NicheMapR and DEB theory I: the microclimate and ectotherm models

Michael Kearney

2019-04-04

Contents

Overview

This document runs simulations illustrating the microclimate model and ectotherm model functions of the NicheMapR package. Another document (part II) illustrates the DEB functions of the NicheMapR package including their integration with the ectotherm model.

Installing NicheMapR and associated packages

Below is the code to install the latest (beta) version of NicheMapR (see Kearney and Porter 2017) directly from github, as well as the microclima package (see Maclean et al. 2019) which has some complementary functions for computing microclimates. It also installs the RNCEP package (Kemp et al. 2012) which provides 6-hourly historical input weather data estimates for anywhere in the world, as well as the Climate Research Unit's (CRU) monthly global climate data (New et al. 2002). You may also install previous non-beta releases of NicheMapR from https://github.com/mrke/NicheMapR/releases Note that to install NicheMapR from github on a Windows machine you will also need to have Rtools installed, which can be found at https://cran.r-project.org/bin/windows/Rtools/

On Linux you may run into trouble when the installation process tries to install the package 'ncdf4'. If so, Google for help but one option that might work is to run the following at the terminal:

```
sudo apt-get install libnetcdf-dev
```

To install on a mac you will need to make sure you have a Fortran compiler installed. If you run the following two lines in the terminal, it should work:

```
curl -O http://r.research.att.com/libs/gfortran-4.8.2-darwin13.tar.bz2
sudo tar fvxj gfortran-4.8.2-darwin13.tar.bz2 -C /
```

Finally, you may need to reinstall a package called 'rcurl' to get 'microclima' to install properly.

```r
install.packages("devtools")
install.packages("RNCEP")
library(devtools)  # load the devtools package
install_github("mrke/NicheMapR")
install_github("ilyamaclean/microclima")
```

```
library(NicheMapR)  # load the NicheMapR package
get.global.climate()  # this will download and unzip a 0.5 gig global monthly climate data
```

Run the microclimate model for the mean day of each month

Run the microclimate model for Brest from the global monthly climate, with all default settings and extract the results.

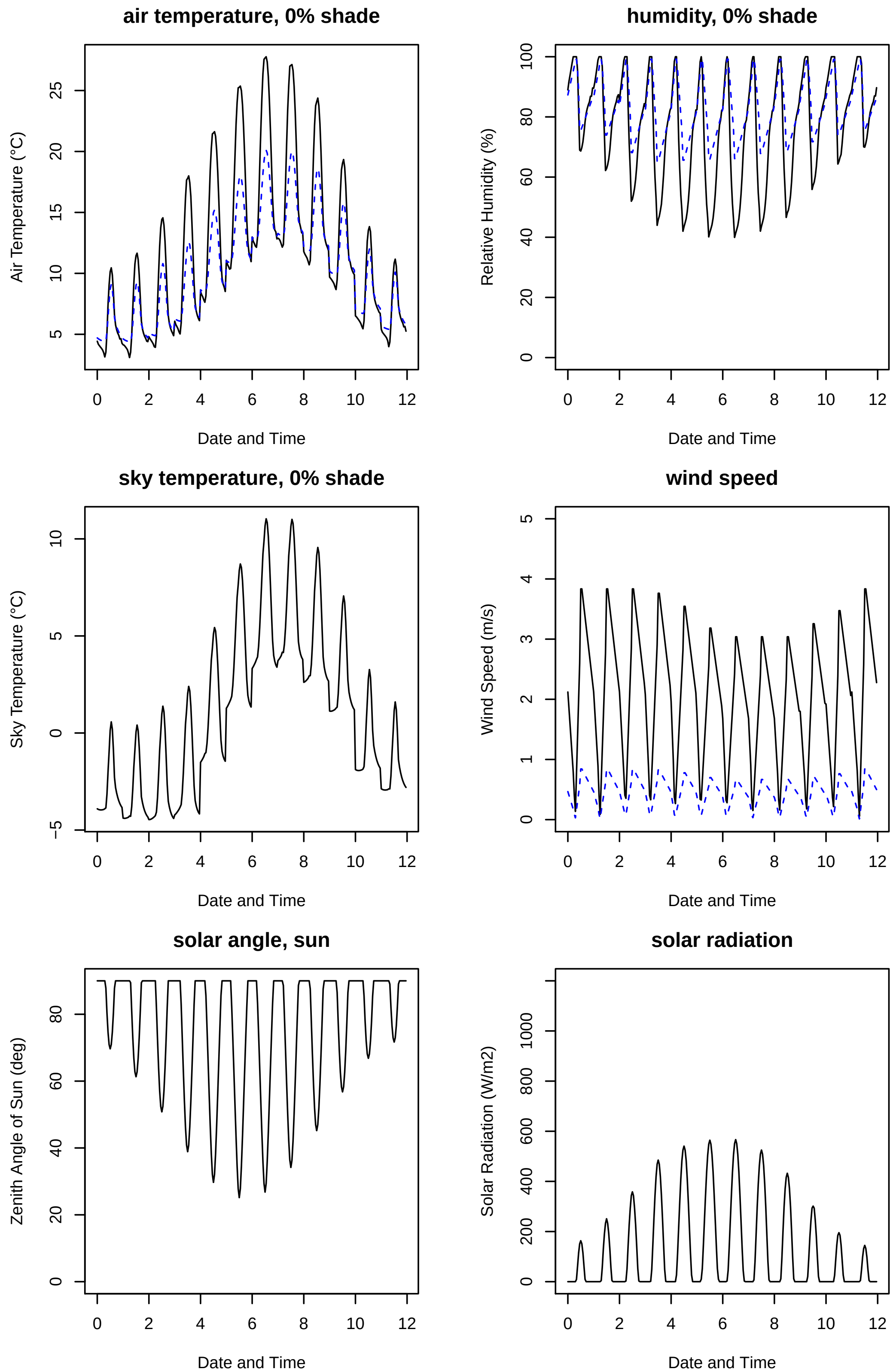
```
# load packages
library(NicheMapR)
library(knitr)  # this is to make nice-looking tables within the R Markdown document

loc <- c(-4.508, 48.427)  # set location - decimal degrees 'c(long, lat)'

# call the microclimate model, global climate database
# implementation
micro <- micro_global(loc = loc)

metout <- as.data.frame(micro$metout)  # above ground microclimatic conditions, min shade
shadmet <- as.data.frame(micro$shadmet)  # above ground microclimatic conditions, max shade
soil <- as.data.frame(micro$soil)  # soil temperatures, minimum shade
shadsoil <- as.data.frame(micro$shadsoil)  # soil temperatures, maximum shade

# append mock dates
days <- rep(seq(1, 12), 24)
days <- days[order(days)]
dates <- days + metout$TIME/60/24 - 1  # dates for hourly output
dates2 <- seq(1, 12, 1)  # dates for daily output
plotmetout <- cbind(dates, metout)
plotsoil <- cbind(dates, soil)
plotshadmet <- cbind(dates, shadmet)
plotshadsoil <- cbind(dates, shadsoil)

# extract shade values for plot labelling
minshade <- micro$minshade
maxshade <- micro$maxshade
```

