Session D6

Hybrid downscaling methods

How can CORDEX benefit from statistical approaches?

Abdelkader Mezghani (MET Norway) and Stefan Sobolowski (NORCE)

Motivation of the session

Downscaling is a key aspect in most studies of regional climate change and associated consequences, as it reduces the information gap between coarse-grained global climate model output and the local scales at which climate impacts manifest. While the dynamical downscaling approaches are primarily based on the **physical understanding** of processes and phenomena, statistical downscaling techniques focus more on reproducing the **statistical properties** of particular climate variables or phenomena such as the mean, variability and extremes. The two different approaches have different strengths and weaknesses, which implies that they complement each other. They can also be combined to **provide a more powerful framework for studying the regional climate**. For instance, empirical-statistical downscaling can be used to identify the dependency between large and small scales simulated by regional climate models. Outputs from regional climate models can also be used to train statistical models to **test the methods** such as stationarity. The two approaches can also be **combined to emulate regional climate models** driven by large ensembles of global climate models.

Aims of the session

- Bring researchers from the **RCM and ESD communities together** to discuss, interact, and share findings and ideas on how to combine both methods to produce more reliable and more robust climate projections.

- **Establish guidelines** on how to merge ESD and RCM results, eventually **suggest a protocol** or a road map on how to do this.

- Better **integrate these efforts into existing CORDEX activities**, especially, through FPS

- **Communicate** the outcomes of the session.

Motivating questions

- Can we validate and **expand RCM results** to cover the full multi-model ensemble of GCMs using ESD and hybrid methods?

- Can we use ESD to study how the **physical connections** are captured? e.g. non-convective versus convective RCMs?

- Can we **build a consistent framework** to be used in CORDEX FPS as a protocol?

Norwegian
Meteorological
Institute

Climate Simulations based on dynamical and statistical downscaling

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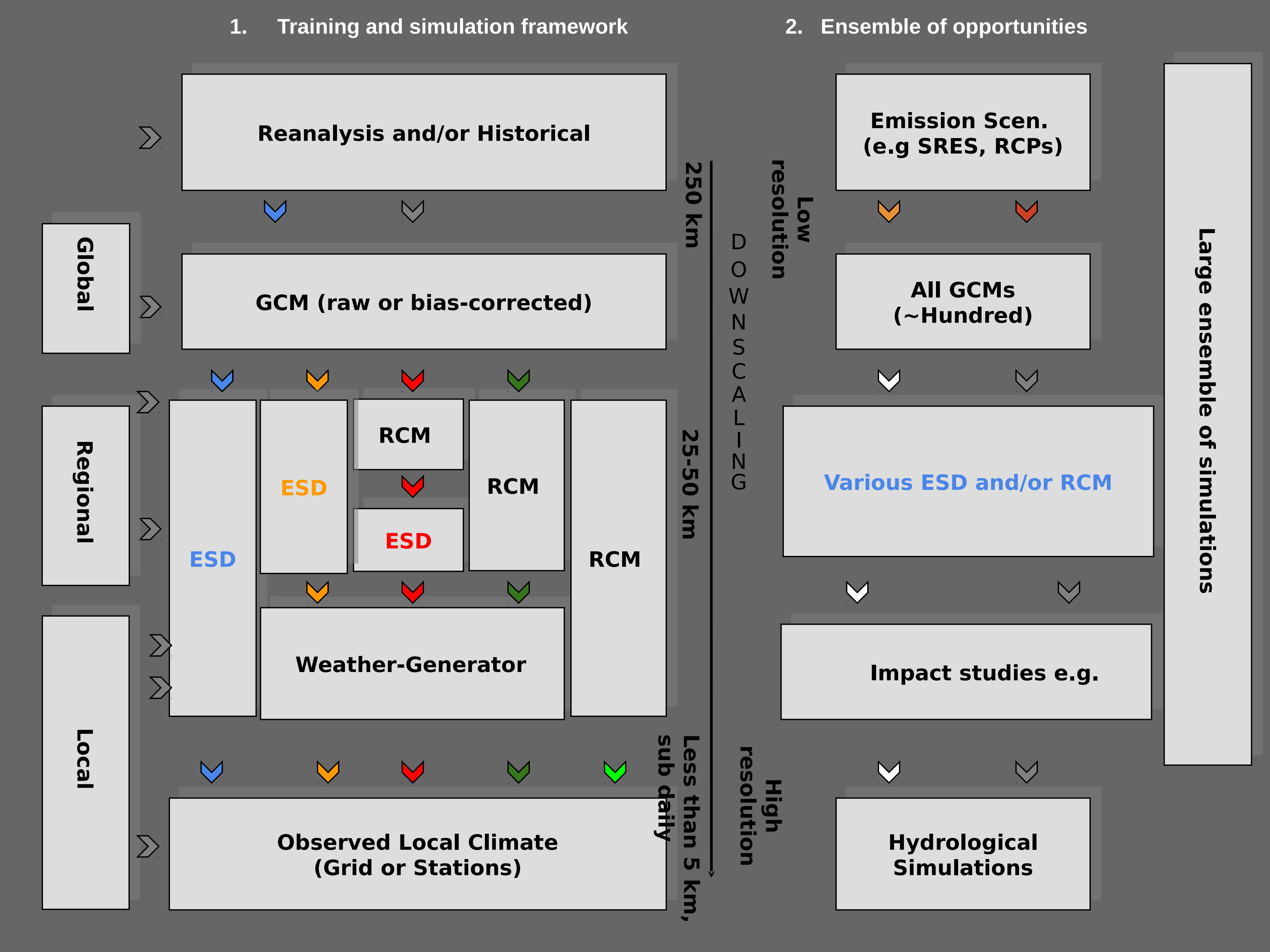
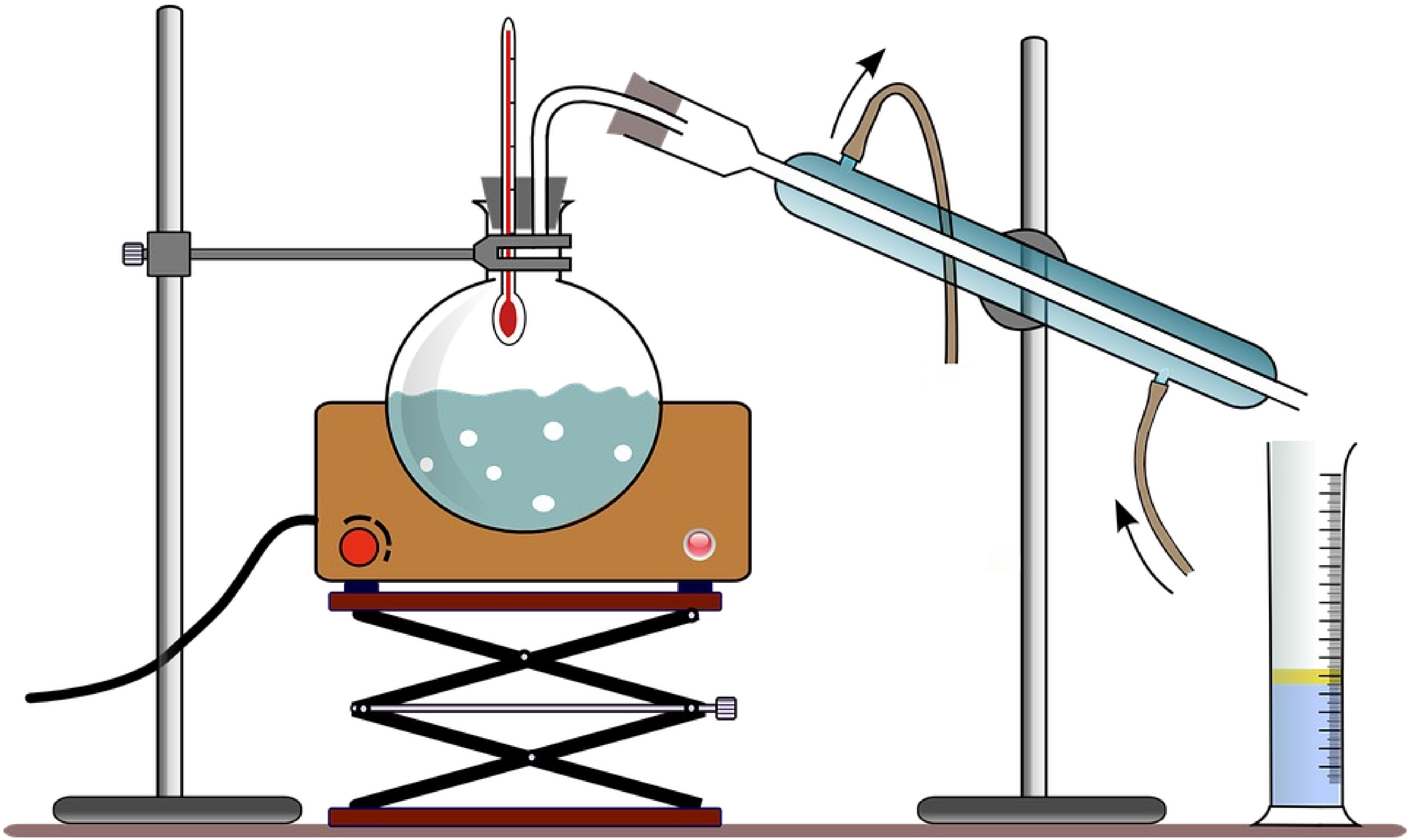
RCMs & ESD

- **RCMs** source = primitive physical equations + parameterisation (“tuning”) + bias adjustment (“tuning”) - **empirical data for evaluation**.
- **ESD** source = empirical equations + statistical theory.
- **Empirical data** for both training & evaluation
- **Stationarity** assumptions for both?
- ESD is a **useful too** for understanding RCMs (“pseudo-reality”)
- **ESD & RCMs**: different & independent strengths.

