Schweizerische Eidgenossenschaft
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Swiss Confederation

Federal Department of Home Affairs FDHA
Federal Office of Meteorology and Climatology MeteoSwiss

DYNAMICAL DOWNSCALING

Sven Kotlarski
Federal Office of Meteorology and Climatology MeteoSwiss, Zurich

4th VALUE Training School: **Validating Regional Climate Projections**
Trieste, October 2015

OUTLINE

1. Dynamical Downscaling: The Rationale
2. Dynamical Downscaling: The Technique
3. Added Value
4. Regional Climate Projections

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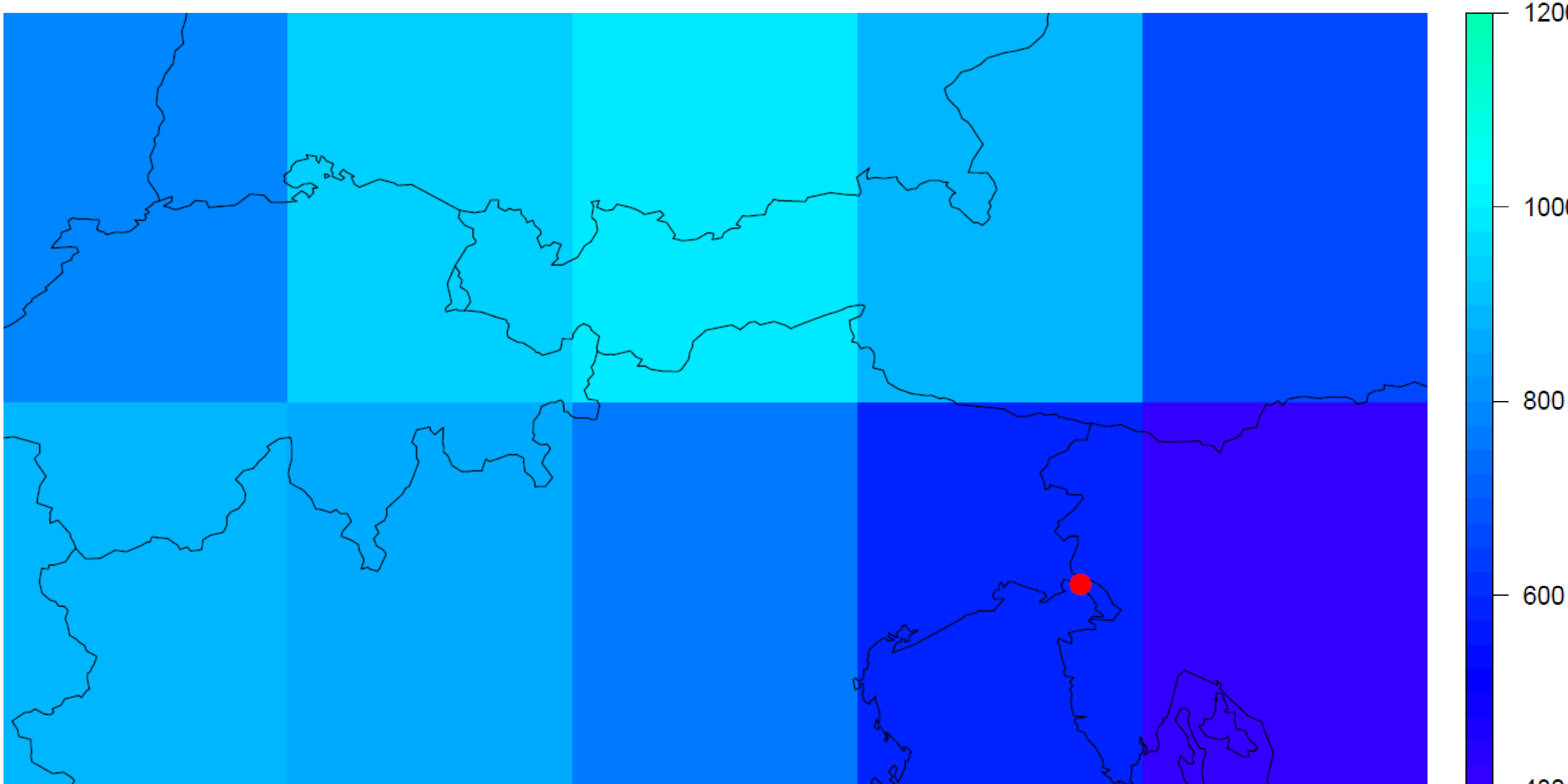
http://www2.units.it/triestejoyce/trieste.html

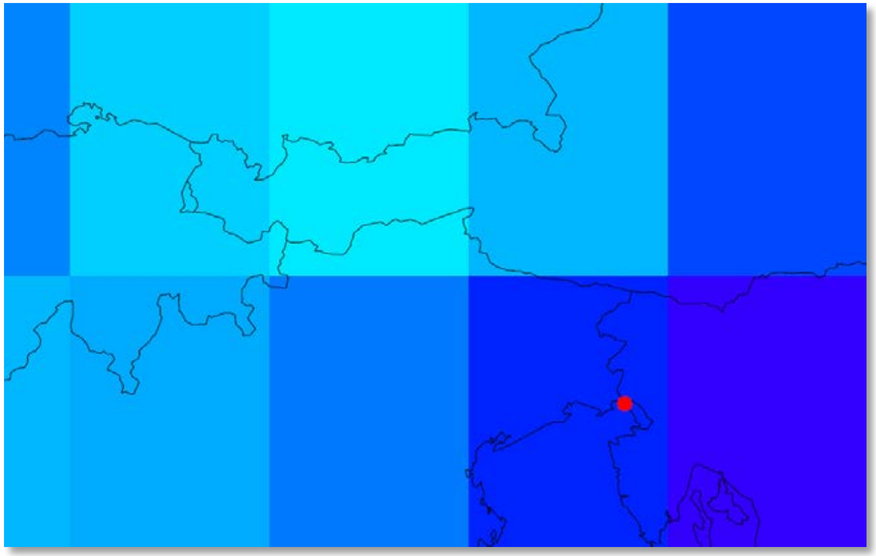
The Alps as seen by a state-of-the-art GCM (MPI-ESM-LR, 1.875°)



7.8 * 1.000.000.000.000.000.000.000.000

Piz Daint at the *Swiss National Supercomputing Centre* (CSCS)
www.cscs.ch

Limited Computing Resources



Global climate models (GCMs) as primary tools for climate projections

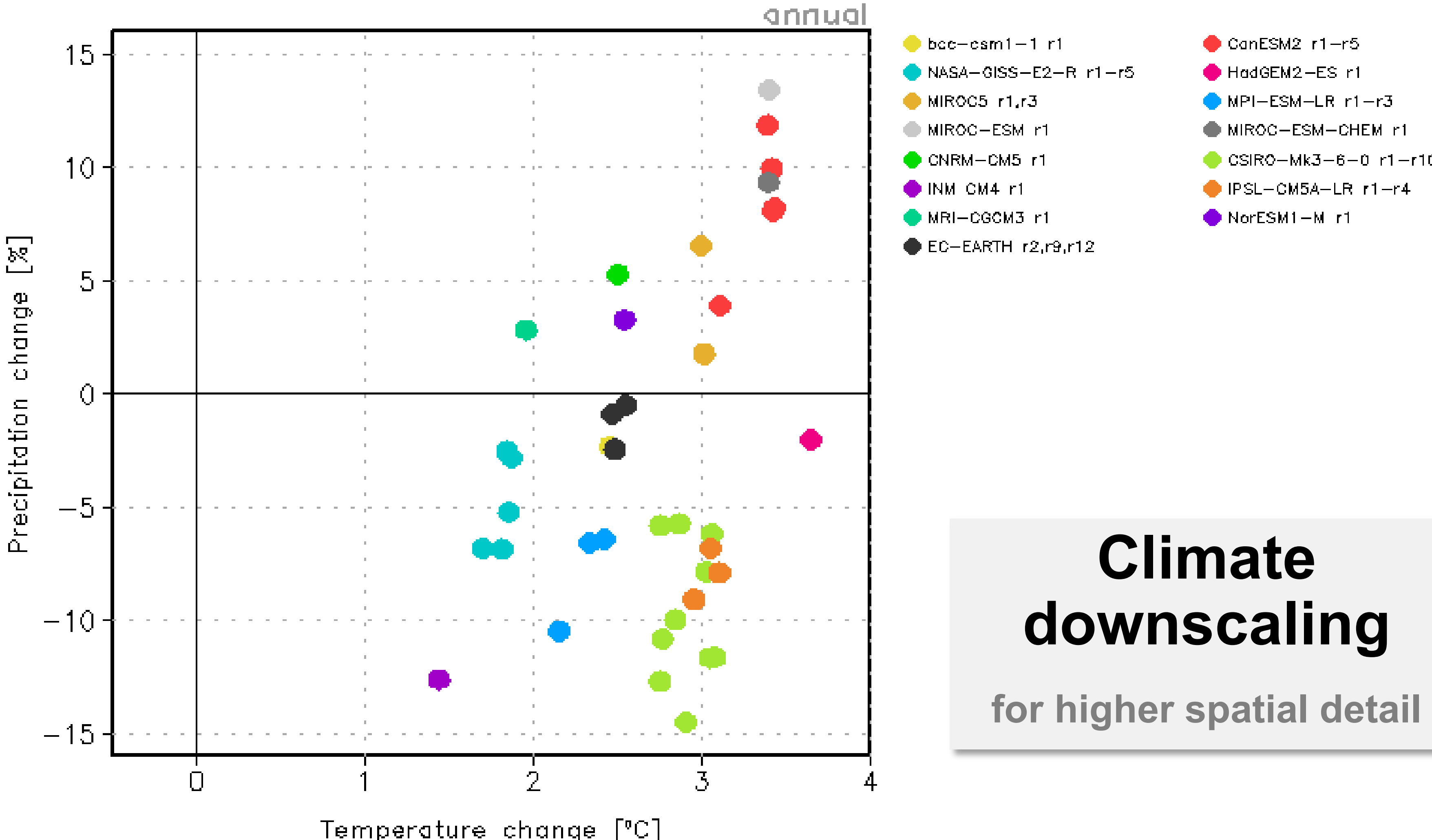
Spatial resolution limited by available computing resources

Limited capability to

represent regional/local climate forcings (e.g. surface)
represent mesoscale dynamics
local conditions at which climate impacts are often experienced

GCM Projections

Mean temperature change vs. mean precipitation change,
1971-2000 to 2070-2099, RCP4.5 emission scenario, European Alps



Climate downscaling

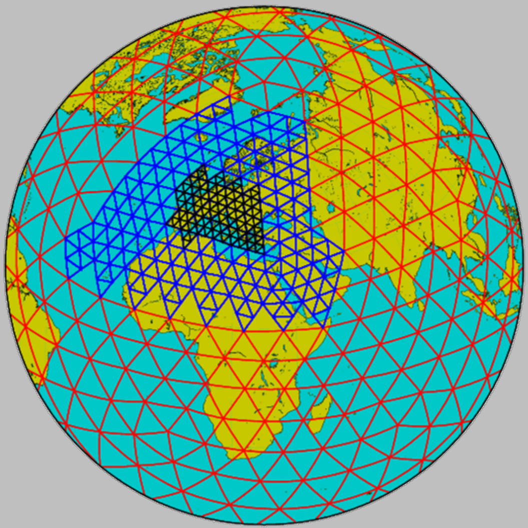
for higher spatial detail

Kotlarski 2012, unpublished

Climate Downscaling

Translate the large-scale features as represented by a GCM into regional / local conditions.