Plot the microclimate model output

The following code plots the aboveground conditions under the minimum shade scenario (full sun).

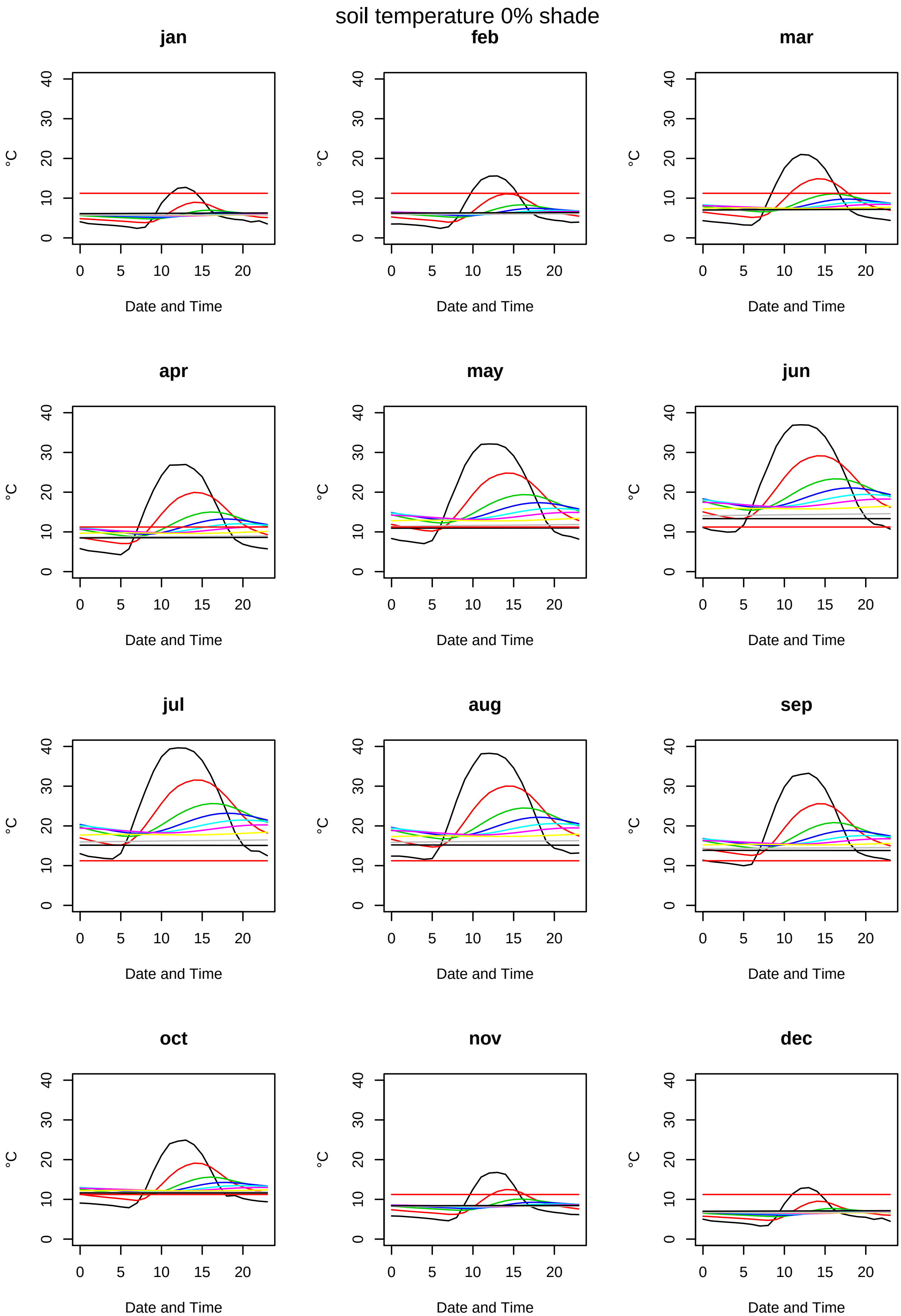
```
# plotting above-ground conditions in minimum shade
par(mfrow = c(3, 2))  # three rows of two columns
par(oma = c(2, 1, 1, 2) + 1)  # margin spacing
par(mar = c(2, 2, 1, 1) + 2)  # margin spacing
par(mgp = c(3, 1, 0))  # margin spacing
with(plotmetout, {
    plot(TALOC ~ dates, xlab = "Date and Time", ylab = "Air Temperature (°C)",
        type = "l", main = paste("air temperature, ", minshade,
            "% shade", sep = ""))
})
with(plotmetout, {
    points(TAREF ~ dates, xlab = "Date and Time", ylab = "Air Temperature (°C)",
        type = "l", lty = 2, col = "blue")
```

```r
})
with(plotmetout, {
    plot(RHLOC ~ dates, xlab = "Date and Time", ylab = "Relative Humidity (%)",
        type = "l", ylim = c(0, 100), main = paste("humidity, ",
            minshade, "% shade", sep = ""))
})
with(plotmetout, {
    points(RH ~ dates, xlab = "Date and Time", ylab = "Relative Humidity (%)",
        type = "l", col = "blue", lty = 2, ylim = c(0, 100))
})
with(plotmetout, {
    plot(TSKYC ~ dates, xlab = "Date and Time", ylab = "Sky Temperature (°C)",
        type = "l", main = paste("sky temperature, ", minshade,
            "% shade", sep = ""))
})
with(plotmetout, {
    plot(VREF ~ dates, xlab = "Date and Time", ylab = "Wind Speed (m/s)",
        type = "l", main = "wind speed", ylim = c(0, 5))
})
with(plotmetout, {
    points(VLOC ~ dates, xlab = "Date and Time", ylab = "Wind Speed (m/s)",
        type = "l", lty = 2, col = "blue")
})
with(plotmetout, {
    plot(ZEN ~ dates, xlab = "Date and Time", ylab = "Zenith Angle of Sun (deg)",
        type = "l", main = "solar angle, sun", ylim = c(0, 90))
})
with(plotmetout, {
    plot(SOLR ~ dates, xlab = "Date and Time", ylab = "Solar Radiation (W/m2)",
        type = "l", main = "solar radiation", ylim = c(0, 1200))
})
```


