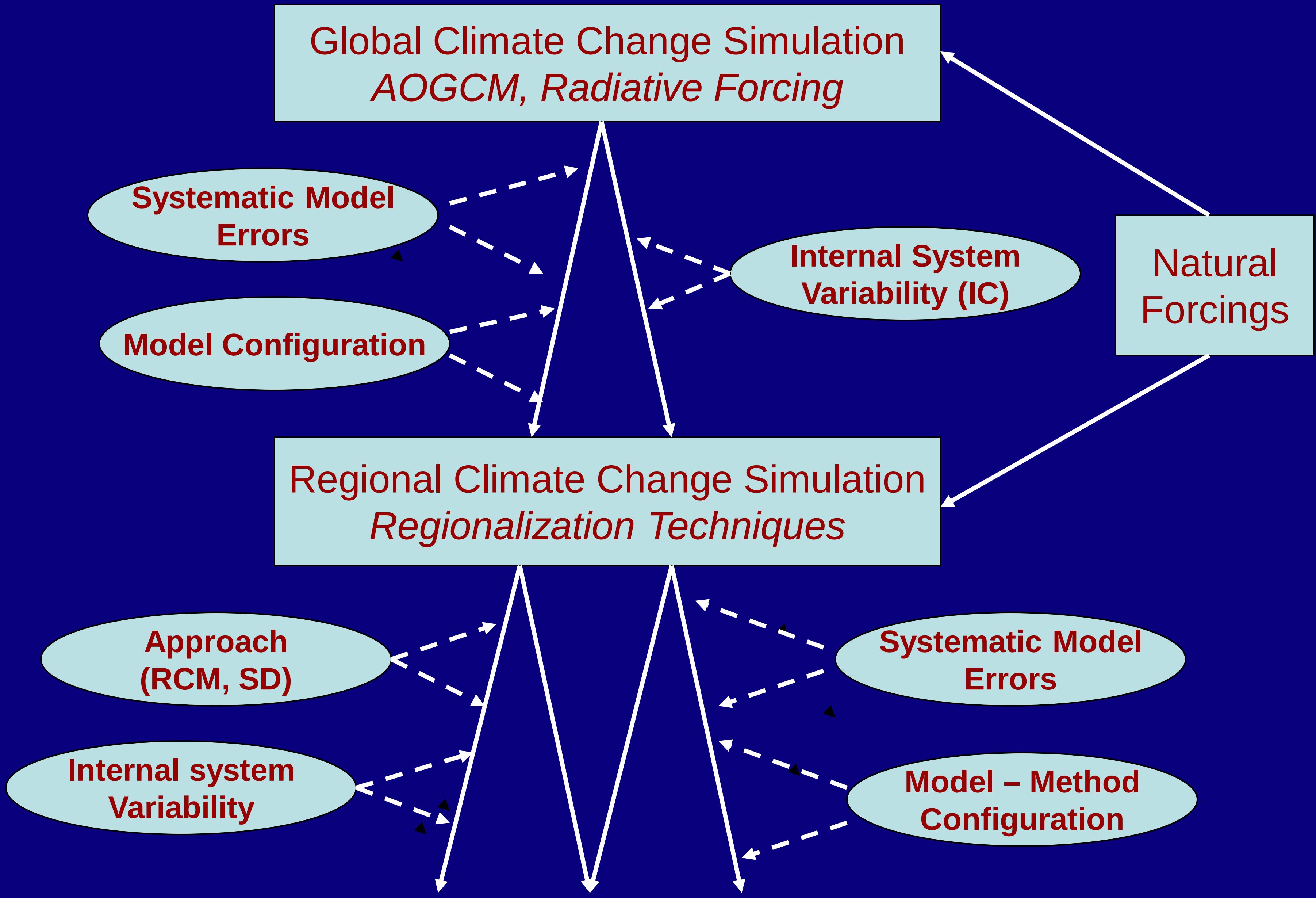
Several tools are today available for producing climate information for regions



Cascade of uncertainty in regional climate projections

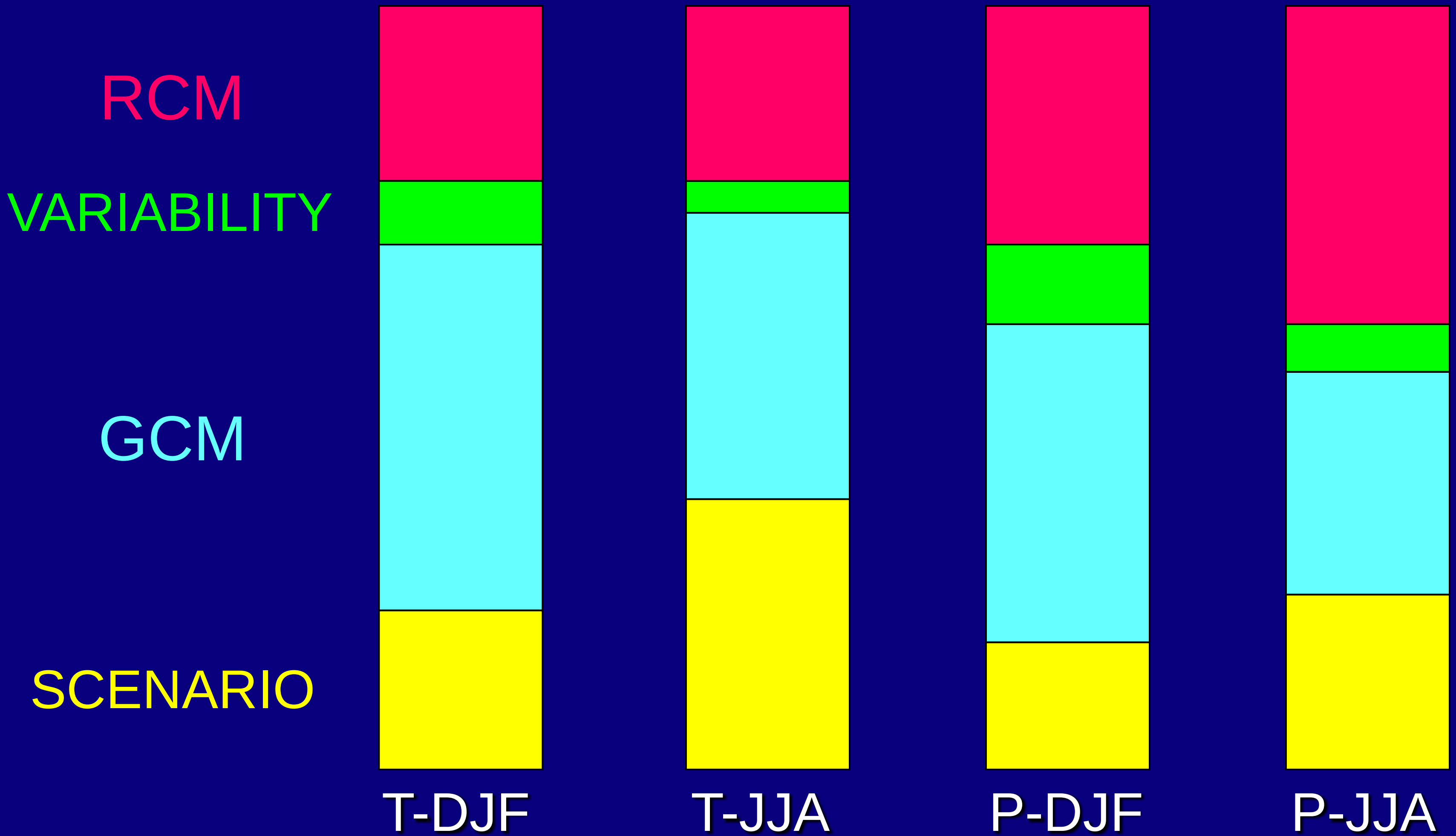


Climate Modeling Segment of the Uncertainty Cascade

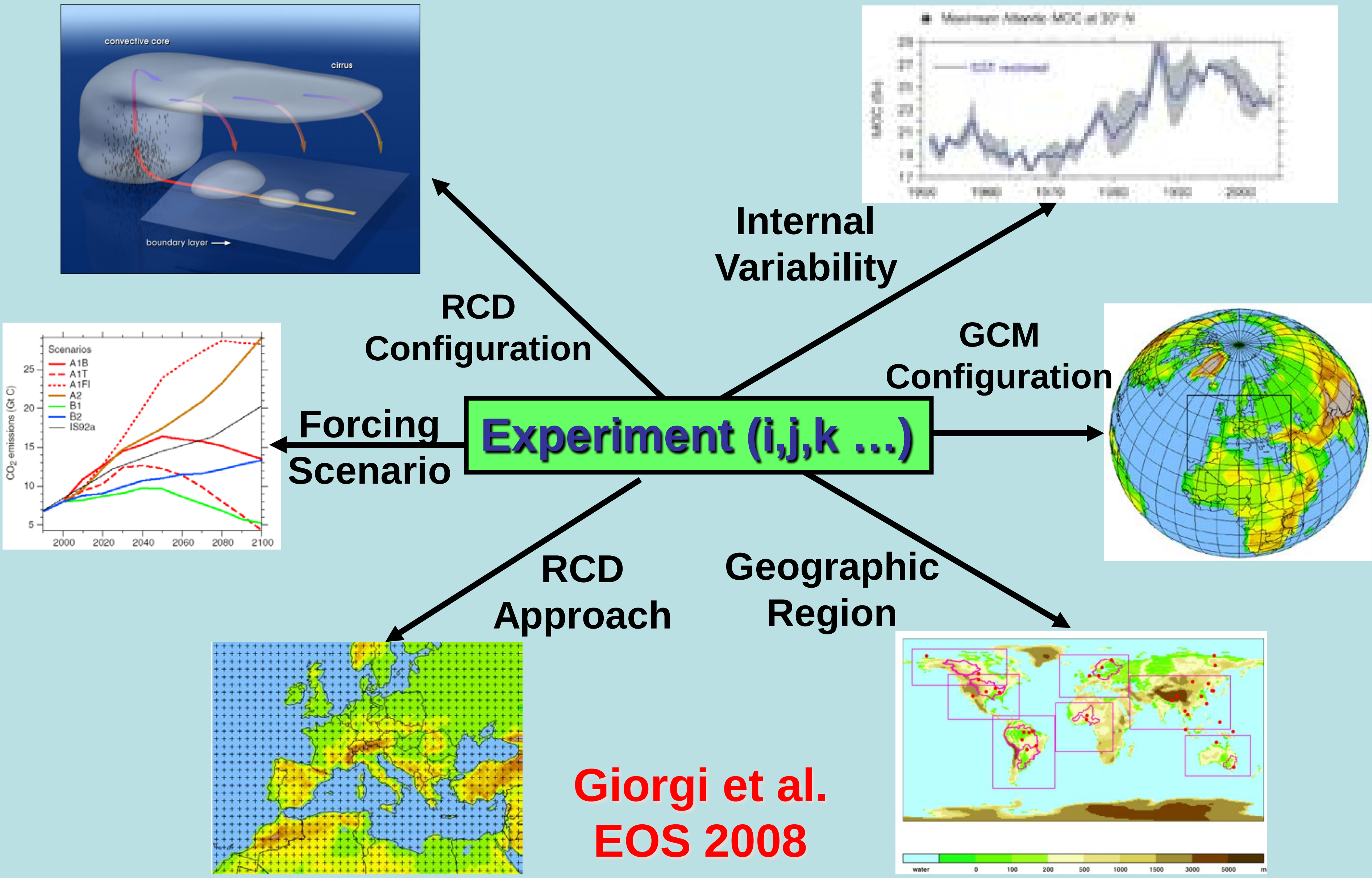


Sources of uncertainty in the simulation of temperature and precipitation change (2071-2100 minus 1961-1990) by the ensemble of PRUDENCE simulations (whole Europe)

