Full code for Example 1 of the paper 'climate4R: An Ecosystem of R packages for Climate Data Access, Post-processing and Bias Correction'

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Contents

1 Introduction

Packages in `climate4R`:

```
library(devtools)
install_github(c("SantanderMetGroup/loadeR",
                 "SantanderMetGroup/loadeR.java",
                 "SantanderMetGroup/transformeR",
                 "SantanderMetGroup/visualizeR",
                 "SantanderMetGroup/downscaleR",
                 "SantanderMetGroup/climate4R.climdex")
```

```
library(loadeR)
library(transformeR)
library(visualizeR)
library(downscaleR)
library(climate4R.climdex)
```

2 Example 1: Climate Indices from CORDEX Projections

2.1 Loading, collocating and harmonizing data

Define the study area.

```
lon <- c(-10, 20)
lat <- c(35, 46)
```

2.1.1 Cliamte data loading from OpenDap server: E-OBS observational data

Overview of the dataset with function `dataInventory`:

```
eobs<-"http://opendap.knmi.nl/knmi/thredds/dodsC/e-obs_0.25regular/tx_0.25deg_reg_v16.0.nc"
di <- dataInventory(eobs)
```

Loading with `loadGridData`:

```
SU <- loadGridData(eobs, var = "tx",
                   season = 1:12,
                   years = 1971:2000,
                   lonLim = lon,
                   latLim = lat,
                   aggr.m = "sum",
                   condition = "GT",
                   threshold = 25)
```

2.1.1.1 Using a dictionary

Standard variable naming:

```
## dictionary: standard names
C4R.vocabulary()
```

```
##    identifier                          standard_name           units
## 1        hurs               2-meter relative humidity               %
## 2     hursmax       maximum 2-meter relative humidity               %
## 3     hursmin       minimum 2-meter relative humidity               %
## 4         hus                         specific humidity         kg.kg-1
## 5        huss               2-meter specific humidity         kg.kg-1
## 6     hussmax       maximum 2-meter specific humidity         kg.kg-1
## 7     hussmin       minimum 2-meter specific humidity         kg.kg-1
## 8          lm                          land binary mask               1
## 9        orog                          surface altitude               m
## 10         ps           air pressure at surface level              Pa
## 11        psl               air pressure at sea level              Pa
## 12       rlds  surface downwelling longwave radiation           W.m-2
## 13       rlut              toa outgoing longwave flux           W.m-2
## 14       rsds surface downwelling shortwave radiation           W.m-2
## 15      sftlf                       land area fraction               1
## 16         ta                          air temperature degrees Celsius
## 17        tas                 2-meter air temperature degrees Celsius
## 18     tasmax             maximum 2-m air temperature degrees Celsius
## 19     tasmin             minimum 2-m air temperature degrees Celsius
## 20       tdps            2-meter dewpoint temperature degrees Celsius
## 21         pr              total precipitation amount              mm
## 22        prr                   total rainfall amount              mm
## 23       prsn                   total snowfall amount              mm
## 24         ua                            eastward wind           m.s-1
## 25        uas              eastward near-surface wind           m.s-1
## 26         va                           northward wind           m.s-1
## 27        vas             northward near-surface wind           m.s-1
## 28        wss                 near-surface wind speed           m.s-1
## 29     wssmax         maximum near-surface wind speed           m.s-1
## 30        wsg                       wind speed of gust           m.s-1
```

```
## 31     wsgmax              maximum wind speed of gust           m.s-1
## 32          z                             geopotential         m2.s-2
## 33         zg                    geopotential height              m
## 34         zs                   surface geopotential         m2.s-2
## 35        zsg             surface geopotential height              m
```

Create dic file (dictionary explained in the `loadeR` wiki: https://github.com/SantanderMetGroup/loadeR/wiki/Harmonization)

```
file.create("dicEOBS.dic")
writeLines(c("identifier,short_name,time_step,lower_time_bound,upper_time_bound,
             cell_method,offset,scale,deaccum,derived,interface",
             "tasmax,tx,24h,0,24,max,0,1,0,0,"), "dicEOBS.dic")
```

