

# Package: sirad (via r-universe)

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**Type** Package

**Title** Functions for Calculating Daily Solar Radiation and  
Evapotranspiration

**Version** 2.3-3

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**Description** Calculating daily global solar radiation at horizontal surface using several well-known models (i.e. Angstrom-PreScott, Supit-Van Kappel, Hargreaves, Bristow and Campbell, and Mahmood-Hubbard), and model calibration based on ground-truth data, and (3) model auto-calibration. The FAO Penmann-Monteith equation to calculate evapotranspiration is also included.

**URL** <http://sirad.r-forge.r-project.org/>,  
<http://mars.jrc.ec.europa.eu/mars/Projects/Solar-Radiation-in-MCYFS>,  
<http://jbojanowski.pl>

**Imports** stats, zoo, raster

**License** GPL-2

**LazyLoad** yes

**LazyData** yes

**Depends** R (>= 3.0.0)

**Repository** <https://r-forge.r-universe.dev>

**RemoteUrl** <https://github.com/r-forge/sirad>

**RemoteRef** HEAD

**RemoteSha** 88c0491b4e470854bfe8eda5a0b7540617249d75

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 sirad-package

*Functions for calculating daily solar radiation and evapotranspiration*


---

### Description

Calculates daily solar radiation at horizontal surface using several well-known models (Bristow-Campbell, Hargreaves, Supit-Van Kappel, Mahmood-Hubbard, Angstrom-PreScott). It also includes functions for model calibration based on ground-truth data as well as a function for auto-calibration. The FAO Penmann-Monteith equation to calculate evapotranspiration is also included.

**Details**

Package: sirad  
Type: Package  
Version: 2.3-3  
Date: 2016-10-17  
License: GPL-2  
LazyLoad: yes

**Author(s)**

Jedrzej S. Bojanowski

Maintainer: Jedrzej S. Bojanowski <jedrzej.bojanowski@gmail.com>

**Examples**

```
require(zoo)
data(Metdata)
A <- 0.21
B <- 0.57
sunshine <- Metdata$meteo$SUNSHINE
days <- Metdata$meteo$DAY
lat <- Metdata$LATITUDE
lon <- Metdata$LONGITUDE
plot(zoo(ap(days=days, lat=lat, lon=lon, extraT=NULL, A=A, B=B, SSD=sunshine), order.by=days))
```

---

ap

*Angstrom-Prescott solar radiation model*

---

**Description**

Angstrom-Prescott model is used to calculate daily global irradiance for a horizontal surface based on sunshine duration.

**Usage**

```
ap(days, lat, lon, extraT=NULL, A=NA, B=NA, SSD)
```

**Arguments**

days            Vector of class 'Date' of length n.  
lat              Latitude in decimal degrees.  
lon               Longitude in decimal degrees.

extraT	Optional. Vector of length n of extraterrestrial solar radiation [MJm-2]. If 'NULL' then it is calculated by the function. Providing extraterrestrial solar radiation speeds up the computation
A	Angstrom-Prescott model 'A' coefficient. If 'NA' then A is derived from the map of interpolated coefficients estimated from Meteosat solar radiation data. See details.
B	Angstrom-Prescott model 'B' coefficient. If 'NA' then B is derived from the map of interpolated coefficients estimated from Meteosat solar radiation data. See details.
SSD	Vector of length n containing sunshine duration [in hours].

### Details

Model proposed by Angstrom (1924) and modified by Prescott (1940) assumed linear relationship between: (1) a proportion of bright sunshine hours and astronomical day length and (2) proportion of incoming daily global solar radiation and daily extra-terrestrial radiation. This linear relationship is described by empirical model coefficients: A - intercept, B - slope. Both astronomical day length and daily extra-terrestrial radiation are calculated within this function based on location and time. Model coefficients A and B (if not provided) are derived from interpolated Meteosat-based coefficients from Bojanowski et al. 2013.

### Value

Vector of length n of daily solar radiation [MJm-2].

### Note

SSD input can contain NA's, but length of vectors 'SSD' and 'days' has to be the identical.

### Author(s)

Jedrzej S. Bojanowski

### References

- Bojanowski, J.S., Vrieling, A., Skidmore, A.K., 2013. Calibration of solar radiation models for Europe using Meteosat Second Generation and weather station data. *Agricultural and Forest Meteorology* 176:1-9.
- Angstrom, A., 1924. Solar and terrestrial radiation. *Quarterly Journal of the Royal Meteorological Society*, 50:121-125.
- Prescott, J.A., 1940. Evaporation from a water surface in relation to solar radiation. *Transactions of the Royal Society of South Australia*, 64:114-118.

### See Also

'apcal' to calibrate the model

**Examples**

```

require(zoo)
#A <- 0.21
#B <- 0.57
sunshine <- Metdata$meteo$SUNSHINE
days <- Metdata$meteo$DAY
lat <- Metdata$LATITUDE
lon <- Metdata$LONGITUDE
plot(zoo(ap(days,lat,lon, extraT=NULL,A=NA,B=NA,sunshine),order.by=days))

```

apcal

*Calibrate Angstrom-Prescott model***Description**

Function estimates Angstrom-Prescott model coefficients 'A' and 'B' based on reference data

**Usage**

```
apcal(lat, days, rad_mea,extraT=NULL, DL=NULL, SSD)
```

**Arguments**

lat	Latitude in decimal degrees.
days	Vector of class 'Date' of length n.
rad_mea	Vector of length n containing reference (e.g. measured) solar radiation [MJm-2].
extraT	Optional. Vector of length n of extraterrestrial solar radiation [MJm-2]. If 'NULL' then it is calculated by the function. Providing extraterrestrial solar radiation speeds up the computation
DL	Optional. Vector of length n of day length [h]. If 'NULL' then it is calculated by the function. Providing day length speeds up the computation
SSD	Vector of length n containing sunshine duration [in hours].

