IS-ENES3 Climate Impact Autumn School
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# From GCM to regional applications

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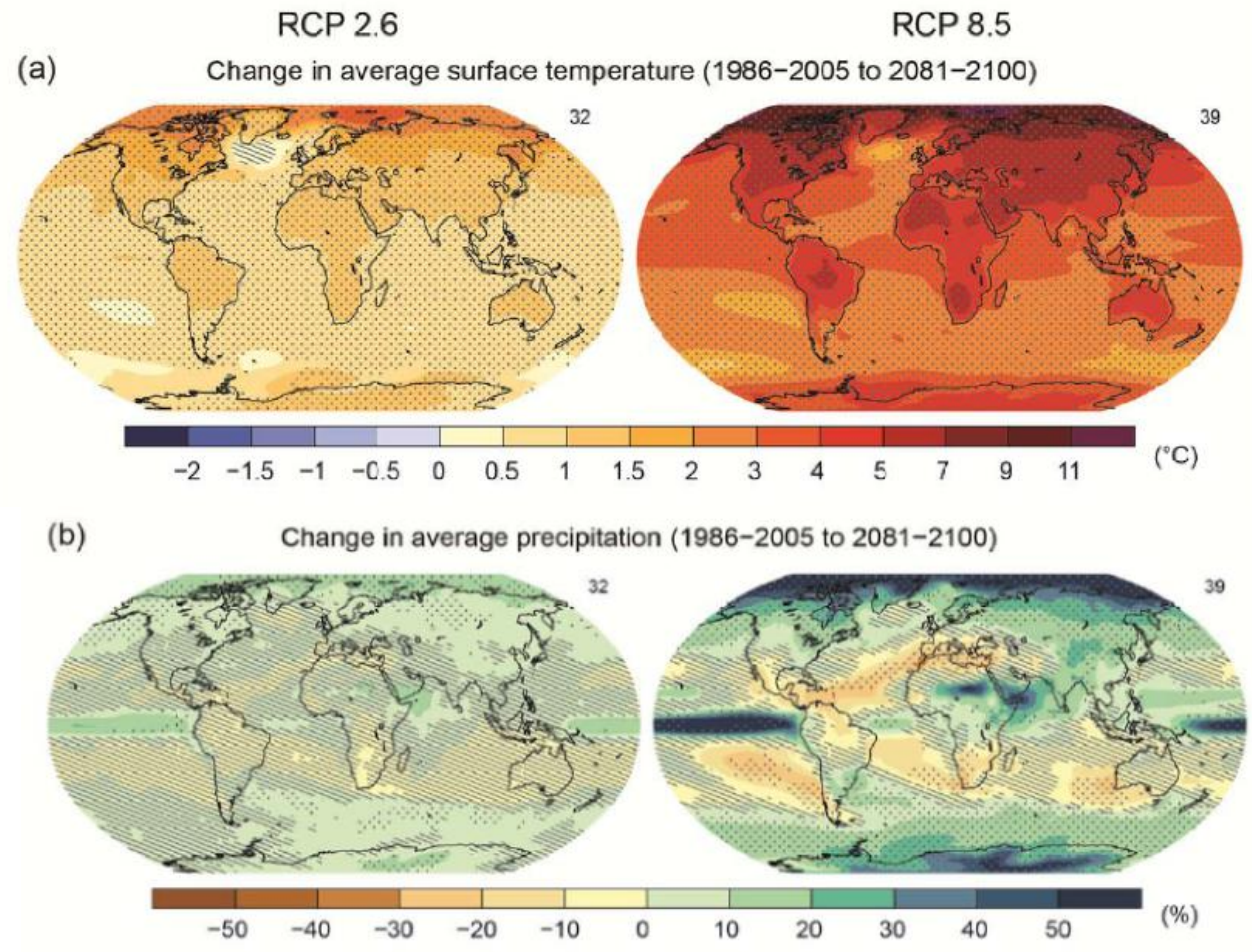
# Outline

- GCMs and their problems to provide regional/local information
- Resolution examples
- Downscaling techniques (dynamical, statistical),
- Dynamical downscaling (nudging, one way, two way)
- Added value (extreme precipitation)
- CORDEX (coverage, CORE experiments)
- EuroCORDEX, FPS
- Validation (reference data – observation, reanalyses – possible biases as well)
- Scenarios projections
- Bias adjustment
- Weather generators
- Conclusions

# GCM vs. regional/local information

**GCMs provide:**

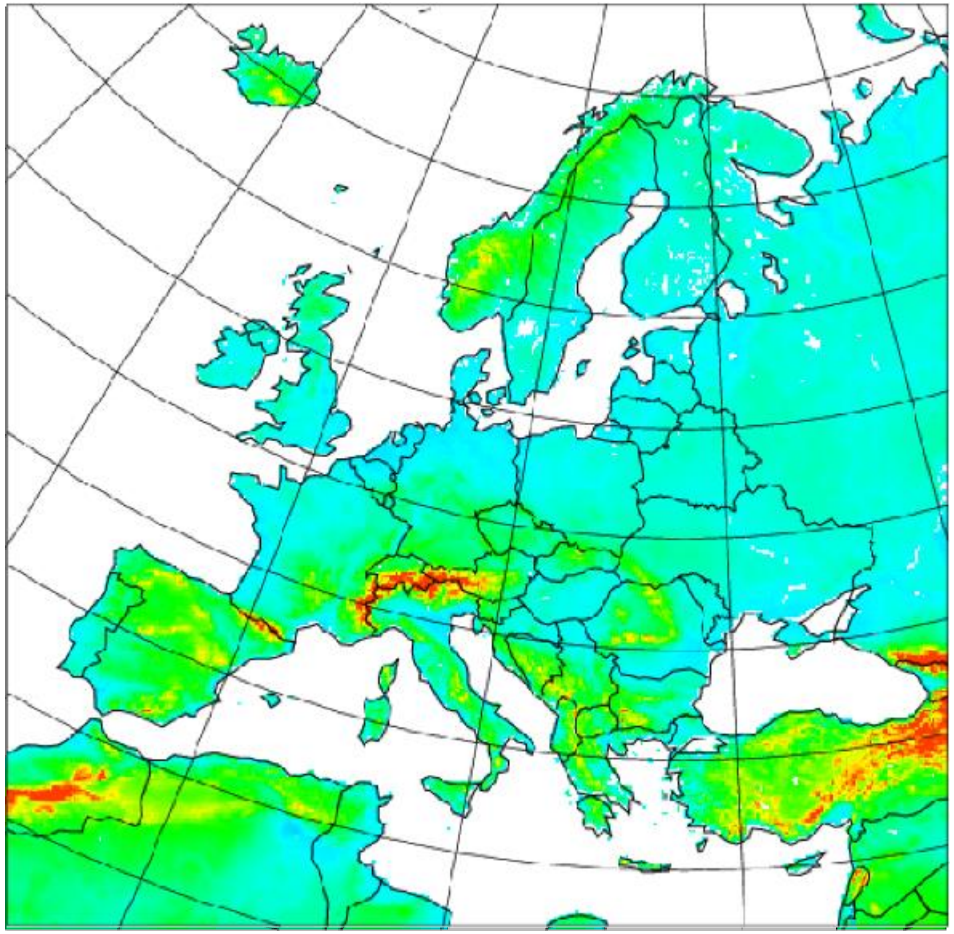
- Global to continental scale picture, regional scale limited by the resolution
- By ESM can provide full spread of climate system components interactions
- Global teleconnections effects



# GCM vs. regional/local information

**GCMs have problems due to lack of resolution:**

- Scale of topography (real heights, slopes, orographic features, …)
- Scale of land-use (coast line shapes, water bodies, etc.)
- Scale of land-surface processes (land-sea interactions, snow albedo feedback, urban effects)



Resolution

300km

50km

10km

(J. H. Christensen)

# Problems with GCM

- GCMs can reproduce climate features on large scales, but their accuracy decreases when proceeding from continental to regional and local scales because of the lack of resolution.

- This is especially true for surface fields, such as precipitation, surface air temperature and their extremes, which are critically affected by topography and land use

- However, in many applications, particularly related to the assessment of climate change impacts, the information on surface climate change at regional to local scale is fundamental.

# Downscaling techniques

**To get from large scale patterns to regional/local information in high resolution (high resolution scenarios):**

- **dynamical downscaling**, i.e., nesting of a fine scale limited area model (or Regional Climate Model, RCM) within the GCM (similarly like commonly done in NWP)

- **statistical downscaling**, i.e., identification of statistical relationships between large-scale fields and local surface climate elements

The former approach seems more correct from a physical point of view physical consistency between the variables, but much more demanding on computer resources, than the latter one

# Statistical downscaling

Identification of statistical relationships between large-scale fields and local surface climate elements:

- **Machine learning** – data mining, predictors – upper levels temperature, geopotential, circulation types, etc., predictands – surface climate characteristics, extremes, other variables not simulated by GCMs (or even RCMs)
  - Regression analysis – multiple linear regression methods, …
  - Artificial inteligence techniques – neural networks
  - Weather pattern-based approaches
  - Stochastic weather generators

NEEDS DATA (OBSERVATIONS, REANALYSIS)

Mostly used to resolve spatial variability, but possible as well for temporal resolution. Assumption of stationarity to obtain the relationships and to use them for the future – need not be valid.

