Downscaling tools for adapting climate predictions to the user's needs


Maialen Iturbide
miturbide@ifca.unican.es
Santander Meteorology Group

http://www.meteo.unican.es/udg-wiki
1. The ECOMS User Data Gateway (UDG)
   - Harmonized access to virtual datasets
   - Transparent access using R: examples (loadR.ECOMS)

2. R package downscaleR for downscaling
   - Worked bias correction example
   - Worked downscaling example

3. Integration with other R tools
   - Verification (easyVerification)
   - Forecast skill visualization (visualizeR)

4. Key links

http://www.meteo.unican.es

Contents

2012-2016
An R-based integrated framework for (remotely) accessing and processing climate data

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1) Authentication
2) R-based data access.

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1) **Authentication**
2) **R-based data access**

Public and restricted data via virtual catalogs, allowing harmonization (a single vocabulary) and data collocation.

Existing visualization, validation and downscaling packages are transparently linked to UDG using common data structures.
ECOMS-UDG provides harmonized access to daily data.

- **observations** (WFDEI),
- **reanalysis** (NCEP-R1, ERA-Interim)
- **seasonal forecasting**, including hindcasts from state-of-the-art models: ECMWF-System4, NCEP-CFSv2, UKMO-Glosea5.

**User-tailored** design (SPECS and EUPORIAS) including the variables typically needed for impact studies, mostly at surface level: **precip**, **temp**, **wind speed**, **humidity**, **radiations**, **SLP**, but also **upper-air** information at 1000, 850, 700, 500, 300, 200 mb (for statistical downscaling).
**ECOMS-UDG** provides **harmonized** access to locally stored daily data.

https://meteo.unican.es/trac/wiki/udg/ecoms/dataserver/catalog

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The ECOMS UDG collects and provides information (mainly at 6-hourly and/or daily resolution) for a reduced number of variables from a number of datasets (seasonal hindcasts, reanalysis and observations) obtained from different data providers. The following list of variables has been identified according to the user's needs, receiving feedback from EUPORIAS WP22 (climate information indices, CliS), WP23 (impact models), WP21 (calibration and downscaling) and SPECs WP61 (pilot applications) and WP52 (calibration and downscaling). See the section on the assessment of user's needs for more details.

Note that the R names below correspond to the vocabulary names used in the R data access package for homogenization purposes. Note that, data homogenization and aggregation (i.e. daily means from 6h data) is only provided through the R data access package.

In order to specify the particular **temporal frequency/aggregation** available for the variables in the different datasets, the following codes are used in the table below: 6h (6-hourly instantaneous data). 12h (12-hourly instantaneous data). 24h (24-hourly instantaneous data). DM (daily mean value). DX (daily maximum value). DN (daily minimum value). DA (daily accumulated data). DAR (accumulated since the initialization time – runtime) NOTE: The R package performs deaccumulation on a daily basis to match the standard definition. (**static field**)

In the table below, boldface codes (e.g. 6h) indicate variables already available through the ECOMS UDG. Italic are used for work in progress (variables to be included in the next update). e indicates that a variable exists in the original dataset but it is not planned to be included yet in ECOMS-UDG; **blanks** indicate that the variables do not exist in the original dataset. Codes ended by (*) indicate variables which do NOT exist in the dataset, but are derived/approximated from other available ones through the R data access package. For more details on the particular approximations used see the conversion formulae. Variables ended by (θ) indicate daily aggregated values obtained from the corresponding original 3-hourly data.