Repit loading operation but using the created dictionaty file:

```
SU <- loadGridData(eobs,
                           var = "tasmax",
                           season = 1:12,
                           lonLim = lon,
                           latLim = lat,
                           years = 1971:2000,
                           aggr.m = "sum",
                           threshold = 25,
                           condition = "GT",
                           dictionary = "dicEOBS.dic")
```

2.1.1.2 Annual aggregation using `transformeR`

```
SU.annual <- aggregateGrid(SU, aggr.y = list(FUN = "sum"))
```

2.1.1.3 visualization using `visualizeR`

First we create color palettes

```
library(RColorBrewer)
colstx <- rev(brewer.pal(n = 9, "Spectral"))
colsindex <- rev(brewer.pal(n = 9, "RdYlBu"))
colsdelta <- brewer.pal(n = 9, "Reds")
colsbias <- brewer.pal(n = 9, "PiYG")
colssd <- brewer.pal(n = 9, "Blues")
```

```
spatialPlot(climatology(SU.annual), backdrop.theme = "countries",
            at = seq(0, 260, 10), col.regions = colorRampPalette(colsindex))
```

2.1.2 Cliamte data loading from local files: CORDEX climate change projections

```
#historical data
wdch <- "/myDirectoryOfHistoricalData/"
#climate change data
wdc <- "/myDirectoryOfClimateChangeData/"
list.files(wdc, recursive = T)
```

```
## character(0)
```

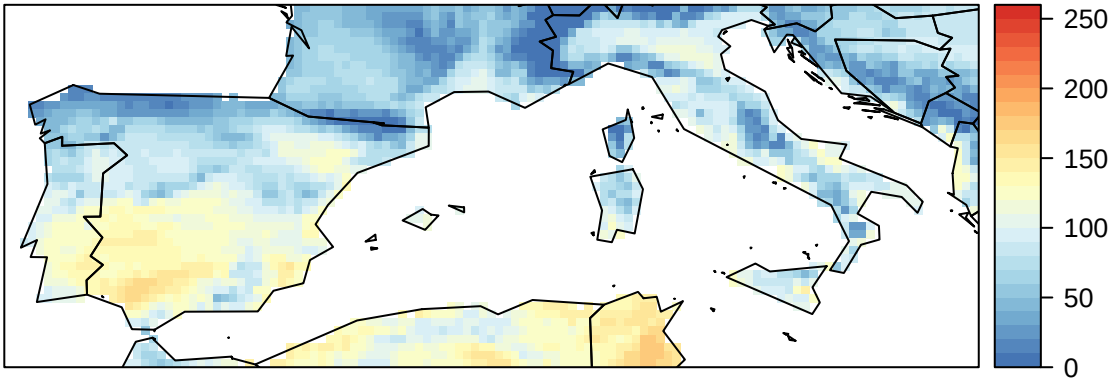

Figure 1: Southern Europe summer days for E-OBS and the historical period 1971-2000. Fig. 2a in the manuscript.

Create catalogs:

```
makeAggregatedDataset(source.dir = wdc, recursive = T, ncml.file = "CDX_rcp85.ncml")
makeAggregatedDataset(source.dir = wdch, recursive = T, ncml.file = "CDX_hist.ncml")
```