(Note: the scenario range is about half of the full IPCC range, the GCM range does not cover the full IPCC range) (Adapted from Deque et al. 2007)



Large ensembles are needed to explore the uncertainty space



Giorgi et al. EOS 2008

The COordinated Regional Downscaling Experiment (CORDEX)

The CORDEX vision is to advance and coordinate the science and application of regional climate downscaling through global partnerships

- To better understand relevant regional/local climate phenomena, their variability and changes through downscaling
- To evaluate and improve regional climate downscaling models and techniques (RCM, ESD, VAR-AGCM, HIR-AGCM)
- To produce large coordinated sets of regional downscaled projections worldwide
- To foster communication and knowledge exchange with users of regional climate information

Ensembles of regional projections are available for most domains (ds = 50 km)

CORDEX-S. ASIA

CORDEX-South Asia Multi Models Output

Historical (1950 – 2005) | Evaluation Run (1989 – 2008) | RCP 4.5

Variable name (Monthly and Daily)	SMHI-RCA4	IITM-RegCM4-GFDL	IITM-RegCM4-LMDZ	COSMO-CLM	IITM-LMDZ
Institute's / Data Providers	Rossby Centre, SMHI	CCCR-IITM, Pune	CCCR-IITM, Pune	Goethe Inst - Univ. of Frankfurt	CCCR-IITM, Pune
Rainfall (pr)	✓	✓	✓	✓	✓
Surface Air Temperature (tas)	✓	✓	✓	✓	✓
Surface Air Temp. Maximum (tasmax)	✓	✓	✓	--	✓
Surface Air Temp. Minimum (tasmin)	✓	✓	✓	--	✓
Sea-level Pressure (psl)	✓	✓	✓	--	✓
Surface Specific Humidity (huss)	✓	✓	✓	--	✓
Surface Zonal Wind (uas)	✓	✓	✓	--	✓
Surface Meridonial Wind (vas)	✓	✓	✓	--	✓
Downward Shortwave Radiation (rsds)	--	✓	✓	--	--

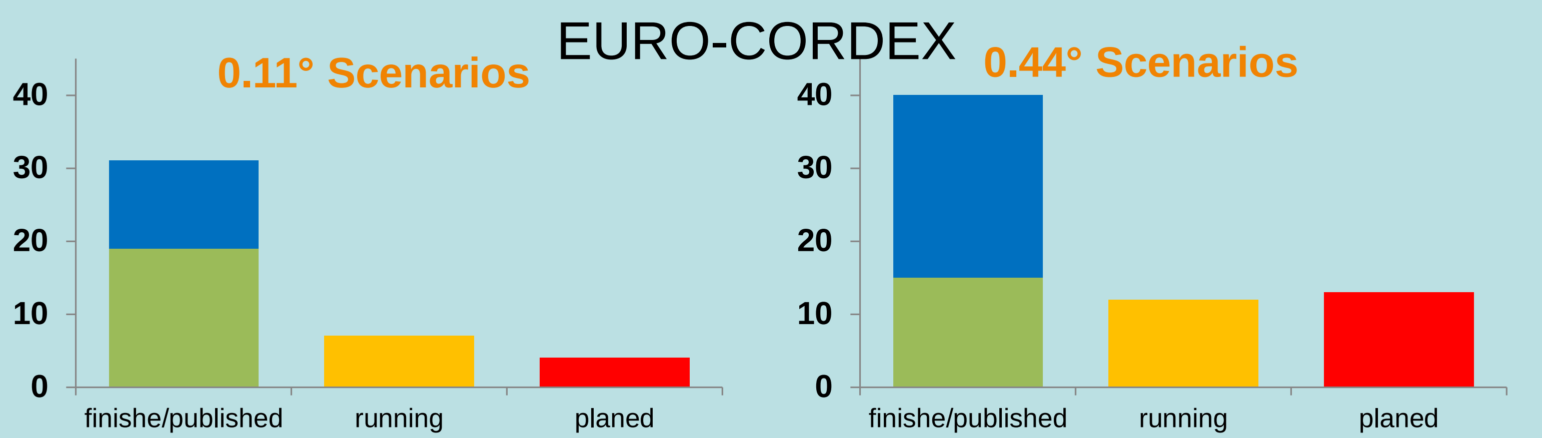
To download the data please click here

Regridding script example, click here to download | script

CORDEX-AFRICA

RCP4.5	BCCR-greenWRF	CCCma-CanRCM4	CLMcom-CCLM4-8	CNRM-ALADIN	CSC-REMO	DMI-HIRHAM5	ICTP-RegCM4	KNMI-RACMO2.2	MOHC-GA3RCM	SMHI-RCA4	UCLM-PROMES	ULL-WRF311	UCAN-WRF34	UQAM-CRCM	sum
CanESM2		■								■				■	3
CNRM-CM5			■	■						■					3
NorESM1-M	■ (blue)									■					1
EC-EARTH (r1)								■							1
EC-EARTH (r3)						■									1
EC-EARTH (r12)			■		■					■					3
HadGEM2-ES			■				■		■ (blue)	■					3
MIROC5										■					1
MPI-ESM-LR			■		■					■				■	4
GFDL-ESM2M										■					1
HADCM3															
sum		1	4	1	2	1	1	1		8				2	21

RCP8.5	BCCR-greenWRF	CCCma-CanRCM4	CLMcom-CCLM4-8	CNRM-ALADIN	CSC-REMO	DMI-HIRHAM5	ICTP-RegCM4	KNMI-RACMO2.2	MOHC-GA3RCM	SMHI-RCA4	UCLM-PROMES	ULL-WRF311	UCAN-WRF34	UQAM-CRCM	sum
CanESM2		■								■					2
CNRM-CM5			■	■						■					3
NorESM1-M	■ (blue)									■					1
EC-EARTH (r1)								■							1
EC-EARTH (r3)						■									1
EC-EARTH (r12)			■		■					■					3
HadGEM2-ES			■				■		■ (blue)	■					3
MIROC5										■					1
MPI-ESM-LR			■		■		■			■					4
GFDL-ESM2M										■					1
HADCM3											■ (blue)				
sum		1	4	1	2	1	2	1		8					19



Emerging scientific challenges

✧ Added value

Internal variability & added value as functions of scale; Very high resolution modeling; Bias correction uncertainties and consistency

✧ Human element

Coupling of regional climate and urban development (e.g. coastal megacities); Land use change; Aerosol effects.

✧ Regional coupled modelling

Ocean-ice-atmosphere; Lakes; Dynamic land surface; Natural fires; Atmospheric chemistry; Carbon cycle; Aerosols; Marine biogeochemistry

✧ Precipitation

Extremes; Convective systems; Coastal storm systems; MJO/Monsoon

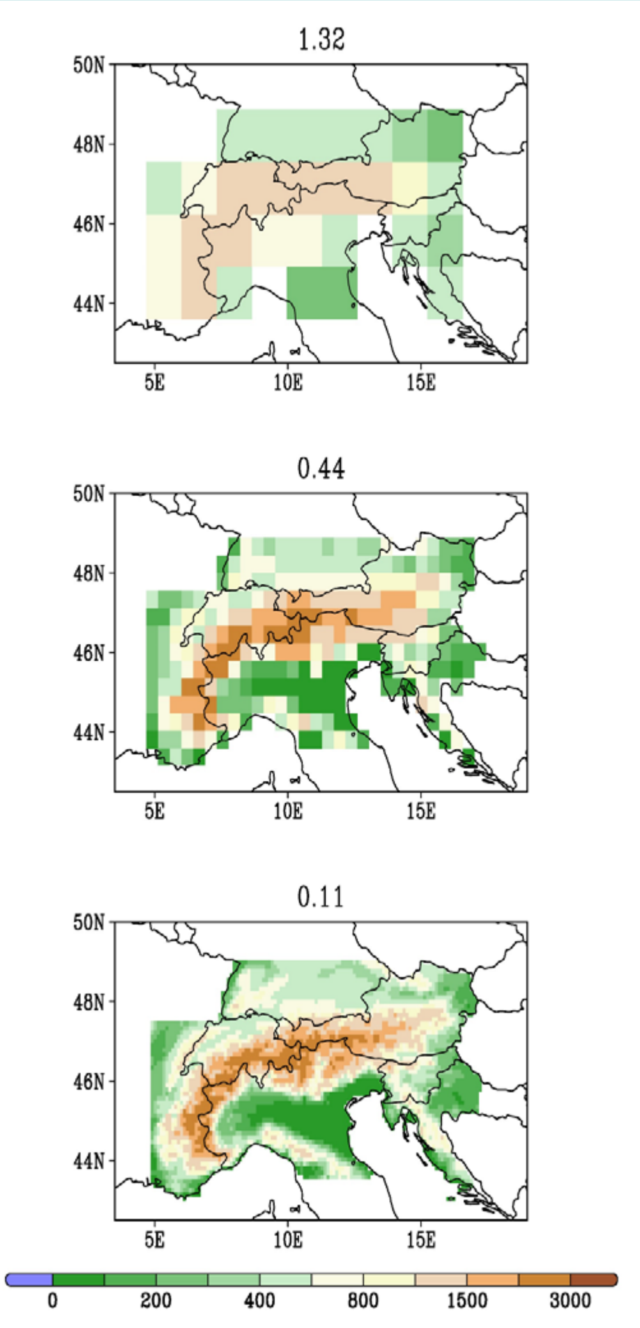
✧ Local wind systems

Wind storms; Strong regional winds; Wind energy

Added value of downscaling: The case of summer precipitation in the European Alps (Torma et al. JGR 2015; Giorgi et al. NatGeo 2016)

- Area characterized by complex, fine scale topographical features which strongly modulate local climate characteristics
- Availability of a high quality, high resolution gridded dataset: EURO4M-APGD (Isotta et al. 2014)
  - Daily precipitation gridded onto a 5 km regular grid
  - Homogenized data from more than 8000 stations
  - Long period of coverage: 1971-2008
- Availability of ensembles of RCM projections from EURO-CORDEX and MED-CORDEX
  - Multiple driving GCMs and nested RCMs
  - Two nominal resolutions: 0.11°, 0.44°
  - Easy accessible open data