<table>
<thead>
<tr>
<th>R name</th>
<th>Variable description</th>
<th>Observations:</th>
<th>Reanalysis:</th>
<th>Seasonal forecasting models:</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>WFDEI</td>
<td>NCEP reanalysis</td>
<td>ERA interim</td>
</tr>
<tr>
<td>tas</td>
<td>Near-Surface air temperature</td>
<td>DM</td>
<td>6h</td>
<td>DM</td>
</tr>
<tr>
<td>tasmax</td>
<td>Daily Maximum Near-Surface Air Temperature</td>
<td>DX(a)</td>
<td>6h</td>
<td>DX</td>
</tr>
<tr>
<td>tasmin</td>
<td>Daily Minimum Near-Surface Air Temperature</td>
<td>DN(a)</td>
<td>6h</td>
<td>DN</td>
</tr>
<tr>
<td>tp</td>
<td>Total precipitation amount</td>
<td>DA</td>
<td>6hA</td>
<td>DA</td>
</tr>
<tr>
<td>psli</td>
<td>Sea Level Pressure</td>
<td>DM</td>
<td>e</td>
<td>6h(*)</td>
</tr>
<tr>
<td>ps</td>
<td>Surface air pressure</td>
<td>e</td>
<td>e</td>
<td>6h(*)</td>
</tr>
<tr>
<td>wss</td>
<td>Wind speed (at 10m)</td>
<td>e</td>
<td>e</td>
<td>6h(*)</td>
</tr>
<tr>
<td>tdp</td>
<td>2m Dewpoint Temperature</td>
<td>e</td>
<td>e</td>
<td>6h(*)</td>
</tr>
<tr>
<td>huss</td>
<td>Surface (2m) specific humidity</td>
<td>DM</td>
<td>e</td>
<td>6h(*)</td>
</tr>
</tbody>
</table>
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2012-2016
loadeR

This allows creating a one-stop entry point for datasets, aggregating multiple files from the same (or different) resources.

Further details and worked examples:
→ https://github.com/SantanderMetGroup/loadeR/wiki

LoadeR.ECOMS

Is the an extended version of loadeR to access data from the ECOMS-UDG.

Further details and worked examples:
→ https://meteo.unican.es/trac/wiki/udg/ecoms/RPackage
library(loadeR.ECOMS)
loginUDG(username = 'jDoe', password = '******')
wfdei <- loadECOMS(dataset = "WFDEI",
                    var = "tp",
                    lonLim = c(-60, -30),
                    latLim = c(-20, 10),
                    season = 7:9,
                    years = 1995:2009)

Define verification times
Season: JAS
Period: 1995-2009

Any other OpeNDAP server can be accessed with the loadeR R package.
However, no harmonization will be available and a knowledge of the dataset (name of variables, etc.) will be required.
A multidisciplinary approach for weather & climate

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Seasonal Forecast (prediction)

<table>
<thead>
<tr>
<th>MAM</th>
<th>JJA</th>
<th>SON</th>
<th>MAM</th>
<th>JJA</th>
<th>SON</th>
</tr>
</thead>
<tbody>
<tr>
<td>2000</td>
<td></td>
<td></td>
<td>2001</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

cfs <- loadECOMS(dataset = 'CFSv2_seasonal',
var = 'tp',
lonLim = c(-20, 10),
latLim = c(2, 35),
members = 1:4,
leadMonth = 1,
season = 7:9,
years = 1995:2009)

Define runtime
May
Initializations

Define members
First 4

Define verification times
Season: JAS
Period: 1995-2009

Target → season

Initialization times (“runtimes”)
Verification times (“forecast times”)
The ECOMS-UDG wiki:
https://meteo.unican.es/trac/wiki/udg/ecoms/dataserver

- User registration
- Available datasets and variables
- Exploration via Web
- APIs for Data Access

