

Heatwave and coldwave duration

Heatwave and coldwave duration is the total duration of “extreme spells”; the total number of days in a season where the temperature exceeds a threshold over a minimum number of consecutive days. Other tools for computing such events are also available, but the novelty of this tool is that the users can select their own thresholds (based on quantiles) and minimum duration of an event. The duration of heatwaves and coldwaves helps to understand potential changes in energy demand.

1- Load dependencies

This example requires the following system libraries:

- libssl-dev
- libnecdf-dev
- cdo

The **ClimProjDiags R package** should be loaded by running the following lines in R once it's integrated into CRAN mirror.

```
library(ClimProjDiags)
```

All the other R packages involved can be installed directly from CRAN and loaded as follows:

```
library(abind)
library(s2dverification)
library(parallel)
```

The illustrative problem is to analyze the daily maximum or minimum air temperature at 2 m to com. The reference period used from the historical simulations to compute a threshold is 1971 - 2000. While, the future scenario chosen is the rcp2.6 during the period 2006 - 2100 for which the heat/cold wave duration will be determined. Finally, the region selected in the northern hemisphere is between -40 - 20 °E and 25 - 60 °N.

The parameters, for a heat wave example, are defined by running the next lines in R:

```
var <- 'tasmx'

start_climatology <- '1971'
end_climatology <- '2000'

start_projection <- '2006'
end_projection <- '2100'

lat <- seq(25, 60, 5)
lon <- seq(-35, 20 ,5)
```

A synthetic sample of data for the reference period is built by adding random perturbation to a sinusoidal function. The latitudinal behavior of the temperature is considered by subtracting randomly a value proportional to the latitud. Furthermore, attributes of time and dimensions are added.

```

tmax_historical <- NULL
grid1 <- 293 - 10 * cos(2 * pi / 365 * (1 : 10958)) + rnorm(10958)
gridlon <- NULL
for (i in 1 : 12) {
  gridlon <- cbind(gridlon, grid1 + rnorm(10958, sd = 5) *
                  cos(2 * pi / 365 * (1 : 10958)))
}
for (j in 1 : 8) {
  gridnew <- apply(gridlon, 2, function(x) {x - rnorm(10958, mean = j * 0.5, sd = 3)})
  tmax_historical <- abind(tmax_historical, gridnew, along = 3)
}
tmax_historical <- InsertDim(InsertDim(tmax_historical, posdim = 1, lendim = 1),
                             posdim = 1, lendim = 1)
names(dim(tmax_historical)) <- c("model", "var", "time", "lon", "lat")
time <- seq(ISOdate(1971, 1, 1), ISOdate(2000, 12, 31), "day")
metadata <- list(time = list(standard_name = 'time', long_name = 'time',
                             calendar = 'proleptic_gregorian',
                             units = 'days since 1970-01-01 00:00:00', prec = 'double',
                             dim = list(list(name = 'time', unlim = FALSE))))
attr(time, "variables") <- metadata
attr(tmax_historical, 'Variables')$dat1$time <- time

```

A similar procedure is considered to build the synthetic data for the future projections. However, a little trend is added.

```

tmax_projection <- NULL
grid1 <- 298 - 10 * cos(2 * pi / 365 * (1 : 34698)) +
        rnorm(34698) + (1 : 34698) * rnorm(1, mean = 4) / 34698
gridlon <- NULL
for (i in 1 : 12) {
  gridlon <- cbind(gridlon, grid1 + rnorm(34698, sd = 5) *
                  cos(2 * pi / 365 * (1 : 34698)))
}
for (j in 1 : 8) {
  gridnew <- apply(gridlon, 2, function(x) {x - rnorm(34698, mean = j * 0.5,
                                                    sd = 3)})
  tmax_projection <- abind(tmax_projection, gridnew, along = 3)
}
tmax_projection <- InsertDim(InsertDim(tmax_projection, posdim = 1, lendim = 1),
                             posdim = 1, lendim = 1)
names(dim(tmax_projection)) <- c("model", "var", "time", "lon", "lat")
time <- seq(ISOdate(2006, 1, 1), ISOdate(2100, 12, 31), "day")
metadata <- list(time = list(standard_name = 'time', long_name = 'time',
                             calendar = 'proleptic_gregorian',
                             units = 'days since 1970-01-01 00:00:00', prec = 'double',
                             dim = list(list(name = 'time', unlim = FALSE))))
attr(time, "variables") <- metadata
attr(tmax_projection, 'Variables')$dat1$time <- time

```

2- Heatwaves

The heatwaves duration is the number of consecutive days for which the maximum temperature is exceeding a threshold over a minimum number of days during summer.