Analysis grids (topography)

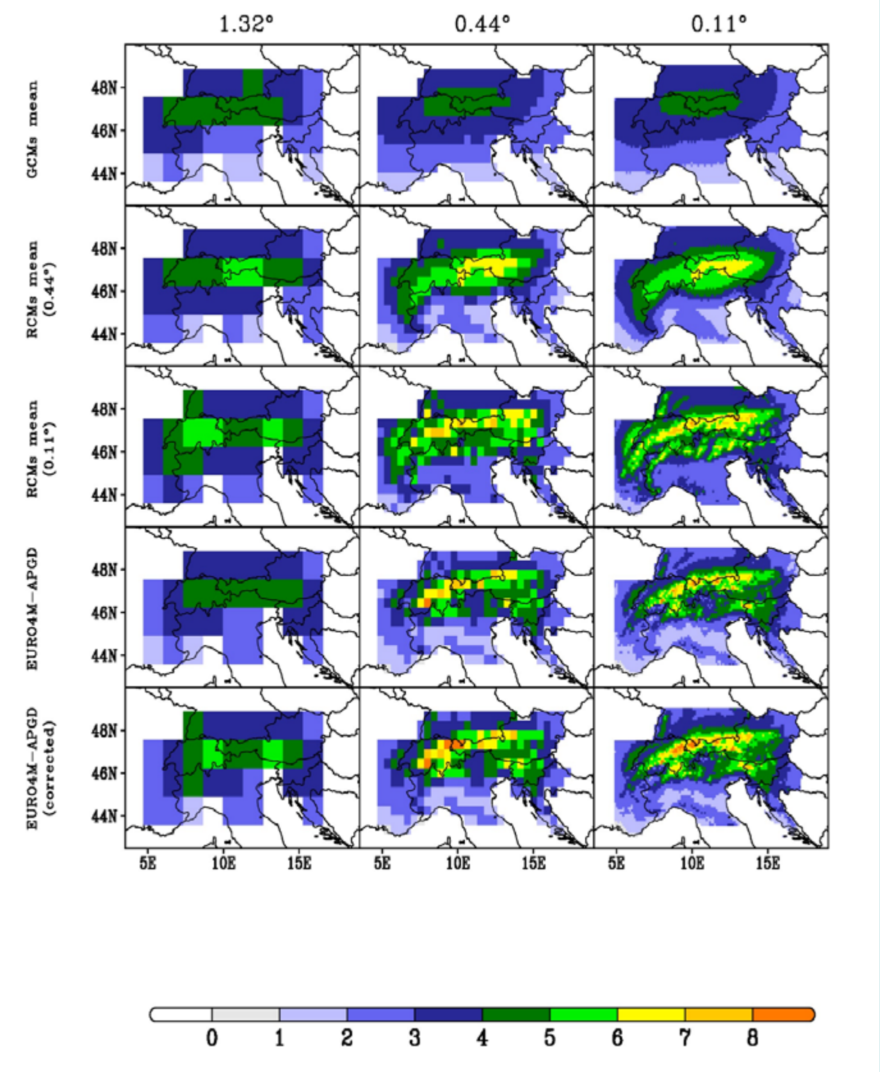


Model ensembles

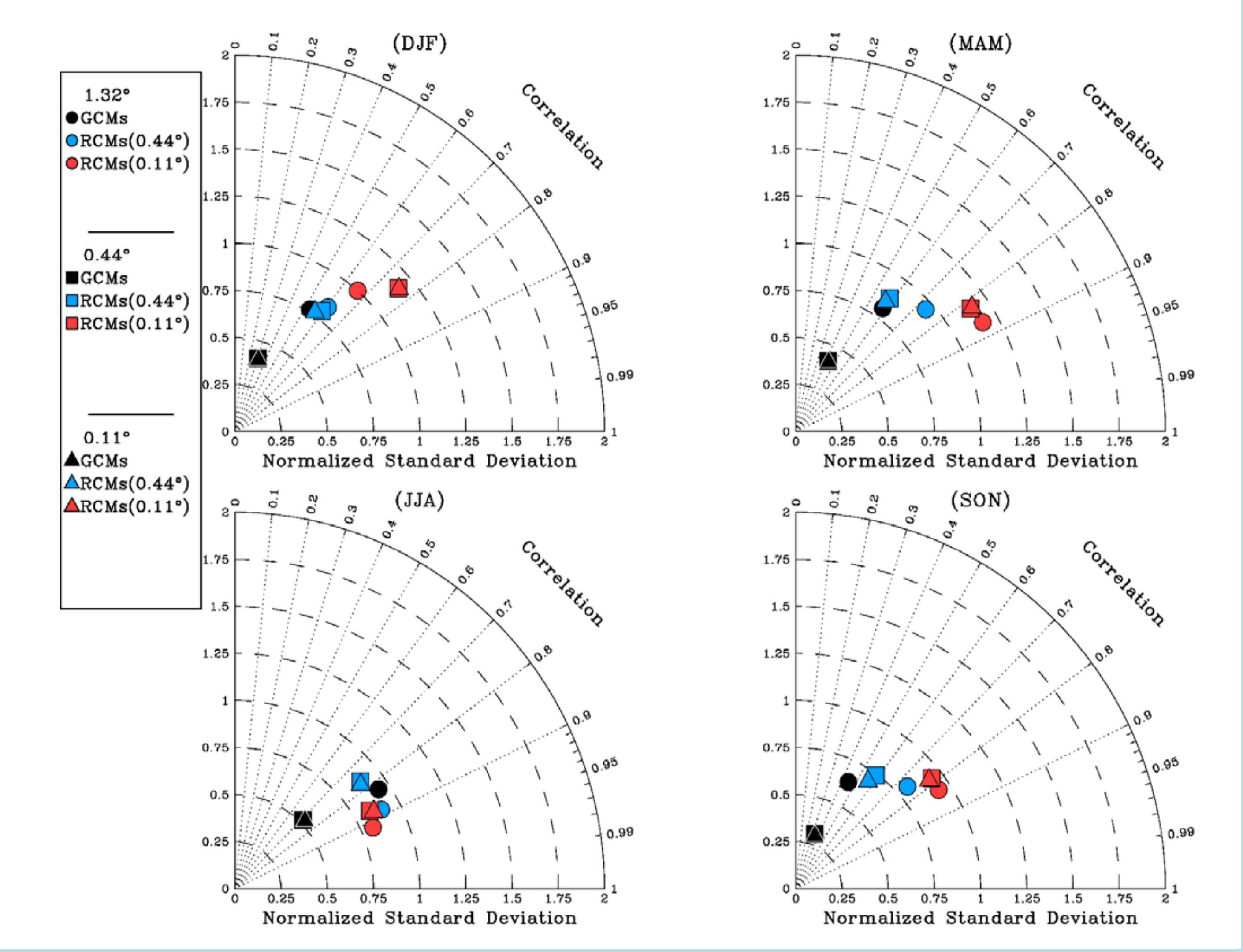
Model	Modelling group	Resolution	Reference
a, CNRM-CM5	Centre National de Recherches Meteorologiques and Centre Europeen de Recherches et de Formation Avancee en Calcul Scientifique, France	1.40625º x 1.40625º	Voldoire et al., 2012
b, EC-EARTH	Irish Centre for High-End Computing, Ireland	1.125º x 1.125º	Hazeleger et al., 2010
c, HadGEM2-ES	Met Office Hadley Centre, UK	1.875º x 1.2413º	Collins et al., 2011
d, MPI-ESM-LR	Max Planck Institute for Meteorology, Germany	1.875º x 1.875º	Jungclaus et al., 2010
ALADIN (a-MC)	Centre National de Recherches Meteorologiques, France	0.44º/0.11º	Colin et al., 2010
CCLM (d-EC)	Climate Limited-area Modelling Community, Germany	0.44º/0.11º	Rockel et al., 2008
RCA4 (c-EC)	Swedish Meteorological and Hydrological Institute, Rossby Centre, Sweden	0.44º/0.11º	Kupiainen et al., 2011
RACMO (b-EC)	Royal Netherlands Meteorological Institute, The Netherlands	0.44º/0.11º	Meijgaard van et al., 2012
RegCM4 (c-MC)	International Centre for Theoretical Physics, Italy	0.44º/0.11º	Giorgi at al., 2012

Ensemble mean seasonal precipitation (1976-2005)

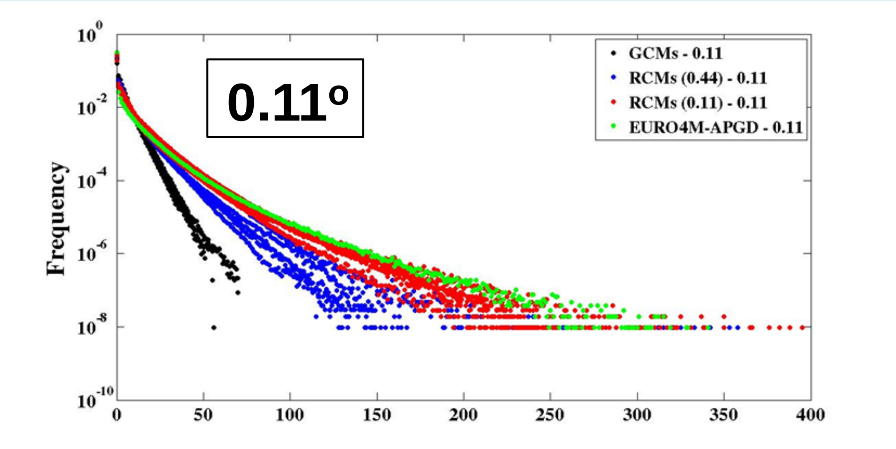
Summer (JJA)