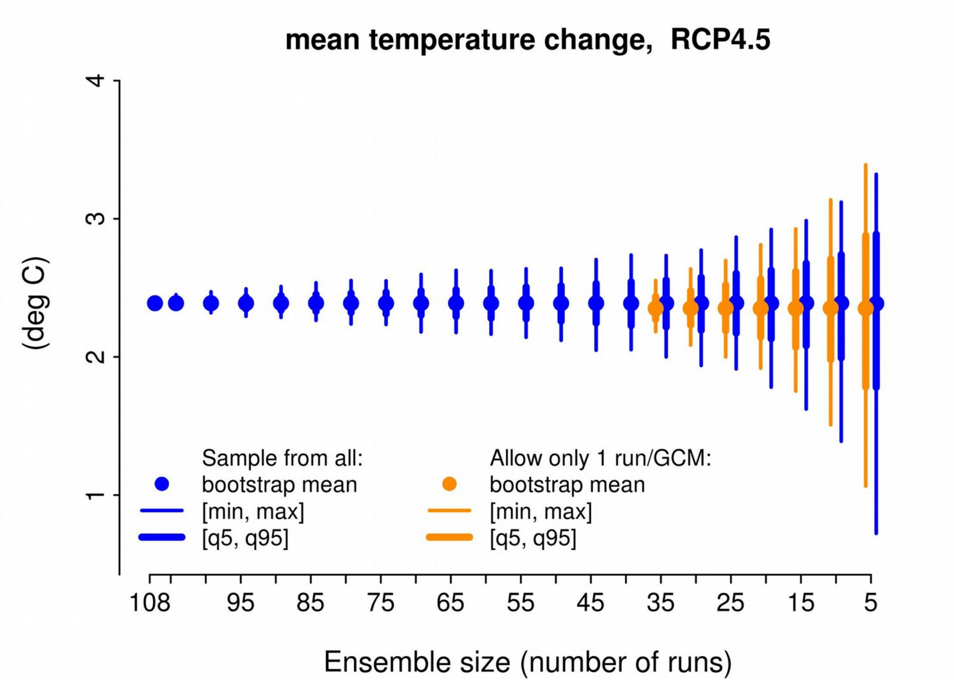


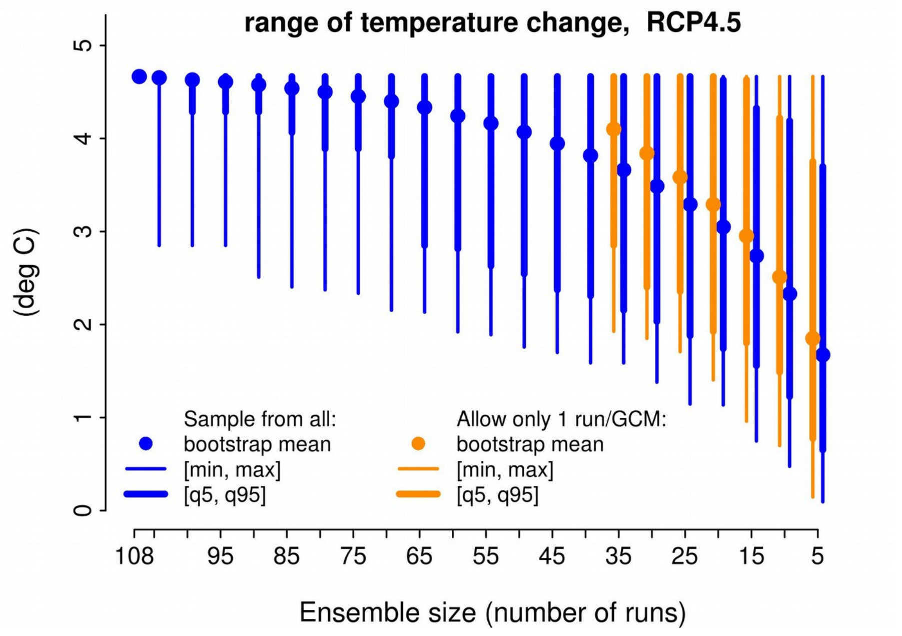
1. Training and simulation framework
2. Ensemble of opportunities
Reanalysis and/or Historical
GCM (raw or bias-corrected)
Global
Regional
Local
ESD
ESD
RCM
ESD
RCM
RCM
Weather-Generator
Observed Local Climate
(Grid or Stations)
250 km
25-50 km
Less than 5 km,
sub daily
DOWNSCALING
Low
resolution
High
resolution
Emission Scen.
(e.g SRES, RCPs)
All GCMs
(~Hundred)
Various ESD and/or RCM
Impact studies e.g.
Hydrological
Simulations
Large ensemble of simulations

Extracting a subset of GCMs prior to downscaling (Bootstrapping over Poland)



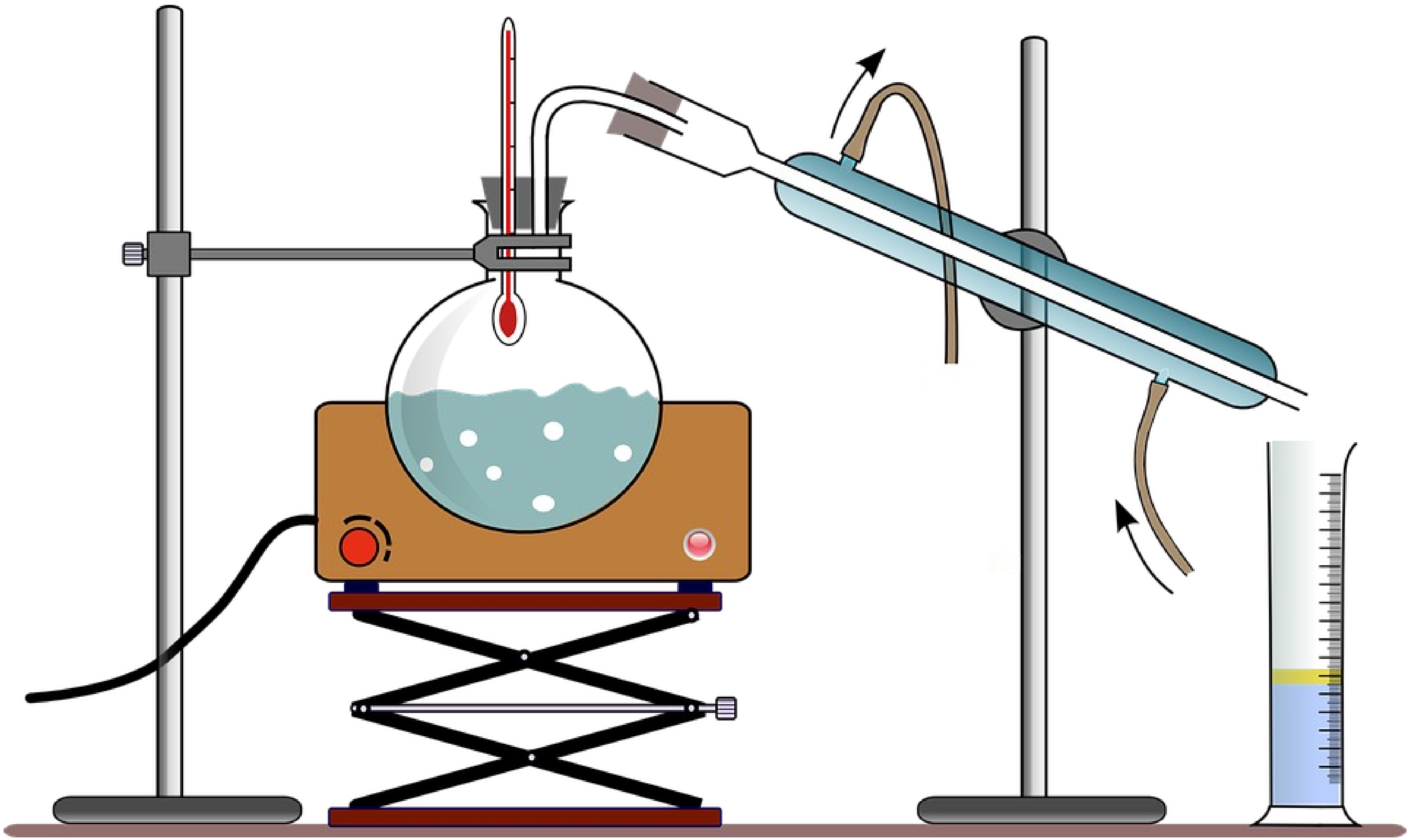
Sampling a subset of GCMs prior to downscaling (Bootstrapping over Poland)





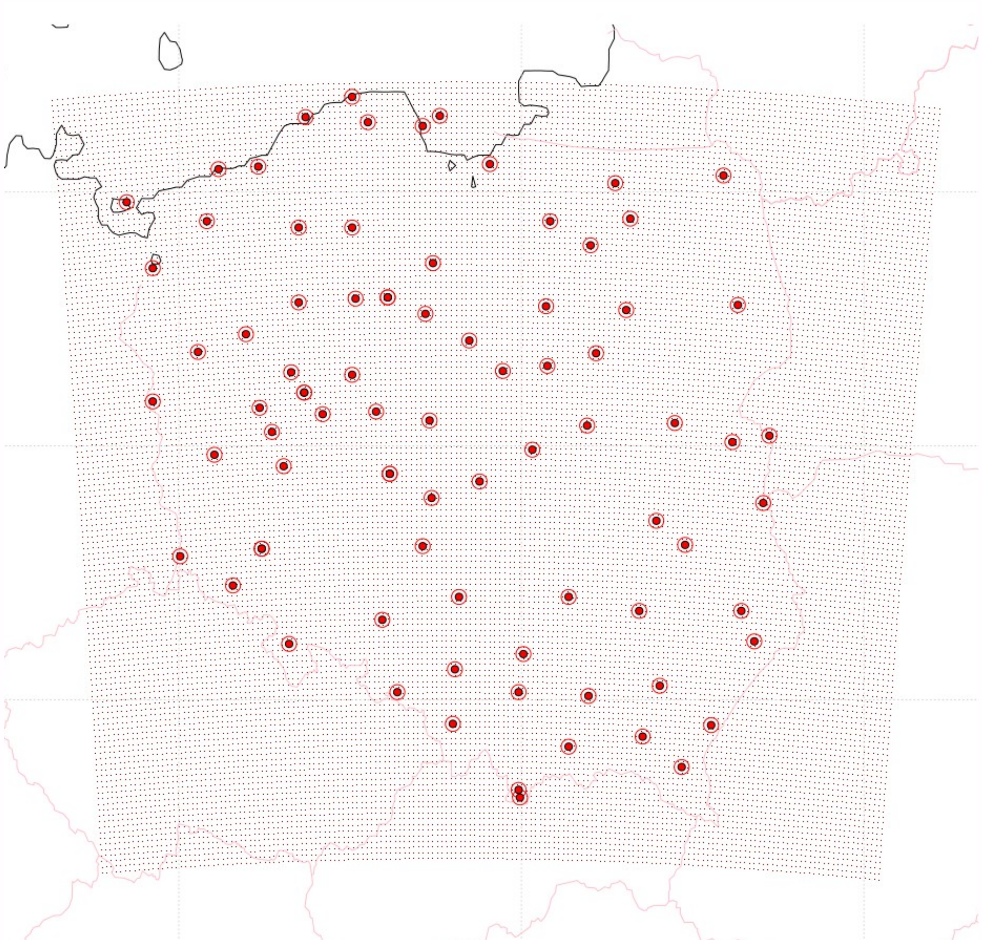
Mezghani et al. 2019 (JAMC)

ESD vs RCM ?



How do we compare ESD with DD?