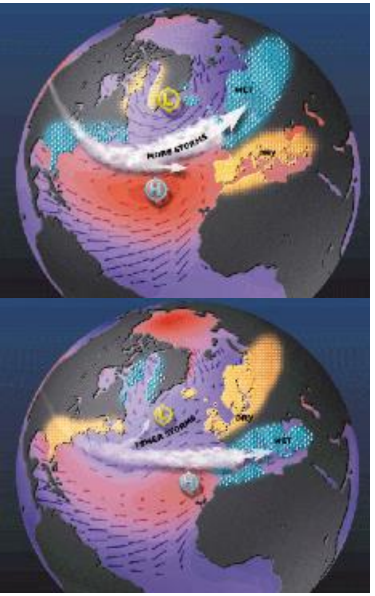
# Dynamical downscaling

**nesting of a fine scale limited area model (or Regional Climate Model, RCM) within the GCM (similarly like commonly done in NWP):**

- **Primitive equations**
  - *Conservation of momentum* - a form of the Navier–Stokes equations (or Newton's second law) describing quasi-horizontal hydrodynamical flow on the Earth's surface
  - *Conservation of mass* - represented by the continuity equation
  - *Conservation of energy* - first law of thermodynamics, i.e. *thermal energy equation*, relating the overall temperature of the system to heat sources and sinks
- other processes and parameterizations – depending on resolution (continuity of water vapor with sources and sinks, short-wave and long-wave radiation, cloud and precipitation physics, boundary layer physics, land surface interactions)

# Why regional climate modelling?

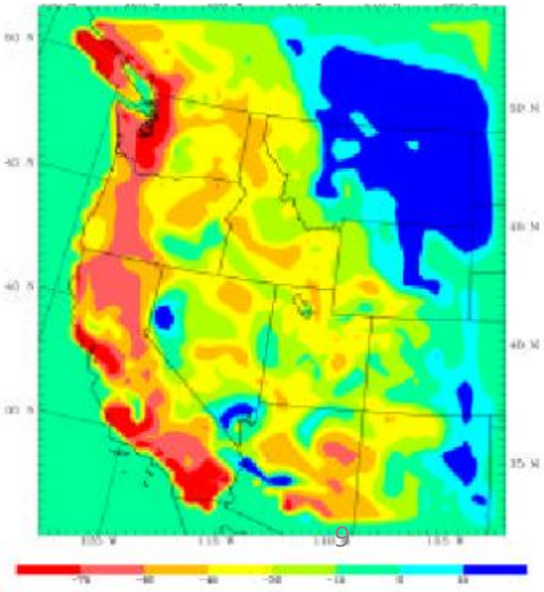
- Regional climates are determined by the interactions of planetary/large scale processes and regional/local scale processes
  - Planetary/large scale forcings and circulations determine the statistics of weather events that characterize the climate of a region
  - Regional and local scale forcings and circulations modulate the regional climate change signal, possibly feeding back to the large scale circulations



In order to simulate climate (and more specifically climate change) at the regional scale it is thus necessary to simulate processes at a wide range of spatial (and temporal) scales

- Practical aspects (hi-res for less resources, higher resolution, etc. – in future with hi-res GCMs?)

Snow pack decrease 2xCO2, Western US



# GCM vs. RCM

## Planetary and large scale processes

Forcings

- Solar radiation input
- Well mixed greenhouse gas concentrations
- Continent-ocean distribution
- Large topographical systems

Effects on the general circulation

- Storm tracks
- Dynamics of the ITCZ
- Planetary wave patterns
- Monsoons
- Modes of the coupled system (NAO, ENSO)

## Regional and local scale processes

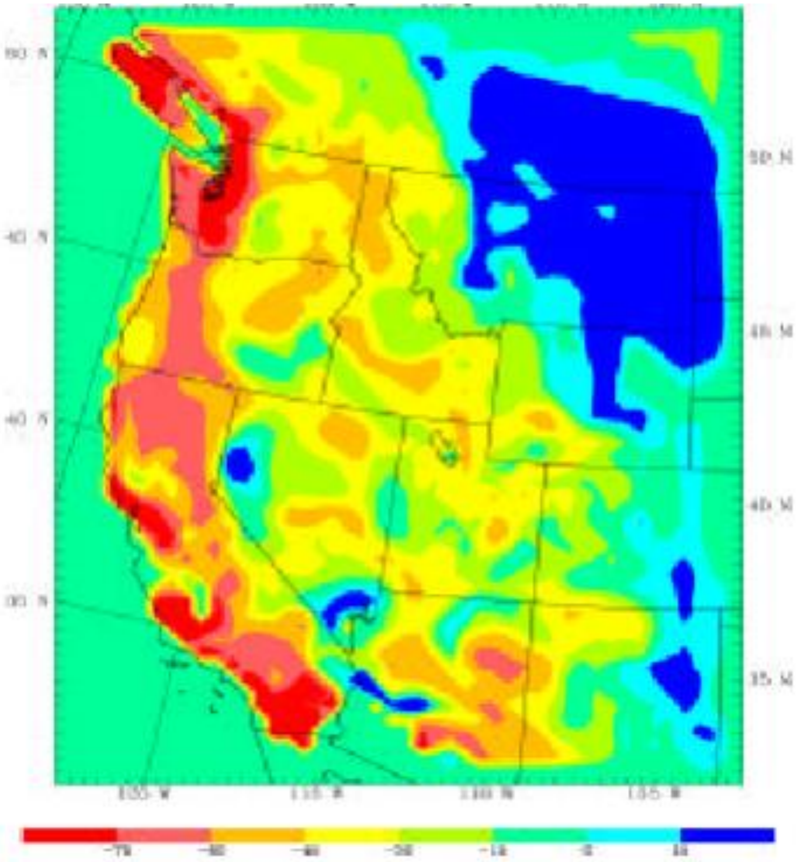
Forcings

- Topography
- Landuse, urbanization
- Coastlines, Islands, Peninsulas
- Inland water, Lakes, SST distribution
- Tropospheric aerosols and gases (e.g. ozone)

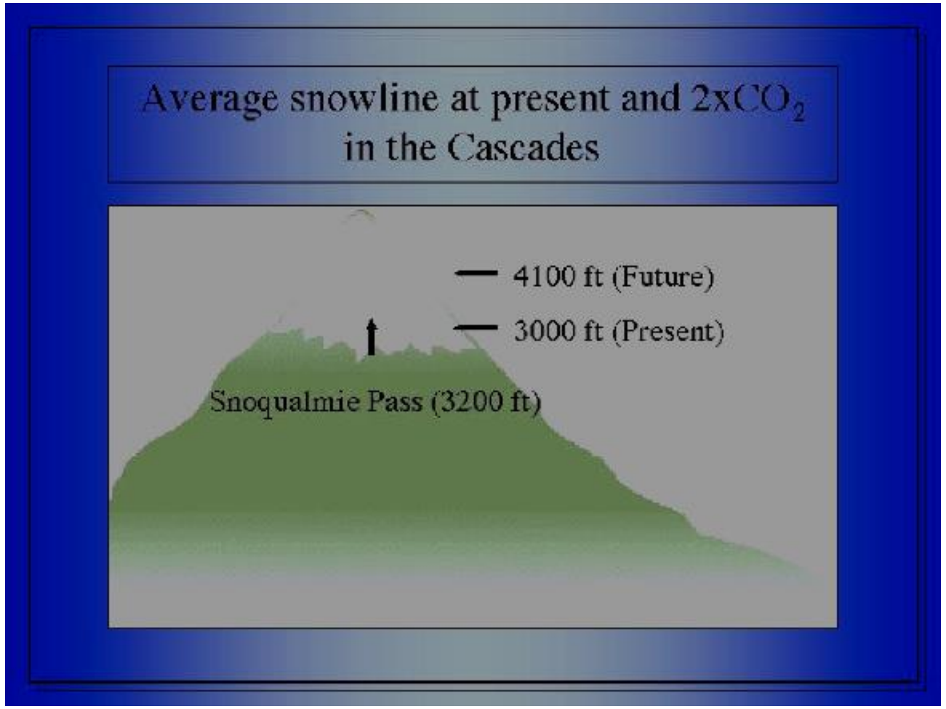
Effects on regional climate

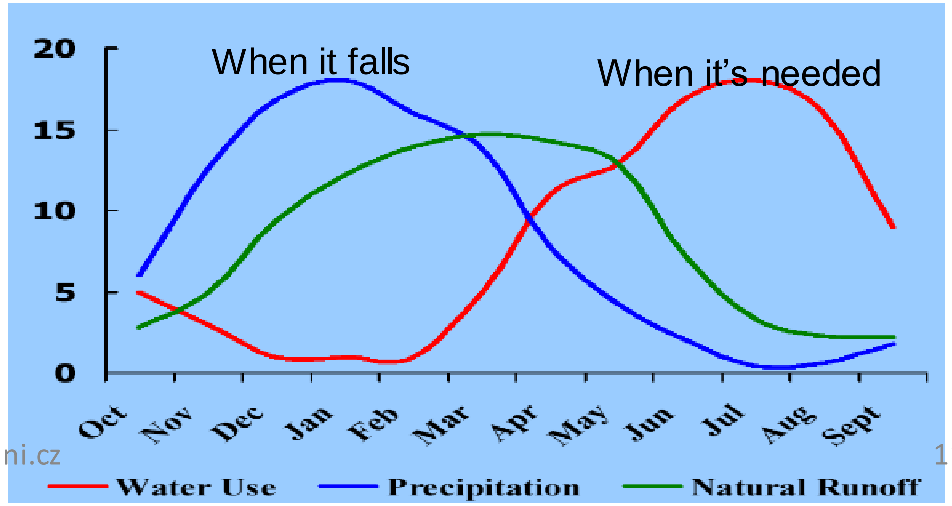
- Precipitation (e.g. orographic uplift, cyclogenesis)
- Surface energy and water budgets
- Mesoscale circulations (surface winds)
- Land-Atmosphere and air-sea interactions
- Extreme events

