Norwegian Meteorological Institute

Empirical statistical downscaling and the esd-package

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16.09.2022

Presentation for Bangladesh Meteorological Institute

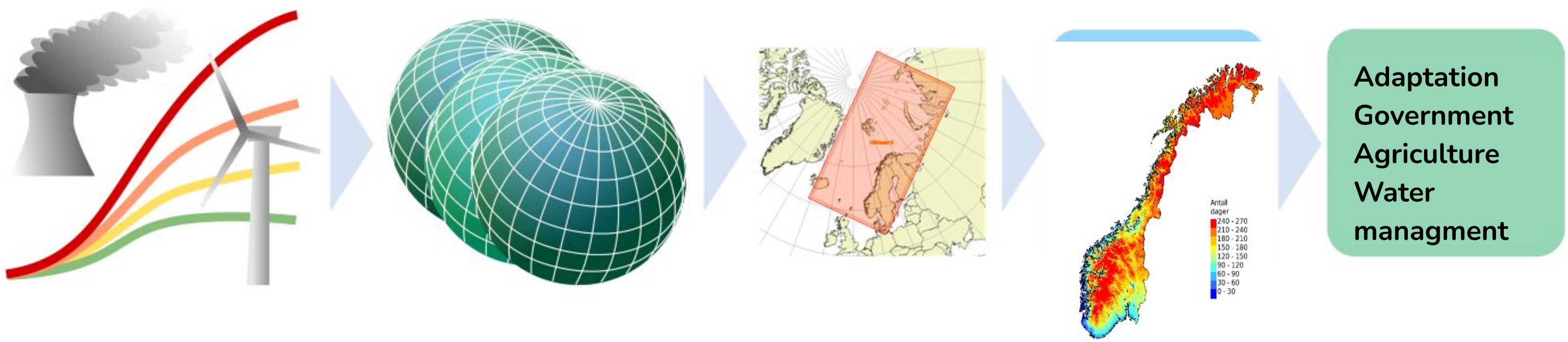
Why downscaling?

→ Global Climate Models (GCMs) simulate the climate of the past, present and future given different emission scenarios.

→ Due to coarse spatial resolution and parametrizations, GCMs typically represent large scale features of climate well, but not the local response.

→ The local climate response to the large scale climate can be estimated by
  - Dynamical downscaling - Regional Climate Models (RCMs)
  - Empirical-statistical downscaling (ESD)

Empirical statistical downscaling



1. Emission scenarios

2. Global climate models

3. Regional climate models

4. National projections

5. Users

Fig: Oskar Landgren, MET

Bias adjustment
Hydrological modeling

Empirical statistical downscaling (ESD)

- \+ Gives climate information for stations from GCM data
- \+ Fast and computationally cheap
- \+ Can be applied to large ensembles
- \- Depends on high quality data and realistic GCM simulations
- \- The predictor-predictand relationships can be non-stationary

Dynamical downscaling

- \+ Gives high resolution (10-50 km) climate information from GCM data
- \+ Resolves small scale atmospheric processes
- \+ Physically consistent response to external forcings
- \- Computationally expensive
- \- Rarely applied to large ensembles of climate scenarios
- \- Requires bias-adjustment

Empirical-statistical downscaling

➔ An empirical-statistical relationship is established between a

- the **predictor**, representing the large scale climate, based on reanalysis data and GCM data

  and

- the **predictand**, which represents the local climate response, based on local weather observations.

➔ The statistical model is applied to GCM data to estimate the local climate response to the large scale climate change.

Different types of ESD methods

- ➔ Transfer Functions: linear or nonlinear regression models
- ➔ Analogs and Weather Typing
- ➔ Weather Generators

The ESD method in the ‘esd’ package is based on transfer functions.

The ESD method in ‘esd’