The loadeR.ECOMS wiki:
https://meteo.unican.es/trac/wiki/udg/ecoms/RPackage

- Installation and Versions
- Authentication
- Data Homogeneization
- Examples
Data loading...

```r
library(loadeR.ECOMS)
loginUDG("username", "password")

# OBSERVATIONS
wfdei <- loadECOMS(dataset = "WFDEI",
  var = "tp",
  lonLim = c(-18, -9),
  latLim = c(9, 16),
  season = 7:9,
  time = "DD",
  aggr.d = "sum",
  Years = 1995:2009)

# SEASONAL FORECAST
cfs <- loadECOMS(dataset = "CFSv2_seasonal",
  var = "tp",
  lonLim = c(-18, -9),
  latLim = c(9, 16),
  Season = 7:9
  time = "DD",
  aggr.d = "sum",
  years = 1995:2009,
  leadMonth = 1,
  members = 1:5)

library(downscaleR)
quickDiagnostics(wfdei, cfs, members = 1, location = c(-15, 11))
```
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• **transformeR** extends the **loadeR** and **loadeR.ECOMS** capabilities for **data manipulation**
  - Regridding/interpolation, subsetting and aggregation
  - PCA/EOF analysis
→ https://github.com/SantanderMetGroup/transformeR

• **downscaleR** has been designed to work with daily data (seasonal predictions, multidecadal projections).
  - **Bias correction/adjustment** (including cross-validation): (Local) Scaling, qq-mapping (various forms), parametric.
  - **Perfect-prog downscaling** (including cross-validation): Analogs, regression (linear and generalized linear)
→ https://github.com/SantanderMetGroup/downscaleR
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Downscaling

Bias Correction (BC) vs Perfect Prognosis (PP)

The PP method can improve the skill of the forecast target variable (daily rainfall)

<table>
<thead>
<tr>
<th>Reanalysis</th>
<th>X</th>
</tr>
</thead>
<tbody>
<tr>
<td>Seasonal predictions</td>
<td>X</td>
</tr>
<tr>
<td>Observations (local)</td>
<td>X</td>
</tr>
</tbody>
</table>

rainfall | large-scale

http://www.meteo.unican.es
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2012-2016
**Bias Correction...**

?biasCorrection

```r
# method local scaling
cal <- biasCorrection(y = wfdei,
                   x = cfs,
                   newdata = cfs,
                   precipitation = TRUE,
                   method = "scaling",
                   scaling.type = "multiplicative")
quickDiagnostics(wfdei, cfs, cal, members = 1, location = c(-15, 11))
```
library(downscaleR)
?biasCorrection

#method local scaling
cal <- biasCorrection(y = wfdei,
                      x = cfs,
                      newdata = cfs,
                      precipitation = TRUE,
                      method = "scaling",
                      scaling.type = "multiplicative")
quickDiagnostics(wfdei, cfs, cal, members = 1, location = c(-15, 11))

#method eqm

cal <- biasCorrection(y = wfdei,
                      x = cfs,
                      newdata = cfs,
                      precipitation = TRUE,
                      method = "eqm",
                      n.quantiles = 100,
                      wet.threshold = 0,
                      extrapolation = "constant")

quickDiagnostics(wfdei, cfs, cal, members = 1, cal, location = c(-15, 11))
Bias Correction...

...#method eqm
cal <- biasCorrection(y = wfdei,
    x = cfs,
    newdata = cfs,
    precipitation = TRUE,
    method = "eqm",
    n.quantiles = 100,
    wet.threshold = 0,
    extrapolation = "constant")

quickDiagnostics(wfdei, cfs, members = 1, cal, location = c(-15, 11))

cfs2 <- interpGrid(cfs, getGrid(wfdei))
quickDiagnostics(wfdei, cfs2, members = 1, location = c(-15, 11), type = "interannual")
Bias Correction...

...#method eqm
cal <- biasCorrection(y = wfdei,
                      x = cfs,
                      newdata = cfs,
                      precipitation = TRUE,
                      method = "eqm",
                      n.quantiles = 100,
                      wet.threshold = 0,
                      extrapolation = "constant")

quickDiagnostics(wfdei, cfs, members = 1, cal, location = c(-15, 11))

cfs2 <- interpGrid(cfs, getGrid(wfdei))
quickDiagnostics(wfdei, cfs2, members = 1, location = c(-15, 11), type = "interannual")

quickDiagnostics(wfdei, cfs, cal, members = 1, location = c(-15, 11), type = "interannual")
Bias Correction...applying cross validation...