# Regional change in Western US snowpack at 2xCO2



Leung et al., Clim. Change, 2003



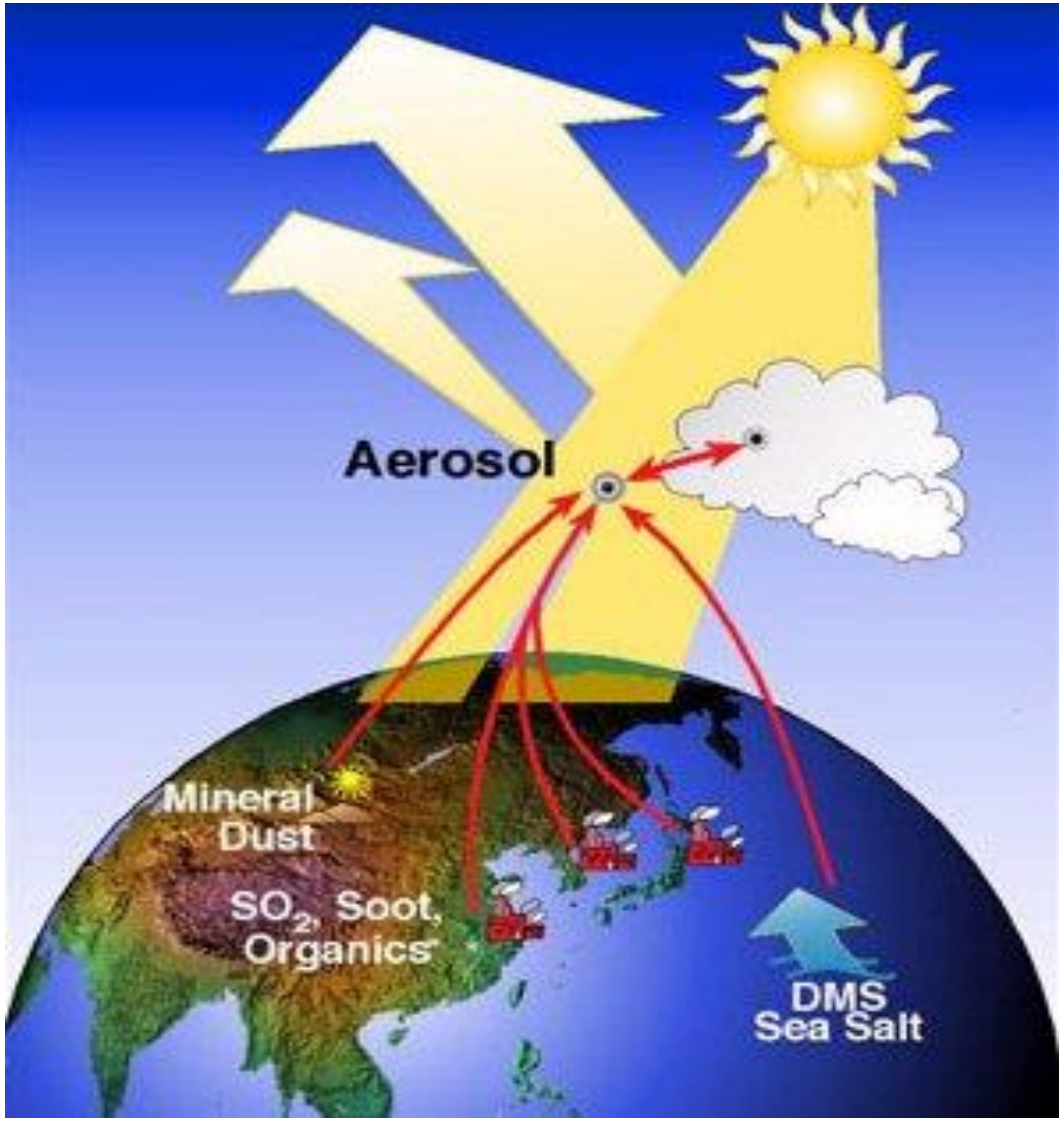




Warmer temperatures should be expected to cause major changes in snowpack (if they are not offset by fortuitous changes in precipitation). Alps? Andes? … ?

Immediate response to a small change – can affect the future picture which not shown by GCMs

# Aerosol forcing

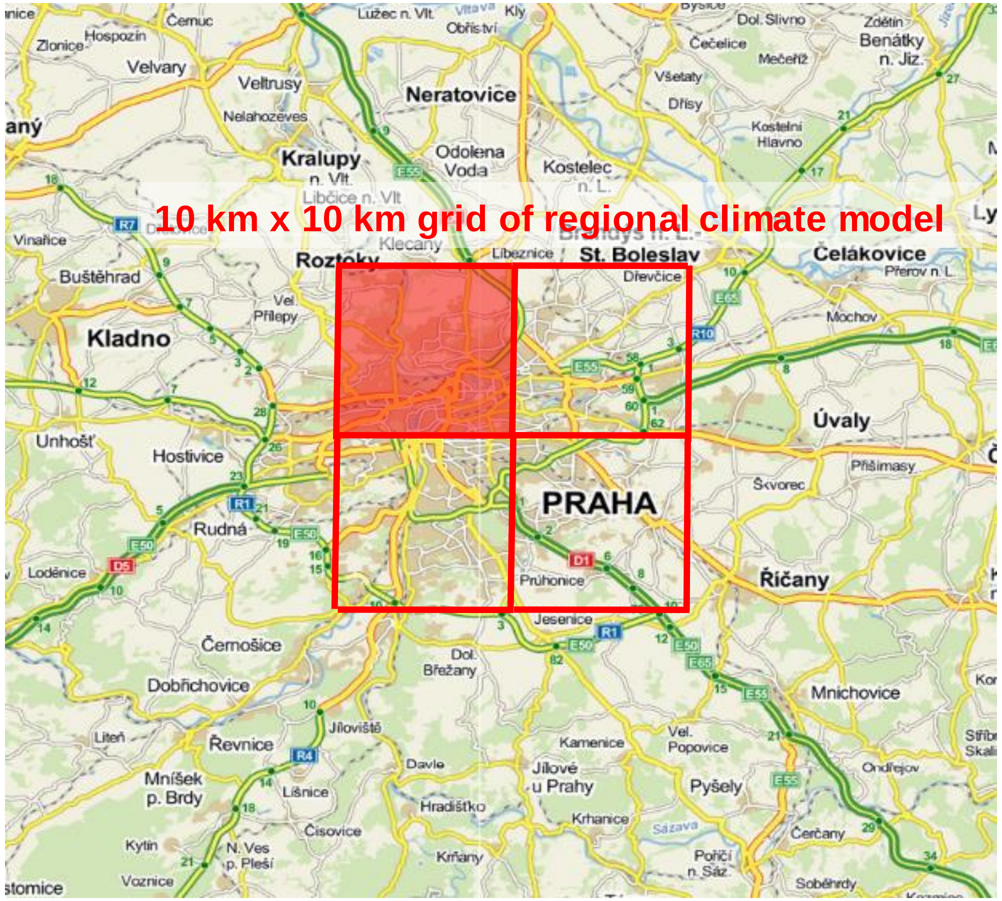
**Direct effects**
Aerosols absorb and reflect solar radiation