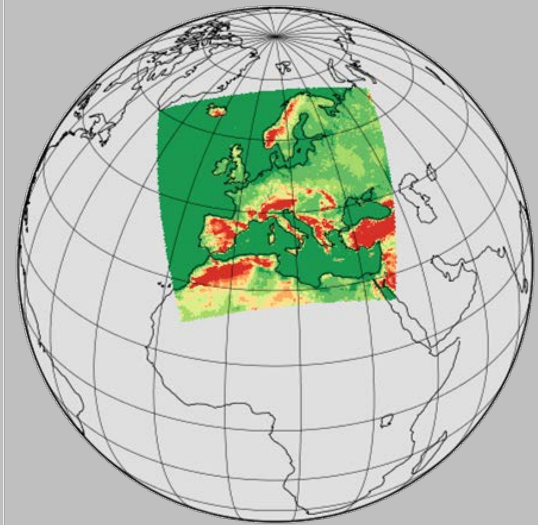
GCM with local refinement



MPI-M Hamburg / ICON

Statistical-empirical downscaling

Dynamical downscaling



OUTLINE

1. Dynamical Downscaling: The Rationale
2. **Dynamical Downscaling: The Technique**
3. Added Value
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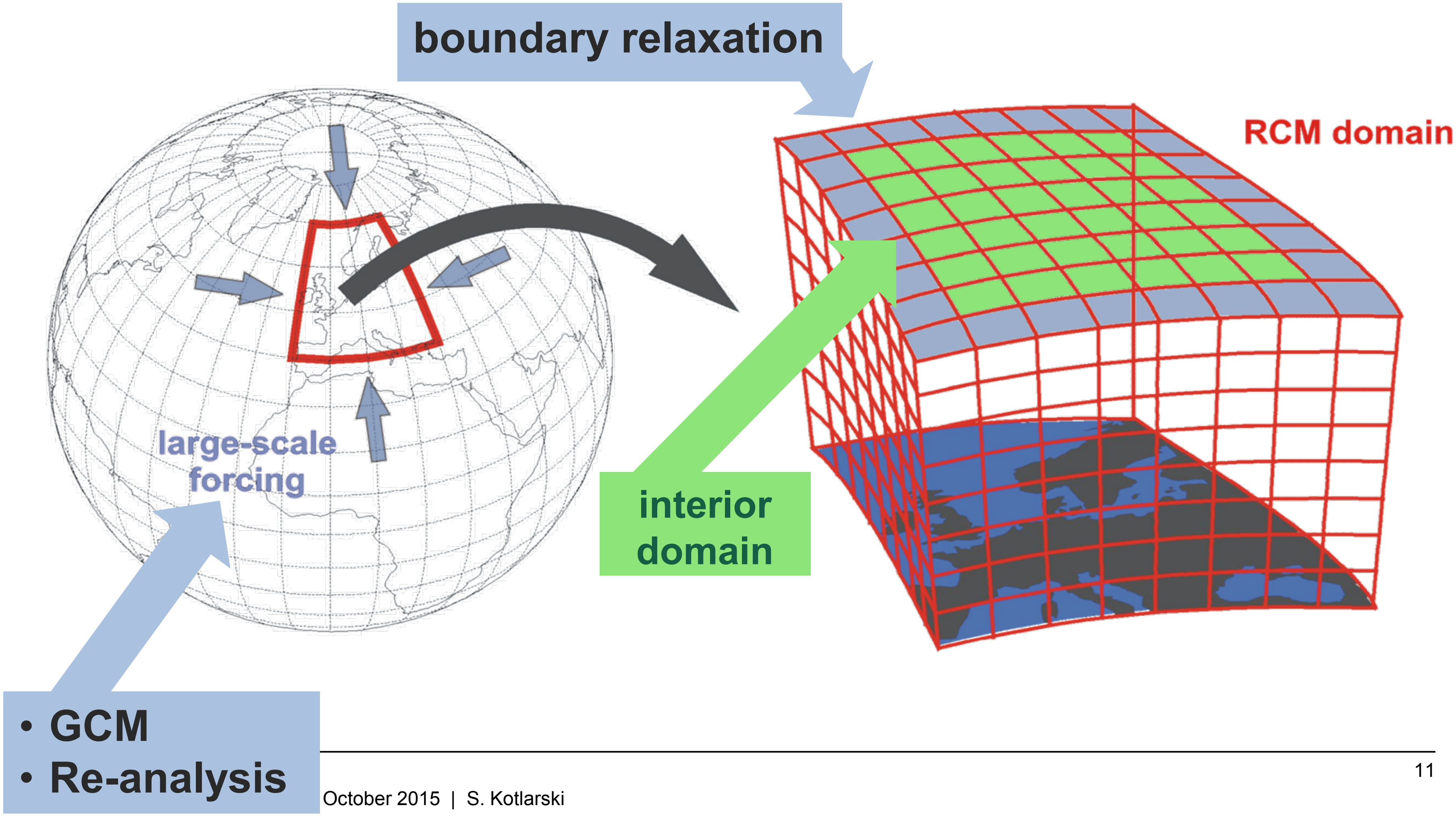
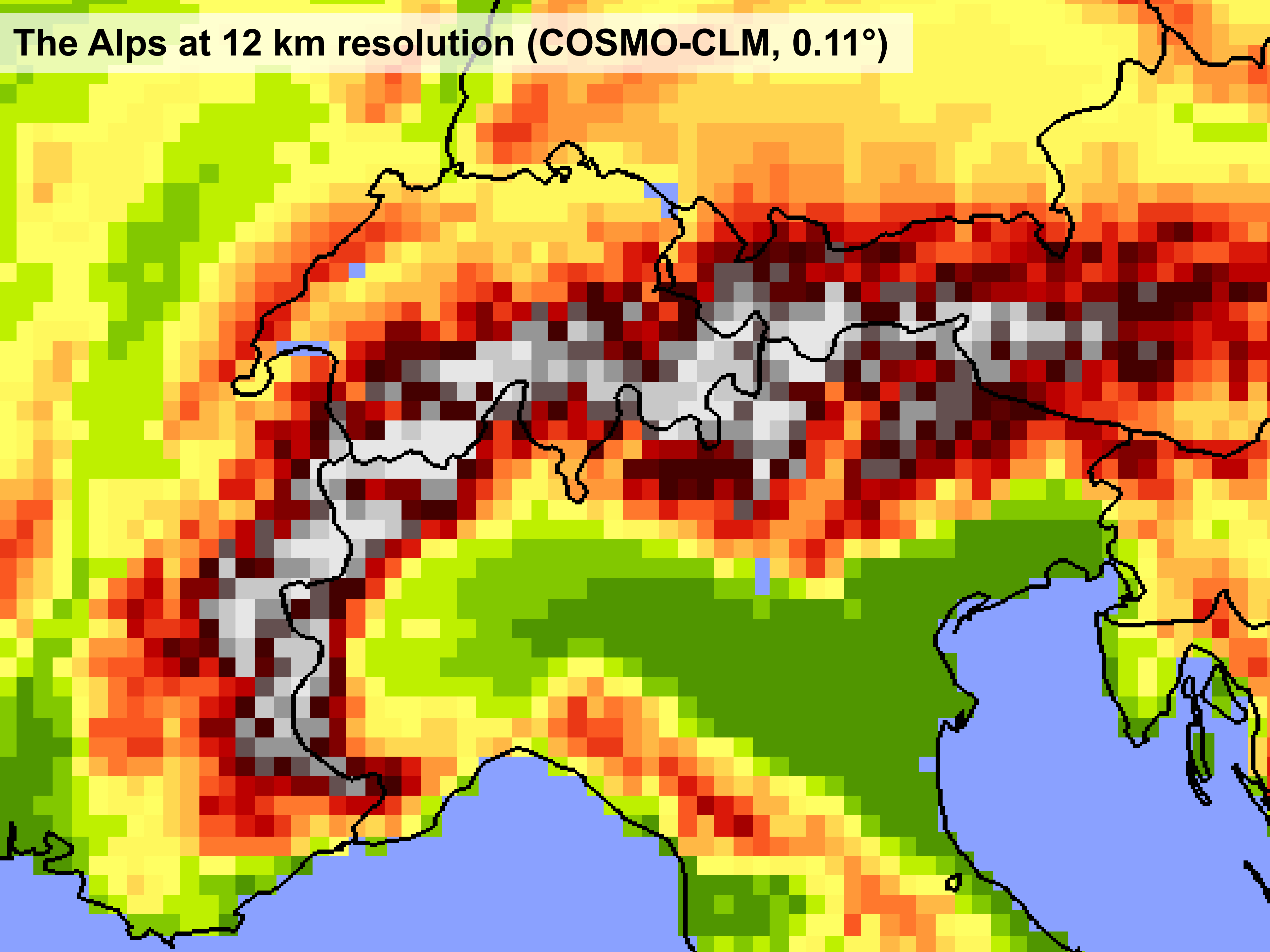
The **Nesting** technique

Apply an atmospheric limited area model (regional climate model, RCM) as a magnifying glass



movie: MPI-M / DKRZ


The Alps at 12 km resolution (COSMO-CLM, 0.11°)

Dynamical Downscaling: Details

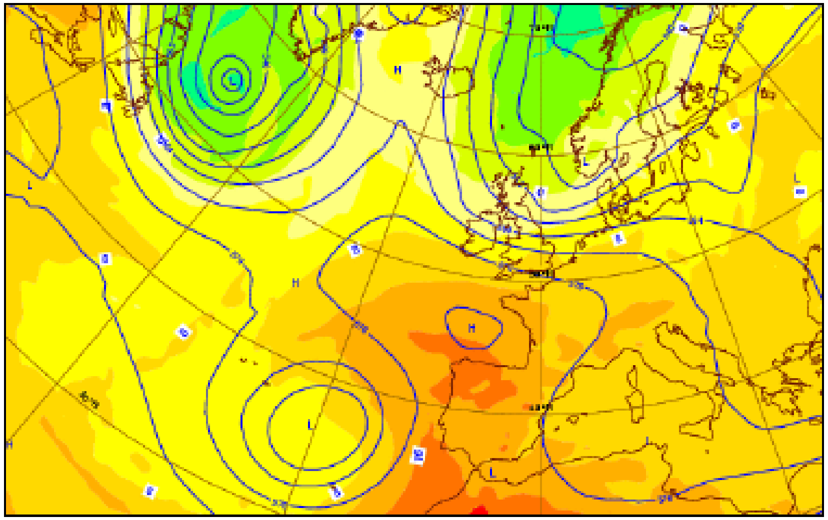
- Origin: **Limited area models** in numerical weather prediction
- Application on climate timescales: Late 1980s (Dickinson et al., 1989, Giorgi 1990)

- "Workhorse" resolution: **10 km – 50 km**
- **Convection-permitting** / **cloud-resolving** applications coming up
- Internal time step: **a few minutes**
- Output interval: **hourly, daily, monthly**

- Nesting typically **one-way** only
- **Two-way nesting** to ensure feedback from finer to coarser scales (e.g. Lorenz and Jacob 2005)
- **(Spectral) Nudging**: Boundary conditions also applied in interior RCM domain -> Prevents disagreement between GCM and RCM large scales

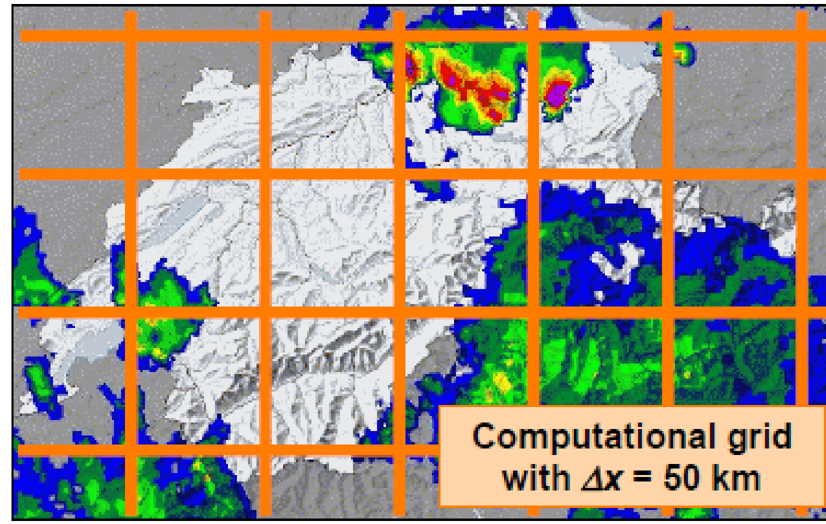
Model Components

DYNAMICS



- Address the **resolved part** of atmospheric dynamics and thermodynamics.
- Solution of the **governing equations of fluid motion on a computational grid**
- Examples of resolved structures: **general circulation of atmosphere, low and high pressure systems, mountain flows**