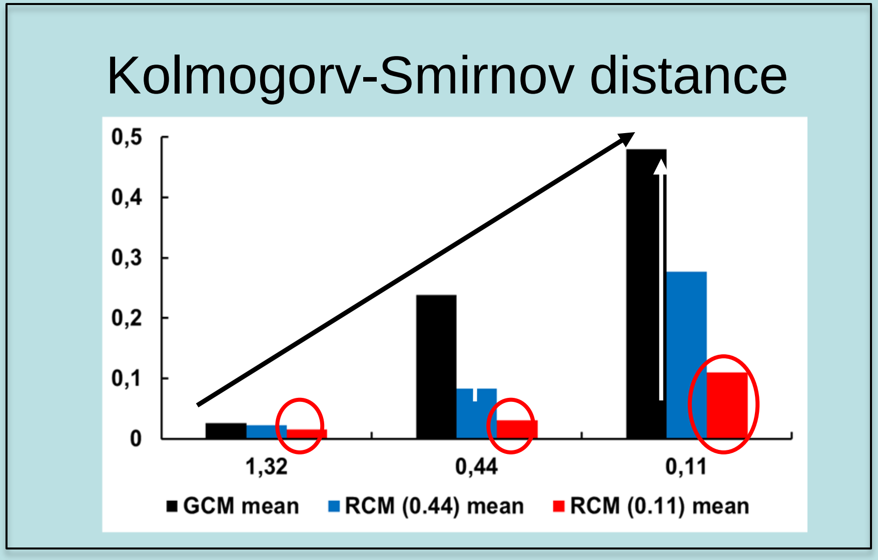


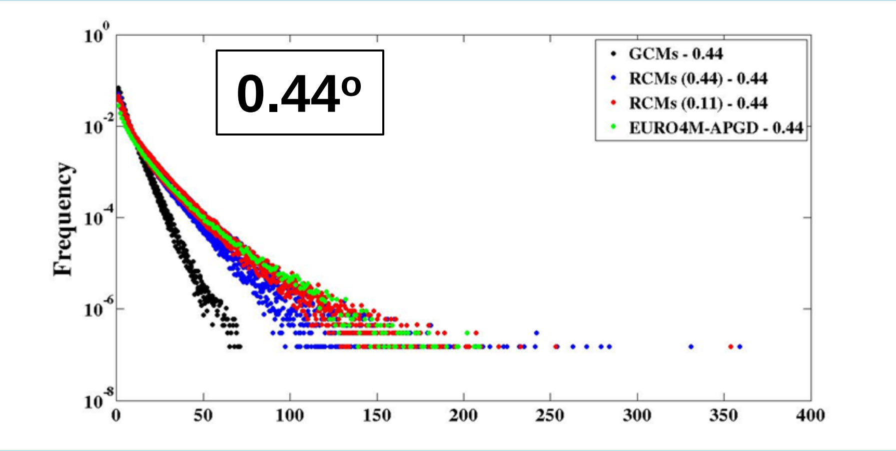
Taylor diagram of mean seasonal precipitation (model vs. obs, 1976-2005)

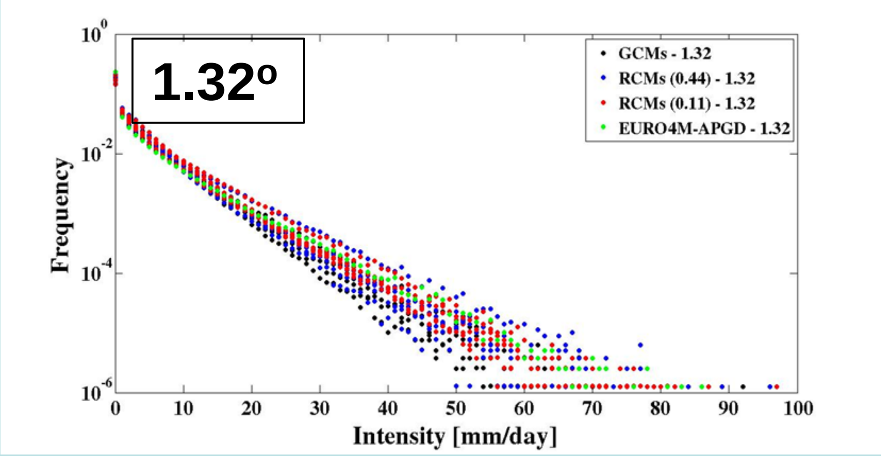


Added value: Simulation of daily precipitation intensity PDF



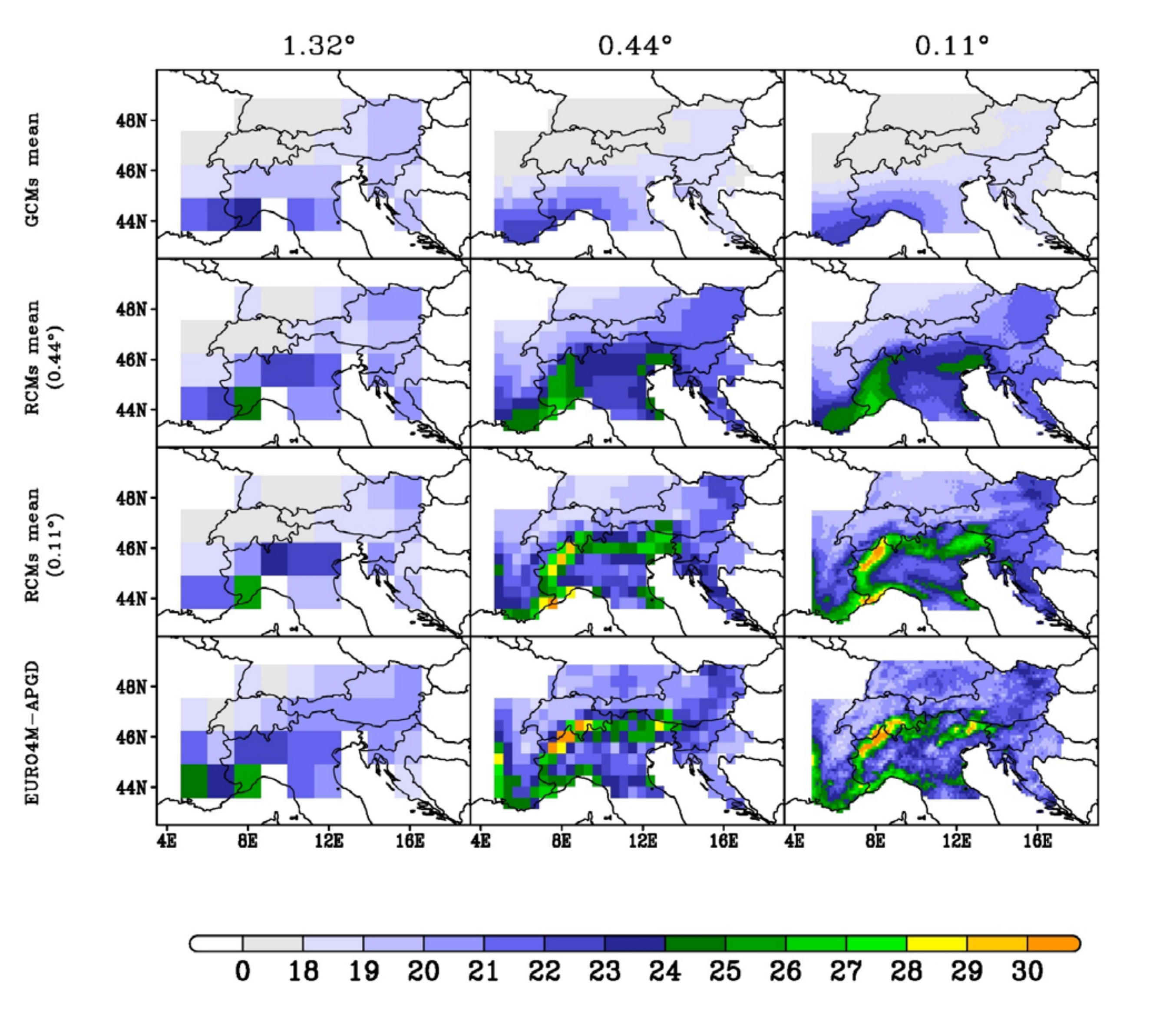






RCMs are always closer to OBS

Ensemble mean R95 for different resolution grids (1976-2005)



Mean

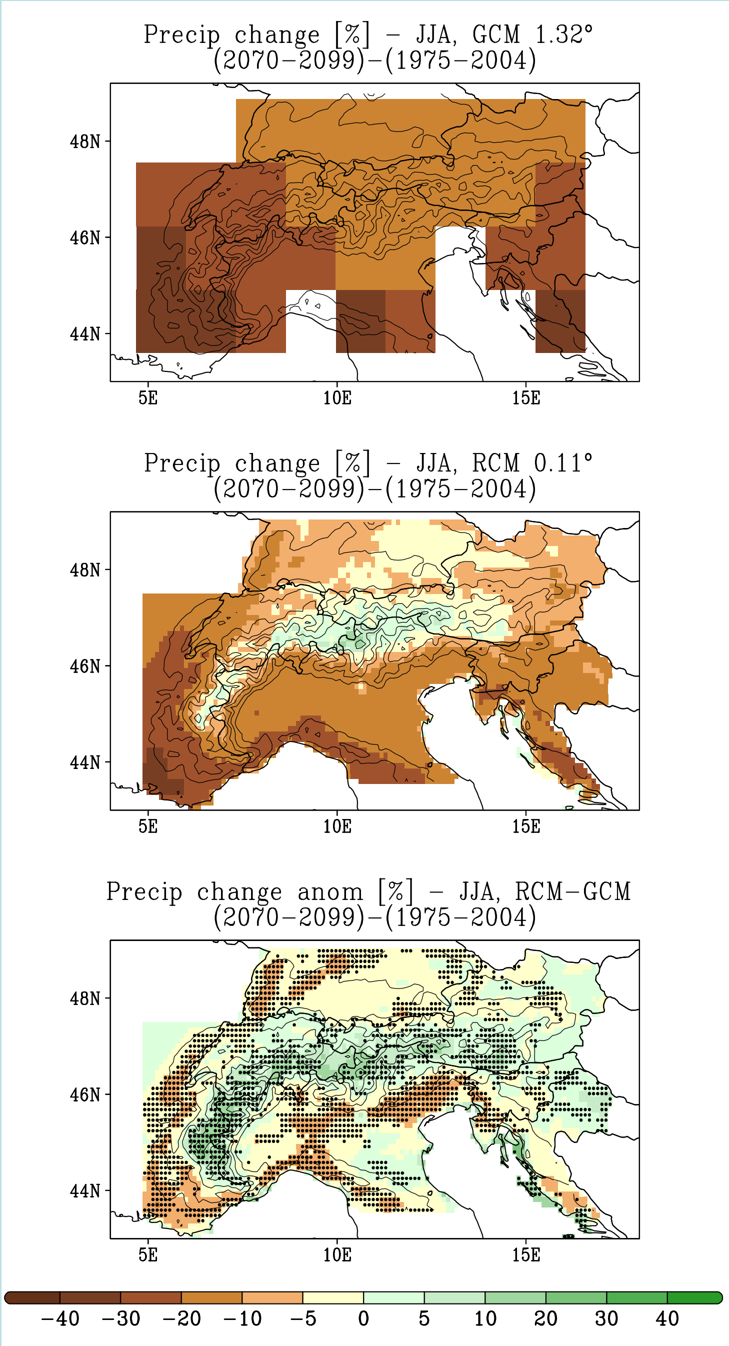
19.5

21.5

22.1

22.2

Is added value reflected in the climate change projections? Summer precipitation change over the Alps