cfs1mem <- subsetGrid(cfs, members = 1)
cal1mem <- subsetGrid(cal, members = 1)

cal.cross <- biasCorrection(y = wfdei,  
    x = cfs1mem, 
    newdata = cfs1mem, 
    precipitation = TRUE, 
    method = "eqm", 
    wet.threshold = 0, 
    cross.val = "loocv")

quickDiagnostics(wfdei, cfs1mem, cal.cross, members = 15, location = c(-15, 11))
Bias Correction... applying a moving window...

```r
?biasCorrection
cal.win <- biasCorrection(y = wfdei,
  x = cfslmem,
  newdata = cfslmem,
  precipitation = TRUE,
  method = "eqm",
  wet.threshold = 0,
  window = c(30, 20))

quickDiagnostics(wfdei, cfslmem, cal.win, location = c(-15, 11))
```
Bias Correction...of a non-observed period...

```r
y <- subsetGrid(wfdei, years = 1995:2004)
x <- subsetGrid(cfs, years = 1995:2004)
newdata <- subsetGrid(cfs, years = 2005:2009)

cal2 <- biasCorrection(y = y, x = x, newdata = newdata,
                       precipitation = TRUE,
                       method = "eqm",
                       wet.threshold = 0.01)
quickDiagnostics(wfdei, cfs, cal2, members = 1, location = c(-15, 11))
```
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Downscaling of System4 MAM precipitation forecast over NE Brazil (January initialization, 15 members)

A relatively complex task usually involving many intermediate steps from data loading to analysis of the results...

... made EASY (10 commands)

... and fully REPRODUCIBLE
Data loading...

# target variable
predictand <- "tp"
wfdei.tp <- loadECOMS(dataset = "WFDEI", var = predictand,
lonLim = c(-60,-30), latLim = c(-20,10),
season = 3:5, years = 1981:2010)

predictor <- c("psl", "ta@850", "hus@850")
# Loading NCEP (Predictors)
NCEP.psl <- loadECOMS(dataset = "NCEP", var = predictor[1],
lonLim = c(-60,-30), latLim = c(-20,10),
season = 3:5, years = 1981:2010)
# Same for ta@850 and hus@850
# Loading System4 predictions (Predictors)
S4 <- loadECOMS(dataset = "System4_seasonal_15", predictor[1],
lonLim = c(-60,-30), latLim = c(-20,10),
season = 3:5, years = 1981:2010,
leadMonth = 2)
# Same for ta@850 and hus@850 (and also tp for a posterior verification).
... data preprocessing ....

```r
predictor <- c("psl", "ta@850", "hus@850")
# Loading NCEP (Predictors)
NCEP.psl <- loadECOMS(dataset = "NCEP", var = predictor[1],
                      lonLim = c(-60,-30), latLim = c(-20,10),
                      season = 3:5, years = 1981:2010)
# Same for ta@850 and hus850
# Loading System4 predictions (Predictand, precip)
S4.psl <- loadECOMS(dataset = "System4_seasonal_15", var = 'predictor[1]',
                     lonLim = c(-60,-30), latLim = c(-20,10),
                     season = 3:5, years = 1981:2010,
                     leadMonth = 2)
# Same for ta@850 and hus850 (and also tp for a posterior verification).
# Interpolating S4 to the NCEP grid, and rescaling
S4.psl <- interpGrid(S4.psl, new.coordinates = getGrid(NCEP.psl))
S4.ta <- interpGrid(S4.ta, new.coordinates = getGrid(NCEP.psl))
S4.hus <- interpGrid(S4.hus, new.coordinates = getGrid(NCEP.psl))

# Predictor datasets for reanalysis and forecast data
NCEP <- makeMultiGrid(NCEP.psl, NCEP.ta850, NCEP.hus850)
S4 <- makeMultiGrid(S4.psl, S4.ta850, S4.hus850)

# Computing EOFs and PCs for reanalysis
ncpe.eof <- computeEOF(NCEP, n.eofs = 15)
S4.sc <- rescaleMonthlyMeans(pred = NCEP, sim = S4)
```
... downscaling and cross-validation ...

