Methods
The r4photobiology suite: sun angles and day length

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Introduction

This article is the second in a series of articles describing the different packages in the R4Photobiology suite. The first article in the series gave an overall description of the suite and the overall design (Aphalo 2015). Starting from the present article, each article in this series will describe features related to individual classes of problems encountered in photobiological research.

There are several different reasons why you may need in your own research to do the calculations described in this article. Local time very rarely agrees with solar time, as solar time varies continuously with E/W longitude while time-zones are discrete and usually 1 h-wide. There is in addition the use of daylight saving time-shifts which in some cases are of more than 1 h. In extreme cases local-time noon may occur as much as 2 h earlier or 3 h later than solar noon (Figure 8.1). When doing UV-B supplementation experiments outdoors, for realism we need to center the period of artificial UV-irradiation on solar noon. Even if we do not use UV supplementation, it is very useful in the case of plants growing in sunlight to report sampling times according to solar time, as gene-expression and physiological activity vary throughout the photoperiod as well as the more obvious circadian leaf movements.

Day and night lengths themselves depend mainly on latitude and date but being able to include the exact location and the actual angular elevation of nearby obstacles like mountains and buildings allows day and night lengths at a specific location to be estimated with greater precision. For some experiments this is important.

When studying photoperiodic responses of plants outdoors vs. in controlled environments it is good to keep in mind that irradiance increases gradually from dawn until sunrise and decreases gradually from sunset until dusk. The critical irradiances perceived as the boundaries of the photoperiod differ between plant species and only rarely correspond to the astronomical sunrise and sunset times usually used to define the daylight period (Takimoto and Ikeda 1961).

When hemispherical canopy images are available, being able to calculate the path of the sun across the sky allows the prediction of when sunflecks will occur on a given day and how long they will last. This type of information has been used to assess the light conditions under which different forest understorey plant species thrive.

The main focus of the 'r4photobiology' suite of R packages is the processing of spectral irradiance data required for quantification of radiation in photobiological research. There is in addition support for calculations related to tri-chromic vision and the position of the sun, and derived quantities such as day and night length. In the current article I describe functions from package 'photobiology' of my authorship, and of other R packages that can be used to calculate the position of the sun and day and night lengths on a certain date and at a given geographical location.

Definitions

The **solar elevation angle** is the angle measured from the horizon to the centre of the solar disk. When the sun is at the zenith its value is $\alpha = 90^{\circ}$. The **solar zenith angle** is the complement of the elevation angle. The zenith angle is measured downwards from the zenith, and abbreviated as θ and related