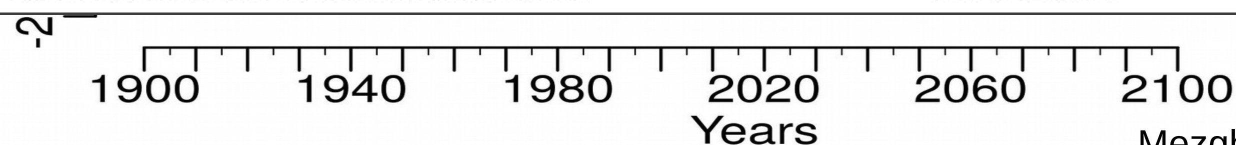
- ESD downscaled on stations (red points),
- BC interpolated on stations (large circles),
- Compute averages across all sites from common sets of ensemble simulations.



Robust downscaling (e.g. Temp @Poland)

RCM (dashed blue) & ESD (dashed red) make use of independent information, but the downscaled results are similar (e.g. RCP4.5)

Expt	Description	No. of simulations RCP4.5: *T—P*	RCP8.5: *T—P*
GCM-All	Ensemble of all CMIP5 GCM simulations as described in Table B1	108—105 runs 39—36 GCMs	81—78 runs 35—35 GCMs
DD-All	Ensemble of all EURO-CORDEX bias-corrected simulations as defined in Table 2	9—9 runs 4+4—4+4 GCMs+RCMs	9—9 runs 4+4—4+4 GCMs+RCMs
ESD-All	Ensemble of all ESD simulations	108—105 runs 39—36 GCMs	81—78 runs 35—35 GCMs
GCM-Com	Ensemble of the subset of GCM-All based on common GCMs used in both DD and ESD	9—8 runs 4—4 GCMs	9—7 runs 4—4 GCMs
ESD-Com	Ensemble of the subset from ESD-All based on the set of GCMs common to both DD and ESD	9—8 runs 4—4 GCMs	9—7 runs 4—4 GCMs



Mezghani et al. 2019 (JAMC)

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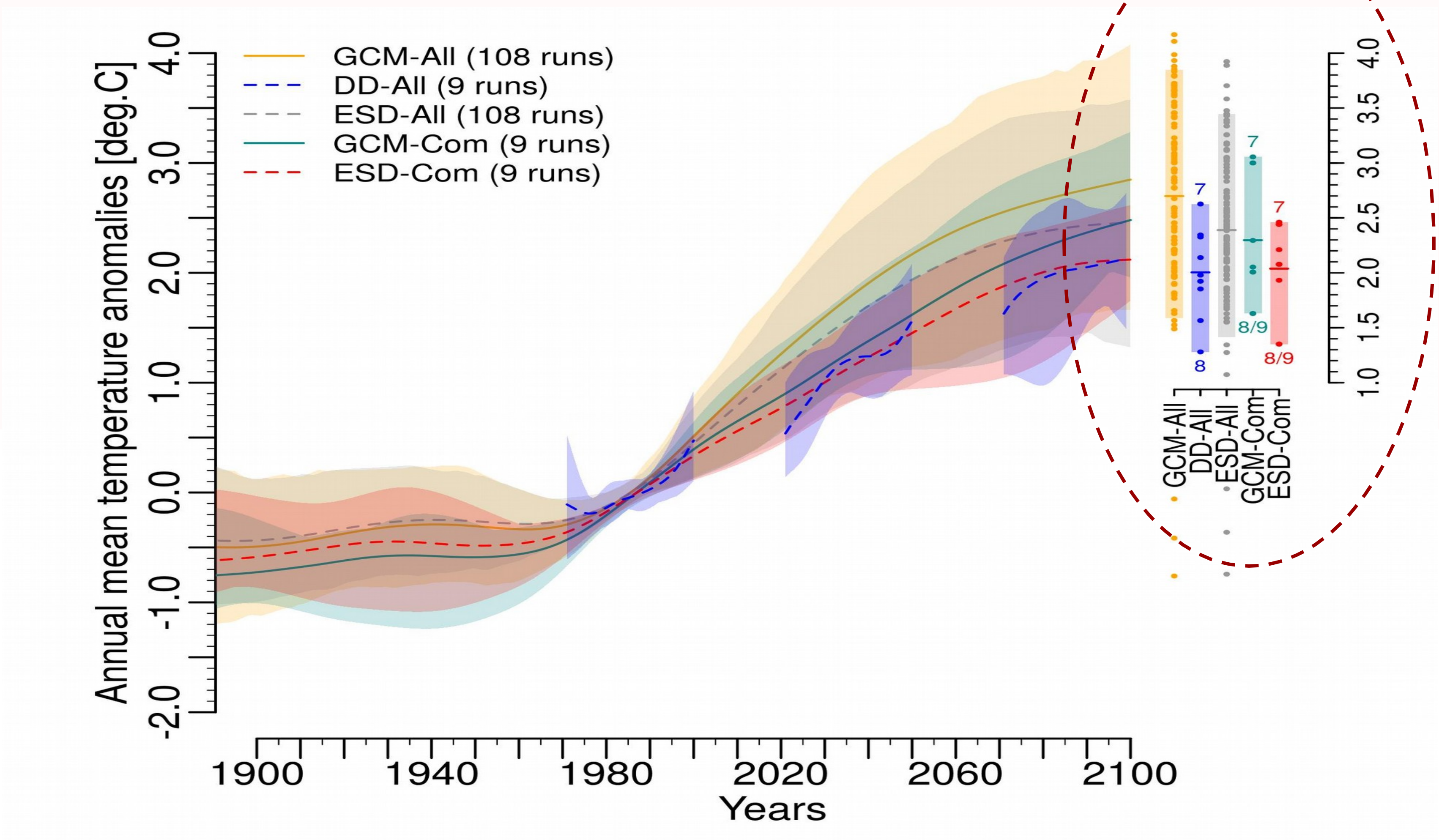
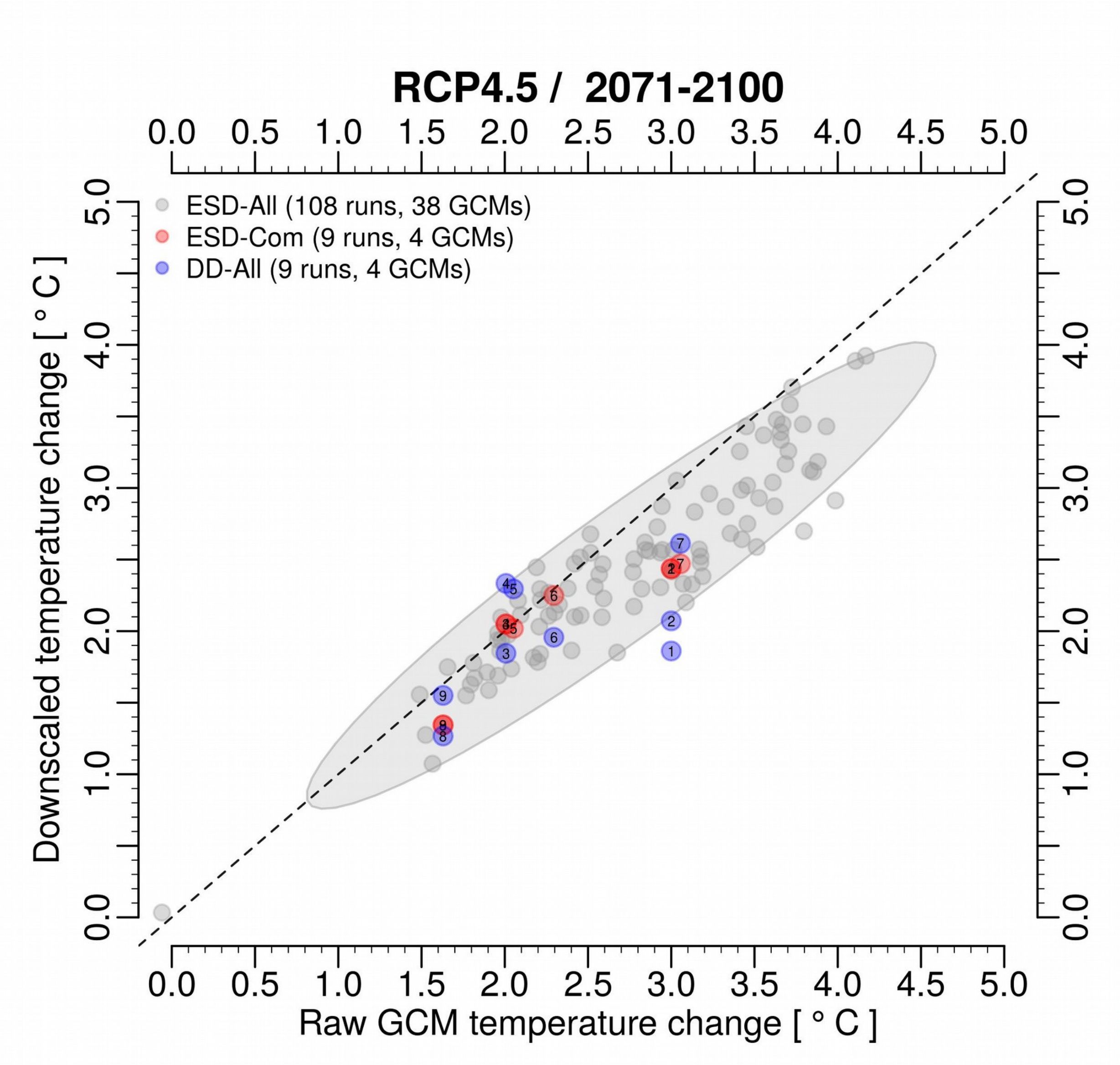
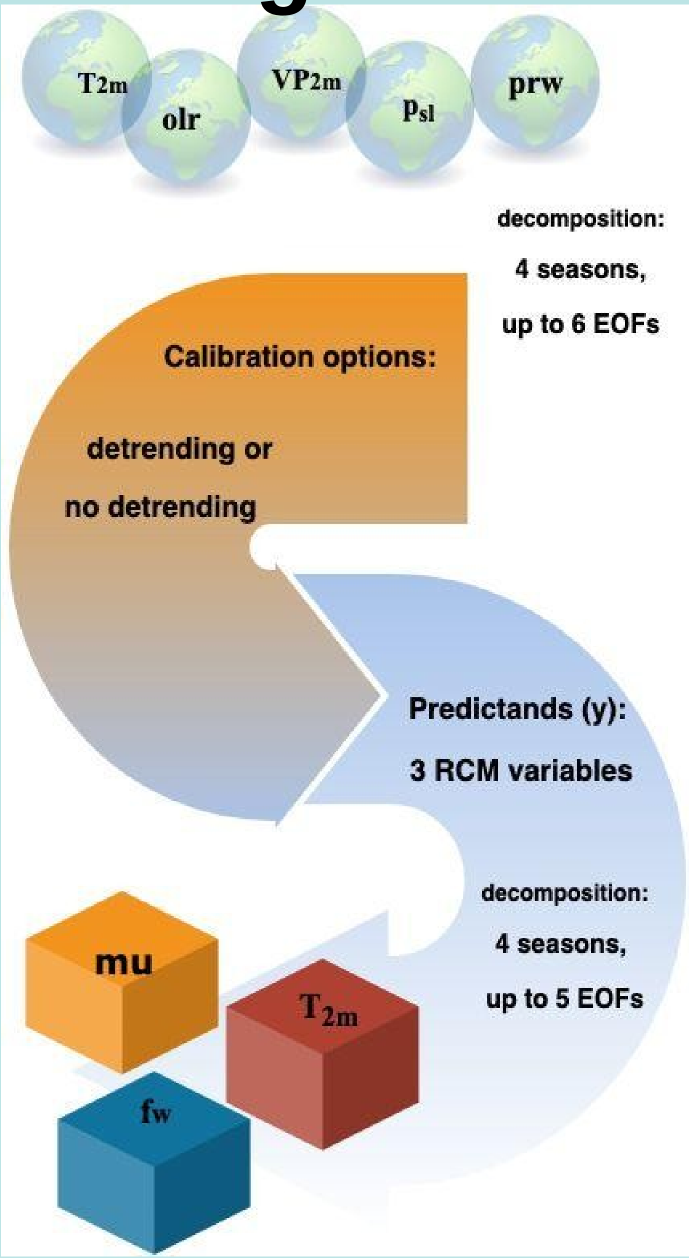