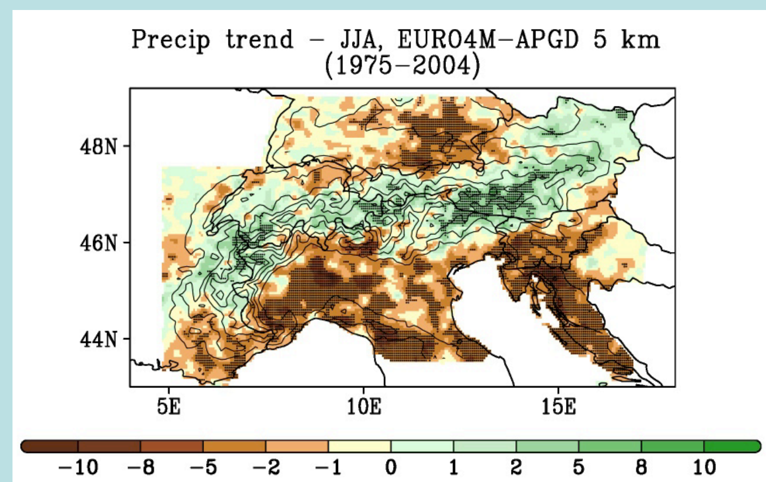
GCMs

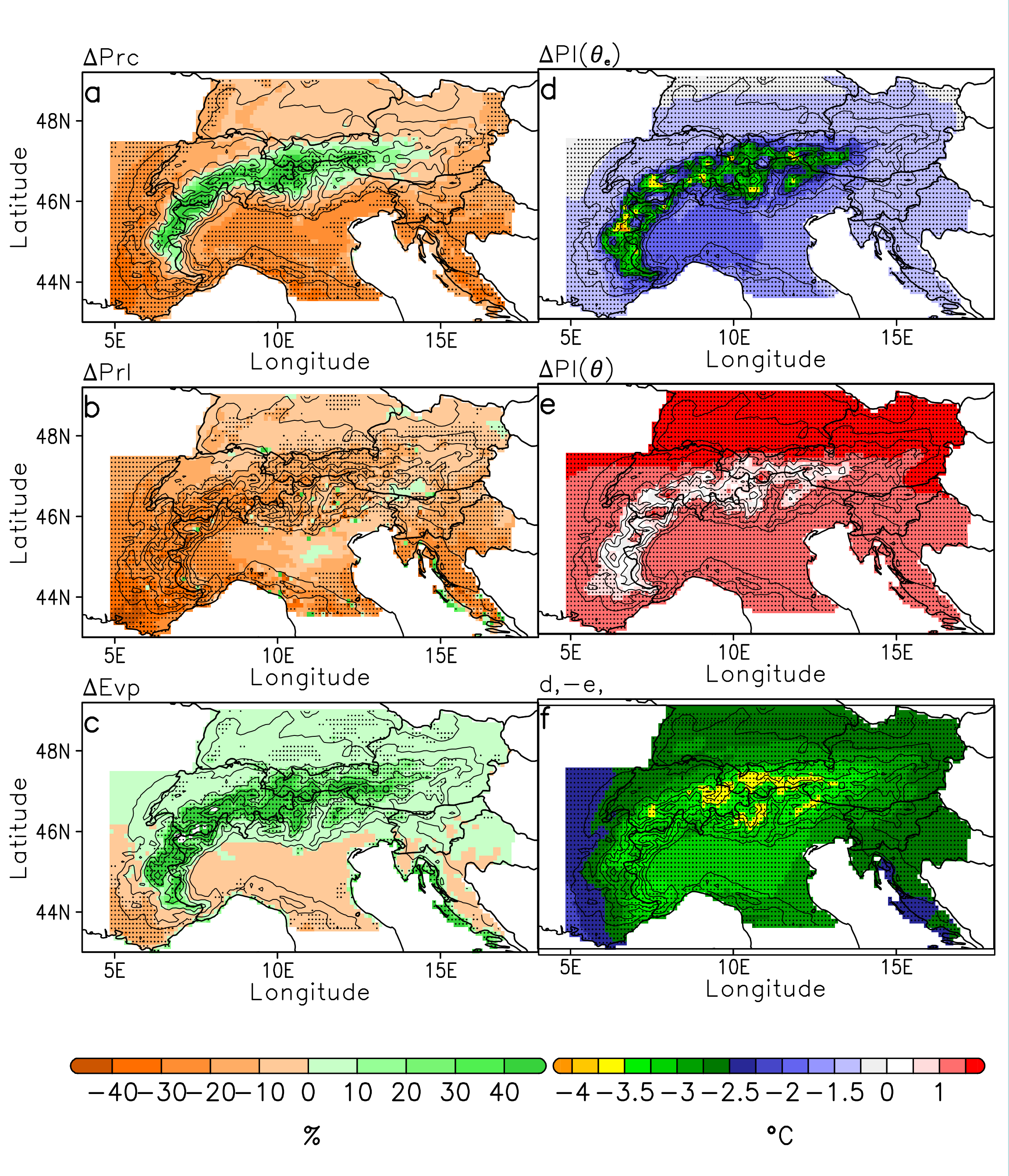
RCMs
0.11°

RCM – GCM
Anomaly

mm/day/century

Observed summer precipitation trend
1975-2004

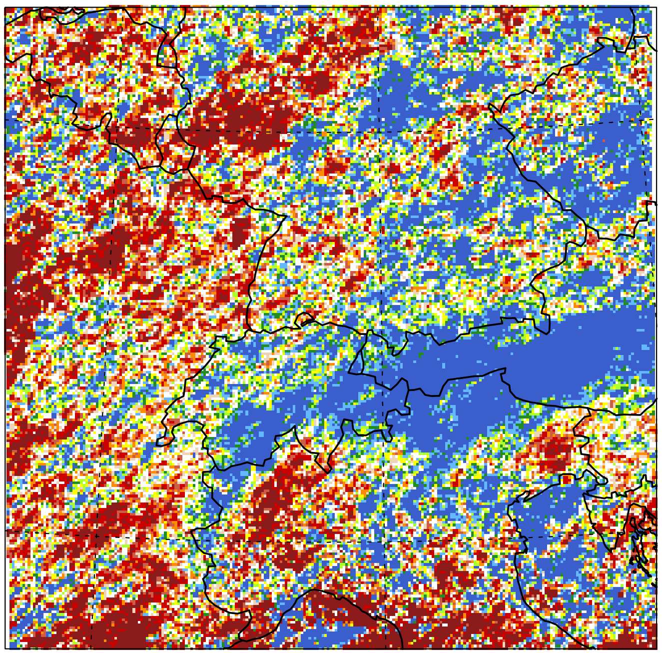




Underlying process: Increase in high elevation instability and convection

Change in convective precipitation over the Alps calculated with a convection permitting model (ΔS = 2 km) (Ban et al. 2015)

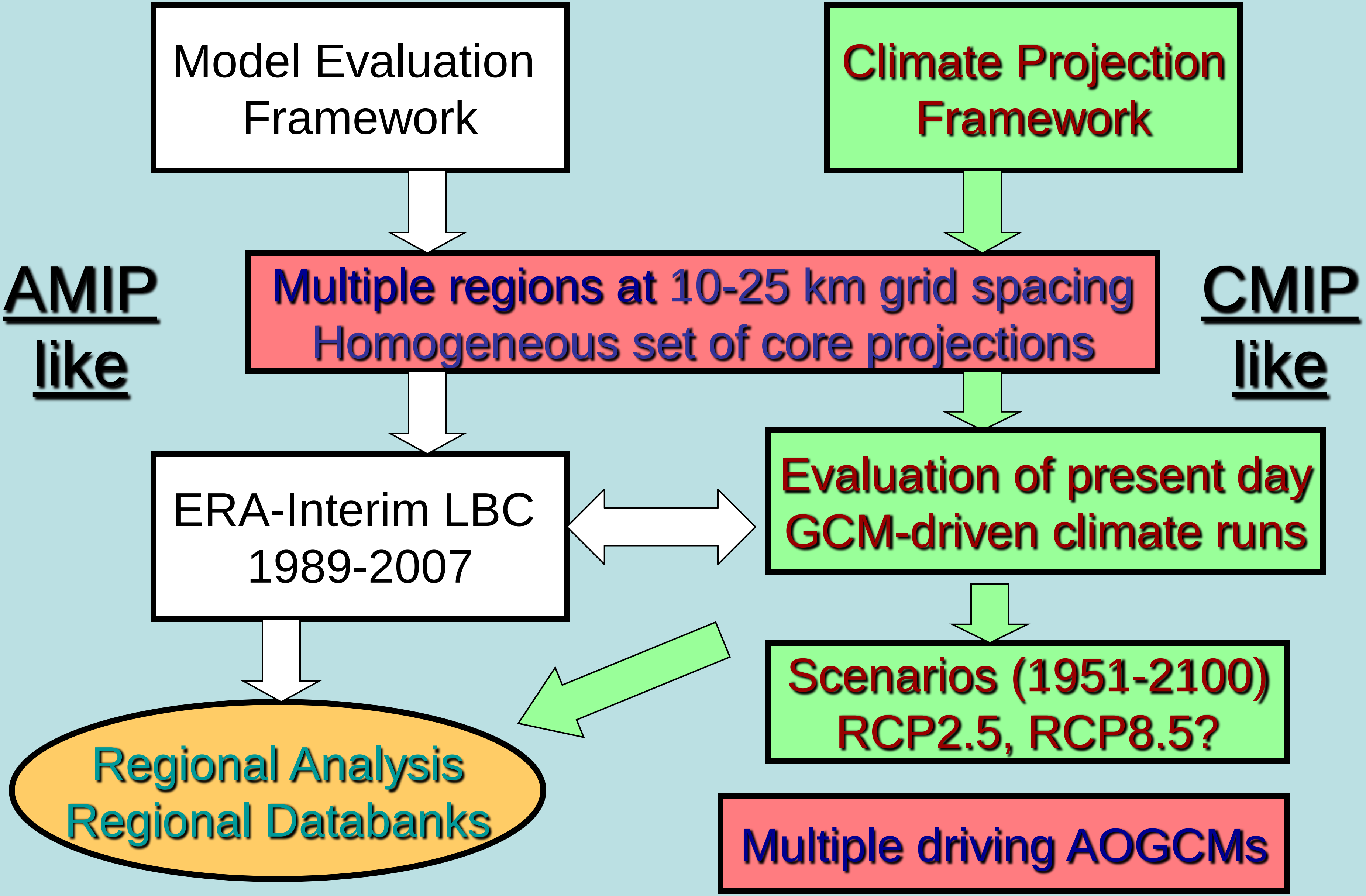
b) 12 km Convective Precipitation



Conclusions: Multiple lines of evidence point to an increase of summer precipitation over high Alpine elevations due to climate warming

- Better simulation of present day summer precipitation at higher resolution
- Identification of an underlying physical process (increase in convective instability)
- Consistency across models
- Consistency across variables (means, extremes, temperature)
- Consistency with observed trends

