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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.

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<http://mars.jrc.ec.europa.eu/mars/Projects/Solar-Radiation-in-MCYFS>,
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Contents

sirad-package	2
ap	3
apcal	5
bc	6
bcauto	7
bccal	9
cst	10
cstRead	11
dayOfYear	12
degrees	13
deltaVP	13
es	14
et0	15
extrat	16
ha	17
hacal	18
hauto	20
Metdata	21
mh	22
modeval	23
psychC	25
radians	26
rnl	26
rns	28
su	29
sucal	30
wind2	32
Index	33

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-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 minimum temperature [C].
tal	Clear sky transmissivity.
BCc	Bristow-Campbell model coefficient 'C' usually equalled 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	<i>Calibrate Bristow-Campbell model</i>
-------	---

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 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	<i>Estimate clear sky transmissivity</i>
-----	--

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⁻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	<i>Mean saturation vapour pressure</i>
----	--

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	<i>FAO Penman-Monteith evapotranspiration equation</i>
-----	--

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	<i>Calculate extraterrestrial solar radiation</i>
--------	---

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	<i>Auto-calibrate Hargreaves model</i>
-------	--

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

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	<i>Net longwave radiation</i>
-----	-------------------------------

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	<i>Net shortwave radiation</i>
-----	--------------------------------

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)
```

Index

- * **package**
 - [sirad-package](#), [2](#)
- [ap](#), [3](#)
- [apcal](#), [5](#)
- [bc](#), [6](#)
- [bcauto](#), [7](#)
- [bccal](#), [9](#)
- [cst](#), [10](#)
- [cstRead](#), [11](#)
- [dayOfYear](#), [12](#)
- [degrees](#), [13](#)
- [deltaVP](#), [13](#)
- [es](#), [14](#)
- [et0](#), [15](#)
- [extrat](#), [16](#)
- [ha](#), [17](#)
- [hacal](#), [18](#)
- [haut0](#), [20](#)
- [Metdata](#), [21](#)
- [mh](#), [22](#)
- [modeval](#), [23](#)
- [psychC](#), [25](#)
- [radians](#), [26](#)
- [rn1](#), [26](#)
- [rns](#), [28](#)
- [sirad \(sirad-package\)](#), [2](#)
- [sirad-package](#), [2](#)
- [su](#), [29](#)
- [sucal](#), [30](#)
- [wind2](#), [32](#)