Mezghani et al. 2018 (JAMC)

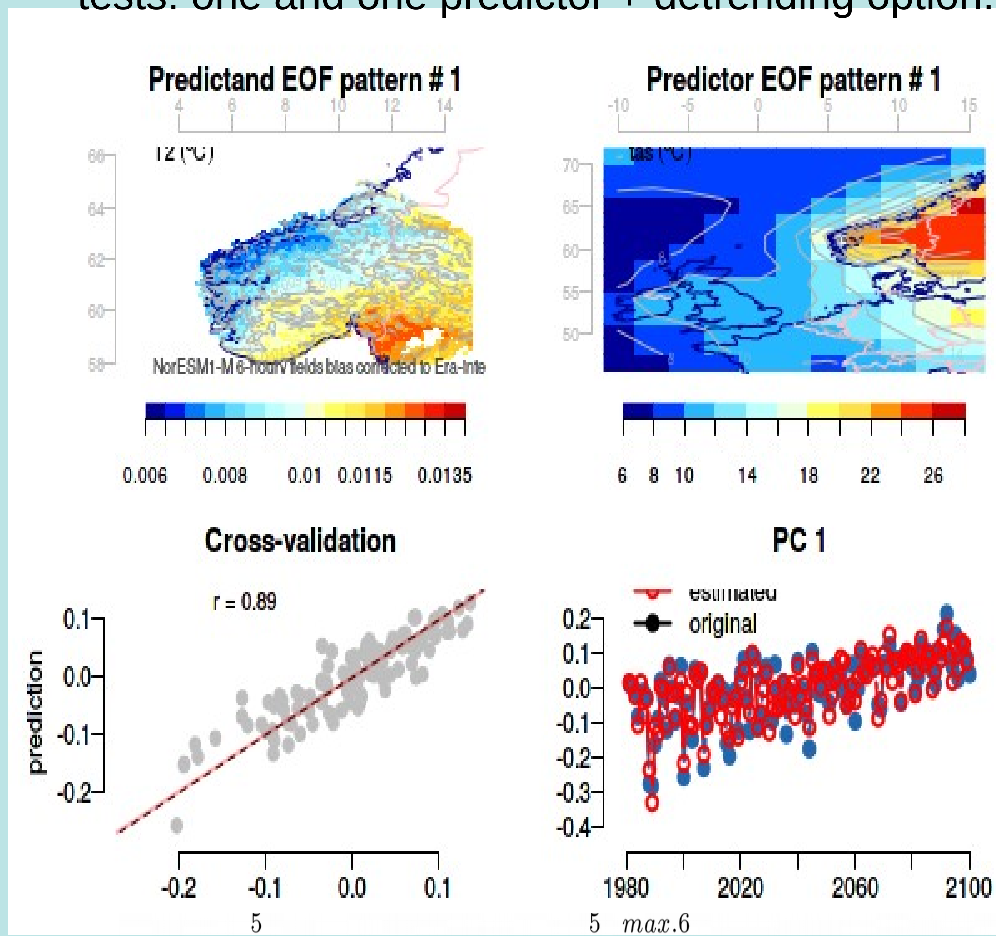
Robust downscaling (e.g. Poland)



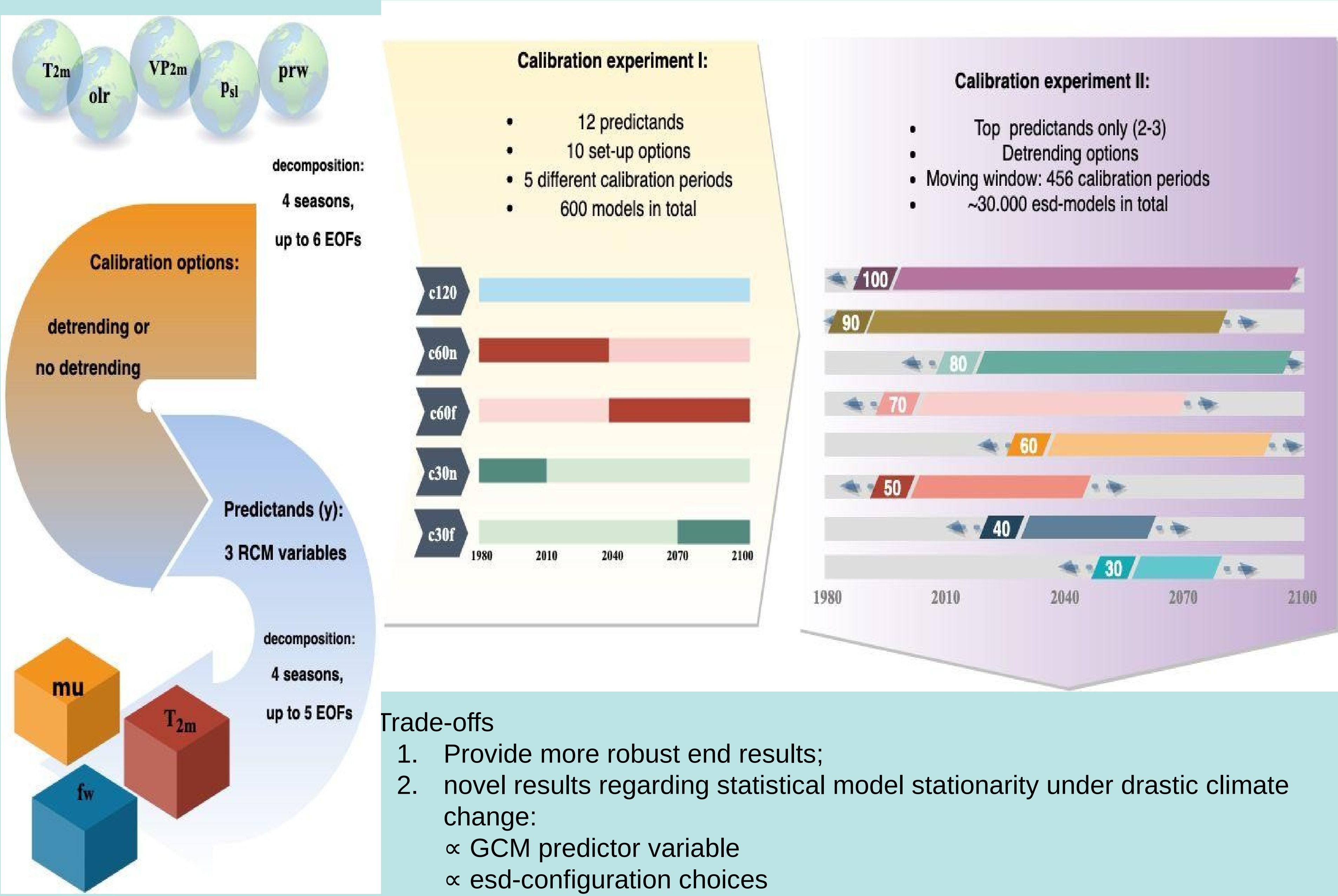
Using RCM to test ESD



- ESD between BC-GCM & RCM (120 years of RCM data.)
- esd emulates RCM-like T2m, fw, µ
- @res: seasonal, 5-6 km
- tests: one and one predictor + detrending option:



$$\hat{\boldsymbol{y}} = \bar{\boldsymbol{y}} + \sum_{j=1}^{5} \widehat{PCy_j}\ EOFy_j = \bar{\boldsymbol{y}} + \sum_{j=1}^{5} \sum_{i=1}^{max.6} (\beta_{0i} + \beta_i\ PCx_i) EOFy_j.$$



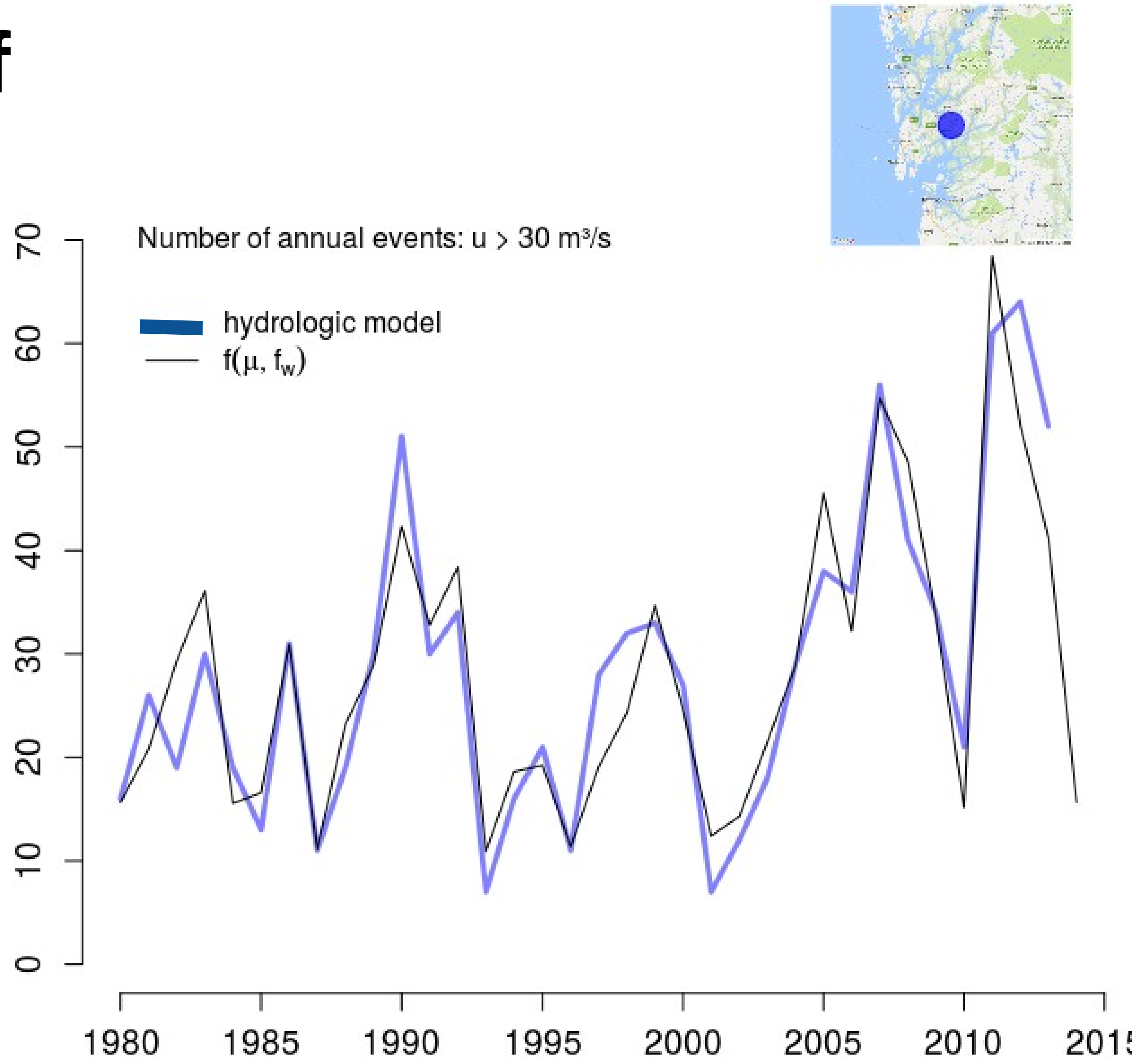
Trade-offs

1. Provide more robust end results;
2. novel results regarding statistical model stationarity under drastic climate change:
   ∝ GCM predictor variable
   ∝ esd-configuration choices