Future Direction I: CORDEX-CORE



Future Direction 2: CORDEX Flagship Pilot Studies

Effects of regional forcings
Land-use change
Urbanization
Aerosols

Intercomparison of different downscaling techniques
(e.g. RCM, ESD)

Interactions with other WCRP projects
(e.g. GEWEX)

Modeling (Added Value) at multiple scales, down to convection permitting.
Model development

Availability/production of high quality, high resolution, multiple variable observations

Development of coupled Regional Earth System Models (RESMs)

Relevance for VIA and adaptation/policy applications
Input to WGRC
FRONTIER PROJECTS

Production of large ensembles for uncertainty characterization

Study of phenomena relevant for regional climate and impacts through targeted experiments (e.g MCS, TC, extremes, monsoon)

The "Distillation" Paradigm

Regional climate information is available from multiple sources (GCMs, RCDs, "post-processing") and needs to be "distilled" to assess its value

Sparsely populated matrix
Choice of GCM-RCD-Scenario
Matrix filling (Pattern Scaling)

Credibility
Multiple lines of evidence
Process understanding
Inter-model/method agreement
Observed trends

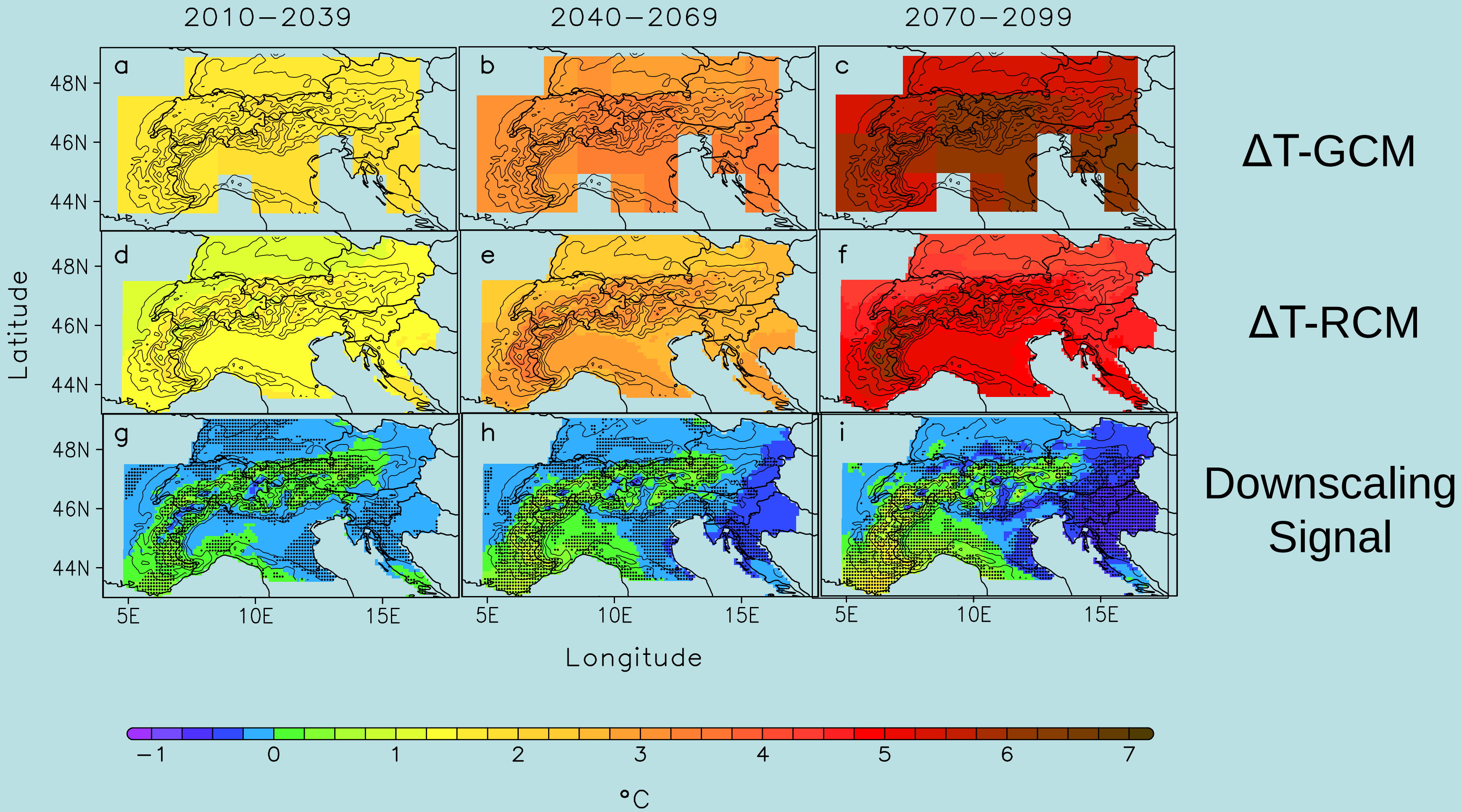
VIA relevance
Higher order statistics
Fine spatial/temporal scales
Non-conventional variables

Systematic model errors
Suitable metrics
Effect on change signal
Bias correction
Model weighting/exclusion

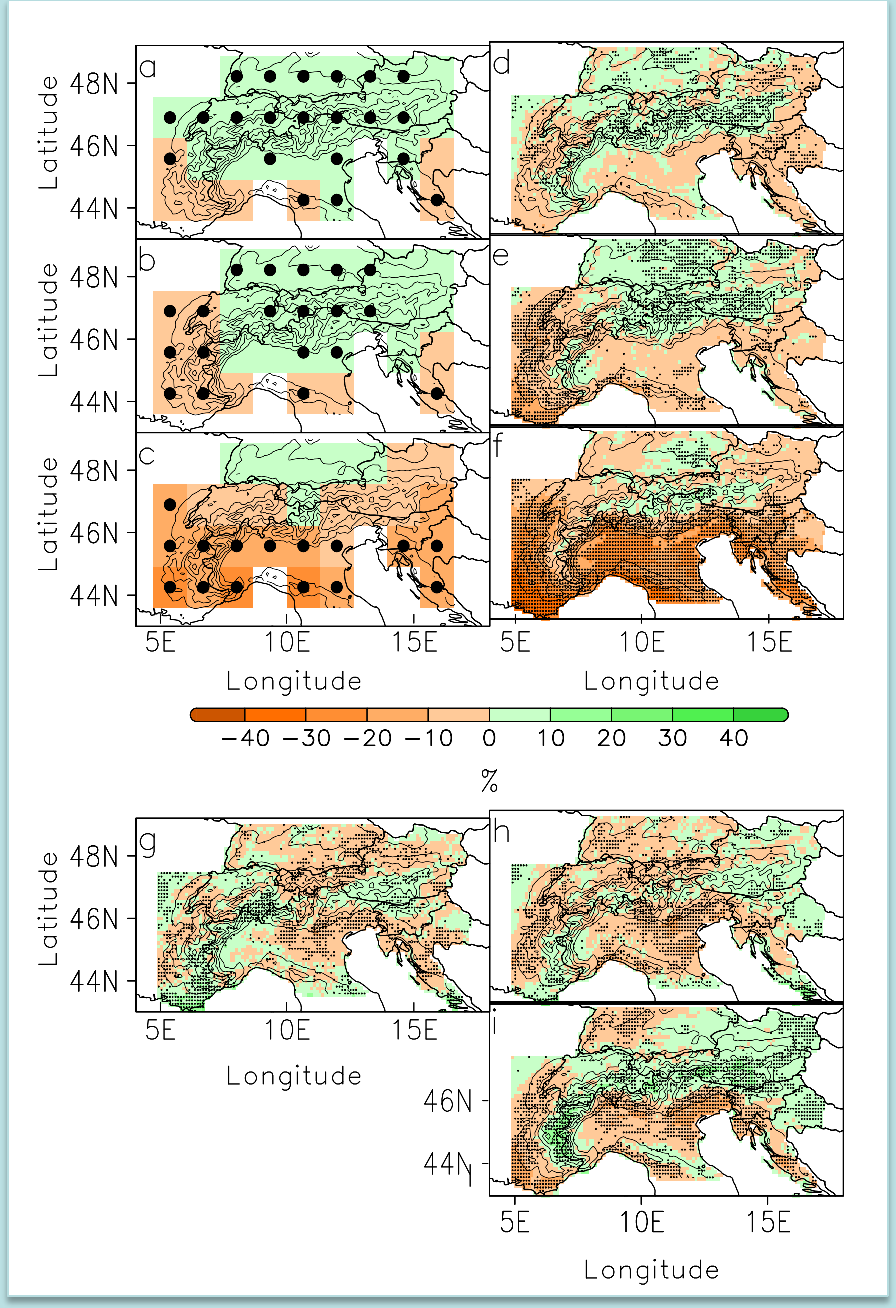
Uncertainty characterization
Intermodel range/standard deviation
PDFs


Thank You

Summer temperature change over the Alps in GCMs and RCMs (0.11°)



GCMs RCMs (0.11°)



2010-2040

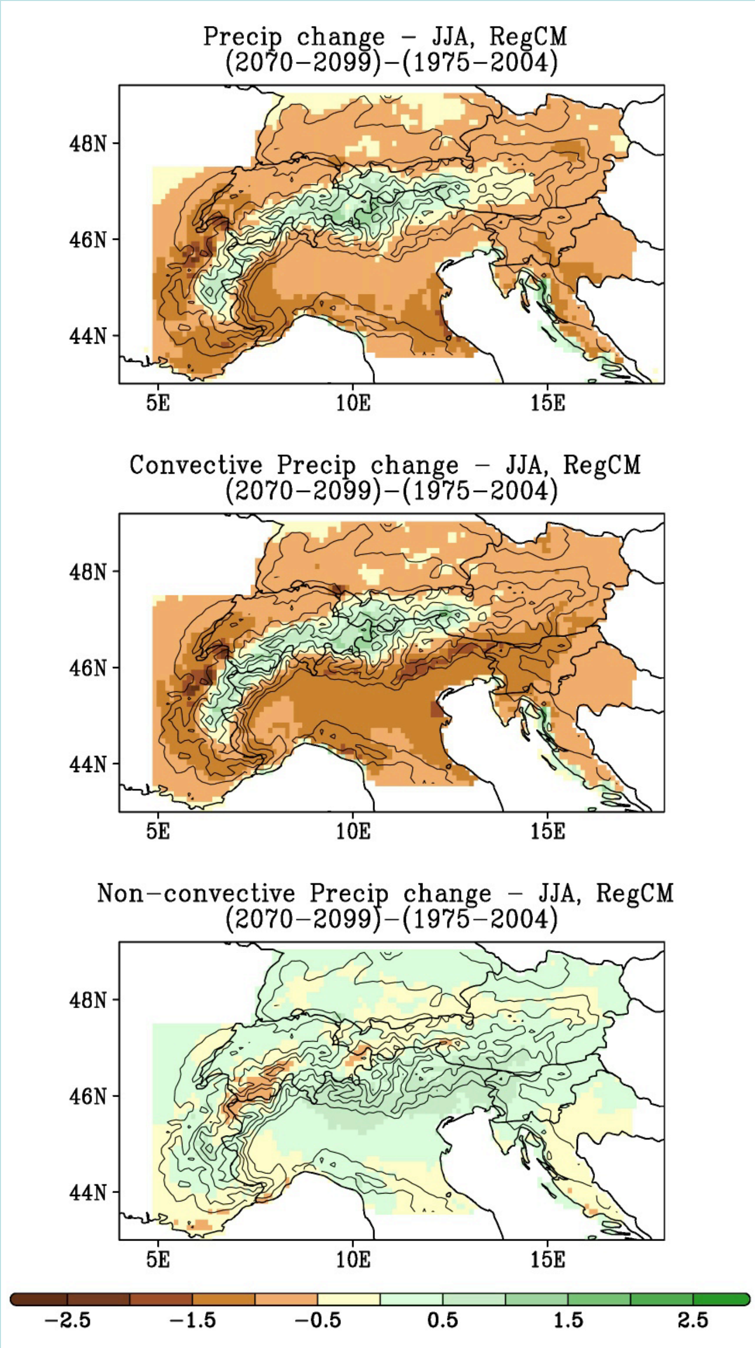
2040-2070

2070-2100

Downscaling Signal

Change in 95% percentile (all days)