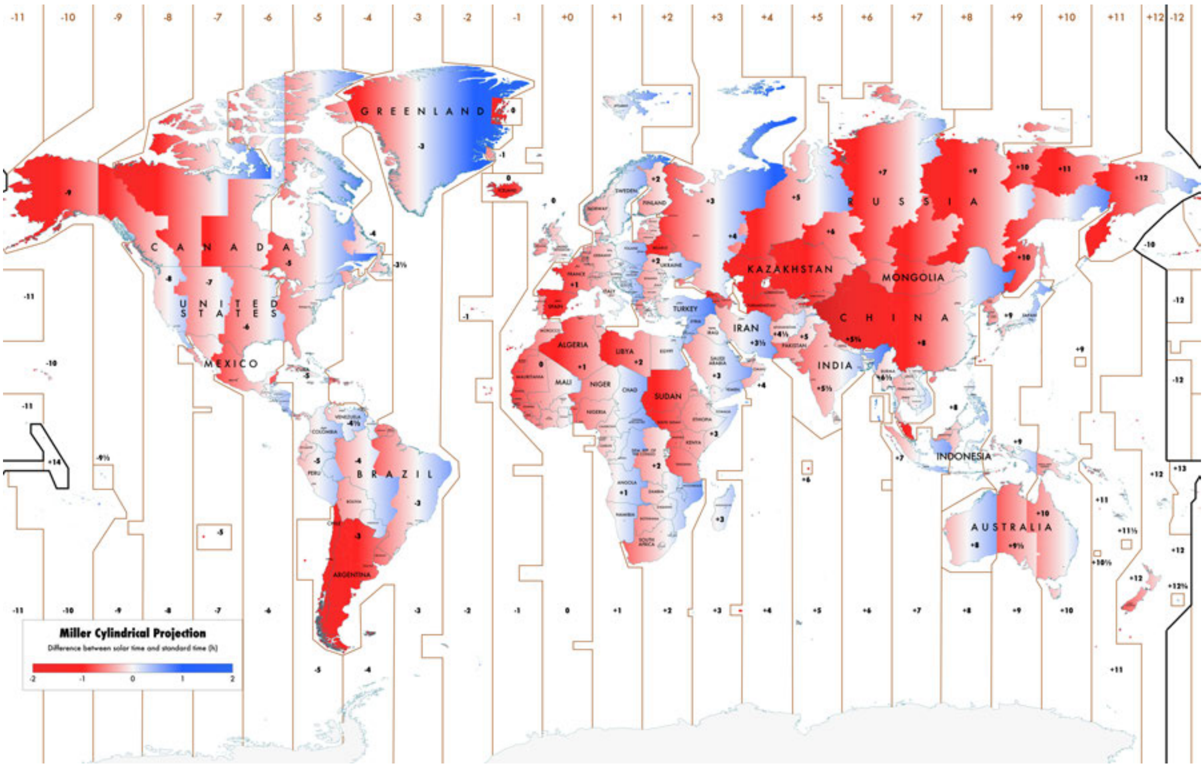


Figure 8.1: Map showing how much the standard local times differed from solar time across the world in 2015. This shift does not take into account the additional, usually -1 h-long shift due to daylight saving time that many countries implement during summer. The map is in the public domain (Maggiolo 2015) and also available through Wikimedia Commons.

to α such that $\alpha + \theta = 90^{\circ}$.

Sunset and sunrise are sometimes defined as the times at which the center of the solar disk is at the horizon—solar elevation angle is zero. Other definitions use other, slightly different, positions to describe these events, i.e. when the center of the solar disk is 0.5° below the horizon. Given that the diameter of the solar disk as seen from Earth is very slightly over 0.5°, this second definition is in practice given by the time when the upper rim of the solar disk is slightly below the horizon, in simpler words when the whole solar disk is occluded.

Twilight are the periods immediately before sunrise and immediately after sunset when, although the solar disk is occluded, sunlight scattered in the atmosphere still makes an important contribution to ambient light (Figure 8.2). In the morning the period of twilight starts at *dawn* and ends at *sunrise*. In the evening twilight starts at *sunset* and ends at *dusk*. There are different operational definitions for dusk and dawn, and although they are defined in terms of (negative) solar elevation angles (α), the definitions had their origin in practical problems. In order of negative elevations of increasing magnitude: a) **civil twilight** ($\alpha = -6^{\circ}$) enough light to see objects outdoors without need of artificial illumination, b) **nautical twilight** ($\alpha = -12^{\circ}$) enough light to make it possible to navigate using the horizon as a guide, and c) **astronomical twilight** ($\alpha = -18^{\circ}$), between dawn and dusk based on this definition (and in the absence of light pollution from artificial light sources) almost all astronomical observations are possible. In the summer, at latitudes $> 48.5^{\circ}$, there are periods when twilight lasts for the whole night.

In practice except at places where topography is completely flat and surrounding objects absent the effective horizon will be above the theoretical horizon, in other words the solar disk will appear later in the morning and/or occlude earlier in the evening than