River run-off

Small catchment.

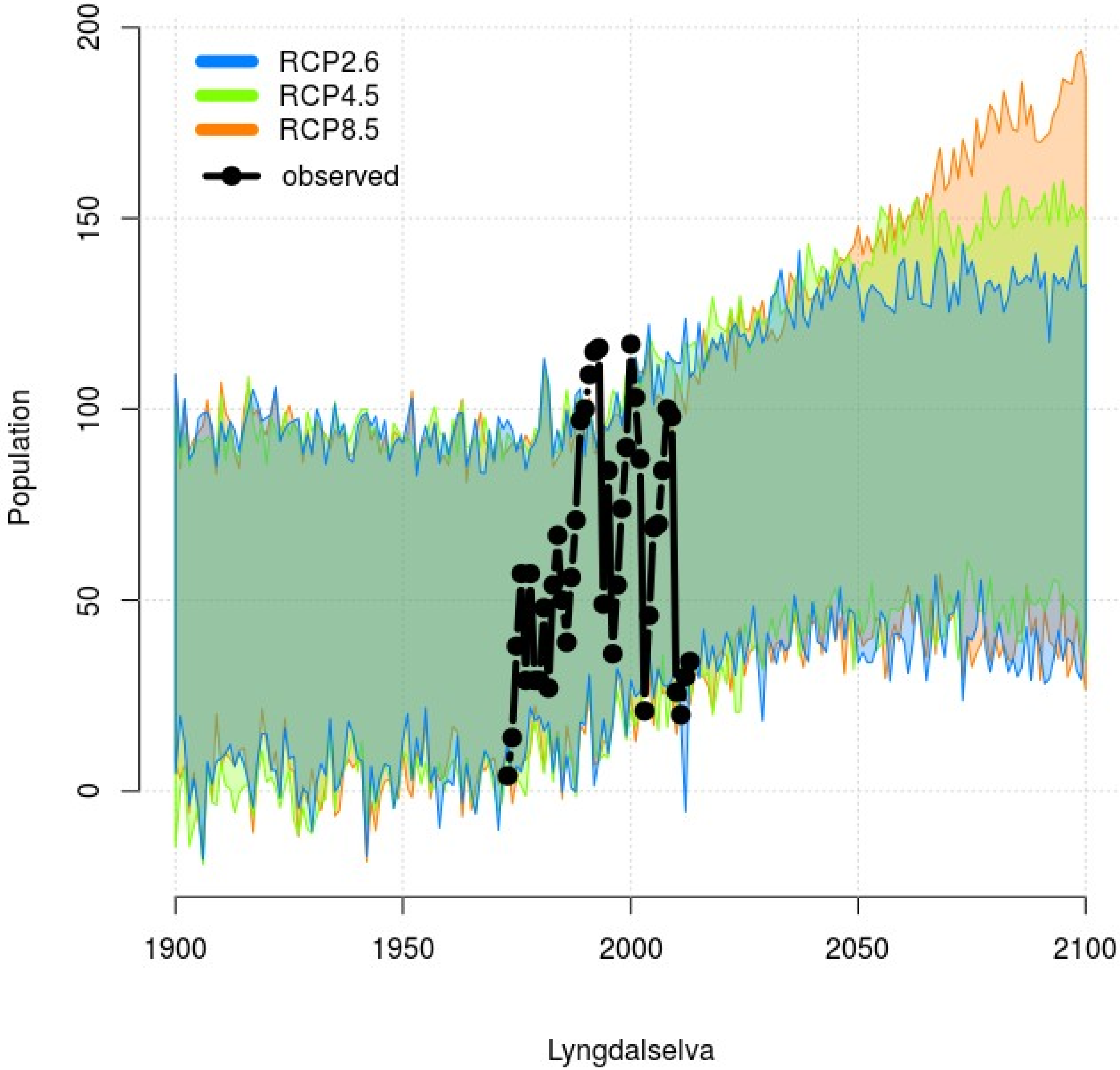
Responds to number of wet days and the rain intensity.



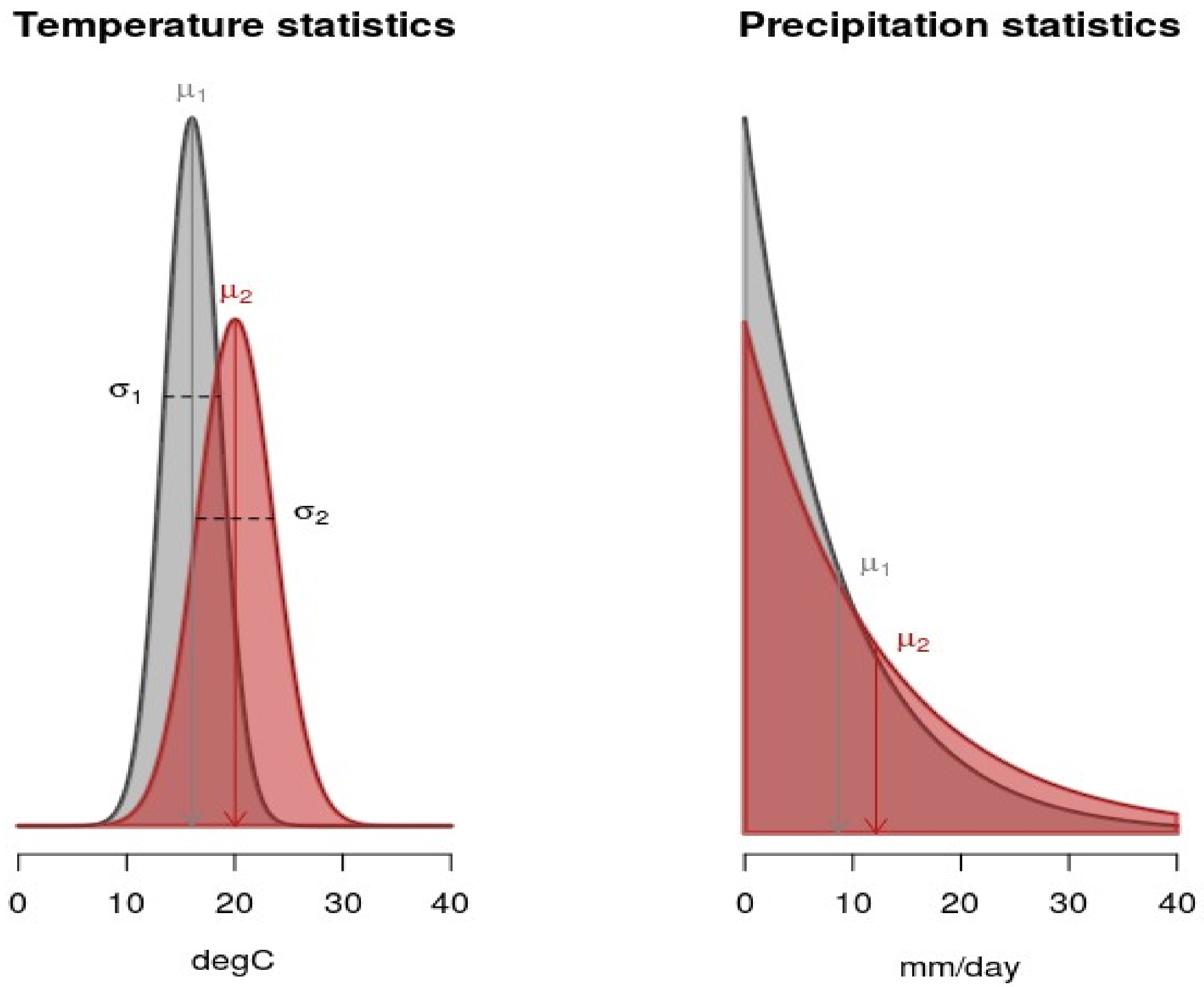
Dipper population

Affected by winter temperature.

