

# MHW timelines for regions of interest

Visualisation of extreme temperature events

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Analysis of the EXEBUS regions of interest. Analysis as follows:

- Use OISST data
- Calculate MHWs and MCSs
- Plot timelines of MHWs and MCSs onto ‘event lines’ using flame plots
- Analyse regions of interest as specified by Marek
- This analysis has not yet removed the long-term linear trend

## Set-up

```
library(tidyverse)
library(data.table)
library(lubridate)
library(heatwaveR)
library(ggthemes)

library(sf)
library(rnaturalearth)
library(rnaturalearthhires)

source("/Users/ajsmits/Domains/R/workshops/tangled_bank/R/extreme_event_horizon.R")
source("../data/bboxes.R")
bbox

##          lonmin lonmax latmin latmax
## BC        12.5  20.00 -42.5 -25.0
## ANG       11.0  14.00 -17.0 -5.6
## ANG.C    13.3  13.70 -11.7 -10.6
## ANG.ABF   11.0  11.50 -16.0 -14.0
## ANG.N     12.6  13.15 -8.8 -8.1
## ANG.Hov   11.0  11.50 -17.0 -5.6
## GOG      -10.5   3.50   0.0   7.0
## GOG.CI    -5.0  -2.50   4.2   4.8
## GOG.G     -1.3   0.80   4.4   5.0
## NWA     -20.5 -15.50  12.5  24.5
## NWA.SG   -17.6 -17.00  13.3  14.3
## NWA.M    -17.5 -16.80  19.0  20.0
## NWA.Hov  -17.8 -17.10  12.5  24.5
## SEAS      68.8  77.00   9.0  16.0
## SEAS.K    75.0  75.90   9.8  10.5
```

- **BC** — Benguela Upwelling System

- **ANG** — Angola
  - **ANG.C** Central Angola (upwelling)
  - **ANG.ABF** Angola-Benguela Front
  - **ANG.N** Northern Angola (downwelling)
- **GOG** — Northern Gulf of Guinea
  - **COG.CI** Cote d'Ivoire Box
  - **COG.G** Ghana Box
- **NWA** — North-west Africa
  - **NWA.SG** Southern Canary System, Senegal and Gambia
  - **NWA.M** Northern Canary System, Northern Mauritania
- **SEAS** — South-eastern Arabian Sea (South-west coast of India)
  - **SEAS.K** South-east Arabian Sea, Kerala upwelling cell

```
csv_dir <- "/Volumes/OceanData/AVHRR_OI-NCEI-L4-GLOB-v2.0/EXEBUS_MHW"
files <- as.list(list.files(csv_dir, recursive = TRUE, pattern = '.csv',
                        full.names = TRUE))
```

## Functions

```
bbox_fun <- function(region) {
  coords <- matrix(c(bbox[region, "lonmin"], bbox[region, "latmin"],
                      bbox[region, "lonmax"], bbox[region, "latmin"],
                      bbox[region, "lonmax"], bbox[region, "latmax"],
                      bbox[region, "lonmin"], bbox[region, "latmax"],
                      bbox[region, "lonmin"], bbox[region, "latmin"]), ncol = 2, byrow = TRUE)

  bbox_poly <- st_polygon(list(coords))
  bbox_sf <- st_sfc(bbox_poly, crs = WGS84_proj)
  return(bbox_sf)
}
```

## Prepare map data

```
WGS84_proj <- "+proj=longlat +datum=WGS84 +no_defs +ellps=WGS84 +towgs84=0,0,0"

world <- ne_countries(returnclass = 'sf',
  scale = 10, type = "countries") |>
  select(continent, sovereign, iso_a3) |>
  st_break_antimeridian(lon_0 = 10) |>
  st_transform(WGS84_proj) |>
  group_by(continent) |>
  summarise()

## Spherical geometry (s2) switched off
## although coordinates are longitude/latitude, st_intersection assumes that they
## are planar

## Warning: attribute variables are assumed to be spatially constant throughout
## all geometries

## Spherical geometry (s2) switched on
```

## Angola

```
ANG_bbox <- bbox_fun("ANG")
ANG.N_bbox <- bbox_fun("ANG.N")
```

```

ANG.C_bbox <- bbox_fun("ANG.C")
ANG.ABF_bbox <- bbox_fun("ANG.ABF")
ANG.Hov_bbox <- bbox_fun("ANG.Hov")

roi_cropped <- world |>
  st_crop(ANG_bbox)

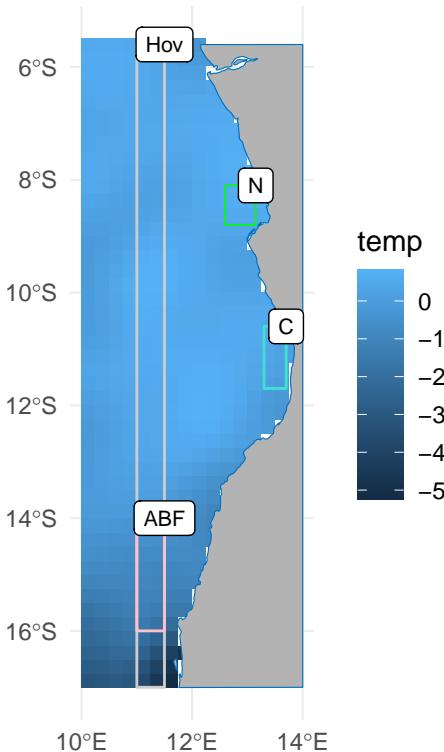
## Warning: attribute variables are assumed to be spatially constant throughout
## all geometries

ANG <- fread(files[[1]]) |>
  filter(between(t, "2011-02-01", "2011-02-28")) |>
  dplyr::mutate(temp = temp - mean(temp)) |>
  dplyr::group_by(lon, lat) |>
  dplyr::summarise(temp = mean(temp), .groups = "drop")

ggplot() +
  geom_raster(data = ANG, aes(x = lon, y = lat, fill = temp)) +
  geom_sf(data = roi_cropped, colour = "#0070C0", fill = "grey70") +
  geom_sf(data = ANG.C_bbox, fill = NA, colour = "turquoise", linewidth = 0.5) +
  geom_sf(data = ANG.Hov_bbox, fill = NA, colour = "grey80", linewidth = 0.5) +
  geom_sf(data = ANG.ABF_bbox, fill = NA, colour = "pink", linewidth = 0.5) +
  geom_sf(data = ANG.N_bbox, fill = NA, colour = "green", linewidth = 0.3) +
  geom_label(data = bbox[3:6,],
             aes(lonmax, latmax,
                  label = c("C", "ABF", "N", "Hov")),
             colour = "black", size = 2.8) +
  scale_y_continuous(breaks = seq(-16, -6, by = 2)) +
  scale_x_continuous(breaks = seq(10, 14, by = 2)) +
  labs(x = NULL, y = NULL,
       title = "Angolan\nregions",
       subtitle = NULL) +
  theme_minimal()