...  

# Interpolating S4 to the NCEP grid, and rescaling  
S4.psl <- interpGrid(S4.psl, new.coordinates = getGrid(NCEP.psl))  
S4.ta <- interpGrid(S4.ta, new.coordinates = getGrid(NCEP.psl))  
S4.hus <- interpGrid(S4.hus, new.coordinates = getGrid(NCEP.psl))  

# Predictor datasets for reanalysis and forecast data  
NCEP <- makeMultiGrid(NCEP.psl, NCEP.ta850, NCEP.hus850)  
S4 <- makeMultiGrid(S4.psl, S4.ta850, S4.hus850)  

# Computing EOFs and PCs for reanalysis  
ncep.eof <- computeEOF(NCEP, n.eofs = 15)  
S4.sc <- rescaleMonthlyMeans(pred = NCEP, sim = S4)  

# Downscaling with Generalized Linear Models  
down <- downscale(obs = wfdei.tp, pred = ncep.eof,  
sim = S4.sc,  
method = "glm",  
n.pcs = 15,  
parallel = TRUE)
... and verification and visualization.

# Interpolating S4 to the NCEP grid, and rescaling
S4.psl <- interpGrid(S4.psl, new.coordinates = getGrid(NCEP.psl))
S4.ta <- interpGrid(S4.ta, new.coordinates = getGrid(NCEP.psl))
S4.hus <- interpGrid(S4.hus, new.coordinates = getGrid(NCEP.psl))

# Predictor datasets for reanalysis and forecast data
NCEP <- makeMultiGrid(NCEP.psl, NCEP.ta850, NCEP.hus850)
S4 <- makeMultiGrid(S4.psl, S4.ta850, S4.hus850)

# Computing EOFs and PCs for reanalysis
ncep.eof <- computeEOF(NCEP, n.eofs = 15)
S4.sc <- rescaleMonthlyMeans(pred = NCEP, sim = S4)

# Downscaling with Generalized Linear Models
down <- 
  downscale(obs = wfdei.tp, pred = ncep.eof, 
             sim = S4.sc, 
             method = "glm", 
             n.pcs = 15, 
             parallel = TRUE)

# Analysis of results
quickDiagnostics(wfdei.tp, S4.tp, down, 
                 type = "interannual")
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easyVerification package. Common validation scores for seasonal forecasting.

Available documentation with worked examples:
http://www.meteo.unican.es/work/downscaler/wiki/docs/ecoms_bias_correction.pdf

Verification of seasonal forecasts from the ECOMS User Data Gateway: a worked example
Joaquín Bedía¹ and Jonas Bhend²

¹Santander Met Group, University of Cantabria - CSIC (Spain)
²Federal Office of Meteorology and Climatology MeteoSwiss, Zurich, Switzerland