Poisson distribusjon



Statistics are remarkably well predictable



“Climate” = “Weather Statistics”

Weather Generator - Principle

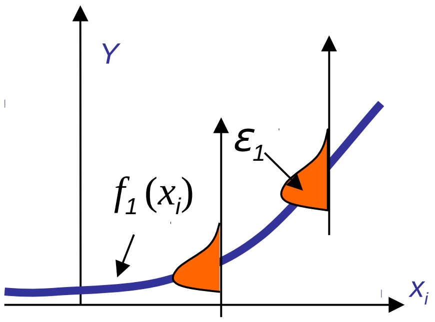
Statistical models usually consist of an empirical relationship for which a set of parameters are estimated so that it best represents the patterns found in the data + stochastic process

Mathematical formulation

Local-Scale = ***f*** (Geography + Large-Scale) + Noise

$$Y = f(G, X) + \varepsilon$$

- Y is the predictand (Quantification of the local scale patterns)
- X is the predictor (Quantification of the large or regional scale patterns)
- ε is a Noise term (Stochastic process)



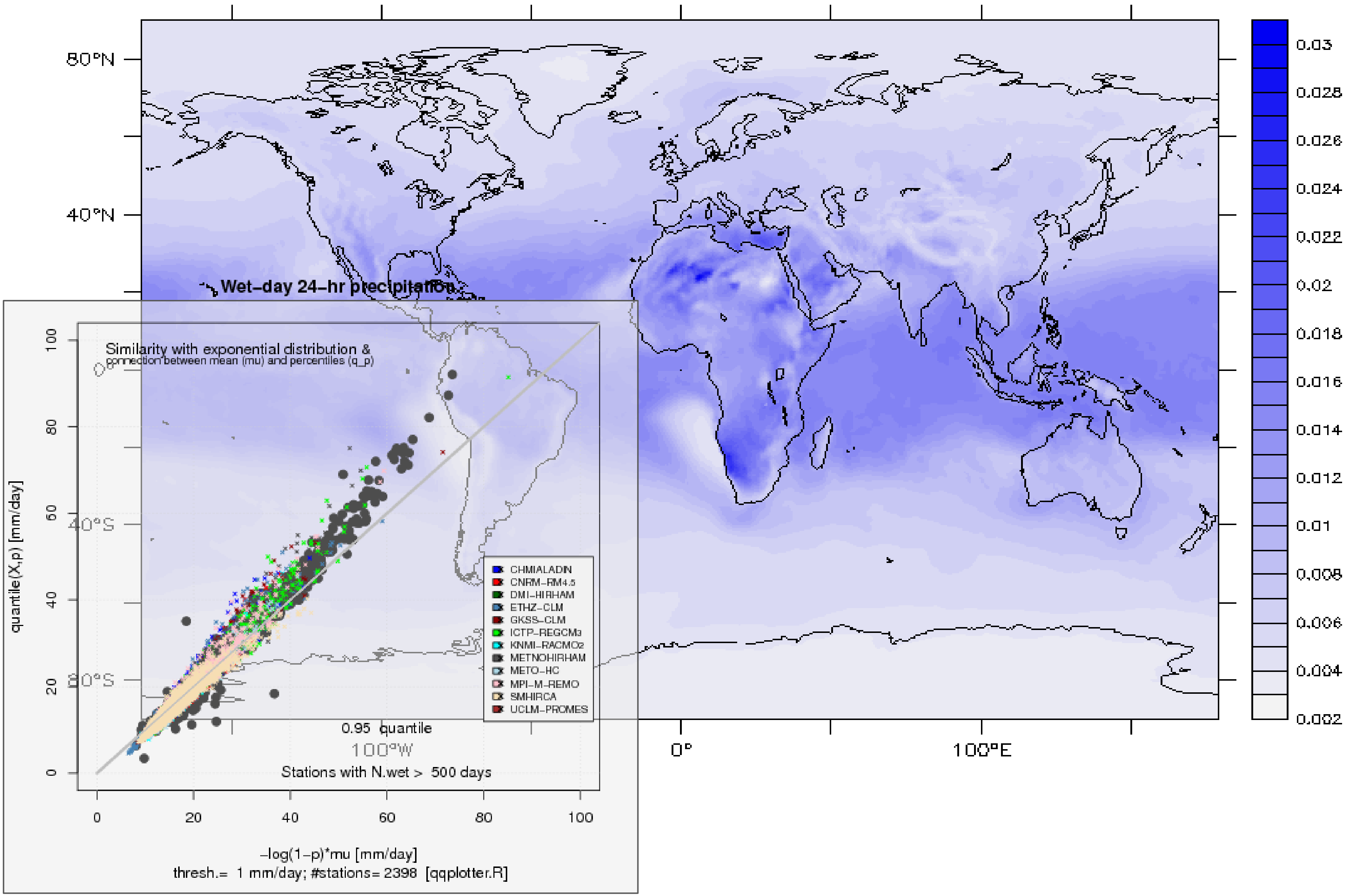
Main message

- *Empirical-statistical downscaling* (**ESD**) can be used to estimate change in *any* variable that is affected by large-scale conditions.

- For climate change projections, downscale “climate” (parameters/ aggregated statistics) rather than “weather” (daily fields/data).

- ESD is suitable for probabilistic information and large multi-model ensembles.

“Climate” = “weather statistics”



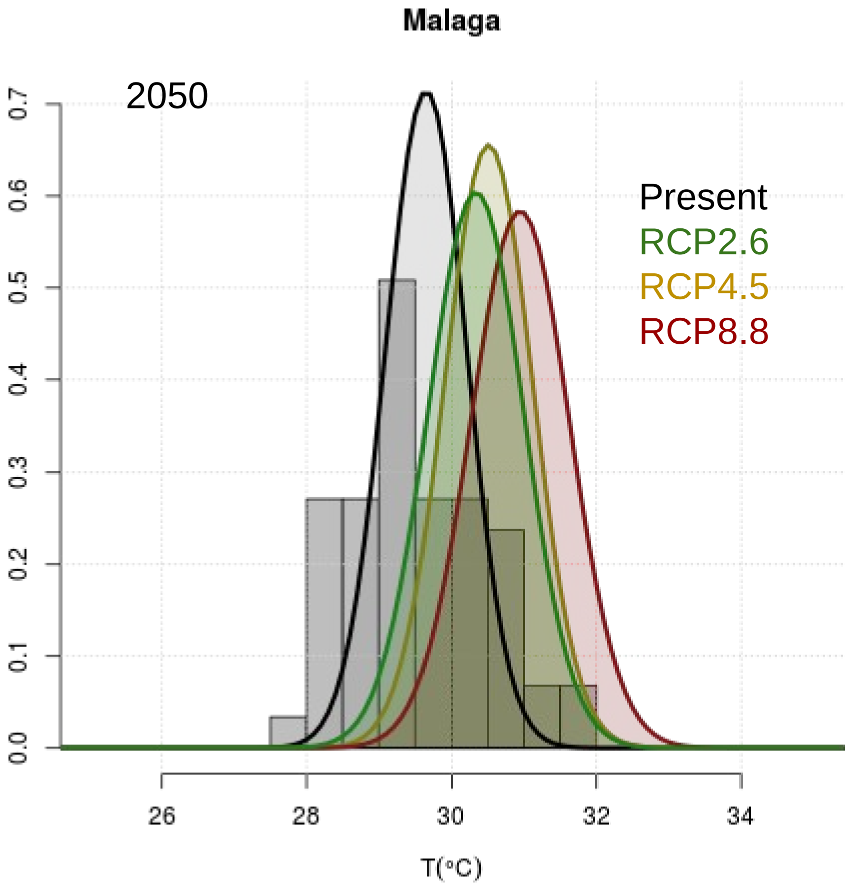
Downscaling statistical parameters

Parameters of pdf

[mean,sd, autocorrelation, …]

Influenced by physical conditions

More predictable than individual outcome



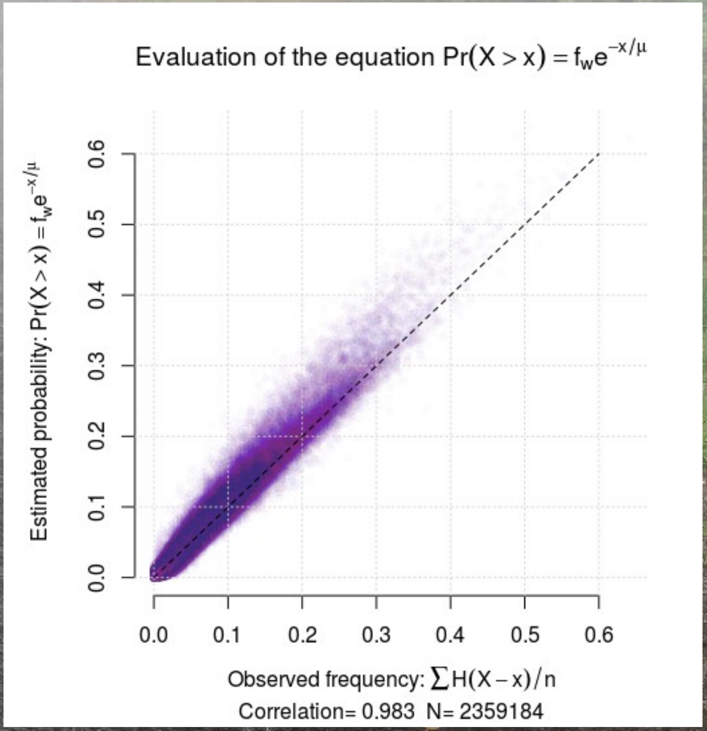
RCM ~ “weather-approach” - ESD ~ ”climate-approach”

Downscaling likelihood of heavy rain

$$Pr(X>x) = f_w e^{-x/\mu}$$

f_w = wet-day frequency

μ = wet-day mean

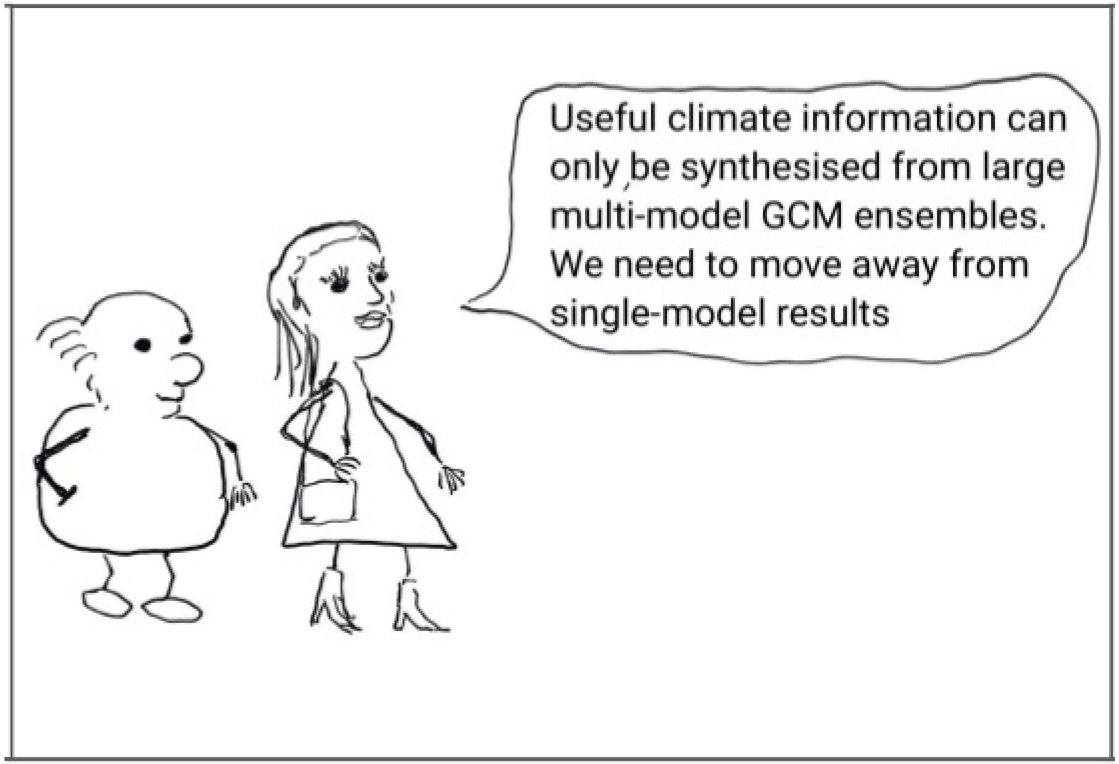


Physical consistency?