PHYSICS



- Representation of **unresolved scales** by **parameterizations** (sub-grid)
- Typically contain **empirical** components and are to some extent **tuned/calibrated**
- Major source of **model uncertainty**
- Examples of parameterized processes: **boundary layer, convection, precipitation, clouds, land surface**

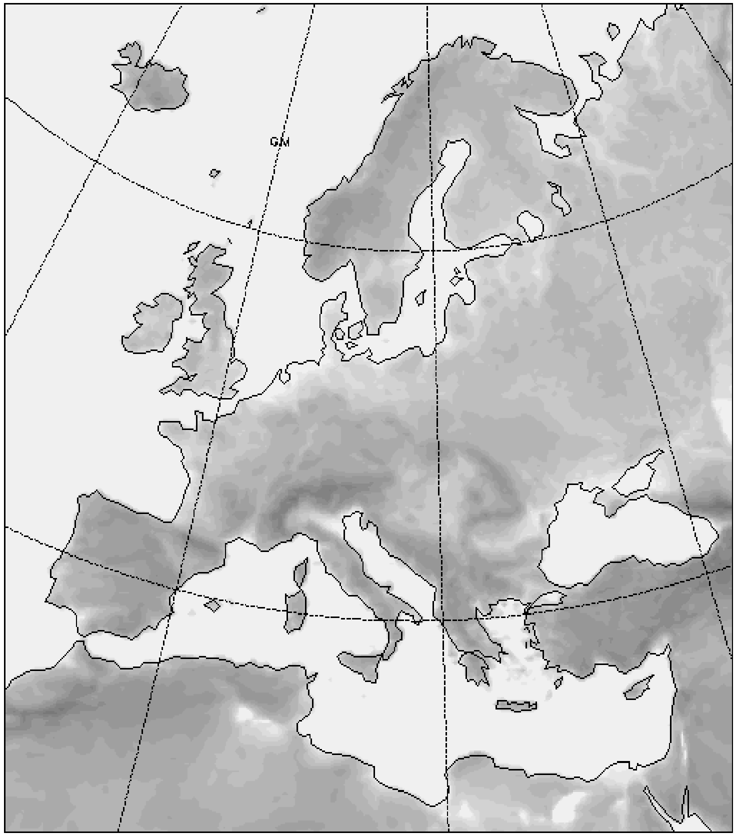
source: C. Schär, IAC ETH

Types of RCM Experiments

boundary forcing (global)

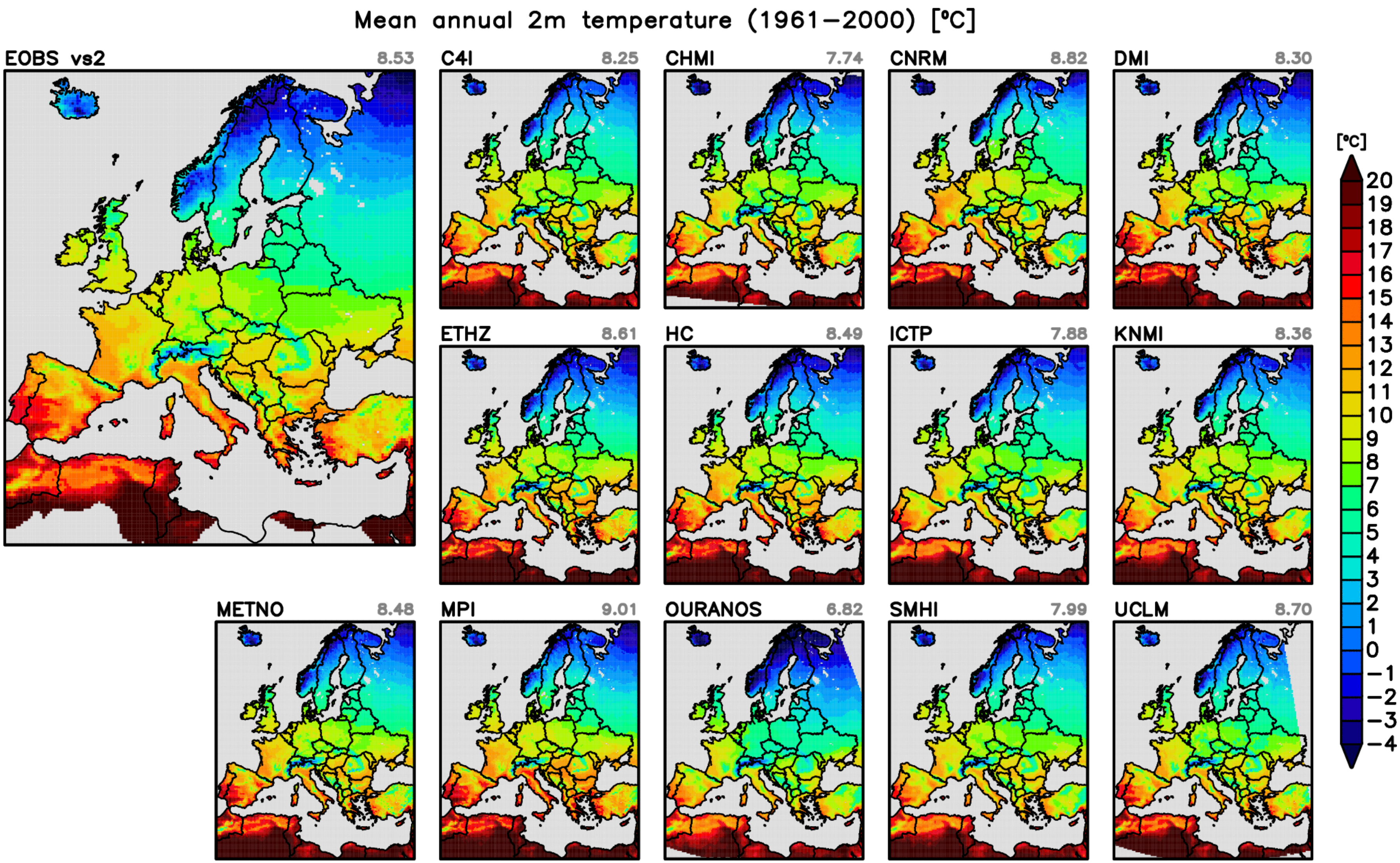
Re-analysis
(perfect boundaries)

RCM

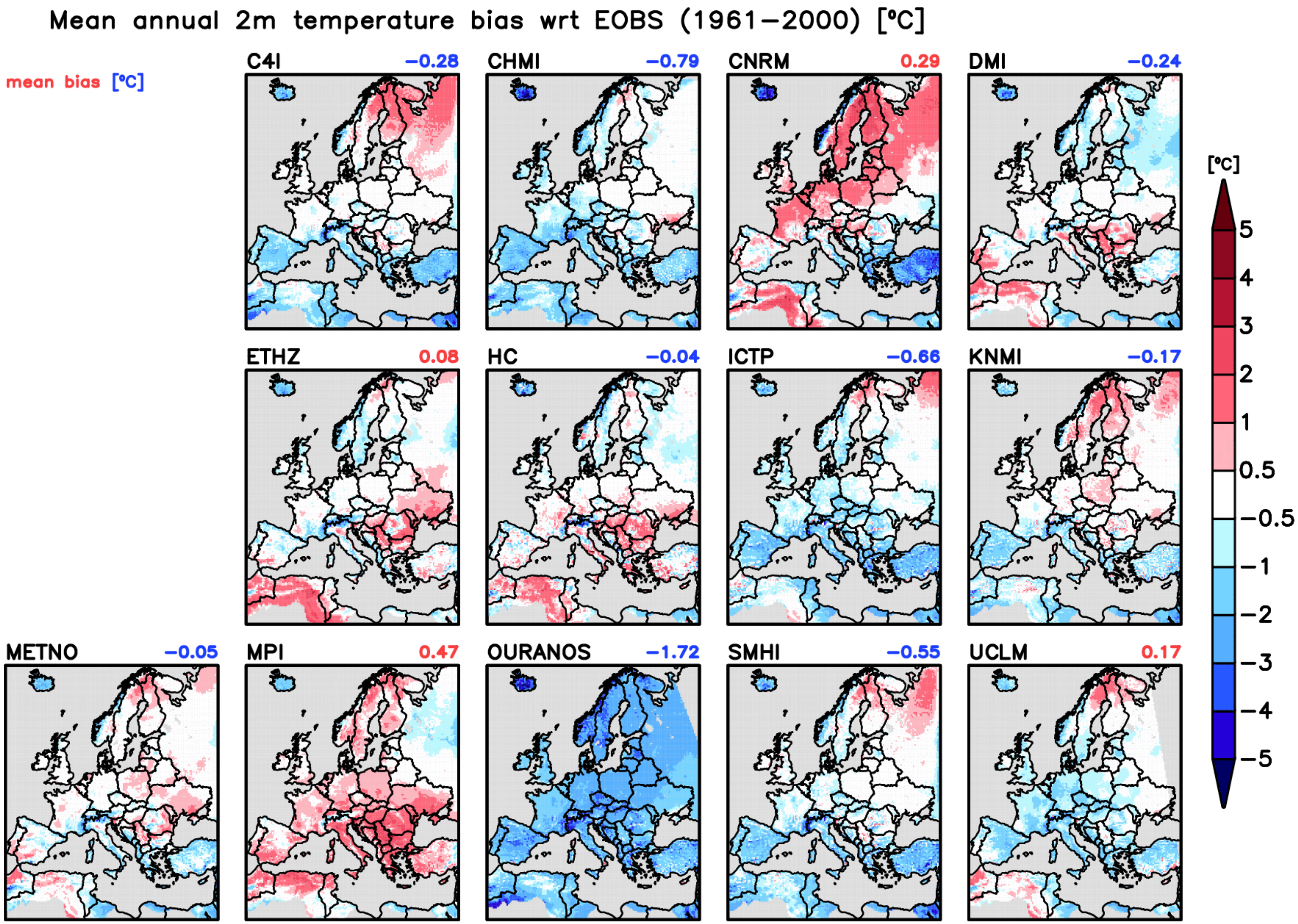


Evaluation of (pure) downscaling

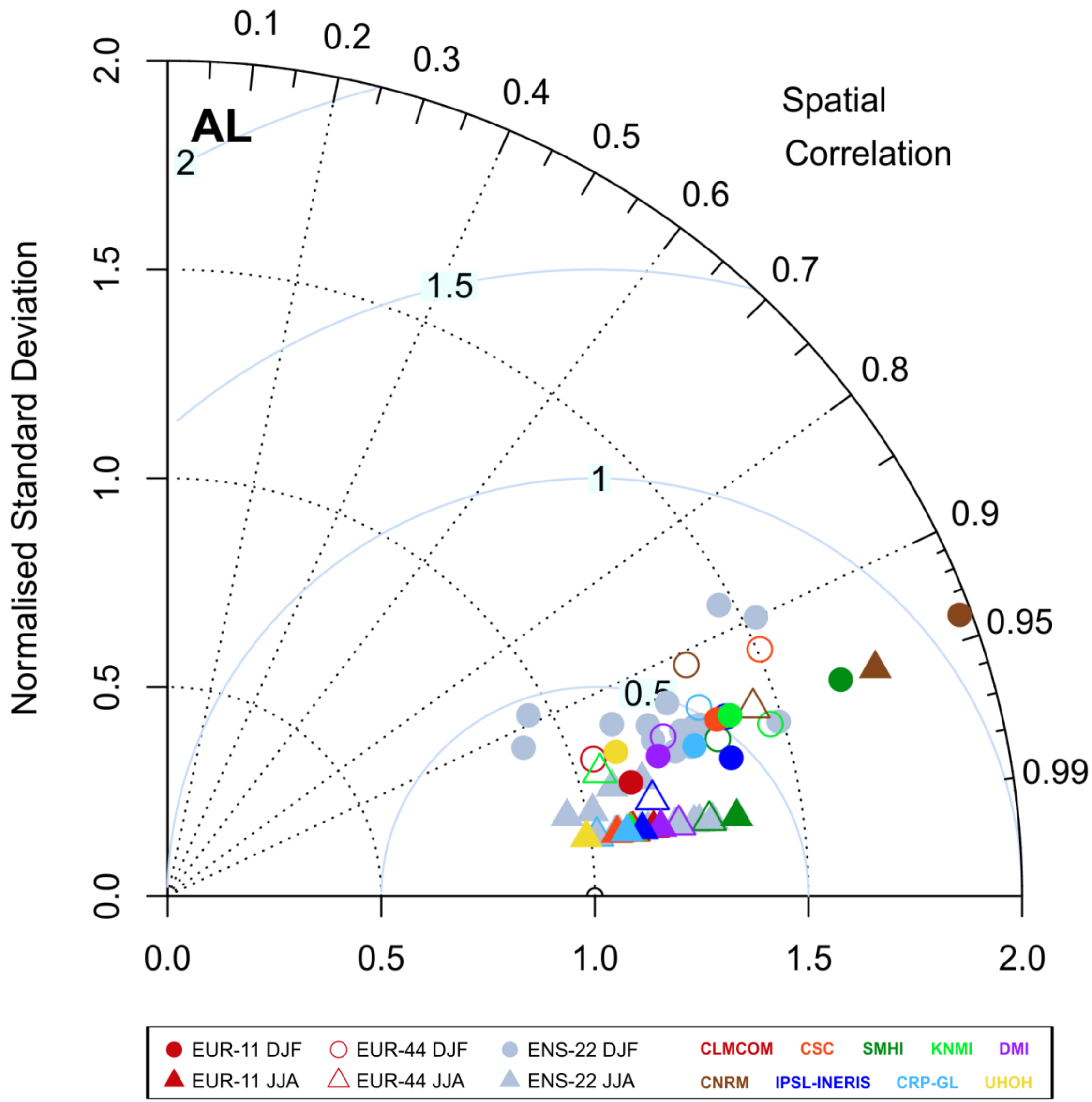
Validation (1)