version 2 - ‘2015-05-18’
Annual aggregation of daily data ...

```r
mean_bc <- aggregateGrid(grid = cal,
                           aggr.y = list(FUN = "mean", na.rm = TRUE))
mean_obs <- aggregateGrid(grid = wfdei,
                           aggr.y = list(FUN = "mean", na.rm = TRUE))
```
... detrending ...

```r
mean_bc <- aggregateGrid(grid = cal,
                        aggr.y = list(FUN = "mean", na.rm = TRUE))
mean_obs <- aggregateGrid(grid = wfdei,
                          aggr.y = list(FUN = "mean", na.rm = TRUE))
pred <- detrendGrid(mean_bc)
obs  <- detrendGrid(mean_obs)
```
ROC Skill score with `easyVerification` ...

```r
mean_bc <- aggregateGrid(grid = cal,
                         aggr.y = list(FUN = "mean", na.rm = TRUE))
mean_obs <- aggregateGrid(grid = wfdei,
                         aggr.y = list(FUN = "mean", na.rm = TRUE))
pred <- detrendGrid(mean_bc)
obs <- detrendGrid(mean_obs)
rocss <- easyVerification::veriApply("EnsRocss",
                         fcst = pred[["Data"]],
                         obs = obs[["Data"]],
                         prob = 2/3, ensdim = 1, tdim = 2)
```
... return to the **loadeR** – **downscaleR** grid format

```r
mean_bc <- aggregateGrid(grid = cal,
                         aggr.y = list(FUN = "mean", na.rm = TRUE))
mean_obs <- aggregateGrid(grid = wfdei,
                          aggr.y = list(FUN = "mean", na.rm = TRUE))
pred <- detrendGrid(mean_bc)
obs <- detrendGrid(mean_obs)
rocss <- easyVerification::veriApply("EnsRocss",
                                    fcst = pred[["Data"]],
                                    obs = obs[["Data"]],
                                    prob = 2/3, ensdim = 1, tdim = 2)
upper.tercile <- easyVeri2grid(easyVeri.mat = rocss$cat2,
                               obs.grid = obs)
```
... and plot the resulting ROCSS map

```r
detrendGrid(unique(prd))
deathGrid(unique(obl))
rocss <- easyVerification::veriApply("EnsRocss",
fcst = pred[["Data"]],
obs = obs[["Data"]],
prob = 2/3, ensdim = 1, tdim = 2)
upper.tercile <- easyVeri2grid(easyVeri.mat = rocss$cat2,
obs.grid = obs)
plotClimatology(upper.tercile,
scales = list(draw = TRUE),
backdrop.theme = "countries"
main = "ROCSS")
```

![ROCSS map](image-url)
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visualizeR package. Special verification plots for forecast skill visualization.

Documentation and worked examples in the wiki:
https://github.com/SantanderMetGroup/visualizeR/wiki
Spatial subset of a region of interest...

pred.sub <- subsetGrid(grid = cal,
                        latLim = c(9.5, 10.2),
                        lonLim = c(-11.5, -10))

obs.sub <- subsetGrid(grid = wfdei,
                       latLim = c(9.5, 10.2),
                       lonLim = c(-11.5, -10))
Tercile Validation Plot

pred.sub <- subsetGrid(grid = pred,
    latLim = c(40,42.5), lonLim = c(24,26.5))
obs.sub <- subsetGrid(grid = obs,
    latLim = c(40,42.5), lonLim = c(24,26.5))
tercileValidation(pred = pred.sub, obs = obs.sub, color.pal = "ypb")

total precipitation amount, jul to sep

Implementation of tercile validation as presented by:
Reliability Plots with reliability categories

Cfs2 ← interpGrid(cfs, new.coordinates = getGrid(wfdei))
reliabilityCategories(obs = cfs2, pred = wfdei, nbins = 3, nboot = 10)

Implementation of reliability as presented by:
Conclusions

- All datasets and variables required by ECOMS users centralized in a single **OpenNDAP Server** (The ECOMS-UDG) with two extra layers for
  - 1) authentication and
  - 2) harmonization

- A suite of **R packages** fully integrated allow performing many different tasks, such as:
  - User friendly access to the ECOMS-UDG
  - Data transformation
  - Downscaling and bias correction
  - Verification
  - Data visualization
  - Specific CII calculation
  - ....

**OPEN-SOURCE BENEFITS**
* Reproducibility
* Customizability
* Flexibility
* Interoperability
* Auditability
...
1. The ECOMS User Data Gateway (UDG)
   – Harmonized access to virtual datasets
   – Transparent access using R: examples

1. `downscaleR`: R extension for downscaling
   – Worked downscaling example
   – Worked bias correction example

2. Integration with other R tools
   – Verification (easyVerification)
   – Forecast skill visualization (visualizer)

3. Key links
UDG wiki with instructions for registration
→ https://meteo.unican.es/trac/wiki/udg/registration

The ECOMS-UDG wiki
→ http://www.meteo.unican.es/udg-wiki/ecoms

Link to R packages (repositories and wiki-s):
→ https://github.com/SantanderMetGroup/