1. Calculate seasonal statistics from station based observations, e.g. the average T_{max} in the monsoon season.

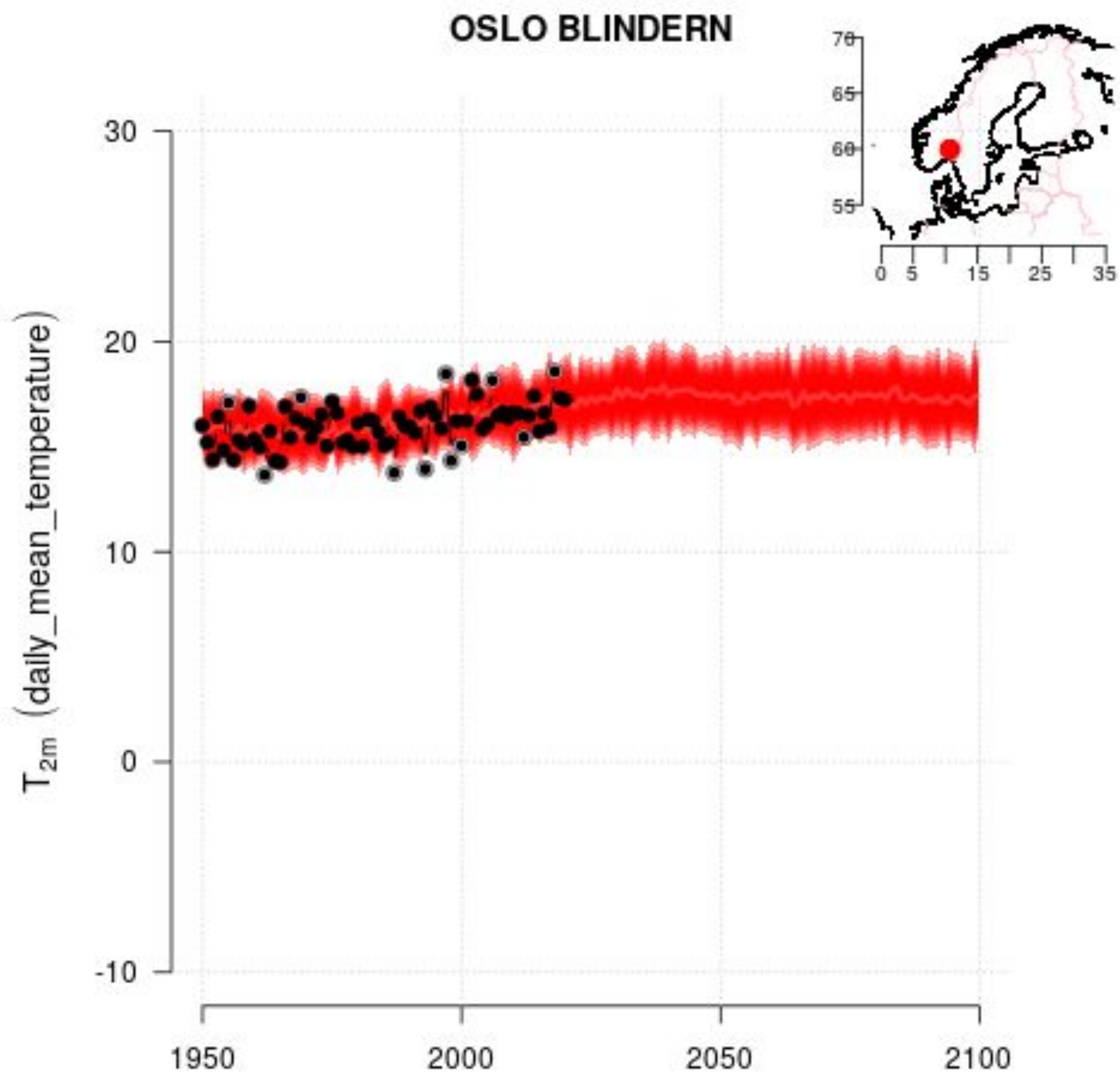
2. Principal Component Analysis (PCA) of the seasonal time series (1)

- reduces dimensionality while preserving variation
- reduces signal-to-noise ratio
- computationally efficient: downscale a few leading principal components rather than hundreds of stations

3. Common Empirical-Orthogonal Function (common EOF) analysis of reanalysis and GCM data

- Find common spatio-temporal patterns in reanalysis and GCM output

4. Fit statistical models between the predictand (2) and predictor (3) by linear regression



Mean temperature in summer (June - August), Oslo, Norway.

Predictor:
mean air temperature from ERA5 & CMIP6, scenario SSP119 (all available models)

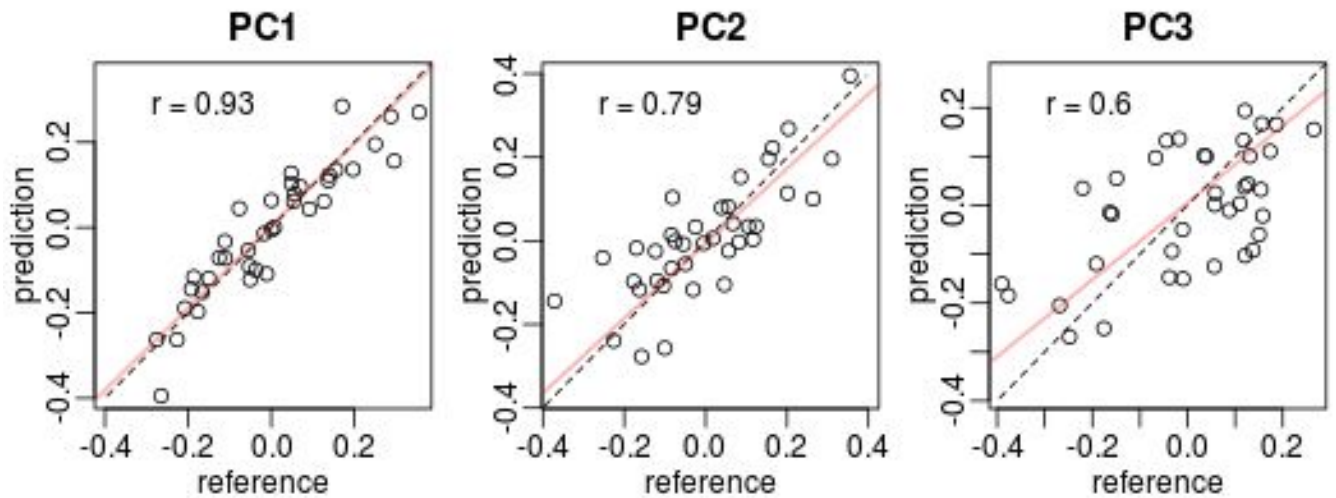
Black: observations
Red: downscaled GCM ensemble