**Details**

Function estimates Angstrom-Prescott model coefficients 'A' and 'B' based on reference (e.g. measured) solar radiation data. It performs a linear regression in which 'rad\_mea' is dependent variable and a proporsion of 'SSD' and astronomical day length is an independent variable.

**Value**

Vector containing:

APa	Angstom-Prescott 'A' coefficient
APb	Angstom-Prescott 'B' coefficient
APr2	Coefficient of determination of performed linear regression

**Author(s)**

Jedrzej S. Bojanowski

**References**

Angstrom, A., 1924. Solar and terrestrial radiation. Quarterly Journal of the Royal Meteorological Society, 50:121-125.  
 Prescott, J.A., 1940. Evaporation from a water surface in relation to solar radiation. Transactions of the Royal Society of South Australia, 64:114-118.

**See Also**

'ap' to use Angstrom-Prescott model

**Examples**

```
## Calibrate the model based on measured data
data(Metdata)
sunshine <- Metdata$meteo$SUNSHINE
days <- Metdata$meteo$DAY
lat <- Metdata$LATITUDE
rad_mea <- Metdata$meteo$RAD_MEA
apcal(lat=lat,days=days,rad_mea,extraT=NULL,DL=NULL,SSD=sunshine)
```

---

 bc

---

*Bristow-Campbell model*


---

**Description**

'bc' calculates daily solar radiation based on daily temperature range using Bristow-Campbell model.

**Usage**

```
bc(days, lat, BCb,extraT=NULL, Tmax, Tmin, BCc = 2, tal)
```

**Arguments**

days	Vector of class 'Date' of length n.
lat	Latitude in decimal degrees.
BCb	Bristow-Campbell model coefficient 'B'.
extraT	Optional. Vector of length n of extraterrestrial solar radiation [MJm-2]. If 'NULL' then it is calculated by the function. Providing extraterrestrial solar radiation speeds up the computation
Tmax	Vector of length n containing daily maximum temperature [C].
Tmin	Vector of length n containing daily minimum temperature [C].
BCc	Bristow-Campbell model coefficient 'C' usually equaled to 2.
tal	Clear sky transmissivity.

**Details**

Bristow and Campbell proposed a method for estimating solar radiation from air temperature measurements. They developed an empirical relationship to express the daily total atmospheric transmittance as a function of daily range in air temperature.

**Value**

Vector of length n of daily solar radiation [MJm<sup>-2</sup>].

**Note**

'Tmax', 'Tmin' can contain NA's, but length of vectors 'Tmax', 'Tmin' and 'days' has to be the same.

**Author(s)**

Jedrzej S. Bojanowski

**References**

Bristow, K.L., Campbell, G.S. 1984. On the relationship between incoming solar radiation and daily maximum and minimum temperature. *Agriculture and Forest Meteorology*, 31:159-166.

**See Also**

'bccal' to calibrate model using reference data, 'bcauto' to perform auto-calibration, and 'ha' to use Hargreaves model to calculate solar radiation based on temperature range.

**Examples**

```
require(zoo)
data(Metdata)
B <- 0.11
tmax <- Metdata$meteo$TEMP_MAX
tmin <- Metdata$meteo$TEMP_MIN
days <- Metdata$meteo$DAY
lat <- Metdata$LATITUDE
plot(zoo(bc(days, lat, Bcb=B,extraT=NULL, tmax, tmin, BCc=2, tal=0.76),order.by=days))
```

---

bcauto

*Auto-calibrate Bristow-Campbell model*

---

**Description**

Function estimates Bristow-Campbell model coefficient 'B' based on auto-calibration procedure

**Usage**

```
bcauto(lat,lon,days,extraT=NULL,Tmax,Tmin,tal,BCc=2,
BCb_guess=0.13,epsilon=0.5,perce=NA,dcoast=NA)
```

**Arguments**

lat	Latitude in decimal degrees.
lon	Longitude in decimal degrees.
days	Vector of class 'Date' of length n.
extraT	Optional. Vector of length n of extraterrestrial solar radiation [MJm-2]. If 'NULL' then it is calculated by the function. Providing extraterrestrial solar radiation speeds up the computation
Tmax	Vector of length n containing daily maximum temperature [C].
Tmin	Vector of length n containing daily minimum temperature [C].
tal	Clear sky transmissivity.
BCc	Bristow-Campbell model coefficient 'C' usually equaled to 2.
BCb_guess	Assumption of Bristow-Campbell coefficient. Default set to 0.13.
epsilon	A value of which potential radiation is decreased. See "details".
perce	Percent of clear days. In 'NA' then perce is estimated based on the Cloud Fraction Cover map.
dcoast	Distance to the coast [km].

**Details**

The auto-calibration method bases on the assumption that on the clear-sky days model should not overpredict potential values. To define those clear-sky days, we estimate daily solar radiation using Bristow and Campbell model with default values of  $B = 0.13$  and  $tal = 0.72$  and we select those days for which estimated daily solar radiation is the closest to the potential values ( $extraT * tal$ ). The number of clear-sky days is estimated based on the mean Cloud Fraction Cover map. Next, based on selected clear-sky days, we perform a non-linear least squares regression to derive B coefficient treating potential values decreased by 'epsilon' as a reference solar radiation values. The analysis of auto-calibration results showed clear correlation between optimal 'epsilon' and distance to the coast. We proposed simplified method in which 'epsilon' is equal to 0.1 MJm-2 or to 0.5 MJm-2 when distance to the coast is smaller or bigger than 15 km respectively.