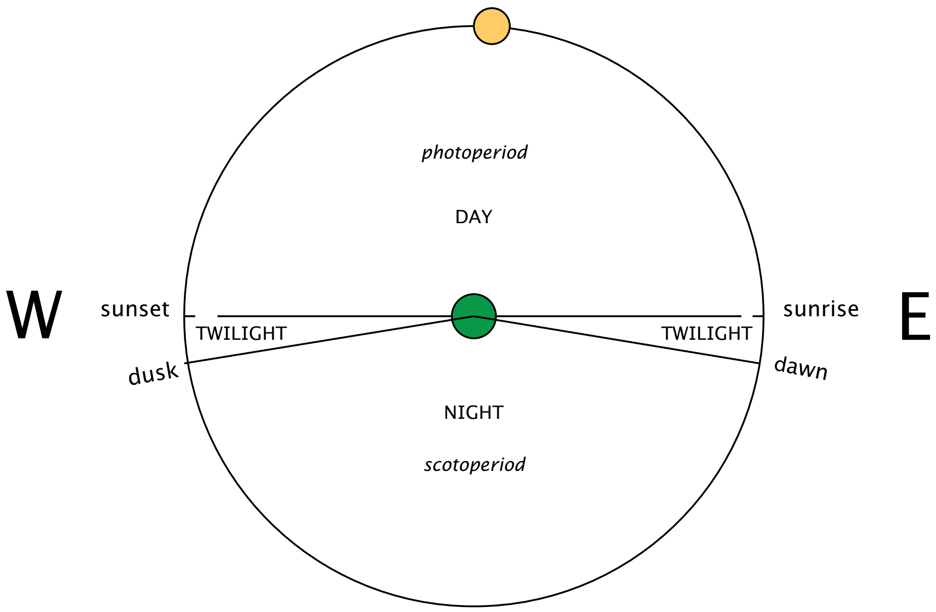


Figure 8.2: Diagram showing the apparent path of the Sun as seen by an observer at a fixed position on the Earth surface. The green disk represents the earth and the yellow disk the sun, E indicates the observer's East and W, West, the horizontal dashed line represents the observer's horizon. The angles between the horizon and the lines delimiting dawn and dusk will depend on the definition of twilight used, and are exaggerated to increase the clarity of the diagram.

when $\alpha = -0.5°$. Although non-standard, in field experiments, calculating the day length based of effective times of solar occlusion at the actual location of the experiment can be very useful.

All the times and angles described in this section can be calculated using functions defined in R package 'photobiology', although the current implementation accepts only a restricted range of dates from 1950 to 2050. To operate with geographic coordinates (geocodes) and times, other R packages will be used as an aid. The balance of this article describes how to do these calculations in practice.

Geographical coordinates

We can obtain geographical coordinates from GPS devices, maps—printed and digital—and by searching for locality names or addresses. For address searches, Google maps is a convenient tool. Package 'ggmap' (Kahle and Wickham 2013) defines functions not only for downloading and plotting maps and satellite images, but also for searching geographical coordinates based on addresses or locality names (Example 8.1).

Times and dates

Package 'lubridate' (Grolemund and Wickham 2011) makes it easy to work with dates and times in R (Examples 8.2 and 8.3). When working with *both dates and times* one should be extremely careful with the handling of time zones and daylight saving times (summer time). The default in R is in most cases to default to the time zone settings of the computer on which R is running. Time zone is passed through parameter `tz`. One should also distinguish between expressing a given time instant in a different time zone, and in calculating a new time instant so that the local time is the same in the new time zone as in the original time zone.

Box 8.1: Example code for obtaining geocodes for a location.

```
library(ggmap)
```

```
library(ggmap)
geocode("Helsinki, Finland")

##     lon   lat
## 1 24.94 60.17

geocode("Helsinki, Finland", output = "latlona")

##     lon   lat           address
## 1 24.94 60.17 helsinki, finland

geocode("Helsinki, Finland", output = "more")

##     lon   lat     type     loctype           address north south  east  west locality
## 1 24.94 60.17 locality approximate helsinki, finland  60.3 60.03 25.25 24.83 Helsinki
##   administrative_area_level_3 administrative_area_level_2 administrative_area_level_1
## 1                    Helsinki                    Helsinki                     Uusimaa
##   country
## 1 Finland
```

```
geocode("Viikinkaari 1, Helsinki, Finland", output = "latlona")

##     lon   lat                              address
## 1 25.02 60.23 viikinkaari 1, 00790 helsinki, finland

geocode("Viikinkaari 1, Helsinki, Finland", output = "more")

##     lon   lat           type loctype                                address north
## 1 25.02 60.23 street_address rooftop viikinkaari 1, 00790 helsinki, finland 60.23
##   south  east  west street_number       route locality administrative_area_level_3
## 1 60.22 25.02 25.02             1 Viikinkaari Helsinki                    Helsinki
##   country postal_code
## 1 Finland       00790
```