Check temperature units:

```
di <- dataInventory("CDX_hist.ncml")
str(di$tasmax)
```

```
## List of 4
##  $ Description: chr "Daily Maximum Near-Surface Air Temperature"
##  $ DataType   : chr "float"
##  $ Units      : chr "K"
##  $ Dimensions :List of 3
##   ..$ time:List of 4
##   .. ..$ Type      : chr "Time"
##   .. ..$ TimeStep  : chr "1.0 days"
##   .. ..$ Units     : chr "days since 1949-12-01 00:00:00"
##   .. ..$ Date_range: chr "1951-01-01T12:00:00Z - 2005-12-31T12:00:00Z"
##   ..$ lat :List of 3
##   .. ..$ Type  : chr "GeoY"
##   .. ..$ Units : chr "degrees"
##   .. ..$ Values: num [1:103] -23.2 -22.8 -22.3 -21.9 -21.4 ...
##   ..$ lon :List of 3
##   .. ..$ Type  : chr "GeoX"
##   .. ..$ Units : chr "degrees"
##   .. ..$ Values: num [1:106] -28.2 -27.8 -27.3 -26.9 -26.4 ...
```

We see that the variable name is standard but not the units. This can be also controlled by a dictionary:

```
file.create("dicCDX.dic")
writeLines(c("identifier,short_name,time_step,lower_time_bound,upper_time_bound,
             cell_method,offset,scale,deaccum,derived,interface",
             "tasmax,tasmax,24h,0,24,max,-273.15,1,0,0,"), "dicCDX.dic")
```

```
SUh <- loadGridData(dataset = "CDX_hist.ncml",
                    var = "tasmax",
                    season = 1:12,
                    lonLim = lon,
```

```
                    latLim = lat,
                    years = 1971:2000,
                    aggr.m = "sum",
                    threshold = 25,
                    condition = "GT",
                    dictionary = "dicCDX.dic")
```

Annual aggragation and visualization of cordex historical data:

```
SUh.annual <- aggregateGrid(SUh, aggr.y = list(FUN = "sum"))
```

```
spatialPlot(climatology(SUh.annual), at = seq(0, 260, 10),
            col.regions = colorRampPalette(colsindex))
```

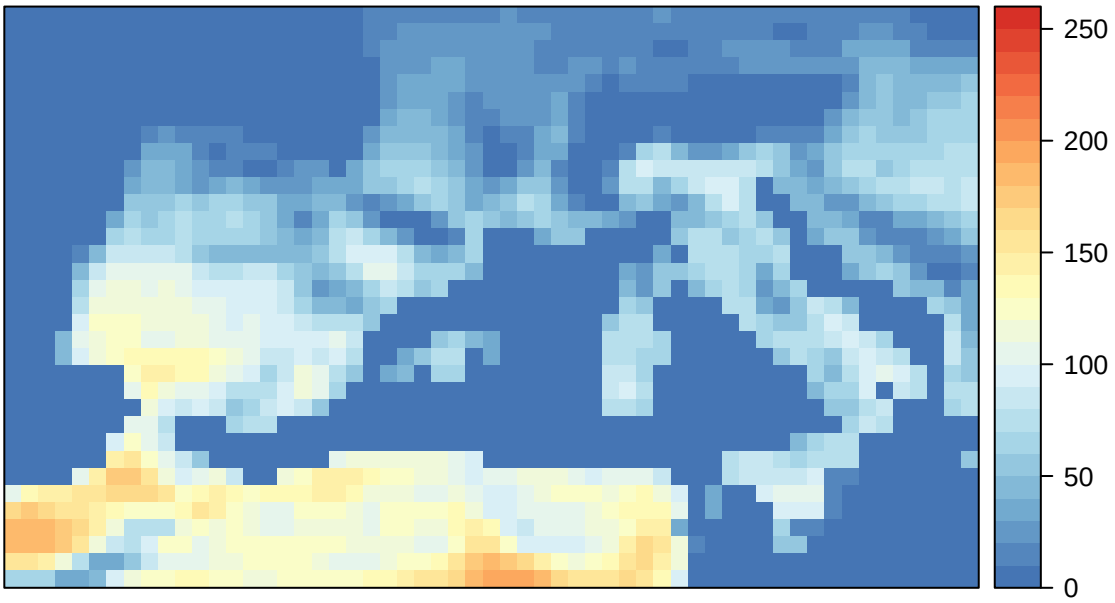

Figure 2: Southern Europe summer days for CORDEX and the historical period 1971-2000. Fig. 2b in the manuscript.