2.1- Defining heatwaves threshold

In this example, the threshold is defined as the 90th percentile of maximum temperature during the period 1971-2000.

The summer data can be picked by `SeasonSelect` function from the **ClimProjDiags** package.

```
summer_tmax_historical <- SeasonSelect(tmax_historical, season = 'JJA')
```

The output of `SeasonSelect` is a list of two elements: data and dates. The selected dates should be consistent: 92 summer days * 30 years = 2760 dates. While the data dimensions also keeps the longitude and latitude dimensions.

```
r > str(summer_tmax_historical) List of 2 $ data : num [1:2760, 1:12, 1:8] 302 285
301 302 312 ... $ dates: POSIXct[1:2760], format: "1971-06-01 12:00:00" "1971-06-04
12:00:00" ...
```

To define the heatwave it is necessary to select the maximum temperature threshold that must be exceeded. In this example, the 90 th percentile of the maximum temperature during the reference period is selected. This calculation is performed using `Threshold` function from **ClimProjDiags** package.

```
quantile <- 0.9
thresholds <- Threshold(data = summer_tmax_historical$data,
                        dates = summer_tmax_historical$dates,
                        calendar = "proleptic_gregorian",
                        qtiles = quantile, ncores = detectCores() -1)
```

The output of `Threshold` is an array of the 92 days of summer in the first dimension and the spatial dimensions in the second and third position in this case:

```
> str(thresholds)
num [1:92, 1:12, 1:8] 310 308 312 309 310 ...
```

2.2- Heatwaves projection

The same selection should be done for the future projection data by applying `SeasonSelect`.

```
summer_tmax_projection <- SeasonSelect(tmax_projection, season = 'JJA')
```

The corresponding output is again a list of two elements: data and dates. The selected dates should be consistent: 92 summer days * (2100 - 2006 + 1) years = 8740 dates.

```
> str(summer_tmax_projection)
List of 2
 $ data : num [1:8740, 1:12, 1:8] 303 300 315 297 298 ...
 $ dates: POSIXct[1:8740], format: "2006-06-01 12:00:00" "2006-06-02 12:00:00"...
```

2.3- Heatwaves duration

The duration of the heatwaves is obtained by using the `WaveDuration` function from **ClimProjDiags** package. By setting `spell.length = 5`, the minimum length of a heatwave is defined as 5 days in this example. So, this function returns the number of days for each summer in which the maximum temperature is exceeding the 90th percentile of the reference period when they occur in a cluster of a minimum length of 5 consecutive days. This means that isolated events are not included.

```
duration <- WaveDuration(data = summer_tmax_projection$data,  
                        threshold = thresholds, op = ">", spell.length = 5,  
                        dates = summer_tmax_projection$dates,  
                        calendar = "proleptic_gregorian")
```

```
> str(duration)  
List of 2  
 $ result: num [1:95, 1:12, 1:8] 5 5 0 5 9 11 5 11 0 5 ...  
 $ years : chr [1:95] "2006-JJA" "2007-JJA" "2008-JJA" "2009-JJA" ...
```

The spatial representation of the maximum, mean and minimum duration of heatwaves can be plotted and saved in the working directory by running:

```
breaks <- seq(0,92,4)  
  
PlotEquiMap(apply(duration$result, c(2, 3), max), lon = lon, lat = lat,  
            brks = breaks, filled.continents = FALSE, title_scale = 0.8,  
            toptitle = "Heat wave duration",  
            cols = heat.colors(length(breaks)-1)[(length(breaks)-1):1],  
            fileout = "SpatialHeatwave.png")
```