Summer precipitation change RegCM (0.11°)



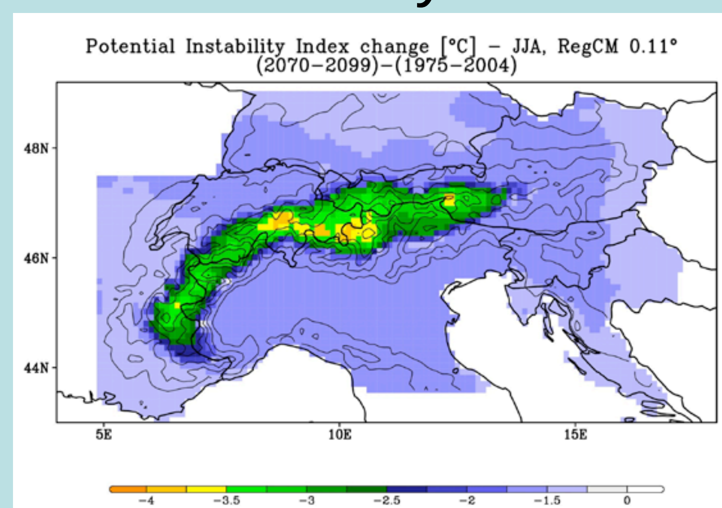
Total

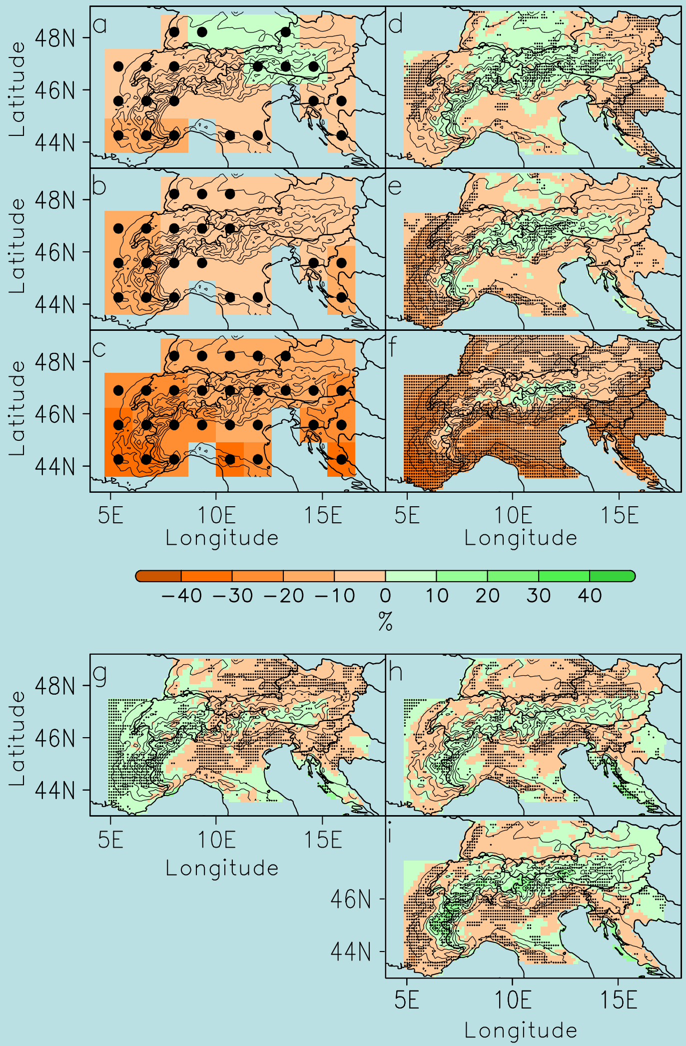
Convective

Non Convective

mm/day/century

Change in Potential Instability Index

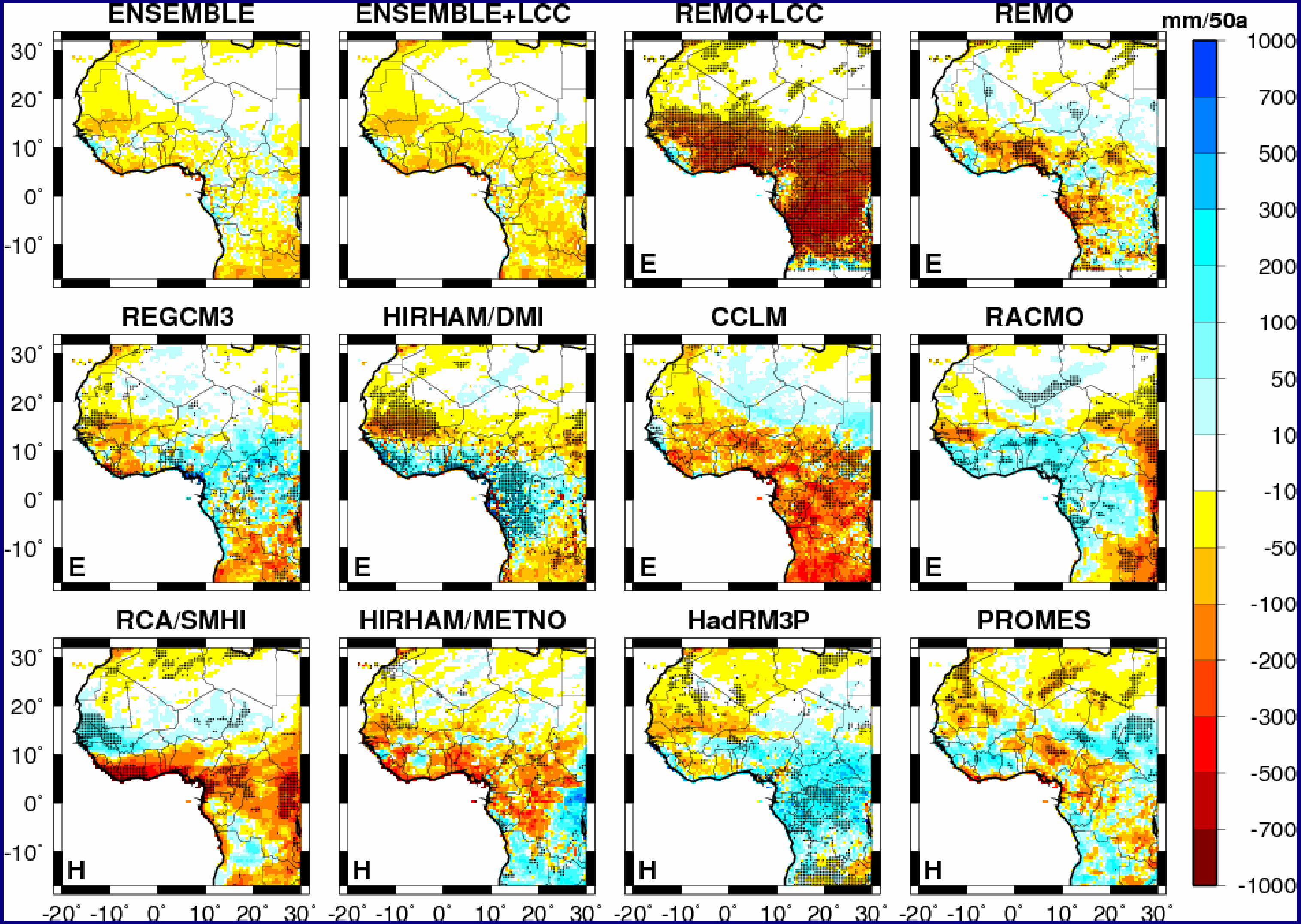




a
b
c
d
e
f
g
h
i
48N
46N
44N
5E
10E
15E
Latitude
Longitude
−40
−30
−20
−10
0
10
20
30
40
%