2.1.3 Bias eobs vs cordex. Illustrates interpGrid

```
SUh.interp <- interpGrid(SUh.annual, getGrid(SU.annual))

eobs.mask <- gridArithmetics(SU.annual, 0, operator = "*")
SUh.interp <- gridArithmetics(SUh.interp, eobs.mask, operator = "+")

bias <- gridArithmetics(SUh.interp, SU.annual, operator = "-")
```

```
spatialPlot(climatology(SUh.interp), backdrop.theme = "countries",
            at = seq(0, 260, 10), col.regions = colorRampPalette(colsindex))
```

```
spatialPlot(climatology(bias), backdrop.theme = "countries",
            at = seq(-100, 100, 10), col.regions = colorRampPalette(colsbias))
```

Loading data for the rcp8.5 scenario and period 2071-2100 using the same dictionary

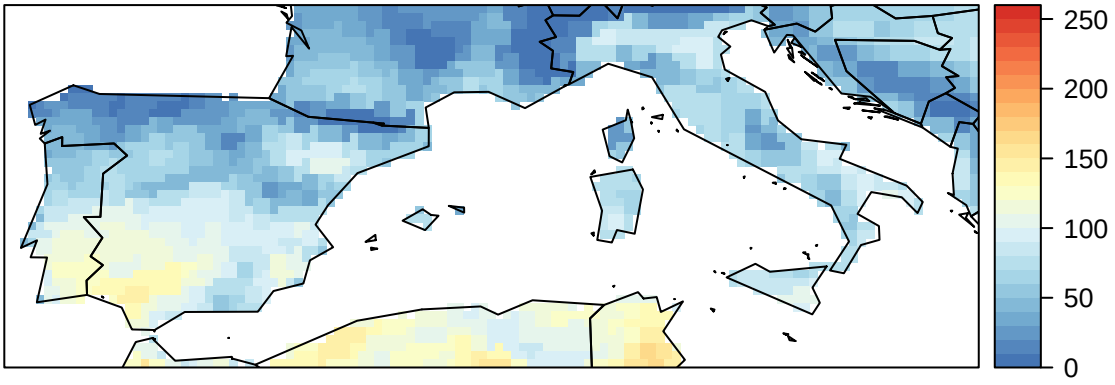

Figure 3: Southern Europe summer days for interpolated CORDEX and the historical period 1971-2000. Fig. 2c in the manuscript.

Figure 4: Southern Europe summer days bias for CORDEX and the historical period 1971-2000. Fig. 2d in the manuscript.

```
# the same dictionary
SUf <- loadGridData(dataset = "CDX_rcp85.ncml",
                    var = "tasmax",
                    season = 1:12,
                    lonLim = lon,
                    latLim = lat,
                    years = 2071:2100,
                    aggr.m = "sum",
                    threshold = 25,
                    condition = "GT",
                    dictionary = "dicCDX.dic")
```

```
SUf.annual <- aggregateGrid(SUf, aggr.y = list(FUN = "sum"))
```

2.1.4 Calculate "Delta" signal

```
SUf.interp <- interpGrid(SUf.annual, getGrid(SU.annual))
SUf.interp <- gridArithmetics(SUf.interp, eobs.mask, operator = "+")

CCsignal <- gridArithmetics(SUf.interp,
                            SUh.interp,
                            operator = "-")
```

```
spatialPlot(climatology(SUf.interp), backdrop.theme = "countries",
            at = seq(0, 260, 10), col.regions = colorRampPalette(colsindex))
```