Choice of predictand and predictor

- ➔ You should pick a predictor that
  - has a strong connection to the predictand
  - represents the climate change signal
  - is realistically represented by the reanalysis and GCM
- ➔ Long time series are required to tune the statistical model
- ➔ The ESD can only be as good as the data that goes into it (obs and GCM)
- ➔ Predictand and predictor domains can influence the results

Validation

➔ Cross-validation for independent comparison.



Cross-validation of the leading principal components of cyclone density for the North Atlantic using Sea Level Pressure (ERA5) as predictor.

Validation

- ➔ Cross-validation for independent comparison.

- ➔ GCMs do not predict the weather, they simulate the climate!

  Don't compare GCM data to observations for specific dates or times.

- ➔ ESD is great for downscaling large ensembles of GCMs. Why downscale many? To capture the internal variability of the climate system and the uncertainty of the climate models.

Installing esd

You can install esd in R using the package devtools:

```
library(devtools)
install_github('metno/esd')
```

See https://github.com/metno/esd for further instructions.

Example of esd usage with GHCND & ERA5 data

Load the esd package and use ‘retrieve’ to read data from a netCDF file containing local precipitation data.

```
# Load the esd package
library(esd)

## Read the predictand
pr <- retrieve('~/Downloads/GHCND.Africa.precip.nc')
## We want to use the annual rainfall totals
pr.ann <- annual(pr,FUN='sum')

## Check the data
map(pr.ann, FUN='mean', cex=2.5, new=FALSE)
```

Local data and ERA5 reanalysis

Use ‘retrieve’ to read ERA5 reanalysis data.

```
# Retrieve ERA5 data
pr.era5 <- retrieve('~/Downloads/era5_tp_sample.nc')

## We want to use the annual rainfall totals
pr.era5.ann <- annual(pr.era5,FUN='sum')

## Check the data
map(pr.era5.ann, FUN='mean', cex=2.5, new=FALSE)
```

Empirical Orthogonal Function (EOF) analysis

Use the function ‘EOF’ to decompose the reanalysis data into a set of spatial patterns with corresponding eigenvalues and time series.

```
# Apply EOF analysis to the ERA5 precipitation data
eof.era5 <- EOF(pr.era5.ann)

## Check the first three EOF patterns
plot(eof.era5, ip=1) ## First pattern
plot(eof.era5, ip=2) ## Second pattern
plot(eof.era5, ip=3) ## Third pattern
```

Empirical-statistical downscaling

Use the function ‘DS’ to downscale precipitation observations from one stations.

```
## Predictand
pr1 <- as.annual(subset(pr, is=1))

## Predictor
eof.era5 <- EOF(as.annual(pr.era5))

## Perform empirical-statistical downscaling
ds1 <- DS(pr1, eof.era5)

## Visualize the results
plot(ds1)
```

Empirical-statistical downscaling

Use the function ‘DS’ to downscale PCA.

```
## Predictand
pr1 <- as.annual(subset(pr, is=1))
pr1.pca <- PCA(pr1)

## Predictor
eof.era5 <- EOF(as.annual(pr.era5))

## Perform empirical-statistical downscaling
ds1 <- DS(pr1, eof.era5)

## Visualize the results
plot(ds1, ip=1) # ip=1: first PC pattern, ip=2: second pattern…
```

Empirical-statistical downscaling

Use the function ‘crossval’ to show the cross validation

```
crossval(ds1, ip=1) ## validation of first PC pattern
crossval(ds1, ip=2) ## validation of second PC pattern
crossval(ds1, ip=3) ## validation of third PC pattern
```

Empirical-statistical downscaling

Ensemble downscaling: combine reanalysis and GCM data with ‘combine’

```
X <- combine(predictor.reanalysis, predictor.gcm)
ceof <- EOF(X)
ds.ceof <- DS(predictand, ceof)

## Common EOF analysis is done automatically for
## multiple GCM files in the function DSensemble
```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