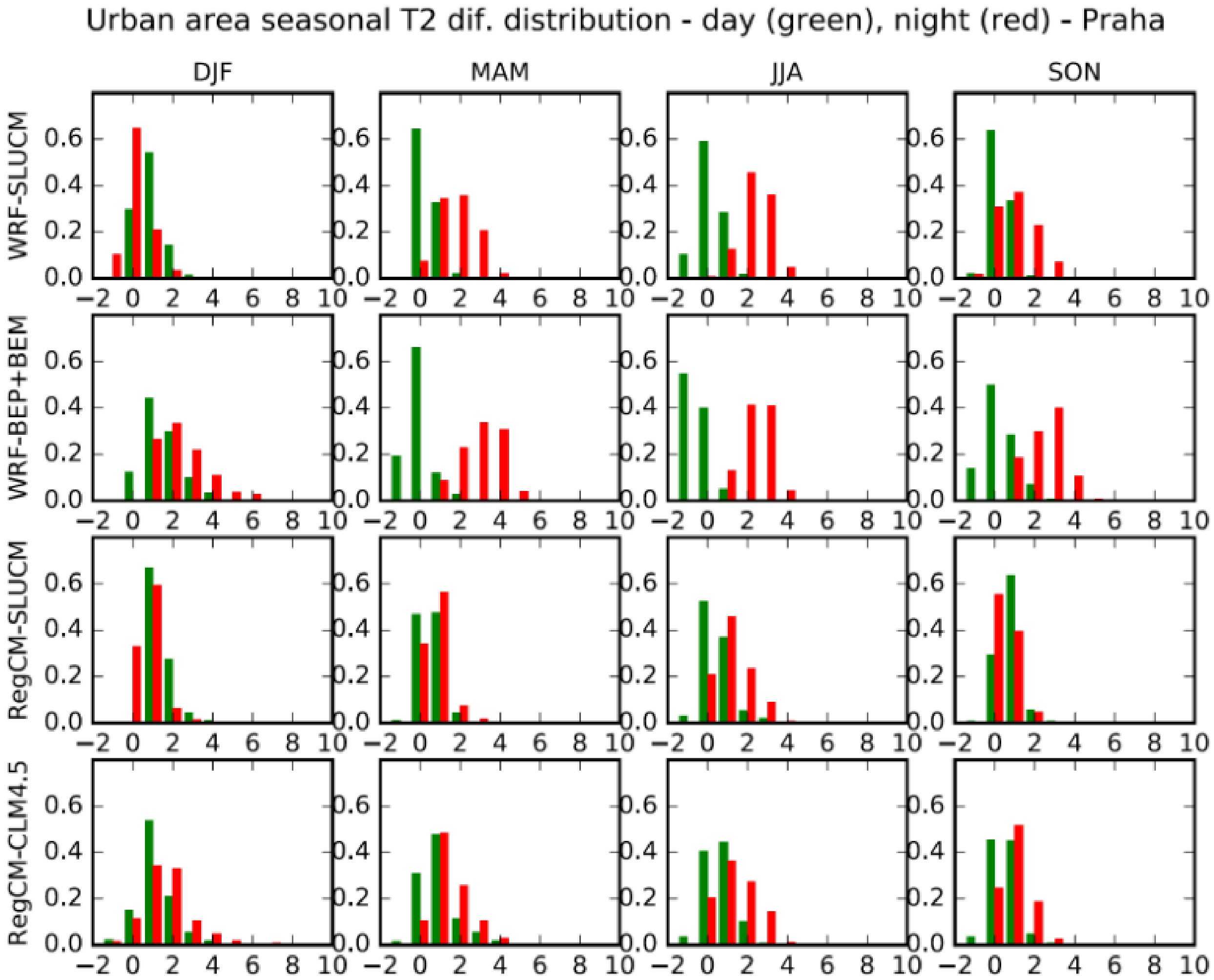



**Indirect effects**
Aerosols change the properties of clouds

# EXTREME EVENTS

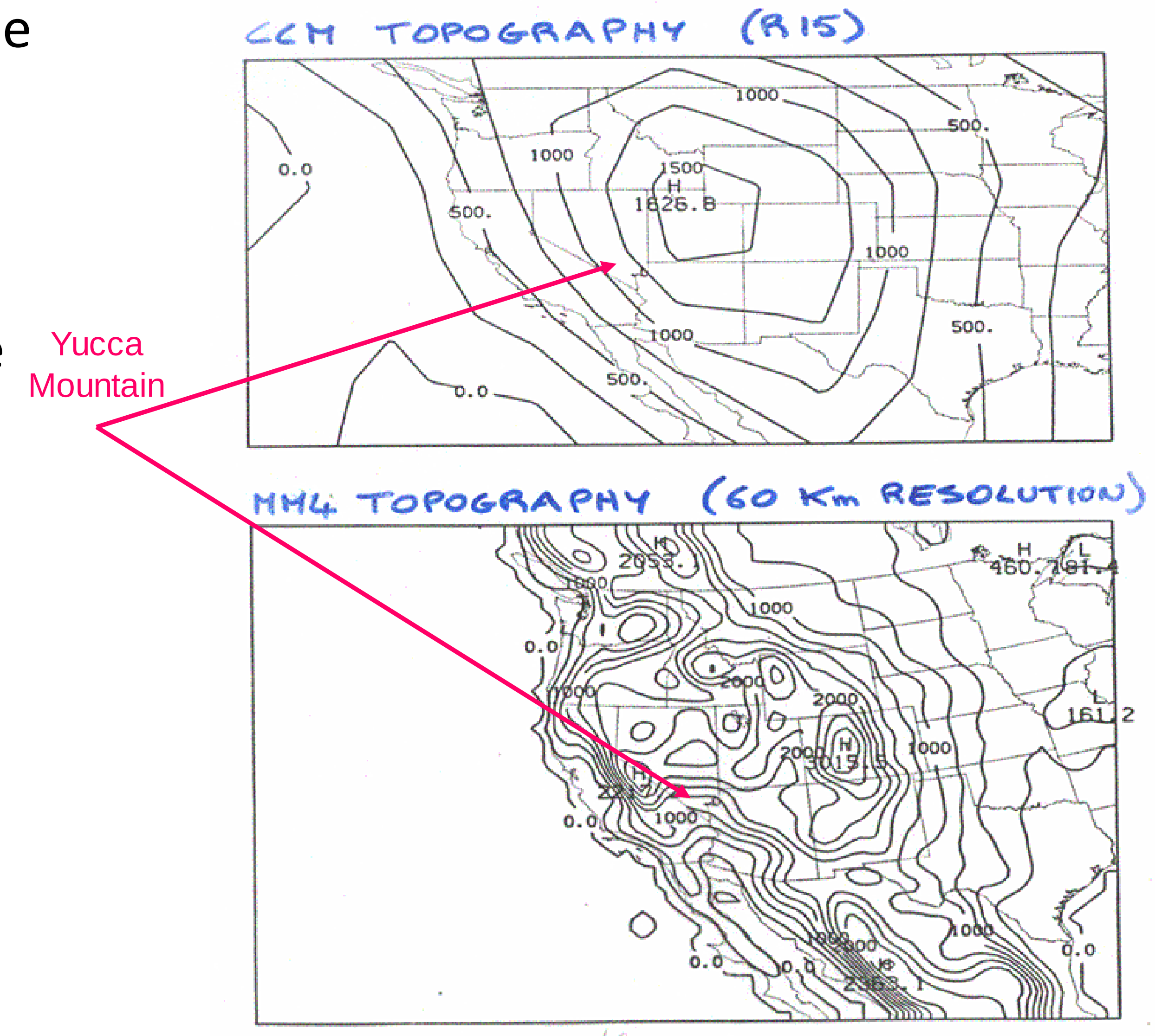
# Urban effects - UHI



# RCM development

- The birth of regional climate modeling - The Yucca Mountain Project (1987), Dickinson et al. (1989) adopted the “nesting” approach to climate problems by generating statistics of large numbers of short LAM simulations driven by GCM. The model used was a modified version of the NCAR/Penn State mesoscale model MM4



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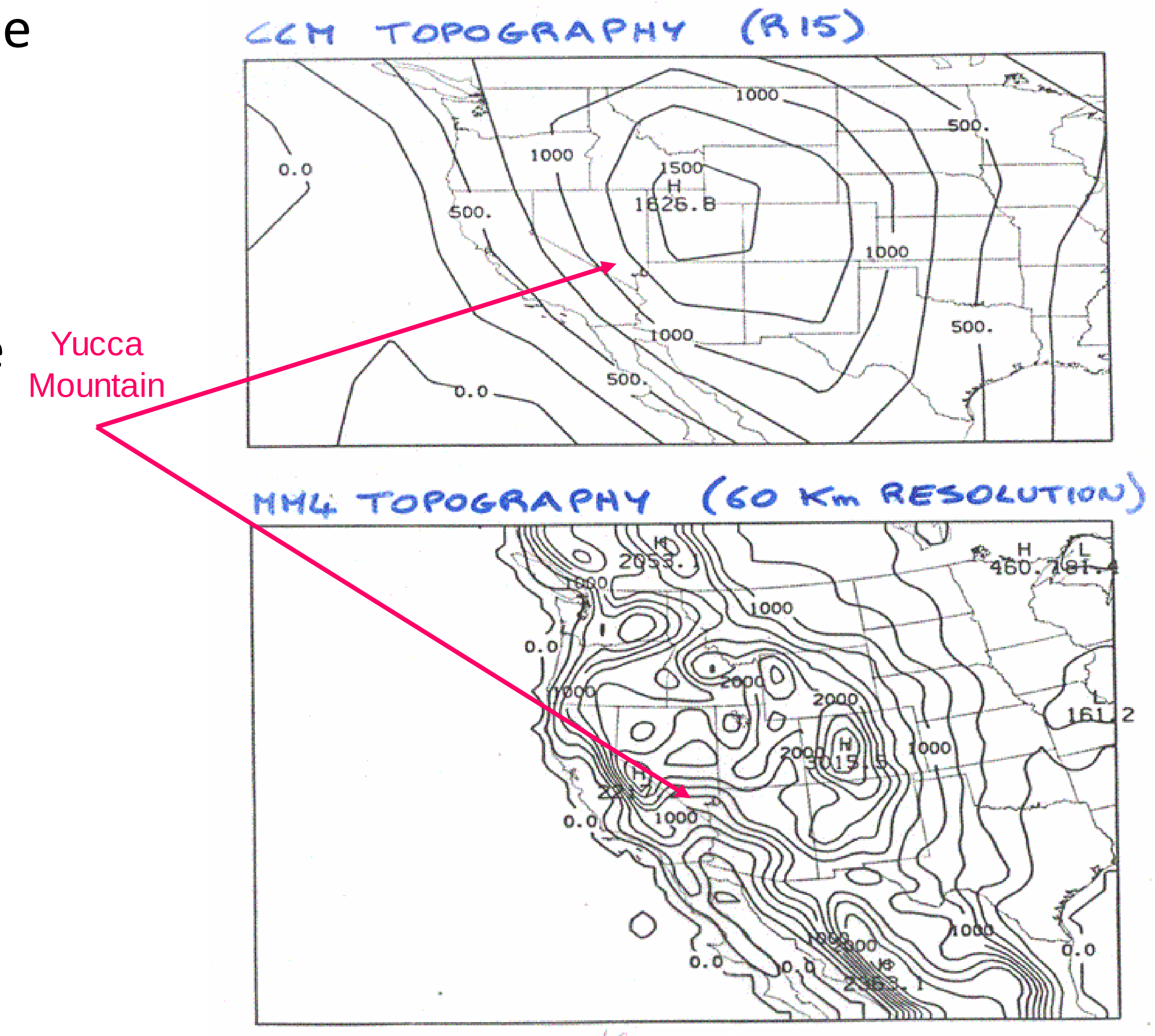
- Giorgi and Bates (1989) and Giorgi (1990) completed the first LAM simulations in “climate mode” (1-month long) driven by ECMWF analyses of observations and by GCM fields, respectively.
- This lead to the first generation of RegCM, based on MM4 with modified radiative transfer and land surface process schemes