**Value**

BCb	Bristow-Campbell 'B' coefficient
-----	----------------------------------

**Author(s)**

Jedrzej S. Bojanowski

**References**

Bojanowski, J.S., Donatelli, M., Skidmore, A.K., Vrieling, A., 2013. An auto-calibration procedure for empirical solar radiation models *Environmental Modelling and Software* 49, 118-128.



**See Also**

'bc' to use Bristow-Campbell model, and 'bcca1' to perform calibration based on reference data.

**Examples**

```
data(Metdata)
tmax <- Metdata$meteo$TEMP_MAX
tmin <- Metdata$meteo$TEMP_MIN
days <- Metdata$meteo$DAY
lat <- Metdata$LATITUDE
lon <- Metdata$LONGITUDE
rad_mea <- Metdata$meteo$RAD_MEA
dcoast <- Metdata$DCOAST

bcauto(lat, lon, days, extraT=NULL, tmax, tmin, perce=NA, dcoast)
```

---

bcca1

*Calibrate Bristow-Campbell model*


---

**Description**

Function estimates Bristow-Campbell model coefficient 'B' based on reference data

**Usage**

```
bcca1(lat, days, rad_mea, extraT=NULL, BCc=2, Tmax, Tmin, tal)
```

**Arguments**

lat	Latitude in decimal degrees.
days	Vector of class 'Date' of length n.
rad_mea	Vector of length n containing reference (e.g. measured) solar radiation [MJm-2].
extraT	Optional. Vector of length n of extraterrestrial solar radiation [MJm-2]. If 'NULL' then it is calculated by the function. Providing extraterrestrial solar radiation speeds up the computation
BCc	Bristow-Campbell model coefficient 'C' usually equaled to 2.
Tmax	Vector of length n containing daily maximum temperature [C].
Tmin	Vector of length n containing daily minimum temperature [C].
tal	Clear sky transmissivity.

**Details**

Function estimates Bristow-Campbell model coefficient 'B' based on reference (e.g. measured) solar radiation data. It performs a non-linear least squares regression.

**Value**

BCb                    Bristow-Campbell 'B' coefficient

**Author(s)**

Jedrzej S. Bojanowski

**References**

Bristow, K.L., and G.S. Campbell. 1984. On the relationship between incoming solar radiation and daily maximum and minimum temperature. *Agriculture and Forest Meteorology*, 31:159-166.

**See Also**

'bc', and 'bcauto' to perform auto-calibration

**Examples**

```
data(Metdata)
tmax <- Metdata$meteo$TEMP_MAX
tmin <- Metdata$meteo$TEMP_MIN
days <- Metdata$meteo$DAY
lat <- Metdata$LATITUDE
rad_mea <- Metdata$meteo$RAD_MEA
bccal(lat, days, rad_mea, extraT=NULL, BCc=2, tmax, tmin, tal=0.76)
```

---

cst

*Estimate clear sky transmissivity*

---

**Description**

Function estimates a clear sky transmissivity based on reference data (e.g. measured)

**Usage**

```
cst(RefRad, days, lat, extraT=NULL, perce = 3, sepYear = FALSE, stat='median')
```

**Arguments**

RefRad	Vector of length n of reference solar radiation data [MJm-2]
days	Vector of class 'Date' of length n.
lat	Latitude in radians
extraT	Optional. Vector of length n of extraterrestrial solar radiation [MJm-2]. If 'NULL' then it is calculated by the function. Providing extraterrestrial solar radiation speeds up the computation
perce	Percent of days to be chosen as clear days

sepYear	Logical value. If 'TRUE' percent of days given by 'perce' of every single year are taken for calculation. If 'FALSE' percent of days given by 'perce' of all years are taken for calculation
stat	Method used to estimate final value of the clear sky transmissivity from the values derived from selected clear-sky days. Default is 'median' which is more conservative, while alternative 'max' is sensitive to outliers. If 'max' is used the value of 'perce' is not important. If 'stat' is numeric then (instead of 'median' or 'max') 'quantile' is used. 'Stat' is sent as quantile's 'probs' parameter. See ?quantile for details

**Value**

Numeric. Clear sky transmissivity.

**Author(s)**

Jedrzej S. Bojanowski

**See Also**

cstRead

**Examples**

```
data(Metdata)
ref <- Metdata$meteo$RAD_MEA
i <- dayOfYear(Metdata$meteo$DAY)
latr <- radians(Metdata$LATITUDE)
cst(ref,i,latr)
```

---

cstRead

*Read values of clear sky transmissivity*

---

**Description**

Read values of clear sky transmissivity map for a given locations (in lat/lon)

**Usage**

```
cstRead(lat,lon)
```

**Arguments**

lat	Latitude in decimal degrees.
lon	Longitude in decimal degrees.

**Value**

Clear sky transmissivity

**Author(s)**

Jedrzej S. Bojanowski

**See Also**

'cst'

**Examples**

```
cstRead(50,16)
```

---

dayOfYear

*Convert 'Date' to number of day in a year*

---

**Description**

Function gives a day number of the year (julian day of the year) based on the date in class 'Date'.

**Usage**

```
dayOfYear(dat)
```

**Arguments**

dat                      Date in class 'Date'.

**Value**

Numeric number of day in a year.