air temperature, 0% shade
Air Temperature (°C)
Date and Time
humidity, 0% shade
Relative Humidity (%)
Date and Time
sky temperature, 0% shade
Sky Temperature (°C)
Date and Time
wind speed
Wind Speed (m/s)
Date and Time
solar angle, sun
Zenith Angle of Sun (deg)
Date and Time
solar radiation
Solar Radiation (W/m2)
Date and Time

The next code plots daily soil temperature for middle day of each at each month for minimum shade.

```
par(mfrow = c(4, 3))  # three four of 1 columns
months <- c("jan", "feb", "mar", "apr", "may", "jun", "jul",
    "aug", "sep", "oct", "nov", "dec")
DOYS <- unique(metout$DOY)
for (j in 1:12) {
    plotsoil <- subset(soil, DOY == DOYS[j])
    for (i in 1:10) {
        if (i == 1) {
            plot(plotsoil[, 2]/60, plotsoil[, i + 2], xlab = "Date and Time",
                ylab = "°C", col = i, type = "l", ylim = c(0,
                  40), main = months[j])
        } else {
            points(plotsoil[, 2]/60, plotsoil[, i + 2], xlab = "Date and Time",
                ylab = "Soil Temperature
    (°C)", col = i,
                type = "l")
        }
    }
}
mtext(paste0("soil temperature ", minshade, "% shade"), side = 3,
    line = -1.5, outer = TRUE)
```


soil temperature 0% shade
jan
feb
mar
apr
may
jun
jul
aug
sep
oct
nov
dec
°C
0 10 20 30 40
0 5 10 15 20
Date and Time

Run the microclimate model with the NCEP historical daily weather data for 2013-2017

This section runs the microclimate model using the NCEP weather data, which is 6-hourly global 2.5 degree (~250 km) resolution data set of a suite of atmospheric variables. The data can be queried via the R package RNCEP (Kemp et al. 2012). We have developed scripts to disaggregate the NCEP data to hourly and downscale it to a finer spatial resolution using the 'microclima' package together with the 'elevatr' package (Kearney et al. in prep.). This adjustment includes elevation effects (via adiabatic lapse rates), coastal effects, cold air drainage and topographic effects (e.g. hill shade). The main inaccuracies will be due to rainfall, which remains at the 250 km resolution (but a vector of local hourly rainfall can be passed to the function and it will use that rainfall instead).