Validation (2)



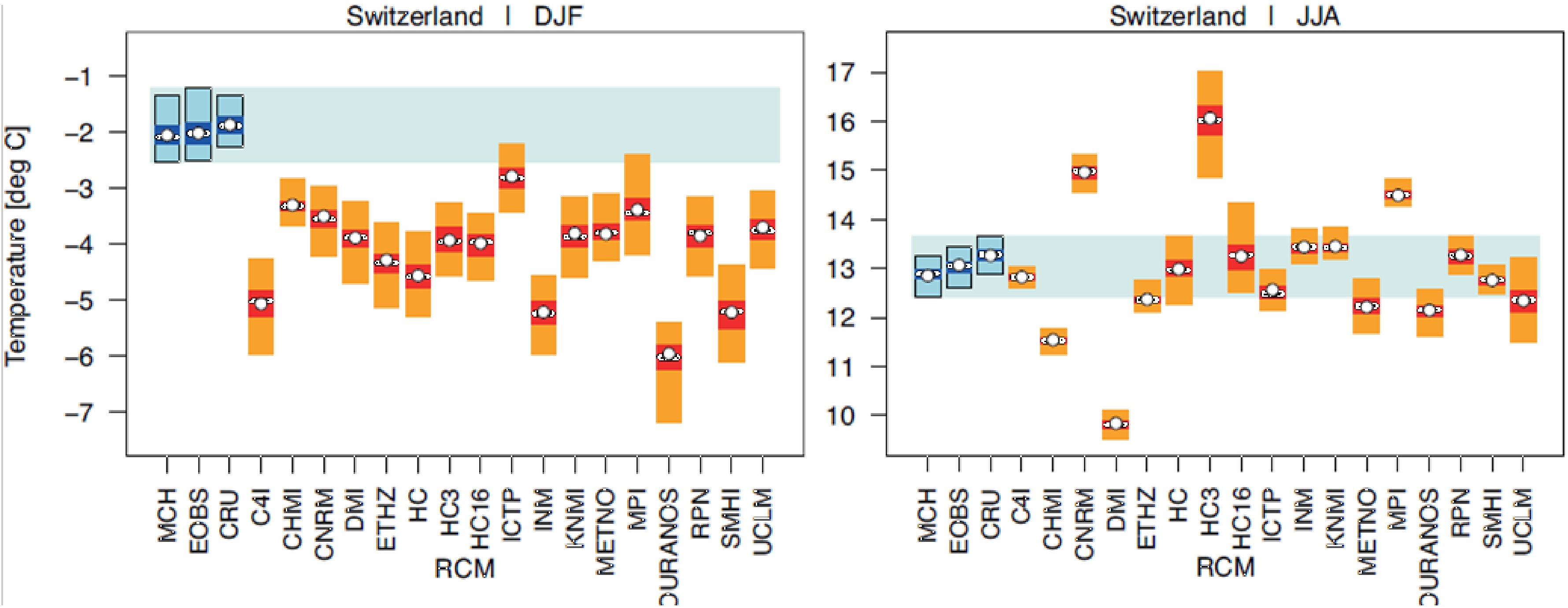
Validation (3)



Kotlarski al. , GMD, 2014

Validation (4)

Mean seasonal temperature over Switzerland in observations and ERA40-driven RCMs (1971-2000)



Jan Rajczak, ETH Zurich

Observational uncertainty!
Uncertainty induced by internal climate variability!

Important, but often neglected:
- Validation of **trends**
- Validation of **physical relations**

Types of RCM Experiments

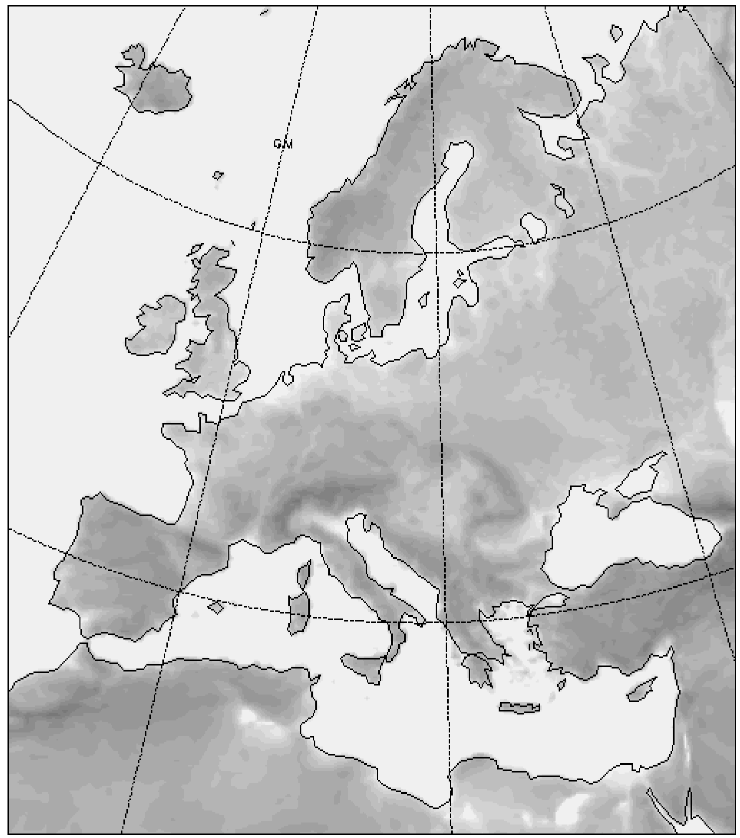
boundary forcing
(global)

RCM

Re-analysis
(perfect boundaries)