Strictly **not** in either RCM nor ESD.

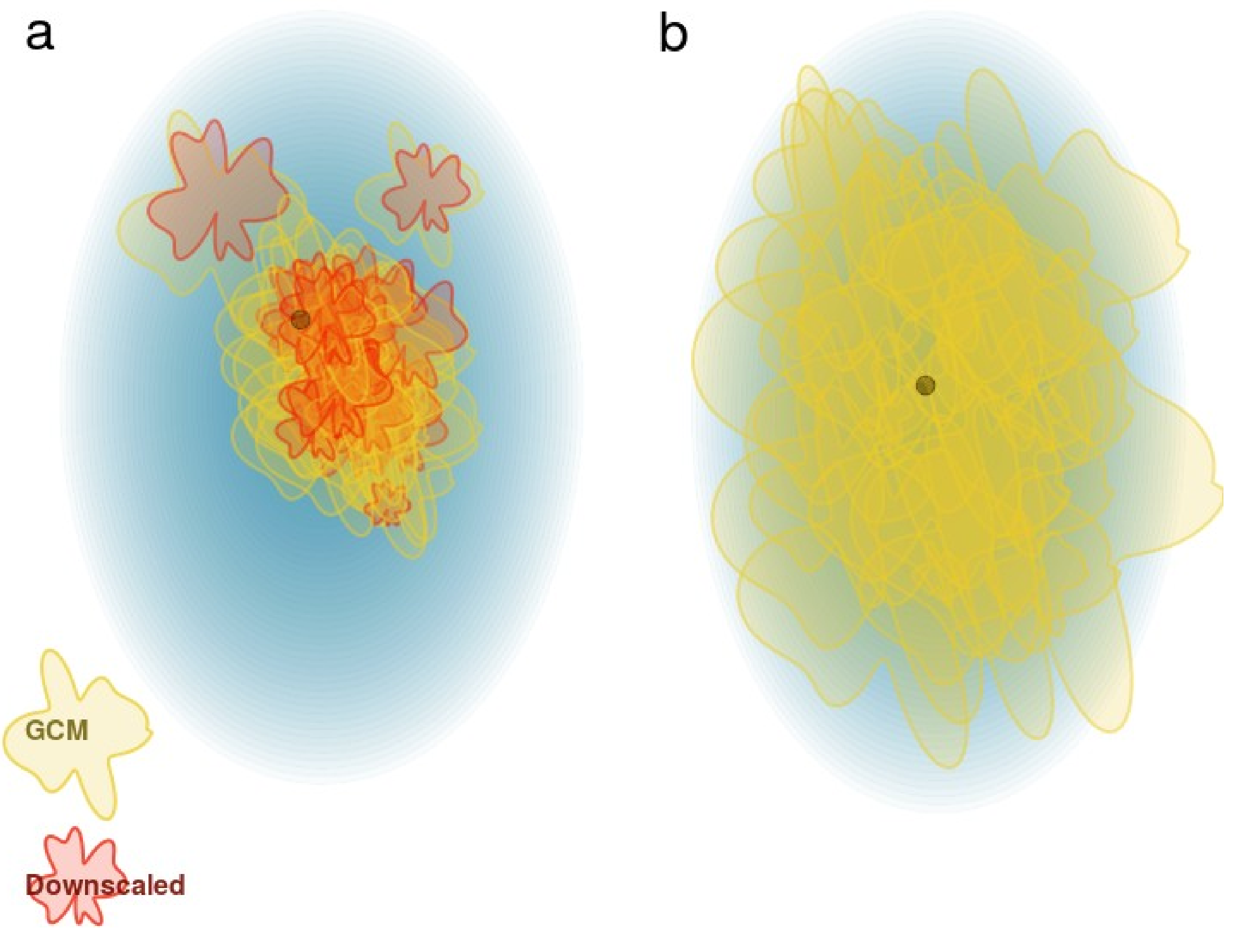
RCM have different energy and mass fluxes than the driving GCM.

ESD: PCA and EOF based methods can conserve inter-variable and spatial covariance.


Useful climate information can only be synthesised from large multi-model GCM ensembles. We need to move away from single-model results

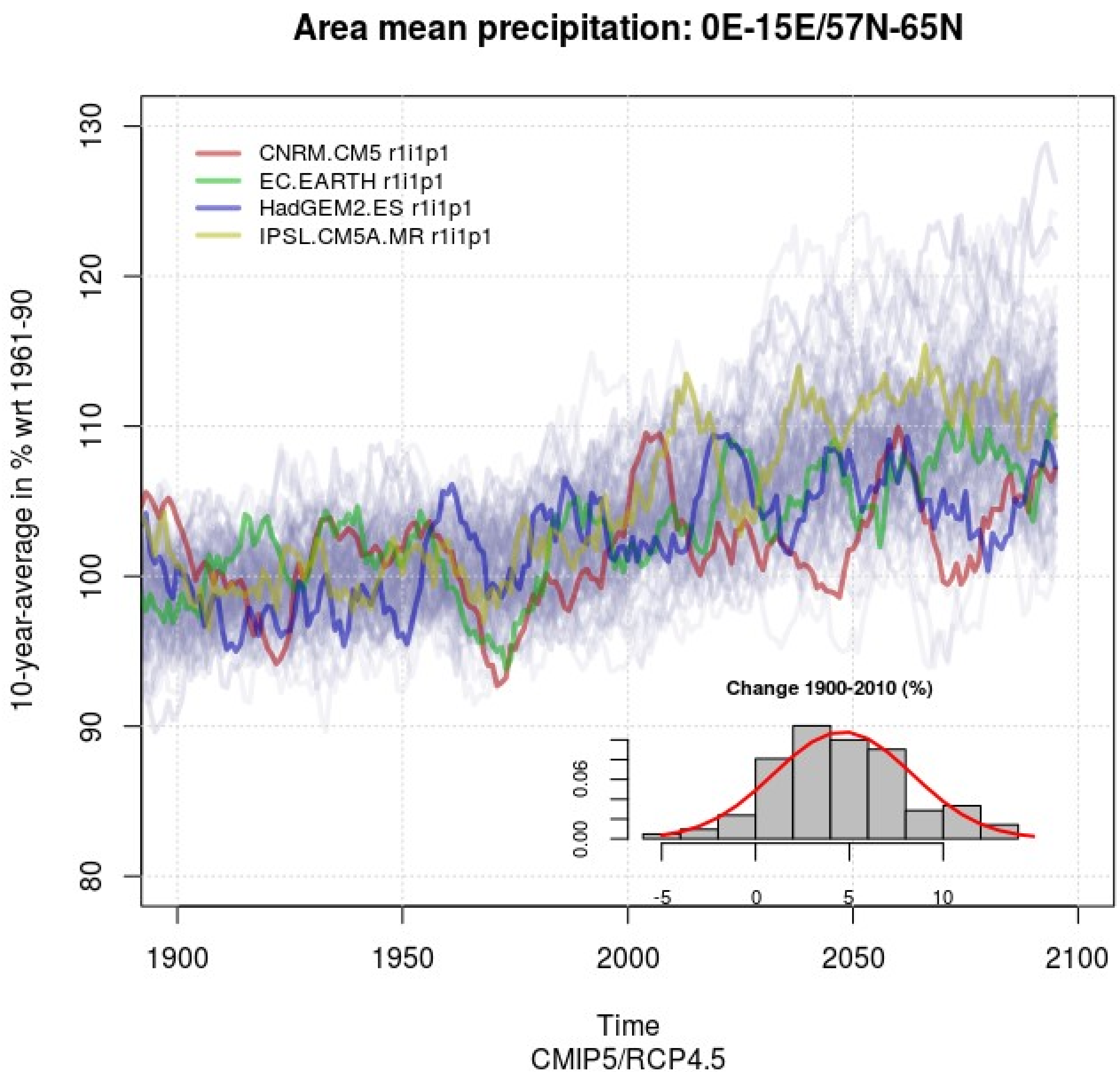
Multi-model ensembles

Problem: not a statistical sample



Non-deterministic natural variations

Ensembles!

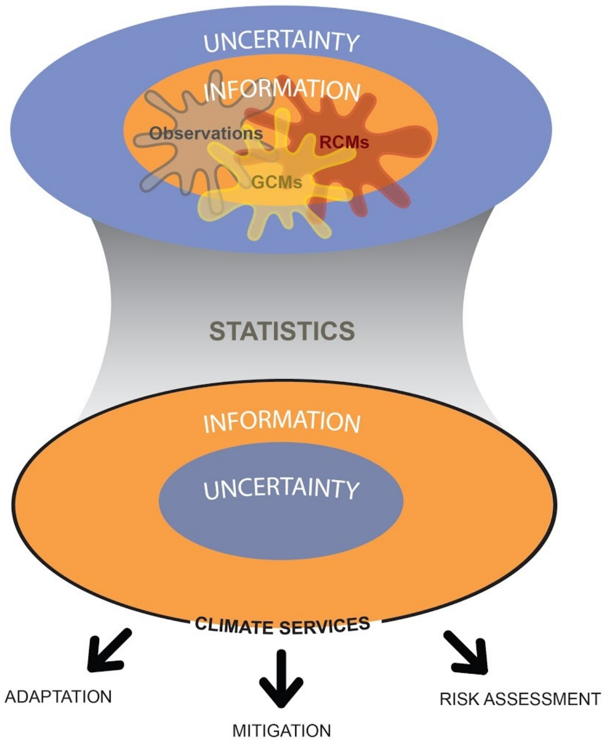


Distillation of robust information

Multiple independent sources of information.

ESD & Statistics apply constraints and makes use of redundancies.

The range of uncertainty is also useful information about sensitivities.