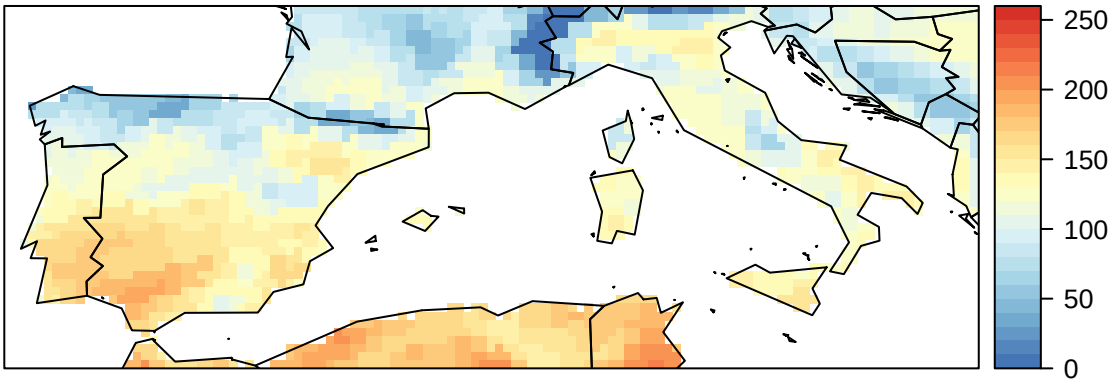

Figure 5: Southern Europe summer days for the interpolated EC-EARTH driven, RCP8.5 scenario in the future period 2071-2100. Fig. 3a in the manuscript.

```
spatialPlot(climatology(CCsignal), backdrop.theme = "countries",
            at = seq(0, 80, 5), col.regions = colorRampPalette(colsdelta))
```

2.2 Post-processing: Bias Correction

```
SUf.bc <- biasCorrection(y = SU, x = SUh, newdata = SUf,
                         method = "scaling", scaling.type = "additive")
SUf.bc.annual <- aggregateGrid(SUf.bc, aggr.y = list(FUN = "sum"))
```

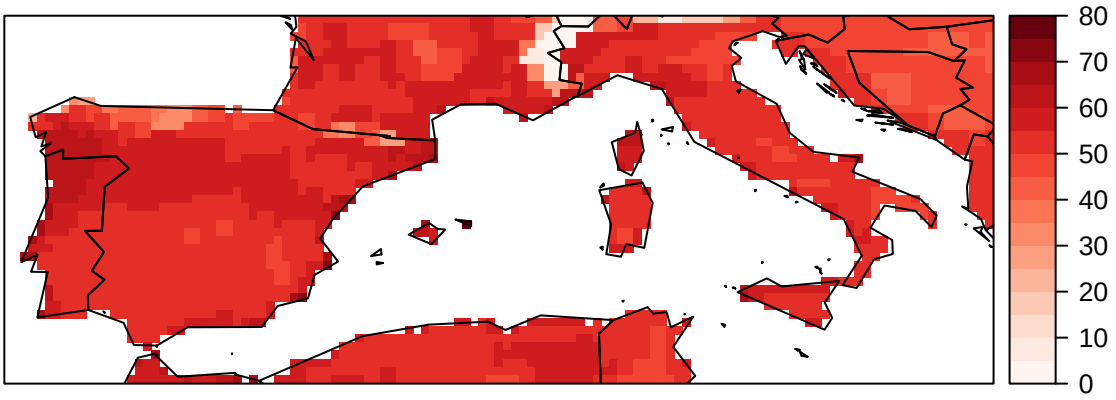

Figure 6: Southern Europe summer days 'delta' for the EC-EARTH driven, RCP8.5 scenario in the future period 2071-2100. Fig. 3b in the manuscript.

```
CCsignal.bc <- gridArithmetics(SUf.bc.annual,
                               SU.annual,
                               operator = "-")
```

```
spatialPlot(climatology(SUf.bc.annual), backdrop.theme = "countries",
            at = seq(0, 260, 10), col.regions = colorRampPalette(colsindex))
```