Day length

Plant photoperiodic responses depend on the length of the photoperiod. Natural photoperiod depends on latitude and day of the year. In addition, in may be of interest to obtain the times at solar noon, sunrise and sunset expressed in the locally used time coordinates or in universal time coordinates. All these values can be calculated with functions in R package 'photobiology' (Example 8.4). Plotting of the length of the day for the whole year at a certain location is also simple if one takes advantage of the recycling rules of the R language to create a vector of dates (Example 8.5). There are different standard definitions in use for twilight corresponding to different positions of the sun below the horizon that can sometimes be useful. More useful to those studying plants is the calculation of the sunset or sunrise times for solar elevations above the horizon corresponding to obstacles such as mountain ridges, nearby tall vegetation or buildings (Example 8.6).

Position of the sun

In addition to finding the times for a given position of the sun in the sky, we may be interested in calculating the position of the sun at a certain time, for example, the exact time

Box 8.2: Example code for obtaining and entering dates and times.

```
library(lubridate)

##
## Attaching package:  'lubridate'
## The following object is masked from 'package:base':
##
##     date
```

Current time can be obtained with function `now()`.

```
now()

## [1] "2016-06-19 17:55:28 UTC"

now(tz = "UTC")

## [1] "2016-06-19 17:55:28 UTC"

now(tz = "EET")

## [1] "2016-06-19 20:55:28 EEST"
```

Current date can be obtained with function `today()`.

```
today()

## [1] "2016-06-19"

today(tz = "UTC")

## [1] "2016-06-19"
```

It is also easy to convert strings into times or dates.

```
ymd_hms("2016-04-15 12:00:00", tz = "EET")

## [1] "2016-04-15 12:00:00 EEST"

ymd_hms("2016/04/15 12.00.00", tz = "EET")

## [1] "2016-04-15 12:00:00 EEST"

ymd_hms("20160415 120000", tz = "EET")

## [1] "2016-04-15 12:00:00 EEST"
```

Box 8.3: Example code for manipulating dates and times.

```
my.time <- mdy_hm("04/15/16 12:00", tz = "EET")
my.time

## [1] "2016-04-15 12:00:00 EEST"
```

When calculating the position of the sun, we may need to increment, decrement, or extract and replace components.

```
hour(my.time)

## [1] 12

day(my.time)

## [1] 15

days(my.time)

## [1] "1460710800d 0H 0M 0S"

wday(my.time)

## [1] 6

wday(my.time, label = TRUE)

## [1] Fri
## Levels: Sun < Mon < Tues < Wed < Thurs < Fri < Sat
```

```
my.time + minutes(10)

## [1] "2016-04-15 12:10:00 EEST"

my.time - hours(2)

## [1] "2016-04-15 10:00:00 EEST"

my.time + hours(0:5)

## [1] "2016-04-15 12:00:00 EEST" "2016-04-15 13:00:00 EEST" "2016-04-15 14:00:00 EEST"
## [4] "2016-04-15 15:00:00 EEST" "2016-04-15 16:00:00 EEST" "2016-04-15 17:00:00 EEST"
```


Box 8.4: Example code for calculation of day length, night length, and position of the sun at a given location.

```
library(photobiology)
```