```

## Angolan regions



```

ANG.N <- fread(files[[1]]) |>
  filter(between(lon, bbox["ANG.N", "lonmin"], bbox["ANG.N", "lonmax"]),
         between(lat, bbox["ANG.N", "latmin"], bbox["ANG.N", "latmax"])) |>
  dplyr::group_by(t) |>
  dplyr::summarise(temp = mean(temp), .groups = "drop")

ANG.C <- fread(files[[1]]) |>
  filter(between(lon, bbox["ANG.C", "lonmin"], bbox["ANG.C", "lonmax"]),
         between(lat, bbox["ANG.C", "latmin"], bbox["ANG.C", "latmax"])) |>
  dplyr::group_by(t) |>
  dplyr::summarise(temp = mean(temp), .groups = "drop")

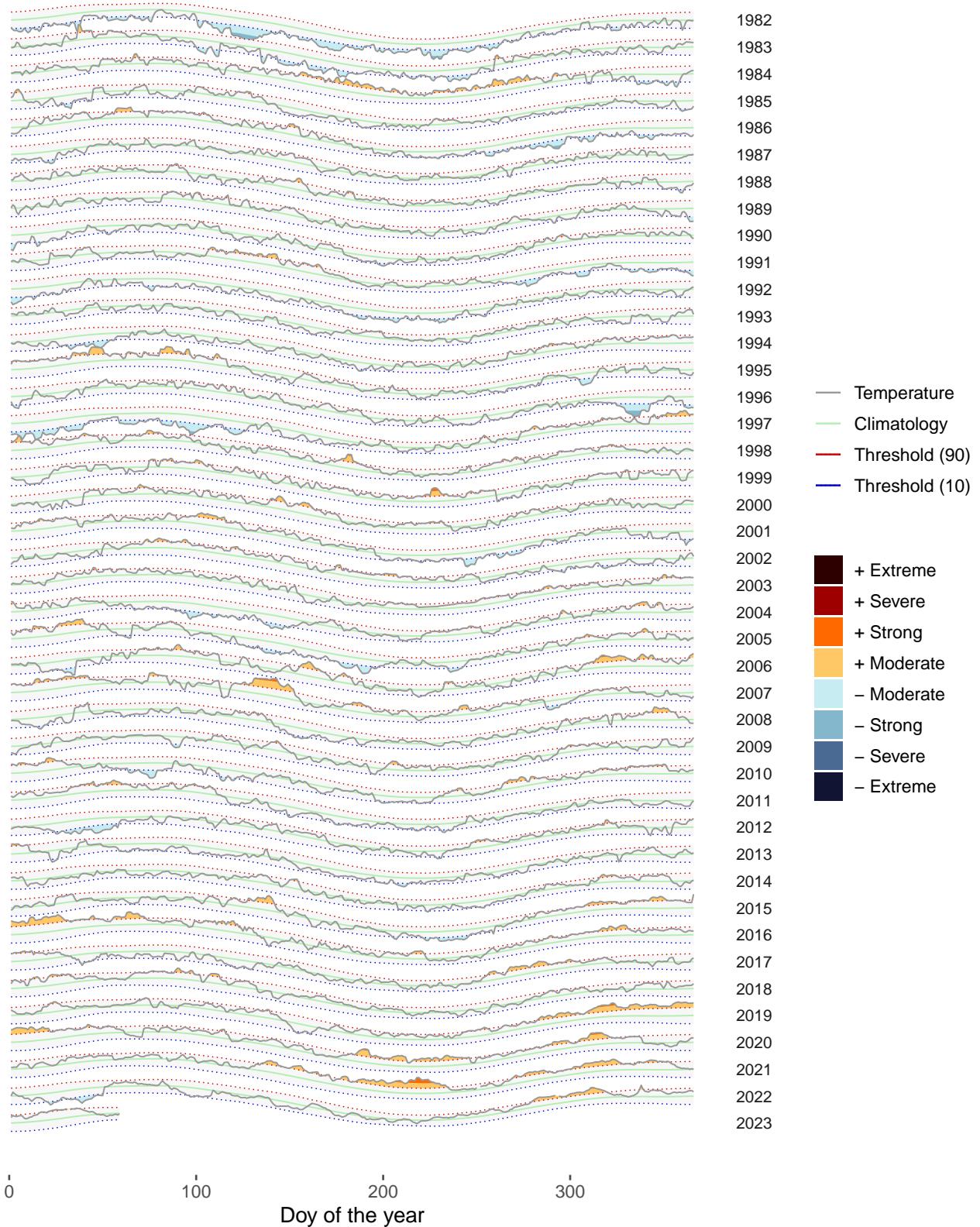
ANG.ABF <- fread(files[[1]]) |>
  filter(between(lon, bbox["ANG.ABF", "lonmin"], bbox["ANG.ABF", "lonmax"]),
         between(lat, bbox["ANG.ABF", "latmin"], bbox["ANG.ABF", "latmax"])) |>
  dplyr::group_by(t) |>
  dplyr::summarise(temp = mean(temp), .groups = "drop")

ANG.N_events <- thresh_fun(ANG.N)
ANG.C_events <- thresh_fun(ANG.C)
ANG.ABF_events <- thresh_fun(ANG.ABF)

horizon_plot(ANG.N_events, title = "Extreme temperature timeline, Northern Angola")

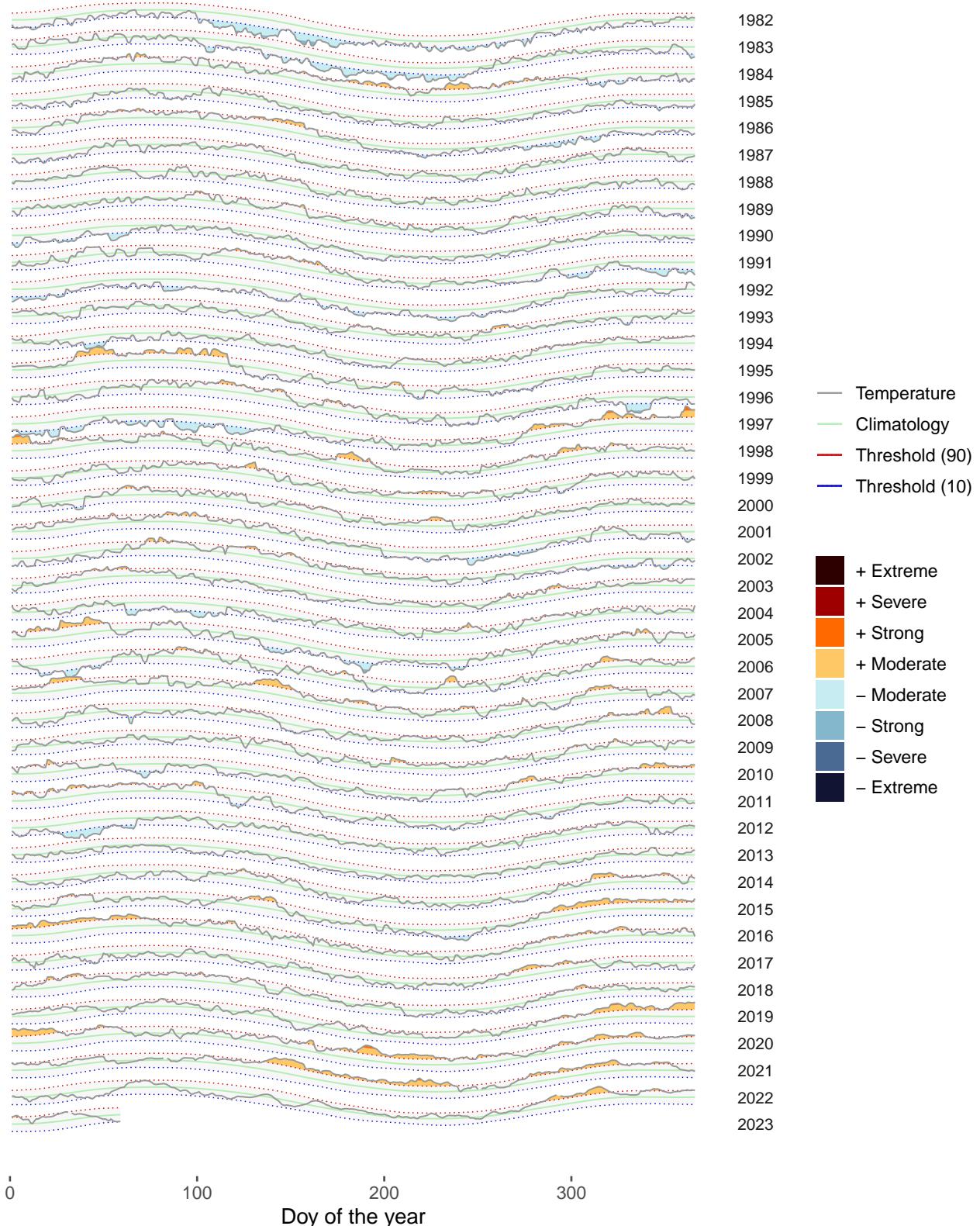
```