GCM
historical GHG

GCM
future GHG

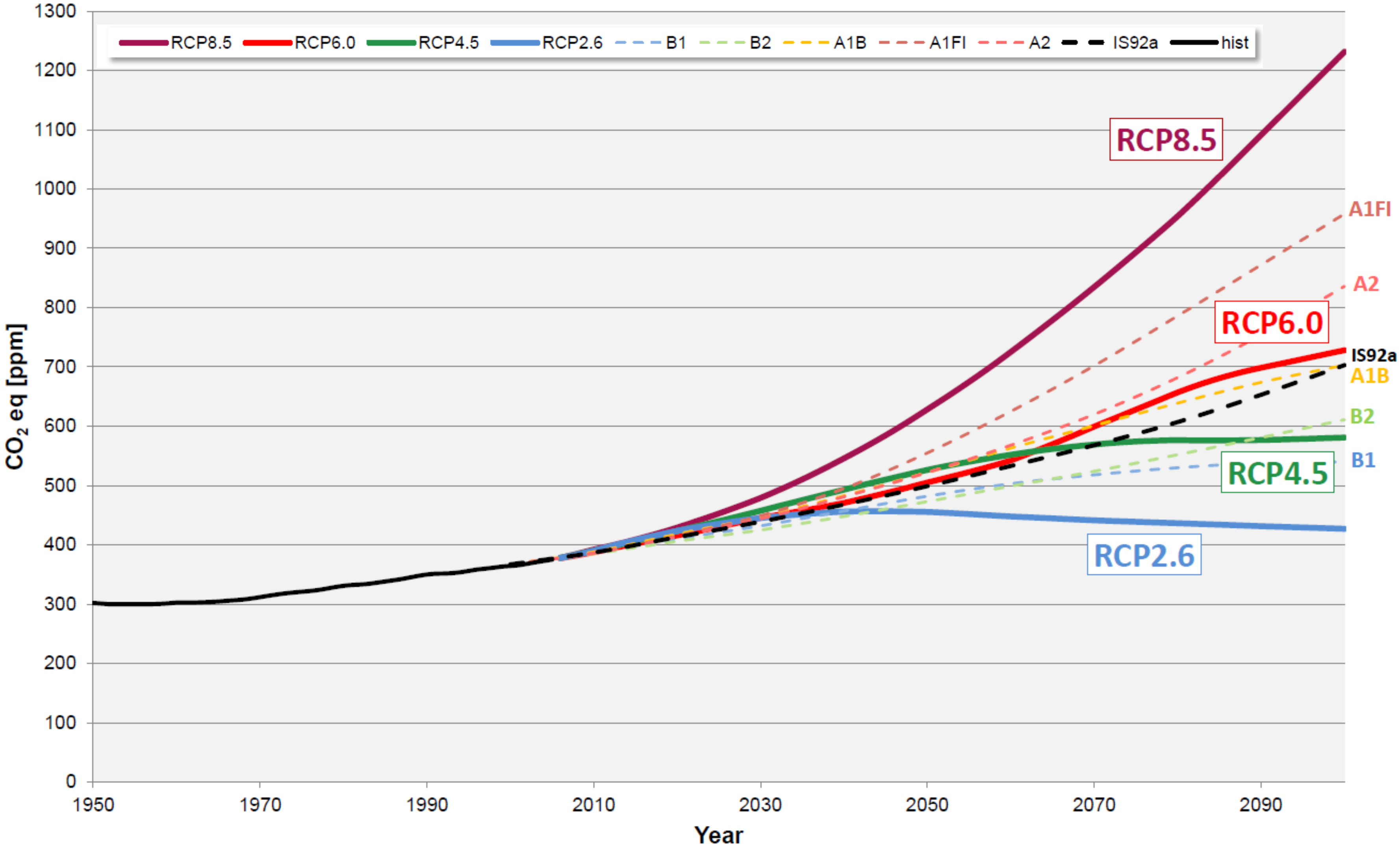


Evaluation of (pure) downscaling

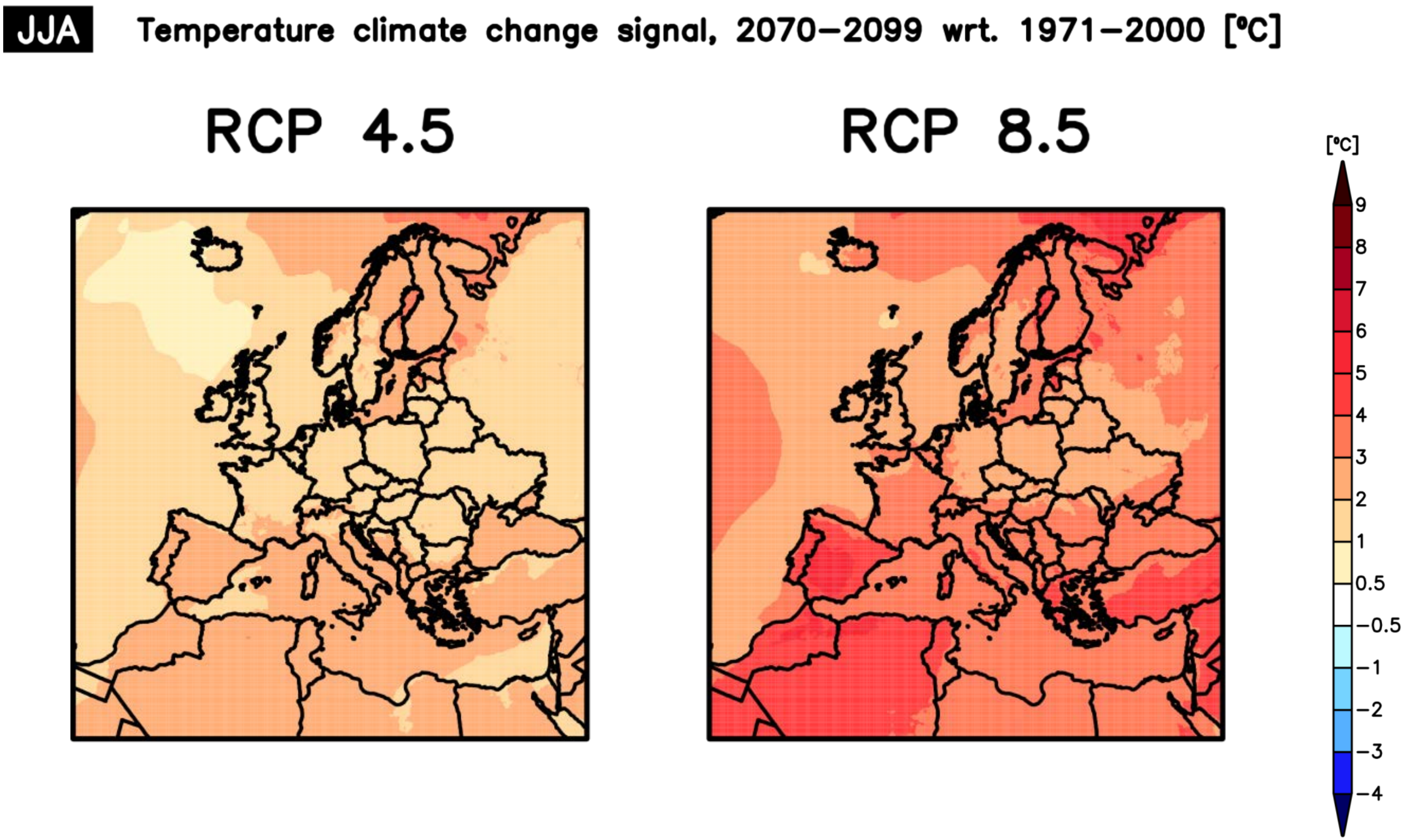
Evaluation of GCM-RCM chain

Climate change

GHG Scenarios



Regional Climate Scenarios (CCLM)



Types of RCM Experiments

boundary forcing (global)

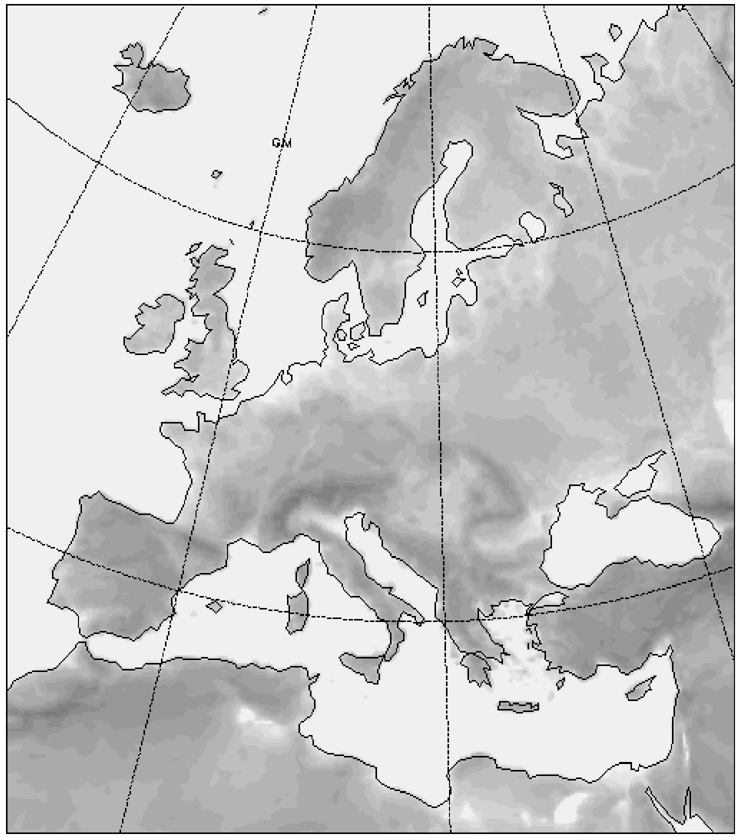
RCM

Re-analysis
(perfect boundaries)

GCM
historical GHG

GCM
future GHG

Re-analysis/GCM
Idealized setups



Evaluation of (pure) downscaling

Evaluation of GCM-RCM chain

Climate change

Sensitivities, process understanding

Dnymical Downscaling: Pros and Cons

+

- **Physically consistent response, including climate feedbacks**
- **Application of models for future periods possible (in principle)**

–

- **Computationally expensive**
- **Advanced expertise required**
- **Limited number of realizations**
- **Limited spatial resolution** (does not target the site scale)
- **Physically based, but calibration required** (often intransparent!)
- **Strongly depends on driving GCM** (*garbage in – garbage out*)
- **"Added value" wrt. GCM not always apparent**

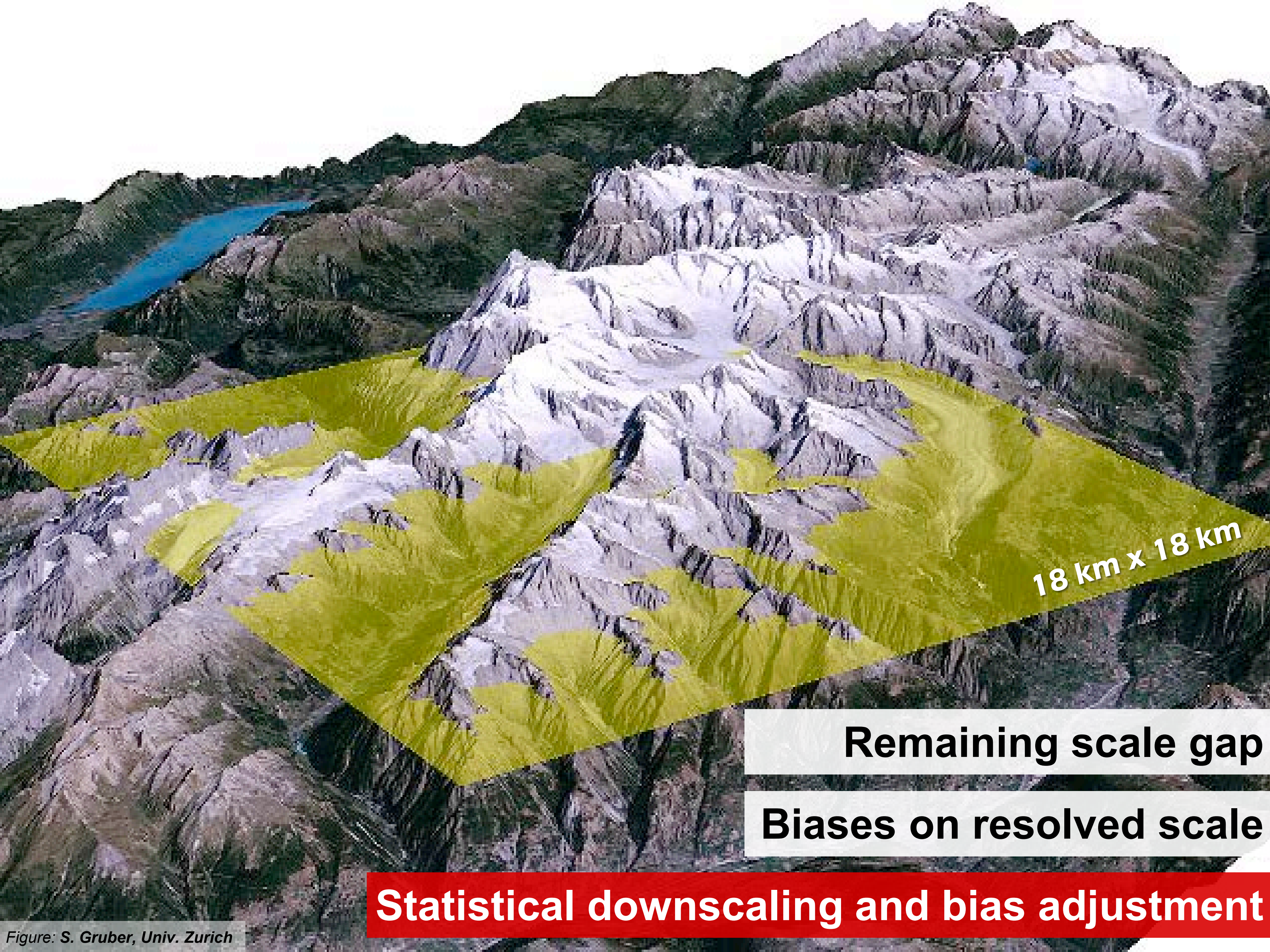


Figure: **S. Gruber, Univ. Zurich**

OUTLINE

1. Dynamical Downscaling: The Rationale
2. Dynamical Downscaling: The Technique
3. **Added Value**
4. Regional Climate Projections

The Added Value (1)

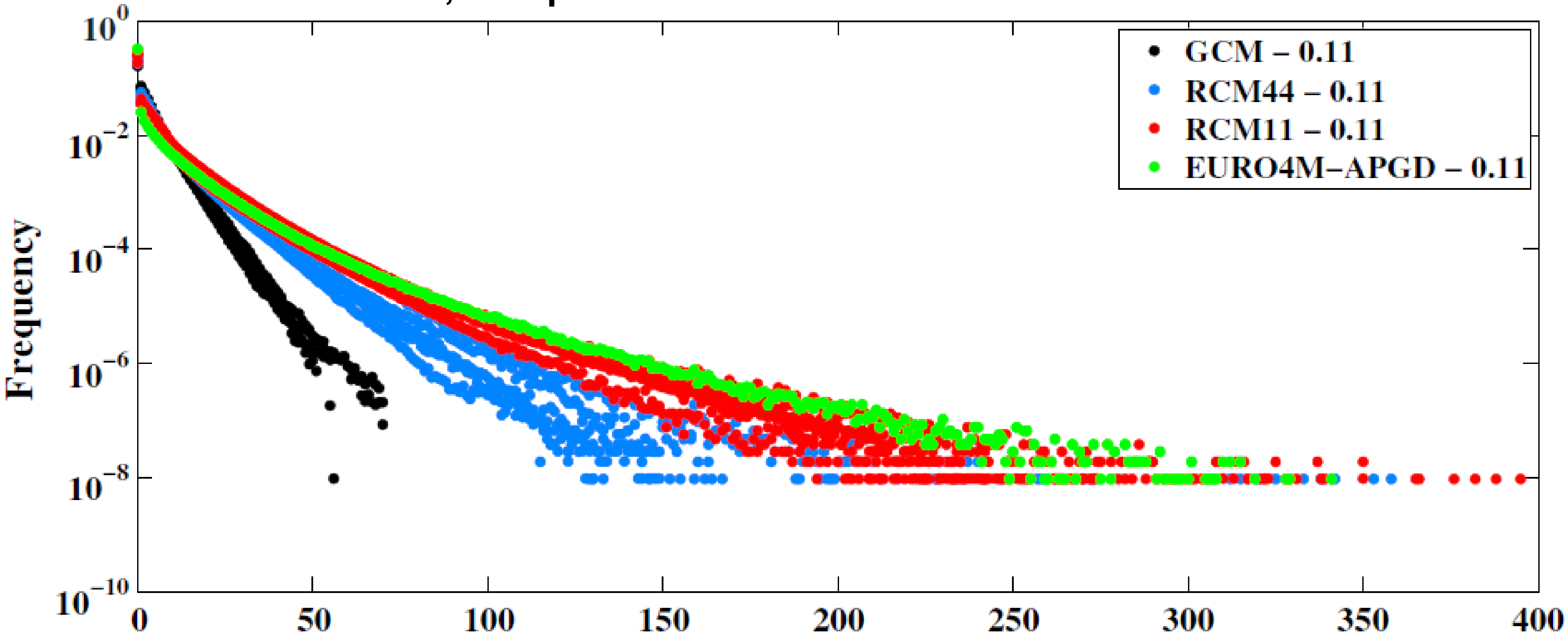
The main job of an RCM is to add finer spatial scales upon the driving coarse resolution data.