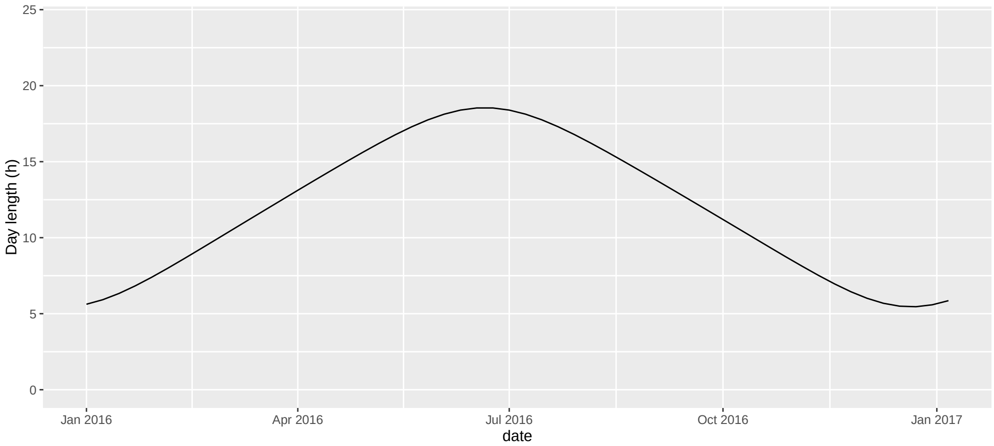
```
my.geocode <- geocode("Helsinki, Finland")
day_length(today(), tz = "EET", geocode = my.geocode)

## [1] 14.65

night_length(today(), tz = "EET", geocode = my.geocode)

## [1] 9.347

sunrise_time(today(),  tz = "EET", geocode = my.geocode)

## [1] "2016-04-18 06:00:43 EEST"

sunset_time(today(),  tz = "EET", geocode = my.geocode)

## [1] "2016-04-18 20:39:55 EEST"
```

Box 8.5: Example code for plotting of day length.

```
library(dplyr)
```

```
dl.df <- data_frame(date = lubridate::ymd("2016-01-01", tz = "EET") + weeks(0:53))
dl.df <- transform(dl.df,
                   day.length = day_length(date, geocode = geocode("Helsinki, Finland")))
```

```
ggplot(dl.df, aes(date, day.length)) +
   geom_line() + ylim(0,24) +
   labs(y = "Day length (h)")
```



Box 8.6: Example code for calculation of the time of occurrence of solar events.

Objects of class "source_spct" can contain geocode and time data as metadata. When they contain it, it is possible to directly calculate the position of the sun at the time and place of measurement.

```
my.location <- geocode("Helsinki, Finland")
my.date <- lubridate::ymd("2016-04-16", tz = "EET")
noon_time(my.date, my.location, tz = "EET")

## [1] "2016-04-16 13:20:20 EEST"

sunrise_time(my.date, my.location, tz = "EET")

## [1] "2016-04-16 06:06:31 EEST"

sunset_time(my.date, my.location, tz = "EET")

## [1] "2016-04-16 20:35:00 EEST"
```

For sunset and sunrise, by default the times returned are those when solar elevation is zero degrees. However, different standard twilight angles can be given by name to change this default.

```
sunset_time(my.date, my.location, twilight = "none", tz = "EET")

## [1] "2016-04-16 20:35:00 EEST"

sunset_time(my.date, my.location, twilight = "civil", tz = "EET")

## [1] "2016-04-16 21:29:32 EEST"

sunset_time(my.date, my.location, twilight = "nautical", tz = "EET")

## [1] "2016-04-16 22:33:30 EEST"

sunset_time(my.date, my.location, twilight = "astronomical", tz = "EET")

## [1] "2016-04-17 00:11:10 EEST"
```

Arbitrary angles expressed in degrees are also accepted as argument for `twilight`, for example to determine sun occlusion by an obstacle such as a nearby mountain or building that is 10° above the theoretical horizon we would use the following code.

```
sunset_time(my.date, my.location, twilight = 10, tz = "EET")

## [1] "2016-04-16 19:12:11 EEST"
```


and location when irradiance was measured. Additional values of interest can be the distance from the Sun to the Earth and the apparent diameter of the solar disc. All these values can be easily calculated (Example 8.7). Objects of the spectral classes defined in package 'photobiology' as described earlier (Aphalo 2015) can contain time and location metadata allowing these calculations (Example 8.8).