## Extreme temperature timeline, Northern Angola



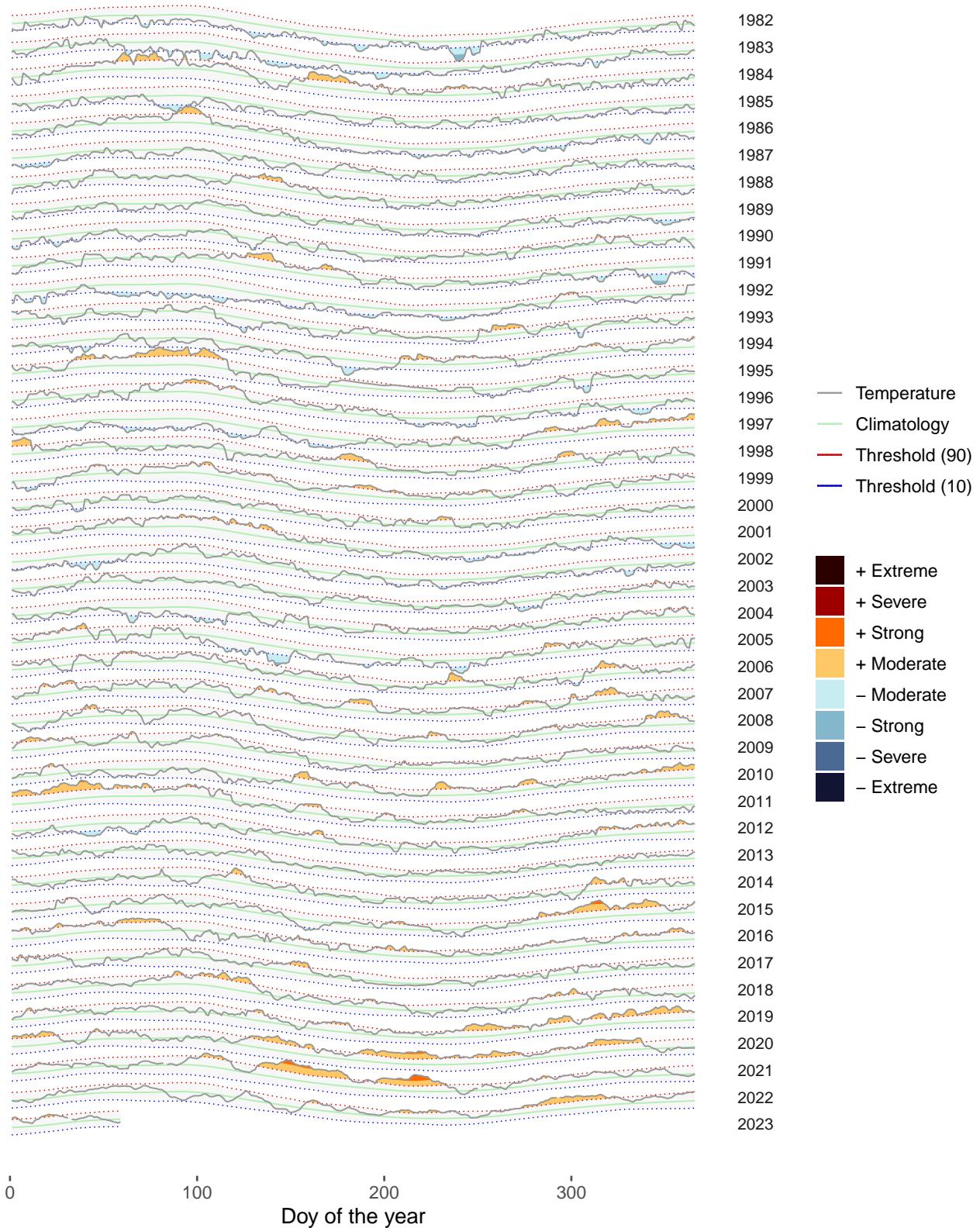
```
horizon_plot(ANG.C_events, title = "Extreme temperature timeline, Central Angola")
```

## Extreme temperature timeline, Central Angola



```
horizon_plot(ANG.ABF_events, title = "Extreme temperature timeline, Angola-Benguela Front")
```