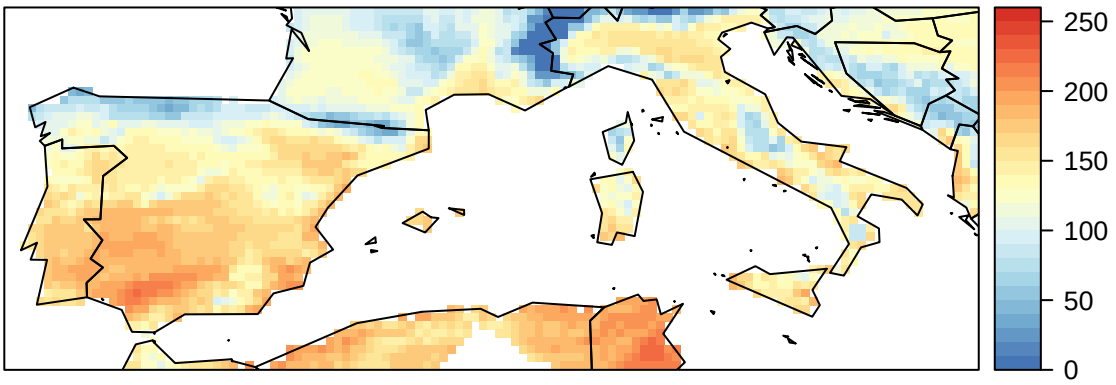

Figure 7: Southern Europe summer days for the bias corrected (additive scaling) EC-EARTH driven, RCP8.5 scenario in the future period 2071-2100. Fig. 3c in the manuscript.

```
spatialPlot(climatology(CCsignal.bc), backdrop.theme = "countries",
            at = seq(0, 80, 5), col.regions = colorRampPalette(colsdelta))
```

```
Z <- lapply(list("E-OBS" = SU.annual, "CDX_hist" = SUh.interp,
                 "CDX_rcp85" = SUf.interp, "CDX_rcp85_corrected" = SUf.bc.annual),
            function(x)  subsetGrid(x, latLim = 41.64, lonLim = -0.89))
cols = c("black", "red", "red", "blue")
temporalPlot(Z, cols = cols, lwd = 0.8, xyplot.custom = list(ylab = "", ylim = c(70, 220),
  key = list(space = "top", lines = list(pch = 15, col = cols, cex = .5),
             text = list(names(Z),
                         cex = .7), columns = 2)))
```

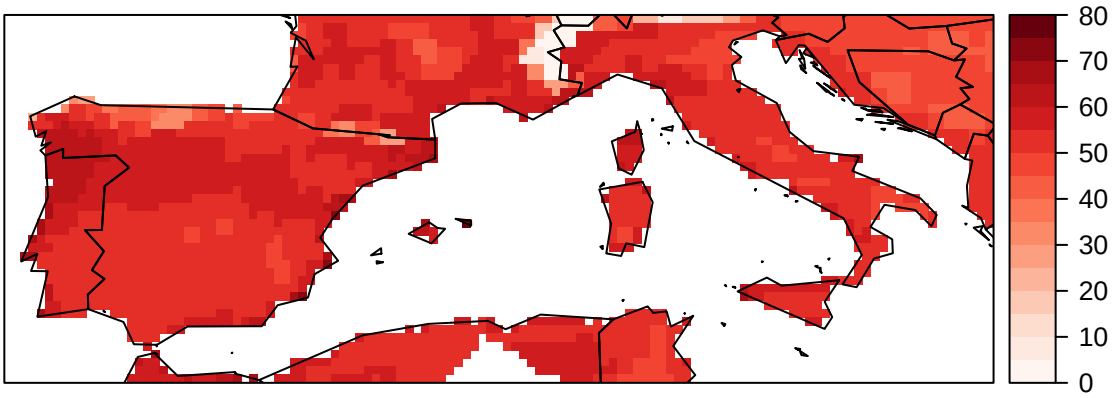

Figure 8: Southern Europe summer days 'delta' for the bias corrected (additive scaling) EC-EARTH driven, RCP8.5 scenario in the future period 2071-2100. Not shown in the manuscript.