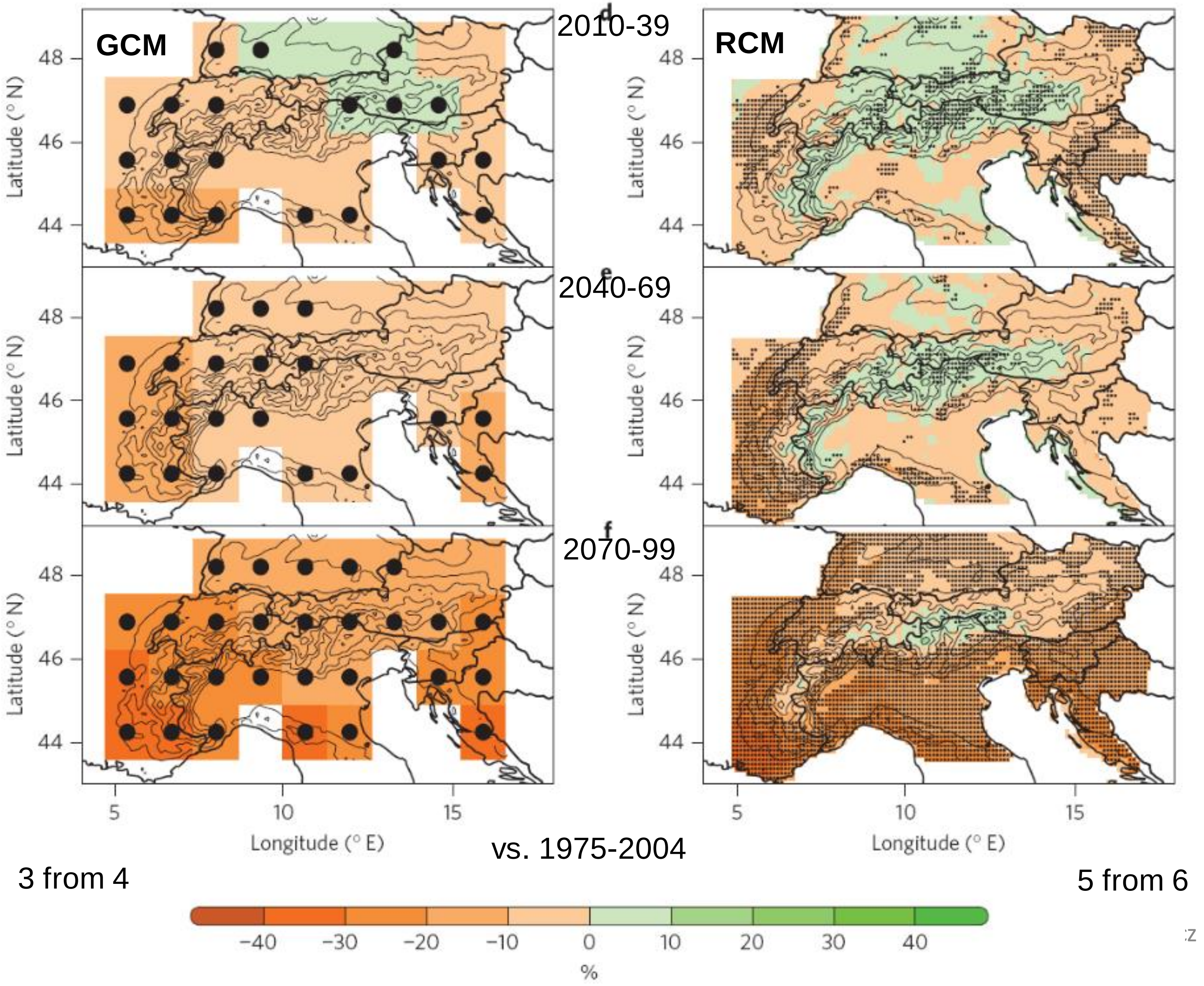


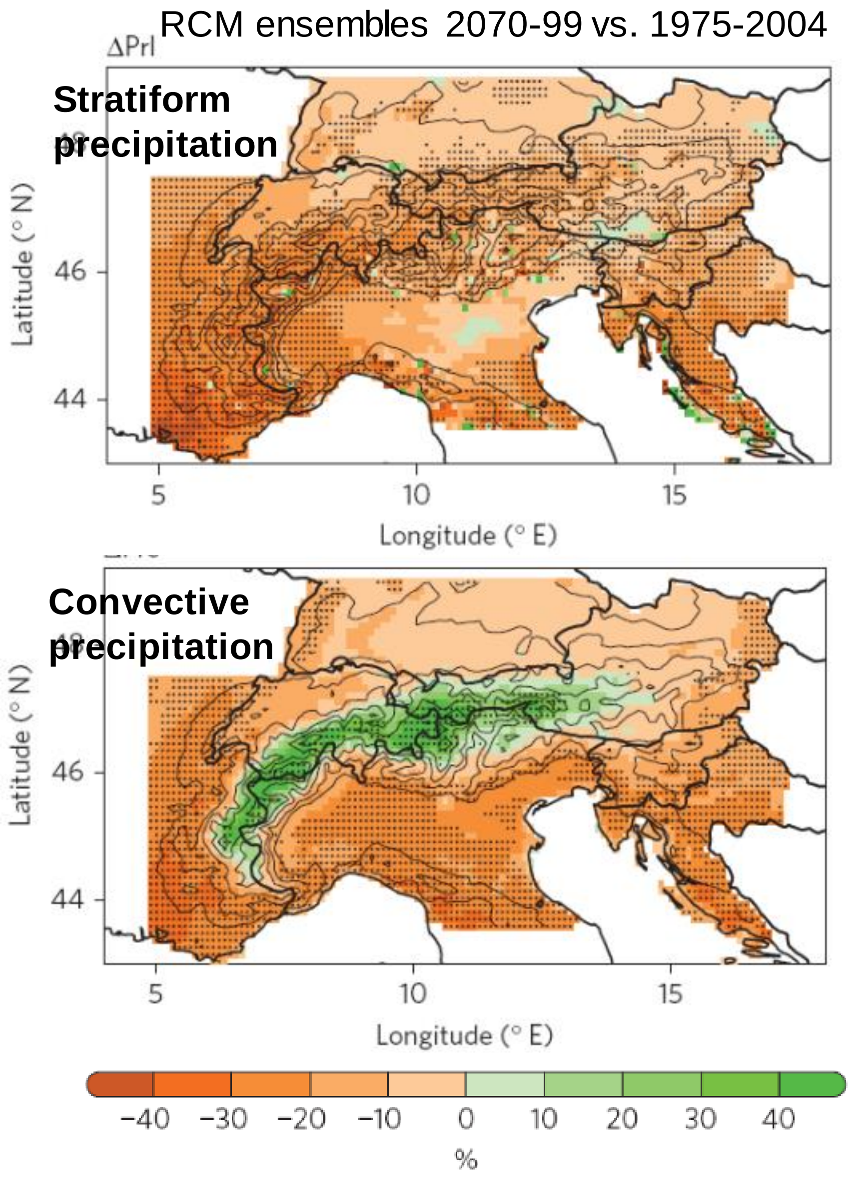
# RCM development

- Model development and validation
  - “Perfect Boundary Condition” experiments
  - Over 20 RCMs available Worldwide
  - Wide range of regional domains and resolutions (10-50 km), CP versions
  - Spectral nudging, one-way vs two-way nesting
- Process studies
  - Land-atmosphere interactions
  - Topographic effects, cyclogenesis
  - Tropical storms, hurricanes
  - Regional hydrologic and energy budgets
- Regional climate system coupling
  - Chemistry/aerosol – atmosphere (Climatic effects of aerosols)
  - Ocean/sea ice-atmosphere
  - Urban canopy models
- Climate change studies
  - Regional signals, variability and extremes
- Paleoclimate studies
- Seasonal prediction
- Impact studies

# Added value

Climate change signal in summer precipitation - Giorgi et al., 2016, Nature Geoscience