**Author(s)**

Jedrzej S. Bojanowski

**Examples**

```
dayOfYear(as.Date("2009-01-11"))
```

---

degrees	<i>Convert radians to degrees</i>
---------	-----------------------------------

---

**Description**

Converts radians to degrees

**Usage**

degrees(radians)

**Arguments**

radians          numeric

**Value**

Degrees.

**Author(s)**

Jedrzej S. Bojanowski

**See Also**

'radians'

**Examples**

degrees(0.95)

---

deltaVP	<i>Slope of saturation vapour pressure curve</i>
---------	--

---

**Description**

'deltaVP' estimates the slope of saturation vapour pressure curve

**Usage**

deltaVP(Tmax,Tmin)

**Arguments**

Tmax              Vector of length n containing daily maximum temperature [C].  
Tmin              Vector of length n containing daily minimum temperature [C].

**Value**

Slope of saturation vapour pressure curve [kPaC<sup>-1</sup>]

**Author(s)**

Jedrzej S. Bojanowski

**References**

Allen, R.G., L.S. Pereira, D. Raes, and M. Smith. 1998. Crop Evapotranspiration: Guidelines for computing crop water requirements. Irrigation and Drainage Paper 56, Food and Agriculture Organization of the United Nations, Rome, pp. 300.

**Examples**

deltaVP(Tmax=17, Tmin=16)

---

es

*Mean saturation vapour pressure*

---

**Description**

'es' calculates mean saturation vapour pressure based on air temperature.

**Usage**

es(Tmax, Tmin)

**Arguments**

Tmax            Vector of length n containing daily maximum temperature [C].  
 Tmin            Vector of length n containing daily minimum temperature [C].

**Value**

Vector of length n of mean saturation vapour pressure [kPa]

**Author(s)**

Jedrzej S. Bojanowski

**References**

Allen, R.G., L.S. Pereira, D. Raes, and M. Smith. 1998. Crop Evapotranspiration: Guidelines for computing crop water requirements. Irrigation and Drainage Paper 56, Food and Agriculture Organization of the United Nations, Rome, pp. 300.

**Examples**

```
es(Tmax=25.1,Tmin=19.1)
```

---

 et0

---

*FAO Penman-Monteith evapotranspiration equation*


---

**Description**

'et0' estimates evapotranspiration based on FAO Penman-Monteith equation

**Usage**

```
et0(Tmax,Tmin, vap_pres,sol_rad,tal,z,uz,meah=10,extraT=NA,days=NA,lat=NA)
```

**Arguments**

Tmax	Vector of length n containing daily maximum temperature [C].
Tmin	Vector of length n containing daily minimum temperature [C].
vap_pres	Vector of length n of mean daily vapour pressure [kPa].
sol_rad	Vector of length n of daily solar radiation [MJm-2d-1].
tal	Clear sky transmissivity [0-1].
z	Altitude above the sea level [m].
uz	Wind speed measured at height 'meah' [ms-1].
meah	The height (above the ground level) of the wind speed measurement [m].
extraT	Optional. Vector of length n of extraterrestrial solar radiation [MJm-2d-1]. If 'NA' then it is calculated by the function. Providing extraterrestrial solar radiation speeds up the computation.
days	Required only if extraT=NA. Vector of class 'Date' of length n.
lat	Required only if extraT=NA. Latitude in decimal degrees.

**Value**

Vector of length n of daily reference evapotranspiration. [mmd-1]

**Author(s)**

Jedrzej S. Bojanowski

**References**

Allen, R.G., L.S. Pereira, D. Raes, and M. Smith. 1998. Crop Evapotranspiration: Guidelines for computing crop water requirements. Irrigation and Drainage Paper 56, Food and Agriculture Organization of the United Nations, Rome, pp. 300.

**Examples**

```

data(Metdata)
tmax <- Metdata$meteo$TEMP_MAX
tmin <- Metdata$meteo$TEMP_MIN
vpres <- Metdata$meteo$VAP_PRES
days <- Metdata$meteo$DAY
lat <- Metdata$LATITUDE
rad_mea <- Metdata$meteo$RAD_MEA
z <- Metdata$ALTITUDE
wind <- Metdata$meteo$WIND_10

tal <- cst(rad_mea, dayOfYear(Metdata$meteo$DAY), radians(Metdata$LATITUDE))

et0(Tmax=tmax, Tmin=tmin, vap_pres=vpres, sol_rad=rad_mea, tal=tal, z=Metdata$ALTITUDE,
uz=wind, meah=10, extraT=NA, days=days, lat=lat)

```

---

 extrat

---

*Calculate extraterrestrial solar radiation*


---

**Description**

'extrat' calculates hourly and daily extraterrestrial solar radiation for a given time and location.

**Usage**

```
extrat(i, lat)
```

**Arguments**

i	day number in the year (julian day)
lat	latitude in radians

**Details**

Solar radiation outside of the earth's atmosphere is called extraterrestrial solar radiation. It can be calculated based on solar geometry.

**Value**

List of 3 elements:

ExtraTerrestrialSolarRadiationDaily

daily sum of extraterrestrial radiation [MJm-2]

TerrestrialSolarRadiationHourly

vector of length 24 of hourly sums of extraterrestrial radiation [MJm-2]

DayLength

day length in hours



**Author(s)**

Jedrzej S. Bojanowski

**Examples**

```
## extraterrestrial radiation and daylength for 1 January and latitude 55 degrees
extrat(dayOfYear("2011-01-01"), radians(55))
```

---

ha	<i>Hargreaves solar radiation model</i>
----	---

---

**Description**

'ha()' calculates daily solar radiation based on daily temperature range using Hargreaves model.