## Extreme temperature timeline, Angola–Benguela Front



Hovmöller diagramme of the region ('Hov') indicated on the map:

```

ANG.Hov <- fread(files[[1]]) |>
  filter(between(lon, bbox["ANG.Hov", "lonmin"], bbox["ANG.Hov", "lonmax"]),
         between(lat, bbox["ANG.Hov", "latmin"], bbox["ANG.Hov", "latmax"])) |>
  dplyr::group_by(t, lat) |>
  dplyr::summarise(temp = mean(temp), .groups = "drop")

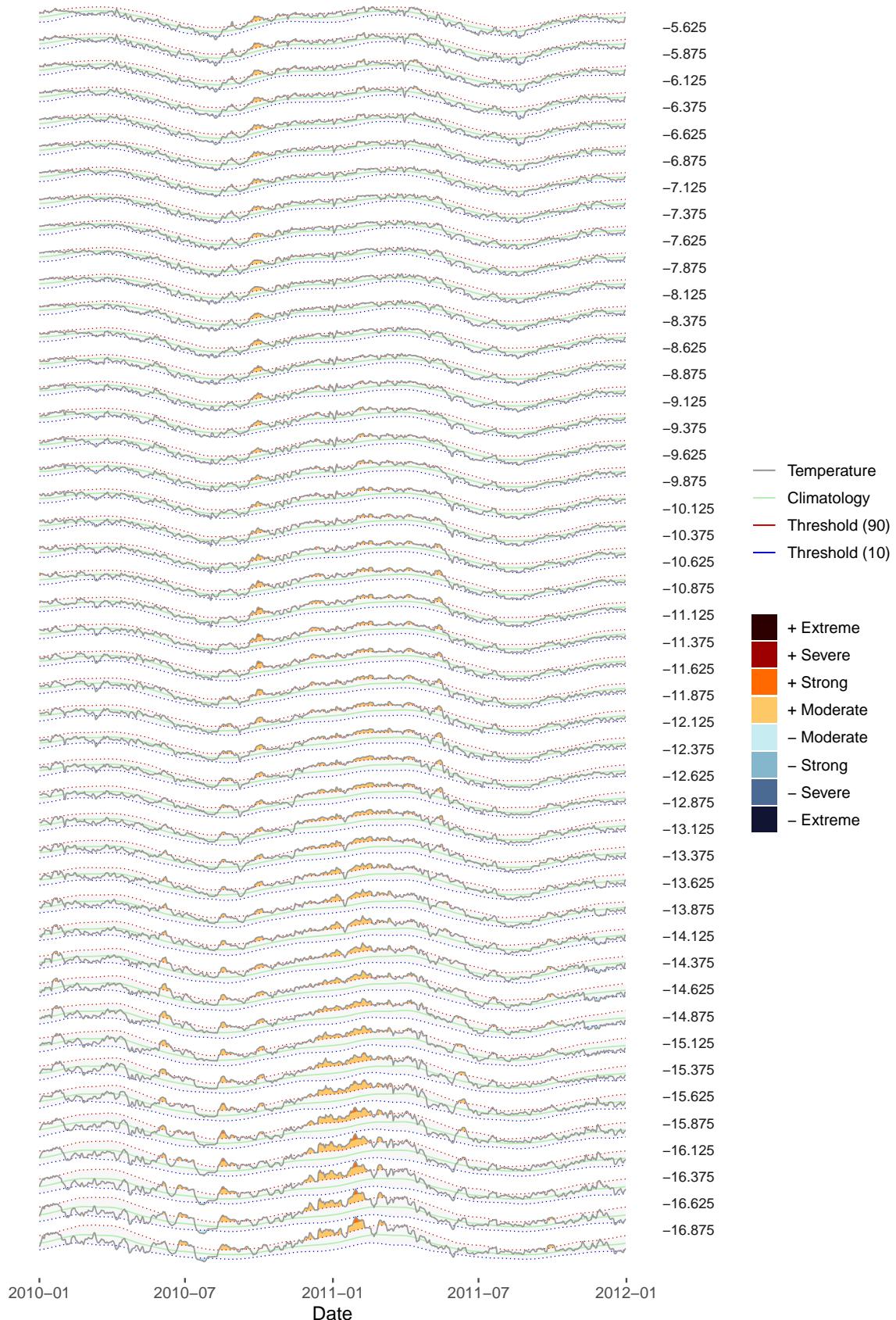
ANG.Hov_events <- plyr::ddply(.data = ANG.Hov, .variables = c("lat"),
                               .fun = thresh_fun, .parallel = TRUE) |>
  filter(between(t, "2010-01-01", "2011-12-31")) |>
  mutate(lat = as_factor(lat))

## Warning in setup_parallel(): No parallel backend registered
## Warning: executing %dopar% sequentially: no parallel backend registered

hovmoller_horizon_plot(ANG.Hov_events, title = "Extreme temperature timeline, Angola")

```

## Extreme temperature timeline, Angola



## Gulf of Guinea

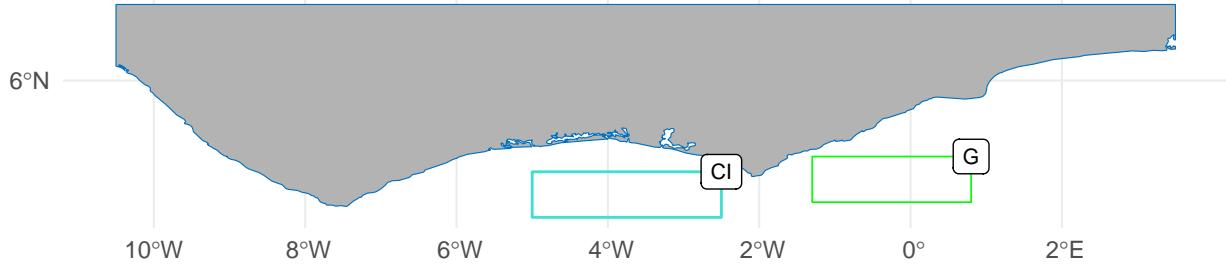
```
GOG_bbox <- bbox_fun("GOG")
GOG.G_bbox <- bbox_fun("GOG.G")
GOG.CI_bbox <- bbox_fun("GOG.CI")

roi_cropped <- world |>
  st_crop(GOG_bbox)

## Warning: attribute variables are assumed to be spatially constant throughout
## all geometries

ggplot() +
  geom_sf(data = roi_cropped, colour = "#0070C0", fill = "grey70") +
  geom_sf(data = GOG.CI_bbox, fill = NA, colour = "turquoise", linewidth = 0.5) +
  geom_sf(data = GOG.G_bbox, fill = NA, colour = "green", linewidth = 0.3) +
  geom_label(data = bbox[8:9,],
    aes(lonmax, latmax,
        label = c("CI", "G")),
    colour = "black", size = 2.8) +
  scale_y_continuous(breaks = seq(0, 6, by = 2)) +
  scale_x_continuous(breaks = seq(-10, 2, by = 2)) +
  labs(x = NULL, y = NULL,
    title = "Gulf of Guinea",
    subtitle = NULL) +
  theme_minimal()
```