The following code runs the 'micro_ncep' function for Brest over the years 2013 to 2017. It will take a while to download all the NCEP data (you can download the data locally and run it from that, specifiying the folder it is in via the argument 'spatial', to speed things up).

```
loc <- c(-4.508, 48.427)  # set location - decimal degrees 'c(long, lat)'

# call the microclimate model, global climate database
# implementation
dstart <- "01/01/2013"
dfinish <- "31/12/2017"

# set depths and height to simulate
DEP <- c(0, 2.5, 5, 10, 15, 20, 30, 50, 100, 200)  # depths to simulate (cm)
Usrhyt <- 0.01  # height of midpoint of animal (m)

# run the microclimate model and extract some output for
# plotting
micro <- micro_ncep(loc = loc, dstart = dstart, dfinish = dfinish,
    DEP = DEP, soilgrids = 1, runshade = 1, Usrhyt = Usrhyt)
```

```
## downloading DEM via package elevatr
## extracting soil texture data from SoilGrids
## downloading weather data with package RNCEP via package microclima
## computing radiation and elevation effects with package microclima
## Extracting rainfall data from NCEP
## Downscaling radiation and wind speed
## Calculating elevation and cold-air drainage effects
## running microclimate model for  1826  days from  2013-01-01  to  2017-12-31 23:00:00  at site  long
##    user  system elapsed
##   74.58    0.29   76.09
```

```
# save the results for later
save(micro, file = "micro.Rda")
# load('micro.Rda') # uncomment this and comment out the two
# lines above once micro_ncep has run

metout <- as.data.frame(micro$metout)  # above ground microclimatic conditions, min shade
shadmet <- as.data.frame(micro$shadmet)  # above ground microclimatic conditions, max shade
soil <- as.data.frame(micro$soil)  # soil temperatures, minimum shade
shadsoil <- as.data.frame(micro$shadsoil)  # soil temperatures, maximum shade

# extract dates
dates <- micro$dates
dates2 <- micro$dates2
```

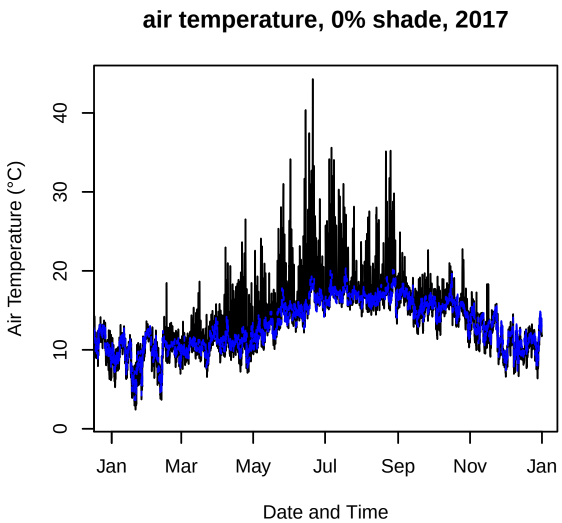
```
plotmetout <- cbind(dates, metout)
plotsoil <- cbind(dates, soil)
plotshadmet <- cbind(dates, shadmet)
plotshadsoil <- cbind(dates, shadsoil)

# extract shade values for plot labelling
minshade <- micro$minshade
maxshade <- micro$maxshade
```

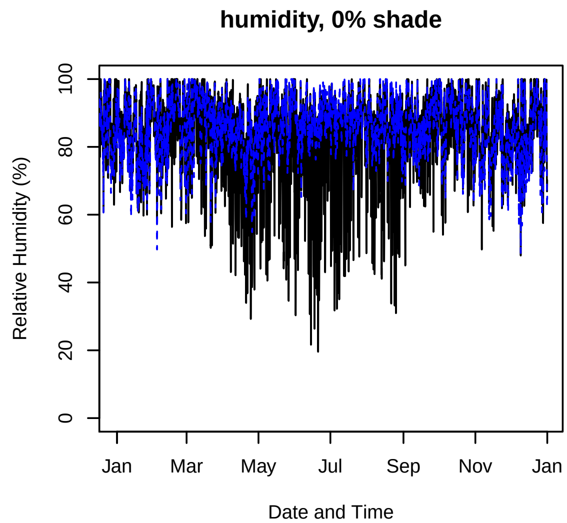
Plot the microclimate model output

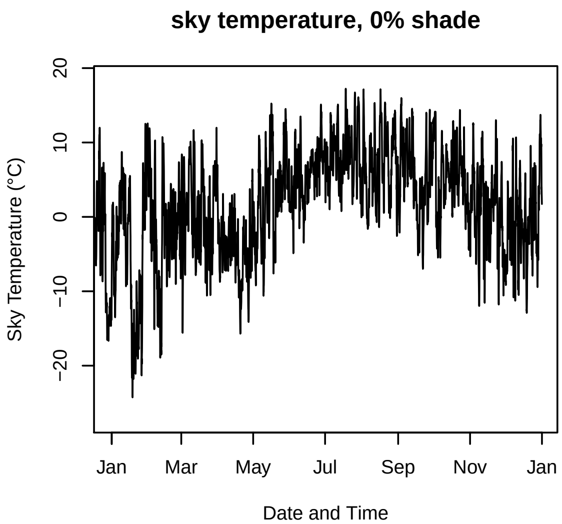
Plotting the aboveground conditions under the minimum shade scenario (full sun) for 2017.