At these scales an added value wrt. to the driving data should be apparent.

- **An RCM won't improve all aspects of a GCM simulation**
- Added value often hard to find for time-averaged quantities or on large spatial scales
- Added value most likely in **frequency distributions and high-order statistics reflecting intense and localized events** (e.g. tails of daily precipitation intensity distribution) and in fine-scale spatial climate variability
- Indication for added value on scales that are common to both the RCM and the driving GCM (Kerkhoff et al., 2014)

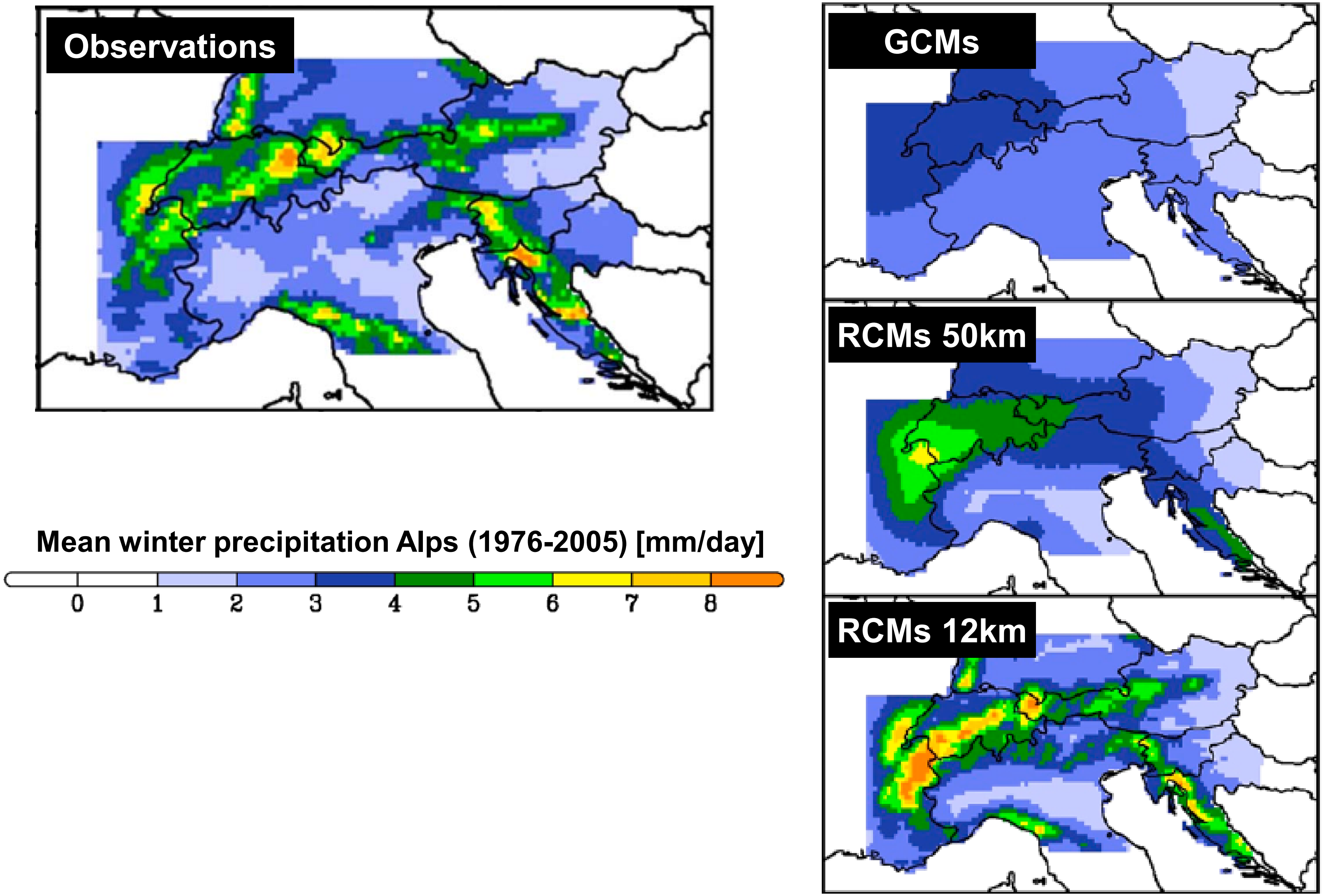
The Added Value (2)

Daily precipitation PDF over the Alps (1976-2005) for models and observations, interpolated to 12 km resolution



Torma et al., 2015

The Added Value (3)

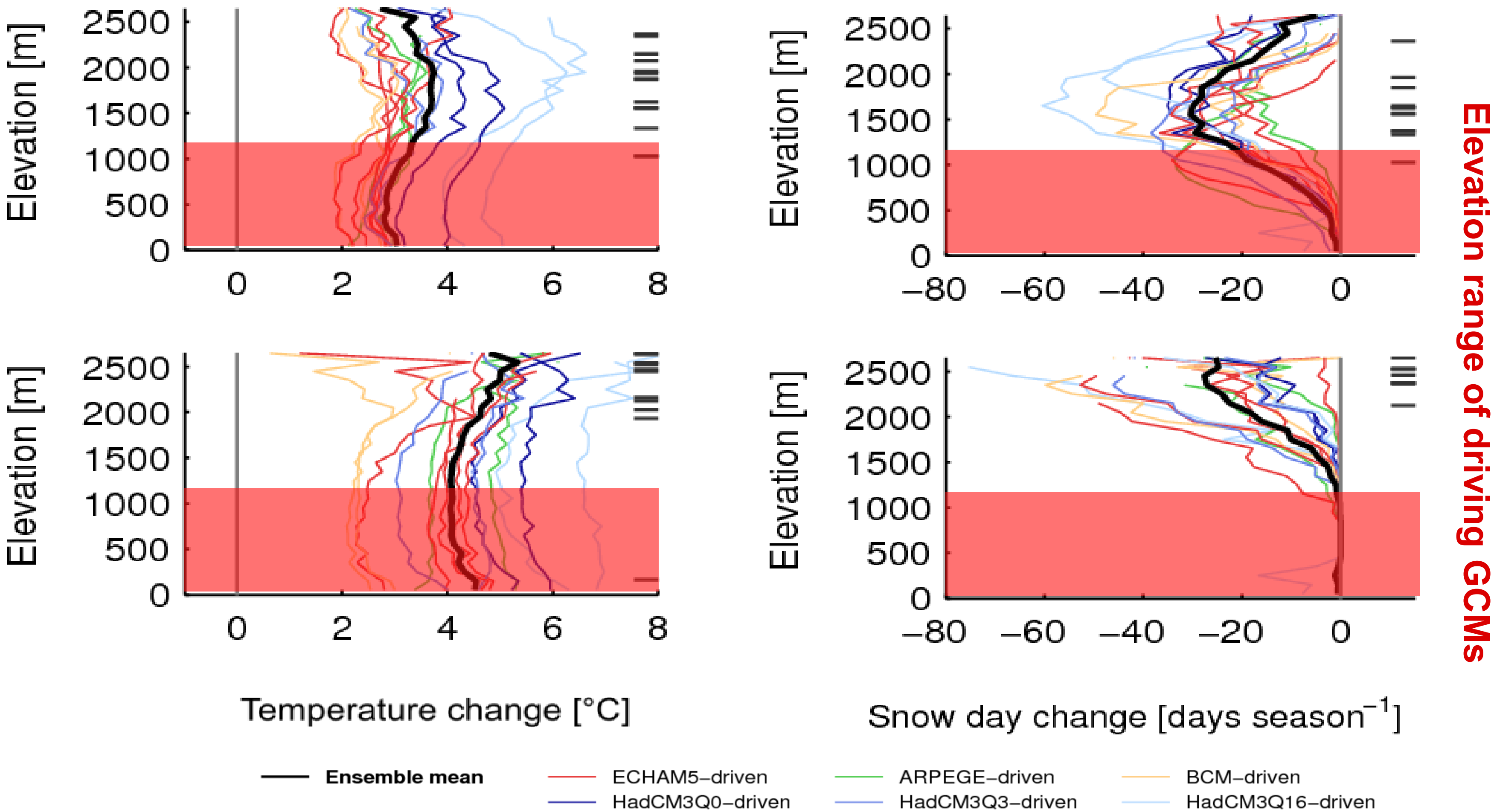


Mean winter precipitation Alps (1976-2005) [mm/day]

Torma et al., 2015

The Added Value (4)

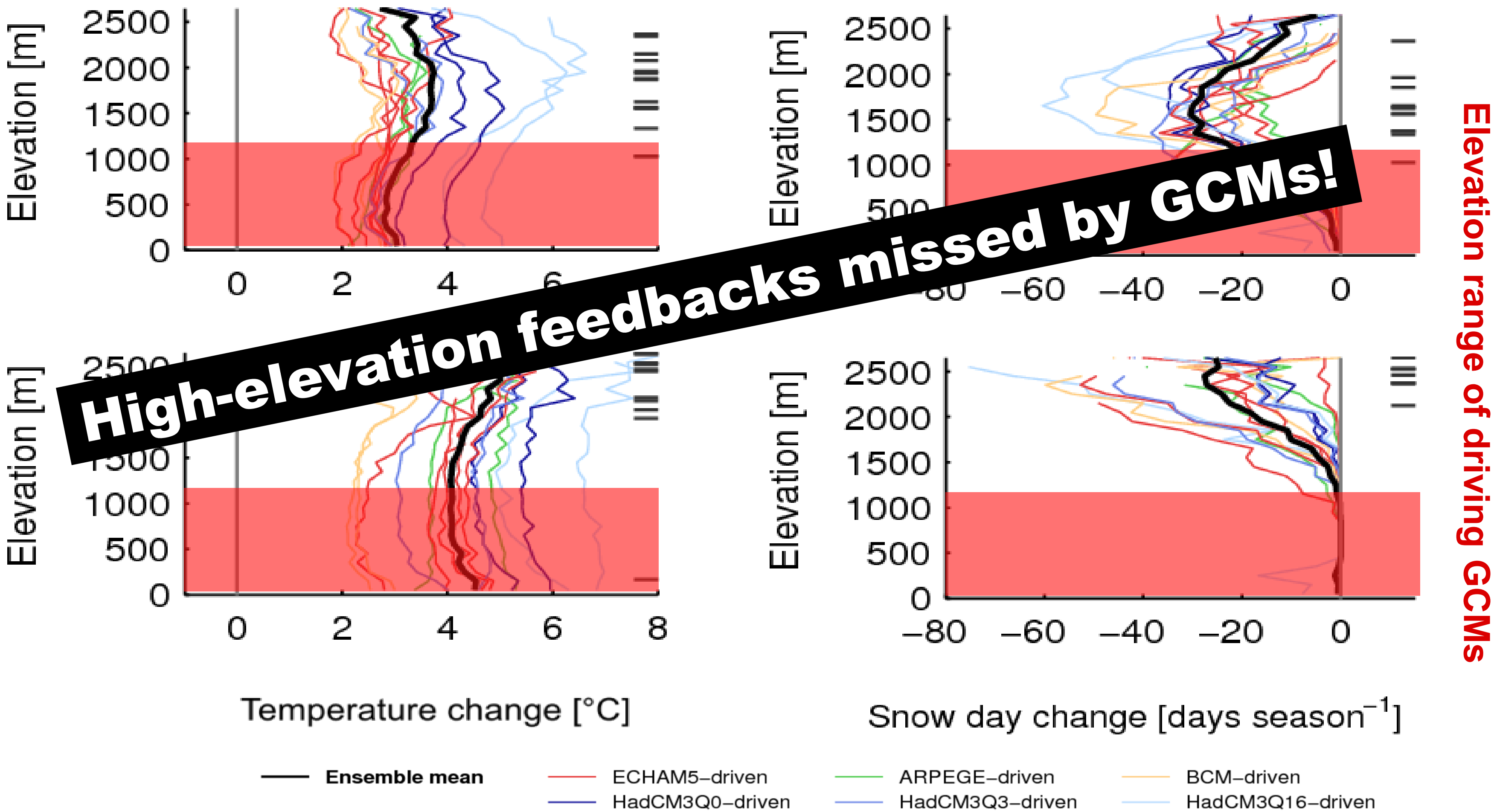
Near-surface climate change until end of 21st century in the ENSEMBLES RCMs (European Alps, SRES A1B)