Precipitation trend 1990-2050

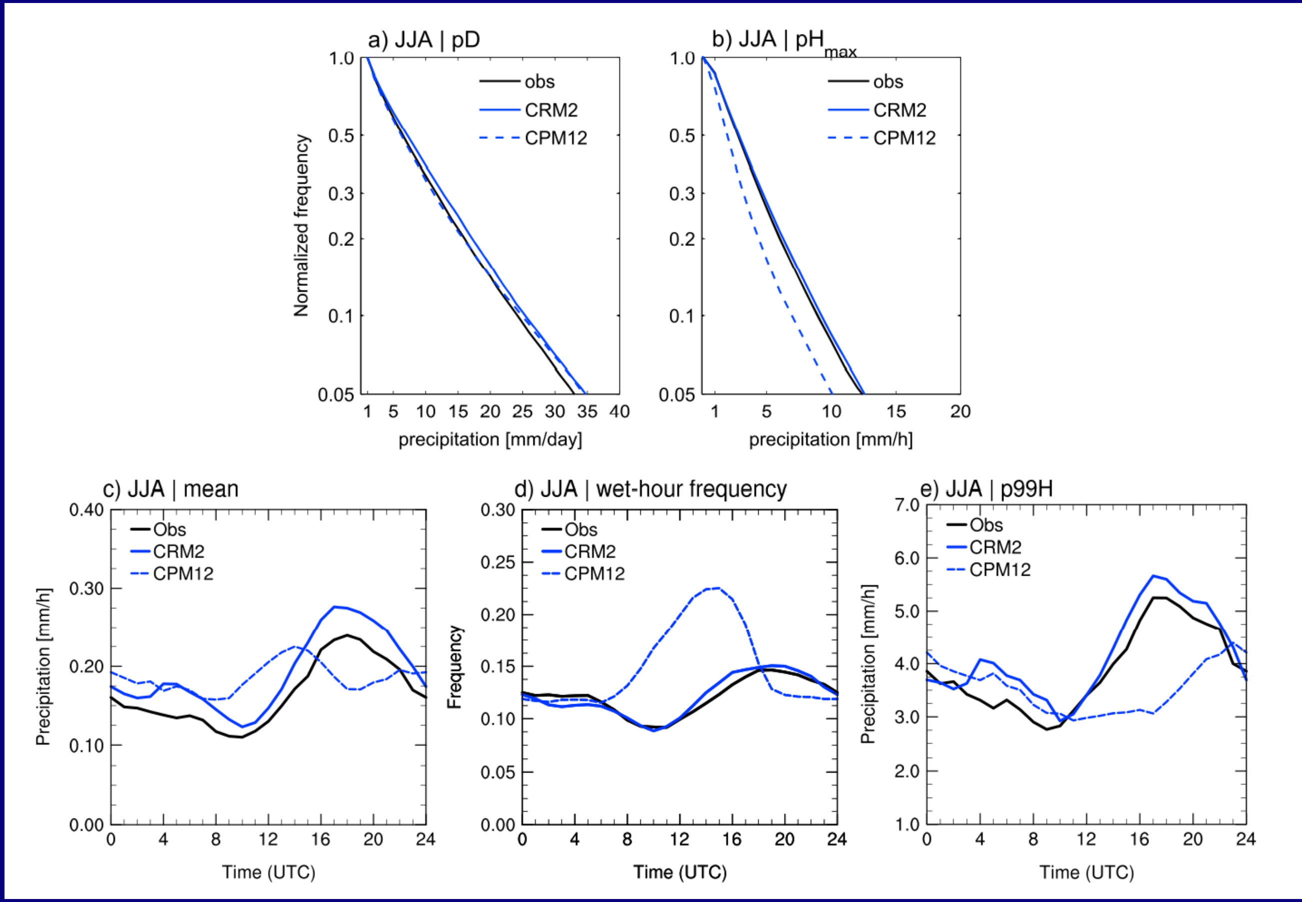
(AMMA Project, Paeth et al. 2011)



ECHAM5 LBC

HadCM3 LBC

Convection permitting modeling



Improvement of the diurnal cycle of precipitation

From Ban et al. GRL (2015)

Cloud resolving modeling

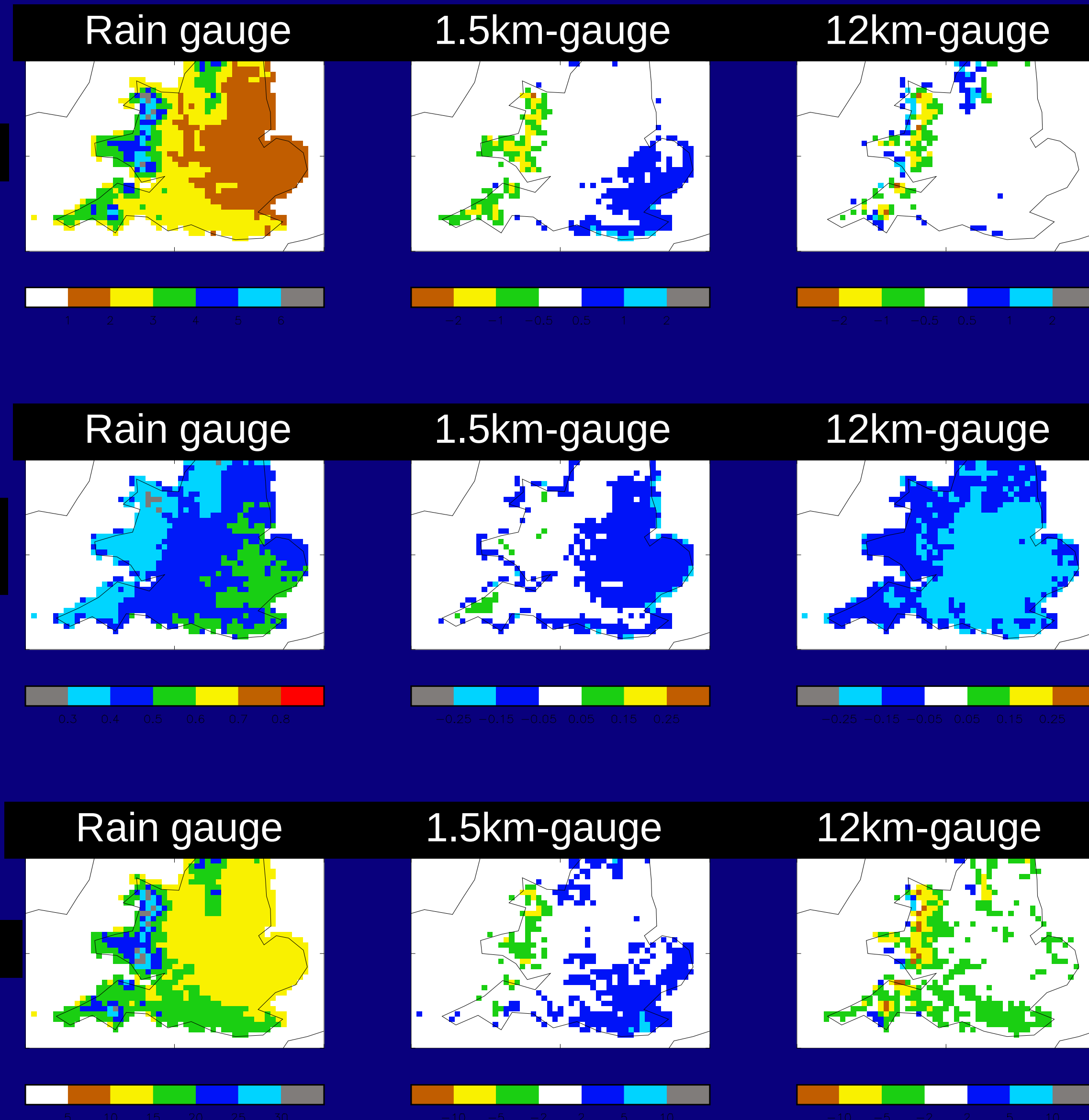
Obs | Bias | Bias

Daily precipitation
(1990-2003)

Mean precip

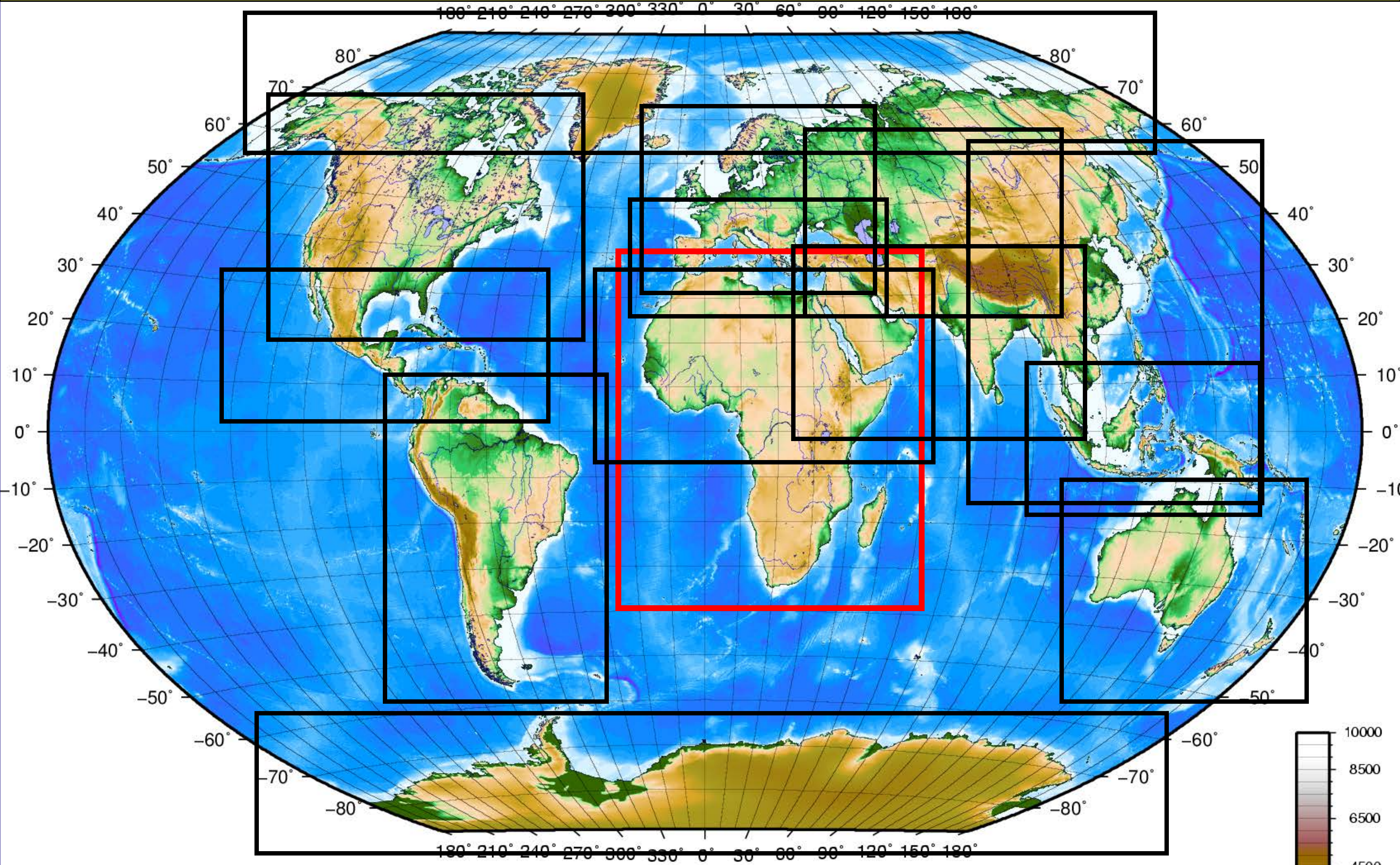
Dry day occurrence

Heavy precip



Courtesy of E. Kendon
UKMO

CORDEX domains



“Nested” Regional Climate Modeling: Technique and Strategy

Motivation: The resolution of GCMs is still too coarse to capture regional and local climate processes

Technique: A “Regional Climate Model” (RCM) is “nested” within a GCM in order to locally increase the model resolution.

- Initial conditions (IC) and lateral boundary conditions (LBC) for the RCM are obtained from the GCM (“One-way Nesting”) or analyses of observations (perfect LBC).

Strategy: The GCM simulates the response of the general circulation to the large scale forcings, the RCM simulates the effect of sub-GCM-grid scale forcings and provides fine scale regional information

- Technique borrowed from NWP