Resources

A web site dedicated to the `r4photobiology` suite of R packages, located at `http://www.r4photobiology.info/` provides installation instructions. Each of the packages contains one or more vignettes like User Guides and/or catalogues of the included data examples, and the individual methods, functions, operators and data objects have been documented with help pages accessible through R's built-in documentation system. A handbook on *Photobiological calculations with R* is being written by myself, Andreas Albert, Titta Kotilainen and T. Matthew Robson. A draft version will be made available on-line in late 2016, and the final version published by the end of 2016.

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The development of the suite has benefited from earlier work by many different people. From the point of view of R code development and coding, the packages and books written by Hadley Wickham and collaborators have been of enormous importance. It is also necessary to acknowledge the contributors to the development of R itself, and the openness of the whole R community for sharing information and tips and their willingness to help through on-line forums. From the perspective of photobiological calculations themselves, many members of the UV4Growth COST Action have contributed 'problems' with their questions, and/or data and use examples that have been very useful for the design and testing of the suite. Some people need to be mentioned specially for their contributions related to algorithms used for calculations and discussions about reliability and reproducibility: Andy McLeod, Lars Olof Björn, Lasse Ylianttila, T. Matthew Robson and Anders Lindfors where the main contributors on these aspect. Titta Kotilainen and T. Matthew Robson have been my *guinea pigs* always willing to give quick feedback on my sometimes not so wise design decisions and showing me new uses of my own code. Other members of the Action, specially the students attending the training schools, have contributed very useful feedback, sometimes in writing and other times with their questions and facial expressions during training events. Several companies and researchers have allowed the inclusion of their data in the suite. They are acknowledged in the documentation. There is one additional person to thank: Nigel Paul. A chat with him at one of the first UV4Growth meetings where we exchanged ideas about the need of making this type of calculations easier, and to improve the reliability and reproducibility of UV research with plants, was what led to my decision of spending a considerable proportion of my work (and free) time during the last three years on the development of the suite.

References

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Takimoto, A. and K. Ikeda (1961). "Effect of Twilight on Photoperiodic Induction in Some Short Day Plants". In: *Plant and Cell Physiology* 2.3, pp. 213–229.

Edited by: T. Kotilainen and T. M. Robson.

Box 8.7: Example code for calculation of the position of the sun.

We can calculate the current position of the sun,

```
sun_angles(geocode = geocode("Helsinki, Finland"))

## $time
## [1] "2016-04-18 17:05:48 UTC"
##
## $longitude
## [1] 24.94
##
## $latitude
## [1] 60.17
##
## $azimuth
## [1] 285.5
##
## $elevation
## [1] 3.998
##
## $diameter
## [1] 0.5309
##
## $distance
## [1] 1.004
```

or at a given time and date, in this case the time when the first UV4Plants Congress is scheduled to start.

```
sun_angles(time = ymd_hms("2016-05-30 14:00:00", tz = "EET"),
           geocode = geocode("Helsinki, Finland"))

## $time
## [1] "2016-05-30 14:00:00 EEST"
##
## $longitude
## [1] 24.94
##
## $latitude
## [1] 60.17
##
## $azimuth
## [1] 195.6
##
## $elevation
## [1] 50.98
##
## $diameter
## [1] 0.5259
##
## $distance
## [1] 1.014
```


Box 8.8: Example code for calculation of the position of the sun at the time of measurement.

Objects of class `"source_spct"` can contain geocode and time data as metadata. If they contain metada, it is possible to calculate the position of the sun at the time and place of measurement.

```
sun_angles(time = getWhenMeasured(sun.spct),
           geocode = getWhereMeasured(sun.spct))

## $time
## [1] "2010-06-22 09:51:00 UTC"
##
## $longitude
## [1] 24.96
##
## $latitude
## [1] 60.21
##
## $azimuth
## [1] 168.1
##
## $elevation
## [1] 52.83
##
## $diameter
## [1] 0.5246
##
## $distance
## [1] 1.016
```