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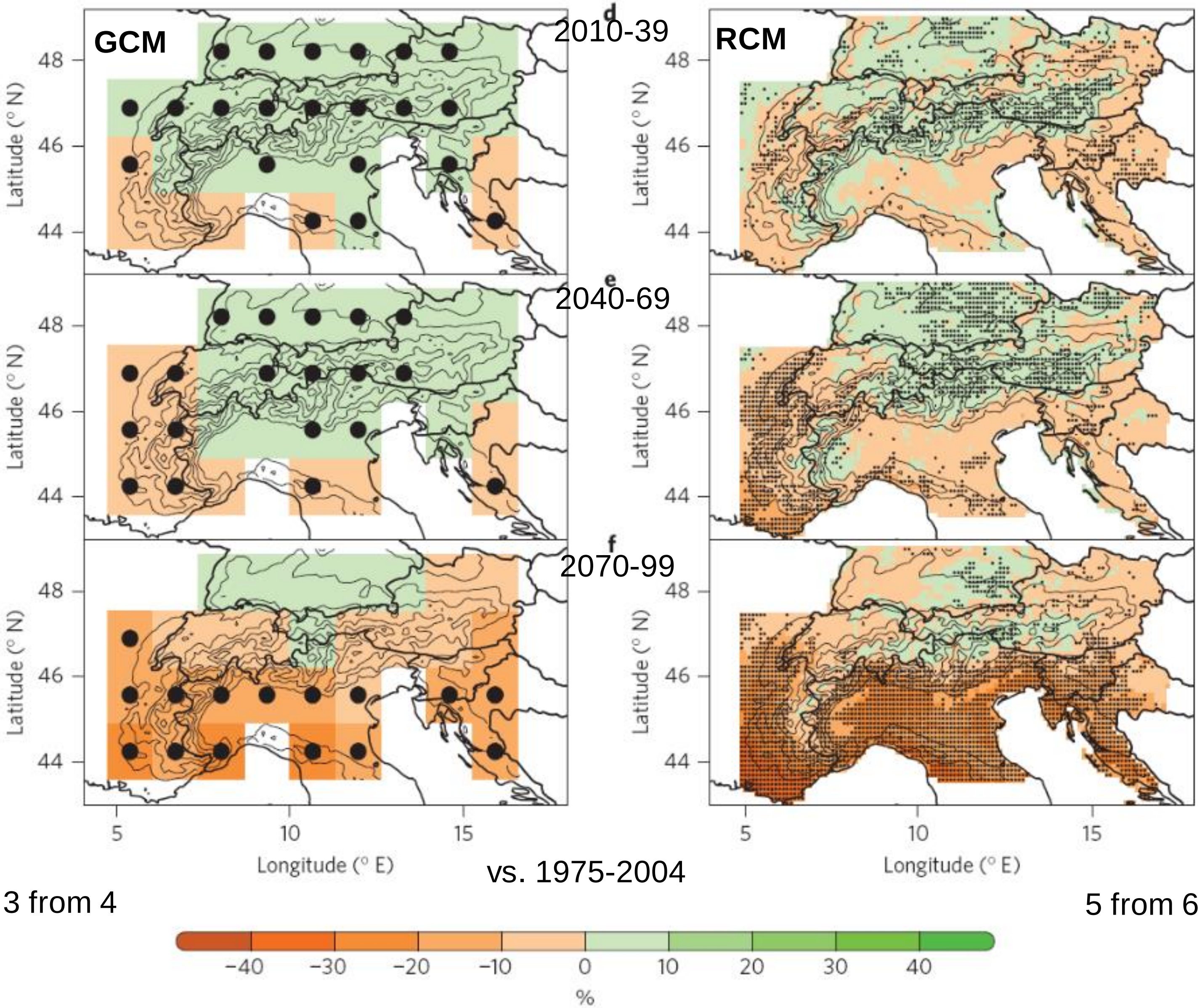
Climate change signal in summer precipitation – R95 Giorgi et al., 2016, Nature Geoscience

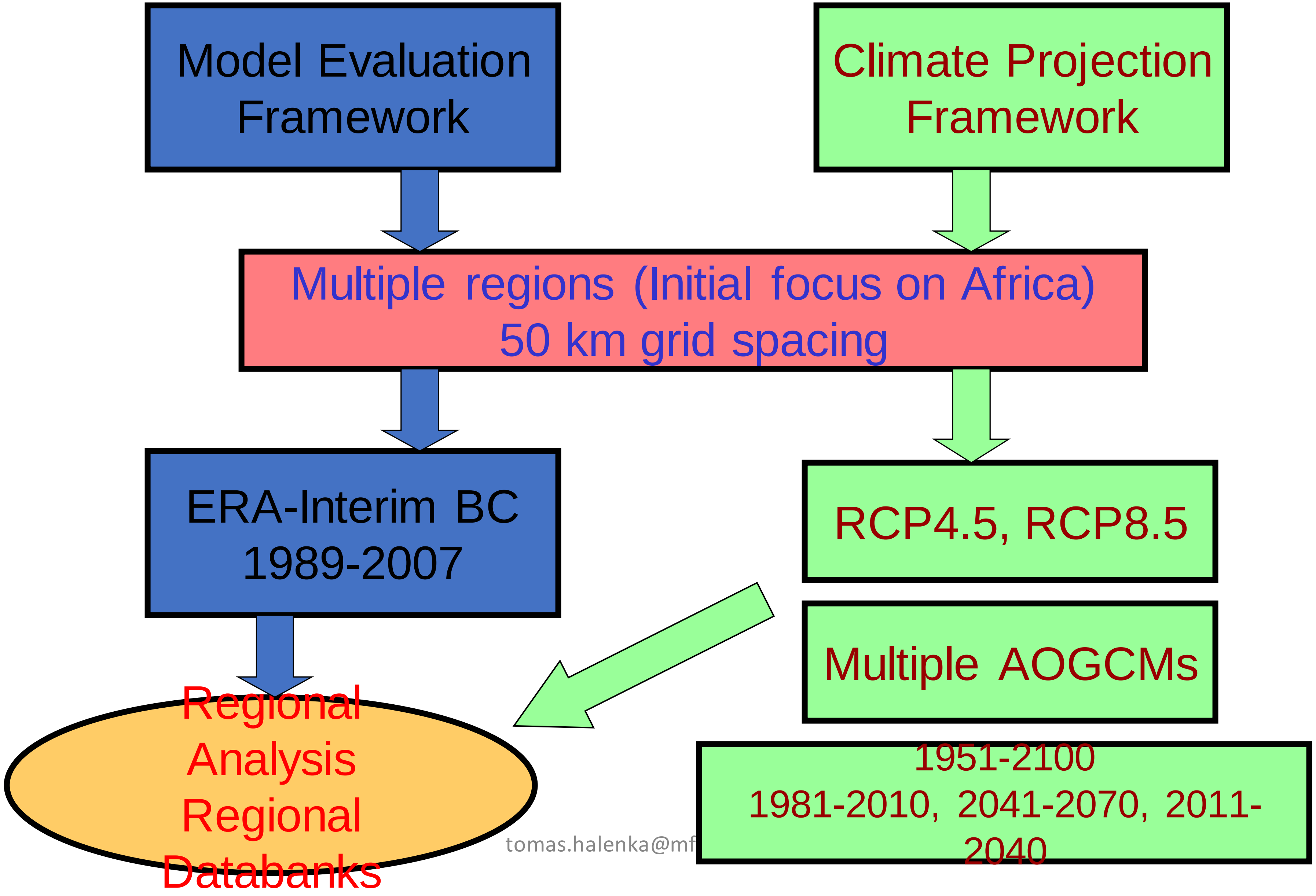


**CORDEX - COordinated Regional climate Downscaling Experiment**

General Aims and Plans for CORDEX Phase 1:

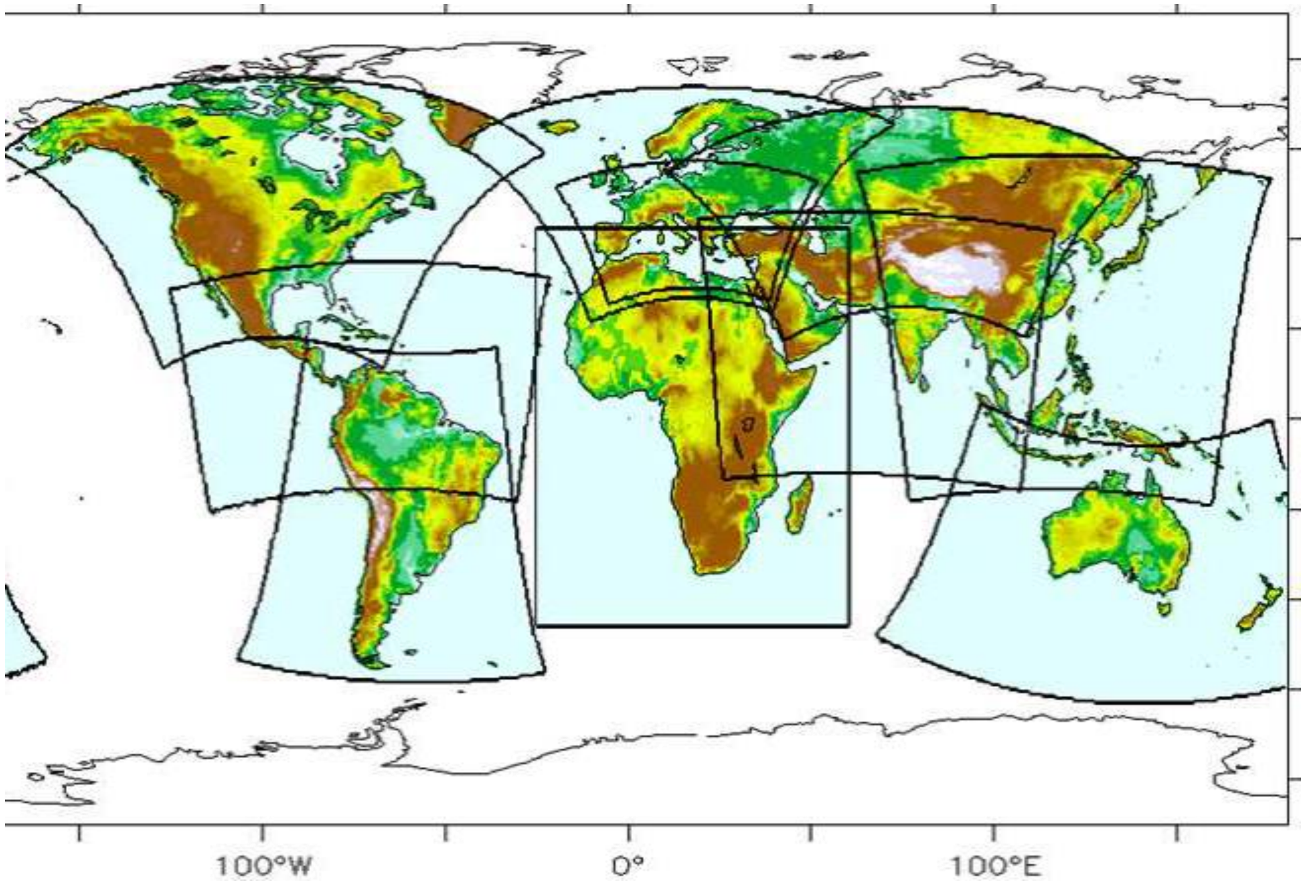
- Provide a set of regional climate scenarios covering the period 1950-2100, for the majority of the populated land-regions of the globe.
- Make these data sets readily available and useable to the impact and adaptation communities.
- Provide a generalized framework for testing and applying regional climate models and downscaling techniques for both the recent past and future scenarios.
- Foster coordination between regional downscaling efforts around the world and encourage participation in the downscaling process by local scientists/organizations