**Usage**

```
ha(days, lat, lon, extraT=NULL, A=NA, B=NA, Tmax, Tmin)
```

**Arguments**

days	Vector of class 'Date' of length n.
lat	Latitude in decimal degrees.
lon	Longitude in decimal degrees.
extraT	Optional. Vector of length n of extraterrestrial solar radiation [MJm-2]. If 'NULL' then it is calculated by the function. Providing extraterrestrial solar radiation speeds up the computation
A	Hargreaves model coefficient 'A'. If 'NA' then A is derived from the map of interpolated coefficients estimated from Meteosat solar radiation data. See details.
B	Hargreaves model coefficient 'B'. If 'NA' then B is derived from the map of interpolated coefficients estimated from Meteosat solar radiation data. See details.
Tmax	Vector of length n containing daily maximum temperature [C].
Tmin	Vector of length n containing daily minimum temperature [C].

**Details**

Hargreaves proposed a method for estimating solar radiation from air temperature measurements. Model coefficients A and B (if not provided) are derived from interpolated Meteosat-based coefficients from Bojanowski et al. 2013.

**Value**

Vector of length n of daily solar radiation [MJm-2].

**Note**

'Tmax', 'Tmin' can contain NA's, but length of vectors 'Tmax', 'Tmin' and 'days' has to be the same.

**Author(s)**

Jedrzej S. Bojanowski

**References**

Bojanowski, J.S., Vrieling, A., Skidmore, A.K., 2013. Calibration of solar radiation models for Europe using Meteosat Second Generation and weather station data. *Agricultural and Forest Meteorology* 176:1-9.

Hargreaves, G.H., Samani, Z.A.. 1892. Estimating potential evapotranspiration. *J. Irrig. Drain. Eng.*, ASCE 108 (3), 225-230.

**See Also**

'hacal' to calibrate model using reference data, 'bc' to use Bristow-Campbell model to calculate solar radiation based on temperature range.

**Examples**

```
require(zoo)
data(Metdata)
tmax <- Metdata$meteo$TEMP_MAX
tmin <- Metdata$meteo$TEMP_MIN
days <- Metdata$meteo$DAY
lat <- Metdata$LATITUDE
lon <- Metdata$LONGITUDE
plot(zoo(ha(days, lat, lon, extraT=NULL, A=NA, B=NA, Tmax=tmax, Tmin=tmin), order.by=days))
```

---

hacal

*Calibrate Hargreaves model*


---

**Description**

Function estimates Hargreaves model coefficients 'A' and 'B' based on reference data

**Usage**

```
hacal(lat, days, rad_mea, extraT=NULL, tmax, tmin)
```

**Arguments**

lat	Latitude in decimal degrees.
days	Vector of class 'Date' of length n.
rad_mea	Vector of length n containing reference (e.g. measured) solar radiation [MJm-2].
extraT	Optional. Vector of length n of extraterrestrial solar radiation [MJm-2]. If 'NULL' then it is calculated by the function. Providing extraterrestrial solar radiation speeds up the computation
tmax	Vector of length n containing daily maximum temperature [C].
tmin	Vector of length n containing daily minimum temperature [C].

**Details**

Function estimates Hargreaves model coefficients 'A' and 'B' based on reference (e.g. measured) solar radiation data. It performs a linear regression.

**Value**

Vector of length 3 containing:

Ha	Hargreaves 'A' coefficient
Hb	Hargreaves 'B' coefficient
Hr2	Coefficient of determination of performed linear regression

**Author(s)**

Jedrzej S. Bojanowski

**References**

Hargreaves, G.H., Samani, Z.A. 1892. Estimating potential evapotranspiration. J. Irrig. Drain. Eng., ASCE 108 (3), 225-230.

**See Also**

'ha'

**Examples**

```
data(Metdata)
tmax <- Metdata$meteo$TEMP_MAX
tmin <- Metdata$meteo$TEMP_MIN
days <- Metdata$meteo$DAY
lat <- Metdata$LATITUDE
rad_mea <- Metdata$meteo$RAD_MEA
hacal(lat=lat,days=days,rad_mea,extraT=NULL,tmax=tmax, tmin=tmin)
```

---

hauto *Auto-calibrate Hargreaves model*

---

### Description

Function estimates Hargreaves model coefficients 'A' and 'B' based on autocalibration procedure

### Usage

```
hauto(lat, lon, days, extraT = NULL, Tmax, Tmin, tal,
      Ha_guess = 0.16, Hb_guess = 0.1, epsilon=0.5, perce = NA)
```

### Arguments

lat	Latitude in decimal degrees.
lon	Longitude in decimal degrees.
days	Vector of class 'Date' of length n.
extraT	Optional. Vector of length n of extraterrestrial solar radiation [MJm-2]. If 'NULL' then it is calculated by the function. Providing extraterrestrial solar radiation speeds up the computation
Tmax	Vector of length n containing daily maximum temperature [C].
Tmin	Vector of length n containing daily minimum temperature [C].
tal	Clear sky transmissivity.
Ha_guess	Assumption of Hargreaves Ha coefficient. Default set to 0.16.
Hb_guess	Assumption of Hargreaves Hb coefficient. Default set to 0.1.
epsilon	A value of which potential radiation is decreased. See "details".
perce	Percent of clear days. Default set to 1.