Examples of ESD in Norway

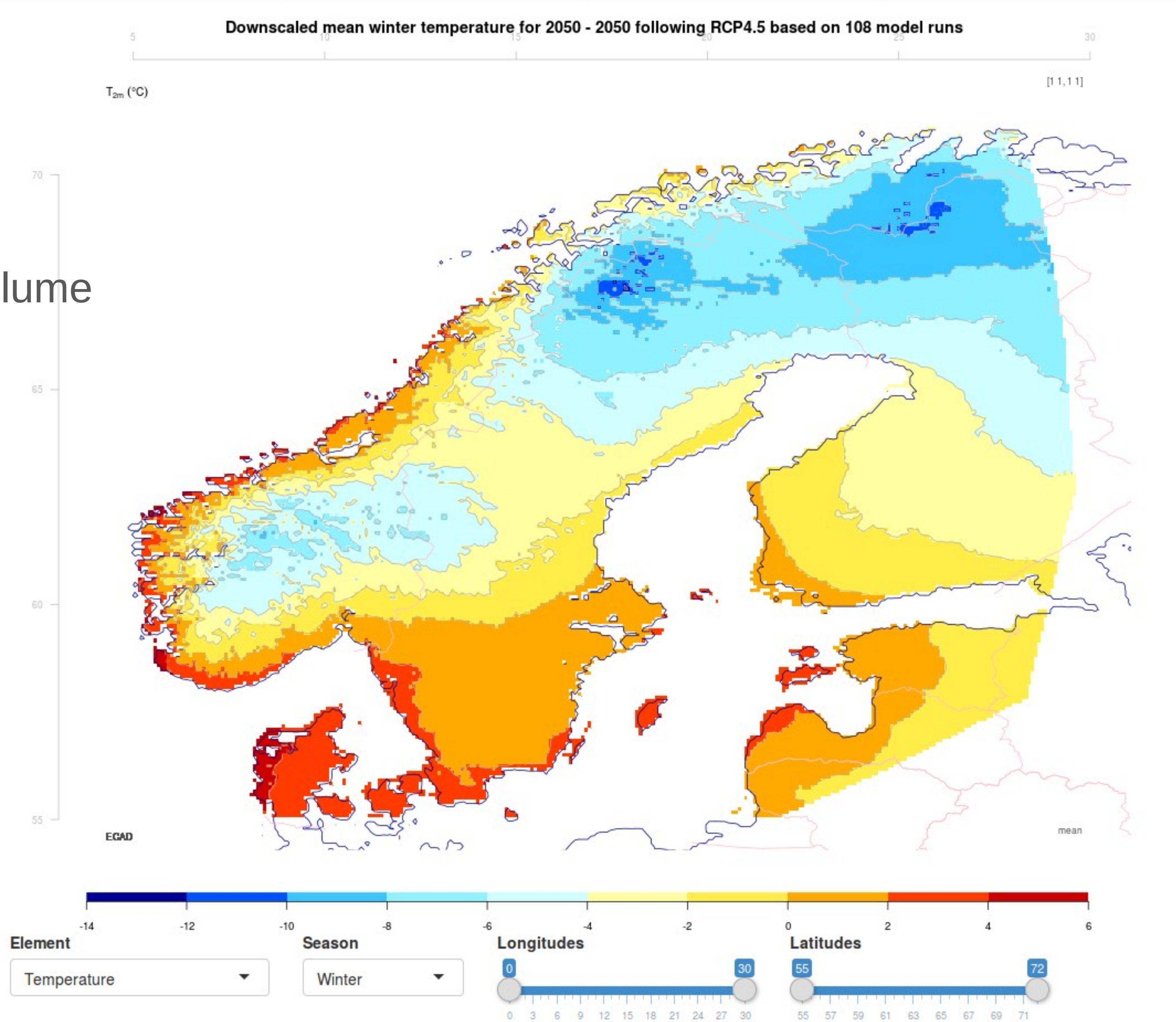
- ESD applied to CMIP5 multi-model ensembles
- Common EOFs (anomalies from reanalysis & GCM): hybrid MOS/PerfectProg.
- Predictand & predictor detrended for calibration, but trend is included in evaluation and projection
- PCA to represent predictand.
- Cross-validation
- Predictand is seasonally aggregated statistics/parameters for pdfs.
- Gridding of downscaled statistics.
- Based on the esd-package:
    - github.com/metno/esd

Observations + model results

Gridded results

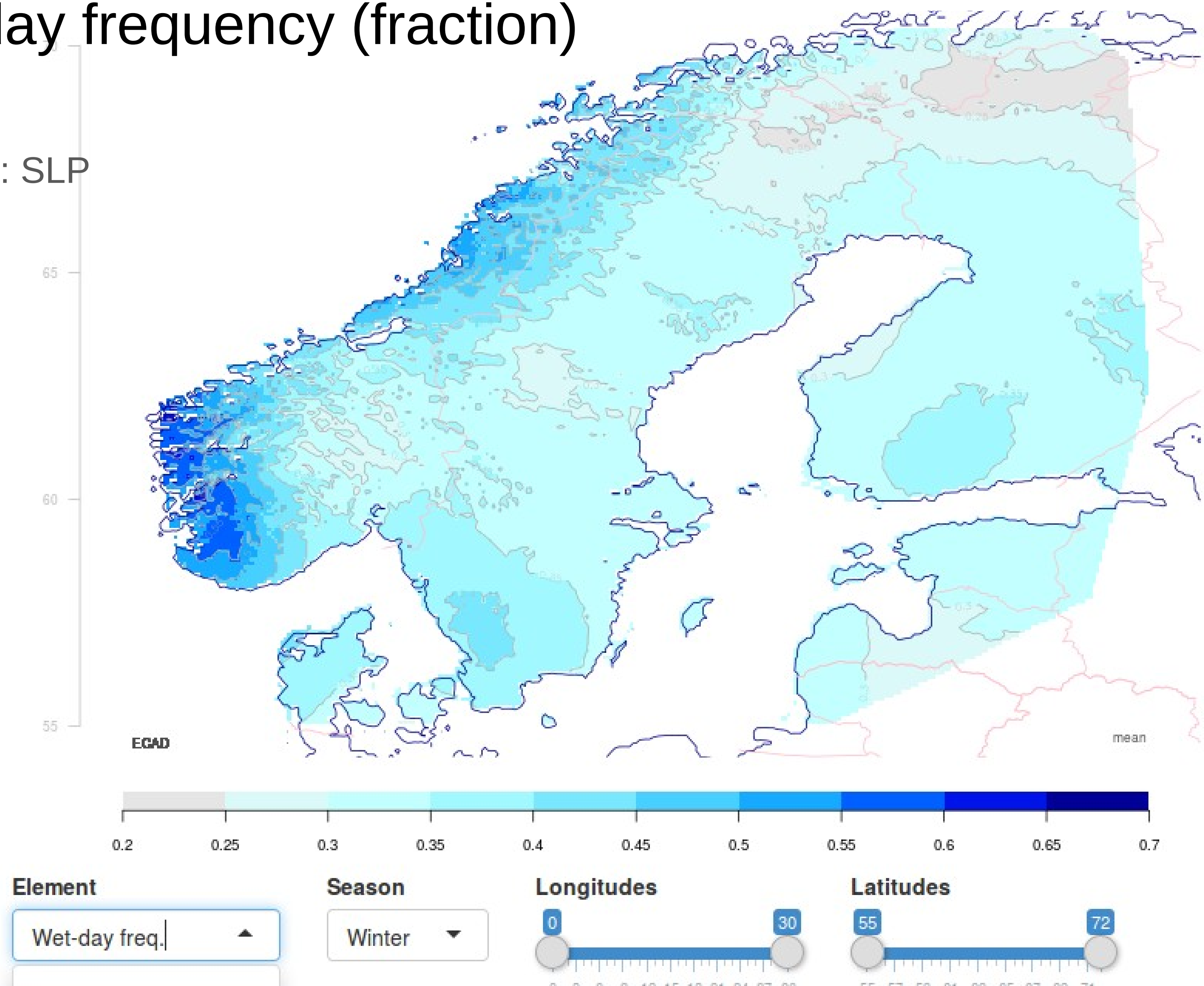
Complicated objects

Compression of data volume

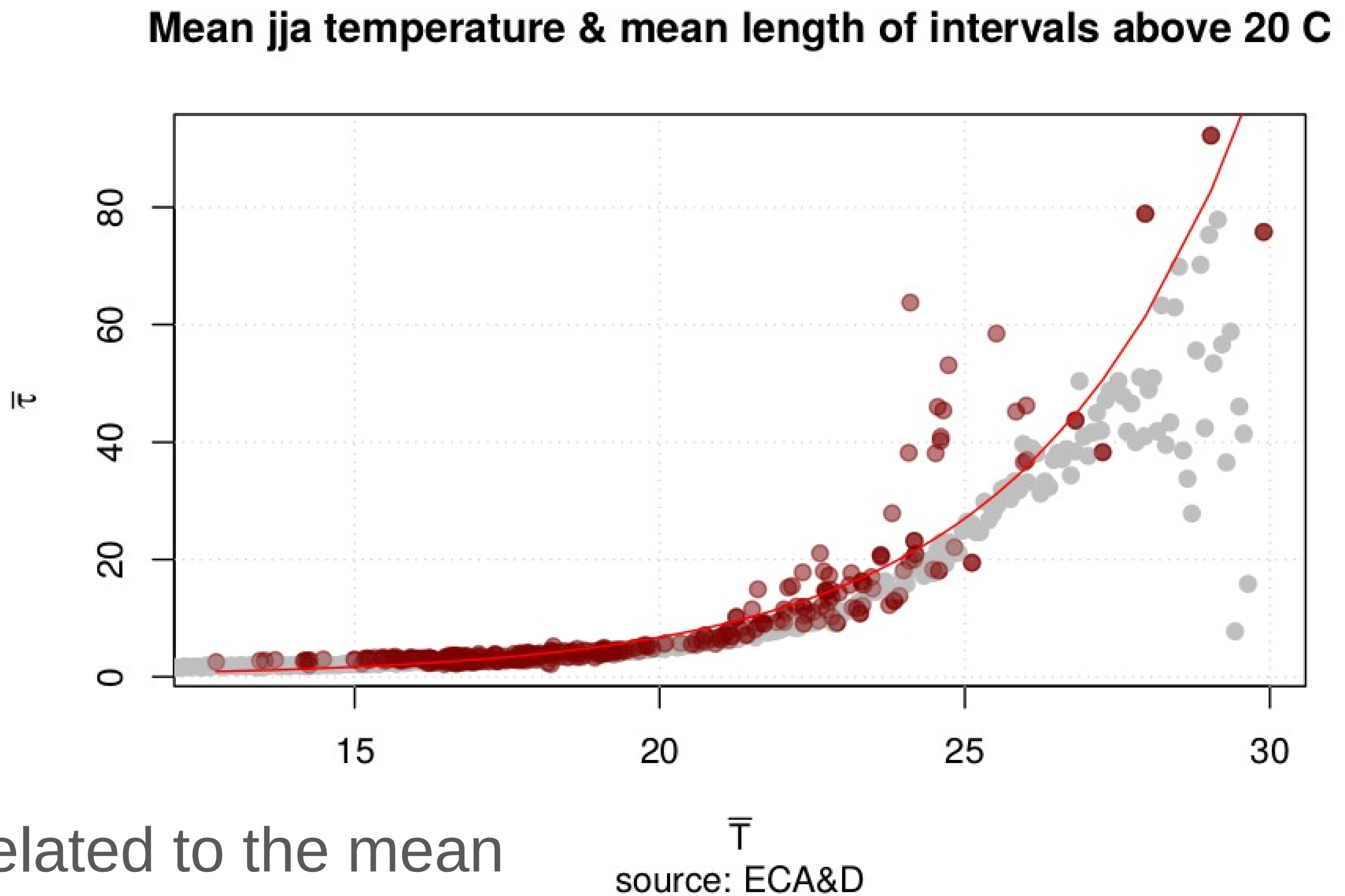


Wet-day frequency (fraction)

Predictor: SLP



Duration of heat waves



Related to the mean

Storm tracks

Storm climate is sensitive to large-scale environment