# CORDEX Phase 1 design



# CORDEX Phase 1

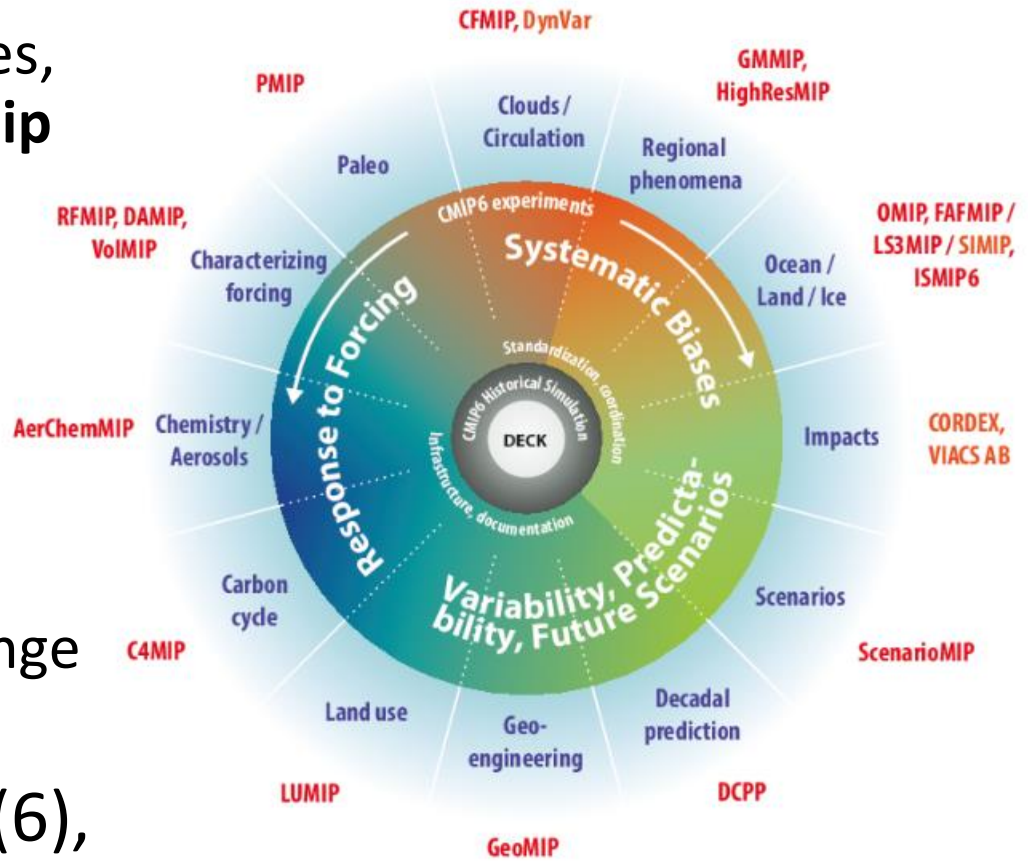
- domains with a resolution of 0.44°x0.44° (approx. 50x50km²)
- Focus on Africa - (mandatory domain)
- High resolution simulations with 0.11°x0.11°(approx. 12x12km²) for Europe (by some participating institutions) - EuroCORDEX



# CORDEX Phase 2

Goals for CORDEX Phase 2:

- To better understand relevant regional/local climate phenomena, their variability and changes, through downscaling – basis for so called **Flagship Pilot Studies** (FPS)
- To evaluate and improve regional climate downscaling models and techniques
- To produce coordinated sets of regional downscaled projections worldwide – basis for **CORDEX CORE – till now based on CMIP5**
- To foster communication and knowledge exchange with users of regional climate information

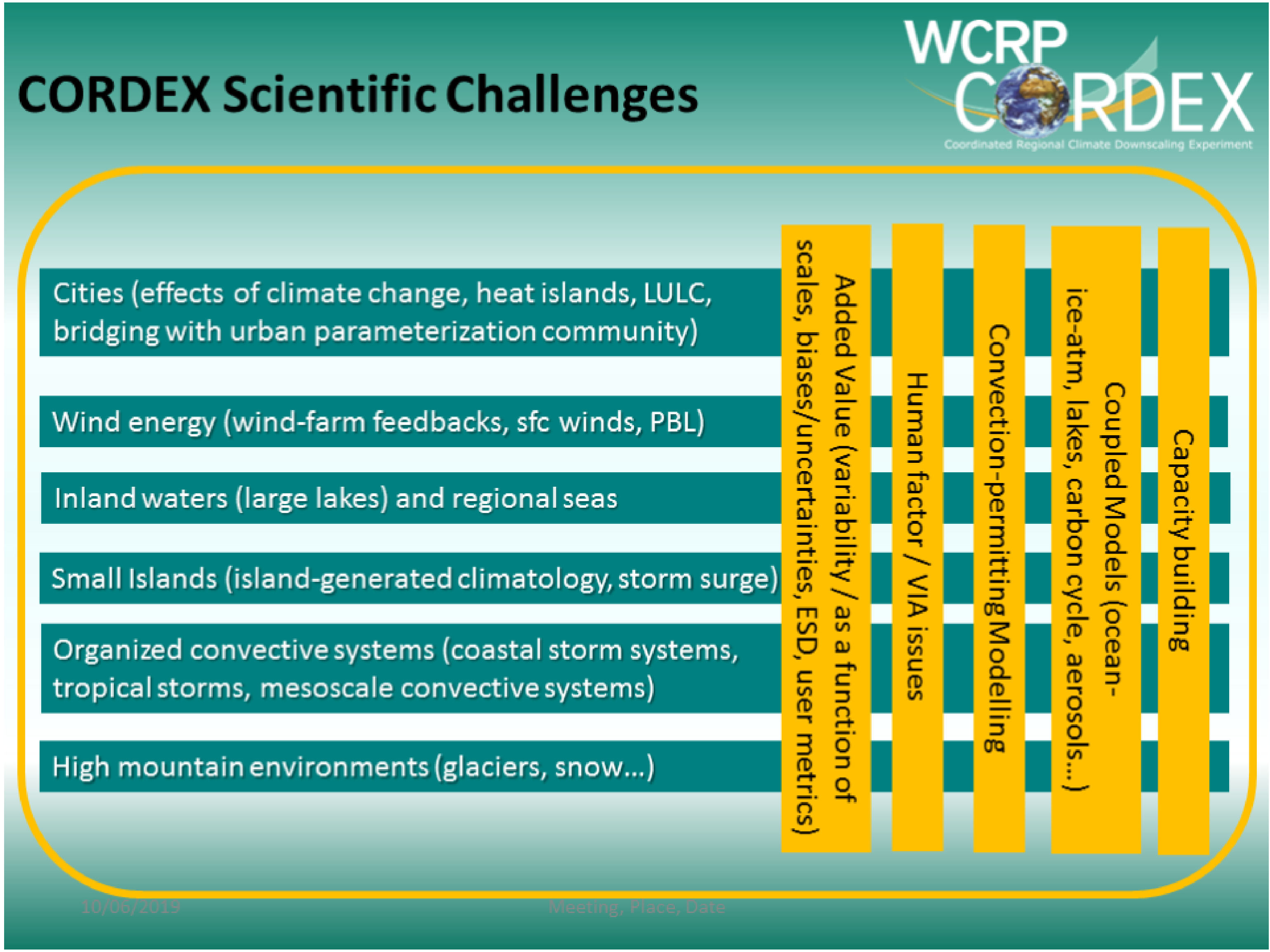



Principles to get close to the structure of CMIP(6), actually, it is a part of CMIP6 endorsed MIPs – further future, data at ESGF, ….