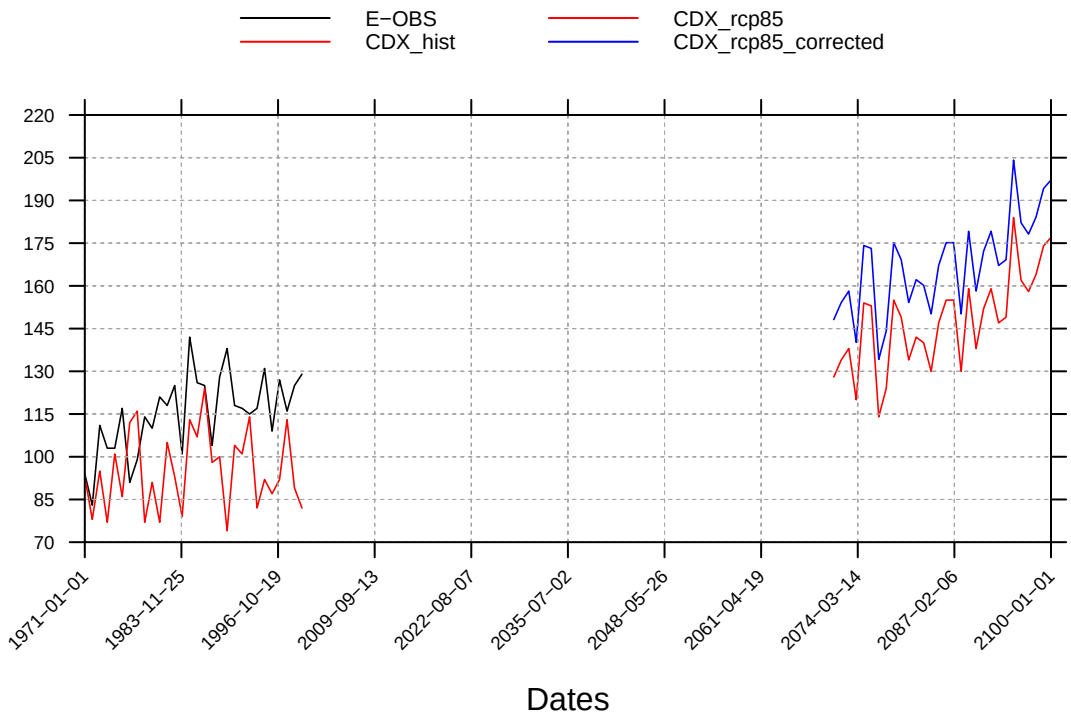

Figure 9: Annual summer days time series for a single gridbox (Zaragoza, Spain) for the observations (E-OBS) and the projection (original and bias corrected) in the historical and future periods. Fig. 4 in the manuscript.

2.3 Working with daily data

```
TX <- loadGridData(eobs,
                   var = "tasmax",
                     season = 1:12,
                         lonLim = lon,
                         latLim = lat,
                         years = 1971:2000,
                         dictionary = "dicEOBS.dic")
TXh <- loadGridData(dataset = "CDX_hist.ncml",
                     var = "tasmax",
                     season = 1:12,
                     lonLim = lon,
                     latLim = lat,
                     years = 1971:2000,
                     dictionary = "dicCDX.dic")
TXf <- loadGridData(dataset = "CDX_rcp85.ncml",
                     var = "tasmax",
                     season = 1:12,
                     lonLim = lon,
                     latLim = lat,
                     years = 2071:2100,
                     dictionary = "dicCDX.dic")
TXf.bc <- biasCorrection(y = TX,
                         x = TXh,
                         newdata = TXf,
                         method = "eqm",
                         window = c(30, 7),
                         extrapolation = "constant")
SUf <- climdexGrid(tx = TXf, index.code = "SU")
SUf.bc <- climdexGrid(tx = TXf.bc, index.code = "SU")
```

```
SUf.interp <- interpGrid(SUf, getGrid(TX))
SUf.interp <- gridArithmetics(SUf.interp, eobs.mask, operator = "+")
```

```
spatialPlot(climatology(SUf.interp), backdrop.theme = "countries",
            at = seq(0, 260, 10), col.regions = colorRampPalette(colsindex))
```