Kotlarski et al., 2015

The Added Value (4)

Near-surface climate change until end of 21st century in the ENSEMBLES RCMs (European Alps, SRES A1B)



Kotlarski et al., 2015

OUTLINE

1. Dynamical Downscaling: The Rationale
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4. **Regional Climate Projections**

Regional Climate Projections:
A Main Application of RCMs

Workflow:

Choice of emission scenario → **Choice of driving GCM** → **Choice of RCM** → **Setup of RCM** → **Interface to subsequent applications**

- Partly subjective choices that will influence final results and introduce projection uncertainties
- Further sources of uncertainty (e.g., internal climate variability)
- Can partly be sampled by large model ensembles

Climate Model Ensembles

EMISSION SCENARIO ENSEMBLES

- **Carry out multiple projections assuming different emission scenarios**

MULTI MODEL ENSEMBLES

- **Combine multiple projections from different models**
- **Ideally: models independent of each other** (typically not given!)
- **Intermodel variability as a measure of uncertainty**

PERTURBED PHYSICS ENSEMBLES

- **Combine different simulations of the <u>same</u> model but with perturbed versions of the original model physics**
- **More systematic sampling possible** (multi model ensembles: *opportunistic* ensembles)
- **Intramodel variability as a measure of uncertainty**

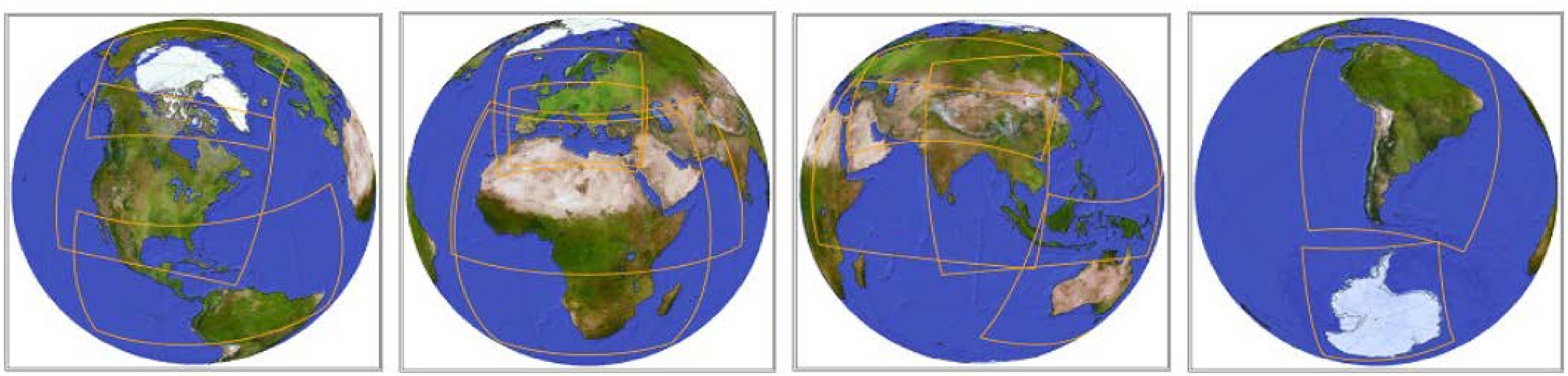
INITIAL CONDITION ENSEMBLES

- **Sampling of internal climate variability**

CORDEX

***Co**ordinated **R**egional Climate **D**ownscaling **Ex**periment*

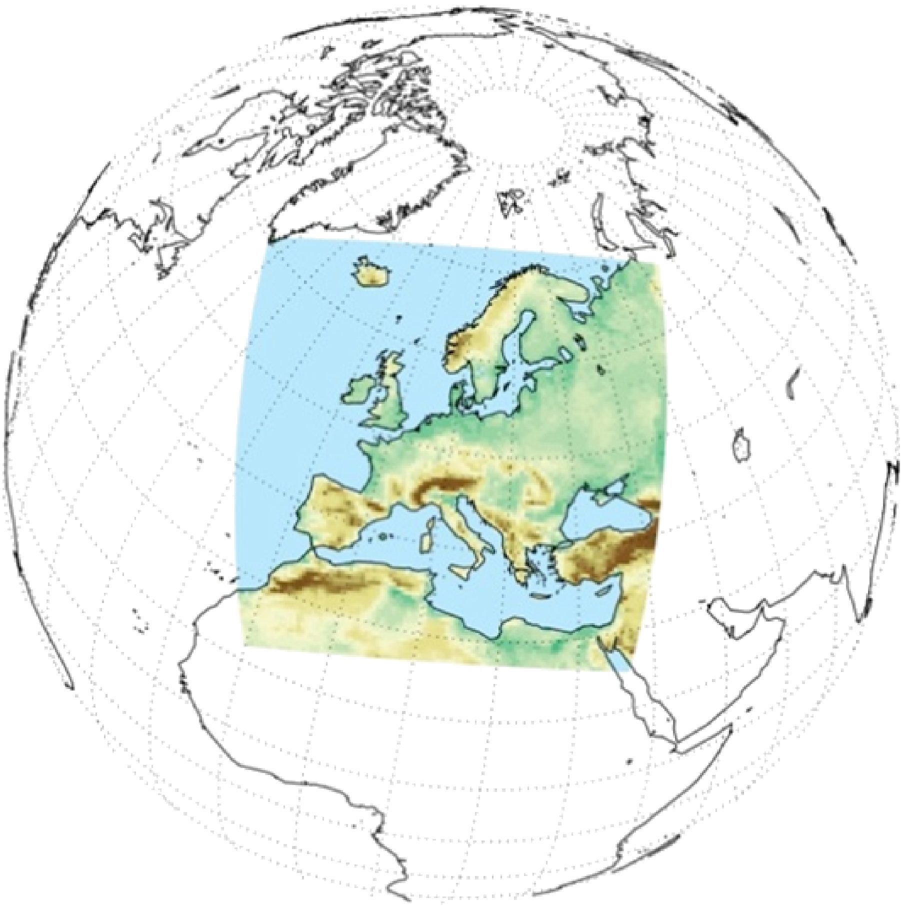
- International framework for next generation of regional climate change projections for all terrestrial regions of the globe *(http://www.cordex.org)*
- Dynamical and statistical downscaling
- Common RCM resolution: 50 km



The CORDEX community has grown to now include 14 domains;