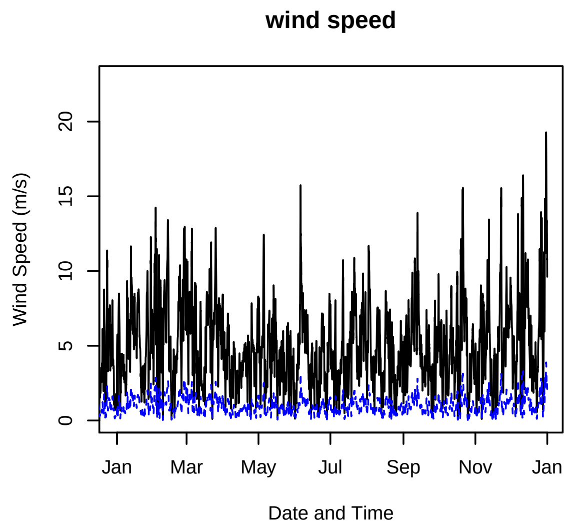
```
par(mfrow = c(3, 2))  # three rows of two columns
# plotting above-ground conditions in minimum shade, 2017
xlim <- c(as.POSIXct("2017-01-01"), as.POSIXct("2017-12-31"))
with(plotmetout, {
    plot(TALOC ~ dates, xlim = xlim, xlab = "Date and Time",
        ylab = "Air Temperature (°C)", type = "l", main = paste("air temperature, ",
            minshade, "% shade, 2017", sep = ""))
})
with(plotmetout, {
    points(TAREF ~ dates, xlab = "Date and Time", ylab = "Air Temperature (°C)",
        type = "l", lty = 2, col = "blue")
})
with(plotmetout, {
    plot(RHLOC ~ dates, xlim = xlim, xlab = "Date and Time",
        ylab = "Relative Humidity (%)", type = "l", ylim = c(0,
            100), main = paste("humidity, ", minshade, "% shade",
            sep = ""))
})
with(plotmetout, {
    points(RH ~ dates, xlab = "Date and Time", ylab = "Relative Humidity (%)",
        type = "l", col = "blue", lty = 2, ylim = c(0, 100))
})
with(plotmetout, {
    plot(TSKYC ~ dates, xlim = xlim, xlab = "Date and Time",
        ylab = "Sky Temperature (°C)", type = "l", main = paste("sky temperature, ",
            minshade, "% shade", sep = ""))
})
with(plotmetout, {
    plot(VREF ~ dates, xlim = xlim, xlab = "Date and Time", ylab = "Wind Speed (m/s)",
        type = "l", main = "wind speed")
})
with(plotmetout, {
    points(VLOC ~ dates, xlab = "Date and Time", ylab = "Wind Speed (m/s)",
        type = "l", lty = 2, col = "blue")
})
with(plotmetout, {
    plot(ZEN ~ dates, xlim = xlim, xlab = "Date and Time", ylab = "Zenith Angle of Sun (deg)",
        type = "l", main = "solar angle, sun")
})
with(plotmetout, {
    plot(SOLR ~ dates, xlim = xlim, xlab = "Date and Time", ylab = "Solar Radiation (W/m2)",
```

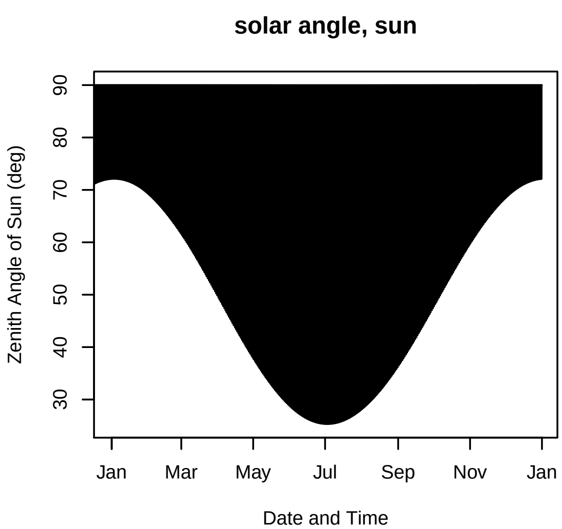
```
        type = "l", main = "solar radiation")
})
```

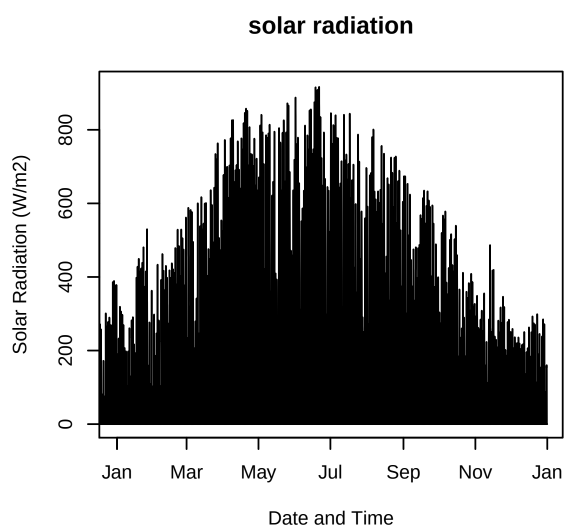

air temperature, 0% shade, 2017
Air Temperature (°C)
0
10
20
30
40
Jan
Mar
May
Jul
Sep
Nov
Jan
Date and Time


humidity, 0% shade
Relative Humidity (%)
0
20
40
60
80
100
Jan
Mar
May
Jul
Sep
Nov
Jan
Date and Time


sky temperature, 0% shade
Sky Temperature (°C)
−20
−10
0
10
20
Jan
Mar
May
Jul
Sep
Nov
Jan
Date and Time