Gulf of Guinea



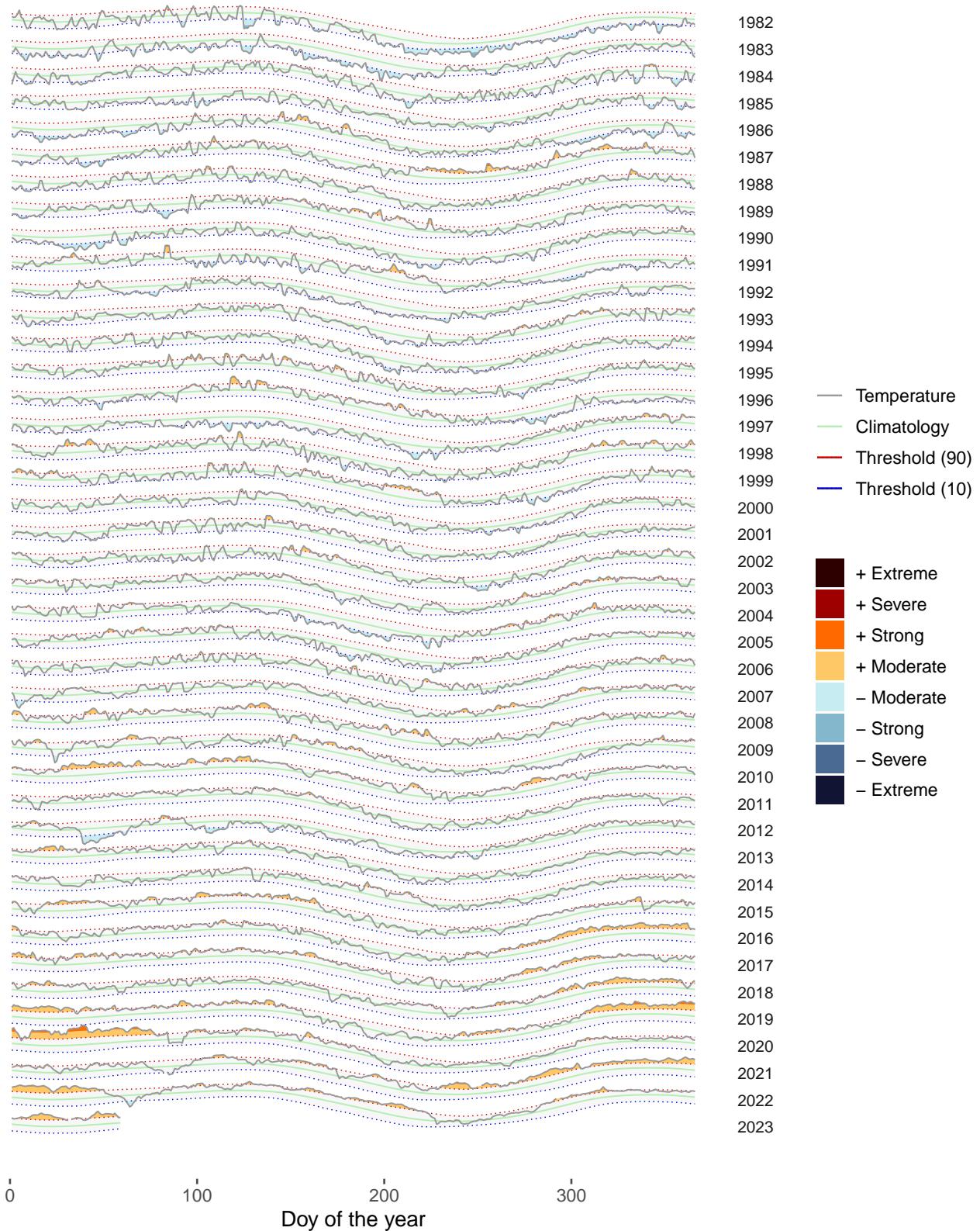
```
GOG.CI <- fread(files[[3]]) |>
  filter(between(lon, bbox["GOG.CI", "lonmin"], bbox["GOG.CI", "lonmax"]),
         between(lat, bbox["GOG.CI", "latmin"], bbox["GOG.CI", "latmax"])) |>
  dplyr::group_by(t) |>
  dplyr::summarise(temp = mean(temp), .groups = "drop")

GOG.G <- fread(files[[3]]) |>
  filter(between(lon, bbox["GOG.G", "lonmin"], bbox["GOG.G", "lonmax"]),
         between(lat, bbox["GOG.G", "latmin"], bbox["GOG.G", "latmax"])) |>
  dplyr::group_by(t) |>
  dplyr::summarise(temp = mean(temp), .groups = "drop")

GOG.CI_events <- thresh_fun(GOG.CI)
GOG.G_events <- thresh_fun(GOG.G)

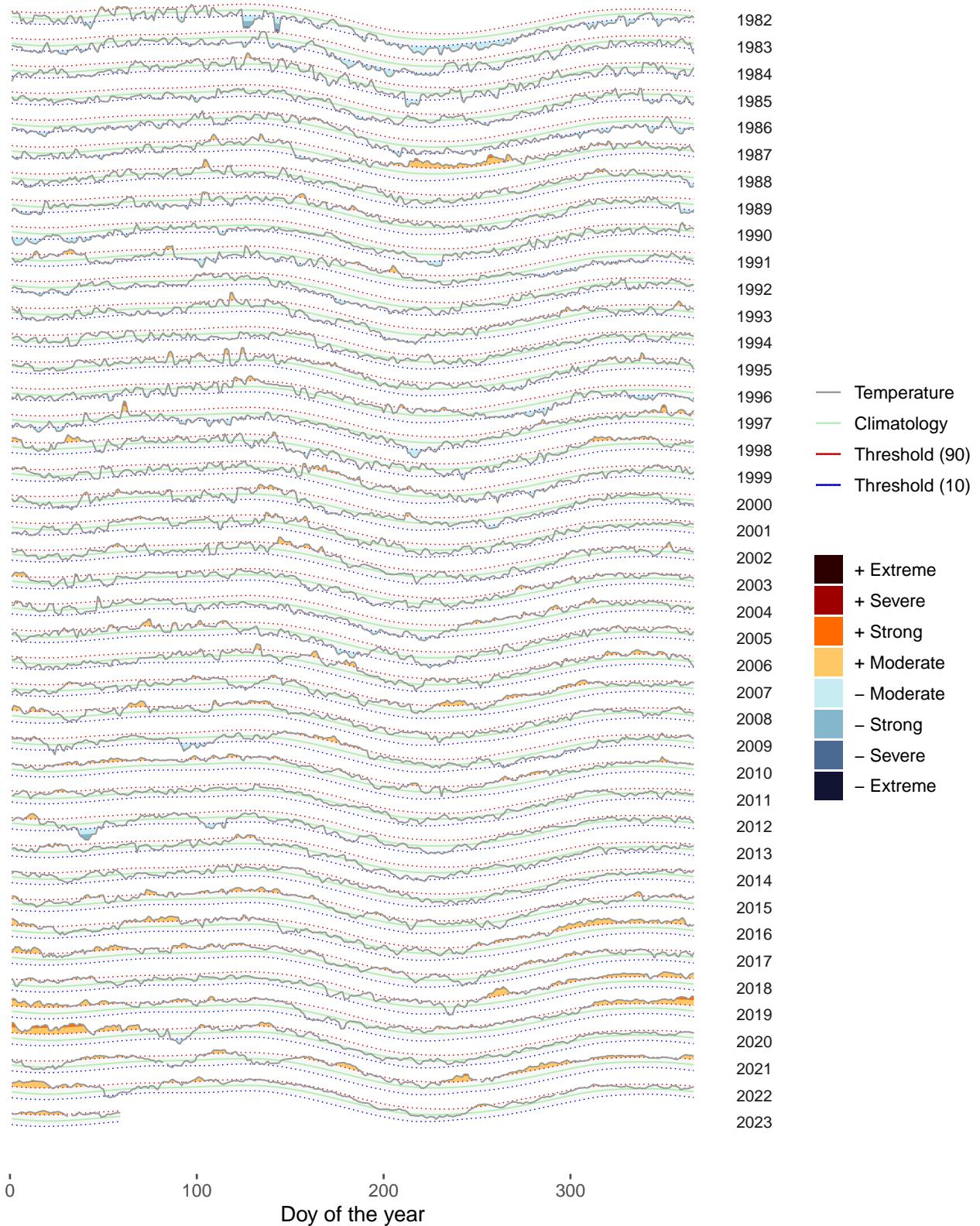
horizon_plot(GOG.CI_events, title = "Extreme temperature timeline, Côte d'Ivoire")
```