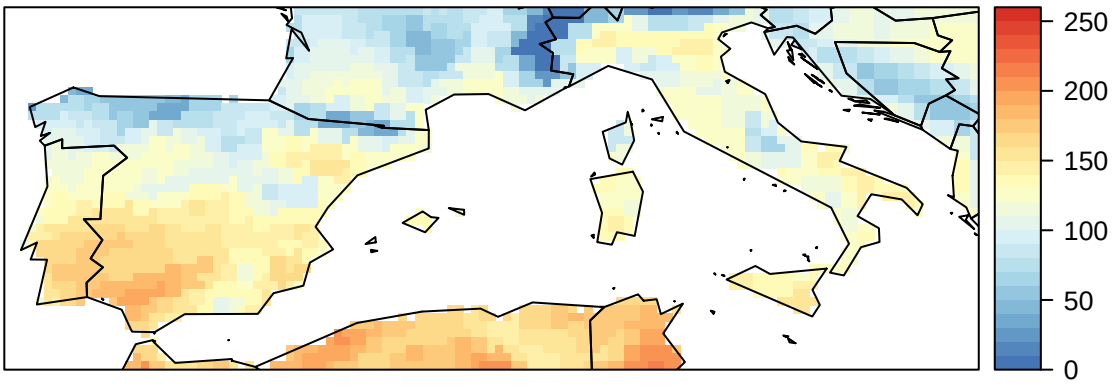

Figure 10: Southern Europe summer days for the EC-EARTH driven, RCP8.5 scenario in the future period 2071-2100 (calculated with package climate4R.climdex from daily data). Not shown in the manuscript.

```
spatialPlot(climatology(SUf.bc), backdrop.theme = "countries",
            at = seq(0, 260, 10), col.regions = colorRampPalette(colsindex))
```

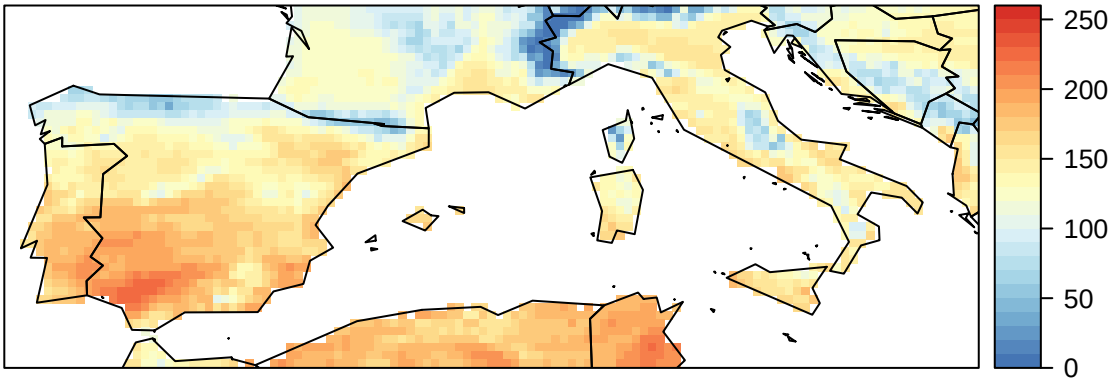

Figure 11: Southern Europe summer days for the bias corrected (emipirical quantile mapping) EC-EARTH driven, RCP8.5 scenario in the future period 2071-2100 (calculated with package climate4R.climdex from daily data). Fig. 5 in the manuscript.