### Details

The auto-calibration method bases on the assumption that on the clear-sky days model should not overpredict potential values. To define those clear-sky days, we estimate daily solar radiation using Hargreaves model with default values of  $A = 0.16$ ,  $B = 0.1$  and  $tal = 0.72$  and we select those days for which estimated daily solar radiation is the closest to the potential values (extra-terrestrial\* $tal$ ). The number of clear-sky days is estimated based on the mean Cloud Fraction Cover map. Next, based on selected clear-sky days, we perform a non-linear least squares regression to derive A and B coefficients treating potential values decreased by 'epsilon' as a reference solar radiation values. The analysis of auto-calibration results showed clear correlation between optimal 'epsilon' and distance to the coast. We proposed simplified method in which 'epsilon' is equal to 0.1 MJm-2 or to 0.5 MJm-2 when distance to the coast is smaller or bigger than 15 km respectively.

**Value**

Vector of length 3 containing:

Ha	Hargreaves 'A' coefficient
Hb	Hargreaves 'B' coefficient
Hr2	Coefficient of determination of performed linear regression

**Author(s)**

Jedrzej S. Bojanowski

**References**

Hargreaves, G.H., Samani, Z.A. 1892. Estimating potential evapotranspiration. *J. Irrig. Drain. Eng.*, ASCE 108 (3), 225-230. Bojanowski, J.S., Donatelli, M., Skidmore, A.K., Vrieling, A., 2013. An auto-calibration procedure for empirical solar radiation models *Environmental Modelling and Software* 49, 118-128.

**See Also**

'hacal'

**Examples**

```
data(Metdata)
Tmax <- Metdata$meteo$TEMP_MAX
Tmin <- Metdata$meteo$TEMP_MIN
days <- Metdata$meteo$DAY
lat <- Metdata$LATITUDE
lon <- Metdata$LONGITUDE
haut0(lat,lon,days,extraT=NULL,Tmax,Tmin,tal=0.76)
```

---

Metdata

*Weather data*

---

**Description**

This dataset contains two years of daily data of sunshine hours, solar radiation, minimum temperature, maximum temperature, cloud coverage, vapour pressure, and wind speed.

**Usage**

```
data(Metdata)
```

**Format**

NAME	chr	Name
LATITUDE	numeric	Latitude (decimal degree)
LONGITUDE	numeric	Longitude (decimal degree)
DCOAST	numeric	Distance to the coast (km)
ALTITUDE	numeric	Altitude above the sea level (m)
DAY	Date	Date
SUNSHINE	numeric	Sunshine (hours)
RAD_MEA	numeric	Solar radiation (MJm-2)
TEMP_MIN	numeric	Minimum temperature (degrees C)
TEMP_MAX	numeric	Maximum temperature (degrees C)
CLOUD_DAYTIME_TOTAL	numeric	Cloud coverage (octas)
VAP_PRES	numeric	Vapour pressure (kPa)
WIND_10	numeric	Wind speed at 10 m height (ms-1)

**Examples**

```
data(Metdata)
str(Metdata)
```

---

 mh

*Mahmood-Hubbard solar radiation model*


---

**Description**

'mh()' calculates daily solar radiation based on daily temperature range using Mahmood-Hubbard model.

**Usage**

```
mh(days, lat, Tmax, Tmin)
```

**Arguments**

days	Vector of class 'Date' of length n.
lat	Latitude in decimal degrees.
Tmax	Vector of length n containing daily maximum temperature [C].
Tmin	Vector of length n containing daily minimum temperature [C].

**Details**

Mahmood and Hubbard proposed a method for estimating solar radiation from air temperature measurements without a need of calibrating empirical coefficients.

**Value**

Vector of length n of daily solar radiation [MJm<sup>-2</sup>].

**Author(s)**

Jedrzej S. Bojanowski

**References**

Mahmood, R., and K.G. Hubbard. 2002. Effect of time of temperature observation and estimation of daily solar radiation for the Northern Great Plains, USA. *Agron. J.*, 94:723-733.

**See Also**

'bc' and 'ha' to calculate solar radiation based on temperature range using different models.

**Examples**

```
require(zoo)
data(Metdata)
tmax <- Metdata$meteo$TEMP_MAX
tmin <- Metdata$meteo$TEMP_MIN
days <- Metdata$meteo$DAY
lat <- Metdata$LATITUDE
plot(zoo(mh(days=days, lat=lat, Tmax=tmax, Tmin=tmin),order.by=days))
```

---

modeval

*Model performance statistics.*

---

**Description**

Function estimates several statistics comparing modelled and reference (measured) values.

**Usage**

```
modeval(calculated,measured,
stat=c("N","pearson","MBE","RMBE","MAE","RMAE","RMSE","RRMSE","R2","slope",
"intercept","EF","SD","CRM","MPE","AC","ACu","ACs"),minlength=4)
```

**Arguments**

calculated	Vector of length n of the calculated (modelled) values.
measured	Vector of length n of the reference (measured) values.
stat	Statistics which are going to be calculated. By default all possible.
minlength	Minimum number of non-NA data pairs. If below this value, the NA's are produced.

**Details**

The two input vectors can include NA's. Only non-NA calculated-measured pairs are used. See 'na.omit' for details.

