Package ‘sirad’

May 9, 2026

Type Package

Title Functions for Calculating Daily Solar Radiation and Evapotranspiration

Version 2.3-3

Date 2016-10-17

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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)

NeedsCompilation no

Repository CRAN

Date/Publication 2016-10-18 01:01:16

Contents

`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, Angrstrom-Prescott). It also includes functions for model calibration based on groud-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 minumum 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-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

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 minumum 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 (extraterrestrial*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 'bccal' 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)
```

---

bccal *Calibrate Bristow-Campbell model*

Description

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

Usage

```
bccal(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 minumum 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 squeres 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 — *Convert radians to degrees*

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 — *Slope of saturation vapour pressure curve*

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 minumum temperature [C].

Value

Slope of saturation vapour pressure curve [kPaC-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

```
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 minumum 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 minumum 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 heith '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 — *Hargreaves solar radiation model*

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 minumum 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., Samini, Z.A.. 1892. Estimating potential evapotranspiration. J. Irrig. Darin. 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 minumum 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., Samini, Z.A. 1892. Estimating potential evapotranspiration. J. Irrig. Darin. 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 minumum 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. Darin. 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
hauto(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 minumum temperature [C].

Details

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

Value

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

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-mesured 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 minumum temperature [C].
z	Altitude above the sea level [m].

Value

Psychrometric constant [kPaC-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

```
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)
```

`rnl` *Net longwave radiation*

Description

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

Usage

```
rnl(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 minumum 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 minumum 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 minumum 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 *Convert wind speed measured at a certain height to the wind speed at 2 meters*

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 avove 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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