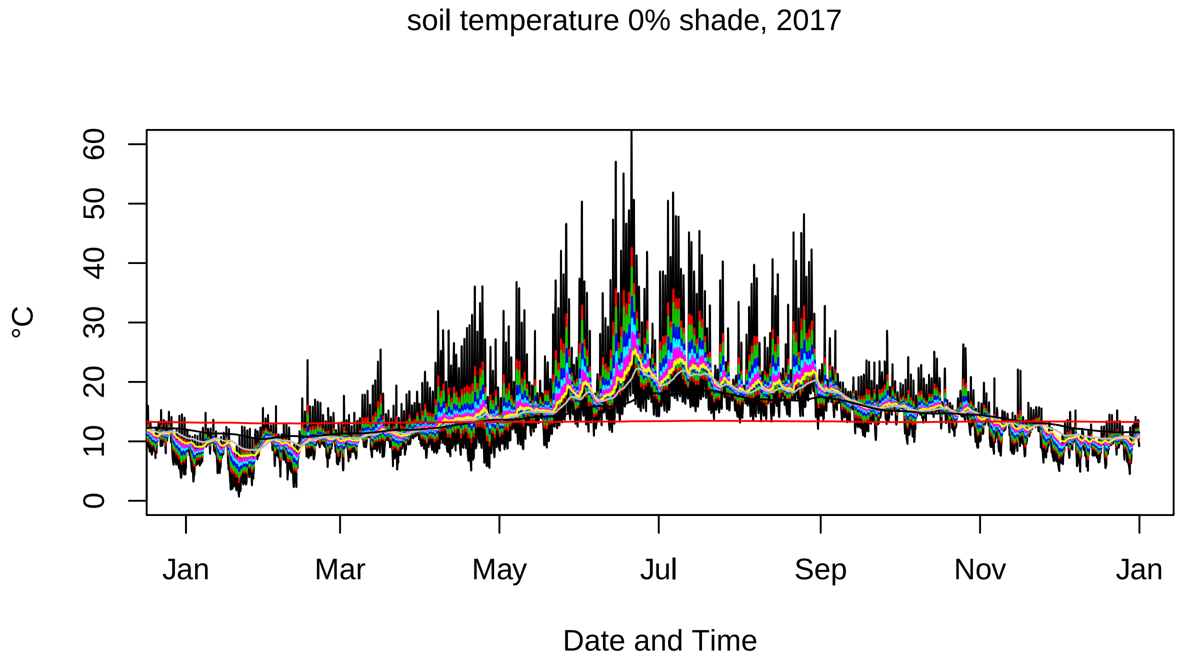

wind speed
Wind Speed (m/s)
0
5
10
15
20
Jan
Mar
May
Jul
Sep
Nov
Jan
Date and Time


solar angle, sun
Zenith Angle of Sun (deg)
30
40
50
60
70
80
90
Jan
Mar
May
Jul
Sep
Nov
Jan
Date and Time


solar radiation
Solar Radiation (W/m2)
0
200
400
600
800
Jan
Mar
May
Jul
Sep
Nov
Jan
Date and Time

Plotting daily soil temperature over the year 2017 at each depth for minimum shade.

```
par(mfrow = c(1, 1))  # three four of 1 columns
for (i in 1:10) {
    if (i == 1) {
        plot(plotsoil[, 1], plotsoil[, i + 3], xlim = xlim, xlab = "Date and Time",
            ylab = "°C", col = i, type = "l", ylim = c(0, 60))
    } else {
        points(plotsoil[, 1], plotsoil[, i + 3], xlab = "Date and Time",
            ylab = "Soil Temperature
    (°C)", col = i, type = "l")
    }
}
mtext(paste0("soil temperature ", minshade, "% shade, 2017"),
    side = 3, line = -1.5, outer = TRUE)
```



Run the ectotherm model to compute the heat budget

This last section runs the ectotherm model of NicheMapR for the sand lizard at the site simulated over 2013 to 2017. The ectotherm model contains the fundamental equations for solving the heat budget, i.e. determining the body temperature that results from a given radiation, convection, conduction and evaporative heat balance. The model includes sophisticated algorithms for behavioural thermoregulation and activity patterns, allowing specification of daily activity phase (nocturnal, diurnal, crepuscular), whether it can seek shade, climb or move underground, and what its body temperature thresholds are for various responses.

First specify some morphological parameters - the shape and solar absorptivity.

```
alpha_min <- 0.8  # minimum solar absorbtivity (dec %)
alpha_max <- 0.85  # maximum solar absorbtivity (dec %)
shape <- 3  # lizard
```

Now specify the thermal physiology and behaviour.

```
T_RB_min <- 15  # min Tb at which they will attempt to leave retreat
T_B_min <- 20  # min Tb at which leaves retreat to bask
T_F_min <- 25  # minimum Tb at which activity occurs
T_F_max <- 40  # maximum Tb at which activity occurs
T_pref <- 33.8  # preferred Tb (will try and regulate to this)
CT_max <- 42  # critical thermal minimum (affects choice of retreat)
CT_min <- 0.7  # critical thermal maximum (affects choice of retreat)
mindepth <- 2  # min depth (node, 1-10) allowed
maxdepth <- 10  # max depth (node, 1-10) allowed
shade_seek <- 1  # shade seeking?
burrow <- 1  # can it burrow?
climb <- 0  # can it climb to thermoregulate?
minshade <- 0  # min available shade?
maxshade <- 90  # min available shade?
nocturn <- 0  # nocturnal activity
crepus <- 0  # crepuscular activity
diurn <- 1  # diurnal activity
```

Run the ectotherm model and retrieve the output.