**Value**

List of 13 statistics:

N	number of observations
person	Pearson's Correlation Coefficient
MBE	Mean (Bias) Error
RMBE	Relative Mean (Bias) Error
MAE	Mean Absolute Error
RMAE	Relative Mean Absolute Error
RMSE	Root Mean Square Error
RRMSE	Relative Root Mean Square Error
R2	Coefficient of determination from linear model
slope	Slope from linear model
intercept	Intercept from linear model
EF	Modelling Efficiency
SD	Standard deviation of differences
CRM	Coefficient of Residual Mass
MPE	Mean Percentage Error
AC	Agreement Coefficient
ACu	Unsystematic Agreement Coefficient
ACs	Systematic Agreement Coefficient

**Author(s)**

Jedrzej S. Bojanowski

**References**

- Bellocchi, G., Acutis, M., Fila, G., Donatelli, M., 2002. An indicator of solar radiation model performance based on a fuzzy expert system. *Agronomy Journal* 94, 1222-1233.
- Ji, L., Gallo, K., 2006. An Agreement Coefficient for image comparison. *Photogrammetric Engineering & Remote Sensing* 72(7), 823-833.



**Examples**

```
data(Metdata)
B <- 0.11
tmax <- Metdata$meteo$TEMP_MAX
tmin <- Metdata$meteo$TEMP_MIN
days <- Metdata$meteo$DAY
lat <- Metdata$LATITUDE
solrad_measured <- Metdata$meteo$RAD_MEA
solrad_BC <- bc(days, lat, extraT=NULL, BCb=B, tmax, tmin, BCc=2, tal=0.76)

modeval(solrad_BC, solrad_measured)
modeval(solrad_BC, solrad_measured, stat="EF")
```

---

psychC

*Psychrometric constant*

---

**Description**

'psychC' estimates the psychrometric constant.

**Usage**

```
psychC(Tmax, Tmin, z)
```

**Arguments**

Tmax	Vector of length n containing daily maximum temperature [C].
Tmin	Vector of length n containing daily minimum temperature [C].
z	Altitude above the sea level [m].

**Value**

Psychrometric constant [kPaC<sup>-1</sup>]

**Author(s)**

Jedrzej S. Bojanowski

**References**

Allen, R.G., L.S. Pereira, D. Raes, and M. Smith. 1998. Crop Evapotranspiration: Guidelines for computing crop water requirements. Irrigation and Drainage Paper 56, Food and Agriculture Organization of the United Nations, Rome, pp. 300.

**Examples**

```
psychC(17, 16, 1800)
```

---

radians                      *Convert degrees to radians*

---

**Description**

Converts degrees to radians

**Usage**

radians(degrees)

**Arguments**

degrees                      numeric

**Value**

Radians.

**Author(s)**

Jedrzej S. Bojanowski

**See Also**

'degrees'

**Examples**

radians(55)

---

rn1                              *Net longwave radiation*

---

**Description**

'rn1' computes daily net energy flux emitted by the Earth's surface.

**Usage**

rn1(Tmax, Tmin, sol\_rad, vap\_pres, extraT, tal)

**Arguments**

Tmax	Vector of length n containing daily maximum temperature [C].
Tmin	Vector of length n containing daily minimum temperature [C].
sol_rad	Vector of length n of daily solar radiation [MJm-2d-1].
vap_pres	Vector of length n of mean daily vapour pressure [kPa].
extraT	Vector of length n of extraterrestrial solar radiation [MJm-2d-1].
tal	Clear sky transmissivity.

**Details**

According to the Stefan-Boltzmann law, the longwave energy emission is proportional to the absolute temperature of the surface raised to the fourth power. This longwave energy is corrected by two factors: humidity ('ea') and cloudiness (estimated based on relation of actual and potential solar radiation. See Allen et al. (1998) for details.

**Value**

Vector of length n of daily net longwave radiation. [MJm-2d-1]

**Author(s)**

Jedrzej S. Bojanowski

**References**

Allen, R.G., L.S. Pereira, D. Raes, and M. Smith. 1998. Crop Evapotranspiration: Guidelines for computing crop water requirements. Irrigation and Drainage Paper 56, Food and Agriculture Organization of the United Nations, Rome, pp. 300.

**See Also**

See 'ea', 'extrat' and 'cst' to calculate necessary input data.

**Examples**

```
rnl(Tmax=25.1,Tmin=19.1,sol_rad=14.5,vap_pres=2.1,extraT=23.5,tal=0.8)
```

---

rns

*Net shortwave radiation*

---

### Description

'rns' computes daily the net shortwave radiation, resulting from the balance between incoming and reflected solar radiation.

### Usage

```
rns(sol_rad,albedo=0.23)
```

### Arguments

sol_rad	Vector of length n of daily solar radiation [MJm-2d-1].
albedo	Albedo or canopy reflection coefficient, which is 0.23 for the hypothetical grass reference crop [dimensionless].

### Details

Daily net shortwave radiation results from the balance between incoming and reflected solar radiation.

### Value

Vector of length n of daily net shortwave radiation. [MJm-2d-1]

### Author(s)

Jedrzej S. Bojanowski

### References

Allen, R.G., L.S. Pereira, D. Raes, and M. Smith. 1998. Crop Evapotranspiration: Guidelines for computing crop water requirements. Irrigation and Drainage Paper 56, Food and Agriculture Organization of the United Nations, Rome, pp. 300.

### Examples

```
rns(sol_rad=14.5)
```

---

su *Supit-Van Kappel solar radiation model*

---

### Description

'su()' calculates daily solar radiation based on daily cloud coverage and temperature range using Supit-Van Kappel model.