# CORDEX Phase 2 - FPS

## Endorsed FPSs

- Africa: Modelling the Southeast African regional Climate
- Central Asia- East Asia: High resolution climate modelling with a focus on convection and associated precipitation over the Third Pole region
- Africa: ELVIC – Climate Extremes in the Lake Victoria Basin
- Africa: Coupled regional modelling of land-atmosphere-ocean interactions over western-southern Africa under climate change
- South America: Extreme precipitation events in Southeastern South America: a proposal for a better understanding and modeling
- Europe+ Mediterranean: Convective phenomena at high resolution over Europe and the Mediterranean
- Europe: Impact of land use changes on climate in Europe across spatial and temporal scales
- Mediterranean: Role of the natural and anthropogenic aerosols in the Mediterranean region: past climate variability and future climate sensitivity
- Mediterranean: Role of the air-sea coupling and small scale ocean processess on regional climate



# RCM simulation validation

## Reanalysis driven simulations

- „Perfect“ boundary conditions experiments
- Validation against original reanalysis => RCM bias
- Validation against observations – the bias can include the bias of the reanalysis

## Control (present) GCM driven simulations

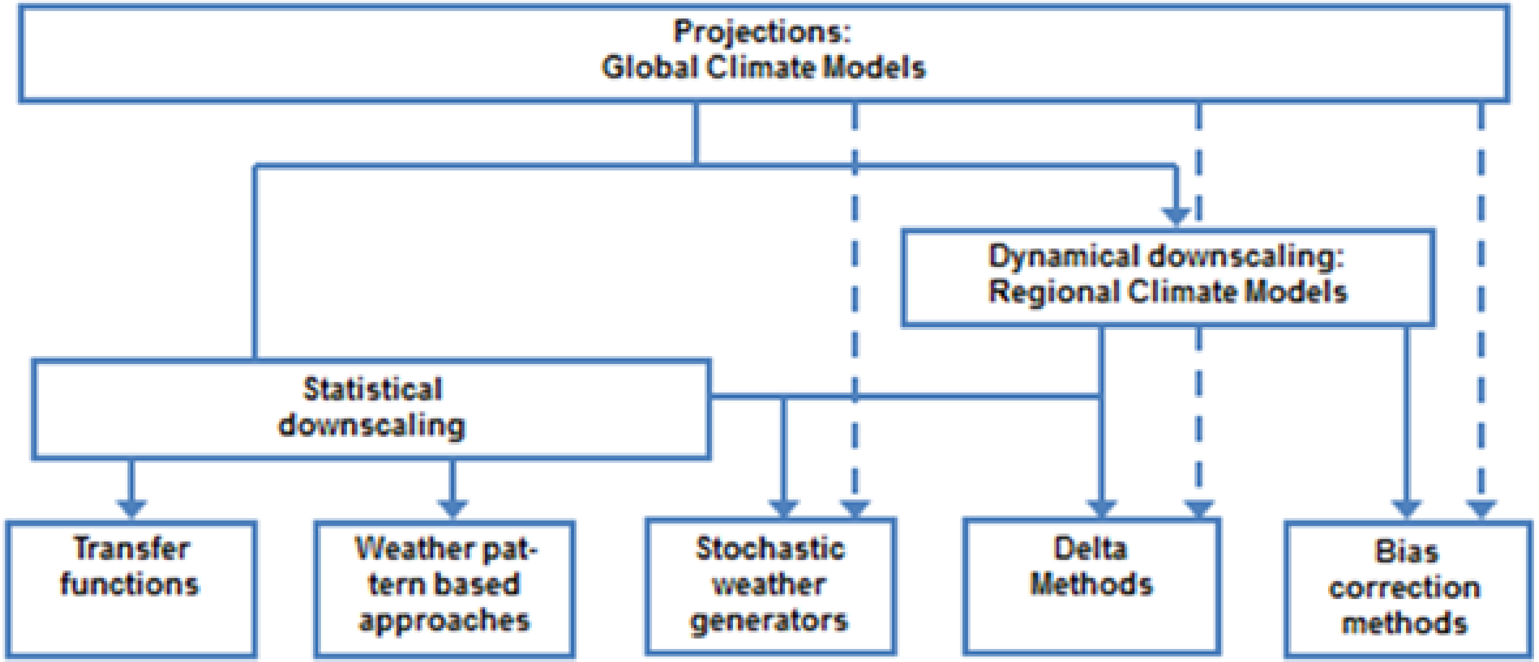
- GCM can perform well in the domain of interest (of validation), but due to errors at the boundary regions the performance of the GCM-RCM couple can be biased despite of the reanalysis driven simulation seems „perfect“

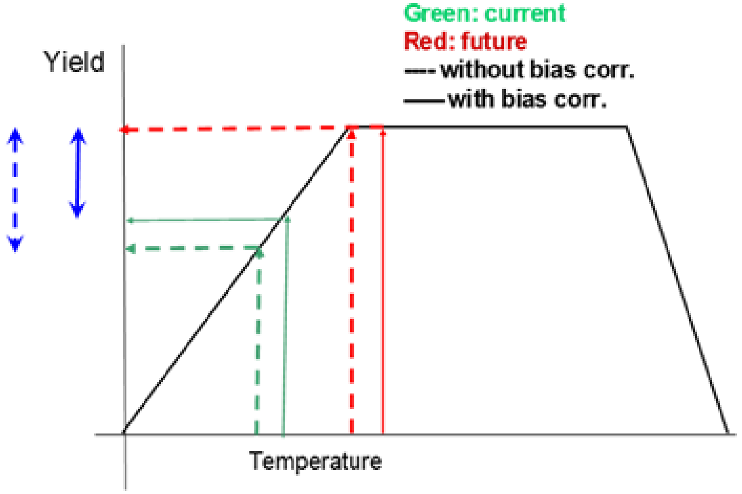
## General remarks

- In very high resolutions direct comparison to observations possible, for lower resolution keep in mind the representativeness of the model outputs for the gridbox
- Full validation has to include differences of higher moments – distribution of the output variables
- Validation outputs can support the **bias adjustment/correction** for scenarios runs

# Scenarios projections

- Ensemble simulations – multimodel ensembles dominate
- More ensemble members (GCM – RCM couples) the better – to assess the spread proper selection of high/mid/low sensitivity GCMs essential in combination with different RCMs
- Attempt to fill the matrix as much as possible, other attempts for statistical methods to estimate the missing pairs available, but ….
- Direct use of simulations outputs difficult due to model biases, especially for impacts assessment where some thresholds applied => bias adjustment necessary



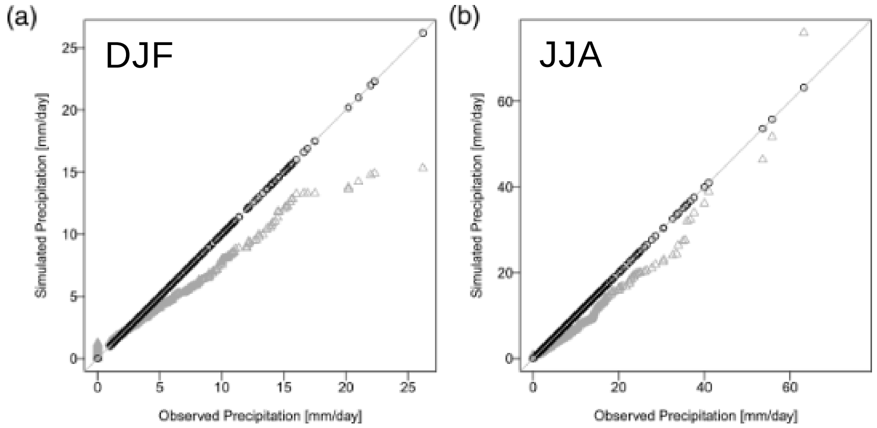



# Bias adjustment (correction)

- RCM itself represents an attempt to reduce the biases due to difference in the representativness of the model gridbox and point observation – physical basis, methods of statistical downscaling can contribute as well
- Delta method – the same as first methods of climate scenarios production – incremental climate scenarios, i.e. to add the climate change signal (by mean difference/ratio of future and control (present) simulations) to the individual observations, possible with the dependance on annual cycle, statistical distribution of the variable, etc.
- Correction method - correction of individual model output scenario data by mean difference/ratio of observations and control (present) simulations. Possible with the dependance on annual cycle, including different variability, statistical distribution, etc.
- Quantile mapping – important for variables with more stochasticity (precipitation) with „less“ normality in the distribution, typical model output of precipitation – drizzling.

Maraun (J. Climate., 2013)

http://www.ccafs-climate.org/bias_correction/




Warning: consistency of the variables can be lost

# Weather generator (Stochastic …)

- Generates the weather patterns of time series for given location based on statistical characteristics (moments) provided (mean, , autovariability, skewness, …..) and further properties, like autocorrelation, stationarity, etc.
- Enable to provide the number of time series of arbitrary length, based on the scenarios outputs (time slices if needed), with the option to set unreliable statistical parameter to the observed or corrected value.
- Attempts to set spatial correlations as well

# Conclusions

- Downscaling – important tool to get localized products for vulnerability and impact assessment, basis for adaptation
- Dynamical x/+ statistical downscaling → bias correction, that is the chain for applications
- Looking for added value of the tools and its development in the concept of impact study

# THANKS FOR YOUR ATTENTION !

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