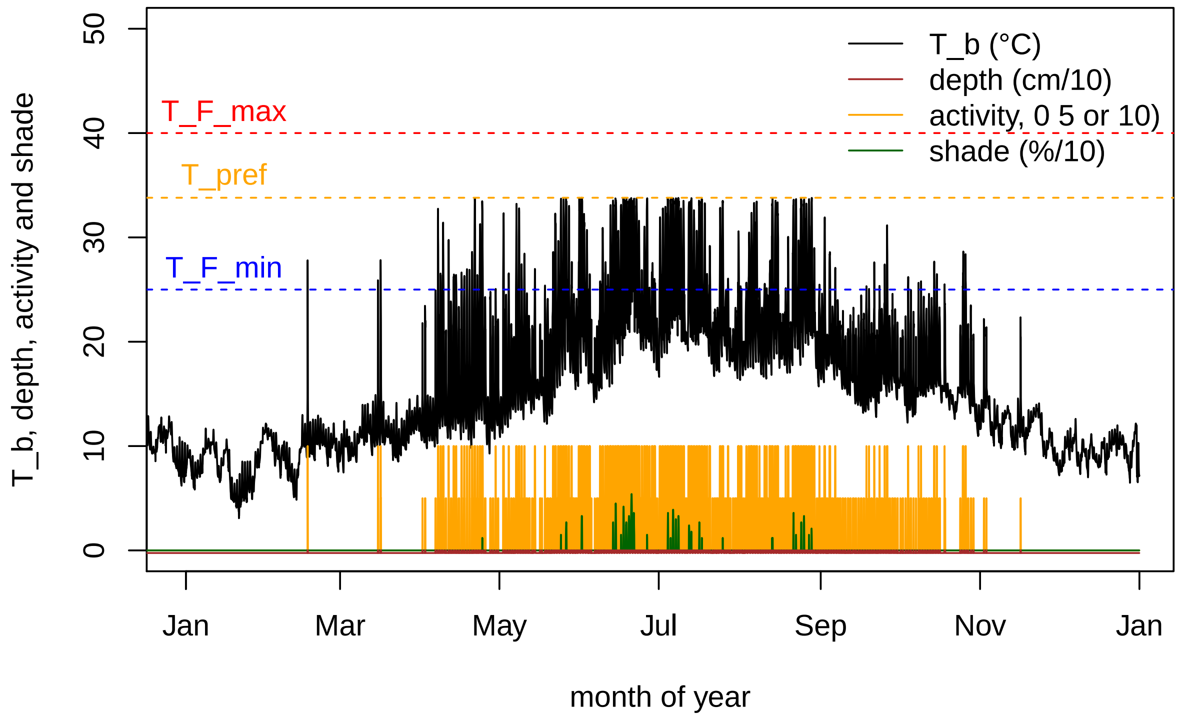
```
ecto <- ectotherm(alpha_max = alpha_max, alpha_min = alpha_min,
    T_F_max = T_F_max, T_F_min = T_F_min, T_B_min = T_B_min,
    T_RB_min = T_RB_min, CT_max = CT_max, CT_min = CT_min, T_pref = T_pref,
    mindepth = mindepth, maxdepth = maxdepth, shade_seek = shade_seek,
    burrow = burrow, climb = climb, minshade = minshade, nocturn = nocturn,
    diurn = diurn, crepus = crepus, maxshades = rep(maxshade,
        length(micro$MAXSHADES)))

# retrieve output
environ <- as.data.frame(ecto$environ)  # behaviour, Tb and environment
enbal <- as.data.frame(ecto$enbal)  # heat balance outputs
masbal <- as.data.frame(ecto$masbal)  # mass balance outputs
environ <- cbind(environ, metout$SOLR)  # add solar radiation for activity window plots
colnames(environ)[ncol(environ)] <- "Solar"

# append mock dates
environ <- as.data.frame(cbind(dates, environ))
masbal <- as.data.frame(cbind(dates, masbal))
enbal <- as.data.frame(cbind(dates, enbal))
```

Plot the ectotherm model results

Finally, we can plot the results, just for 2017. The first plot shows the body temperature trace as well as indicating when the animal was active (0 = inactive, 1 = basking, 2 = foraging, multiplied by 5 on the graph to make it clearer), how much shade it needed (divided by 10 for plotting), and how deep it went underground (again divided by 10).

```
par(mfrow = c(1, 1))  # two rows of 1 columns
with(environ, plot(TC ~ dates, xlim = xlim, ylab = "T_b, depth, activity and shade",
    xlab = "month of year", ylim = c(0, 50), type = "l"))
with(environ, points(ACT * 5 ~ dates, type = "l", col = "orange"))
with(environ, points(SHADE/10 ~ dates, type = "l", col = "dark green"))
with(environ, points(DEP/10 ~ dates, type = "l", col = "brown"))
abline(T_F_max, 0, lty = 2, col = "red")
abline(T_F_min, 0, lty = 2, col = "blue")
```