## Extreme temperature timeline, Cote d'Ivoire



```
horizon_plot(GOG.G_events, title = "Extreme temperature timeline, Ghana")
```

## Extreme temperature timeline, Ghana



## Northwest Africa

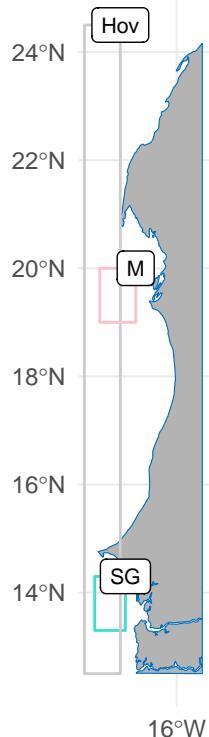
```
NWA_bbox <- bbox_fun("NWA")
NWA.SG_bbox <- bbox_fun("NWA.SG")
NWA.M_bbox <- bbox_fun("NWA.M")
NWA.Hov_bbox <- bbox_fun("NWA.Hov")

roi_cropped <- world |>
  st_crop(NWA_bbox)

## Warning: attribute variables are assumed to be spatially constant throughout
## all geometries

ggplot() +
  geom_sf(data = roi_cropped, colour = "#0070C0", fill = "grey70") +
  geom_sf(data = NWA.SG_bbox, fill = NA, colour = "turquoise", linewidth = 0.5) +
  geom_sf(data = NWA.Hov_bbox, fill = NA, colour = "grey80", linewidth = 0.5) +
  geom_sf(data = NWA.M_bbox, fill = NA, colour = "pink", linewidth = 0.5) +
  geom_label(data = bbox[11:13,],
    aes(lonmax, latmax,
        label = c("SG", "M", "Hov")),
    colour = "black", size = 2.8) +
  scale_y_continuous(breaks = seq(14, 24, by = 2)) +
  scale_x_continuous(breaks = seq(-20, -16, by = 2)) +
  labs(x = NULL, y = NULL,
       title = "Canary\nregions",
       subtitle = NULL) +
  theme_minimal()
```