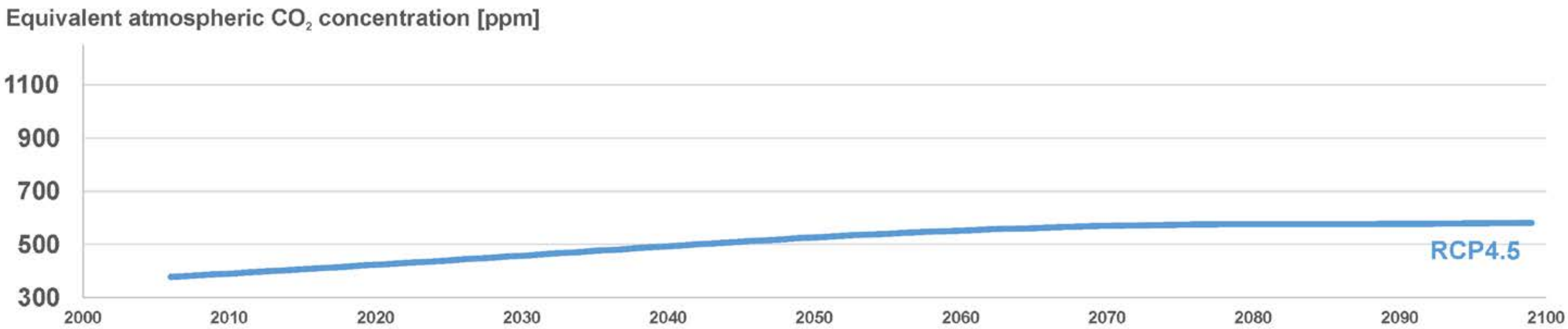
http://wcrp-cordex.ipsl.jussieu.fr

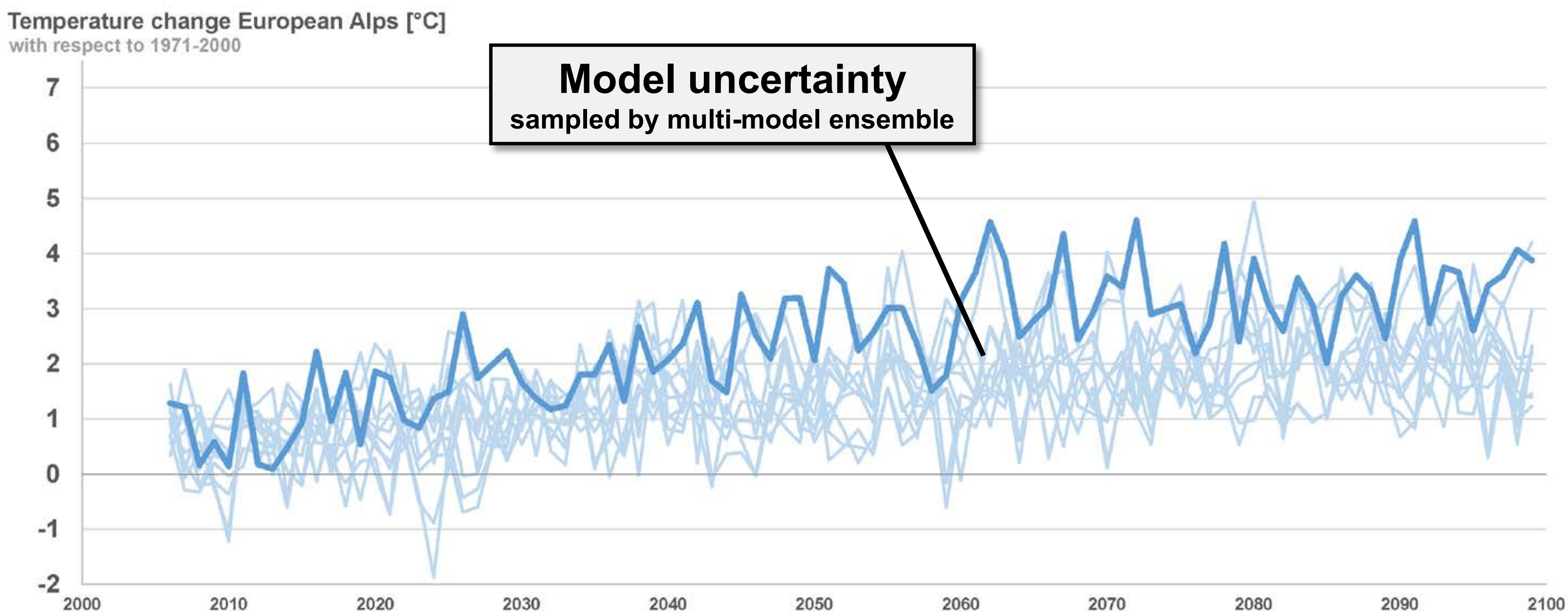
EURO-CORDEX



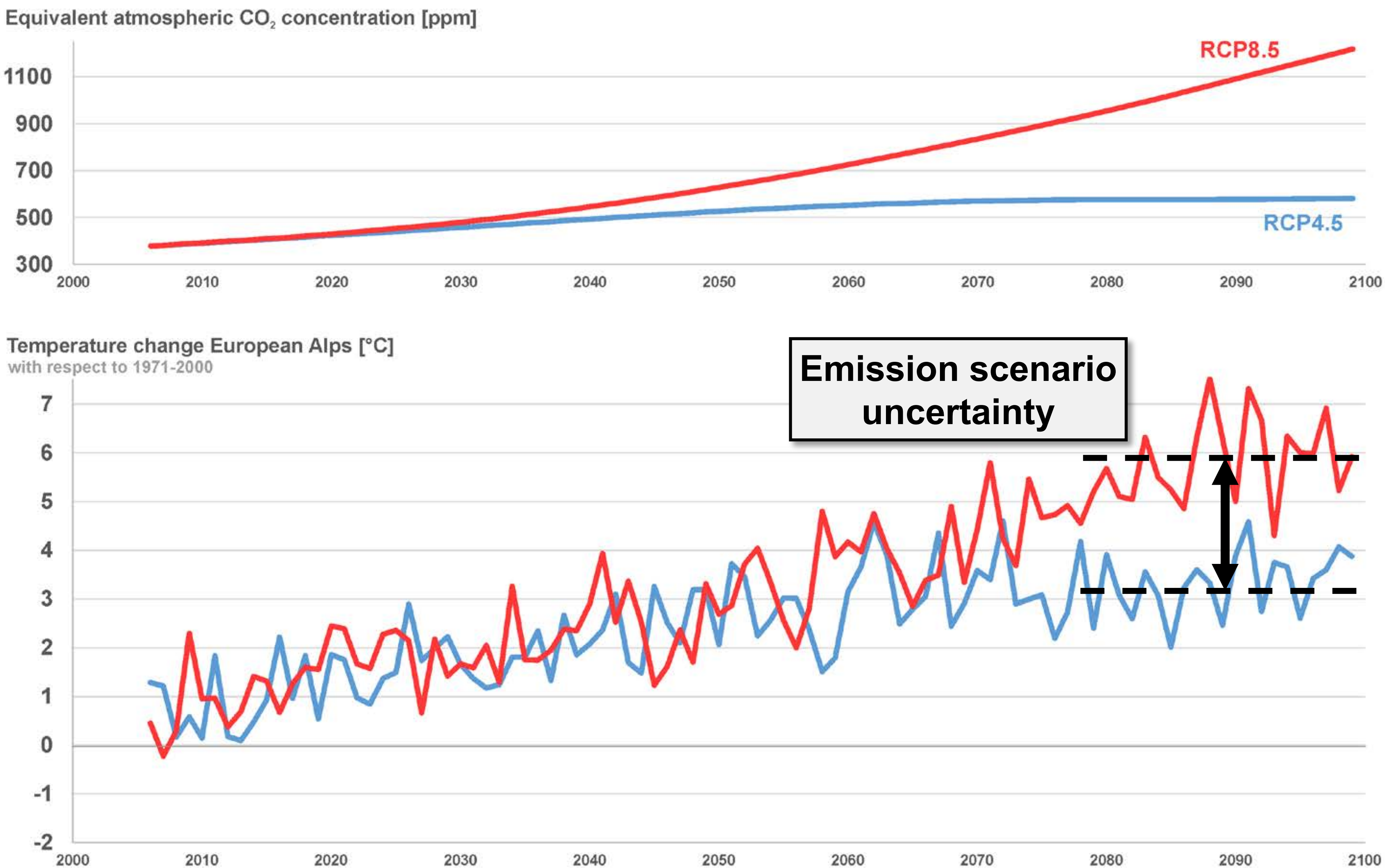
- European branch of CORDEX
  http://www.euro-cordex.net
- **~30 modelling centers** applying **~10 RCMs**
- Empirical-statistical component
- Experiments at **50 km** <u>and</u> **12 km** for European domain
- Re-analysis forcing and GCM forcing (CMIP5)
- Several GHG scenarios (RCPs 2.6, 4.5, 8.5)

EURO-CORDEX Projections (1)



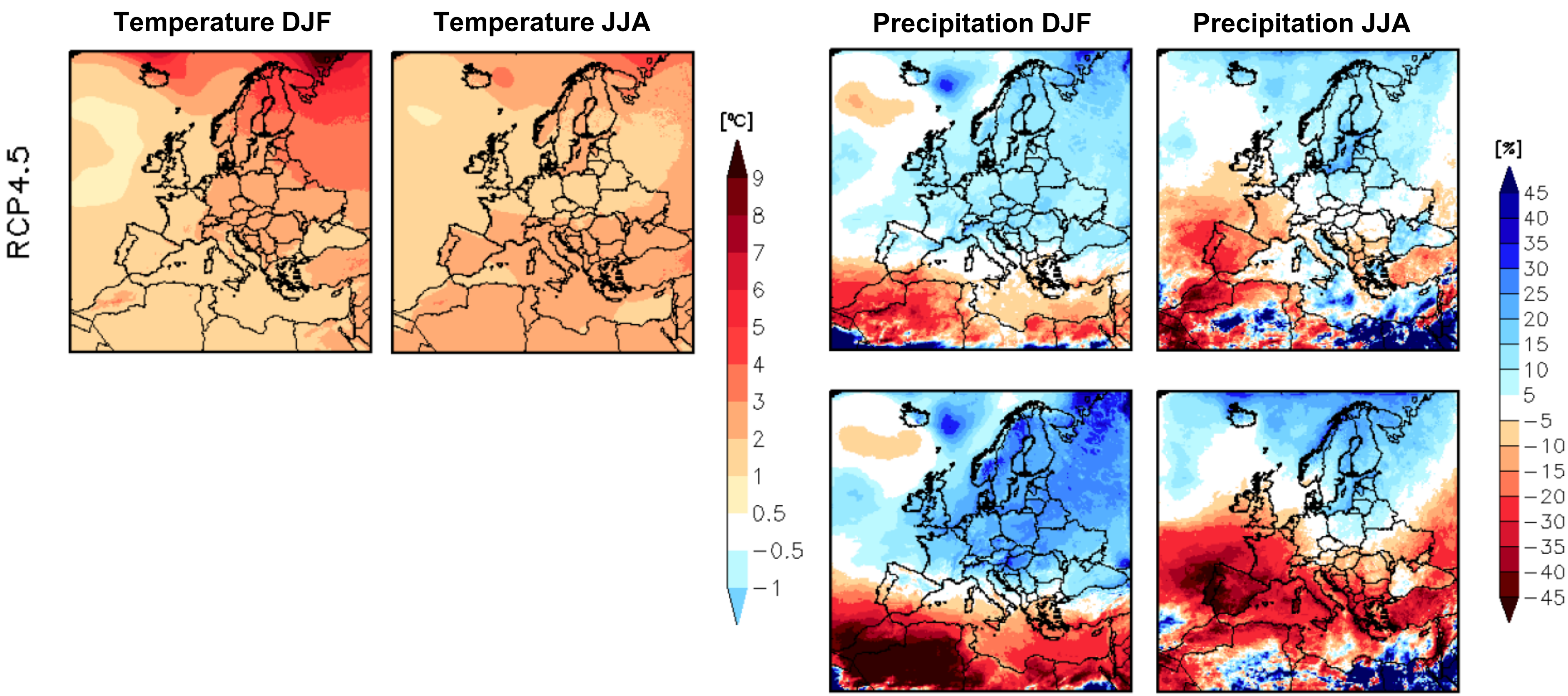


EURO-CORDEX Projections (2)



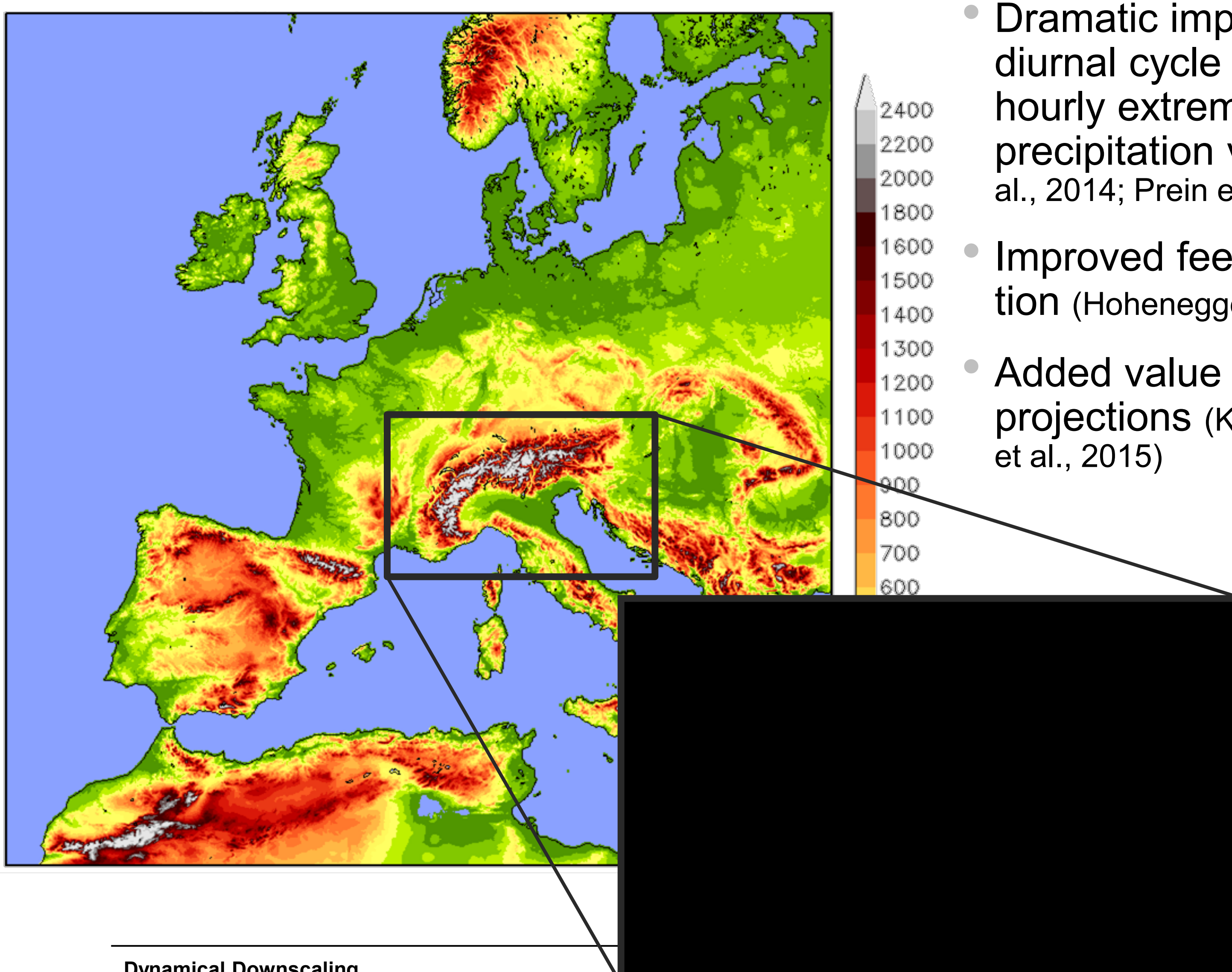
EURO-CORDEX Projections (3)

Ensemble mean change until end of 21st century in EURO-CORDEX 12 km
(12 simulations combining 6 RCMs and 5 GCMs)



Kotlarski et al., submitted

Outlook: Convection-permitting scenarios



- Dramatic improvement of diurnal cycle (including sub-hourly extremes) and spatial precipitation variability (e.g. Ban et al., 2014; Prein et al., 2013)
- Improved feedback representa-tion (Hohenegger et al., 2009)
- Added value for heavy rainfall projections (Kendon et al., 2014; Ban et al., 2015)

But:
High computa-tional costs still limiting!

Summary

- Dynamical downscaling via RCMs to **add detail** onto global climate model results
- Provides **physically consistent responses**, but also has several **limitations**
- Remaining biases and scale gaps require further SD and/or bias adjustment

- **Model validation** as an important component of model development and scenario generation
- Can identify **added value**

- Large **(multi) model** ensembles to sample inherent projection uncertainties (e.g., CORDEX)

Summary

- Dynamical downscaling via RCMs to **add detail** onto global climate model results
- Provides **physically consistent responses**, but also has several **limitations**
- Remaining biases and scale gaps requir… adjustment

THANK YOU

- …portant component of model development …generation
- Can identify **added value**

- Large **(multi) model** ensembles to sample inherent projection uncertainties (e.g., CORDEX)