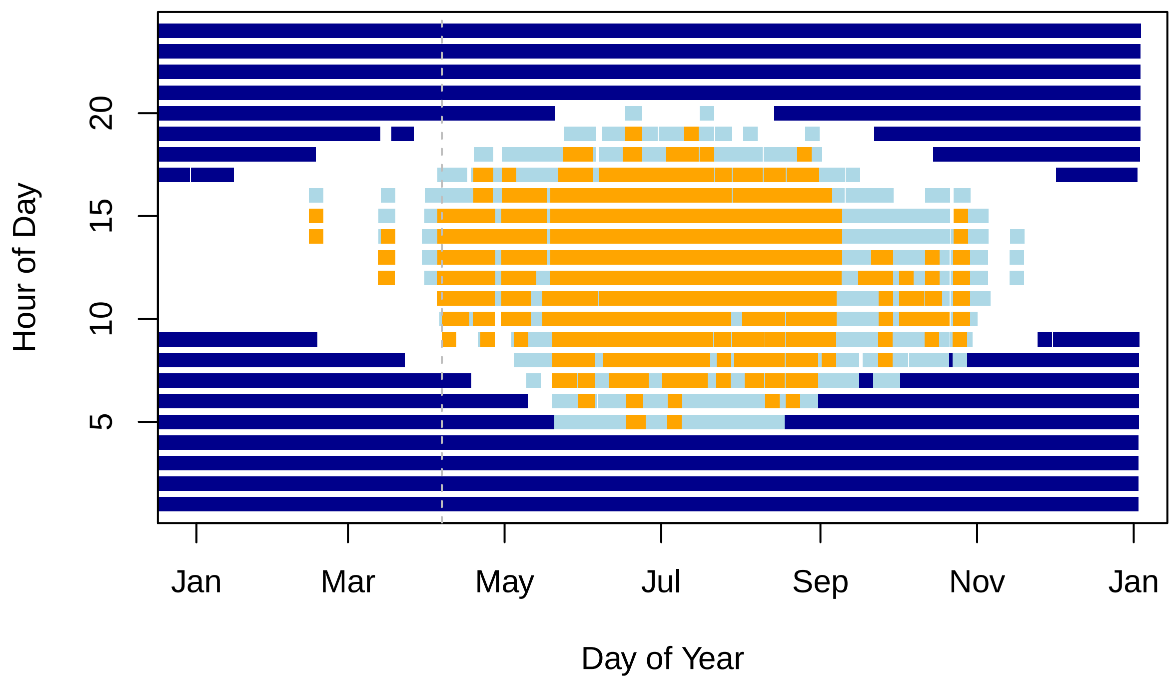
```r
abline(T_pref, 0, lty = 2, col = "orange")
text(xlim[1] + 15 * 3600 * 24, T_F_max + 2, "T_F_max", col = "red")
text(xlim[1] + 15 * 3600 * 24, T_F_min + 2, "T_F_min", col = "blue")
text(xlim[1] + 15 * 3600 * 24, T_pref + 2, "T_pref", col = "orange")
legend(x = xlim[2] - 120 * 3600 * 24, y = T_F_max + 12, legend = c("T_b (°C)",
    "depth (cm/10)", "activity, 0 5 or 10)", "shade (%/10)"),
    col = c("black", "brown", "orange", "dark green"), lty = rep(1,
        4), bty = "n")
```



The second plot shows the seasonal activity window, with day of year along the x and time of day along the y. Night hours are indicated in dark blue, and show the photoperiod change through the year. The light blue points show the periods of basking and the gold points show when activity was possible. This workshop (vertical line) is right at the start of the main activity season for this species, at least in 2017.

```r
# seasonal activity plot (dark blue = night, light blue =
# basking, orange = foraging)
forage <- subset(environ, ACT == 2)
bask <- subset(environ, ACT == 1)
night <- subset(environ, Solar < 1)
day <- subset(environ, Solar >= 1)
with(night, plot(TIME ~ dates, xlim = xlim, ylab = "Hour of Day",
    xlab = "Day of Year", pch = 15, cex = 1, col = "dark blue"))
# nighttime hours
with(bask, points((TIME - 1) ~ dates, pch = 15, cex = 1, col = "light blue"))  # basking T_bs
with(forage, points((TIME - 1) ~ dates, pch = 15, cex = 1, col = "orange"))  # foraging T_bs
```

```
abline(v = as.POSIXct("2017-04-07"), col = "grey", lty = 2)  # date of the workshop
```



References

Kearney, M. R., and Porter, W. P. (2017). NicheMapR - an R package for biophysical modelling: the microclimate model. Ecography. doi:10.1111/ecog.02360

Kemp M. U., Emiel van Loon E., Shamoun-Baranes J. & Bouten W. (2012) RNCEP: global weather and climate data at your fingertips: RNCEP. Methods in Ecology and Evolution 3 , 65–70.

Maclean I. M. D., Mosedale J. R. & Bennie J. J. (2018) Microclima: an R package for modelling meso- and microclimate. Methods in Ecology and Evolution doi: 10.1111/2041-210X.13093.

New M., Lister D., Hulme M. & Makin I. (2002) A high-resolution data set of surface climate over global land areas. Climate Research 21 , 1–25.