Canary  
regions



```

NWA.SG <- fread(files[[4]]) |>
  filter(between(lon, bbox["NWA.SG", "lonmin"], bbox["NWA.SG", "lonmax"]),
         between(lat, bbox["NWA.SG", "latmin"], bbox["NWA.SG", "latmax"])) |>
  dplyr::group_by(t) |>
  dplyr::summarise(temp = mean(temp), .groups = "drop")

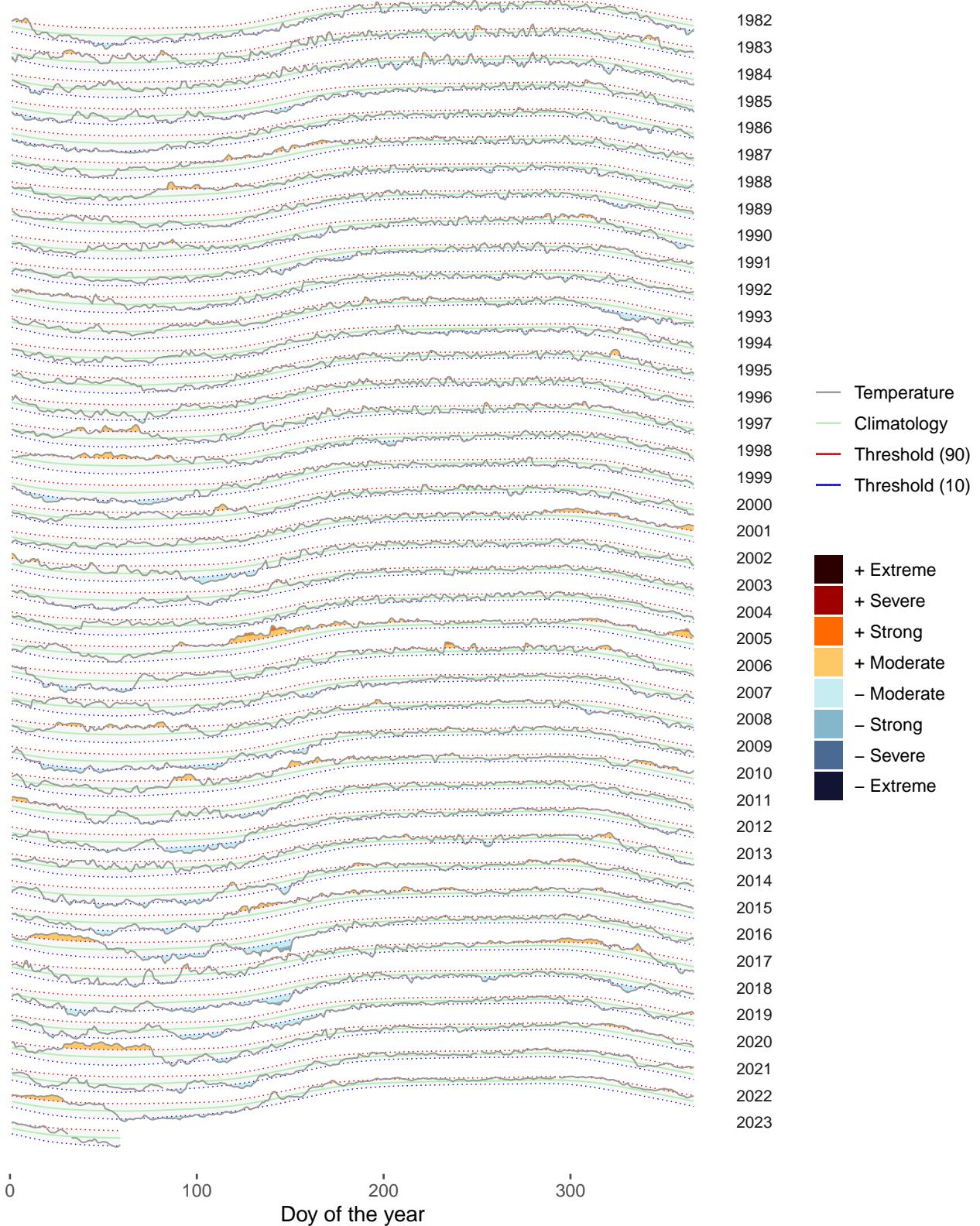
NWA.M <- fread(files[[4]]) |>
  filter(between(lon, bbox["NWA.M", "lonmin"], bbox["NWA.M", "lonmax"]),
         between(lat, bbox["NWA.M", "latmin"], bbox["NWA.M", "latmax"])) |>
  dplyr::group_by(t) |>
  dplyr::summarise(temp = mean(temp), .groups = "drop")

NWA.SG_events <- thresh_fun(NWA.SG)
NWA.M_events <- thresh_fun(NWA.M)

horizon_plot(NWA.SG_events, title = "Extreme temperature timeline, Senegal and Gambia")

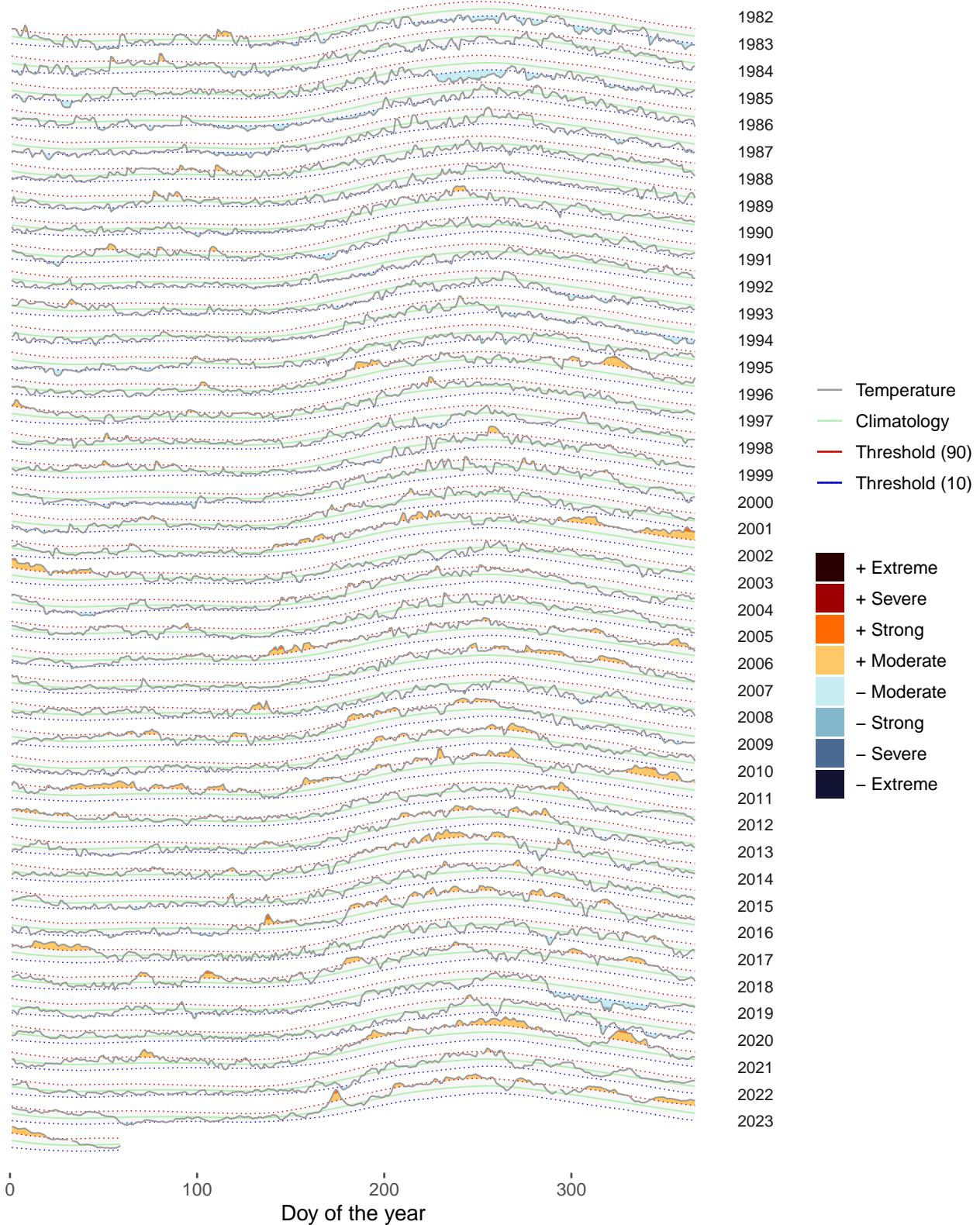
```

## Extreme temperature timeline, Senegal and Gambia



```
horizon_plot(NWA.M_events, title = "Extreme temperature timeline, Northern Mauritania")
```

## Extreme temperature timeline, Northern Mauritania



Hovmöller diagramme of the region ('Hov') indicated on the map:

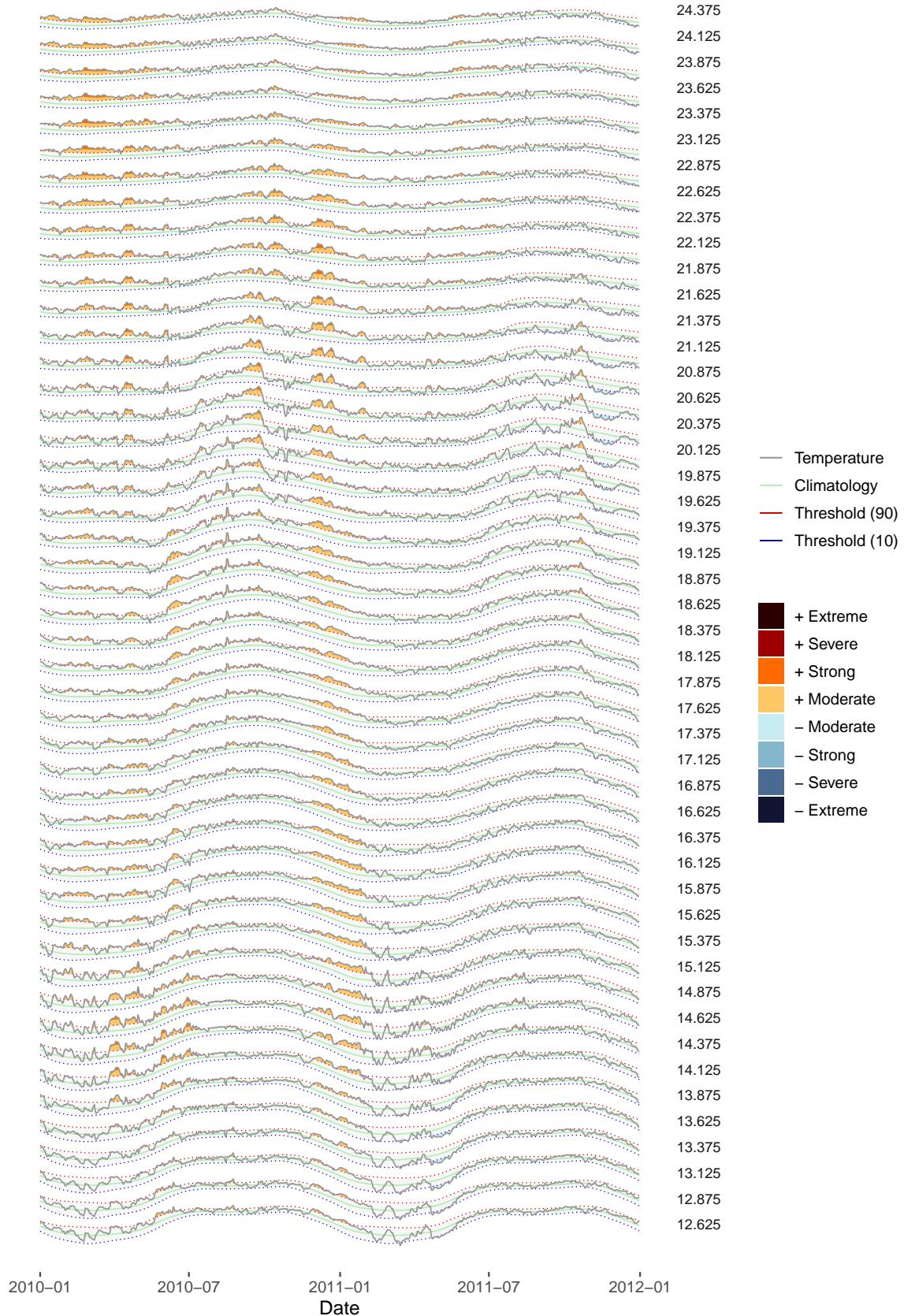
```
NWA.Hov <- fread(files[[4]]) |>
  filter(between(lon, bbox["NWA.Hov", "lonmin"], bbox["NWA.Hov", "lonmax"]),
         between(lat, bbox["NWA.Hov", "latmin"], bbox["NWA.Hov", "latmax"])) |>
  dplyr::group_by(t, lat) |>
  dplyr::summarise(temp = mean(temp), .groups = "drop")

NWA.Hov_events <- plyr::ddply(.data = NWA.Hov, .variables = c("lat"),
                               .fun = thresh_fun, .parallel = TRUE) |>
  filter(between(t, "2010-01-01", "2011-12-31")) |>
  mutate(lat = as_factor(lat))

## Warning in setup_parallel(): No parallel backend registered

hovmoller_horizon_plot(NWA.Hov_events, title = "Extreme temperature timeline, Canary")
```

## Extreme temperature timeline, Canary



## South-eastern Arabian Sea

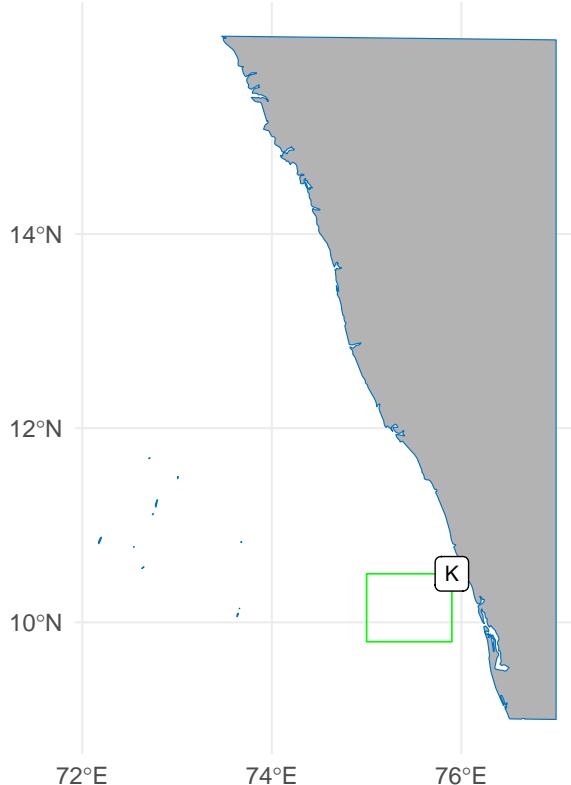
```
SEAS_bbox <- bbox_fun("SEAS")
SEAS.K_bbox <- bbox_fun("SEAS.K")

roi_cropped <- world |>
  st_crop(SEAS_bbox)

## Warning: attribute variables are assumed to be spatially constant throughout
## all geometries

ggplot() +
  geom_sf(data = roi_cropped, colour = "#0070C0", fill = "grey70") +
  geom_sf(data = SEAS.K_bbox, fill = NA, colour = "green", linewidth = 0.3) +
  geom_label(data = bbox[15,],
    aes(lonmax, latmax,
        label = c("K")),
    colour = "black", size = 2.8) +
  scale_y_continuous(breaks = seq(10, 14, by = 2)) +
  scale_x_continuous(breaks = seq(70, 76, by = 2)) +
  labs(x = NULL, y = NULL,
       title = "Southeast Arabian Sea",
       subtitle = NULL) +
  theme_minimal()
```

Southeast Arabian Sea



```
SEAS.K <- fread(files[[5]]) |>
  filter(between(lon, bbox["SEAS.K", "lonmin"], bbox["SEAS.K", "lonmax"]),
         between(lat, bbox["SEAS.K", "latmin"], bbox["SEAS.K", "latmax"])) |>
  dplyr::group_by(t) |>
```

```
dplyr::summarise(temp = mean(temp), .groups = "drop")
SEAS.K_events <- thresh_fun(SEAS.K)
horizon_plot(SEAS.K_events, title = "Extreme temperature timeline, Kerala upwelling cell")
```

## Extreme temperature timeline, Kerala upwelling cell