### Usage

```
su(days, lat, lon, extraT=NULL, A=NA, B=NA, C=NA, tmax, tmin, CC)
```

### Arguments

days	Vector of class 'Date' of length n.
lat	Latitude in decimal degrees.
lon	Longitude in decimal degrees.
extraT	Optional. Vector of length n of extraterrestrial solar radiation [MJm-2]. If 'NULL' then it is calculated by the function. Providing extraterrestrial solar radiation speeds up the computation
A	Supit-Van Kappel model coefficient 'A'. If 'NA' then A is derived from the map of interpolated coefficients estimated from Meteosat solar radiation data. See details.
B	Supit-Van Kappel model coefficient 'B'. If 'NA' then B is derived from the map of interpolated coefficients estimated from Meteosat solar radiation data. See details.
C	Supit-Van Kappel model coefficient 'C'. If 'NA' then C is derived from the map of interpolated coefficients estimated from Meteosat solar radiation data. See details.
tmax	Vector of length n containing daily maximum temperature [C].
tmin	Vector of length n containing daily minimum temperature [C].
CC	Vector of length n containing daily cloud coverage [octas].

### Details

Supit and Van Kappel proposed a method for estimating solar radiation from daily cloud coverage and temperature range. Model coefficients A, B and C (if not provided) are derived from interpolated Meteosat-based coefficients from Bojanowski et al. 2013.

### Value

Vector of length n of daily solar radiation [MJm-2].

**Note**

'CC', 'Tmax', 'Tmin' can contain NA's, but length of vectors 'CC', 'Tmax', 'Tmin' and 'days' has to be the identical.

**Author(s)**

Jedrzej S. Bojanowski

**References**

Bojanowski, J.S., Vrieling, A., Skidmore, A.K., 2013. Calibration of solar radiation models for Europe using Meteosat Second Generation and weather station data. *Agricultural and Forest Meteorology* 176:1-9.

Supit, I. 1994. Global radiation. Publication EUR 15745 EN of the Office for Official Publications of the EU, Luxembourg.

Supit, I., Kappel, R.R. van, 1998. A simple method to estimate global radiation. *Solar Energy*, 63:147-160.

**See Also**

'sucal' to calibrate the model.

**Examples**

```
require(zoo)
data(Metdata)
tmax <- Metdata$meteo$TEMP_MAX
tmin <- Metdata$meteo$TEMP_MIN
cc <- Metdata$meteo$CLOUD_DAYTIME_TOTAL
days <- Metdata$meteo$DAY
lat <- Metdata$LATITUDE
lon <- Metdata$LONGITUDE
plot(zoo(su(days=days, lat=lat, lon=lon, extraT=NULL, A=NA, B=NA,
C=-NA, tmax=tmax, tmin=tmin, CC=cc),order.by=days))
```

---

sucal

*Calibrate Supit-Van Kappel model*

---

**Description**

Function estimates Supit-Van Kappel model coefficients 'A', 'B' and 'C' based on reference data

**Usage**

```
sucal(days, lat, rad_mea, extraT=NULL, tmax, tmin, cc)
```

**Arguments**

days	Vector of class 'Date' of length n.
lat	Latitude in decimal degrees.
rad_mea	Vector of length n containing reference (e.g. measured) solar radiation [MJm-2].
extraT	Optional. Vector of length n of extraterrestrial solar radiation [MJm-2]. If 'NULL' then it is calculated by the function. Providing extraterrestrial solar radiation speeds up the computation
tmax	Vector of length n containing daily maximum temperature [C].
tmin	Vector of length n containing daily minimum temperature [C].
cc	Vector of length n containing daily cloud coverage [octas].

**Details**

Function estimates Supit-Van Kappel model coefficients 'A', 'B' and 'C' based on reference (e.g. measured) solar radiation data. It performs a linear regression.

**Value**

Vector of length 3:

Sa	Supit-Van Kappel 'A' coefficient
Sb	Supit-Van Kappel 'B' coefficient
Sc	Supit-Van Kappel 'C' coefficient
Sr2	Coefficient of determination of performed linear regression

**Author(s)**

Jedrzej S. Bojanowski

**References**

- Supit, I. 1994. Global radiation. Publication EUR 15745 EN of the Office for Official Publications of the EU, Luxembourg.
- Supit, I., Kappel, R.R. van, 1998. A simple method to estimate global radiation. Solar Energy, 63:147-160.

**See Also**

'su'.

**Examples**

```
data(Metdata)
tmax <- Metdata$meteo$TEMP_MAX
tmin <- Metdata$meteo$TEMP_MIN
days <- Metdata$meteo$DAY
lat <- Metdata$LATITUDE
```

```
rad_mea <- Metdata$meteo$RAD_MEA
CC <- Metdata$meteo$CLOUD_DAYTIME_TOTAL
sucal(lat=lat,days=days,rad_mea, extraT=NULL,tmax=tmax, tmin=tmin,cc=CC)
```

---

wind2	<i>Convert wind speed measured at a certain height to the wind speed at 2 meters</i>
-------	--

---

### Description

'wind2' converts a wind speed measured at a certain height 'z' above the ground level to the wind speed at the standard height (2 meters)

### Usage

```
wind2(uz, meah)
```

### Arguments

uz	Wind speed measured at heith 'z' [ms-1].
meah	The height (above the ground level) of the wind speed measurement [m].

### Details

Wind speed is slowest at the surface and increases with height. The measurements taken at different heights above the ground level must be standardized to 2 meters (default in agrometeorology).

### Value

Wind speed at standard 2 meters. [ms-1]

### Author(s)

Jedrzej S. Bojanowski

### References

Allen, R.G., L.S. Pereira, D. Raes, and M. Smith. 1998. Crop Evapotranspiration: Guidelines for computing crop water requirements. Irrigation and Drainage Paper 56, Food and Agriculture Organization of the United Nations, Rome, pp. 300.

### Examples

```
wind2(uz=5, meah=10)
```



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